Appendix A

Avalanche Risk Analysis
John F. Stevens Canyon
Essex, Montana

Burlington Northern/ Santa Fe Railroad Co.
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I. Introduction

Snow avalanches have been a plague to rail traffic in the John Stevens Canyon area of Montana since the Great Northern Railway was constructed. Located along the southern boundary of Glacier National Park in northwest Montana, the canyon has very steep terrain on all sides leading into a deep, narrow bottom. When the strikingly steep topography is combined with the abundant snowfall of the area, large and spectacular avalanches are the result. By the early 1900's a system of snow-sheds was built to alleviate the risk of avalanches along the rail line. While snow-sheds have been fairly effective in lowering avalanche risk in the more frequent running avalanche paths, there are still numerous avalanche paths of longer return periods that lack snow-sheds and are thus still vulnerable to whatever whims nature dishes out.

There have been numerous incidents, close calls, and a few fatalities in the 100 year history of rail traffic through the canyon. Every few years snow conditions set up in just the right manner to result in a significant avalanche cycle. These large avalanche cycles occur on the average of every three to five years, with smaller avalanches occurring almost yearly. As train traffic has increased in modern times, the resulting exposure has increased risk substantially. Encounter probabilities are much higher than in the past simply due to increased exposure. This point was driven home last winter when an empty freight train was stopped in the canyon by an avalanche, then was hit by another avalanche. The resulting loss of fifteen grain cars, plus the impacts to train traffic, are driving a review process to determine appropriate measures for risk reduction. The following report is intended to document the findings of the consultant with respect to avalanche risks, and proposes options for mitigating that risk.

II. Avalanche Atlas

On the following pages are photographic and narrative descriptions of the avalanche paths affecting the BNSF in the canyon. Various descriptive parameters are given for each path as discussed below. These descriptions describe the best available information to date. Considerable refinement of the descriptive data is possible. Hopefully future avalanche workers in the area will continue to update and improve this atlas. One other significant point is that only significant paths affecting the BNSF railroad are described. There are a number of highway related paths that are not covered in this atlas, as well as paths that might infrequently effect the BNSF that do not contribute significantly to the Avalanche Hazard Index in Chapter 3.

An avalanche path is divided into three distinct zones vertically. The “starting zone” is the area of the path that releases snow that results in an avalanche. The snow then enters the “track”, a portion of the mountain that has sufficient steepness to accelerate the avalanche material down-slope. This should not be confused in narrative discussions to the railroad track. Once a large event reaches lower angles near the bottom, particularly where the terrain angle is less than 10 degrees, it enters the “run-out” zone where it begins to decelerate. Small events can stop upslope a considerable distance from the run-out zone, but larger events will carry down-slope further into the run-out. The further out in the run-out zone facilities are located, the less frequent will be the avalanche effects. At the distal margin of the run-out zone avalanche frequencies of once every 100 to 300 years can be anticipated.

Starting Zone Elevation- This parameter is provided to help compare similar starting zone patterns in terms of elevation, aspect, and angle. This is useful in determining paths that might run at a similar time.

Vertical Fall- Vertical elevation drop in the path is related to the potential impact pressures and the type of potential avalanches that might occur. All other factors being equal, paths with larger vertical drops can be expected to create higher impact forces. This factor is taken into consideration in Chapter 3 in the calculation of Avalanche Hazard Index in the differentiation of paths according to their potential to produce either “Light” or “Deep” avalanches. Their effects on trains are calculated differently. The primary factor dividing the two categories is that those avalanche paths having over approximately 1,500 vertical feet were assigned half their avalanches in the “Deep” category, which has considerably more destructive force.

Starting Zone Angle- Steeper starting zones tend to shed their load earlier in a storm cycle, resulting in more frequent but smaller avalanches. The lower angle starting zones, particularly those below 35 degrees, tend to hold their load until later in the cycle. Sometimes this results in storms not lasting long enough to bring out the lower angle paths, but when they do release they tend to produce large events more infrequently. A typical avalanche cycle would tend to progress from the steeper paths releasing to the lower angles ones later in the cycle. The provision of starting zone angles allows a forecaster to make comparisons that might be useful in determining which paths are most likely to release in what sequence.

Aspect- Most of the paths in the study vary only moderately in their slope aspect from East to South. Within the general direction of the path, there are usually different aspects on the different sides of terrain contributing to the path. Almost all the avalanche paths are either cross loaded by prevailing westerly winds blowing across south to southeast aspects, or are heavily loaded due to easterly aspects.

Beta Angle- The Beta Angle is measured from the first point in the avalanche run-out zone that the terrain eases off to 10 degrees to the top of the starting zone. This is useful in determining run-out distance through modeling, although data is needed from a considerable number of paths to accomplish this type of modeling. Reference is given to this point in the narratives for the paths.

Alpha Angle- This is the angle from the point of maximum run-out distance where evidence of damage has occurred to the top of the starting zone.

Run-out Ratio- Useful for run-out modeling, this number is derived by dividing the Alpha angle by the Beta angle.

Frequency from Records- Available avalanche occurrence records have been spotty from 1933 to the present time. A statistically valid data set existed from 1913 until 1933 allowing the establishment of this parameter. Avalanche frequency and magnitude are critical values in the computation of the Avalanche Hazard Index presented in Chapter 3. While these older records had to be relied upon, they may not represent current day conditions because of differences in climate and vegetative cover. A complete record of known avalanches has been graciously provided by Blasé Reardon of USGS and is included as Appendix A in the back of this document.

Frequency from Dendrochronology- With the lack of more recent avalanche occurrence records, a considerable number of trees were cored to provide avalanche occurrence data for the past thirty years. This method of analyzing frequency is inferior to a good data set of observations and can only be viewed with a skeptical viewpoint for determining frequency. It does not help at all in determining the magnitude of events.

Combined Estimated Frequency- This number represents the best interpretation of the existing data for avalanche frequency. This parameter is heavily used in Avalanche Hazard Index computations. The number was derived from old frequency records, a review of tree ring data subject to the location of the samples, and tempered by interviews with current railroad personnel.

Shed Length- Current length of snowsheds.

Fence Length- Length of the signal fence. Not all of this length is necessarily in an avalanche zone, nor is signal fence installed in all avalanche zones or the full length of the zone.

Milepost- Best estimate of the milepost of the avalanche paths east to west. These numbers may be modified slightly by more experience in the field and should not be relied on completely.

Path Width- This number represents the maximum anticipated width of a large avalanche event at the railroad level. When a path width is provided in a location that has an avalanche shed, it represents the width of the path that is unprotected by the shed.

Average Avalanche Width- This parameter is another of the critical factors for computation of the Avalanche Hazard Index. In this case, it was largely derived from the 1913 to 1933 data set and tempered with more contemporary observations.

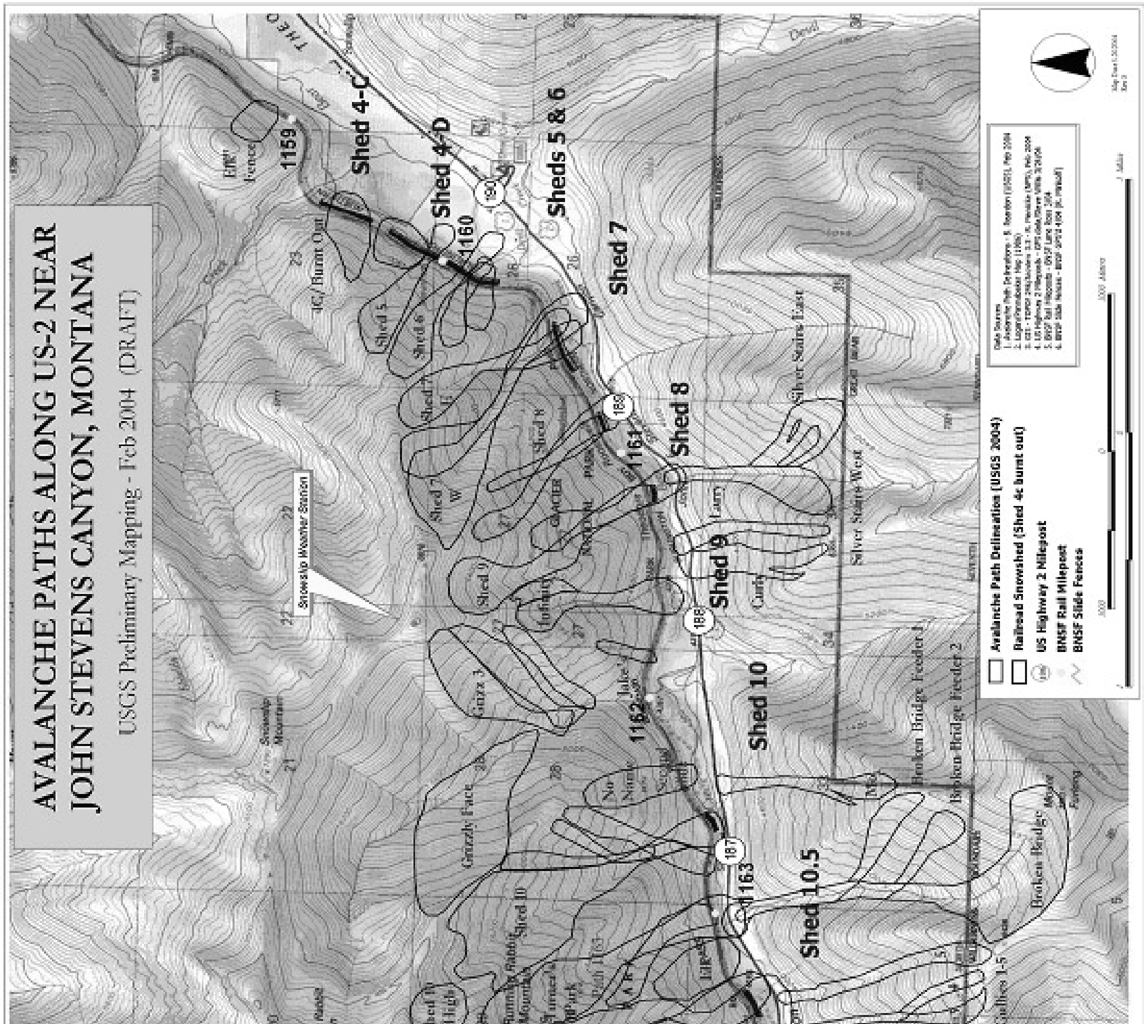
Narrative- A narrative description of each path is provided describing path features.

An overview map of the canyon is provided on the following page. Path descriptions begin after that.
On the left hand page is a photograph of each avalanche path. Inscribed on the photo is an outline describing the anticipated maximum run-out locations, location markers for where the dendrochronology samples were taken, and the path name. Also included are a set of arrows describing the anticipated avalanche flow direction from each path or branch. Some of these flow directions are straight forward, but some are considerably modified by terrain features.

After the photographs of individual paths are a set of two-page photographs that describe the proximity of many of the avalanche paths to each other. This photographic series is important because the nature of the hazard in this canyon is compounded by the fact that so many of the avalanche paths are close together. When one path avalanches and stops a train, there is a high likelihood that another path could well avalanche as well, catching the waiting train. In some cases, a stuck train may be exposed to as many as five other avalanche paths at the same time.

At the end of this section is a mileage comparison chart showing each avalanche path and related highway mileposts.

It should be noted that not all avalanches that can affect the railroad are provided in this atlas. The ones shown are the primary contributors to avalanche risk. Other smaller paths that can affect the tracks are located approximately ½ mile to the west of Shed 11, a large cut-bank near Java East, under rare circumstances Shed 12, and approximately 15 miles north of Essex at Cascadilla Creek. None of these location have any defensive facilities, nor are any anticipated. For this reason, they should be watched carefully during periods of heavy avalanche cycles.


AVALANCHE PATHS ALONG US-2 NEAR
JOHN STEVENS CANYON, MONTANA
USGS Preliminary Mapping - Feb 2004 (DRAFT)
Avalanche Path Delineation (USGS 2004)
Railroad Snowshed (Shed 4c burnt out)
US Highway 2 Milepost
BNSF Rail Milepost
BNSF Slide Fences

Burn Out (Shed 4C)

Burn Out

Starting zone elevation- 5,280 feet

Vertical fall- 840 feet

Starting zone angle- 40 degrees lower
33 degrees upper

Aspect- East Southeast

Beta Angle- 38 degrees

Alpha Angle- 33.8 degrees

Run-out Ratio- 88.9% lower, 84% upper

Frequency from records- 2/year

Frequency from dendro- 1997, 1991

Estimated combined frequency- 2 years

Shed Length- none

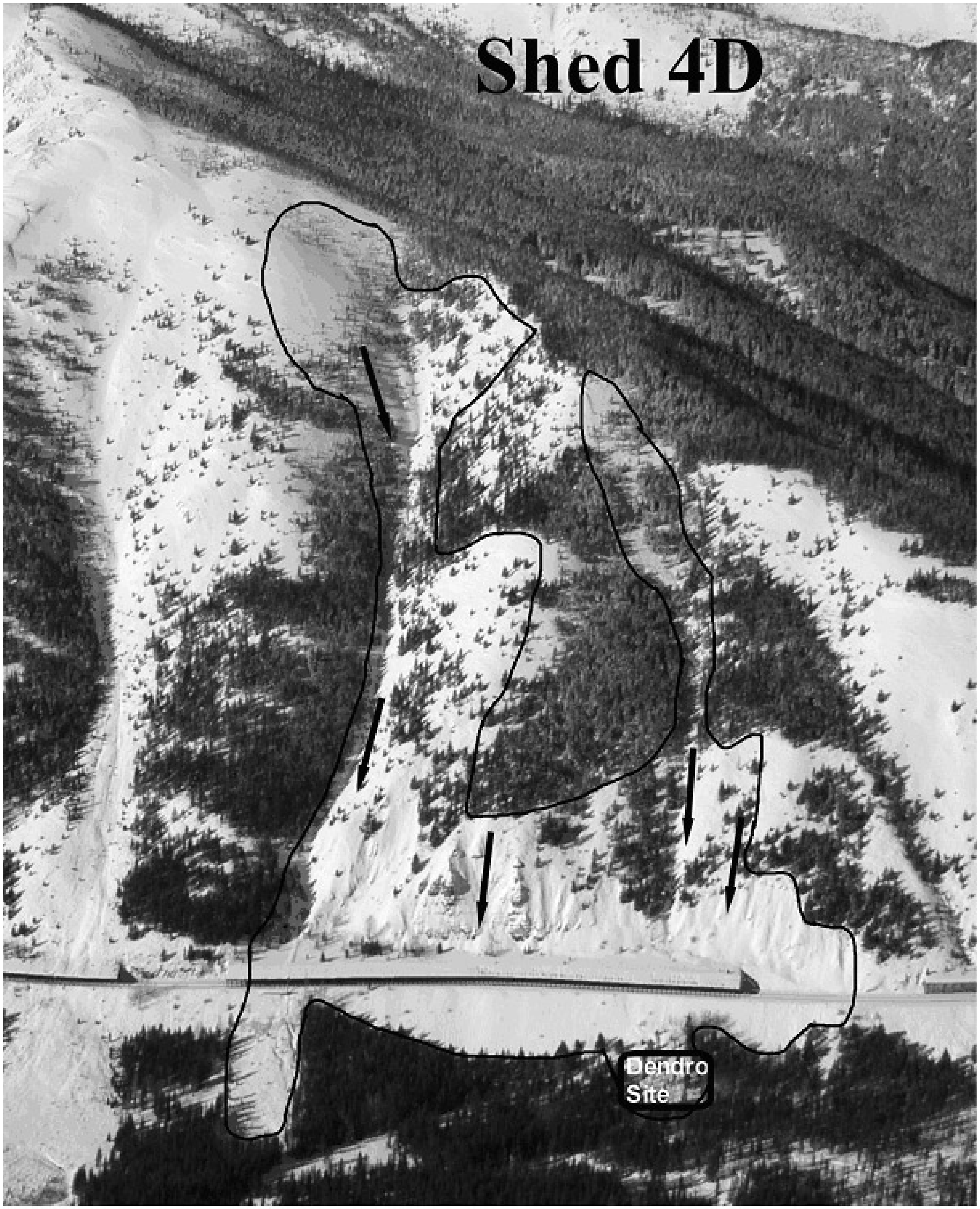
Fence Length- 750 feet

Milepost- 1159.28 to 1159.45

Path Width- 900 feet

Average Avalanche Width- 525 feet

Narrative Description-
Burn out slide path was equipped with a shed that has been consumed by a fire, destroying the structure. The structure wall remains above the tracks. This path is equipped with signal fence from one end of the wall to the other end. Signal boxes are located at either end. The original structure was well placed and protected traffic from any avalanche potential. Without the structure, there is considerable exposure to avalanches from above. The starting zone is broad, slightly convex, and un-forested with few anchors. The average angle from the beta point is 38 degrees. At the top end of the path, terrain angles are 25-33 degrees. The difference in angle between the upper portion of the path and the lower portion could easily result in an avalanche occurring from the steeper, lower slopes being followed a few hours later by an event from the lower angles above. Some rocky outcrops exist in the starting zone and extend down slope to mid path or track. The track is mostly planer with some shallow swales running down slope to the wall. A flat bench exists above the wall, although it is very narrow at eighty feet on the east end and fifty feet on the west. It offers very little relief to slow an avalanche. The signal fence is maintained on the uphill side of the tracks on top of the wall. A signal fence maintainer is exposed to a thirty-foot fall to the tracks if an avalanche occurred. It would not take a significant sized event for an accident to occur. Burn out is a frequent avalanche producer according to interviews with past and current railroad personnel. It is one of their biggest concerns because of the exposure to a fall and the consequences of landing on the tracks and the burial that could result. Field collections took place near the alpha point and revealed damaged timber, flagged and scarred trees, and considerable signal fence wire assumingly deposited by avalanche activity.


Shed 4D
Dendro
Site

<u>**Shed 4D**</u>

<u>Starting zone elevation-</u> 5,600 feet

<u>Vertical fall-</u> 1,200 feet

<u>Starting zone angle</u>- 33 degrees

<u>Aspect-</u> South

<u>Beta Angle-</u> 31 degrees

<u>Alpha Angle-</u> 27 degrees

<u>Run-out Ratio</u>- 87%

<u>Frequency from records-</u> none

<u>Frequency from dendro-</u> 1998, 1996

<u>Estimated combined frequency</u>- none, adequately protected

<u>Shed Length-</u> 1,100 feet

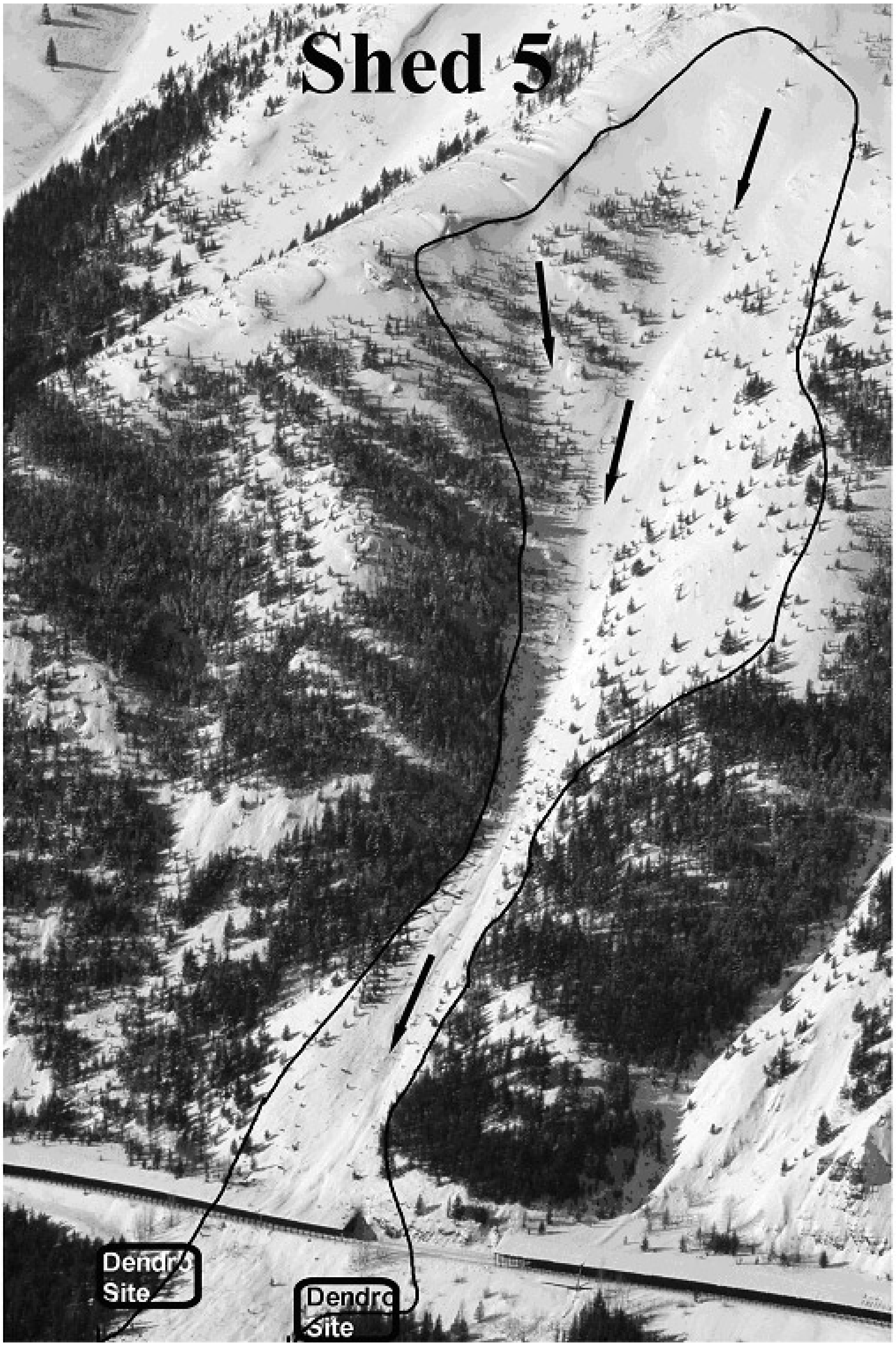
<u>Fence Length-</u> none

<u>Milepost-</u> 1159.70 to 1159.91

<u>Path Width-</u> 1,100 feet

<u>Average Avalanche Width-</u> none

<u>Narrative Description-</u>
The 4D path is forested and steep. The path has a distinctive gully that runs from east to west in direction. Most of the trees are flagged and show damage from slide events that are channeled into the gully. From top to bottom, the path is steep as seen in the alpha/beta relationship. The path gets even steeper as it nears the tracks. This shed seems well placed and shows little evidence of being breached on either side in recent history.


Shed 5
Dendro
Site
Dendro
Site

Shed 5

Starting zone elevation- 6,100 feet

Vertical fall- 1,700 feet

Starting zone angle- 35 degrees

Aspect- East Southeast

Beta Angle- 33 degrees

Alpha Angle- 29.4 degrees

Run-out Ratio- 89.1%

Frequency from records- 5 years

Frequency from dendro- 1992, 1991

Estimated combined frequency- 20 years

Shed Length- 380 feet

Fence Length- none

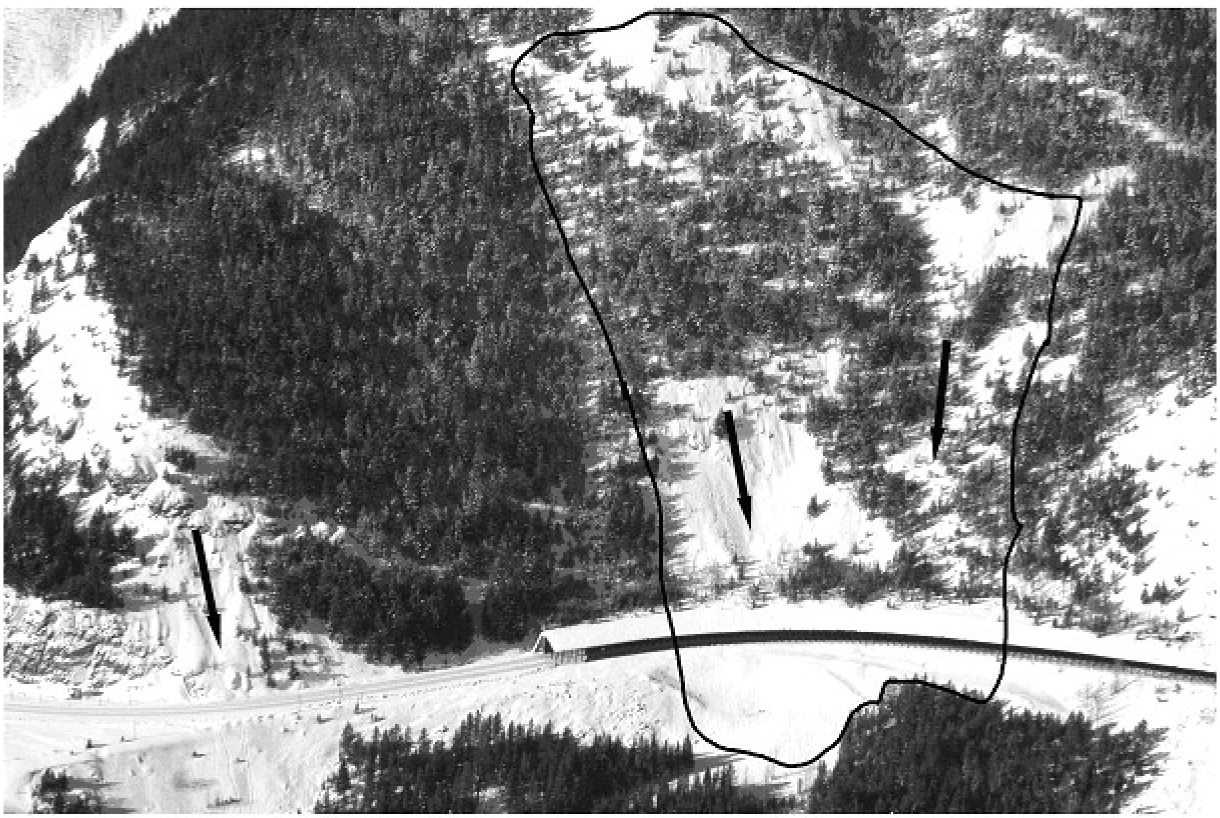
Milepost- 1159.91 to 1160.02

Path Width- 550 feet

Average Avalanche Width- 150 feet

Narrative Description-
The shed 5 avalanche path is a steep slope with a much defined track and trim line. The starting zone angle is approximately 35 degrees with a broad convex bulge that rolls into the track. This path has a good-sized swale at the top that would likely act as a snow fetch with the prevailing winds. The slope angle gets steeper in the track and narrows into a distinct gully about 300 feet wide and retains slope angles of 25 degrees all the way to the shed. The East side of the shed is short, leaving 100 to 150 feet of track exposed to a potentially high velocity, moderate volume avalanche. The potential breach area is poorly vegetated and what trees that exist show damage and are flagged.

Shed 6



Shed 6

Starting zone elevation- 5,400 feet

Vertical fall- 900 feet

Starting zone angle- 39 degrees

Aspect- East Southeast

Beta Angle- 37 degrees

Alpha Angle- 32.8 degrees

Run-out Ratio- 88.6%

Frequency from records- none

Frequency from dendro- Not taken

Estimated combined frequency- none

Shed Length- 820 feet

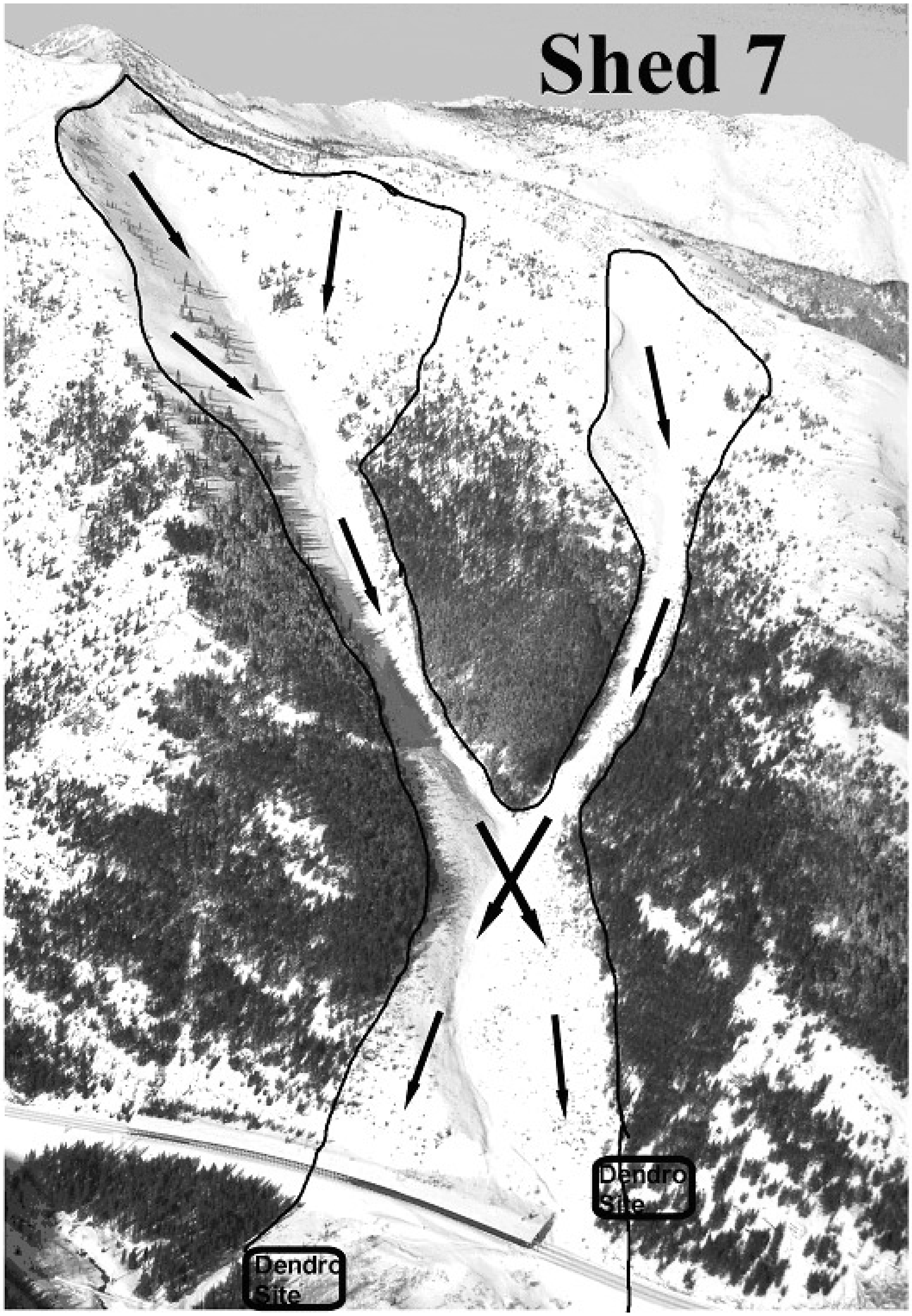
Fence Length- none

Milepost- 1160.02 to 1160.17

Path Width- 800 feet

Average Avalanche Width- none, adequately protected

Narrative Description-
The Shed 6 avalanche path has a steep, rocky starting zone with dispersed timber in bands. The timber is not dense enough to provide good anchors for snow stability, although analysis of old photographs show that it is thickening over time. The slope angles remain steep all the way to the shed, which is well placed. Shed 6 path has a history of producing large events in the past. Looking at photos from the 60's, it has since re-vegetated and large events do not seem likely with the present timber growth.


Shed 7
Dendro Site
Dendro Site

Shed 7

Starting zone elevation- 6,760 feet

Vertical fall- 2,300 feet

Starting zone angle- 35 degrees East branch
33 degrees West branch

Aspect- South to Southeast

Beta Angle- 33 degrees East, 25 West

Alpha Angle- 25.5 degrees East, 21.8 West

Run-out Ratio- 87.2% East, 77.3% West

Frequency from records- 1 to 2 years

Frequency from dendro- 2002, 1996, 1995, 1994, 1991, 1985, 1975

Estimated combined frequency- 3 years

Shed Length- 1,000 feet

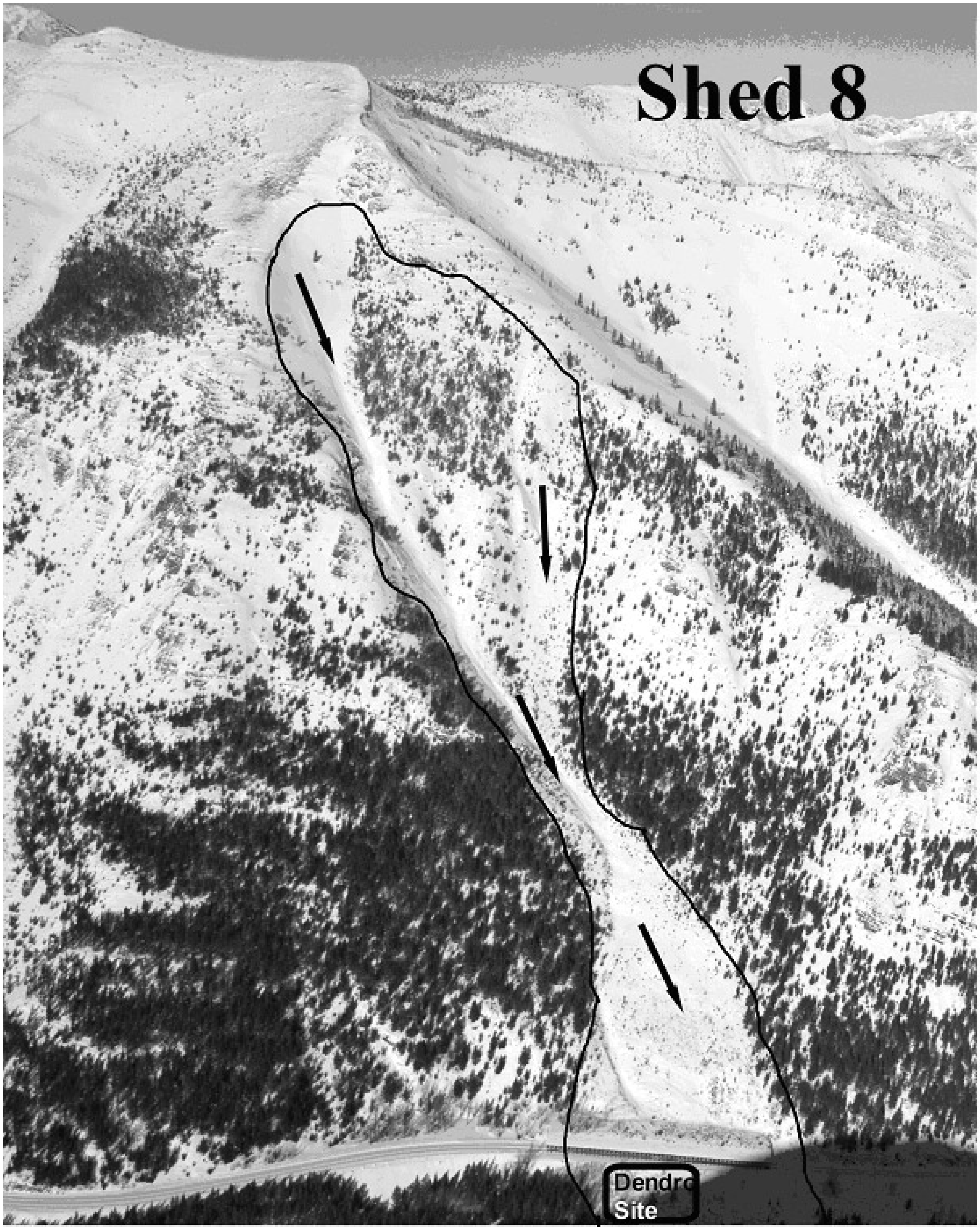
Fence Length- 100 feet

Milepost- 1160.49 to 1160.68

Path Width- 1,150 feet

Average Avalanche Width- 150 feet

Narrative Description-
The Shed 7 avalanche path has multiple starting zones and two distinct gullies. The western flank receives a lot of wind loading from westerly directions. The East flank has good cross loading potential. Both starting zones are grassy and poorly vegetated. The western portion has starting zone angles in the 30 to 35 degree range, with the eastern zone being 2 to 5 degrees steeper. Mid track the paths converge with conflicting directions. The Western flanks flow will affect the east side of the path and vise versa for the Eastern flank. Both paths have very defined trim lines that follow the gullied topography. Upslope of the railroad approximately 1,000 feet the paths converge and the avalanche track becomes mostly planar. The Eastern side of the shed is commonly breached from avalanches emanating from the western starting zone. Given the relatively low angle of the starting zone, it is likely that this path holds snow until a significant load is reached before releasing. This virtually assures that larger avalanches are common in this path. According to field personnel, this is almost a yearly occurrence. The area where the shed is breached has signal wire that routinely needs repair after avalanche activity. The protective shed is somewhat short. Any large avalanche has significant potential to produce large volumes of debris on the tracks and near hwy 2. Given the nature of the path, large events can be expected to have very high impact pressures with resulting high potential for loss. The signal box is exposed and has been destroyed in recent history (96-97). Highway 2 is also threatened by this path, although it is considerably downhill from the railroad.


Shed 8
Dendro
Site

Shed 8

Starting zone elevation- 6,520 feet

Vertical fall- 2,100 feet

Starting zone angle- 37 degrees

Aspect- Southeast

Beta Angle- 34 degrees

Alpha Angle- 30.2 degrees

Run-out Ratio- 88.8%

Frequency from records- 5 years

Frequency from dendro- no good response

Estimated combined frequency- 20 years

Shed Length- 650 feet

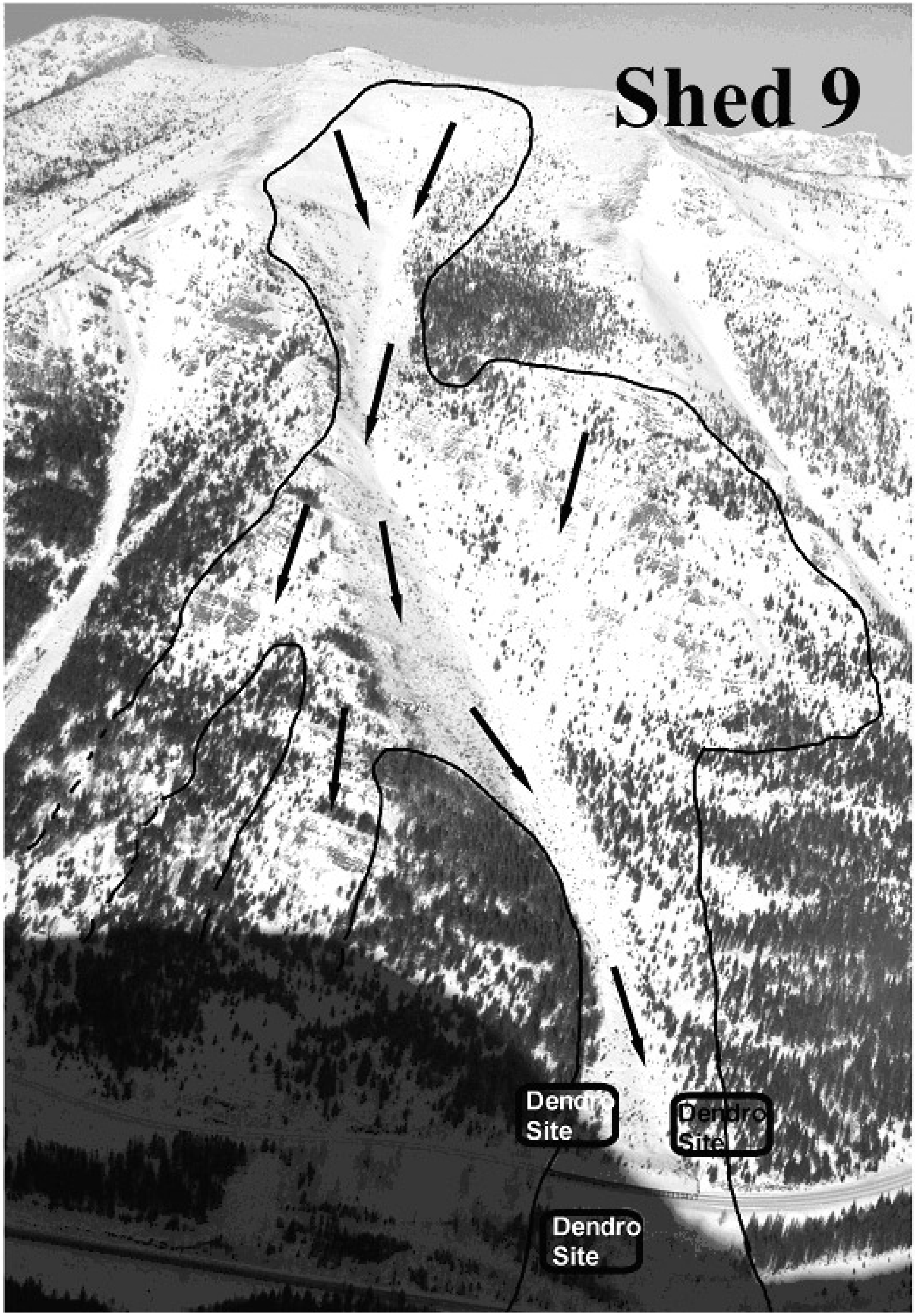
Fence Length- none

Milepost- 1160.85 to 1160.98

Path Width- 800 feet

Average Avalanche Width- 100 feet

Narrative Description-
Shed 8 has a steep starting zone with many rocks and outcroppings with an average angle 37 to 40 degrees. It becomes channeled one third of the way down the track length and takes a more easterly direction. Multiple starting zones exist on the Northwesterly wall, which is sparsely forested with steep rocky starting zones. The Eastern ridge has a starting zone feeding the main track for its entire length until it meets the railroad below. Cornice formations develop on the west side of the starting zone. The main track of the path holds consistent angles that exceed 30 degrees in places, and is no shallower then 20 degrees until it meets the railroad. Interviews with rail crews support that it is a common producer. The shed appears somewhat short and could be breached on the east and west side if a large magnitude event takes place. Timber on the east side of the shed shows damage and general flow dynamics would send slides to the east side of the shed, rather then to the center or West side. The timber down slope of the shed is damaged and destroyed. There is significant tree damage at the Alpha point, which is across Highway 2 and up hill on the north facing slopes.


Shed 9
Dendro Site
Dendro Site
Dendro Site

Shed 9

Starting zone elevation- 6,800 feet

Vertical fall- 2,550 feet

Starting zone angle- Upper 32 degrees
Lower 40 degrees

Aspect- South to Southeast

Beta Angle- 27.9 degrees

Alpha Angle- 23.8 degrees

Run-out Ratio- 85.3%

Frequency from records- 10 years

Frequency from dendro- 2002, 2000, 1995, 1991, 1990, 1989, 1988, 1981, 1980, 1978

Estimated combined frequency- 10 years

Shed Length- 400 feet

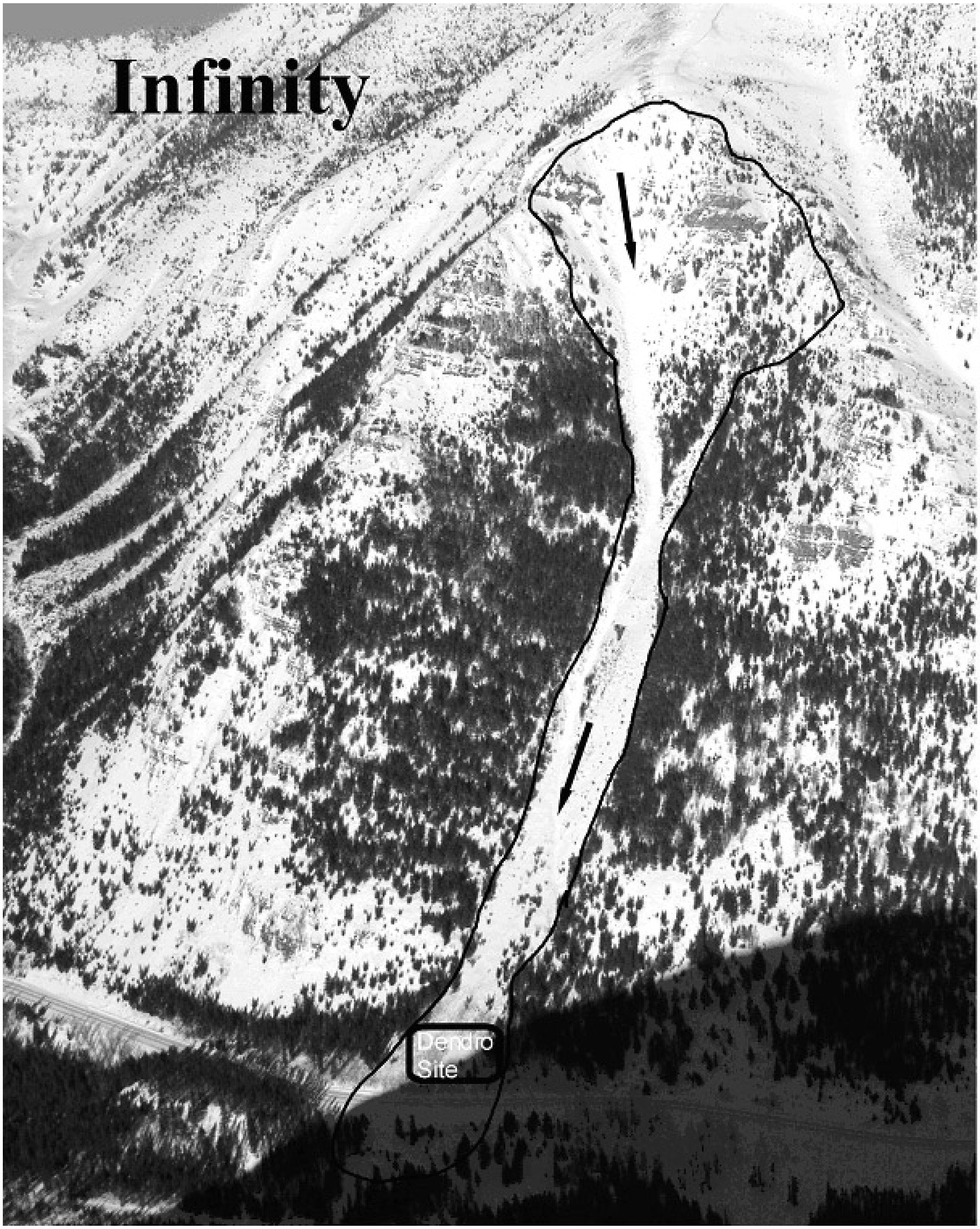
Fence Length- none

Milepost- 1161.22 to 1161.30

Path Width- 500 feet

Average Avalanche Width- 100 feet

Narrative Description- Shed 9 avalanche path is broken into two distinctive starting zones. The upper starting zone is a broad concave slope of 28-32 degrees that acts as a snow fetch with the prevailing wind direction. Cornice formations develop on the western flank of the path. The lower starting zone is in very steep rock bands with an average angle of 40 degrees, and is east of the avalanche track. Ground cover consists of rocky outcroppings and very few vegetative anchors. The track narrows significantly one quarter of the way down the path and becomes an incised gully. The flow direction from the upper path undergoes an approximately 20 degree angle change when it enters the incised gully. Flow dynamics take the avalanche onto the western wall of the gully at this location. In a large and infrequent event, this flow can leave the gully and overtop the ridge, cleaning off the adjacent face between here and the Infinity path, possibly triggering Infinity as well. The mid section of the track has a 25 degree angle and holds this angle until 500 feet above the shed. The shed shows timber damage with evidence of avalanche activity breaching the east end of the shed. Any avalanche running past the shed will almost certainly hit the creek bottom and the adjacent road. This is an impressive path with high potential for road exposure as well. A signal fence is maintained on the East end of the shed. The lower angle starting zone is likely to build up large snow loads before releasing, resulting in infrequent but very large events from this path. The potential for the path to overtop the west ridge must be taken into consideration during periods of extremely large avalanche activity. The resulting avalanche could clear the hillside of timber in a broad swath and impact the railroad heavily. While there is no record to indicate this has happened, there is physical evidence of overtopping, and the topographic characteristics are such that this is possible. The potential for this type of event is not taken into consideration in the risk assessment, but the lead forecaster should always keep this in mind.


Infinity
Dendro
Site

Infinity

Starting zone elevation- 6,160 feet

Vertical fall- 1,900 feet

Starting zone angle- 42 degrees

Aspect- South

Beta Angle- 38 degrees

Alpha Angle- 30.8 degrees

Run-out Ratio- 81.1%

Frequency from records- 5 years

Frequency from dendro- 1997, 1987

Estimated combined frequency- 10 years

Shed Length- none

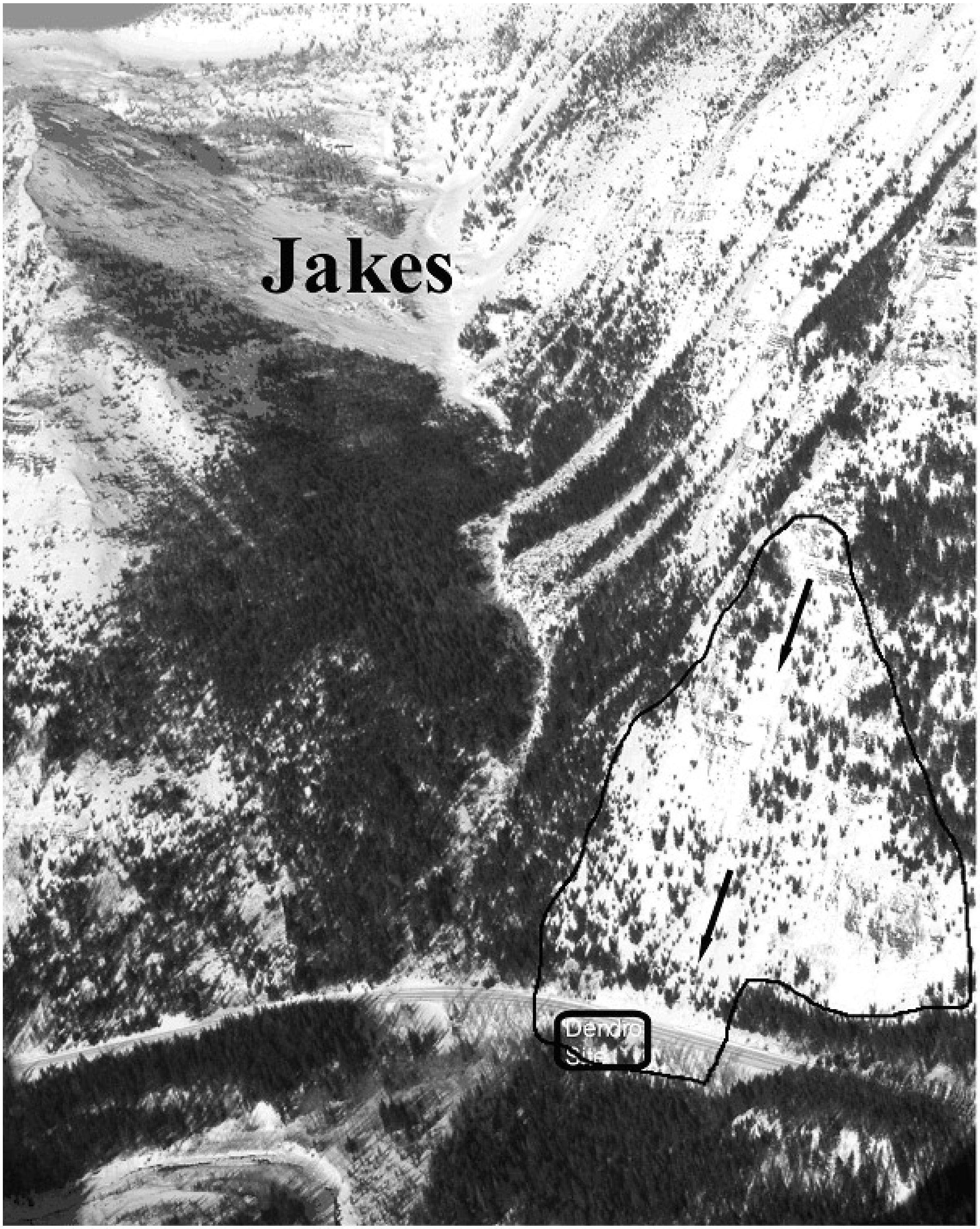
Fence Length- none

Milepost- 1161.50 to 1161.58

Path Width- 400 feet

Average Avalanche Width- 277 feet

Narrative Description-
Infinity is a lower elevation slide zone, which has about half the run of the surrounding paths. It has a steep starting zone and retains that pitch for more then half of its length. It is constricted by an incised gully with defined trim lines. The starting zone is erosive, stepped rocks with horizontal benches running east to west. Numerous starting zones exist down the track on both sides of the path. Near the mid point, the angle eases to approximately 25 degrees, and finally eases to the beta point at 1,000 feet above the railroad. The run-out zone is all deciduous trees that show signs of avalanche damage. This path is not a frequent producer in recent times according to maintenance personnel. However, considering its size and potential volume it can definitely affect the tracks below during a large magnitude event. No signal fences are maintained across the path. In the event of an undetected avalanche, it is possible that a train could run in to the resulting debris at full track speed, increasing the possibility of a derailment.


Jakes
Dendro
Site

Jakes

Starting zone elevation- 5,680 feet

Vertical fall- 1,350 feet

Starting zone angle- 40 degrees

Aspect- South

Beta Angle- 37 degrees

Alpha Angle- 32.2%

Run-out Ratio- 87%

Frequency from records- 2 years

Frequency from dendro- 1999, 1991, 1985

Estimated combined frequency- 3 years

Shed Length- none

Fence Length- 600 feet

Milepost- 1161.89 to 1162.00

Path Width- 600 feet

Average Avalanche Width- 200 feet

Narrative Description-
Jakes path is a low elevation path surrounded by dispersed conifers. This path has a steep starting zone with angles of 40 degrees or more. Bands of erosive rock run throughout the starting zone and continue down the track to mid-slope. As the path continues down slope it widens out to approximately 200 meters wide and hits the railroad with very little relief in the angle. The trees surrounding the east side of the railroad all show damage of frequent activity, which supports the history reported by rail crews. A signal fence is maintained on the east side of the tracks and requires maintenance almost every winter. Most significant events would affect the track with debris.