
Grizzly/(Turner Park)

Grizzly

Starting zone elevation- 7,000 feet

Vertical fall- 2,800 feet

Starting zone angle- 38 degrees

Aspect- Southwest

Beta Angle- NA

Alpha Angle- 28.8%

Run-out Ratio- NA

Frequency from records- 100 years

Frequency from dendro- none

Estimated combined frequency- 100 years

Shed Length- none

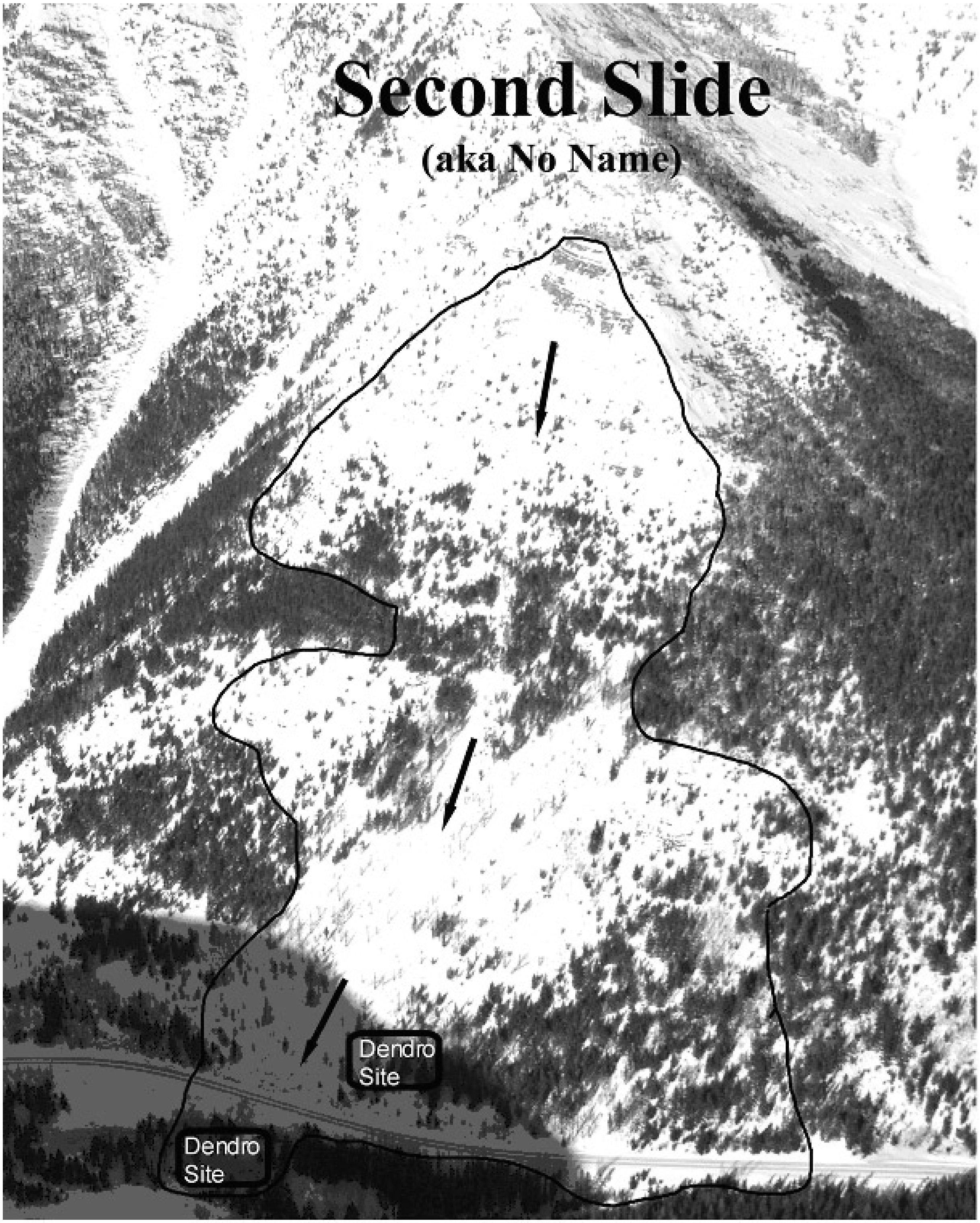
Fence Length- none

Milepost- 1162.05 to 1162.10

Path Width- 100 feet

Average Avalanche Width- 100 feet

Narrative Description-
Grizzly is a complex of gullies well uphill of the railroad. This path is unlikely to influence the track significantly due to low return frequency so the corresponding avalanche hazard index for a moving train is very low. Should it avalanche however, it would result in train traffic stopping in adjacent avalanche paths that have a high frequency. For this reason, the forecaster and program managers should be aware that it is possible for this avalanche path to run to the track.
Old timers working on the line know the area uphill of this avalanche path as Turner Park. This name was more recently applied to the avalanche path at Milepost 1163. For the sake of clarification, we are using Turner Park as an alternate name for the Grizzly path and sticking with Path 1163 for the path further to the west.


Second Slide
(aka No Name)
Dendro
Site
Dendro
Site

Second Slide

Starting zone elevation- 5,800 feet

Vertical fall- 1,600 feet

Starting zone angle- 40 degrees

Aspect- South Southeast

Beta Angle- 39 degrees

Alpha Angle- 32.2 degrees

Run-out Ratio- 87%

Frequency from records- 3 years

Frequency from dendro- no reliable cores

Estimated combined frequency- 5 years

Shed Length- none

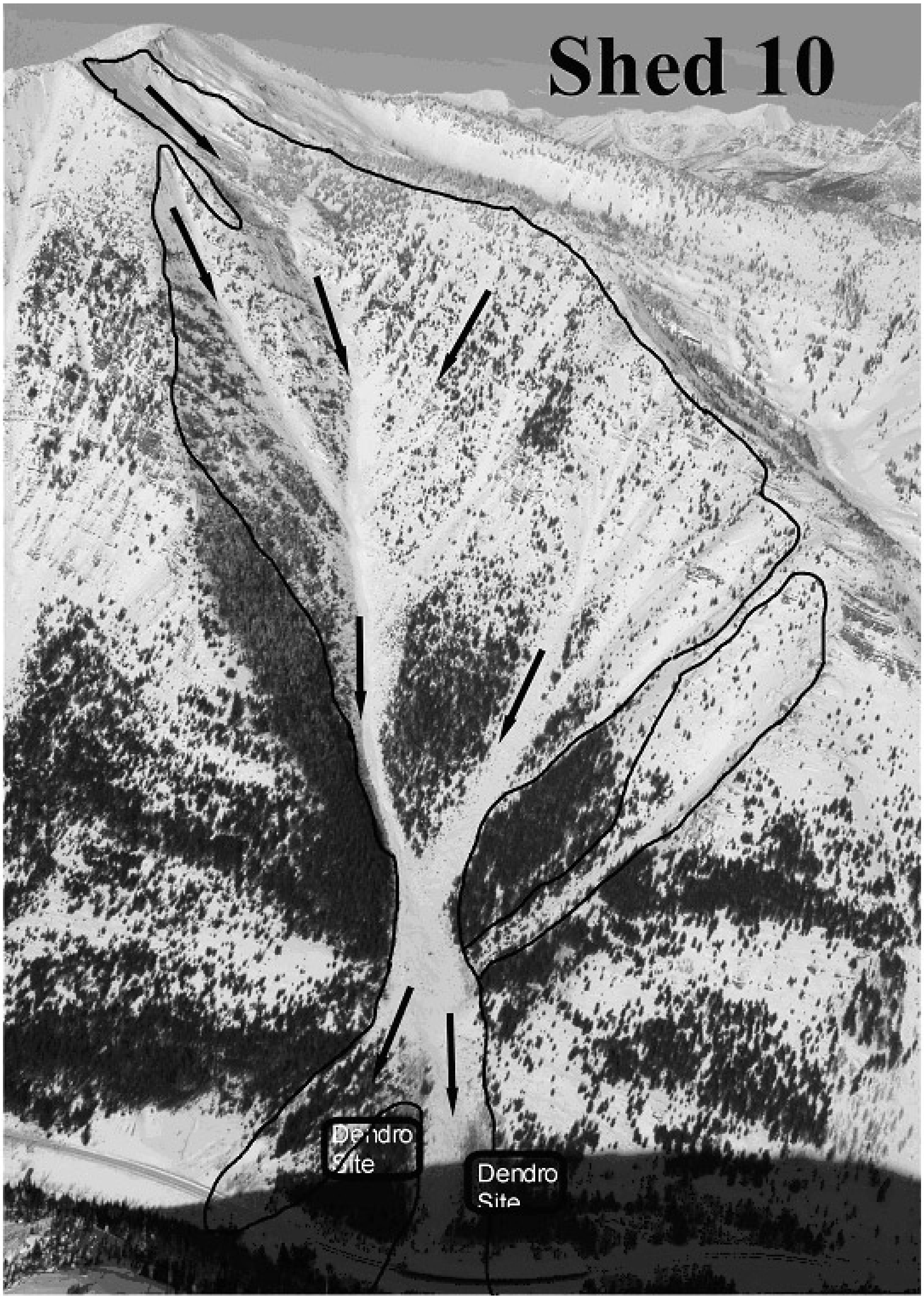
Fence Length- 440 feet

Milepost- 1162.42 to 1162.50

Path Width- 440 feet

Average Avalanche Width- 200 feet

Narrative Description-
Second Slide path is a face on the lower slopes west of the Turner Park drainage. It has an approximate 1,500 foot elevation drop to the tracks. The starting zone has slope angles of 35 to 40 degrees and is planer with vegetation that shows signs of frequent avalanche activity. Mid track, there is a dispersed band of timber and a shallow gully, which focuses the flow through distinct corridors that open up into a secondary open glade. This glade has burned out timber from a fire in the 1970's. This lack of timber would suggest that slides might be more frequent because the original slope support of timber does not exist. Slope angles in the second opening are 30 to 35 degrees and retain this angle to within 300 feet of the railroad. The angles directly above the railroad are 20 degrees. This is the site of the 2003-04 accident where the train was hit while stopped by the slide down the tracks at 1163. It has a history that is somewhat frequent, as repair of signal fence history would suggest. The signal fence is placed across the entire path to the east north side of the tracks. This path was formerly known as No Name, but due to last year's circumstance, Second Slide seems appropriate.


Shed 10
Dendro Site
Dendro Site

Shed 10

Starting zone elevation- 6,800 feet

Vertical fall- 2,700 feet

Starting zone angle- 32 to 40 degrees

Aspect- South Southeast

Beta Angle- 32 degrees

Alpha Angle- 27 degrees

Run-out Ratio- 84.4%

Frequency from records- 30 years

Frequency from dendro- 1996, 1992

Estimated combined frequency- 50 years

Shed Length- 500 feet

Fence Length- 350 feet

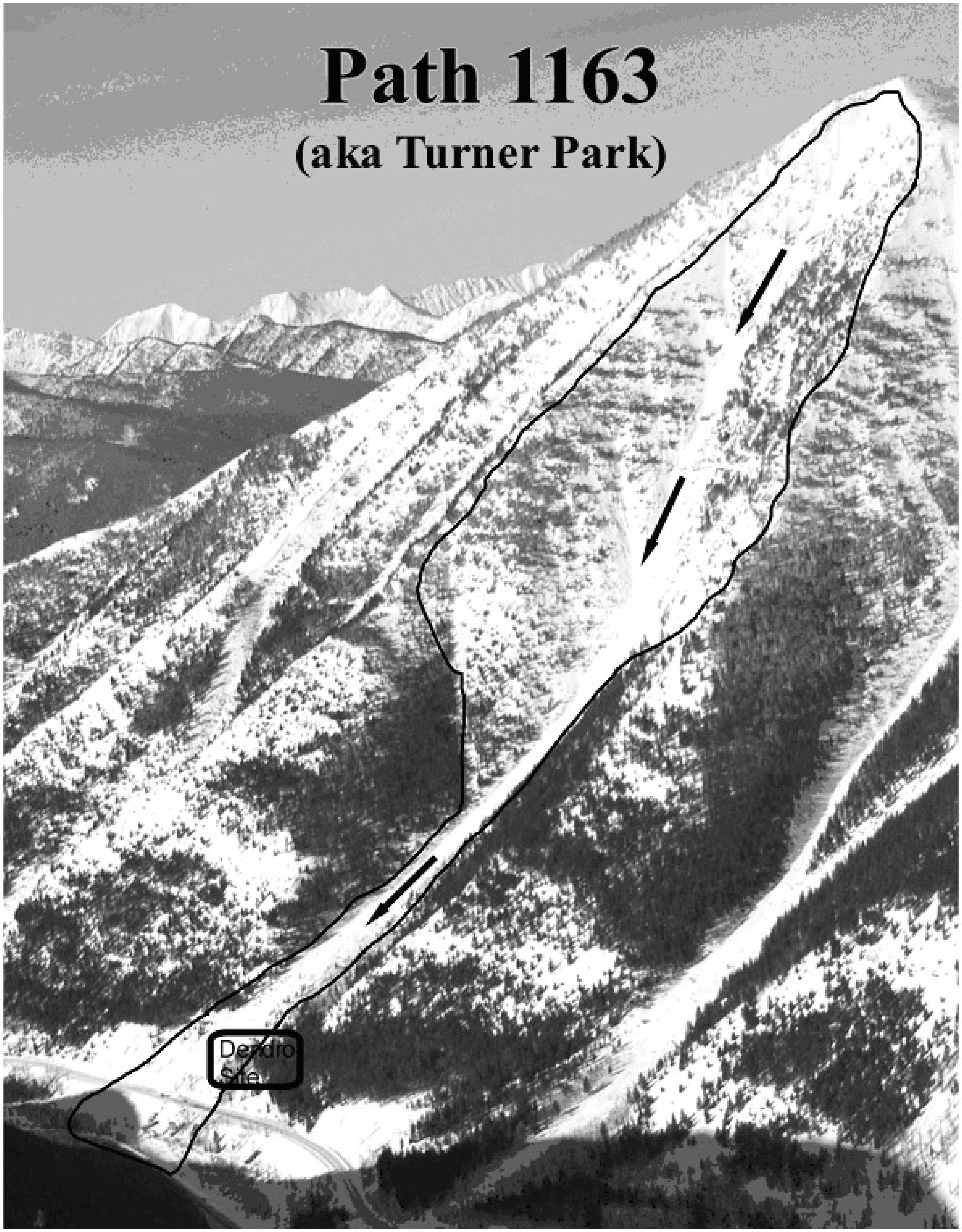
Milepost- 1162.65 to 1162.88

Path Width- 1,100 feet

Average Avalanche Width- 200 feet

Narrative Description- The Shed 10 slide path is a very complex and steep slide path with many starting zones and three distinct tracks. Each track is incised and devoid of timber. The western path starts at the peak and has an angle of 35 to 40 degrees. This path becomes a gully and tracks in an Easterly direction until joining the confluence of the central path. The starting zone is broad, cornices often form, and is concave which provides a good snow fetch from the prevailing winds. The central path between the two peaks of the path has a starting zone angle 32 to 35 degrees. The track takes a strait run towards the shed and retains an angle of 25-30 degrees with many rock outcroppings and rollovers. The eastern flank is the steepest of the three and has more opportunity to generate volume because of the broad rocky starting zone. The angle is 33 to 38 degrees and has few anchors to support snow. Unlike the other two flanks, the east path stays broad and planer until it reaches the confluence with the other two. The flow dynamics from this branch would cross the main gully and run in a westerly direction. This branch has the characteristics that would breach the shed on the west side as it has in recent history as evidenced by the destruction of timber above and below the shed. Some evidence of shed breach on the East side of the shed exists, but does not appear to be as often or destructive as on the west side of the shed. The west side of the shed has massive timber buildup, stacked in the flow direction. There is a signal fence on the west end of the shed running from an exterior box. From the box, the signal fence runs a thousand meters to another box out of the potential slide path. The box outside the shed is exposed and any person maintaining the fence would be in harms way if an event were to occur.

The path maintains a 20 degree angle all the way to the shed. During large magnitude events, the timber across the highway and guardrails has been destroyed on many occasions in recent history. Historical records demonstrate the shed breach to the west.


Path 1163
(aka Turner Park)
Dendro
Site

<u>1163</u>

<u>Starting zone elevation-</u> 7,320 feet

<u>Vertical fall-</u> 3,250 feet

<u>Starting zone angle</u>- 40 degrees

<u>Aspect-</u> South Southeast

<u>Beta Angle-</u> 38 degrees

<u>Alpha Angle-</u> 31.3 degrees

<u>Run-out Ratio</u>- 82.4%

<u>Frequency from records-</u> 3 years

<u>Frequency from dendro-</u> 2001, 1990

<u>Estimated combined frequency</u>- 5 years

<u>Shed Length-</u> none

<u>Fence Length-</u> 2,140 feet

<u>Milepost-</u> 1163.00 to 1163.40

<u>Path Width-</u> 2,112 feet

<u>Average Avalanche Width-</u> 300 feet

<u>Narrative Description-</u> Slide Path 1163, so named because of it's proximity to that milepost, is a major gully between shed 10 and shed 10.7 with a starting zone on the same mountain and elevation as the adjacent paths. The adjacent paths have sheds but 1163 does not. A signal fence is maintained along the tracks for the paths entire length. The starting zone is concave and broad, with many rocks and outcroppings. Vegetation is sparse, dispersed on the sides of the path, and has a much defined trim line on both sides below mid track. The track is a channelized gully with an aggressive gradient all the way to the beta point. The beta point is a shallow flat in the track that is approximately 600 feet long. Beyond the beta point, the slope pitches back to 20-25 degrees and maintains this angle past the railroad and into the creek bottom. This path has a history of running and requires signal fence repair on a somewhat frequent basis. More frequent events run to the bench at the beta point stop there. With only a few small slides into the beta area the path would loose its deceleration characteristics from deposition filling in the described flat in the path. Any major cycle that has the potential of affecting any of the other sheds, could produce an avalanche that would over run the railroad on Path 1163. The type of slide would certainly play a role in how far events will travel. Wet avalanches may not affect the tracks as likely as a dry snow, powder avalanche. A dry snow event will carry its momentum further down-slope. The avalanche of 2003-04 winter that impacted a train was just that kind of slide. It was not a big event that had deposition from wall to wall, but was a fast runner with a smaller deposition area that had significant momentum. Looking from the bottom, 1163 is one of the more impressive slide paths, with classic shape and characteristics. This path was given the name Turner Park in more recent times, although historical indications are that the original area of Turner Park is further up canyon.


Shed 10.7
Elk Path
Dendro
Site

Shed 10.7

Starting zone elevation- 7,180 feet

Vertical fall- 3,150 feet

Starting zone angle- 36 to 40 degrees

Aspect- South Southeast

Beta Angle- 30 degrees

Alpha Angle- 27 degrees

Run-out Ratio- 90%

Frequency from records- 10 years

Frequency from dendro- 2001, 1987, 1982

Estimated combined frequency - 10 years

Shed Length- 670 feet

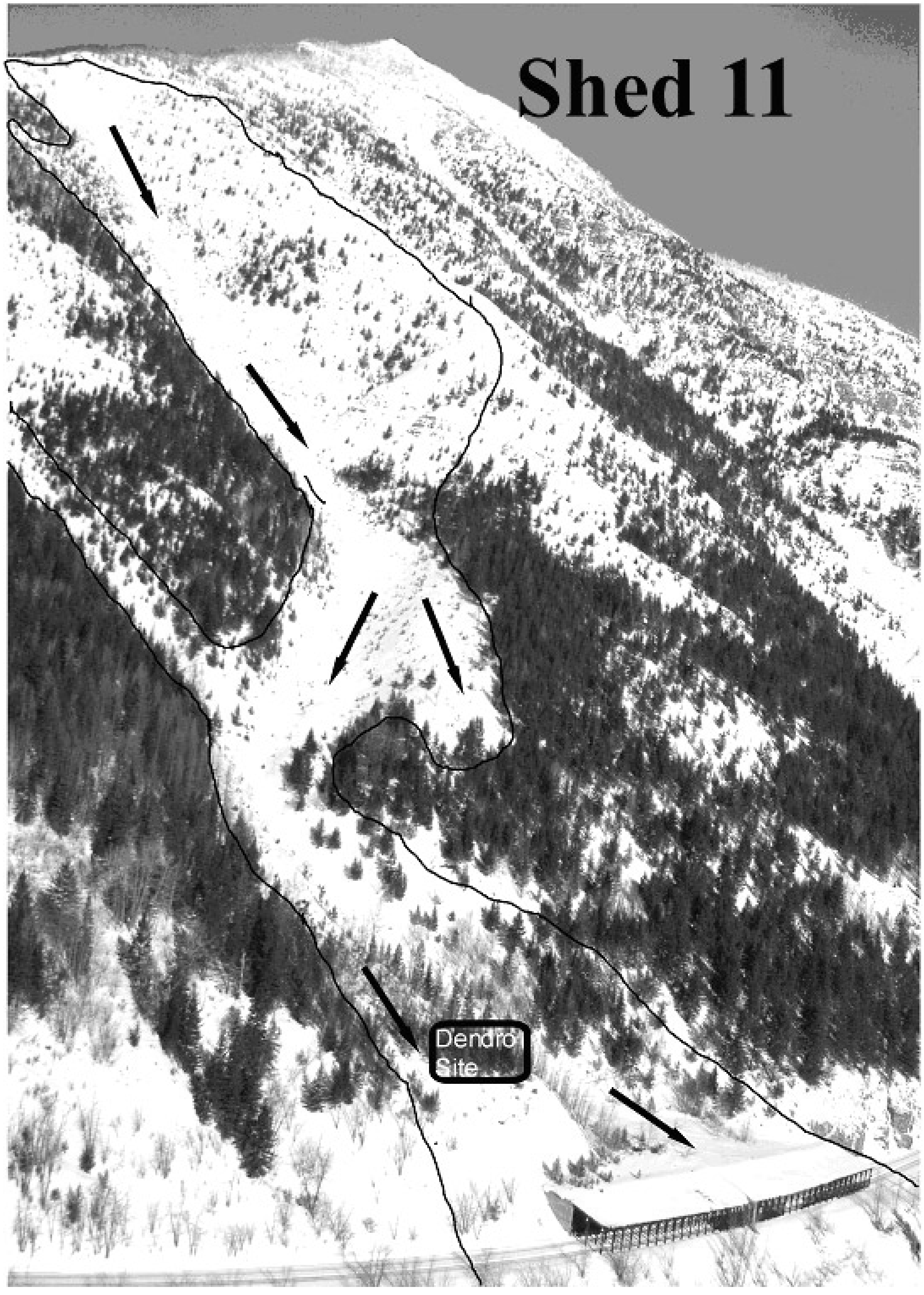
Fence Length- 550 feet

Milepost- 1163.40 to 1163.63

Path Width- 1,200 feet

Average Avalanche Width- 350 feet

Narrative Description-
Shed 10.7 is a frequent producer and is equipped with a shed to provide protection. The starting zone is concave with an average slope angle of 35 to 40 degrees. It gets steeper as it enters the track and makes a turn to the west. Beyond the turn, the slope becomes more planer and broad, retaining a slope angle of 30 degrees until it hits the beta point just above the shed. Two significant characteristics of this path are the natural deflection berm mid track and the shallow swale down slope near the shed. The deflection berm has a significant effect on the flow dynamics by redirecting avalanches to the west. The larger the avalanche event the further west it is diverted. This berm is the feature that is responsible for the shed being breached on the west side. The second feature, the swale near the bottom, is significant for smaller, more frequent events. The swale will channel debris back from small events towards the shed direction. A large powder avalanche is the major concern and destructive mechanism for shed breach. Evidence of shed breach is obvious from the surrounding vegetation. There are large quantities of destroyed timber above the signal fence on the west end of the shed, and almost all the trees are flagged and leaning in the breach/flow direction. The signal fence maintenance crew reports that alarms on this path are common. The signal box is in an exposed area outside of the shed on the west end. Historical records indicate very large avalanches from this path, often carrying into the valley floor and burying Highway 2 significantly.


Shed 11
Dendro Site

Shed 11

Starting zone elevation- 6,400 feet

Vertical fall- 2,200 feet

Starting zone angle- 37 degrees

Aspect- South

Beta Angle- 27 degrees

Alpha Angle- 23 degrees

Run-out Ratio- 85.2%

Frequency from records- 10 years

Frequency from dendro- 1997

Estimated combined frequency- 20 years

Shed Length- 400 feet

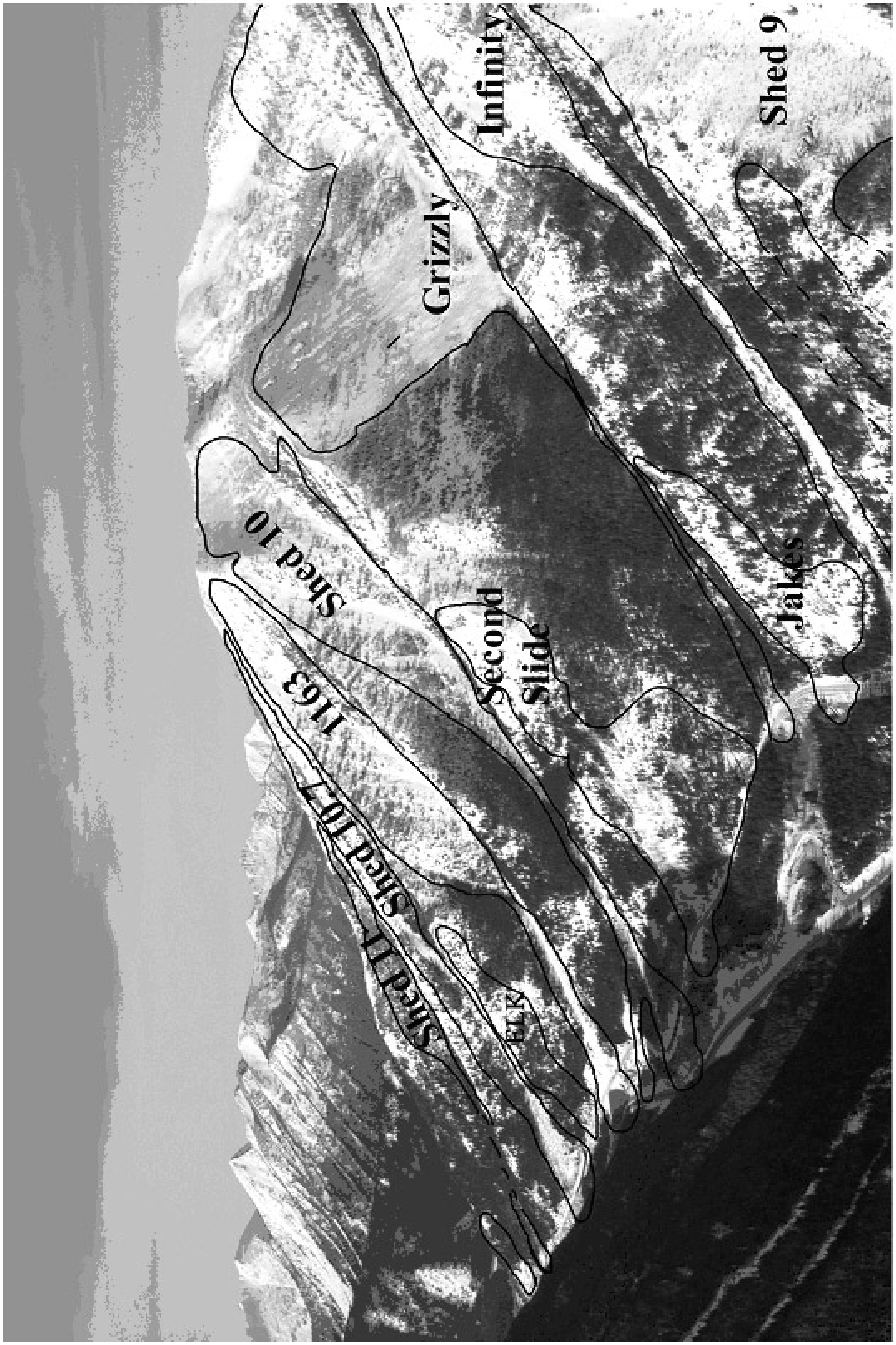
Fence Length- none

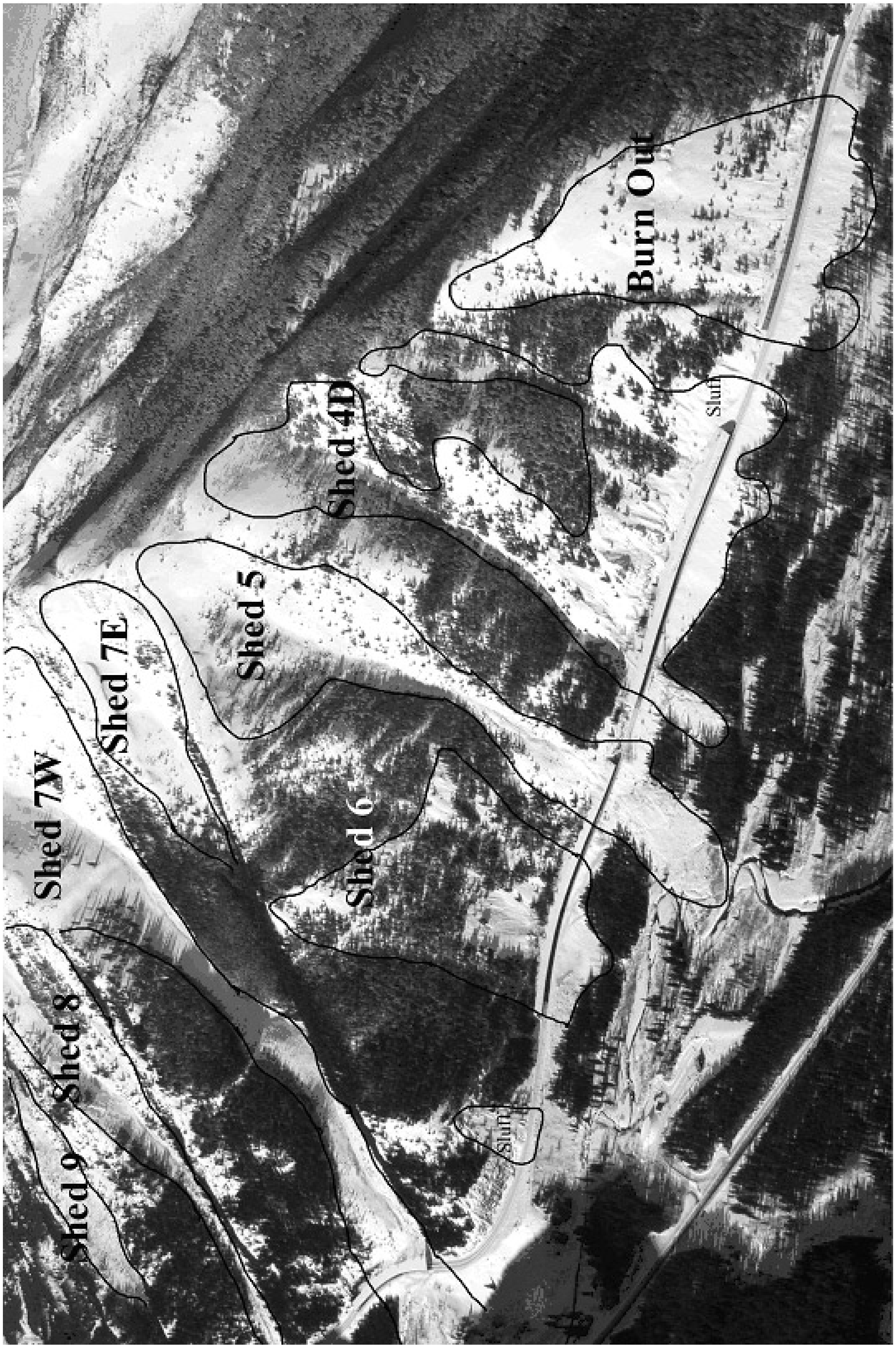
Milepost- 1163.81 to 1163.89

Path Width- 500 feet

Average Avalanche Width- 100 feet

Narrative Description-
Shed 11 path has a broad starting zone with a prominent rock band running laterally from ridge to ridge. The slope is concave with a few conifers on the southwest facing side. Otherwise, it is grassy with some rock outcroppings. The path quickly becomes deeply incised and no more then a 200' foot wide at the beta point just above the shed. The Alpha point is far below at the hwy where more damaged timber exists. The shape of the path near the shed is much channeled. This is the reason that the shed is reasonably effective and not breached in recent times on either side. The shed is in good shape and well placed, although the historical record indicates some breaching. Highway 2 is the deposition zone. Large events will send snow over the highway and up the opposing slope, which is more of a concern for the MDOT.


Shed 9
Infinity
Grizzly
Jakes
Second Slide
Shed 10
1163
Shed 10.7
Shed 11
ELK


Burn Out
Shed 4D
Shed 5
Shed 7E
Shed 7W
Shed 6
Shed 8
Shed 9

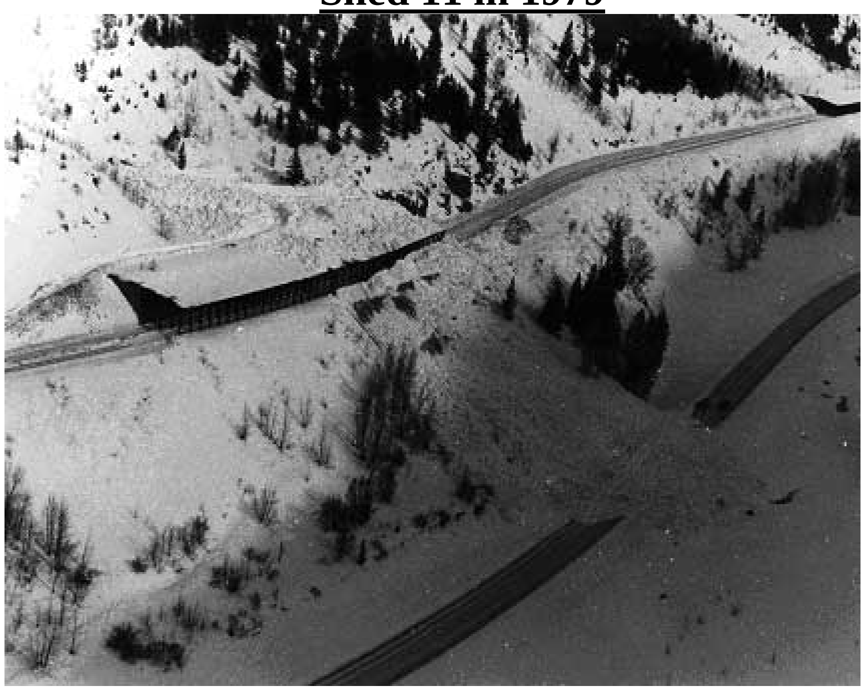
John Stevens Canyon
Avalanche Path and Safety Zone Locations

Path Name	Rail Mileage	Road Mileage from West Milepost 180=0.0	Threatened Infrastructure
Shed 12	1168.35	180.6	Rail
Never Runs		182.3	Road
Goat Lick		182.5	Road
Hanging Face		182.9 to 183.0	Road
I-Beam		183.7	Road
SAFETY ZONE		**183.9 to 185.5**	
Shed 11	1163.8 to 1163.89	185.8 to 185.9	Road and Rail
SAFETY ZONE		**186.0 to 186.1**	
Question Mark		186.2	Road
Shed 10.7	1163.48 to 1163.63	186.2 to 186.4	Road and Rail
Elk	1163.42 to 1163.45		
1163	1163.00 to 1163.40	186.7 to 186.8	Road and Rail
Broken Bridge		186.7 to 186.8	Road
Shed 10	1162.65 to 1162.74	187.1	Rail
Second Slide	1162.42 to 1162.50		
SAFETY ZONE		**187.0 to 187.4**	
Grizzly	1162.05 to 1162.10	187.5 to 187.6	Rail
Jakes	1161.89 to 1162.00	187.7 to 187.8	Rail
Infinity	1161.50 to 1161.58	188.0 to 188.1	Rail
Three Stooges		188.1 to 188.3	Road and Rail
Shed 9	1161.22 to 1161.29	188.5 to 188.6	Road and Rail
Silver Staircase	1161.27	188.6	Road
SAFETY ZONE		**188.7**	
Shed 8	1160.85 to 1160.97	188.9 to 189.0	Road and Rail
Shed 7	1160.49 to 1160.68	189.1 to 189.3	Road and Rail
Shed 6	1160.08	189.8 to 189.9	Rail
Shed 5	1159.94 to 1160.02	190.0 to 190.1	Rail
Shed 4-D	1159.67 to 1159.70	190.2 to 190.4	Rail
Burn Out	1159.28 to 1159.45		
		Ending Milepost 190.4	

Selected Historical Photographs

Sheds 5 and 6 in 1979

Shed 11 in 1979



III. Hazard Analysis

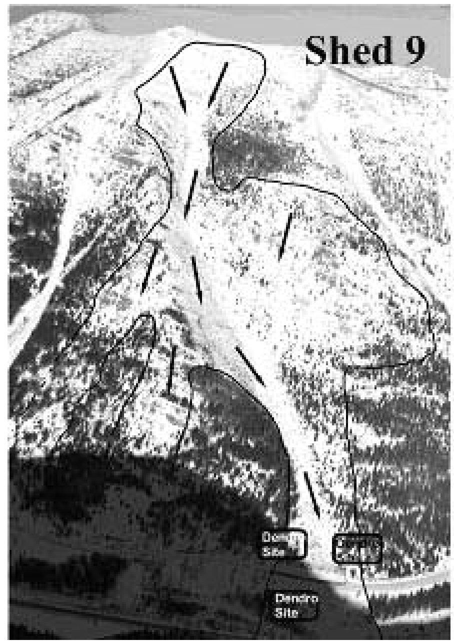
In order to provide a quantitative recommendation for appropriate mitigation techniques, it is necessary to compute the Avalanche Hazard Index. This index was developed in the 1970's and 1980's (Schaerer, 1989) to provide a comparative assessment of risk on various public highways and derive risk-based mitigation schemes. This work was later refined and modified to include railroads by the author in 1994. Formulas and equations used in this process are well accepted tools in the avalanche field, and allow comparison of avalanche risks to those undertaken in other areas such as normal highway traffic and the types of risks we take in our everyday lives. The ability to "normalize" the risk comparisons is an important tool for ensuring the outcome of the plan is consistent with other risk mitigation techniques and standards.

3.1. Input parameters

3.1.1. Frequency/magnitude relationship

Of paramount importance in quantifying avalanche hazard is the frequency and size of avalanche events for each path. The longer and more consistent these records are, the more accurate the computation of avalanche risk is. The equations used to compute risk in their base mode are used to calculate encounter probability. This is an expression of the amount of traffic passing under an avalanche path in comparison to the size and frequency of avalanches. Considerable efforts were expended to find consistent records for this purpose, but they are simply not available in more recent history. There is anecdotal information that can be helpful in terms of establishing the frequency of major avalanche winters, but the more recent information is not specific enough to be relied upon for the purpose of risk computations.

The historical database used for this analysis was derived through consistent records taken in the early 1900's for a period of 22 years. These older records systematically recorded date, time, location, and size for all avalanche events between 1910 and 1932. We know that a significant fire event swept the canyon about 1910 and would therefore expect that regeneration of tree cover has resulted in lessening the avalanche risk in some locations. In locations where there are still obvious avalanche chutes, this re-growth probably plays no role in changing the frequency or magnitude of avalanche events. In some cases, like the path known as "Elk" in the data set, the location is heavily filled with trees and is therefore unlikely to produce a number of events to the track level. One must be careful not to rule these paths out of contention altogether because in terrain this steep unusual avalanche events can clean out old timber and show up in odd locations. An example of the re-growth of vegetation is provided in comparing pictures taken in 1979 of the Shed 9 area to those taken last year.

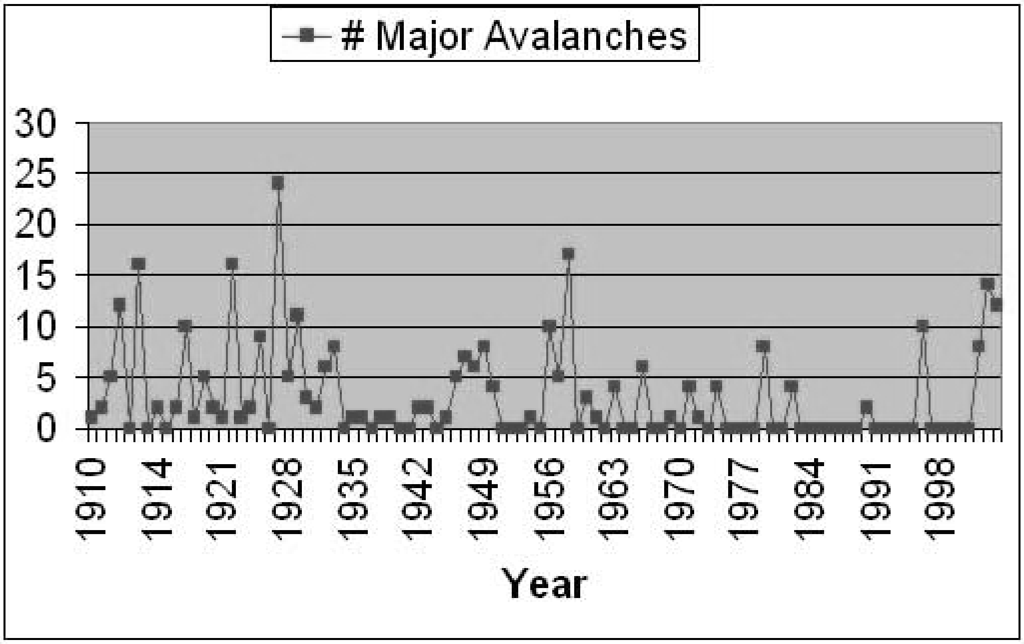


Augmenting this older information with more current information, this study analyzed tree ring cores in most of the avalanche paths. This sample of over 200 cores was analyzed to determine the periodicity of reaction wood from avalanche impacts. The derived information was used along with old records, topography, and current vegetative cover to derive both avalanche frequency and magnitude or length of deposit on the track. There are inherent inaccuracies in combining these methods to derive these important parameters. As time goes on a set of more consistent records can be kept that will help to adjust the derived risk equations.

3.1.2. Major Avalanche Cycles

Time periods that produce a number of large avalanche events are reasonably easy to quantify. Workers that have been around for a number of years have usually seen a number of events. Newspapers commonly log events that disrupt traffic or cause problems to the railroad. Though the record base for identifying big avalanche cycles may not be perfect, the available information does help identify a rough periodicity to major outbreaks of “avalanche weather”. Based on the evidence, major avalanche cycles occur in the area approximately every three years over the past 95 years of records. In the past fifteen years, the period is more on the order of five year intervals, although this may be an aberration due to the lack of good record keeping. There is sufficient information in the database to say that avalanches are not an usual occurrence in the canyon, and major avalanche cycles can be expected to disrupt traffic and threaten people on some fairly regular interval into the future. This is particularly important in terms of mitigation alternatives. The economic impacts experienced last winter can be expected to repeat themselves on a regular interval, resulting in comparable losses on the average of once every three to seven years.

Figure 3.1-Major Avalanche Cycles



3.1.3. Traffic

Rail and support traffic are important input parameters. The more traffic there is and the slower it is moving, the greater the risk. As the BNSF is a high volume line moving up to 40 long trains per day, this factor is expected to affect the risk factors considerably. Also an important traffic factor is the type of rail traffic. Freight cars with no one aboard do not register the same type of concern in terms of risk as a fully loaded Amtrak car. The type of cargo hauled in the freight cars is a consideration, particularly if high volumes of hazardous materials are carried. Locomotives are quite expensive and have crews aboard, compounding risk contribution. Work crews contribute to risk but are calculated separately.

For calculating encounter probability, the average number of cars, locomotives, passenger cars, and mini-dozers per day were derived. This was used in the encounter calculations to derive a probability for each category, which helps to identify the risk contributed by each class of traffic. There is also an input factor for the speed of traffic, stopping distance, and the length of the cars since they all effect encounter probability.

3.1.4. Damage and Cost

Imbedded in the Avalanche Hazard Index is a calculation for economic impacts resulting from avalanche encounters. In the event of an encounter, probabilities are assigned to the event with respect to the potential for damage and/or loss of life. A value is then assigned to each class of vehicle. For the sake of these computations, a value of $100,000 was assigned to rail cars, $3,000,000 to locomotives, $25,000,000 to passenger cars, and $2,000,000 to the minidozers used for clearing snow. These values can be adjusted at the discretion of management at BNSF should they seem inappropriate. In the case of being hit by an avalanche, the probability of this encounter resulting in the described damage is also used in the equations. Avalanches are differentiated between “light” avalanches that are smaller and have less impact force, and “deep” with higher volumes and more impact force. Several paths only have “light” avalanches on them. Other paths were assigned a value of half to each category. The probability of an avalanche impact resulting in the described damage is given below as:

Figure 3.2-Damage Probability

	Freight Car	Locomotive	Passenger Car	Minidozer
Light	50%	20%	10%	10%
Deep	80%	50%	50%	50%

3.2. Encounter Probability

The following two graphs provide the computed encounter probabilities for the significant paths in the canyon. In this case, the probabilities are given as units or cars hit per year on the average. Actual incidents have occurred numerous times in the past, but the computed results are somewhat higher than events that have actually occurred. This variance is likely attributable to closures forced on the line by avalanche events.

3.2.1. Probability by path

On the following page, Figure 3.3, the annual frequency for each avalanche path is given. These provide an easy overview as to which paths are the most likely to run to the track level.

Figure 3.3-Encounter Probability by Path

Name	Return Period	Width in meters	Path Totals
Burn Out	2	159.09	0.82
Shed 5	20	45.45	0.06
Shed 7	3	36.36	0.36
Shed 8	20	30.30	0.05
Shed 9	10	30.30	0.11
Infinity	10	78.79	0.13
Jakes	3	60.61	0.40
Grizzly	100	30.30	0.01
Second Slide	3	66.67	0.41
Shed 10	10	60.61	0.12
Path 1163	5	90.91	0.27
Elk	50	36.36	0.02
Shed 10.7	10	103.03	0.14
Shed 11	20	37.88	0.05
Total			**2.94**

From this analysis, it is obvious that the probability of an encounter is highest in the Burn Out path, followed by Second Slide, Jakes, Shed 7, and 1163 in that order.

3.2.2. Probability by Equipment Type

In this computation, the calculated annual encounters for each equipment type are given.

Figure 3.4- Encounter Probability by Equipment Type

Name	Freight	Locomotive	Passenger	Minidozer
Burn Out	0.7694	0.0419	0.0097	0.0001
Shed 5	0.0526	0.0029	0.0007	0.0002
Shed 7	0.3376	0.0184	0.0043	0.0003
Shed 8	0.0493	0.0027	0.0006	0.0003
Shed 9	0.0987	0.0054	0.0013	0.0003
Infinity	0.1195	0.0065	0.0015	0.0001
Jakes	0.3723	0.0203	0.0047	0.0002
Grizzly	0.0099	0.0005	0.0001	0.0003
Second Slide	0.3809	0.0208	0.0048	0.0002
Shed 10	0.1117	0.0061	0.0014	0.0002
Path 1163	0.2493	0.0136	0.0032	0.0001
Elk	0.0203	0.0011	0.0003	0.0003
Shed 10.7	0.1299	0.0071	0.0016	0.0001
Shed 11	0.0510	0.0028	0.0006	0.0003
Total	**2.7523**	**0.1500**	**0.0349**	**0.0029**

Without any mitigation efforts, on the average there would be 2.7 freight cars hit per year. One locomotive would be hit every roughly 7 years and one passenger car hit every 33 years. The mini-dozers would be hit on the average once every 500 years. The most closely matched record of actual results is in the locomotive category in which there are numerous examples of locomotives being hit and some of them destroyed. Actual damage to freight cars is not as well documented or doesn't track closely to computed results, although last winter's 15 cars is computed as a 6 year allotment of damage. With respect to passenger trains, the most likely scenario is that several cars would be hit once every roughly 100 years, so there is some probability that this scenario has not played out in the observed time frame.

3.3. Avalanche Hazard Index (AHI)

Once the encounter probabilities are determined, a calculation of risk can be derived. The equations used are "normalized" to express risk on the basis of the numerical value of one (1) being comparable to the types of risk we take in our everyday lives. These equations were specifically developed for use in highway avalanche situations, so the index of one yields losses comparable to those experienced in normal driving conditions. Thus, a computed index of 100 would mean the anticipated losses would be 100 times the loss rate experienced in a public highway situation. By way of comparison, the riskiest highway avalanche location in North America, Rogers Pass in British Columbia, has an AHI of 1,003. The Alaska Railroad, where there is an active avalanche mitigation program, has an index of 20. In most cases, an index above 10 is sufficient to warrant some type of risk mitigation program. Almost all highway situations with an index of over 40 have a full time avalanche management program operating to reduce risk.

The computed AHI has two different categories, one for moving traffic and one for stopped traffic. The computations used for these categories are somewhat different. The moving category uses the frequency and width of avalanches along with traffic levels to compute risk. In a large number of locations, if a train is stopped by an avalanche it is exposed to four or five other avalanche paths along its length. Given the fact that the terrain is similar in exposure, aspect, and elevation it is likely that once the canyon becomes critically unstable, it unloads avalanches from numerous paths in a short period of time. Historical records point to this pattern of behavior as well. For that reason, once a train has stopped the probability of an avalanche in the next few hours in an adjacent path is quite high, and the resulting computed AHI for waiting traffic is substantial.

With respect to the waiting traffic, assumptions were made as to the probability of adjacent avalanche paths running in a given time period. Observations from other locations have given that probability as ranging from 5% to 30% over a 2 hour period. In this case, we have assumed a probability of 20% in a two hour time period based on the historical record. The two hour time frame is assumed as the minimum amount of time it takes to clear the trains at the head end, back them down hill and out of the avalanche zones, or assist them back uphill and out of the hazard.

An assumption was also made that only half the train traffic would fall into the waiting category. Eastbound train traffic encountering an avalanche can easily back downhill out of the avalanche zones. Westbound trains lack the power to back uphill and thus are stuck until rescued from one end or another.

Procedures are outlined in Chapter 4 to mitigate the risk of waiting traffic being hit by an avalanche in an adjacent path. Procedures will need to be established to minimize the holding time in avalanche run-out zones for any trains in the area.

3.3.1. Avalanche Hazard Index by Path

Computed values for each path are provided in the following table.

Figure 3.5- Avalanche Hazard Index by Path

Name	Light	Deep	Moving Sub-total	Waiting Sub-total	Total
Burn Out	9.54		9.54	2.16	11.70
Shed 5	0.33	1.23	1.56	4.83	6.39
Shed 7	2.09	7.86	9.95	5.60	15.55
Shed 8	0.31	1.16	1.46	2.82	4.28
Shed 9	0.61	2.30	2.92	3.77	6.69
Infinity	0.74	2.78	3.52	3.65	7.17
Jakes	4.62		4.62	3.83	8.44
Grizzly	0.13		0.13	4.82	4.94
Second Slide	4.72		4.72	4.53	9.25
Shed 10	0.69	2.60	3.29	5.00	8.29
Path 1163	1.55	5.80	7.34	3.41	10.75
Elk	0.25		0.25	3.78	4.03
Shed 10.7	0.81	3.02	3.83	3.91	7.74
Shed 11	0.32	1.19	1.51	3.70	5.21
		Sub-total	**54.64**	**55.80**	**110.45**

Analysis of this table shows that the hazard index is not directly related to the encounter probability on a given path. Note that Grizzly, which has a frequency of once every 100 years and thus a very low hazard index for moving traffic, contributes a significant index number when it does hit the tracks by backing up traffic into all the adjacent avalanche paths. Burn Out has a high moving index, but a low waiting index because a train stopped by this path on one side is not exposed to any avalanches, and on the other is in a fairly protected location.

The paths that require the most attention become obvious in this calculation. In order of importance the most critical are Shed 7, Burn Out, 1163, Second Slide, Jakes, Shed 10.7, and Infinity.

IV. Mitigation

Clearly, the computed index range is above the normal threshold for action. This section addresses a range of risk mitigation alternatives to bring the AHI down to an acceptable range. The range of alternatives is also analyzed for cost to benefit ratios.

4.1. Overview

The following section discusses some interrelated topics that affect all mitigation alternatives. They are topical as issues the authors have seen arise over years of putting these types of programs into effect, and thus relate to the set of expectations various entities might have about how the program should operate.

4.1.1. Institutionalizing an Avalanche Program

It takes a number of years for avalanche awareness to become infused in a company's culture. At first there are usually some skeptics that feel a program is not necessary, and do not have a good understanding of the risks that have become accepted. These risks are typically accepted as long as there is not a big catastrophe with resulting loss of life. There is typically a feeling that not much can be done about avalanches, which is not true. The current report was a direct result of last winter's accident. While there was no loss of life, just damage to rail cars and loss of revenue, there were a number of close calls with people sorting out the accident. Clearly, BNSF has made the commitment to change their approach to avalanches in the Canyon by tasking this study. The results of the changes will manifest themselves slowly in operations and it will only be down the road five to ten years that people will look back and wonder how they tolerated doing things the "old" way for so long.

4.1.2. Staying the Course

Avalanche programs cost money and time. Sometimes there may be a period of two or three years where there is little avalanche activity. Analysts sensitive to budget issues will look to the program as being expensive for the results produced. They will need to keep in mind that large avalanche events are cyclical in nature. The investments are made just to be able to handle periodic outbreaks of activity in a safe manner. It is important to keep the proposed mitigation systems in place, ready for these events to come along. Another way of looking at mitigation is that it is comparable to an insurance policy.

Another important point is that there is no foolproof mitigation system when it comes to dealing with avalanches. Programs are put into place to cut the odds of an unfortunate event happening. There are too many variables in avalanche behavior to ensure that nothing will happen after a program is in place. It is important to understand that avalanche programs are effective in reducing risk, but not eliminating it. For that reason, there is some small probability that the line could go on as it is for another 100 years without a bad accident happening. There is also some small probability that the investment could be made into reducing avalanche risk and there is a bad accident the first year of the new program. The probabilities however, are against either of these scenarios but are in favor of a measured approach towards risk reduction.

4.1.3. Approximating the State of the Art

As in all fields, the “state of the art” in avalanche programs is constantly changing and being upgraded. As time goes on there is more reliance on technology, although field work still remains a core endeavor. Avalanche programs that approximate the “state of the art” have generally withstood legal scrutiny in the event of an accident. Those who are cognizant of the risk but choose to either run a sub-standard program or none at all have not fared as well in the legal system. Between the pressures of the legal system, the workman’s compensation program, and the requirements under the federal “right to know” laws about workplace safety, the need to keep the system operating close to the “state of the art” is apparent. This requires on-going modifications to the program and a commitment to sending personnel to an adequate amount of training and workshops to keep them abreast of recent developments that might be incorporated into the system.

4.1.4. Realistic implementation time frames

Whatever mitigation methods are accepted, it is likely to take several years to implement the program. Defensive structures take time to design and build. If military artillery is decided on, it will take two to four years to acquire and establish the platforms and storage facilities. Permits will be necessary for any activities in Glacier National Park. This will undoubtedly trigger a thorough NEPA environmental review with attendant controversy. Meanwhile the risk will continue to be present in some form during the implementation period. The important issue is to implement those parts of the program that can be done immediately, and continue working hard to implement the other parts as time and budget allow. Bringing the risk index down to the ultimate goal in one year is not realistic. Avoiding big accidents in the first year by using forecasting and closures along with other procedures <u>is</u> realistic. The reality is that the avalanche risk is only high for fairly short time periods spaced out chronologically. A good avalanche forecaster can reasonably predict these short time periods and implement risk reduction strategies with whatever tools are available to them at that time. As time goes on and the program matures, more tools will become available to assist in this endeavor, helping to reduce the risk towards the ultimate goal.

4.1.5. Environmental constraints

Nationally there has been no significant environmental controversy over the application of avalanche risk reduction strategies. Most of the major highway and railroad programs use military artillery fired from the valley floor to control risk. This has been a time proven and effective method of risk reduction. However, there are likely to be sensitivities to introducing explosive control to the southern edge of Glacier National Park. There may be issues with introducing fixed facilities such as avalanche detectors onto park lands as well because of their designation as proposed wilderness.

John Stevens Canyon is an important winter wildlife corridor that possibly contains species of concern. Explosives control could put some of these animals at risk. The area is used by ski touring parties that may be exposed to avalanches created by an explosives control program. The residue from explosives and possible duds could be a hazard. Offsetting these issues of concern are the risk to personnel presented by the avalanche hazard, and the possibility that an avalanche event could result in the spill of hazardous materials into the Wild and Scenic River corridor. Even spilling grain in the corridor has had negative consequences to wildlife in the area. These issues will need to be carefully weighed by the affected stakeholders. An open dialogue will be important in balancing objectives.

In weighing out the potential issues, it will be important for stakeholders to keep in mind the importance of maintaining the values of Glacier National Park. One of the most important mandates is to apply the minimum acceptable tool to accomplish a goal. As an example, if a load of material needs to go into a site in the park and can be transported by backpacking instead of helicopter, even though it might cost more this is the approach that would likely be undertaken by the park. Balancing these objectives out is beyond the scope of this analysis and will likely occur in some later process, but the application of park values has been considered in the mitigation alternatives and options are forwarded that may better fit these principals.

4.2. Risk to Personnel

While the majority of the risk identified in the Avalanche Hazard Index is directly related to the number of freight cars, risk to personnel from avalanches is a significant factor as well. Modern standards for workplace safety dictate an aggressive approach to managing avalanche risk to workers on the line. Without mitigation efforts, the risk tends to be quite considerable for some classes of workers. Foremost in this category are the signalman. Their job requires that they repair slide fences in avalanche run-out zones during periods of the highest risk. They are also unprotected by being out in the open without a vehicle around them. A relatively low loss rate in the canyon is likely just the fact that there is not a considerable amount of man-hours spent annually in avalanche zones. Another probable protection factor is that when avalanche cycles start coming on, some of the work crews have curtailed their activities in avalanche zones until conditions improved.

On the following table, annual exposure rates are calculated for each class of worker. In all cases, the probability of a fatality from an encounter is assigned and used to adjust the exposure minutes. Unfortunately, with avalanches as big as those in the canyon, the probability of an event resulting in a fatality is relatively high. The assigned probabilities range from a high of 80% for signalman, to a low of 20% for trainman.

Figure 4.1-Annual Exposure by worker class

	Exposure min./year	Minutes/ week	# of weeks	Fatality Probability	Risk min. per year
Signalman	4,500	450	10	80%	3,600
Minidozer	960	96	10	40%	384
Inspector	1,300	50	26	50%	650
Track worker	480	120	4	60%	288
Train crew	3,640	140	26	20%	728
Operator	1,200	1,200	1	40%	480

On the following page, Figure 4.2 documents the computed encounter probability as well as giving possible fatality rates that can be compared to current safety records for other activities along the line.

Figure 4.2-Personnel Risk Calculations

Name	Return Prd.	Signalman	Minidozer	Inspector	Track worker	Train crew	Operator
Burn Out	2	0.00156	0.00013	0.00023	0.00010	0.00025	0.00017
Shed 5	20	0.00002	0.00000	0.00000	0.00000	0.00000	0.00000
Shed 7	3	0.00017	0.00001	0.00003	0.00001	0.00003	0.00002
Shed 8	20	0.00002	0.00000	0.00000	0.00000	0.00000	0.00000
Shed 9	10	0.00003	0.00000	0.00001	0.00000	0.00001	0.00000
Infinity	10	0.00014	0.00001	0.00002	0.00001	0.00002	0.00001
Jakes	3	0.00069	0.00006	0.00010	0.00004	0.00011	0.00007
Grizzly	100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Second Slide	3	0.00052	0.00004	0.00008	0.00003	0.00008	0.00006
Shed 10	10	0.00012	0.00001	0.00002	0.00001	0.00002	0.00001
Path 1163	5	0.00083	0.00007	0.00012	0.00005	0.00013	0.00009
Elk	50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Shed 10.7	10	0.00019	0.00002	0.00003	0.00001	0.00003	0.00002
Shed 11	20	0.00003	0.00000	0.00000	0.00000	0.00000	0.00000
Fatality probability/yr.		0.43%	0.04%	0.06%	0.03%	0.07%	0.05%
Fatality rate/200,000 MH		**0.43**	**0.04**	**0.06**	**0.03**	**0.07**	**0.05**
Man hrs./season		2000	2000	2000	3000	9000	1000
Avg. # of years for fatality		231	2705	1598	2405	317	4329

From these calculations, it is obvious that protecting signalman is the most important item that can be done to lessen risk to personnel. Unique and specific steps should be taken to provide signalman with additional safety margins. Since the other classes of exposed personnel have fairly similar individual exposure rates, a broad approach that reduces overall risks can be used to lessen the risk to these workers.

Safety statistics provided by BNSF show an average fatality rate on the entire railroad as approximately 1 per 15,000,000 man hours, or a rate of .013 per 200,000 man hours. The computed rates above, with the exception of the signalmen, are between 2 and 4 times higher. Whichever mitigation method is chosen in the following section will reduce this risk by approximately 80%-90%, which should bring the calculated risk in line with other risk factors.

4.2.1. Signalman Risk Reduction

There are various options that can be used to lessen avalanche risk to signalman. These methods will need to be analyzed and incorporated into the proposed risk mitigation program as appropriate.

The first and perhaps simplest method is to live with the consequences of avalanches taking out signal fences until the snow-pack stabilizes enough to repair the fence. The result would be trains operating at restricted speed two to three times per winter for periods of 24-48 hours. The effect on train traffic could be significant enough that this is not a chosen method, but it should be analyzed as an option. In the case that this option is chosen, it would require the use of a qualified avalanche forecaster to choose those times when it is appropriate to repair the fences.

Either with or without the delayed repair approach outlined above, any repair of the fencing should be done under strict entry protocols similar to those employed in closed space entry programs. There should always be a spotter for further avalanche activity, good communications to the work crew, avalanche rescue equipment on all parties, an escape route planned, and at least one rescuer in a nearby avalanche safe zone for every worker in the avalanche zone plus one person.

Wherever possible, exposed signal boxes should be re-located to protected positions. This will help minimize the amount of exposure time for workers.

In the case of the Burn Out slide path, explosive control work should be considered to safeguard workers prior to them entering the zone. There may be times when the stability is sufficiently good to bypass this approach, but the consequences of getting caught in even a very small avalanche here are severe due to the high wall above the tracks.

Advanced detection capabilities should be considered that employ remote sensors to detect avalanches and trigger alarms or set signals. Typically, a set of Doppler radars and geophones do the sensing for avalanche detection. These systems are operating on the Swiss Rail and Alaska Railroad with some success. They can be placed in such a position that workers are not required to attend to them in the winter. Signalman would thus be relieved of the necessity of maintaining the wire in the run-out zones.

The downside to this approach is it would require some permanent installations in Glacier National Park. This may not be feasible from an environmental perspective.

A combination of these approaches could also be used to bring the risk rate down to a comparable level with other workers. As an example, an approach that used explosives when needed on Burn-out to reduce the risk there by 80%, delayed replacement of signal wire on paths with a 10 year or more return period, used the rescue team/buddy system approach for a 10% reduction, installed a longer snow-shed at Shed 7, and used advance detection on a few key paths would reduce the risk to a level identified in the following table.

Figure 4.3-Signalman Risk Reduction

Name	**Return Period**	**Base Probability**	**Buddy System**	**Hand Charges**	**Delay Wiring**	**Extend Shed**	**New Detector**	**Revised Probability**
Burn Out	2	0.00156	0.00016	0.00113				0.00028
Shed 5	20	0.00002	0.00000		0.00001			0.00001
Shed 7	3	0.00017				0.00017		0.00000
Shed 8	20	0.00002	0.00000		0.00001			0.00001
Shed 9	10	0.00003	0.00000		0.00002			0.00001
Infinity	10	0.00014	0.00001		0.00007			0.00006
Jakes	3	0.00069					0.00069	0.00000
Grizzly	100	0.00000	0.00000					0.00000
Second Slide	3	0.00052					0.00052	0.00000
Shed 10	10	0.00012	0.00001		0.00006			0.00005
Path 1163	5	0.00083					0.00083	0.00000
Elk	50	0.00000	0.00000		0.00000			0.00000
Shed 10.7	10	0.00019	0.00002		0.00010			0.00008
Shed 11	20	0.00003	0.00000		0.00001			0.00001
Fatality probability/yr.		0.43%						0.05%
Fatalities/200,000 MH		**0.43**						**0.05**
Man hrs. per season		2000						2000
Avg. # of years for fatality		**231**						**2000**

Of these strategies, the most difficult to achieve may be the installation of advanced detection systems. While these systems are in use in other locations, they have not been tied into signal systems in the U.S. yet. Their reliability will need to be proven over a period of time before they are accepted as the primary means of avalanche detection. There is also a rate of false alarms with these systems that will need to be adjusted for operationally.

The principal reason detectors are used is to keep train speeds at normal levels. The most likely damage to a train is caused when it runs into an avalanche deposit from a previously released avalanche and derails. This sticks the train in adjacent avalanche paths for a period of hours to days as well as causing other complications. For this reason, detection systems are used to allow normal traffic flow until an avalanche disrupts the system. Once the detectors are triggered, train traffic slows to restricted speed in order to avoid running into an avalanche deposit. The problem with the current system is that it also has a high false alarm rate when wires are stretched by snow creep, affected by small sluffs, or otherwise grounded out. In this case, the current approach demands that a signalman fix the problem before traffic can resume normal speed. Slowing down trains increases the likelihood of getting hit by a moving avalanche proportionately. The ideal system would be quickly re-set upon verification that no avalanche is on the tracks, and reliably alarm when avalanche events occur but not for other reasons. The advanced detection systems can likely reach this goal while there is no chance the old signal fence system can ever achieve it. Therefore, movement towards implementing the more advanced systems and working with the FRA to address the reliability concerns appears to be the best course. In all likelihood, the improvements would pay for themselves over time because of reduced personnel costs. Some patience will be required however as the technology is relatively new and requires trouble shooting and adjustment of variables before it can achieve the desired results.

4.2.2. Other worker risk reduction

In the case of the other classes of workers, proposed mitigation alternatives will effectively reduce their risk level by between 80% and 90% from current levels. The application of these alternatives will also apply to the residual risk factors for signalman as well. Any approach will require a considerable investment in implementing solid avalanche training and risk mitigation techniques into the work force.

One important note with respect to trainmen is that strategies need to be in place to keep them from having to walk along any stuck trains to tie down hand brakes. If a train is delayed or stopped by an avalanche, the risk of another avalanche in an adjacent path is inherently high. Procedures should be in place to get the delayed train out of the canyon without the train crew having to leave the relative protection of the locomotive.

One of the major factors that will help lower the risk level is putting policies in place that promote the longevity of workers in avalanche territory. There is a knowledge base inherent in this type of work that accumulates over a period of years. Achieving a low turnover rate is very important in building a core of experienced people capable of handling any avalanche crisis that arises. Of particular importance is the continuity of the avalanche forecaster, signalman, and mini-dozer operators as they are the core people that have to respond to avalanche situations.

4.2.3. Amtrak

Almost 8 % of the total derived avalanche hazard is generated by running one passenger train per day each direction on the line. While the potential for an avalanche to hit a passenger train is relatively low, the consequences from the encounter are very high, and thus the risk index contribution is great. Running passenger trains through periods of high avalanche activity represents a very large risk to BNSF. Serious consideration should be given to diverting this passenger traffic to other modes of transport during periods of moderate to high avalanche potential.

4.3. Avalanche Hazard Index mitigation

Several different options are identified below for reducing the overall Avalanche Hazard Index to an acceptable level. These approaches might mirror closely the alternatives that would be required for a NEPA analysis.

Several factors go into determining the proposed acceptable risk index level. One is the industry accepted standards of 10 for implementing some type of risk reduction strategy such as closures, and 40 for implementing a full avalanche program. While a goal level of 1 would be the desired level in a highway situation, since a majority of the identified index for BNSF is derived by objects that have no people on board, and we have discussed risk reduction strategies for people separately, it may be acceptable to reduce the index with mitigation strategies to a level of between 5 and 10. This also has the attendant benefit of reducing the expected impacts on park resource values somewhat.

This analysis assumes that long closure periods in any but the most extreme avalanche conditions are basically unacceptable to this national transportation corridor. The flow of interstate commerce through this line is vital to a variety of business sectors across the country. Quantifying the hard costs of stopping train traffic is fairly easy, but calculating the soft costs in terms of impacts to other business and services is difficult. As the country moves increasingly to just-in-time delivery of goods, this vitality becomes more important. For that reason, discussion of options that envision accepting long closure periods has not been entertained.

4.3.1. Snowsheds

Avalanches were such a significant problem shortly after the line was built that snowsheds were built to mitigate the most problematic areas. The majority of serious avalanche terrain is currently protected by snowsheds. Maintenance of these sheds costs around $40,000 per year according to BNSF personnel. While the most frequent running paths have been protected, the remaining paths identified as contributing to the current AHI either have no sheds because they run infrequently, or the existing sheds are breached on one or both ends occasionally. From the standpoint of protection against avalanche hazards, snowsheds provide almost complete protection when they are long enough to prevent breach on the ends. They cost approximately $7,000 per foot to build according to recent BNSF estimates. Track structure inside snowsheds is somewhat more difficult to maintain than track outside the sheds, so there is either a resulting higher cost to maintenance of track or lowered maintenance standards.

In order to reduce the avalanche risk index to an appropriate level, a considerable footage of new showshed construction would be required. The following table identifies the required lengths and locations in order to bring the index value down to the proposed target.

One of the advantages of implementing this mitigation approach is the almost complete protection of personnel without further investment in an annually recurring avalanche program. Another is the negligible effect on park values and environmental resources. The disadvantage is the very high initial capital costs required to implement the strategy. In a corporate environment where there is competition for capital to mitigate other risk considerations as well, the ability to generate the large sums required for this approach may be compromised.

Figure 4.4- Mitigation by Snowsheds

Slide Path	Existing Shed length	Fence Length		New Shed Length
Burn Out		750		900
Shed 5	380			100
Shed 6	820			
Shed 7	1,000	100		150
Shed 8	650			100
Shed 9	400			100
Infinity				400
Jakes		600		600
Grizzly				
Second Slide		440		440
Shed 10	500			
Path 1163		2,140		1,200
Elk				
Shed 10.7	670			550
Shed 11	400			150
Current Total	**4,820**	**Total New**		**4,690**
	Cost @$7,000/ft		**$**	**32,830,000**
50 year life cycle-annual replacement cost			**$**	**656,600**
	Annual New Maintenance Estimate		**$**	**38,921**
	Total annual costs		**$**	**695,521**

Residual risk levels derived from this approach would be a total AHI of 7.71 between the Elk, Grizzly, and Shed 10 paths, which would remain unprotected.

4.3.2. Snowsheds and Avalanche Management Program

Combining the installation of several key snowsheds with an avalanche management program offers an alternative to the all-shed approach. This strategy would be used to mitigate the risk in the highest index paths with snowsheds, and initiate an active avalanche management program involving forecasting and explosive control for other paths. The combination would result in lower capital costs than the all-shed approach, but offer lower environmental impacts than an approach that only utilizes a management program.

Using this scenario, an expected result would be as follows:

Figure 4.5-Sheds with Avalanche Program

Name	**Base AHI**	**Shed Feet**	**Snow Shed Reduction**	**Revised AHI After Sheds**	**Program @ 70%**	**Final AHI**
Burn Out	11.70	900		9.54	8.58	0.95
Shed 5	6.39	100	6.39	0.00	0.00	0.00
Shed 7	15.55	150	15.55	0.00	0.00	0.00
Shed 8	4.28			2.07	1.45	0.62
Shed 9	6.69	100	6.69	0.00	0.00	0.00
Infinity	7.17	400		3.99	2.79	1.20
Jakes	8.44	600	8.44	0.00	0.00	0.00
Grizzly	4.94	0		2.65	1.85	0.79
Second Slide	9.25	440	9.25	0.00	0.00	0.00
Shed 10	8.29	350		6.07	4.25	1.82
Path 1163	10.75	1,200		8.70	6.09	2.61
Elk	4.03	0		3.03	2.12	0.91
Shed 10.7	7.74	550		6.60	4.62	1.98
Shed 11	5.21	150	5.21	0.00	0.00	0.00
Total	**110.43**		**67.78**	**42.65**	**31.76**	**10.89**

	New Shed footage	1,540	Annual cost shed maintenance	$12,782
Capital cost	New Shed Costs	$10,780,000	Annual cost snowshed capital	$215,600
Capital cost	Detection systems	$1,200,000	Annual cost program capital	$115,000
Capital cost	Forecast and control	$1,100,000	Annual program budget	$120,000
Total capital cost		**$13,080,000**	**Total annual cost**	**$463,382**

Application of an avalanche management program consisting of forecasting, control, rescue, and training has been shown to be between 80% and 90% effective in reducing risk. The program proposed above would likely only achieve a risk reduction level of 70% if an emphasis were placed on minimizing explosives use. There is an assumption made that a program would focus on a key test slope first, Burn Out, in order to make stability evaluations with explosives. For this reason, the risk reduction at Burn Out would be closer to 90%. Once key indicators point to wide spread instability, explosives would then be used on other selective paths to field truth the assessment and to mitigate the risk. Strategies would be developed to keep the goal of risk reduction high while at the same time minimizing the environmental impacts as much as possible.

The combined approach would minimize the amount of up-front capital costs required for risk reduction and be quicker to bring on line than the all snowshed approach. It would have somewhat higher on-going costs however, and the environmental issues would be more significant.

4.3.3. Avalanche Management Program with two Snowsheds

This approach would use a forecasting and control program as the primary means of defense along with two snowsheds to eliminate the risk at Shed 7 and Shed 9. The avalanche program would be conducted along similar lines to those in other mountainous locations in North America. Although other options are available for explosives control, the primary means envisioned for this analysis would be artillery due to very low acquisition and maintenance costs. This would result in an approximately 80% reduction in risk levels. During periods of the most extreme avalanche situations, closures might be necessary to mitigate the residual risk levels for an additional 50% reduction. An assumption is made in this scenario that closures of between 2 and 4 hours are tolerable with little or no loss of revenue opportunity to BNSF. These time periods would allow the management program to mitigate the risk to acceptable levels in all but the most extreme circumstances. Risk to personnel is significantly reduced, partially by the generous allowance for new detection systems, and risk to the Amtrak train is greatly reduced.

Part of this strategy depends on construction of two shorter snowsheds. Shed 7 should be extended to deal with the relatively high AHI produced in this location, and Shed 9 should be extended because the starting zone cannot be effectively targeted by artillery.

Substituting other means of avalanche initiation would result in significantly higher capital costs due to the number of paths that would require fixed facilities to control them. Advanced detection systems are anticipated within the proposed budget for this approach.

Figure 4.6-Avalanche Management Program w/ 2 Sheds

Name	Base AHI	Shed Feet	Shed Reduce	Sub AHI	Program at 80%	Sub AHI	Closure at 50%	Final AHI
Burn Out	11.70			9.88	7.90	1.98	0.99	0.99
Shed 5	6.39			5.25	4.20	1.05	0.52	0.52
Shed 7	15.55	150	15.55	0.01	0.01	0.00	0.00	0.00
Shed 8	4.28			3.15	2.52	0.63	0.31	0.31
Shed 9	6.69	100	6.69	0.01	0.01	0.00	0.00	0.00
Infinity	7.17			6.01	4.81	1.20	0.60	0.60
Jakes	8.44			8.22	6.57	1.64	0.82	0.82
Grizzly	4.94			4.71	3.77	0.94	0.47	0.47
Second Slide	9.25			9.25	7.40	1.85	0.93	0.93
Shed 10	8.29			8.29	6.63	1.66	0.83	0.83
Path 1163	10.75			10.75	8.60	2.15	1.08	1.08
Elk	4.03			4.03	3.23	0.81	0.40	0.40
Shed 10.7	7.74			7.74	6.19	1.55	0.77	0.77
Shed 11	5.21			5.21	4.17	1.04	0.52	0.52
Total	**110.43**		**27.91**	**82.52**	**66.02**	**16.50**		**8.25**

	New Shed footage	250	Annual snowshed maintenance	$2,075
Capital cost	New Shed Costs	$1,750,000	Annual snowshed capital	$35,000
Capital cost	Detection systems	$1,700,000	Annual program capital	$160,000
Capital cost	Forecasting	$1,500,000	Annual program budget	$150,000
Total capital cost		**$4,950,000**	**Total annual cost**	**$347,075**

Mitigating avalanche risk through this approach has both the lowest capital costs, and the lowest annual costs to achieve the desired results. It would also have the highest impacts to park values and environmental resources. Careful analysis of environmental consequences and options for mitigating those consequences may reveal opportunities to conduct the described program without major environmental impacts. Similar approaches are used for avalanche mitigation on many national forests in the U.S., and in a number of National Parks in Canada without a significant amount of known impacts. Two national parks in the U.S., Yellowstone and North Cascades, have used artillery consistently for a period of time to mitigate avalanche risk. This approach would likely need to be a joint operation between BNSF and the Montana Department of Highways. The same avalanche paths affect both entities so a coordinated approach would be of paramount importance.

4.3.4. Summary of Mitigation options

The following table provides a summary of the identified options for mitigating avalanche risk in the John Stevens Canyon area to an acceptable level.

Figure 4.7-Mitigation Comparison

	Snowsheds	**Sheds w/ mgt.**	**Mgt. w/ 2 Sheds**
Capital Cost-Sheds	$32,830,000	$10,780,000	$1,750,000
Capital Cost-Program		$2,300,000	$3,200,000
Total Capital Required	**$32,830,000**	**$13,080,000**	**$4,950,000**
Annualized Shed Capital	$656,600	$215,600	$35,000
Annualized Program Capital		$115,000	$160,000
Annual Shed Maintenance	$38,921	$12,782	$2,075
Annual Program Cost		$120,000	$150,000
Total Annual Costs	**$695,521**	**$463,382**	**$347,075**
50 year life costs	34,776,058	23,169,100	17,353,750
Environmental impacts	Very low	Low	Moderate
Final AHI Level	**7.71**	**10.89**	**8.25**

Results show clearly that the key issue with respect to mitigation alternatives revolves around the conflict between capital investment and environmental impacts. All the proposed options will meet the requirement of lowering the AHI to an appropriate level. Decision makers within BNSF and Glacier National Park will need to have a lengthy dialogue to choose an appropriate alternative.

4.4. Recommendations for 2004/2005 Season

Implementation of the alternatives described above could take several years to accomplish. In the interim, active steps should be taken to lower the risk to the extent possible. For this reason, the following risk lowering recommendations are made as an interim step towards the final solution.

4.4.1. Avalanche Forecaster

Hiring an avalanche forecaster is recommended to administer the avalanche program. BNSF may be able to work out an arrangement for shared costs with the Montana Highway Department, but should assume the lead role. BNSF has the most at risk in the canyon, and has the highest economic consequences. Hiring the forecaster as an employee makes them a stakeholder in the outcome of their decisions and gives BNSF the best possible opportunity to run trains safely and efficiently in the face of avalanche risks. There are other rationale’s that must also be considered.

Relying on a forecast from the Glacier Country Avalanche Center (GCAC) can be problematic. Their whole purpose is to provide generalized forecasts for the region, not site specific analysis. As an example, GCAC would probably be unwilling to say it is safe for BNSF to allow signalmen to replace the wire above the Burnout shed and to accept the responsibility of this decision. If there was an accident, they might be held liable for their decision. Additionally, BNSF needs to have some control over the process to ensure that recommendations are not so conservative that it impedes severely on operations.

There is a considerable amount of work to do in the first two to three years of a program to get procedures, training, and other safety items established institutionally. While the avalanche problem is not a daily or weekly occurrence, the threat of significant avalanche events almost certainly happens several times per year. Without a full time presence, it is unlikely that a thorough training program would be conducted. Without the preparation time on a number of fronts, when the time comes to act, BNSF probably will not be prepared.

Virtually every other location in North America that has a comparable problem, and many areas that have a less significant problem, employ the use of a full time avalanche forecaster. This person's job is to conduct training, help establish good risk reduction procedures, write and update a safety plan, conduct day to day analysis of the snow-pack and weather conditions, and to implement explosives work when needed. They provide recommendations based on their analysis with respect to the risk activities that are being conducted in the avalanche zones. In this case, a forecaster would likely be on site whenever substantial work is done in the avalanche zones by signalmen as well.

Continuity is very important in this position. Forecasters develop an understanding of local avalanche behavior over time that leads to substantially better results in terms of their forecasts. Having the same person come back every year is important to the programs success.

4.4.2. Policies and Procedures

In conjunction with the forecaster, BNSF should establish a three tier system of avalanche warning. Under the "No Restrictions" phase, avalanches are unlikely but still possible so crews still need to be diligent about using good avalanche practices that they would be taught.

The second tier, "Avalanche Warning" would be put into effect when avalanches to the track level are likely to occur in the near term. This would institute a series of protective measures described below. The third tier would be track closure until the hazard diminishes either through natural stabilization or explosive risk reduction.

Protective measures under an "Avalanche Warning" should be used to help reduce the risk in certain areas. Signal crews should be precluded from entering the avalanche run-out zones without approval from the forecaster. Maintenance of way crews clearing snow will need to use a buddy system to track each other and have additional crews close by in case a rescue is needed. They would also need to work under the guidance of the forecaster so they knew where the riskiest locations were and could thus limit their exposure time in these locations.

Westbound trains should be held at Summit until the train ahead clears Java East or West. The risk to trains is substantially increased when they have to stop during a period of high avalanche instability. Should a westbound train encounter an avalanche on the tracks and have to stop, the remainder of the train is exposed to avalanches from other avalanche paths. It takes a considerable period of time to mount an effort to clear the head end of the train, plus there is substantial risk to doing this work. In the event a train is stopped, the next westbound train would be able to tie down their train on the Summit and proceed down the grade with light engines to connect into the rear of the stuck train and help pull them back uphill to a safe location. This would roughly halve the exposure time to the stuck train and thus reduce the risk by at least that amount. Alternatively, a helper consist with crew could be on standby at Blacktail ready to assist if needed. This would save even more valuable time. The cost of doing this for a few short time periods a year is fairly negligible compared to the potential consequences of taking too much time to get a train out of avalanche zones.

Safe zones should be established for both crews and trains. Permission for an eastbound train to quickly back out of avalanche zones needs to be established as well as procedures to ensure that trainman don't have to get out of a train.

The "warning" designation should also be used to trigger permission to test avalanche stability with explosives on the 'Burnout" slide path. This path would be used as an indicator slope for stability in other locations, even though it is probably only indicative of the stability at the mid-slope elevation. Permission for this approach will need to be obtained from the National Park Service. There are several reasons this slope is appropriate for using as a test slope. The first is that it can be easily swept visually to ensure that there is no wildlife or people in the run-out zone. The starting zone is relatively easy to access on skis during high snowfall and lowered visibility so it is an all-weather option for testing stability. The third reason is that it by far represents the most significant risk to signalmen working on the detection systems. This location suffers from frequent avalanches, and has a thirty foot fall to the track level if someone were caught in the signal fence area. Survival of even a small avalanche event by the signalmen at this location is unlikely because of this drop, and thus the need to have more frequent slope stability testing is apparent. Lastly, the stability of the mid-slope portions of the other avalanche paths in the canyon is important to the overall size of the avalanches generated. For that reason, slope stability tests on this location can help gauge anticipated results in other locations. The Amtrak train should be diverted through Montana Rail Link during this time period in order to reduce risk.

Once the avalanche stability situation reaches a critical state where natural avalanches are occurring, a closure will need to be placed. At this stage, it is apparent that the risk has become too substantial to warrant further work activity and all crews except the avalanche team would be called back to base and train traffic curtailed. While closures are never a popular option from an economic viewpoint, the potential downside of trying to run through these conditions should also be considered. Once a closure period is reached, the certainty level for avalanche is fairly high and thus the potential for economic loss or loss of life is also substantial. A portion of the lost revenue from freight traffic can be made up either at a later date, or by moving traffic to another carrier temporarily. The loss of a life or damage to costly hardware cannot be made whole. Once a closure period is reached, there should also be an automatic authorization for helicopter bombing of selected avalanche paths. It is fair to argue at this point that a state of emergency has been declared through the closure action, and thus the necessity of reacting to that emergency is triggered. Any explosive risk reduction will need to take into account the necessary park procedures such as the minimal use of a tool (bombing only those paths that will give a good stability test first before bombing to reduce risk), and consideration of park values such as ensuring that there is no wildlife in the avalanche run-out zones. A plan for accomplishing this work would be one of the first tasks a forecaster would need to undertake, with approval of the plan by the National Park Service being a critical focus.

4.4.3. Training

Education regarding avalanche risk and mitigation methods is critically important to reducing the risks taken. An educated work force will greatly assist in overall risk reduction because of the ability to make appropriate decisions at critical times. For that reason, an important goal for this year is to begin the process of institutionalizing avalanche knowledge among railroad workers. The ability to accomplish this is greatly enhanced when the same workers come back to work in avalanche territory year after year. Management and the unions need to work together to accomplish this goal in order to better safeguard the work force. High turnover rates will greatly increase the amount of training effort required and/or compromise the ability of the work force to make intelligent decisions with respect to avalanche risks.

As a minimum, workers exposed to avalanche risks should be given a one day avalanche awareness training session. The forum for this training should be tailored to the unique conditions the workers will be operating in. One can liken this training to the type of training required for closed space entry, i.e. a discussion of the risks involved and the means used to help mitigate those risks. In the case of basic avalanche awareness, a typical course would outline the basics of avalanche formation, what constitutes avalanche risk, methods and procedures used to lower avalanche risk, and site specific analysis of the terrain and avalanche paths. Rescue procedures should also be discussed and practiced. Workers should ideally receive this training before they were allowed to bid into avalanche territory, but for this year that is probably not realistic until a scheme for how to accomplish this goal is finalized. In the interim, a good target is to have people trained within two weeks of bidding jobs. Given the closure scheme outlined above, trainmen will be adequately protected without this training. The classes of workers that will need this training include line management, line foreman in avalanche territory, track inspectors, operators, signalmen, and all track workers holding bids at Essex. It will also help to extend this training when possible to those workers holding steady bids in adjacent locations in the event they are needed to respond to an emergency. Within these groups, certain classes of workers may need additional training that can be accomplished on the job.

Signalmen have the highest exposure to risk of any class of worker. They are directly exposed to impacts without the protection of a vehicle around them. They also must spend a considerable amount of time in avalanche run-out zones in order to repair signal fences. Additional protective measures are needed to help them reduce their risk. Initially, they should work with the avalanche forecaster whenever they are working in an avalanche run-out zone. The forecaster will help them establish good practices to help safeguard their activities. Among these practices are having a spotter monitoring for avalanche activity, having an escape route, providing for a swift rescue capability, and avoiding those times where natural avalanche activity is imminent. In the case of the Burnout avalanche path, signal crews should never work in this location without the avalanche forecaster on-site to help them in risk assessment. Once good avalanche procedures become a part of their routine, the necessity of having the forecaster there can be reduced significantly.

Operators, Mini-dozer operators, and Snow Fleet operators also have substantial exposure. They inherently need to do their work during periods when avalanche hazard is rising to substantial levels. They also will need to initially work with the forecaster to establish good working procedures. Among these procedures would be calling in and out of avalanche paths as they cross them, working in teams where one person watches another while they cross avalanche paths, ensuring that each working unit is equipped with rescue gear and the ability to use it, and using spotters when cleaning up avalanche debris. Cleaning up avalanches poses a substantial risk because of the time spent in an avalanche run-out zone and the potential for additional avalanches to run down the same path. Special procedures should be established for clearing avalanches in order to have appropriate rescue capability and good assessment of the potential for further avalanche activity in the path.

Track Inspectors and maintenance workers are also exposed to a degree of avalanche risk. Inspectors spend a considerable amount of time over the winter traversing through avalanche run-out zones. They should be well versed on where those zones are and possibly modify their inspection schedule to inspect track in avalanche zones during periods of good stability and in other locations during periods of poor avalanche stability. Rail workers should not take on work in avalanche run-out zones unless absolutely necessary, and then should consult with the avalanche forecaster to ensure that the stability is good enough to undertake the work. Limiting exposure time is a key factor in limiting risk to these classes of workers.

In all cases, continuing discussion by the avalanche forecaster about what they are seeing, and why certain procedures are used will lead to a better understanding of avalanche risks by the exposed workers. This process can take several years to institutionalize, but good efforts this year will help speed the process.

This summary is intended to provide you some guidance for work that can be implemented this year and help reduce avalanche risk this year. Next year there will be additional steps that can be undertaken to further reduce risk. The situation is fairly fluid and dynamic in establishing an avalanche risk reduction program. Good strategies will emerge that are not currently anticipated and should be embraced.

V. Summary

The combination of steep mountains and heavy snowfall combine in the John Stevens Canyon area of Montana near Marias Pass to create significant avalanche potential. The BNSF corridor through the area is exposed to a considerable number of avalanche paths. Risk from avalanches has been partially mitigated by installation of snowsheds in the historically most active avalanche paths. A residual risk factor exists from paths that run less frequently that has not been adequately mitigated. Over the years, a long record of closed calls and accidents point to the need to mitigate this risk.

There are a total of 14 avalanche paths along a length of 4.2 miles that combine to create a significant hazard. Historical records show that due to similar topography, aspect, and elevation, most of these avalanche paths tend to become critically unstable at close to the same time. For that reason when one avalanche has occurred there is a high likelihood of adjacent avalanche paths running. This compounds the risk substantially.

Computations were done to determine the Avalanche Hazard Index or AHI. An AHI of one (1) is comparable to the risk level during normal driving on public highways and the other kinds of risks we take in everyday life. The computed Hazard Index for the canyon is one hundred ten (110). While this value appears high, it is in line with other similar avalanche situations where the application of risk mitigation strategies has reduced the risk to an acceptable level.

Risk Mitigation strategies were devised that would result in reducing the AHI to a level between five (5) and ten (10). Given that a significant amount of the risk is derived by the volume of freight cars running through the canyon that have no people on them, and that other public highway situations exist that tolerate risk indexes up to 10, it was felt these values could be applied to this avalanche situation. The mitigation strategies range from an all-snowshed approach, to an approach that primarily depends on forecasting and the use of military artillery or other explosives devices to mitigate risk. Capital costs varied from a high in the range of $32 million for the snowshed approach, through a middle solution in the $12,000,000 range, to a low of roughly $5,000,000. Apart from the annualized cost of capital, the annual operating costs are highest for the approach that has the lowest capital costs.

Given the origin of avalanches in Glacier National Park (GNP), a heightened awareness of environmental issues is likely to affect any mitigation decisions. The lowest cost approach also carries higher impacts to park values with it. There will be a need for dialogue between BNSF and GNP to work through those issues.

Finally, a list of short term recommendations has been provided for this year that envision hiring an avalanche forecaster, changing key policies and procedures, increased training and rescue capability, and methods that would be used to decrease risk to personnel.

Acknowledgments

The author wants to thank numerous people for their contributions to this report. Without them, this report would not have been possible. The assistance of Blasé Reardon of U.S. Geological Survey was particularly important. His research and recording of the historical avalanche history in the canyon was an invaluable tool. In addition, project support was provided by many people within BNSF, notably including Leo Yudysky, Mike Armstrong, Robert Rindy, Lane Ross, and Aaron Hegeman. I also wish to thank Darwon Stoneman for his support last winter and the use of his aerial photographs of the project site.

References

Schaerer, Peter 1989, The Avalanche Hazard Index, Annals of Glaciology #13, Page 241-247, International Glaciology Society

Jamieson, McClung, Schaerer, Stethem, 2002, Land Managers Guide to Snow Avalanche Hazards in Canada, Canadian Avalanche Association

Reardon, Fagre, Steiner, 2004, Natural Avalanches and Transportation: A Case Study from Glacier National Park, Montana, USA, Proceedings of the International Snow Science Workshop

Hamre, 1996, Computation of Avalanche Risk, Alaska Railroad, Internal review of avalanche risk for a railroad with modifications to avalanche hazard index to adapt to railroad use.

Appendix A
Avalanche History

On the following pages, the historical avalanche history is provided. These records, painstakingly gathered by Blasé Reardon and others at U.S. Geological Survey, provide the best-known record of avalanches in John Stevens Canyon. The data should be viewed as provisional data and is subject to modification as new information is gathered and/or old information is refined.