DRAFT
AVALANCHE HAZARD
ASSESSMENT & MITIGATION REPORT

SYLVAN PASS,
YELLOWSTONE NATIONAL PARK

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1.0 Executive Summary

The East Entrance Road through Sylvan Pass in Yellowstone National Park has a long history of impacts from avalanches. The purpose of this study has been to identify the hazards from avalanches associated with travel through the pass, identify safety concerns associated with the hazard management program and to present hazard mitigation strategy options.

The efforts conducted have determined that snow avalanches large enough to violently sweep vehicles off of the road and cause serious injury or death to the occupants are a hazard to snowmobiles, snow coaches and snow surface grooming equipment in the winter and wheeled vehicles including cars, trucks and snowplows in the fall and spring.

Several potential alternatives exist to completely eliminate the hazard from avalanches to road travelers. They include rerouting the road to avoid the hazard, building a protective cover (snowshed) over the road or keeping the road closed to all traffic during the period of October through June (depending on the season) when the avalanche paths of concern are snow covered.

Avalanche hazard mitigation programs to keep roads open during winter conditions are based on the premise that experienced and well-trained avalanche specialist can determine when conditions are potentially dangerous, temporarily close the road, use explosives to test the stability of the snow and reduce the hazard by creating small avalanches in a controlled environment. An avalanche hazard mitigation program greatly decreases the potential for a traveler to be seriously injured on killed in an avalanche but does not completely eliminate this possibility.

A program to assess and mitigate the hazard on Sylvan Pass has been operational since the 1970's. For over 30 years this program has relied upon artillery to assess the stability of the snow and reduce the hazard for the purpose of quickly reopening the road to travel. In North America artillery has a long history as an effective and safe tool for mitigating avalanche hazards to roads, railways and ski areas. To address safety concerns the National Park Service (NPS) has recently replaced the tasks conducted by artillery with a specialized contract crew that drops explosive hand charges from a helicopter.

This report provides an overview of the past and current operations. Safety concerns to the public and NPS employees are identified and discussed. Alternate hazard mitigation strategies exist and are presented.

2.0 Introduction

The East Entrance Road in Yellowstone National Park is one of five major arteries for vehicle traffic into the park. This road crosses over the Absaroka Mountain Range through Sylvan Pass. Sylvan Pass is the location of active avalanche paths that impact the roadway.

The purpose of this study has been to identify snow avalanche safety issues on Sylvan Pass. The goal of this study has been to identify the hazards from avalanches associated with travel on the East Entrance Road and to review alternative mitigation strategies. To accomplish this task a review of the existing avalanche mitigation program has been conducted. These efforts included a review of available records, interviews with personnel familiar with winter operations, and a visit to the pass in winter conditions.

Section 3.0 of this report identifies hazards to the public and personnel involved in the management of these hazards. Section 4.0 presents hazard mitigation alternatives. References are provided in Section 5.0 and Section 6.0 provides a biography of this reports chief contributor. The work performed for this study is provided in response to the National Park Service (NPS) Request For Quotation No. Q1571060030. The authorization for this work to commence was provided in an Order For Supplies Or Services issued on August 25, 2006.

This study only evaluates the hazard to travelers on the road and to NPS personnel responsible for the management of that hazard. It is based on the sources of information referenced.

3.0 Avalanche Hazard Assessment

3.1 Background Information

This section provides information regarding the location and setting on Sylvan Pass that pertains to the avalanche hazard and a history of the pass with respect to the management of winter travel and avalanche hazards. A summary of avalanche fatalities that have occurred in the park is also included.

Location/Setting

At Sylvan Pass the East Entrance Road crosses over the height of the land at an elevation of 8,555 feet between the steep slopes of Top Notch Peak (10,238 feet) to the south, and Hoyt (10,506 feet) and Avalanche Peaks to the north. The road is 28 miles in length. Sylvan Pass is 7 miles from the east entrance of the park and 21 miles from NPS facilities at Lake Village. The location of the East Entrance Road is shown on Figure 1. The layout of the road is shown on Figure 2. The road, avalanche paths that impact it, and the location of a gun mount for artillery is provided on Figure 3. This figure also shows the location of a service road that provides summer access to the gun mount. The locations of smaller avalanche paths in the vicinity of the gun mount and the service road are also shown. A list of the physical attributes of the avalanche paths that impact the East Entrance Road is provided in Table 1.

This area receives a great deal of snow and is extremely windy. At these elevations snow can fall during all months of the year. Snow begins to accumulate in September, can reach depths of five to fifteen feet during the winter, and melts in June or July.

Snowplows are used to keep the road open until early November, after which their use is discontinued and the road is closed to public traffic. Snow removal equipment is mobilized in April for the purpose of reopening the road to wheeled traffic in May. From December through March the road is machine groomed for over-snow vehicle use. During the shoulder seasons the road is subject to administrative and maintenance vehicle use.

Sylvan Pass History

Before the East Entrance Road was constructed in the early 1900's, Indians and early travelers in the area used trails through Sylvan Pass and other passes in the area to cross over the Absaroka Mountain Range. Initially the road was open for summer travel only. Later on, maintenance crews shoveled through the last remaining snow in June to get the pass open earlier.

In the 1960's the NPS desired to improve public winter access to the interior of the park. Snowmobiles and snow coaches were introduced to attain this goal and were allowed seasonal access to the park roads. Snow grooming equipment was necessary to prepare the snow surface of the park roads for this type of travel.

The hazard to the East Entrance Road from avalanches was well known. Early on, before Yellowstone became a national park, soldiers were ordered not to ski over the pass due to avalanche hazards. In the early 1970's an avalanche hazard mitigation program was instituted to protect the snow grooming personnel and the public. By the end of the 1990's snowmobile use became so popular that environmental concerns arose. A temporary management plan currently requires visitors on snowmachines to be accompanied by a guide, limits the number of snowmobiles allowed in the park, and permits commercial snow coaches as an alternative winter transportation option.

Park records indicate 4,183 visitors passed through the east entrance during the 2001 winter season on 3,494 snowmobiles. During the 2005/06 winter season these records indicate 947 visitors passed through the east entrance via 635 snowmobiles and 23 snow coaches.

Avalanche Fatalities in Yellowstone National Park

There have been six avalanche fatalities in Yellowstone. Three of these occurred prior to 1917 in the northwestern portion of the park. Two of these were soldiers and the other was a person riding in a horse drawn sleigh halfway between Mammoth Hot Springs and Gardiner, Montana (Lee 1995).

The other three fatalities occurred after 1991. On February 22, 1992 Gregory Felzien died while tracking mountain lions in the Lamar Valley. On March 3, 1997 Yellowstone Park research geologist Rick Hutchinson and Diane Dustman, a visiting seismic geologist, died on Factory Hill near Mount Sheridan in the Heart Lake area.

No avalanche fatalities are known to have occurred in the Sylvan Pass area.

3.2 Avalanche Hazard Characterization

Avalanches have been a safety concern to travelers on the East Entrance Road since it was opened to motorized winter travel in the 1970's. Avalanche hazard is defined as the expected frequency of damage and loss as the result of an interaction between an avalanche and objects and persons (Schaerer 1988). There are two components to this hazard. One is the frequency of an encounter in a given period of time, the other is the nature and magnitude of the resulting damage which in turn is a function of the nature of the avalanche.

An idealized classification system based on an avalanches effect to travel exists (Schaerer 1988). This scheme classifies dry snow avalanches as powder snow, slough, light snow, deep snow or plunging snow events. An abbreviated version of this scheme follows.

Powder snow events deposit less than 3.5 inches of snow on a roadway. These events produce conditions similar to those encountered from blowing snow. Poor visibility may cause drivers to collide with a snowbank or another vehicle. In most cases only minor damages occur.

Sloughs are slow moving flows of snow that typically originate from short steep slopes. Deep snow can be deposited on one shoulder of the road. Deposits that cross the road are generally less than 11 inches deep. Drivers are usually able to go around the deposition.

Light Snow events deposit 12 to 37 inches of snow on the roadway. These events can push cars off of the road but are not likely to bury them. A vehicle pushed over a steep slope can incur severe damage.

Deep snow events cross the roadway and deposit over 37 inches of debris. These events sweep vehicles off the road. Severe damage and death from trauma or burial in the snow is possible.

Plunging events involve high-speed avalanches that have fallen over long steep slopes and cliffs. These events are extremely destructive.

To assess the avalanche hazard to this roadway this study has reviewed available information regarding the nature of the avalanches involved in this setting and the potential for these avalanches to interact with winter travelers. The primary resources used to characterize the avalanche hazard on Sylvan Pass were topographic maps, aerial photographs, historic records and interviews with personnel knowledgeable with the existing avalanche mitigation program. This effort included a visit to the Sylvan Pass area by an avalanche specialist who is familiar with avalanche assessment and mitigation programs in North America, Europe and New Zealand. The results of this analysis are summarized as follows.

The East Entrance Road runs through Sylvan Pass in an east-west direction. A 5,000-foot long segment of the road at Sylvan Pass crosses through terrain that is known to produce powder, light and deep snow avalanche events that impact the road. This terrain does not produce plunging events. The remaining portion of the road to the East Entrance and Lake Village has a few steep hillsides, banks, and road cuts that can slough minor deposits of snow onto the roadway during unstable conditions.

Figure 3 shows the Sylvan Pass segment of the road and avalanche paths of concern. Avalanches that impact the roadway initiate from starting zones situated above the road. After release, they flow down gullies between rocky outcrops towards, to, and sometimes over, the roadway. The size and length of these avalanches varies depending on the volume of moving snow involved and conditions at the time of release.

The exact location of the road through the pass has changed over the years, however its basic course has been confined to a narrow passageway that goes up and down the drainages that flow east and west from the top of the pass. Over the years there have been massive earthworks conducted in this passageway. A huge volume of material has been excavated and used for road building purposes. These earthworks have repeatedly changed the detailed topography of the roadway and may have removed vegetation in portions of the avalanche paths that can provide insight into the frequency and size of historical events.

To assess the hazard from avalanches to travelers on the East Entrance Road the topographical attributes of the avalanche paths of concern have been investigated. All of the avalanche paths that have historically impacted the road originate from starting zones on the north side of the road. The starting zones of these avalanche paths are numbered according to artillery target designations. Other dangerous avalanche paths on both sides of the road in Sylvan Pass exist. This assessment does not evaluate the hazard associated with avalanche paths that are not known to impact the road or the gun mount area.

Outlines of avalanche starting zones, artillery targets (numbered) and outlines of the estimated extent of a large avalanche initiated from these target areas are shown on Figure 3. During periods of severe widespread instability some of these paths may overlap and release simultaneously. In extreme or unusual circumstances, areas between the delineated slide paths (areas between paths 16 & 17 and paths 17 & 18) could also fail and potentially impact the road.

Avalanche paths are comprised of starting zones, tracks and runout zones. The starting zones are located in the upper portion of a path. Snow accumulates in starting zones and under certain conditions can collapse or fail and flow down the track of the avalanche path. Some avalanche paths have multiple starting zones. The runout zone is located in the lower portion of the track where the slope becomes less steep and the avalanche stops. The majority of the snow entrained in a flowing avalanche is typically deposited in the runout zone.

To characterize the hazard presented by these paths to the road the physical attributes of the portions of the avalanche path above and to the road have been investigated. The accurate delineation and characterization of the portions of the paths below the road that do not impact any other features of concern was not considered to be a goal of this study.

Avalanche Path Attributes

The physical attributes of the terrain where avalanches occur can provide insight into the magnitude and frequency of resultant avalanches. An understanding of the attributes of the avalanche starting zones can help forecasters to anticipate when snow in these paths may become unstable. Knowledge of the physical attributes of a slide path at its intersection with the road can be an important consideration in the selection of potential mitigation options. Selected physical attributes were determined for each of the slide paths that are known to have historically impacted the East Entrance Road and are listed in Table 1. A discussion of these attributes follows.

Starting Zone Elevations

The average elevation of the starting zone of the avalanche paths that impact the road is 9,096 feet above sea level. All of these starting zones are located between an elevation 8,692 and 9,363 feet. The range of elevations of these starting zones is 671 feet. The elevations of these starting zones are similar. Avalanche paths with similar elevations tend to become unstable during similar conditions.

Starting Zone Aspects

The aspect of the starting zone is defined as the compass direction that the starting zone slope faces. The average aspect of the avalanche starting zones that impact the road is 205 degrees (south-southwest). The aspect of these starting zones is distributed across a range of 46 degrees from 184 to 230 degrees (south to southwest). The aspects of these starting zones are similar. Avalanche paths with similar aspects tend to become unstable during similar conditions. In general weaknesses associated with buried faceted snow tend to persist longer on northerly aspects than southerly aspects. Southerly aspects are favorable areas for the development of sun and radiation re-crystallization crusts. These crusts can become sliding layers and can also provide strength to a snowpack.

Starting Zone Slope Angles

Most avalanches initiate on a 30 to 45 degree slope. A slope angle of 38 degrees is an ideal slope angle for avalanche initiation. The average slope angle of these starting zones is 38 degrees. The mean maximum slope angle of these starting zones is 47 degrees. The mean minimum slope angle of these starting zones is 33 degrees. Avalanche paths with similar slope angles tend to become unstable under similar conditions.

Length of Avalanche Tracks Above the Road

The distance from the starting zone of each path to the road was determined. The average distance from the starting zone to the roadway along the avalanche tracks was 1,160 feet. These distances ranged from 1,646 feet to 518 feet. Paths 1, 8C, 17, 18 and 18B have shorter track lengths above the road than the others. The length of these tracks above the road ranges from 518 to 739 feet. The length of the remaining tracks range from 925 to 1646 feet.

Elevation Difference between the Avalanche Starting Zones and the Road

The difference in the elevation (vertical drop) between avalanche starting zones and the road was determined. The average vertical drop was 613 feet. The vertical drop ranged from 337 to 901 feet. Paths 1, 8C, 17, 18 and 18B have shorter vertical drops than the other paths. The vertical drop of these tracks ranges from 337 to 406 feet. The vertical drop of the remaining tracks ranges from 505 to 901 feet.

Avalanche Track Angle above the Road

The slope angle of the avalanche track from the starting zone to its intersection with the road was calculated. The average angle of the track above the road was 32 degrees. This angle ranges from 27 to 41 degrees.

Width of Avalanche Track at the Road

The width of the avalanche tracks at the road varies depending on the volume of snow in each avalanche event on a specific avalanche path. A maximum width for a large sized avalanche relative to the size of a specific track was estimated based on the topography of the track and vegetation patterns observed along the parameter of the track. The average maximum width for these avalanche paths at the road is 243 feet. The width of the tracks at the road ranged from 89 to 600 feet.

Runout Zones

The runout zone of an avalanche path is defined as the portion of the avalanche track or path where the steepness of the slope along the track lessens to the point where the mass of the snow in the avalanche begins to slow down and is deposited.

The extent of the area of the runout zone where the avalanche debris is deposited varies depending on the volume of snow incorporated in each avalanche event. Small avalanches with low volumes of snow run only short distances and in many cases would not run far enough along a track to reach the road. Medium sized avalanches could run to the road and would likely impact a portion of the road less than the maximum width determined for larger events. Large avalanches would cross the road and likely impact the maximum width of the road estimated for each slide path. The delineation of the extent of runout zones below the road if they did not have potential to impact the area of the gun mount was not considered to be essential to the purpose of this study and was therefore only delineated in a cursory manner.

The physical attributes of the avalanche starting zones that impact the East Entrance Road are similar with respect to elevation, aspect and starting zone slope angle. These starting zones are also close to each other with respect to distance and therefore meteorological conditions that create unstable conditions likely occur in these starting zones at the same time. The starting zone slope angles of these avalanche paths are ideal for artificial and natural avalanche initiation.

The length and slope angle of these avalanche tracks above the road are sufficient to produce powder, light, and deep snow avalanches. These events could obscure visibility, push a vehicle off the road, or violently sweep a vehicle from the road and severely damage or bury a vehicle. In addition the downhill side of the road is the location of steep slopes along a portion of the road in the zone of avalanche impacts. The consequences to a vehicle being hit by a large fast moving avalanche on one of these paths are severe. Serious injury, death by trauma, or suffocation could occur to the occupants of a vehicle.

Avalanche Frequency

Knowledge of the return period or frequency of avalanche events is an essential component of an avalanche hazard assessment.

A trigger is necessary to start an avalanche in motion. Snowfall, rainfall, drifting snow, sunshine and rapid rises in temperatures are examples of natural triggers that can initiate the failure of an unstable slope and cause an avalanche. Explosive charges, artillery or the weight of a skier, snowmobile, snow groomer or other winter traveler are artificial triggers that can release avalanches.

The NPS has an existing avalanche hazard mitigation program for Sylvan Pass. This program monitors avalanche conditions and closes the pass when conditions are suspected to be unstable. During the closure, depending on the severity of the hazard, a highly trained crew fires explosive rounds into the avalanche starting zones. These efforts enable the hazard forecasting team to test the stability of the snow. If unstable conditions exist avalanches occur and the hazard is reduced. By conducting numerous missions expertly timed with periods of instability skilled specialist can trigger frequent small avalanches as opposed to occasional large avalanches. This methodology of constantly triggering small avalanches during identified periods of instability is the industry standard for mitigating avalanche hazards on highways and at ski resorts.

The crews on Sylvan Pass have been triggering avalanches with artillery for over 30 years. In the 1970's hazard reduction missions were infrequent and were only conducted after big storms or in the spring before plowing operations began. With this mode of operation large avalanches were triggered when conditions were favorable.

As traffic increased, hazard reduction missions became more frequent. A former employee, who participated in this program for 22 years, reported that there was a large variation in the number of avalanches artificially triggered on a year-by-year basis (Lounsbury 2006). He estimated 120 to 130 slides were triggered by artillery during a season with a lot of avalanches and 60 to 80 were triggered during seasons with minimal avalanche activity.

This former program leader estimated 20 to 30 natural events might occur during a very active season. He reported that the occurrence of naturally triggered avalanches decreased significantly when hazard reduction mission were conducted more frequently. It is generally accepted that the use of explosives as a mitigation strategy can reduce the occurrence of natural occurring avalanches by as much as 90% (Schaerer 1988).

Mission records from the last eight seasons were available and reviewed. These records provide general information with respect to the number of avalanches triggered and if the slides crossed the road. This review indicates approximately 300 avalanches were triggered by these missions. Sixty-eight of these avalanches are believed to have run to or across the road. Three natural avalanches were noted to have crossed the road on these mission records. Not all natural avalanches that occurred during this period are believed to be included in these records.

Avalanche Hazard Index

The Avalanche Hazard Index (AHI) is a numerical expression of damage and loss caused by the interaction between snow avalanches and vehicles on a road (Schaerer 1988). The index is determined by multiplying the frequencies of moving and waiting vehicles being hit by various types of avalanches (slough, powder, light, deep, and plunging) by a weighting that reflects the severity of the consequences. Its calculation is based on estimates of the types of avalanches, their widths on the road, frequencies of occurrence and the relation of timing with respect to avalanches in adjacent avalanche paths.

The formula to calculate an avalanche hazard index on Sylvan Pass could be modified for over snow vehicle traffic, however an essential component of the calculation is the frequency of natural avalanche activity for the different types of avalanche events that impact the roadway at each known path. In the case of Sylvan Pass an avalanche mitigation program that routinely artificially triggers avalanches has been in place for over 30 years. Appropriate data regarding the frequency of natural avalanche occurrences on these paths is not available. Without natural avalanche frequency data this calculation would not be valid.

Schaerer states that elimination of all hazards to a road from avalanches can be expensive and may not be feasible. He suggests that an acceptable risk from avalanches to a road would lie somewhere between the risk from other natural disasters and from traffic accidents. Using his calculations an avalanche hazard index of 1 is considered to be acceptable.

Schaerer reports that the section of the Trans-Canadian Highway that crosses the Selkirk Mountains through Rogers Pass in British Columbia has the highest avalanche hazard of all roads in Canada. He calculated an AHI of 1004 without a mitigation program. He further reports that mitigation efforts employed reduce the AHI for this section of highway to 0.8.

Gun Mount Access

Large dangerous avalanche paths also exist on the south side of the pass**,** however none of these paths have been reported to have historically impacted the East Entrance Road. The gun mount for military weapons is located on the south side of the East Entrance Road at a location that is shown on Figure 3. There are three small avalanche paths in the vicinity of this service road. These paths are only a few hundred feet long and slide infrequently, however they are capable of producing avalanches that could injure, bury, or kill a person. Their estimated locations are outlined on Figure 3.

Wet Snow Avalanches

Assessment efforts conducted above relate to hazards associated with dry snow avalanches. Wet snow avalanches generally move slower and don't run as far as dry snow avalanches but can also sweep vehicles off the road and bury and kill of injure the occupants. Wet snow avalanches occur when temperatures are warm enough for at least a portion of the snow entrained in the avalanche to be damp. Wet snow avalanches typically occur during rain on snow events or when the snow surface is exposed to intense sunshine, a rapid rise in temperature, or during an extended period with air temperatures above freezing. Wet slides can occur during the period of winter use but are more likely to occur at the onset or during the melting season. Wet snow avalanches are problematic compared to dry snow avalanches with respect to hazard forecasting and mitigation.

Spring, Summer & Fall Operations

The avalanche hazard is a function of the nature of the avalanches, the frequency of avalanche occurrences and the likelihood of an object or person being beneath the avalanche when it occurs. During spring plowing operations plow drivers are likely to spend more time beneath each avalanche path than a typical traveler who quickly passes through an avalanche path on the road.

After the road has been cleared of snow, it is opened for summer (wheeled) vehicle traffic. Until the snow is sufficiently melted, the avalanche paths above the road can produce dry and wet snow avalanches that could equal the destructive force of avalanches experienced during the winter season. The volume of summer traffic is believed to be higher than the current volume of winter traffic.

3.3 Mitigation Program Overview

The need for an avalanche hazard mitigation program was apparent before grooming operations for snowmobile travel began in the 1970's. For over 30 years a specialized team has used hazard evaluation skills and artillery to mitigate the avalanche hazard. Operations are based out of facilities located in Lake Village and at the East Entrance to the park.

The primary purpose of the mitigation team has been to monitor conditions and close the road to all forms of traffic when dangerous conditions occur. When conditions are determined to be appropriate, the team uses explosives to assess and reduce the hazard and potentially reopen the road.

The program has relied upon military weapons (recoilless rifles or howitzers) since it started. These weapons fire explosive rounds into avalanche starting zones from a gun mount located on the south side of the pass. The artillery enables the crew to test the stability of the snow and attempts to reduce the hazard by triggering frequent small avalanches. This methodology is common among crews who manage highways and ski areas in avalanche prone areas. Two seasons ago a helicopter was introduced as a method to deploy explosives to avalanche starting zones.

3.3.1 Program History

A former member of the mitigation team for 22 years who also had some knowledge of the program prior to that time, provided insight into the historical operations of the Sylvan Pass avalanche hazard assessment and mitigation program (Lounsbury 2006). He reported that a 105 mm recoilless rifle was used in the early 1970's. It was mounted on a steel platform close to the location of the present gun mount. After one or two seasons this weapon was replaced with a 75 mm recoilless rifle. A 102 105mm Howitzer replaced the recoilless rifle in the mid 1990's. Another artillery professional familiar with the program believed a 106 recoilless rifle was used for a period before the Howitzer and after the 75 mm recoilless rifle (Livingood 2007).

In the 1970's there were few artillery missions. The artillery was used only after large storms or when the road was to be plowed in the spring. Avalanches typically occurred during storm cycles and periods with high winds. As traffic increased grooming occurred at night and the number of missions increased. Early crews were inexperienced and untrained. During the 1980's formal military weapons operations training began and workers were trained to use avalanche rescue transceivers.

In 2004 NPS safety concerns with the existing artillery program resulted in the decision to contract a helicopter and crew to drop explosives from the air into avalanche starting zones. Helicopter missions became part of the program during winter 2004/2005 and played a substantial role in the 2005/2006 season. The mitigation team has been directed that all explosives deployment be conducted by helicopter except in the case of an emergency during the 2006/2007season.

Snowmobile traffic through the east entrance increased during the 1980's to an estimated volume of 100 machines per day (Lounsbury 2006). Since 2000 the use of snowmobiles in this area has decreased and snow coaches have been introduced. For the past two seasons snowmobiles were required to be accompanied by guides and numbers were limited at the east entrance station to a daily maximum of 40 snowmobiles. Winter traffic through the east entrance was estimated to be 12 snowmobiles per day last season and 1 snowcoach every 3 to 4 days.

3.3.2 Current Operations

A review of program operating procedures was conducted with NPS personnel during a site visit on November 8th and 9th. Copies of Operational Profiles, Forecasting Guidelines, a Howitzer Operation Plan, Helicopter Operations Plan, program records, daily operations, mission specific topics, training and education policies were discussed and reviewed.

The forecasting and mitigation crew is comprised of a core group of highly experienced employees. Every day from November to May depending on snow conditions members of the crew review data and information from a variety of available resources and make an assessment of the hazard to travelers on the road. When conditions merit the road is closed. Helicopter missions are conducted to test conditions and mitigate the hazard. Conditions are continually monitored and hazards reassessed.

The resources used to assess the hazard include meteorological observations made by NPS program personnel at the Lake and East Entrance facilities. They also include daily reviews of the weather forecast provided by the National Weather Service and other sources. Other resources include Backcountry Avalanche Forecasts issued by the Bridger-Teton National Forest, and the Gallatin National Forest Avalanche Centers located in Teton Village, Wyoming, and Bozeman, Montana, and data from a remote National Resources Conservation Service (NRCS) snow survey station (Snowtel site) located near Sylvan Lake on the west side of Sylvan Pass.

The Sylvan Pass Snowtel site provides air temperature and precipitation data that is used by the NRCS to forecast and manage water supplies. These resources do not include any real time data for wind speeds and direction from the Sylvan Pass area. Wind speed and direction are critical parameters associated with the assessment of avalanche hazards.

This program currently does not operate specialized weather stations in the vicinity of the avalanche paths. This practice would greatly enhance the ability of this program to assess the hazard. Specialized weather stations that provide real time data regarding wind direction, wind speeds, temperatures, snow depths and precipitation rates from the area of concern are an industry standard for similar programs in North America and Europe.

Remote weather stations should be installed and equipped with instrumentation that will operate in the severe conditions that exist on Sylvan Pass and provide data that is specific to the needs of this NPS avalanche hazard assessment and mitigation program.

3.3.3 Comparison to Other Programs

Other programs that assess and mitigate avalanche hazard to transportation corridors and ski areas exist in North America. These programs are similar in that they rely upon highly trained personnel to monitor conditions and manage the hazard from avalanches. The primary mitigation practice is to close access when conditions dictate. In most cases economic needs typically call for quick action to address the hazard and abate economic impacts. Explosives are clearly the industry standard to accomplish this task.

The Sylvan Pass program differs from other programs in that it is conducted for the purpose of addressing the avalanche hazard to over snow vehicle use in a recreational setting. Other programs used for comparison assess and mitigate the hazard to plowed roads, railways or ski areas. Automobile and truck traffic volumes for some of these other programs were reported to range from 400 to 22,000 vehicles per day (Bachman 2007). Current winter traffic volumes for Sylvan Pass have been reported to be in the order of 8 to 12 vehicles per day.

Artillery has historically been a tool of choice for explosive delivery in North America. Recent innovations include non-military devices to deliver explosive projectiles and fixed place explosive delivery devices. In ski areas hand charge delivery by ski patrollers is prevalent. In the majority of mitigation programs the helicopter delivery of explosives is a supplementary role. A brief overview of other programs in North America follows. Explanations of some of the mitigation methods and devices referenced below are provided in Section 4.0 Avalanche Hazard Mitigation Strategies of this report.

The following programs were used for comparision: Alaska Department of Transportation (AKDOT), California Department of Transportation (CADOT), Colorado Department of Transportation (CODOT), Utah Department of Transportation (UDOT); Washington State Department of Transportation (WADOT), the Wyoming Department of Transportation (WYDOT) and the highway department of British Columbia in Canada.

In Alaska the DOT uses Howitzers to protect roadways over Thompson Pass and near Juneau. Recoilless rifles are used along the Seward Highway and on Atigun Pass. The portion of this program that addresses the Seward Highway averages about 12 to 15 artillery missions per year. An estimated 300 artillery rounds are fired per year.

The Washington Department of Transportation conducts an estimated 32 avalanche hazard reduction missions per year to protect highways over Stevens and Snoqualamie Passes. Their program uses four recoilless rifles, one Howitzer, four M60A3 Battle Tanks, one Avalanche Guard (a fixed place solid propellant explosive delivery system), fixed place aerial explosive delivery cables, hand charge routes supported by tracked oversnow vehicles and occasional helicopter missions. The Avalanche Program Coordinator estimated they fired an average of 150 artillery rounds per year.

The Wyoming DOT uses a Howitzer to mitigate avalanche hazard on Teton Pass and in Hoback Canyon. This program uses two Avalanche Guards and four GASEX (fixed position explosive detonating devices) on the Glory Bowl and Twin Slide avalanche paths. This program is using infrasonic sensors to detect natural occurring avalanches that impact the highway as they occur. These sensors also detect small avalanches that occur naturally or are initiated by mitigation efforts. Knowledge from those observations useful in the decision making process associated with managing the avalanche hazard to this highway. These sensors can also remotely confirm the detonation of explosive charges during storm conditions. This program uses snow sails to disrupt snow deposition in an avalanche starting zone as a method to mitigate impacts to a highway south of Jackson, Wyoming.

The Utah DOT uses artillery and avalaunchers (a non-military explosive projectile delivery device) to mitigate the threat of avalanches to busy highways. Infrasonic sensors have been recently installed to detect spontaneously released avalanches that impact the highway in Little Cottonwood Canyon.

The Colorado DOT uses six howitzers, at least five avalaunchers and helicopter missions to reduce the avalanche hazard on numerous passes and transportation corridors in the state. The California DOT uses one avalauncher, two GAZEX devices, hand charge routes, two LoCats (infrequently) and on rare occasions helicopter missions.

The province of British Columbia in Canada has an extensive avalanche mitigation program for its highways. The section of the Trans-Canada Highway that passes through Rogers Pass has the highest avalanche hazard of all roads in Canada (Schaerer 1988). Sixty-five avalanche paths threaten this section of highway. It had a winter traffic volume of 1700 vehicles per day in 1987. Schaerer calculated that without an avalanche hazard mitigation program this section of highway would have an AHI of 1004. Engineering designs including snow sheds, retaining barriers in starting zones, earth dikes and earth mounds were used to reduce the AHI to 235. An extensive artillery program was used to further reduce the AHI to 27. Frequent road patrols that keep the exposure time of waiting vehicles to less than one hour and signage that attempts to keep waiting vehicles from stopping in avalanche paths and road closures were used to address the residual hazard. Schaerer reported in 1988 that on average two uncontrolled light-snow avalanches were observed to impact the road per year (that resulted in an AHI of 0.8).

Railroads in Alaska, Montana and Canada have avalanche hazard mitigation programs. The Alaska and Canadian programs use artillery. Alaska Railroads uses a Howitzer on the Seward Railroad Transportation corridor and has two other Howitzers mounted on railcars that are used on other rail lines. The Burlington Northern-Santa Fe railroad has recently proposed using artillery in Glacier National Park, although the NPS opposes this proposal.

Many ski resorts in North American also have avalanche mitigation programs. The programs at Alyeska in Alaska; Alta and Snowbird in Utah; Bridger Bowl in Montana Alpine Meadows and Mammoth Mountain in California; Las Vegas Resort in Nevada, Taos in New Mexico and Jackson Hole in Wyoming all have historically used artillery as a avalanche hazard reduction tool. Many of these resorts also use avalaunchers and most run routes where ski patrollers deploy hand charges. Helicopters are occasionally used in ski area applications

In Wyoming, Montana, Utah and Idaho over 10,000 miles of trails and unplowed roads are machine groomed for winter travel. Snowmobilers, cross-country skiers, walkers, dogsledders, snow coaches and snowshoers use these trails. Although best efforts have been made to avoid avalanche hazards sections of these trails pass through avalanche prone terrain and are impacted by natural and human triggered avalanches during periods of instability. Recreational users and workers who maintain these trails are exposed to avalanche hazards. None of these routes are known to have active avalanche hazard assessment and mitigation programs. Educational efforts are being developed to raise the avalanche awareness of this hazard to the public. The State of Wyoming through its Department of State Parks and Cultural Resources has obtained grants to map avalanche paths that impact portions of the machine groomed trail network in Western Wyoming.

3.3.4 Mitigation Program Hazards

Avalanche forecasters and mitigation crews are exposed to hazards as they perform their jobs. In this section hazards associated with the Sylvan Pass program are presented and discussed.

Reconnaissance Patrols

Reconnaissance patrols are conducted to evaluate conditions and are an essential component of daily avalanche hazard assessment efforts. These patrols are conducted on snowmobiles. The purpose of these patrols is to obtain site-specific data regarding the assessment of the avalanche hazard. Prior to each patrol, an in-depth analysis of the expected hazard is conducted from the Lake Village and/or the East Entrance. The results of this evaluation are used to develop an appropriate scope of work for that days patrol.

Standard protocol requires that workers travel in groups of at least two and are experienced in avalanche hazard assessment methodology, trained in safe travel procedures, and equipped and trained to perform avalanche rescues. Along the way observations regarding conditions and snow stability are made. As patrollers approach Sylvan Pass conditions are assessed and the decision is made to continue or discontinue travel beneath the avalanche paths.

It is customary practice for ski patrollers at resorts and transportation corridor personnel to pass through avalanche terrain before it is cleared for maintenance personnel to enter or opened to the public. When conditions warrant, the Sylvan Pass NPS personnel pass beneath the avalanche paths of concern for the purposes of assessing the hazard before opening the road to public travel. If it is determined that significant danger exist these workers do not expose themselves or the public to this hazard.

A NPS service ranger died on a reconnaissance patrol on Sylvan Pass in January 1994 when he drove his snowmobile off the road during whiteout conditions. Snowmobile safety and training courses and annual refresher courses are required for all park employees who use snowmobiles.

The interior of Yellowstone National Park experiences some of the coldest temperatures in the continental United States. Sylvan Pass is very windy. Very cold temperatures and windy conditions can combine to create extreme wind chill conditions. Frostbite, hypothermia and cold exposure are serious hazards to workers in this environment. A heated enclosed shelter exists at the gun mount. The Howitzer can operate in temperatures as low as 40 degrees below zero, however the use of this weapon in the severe cold environment of Sylvan Pass has resulted in occasional equipment failure. The Sylvan Pass team has developed methods to address these challenges.

Artillery Missions

The use of artillery is widespread in the military. The safe operation of military weapons and storage and handling of explosive rounds requires weapon specific training and practice. Training and practice regarding the use of artillery in the Sylvan Pass program has been and continues to be a high priority. Since 1996 the Sylvan Pass program has contracted experts to provide a three-day weapon specific training course to the Sylvan Pass crew. This training includes a review of weapon operation and maintenance procedures, borehole and blind-fire sighting exercises, a review of procedures to address misfires and other potential problems, dry fire exercises, and a practice live-fire mission on Sylvan Pass. Personnel from outside programs that use artillery attend these training sessions.

The Sylvan Pass mitigation team members belong to the Avalanche Artillery Users of North America Committee (AAUNAC), a group that represents the non-military artillery users of North America. Participation in this organization helps keep the mitigation team abreast of the latest developments in artillery use.

Each avalanche artillery program in North America has hazard considerations that are common to snow avalanche hazard mitigation applications and specific to the setting of each individual application. For the Sylvan Pass program these hazards have been identified, assessed and managed for over 30 years. The hazards specific to this program include threats to the gun crew as they approach the gun mount and threats to the crew while they occupy the gun mount. Undetonated ordinance and overshoots are threats to the public that are common to all programs that use artillery.

To get from Lake Village to the Howitzer, the NPS gunners must pass through the runout zone of avalanches that initiate from starting zones 1 through 8 on the north side of the road (Figure 3). These starting zones are known to produce light and deep snow avalanches that can impact the road. Consequences could be severe if an avalanche struck a team member. Members of the gun crew from the East Entrance Station do not travel across the pass before artillery missions are conducted when significant hazards from avalanches are anticipated.

The decision to conduct a reconnaissance patrol, travel to the gun mount or open the pass to the public is a reasonable and calculated risk based on the information available and the knowledge and experience of the members of the avalanche hazard assessment and mitigation program. Risk based decisions are made by NPS personnel who fight fires and perform technical climbing rescues. The safety of team members and the public is dependant on the resources available to make this assessment and the skill and experience of the forecasters.

Travel through the lower end of avalanche paths before avalanche reduction efforts are conducted is to be avoided in an ideal situation. Avalanche mitigation programs attempt to locate gun mounts in locations that are not threatened by avalanches, with an access route that is not threatened by avalanches. However, this ideal situation is not always possible. This scenario is not unique to this program. In Jackson, Wyoming a school campus has been recently constructed in avalanche terrain. Gun mounts and other structures at some ski resorts are located in avalanche paths. In the populated alpine valleys of the European Alps humans reside in the runout zones of major avalanche paths. In these instances conditions are monitored, experts continually assess the situation and contingency plans exist to mange the hazard.

Most artillery missions at Sylvan Pass involve precision targeting of unstable wind drifts high in the avalanche starting zones. In many scenarios it is reasonable to travel to the gun mount. There are certainly other scenarios when the crew, based on its assessment of the hazard would not approach the gun mount until conditions change. Safe travel procedures dictate that travelers passing through avalanche terrain are well spaced when they cross these paths and are properly equipped and well trained in avalanche rescue techniques.

Section 4.0 Avalanche Hazard Mitigation Strategies of this report presents supplemental mitigation alternatives that could further address this hazard.

There are avalanche paths on the south side of the pass that can cross the summer access road to the gun mount. Compared to their counterparts on the north side of the highway these paths are small in area and have short running lengths in the order of several hundred feet.

Although these paths are relatively small they are big enough to catch and bury a person with potentially fatal consequences. These paths have been the location of several near misses. Due to their limited extent and infrequent activity the hazard associated with these paths may have been underestimated in the past. The gun mount can be approached without crossing through these paths.

The exact location of the gun mount has been moved several times since the 1970's in an effort protect it from avalanche hazards. Reloaction of the gun mount has also occurred as a result of massive earthworks conducted, associated with road maintenance projects. Even through the detailed topography of the location has been changed, the gun mount position is understood to have remained in the same general area for the life of the program.

One potential hazard to the gun mount is for an avalanche to release from avalanche starting zone 8C and flow across the East Entrance Road towards the mount. The attributes of this path are provided in Table 1. This table lists the slope of this path as 27 degrees. This path is less steep than any of the other paths that impact the road. This path also has one of the shorter track distances from the starting zone to the road (739 feet) and a short vertical drop (342 feet). The topography on the south side of the road flattens almost immediately on the downhill side of the road, and then goes uphill to the gun mount.

This path has been observed to produce slides that have crossed the East Entrance Road. In over thirty years of operation none of the events witnessed on this path, either naturally or artificially triggered, were reported to have run to or close to the present gun mount (Loundsbury 2006, Keator 2006). Earthworks designed to deflect or retard the advancement of an avalanche could be constructed between the road and the gun mount, however the thirty plus year record of events indicate this effort may not be necessary. The results of daily avalanche hazard assessment efforts can be used to determine when an extreme event is possible and this mount should not be approached or occupied.

Steep cliffs are located to the south (behind) of the gun mount. Snow cornices develop on the ridgeline along the top of these cliffs. In the past, on a mission when the recoilless rifle was in use, a section of cornice fell from this ridgeline. The cornice triggered a small avalanche on the slope above the gun mount. Debris from this avalanche partially buried government snowmobiles and a portion of the gun mount ammunition magazine. Recoilless rifles produce a destructive back blast that can kill a human or damage equipment in a defined area behind the weapon. Firing procedures address this hazard.

A recoilless rifle has not been used at this site since the early 1990's. Howitzers do not emit a back blast.

To mitigate the hazard from the above instance the location of the gun mount has been moved. A rock berm reinforced with a spine of concrete Jersey Barricades has also been constructed behind the mount and cornice development is monitored. The decision to occupy this gun mount should include an evaluation of the potential hazard from a cornice drop. Cornice drops typically occur during a period of rapid warming, during an extended period of above freezing temperatures or during or following a blowing snow event. Knowledge of on-site meteorological conditions is an essential component of this evaluation process. Recent or occurring cornice drops along the ridge above the gun mount or along similar ridges are key indicators of the potential hazard. In unusual situations a contract helicopter crew may be able to land near the cornice and place hand charges to test its stability and potentially trigger the cornice under controlled conditions.

Rocks have been observed to fall from this steep cliff and bounce or roll towards the mount. The most likely time for this to occur is when temperatures are above freezing. None of this falling material is understood to have damaged any of the permanent structures located at the mount. To mitigate this hazard a rock berm reinforced with a spine of concrete Jersey Barricades has been constructed above the gun mount. The decision to occupy this gun mount should include an evaluation of the potential for rock fall to occur. Above freezing temperatures, rapid warming, evidence of recent or occurring rock fall activity at this site or other similar locations are key indicators that can be used in this evaluation process.

The explosive projectiles used by the Howitzer are anti-personnel warheads that are designed to produce flying metal fragments (shrapnel) when they explode. AAUNAC has adopted a shrapnel fly distance of 464 meters based on army research data for the Howitzer (Weingart 1994, Hendrickson 1994). This shrapnel fly distance has been accepted by all of the representatives who are members of AAUNAC including the NPS, USFS, and North American Highway and Railroad departments. A team of British researchers conducted studies that indicate the fly distance of shrapnel from anti-personnel rounds is projected sideways and forward from the shell's axis and that almost nothing goes backward. The distance from the gun mount to starting zone 8C may be close to or less than 464 meters. A site survey could be conducted to determine this actual distance and the distance to starting zones 8, 8B, 9, 9B and 10.

Unexploded ordinance, commonly referred to as duds, is a consequence of avalanche artillery programs. From the 1970's to the early 1990's many programs used 75 mm recoilless rifles. This weapon and its ammunition had not been in production for many years. As this ammunition aged, increased dud rates resulted and the amount of ammunition remaining became a concern. In the 1990's YNP and many other programs retired their 75 mm recoilless rifles.

Unexploded ordinance have the potential to explode. Unexploded duds should not be handled and are a potential threat to the public. Areas where duds may exist are closed and signs are posted to alert and educate the public regarding this hazard. When duds occur their location is documented on mission records. In summer searches are then conducted in an attempt to locate them. When duds are found their location is marked and specialist from the military are deployed to destroy them. These procedures are customary practice for North American avalanche programs.

A former program manager estimated there was an average of five to six duds every year in the early 1980's (Lounsbury 2006). He estimated that at the end of the life of the 75mm recoilless rifle there were 15 to 18 duds per season. Records detailing how many duds occurred prior to the replacement of the recoilless rifle with the Howitzer and how many were located and destroyed were not available. Since the Howitzer replaced the recoilless rifle over ten years ago there have been 8 duds. Two of these were found and destroyed.

Dud rates for the Alaska DOT artillery program were reported to be 0.25%. The Washington State DOT reported no duds from the artillery program in the last nine years. The military has recently introduced new quality control procedures for Howitzer ammunition. The new procedures direct military personnel to open, inspect and repack ammunition containers before they are shipped to users.

At Sylvan Pass the steep angle of the slide paths above the road creates the potential for duds to roll downhill onto the road. This scenario has occurred in the past and presents a hazard to road travelers and the maintenance crews that plow the road. In the past a motorist on the East Entrance Road is reported to have picked up an unexploded ordinance and transported it to the Fishing Bridge Visitor Center. A similar event occurred near Teton Pass in the Bridger-Teton National Forest in Wyoming when a hiker picked up an unexploded ordinance from the WYDOT avalanche mitigation program and brought it home. It is currently procedure for NPS personnel to search the road with a metal detector before spring snowplow operations begin.

Motorized winter travelers are currently required to be accompanied by guides. Guides could be educated with respect to the potential for duds to be encountered. Park visitors in cars pass through entrance stations to get into the park. At these points they receive written and verbal information. These entrance stations are an excellent venue for the NPS to provide these visitors with educational information regarding the potential hazards associated with unexploded ordinance in the Sylvan Pass area and other areas of the park where artillery and/or explosives have been historically used for avalanche mitigation purposes. This material could include a map showing the areas of concern, pictures of duds and instructions regarding how to proceed if a dud is encountered.

Another potential concern with the use of artillery is the potential for an overshoot. An improperly directed shot could miss its intended target and travel as far as seven miles from its point of origin. No overshoots were reported to have occurred at Sylvan Pass with the existing Howitzer. The Utah DOT recently had an overshoot that landed in a residential neighborhood. There were no injuries associated with this event. An investigation of this incident determined that failure to follow standard operating procedures created the potential for this incident to occur. This investigation did not result in the termination of the use of artillery at this location. An overshoot bar could be installed at the Sylvan Pass gun mount to help insure overshoots do not occur. An overshoot bar prevents to barrel of the weapon from being pointed in a direction that would result in an overshoot.

Helicopter Missions

The use of helicopters to deploy explosive charges for the purpose of avalanche hazard reduction is not uncommon, however the majority of helicopter use associated with highway programs is as a supplement to other mitigation methods. Safe operations rely upon trained personnel familiar with the handling of explosives and pilots with experience in mountainous terrain. These missions require the helicopter to fly close to the ground surface in steep rugged terrain and can become dangerous during periods of increasing wind and/or decreasing visibility. They are not possible during periods of limited visibility or high winds. Helicopters contracted for the Sylvan Pass program operate out of Billings, Montana.

Hand charges deployed from a helicopter can also fail to detonate. These hand charges are tagged with specialized chips that enable them to be located with a detection device. Located hand charges are destroyed according to the explosives manufacturers protocols. During the 2005/2006 season there were two duds deployed by helicopter. Both were recovered and destroyed. During the 2006/2007season there have been four helicopter-deployed duds to date. Two of these have been located and destroyed. The potential exists for the other two to be located and destroyed at a future date.

3.5 Avalanche Hazard Assessment Findings

A 5,000-foot long section the East Entrance Road through Sylvan Pass has a well-documented history of impacts from snow avalanches. Avalanches that impact the road originate from starting zones on steep slopes on the north side of the road. The destructive forces associated with these avalanches can violently sweep a vehicle from the road and severely injure or kill its occupants. This hazard is a threat to winter users, wheeled traffic in the late spring and fall, snowplow drivers and maintenance personnel who clear the road of snow in April and May and administrative travelers on the road in the shoulder seasons.

A small group of highly trained and experienced NPS personnel based in Lake Village and the East Entrance Station have successfully managed this hazard for over 30 years. The success of this and other similar programs in North American are based on the premise that experienced and well-trained specialists can determine when conditions are unstable and take appropriate action. These actions include closing the road to all traffic when necessary and using explosives to test the stability. Programs that actively use explosives are accepted to be very effective in reducing the number of large natural avalanches by triggering frequent small events in a controlled environment. This program has a significant history of accomplishing this goal.

This crew has performed this task without the benefit of real time meteorological data from the area of concern. Continual real time information regarding wind speeds and direction, air temperatures and snowfall are essential data for the mitigation team and an industry standard for this type of program.

The lack of essential meteorological instrumentation is a safety concern. To be useful this equipment must be properly sited, reliable in a severe environment and produce data essential to the decision making process. Data interpretation is a skill that can be enhanced by specialized training and experience.

A key component of the program has involved the use of artillery to test slope stability and reduce the hazard by triggering avalanches when unstable conditions exist. In North America the use of artillery has proven to be an effective and safe method for the mitigation of avalanche threats to roads, railways and ski areas.

Previous efforts by the NPS have identified safety concerns associated with the artillery program. These concerns include threats to the public and the team that manages this hazard. Threats to the public include natural occurring avalanche events, unexplored ordinance and overshoots. Safety concerns for the NPS mitigation team include threats from rock fall, cornice drops, avalanches, shrapnel and a severe winter environment.

To address these concerns the NPS has replaced the tasks previously conducted by the artillery program with a specialized contract crew that drops explosive hand charges from a helicopter.

Avalanche hazard mitgation programs strive to prevent large volumes of snow from building up on unstable snow covered slopes that could result in large dangerous avalanches. This is accomplished by using explosives to trigger numerous small avalanches when conditions are unstable. The most effective time to trigger these small avalanches is during a storm when these slopes are being rapidly loaded with new snow. The inability of helicopters to fly during periods of poor visibility and or gusty or high winds limits the ability of helicopters to trigger avalanche during storm periods.

This change in management approach is likely to result in an increase in the amount of time the road is closed due to avalanche hazards. In addition the inability of helicopter missions to be conducted during storm conditions could result in an increase in the number of large and natural released avalanches that impact the road.

The majority of programs that use helicopters for road mitigation programs use them as a supplement to artillery or other devices that can reliably deliver explosives during storm conditions. The helicopter is a good supplement to the artillery program on Sylvan Pass. The option to use a helicopter is a good resource for the mitigation team when conditions are believed to be too dangerous to approach or occupy the gun mount, for deployment of charges in starting zone 8C if an extreme event is a concern and on occasion to precisely target starting zones 17, 18 and 18B, which are more oblique to the gun, mount than the other starting zones.

The results of this assessment indicate that travel on this road should not occur when the avalanche paths of concern are snow covered (October through June) without an active avalanche hazard assessment and management program. Alternative mitigation strategies for the management of the avalanche hazard on Sylvan exist and are presented in the next section of this report. Any mitigation alternative that allows traffic over the pass when the avalanche paths of concern are snow covered will not completely eliminate the hazard to travelers from avalanches. Uncontrolled avalanches can occur and persons traveling on the road in the path of one of these avalanches could die or be seriously injured. Avalanche hazard assessment and mitigation programs greatly decrease the chance that someone will be caught on the road but do not completely eliminate this possibility.

Mitigation programs that include the storage and handling of explosives are subject to security concerns and Bureau of Alcohol, Tobacco and Firearms and Department of Homeland Security compliance requirements.

The historic use of artillery and the present use of explosive hand charges have resulted in the presence of unattended ordinance and hand charges in the Sylvan Pass area. These duds pose a threat to the public and NPS personnel. The Sylvan Pass program and other artillery programs in North America replaced recoilless rifles with Howitzers in the 1990's to address high dud rates. Helicopter deployed explosives are equipped with chips that can be located with a searching device. These actions have significantly reduced the dud rate for this and other programs, however duds continue to occur and present a threat to winter travelers, snowplow drivers, summer travelers and backcountry users.

At the time of this report two hand charges and blasting caps are unaccounted for from this season's effort. In addition there have been six non-recovered artillery duds since the Howitzer replaced the recoilless rifle ten years ago. Previous use of artillery has resulted in an unknown number of unexploded ordinances.

To address this hazard, areas where duds are possible are closed to travel and signs are posted to alert the public to this hazard. Public education is an excellent option to mitigate this hazard. Motorized travelers in the park pass through entrance gates. These gates are excellent venues to disseminate information regarding the hazard from duds and avalanches. Information provided could include maps of the areas of concern, pictures of duds and instructions on how to proceed if a dud is encountered. Information regarding safe travel techniques, such as not stopping in avalanche paths, would benefit all travelers on the road.

Winter motorized travelers are currently required to be accompanied by guides. These guides also present an excellent venue to disseminate dud and avalanche hazard awareness information to the public. Daily communications and an exchange of information regarding avalanche conditions between the guides and the NPS mitigation team is a mitigation management option that would greatly increase the safety to winter pass users.

Alternative dud detection methods could be explored such as specially trained dogs from the military or the Department of Homeland Security. Searches with metal detectors may also be a possibility.

A review of historic avalanche fatalities in the park identified three that occurred before 1918 and three that have occurred since 1991. The recent fatalities were all field scientists, two of which died near Mount Sheridan in the Heart Lake area and one who died in the Lamar Valley area. Two of the earlier fatalities were soldiers and the third was a person riding in a horse drawn sled between Mammoth Hot Springs and Gardiner, Montana.

It is likely that other park personnel are exposed to avalanche hazards in the backcountry and avalanche hazards exist on other park roads. The level of avalanche expertise processed by the personnel in the Sylvan Pass avalanche program is sophisticated and a tremendous asset to the park. The expertise of the Sylvan Pass program would be useful to other park employees who work in avalanche prone terrain.

4.0 Avalanche Hazard Mitigation Strategies

Sylvan Pass has an existing avalanche hazard assessment and mitigation program. This section of the report presents and discusses mitigation strategies that could replace, or supplement the existing program. Topics covered include road management alternatives, explosive delivery options and engineering designs. Wilderness values and engineering considerations may preclude some of the alternatives discussed. Feasibility studies are likely to be necessary if any of these alternatives are to be considered.

Hazard Management Alternatives

Alternative road management options are available to address the hazard from avalanches to the East Entrance Road.

To completely eliminate the avalanche hazard the East Entrance Road would be required to be closed during the period when there is snow in the avalanche paths that can impact the road. Depending on the season this period could extend from early fall to late spring.

An alternative is to use avalanche hazard forecasting expertise to open the road when the avalanche hazard is low and close the road during unstable periods. This alternative would not employ active avalanche hazard reduction efforts. This alternative would not completely eliminate the hazard to travelers from avalanches as avalanche hazard forecasting techniques have limitations and unexpected rapid changes in conditions can quickly destabilize the snow. Without the use of explosives to test snow stability it is likely that a more conservation closure management would result. This alternative would result in significantly longer road closures then are now experienced.

The current management program uses avalanche hazard forecasting expertise to close the road when hazardous conditions are expected and includes the use of explosives to test the stability and reduce the hazard for the purpose of reopening the road.

Explosives are a proven method used to test stability and reduce the hazard by triggering avalanches in a controlled environment. The use of explosives is not effective if the timing of detonations does not coincide with periods of instability. Spontaneous released avalanches can occur after explosives have been used and a road is reopened if conditions change and create instability that was not present when the explosives were used. Therefore avalanche hazard forecasting expertise is fundamental to the effective use of explosives to mitigate avalanche hazards. Specialized remote weather stations are an industry standard for roadway avalanche mitigation programs.

Another possible resource to the program is available in emerging technology that uses infrasonic sensors to monitor avalanche activity. Avalanches and explosives emit distinctive infrasonic (sub-audible) sound signatures that can be detected in near real time by remote instrumentation (Scott et al 2006). This technology has the ability to detect avalanches as they occur and can remotely confirm the detonation of explosive charges during inclement weather (limited visibility and high winds). This tool could immediately alert road managers to the occurrence of an unexpected avalanche event that had either impacted the road or may indicate that conditions have rapidly become unstable and the road should be closed. This tool can also tell program personnel if avalanche mitigation efforts are producing small avalanches that don't make to the road during periods of poor visibility. This knowledge has been found to be useful to managers in the hazard reassessment and decision making process used by the Wyoming DOT on Teton Pass.

Avalanche awareness & safe travel techniques are information that would be beneficial to road travelers. In addition NPS personnel should be trained, equipped and prepared to assess the hazard and perform effective rescues.

Avalanche Hazard Reduction – Explosive Delivery Alternatives

The avalanche that impact the East Entrance Road are similar with respect to the elevation, aspect and slope angle of their starting zones. In addition the steepness of the starting zones of these avalanche paths is conducive for artificial triggering by explosives. Mitigation missions using explosives are likely to be effective because similar conditions with respect to instability are likely to be encountered at the same time in all of the starting zones. Varieties of mechanisms exist to deliver explosives to unstable slopes and are discussed below.

Artillery is proven to be an effective and safe explosive delivery method for the mitigation of avalanche hazards to road and railways in North America. The precise targeting necessary to address the buildup of unstable snow in the starting zones of the Sylvan Pass avalanche paths and the similar attributes of these starting zones makes artillery the preferred mitigation option from an avalanche hazard reduction perspective. Unexploded rounds, overshoots, shrapnel and threats to the gunners from avalanches, cornice drops and rockfall are concerns that have been identified by this study. Mitigation actions to address these concerns have been discussed in previous sections of this report. Some supplemental mitigation strategies to further protect NPS personnel in the artillery program are available and are included in the following text.

The helicopter deployment of explosives is a method that was introduced two seasons ago to address some of the safety concerns associated with the artillery program. Helicopter missions played a substantial role during the 2005/2006season and have been used exclusively to date during the 2006/2007season. The ability to perform helicopter missions during storm conditions is at times limited. The consequences of this limitation are longer road closure periods and a potential increase in the frequency of natural avalanches and the size of avalanches both natural and triggered. Helicopter missions provide the advantages of increasing the probability of retrieving duds and increase the ability of the program to precisely target some of the starting zones. It also provides an alternative to the existing program when conditions are too hazardous to get to the gun mount. Helicopter missions are considered to be a viable explosive delivery alternative and an excellent supplement to the artillery program.

Avalaunchers

Avalaunchers are commercially available non-military devices that use compressed gas to propel explosives projectiles into avalanche starting zones in a manner similar to artillery. Avalaunchers are widely used in the ski industry and by highway programs. The charges used can be equipped with a chip that can be located with a search device in the event the charge does not detonate. The avalauncher projectiles are propelled at lower velocities than artillery rounds and precise targeting can be difficult especially in high wind conditions. Precise targeting is essential for most Sylvan Pass missions. Operation of avalaunchers can also be difficult in extremely cold environments. This use of an avalauncher at Sylvan Pass is considered to be a viable explosive delivery alternative.

Hand Charge Routes

The delivery of hand charges by personnel on skis is a common practice at ski areas and a method that is used by some highway programs and has been used by the NPS at other locations in Yellowstone National Park. The methodology requires the personnel involved to have good skiing skills and explosive handling training and experience. Hand charges can also be fitted with chips to enhance dud recovery efforts. It is understood that NPS employees are no longer allowed handle hand charges.

The topography of the terrain on the north side of the East Entrance Road is appropriate for hand charge routes. A safe hand charge route could originate from the woods on the west side of the path and access the ridge above the starting zones. This well-defined route is not exposed to avalanche hazards. The incorporation of an aerial cable delivery system with hand charge routes would likely increase the effectiveness, decrease manpower requirements and increase the safety of this alternative.

A reduced version of this alternative could result in the safe and effective delivery of explosives to starting zones 1 through 8B that threaten access to the gun mount. These starting zones are approximately 400 to 800 feet above the elevation of the road. The deployment of hand charges in these starting zones would provide stability information and greatly reduce the hazard from crossing beneath these avalanche paths on the way to the gun mount.

A change in park policy and proper training could enabled NPS personnel to safely deploy hand charges to starting zones 1 through 8B before they cross beneath these avalanche paths on the way to the gun mount. Hand charges could also be used to mitigate the hazard from smaller avalanche paths in the vicinity of the gun mount and starting zones 17, 18, and 18B (from the east), and at other road locations in the park.

Aerial Cable Delivery Systems

Elaborate systems that use cable suspended from towers to delivery explosives are widely used in the Alps. Less elaborate systems are used at ski areas in North America. These systems are considered to be effective and safe. The installation of a cable delivery system on Sylvan Pass is considered to be a viable alternative. These systems require a minimal amount of manpower to operate. A tower and cable system would present visual impacts. A less elaborate system could be used in conjunction with hand charge routes.

A reduced version of this alternative could safely and effectively address staring zones 1 through 8B and reduce the hazard associated with passing beneath these starting zones to access the gun mount.

GAZEX

GAZEX is a commercially available fixed location product that uses a mixture of combustible gases to create remotely triggered explosions. This alternative requires the installation of explosion chambers and gas storage and delivery structures in or near the avalanche starting zones. Controls are used to remotely transfer stored gases into the combustion chamber and detonate a mixture of these gases with an ignition source. This alternative would present visual impacts but is considered to be an effective and safe alternative. A helicopter is typically used to install and re-supply these devices.

The installation of one or more of these devices near starting zone 1 through 8B would effectively and safely address these staring zones and reduce the hazard associated with passing beneath these starting zones to access the gun mount. At least several GAZEX devices would be necessary to address all avalanche starting zones that impact the road.

Avalanche Guard

The Avalanche Guard and similar products produced by other manufactures is a commercially available product that is used by the Wyoming DOT on Teton Pass, by the Washington State DOT and ski areas. It is also a fixed location product. It uses solid propellant to deliver explosive charges to avalanche starting zones. The explosive charges are stored in a secure magazine that is mounted on a pole near the avalanche starting zones. Controls are used to remotely open the magazine and fire the charges into the starting zones. This alternative would present visual impacts but is considered to be an effective and safe alternative. Similar products by different manufacturers have been developed and are used in the Alps. A helicopter is typically used to install and re-supply these devices.

The installation of one or more of these devices near starting zones 1 through 8B would effectively and safely address these staring zones and reduce the hazard associated with passing beneath these starting zones to access the gun mount.

LoCat

LoCat is a commercial non-military explosive delivery system similar to artillery and avalaunchers that is used on an infrequent basis by the California DOT. A LoCat tested at the Jackson Hole Mountain Resort in the 1990's was reported to have performed poorly in cold conditions.

Engineering Designs

Any construction effort associated with engineering designs or previously discussed devices will need to consider the environment of Sylvan Pass. These considerations likely include but are not limited to construction on talus slopes in areas with potentially incompetent bedrock, buried ice or permafrost; extreme weather conditions and the environmental sensitive nature of this setting. Proven designs exist in numerous similar environments in North America and Europe and are therefore worthy of discussion.

Deflection Berms & Mounds

This mitigation option involves the construction of structures or features to deflect the flow of avalanches away from areas of concern or to disrupt the flow and retard the forward advance of an avalanche. Deflection berms and avalanche track mounds are proven effective alternatives. The berms redirect the avalanches away from the structures of concern and the mounds are successful in decreasing the running length of an avalanche. These alternatives typically are constructed in the runout zone of an avalanche path.

A berm has been constructed uphill of the gun mount in an effort to provide protection to the mount occupants from the potential for small but dangerous avalanches and rockfall to impact this area. An engineering study could evaluate the potential effectiveness of the existing berm and if necessary provide specifications and a projected cost for a more effective protective feature.

A deflection structure or mounds are also a potential mitigation option to protect the gun mount from a large avalanche descending from starting zone 8C. There appears to be space and sufficient material between the East Entrance Road and the gun mount to accomplish this task.

Avalanche paths that cross the road from the other staring zones on the north side of the road are steep at their intersection with the road. Based on the attributes of these paths it is believed that it is unlikely that deflection berms or mounds would be effective mitigation alternatives for these paths. An engineering study could determine the feasibility of engineering designs and provide construction specifications and estimated costs.

Wind Sails

This mitigation option involves the construction of specially designed sails or wind fences that disrupt the pattern of snow deposition by wind in avalanche starting zones. This mitigation alternative has been used on an avalanche path that impacts a highway south of Jackson, Wyoming. At this location the starting zone is in critical game habitat and this passive mitigation option has likely decreased but not eliminated the necessity for explosives use at this location. This alternative can be effective in reducing the frequency of avalanche events, but may not be effective in eliminating large natural avalanches.

Snow Fencing

This mitigation option involves the construction of specialized fencing in multiple parallel lines along elevation contours in avalanche starting zones. The fencing holds the snow in the starting zones and prevents it from moving downhill in unstable conditions. Snow fences are common in the Alps and have proven to be an effective and safe mitigation alternative. Snow fencing is expensive and presents visual impacts. From an avalanche hazard mitigation perspective snow fences are considered to be an excellent mitigation alternative. The Swiss and other European countries have extensive experience constructing avalanche snow fences in difficult environments.

Snow Sheds

Snow sheds are enclosed structures that cover the roadway and are designed to allow avalanches to flow over the top of the structure while protecting the vehicles within the sheds from the destructive forces of avalanches. Snow sheds are expensive. Properly designed show sheds would be an excellent mitigation alternative on Sylvan Pass. This option could eliminate the avalanche hazard along the 5,000 feet area of identified impacts. A reduced version of this strategy could involve construction of a snow shed beneath starting zones 1 through 8B to provide safe access to the gun mount. Providing a snow surface in the snow sheds for over snow vehicle travel would be a unique challenge.

Tunnel

The construction of a tunnel to bypass the 5,000-foot section of impacted road would eliminate the avalanche hazard. In addition a tunnel would address summer road maintenance problems (mudflows, rockfalls, slumping road bed, etc.) that have resulted in road closings and repairs. Providing a snow surface in the tunnel for over snow vehicle travel would be a unique challenge.

Rerouting the Road

An alternative route for the road over Jones or Cold Creek Passes is a mitigation alternative that may provide a travel corridor over the Absaroka Mountain Range that is not exposed to avalanche hazards or has less or more easily managed hazards. Both Jones and Cold Creek Passes are in designated wilderness and may not be viable alternative due to wilderness value concerns.

5.0 References

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6.0 Chief Contributor Biography

Bob Comey has over 28 years of avalanche assessment and mitigation experience. He has been employed as an avalanche forecaster for the Jackson Hole Mountain Resort and the Bridger-Teton National Forest since 1992. He has been the lead avalanche forecaster for the avalanche mitigation program at the Jackson Hole Mountain Resort and the director and lead avalanche forecaster for the Bridger-Teton National Forest Avalanche Center since 1997. In his position Bob is responsible for the daily assessment of the avalanche hazard in the resort and in the backcountry and communication of this assessment to patrollers conducting avalanche hazard reduction efforts and to the public via daily backcountry avalanche hazard bulletins posted on the internet and via a telephone hotline.

His responsibilities include running daily avalanche hazard control routes, monitoring the stability of the snowpack at the resort and in the backcountry, monitoring and recording snowfall and meteorological parameters at 12 resort and backcountry weather stations and maintaining and manipulating a 40-year database of meteorological observations and resultant avalanche events.

Bob's ski area duties include the daily use of explosive hand charges and aerial explosive delivery systems. His interaction with the Wyoming Department of Transportation avalanche mitigation program for Teton Pass has provided knowledge regarding the use of the Avalanche Guard and GASEX explosive delivery systems. Bob was involved in experimental use of large explosive charges as an avalanche mitigation tool in the early 1990's. Large explosive charges are now a commonly used mitigation tool. Bob's has conducted numerous helicopter explosive mitigation missions at a wide variety of locations and developed operation plans that have used helicopter delivered explosives to mitigate avalanche hazard to seismic exploration field crews.

His training includes attendance of artillery and avalauncher training classes and he has overseen the use of avalaunchers, an avalanche pipe and artillery (75mm, 105mm and 106mm recoilless rifles, and M102 105mm Howitzer). He has previously attended the artillery training session for the Sylvan Pass program that included a live fire training mission on Sylvan Pass with their M 102 105mm Howitzer. He has skied down the avalanche paths on Avalanche Peak in Sylvan Pass that impact the East Entrance Road in May after this road has opened to wheeled vehicle traffic.

Bob is also knowledgeable regarding the use of passive avalanche mitigation methods including snow fencing, snow sails and area closures. Bob is also familiar with engineering designs (diversion structures and snowsheds) for hazard mitigation.

Bob helped host the International Snow Science Workshop (ISSW) at the Jackson Hole Mountain Resort in September 2004. He attended the ISSW in Telluride, Colorado in 2006 and attended previous ISSWs at Snowbird, Utah in 1994, Banff, Canada in 1996, SunRiver, Oregon in 1998, Big Sky, Montana in 2000 and Penticton, Canada in 2002. These week long meetings of avalanche professionals from around the world have helped to keep Bob abreast of new developments regarding avalanche hazard assessment and mitigation.

Bob was chosen by the U.S. Forest Service National Avalanche Center to participate in an international avalanche forecaster exchange with the Swiss Federal Institute for Snow and Avalanche Research (SLF) located in Davos, Switzerland in March 2006. For four weeks Bob worked with Swiss forecasters at the SLF in the daily assessment of the avalanche hazard for Switzerland. This experienced greatly enhanced Bob's knowledge of avalanche assessment and mitigation methods and operations.

Bob is a professional member of the American Avalanche Association and a Wyoming Professional Geologist. Bob attended the National Avalanche School in 1990's and has recently taught several field sessions of the National Avalanche School. Bob received a degree in geology from the University of Maine @ Orono where he also took graduate level courses in glaciology, glacial geology, climatology, and avalanche dynamics.

In a partnership between the Wyoming State Trails Program and the BTAC Bob has obtained six grants from the Federal Highway Administration's Recreational Trail Program.

The Western Trails Avalanche Project (2001-2003) extended the daily avalanche forecast issued by the Bridger-Teton Avalanche Center into areas frequented by recreational snowmachiners. This task was accomplished by the installation and operation of state-of –the-art remote automated weather stations and using the data from these stations to create daily avalanche forecast bulletins for the Continental Divide/Togwotee Pass and Southwest Trails/Greys River areas. This project was highly successful and received a national award in 2004 from the Coalition For Recreational Trails in recognition of its outstanding use of Recreational Trails Program funds. Over half a million users view the daily avalanche forecast bulletins issued by the Bridger-Teton Avalanche Center every season.

The Avalanche Mapping and Education Project (2004-2009) is in the process of assessing and mitigating avalanche hazards to the Wyoming State Trails Program winter system of machine groomed trails. To accomplish these goals Global Positioning Satellite (GPS) and Geographic Information System (GIS) technologies are being employed. The potential avalanche hazard to nearly 1,000 miles of machine prepared trails is in the process of being assessed and mapped. Mitigation of the identified hazards will be primarily accomplished by user education. Maps that assess the avalanche hazard to the trail system and avalanche hazard education text regarding safe travel techniques, rescue methods/equipment and mitigation of avalanche hazard using avalanche forecast bulletins and field observations will be posted on the internet.

Since 2001 Bob has been the primary source of avalanche expertise for on-going avalanche research project funded by Federal Highway Administration, National Science Foundation and Wyoming Department of Transportation Research Grants. The goal of this project has been to determine the feasibility of using infrasonic sensors as a tool in the mitigation of avalanche hazards in transportation corridors. The work conducted has established that avalanches emit a unique sub-audible infrasonic signal that is detectable by remote sensors in near real time.

The field research conducted for this project occurred at the Jackson Hole Mountain Resort in controlled conditions under his direct supervision. The knowledge gained during these efforts has been applied and further developed on major avalanche paths that impact Wyoming Highway 22 over Teton Pass. The research phase of this project is nearly complete. With Bobs help a permanent installation was completed on Teton Pass. This innovative new technology has been applied to a highway setting in Little Cottonwood Canyon in Utah and has been proposed in Glacier National Park to monitor avalanche mitigation efforts by artillery along a railroad transportation corridor.

Information complied by Bob was the primary resource for Chapter 15 (Snow Avalanches) of the Wyoming Multi-Hazard Mitigation Plan developed by the Wyoming Office of Homeland Security. Bob was also a primary source of avalanche hazard assessment and mitigation information for the “Be Prepared” Natural Hazards Mapping and Awareness Project.

Bob’s assessment experience includes a review of an Avalanche Hazard Assessment Report for the proposed location of the new Teton Science School Campus near Jackson, Wyoming and an assessment of the avalanche hazard to a residential parcel in the Phillips Canyon area of Teton County, Wyoming.

From 1985 to 1986 Bob provided avalanche assessment and mitigation services as an avalanche forecaster, ski patroller and backcountry guide to the Cardrona Alpine Ski Area and Pisa Backcountry Ski Resorts in New Zealand. These efforts included assessment and mitigation of avalanche impacts to these resorts and the access roads, and developing a management plan to address avalanche hazards for guided parties in the backcountry.

From 1979-1985 he developed safety plans for the operation of geophysical oil & gas exploration field crews conducting winter seismic surveys in avalanche terrain of the west. Avalanche assessment and mitigation skills including the use of explosives and helicopters were used to mitigate the avalanche hazard for these field crews.