SNOW AVALANCHE HAZARD ANALYSIS AND MAPPING

for

THE VILLAGE OF TAOS SKI VALLEY TAOS COUNTY, NEW MEXICO, USA

Prepared for:

Village of Taos Ski Valley
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Taos Ski Valley, NM 87525

Prepared by:

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Reviewed by:
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August 14, 2023

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August 14, 2023

Patrick Nicholson
Planning Director
Village of Taos Ski Valley
PO Box 100
Taos Ski Valley, NM 87525
Via email

RE: Avalanche Hazard Mapping and Recommendations
The Village of Taos Ski Valley, New Mexico

Dear Mr. Nicholson:

We are pleased to present this Avalanche Hazard Report and Maps. The mapping builds on previous work and incorporates new data, methods and research to improve the quality of maps compared to the village's existing Avalanche Hazard Maps prepared by Arthur I. Mears, P.E., Inc. in 2001. We have considered comments on our preliminary report and maps from the public, local avalanche professionals and staff at Taos Ski Valley, Inc. (TSVI). Specific changes made to our April 14, 2023 Draft Maps include:

- We have considered fire mitigation forest thinning on permitted USFS lands based on information provided by TSVI. This resulted in changes to mapping of the "Minnesotas" avalanche paths (Path #26).
- We have added street names to the maps.
- We have distinguished between avalanches that originate in-bounds and may be controlled by TSVI using various methods of snow compaction and intentional artificial triggering of avalanches from avalanches originating out-of-bounds.

We have enjoyed working with you and other community members on this important project. If you have any questions, please contact us.

Sincerely,
Wilbur Engineering, Inc.

Chris Wilbur, P.E.
New Mexico license #14901

Arthur I. Mears, P.E., Inc.

Art Mears, P.E. (Colorado)

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1. Background

This report describes an updated avalanche hazard mapping study for the Village of Taos Ski Valley. An avalanche hazard map was prepared in February 2001 (Ref. 1). Since that time, additional data on climate and avalanches have become available, methods have advanced, and new terrain and aerial imagery have become available. Figure 1 shows a site location map.

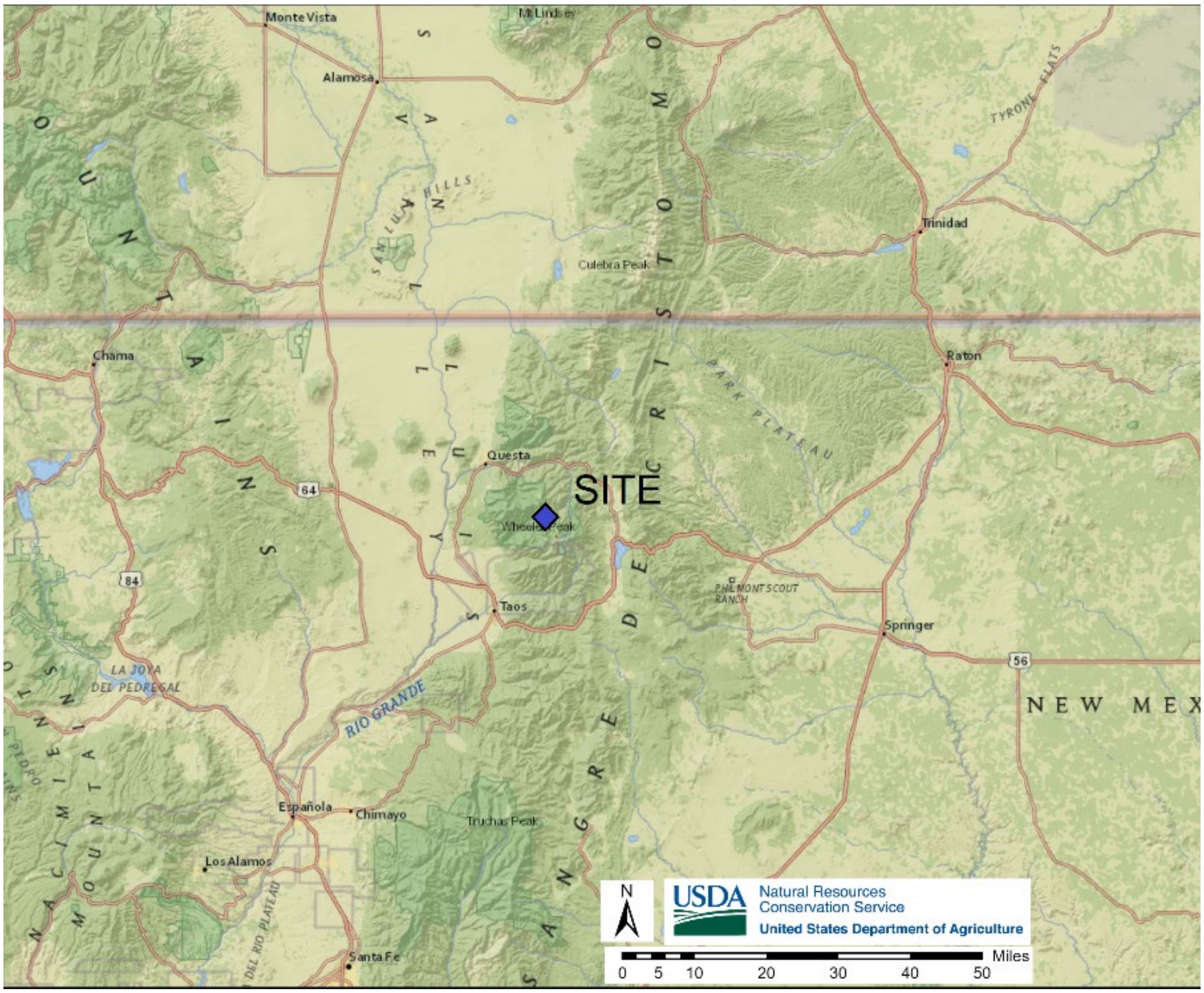

Figure 1 – Site Location

2. Objectives

This report has the following **objectives**:

1. Describe the regional snow and avalanche climate.
2. Determine the runout limits of snow avalanches with average return periods of 100-years and 300-years or annual exceedance probabilities of 1.0 percent and 0.3-percent;
3. Describe methods used to develop the Avalanche Hazard Map.
4. Delineate Avalanche Zones as defined in this report.
    a. High Hazard (Red) – frequent or high energy[1] avalanches zones.
    b. Moderate Hazard (Blue) – low frequency and low-medium energy[2].
    c. Low Hazard (Yellow) – areas subject to low probability/low energy dense flowing avalanches or medium-frequency/low energy powder avalanche impacts[3].
5. Describe avalanche risks in relation to the land use, along with uncertainties, and recommendations for mitigating avalanches hazards within and near the defined hazard zones.
6. Provide information and guidance on the existing avalanche ordinance and potential future revisions.

3. Limitations

This report also has the following **limitations**, which must be understood by all those relying on the results, conclusions, and recommendations:

1. The Avalanche Hazard Maps are intended to guide land use planning and community awareness of potential avalanche hazard areas. They are not intended for assessing individual sites.
2. Avalanches larger than the mapped avalanche runouts are possible, even though the probabilities are low.
3. The avalanche hazard assessment is based on current forest and climatic conditions. Changes in forest cover and/or climatic conditions could increase or decrease the avalanche hazard.

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[1] The *Red Zone* is an area where avalanches have a return period of 30 years or less or produce impact pressures of 600 lbs/ft^2 or greater on a flat surface normal to flow.
[2] The *Blue Zone* is defined as an area where avalanches have a return period ranging from 30 to 100 years (3% to 1.0% annual probability) and where avalanches produce impact pressures of less than 600 lbs/ft^2 on a flat surface normal to flow.
[3] The *Yellow Zone* is defined as an area where avalanches have estimated average return periods between 100 and 300-years and powder pressures are less than 60 psf.

4. This study is site and time specific. It should not be applied to lands outside of the current village limits nor should it be relied upon without updating in the future when additional data and improved methods become available.
5. The effects of ongoing and future fire mitigation efforts on avalanche hazards are difficult to quantify and will depend on the specific mitigation measures and site conditions and are not considered in this study.
6. Site specific avalanche mitigation of structures including buildings, roads, and parking areas are beyond the scope of this study.
7. This report does not address avalanche risks to persons traveling, working in or recreating in avalanche terrain. It is intended for land-use planning purposes only.

4. Methods

The avalanche hazard mapping and recommendations presented in this report are based on:

1. Site observations made by Chris Wilbur, P.E. on September 15 and 16, 2022 and January 13, March 19, and April 11, 2023.
2. Interviews and email correspondence with knowledgeable persons, including Rachel Moscarella, Kevin Beardsley, Alex Mithoefer (TSVI Snow Safety) and Andy Bond (Taos Avalanche Center).
3. Analysis of aerial photos of various dates and sources (Village of Taos Ski Valley GIS, Taos Ski Valley, Inc., USGS, NAIP, Google Earth, Bing);
4. Review of historic weather data, including the Poco Gusto site from Taos Ski Valley, Inc., NRCS Powderhorn SNOTEL, and Taos Municipal Airport.
5. Terrain analysis using 2015 LiDAR data from the USGS National Map.
6. Application of statistical avalanche runout models.
7. Avalanche dynamic modeling with the Swiss program, RAMMS, Version 1.80 utilizing a digital elevation model (DEM) developed from the LiDAR data.
8. Avalanche dynamic modeling of the suspension component with the Swiss program, RAMMS:Extended, version 2.7.90.
9. A review of published documents on the effects of forests on avalanche processes.
10. Our local and regional knowledge of terrain, climate and avalanche hazards.

5. Snow Climate

The Taos Ski Valley and Sangre de Cristo mountains are characterized by a continental snow climate typical of high elevations in northern New Mexico. Average annual precipitation at the Village of Taos Ski Valley is 20.5 inches and average snowfall is about 146 inches. Average January low and high temperatures are 4°F and 21°F, respectively. Precipitation generally increases and temperatures decrease at higher elevations. This relatively dry, sunny snow climate commonly has a shallow weak early-season snowpack that can persist throughout the winter and spring. The weak lower snowpack can become overloaded by snow slabs that form during large storms and wind events, resulting in instability and widespread natural and triggered avalanche activity. Wet avalanches are common during springtime warm weather, including after the ski area is closed. Weather and climate data are presented in Appendix A.

6. Avalanche Terrain

Figure 2 shows a slope-angle map derived from the USGS 2015 LiDAR data. Figure 3 shows an aspect map. The orange and red colors on the slope map indicate potential avalanche starting zones. Most avalanche starting zones[4] have slope angles of between 30 and 45 degrees. Northerly aspects that will accumulate a deeper and colder snowpack than other aspects. Southerly aspects will hold less snow causing surface roughness to reduce the probability and size of avalanches. However, prolonged storms can result in large avalanches on south-facing terrain. Prevailing winds will transport snow onto NE through SE aspects. Less common easterly winds can load starting zones above timberline on the east side of the Lake Fork.

Avalanche tracks[5] at the site range from gullies to sub-planar slopes. Some of the lower tracks turn abruptly at the main valley. The avalanche runout zones[6] include relatively steep channels, valley bottoms and debris fans. Many of the runout zones at the site are relatively steep (>10-degrees) because the size of avalanche releases is inhibited by forested starting zones. Exceptions occur above timberline and in disturbed areas such as the Mineslide path.

Figure 4 shows evidence of an undocumented large avalanche at the Northside that destroyed forests at the site in the early 1960s. This avalanche might have occurred during a major avalanche cycle in the southern Rocky Mountains that occurred in late January 1962. An avalanche cycle in the mid-1990s also extended into forested terrain at the southern end of the map area.

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[4] The *Starting Zone* of an avalanche is the area where snow releases, accelerates and increases in mass.
[5] The *Track* of an avalanche is the area where maximum velocity and mass are attained.
[6] The *Runout Zone* is the area where avalanches decelerate, deposit and come to a stop.

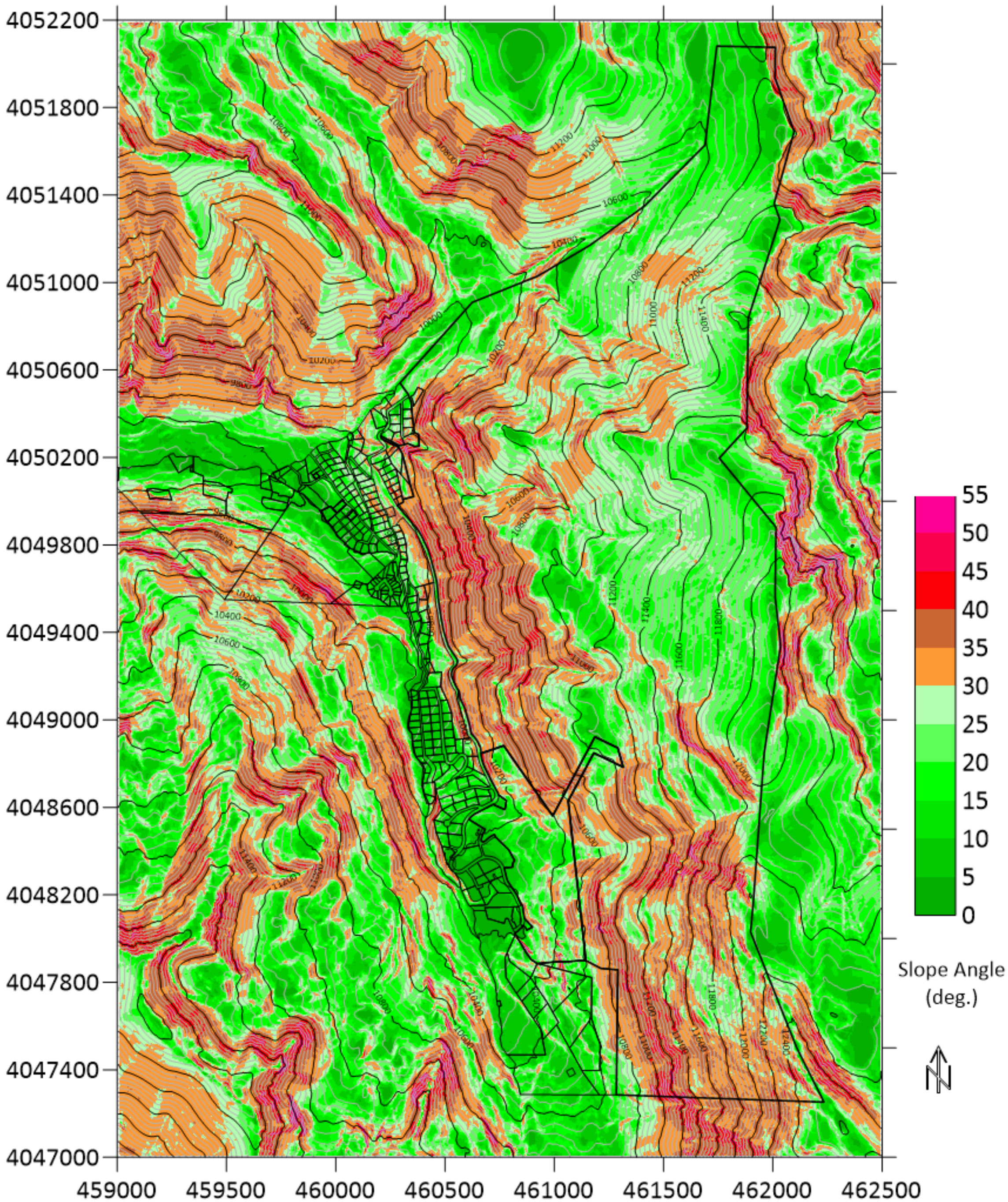

Figure 2 – Slope Map

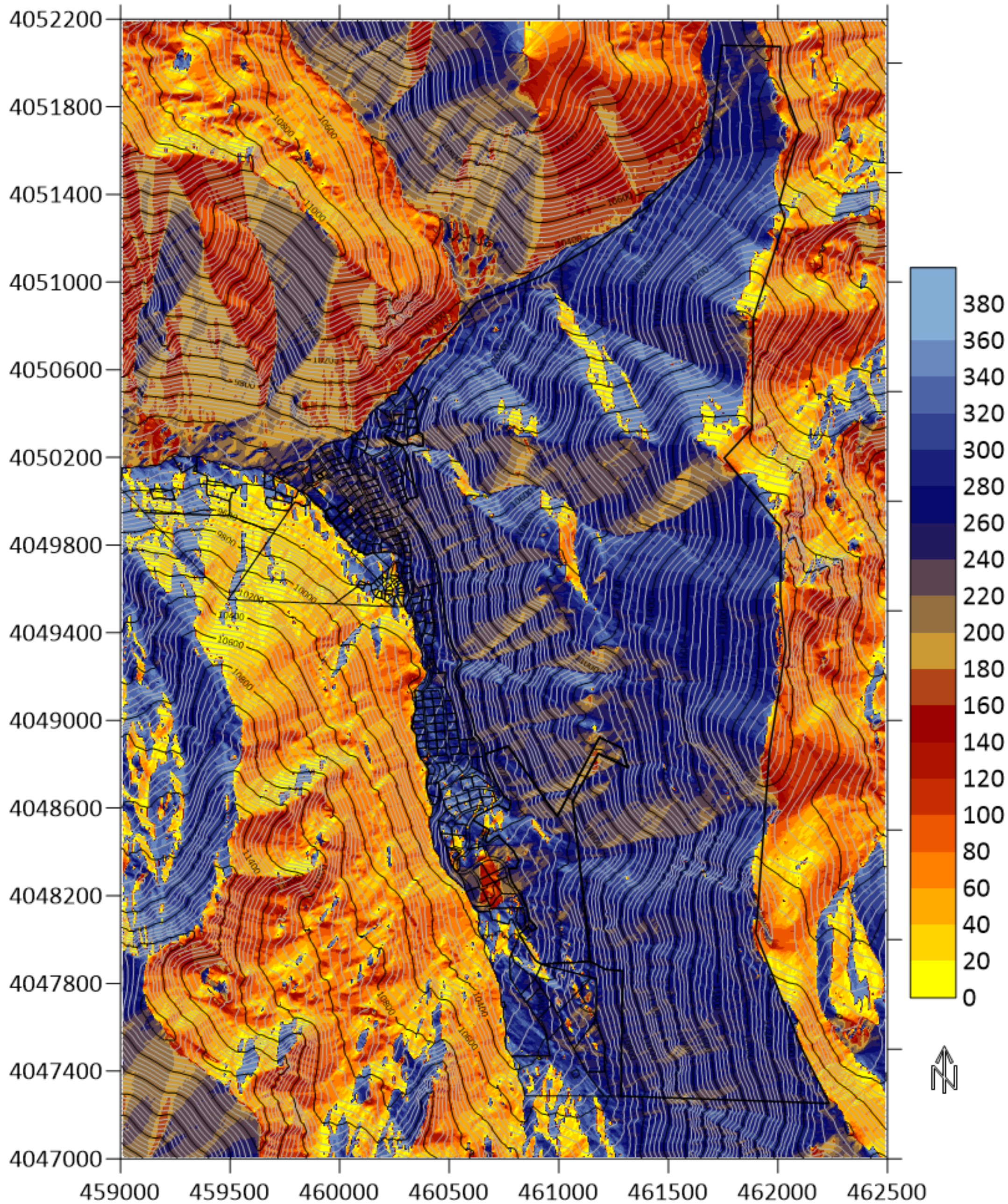

Figure 3 – Aspect Map

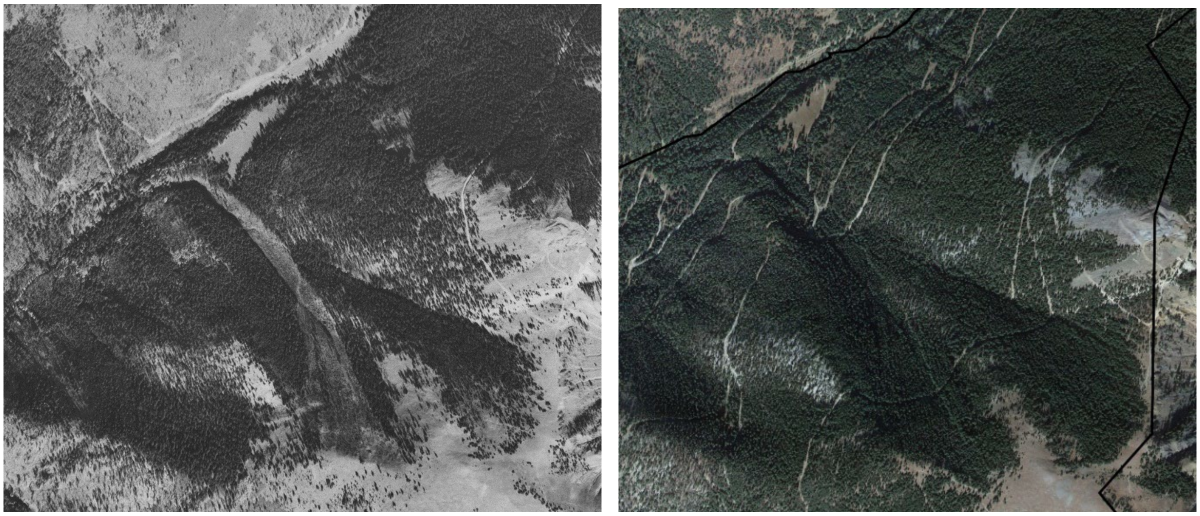

Figure 4 – 1962 Arial Image of Trim Line near Jean's Meadow
(Sources: USGS 9-8-1962 Flight, Google Earth, 5-16-2021)

7. Statistical Avalanche Runout Models

We applied statistical avalanche runout models from eight avalanche climates to estimate potential ranges of extreme (100 to 300-year average return periods) avalanche runout distances for selected paths (Ref. 2). These models use a centerline profile of the avalanche path and incorporate the "beta-point" which is the location where the slope angle decreases to 10-degrees. No regional or site-specific models exist for the Taos Ski Valley area, so the statistical models are intended only as a supplemental method to bracket likely ranges of extreme runouts. Figure 5 shows centerline profiles with mapped and modeled runouts of selected avalanche paths.

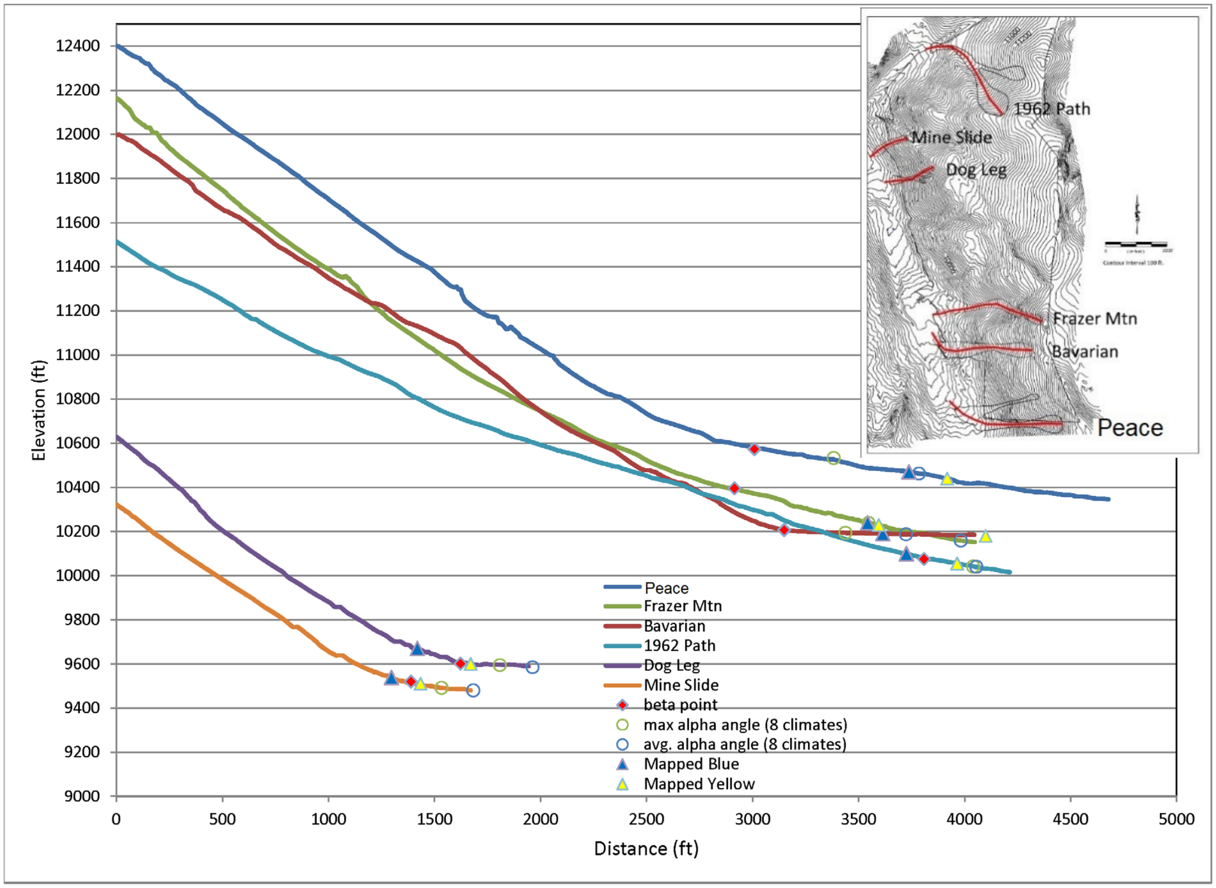

Figure 5 – Avalanche Profiles and Locations

8. Forest Conditions

The role of forests in preventing snow avalanches in steep terrain has long been recognized in Europe where destructive avalanches resulted from tree removal for buildings and firewood. More recently, fires and logging operations in the U.S. and Canada have led to a better understanding of the role of forests in avalanche prevention and mitigation. The following factors have been found to reduce avalanche release frequencies, sizes and runout distances:

1. Tree canopy coverage, especially conifers, influences snow accumulation depth and variability; Tree canopy disrupts snowpack structure and reduces crusts and continuous weak layers; Tree canopy changes snowpack energy balance caused by incoming and outgoing radiation resulting in a generally stronger snowpack;

2. Tree trunks anchor the snowpack in *starting zones* by mechanical resistance to creep, glide and slab failure. This effect is dependent on relatively high density of medium-large trees per acre.
3. Forests in the *track* and *runout zones* have a relatively small effect on runout distance compared to the above factors. The effects of friction and energy dissipation due to forest impacts in avalanche tracks and runout zones generally decrease with increasing avalanche mass.

The combination of factors listed above cause healthy conifer forests to be more effective than deciduous or mixed forests, or snags at preventing avalanche release. A decrease in forest density and canopy coverage can result from several causes, including insect mortality, forest fire, logging and thinning, and blowdown.

The forest fire history of the upper Rio Hondo watershed is described in Ref. 3, including a map of a high-severity fire that impacted much of the site in 1842 during a severe drought. The 1842 fire burned bristlecone pines near timberline. The report includes several historic (~1903) photos indicating severe burn areas at the Northside and the east side of the Lake Fork. Figure 6 shows a historic photo of Twining and the Mineslide path.

Figure 6 – Historic Photo of Mineslide and Northside Area
(Source: USFS interpretive sign, © private photo)

Fire mitigation including thinning and mastication, on private lands and public lands within the ski resort's permit area have been ongoing since 2018. Figure 7 shows fuel Treatment priorities areas, including Amizette, Bull of the Woods, Wild West, Minnesotas, and Phoenix Springs in Kachina Basin. Figure 8 shows fire mitigation forest thinning areas in the Kachina basin.

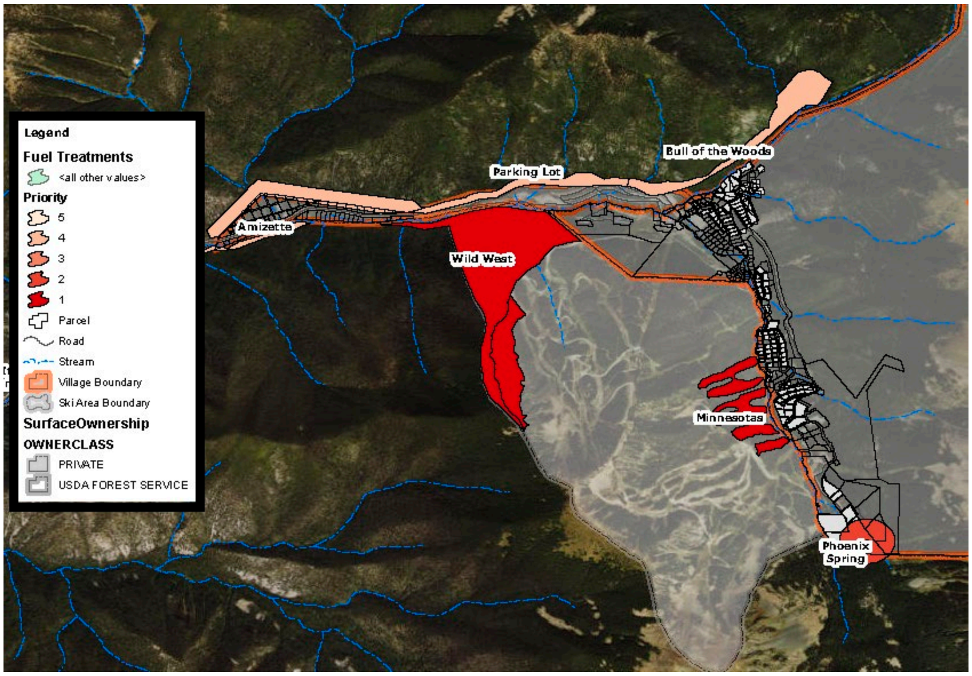

Figure 7 – Rio Grande Water Fund - Fuel Treatment 2018
(excerpt; provided by TSVI)

A major forest blowdown event occurred in mid-December 2021, destroying and damaging numerous buildings in Taos county, resulting a county-wide state of emergency declaration. Thousands of trees were blown down above Twining Road near the Bavarian Restaurant, the Phoenix, Lift 4 and on both sides of the valley up the William's Lake trail. Figure 9 shows a map of the blowdown area near the site. Figure 10 shows a photo of the blowdown area taken in August 2022.

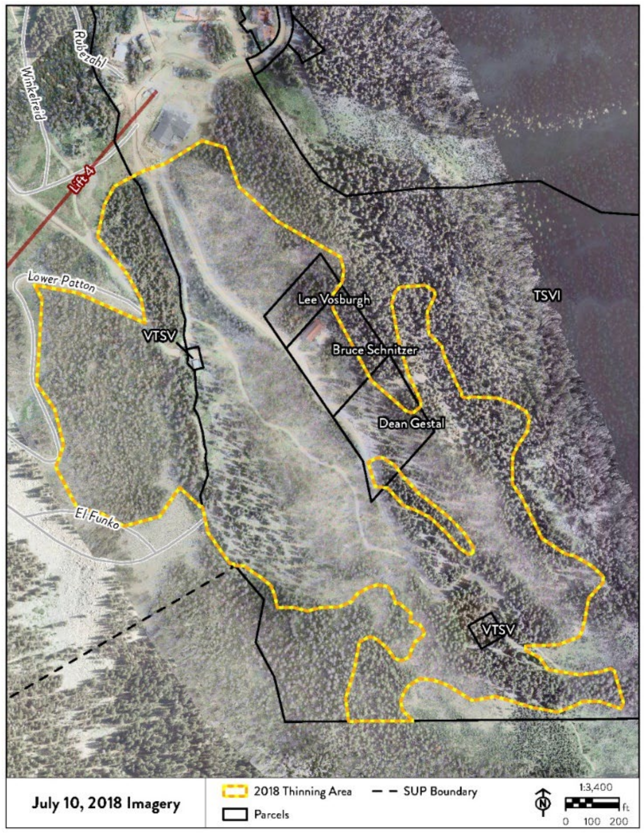

Figure 8 – Kachina Basin Fire Mitigation Area
(Image provided by TSVI)

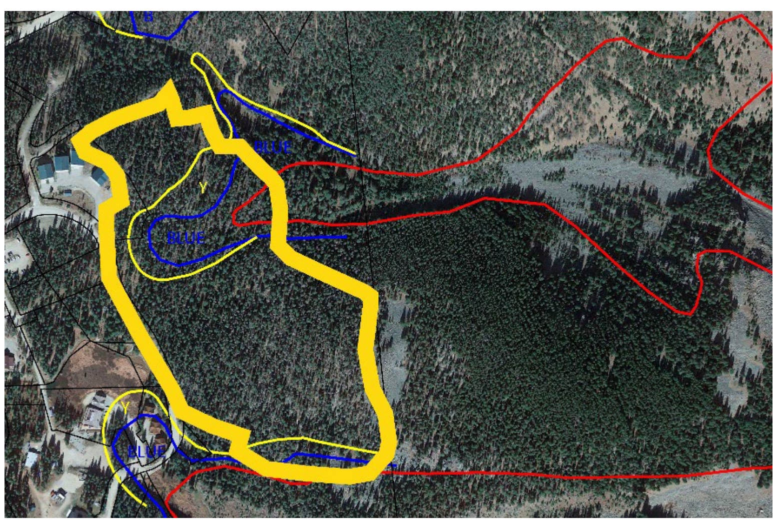

Figure 9 – Map of December 2021 Severe Blowdown Area
(Source: DEI Report, Ref. 4)

A Forest Management Plan for the Northside at Taos Ski Valley was prepared in 2020 by Dolecek Enterprises Inc. (DEI), Forest Management Specialists (Ref. 4). The plan describes declining forest heath over the last 30 years at the Northside at Taos Ski Valley and throughout the Southwest. The Northside at Taos Ski Valley is classified as a very high fire risk, with potential for severe fire intensity on the New Mexico Fire Risk Portal. The DEI Report includes a prescription for the 1962 avalanche path starting zone based on the high basal area (238) and its location above the Bull of the Woods spring.

Figure 10 – Photo of December 2021 Blowdown Area
(Chris Wilbur Photo, August 2022)

We observed areas of thinning during our field observations, including lop and pile in potential avalanche starting zones. Figure 11 shows a forest canopy height from the Frontside derived from 2015 LiDAR data. Figure 12 shows a canopy height map from the Northside. These figures are based on pre-fire mitigation conditions. Additional forest and vegetation photos and their locations are shown in Appendix B.

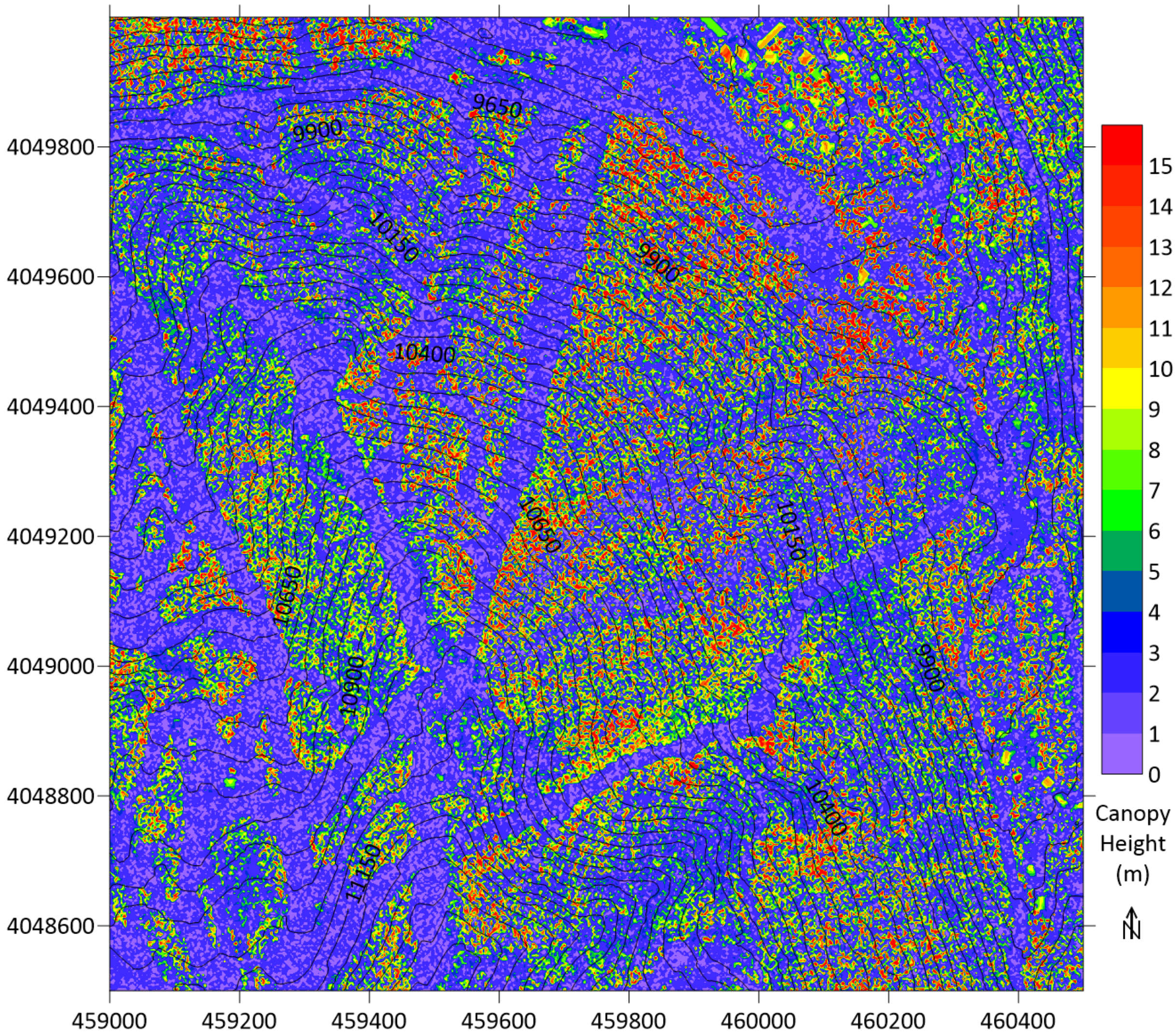

Figure 11 – Frontside Canopy Height
(derived from 2015 LiDAR data, WGS 84, UTM Zone 13N, 0.5m res. grid)

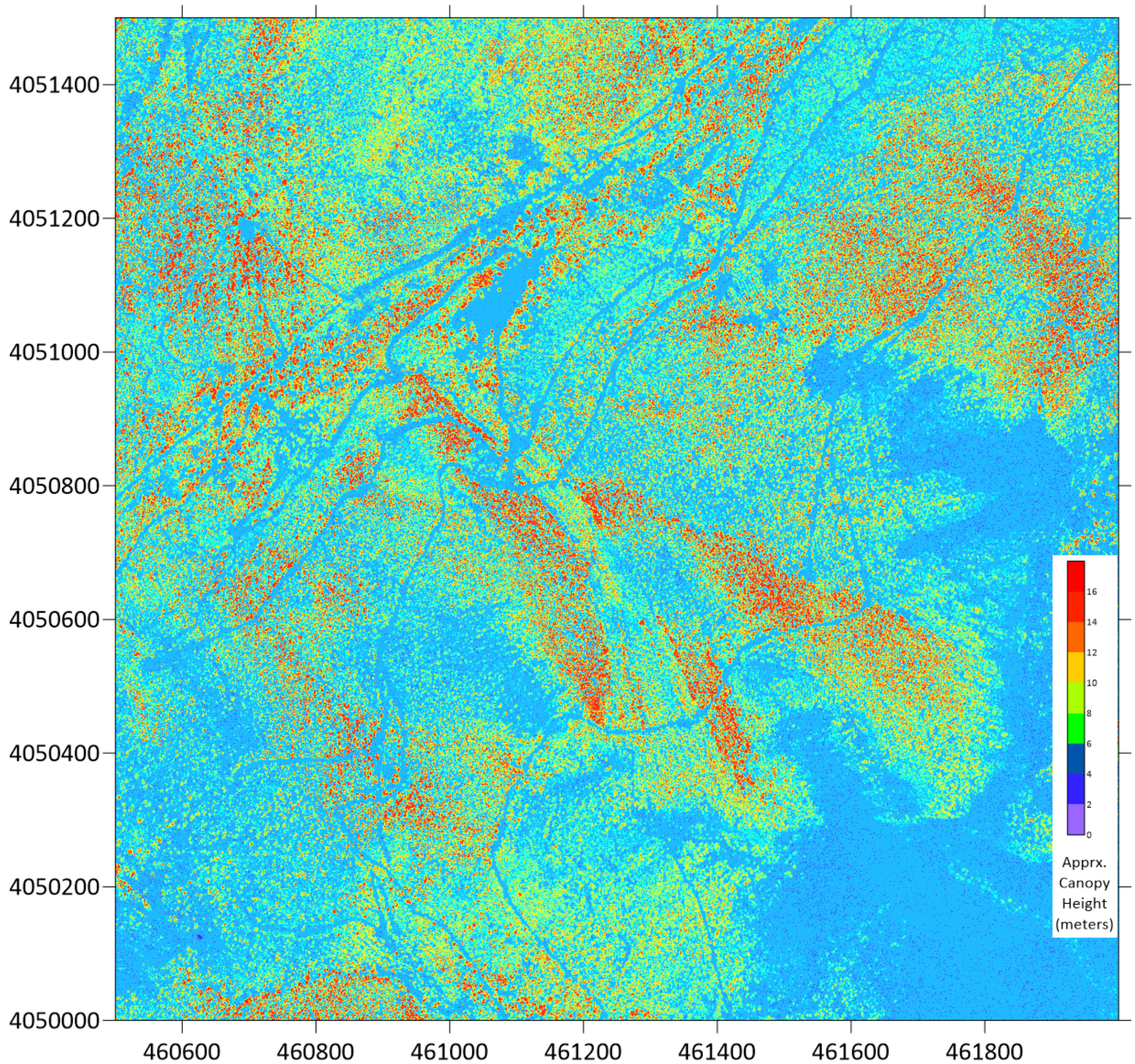

Figure 12 – Northside 1962 Path and Adjacent Areas Canopy Height
(derived from 2015 LiDAR data, WGS 84, UTM Zone 13N, 0.5m res. grid)

9. Avalanche Dynamics Modeling

We used the Swiss avalanche dynamics program RAMMS to evaluate flow directions, flow thicknesses, velocities and runouts for the various potential avalanche starting zones and paths. We applied a range of parameters to evaluate sensitivity and the influence of release areas, friction and flow regimes. Friction parameters were based on calibration guidelines provided in the RAMMS Version 1.7.2 User Manual and based on elevation, avalanche size, terrain shape and return period. High elevation friction parameters (greater than 1500 meters in Switzerland) were assumed due to relatively dry cold snowpack conditions. We included cohesion and forest friction to improve calibration for small forested paths. The model calibration was based on our experience with other avalanches, including documented historic avalanches at Taos Ski Valley.

Figure 13 shows representative model results for the dense flowing core of the 100-year avalanche. Figure 14 shows representative model results for the suspension component of a 100-year avalanche. Model input assumptions and additional results are presented in Appendix C.

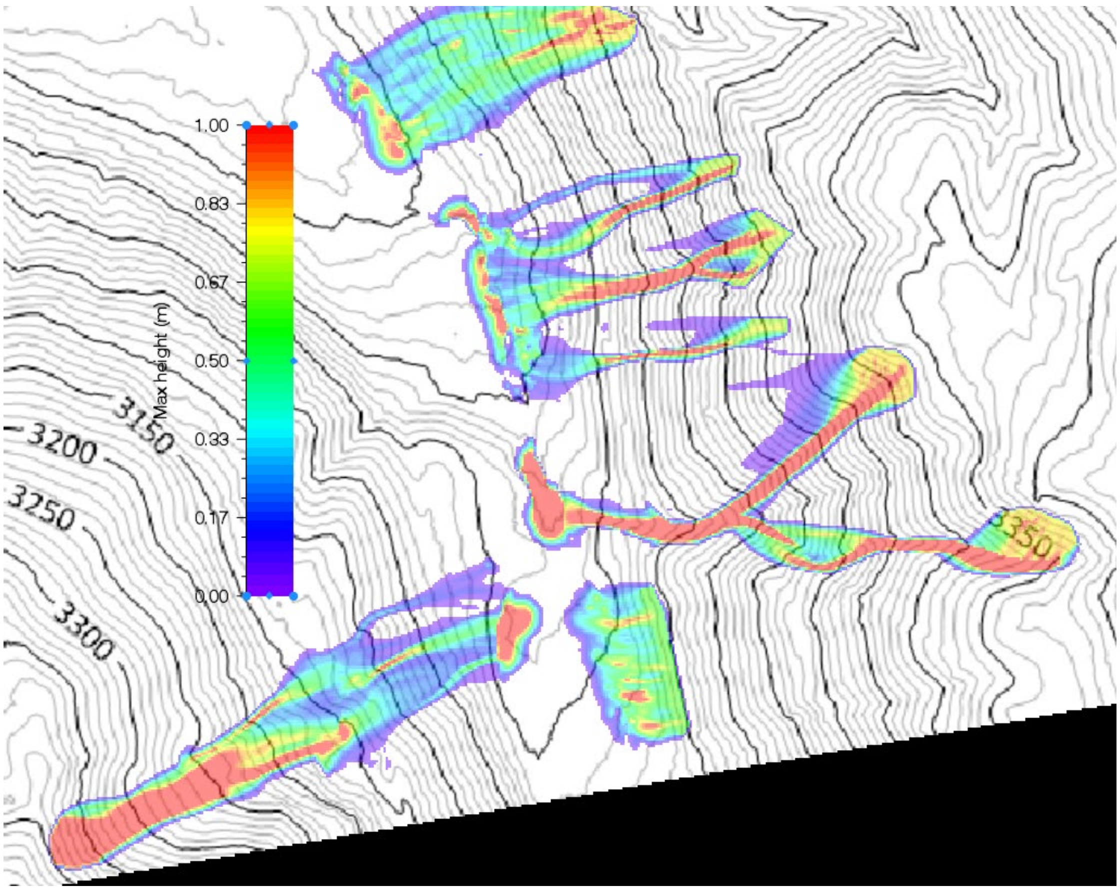

Figure 13 – Representative RAMMS Model Results

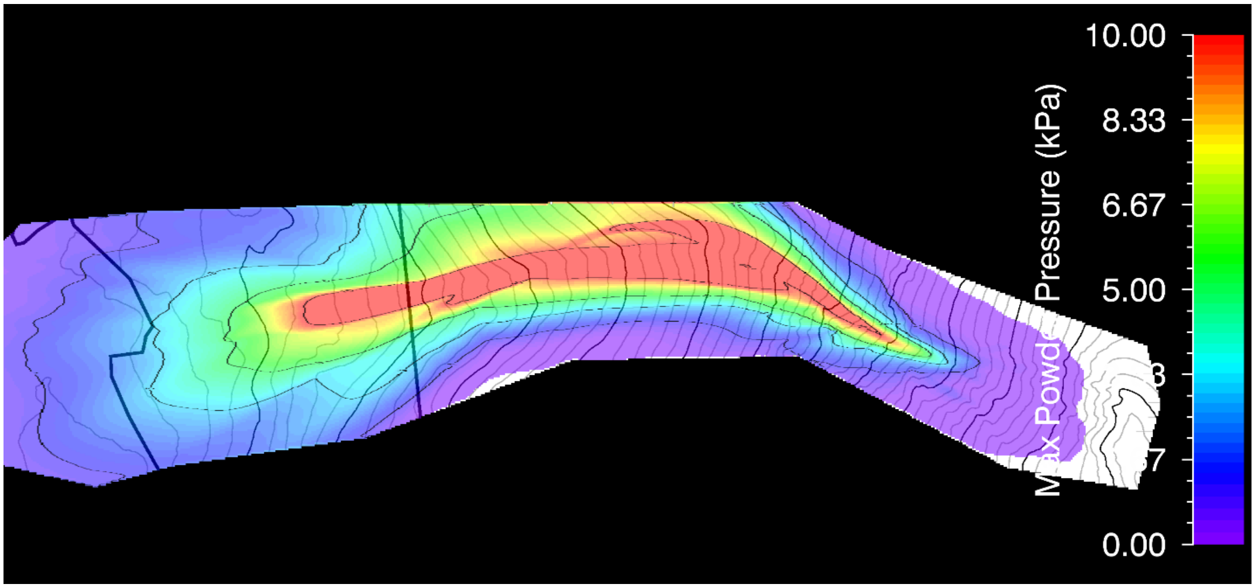

Figure 14 – Bavarian Path Powder Pressure from RAMMS:Extended Model

10. Findings

Based on the methods described in this report, we developed Avalanche Hazard Maps for the entire village limits (Index and Maps 1 through 5). The avalanche hazard zone definitions are consistent with those in the report by Arthur I. Mears, P.E., Inc. *Snow Avalanche Mapping and Zoning with Land Use Recommendations,* prepared for the Village of Taos Ski Valley in 2001, except that the Yellow (Low) Avalanche Hazard Zone has been added. The Red and Blue Zone definitions are unchanged. The available topography, aerial imagery and avalanche dynamics models have significantly improved since the 2001 Avalanche Hazard Maps.

Each of the methods used to develop the avalanche hazard maps was weighted based on our relative confidence in the method. Weighting was similarly high for field vegetation observations, aerial image analysis, terrain analysis and dynamics modeling. Statistical methods were underweighted primarily due to forests that inhibit avalanche releases and the relatively low snow depths on southerly aspects.

Fire mitigation measures in many areas steeper than 30 degrees have reduced forest density from pre-mitigation conditions. As a result, the frequency and size of avalanches in these areas is likely to increase compared to historic conditions. Over time, as the forests grow, the hazards may decrease and approach historic levels. The Avalanche hazard maps reflect current forest conditions, including thinning that has occurred to date. Prevention of high-intensity fires in the starting zones is critical because complete loss of forest in the starting zones would increase the hazard boundaries well beyond the limits for current conditions.

Snow compaction and layer disruptions from ski area operations will significantly reduce the frequencies and sizes of avalanches with return periods up to about 30-years. Between return periods of 30- and 100-years declining reductions in hazard will occur. Compaction operations' effects on 300-year avalanches will be negligible.

11. Uncertainties

There are several sources of uncertainty that could affect current and future avalanche hazards. We describe these briefly below.

Avalanche Processes

Avalanche mapping science has advanced considerably in recent years, but it is still an immature science. The latest avalanche dynamics models under development consider snow temperature and avalanche flow regimes in a thermodynamic context, which has relevance in a warming climate. However, large uncertainties exist about the input parameters and applicability to various snow-avalanche climates. This high elevation-low latitude, windy snow climate differs from those in Europe where much of the science and models were developed.

Data and Records

Public historic records are very limited, incomplete and private records are not readily available.

Climate Change

Avalanches of concern for land use planning are affected by forest conditions (especially in the starting zones), snow temperatures, precipitation intensities and snowpack structure. These factors are likely to change over time in a warming climate. Combined, some climate factors offset others, but any of them could result in higher frequencies and magnitudes of unusually long-running avalanches. There are large uncertainties, but it is likely that avalanche frequency-magnitudes will change over time. It is our opinion that avalanche hazards in this snow climate may increase in the next decades due to increases in storm intensities, precipitation and winds. Warming temperatures may have the effect of allowing thicker snow slabs to accumulate on low to moderate angle starting zones (30-35 degrees) before large releases. Such avalanches will have long runouts for both wet and dry releases. Rain-on-snow events can trigger avalanches and these events are expected to become more frequent in a warming climate.

Forest Conditions

The high-elevation, subalpine forests play a crucial role in avalanche mitigation on all aspects. Current forest conditions on many steep northerly slopes (>30-degrees) prevent the release of large avalanches. Loss of forests caused by fire, blowdown, clearing or any other cause will adversely affect the avalanche hazards, increasing the frequency and magnitude of avalanches. Conversely, active management of tree spacings, canopy densities, ages, species and ground cover could stabilize and eventually reduce avalanche hazards levels. While efforts to improve forest health are planned and underway, it is impossible for us to predict future forest conditions.

Table 1 summarizes literature related to forest density and avalanche release (Ref. 5, 6, 7 & 8). The data in Table 1 are based on a very short period of observation and do not necessary apply to long-return period avalanches.

Table 1 - Protection Forest Guidelines

Reference	slope angle	min. diameter (in)	trees per acre	avg spacing (ft)	canopy cover (%)	Comments
McClung & Schaerer	gentle	-	200	15	-	refers to mechanical prevention of trunks; no canopy effects
	steep	-	400	10	-	
Schneebli	32-42 deg	6	70-180	16-25	30-80	Swiss field study of 5 forest types; extreme events not represented
Weir	-	5-6	400	10	-	Cedar-hemlock forest interior B.C.
Jamieson	-	6	80	23	-	References Swiss data

12. Avalanche Risk

The following information is intended to provide context for the recommendations provided in the following section of this report, especially as they relate to hazard zoning, land use, occupied buildings, and exposure to avalanche hazards.

Avalanche risk is defined as the probability of injury, death or losses caused by an avalanche. Risk can be expressed as the product of probability, magnitude, exposure and vulnerability. Each component contributes to the risk.

$$R = f(P, M, E, V)$$

Risk, R, can be reduced to an acceptable level by reducing any one or more of the risk factors. Zoning maps reflect the probability-magnitude elements. Land use decisions (dwelling locations and unit-density) and mitigation designs (structural, architectural, civil) affect the exposure and vulnerability components. Exposure (E) includes both time and numbers of people or value of resources for a given location. Exposure can be reduced by structural and architectural designs that place high occupancy uses in protected areas. This is particularly important for outdoor uses such as hot tubs, entries and outdoor living spaces. Vulnerability (V) is the resistance to loss. Persons inside of buildings designed for avalanche impact have a high level of protection, but outside of buildings, vulnerability is high. Vulnerability for persons outside of buildings is best managed by designs and user awareness that minimize the time of exposure.

Each component of risk involves uncertainties. The probability-magnitude uncertainties for avalanche hazards are generally larger than the uncertainties for vulnerabilities due to the short historic record and limitations of avalanche mapping science.

13. Recommendations

Land Use

1. No occupied or valuable structures should be constructed in the Red Avalanche Hazard Zones.
2. Occupied and valuable structures should be located outside of the Blue and Yellow Zones, wherever practical. Many jurisdictions in the U.S. allow residential and commercial construction in the Blue Zone with structural avalanche mitigation. The Yellow Zone is not widely used in the U.S. and is often advisory.
3. If low-occupancy, residential or commercial structures are constructed in the Blue Avalanche Hazard Zones, they should be located as low as practical in the Blue Zone and designed to withstand avalanche impact and static loads. Avalanche loads cannot be determined until the location, geometry and orientation of the structures are known.
4. No critical structures should be constructed in the Red, Blue or Yellow Zones. Critical structures include emergency response facilities (police, fire, ambulance, clinics), hospitals and schools.
5. No high-occupancy structures (hotels, apartments, auditoriums, condominiums, etc.) should be constructed in the Red or Blue Zones.
6. Based on uncertainties, occupied structures in the Yellow (Low) Avalanche Hazard Zone should be designed to withstand avalanche impact and static loads. In larger avalanche paths (more than 1000 vertical foot fall), stagnation pressures from the suspension component (powder blast) can act to heights of 50-feet or more. Avalanche loads cannot be determined until the location, geometry and orientation of the structures are known.

7. Site and architectural designs should address avalanche hazards in the Blue and Yellow Zones. Building entries and outdoor living spaces, especially hot tubs and heated outdoor spaces, should be placed in protected areas away from the avalanche-facing side of the building. In cases where this is not practical, evacuation plans for exposed areas should be made and implemented. Windows and doors on the uphill side should be avoided or designed for impact.
8. All utilities in avalanche zones should be buried. Gas lines, utility meters and fire hydrants in avalanche zones should be protected to prevent damage.
9. It is possible to achieve a high level of avalanche protection for occupants inside specially designed, reinforced buildings, but persons and pets outside will not be protected. Therefore, it is prudent for occupants and guests of residential buildings in and near avalanche hazard zones to become educated and keep current on local avalanche conditions, including the local and regional avalanche danger forecasts. However, reliance upon forecasts and avoiding avalanche zones during elevated avalanche danger conditions can reduce, but not eliminate avalanche risk, especially to persons outside of buildings.

Avalanche Ordinance

The following is from Ordinance 17-030:

SECTION 7. GENERAL PROVISIONS.

Part 6. Avalanche Design Requirements

Prior to the Village issuing a building permit for the construction of a new, freestanding building to be occupied by one or more persons, the applicant must provide the following to the Village for review by the Planning Officer:

1. A written report analyzing the potential avalanche hazards and the potential physical forces, if any, created thereby upon the proposed improvement or structure, and;

2. A structural analysis of the proposed building or structure prepared and sealed by a New Mexico licensed engineer reflecting an engineering analysis and design which states that the design of the building or structure can withstand the potential force from an avalanche as set forth in the avalanche report referred above. This analysis shall be required only if the referenced report indicates that an avalanche hazard exists.

3. The issuance of a building permit by the Village shall not be construed to mean that the Village agrees that the proposed building will withstand an avalanche.

The ordinance does not incorporate the 2001 Avalanche Hazard Maps or distinguish between different (Red or Blue) hazard zones. In the U.S., local jurisdictions determine restrictions and requirements for development in avalanche zones. The ranges of restrictions vary from none or few to severe. These are policy decisions that have significant impacts on public and private properties. We offer some general guidelines and recommendations:

1. The recommendations in the previous section should be incorporated, including distinguishing between hazard zones and allowable land uses, particularly for the Blue and Red Zones.
2. The issue of non-conforming structures (e.g., unreinforced buildings in Blue Zones) should be addressed by informing owners and occupants and addressing future additions, improvements or avalanche defenses prior to issuing building permits.
3. The ordinance should allow for review and adjustment of avalanche zones based on analyses by a qualified avalanche professional.
4. We recommend incorporating avalanche hazard maps into the ordinance with procedures for amendments to the avalanche hazard maps.
5. We recommend requiring that new construction, including buildings, walls and site grading, do not adversely impact avalanche hazards on other properties, including public roads and utilities.
6. We recommend developing a list of criteria for reviewing developments in avalanche zones.
7. We recommend that public officials review avalanche ordinances from other jurisdictions, including Vail, Colorado, Pitkin County Colorado, Ketchum, Idaho and Blaine County, Idaho.
8. We recommend that thinning be limited on slopes steeper than 30 degrees to the minimum conifer tree densities for trees 6” diameter and larger per Figure 14 to the maximum extent practical. Deciduous and dead/snag tree densities should be double those shown in Figure 14 for avalanche protection. Tree spacing should be relatively even and staggered to avoid fall-line clearings longer than about 50 to 100-feet of slope distance.

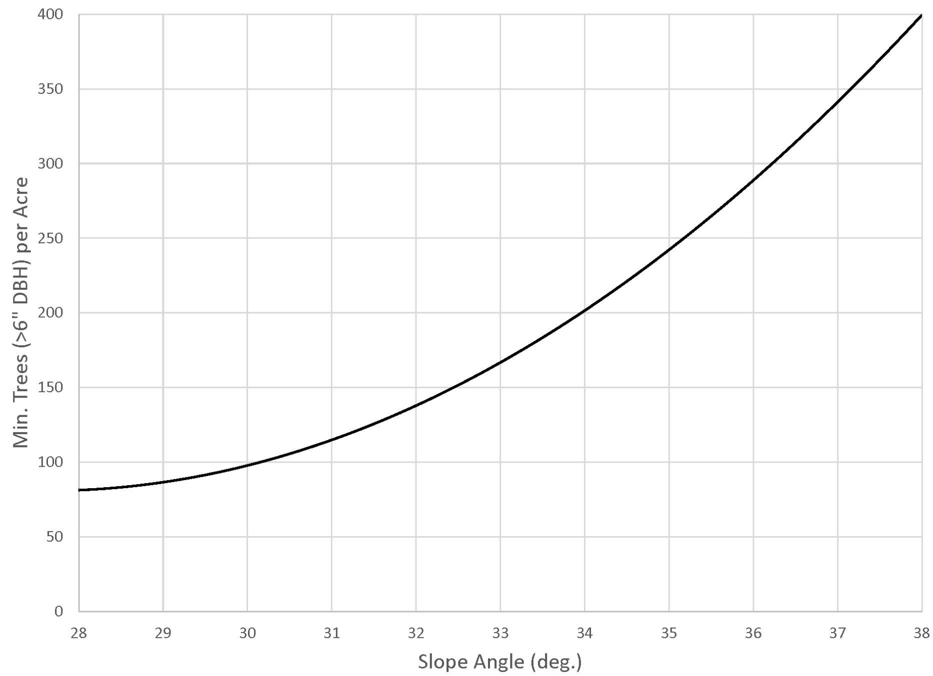

Figure 15 – Minimum Conifer Densities vs. Slope for Avalanche Protection

14. References

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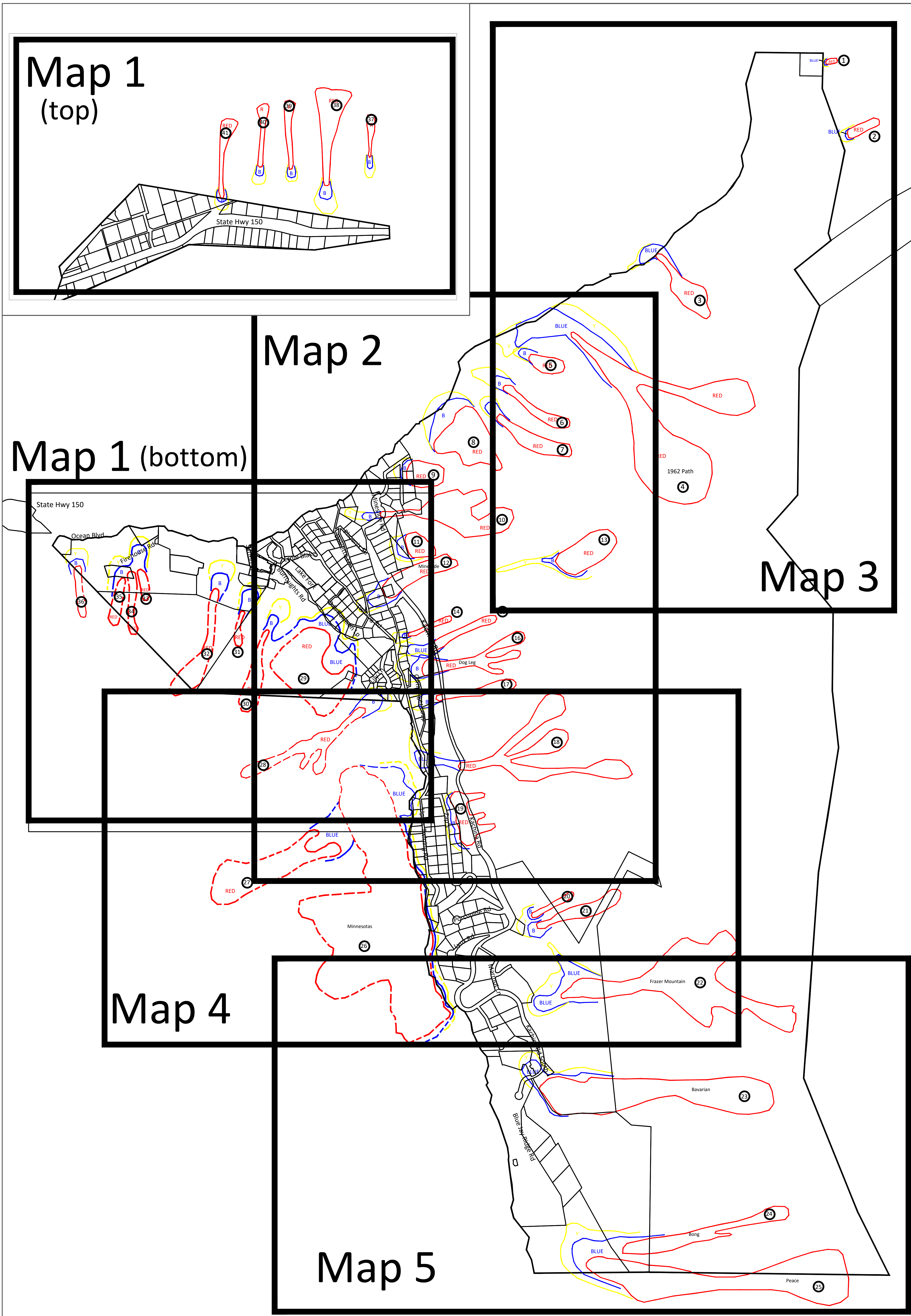
8. Teich, M., Bartelt, P., Grêt-Regamey, A. and Bebi, P.,2012. Snow avalanches in forested terrain:Influence of forest parameters, topography and avalanche characteristics on runout distance. Arctic, Antarctic, and Alpine Research 44(4), 509-519.

15. Warranty

You as my client should know that while our company can and does attempt to uphold high professional standards, the state of scientific and engineering knowledge is incomplete, and does not permit certainty. The complex phenomena involved in avalanches cannot be perfectly evaluated and predicted, and methods used to predict avalanche behavior change as new research becomes available. While we can and will offer our best professional judgment, we cannot and do not offer any warranty or guarantee of results.

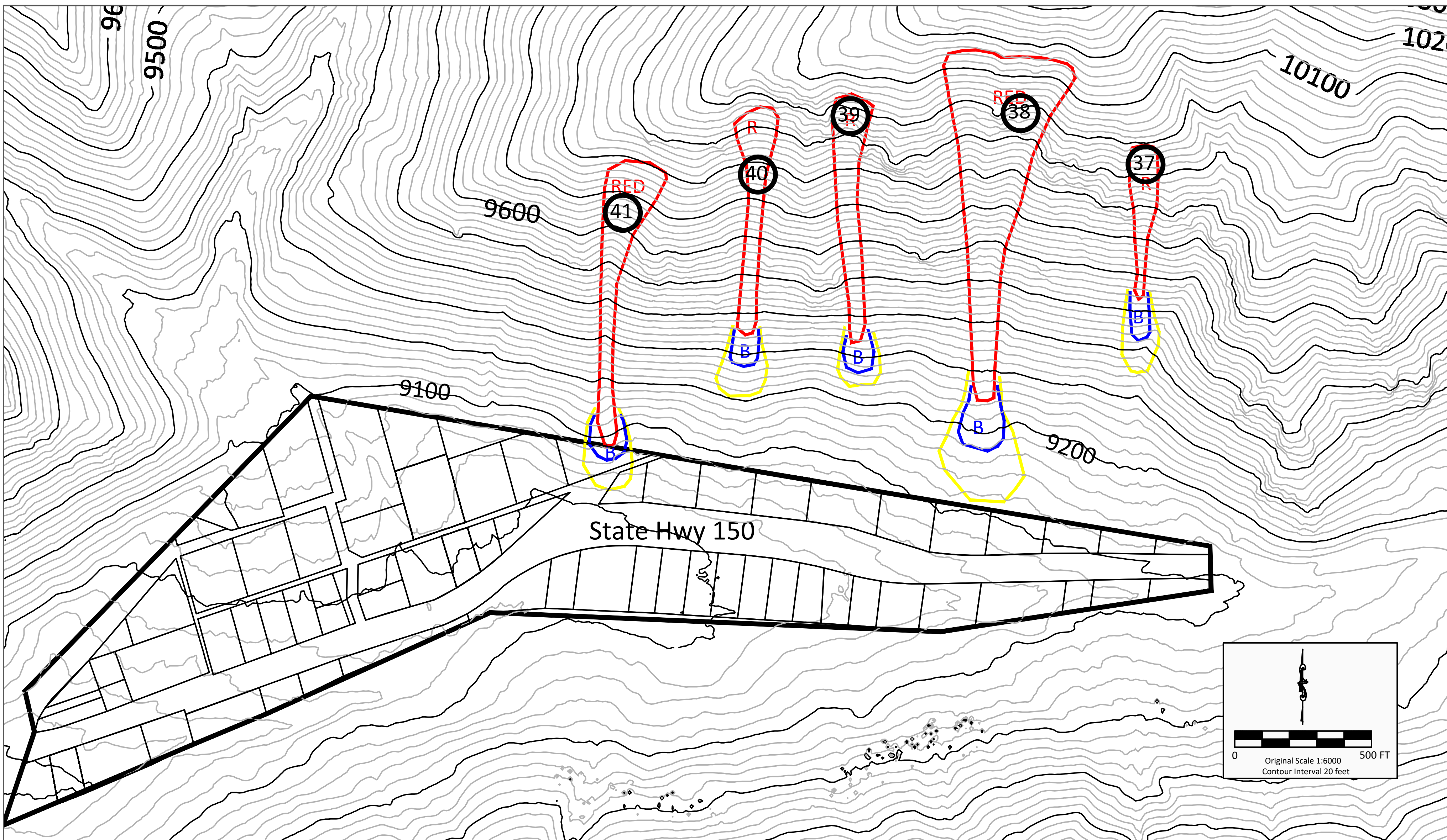


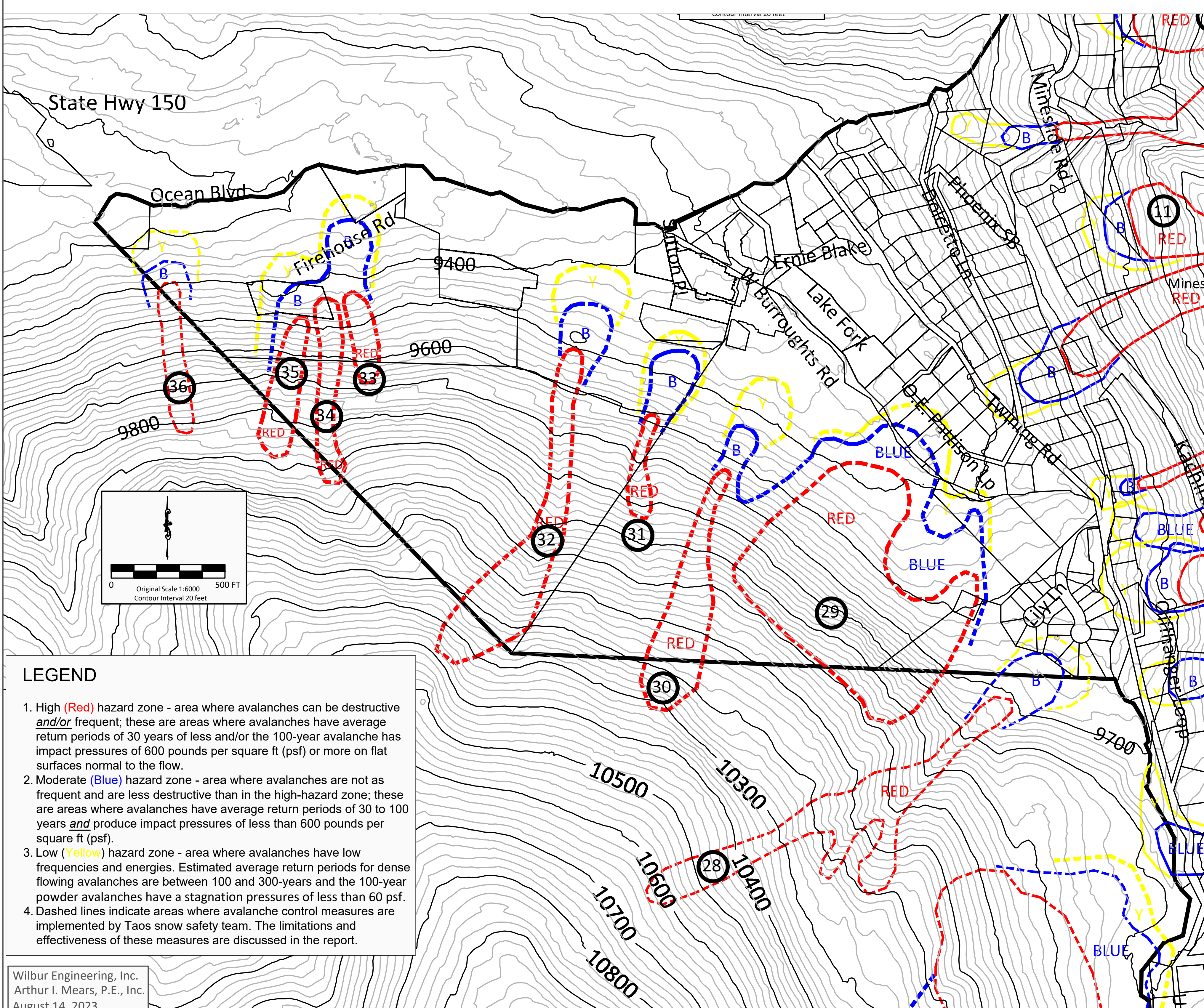
Wilbur Engineering, Inc.
Arthur I. Mears, P.E., Inc.
August 14, 2023

Avalanche Hazard Map

Index Map

Village of Taos Ski Valley, New Mexico, USA





LEGEND

1. High (Red) hazard zone - area where avalanches can be destructive *and/or* frequent; these are areas where avalanches have average return periods of 30 years of less and/or the 100-year avalanche has impact pressures of 600 pounds per square ft (psf) or more on flat surfaces normal to the flow.
2. Moderate (Blue) hazard zone - area where avalanches are not as frequent and are less destructive than in the high-hazard zone; these are areas where avalanches have average return periods of 30 to 100 years *and* produce impact pressures of less than 600 pounds per square ft (psf).
3. Low (Yellow) hazard zone - area where avalanches have low frequencies and energies. Estimated average return periods for dense flowing avalanches are between 100 and 300-years and the 100-year powder avalanches have a stagnation pressures of less than 60 psf.
4. Dashed lines indicate areas where avalanche control measures are implemented by Taos snow safety team. The limitations and effectiveness of these measures are discussed in the report.

Wilbur Engineering, Inc.
Arthur I. Mears, P.E., Inc.
August 14, 2023

NOTES

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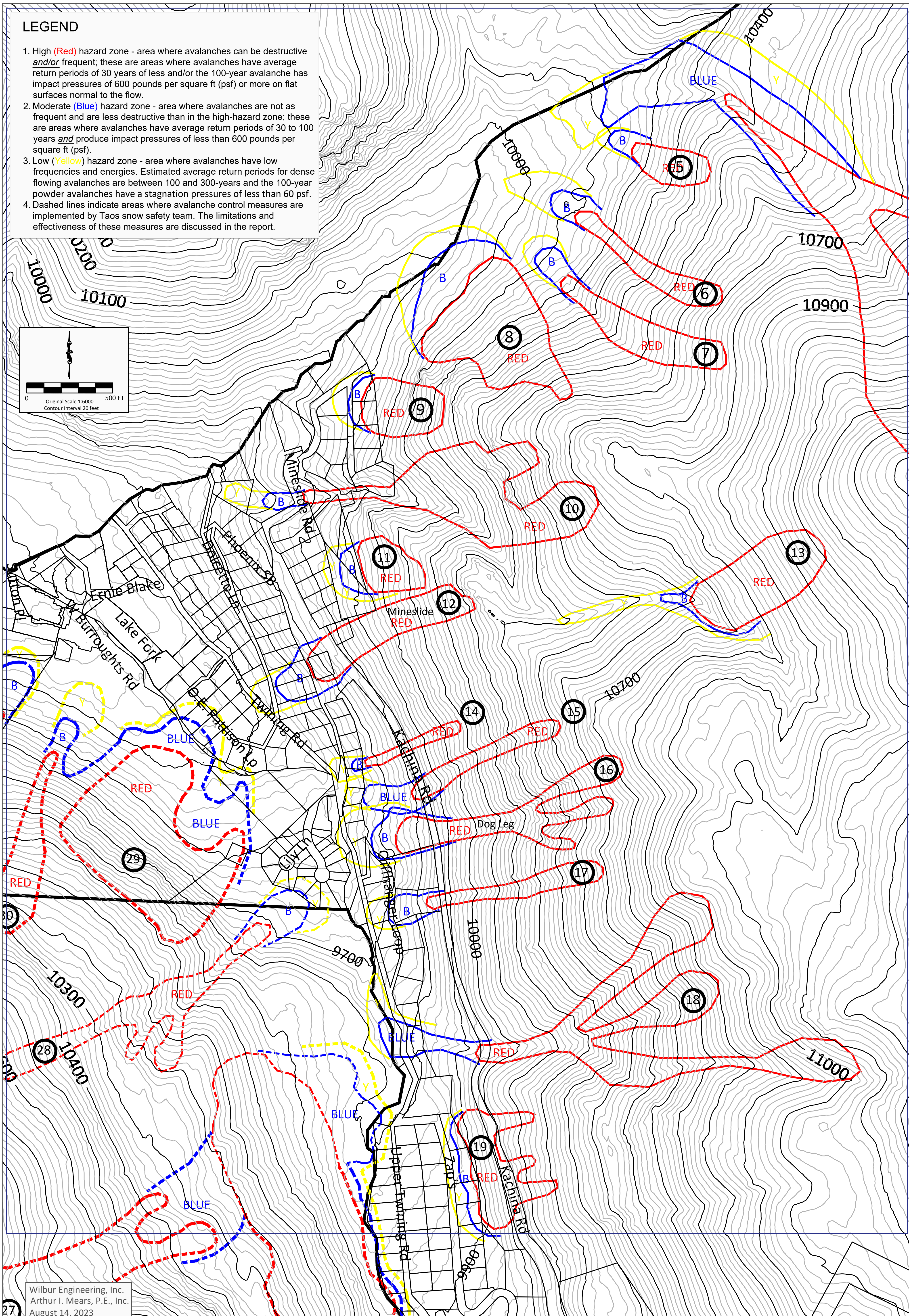
Avalanche Hazard Map

Amizette & West End

Village of Taos Ski Valley, New Mexico, USA

Map

1



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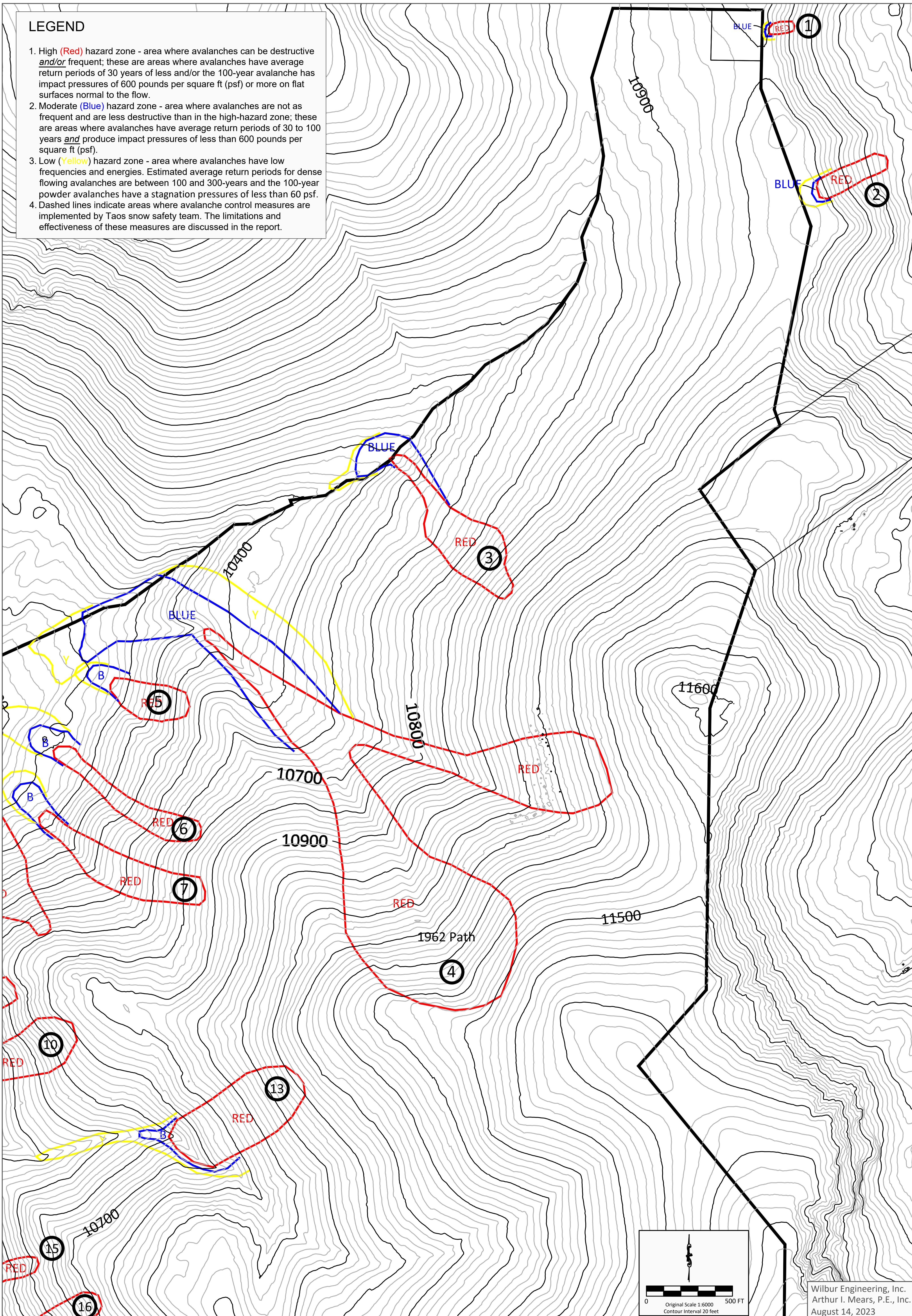
Avalanche Hazard Map
Lower Twining Road
Village of Taos Ski Valley, New Mexico, USA

Map
2



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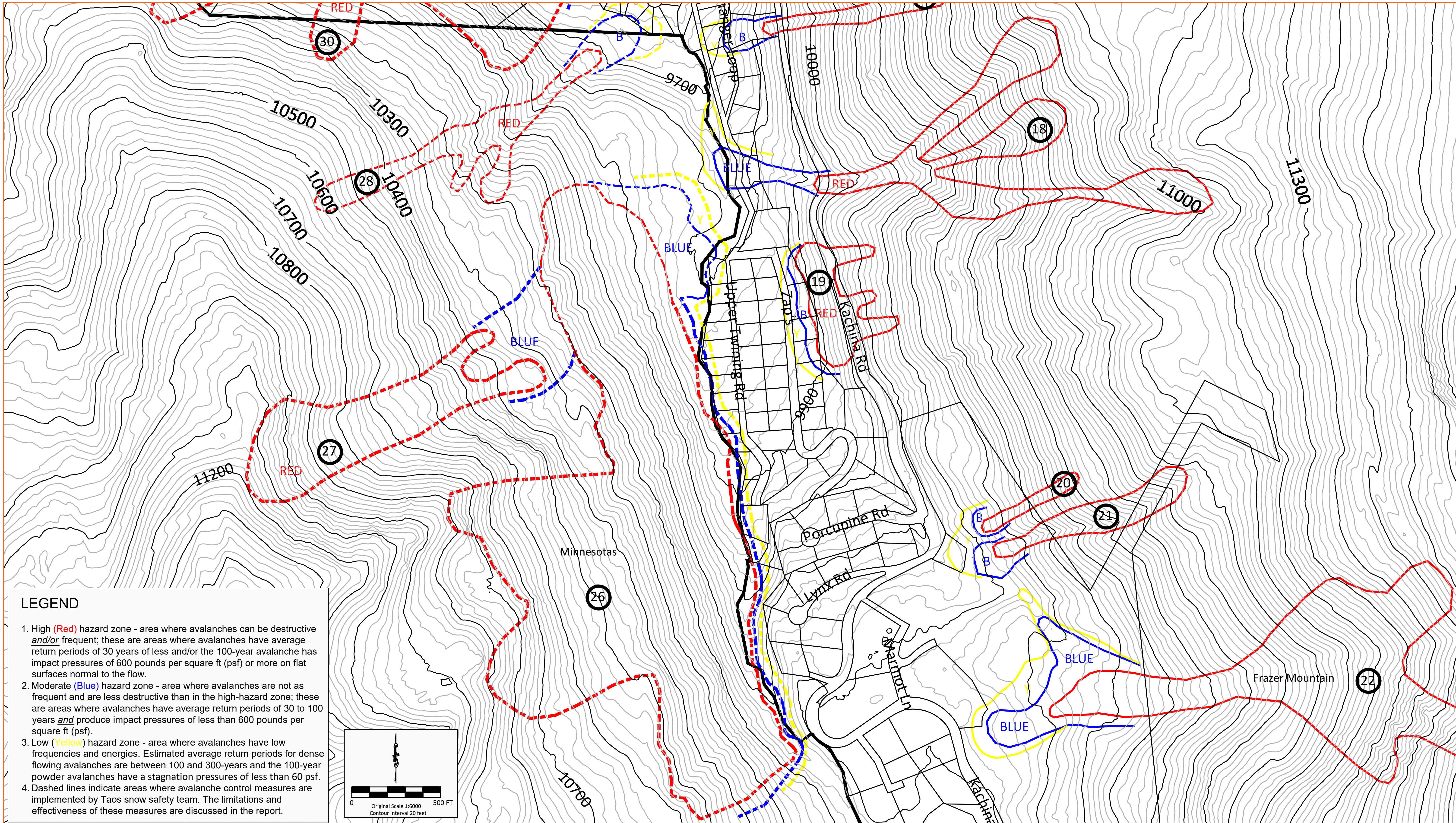
Avalanche Hazard Map
Northside
Village of Taos Ski Valley, New Mexico, USA

Map
3



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Avalanche Hazard Map

Upper Twining Road

Village of Taos Ski Valley, New Mexico, USA

Map

4

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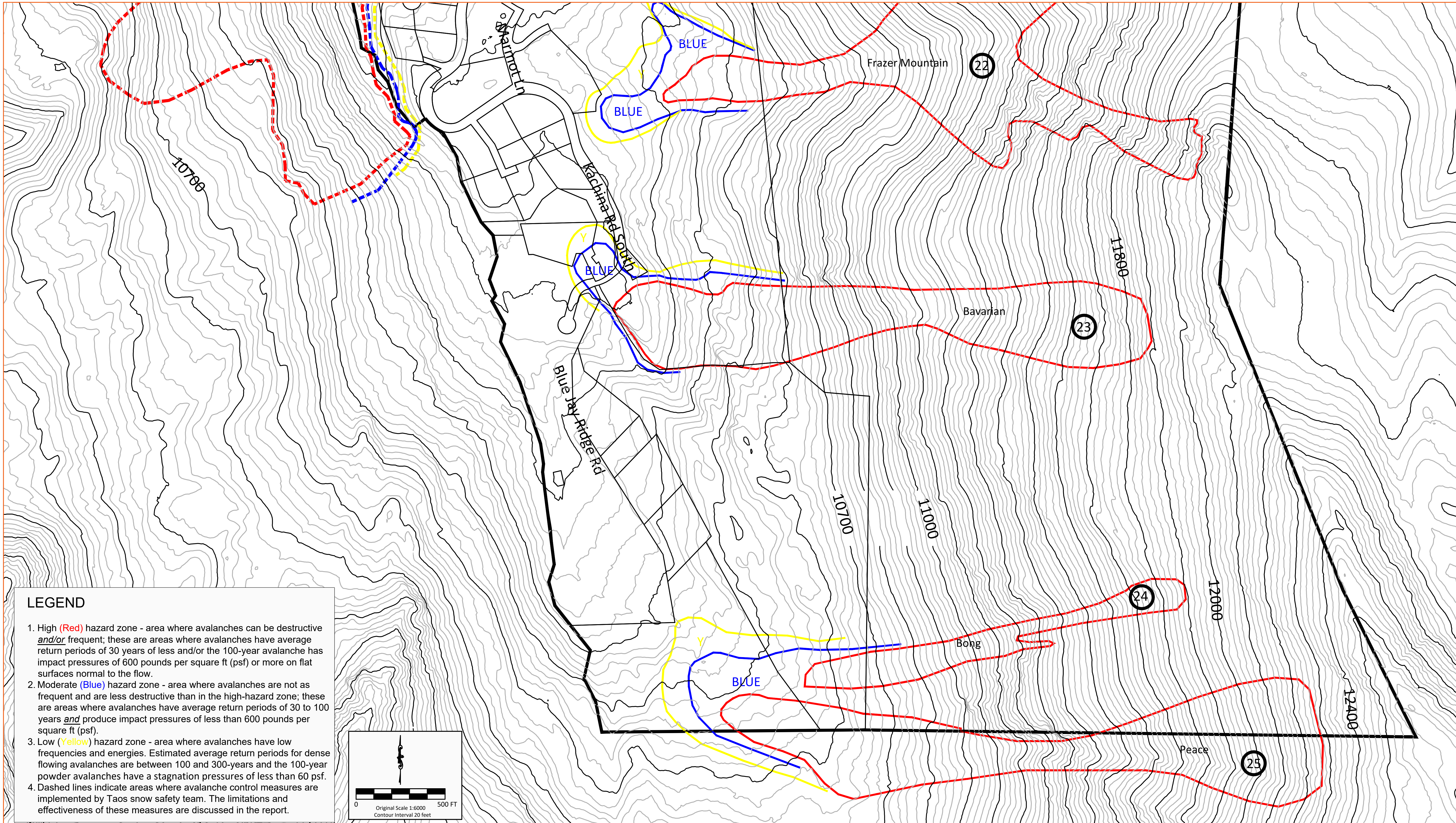
August 14, 2023



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Avalanche Hazard Map

Kachina Basin

Village of Taos Ski Valley, New Mexico, USA

Map
5

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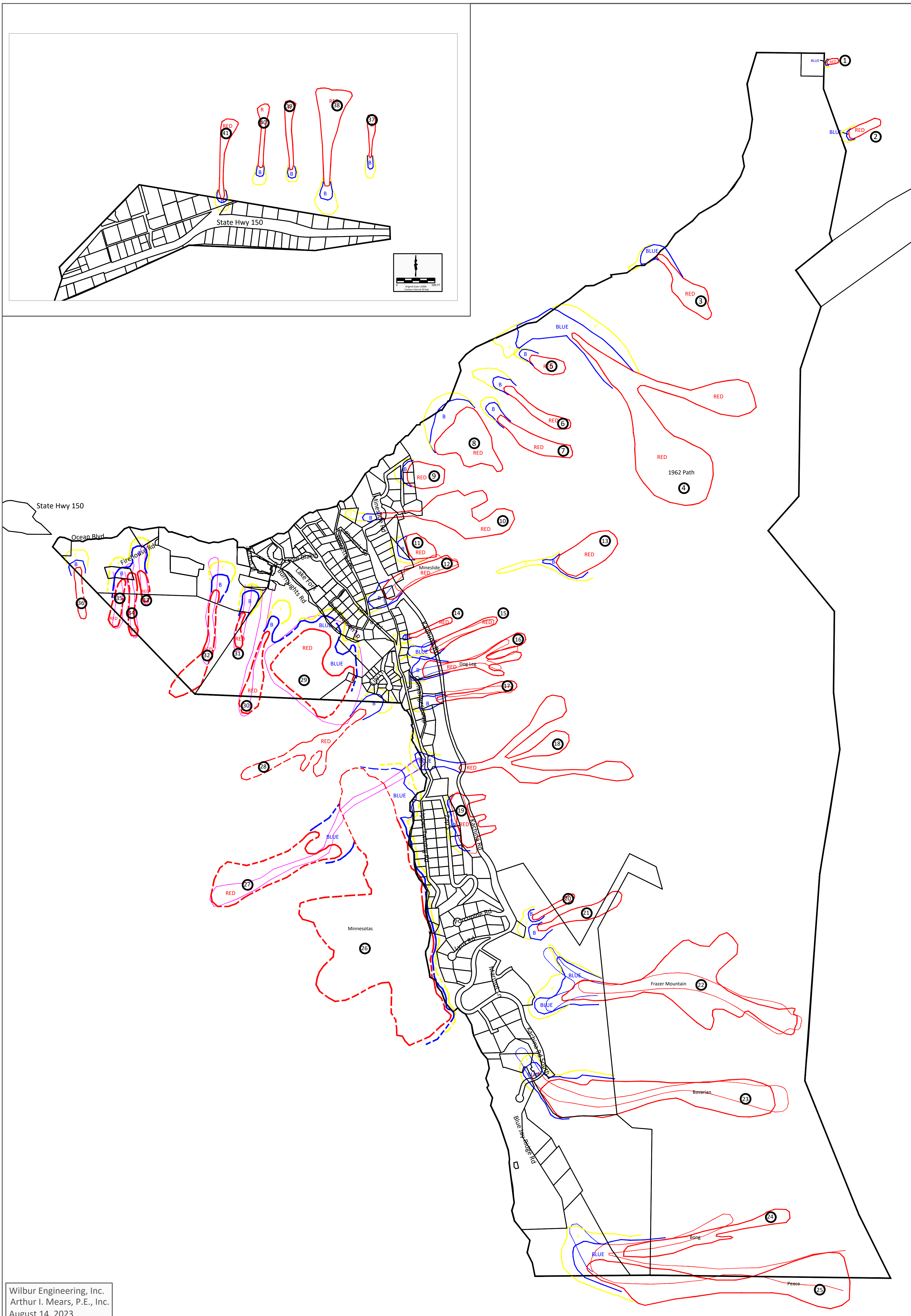
August 14, 2023



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August 14, 2023

2023
- Yellow (Low)
- Blue (Moderate)
- Red (High)

2001
- Blue (Moderate)
- Red (High)
- Controlled by TSVI

Avalanche Hazard Map Revisions

2001-2023 Map Comparison

Village of Taos Ski Valley, New Mexico, USA

Map 6

Appendix A
Climate Data

Poco Gusto Weather Station, el. 10,860’

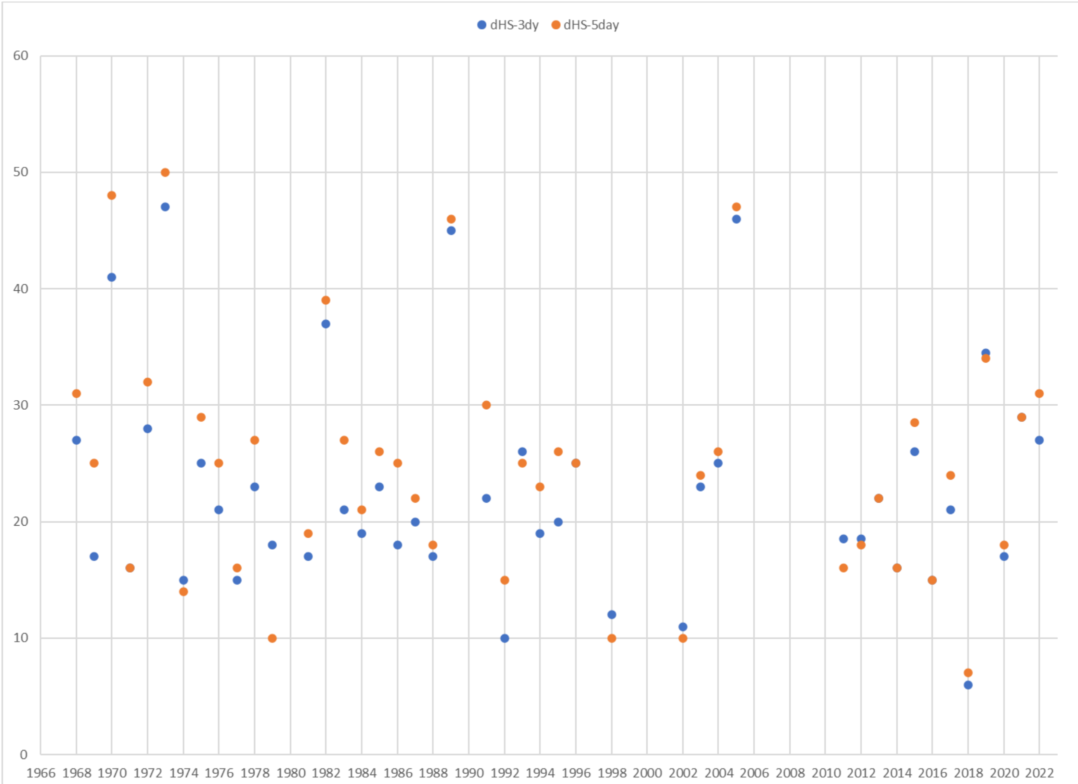
rank	3-day SWE		5-day SWE		delta-HS 3-day		delta-HS 5-day	
1	2019	5.35	2008	6.51	1973	47	1973	50
2	1989	4.85	2019	5.85	2005	46	1970	48
3	2008	4.64	1989	4.95	1989	45	2005	47
4	1978	3.50	2017	4.55	1970	41	1989	46
5	2017	3.35	1978	4.25	1982	37	1982	39
6	2021	3.20	2022	4.10	2019	35	2019	34
7	2022	3.10	1995	3.65	2021	29	1972	32
8	2004	2.92	2001	3.60	1972	28	2022	31
9	2001	2.80	1985	3.30	2022	27	1968	31
10	1985	2.79	2021	3.20	1968	27	1991	30

Notes:

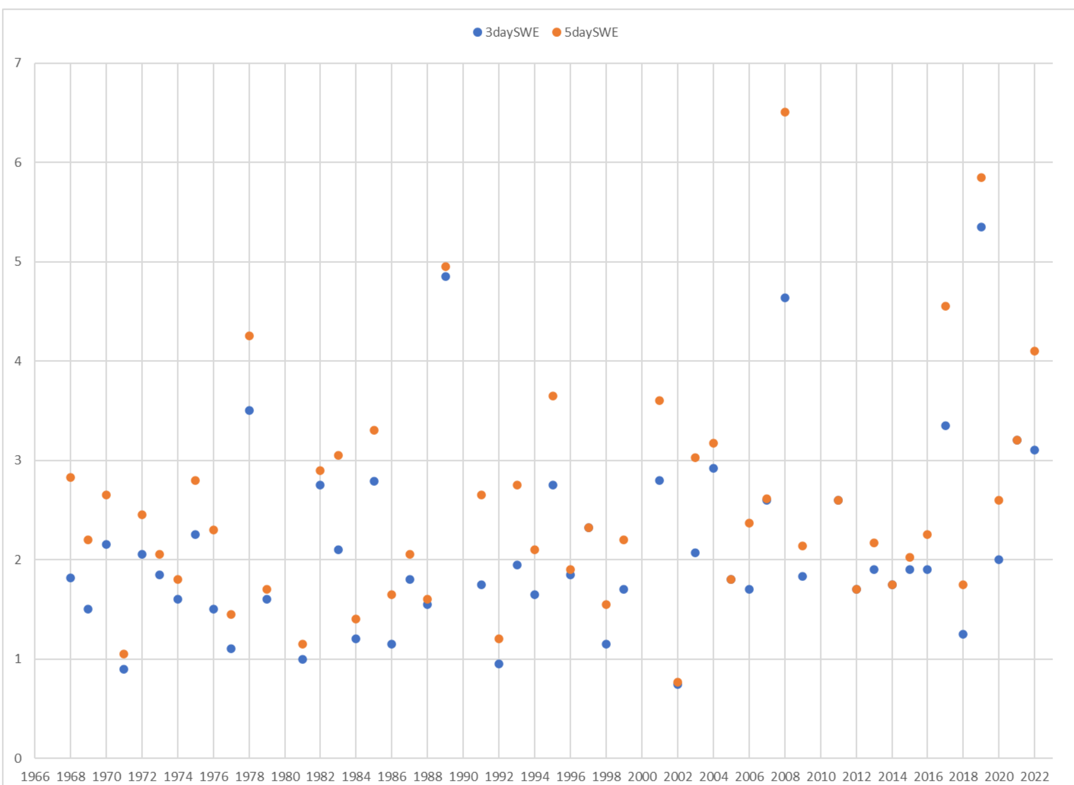
1. Data provided by TSV Ski Patrol in inches from Poco Gusto, el. 10,860 ft.
2. SWE period of record: 51/55 years
3. HS period of record 43/55 years
4. missing all data:1980, 1990, 2000, 2010
5. missing HS data: 1999-2001, 2006-2009

Chronological Storm Dates

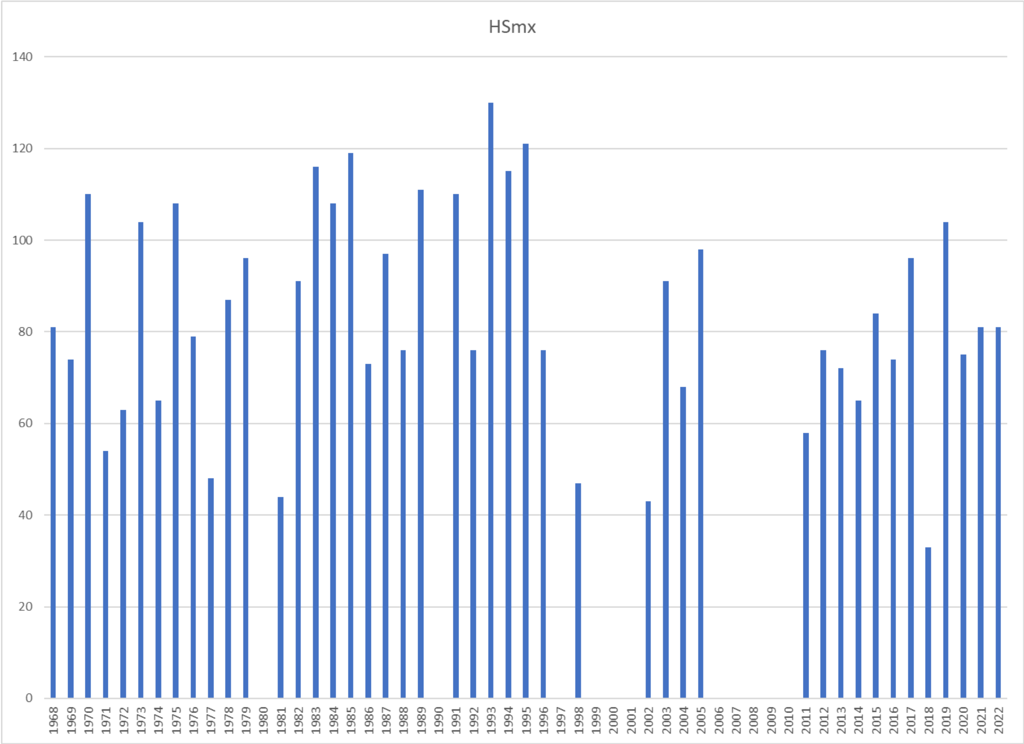
	HSmx	HSmx-3day-avg	HN-max	HW-max	dHS-3dy	dHS-5day	3daySWE	5day-SWE	mid-storm
1970	110	79	22	1.15	41	48	2.15	2.65	3/31/1970
1973	104	77	18	1.05	47	50	1.85	2.05	12/29/1972
1975	108	84	20.5	1.15	25	29	2.25	2.8	3/10/1975
1978	87	77	16	1.8	23	27	3.5	4.25	3/2/1978
1982	91	84	34	2.05	37	39	2.75	2.9	2/4/1982
1983	116	105	12	0.9	21	27	2.1	3.05	3/20/1983
1985	119	100	16	2	23	26	2.79	3.3	3/12/1985
1989	111		36	2.85	45	46	4.85	4.95	2/5/1989
1991	110		18	1.7	22	30	1.75	2.65	12/15/1990
1993	130	107	16	1.15	26	25	1.95	2.75	1/10/1993
1994	115	122	16	1.2	19	23	1.65	2.1	3/27/1994
1995	121	104	12	1.5	20	26	2.75	3.65	3/4/1995
2001							2.8	3.6	4/7/2001
2005	98		11	1.75	46	47	1.8	1.8	12/30/2004
2008			18	2.9			4.64	6.51	12/10/2007
2017	96	68	19	2.3	21	24	3.35	4.55	1/8/2017
2019	104	71	28	3	34.5	34	5.35	5.85	3/14/2019

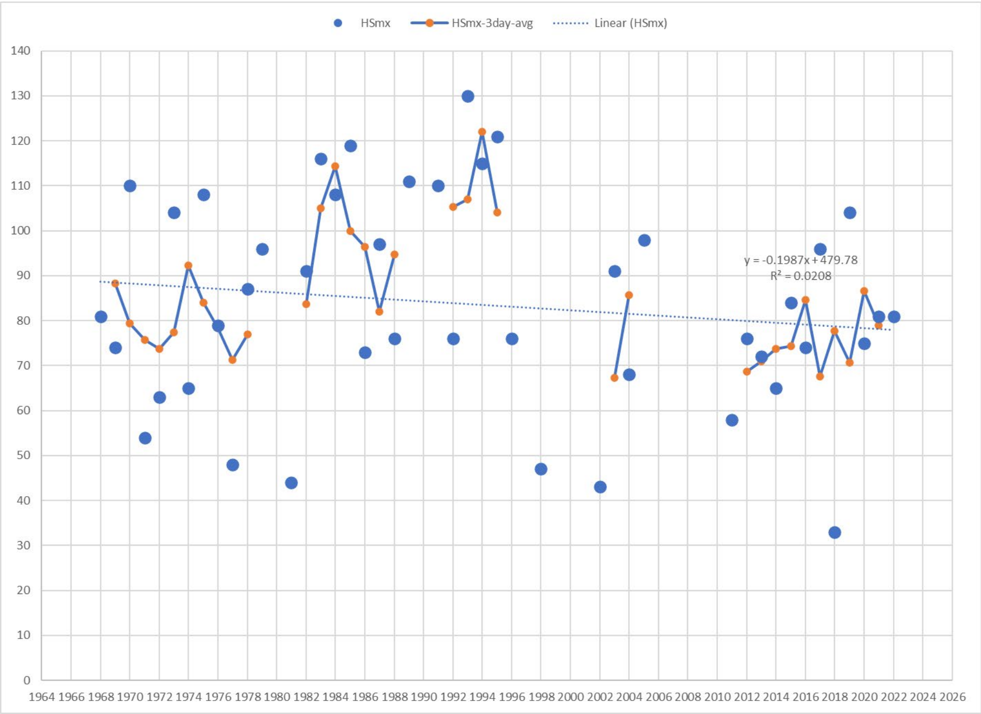


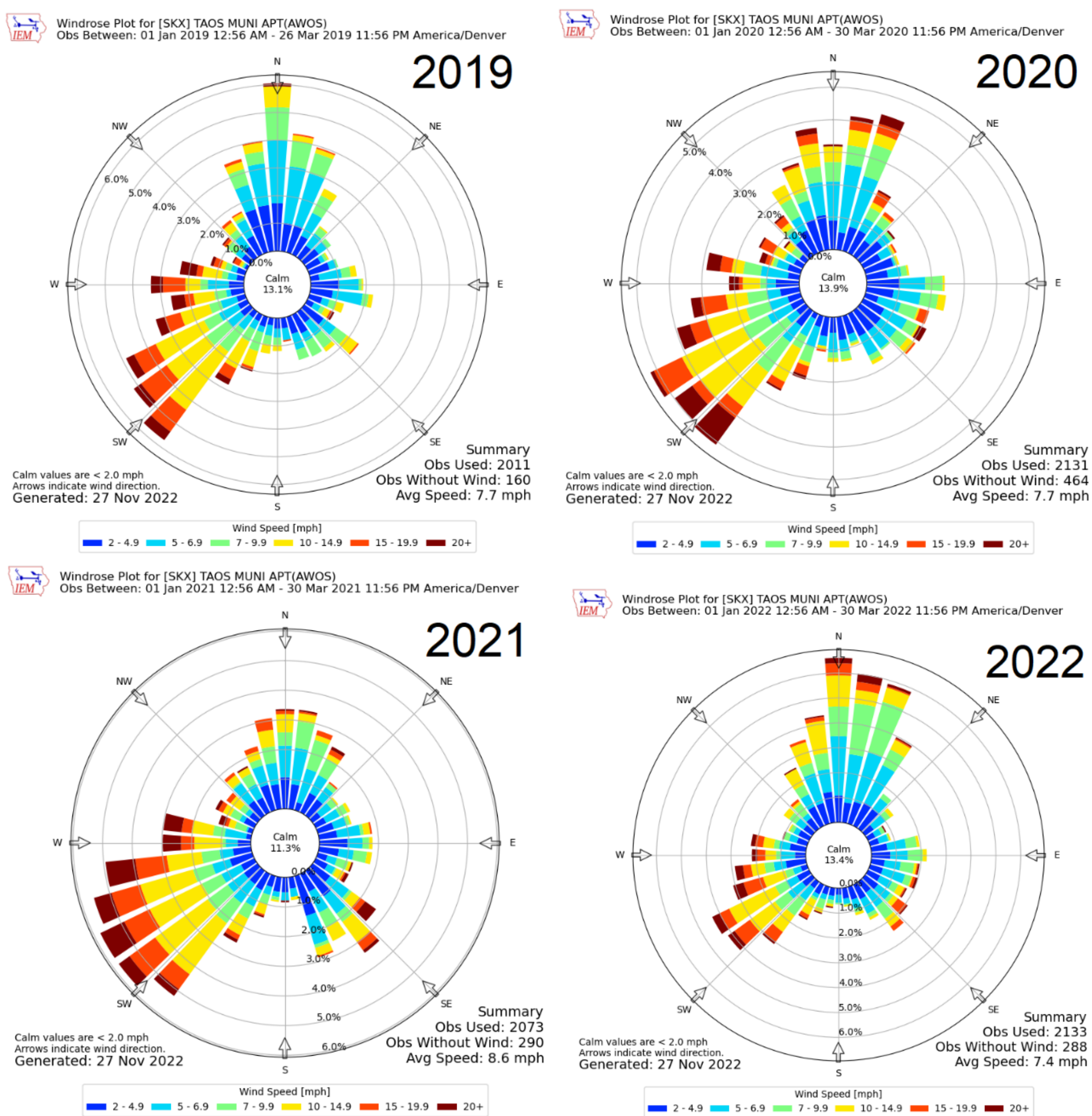
dHS-3dy dHS-5day
60
50
40
30
20
10
0
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022



3daySWE 5daySWE
7
6
5
4
3
2
1
0
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022


HSmx


HSmx
HSmx-3day-avg
Linear (HSmx)
y = -0.1987x + 479.78
R² = 0.0208



Taos Airport Wind Roses for Jan-Mar, 2019-2022

Taos Powderhorn SNOTEL
Site Number: 1168
Elevation: 11045 feet
Reporting since: 2010-08-09

Appendix B
Site Photos

Location low in Jean's meadow; branches stripped on large tree to 16+ feet

Lop and pile area in 1962 avalanche path

Frazer, Bavarian, Bong, Peace paths
Chris Wilbur photo, Jan. 11, 2008

Dog Leg Path
Chris Wilbur photo, Jan. 11, 2008

Mineslide Feb. 9, 2011

Fire Mitigation and Blowdown Area (lop and pile)

Chris Wilbur photo, April 12, 2023

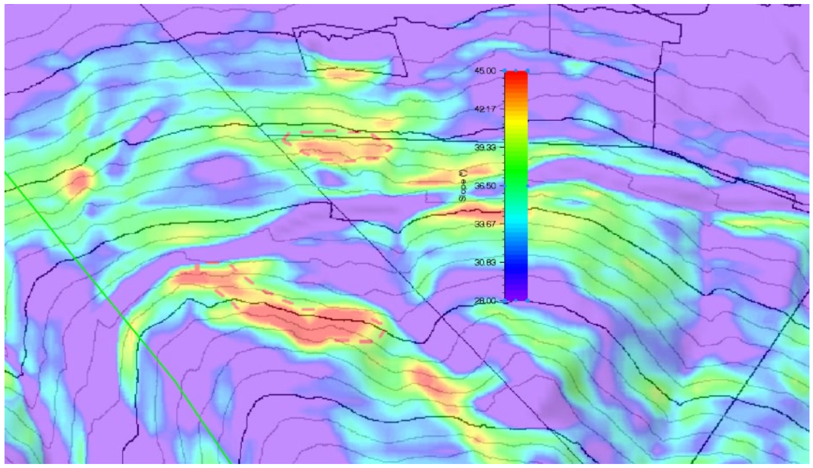
Appendix C
RAMMS Parameters & Results for Design Magnitude Avalanche

*** Important Note: ***

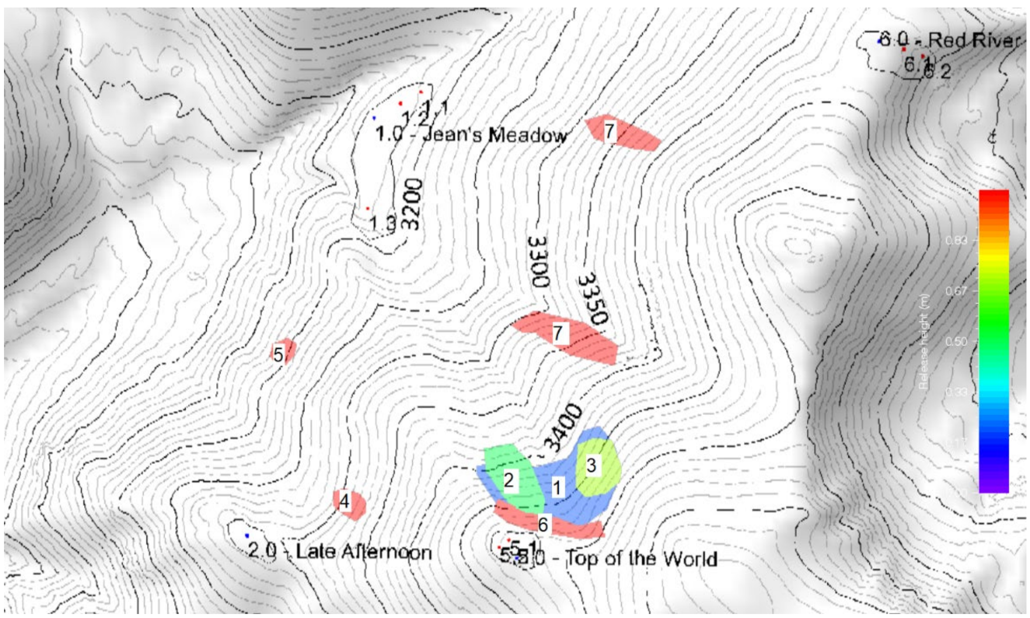
Interpretation of avalanche dynamics model results requires an understanding of the model assumptions, simplifications and limitations of the underlying equations of motion. The models do not accurately show wet avalanche runouts, flow heights or impact pressures, or the variations in avalanche properties with depth, including density and velocity.

		Release				cohesion	Comments
Run No.	res.	name	ht. (m)	vol(m3)	Friction	(Pa)	
Snowbear Condos							
run1	5	R1	0.8	6,200	S100	0	upper rel. Snowbear
run2	5	R1	0.8	6,200	S100-for	0	add forest friction
run3	5	R2	0.7	2,300	T100	0	lower rel Snowbear
run4	5	R1	0.7	2,300	T100-for	0	add forest friction
NTSV-front							
run6	3	R2	0.8	15,700	T100	100	7 tiny rel. front side
run7	3	R3	0.6-1.0	24,500	S100	0	8 rel. mid valley - runs too far
run8	3	R3	0.6-1.0	24,500	T100	0	8 rel. mid valley - still runs too far
run9	3	R3	0.6-1.0	24,500	T100	200	Add C
Amizet							
run10	3	R1	0.5	5,400	T100	100	5 tiny rel.
run11	3	R1	0.5	5,400	T100	200	incr C
HSB							
run8	2	R1	0.5		T30	0	30-yr
run9	2	R1	0.65		T100		same rel, diff hts
run5	2	R1	0.75	2000	T30	0	30-100-yr
run10	2	R1	0.85		T300		same rel, diff hts
run6	2	R1	0.9	2400	T100	0	100-yr
run7	2	R1	1.05	2800	T300	0	300-yr

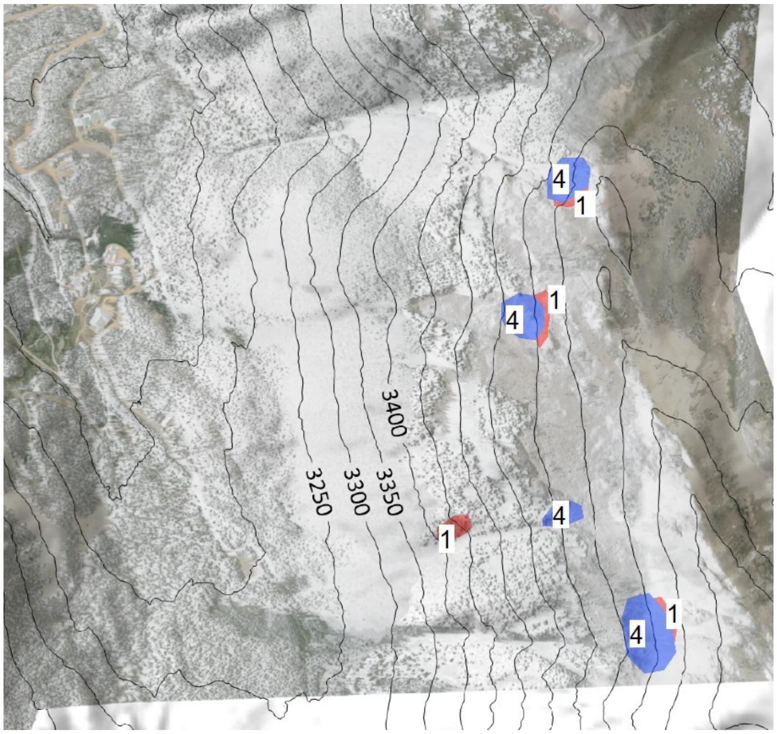
1962 path - Cabin 1.3							
run 1	5	R1	1.0	36,600	M100	0	Jeans mdw - hits cabin 1.3
run 2	5	R1	1.0	36,600	M300	0	300-yr friction
run 3	5	R1	1.0	36,600	M300	100	300-yr add C
run 4	5	R1	0.7	25,600	M100	0	smaller rel
run 5	5	R1	0.7	25,600	M100	100	add C
run 6	5	R1	0.7	25,600	M100	200	addl C
run 7	5	R2	1.0	11,300	S100	0	100yr Wind-loading rel
run 8	5	R3	1.0	9,300	S100	0	E rel. sparce forest
run 9	5	R3	1.2	11,100	S100	0	incr rel ht
run 10	5	R3	1.2	11,100	S300	0	300-yr friction
Late Afternoon paths							
run 11	5	R4	1.0	3,200	T100	0	W of L Afternoon
run 12	5	R5	1.0	5,500	T100	0	N of L Afternoon
run 13	5	R6	1.2	9,600	S100	0	cornice-drift rel 100-yr
run 14	5	R6	1.2	9,600	S100	150	Hi C
run 15		R6	1.2	9,600	S100	75	Low C
run 16	5	R7	0.8	14,800	T100	0	2 east rel.
run 17	5	R7	0.8	14,800	T100	150	1 east rel.
Mineslide, Dog leg							
run 18	3	R1	0.7	1,030	T100	0	
run 19	3	R2	0.7	1,850	T100	0	N release
run 20	3	R3	0.7	920	T100	0	S release
run 21	3	R4	0.7	800	T100	0	wider S rel.
run 22	3	R4	0.7	800	T100	0	10% cutoff vol; dep matches 2019
run 23	3	R4	0.8	915	T100	0	calibrated to 2019
run 24	3	R4	0.9	1,030	T100	0	100-yr design-magnitude
run 25	3	R2	0.5	1,320	T100	0	
run 26	3	R2	0.5	1,320	T100	0	10% cutoff vol
run 27	3	R5	0.8	4,840	T300	0	300-yr
run 28	3	R6	0.8	2,300	T100	0	ext rel N
run 29	3	R7	1.0	1,500	T100	0	adj rel per terrain
Frazer, Bavarian, Bong				N-vol(m3)	S-vol(m3)		
run 30	3	R1	1.2	14,500	11,700	M100	initial run
run 31	3	R2	1/0/1.2	12,000	11,700	M100	adj rel. ht for terrain
run 32	3	R3	1/0/1.2	17,800	13,700	M100	revise R2 to fit forest
run 33	3	R4	.75/85	8,100	13,100	S30	30-yr
run 34	3	R5	.9/1.1	9,700	16,900	M100	100-yr
run 35	3	R6	.8/1.1	8,700	16,900	M100	100-yr reduce N rel sli
run 36	3	R7	1.0/1.3	10,800	20,000	M300	300-yr
run 37	3	R6-for	.8/1.1	8,700	16,900	M100	add forest friction
run 38	3	R7-for	1.0/1.3	10,800	20,000	M300	300-yr-forest friction
run 39	3	R8	1.1	14,900	-	M300	incr. 300-yr vol.
run 40	3	R8	1.5	18,700	-	M300	incr rel ht. 300-yr vol.
run 41	3	R4	1.3-1.5	14,100	37,100	M300	300-yr Bav big
run 42	3	R1	1.2	27,000	S100	0	rel from RB
run 43	3	R1	1.2	28,300	S100	0	adj rel per aerial, esp Bong
run 44	3	R3	1.3	40,400	S300	0	300-yr



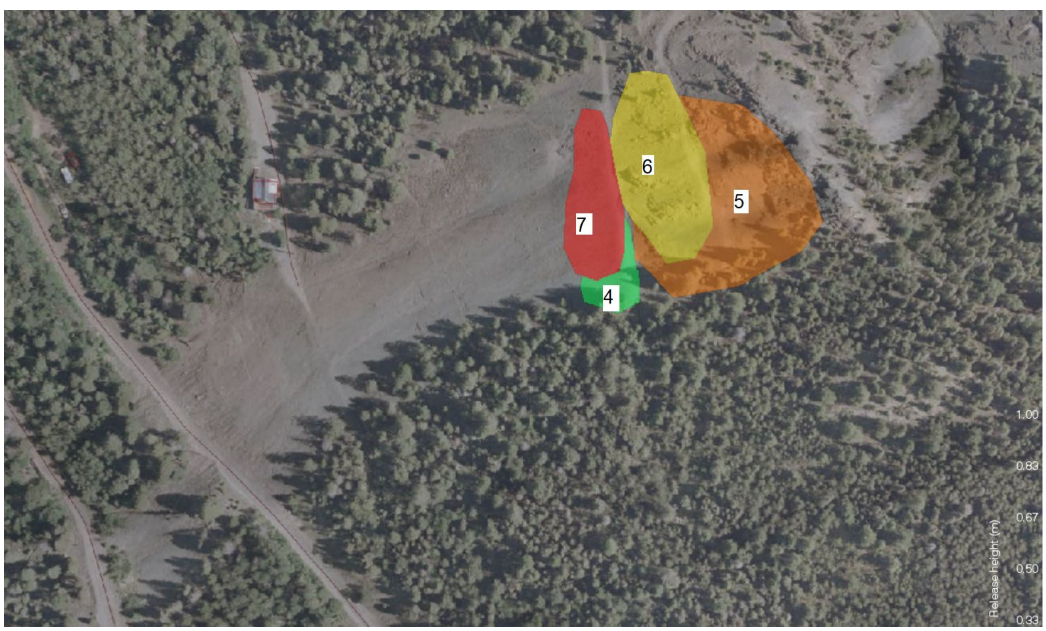
Release areas – above Snow Bear Lodge



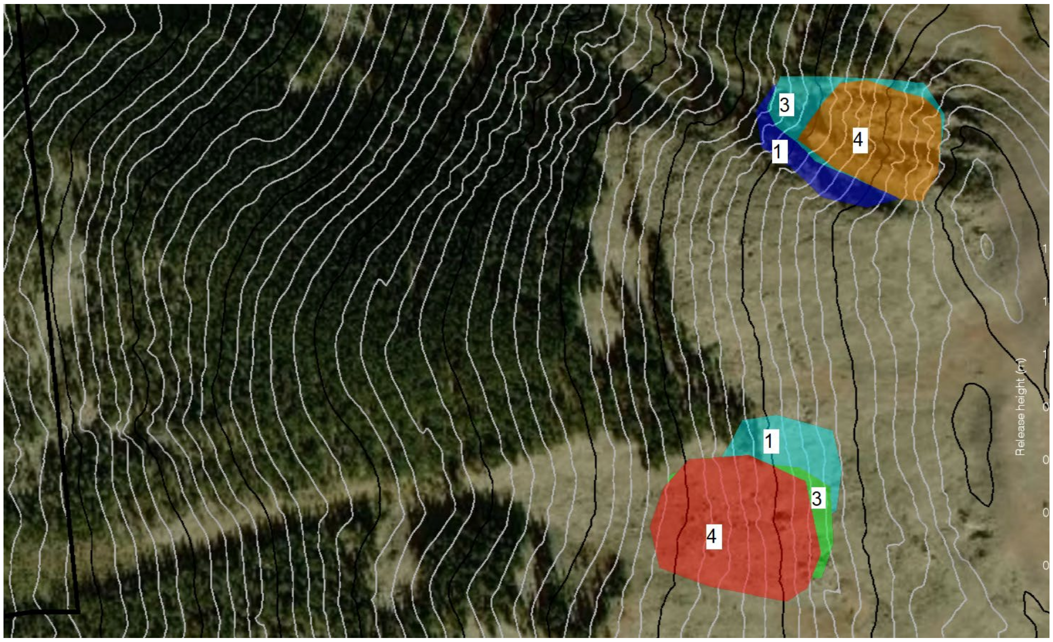
Release areas - Northside



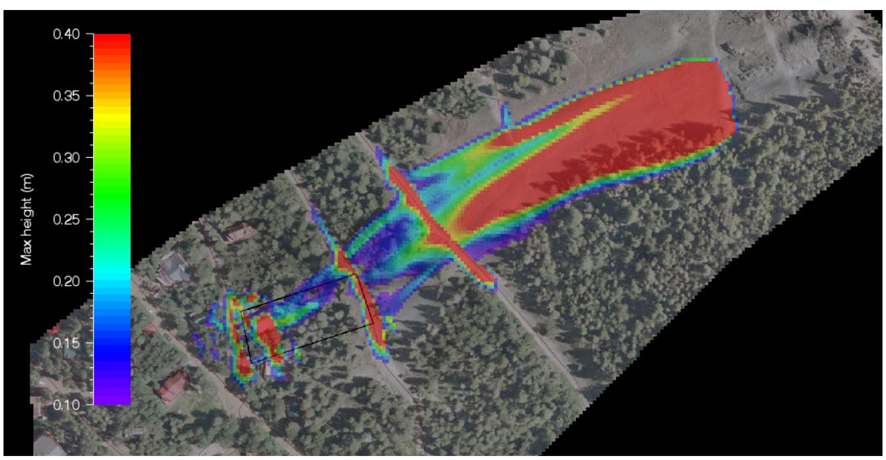
Release areas – Dog leg area



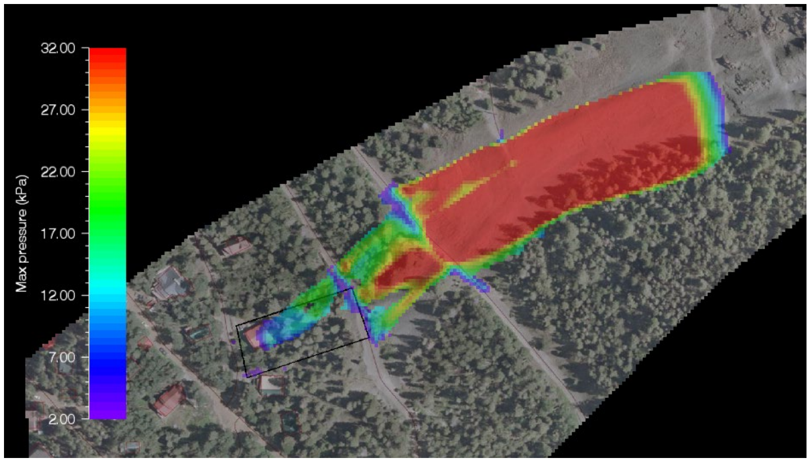
Release areas - Mineslide



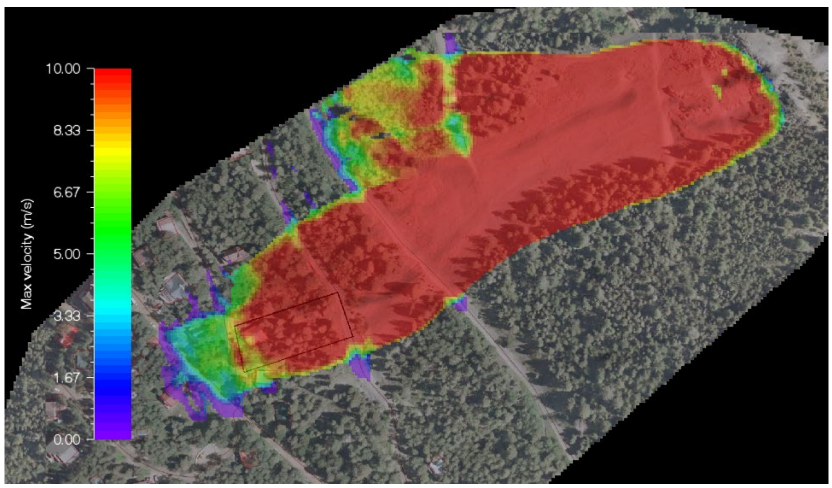
Release areas – Frazer, Bavarian



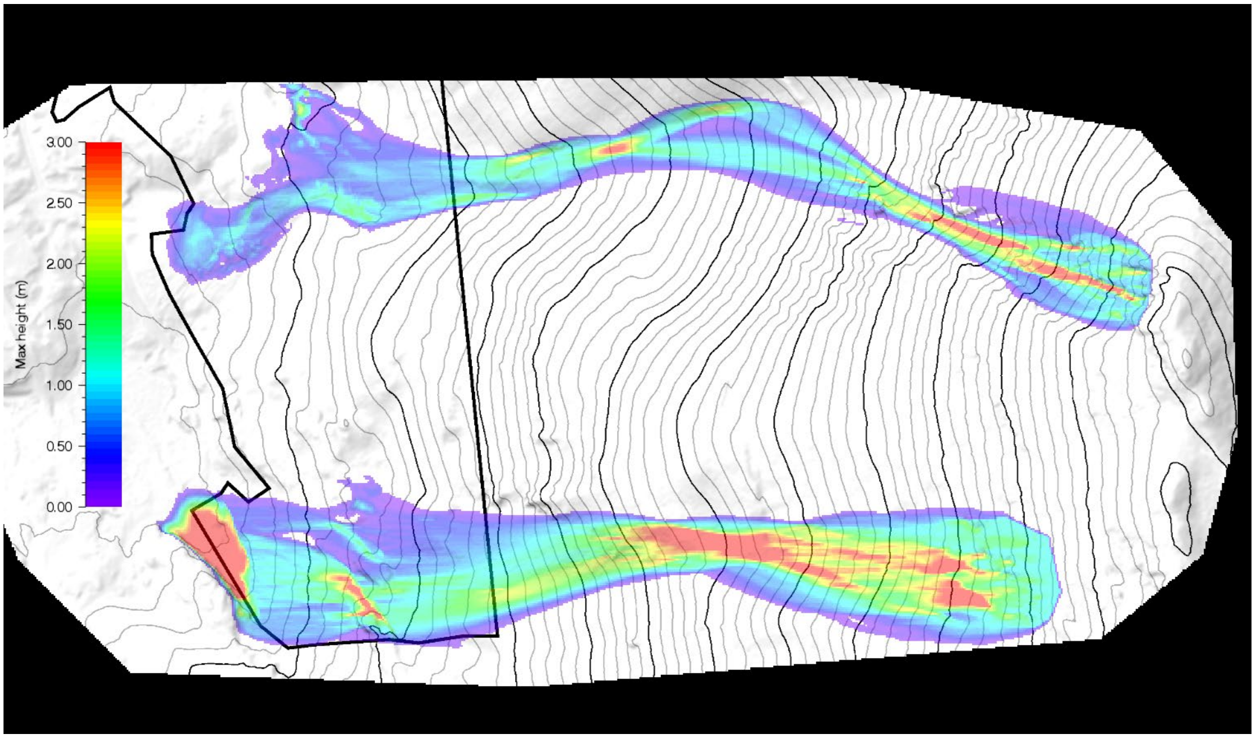
Mineslide Run 24 – height



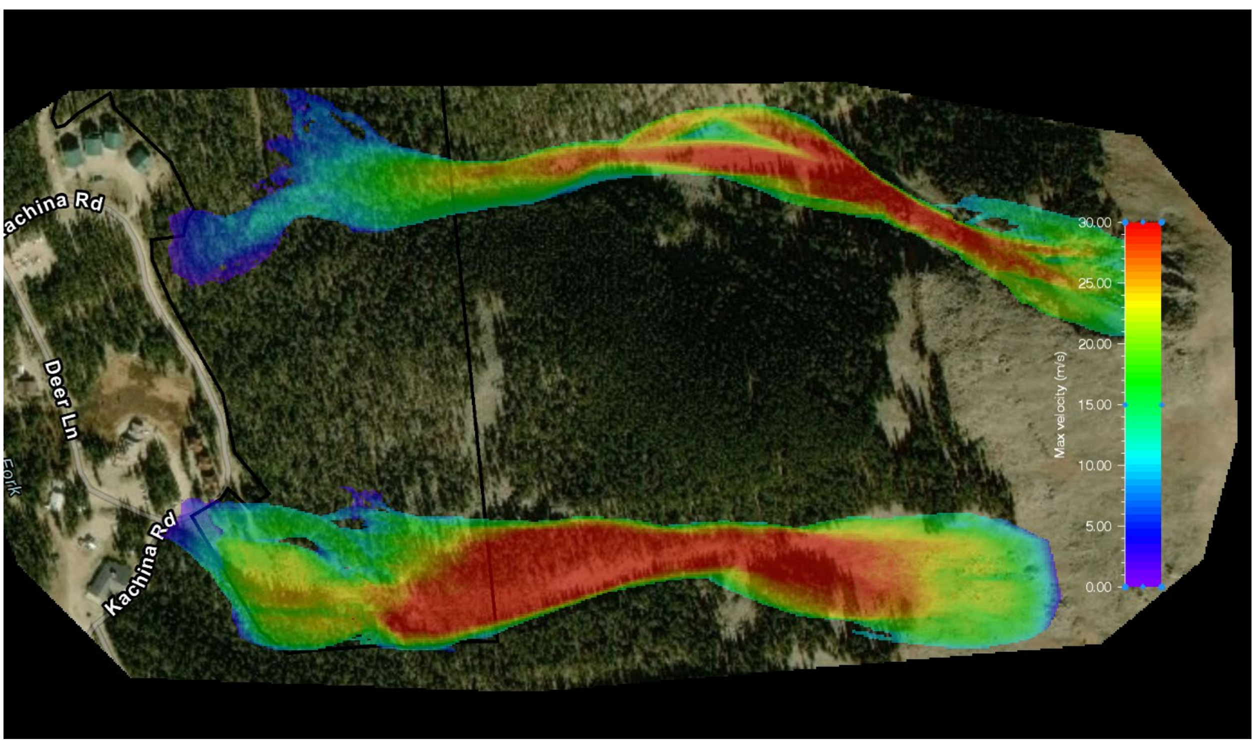
Mineslide Run 24 – pressure



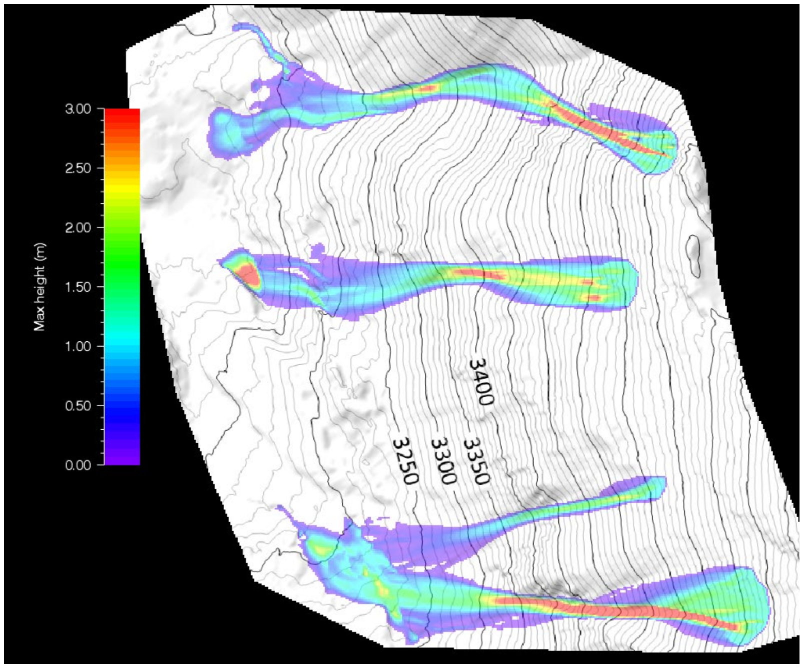
Mineslide Run 27 – velocity



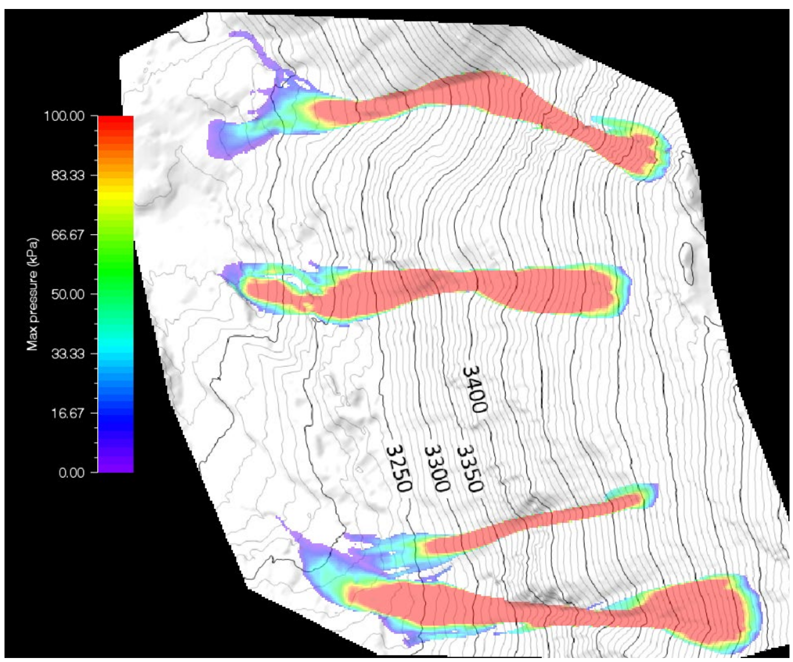
Run 36 – maximum flow heights, Bavarian & Frazier Mtn.



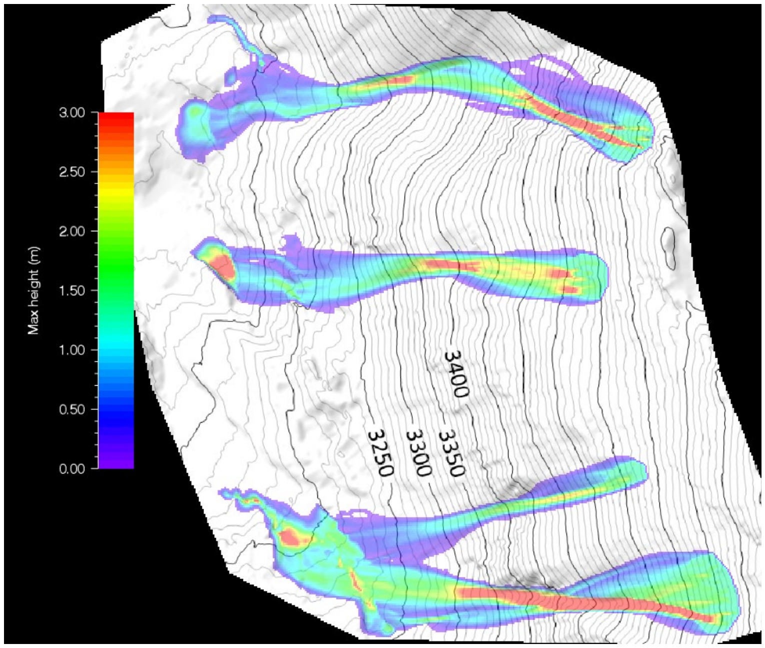
Run 36 – maximum velocities, Bavarian & Frazier Mtn.



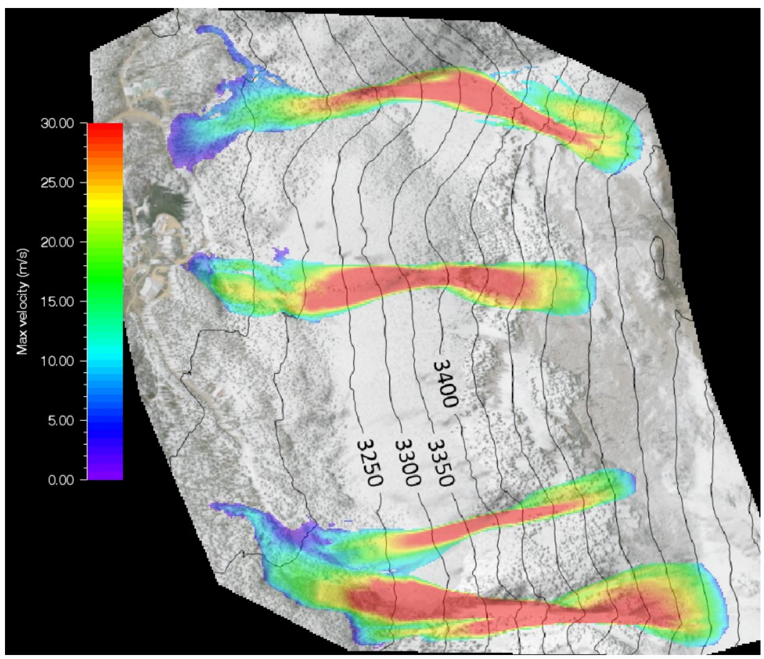
Run 43 – maximum flow heights, Frazier, Bavarian, Bong, Peace



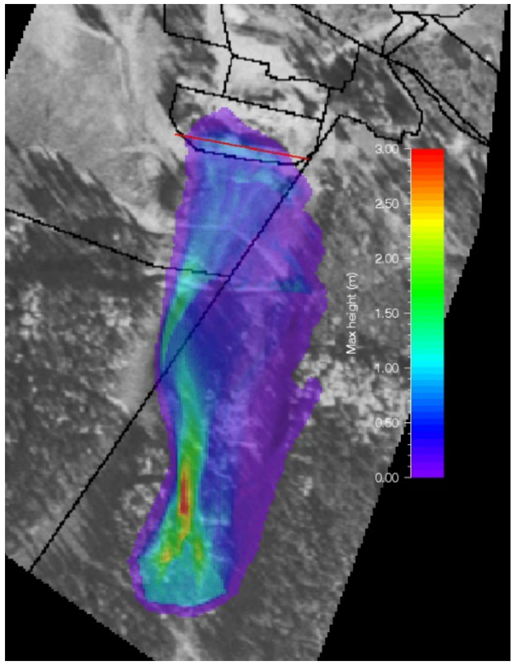
Run 43 – maximum pressures, Frazier, Bavarian, Bong, Peace



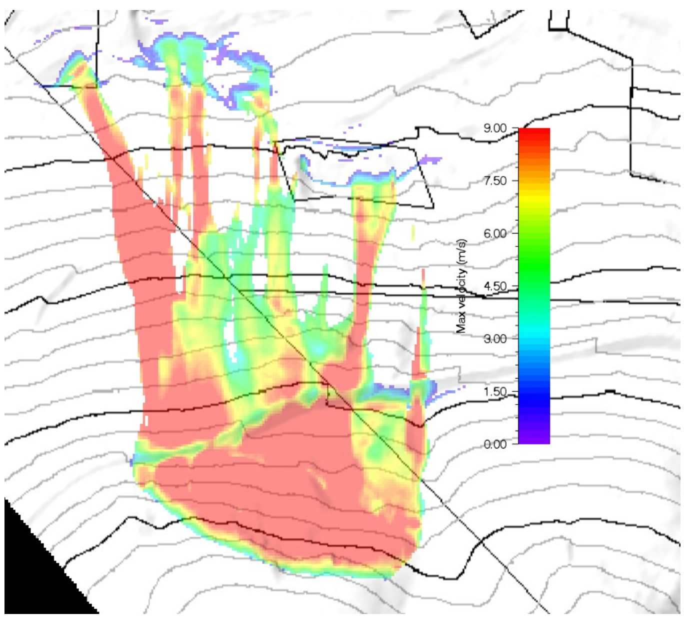
Run 44 – maximum flow heights, Frazier, Bavarian, Bong, Peace



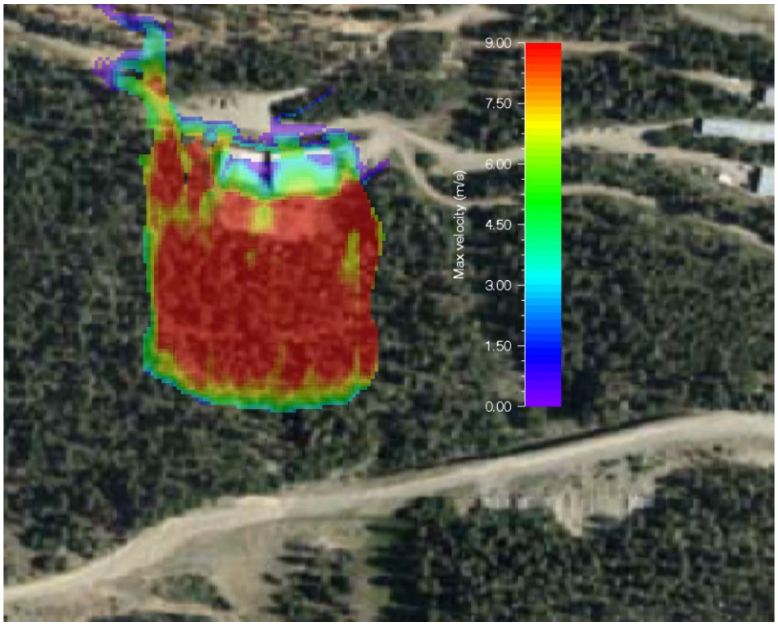
Run 44 – maximum pressures, Frazier, Bavarian, Bong, Peace



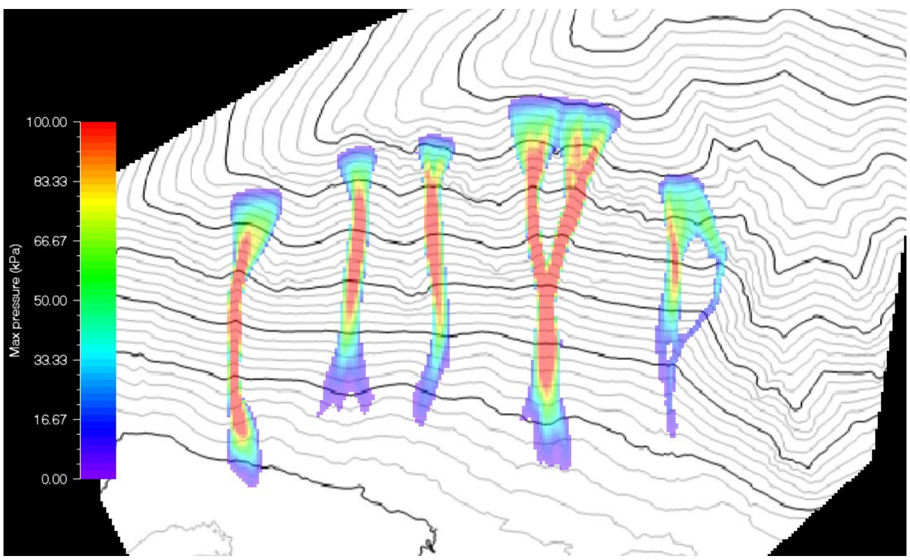
HSB Run 6 – height



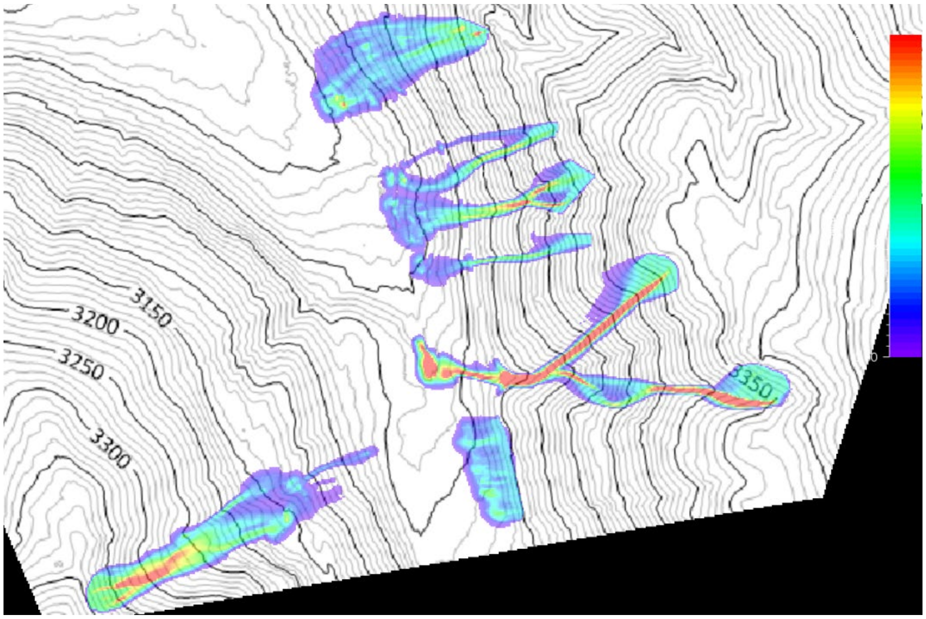
Snowbear Run 4 – height

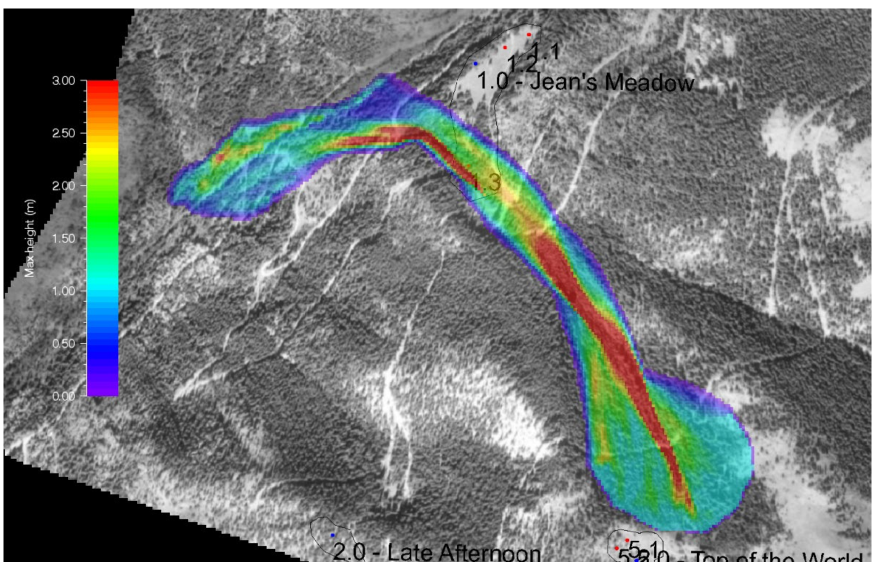


Snowbear Run 3 – height

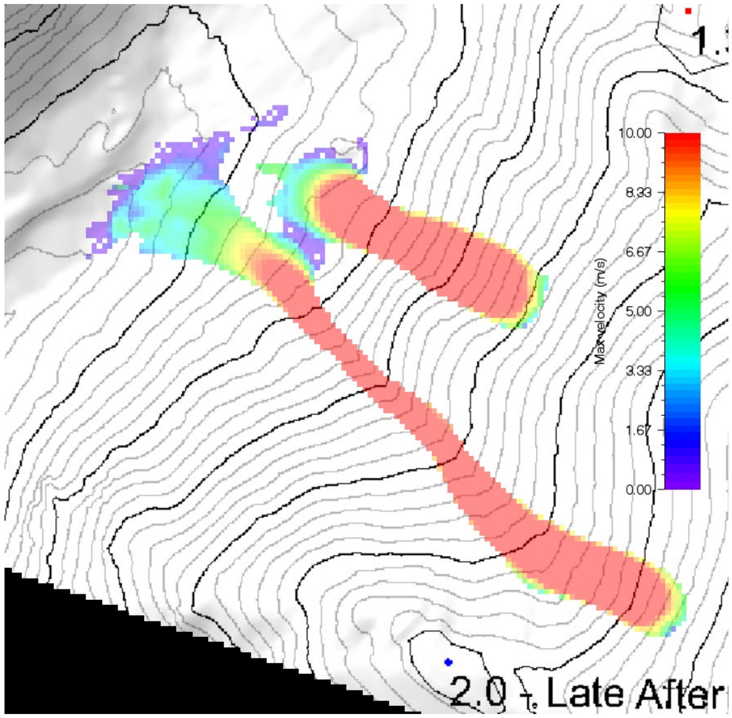


Amizette Run 11 – height





Northside Run 3 – height



Northside Run 12 – velocity