AVALANCHE: RISKS AND MITIGATION

4.1 Identifying and Profiling Avalanche Hazards

Avalanches are a rapid down-slope movement of snow, ice and debris triggered by ground shaking, sound, or human or animal movement. Avalanches consist of a starting zone where the ice or snow breaks loose, a track which is the grade or channel the debris slides down and a run-out zone where the snow is deposited.

Since the 2014 plan, Utah has had numerous avalanches. Avalanches are one the most deadly type of natural disaster in Utah. Between 1958 and 2017 avalanches killed 117 people in the state accounting for 52% of severe weather related deaths.

Items of significance in the 2019 plan include the construction of permanent structures like the snow deflection dam in Park City designed to limit the size of snow slides and stop small avalanches before they gain momentum and do significant damage. The Utah Department of Transportation (UDOT) protects road and railroad infrastructure by utilizing artillery and explosives to test snowpack stability and trigger small avalanches. Utah's ski resorts use helicopters and hand thrown explosives to mitigate avalanche dangers in their parks.

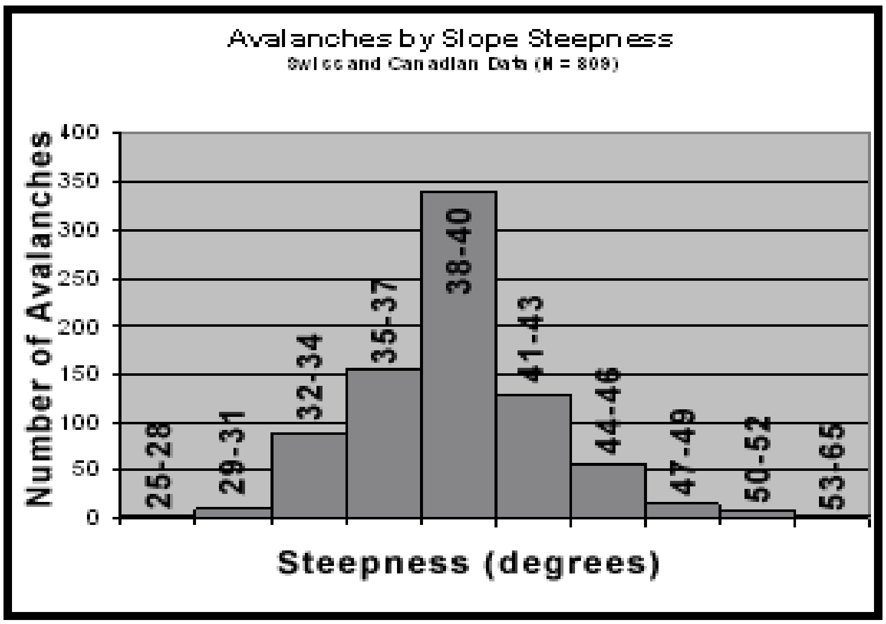
The Utah Avalanche Forecast Center (UAFC) has made progress forecasting and identifying avalanche risks. By utilizing new technology UAFC is able to provide up-to-date information on their website and hotline on weather conditions, snow stability and avalanche danger ratings for areas across the State of Utah. UAFC and Utah ski resorts have also increased their efforts to educate outdoor enthusiasts and city and county emergency managers about avalanche hazards so the public can safely recreate in Utah during the winter months.

An avalanche is a mass of snow, ice, and debris sliding rapidly down steep slopes. Snow avalanches occur in the mountains of Utah during the winter and spring seasons as a result of snow accumulation and unstable snowpack conditions. January through April avalanche risks are the highest in Utah where they pose a significant mountain hazard. Annually, avalanches account for more deaths than earthquakes in the US. Determining the probability of an avalanche occurring can help save money and protect human life.

The two primary factors impacting avalanche activity are weather and terrain. Large, frequent storms deposit snow on steep slopes to create avalanche hazards.[1] Additional factors that contribute to slope stability are the amount of snow, rate of accumulation, moisture content, wind speed and direction and type of snow crystals.

Topography also plays a vital role in avalanche dynamics. Slope angles between 30 to 45 degrees are optimal for avalanches. The risk of avalanches decreases on slope angles below 30 degrees. At 50 or more degrees they tend to produce sluff or loose snow avalanches that account for only a small percentage of avalanche deaths and property damage annually.

Figure 1. Avalanche Occurrence by Slope Steepness



Source: Utah Avalanche Center[2]

Types of Avalanches Common in Utah

Dry or slab avalanches occur when a cohesive layer of snow fractures or shatters like a pane of glass and slides as a unit down the mountainside breaking apart as it slides, typically producing a snow dust cloud. Slab avalanches occur when additional weight is added rapidly to the snow pack, overloading the buried, weaker layers of snow. Dry snow avalanches usually travel between 60-80 miles per hour, reaching this speed within five seconds of the fracture and resulting in the deadliest form of snow avalanche.

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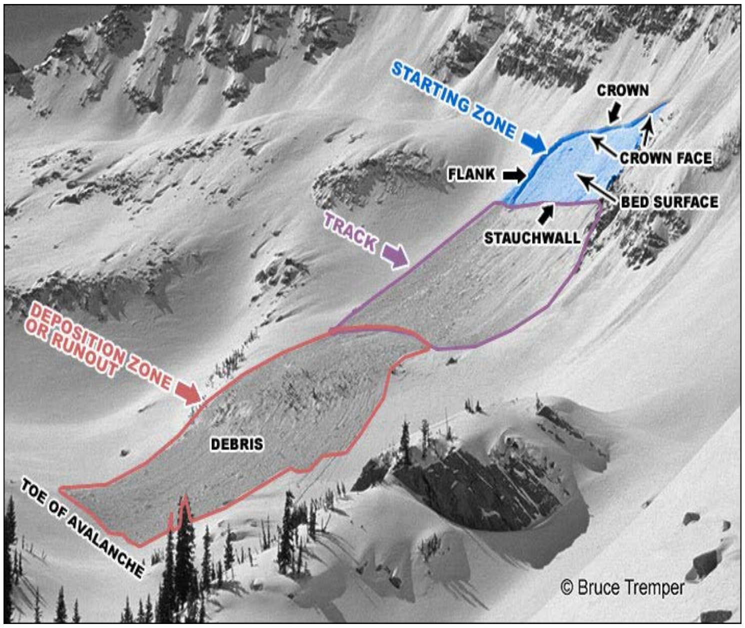
[1] Eldredge, Sandra N. *Utah natural hazards handbook: a cooperative project*. Salt Lake City, Utah The Division, 1992.

[2] UAC : www.utahavalanchecenter.org

Wet avalanches occur when percolating water dissolves the bonds between the snow grains in a pre-existing snow pack, decreasing the strength of the buried weak layer. Strong sun or warm temperatures can melt the snow and create wet avalanches. Wet avalanches usually travel about 20 miles per hour.

Figure 2. Avalanche Zones



Source Utah Avalanche Center

Starting zone

The starting zone[3] is the area near or at the top of an avalanche path. This is where unstable snow breaks loose from the snow cover and starts to slide. The starting zone of a particular slab avalanche has a flank wall, stauchwall, and crown wall. The flank is the side boundary of a slab avalanche, the stauchwall is the downslope boundary of a slab where it rides up over the snow below, and the crown is the upper fracture surface of a slab avalanche.

Track

The track is the avalanche path or channel that an avalanche follows as it goes down the slope. Typically, a large vertical clearing of trees or chute-like clearings are often signs that an avalanche occurs frequently in that area.

Deposition Zone or Runout

The runout zone is where the snow and debris eventually slow down and come to a stop. Typically, this is where the largest debris or snow pile up.

Locations/probability

[3] "Starting Zone." National avalanche center. Accessed October 15, 2017. http://www.fsavalanche.org/starting-zone/

Avalanches occur in the steep mountainous areas of Utah that receive significant amounts of snow. There are many factors that may affect the likelihood of an avalanche occurring in a given area including weather, temperature, slope steepness, slope orientation, wind direction, terrain, vegetation, and snowpack conditions. A combination of these factors will determine if an area has low, moderate, or high avalanche risk. Some of the conditions change daily or hourly, which makes predicting future avalanche probability difficult, but high risk areas tend to have reoccurring avalanches, increasing the likelihood of making more accurate predictions.

Vegetation and Avalanches

Looking at the landscape vegetation often helps to predict the probability of an avalanche occurring in an area. Forests that have large areas cleared down steep mountain slopes indicate an avalanche has occurred and could reoccur. Tree-ring analysis can also help indicate avalanche frequency when an area is lacking historical data to reference. The tree-ring record indicates avalanche occurrence through the reaction of the wood, abrupt changes in growth rate, age of scars from avalanche impact, age of trees in reforested tracks and a new leader from fracturing the top of the tree. The major caveat to using vegetation as an indicator of avalanche frequency is that several other factors influence vegetation growth like wildfires and logging.

Return period	Vegetation Indicators
1-10 years:	Track supports grasses, shrubs, and flexible species (e.g., alder and willow). Patches of bare soil may be present, no trees higher than 1-2 m. No dead wood from large trees except at edges or end of runout zone.
10-30 years:	Predominantly pioneer species. Dense growth of small trees and young trees similar to adjacent forest. Broken timber on ground at path boundaries. Increment core data may be useful.
30-100 years:	Mature pioneering species of uniform age (e.g., non-coniferous), and young trees of conifer species, old and partially decomposed debris. Increment core data useful.
More than 100 years:	Mature, uniform-age trees of climax species. Increment core data may be required.

Figure 3. Vegetation growth and avalanche frequency[4]

Warming winter temperatures weaken the snow pack and early season rains form a crust on the snow which contribute to increased frequency and severity of avalanche events.[5] New land development or changes to the landscape also contribute to avalanche occurrences. Wildfires and other natural disasters can also cause an area to have a higher likelihood of avalanches.

Landscape Changes

Drought conditions and warming temperatures contribute to a longer and more severe wildfire season in Utah and the resulting burn scars pose landslide and avalanche hazards. In 2018 fires in Huntington Canyon in Emery County and the Dollar Ridge Fire in Duchesne County consumed large numbers of trees in avalanche

[4] Simonson, Sara E., Ethan M. Greene, Steven R. Fassnacht, Thomas J. Stohlgren, and Chris C. Landry. "Practical Methods for Using Vegetation Patterns to Estimate Avalanche Frequency and Magnitude." 2010 International Snow Science Workshop, 2010. Accessed October 11, 2017. http://arc.lib.montana.edu/snow-science/objects/ISSW_P-045.pdf.

terrain above county roads. Officials fear these burn scars could contribute to the area's avalanche and landslide vulnerability.

Extent/Magnitude

Table 1. North American Public Avalanche Danger Scale

Danger Level	Travel advice	Likelihood of avalanches	Avalanche size and distribution
5 – Extreme	Avoid all avalanche terrain	Natural and human-triggered avalanches certain	Large to very large avalanches in many areas
4 – High	Very dangerous avalanche conditions. Travel in avalanche terrain not recommended	Natural avalanches likely; human-triggered avalanches very likely	Large avalanches in many areas; or very large avalanches in specific areas
3 – Considerable	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision making essential	Natural avalanches possible; human-triggered avalanches likely	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas
2 – Moderate	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern	Natural avalanches unlikely; human-triggered avalanches possible	Small avalanches in specific areas; or large avalanches in isolated areas
1 – Low	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features	Natural and human-triggered avalanches unlikely	Small avalanches in isolated areas or extreme terrain

Source Statham et al., 2010[6]

Avalanches are extremely destructive if they cross highways or railway systems impeding the path of vehicles or trains and potentially injuring or killing the occupants. The impact pressure

[6] https://cdn.ymaws.com/www.avalancheassociation.ca/resource/resmgr/standards_docs/tasarm_english.pdf

of an avalanche ranges from relatively harmless blasts of powder snow clouds, to a dense and highly destructive mix of snow and debris capable of destroying reinforced concrete structures. Engineers determine what type of mitigation method should be utilized based on possible impact pressure calculations in the runout zone.

Figure 4. Avalanche Impact Pressure related to Damage

Impact Pressure *kPa*	*lbs/ft²*	Potential Damage
2-4	40-80	Break windows
3-6	60-100	Push in doors, damage walls, roofs
10	200	Severely damage wood frame structures
20-30	400-600	Destroy wood-frame structures, break trees
50-100	1000-2000	Destroy mature forests
>300	>6000	Move large boulders

Source FEMA

Property Damage History

Since 1998, Utah has had a total of $70,000 in property damage directly related to avalanches. On March 14, 1998 six avalanches up Little Cottonwood Canyon swept vehicles off the road and injured five people for a total cost of over $50,000 in property damage. On March 14, 2002 an avalanche caused $20,000 in property damage when it swept into Alta Ski Resort's parking lot and damaged several vehicles.

Fatalities

The United States has had 1,047 avalanche deaths since 1951[7] and Utah ranks fourth highest of the 50 states with an average of four fatalities annually for the past twenty years.[8] The greatest number of human casualties are from outdoor recreationalists, primarily skiers, who either trigger the avalanche or end up in the crossfire of the avalanche's path. The Utah Avalanche Center has investigated every reported avalanche incident since 1958, recording the location, date, trigger and if the person was buried, caught, carried, injured or killed. This information indicates which areas have a higher avalanche danger, what times of the year are a higher risk, what is the most common trigger and how many injuries or fatalities have occurred due to avalanches.

[7] CAIC: http://avalanche.state.co.us/accidents/statistics-and-reporting/

[8] Avalanche Fatalities Utah Avalanche Center http://avalanche.state.co.us/

There are 8 major avalanche zones in Utah. These include: Logan, Ogden, Salt Lake, Provo, Uintas, Skyline, Southwest, Moab, and Abajos.

Map 1. Utah Avalanche Zones

Map 2. Avalanche Fatalities in Utah by County

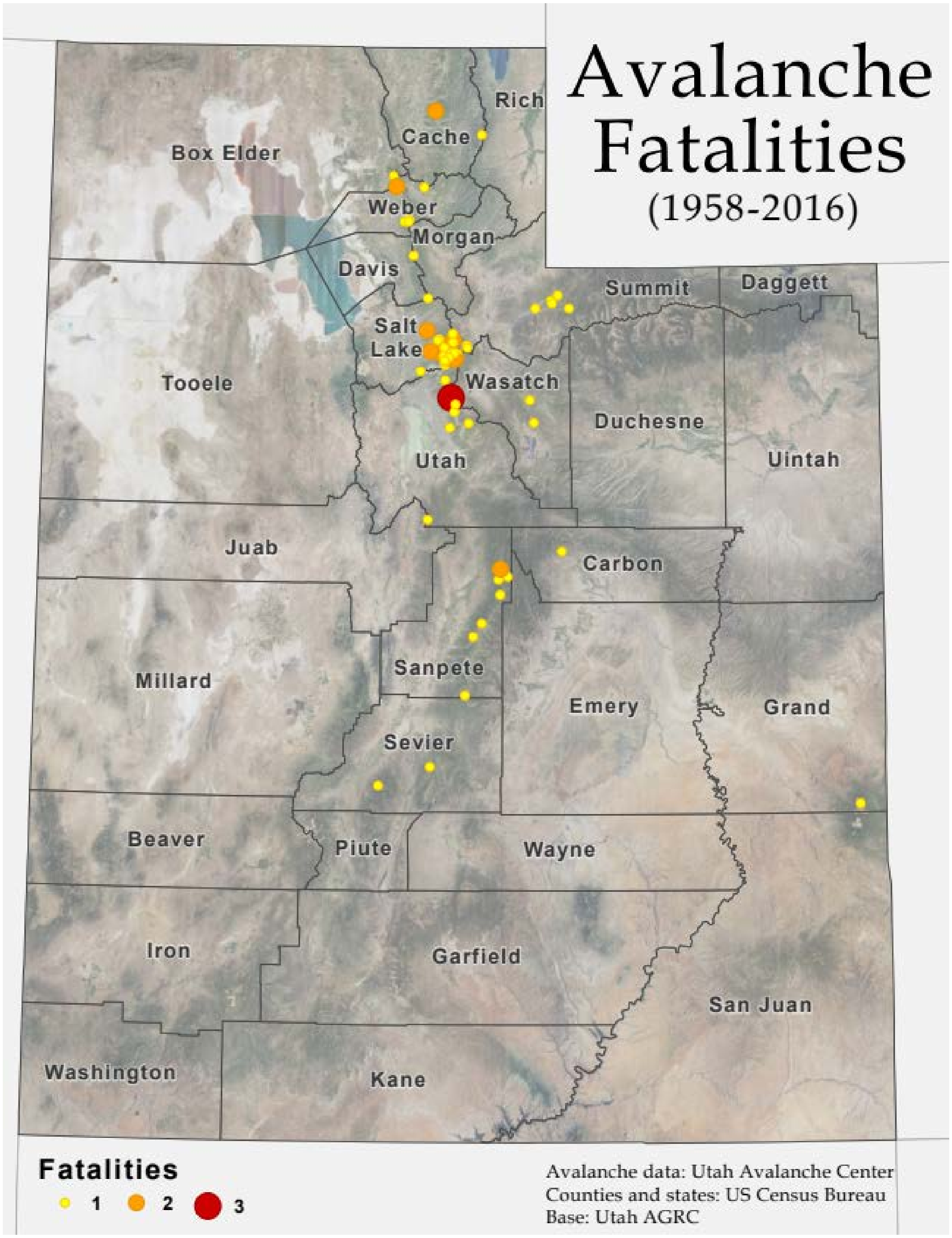


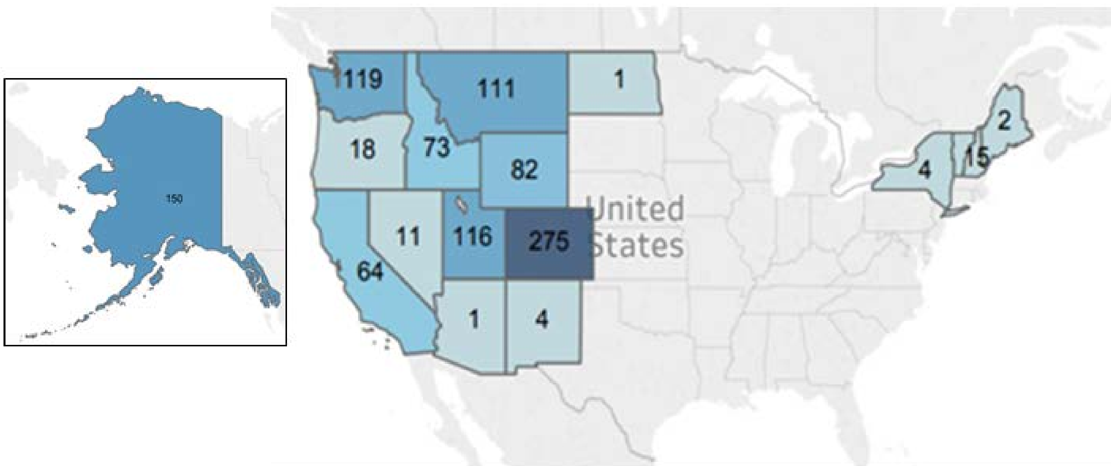
Table 2. Avalanche Fatalities in Utah 1958 - 2017

Date	Number Killed	Region	Place	Trigger
03/09/1958	1	Ogden	Snowbasin	Skier
03/29/1964	1	Ogden	Taylor Canyon	Skier
12/31/1965	1	Salt Lake	Park City Ski Resort	Skier
02/12/1967	2	Salt Lake	Pharoahs Glen	Hiker
02/19/1968	1	Provo	Rock Canyon	Natural
01/20/1970	1	Salt Lake	Peruvian Ridge	Skier
12/29/1973	1	Salt Lake	Canyons Ski Resort	Skier
01/06/1976	1	Salt Lake	Alta Ski Area	Skier
03/03/1977	1	Salt Lake	Snowbird Ski Resort	Skier
01/19/1979	1	None	Helper	Natural
04/02/1979	1	Salt Lake	Lake Desolation	Skier
01/11/1980	1	Salt Lake	Evergreen Ridge	Skier
02/01/1981	1	Salt Lake	Doughnut Falls	Skier
03/01/1981	1	Salt Lake	Porter Fork	Skier
03/22/1982	1	Salt Lake	Murdock Peak	Skier
01/02/1984	1	Salt Lake	Little Superior	Skier
02/22/1985	1	Ogden	Powder Mountain	Skier
03/19/1985	1	Salt Lake	Park City Ski Resort	Skier
11/13/1985	2	Salt Lake	Sunset Peak	Skier
01/06/1986	1	Provo	Water Hollow	Skier
02/17/1986	1	Salt Lake	Brighton Hill	Snowboarder
02/19/1986	1	Salt Lake	Alta Ski Area	Natural
11/20/1986	1	Salt Lake	Alta Ski Area	Hiker
02/15/1987	1	Salt Lake	Figure 8 Hill	Skier
11/25/1989	1	Logan	Tony Grove Lake	Skier
02/12/1992	4	Moab	Gold Basin	Skier
04/01/1992	1	Salt Lake	Snowbird periphery	Skier
01/16/1993	1	Provo	Sundance	Skier
02/25/1993	1	Salt Lake	Pinecrest	Skier
04/03/1993	1	Salt Lake	Wolverine Cirque	Skier
02/18/1994	1	Salt Lake	10420	Skier
11/7/1994	1	Salt Lake	Snowbird Ski Resort	Skier
01/14/1995	2	Ogden	Ben Lomond	Snowmobiler
01/23/1995	1	None	Midway	Unknown
02/12/1995	1	Salt Lake	Gobblers Knob	Skier
02/02/1996	1	Salt Lake	Solitude	
03/27/1996	1	Salt Lake	Maybird Gulch	Skier
12/7/1996	1	Ogden	Bountiful Peak	Snowmobiler
12/26/1996	1	Salt Lake	Flagstaff Gully	Snowboarder
01/11/1997	3	Logan	Logan	Natural
01/25/1997	1	Provo	The Fang	Natural
01/17/1998	1	Uintas	Coalville	Snowmobiler

01/17/1998	1	Skyline	Pleasant Creek	Snowmobiler
02/26/1998	1	Ogden	Ogden	Hiker
11/7/1998	1	Salt Lake	Snowbird Ski Resort	Snowboarder
01/02/1999	2	Skyline	Big Drift/Skyline Summit	Snowboarder
01/29/1999	1	Provo	Mt Nebo	Snowmobiler
02/06/1999	1	Salt Lake	Little Willow Canyon	Hiker
01/11/2000	2	Salt Lake	Squaretop	Skier
12/14/2000	1	Ogden	Willard Peak	Snowmobiler
02/28/2001	1	Salt Lake	Red Cliffs	Skier
03/10/2001	2	Uintas	Uintas	Snowmobiler
04/28/2001	2	Salt Lake	Stairs Gulch	Natural
01/31/2002	1	Uintas	Windy Ridge	Skier
03/16/2002	2	Salt Lake	Pioneer Peak	Snowboarder
02/15/2003	1	Salt Lake	Gobblers Knob	Skier
12/26/2003	3	Provo	Aspen Grove	Natural
02/26/2004	1	Salt Lake	Daly Canyon	Snowshoer
12/10/2004	1	Salt Lake	Twin Lakes Pass	Skier
12/11/2004	2	Salt Lake	Mineral Fork	Unknown
12/11/2004	1	Uintas	Trout Creek	Snowmobiler
01/08/2005	1	Skyline	Ephraim Canyon	Snowboarder
01/08/2005	1	Skyline	Choke Cherry Ridge	Snowmobiler
01/14/2005	1	Salt Lake	Dutch Draw	Snowboarder
03/31/2005	1	Ogden	Whiskey Hill	Snowmobiler
12/31/2005	1	Provo	American Fork	Unknown
03/11/2006	1	Ogden	Taylor Canyon	Snowboarder
04/03/2006	1	Salt Lake	Pioneer Peak	Snowboarder
02/17/2007	1	Uintas	Buck Basin	Snowmobiler
02/17/2007	1	None	Signal Mountain	Snowmobiler
02/18/2007	1	Ogden	Hells Canyon	Skier
02/21/2007	1	Salt Lake	Gobblers Knob	Skier
12/23/2007	1	Salt Lake	Canyons Ski Resort	Skier
12/25/2007	1	Uintas	Super Bowl	Snowmobiler
12/31/2007	1	Uintas	Co-op Creek	Snowmobiler
12/14/2008	1	Salt Lake	Snowbird Ski Resort	Skier
12/24/2008	2	Logan	Logan Peak	Snowmobiler
12/30/2008	1	Uintas	Yamaha Hill	Snowmobiler
01/24/2010	1	Ogden	Hells Canyon	Skier
01/27/2010	1	Salt Lake	Meadows	Skier
01/29/2010	1	Salt Lake	Grandview Peak	Snowmobiler
04/04/2010	1	Ogden	Francis Peak	Snowmobiler
11/26/2010	1	Uintas	Cherry Hill	Snowmobiler
03/26/2011	1	Skyline	Horseshoe Mountain	Skier
11/13/2011	1	Salt Lake	Gad Valley	Snowboarder
01/28/2012	1	Salt Lake	Kessler Peak	Snowboarder
02/05/2012	1	Skyline	Lost Creek Reservoir	Snowmobiler
02/23/2012	1	Salt Lake	Dutch Draw	Snowboarder
03/03/2012	1	Moab	Beaver Basin	Snowmobiler

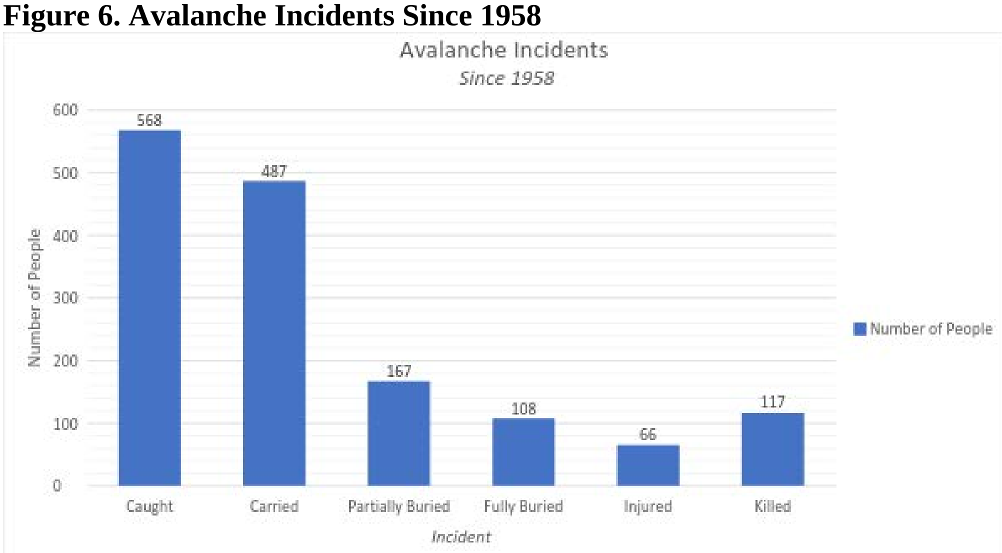
01/18/2013	2	Uintas	West Fork of Duchesne	Snowmobiler
03/01/2013	1	Skyline	White Mountain	Snowmobiler
04/11/2013	1	Salt Lake	Kessler Slabs	Skier
02/08/2014	1	Salt Lake	Tibble Fork	Snowshoer
02/09/2014	1	Skyline	Huntington Reservior	Snowmobiler
03/07/2014	1	Uintas	Gold Hill	Snowmobiler
03/04/2015	1	Ogden	Hells Canyon	Snowboarder
01/21/2016	1	Salt Lake	Gobblers Knob	Skier
01/31/2016	1	Salt Lake	Pointy Peak	Skier
Total	**116**			

Figure 5. Avalanche Fatalities by State 1958 - 2017



Source Colorado Avalanche Information Center

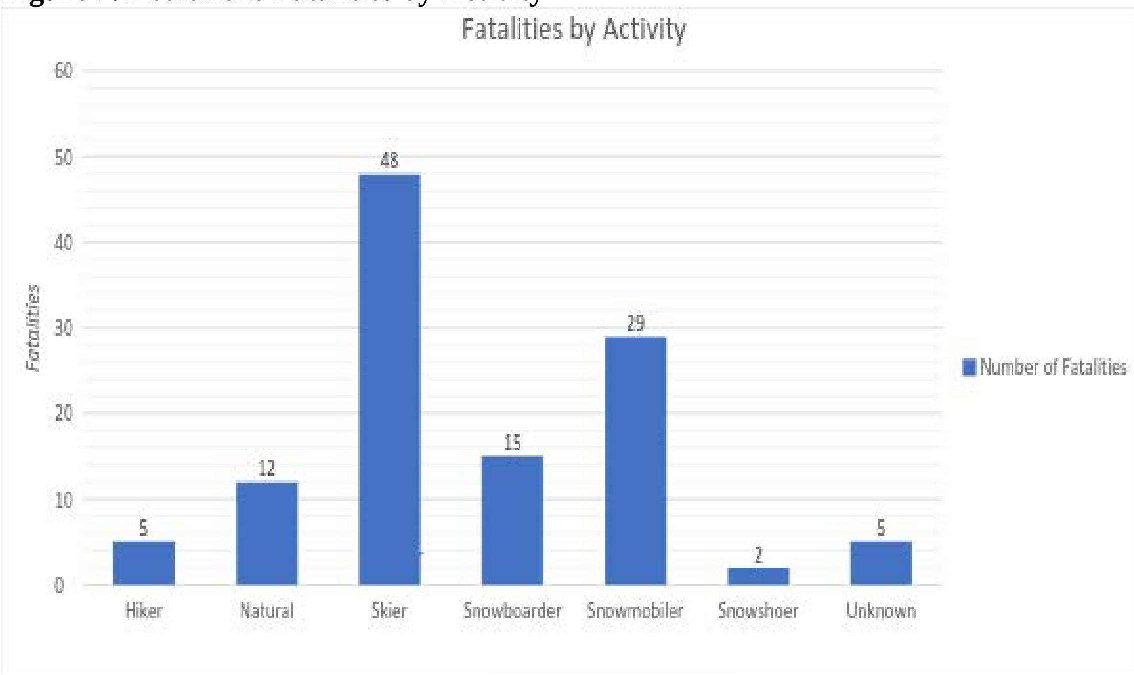
Figure 6. Avalanche Incidents Since 1958



Data Source Utah Avalanche Center

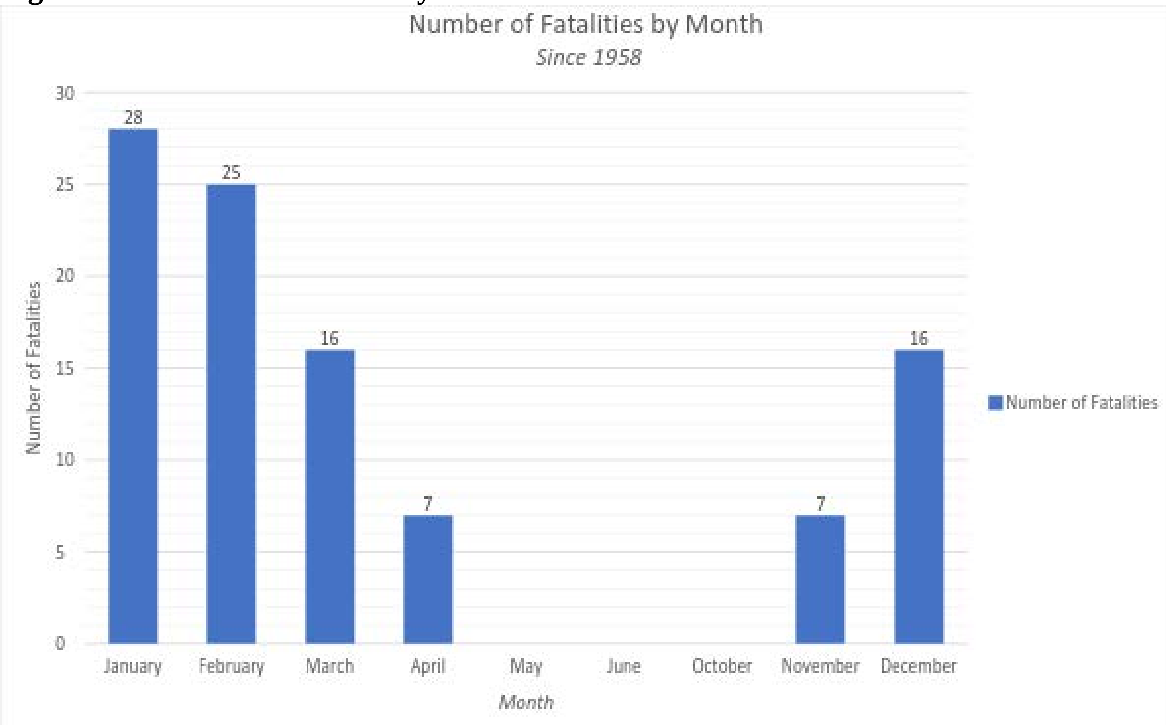
The majority of avalanche deaths involve outdoor recreationalists, primarily skiers, who are caught in and carried by an avalanche. According to the data, the two most dangerous months for avalanche fatalities in Utah are January and February.

Figure 7. Avalanche Fatalities by Activity



Data Source Utah Avalanche Center

Figure 8. Avalanche Fatalities by Month



Data Source Utah Avalanche Center

4.2 Assessment of Local Avalanche Vulnerability and Potential Losses

Several of the 116 avalanche deaths in Utah between 1958 and 2017 occurred at nine of Utah's 14 ski resorts, with fatalities reported at Alta, Brighton, Canyons, Park City, Powder Mountain, Solitude, Snowbasin, Snowbird, and Sundance. Eight regions in Utah Logan, Ogden, Salt Lake, Provo, the Uintas, Skyline, Moab, and the Abajos (Blue Mountains) have all experienced significant avalanches. Since 1998, it is estimated that Utah has had a total of $70,000 in property damage directly related to avalanches.

Most of the LHMPs do not address avalanche as a major hazard or just briefly mention it. Salt Lake County and Davis counties do address avalanche, with Salt Lake County providing the most information. The information below is taken from the current Salt Lake County Davis County LHMPs:

Avalanche risk in Salt Lake County is primarily found in the Wasatch Mountains, particularly in Big and Little Cottonwood Canyons. The Town of Alta is particularly at risk to the impacts of avalanches. State Highway 210 follows Little Cottonwood Creek for the length of Little Cottonwood Canyon and serves as the primary access route to the town. Culvert blockages, bank erosion, landslides, and avalanches all have the potential to close down the town's only arterial connection with the rest of the county.

Highway 210 also has the highest avalanche hazard---rating index of any major roadway in the country. At times when UDOT and Alta agree that conditions are unsafe, the town goes into an Interlodge Alert, meaning all occupants of the town (including both visitors and residents) must remain indoors until conditions are deemed safe. During large storm cycles, an Interlodge can last days until the storm cycle is over and proper avalanche control work has been performed.

The Town's General Plan (dated November 2005, Updated 2013) covers Highway 210 access and possible mitigation activities to keep this critical road open (Figure 50). It also provides background on the Little Cottonwood Canyon Road Committee, a group consisting of representatives from Alta, Snowbird, Salt Lake County (including the Unified Fire Authority), UDOT, UTA, and USFS, that meet monthly to discuss access, usage, and safety and security issues related to the canyon road. No Evacuation Plan exists at this time, however it is something that the Town would like to accomplish.

There currently is no standard for quantifying avalanche magnitude. Our county uses the following measurements to quantify avalanche magnitude:

- Number of injuries and/or fatalities
- Depth of snow on the road
- Time to remove snow so that the roads are passable
- Number of days it takes for people to be able to return from the mountain resort

In 1983, a large avalanche completely covered Highway 210, buried a number of automobiles and wiped out the first floor of the Peruvian Lodge (Figures 51 and 52). A Salt Lake City motorist was seriously injured in a 1998 avalanche in Little Cottonwood Canyon.

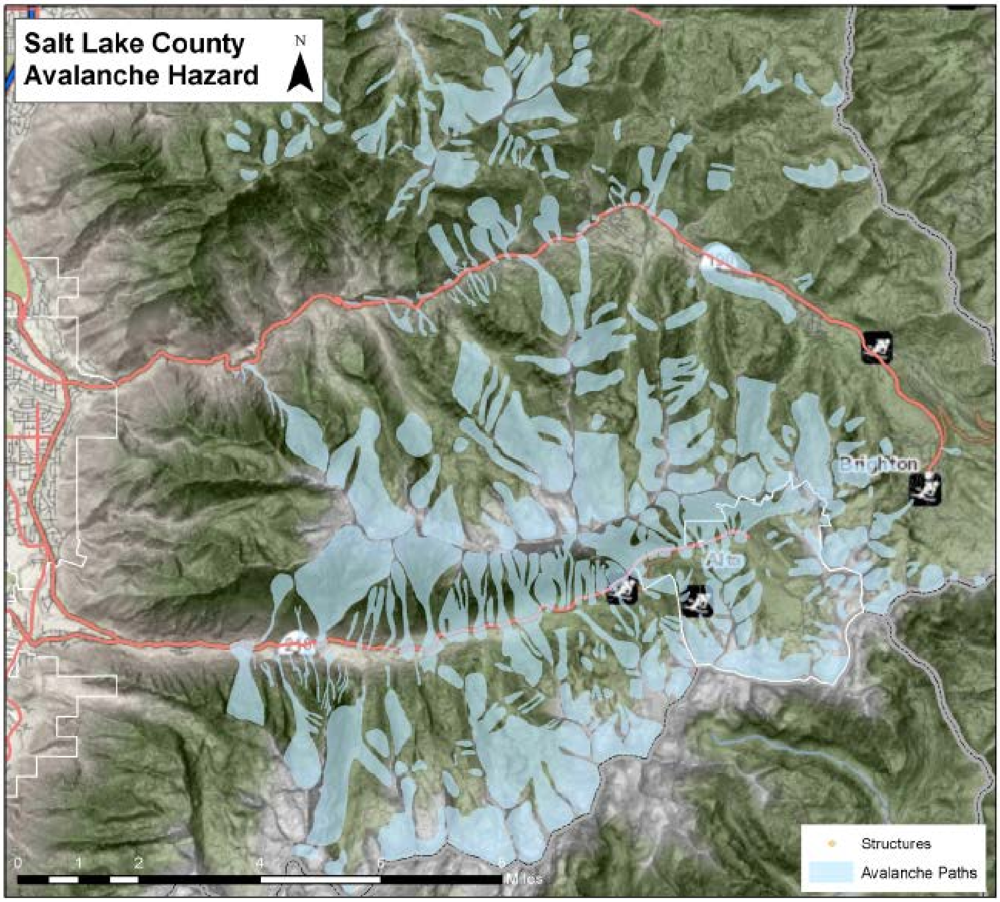
In general, Alta does not have any ordinances or land use regulations specifically for avalanche hazards. They are beginning to implement avalanche analysis into their construction design and the new Town Hall building was constructed to withstand a 1%---annual---chance avalanche hazard. The update to Alta Ski Lifts Master Plan does cover potential considerations for avalanche mitigation. This represents an important first step for the town and ski area as their current methods (firing artillery shells) are becoming outdated.

Additionally, these methods may no longer be available to them in the near future—and they are currently 100% dependent on the current method in order to function as a town and from an economic standpoint. The town has received communication from the U.S. Department of Defense informing them that they need to consider alternative methods for control work, as artillery will soon be unavailable.

Vulnerability Assessment:
95 Structures within Avalanche Paths
56 Commercial – $54,647,250

1 Government – $183,696
38 Residential – $2,869,264

Although the Town of Alta only has a population of 383 (per the town's website), it has a significant, fluctuating tourist population, which would be greatly impacted if Highway 210 is blocked by an avalanche.



Source: Salt Lake County Multi-Jurisdictional Multi-Hazard Mitigation Plan 2015

SL County 2015 Plan
Alta Strategies

- Establishment of lift---served skiing on open slopes on the north side of Little Cottonwood Canyon in the Town of Alta.
- Installation of Gaz---ex remote detonation devices, 9 of which are currently in place on Mt. Superior above the Snowbird Village, outside of the Town of Alta boundaries. Gaz---ex devices cost roughly $200,000 each for materials and installation, and a large number of individual devices would be required to provide the same level of hazard mitigation currently provided by artillery.
- Installation of snow fences in avalanche path starting zones above the Town of Alta. Many of the paths that affect the Town of Alta originate uphill and outside of the Town of Alta boundaries.

Davis County 2016 LHMP 2009 goals

Action 2: Encourage avalanche preparedness for county backcountry users.

Status: Ongoing: Davis County participates in the Avalanche Warning System Forecast Center in Salt Lake City. The county has a public service broadcast station, AM 700, that is utilized to continually broadcast NWS forecast information for severe weather.

Action 3: Install avalanche warning signs in Farmington Canyon.

Status: Completed: Davis County has installed avalanche information warning signs at the entrances to Farmington, Bountiful, and North Canyons. Unfortunately, these signs are periodically vandalized, requiring repair and/or replacement.

Davis County 2016 LHMP Actions

Action 2: Encourage avalanche preparedness for county backcountry users.

Time Frame: 1-6 years

Funding: County

Estimated Cost: Minimal

Staff: County Emergency Management

Jurisdictions: County wide

4.3 Assessment of State Avalanche Vulnerability and Potential Losses

An analysis was performed by overlaying GIS point data of state-owned facilities with avalanche risk areas. The results showed a total of 442 state-owned facilities being within avalanche risk areas for a total replacement cost of $1,512,371,298. For a complete list of all the state-owned facilities in avalanche risk areas see the appendix.

Table 3. State-owned Facilities in Avalanche Areas

Avalanche Area	State-owned Facilities	Replacement Value
Logan	48	$26,922,852
Ogden	54	$63,815,287
Salt Lake	278	$1,410,557,709
Provo	32	$4,033,639
Uintas	10	$2,750,268
Skyline	8	$2,019,961
Southwest	11	$1,885,909
Abajos	1	$385,673
Total	**442**	**$1,512,371,298**

An analysis of critical infrastructure within avalanche areas throughout the state shows that there are 109 critical structures and 10,984 miles of critical lines within avalanche areas. For a complete list of the critical infrastructure in avalanche areas see the appendix.

Table 4. Critical Infrastructure in Avalanche Areas

Critical Infrastructure within Avalanche Areas	
	#
Airports	1
Electric Substations	30
Powerplants	2
Healthcare Facilities	15
Schools	37
Police Stations	5
Fire Stations	19
	Miles
Railroads	62
Local Roads	10005
Highways and Interstates	570
NPMS Pipelines	0.005065
Transmission Lines	347

Climate Change Impacts

Climate change will cause complex changes to avalanche risk in Utah. Avalanche risk on any given day during winter is related snowpack, daily weather and the accumulation of weather conditions throughout the winter season. There are no clear-cut projections of future avalanche risk. However, two aspects of climate change will specifically affect avalanche risk. One, warmer temperatures will cause less snow to fall at lower elevations and an increase in rain-on-snow events. Two, changes in weather patterns will change avalanche risk.

Warmer temperatures will cause both increases and decreases to avalanche risk. Warmer temperatures will cause a reduction in low- to mid-elevation snowpacks and more rain at low elevations during some years. Less low elevation snow and more rain will reduce avalanche risk because many low elevation avalanche paths will not be snow-covered during warmer years. However, when rain falls on snow, avalanche risk increases rapidly; the most destructive avalanches often occur due to rain, wet snow and warm temperatures. Climate change will increase the incidence of extreme precipitation events and change weather patterns. Extreme, or heavy snowfall events will increase the risk of avalanches. It is unknown precisely how climate change will impact winter weather patterns in Utah; changes in winter weather patterns will certainly change avalanche risk. A final impact of changes in weather patterns comes from an increase in the risk for drought. The Intermountain West is prone to both severe winter storms and long periods of winter drought. It is likely that winter drought will increase in Utah. An increase in winter drought will also increase the risk of avalanche. During periods of drought in winter, a snowpack undergoes changes to the snow surface and within the snowpack that typically increase avalanche danger after the next snowfall.

4.4 Mitigation Efforts for Avalanche Hazards

Avalanche mitigation strategies can be divided into two categories: structural and non-structural mitigation measures. Structural methods include changing the landscape by diversion structures, dams, retarding structures and starting zone structures designed to prevent avalanche initiation. Non-structural methods include avoidance through temporary evacuation or land use restrictions and artificial avalanche triggering. Both of these methods involve avalanche forecasting. UDOT and every ski resort in the state has an avalanche forecasting program. UAFC provides avalanche advice to help mitigate risk including weather, snow stability and avalanche danger ratings for areas across the state that are popular with backcountry recreationalists.

Ordinances and Regulations

In 2002 the State of Utah created an ordinance with avalanche hazard zoning for Salt Lake County ski areas and Big Cottonwood Canyon, Little Cottonwood Canyon, and Provo Canyon.[9] The zoning ordinance was based on similar regulations established in other ski area towns in the western United States and created a red zone where development was prohibited because avalanches were too frequent or too large to mitigate. A blue zone allowed residential development with engineered mitigation strategies.[10]

The Town of Alta adopted a regulation requiring that an avalanche expert certify that any proposed structure will withstand the impact of an avalanche.[11]

Structural

Structural mitigation is warranted in areas where people and property may be exposed to a higher risk of avalanche occurrence over longer periods of time. There are three types of structural mitigation, direct protection by deflecting or channelizing avalanches, arresting and

[9] *Scroggin, David, and L. Batatian. Avalanche Hazard Investigations, Zoning, and Ordinances, Utah, Part 2 . Report. 2008. Accessed October 30, 2017. http://www.issw2008.com/papers/P_*

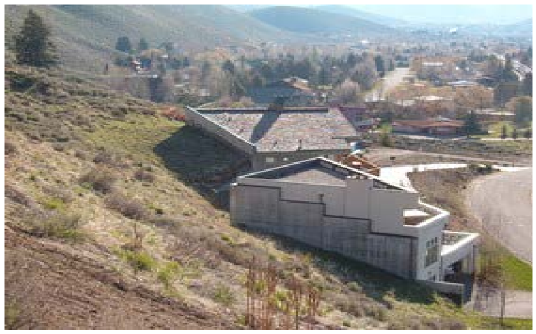
[10] Arthur I. Mears, P.E., Inc & Wilbur Engineering, Inc. "Topics." Advances in avalanche science and engineering since CGS Bulletin 49. Accessed October 25, 2017. http://mearsandwilbur.com/more_topics.html#climate_change.

[11] Eldredge, Sandra N. *Utah natural hazards handbook: a cooperative project*. Salt Lake City, Utah The Division, 1992

storing snow and preventing or reducing the released slab size. Mitigating avalanche damage requires a knowledge of the snowpack depth and density, ground contours and the stress on the snowpack at the avalanche start zone.[12]

Direct Protection

Direct protection structures are incorporated into the design of the building and safeguard an isolated structure to allow it to withstand the impact pressure of an avalanche. These structures are most effective on slopes of 12 to 20 degrees, steeper slopes generate high velocity avalanches which can overwhelm the structure.



Residential structure, Ketchum Idaho
Source Chris Wilbur

Future Avalanche Hazard Mitigation Efforts

The Utah Department of Water Resources (DWR) monitors snowfall amounts and water content but does not actively monitor avalanche probability or occurrences. The Utah Avalanche Center is a 501(c) (3) non-profit organization with offices in Logan, Salt Lake City and Moab that provides information about avalanche danger to backcountry travelers so they can mitigate their risks while recreating in Utah. The organization is a partnership between the U.S. Forest Service and the private sector and relies heavily on private contributions and volunteer support.

Deflection and channelizing

Deflecting structures are built with the intent of changing the flow of a slide to limit and redirect the avalanche's natural runout zone. An example of deflection is a splitting wedge which is a reinforced concrete or steel wedge designed to divert avalanches around either side of a structure. Channelizing is most effective on 12 to 20 degree slopes and is commonly used when multiple structures need to be protected.

[12] Mears, I. Anchorage snow avalanche zoning analysis. Anchorage, AK: Municipality of Anchorage, 1982.

Deflection Dam, Park City, Utah
Source Chris Wilbur

Masonry Deflection Wedge, Val d'Aran, Spain
Source Chris Wilbur

Starting Zone Measures

Permanent structures are built on the mountain to provide support to the snow cover and limit the size of slides by stopping small avalanches before they gain momentum and impeding fracture propagation in the snow. Snowpack support structures are typically more expensive and are only justified in already inhabited areas with limited precautionary evacuation measures. These engineered rigid supporting structures or nets are arranged to retain snow and prevent large avalanches. Snow collection fences are walls or panels arranged to induce irregular wind patterns that forces snow to accumulate in certain places, breaking the continuity of slabs. This mitigation effort is only useful in areas where wind is a major contributing factor in avalanche formation.

Non-Structural Artillery or Active Control

UDOT uses artillery or active control to test snowpack stability and trigger small avalanches with explosives as a cost-effective mitigation tactic to protect roads, railroads, and ski areas. In Utah helicopter, avaluancher, hand thrown explosives and gaz-ex avalanche control methods are utilized.

Helicopter Avalanche Control

Helicopter avalanche control is useful in areas difficult to access when time constraints are a factor but there are limitations, helicopters can only fly under ideal weather conditions and officials must close roads around detonation zones. Most helicopter avalanche control work in Utah is utilized up Big and Little Cottonwood Canyons.

Dry slab avalanche with a significant powder component triggered using helicopter explosives
D. Wilson Photo[13]

Avalauncher Avalanche Control

The Avalauncher is mounted on a trailer and towed to open target areas where range and accuracy are limited. UDOT uses the avalauncher in Big Cottonwood Canyon.

Hand Thrown Explosives

In Utah, hand thrown explosives are used during helicopter avalanche control and in certain locations in close proximity to the roads up Little and Big Cottonwood Canyons.

Gaz-ex Avalanche Control

The gaz-ex system uses a mixture of oxygen and propane in a large steel pipe to create an explosion above the surface of the snow. Detonation is controlled using radio telemetry and a laptop computer. Although operational and maintenance problems arise periodically, the gaz-ex system is an effective tool in Utah’s highway avalanche safety mitigation efforts. It is primarily used at Alta Bypass Road and above Snowbird Village.

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[13] Canadian Avalanche Association. (2016). Technical Aspects of Snow Avalanche Risk Management─Resources and Guidelines for Avalanche Practitioners in Canada (C. Campbell, S. Conger, B. Gould, P. Haegeli, B. Jamieson, & G. Statham Eds.). Revelstoke, BC, Canada: Canadian Avalanche Association.

UAFC works to mitigate avalanche risk by providing information available to the public on weather conditions, snow stability and avalanche danger ratings for areas across the state that are popular with backcountry recreationalists. UAFC experts provide low or no cost avalanche education similar to the avalanche education offered by the Forecast Service Utah Avalanche Center (UAC) to increase the avalanche skill base among the various users groups. Ski resorts in Utah also offer avalanche training, conduct training specific to snowmobilers, snowshoe and back country skiing communities, and increase the avalanche knowledge of city and county emergency managers.

The UAFC is also continually working to enhance their avalanche knowledge and warning capabilities by utilizing new technology and supporting and funding the UAC's infrastructure of warning systems. Avalanche warnings are posted on the UAC's website and to an audio hotline each morning.

UAFC is continually working to ensure that all people have basic information relating to avalanche mitigation and response by disseminating print, broadcast and social media brochures, public service announcements, etc. Awareness weeks could be utilized in the future to provide preparedness and response information on avalanches.