3. Development and Evaluation of Alternatives

Team Process

Stakeholder Meetings

As mentioned in Chapter 1, the SR-210 Transportation Study involved a large group of stakeholders. They included representatives from UDOT, Town of Alta, USFS, Snowbird, Alta Ski Lifts Co., Save Our Canyons, Salt Lake County Planning, Salt Lake County Sheriff, Salt Lake City Public Utilities, UTA, and WFRC. This group met several times over the course of the study to provide input on canyon issues, and present feedback to the solutions proposed in this study. On October 11, 2005, the stakeholders generated the "universe of alternatives". This list encompassed every suggestion made towards reducing the avalanche hazard on SR-210, and is shown in Table 3-1.

Focus Group Meetings

The consultant team met with several smaller focus groups to clarify the alternatives and gather more information about the issues faced in the canyon. These groups included UDOT Avalanche Control, UDOT Region 2, UDOT Maintenance, UDOT TOC, Save Our Canyons, UTA, and the United States Forest Service Wasatch-Cache Ranger District.

Methodology

Avalanche Hazard Index (AHI)

As discussed elsewhere in this document, the Avalanche Hazard Index (AHI) assesses the avalanche risk to traffic. The index indicates the probability of moving and waiting vehicles being hit by various types of avalanches, and takes several factors into consideration:

- Average daily traffic
- Traffic speeds
- Average length of avalanche debris on the roadway centerline
- Vehicle braking
- Avalanche frequency

The AHI method is commonly used in the United States, Canada and New Zealand to quantify the avalanche hazard for roads. The AHI is helpful when comparing avalanche hazard among different roads and avalanche control types, identifying high-priority avalanche paths, evaluating effectiveness of proposed avalanche control measures, and calculating risks to future traffic based on traffic growth projections. Highways are categorized with respect to the AHI as described in Table 3-2.

Table 3-1: Universe of Alternatives

	Name	*Objectives*	*Where else used?*	*Category**
1	Infrasound sensing	Improved forecasting	Wyoming	A
2	Improving forecasting	Reduce avalanche hazard	NA	A

	Name	*Objectives*	*Where else used?*	*Category**
3	Improving control operations	Reduce avalanche hazard	NA	A
4	Better preparedness of lodges	Reduce avalanche hazard to individuals in the Town of Alta and at Snowbird	Iceland	A
5	Streamline max. security measures	Reduce avalanche hazard to individuals in the Town of Alta and at Snowbird	St. Anton, Austria (GIS tools); Iceland (centralized avalanche monitoring and evacuation responsibility)	A
6	Guide berms (parallel or perpendicular)	Reduce avalanche hazard	British Columbia, Colorado, Alaska, Iceland	A
7	Gaz-Ex	Reduce avalanche hazard	Snowbasin, Brighton	A
8	Avalanche Guard	Reduce avalanche hazard	Austria	A
9	Lift-service to slopes above Alta (compaction)	Reduce avalanche hazard	Existing strategy at ski resorts	A
10	Snow fencing	Reduce avalanche hazard	Washington, Montana, British Columbia, Japan	A
11	Snow sheds	Reduce avalanche hazard	British Columbia, Colorado, Washington	A, R
12	Nighttime operations	Reduce hazard to private vehicles	UDOT (non-canyon operations)	A, R
13	Parking lot metering on hazard days, or temporary parking lot exit closure at select locations	Reduce congestion in slide paths, reduce hazard to private vehicles		D
14	Stagger lift closure times, lodge closure times	Reduce congestion in slide paths, reduce hazard to private vehicles	Staggered lift closure already practiced in many locations	D
15	Increase attractiveness of transit	Reduce number of private vehicles in slide paths	Innsbruck, Austria "Club Innsbruck bus"	D
16	Toll road	Encourage carpools or transit to avoid/minimize fee, reduce number of private vehicles in slide path	Millcreek Canyon; Mt Fuji, Japan	D, R, T
17	Improve evacuation plans	Better control over guest movements at resort when interlodge and maximum security measures are necessary	St. Anton, Austria (GIS tools); Iceland (centralized avalanche monitoring and evacuation responsibility)	D, T
18	Increase UDOT equipment upcanyon	Improve ability to remove snow/manage incidents in slide paths, allowing better traffic movement and reducing hazard to private vehicles	Washington State DOT	D, T
19	Incident management in canyon	Improve ability to remove snow/manage incidents in slide paths, allowing better traffic movement and	I-70 in Glenwood Canyon, Colorado (Hanging Lake Tunnel)	D, T

	Name	*Objectives*	*Where else used?*	*Category**
		reducing hazard to private vehicles		
20	One-way operations	Improve traffic flow, reduce hazard to private vehicles	Laguna Beach, Malibu	D, T
21	Ban private vehicles in winter	Eliminates hazard to private vehicles	Zion National Park; Sans Fee, Switzerland	D, T
22	More buses	Increase transit opportunities, reduce hazard to private vehicles	Zion National Park, Yosemite National Park, Breckenridge, Sun Valley, Telluride, Whistler, Deer Valley	M
23	Trains	Increase transit opportunities, reduce hazard to private vehicles	Austria, Edmonton/ Jasper/Vancouver; Jungfrau Region, Switzerland	M
24	Better changing areas	Encourage transit use, reduce hazard to private vehicles		M
25	People-mover lift	Increase transit opportunities, reduce hazard to private vehicles	The Canyons, Snowmass	M, D
26	Rideshare programs	Encourage carpools, reduce hazard to private vehicles	Whistler	M, D
27	Improve park-and-ride facilities	Encourage carpools or transit, reduce number of private vehicles in slide path	Oakland CA (BART)	M, D
28	Road realignment	Reduce avalanche hazard to vehicles	British Columbia, Alta	R
29	Tunnel	Eliminate avalanche hazard to all vehicles	British Columbia, Austria, Norway, Switzerland	R
30	Construct emergency turnarounds (strategically located)	Provide places for vehicles to turn around if avalanches block the road	Other Wasatch Front canyons	R, T
31	Roadway pavement monitoring	Automatically alert UDOT staff of poor roadway conditions	Salt Lake Valley	R, T
32	Increased enforcement of chains/4WD restrictions	Reduce number of unprepared private vehicles, reduce opportunities for crashes and road blockage, reduce time spent waiting in line in the canyon	Oregon HP (I-5 Siskiyou Summit)	T
33	Intelligent Transportation Systems (Smart Canyon)	Better communication to drivers of conditions, improved monitoring by UDOT	I-70 in Glenwood Canyon, Colorado	T, D
34	Better prepared vehicles/drivers in canyon	Reduce number of unprepared private vehicles, reduce opportunities for crashes and road blockage, reduce time spent waiting in line in the canyon	Oregon HP (Two-day program give warnings and hand out informative literature)	T, D

	Name	*Objectives*	*Where else used?*	*Category**
35	Paid parking	encourage carpools or transit, reduce number of private vehicles in slide path	Jackson Hole, Telluride, Breckenridge	D
36	Priority parking	Encourage carpools, reduce hazard to private vehicles	Jackson Hole	D
37	Additional bypass road by White Pine	Remove all vehicles from high-risk avalanche paths	British Columbia, Alta	R, T
38	Remote control avalanche gates	Restricts all vehicle access on high hazard days	Alaska, British Columbia	R, T
39	VMS at key decision points	Provide decision-making information before canyon users drive up canyon, encourage carpooling and transit use, reduce number of private vehicles in canyon	A20 London Road in Maidstone, UK; I-70 in Glenwood Canyon, Colorado	T, D
40	Lot monitoring	Provide decision-making information before canyon users drive up canyon, encourage carpooling and transit use, reduce number of private vehicles in canyon	Yosemite National Park, Stratford upon Avon (UK),	T, D
41	More CCTV	Provide better information on canyon wide conditions to UDOT staff	I-70 in Glenwood Canyon, Colorado	T, D
42	VMS at top of chairlifts	Communicate road closures to skiers before they are on the road	NA	T, D
43	New artillery gun near Tanner's	Provide better accuracy and reliability for controlling White Pine Chutes 3 & 4.	Throughout Little Cottonwood Canyon	A
	*A Avalanche R Roadway T Traffic D Demand Management M Multi-modal			

Table 3-2: Category of Hazard

Very Low	< 1
Low	1 - 10
Moderate	10 – 40
High	40 – 150
Very High	>150
Source: Schaerer, 1989	

When a historic record of avalanche occurrence is available (such as at SR-210), the baseline AHI can be calculated using the frequency of all avalanches (whether the road is open or closed) or by looking only at those avalanches that occur with the road open (Road Open Avalanche Hazard Index or ROHI). This is the residual risk on the road with avalanche control operations taken into account. The analysis of the alternatives discussed in this report refers primarily to the ROHI, because this analysis assumed that the current avalanche control operations will continue in Little Cottonwood Canyon. If future events cause a discontinuation of the existing avalanche control program, the avalanche risks would be higher.

It is important to note that although much of the analysis on the alternatives focuses on the AHI, this is only one metric. There are many other criteria that should be used as the alternatives move forward in the project development process. The following discussion is from a planning level risk reduction and does not fully take into account factors such as the whole range of environmental impacts, ability to fund the projects, institutional concerns such as permitting, general public and special interest perspectives, and last but not least, the “human factor”; the combined experience of the snow safety experts who have lived and worked the Little Cottonwood Canyon for many years.

Constraints and Issues

Wilderness

As discussed in the Existing Conditions chapter, wilderness areas are a major constraint in Little Cottonwood Canyon. Wilderness is a land use designation enacted by Congress, and Little Cottonwood Canyon contains two separate wilderness areas: Twin Peaks Wilderness Area, on the north side of SR-210, and Lone Peak Wilderness to the south of the road. The boundary of the Twin Peaks Wilderness is set 600’ north of SR-210, and the boundary of Lone Peak Wilderness is Little Cottonwood Creek. The 600’ offset from SR-210 for the Twin Peaks Wilderness boundary sets the limit of activity related to the roadway. Modification to the roadway or current maintenance strategies will not impact the wilderness area if they occur only within the 600’ boundary.

If a change in avalanche control operations is needed, USFS would examine alternatives in the following order:

1. Alternatives that are outside wilderness boundaries (within the 600’ roadway corridor).
2. Options that are in wilderness boundaries but that won’t impact the wilderness designation such as temporary sensors during the snow season.
3. Options that are in wilderness boundaries and may affect the wilderness designation, therefore requiring a modification of the designation language, such as installation of permanent devices like a weather station or Gazex within the Area.
4. Options that would require a change in the Wilderness Area boundaries and have significant environmental impacts, such as realigning the road.

The USFS has no authority to modify provisions of the Wilderness Act. This means that if any proposed alternatives violate the regulations of the Wilderness Act, Congress must approve those strategies. Any permanent structures (i.e., new roads, Gazex shelters or exploders, or anything else requiring permanent placement) proposed within the wilderness areas would likely require an act of Congress, as well as preparation of an environmental study. The level of study, whether an Environmental Assessment or an Environmental Impact Statement (EIS), would be determined once the decision is made to pursue as an option.

A significant issue is that a change in wilderness area boundary in Little Cottonwood Canyon might be viewed as a precedent for other areas, and national special interest groups (i.e., the Sierra Club, the Wilderness Society) may object. These groups tend to watch cases like this closely, and word spreads quickly among their subscribers. If Congress approved a change in the Twin Peaks wilderness (north of SR-210), the language would have to contain a rider stating that the change is only to permit for avalanche control. An option would be to retain the current boundary, but allow permitted use of the wilderness area. Depending on the proposed use, this may, or may not be as contentious an issue.

Slope

While detailed plan and profile information was not readily available for the purpose of this study, the observed road grades on SR-210 are steep. In addition, the slopes on either side of SR-210 are steep as well. Most realignments of the road (including minor realignments associated with "tunneling" segments of SR-210) would be a challenge to design, because any reduction in grade over one segment will require an increase in grade elsewhere. In addition, cut and fill of earthwork would likely be significant for a realignment alternative.

Environmental Clearance

The alternatives in this chapter involve a range of environmental clearance requirements. In this document, the alternatives are discussed in order of increasing complexity of environmental study. Some elements, such as paid parking programs and improved incident management, are operational strategies and do not require environmental study. Other options, such as installing a traffic signal at Snowbird Entry 1, qualify as a Categorical Exclusion (CE) under the National Environmental Policy Act (NEPA) and can be processed through UDOT rather than through a federal government agency. Alternatives that may have significant environmental impacts will require an Environmental Assessment (EA) or an Environmental Impact Statement (EIS), to determine what effect these alternatives will have on the environment and what mitigation measures may be necessary if the alternatives are approved. The highest level of environmental study that would likely be required for any of the alternatives discussed in this report is the EIS, for those alternatives involving a change in wilderness land use designation.

Economic Fairness

Among the goals and objectives established for this study was "maintain/enhance economic viability". Alta and Snowbird ski resorts are both stakeholders in the operations of Little Cottonwood Canyon, and they are the primary contributors to traffic volumes on SR-210. Measures taken to reduce the avalanche hazard in the canyon should consider the impacts on the economic activities at Alta and Snowbird. For instance, converting SR-210 to a toll road may cause Alta and Snowbird to lose business to resorts in Big Cottonwood Canyon or Park City. The prohibition of private vehicles on SR-210 during the winter might have the same effect. In contrast, a rail line up Little Cottonwood Canyon might have enough cachet to become a tourist destination, thereby increasing visitation to Alta and Snowbird.

Artillery Availability

As mentioned in the discussion of existing conditions, UDOT relies on two Recoilless Rifles and one Howitzer for avalanche control work, using an average of 495 rounds of ammunition every year. These ammunition supplies are available to UDOT only at the discretion of the U.S. military, and can be revoked at any time. Given the current military activities taking place overseas, the overall military supply is strained; this means that the ammunitions allotted to UDOT for avalanche control may soon be directed elsewhere, or that the cost of obtaining the ammunitions will rise enough to be unattainable for UDOT. Also, the relatively recent misfiring of military artillery into a Pleasant Grove neighborhood proved to be a significant public safety concern (not to mention public relations) for UDOT. If another similar mistake were to occur, UDOT's access to military artillery for avalanche control work may be cut off.

An end to the ammunition supply would drastically change the way avalanche hazards are handled in Little Cottonwood Canyon. Without an alternate method of active or passive avalanche control in place, canyon users will be at the mercy of conditions. Canyon road closures will occur much more frequently and will last longer (days, instead of hours), leading to more complaints from the public and more money lost by the resorts. These factors contribute to the need for an expedient way to reduce risk on SR-210, and to the necessity of identifying a long-term solution for the canyon.

Alternatives by Strategy

Strategy Evaluation

Several strategies could be pursued for future avalanche and transportation control measures in Little Cottonwood Canyon. The strategies discussed in this section achieve the following objectives, as stated in previous sections of this report:

- Reduce SR-210's avalanche hazard index
- Reduce dependence on military artillery
- Provide a range of recommendations, including short-term and long-term solutions

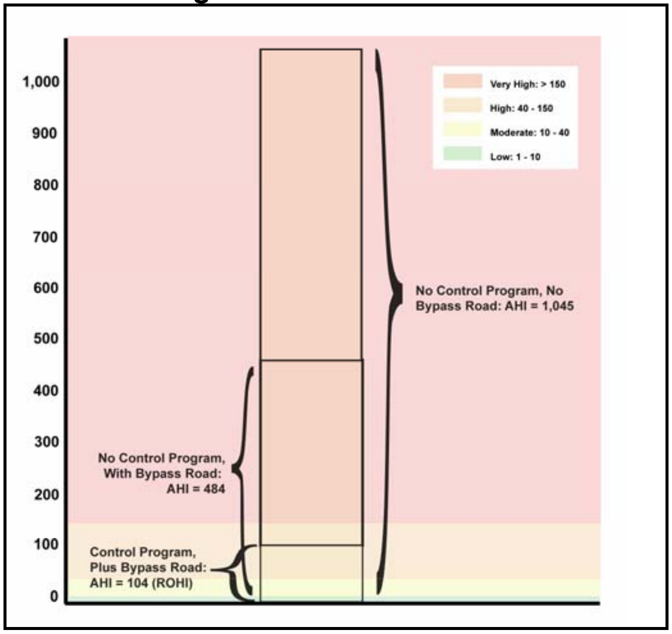
In addition, many of these strategies improve avalanche hazard forecasting and increase efficiency of existing control operations. The strategies discussed in this report meet the remaining objectives (safely accommodate a variety of travel modes, focus on environmentally sensitive solutions, and maintain/enhance economic viability) in varying degrees.

The baseline AHI analysis in the previous section of this study identified the Mid-Canyon section of SR-210 as the highest priority for reducing the avalanche hazard, followed in order by Snowbird Village, Town of Alta, and Lower Canyon. These assume that the Superior Bypass Road is in effect, and therefore improvements in Hellgate Superior have not been identified. An analysis of only those avalanches which had occurred with the road open (ROHI) yielded a similar result, in that the priorities were the Mid-Canyon followed by Snowbird Village.

The Road Open Hazard Index (ROHI) reflects what the avalanche risk to the road is on a day-to-day basis, since it takes into account the risks that are reduced by the current control program, whereas the AHI is what occurs without the current program. For example, without any of the current program in place, the AHI for Little Cottonwood Canyon is 1,045 - an off-the-charts value. However, with the program plus the bypass road in place, the AHI is 104, in the high hazard category (Table 3-2). See Figure 3-1 for an illustration of the AHI vs. the ROHI.

As stated earlier in this chapter, the AHI is only one indicator of effectiveness of any alternatives and the reader should keep this perspective in mind. Two different scenarios could have the same AHI, but result in conditions that differ in their risk. The AHI does not account for how certain, predictable, or manageable the remaining risk is. There are many more detailed criteria that would need to be evaluated and compared as alternatives discussed here are further evaluated in preparation for implementation.

Figure 3-1: AHI vs. ROHI



The following assessment of risk for the future options (if quantifiable) refers to the impact on the ROHI. In other words, it determines how each option would reduce the residual risk over and above the existing artillery program. The options discussed in this report have been effective on other similar transportation routes. Early rounds of brainstorming generated many (over 40) ideas for achieving the objectives stated in this report; however, some of these ideas were eliminated from further analysis due to a lack of feasibility or relative effectiveness. The remaining options discussed in further detail here are the options that provide a meaningful and demonstrable reduction in AHI, if quantifiable.

The following sections of this report summarize the remaining alternatives in further detail. These alternatives are grouped into four general strategy categories, for discussion purposes:

- Avalanche forecasting
- Transportation
- Active Avalanche Control
- Passive Avalanche Control

AHI or ROHI reduction analyses were applied to each option (where appropriate) and are included in the discussions of the alternatives. Each strategy group discussion includes a table comparing the alternatives within that strategy, and how each applicable strategy reduces the avalanche hazard on SR-210.

Avalanche Forecasting Strategies

The existing SR-210 avalanche forecasting program is one of the leading programs of its kind in North America. Key factors in the success of the forecasting program include:

- Long term experience of the personnel (UDOT, Alta and Snowbird) in observation, decision making and operations in Little Cottonwood Canyon
- A 30-year database for the road

- A network of manual and remote weather stations along the highway and in the ski areas
- Accessible snow observation sites at the elevation and aspect of the avalanche starting zones
- The concentrated geographic region of the SR-210 avalanche paths, their similarity of aspect and the resultant similar snow and weather patterns
- High-quality local weather forecasts produced by Alta's resident meteorologist along with the National Weather Service
- Availability of explosive testing options

The evolution of avalanche hazard evaluation and avalanche control on SR-210 is one of the most important factors in risk reduction over time. The probability of unexpected avalanches with the road open is reduced with increasing expertise in forecasting and operations. Retention of this expertise must be a priority. Further improvements to the existing forecasting program could be gained by:

- Remote sensing of avalanche activity
- Improved information access in forecaster vehicles (links to weather stations, traffic, and other sensors)

Remote Sensing of Avalanche Activity

The forecast for the highway can be refined if the forecasters know the size, timing and location of natural or controlled avalanches. Improved forecasting will lead to improved timing of closures and control operations, and reduce the likelihood of unexpected avalanches with the road open or road closures for unnecessarily lengthy periods of time.

At present only White Pine Chute 1 has a sensor to indicate avalanches in the runout zone. This sensor is a tilt switch suspended on a cable across a gully approximately 1000' above the road. A passing avalanche triggers a radio signal, which alerts UDOT staff. At all other sites forecasters rely on visual reference or audible sound of avalanches to track occurrences. During storms or under limited visibility, little information is available unless avalanches run nearby or onto the road.

Infrasound sensing is a new technology used to detect low frequency sound resulting from moving avalanches. This technology has been successfully tested at Jackson Hole Ski Area and at Teton Pass, Wyoming (Comey & Mendenhall 2004). The sensor array is laid on the ground surface in summer near the avalanche paths, and linked to a data logger and transmitter. By placing multiple sensors in strategic locations, the location, timing and size of avalanches can be tracked on several adjacent avalanche paths. At Jackson Hole, small and medium sized avalanches were tracked from a distance of 1.2 miles. An array of remote sensors should be developed for all potential runout zones along SR-210.

The extent of institutional challenges, for the purposes of this evaluation, has been categorized according to scale shown in Table 3-3. Table 3-4 summarizes the forecasting options discussed in this section presenting their effect on the ROHI, with current artillery in place, benefits, impacts, estimated costs and the likely institutional challenges that would have to be overcome to allow implementation.

Table 3-3: Scale of Institutional Challenges

Score	*Description of Level of Challenge*
1	None – Provide consideration of the built and natural environment
2	Low – Minimal level of State/Fed documentation and/or permitting
3	Moderate – Will require efforts such as an Environmental Assessment; requires moderate effort
4	High – Can be done, but will require a high level environmental effort with lots of agency and/or public commitments
5	Extreme – Project would get national level scrutiny, possible Congressional involvement, high cost in terms of money and willpower
Other	Constructability, Cost, Safety

Source: Fehr & Peers, June 2006

Table 3-4: Forecasting Options Summary

Option	*Risk Reduction (Road Open with Current Artillery)*	*Other Benefits*	*Approx. Cost*	*Other Impacts*	*Institutional Challenge*
Avalanche Sensors	est. 4%	Improved avalanche forecast accuracy and closure timing	$150,000		1
Retention of forecasting team expertise	Intangible	Expertise is essential to current operation	Priceless		3
Improved in-vehicle information for forecasters	Intangible	Improved response time to changing conditions during storms	$15,000	Potential for information overload	1

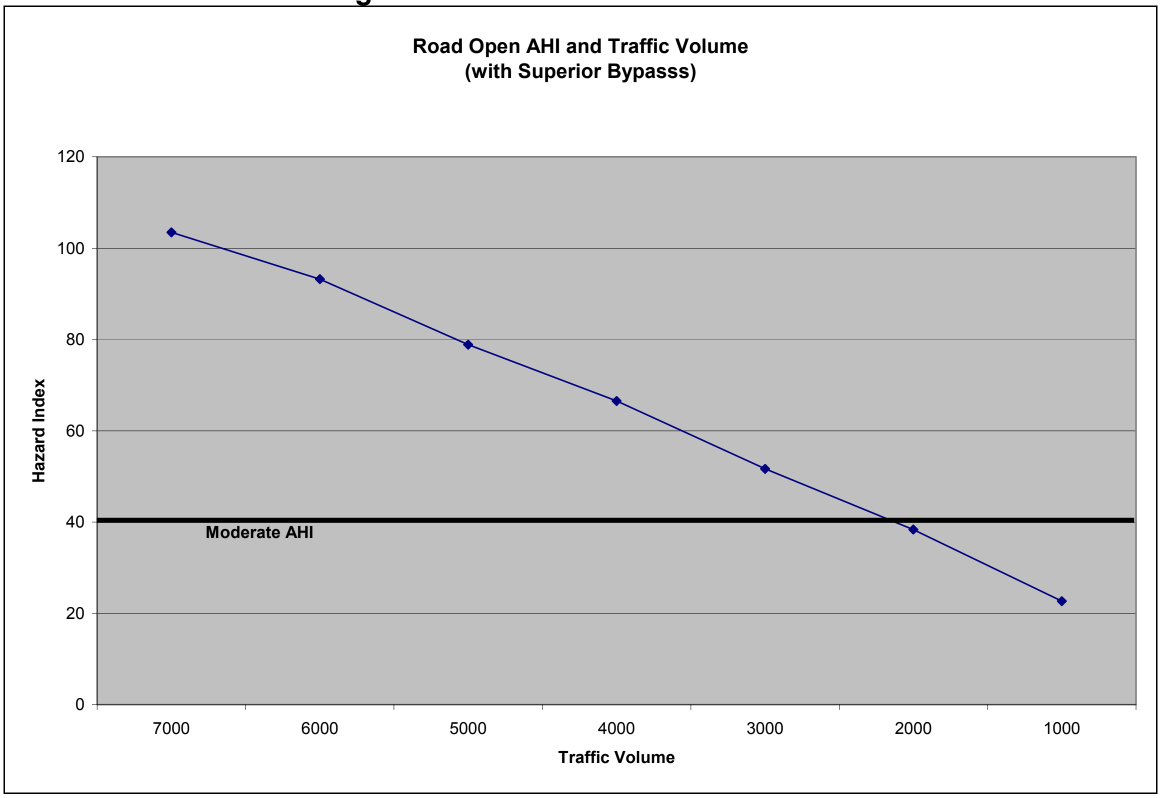
Source: Fehr & Peers, June 2006

Transportation Strategies

Transportation options involve a variety of different concepts, from concepts that change the existing roadway network (closing roads, adding new connections) to ultimately increase vehicle speeds and/or decrease the number of vehicles on SR-210 to concepts that change the transportation mode of travelers using SR-210. Examples include installation of traffic metering at resort driveways, paid parking programs at the ski resorts, and improved transit amenities (shelters, passenger information systems, park-and-ride facilities). This category also includes improved maintenance and incident management measures, so disabled vehicles can be removed quickly from the roadway and traffic flow can be optimized. Environmental clearance for traffic and transit improvements is minimal, and many of these measures could be implemented in the next five years.

Reduced traffic volume will reduce the avalanche hazard index. The relationship between traffic volume and the ROHI (with the existing artillery program) is illustrated in Figure 3-2. As the figure shows, there is a clear relationship between reduction of traffic volume and reduction of risk.

Figure 3-2: ROHI and Traffic Volume



Combinations of avalanche control strategies and reduced traffic volume could be used to reduce the avalanche hazard index.

<u>Incident Management</u>

Improved incident management capabilities for avalanche control operations staff would allow better communication and coordination between the staff and other emergency personnel. In addition, if UDOT's canyon staff had the ability to clear disabled vehicles from the roadway, this would improve AHI and ROHI by maintaining vehicle speeds rather than allowing disabled vehicles to block traffic and encouraging "rubbernecking".

<u>One-Way Traffic Evacuation</u>

Currently SR-210 is a two-lane facility, with one lane per direction. When the majority of day-skiers leave the resorts at the end of the day, downhill traffic is limited to using the westbound lane only, uphill traffic using the eastbound lane is minimal. On days when the avalanche hazard is high and the road is still open, the risk to individual vehicles would be reduced if traffic on SR-210 were restricted to westbound only in both lanes. This would increase the capacity of the roadway to evacuate the high volume of downhill canyon traffic. Adding capacity to SR-210 in this manner would increase vehicle speeds as congestion is alleviated. Since the avalanche hazard index rating is based on vehicle speeds (among other things), increased speeds would decrease the rating. While the existing cross-section would largely remain the same, some infrastructure modifications would be necessary. Emergency personnel would need to be able to access the upper part of the canyon by traveling eastbound on SR-210, and auxiliary lanes would be necessary in some locations to accommodate those vehicles. Preliminary analysis demonstrates that conditions could indeed be improved using this strategy. However, this concept creates a whole different set of operational and institutional problems such as driver expectancy, safety, signing, and accessibility for uphill traffic.

Signal Installation

As described above, when the majority of day skiers leave the resorts at the end of the day, the peak traffic volumes create congestion for westbound travel on SR-210. Traffic unloading from Alta that is already on SR-210 has the right-of-way at the four Snowbird access points, and vehicles attempting to access SR-210 from Snowbird must wait for gaps to enter the traffic stream. Under normal right-of-way rules, these gaps are extremely infrequent. SR-210 drivers are aware of the lack of gaps and the westbound traffic stream stops frequently to allow vehicles to exit Snowbird. These "courtesy gaps" contribute to a decrease in travel speed on SR-210. In turn, decreasing speed is a factor in higher avalanche risk, since more time is spent waiting in avalanche paths. Both observed and simulated conditions suggest that the ad-hoc way drivers create and accept gaps on SR-210 at Snowbird Entry 1 causes considerable delay. Signalizing this location could balance the traffic flow, clearing queues and preventing buildup of long queues at this approach. This method would demonstrate to SR-210 drivers that the people attempting to leave Snowbird would be given a protected phase at the signal to access SR-210, removing the need for drivers to create "courtesy gaps". Preliminary traffic operational analyses have shown that the implementation of a traffic signal at Snowbird entry 1 successfully alleviated the congestion problem associated with 'courtesy gaps', and also significantly reduces the number of vehicles that sit in congestion in avalanche paths on SR-210 east of Snowbird entry 1. Refer to the Appendix of this report for a technical memorandum regarding traffic operations.

Turnarounds/Staging Areas

SR-210 has nine designated staging areas, which are considered relatively safe from avalanches. One way to improve safety on SR-210 involves widening staging areas enough to allow cars and trucks to turn around with a single point turn. A worst-case scenario for SR-210 is for an avalanche to cover the road when it is open to traffic. This causes a line of cars to queue behind the debris, becoming targets for a subsequent avalanche. In this scenario, it is critical to move traffic off the roadway quickly to assess the need for additional control work prior to clearing the road. Adding turnarounds in selected locations could expedite the process of clearing the road. Analysis of the turnaround alternatives is summarized in this section.

Two staging areas were selected to analyze turnaround alternatives: immediately east of White Pine, and immediately east of Little Pine. These two areas were selected to determine a range of costs associated with improving a staging area in general. The area east of White Pine was selected to represent the higher end of the cost spectrum. At this location there is a drop-off very close to the creek. Widening would require walks. The area east of Little Pine was selected to represent the lower end of the cost spectrum. There terrain here is relatively flat and the creek farther away. Improving the staging areas could reduce the avalanche risk to traffic on the roadway by an estimated 5%. This assumes the waiting time to clear traffic from the hazardous areas is reduced from 60 to 55 minutes, following a natural avalanche blocking the road. Preliminary cost estimates for turnarounds are shown in Table 3-5. As shown in the table, the cost estimates consider two options for each staging area turnaround: sufficient space to allow a passenger car to complete a U-turn, and space for a single-unit truck to complete a U-turn. These estimates should be used for planning purposes only. See the Appendix for the complete technical memorandum on turnarounds (as well as several other passive control options).

Table 3-5: Turnaround Alternative Summary

Alternative		*Cost*
Location	*Vehicle Accommodated*	
East of White Pine	Passenger car	$850,000
East of White Pine	Single-unit truck	$1,500,000
East of Little Pine	Passenger car	$225,000
East of Little Pine	Single-unit truck	$450,000
Source: HW Lochner, May 2006		

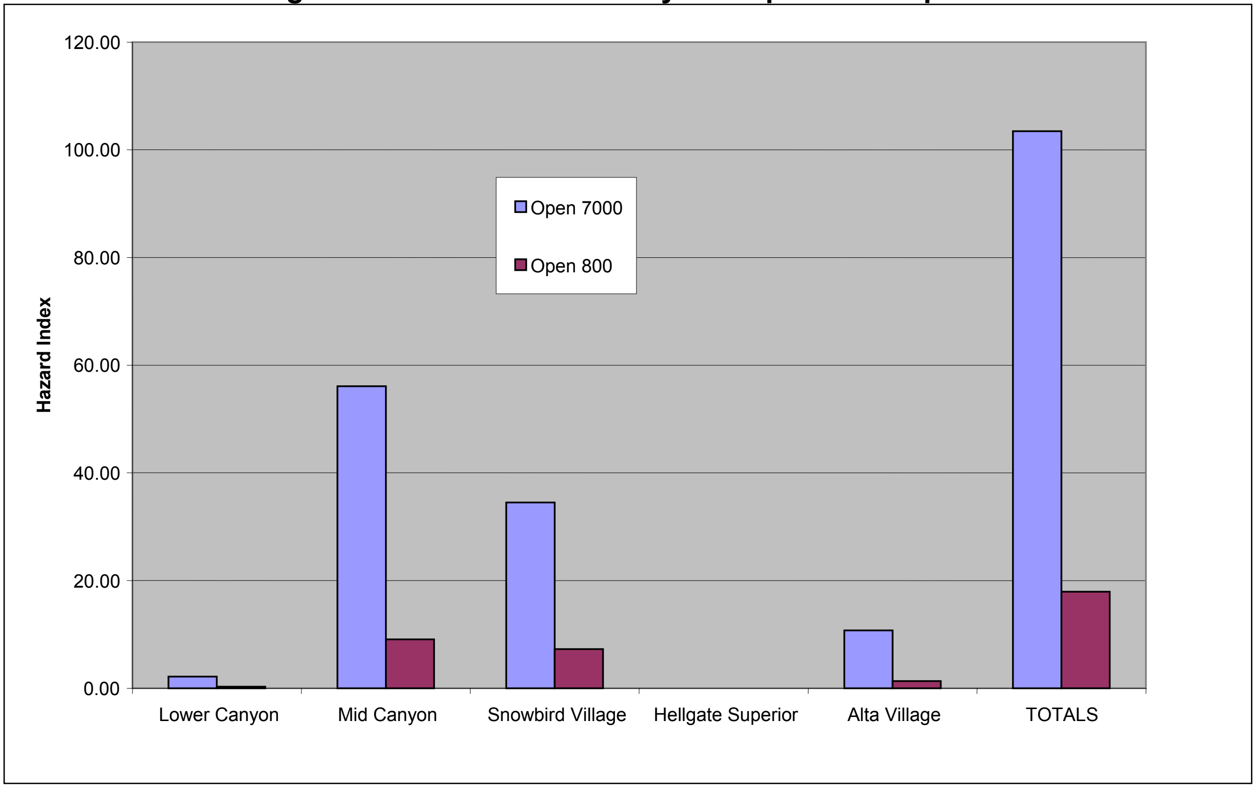
<u>Bus-Only Transportation – SR-210</u>

Reduced traffic volume and/or improved traffic flow will reduce the avalanche hazard on the road. As traffic volumes increase, so does the likelihood that a vehicle will be hit by an avalanche. The slower the traffic flow, the longer each vehicle is exposed to an avalanche which might occur. If traffic is stopped for an extended period by an avalanche deposit or by disabled vehicles, the hazard rises further. This is compounded if drivers leave those vehicles to assist others.

Mass transit by bus is one way to reduce the number of vehicles on the road. Assuming that all private auto traffic could be eliminated, the number of vehicles could be reduced from 7,000 to 800. If the current artillery program is continued this reduction in traffic reduces the ROHI 83%. This ROHI reduction is from a high hazard index (104) to a moderate (18) hazard index (see Figure 3-3). See the Appendix for a technical memorandum on the bus-only alternative.

While initially it appears to be a very attractive solution, there are actually several significant concerns. The main concern is that parking for bus riders would still have to be supplied outside of the canyon. And to be most efficient, this parking should be clustered into as few places as possible. That means that anywhere from 4,000 to 5,000 parking stalls need to be supplied for users in Little Cottonwood Canyon alone. (It is safe to assume that if this strategy were applied to Snowbird and Alta, the same would apply to Brighton and Solitude in Big Cottonwood Canyon.) Finding the land and the money to provide all this parking could easily exceed $50 million.

Figure 3-3: ROHI for Bus-Only Transportation Option



<u>Rail</u>

Rail alternatives were analyzed to determine the most appropriate options for Little Cottonwood Canyon. The evaluation of rail options focused primarily on three deciding factors: passenger capacity, estimated costs, and geographic compatibility. To be considered feasible, a rail option would be required to meet the corridor's capacity needs, entail capital and operating costs that meet the criteria for the Federal Transit Administration's New Starts program, and have physical characteristics that make it a suitable fit for the canyon. Rail options analyzed for SR-210 include:

- Maglev
- Heavy rail
- Commuter rail
- Monorail
- CABLE liner
- Cog (rack) railway
- Light rail transit/streetcar
- Funicular
- Aerial Tram

Several of these options were eliminated from consideration following a suitability analysis. Alternatives considered appropriate for Little Cottonwood Canyon included CABLE liner, cog railway, and aerial tram. See Table 3-6 for a comparison of system characteristics for these alternatives. A more detailed discussion of these alternatives can be found in a technical memorandum included in the Appendix to this report.

If the railway were built a road would still be required for service vehicles and emergency access. If this occurred, the traffic volume on the service road would drop such that the ROHI would drop to a moderate or low level. The goal of keeping the railway open combined with safety standards for new rail construction would mean that structures such as snow sheds and tunnels would be required at most of the avalanche paths which affected the rail alignment. An assessment of the risk to the rail line would require a proposed alignment and mitigation strategy.

Table 3-6: Comparison of Transit System Characteristics

SPEED AND CAPACITY			
	Cog Railway	*Cable Liner*	*Aerial Tram*
Vehicle status during loading/unloading	Fully stopped	Moving .92 ft/second (standard)	Moving .92 feet/second
Loading/unloading time	Determined by scheduling	10-15 seconds (standard) 20-30+ seconds for ski service	10-15 seconds (standard) 20-30 seconds for ski service
Intermediate stops	Yes	Yes	Possible but less practical or easy compared to other alternatives
Flexibility to increase capacity	Yes	Yes	Yes
Flexibility to expand/extend the system	Yes	Yes	No
ALIGNMENTS			
	Cog Railway	*Cable Liner*	*Aerial Tram*
Tunnel, covered shed or berms allowed?	Yes	Yes	No
Horizontal alignment	Moderate to Low	Low; designed for 165 ft radius; min 98 ft with lower speeds	Straight only
Can travel steep slopes and grades	Yes	About 10% for a standard design	Yes
Space requirements	High	Can be varied with double or single tracks	High
Pedestrian crossing	Signal warnings / cross bars	Signal warnings	N/A
Terminals	Longer terminals if cars are added; multiple loading	Shorter terminals due to continuous movement of passengers; garage required for cars.	Shorter terminals due to continuous movement of passengers; garage required for cars.
SYSTEMS OPERATIONS			
	Cog Railway	*Cable Liner*	*Aerial Tram*
Automation level	Needs a driver	System Supervision recommended	Systems Control required
Vulnerability to winds	None	None	Slower speeds or closure required
Snow and Ice	Little to None	Little to None	None
Emergency Rescue	Easily accessible	Easily Accessible	Difficult

QUALITY OF SERVICE TO RIDERS			
	Cog Railway	*Cable Liner*	*Aerial Tram*
Station Comfort	Moderate to Low; headways are not as flexible – no loop service without "figure 8" track switches	Moderate; shorter waiting time if all cars are in operation	Moderate; shorter waiting time if all cars are in operation
Vehicle Comfort	High; large and flexible seating and storage capacity	Moderate	Moderate to low; small seating and storage capacity
Safety	High	No car attendant	No car attendant
Disabled Access	Yes	Very limited stopping time may not meet ADA requirements	Very limited stopping time may not meet ADA requirements
Heating and Air Conditioning	Yes	Yes	Yes
Public Acceptance	Likely low in this area	New service, unknown	Moderate; some people would be afraid of height
Noise	High	Low	Low
Visual	High	High	High
Source: Carter + Burgess, April 2006			

Improved Park-and-Ride Network

Increasing park-and-ride utilization and capacity can encourage transit use and carpooling. While some park-and-ride lots used by skiers frequently fill to capacity, others remain underutilized. For instance, the park-and-ride lot at the mouth of Big Cottonwood Canyon is popular with skiers, but another lot on Wasatch Boulevard near 6200 South was almost vacant on a weekend day during the winter. Improving signage of underutilized lots can increase usage (see the following ITS section for a discussion of park-and-ride signage. See also the park and ride lot utilization data in Table 2-12 on p.39).

Creating a balance of parking use at these ski park and ride lots is an important short term project that will help reduce private vehicle use in the canyon. "Capturing" potential transit users or carpoolers with available parking is key. Once someone drives past the lots on the periphery (i.e. Alta Rec Center) to the lot at the mouth of the canyon and realize that it is full, then they most likely will not turn around and backtrack to a different lot, even if it is relatively empty, thus adding another car to canyon traffic. Another benefit of improving the park and ride network is that the earlier one can catch a bus, the better chances of getting a seat since the buses can get full before the last stop at the lot at the mouth of the canyon.

In the short term (Fall 2006), new and improved "wayfinding" signs such as the one pictured above will be installed at all the ski park and rides.

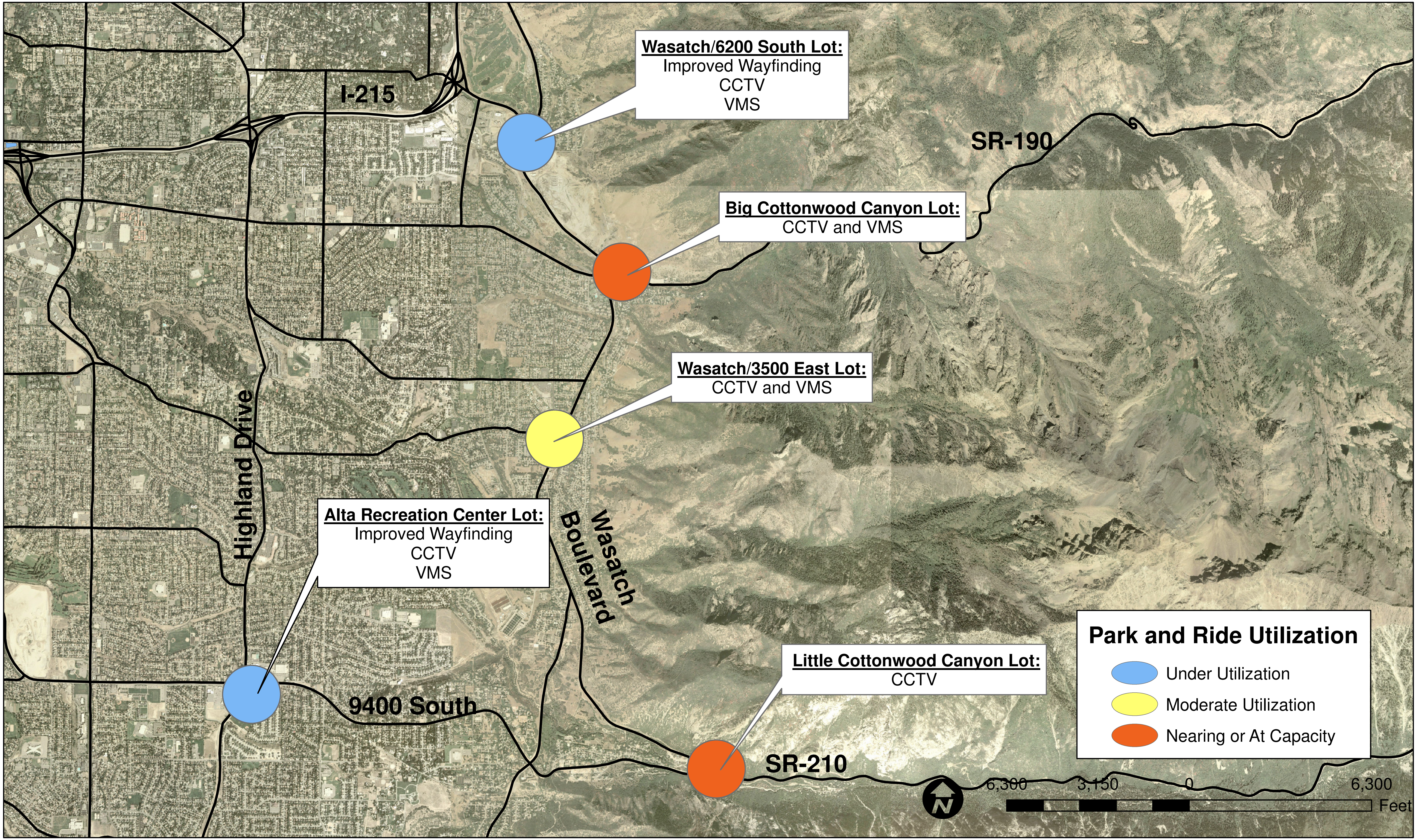
Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) use a variety of technologies to improve transportation system performance, and improve the overall quality and reliability of communication to canyon users. In Little Cottonwood Canyon, ITS applications can provide information to both snow safety personnel and canyon users. These could include the following measures:

- Variable message signs (VMS) communicating road conditions or closures to skiers at in-resort locations (for instance, in lodges or near chairlifts)
- Closed circuit television (CCTV) connecting to UTA and the UDOT TOC, assisting in real-time evaluation of road conditions and availability of park-and-ride spaces
- VMS along I-215 or Wasatch Boulevard near park-and-ride lots, providing real-time information on the number of parking spaces available or impending arrivals of ski buses
- The ski resorts should explore implementation of real-time information via VMS so that skiers can be informed of potential hazardous canyon conditions. If this information is more readily available, then skiers can make their departure plans accordingly.

Figure 3-4 shows the potential ITS-related improvements to the existing ski park and ride network. A simple measure of effectiveness of this effort will be increased utilization of the Wasatch/6200 lot and the Alta Recreation Center lot. In addition, we should expect a corresponding increase in transit ridership.

Table 3-7 presents a summary of all the transportation options discussed in this section.



UDOT GOING THE EXTRA MILE

Figure 3-4: Potential Park-and-Ride Improvements

Sources: Utah Department of Transportation (Roads) Note: The data presented is subject to error.

Table 3-7: Transportation Options Summary

Short-Term Transportation Options				
Option	*Risk Reduction (with artillery)*	*Other Benefits*	*Cost*	*Challenge*
Resort driveway lot metering (6)	est. 3%	Will better hold vehicles during control work. Will allow traffic to be "metered" onto SR-210.	$250,000 per driveway	1
In-resort road condition VMS	est. 2%	Would provide real-time information while still on mountain	$30,000	1
Improve wayfinding to Park and Rides	est. 2%	Minimal	$20,000	1
Improve passenger shelters (signing, lighting)	est. 1%	Better use of transit		1
Passenger information system (your next bus is…)	est. 1%	Minimal		2
More plowing equipment (in "snake" slow speed capability; plow shed at Alta)	Intangible	Improved traffic flow and reduced delay during storms		1
Staging Areas/Turnarounds	est. 3%	Incident management		2
Stagger resort closings on high hazard days	up to 5%	Reduced delays and uncertainty		1
Additional transit amenities	Intangible	Happier skiers		1
Increase size of bus fleet to provide greater frequency and more express service	est. 5 - 10%	One additional full bus removes approximately 20 vehicles from the road	Capital cost of $1.5 million, annual operating and maintenance costs of $250,000	2
Long-Term Transportation Options				
Option	*Risk Reduction (with artillery)*	*Other Benefits*	*Cost*	*Challenge*
Paid parking program/tolling	est. 10%	Possible 5 - 10% decrease in ADT		2
One way traffic operations	Up to 5%	Improved travel time reliability		3
Park and Ride CCTV (5 lots) tied to TOC/UTA	est. 3%	Camera system tie to UDOT/UTA - alert motorists of availability at key decision points	$600,000	1
Bus-only Option (800 ADT)	83%	Improved air quality (VMT reduced by approximately 85,000 miles per day)	Capital cost of $55 million, annual operating and maintenance costs of $2.5 million	4

Rail (would also require protection at avalanche paths e.g. sheds, tunnels)	est. 80% +	High	Capital cost of $400 million, annual operating and maintenance costs of $10 million	4
Aerial Tram	est. 90%	High	Capital cost of $100 million, annual operating and maintenance costs of $1 million	4
Canyon tunnel	Intangible	Secondary access to LCC if SR-210 closure is necessary/desired	$1.8 billion	5

Active Avalanche Control Strategies

Active avalanche control refers to techniques that actively trigger avalanches (as compared to passive strategies such as snow sheds, which do not need to be activated to provide avalanche control benefits). As discussed earlier in this section, the program currently relies on three pieces of artillery (two recoilless rifles and a Howitzer) for active avalanche control in Little Cottonwood Canyon. At present rates of utilization, there is an eight- to nine-year supply of ammunition for both recoilless rifles. If only the Peruvian Ridge Recoilless Rifle is used, the supply is projected to last 12.5 years. In either event, other avenues of active avalanche control should be explored. See Table 3-8 for a summary of the active avalanche control options discussed for SR-210.

Gazex and Avalanche Guard

Gazex systems are installed near the starting zone of an avalanche path, and utilize gas-fueled explosions to trigger avalanche activity. The installations consist of a shelter supported by a wood platform, which houses the gas metering devices and the gas supply. The shelter sends oxygen and propane through polyethylene pipes to a small number of exploders, which in turn trigger the avalanche. Gazex systems are already in place at the Snowbasin and Brighton ski resorts, as well as in several other locations throughout the West.

Avalanche Guard systems are installed near avalanche starting zones using foundations or rock anchors. They contain up to ten explosive charges within a protective cabinet. These charges are launched remotely, and a solar panel provides the electricity necessary for operation. Avalanche Guards can cover an area up to 500’, using different propellant charges. Avalanche Guards are used in Europe, and are becoming more common in North America.

According to the AHI analysis provided in this report, the Snowbird Village section of Little Cottonwood Canyon is the second-highest priority for reducing avalanche hazard. Gazex (Figure 3-5) and Avalanche Guard (Figure 3-6) are both potential replacements for artillery at Snowbird Village. The advantages of these are compared in Table 3-8. The installation costs of Gazex and Avalanche Guard have proven to be similar on other projects. Noise of operation would remain a factor in all cases. The particular techniques improve the reliability of an avalanche control program, but would not eliminate the possibility of natural or controlled avalanches hitting SR-210.

Figure 3-5: A Gazex exploder in Val Thorens, France.

Figure 3-6: An Avalanche Guard at Schrun, Austria.

Table 3-8: Examples of Active Avalanche Control Systems

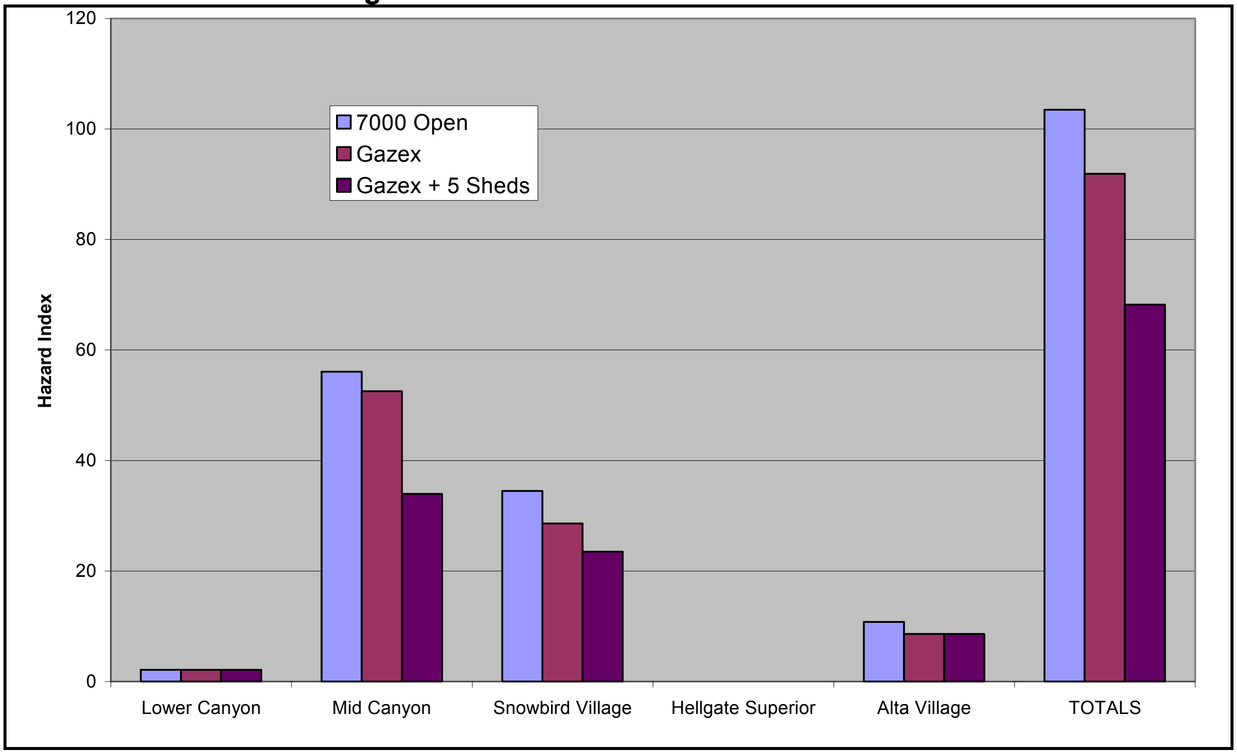
Option	*Advantages*	*Disadvantages*
Artillery	• Status Quo (no new capital cost) • Ability to shift targets • A proven system	• Limited supply of rounds • Dud rounds • Shrapnel potentially affecting village area • Firing over inhabited areas
Gazex	• Larger explosive charge • 20 min firing time versus 40 min artillery • Capacity can be expanded by additional gas modules allowing full season supply.	• New capital cost • Fixed targets
Avalanche Guard	• Units can be moved by installing a simple footing	• New Capital cost • 10 round capacity requires a helicopter landing pad for mid season refills • Potential for duds remains (low probability with double priming)
Source: Chris Stethem and Associates, April 2006		

Firing time of the artillery and Avalanche Guard would be similar. Given the large explosive charge, the elimination of the dud potential and the shot capacity, the Gazex has the advantage in meeting the needs of Snowbird Village (see Figure 3-8 for preliminary Gazex locations). The proposed Gazex array includes a minimum 16 exploders:

- Hilton supply shelter plus four high target exploders (est. $0.5 million)
- Lodge Corner supply shelter plus six low exploders (est. $0.7 million)
- 10 Springs supply shelter plus six exploders (est. $0.7 million)

The ROHI with the Gazex (Figure 3-7) would be reduced by approximately 11%. This is because the large charges fired by the Gazex during control closures would be more effective blasts than artillery and therefore reduce the likelihood of a secondary road open avalanche (after morning avalanche control). Midday control missions would not change significantly. Clearance of the runout zones in Snowbird Village would still be necessary, and would require closing the ski area and moving people indoors. If the Gazex option were built at Snowbird, the Valley 105 Howitzer mount should be adjusted to allow firing on targets such as Monte Christo high. The experiences gained from this project will be able to inform subsequent decisions to implement Gazex, or a similar technology on a larger scale.

Figure 3-7: Reduction of ROHI with Gazex



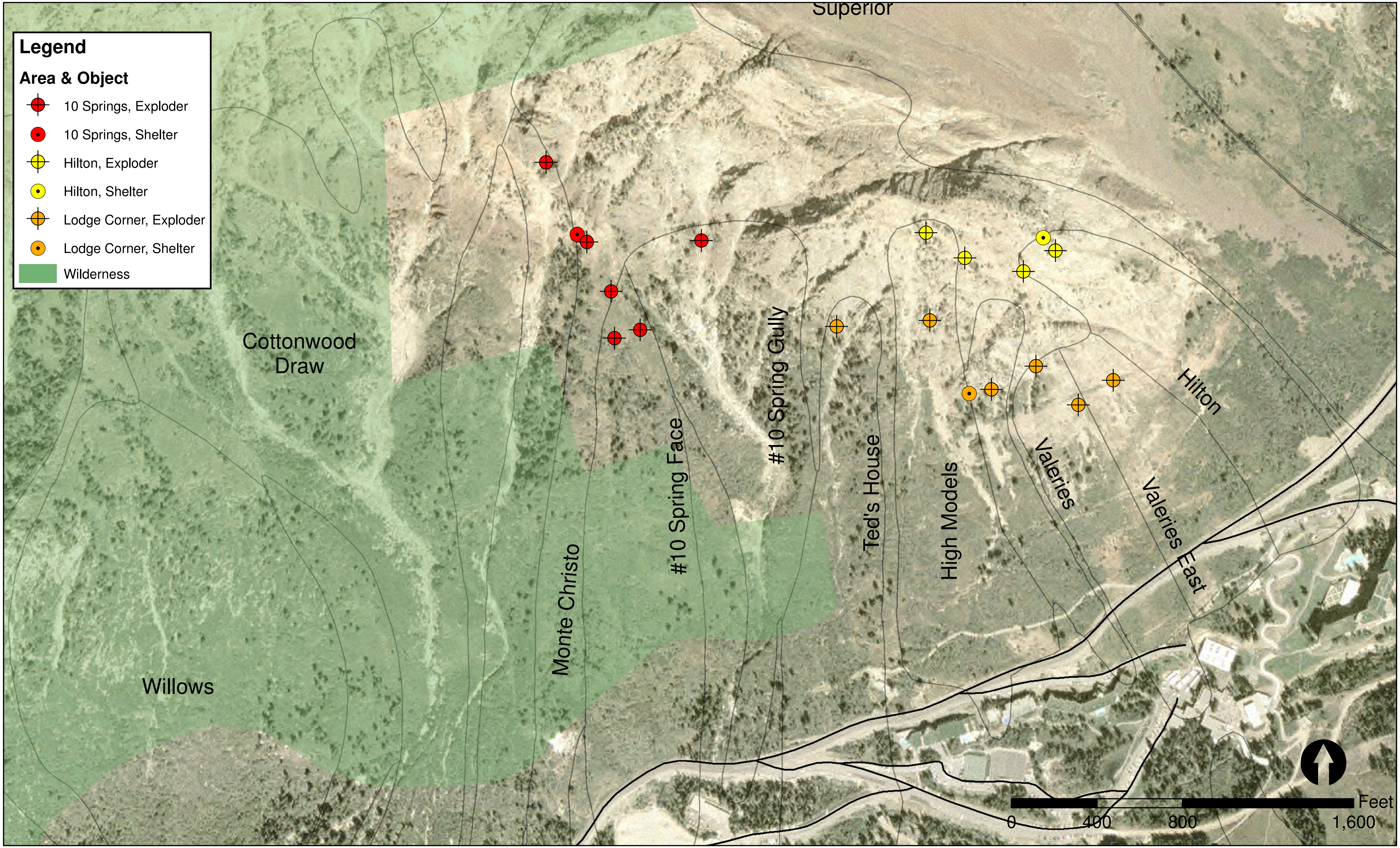


Figure 3-8: Preliminary Gazex Locations

Artillery at White Pine

In analyzing the potential for snow sheds at White Pine Chutes (WPC) (see the "Passive Avalanche Control by Structures" section of this report), it is apparent that WPC 1 and 2 are well managed in the existing artillery program but that the residual risk at WPC 3 and 4 remains significant. Targeting the WPC is challenging from the Valley Howitzer given the small and oblique targets, but increased control at WPC 3 and 4 should still be considered.

An additional gun position could improve targeting at the WPC area. This gun position would also allow targeting of the southwest-facing starting zones of White Pine, which are not accessible from the Valley Howitzer. A new gun position would require firing pad and protective shelter, at a cost of approximately $100,000. Winter access, ammunition storage, and location are all issues that still need to be resolved relating to this option.

Remote avalanche control systems at WPC or WP are simpler than comparable artillery from the perspective of operations in the canyon, if approval could be gained to build these installations in the wilderness area. The costs for remote explosives system (such as Gazex) to cover WPC 3 and 4 would be near $600,000. Further study should determine if artillery and remote systems could work together, or if the shrapnel hazard requires that one or the other must be used.

Remote Explosives at Hellgate Superior

The Peruvian Ridge recoilless ammunition supply will run out in eight to twelve years. Two choices to replace this are evident at this time:

- Replace the rifle with a 105 mm Howitzer or equivalent
- Build remote explosive systems (Gazex or Avalanche Guard) in the Hellgate Superior targets

The targets are well defined in the terrain and would be suited to remote systems.

Skier Compaction

Compaction of the snow cover by skiing is increasing due to a rise in ski touring on the south facing slopes above Alta. Compaction reduces the likelihood of large deep slab avalanches by mixing and strengthening snow layers. Fewer deep avalanches mean a reduced risk to the highway and to buildings in the Town of Alta.

Alta Ski Lifts is studying its expansion options, and one option includes new ski lifts on the south-facing slopes above Alta Village. This could cause widespread skier compaction, thereby decreasing the risk of large destructive avalanches at Alta. Ski lifts would also provide access to the avalanche starting zones for control teams, reducing the need for artillery rounds fired from Peruvian Ridge. Shrapnel from artillery would no longer be a factor.

It should be understood that even with significant skier compaction of the avalanche paths above the Town of Alta, large avalanches will, on occasion, still occur. Although they will be much less frequent than under current conditions, the road between East Hellgate and Grizzly as well as numerous buildings in the Town of Alta, will be still be threatened.

Table 3-9: Active Control Option Summary

Option	*Risk Reduction (Road Open with Current Artillery)*	*Other Benefits*	*Cost*	*Other Impacts*	*Challenge*
New Gun for WPC, WP	est. 5%	Improved artillery targeting	100,000	Access? Construction in Tanners Campground; future of guns?	2
Gazex @ Snowbird Village (Hilton, Valerie's, 10 Springs)	11%	Reduced artillery use; no duds or shrapnel; no shooting over buildings	$1.9 million	Visual impact	2
Gazex @ Mid-Canyon	est. 10%	Reduced artillery use; no duds or shrapnel; control of blind targets	$8 million	Wilderness area; visual impact; fixed targets	4
Gazex @ Superior/Alta	est. 5 - 10%	Reduced artillery use; no duds or shrapnel; no shooting over buildings	$4.5 million	Visual impact; fixed targets	2

Passive Avalanche Control Strategies

Passive or structural avalanche control measures are used on several very high and high hazard highways in North America and overseas. The options described in Table 3-10 are feasible on SR-210. The proposed structures can reduce the frequency of avalanches which reach the road, or reduce the number of avalanche paths affecting the road. See Table 3-10 for a summary of the potential passive control options for SR-210.

Table 3-10: Passive Control Options

Option	*Objective*	*Where Used*
Snow Sheds	Pass avalanches over highway	Rogers Pass (BC); Red Mountain Pass (CO); I-90 Snoqualmie Pass (WA); Coquilhalla Highway (BC); Wolf Creek Pass (CO); European Alps
Earth Berms (parallel or perpendicular)	Redirect or reduce avalanche runout	Rogers Pass (BC); Coquilhalla Highway (BC); I - 70 east of Loveland Pass (CO); Kicking Horse Pass (BC); Seward Highway (AK); European Alps; Iceland.
Earth Mounds	Break up flow and slow runout of avalanches	Rogers Pass (BC); Coquilhalla Highway (BC); Bear Pass (BC); Sunshine ski area road (AB); Sunshine Ski Area Road (AB); European Alps.
Supporting Nets or Fences	Anchor the snow and stop avalanches from starting	Alpental (WA); Big Sky (MT); Rogers Pass (BC); European Alps; Japan
Tunnels	Avoid avalanche paths	MacDonald Rail Tunnel, Rogers Pass (BC); Arlberg Pass, Austria; Mt. Blanc, France-Italy; Fluela, Gotthard and Lukmanier Passes, Switzerland; Norway; Japan.
Relocation	Avoid avalanche paths	Superior Bypass; Skeena Highway 16 (BC); Bear Pass (BC).

Source: Chris Stethem and Associates, April 2006

Snow Sheds

The White Pine area of Mid-Canyon is a key location for avalanche hazard. Snow sheds (Figure 3-9) are one widely used option that is applicable in this location. Schaerer (1999) made recommendations for snow shed design at the White Pine Chutes (WPC).

Figure 3-9: An avalanche deposit over a snowshed at Rogers Pass, BC.

The return period of all avalanches which reach the road at WPC is summarized in Table 3-11. The data shows that regardless of whether the road is open or closed (Road Open + Closed Return Period), the return period for WPC 1 and 2 are the locations of concern, with a return period for all avalanches of 1.2 and 1.7 years respectively. Considering the return period for avalanches that hit the road when the road is open (Road Open Return Period) the current artillery, road closure and clearance program is more effective in WPC1 and 2, than WPC 3 and 4 since the Road Open Return Period for all avalanches at WPC 1 and 2 are much longer than those at WPC 3 and 4 (32.5 and 28.2 compared to 16.25 and 15).

Table 3-11: Return Period of Avalanches at WPC

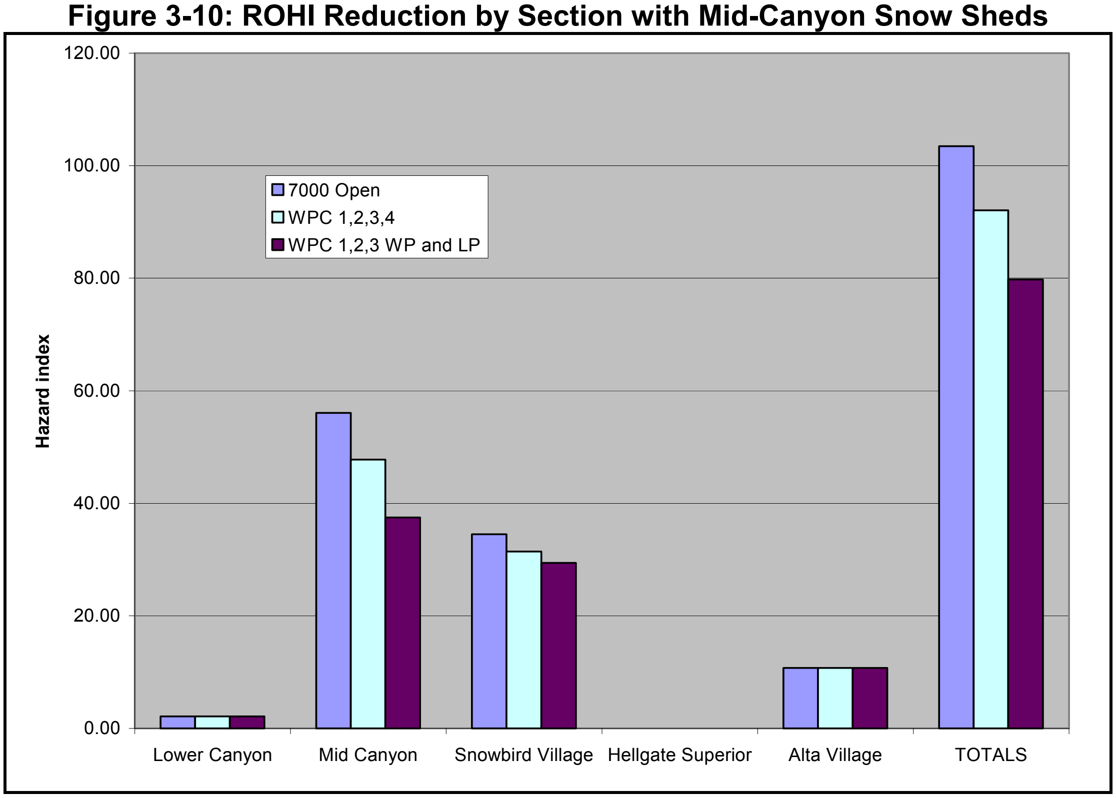
Road Open + Closed Return Period (years)			
Location	*Light Snow*	*Deep Snow*	*All Avalanches*
WPC 4	11.0	6.6	4.4
WPC 3	4.7	11.0	3.9
WPC 2	2.4	2.5	1.2
WPC 1	3.3	3.7	1.7
Road Open Return Period (years)			
Location	*Light Snow*	*Deep Snow*	*All Avalanches*
WPC 4	50	15	16.25
WPC 3	30	30	15.00
WPC 2	30	100	32.50
WPC 1	15	100	28.80
Source: Chris Stethem and Associates, April 2006			

The potential for ROHI reduction by snow sheds in Mid-Canyon is illustrated in Figure 3-10. The ROHI reductions are:

- 11% for snow sheds at WPC 1, 2, 3 and 4
- 29% for snow sheds at WPC 1, 2, 3 and 4, White Pine, and Little Pine

The ROHI reductions would be minimal for sheds at WPC 1 and 2 alone because of the artillery program's success in bringing down avalanches under artillery control road closures.

Figure 3-10: ROHI Reduction by Section with Mid-Canyon Snow Sheds



Another factor to consider is that the White Pine Chutes (in particular WPC 1 and 2) tend to run first during a high precipitation intensity storm cycle. Snow sheds and avalanche sensors at these locations would give more time to close the road in an orderly manner and clear the traffic during periods of heavy traffic volume.

The reduction in the baseline AHI due to snow sheds should also be considered. This is the same as saying, "if there were no artillery program in White Pine, how much would snow sheds reduce the avalanche hazard?" The reduction of the baseline AHI is:

- 17% for snow sheds at WPC 1, 2, 3 and 4
- 34% for snow sheds at WPC 1, 2, 3 and 4, White Pine, and Little Pine

Snow sheds can result in other hazards to traffic such as reduced visibility or icing at the snow shed entrances. These risks can be reduced by:

- Lighting to improve visibility
- Frequent maintenance to assure traction
- Impact absorbing structures to reduce severity of crashes at snow shed entrances

Table 3-12 provides a construction cost estimate for each snow shed option, in 2010 dollars. The cost estimates include environmental clearance, engineering, mobilization, mitigation, and contingency. See the Appendix for a more detailed discussion of the snow shed cost estimates.

Table 3-12: Cost Estimates for Snow Shed Options

Paths Covered	*Shed Length*	*2010 Project Cost*
WPC 1 – 4	1,235'	$29.5 million
WPC 1 – 4, White Pine, and Little Pine	2,485'	$58.7 million
Source: H.W. Lochner, May 2006		

Earth Berms

One possible alternative is to construct berms that could prevent avalanche debris from reaching the road. Berms have been utilized in British Columbia (Roger's Pass, Coquihalla Highway, Kicking Horse Pass), Colorado (I-70 east of Loveland Pass), and Alaska (Seward Highway). "China Wall" is an existing earth berm that sits at the base of the White Pine avalanche path, which is traditionally used to collect avalanche debris from White Pine. It consists of a stone facing backed by an earth berm and excavation.

The history of China Wall is murky: investigations into its origins and historical status were inconclusive, and the relevant state agencies had little information on its existence. Currently, when avalanche activity occurs at White Pine and is caught by China Wall, the excavated space must then be "mucked out" to contain debris from subsequent slides. In addition, the berm is not sufficiently tall to prevent all debris from reaching SR-210: on occasion, slide debris passes over the top of the berm and onto the road. The effective height is 21' at the east end and tapers to 0' at the west end (Figure 3-11).

A short-term structural option is to enhance the China Wall berm by extending it across the full width of the avalanche path (650') and increasing its effective height to 36'. This includes completion of the excavation above the berm across the full width of the path. To balance the cut and fill from China Wall, another 36' stopping berm could be built perpendicular to SR-210 at

Little Pine (Figure 3-12) over a width of 600'. This cut and fill balance would minimize the cost of removal of excess material from the project area. See the Appendix of this report for a detailed discussion of the berm options, including cut and fill diagrams.

A second option for balance of cut and fill is to expand existing staging areas (safe zones) to store traffic between avalanche paths. The priorities would be the staging areas immediately east of White Pine, east of Little Pine, and east of Tanners (in that order). Material could also be used to widen the narrow shoulder at White Pine Chutes 3 and 4.

Constructing berms at White Pine and Little Pine would not prevent all avalanches from reaching the highway. The 36' design height is intended to stop an avalanche traveling at roughly 50 feet per second (15 ms^{-1}). Once the berm is filled with avalanche deposition it becomes ineffective, so cleaning out the snow deposits is important. Some large and fast moving avalanches would still jump over the berm but the frequency of effect to the highway would be reduced. The projected cost to construct berms at White Pine and Little Pine is approximately $5.1 million in 2010 dollars. The cost estimate includes engineering, environmental clearance, mobilization, excavation, mitigation, and contingency; it assumes that material excavated from White Pine will be used for a berm at Little Pine or in some other application, and that disposal of excess fill will be unnecessary.

Figure 3-11: China Wall looking west (the highway is to the left of the photograph).

The snowcat is building up a snow berm from a previous avalanche deposit to enhance the effect of the stopping dam for subsequent avalanches. The snow berm height shown was not sufficient to stop the next avalanche in February 2006.

Table 3-13: Avalanche Return Periods at White Pine and Little Pine

Location	*Record of All Avalanches*		*Record of Road Open Avalanches*	
	T Light (y)	*T Deep (y)*	*T Light (y)*	*T Deep (y)*
White Pine	5.2	2.8	15	7.5
Little Pine	2.2	1.9	6	15

Table 3-14: Estimates of Reduced Return Periods with Berms

Location	*All Avalanches*		*Road Open*	
	T Light (y)	*T Deep (y)*	*T Light (y)*	*T Deep (y)*
White Pine	3.4	10	15	30
Little Pine	3.4	15.5	15	30

Figure 3-12: The Little Pine avalanche path and potential berm location.

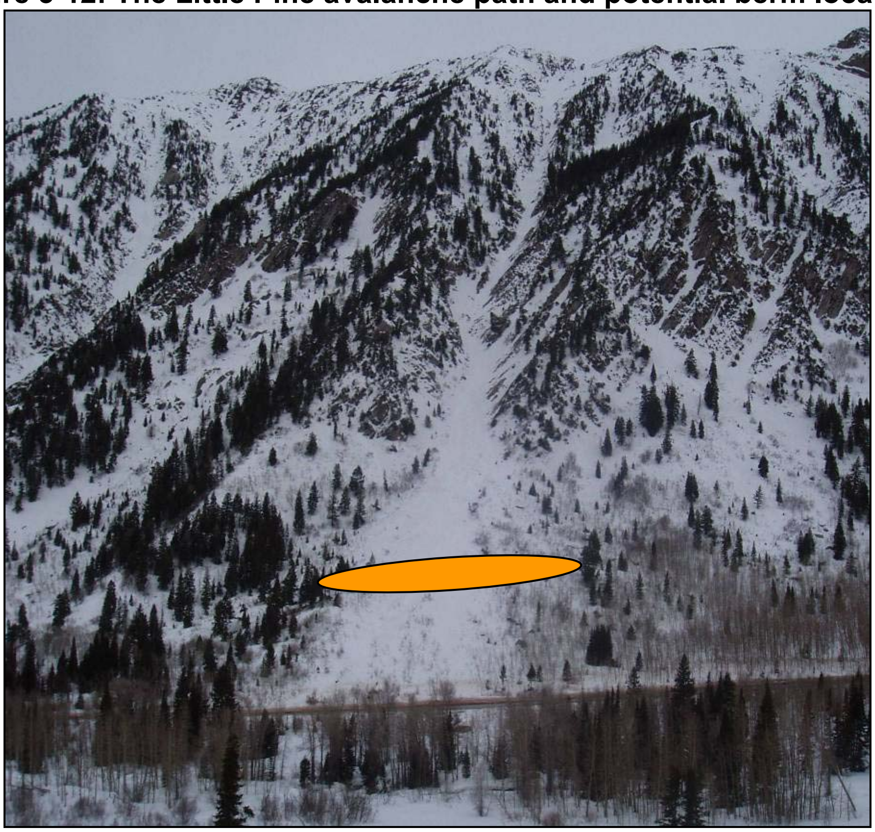
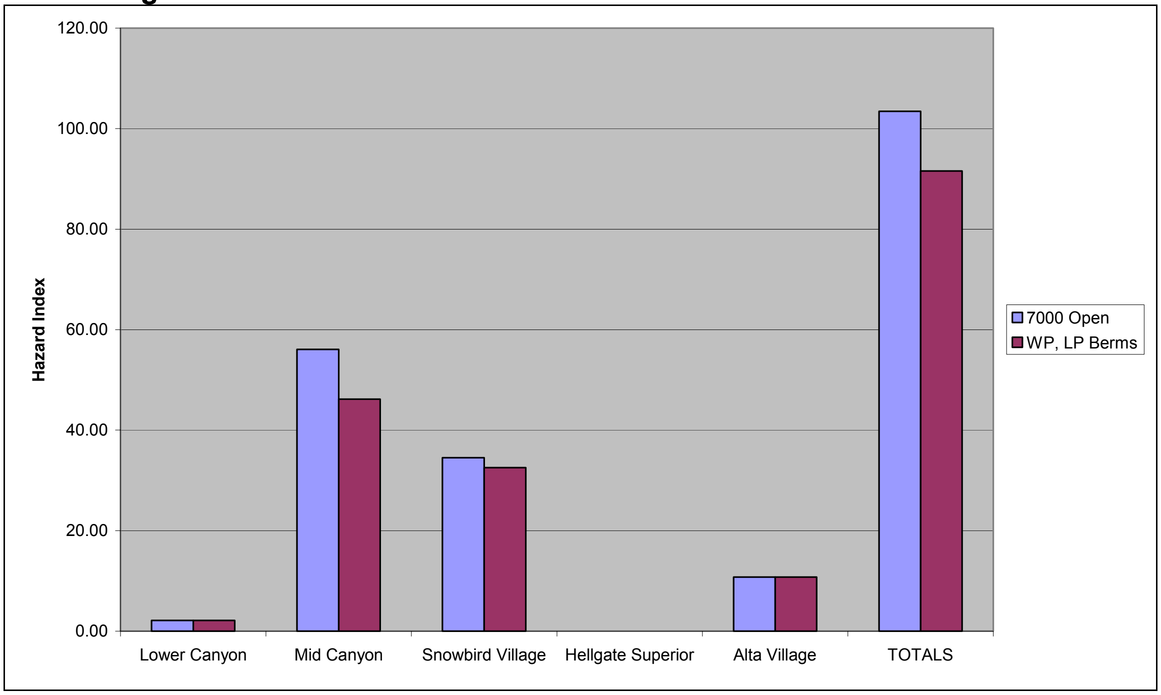


Figure 3-13: ROHI Reduction with White Pine and Little Pine Berms



In the All Avalanches category of Table 3-14 a frequency of light snow deposits (<3 ft.) on the road of 3.4 years is estimated. This is conservative, and accounts for the light flow component of a fast-moving dry avalanche which would jump the berm and cross the road. These would be both natural and artificially triggered and most would occur under road closure.

Figure 3-13 indicates how the hazard index with the existing artillery program can be reduced by constructing berms. The ROHI reductions for two berms or a combination of berms and snow sheds are:

- 11% for the White Pine and Little Pine berms
- 14% for the White Pine, Little Pine berms and White Pine Chutes 1,2 Snow sheds
- 23% for the 5 snow sheds in White Pine Chutes 1,2,3, White Pine and Little Pine
- 22.5% for the 4 sheds for White Pine Chutes and the 2 berms at White Pine and Little Pine

If there were no artillery program and the impact of berms or a combination of sheds and berms were considered then the hazard reductions would be:

- 11% for the White Pine and Little Pine Berms
- 24% for the White Pine and Little Pine Berms and WPC 1 and 2 snowsheds
- 31% for the 5 snowsheds in WPC 1, 2, 3, White Pine and Little Pine

It is important to note that snow sheds have a greater effect because they pass avalanches over the road and largely eliminate the avalanche hazard, whereas berms do not prevent large avalanches from reaching the road.

Snow Fencing

Snow support nets or fences could be built to prevent avalanches from starting at some or all of the avalanche paths in the Snowbird Village group. These nets are suspended from a system of support posts and anchor cables secured to soil or rock anchors. They are used widely in Europe (Figure 3-14 and Figure 3-15) where there is a shortage of developable land and a long history of public-private partnerships in building defense structures above villages.

Figure 3-14: Multiple rows of snow support fences built to prevent avalanches from starting above Lech, Austria.

Figure 3-15: Snow support nets used to anchor snow in the starting zone above a village in Iceland (photo source: El Montagne)

To estimate potential snow fencing costs, a unit cost of $0.5 million per hectare (2.2 acres) was used for nets (the costs are approximately $1.0 million per hectare for rigid fences). These are rough estimates for conceptual design purposes. The design snowpack height is 18' or a depth perpendicular to the slope of 12.1' to 14.7' (depending on incline). Table 3-15 provides the estimates for areas and costs for snow support nets.

Table 3-15: Snow Support Nets at Snowbird Village

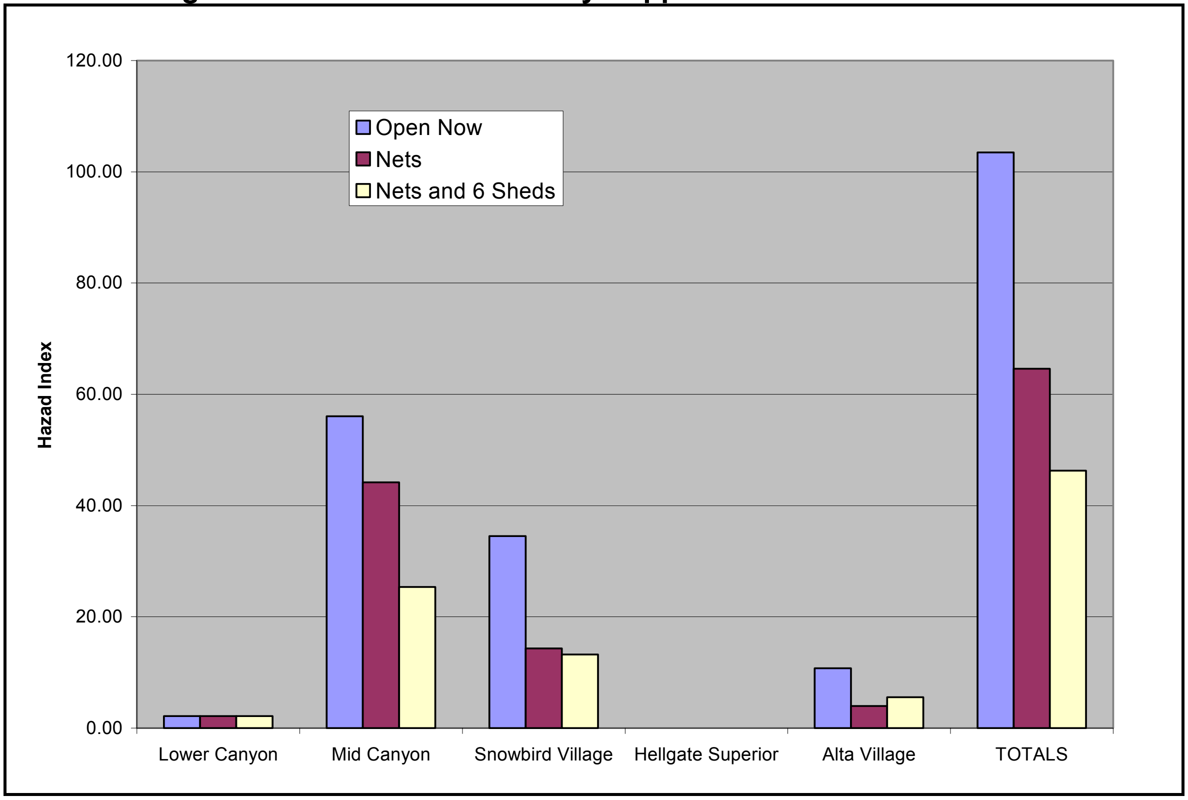
Site	*Area*		*Depth*	*Est. Cost*
	Acres	*Ha*	*ft*	
10 Springs Face	12.5	5.1	13.8	$2.6 million
10 Springs Gully	18.1	7.3	14.7	$3.65 million
Ted's House	5.1	2.1	14.1	$1.05 million
High Models	9.1	3.7	12.1-13.8	$1.85 million
Lodge Corner	3.7	1.5	13.5	$0.75 million
Valerie's	6.0	2.4	13.5	$1.2 million
Valerie's East	4.1	1.7	13.1	$0.85 million
Hilton	12.4	4.1	13.5	$2.05 million
Total	**71.0**	**27.9**		**$14 million**

Summer study is required to determine if snow netting is feasible for Snowbird Village. A residual risk of small avalanches from short steep slopes below or between the nets could remain, depending on the design.

The ROHI reduction for snow support structures in all of the paths listed in Table 3-15 is illustrated in Figure 3-16. The reduction in the hazard index by constructing the Snowbird nets (with the existing artillery program on the rest of the road) is 38%. The combination of snow support nets at Snowbird Village and snow sheds at WPC 1, 2, 3, 4, White Pine and Little Pine results in a near moderate Road Open Hazard Index (a 55% reduction over the present hazard with the artillery program in place).

In comparison, the baseline AHI is reduced by 28% with support nets at Snowbird. The fact that the ROHI reduction is more significant than the AHI reduction means that the existing artillery program is less effective at Snowbird Village than in other areas of the canyon. It also indicates that a large portion of the unexpected avalanches to the open road are occurring at Snowbird Village. As a result, adding support nets at Snowbird Village may contribute more to the safety of the open road than some of the other alternatives discussed in this report.

Figure 3-16: ROHI Reduction by Support Nets and Snow Sheds



Road Relocation

Alpentech, Inc. completed a preliminary study for Alta Ski Lifts Co. regarding realignment of the mid-canyon section of SR-210 (*Proposal for State Highway 210 Realignment, Mid-Canyon Section, Little Cottonwood Canyon, Salt Lake County,* June 29, 2004). Because topographic mapping is not readily available at this time, the Alpentech relocation alignment was used for analysis rather than generating a new alignment. The proposed relocation is between the Old Mill avalanche path on the west and the Willows path on the east. The total length of the proposed realignment is roughly 15,000 feet, or 2.8 miles. It is on the south side of the Canyon, and would require two new crossings of Little Cottonwood Creek, as shown on Figure 3-17.

The proposed realignment would avoid several avalanche paths on the north side that have reached the road: Maybird, Tanner's, White Pine Chutes, White Pine, and Little Pine. However, it would traverse four avalanche paths on the south side that does not reach the existing road: Display Ridge, Scotty's Notch, Scotty's Bowl, and Coffin Chute. Both the existing and proposed alignments cross Little Pine East and the Willows avalanche paths. The criteria Alpentech used for the relocation were to avoid as many avalanche paths as possible, and to keep the grade at 10% or less. Reduction of the avalanche hazard index when the road is open to traffic with this realignment is estimated at 42%.

The Alpentech road relocation has several associated issues. First, it traverses the Lone Peak Wilderness Area. Resistance from the public and interest groups such as Save Our Canyons would be intense. In addition, relocating through the wilderness area would require an act of Congress, involving extensive coordination, public involvement, and environmental study. It is possible to develop an alignment that could avoid the wilderness area. However, it would bisect the Tanner's Flat Campground, potentially destroying that resource.

Second, it may potentially impact extremely valuable resources: Little Cottonwood Creek, Riparian Habitat Conservation Areas, and water quality for the watershed. Moving the road closer to the creek may jeopardize water quality, because runoff would have less distance to pass through vegetated areas before reaching the creek. Salt Lake City Corporation may resist an alignment adjacent to the creek. Finally, slopes on the south side of the canyon do not receive as much sunlight as those on the north side. As a result, the relocation might be icier than the existing road. Snow would not melt as quickly and storage could be an issue. Last, a new road could cut access to popular climbing and bouldering routes located along the north side of the canyon.

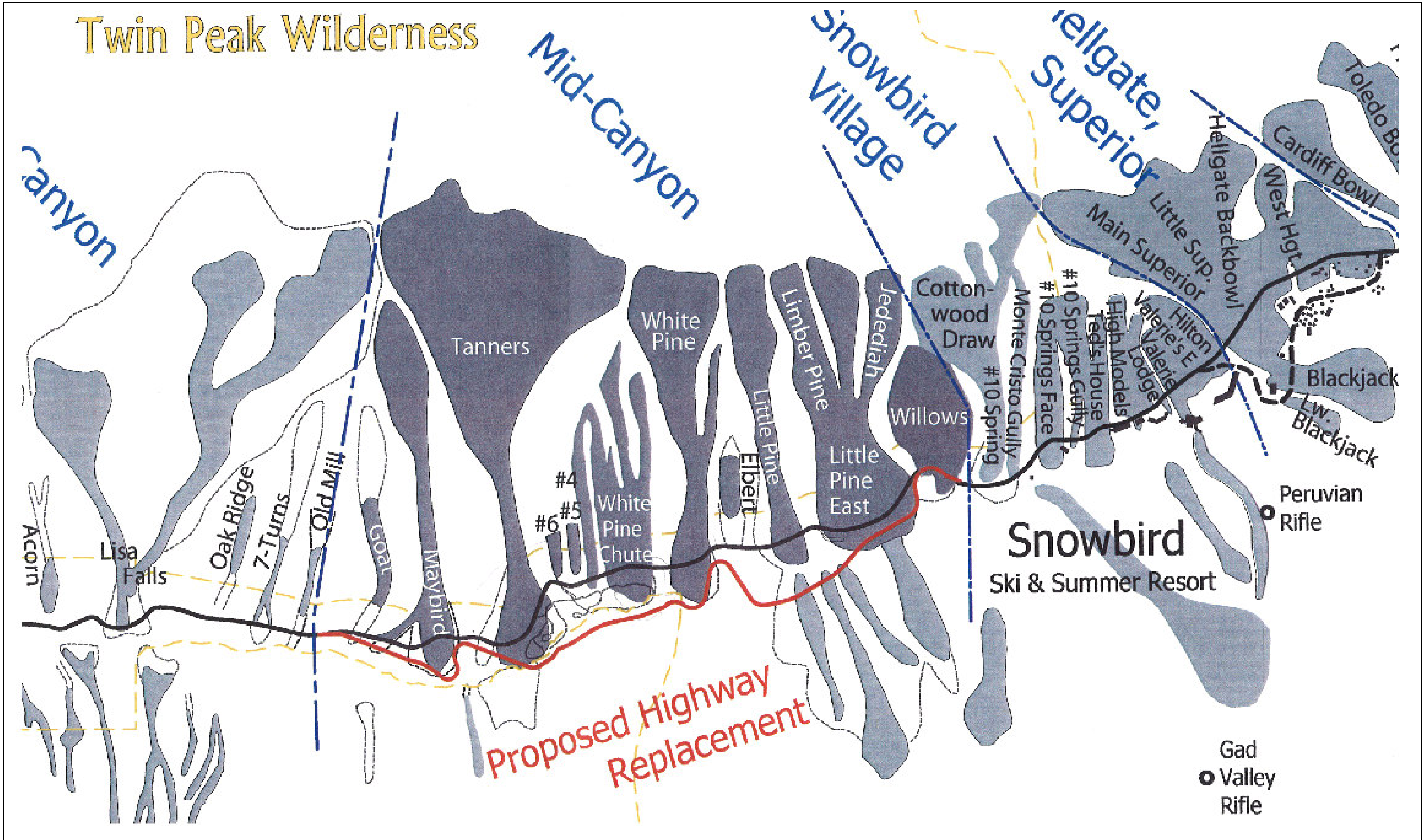
As noted above, the alignment and grade from the Alpentech study were used as a basis for this cost estimate without modification. However, the typical cross-section was modified to reflect current design standards for this cost estimate. Cost estimates for two relocation concepts were developed using Alpentech's alignment and grade:

- A modified typical section to meet clear zone requirements without barriers
- A modified typical section with barriers

Table 3-16 shows the preliminary cost estimates for the relocation alternatives. See the Appendix for the complete technical memorandum on the relocation alternatives (as well as several other passive control options).

Table 3-16: Relocation Alternatives Cost Estimate

Relocation Alternative Concept	*Estimated 2010 Cost*
Without barriers	$56 million
With barriers	$61.5 million
Source: H.W. Lochner, May 2006	



UDOT GOING THE EXTRA MILE

Figure 3-17: Alpentech Road Relocation

Figure 3-18: ROHI Reduction: Five Snow Sheds vs. Mid-Canyon Relocation

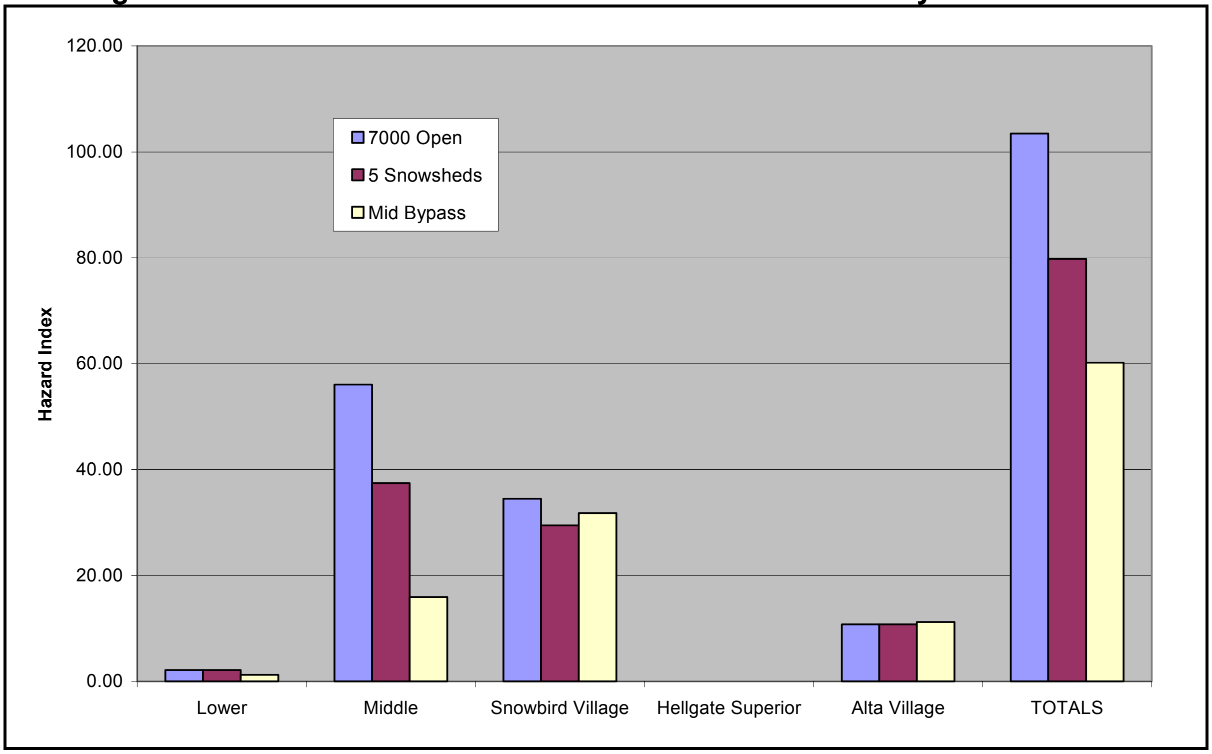


Figure 3-18 compares the risk reduction (using the ROHI) for the current conditions (7000 open) versus the five snow shed and Mid-Canyon bypass options.

The ROHI reductions (over and above the existing artillery program) for these combinations are:

- 23% for the five snow sheds (WPC 1,2,3, White Pine and Little Pine)
- 42% for the Mid-Canyon relocation

In the absence of an artillery program, the reductions to the baseline hazard index would be:

- 31% for the five snow sheds
- 51% for the Mid-Canyon relocation

Other important considerations for Mid-Canyon relocation include:

- Environmental impacts to the creek
- Resistance from public and special interest groups
- Impact on the Lone Peak Wilderness Area
- Avalanche control which would be required at the north-facing paths (which do not presently effect the highway)
- Access to climbing and bouldering routes
- Ice and snow potential on north-facing slope

Tunnel

Tunnels are widely used to reduce avalanche hazard, decrease highway closures, and improve traffic flow in Scandinavia and Europe. The tunnel alternative analyzed in this study would extend from the Little Cottonwood Canyon park-and-ride lot to the east end of SR-210's existing pavement. This 8 mile tunnel would provide two lanes, one in each direction. Portal locations considered include White Pine Trailhead, Snowbird Entries 1 and 2, Snowbird Plaza, and the lower lot at Alta, as well as either end of the tunnel. It would pass beneath privately-owned land and National Forest and potentially the Twin Peaks Wilderness Area.

Several issues are associated with the tunnel alternative. First, SR-210 has received a grant for Scenic Byway status. Scenic Byway status may not be compatible with a tunnel. A second issue is access to numerous trailheads, rock and/or ice climbing routes, campgrounds, and other properties along SR-210. Third, cost is a major factor. The estimated cost to construct a tunnel as described above is roughly $1.8 billion. Shorter tunnels to avoid certain sections of the road or specific avalanche paths are also a possibility, but were not analyzed for this study. See the Appendix for the complete technical memorandum on the tunnel alternative (as well as several other passive control options).

Other Options Without Artillery

If there were no artillery available for the road, other avalanche control options would be necessary to cover all the avalanche paths in the canyon. Several of these would impact the Twin Peaks Wilderness Area. Examples of these options include:

- Construction of earth mounds in some of the avalanche runout zones with the objective of retarding the avalanche runout. Locations where these could have a significant effect would include Tanners, Maybird and Little Pine East;
- Remote explosives systems in the starting zones of the Mid-Canyon avalanche paths. These would be extensive complex systems given the geography, and detailed study would be required to establish the priorities for implementation;
- Increased use of avalauncher guns at short range targets such as White Pine Chutes and Willows (from multiple gun positions). Improvements in the accuracy of the weapon with new Delta K projectile design make this a reasonable consideration;
- Greater use of snowsheds;
- Increased closure of the road to allow natural stabilization or to wait for windows in which helicopter bombing can be accomplished. This would be a drastic increase in the number of closure days over the present.

Table 3-17 summarizes the passive control options.

Table 3-17: Passive Control Options Summary

Option	*Risk Reduction (Over Current Road Open with Artillery)*	*Baseline Risk Reduction (no Artillery Program)*	*Other Benefits*	*Estimated 2010 Cost*	*Challenge*
Two berms at White Pine and Little Pine	11%	11%	Source of fill for other projects	$5.1 million	2
Relocation of SR-210 at mid-canyon	42%	51%	Reduced closures	$61.5 million	5
Snowsheds at WPC 1 & 2	2%	13%	Reduction of artillery, avalanches pass over the road	$16.1 million	3
Snowsheds at WPC 1, 2 & 3	5%	15%	Reduction of artillery, avalanches pass over the road	$21.3 million	3
Snowsheds at WPC 1 - 4	11%	17%	Reduction of artillery, avalanches pass over the road	$29.5 million	3
Snowsheds @ WPC 1 - 3, White Pine, and Little Pine	23%	31%	Reduction of artillery, avalanches pass over the road	$50.5 million	3
Snowsheds @ WPC 1 - 4, White Pine, and Little Pine	29%	34%	Reduction of artillery, avalanches pass over the road	$58.7 million	3
Snow support nets at Snowbird	38%	28%	No shrapnel or firing over buildings; reduced closures	$14 million	2