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AVALANCHE HAZARD INDEX FOR COLORADO HIGHWAYS

Colorado Department of Transportation
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13. ABSTRACT (Maximum 200 words)
This study conducted an inventory of existing avalanche paths along Colorado Highways. Information was collected on the size and type of each avalanche path, the historical frequency of avalanche occurrences, the number of avalanche tracks, the length of highway exposed, the volume of traffic on the road, the traffic peak characteristics, the speed of traffic and the consequences of an avalanche encounter with a vehicle. This information was used to generate an Avalanche Hazard Index (AHI) for Colorado Highways. The concept of the AHI has been used in the past as a quantitative measure of the avalanche hazard to traffic. The AHI values calculated in this study are considered relative values and can be used to compare the hazards of particular avalanche paths or avalanche prone routes in Colorado.

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1 OBJECTIVES AND LIMITATIONS

1.1 OBJECTIVES

This analysis of snow avalanche hazard on Colorado highways was requested by the Colorado Department of Transportation. As outlined in RFP #94–777, this study has the following **objectives**:

a. Quantification of the avalanche hazard on designated highways and on individual avalanche paths through calculation of an avalanche hazard index (AHI) that quantifies hazard to moving and waiting traffic;

b. Discussion of general avalanche hazard mitigation strategies on highways and individual avalanche areas; and

c. Recommendations about the numerical AHI level at which mitigation strategies become appropriate.

The avalanche hazard index (AHI) values in this study have been calculated using the method outlined by Schaerer (1989), which is discussed in Section 2 of this report.

1.2 LIMITATIONS

This study also has the following **limitations** which should be understood by all those using the results:

a. The AHI values calculated in this study are relative (or index) values only. Although these values may be correlated with the actual hazard or damage potential in given areas they do not represent encounter probabilities between vehicles and avalanches.

b. The AHI values are estimates which are based on the best currently available data and interpretation of avalanche frequency, size, and behavior. Much of the information is based on personal knowledge of each area. If more detailed data become available, the results and conclusions presented here may be modified.

c. Avalanche control or mitigation (active or structural methods), if applied or modified in certain areas, may reduce the AHI as discussed in Section 5.

d. The avalanche control alternatives and recommendations discussed for the most serious avalanche paths and areas in Section 5 have not been based on site specific feasibility studies, such studies may modify some of the conclusions presented here.

2 THE AVALANCHE HAZARD INDEX (AHI)

2.1 INTRODUCTION

The avalanche–hazard index (AHI) is a numerical expression representing damage and loss potential as the result of an interaction between snow avalanches and vehicles on a road (Schaerer, 1989). The concept was first developed in Canada (Avalanche task force, 1974), and has been applied at various locations in North America and New Zealand (Fitzharris and Owens, 1980; Armstrong, 1981; Mears and Newcomb (unpublished); Mears and Alaska Mountain Safety Center, 1992). The AHI has been Calculated in this study for 23 different Colorado Mountain highways that are exposed to avalanches.

As defined by Schaerer, 1989, avalanche hazard is the expected frequency of damage and loss as the result of an interaction between an avalanche and objects or persons. Hazard contains two elements, (a) the frequency (or probability) of an encounter and (b) the nature and magnitude of the resulting damage from the avalanche.

2.2 DAMAGE POTENTIAL AND WEIGHTING THE CONSEQUENCES

The severity of the potential damage is used to define three idealized classes of avalanches as follows.

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

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

Plunging Snow. Plunging snow avalanches fall onto a road at high speeds after descending steep terrain or push vehicles off the road down a steep slope. **Plunging snow avalanches are assigned a weighting factor of 12.** Many Colorado avalanches must be classified as the plunging–snow type because at many sites highways cross avalanches on a steep slope where an avalanche encounter can push a vehicle down a steep slope.

2.3 AVALANCHE FREQUENCY AND WIDTH

Avalanche frequency and width (length of road covered) must be estimated for each path separately for light snow, deep snow, and plunging snow. Frequency is expressed as the average number of occurrences of a given type of avalanche in a given path per year. The average avalanche width for each type of avalanche in each path is also estimated. Both frequency and width are determined from highway records and field evidence, as discussed in Section 3.

2.4 CALCULATING THE AHI

The AHI is calculated by multiplying the frequencies of moving and waiting vehicles being hit by various types of avalanches by the weighting factor discussed in Section 2.2. The encounter probability, P is calculated

$$P = P_M + P_W, \text{ where} \quad (1)$$

P_M is the probability of a moving vehicle being hit by an avalanche and P_W is the probability of a waiting vehicle being hit by a second avalanche in the same path or by adjacent avalanches. When avalanches are closely spaced, as they are on Red Mountain Pass, P becomes large even though traffic volume is light. The moving vehicle encounter probability, P_M is calculated

$$P_M = f(N,L,D,T,V), \text{ where} \quad (2)$$

N = average winter traffic volume, L = average roadway length covered by avalanches of a given class, D = vehicle stopping distance, T = return period of avalanches of a given class, in years, and V = average vehicle speed (which also controls D). The calculation in (2) is repeated for each avalanche path and each class of avalanche in that path. The term P_M becomes an important factor only when traffic volume is very high as on I–70 through Ten Mile Canyon. The waiting vehicle encounter probability P_W is calculated

$$P_W = f(p_s,N,T) + 0.5f(p'_s,N,T), \text{ where} \quad (3)$$

p_s = probability of an avalanche in an adjacent path hitting stopped traffic during a waiting period ranging from 0.5 to 2.0 hours, depending on emergency response time, N is the number of vehicles exposed (depending on traffic volume, response time, and the spacing of avalanches), T is the avalanche return period in years, and p'_s is the probability of a second avalanche in the path that caused the traffic blockage.

The avalanche hazard index (AHI) is calculated for *each path, i,* as follows:

$$AHI_i = \Sigma\, W_j\,(P_{Mj} + P_{Wj}), \text{ where} \quad (4)$$

the subscript j refers to the three classes of avalanches and are assigned weighting factors 3, 10, and 12 (Section 2.2).

Finally, a cumulative AHI_H is calculated for each segment of highway affected by avalanches as follows:

$$AHI_H = \Sigma\, AHI_i, \quad (5)$$

where $1 \le i \le n$, and n is the number of paths on the highway segment, H, considered.

As discussed by Schaerer (1989), each avalanche path (together with its neighboring paths) was assumed to be independent of other avalanche paths on the road. Therefore, the same avalanche was assumed to hit both moving and waiting traffic each time it occurred after another avalanche had already covered the road. It could be argued that the hazard index could be made more realistic by taking into account that the traffic stops after one avalanche occurrence and that each avalanche can strike vehicles only once. However, this would not allow a comparison between individual avalanche paths which is one of the primary objectives of this analysis. Therefore a simpler approach was adopted to calculate the index.

The calculations outlined above were computed on a spreadsheet developed for this project. Details of the spreadsheet parameters are given in Appendix A of this report.

3 COLLECTION AND RELIABILITY OF THE DATA BASE

3.1 DATA COLLECTION

The results of the analysis, of course, are only as reliable as the data used. The data describing avalanche frequency, width and depth used in this study were collected from various sources as follows:

a. Interviews and discussions. Colorado Department of Transportation (CDOT) personnel and other local sources were asked about their knowledge of avalanche frequency and characteristics where local knowledge was available. However, definitive statistical information that could be used in the AHI analysis usually could not be obtained from interviews. Instead, only general information about relative frequency was available in areas where avalanches are not a major maintenance problem. In such cases, frequency data could only be placed in classes such as "nearly every year (annual frequency = 0.30–1.0)," "every few years (annual frequency = 0.10 – 0.30)," "rarely (annual frequency = 0.03 – 0.10," or "never been observed" (annual frequency = 0.01 – 0.03).

b. Maintenance records. CDOT Maintenance records were used where they were available. Detailed records, particularly of triggered avalanches, are available at locations where avalanches are a major concern and constitute a significant hazard (e.g., Red Mountain Pass, Coal Bank/Molas Passes, Loveland Pass, Berthoud Pass, Wolf Creek Pass). Even at these locations, data on naturally-occurring avalanches was not as reliable, particularly when avalanches closed the highway and additional avalanches occurred during the closed periods and were not observed until hours or days after occurrence.

c. Estimates based on experience. Personal experience, based on observations of avalanche behavior and characteristics at various Colorado elevations and exposures, was used to supplement the data base.

d. Vegetative indicators. Damage to trees and other vegetation growing in avalanche paths and/or the type and age distribution of vegetation was used to infer avalanche frequency and size.

e. Winter average daily traffic (WADT) was estimated from CDOT traffic counts and seasonal adjustment factors.

3.2 DATA RELIABILITY AND USE

The data presented in this report is "internally consistent," and thus can be used to compare the avalanche hazard on one Colorado highway, group of avalanche paths, or single avalanche path with the hazard in other areas within the state. This internal consistency is a natural consequence of the fact that one person (A. I. Mears) calculated the AHI–values in all areas. This ensures that the avalanche hazard indexing method was applied in a similar way in each of these areas. For example, very small avalanches and "bankslides" that would not block the highway were ignored in the analysis because vehicles probably would not be damaged and/or vehicles could drive around the avalanche debris and thus would not be forced to wait under adjacent avalanche paths. Avalanches capable of pushing a vehicle off the highway into a steep gorge where severe damage is likely were classified as "plunging" avalanches, the most serious hazard category.

There can be no guarantee, however, that the AHI values calculated on Colorado Highways would be directly comparable with those calculated on highways in other states or countries. This is true because differences probably exist between the methods used to compute the AHI, data reliability probably differs from one area to the next, and other assumptions used in applying the AHI-method probably exist.

4 AHI VALUES ON COLORADO HIGHWAYS

4.1 HAZARD LISTING

Table 4–1 lists the avalanche hazard index (AHI) computed on 22 Colorado mountain highways. Details of the AHI of individual avalanche paths are in Appendix B.

Table 4–1. Avalanche Hazard and Mitigation Recommendations

HIGHWAY	WADT	AHIM	AHIW	AHI	MITIGATION
Berthoud Pass (US 40)	5132	39.8	52.8	93	B,C,D,E
Cameron Pass (SH 14)	356	0.2	1.8	2	A
Silverton–Gladstone (SH110)	100	0.9	48.5	49	B,C,D
Creed–South Fork (SH 149)	786	0.1	1.4	2	A
Cumbres/LaManga (SH 17)	333	0.2	2.6	3	A
Douglas Pass ((SH 139)	575	0.6	8.1	9	B
Fremont Pass (SH 91)	2102	0.5	1.9	2	A
Grand Mesa (SH 65)	276	0.3	12.0	12	B,C
Independence Pass (SH 82)	(1000)	39.4	347.7	387	F
Lizard Head Pass (SH 145)	972	4.4	25.6	39	B,C,D
Loveland Pass (US 6)	1051	12.5	67.8	80	B,C,D,E
McClure Pass (SH 133)	684	2.1	22.7	25	B,C,D
Molas/Coal Bank (US 550)	1058	12.7	94.9	108	B,C,D,E
Monarch Pass (US 50)	3167	5.9	16.9	23	B,C,D
Poncha Pass (US 285)	3905	0.2	0.2	<1	A
Red Mt. Pass (US 550)	863	32.4	302.6	335	B,C,D,E
Snowmass Canyon (SH 82)	13400	7.2	3.1	10	B
Ten Mile Canyon (I 70)	17763	12.6	3.6	16	B,C,D
Tennessee Pass (US 24)	2102	1.7	3.4	5	B
Tunnel Approaches (I 70)	20907	21.8	5.5	27	B,C,D
Vail Pass (I 70)	20051	1.6	3.4	5	B
Willow Ck. Pass (SH 125)	272	0.1	0.9	1	A
Wolf Ck. Pass (US 160)	1455	10.1	43.4	54	B,C,D

* Independence Pass is not open in winter; WADT = 1000 was assumed.

NOTES: Column 2: WADT from Colorado Dept. of Transportation data
Column 3: AHIM – Hazard to moving traffic
Column 4: AHIW – Hazard to waiting traffic
Column 5: AHI = ADIM + AHIW
Column 6: General mitigation recommendations (see below)

The following highway hazard ratings, based on the calculated AHI values and personal experience on the Colorado highways have been defined for use in this study.

Table 4–2. Hazard categories, based on AHI

AHI Value	Hazard Designation	# of Colorado Highways
< 10	Very Low	9
10 – 29	Low	6
30–49	Moderate	3
50–99	High	3
>100	Very High	3*

* Includes Independence Pass, which is currently closed during winter.

The mitigation recommendations listed in column 6 of Table 4–1 are defined as follows:

A: No mitigation is recommended.

B: Observations should be taken and advisories issued during periods of major snowpack instability (major storms; extremely warm spring weather, etc.).

C: Daily observations and forecasts by trained observers is necessary; closure may be required at times.

D: Closure and explosive control (when advised by trained observers) will be probably be required several times each season.

E: Special types of mitigation (see Section 5), including realignment, structural, special explosive devices, is recommended.

F: Continue to keep highway closed during winter.

4.2 SENSITIVITY OF AHI TO DAILY TRAFFIC VOLUMES

As discussed in Section 2 of this report, the AHI is composed of two parts: a) the hazard to moving traffic (AHIM) and b) the hazard to traffic that has been blocked by an avalanche and is waiting under adjacent avalanche paths (AHIW). Thus AHI = AHIM + AHIW. A highway with numerous, closely-spaced, relatively frequently running avalanches will have a high AHI even if traffic volume is light (e.g. Red Mt. Pass). On such highways, the AHI is strongly dominated by the risk to waiting traffic because there exist numerous areas along the road where vehicles can be stopped by an avalanche and will wait under adjacent paths. The sensitivity of AHI to traffic volumes ranging from WADT values ranging from 500 to 20,000 is shown on Figures 4.1 and 4.2.

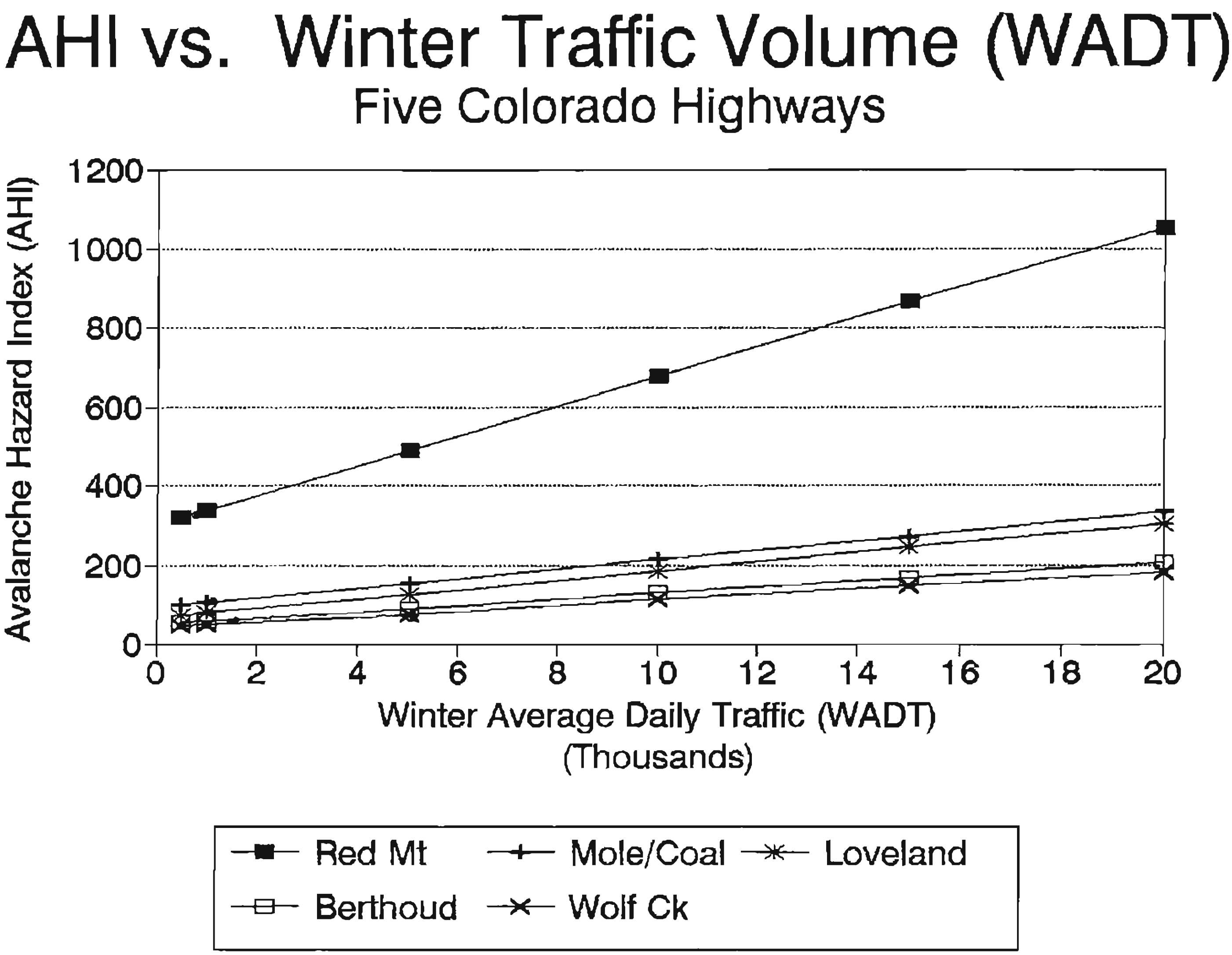

Figure 4.1 Sensitivity of the five most hazardous highways (Red Mt. Pass, Molas/Coal Bank Passes, Berthoud Pass, Loveland Pass, Wolf Creek Pass) to traffic volumes ranging from 500 - 20,000 ADT. Current winter average daily traffic (WADT) is shown with a dot.

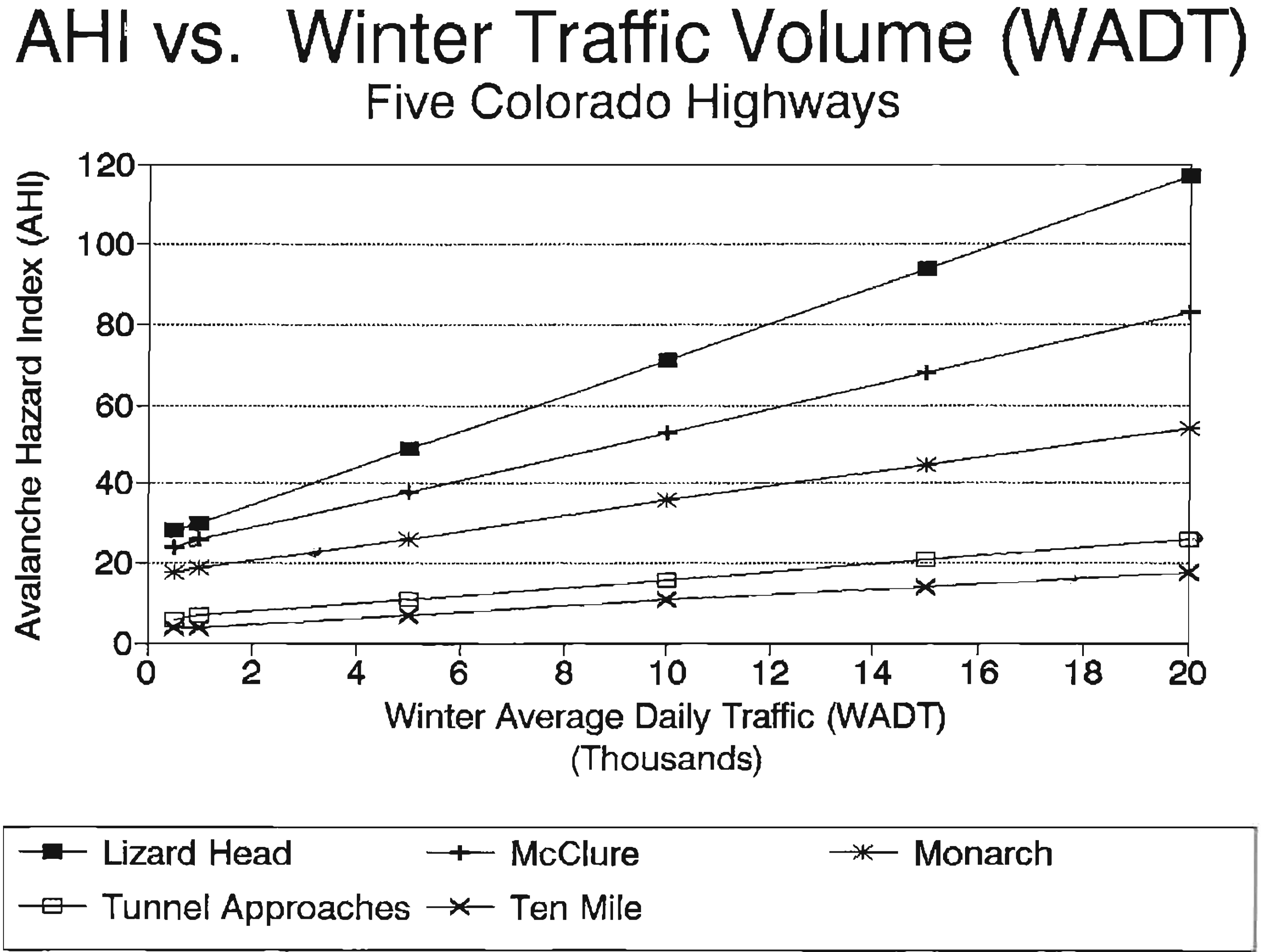

Figure 4.2. Sensitivity of the next five (also see Figure 4.1) most hazardous highways (Lizard Head Pass, Tunnel Approaches, McClure Pass, Monarch Pass, Ten Mile Canyon) to traffic volumes ranging from 500 - 20,000 ADT. Current winter average daily traffic (WADT) is shown with a dot.

5 MOST HAZARDOUS AVALANCHE AREAS

5.1 INTRODUCTION

Numerous areas on Colorado Highways are particularly hazardous because of avalanche frequency, width, and consequences of encounter with a vehicle (Table 5-1). In some cases, the potential hazard in some of these individual areas is significantly larger than the hazard on numerous highways (compare AHI values on Tables 4-1 to 5-1). Because of this high concentration of hazard, special attention to mitigation is justified to reduce the risk to acceptable levels.

TABLE 5-1. Most Hazardous Avalanche Areas

AVALANCHE AREA	HIGHWAY AREA	AHI-N[1]	AHI-C[2]
Brooklyns	Red Mt. Pass (US 550)	76	15
Mother Cline	Red Mt. Pass (US 550)	67	20
Sisters 1-6	Loveland Pass (US 6)	57	17
Riverside Group	Red Mt. Pass (US 550)	42	21
Eagle/Telescope	Red Mt. Pass (US 550)	38	19
Stanley	Berthoud Pass (US 40)	31	9
Rockwall	Red Mt. Pass (US 550)	29	15
W. Lime Creek	Molas/Coal Bank (US 550)	25	0
Big Slide	Monarch Pass (US 50)	19	10
E. Lime Creek	Molas/Coal Bank (US 550)	19	0
Champion	Molas/Coal Bank (US 550)	17	9
Silver Ledge	Red Mt. Pass (US 550)	15	8
Blue Point	Red Mt. Pass (US 550)	12	6
Cliffs	Grand Mesa (SH 65)	11	6

[1] AHI-N: The avalanche hazard index during natural conditions
[2] AHI-C: The avalanche hazard index after the recommended control is used

5.2 RECOMMENDED MITIGATION OF HIGH-HAZARD AREAS

BROOKLYNS; RED MT. PASS, US 550 (AHI = 76)

The Brooklyns area is particularly hazardous because avalanches reach the highway in most paths more than once each year, similar starting zone orientations ensure a high probability of avalanches in an adjacent path after one has blocked the road, and avalanche debris can be deep and highly destructive to a waiting or moving vehicle.

The complexity, extent, and steepness of the terrain eliminates practical consideration of supporting structures in the starting zone, GAZ.EX exploders or bomb trams, earthen barriers in the track, or avalanche sheds. However the valley is relatively wide and flat below the Brooklyns and would enable highway realignment approximately 100–300 feet to the west. Because the existing highway would serve as an avalanche catching structure and a small percentage of avalanches would reach very far to the west of the existing road, careful realignment could reduce the hazard by an estimated 80% from the current level. *Throughout this section the hazard-reduction estimates are based on reduction from the current level.* This mitigation option would actually *increase* the hazard from the Imogene (possibly by a factor of two), but the Imogene avalanche by itself is a small part of the hazard on Red Mountain Pass (AHI = 1.2), thus doubling the hazard in Imogene would be more than offset by the 80% reduction in the hazard in the Brooklyns.

MOTHER CLINE; RED MT. PASS, US 550 (AHI = 67)

The Mother Cline area is particularly hazardous because unstable dry or wet snow slabs develop on steep, smooth, northwest-facing bedrock outcroppings. Melt water percolation between the bedrock and the snow slabs can lead to wet snow avalanche releases, particularly during late-winter and spring thaw periods (mostly during late afternoon or evening), and dry slabs do may not bond readily to the rock outcroppings. In addition, extensive icicle development also threatens the highway, avalanches are the "plunging variety" and can fall onto a vehicle or push a vehicle into the gorge, and multiple avalanches can block traffic which may stop under adjacent, similar avalanche terrain within the Mother Cline group.

A "GAZ.EX" exploder system would be appropriate in the Mother Cline. Two exploders could be mounted on the bedrock starting zone and might produce effective shock propagation over all the starting zones. The exploders could be solidly anchored to the bedrock. The high shock energy would also be effective in releasing wet snow avalanches. Remote triggering of a GAZ.EX system could be conducted easily, quickly, and safely by one or two people. A GAZ.EX installation could reduce the hazard by an estimated 70% but would not reduce (may actually increase) the amount of avalanche debris to be removed from the highway.

SISTERS #1–#6; LOVELAND PASS, US 6 (AHI = 57)

Most of the avalanche hazard on Loveland Pass is concentrated in the Sisters which is particularly hazardous because all paths are strongly wind loaded, the terrain is steep to the highway, the avalanches are closely spaced, and release in one path is likely to be followed soon by release in an adjacent path.

Wind fences located on low gradient terrain south and west of the starting zones could prevent most of the avalanches that initiate as a result of wind transportation of snow. This accounts for most of the avalanches in the Sisters. Wind fences would probably reduce the hazard by approximately 70% and would reduce snow removal costs and exposure of maintenance personnel.

RIVERSIDE GROUP; RED MT. PASS, US 550 (AHI = 42)

The "Riverside Group" includes the East Riverside (with a 180–foot long shed already in place), the Riverside South, Riverside Right, Riverside Left, and the West Riverside. The area is particularly hazardous because of the high-velocity plunging avalanches that occur regularly, the lack of warning on the highway, the extreme danger to rescue or cleanup operations, and the fact that explosive release in the steep, complex starting zones cannot always be assumed to be reliable because of starting zone sizes and complexities. Approximately 50% of the hazard is concentrated in the Riverside Left (the avalanche path responsible for the 1992 fatality).

The only feasible and reliable solution is an extension of the avalanche shed to the north, to cover the highway in the Riverside Left area. This recommended mitigation alternative would reduce the overall hazard to 50% of the current level in the Riverside group. A shed extension would also reduce (by approximately 50%) the amount of cleanup required on the highway.

EAGLE/TELESCOPE GROUP; RED MT. PASS, US 550 (AHI = 38)

This Eagle/Telescope group is comprised of large, frequent avalanches that are generally cross–loaded by west winds. This cross loading results in the most frequent avalanche hazard. When the largest avalanches occur, cross loading may not be as important because entire starting zones collect snow more uniformly, but large avalanches are not annual events.

Because the majority of avalanches result from the wind–loading effects discussed above, and because an active avalanche forecasting program is already in place, wind sensors should be installed on the ridge crest to enable more reliable forecasting in these paths. This would reduce the hazard to approximately 50% of the current level. Highway cleanup efforts would not be reduced as a result of this mitigation.

STANLEY; BERTHOUD PASS, US 40 (AHI = 31)

The Stanley is a large, frequent avalanche path located in a Front Range area of known strong winds, and smooth snow accumulation areas up wind from starting zones. The majority of avalanches in the Stanley result from snow deposition into the left (looking up) side of the main starting zone over a elevation range of 500–1000 vertical feet.

Wind fences (3 or 4 rows) should be located on the ridge above timberline to reduce the amount of snow transported into the starting zone. This would reduce the hazard by an estimated 70%. The amount of avalanche debris deposited on the highway would also be reduced, thus maintenance would be simplified.

ROCKWALL GROUP; RED MT. PASS, US 550 (AHI = 29)

This group of paths (known collectively as "Rockwall") produces moderate–sized, frequent avalanches that plunge onto US 550 and can easily push a vehicle off the highway.

The ultimate mitigation solution would be a light avalanche shed open on the downhill end. However, since the affected highway length is approximately 2,000 feet, a shed would be too expensive at this location. Starting zones are also too complex to install supporting structures or GAZ.EX. The only feasible mitigation alternative is to continue with the avalanche forecasting program on the highway. Forecast accuracy would be improved if the wind sensor discussed above under "Eagle/Telescope" were installed. Mitigation in this path would reduce the hazard to 50% of natural level. Highway cleanup efforts would not be reduced as a result of this mitigation.

WEST LIME CREEK; MOLAS/COAL BANK PASSES, US 550 (AHI = 25)

The West Lime Creek avalanche path(s) affect more than 2,000 feet of US 550 near Coal Bank Pass. Avalanches fall from steep upper slopes (above a prominent cliff band) or moderately steep lower slopes. Long fracture lines are possible in which all or most of the avalanche path can release simultaneously, or portions of the path can release as individual smaller paths thus exposing vehicles to adjacent avalanches after traffic has been blocked. The extensive starting zones and terrain that remains steep to the highway precludes fixed starting–zone structural or fixed blaster mitigation or earthen barriers, dams, or other avalanche energy dissipators in the track. The extensive highway length precludes the use of avalanche sheds.

The recommended form of avalanche mitigation is realignment of highway 550 to the east on avalanche–free terrain. This would also eliminate hazard from the East Lime Creek avalanche area which presents a similar hazard. The West and East Lime Creek avalanche paths together have an AHI value of 44, a value that would be reduced to zero if the recommended mitigation were used. Alternately, the avalanche forecasting, highway closure and explosive control, should continue to be conducted after close consultation with trained observers. This would reduce the hazard to approximately 50% of the present level in both paths.

BIG SLIDE; MONARCH PASS, US 50 (AHI = 19)

Big Slide, approximately 0.5 mile below the Monarch Ski Area, is located on steep, broken terrain on which avalanches fall as much as 800 feet above US 50, plunging onto the west-bound lane. By itself, Big Slide constitutes nearly all of the hazard on Monarch Pass. Hazard can be particularly severe during heavy snowstorms which are also the times when traffic is drawn to the Monarch Ski Area because of good skiing conditions. Major avalanches can sweep vehicles off both lanes into the gorge even though the road is three lanes wide because of a passing lane. Starting zone mitigation (supporting structures or fixed gas exploders) are not reasonable alternatives because of the complexity of the steep starting zone terrain and apparent lack of good anchors for either structures or exploders. The steep terrain also precludes structures in the track or lower runout zone. An avalanche shed is probably not economically feasible because of the required structure length (300–500 feet) and width (approximately 50–foot width of the 3–lane).

The only feasible form of mitigation is a) forecasting for snowpack instability, b) closure, and c) delivery of explosives by avalauncher or hand charge routes. Close cooperation with the Monarch Ski Area snow safety personnel is essential and installation of snowpack and weather sensors near the top of Big Slide is recommended. These steps will reduce the hazard to approximately 50% of the natural hazard.

EAST LIME CREEK; MOLAS/COAL BANK PASSES, US 550 (AHI = 19)

East Lime Creek has many of the terrain, weather, snowpack and avalanche characteristics discussed for West Lime Creek. Avalanche frequency is less than at West Lime Creek because of slightly less steep terrain and more rapid snowpack stabilization because of exposure, however, similar to West Lime Creek, the East Lime Creek avalanche can affect more than 2,000 feet of highway, can release at one time or in parts and therefore can stop traffic under adjacent avalanche areas.

Mitigation for East Lime Creek would be accomplished by realignment (discussed under West Lime Creek, above). This would eliminate the avalanche hazard. Alternately, as with West Lime Creek, the avalanche forecasting, highway closure and explosive control, conducted after close consultation with trained observers, should be continued. The forecast/control procedure would reduce the hazard to approximately 50% of the current level in both paths.

OTHER PATHS (TABLE 5–1) WITH AHI > 10

The other paths listed on Table 5–1 with AHI > 10 (Champion, Silver Ledge, and Blue Point on US 550 and Cliffs on Grand Mesa [SH 65]) all require special attention because of relatively high avalanche hazard. However expensive structural control is not justified. In each of these areas the avalanche hazard should be mitigated by careful monitoring of the snowpack, weather, and avalanche conditions (as is being conducted now under the CDOT/CAIC agreement).

5.3 HAZARD REDUCTION THROUGH SPECIAL MITIGATION

Table 5–2 indicates the approximate reduction in avalanche hazard that would result if the special mitigation methods discussed in Section 5.2 were used. The most significant hazard reduction would occur on Red Mt. Pass, Molas & Coal Bank Passes, Loveland Pass, and Berthoud Pass.

TABLE 5–2. Hazard Reduction on Various Routes

PASS	AHI (Before Mitigation)	AHI (After Mitigation)
Red Mountain Pass	335	173
Molas/Coal Bank Passes	108	64
Loveland Pass	80	33
Berthoud Pass	93	71

The largest numerical reduction in AHI would result on Red Mountain Pass, a reduction from 335 to 173 = 162. However, although cost estimates are beyond the scope of this study, this would probably also be the most expensive highway mitigation. The largest percentage hazard reduction would be on Loveland Pass, a 59% AHI reduction (from 80 to 33). The mitigation on Loveland Pass would probably be relatively inexpensive.

APPENDIX A. DESCRIPTION OF SPREADSHEET

Calculation of all AHI values were done on a spreadsheet (Quatto Pro 3.1) which is being provided on disk with this report. Description of this spreadsheet and various formulas used are given here.

AHI SPREADSHEET (on Quattro Pro 3.1)

Column	Formula	Designator	Description
A	No	Path	Avalanche path name
B	No	Number	Avalanche path number
C	No	ADT	Avg. Daily Traffic (ADT)
D	No	Velocity	Traffic velocity at aval.
E	(1)	StopDist	Stopping distance at aval.
F	No	L Max	Max. (trimline) length
G	No	L P	Length Plunging Aval.
H	No	L D	Length Deep Aval.
I	No	L L	Length Light Aval.
J	No	F P	# plunging aval. per year
K	No	F D	# deep aval. per year
L	No	F L	# light aval. per year
M	(2)	PM P	Moving encounter Prob. (Plung.)
N	(3)	PM D	Moving encounter prob. (Deep)
O	(4)	PM L	Moving encounter prob. (Light)
P	(5)	AHI MP	AHI Moving (Plunging)
Q	(6)	AHI MD	AHI Moving (Deep)
R	(7)	AHI ML	AHI Moving (Light)
S	No	P 2nd	Prob. of second aval.
T	(8)	N Wait P	# waiting vehicles (Plunging)
U	(9)	N Wait D	# waiting vehicles (Deep)
V	(10)	N Wait L	# waiting vehicles (Light)
W	(11)	PW P	Waiting encounter prob. (Plung.)
X	(12)	PW D	Waiting encounter prob. (Deep)
Y	(13)	PW L	Waiting encounter prob. (Light)
Z	(14)	AHI WP	AHI - waiting (Plunging)
AA	(15)	AHI WD	AHI - waiting (Deep)
AB	(16)	AHI WL	AHI - waiting (Light)
AC	(17)	PM	Moving encounter prob. (overall)
AD	(18)	PW	Waiting encounter prob. (overall)
AE	(19)	AHI	AHI for path (overall)

AHI SPREADSHEET FORMULAS (QUATTRO PRO)

Column	Form. #	Formula
E	(1)	StopDist = +(D11*(22/15)*0.9) + ((22/15)*D11*(22/15)*D11)/12.88
M	(2)	PM P = +(J11)*(C11)*(E11+G11)/(D11*5280*24)
N	(3)	PM D = +(K11)*(C11)*(E11+H11)/(D11*5280*24)
O	(4)	PM L = +(L11)*(C11)*(E11+I11)/(D11*5280*24)
P	(5)	AHI MP = +M11*12
Q	(6)	AHI MD = +N11*10
R	(7)	AHI ML = +O11*3
T	(8)	N Wait P = +G11/50
U	(9)	N Wait D = +H11/50
V	(10)	N Wait L = +I11/50
W	(11)	PW P = +S11*T11*J11
X	(12)	PW D = +S11*U11*K11
Y	(13)	PW L = +S11*V11*L11
Z	(14)	AHI WP = +W11*12
AA	(15)	AHI WD = +X11*10
AB	(16)	AHI WL = +Y11*3
AC	(17)	PM = +M11 + N11 + O11
AD	(18)	PW = +W11 + X11 + Y11
AE	(19)	AHI = +P11 + Q11 + R11 + Z11 + AA11 + AB11

APPENDIX B: AHI ON VARIOUS HIGHWAYS AND AVALANCHE PATHS

Tables 4-3 through 4-26 provide the results of the AHI calculations on all avalanche paths considered in this study. Small bank slides have not been included even though they are listed in the various avalanche atlases because they will not block the highway.

The following data are tabulated: (a) avalanche path name, (b) AHI for moving traffic AHI-M, (c) AHI for waiting traffic (AHI-W), (d) composite AHI ([AHI-M] + [AHI-W]).

Table 4-3. Berthoud Pass (US 40) AHI values by path

Name	AHI-M	AHI-W	AHI
Dam	0.3	0.5	0.8
Aspen	0.2	0.2	0.3
Campground	0.1	0.1	0.2
Berthoud Falls	0.1	0.1	0.2
L. Stanley	0.6	1.0	1.6
Stanley	11.2	20.1	31.3
Stanley Banks	1.7	3.6	5.3
HoopBank A	0.1	0.1	0.2
HoopBank B	0.1	0.1	0.2
Floral Park	4.1	2.0	6.2
BM Bank	1.8	2.2	4.0
Eighty	3.5	2.2	5.7
Ninety	0.5	0.5	1.0
Aqueduct	0.0	0.0	0.0
Cursec Banks	4.6	4.7	9.4
One-ten	0.5	0.7	1.2
One-twenty	0.5	0.2	0.7
One-forty	0.0	0.0	0.0
Two Hundred	0.2	0.1	0.2
Two-forty	0.1	0.1	0.3
Twin Cone Banks	1.2	2.6	3.8
Spruce Banks	2.2	3.5	5.7

Name	AHI–M	AHI–W	AHI
No Name Banks	3.2	5.9	9.1
Crib	3.1	2.1	5.2
TOTAL	39.8	52.8	92.6

AHI–M: Hazard to moving traffic
AHI–W: Hazard to waiting traffic
AHI: Composite AHI (AHI–M + AHI–W) for avalanche path

Table 4-4. Cameron Pass (SH 14)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Diamond Pk	0.0	0.0	0.0
U. Cameron	0.0	0.3	0.3
M. Cameron	0.0	0.3	0.3
Slot	0.0	0.1	0.1
L. Cameron	0.0	0.4	0.4
Crags	0.0	0.6	0.7
Back Diamond	0.0	0.0	0.0
Snake	0.0	0.0	0.0
TOTALS	0.2	1.8	1.9

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-5. Silverton – Gladstone (SH 110)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Bend	0.0	0.0	0.0
Henrietta Gl.	0.0	0.0	0.0
Irene	0.1	5.0	5.1
Topeka	0.0	0.3	0.3
Ohio Gl	0.0	0.3	0.3
Porcupine Gl	0.0	0.1	0.1
Red Pt. S.	0.0	1.2	1.2
Red Pt. N	0.0	1.2	1.2
Minnesota	0.1	6.0	6.1
Bad Number	0.1	5.3	5.4
Erie	0.0	0.8	0.8
Michigan	0.0	0.8	0.8
Fairview	0.1	6.8	6.9
Beatles	0.0	0.2	0.2
Stones	0.0	0.1	0.1
Who	0.0	0.1	0.1
Creme	0.0	0.2	0.2
Georgia Gl	0.1	6.6	6.7
Stump	0.0	0.4	0.4
Prospect	0.0	0.0	0.1
Black Jack	0.0	0.0	0.1
Dump South	0.0	0.3	0.4
Dump North	0.0	0.3	0.4
Dry Gl. N	0.0	1.0	1.0
W Jump A	0.0	0.1	0.1
W Jump B	0.0	0.3	0.3

NAME	AHI-M	AHI-W	AHI
Mogul	0.1	4.3	4.3
Rope	0.0	0.0	0.0
E Jump	0.0	0.2	0.3
SE Jump	0.0	0.1	0.1
Halftrack	0.0	0.0	0.0
Dry Gl S	0.0	0.7	0.7
RMYF	0.0	0.2	0.2
Tiger Gl	0.0	0.7	0.7
Billboard	0.1	4.6	4.7
Grassy Gl	0.0	0.1	0.1
Illinois Gl	0.0	0.0	0.0
Maybe So	0.0	0.1	0.1
Maybe Not	0.0	0.1	0.1
Vikik	0.0	0.0	0.0
TOTALS	0.9	48.5	49.4

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-6. Creed - South Fork (SH 149)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Aspens	0.0	0.0	0.0
Wag Wheel B	0.0	0.6	0.6
Wag Wheel A	0.1	0.8	0.9
TOTALS	0.1	1.4	1.5

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-7. Cucharas Pass
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Boyd Mt.	0.0	0.2	0.2
Wildcat Bank	0.0	0.1	0.1
Wildcat	0.0	0.1	0.1
TOTALS	0.0	0.3	0.3

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composit AHI (AHI-M + AHI-W)

Table 4-8. Cumbres & LaManga Passes
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Windy Point	0.0	0.2	0.2
Rail Banks	0.1	1.1	1.1
Toltec	0.1	0.8	0.9
Rocks	0.0	0.3	0.3
Three.eight	0.0	0.1	0.1
Camp	0.0	0.0	0.0
TOTALS	0.2	2.5	2.7

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-9. Douglas Pass (SH 139)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Banks	0.0	0.0	0.0
Headwall	0.3	4.9	5.2
Pipeline	0.1	2.3	2.4
Tower	0.1	0.3	0.3
Earl	0.0	0.2	0.3
North Chute	0.0	0.1	0.1
West Face	0.0	0.1	0.1
North Bank	0.0	0.1	0.2
TOTALS	0.6	8.1	8.7

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4–10. Fremont Pass (SH 91)
Avalanche Path AHI

NAME	AHI–M	AHI–W	AHI
Mt. Zion 1	0.1	0.2	0.2
Mt. Zion 2	0.0	0.0	0.1
Mt. Zion 3	0.0	0.1	0.1
Mt. Zion 4	0.0	0.1	0.1
Mt. Zion 5	0.0	0.1	0.1
Mt. Zion 6	0.0	0.1	0.1
Buckeye A	0.0	0.0	0.1
Buckeye B	0.0	0.0	0.1
Graveline	0.1	0.2	0.3
Resolution	0.1	0.4	0.5
Y Chute	0.0	0.0	0.1
K Chute	0.0	0.1	0.1
S Chute	0.0	0.1	0.1
TOTALS	0.5	1.4	1.9

AHI–M: Hazard to moving traffic
AHI–W: Hazard to waiting traffic
AHI: Composite AHI (AHI–M + AHI–W)

Table 4–11. Grand Mesa (SH 65)
Avalanche Path AHI

NAME	AHI–M	AHI–W	AHI
Cliffs	0.2	10.6	10.8
Aspen Bank	0.1	1.4	1.5
TOTALS	0.3	12.0	12.3

AHI–M: Hazard to moving traffic
AHI–W: Hazard to moving traffic
AHI: Composite AHI (AHI–M + AHI–W)

Table 4-12. Independence Pass (SH 82)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Gordon Gulch	0.0	0.1	0.1
Parry	0.0	0.1	0.1
White Star	0.0	0.1	0.1
Gage	0.0	0.0	0.0
Slot	0.0	0.0	0.0
Smith Gulch	0.0	0.0	0.0
Arlington	0.0	0.0	0.0
Monitor	0.0	0.3	0.3
Last Chance	0.0	0.3	0.3
Hayden	0.0	0.1	0.1
Mears 12	0.0	0.1	0.1
Mears 13	0.0	0.1	0.1
Fingers A	0.0	0.1	0.1
Fingers B	0.0	0.1	0.1
Fingers C	0.0	0.1	0.1
Campground	0.1	0.5	0.6
Everett A	0.1	0.4	0.4
Star Mt. A	0.1	0.7	0.7
Everett B	0.1	0.9	1.0
Star Mt. B	0.1	1.3	1.5
Everett C	0.1	1.6	1.7
Star Mt. C	0.0	0.3	0.4
Everett D	0.3	2.2	2.5
Star Mt. D	0.0	0.3	0.3
Everett E	0.1	0.9	1.0

NAME	AHI-M	AHI-W	AHI
Star Mt. E	0.0	0.2	0.2
Gate	0.0	0.1	0.1
Brumley	0.0	0.2	0.2
Lake Ck.A	0.1	0.3	0.4
Lake Ck.B	0.1	0.4	0.5
Lake Ck.C	0.3	0.5	0.8
S-back	0.9	4.2	5.1
Beeler L	0.9	9.8	10.7
Beeler U	15.1	144.0	159.1
Big L	1.0	9.5	10.5
Big U	3.1	22.2	25.4
Gulch L	0.4	4.4	4.8
Gulch U	1.9	16.7	18.5
Mountain Boy	0.5	1.2	1.7
E. Roaring Fk.	9.6	90.0	99.6
W. Roaring Fk.	2.6	21.1	23.7
Hunter	0.2	1.1	1.3
Prospect Hill	0.4	4.4	4.8
Inde A	0.0	0.0	0.0
Inde B	0.0	0.1	0.1
Inde C	0.0	0.1	0.1
Inde D	0.0	0.1	0.1
Lost Man	0.1	0.2	0.3
William	0.1	0.4	0.4
Grn.Mt. A	0.3	2.4	2.6
Grn.Mt.B	0.3	2.6	2.9
Grotto	0.0	0.1	0.2
Punchbowl	0.0	0.1	0.2

NAME	AHI-M	AHI-W	AHI
Tagerts A	0.0	0.1	0.1
Tagerts B	0.0	0.1	0.1
Tagerts C	0.0	0.1	0.1
Difficult	0.0	0.1	0.1
Inde Bowl	0.0	0.1	0.1
Smuggler	0.0	0.4	0.4
TOTALS	39.4	347.7	387.1

AHI-M: Hazard to moving traffic
AHI-W: Hazard to moving traffic
AHI: Composite AHI (AHI-M + AHI-W)

NOTE: Independence Pass is closed during the avalanche season. A winter average daily traffic (WADT) of 1000 was assumed in calculations. Reliable data on avalanche frequency and width were not available, therefore frequency and width estimates based on terrain, vegetation and susceptibility to wind-transported snow were made. If Independence Pass were ever opened during the entire winter, the avalanche hazard would be in the same range as avalanche hazard on Red Mountain Pass.

4–13. Lizard Head Pass (SH 145)
Avalanche Path AHI

NAME	AHI–M	AHI–W	AHI
Montelores	0.6	4.1	4.7
Scotch Ck.	0.4	2.3	2.6
Scotch Ck. Trees	0.2	0.5	0.7
Rockslide	0.0	0.0	0.1
Ball Park	0.2	0.8	1.1
Spear	0.0	0.1	0.1
Aztec Gulch	0.0	0.1	0.1
S. Ranger	0.4	3.0	3.4
N. Ranger	0.0	0.1	0.1
Yellow Spr. Wall	0.6	6.7	7.2
Yellow Spr. Gully	0.7	2.9	3.6
Peterson	0.4	1.5	1.8
Burns S.	0.0	0.1	0.2
Burns	0.4	1.6	2.0
Baker S.	0.0	0.1	0.2
Baker	0.2	0.6	0.8
Baker N.	0.1	0.3	0.4
Fry Grade	0.1	0.4	0.4
Highline	0.0	0.0	0.0
S Coal Ck S	0.1	0.4	0.5
Coal Ck S	0.1	0.3	0.3
Coal Ck	0.1	0.3	0.3
Coal Ck N	0.1	0.1	0.2
Coke Ovens S	0.1	0.4	0.5
Coke Ovens	0.1	0.4	0.5
Coke Ovens N	0.1	0.4	0.5

NAME	AHI-M	AHI-W	AHI
Barlow Banks	0.0	0.1	0.1
Slate Ck A	0.0	0.1	0.1
Slate Ck B	0.0	0.1	0.1
Slate Ck C	0.0	0.1	0.1
Slate Ck D	0.0	0.1	0.1
Slate Ck E	0.0	0.1	0.1
Slate Ck F	0.0	0.1	0.2
Slate Ck Bank	0.1	0.3	0.4
Snow Spur SW	0.0	0.0	0.0
Snow Spur E	0.0	0.0	0.0
Snow Spur NW	0.4	2.3	2.7
Yellow Mt	0.1	0.5	0.7
Mudslide	0.1	0.4	0.5
Waterpipe	0.2	0.2	0.4
Drain	0.2	0.4	0.7
Butterfly	0.0	0.0	0.1
Moth	0.0	0.0	0.1
Panther	0.0	0.0	0.1
Cub	0.0	0.0	0.1
Six	0.1	0.3	0.4
Ophir Needle	0.0	0.0	0.1
TOTALS	6.5	32.9	39.4

Table 4-14. Loveland Pass (US 6)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Loveland Barn Bank	0.1	0.2	0.2
Sleeper	0.3	2.9	3.2
Sis 1A	0.2	1.0	1.1
Sis 1	1.5	10.7	12.1
Sis 2A	0.6	3.3	3.9
Sis 2	1.3	7.3	8.6
Sis 3	2.0	8.9	10.9
Sis 4	1.5	6.5	8.1
Sis 5	0.2	0.7	0.9
Sis 6	2.3	15.1	17.5
Sis 7	0.4	1.1	1.6
Scotty's	0.7	4.9	5.6
Outward Bound	0.1	0.6	0.7
Boy Scout	0.1	0.3	0.4
Five Car	0.3	0.9	1.2
Textbook	0.2	0.5	0.6
No Name	0.0	0.1	0.1
Grizzly	0.0	0.1	0.1
Lil Prof	0.3	2.4	2.7
A Lil Prof	0.0	0.0	0.1
Pallavicini	0.0	0.1	0.1
Black Widow	0.2	0.2	0.5
Happy End	0.1	0.1	0.2
TOTALS	12.5	67.8	80.3

AHI-M: Hazard to moving traffic/ AHI-W: Hazard to waiting traffic/ AHI=(AHI-M)+(AHI-W)

Table 4-15. McClure Pass (SH 133)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Short Cut Bank	0.1	0.8	0.9
Long Cut Bank	0.3	4.8	5.1
Headaches	0.1	1.4	1.5
Short Chute Right	0.2	1.6	1.8
Lone Tree (U)	0.3	1.6	1.9
Short Chute Left	0.2	1.6	1.8
Flatiron	0.5	7.9	8.4
Hairpin Bowl	0.1	0.7	0.8
Hairpin Banks (U)	0.1	0.8	0.9
Hairpin Banks (L)	0.0	0.2	0.2
Hairpin Bowl (L)	0.0	0.4	0.4
Lone Tree Bowl (L)	0.0	0.4	0.4
Bears Bank	0.0	0.0	0.0
Upper Campground	0.0	0.0	0.1
Middle Campground	0.0	0.1	0.1
Lower Campground	0.0	0.1	0.1
Crystal One	0.0	0.2	0.2
Crystal Two	0.0	0.0	0.1
Penny	0.0	0.0	0.1
Nickel	0.0	0.0	0.1
Dime	0.0	0.1	0.1
Quarter	0.0	0.1	0.1
TOTALS	2.1	22.7	24.9

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-16. Molas & Coal Bank Passes (US 550)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Gladstone North	0.0	0.1	0.1
Gladstone S.	0.0	0.2	0.2
Jennie Parker N.	0.6	4.4	5.0
Jennie Parker S.	0.6	4.4	5.0
Peacock	0.5	1.7	2.1
Harley Short	0.4	2.7	3.1
Champion	2.6	14.1	16.7
Deadwood	0.1	0.2	0.2
Deadwood Gl.	0.0	0.0	0.0
Kino Mine	0.0	0.1	0.1
Waterfall	0.5	2.5	3.0
M Forest	0.0	0.2	0.2
Springs	0.2	0.9	1.1
E. Lime Ck	1.7	17.2	19.0
W. Lime Ck	1.8	23.6	25.4
Deer Ck N	0.1	0.9	1.0
Deer Ck S	0.2	1.1	1.4
Swamp	0.2	0.9	1.1
H Brown	1.2	7.4	8.6
Coal Bank	0.6	4.3	4.9
Coal Ck E	0.2	1.2	1.4
Coal Ck W	0.7	5.1	5.8
Engin A	0.1	0.3	0.4
Engin B	0.1	0.2	0.3
Engin C	0.1	0.7	0.8
N. Lime Ck	0.1	0.6	0.7
TOTALS	12.7	94.9	107.6

AHI–M:	Hazard to moving traffic
AHI–W:	Hazard to waiting traffic
AHI:	Composite AHI (AHI–M + AHI–W)

Table 4-17. Monarch Pass (US 50)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Crest Bowl	0.3	0.6	0.8
Gracie's	0.2	0.2	0.4
Gunbarrel Trees	0.1	0.2	0.3
Big Slide	4.5	14.7	19.2
Dog Creek	0.1	0.1	0.1
Taco Ridge	0.0	0.0	0.1
Little Slide	0.7	1.0	1.8
Syncline Hill	0.0	0.1	0.1
TOTALS	6.0	16.9	22.8

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M = AHI-W)

Table 4–18. Poncha Pass (US 285)
Avalanche Path AHI

NAME	AHI–M	AHI–W	AHI
MP 122	0.238258	0.1611	0.399358
TOTAL	0.238258	0.1611	0.399358

AHI–M: Hazard to moving traffic
AHI–W: Hazard to waiting traffic
AHI: Composite AHI (AHI–M + AHI–W)

Table 4-19. Red Mountain Pass (US 550)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Anvil	0.0	0.1	0.1
Water Gauge	0.0	0.1	0.1
Old S. Min. Rd.	0.0	0.1	0.1
Pit	0.1	0.4	0.5
Thirty	0.0	0.1	0.1
Zuni	0.0	0.1	0.1
Hopi	0.0	0.0	0.1
Camp	0.0	0.0	0.1
L. Cement	0.0	0.3	0.3
Cement Fill	0.7	4.4	5.0
Barton S.	0.0	0.0	0.0
Barton N.	0.1	0.1	0.1
Ophir Rd.	0.0	0.0	0.0
Blackburn	0.2	0.7	0.9
Benny Long	0.2	0.9	1.1
Brooklyns	5.1	70.8	75.9
Cemetery	0.1	0.5	0.6
First Twin	0.1	0.4	0.4
Red Mt Pass	0.0	0.0	0.0
Albany Gulch	0.0	0.0	0.0
E Guadalupe	0.2	1.4	1.6
Slippery Jim	0.6	3.5	4.1
E. River S.	1.2	8.0	9.2
E. River R.	0.5	2.2	2.7
E Riverside	0.6	4.2	4.8
E River Left	2.2	18.4	20.6
N Emergency	0.1	0.3	0.4
Cliff	0.1	0.7	0.9

NAME	AHI-M	AHI-W	AHI
Dunsmore	0.1	0.7	0.8
Mother Cline	4.8	62.3	67.0
Silver Point	0.6	2.1	2.7
Ruby Wall	0.5	3.1	3.7
Jackpot	0.0	0.1	0.2
White Fir	0.0	0.1	0.1
Silver Gulch	0.0	0.1	0.1
W Riverside	0.6	4.0	4.5
W Guadalupe	0.4	4.3	4.7
Ironton	0.0	0.1	0.2
Full Moon	0.0	0.0	0.0
Richmond	0.0	0.1	0.1
McIntyre	0.0	0.1	0.2
Galena Lion	0.0	0.1	0.2
Governor	0.0	0.1	0.1
King	0.0	0.1	0.1
Thompson	0.3	1.7	2.1
Barstow	0.1	0.2	0.2
Idarado	0.3	0.6	0.8
Willow Swamp	1.1	6.9	8.0
Blue Willow	0.6	3.5	4.1
Blue Point	1.5	10.2	11.7
Snowflake	0.2	0.9	1.1
Fence	0.0	0.2	0.2
Runoff	0.0	0.0	0.0
Silver Ledge N	0.0	0.0	0.0
Silver Ledge	1.5	13.8	15.4
Rockwall	2.2	26.4	28.6
Silver Ledge Mill (U)	0.3	1.4	1.8
Porcupine (U)	0.2	0.9	1.1

NAME	AHI–M	AHI–W	AHI
Eagle (U)	1.9	20.2	22.1
Telescope (U)	1.5	14.0	15.5
Muleshoe	0.5	2.3	2.7
Telescope (L)	0.2	0.9	1.0
Eagle (L)	0.2	1.2	1.4
Porcupine (L)	0.0	0.0	0.1
Silver Ledge Mill (L)	0.0	0.1	0.1
Imogene	0.2	1.1	1.2
Battleship	0.1	0.8	0.9
Pumphouse	0.0	0.1	0.1
N Star	0.0	0.0	0.1
TOTALS	32.4	302.6	335.0

AHI–M: Hazard to moving traffic
AHI–W: Hazard to waiting traffic
AHI: Composite AHI (AHI–M + AHI–W)

Table 4-20. Basalt - Aspen (SH 82)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Shale Bluffs	3.4	2.4	5.8
Watson	0.3	0.1	0.4
Footbridge	0.2	0.0	0.2
Cerise	0.2	0.0	0.2
Eli	0.2	0.0	0.2
Grande	0.3	0.1	0.4
Rio	0.2	0.1	0.3
Ditch	0.4	0.1	0.5
Wheatley	0.4	0.1	0.4
Eye	0.4	0.1	0.4
Jay	0.4	0.1	0.4
King	0.4	0.1	0.5
Arbaney	0.3	0.0	0.3
TOTALS	7.2	3.1	10.2

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-21. Ten Mile Canyon (I-70)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
King Soloman	0.2	0.0	0.3
Excelsior	0.3	0.1	0.5
TMC 1	0.3	0.0	0.3
TMC 2	0.3	0.0	0.3
Mears 4	0.3	0.1	0.4
TMC 3	0.2	0.0	0.2
TMC 4	0.2	0.0	0.2
TMC 5	0.2	0.0	0.2
Mary Verna	0.3	0.0	0.3
Uneva	0.3	0.0	0.3
Mears 5	0.5	0.2	0.7
Mears 6	0.5	0.1	0.6
Little Tim	0.5	0.1	0.6
Daniel	0.5	0.1	0.6
Mears 7	0.5	0.1	0.6
Mears 8	0.6	0.2	0.7
Mears 9	0.8	0.3	1.1
Mears 10	0.9	0.4	1.2
Mears 11	0.9	0.4	1.2
Ponds	0.5	0.3	0.7
Wheeler A	0.3	0.1	0.3
Wheeler B	0.3	0.1	0.3
Mears 12	0.3	0.1	0.3
Copper Exit	3.0	0.8	3.8
Mears 13	0.0	0.0	0.0
TOTALS	12.6	3.6	16.1

AHI–M: Hazard to moving traffic
AHI–W: Hazard to waiting traffic
AHI: Composite AHI (AHI–M + AHI–W)

Table 4-22. Tennessee Pass (US 24)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Switchback	0.7	2.1	2.8
Eagle	0.2	0.1	0.4
Gilman	0.1	0.0	0.1
Water Tank	0.1	0.0	0.1
Cliff Banks	0.3	0.8	1.1
Red Cliff	0.1	0.2	0.3
Pando	0.0	0.0	0.0
Yodder	0.0	0.0	0.1
Rule	0.0	0.0	0.1
TOTALS	1.7	3.4	5.1

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-23. Tunnel Approaches (I - 70)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Highbridge	0.1	0.0	0.1
Peru	0.1	0.0	0.1
Snowdrift	0.2	0.0	0.2
Pendletons	0.3	0.0	0.3
Pendleton Mt.	0.3	0.0	0.3
L. Brown's	0.1	0.0	0.1
Brown Mt.	0.2	0.0	0.3
Pinkerton	0.4	0.1	0.5
Cloud Gl.	0.4	0.1	0.5
Deadman Gl.	0.1	0.0	0.1
Ganley	0.1	0.0	0.1
Thompson gl.	0.3	0.1	0.4
Bard	0.3	0.1	0.4
Bethel	2.8	0.7	3.5
Lazy Susan	0.5	0.1	0.6
Batch Plant	1.8	0.5	2.3
Straight Ck. 1	1.6	0.4	2.0
Straight Ck. 2	1.6	0.4	2.0
Straight Ck. 3	1.0	0.2	1.2
Whistler Cliff	1.1	0.3	1.4
Whistler West	1.0	0.3	1.3
Whistler	1.0	0.3	1.3
Whistler East	0.9	0.2	1.1
Slide A	4.3	1.6	5.9
Slide B	1.2	0.2	1.4
TOTALS	21.8	5.5	27.3

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-24. Vail Pass (I-70)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Narrows	3.0	1.5	4.5
Marvine	0.4	0.1	0.5
TOTALS	3.4	1.6	5.0

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite hazard (AHI-M + AHI-W)

Table 4-25. Willow Creek Pass (SH 125)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Willow 1	0.0	0.0	0.1
Willow 2	0.0	0.1	0.1
Willow 3	0.0	0.1	0.1
Willow 4	0.0	0.0	0.1
Willow 5	0.0	0.3	0.3
Willow 6	0.0	0.2	0.2
Willow 7	0.0	0.1	0.1
Willow 8	0.0	0.1	0.1
TOTALS	0.1	0.9	1.0

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

Table 4-26. Wolf Creek Pass (US 160)
Avalanche Path AHI

NAME	AHI-M	AHI-W	AHI
Half Bridge	0.1	0.7	0.8
Palisades	1.1	4.1	5.1
Tunnel Curve	0.3	0.9	1.3
Hairpin	0.5	2.2	2.8
Switchback	0.1	0.4	0.6
Stud Muffin	0.7	2.9	3.6
Stud Muffin 2	0.4	1.9	2.3
Little Coyote	0.0	0.2	0.2
Upper Coyote	0.1	0.2	0.3
Big Coyote	0.9	5.3	6.2
Boulder Ck. W.	0.3	1.2	1.5
Snowflake	0.5	2.3	2.8
Sheep Bank	0.3	1.4	1.7
Camp	0.1	0.2	0.2
Pit Gully	0.2	0.6	0.8
Pit	0.4	1.7	2.1
Pit Fingers	0.1	0.2	0.3
Mud Hump	0.1	0.2	0.3
Kathy	0.1	0.4	0.5
Andrew	0.4	1.7	2.1
Daniel	0.4	2.4	2.9
Stephen	0.3	1.4	1.7
Navajo	0.0	0.1	0.2
Lobo	0.0	0.1	0.1
Alberta Shoulder	0.1	0.2	0.2
Alberta	0.1	0.2	0.2
Alberta Cousin	0.0	0.1	0.1
170	0.1	0.0	0.1
Pass Ck. Lake	0.1	0.1	0.2

NAME	AHI-M	AHI-W	AHI
Tucker Ponds Roadhead	0.1	0.1	0.2
Moore's	0.1	0.1	0.2
173.85	0.1	0.3	0.4
Narrows	0.2	1.1	1.3
Narrows Fingers	0.9	5.5	6.4
Narrows East	0.1	0.3	0.4
Big Meadows	0.1	0.5	0.6
Big Meadow Cliff	0.2	0.8	1.0
Columbine	0.2	0.8	1.0
Wolf Ck. Ranch	0.0	0.0	0.0
Park Ck. Roadhead	0.0	0.0	0.0
Fun Valley	0.2	0.7	0.8
TOTALS	10.1	43.4	53.5

AHI-M: Hazard to moving traffic
AHI-W: Hazard to waiting traffic
AHI: Composite AHI (AHI-M + AHI-W)

REFERENCES

Armstrong, B., 1981. A quantitative analysis of avalanche hazard on U.S. 550, southwestern Colorado. Proc. West. Snow Conf. 49: 95–104.

Avalanche Task Force, 1974. Report on findings and recommendations. Appendix II, Victoria, B.C., British Columbia Department of Highways.

Mears, A.I., and R. Newcomb. Avalanche hazard analysis of SH 22, Teton Pass, Wyoming. Unpublished report to Wyoming Highway Department.

Mears, A.I., Fesler, D., and Fredston, J. 1991. Avalanche hazard analysis and mitigation recommendations for Thane Road, Juneau, Alaska. Unpublished report to the Alaska Department of Transportation and Public Facilities.

Schaerer, P., 1989. The avalanche-hazard index. Annals of Glaciology 13:241–247.

Bachman, D., Personal communication.

Hogan, D., Personal communication.

Fink, E., Personal communication.