TOWN OF VAIL

1309 Elkhorn Drive
Vail, Colorado 81657
vailgov.com

Public Works/Transportation Department
970.479.2158
970.479.2166 fax

November 28, 2017

This cover sheet is included on three documents commissioned in the summer of 2015 for the purpose of submitting a proposal to the Planning and Environmental Commission (PEC) to “renovate and extend” the Vail Trail. The documents are provided separately to reduce file size. They include:

1) Vail Trail Extension – Eastern Segment: Environmental Impact Report
2) Vail Trail Extension – Western Segment: Environmental Impact Report
3) Draft Rockfall, Avalanche and Debris Flow Hazard and Risk Assessment for Town of Vail Trail Improvements and Extension

At the time the reports were commissioned, the town was proposing two trail projects. The first project proposed to widen and realign segments of the existing Vail Trail (connecting Golden Peak to the Golf Course Clubhouse) and to extend it eastward to the Katsos Open Space. This is the “Western Segment”. The second project proposed to add new trail across the Katsos Open Space towards the Vail Memorial Park, the “Eastern Segment”. Both projects required PEC and Forest Service approval and these reports were the first step in that approval process.

A third study was commissioned to review the potential of rockfall/avalanche hazards due to new/realigned trail segments in that area.

In April of 2016, the Town Council directed staff to halt all ongoing work on the Vail Trail projects due to public concerns and to instead work towards an update of the 1994 Comprehensive Open Lands Plan which included a trails component.

Please note the following when reviewing these documents:

- The Western Segment was proposed to be widened and partially realigned. That is no longer a recommendation. Instead, the Open Lands Plan Update recommends leaving the existing Vail Trail as a narrow, meandering trail, largely in its existing condition. The extension on the eastern end would require additional evaluation.
- The studies evaluate a specific trail alignment that was flagged in 2015. The studies anticipate the trail would be constructed within 25’ of that flagged alignment. Trail ideas identified in the Open Lands Plan Update do not propose specific trail alignments and are instead simply conceptual connections. The alignments proposed for the 2015 Vail Trail projects may no longer be relevant given the recommendations of the OLP Update.
- These documents were never submitted as part of a formal PEC or USFS review.

DRAFT
ROCKFALL, AVALANCHE AND
DEBRIS FLOW HAZARD
AND RISK ASSESSMENT

for

TOWN OF VAIL TRAIL
IMPROVMENTS AND EXTENSION
EAGLE COUNTY, COLORADO

Prepared for:

Gregg Barrie
Senior Landscape Architect
Public Works Department
Town of Vail

Prepared by:

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

and

Wilbur Engineering, Inc.
Durango, Colorado

April 26, 2016

Arthur I. Mears, P.E., Inc.
Natural Hazards Consultants
555 County Road 16
Gunnison, CO 81230
Tel/Fax: (970) 641-3236

April 26, 2016

Gregg Barrie
Senior Landscape Architect
Public Works Department
Town of Vail
Via email

Re: DRAFT Report - Avalanche, Debris Flow and Rockfall Hazard Impact Assessments
The Vail Trail Proposed Improvements and Extension, Vail, Colorado

Dear Mr. Barrie:

This letter presents our preliminary assessment of the effects of a proposed trail extension and realignment of the Vail Trail. It is based on a review is existing information and study of terrain and aerial photos. The conclusions and recommendations should be considered preliminary and subject to change based on observations to be made during snow-free conditions.

We hope that this report provides the information that you need at this time. Please let us know when we should schedule our site visit and field observations. Chris Wilbur and I look forward to discussing the preliminary findings of this report with you and completing the next phase of this project.

Sincerely,

Arthur I. Mears, P.E

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Objectives

This report has the following **objectives**:

1. Describe the geologic hazards[1] that can affect the existing and proposed trail and adjacent resources.
2. Summarize existing geologic hazard information, including hazard maps, reports and photos.
3. Describe the methods, assumptions and findings on potential impacts to geologic hazards that will result from proposed trail re-alignments and extensions.
4. Make recommendations, including conceptual mitigation measures for any areas identified where the proposed trail improvements cause an increase in geologic hazards.

Limitations

This Preliminary Report also has the following **limitations** which must be understood by all those relying on the conclusions and recommendations presented in this report:

1. The findings, conclusions and recommendations are subject to revision following on-site field observations made during snow-free conditions.
2. This report is limited to assessment of the geologic hazards of snow avalanches, debris flows, debris avalanches and rockfall. Other geologic hazards including, but not limited to landslides, expansive soils, earthquakes are not within the scope of this report.
3. The scope does not include geotechnical engineering, local or global slope stability evaluations, civil engineering designs or any other disciplines outside of those listed above.
4. We have assumed that all residential structures within the mapped geologic hazard zones adopted by the town of Vail have been designed and constructed to mitigate their current (pre-trail construction) exposure to geologic hazards or that the owners and residents are aware of their exposure to existing geologic hazards.
5. This report is site & time specific. Geologic hazards vary widely with location and the findings of this report should not be applied to other sites. New data and methods will improve our understanding of the geologic processes, as well as forecasting, detecting and mitigation measures in the future.
6. We have assumed existing forest, terrain and climatic conditions. Changes to these conditions could increase or decrease the geologic hazards.

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[1] Geologic hazards in this report are subject to limitation #2 described below.

Background

The town of Vail plans to extend the existing Vail Trail about 11,800 feet to the east and re-align about 2500 feet of existing trail, as shown in Figure 1. The planned extension and re-alignment will result in tree removal and grading that may affect existing known geologic hazard areas. The town's land use code requires that development in geologically sensitive areas "will not increase the hazard to other property or structures, or to public buildings, rights of way, roads, streets, easements, utilities or facilities or other properties of any kind." This report describes existing information on geologic hazards, evaluates potential impacts of the trail improvements and provides recommendations to mitigate potential adverse impacts of trail construction, including related grading and vegetation removal.

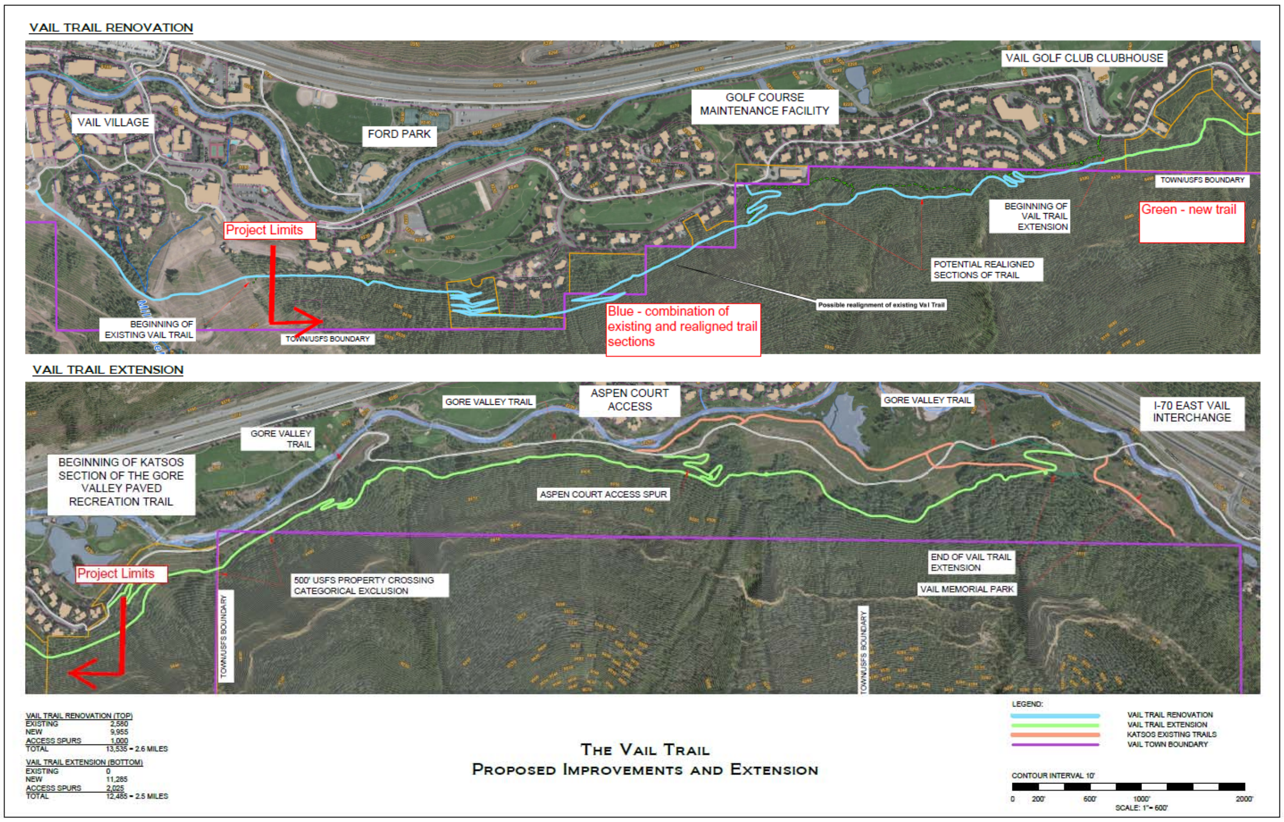

Figure 1 – Project Location on Aerial Photo

Site Conditions

Figure 2 shows the project area on a topographic map shaded to indicate slope steepness. The slopes above the trail extend from 1200 to over 2100 vertical feet above the site with typical slope angles of 25 to 45 degrees. The trail alignment crosses slopes ranging from

17 degrees above Vail Valley Drive to 38 degrees above Golf Terrace. A series of cliffs bands exists above most of the trail. At the west end cliffs are about 40 feet tall and their bases are about 500 feet above the trail. The eastern section of the trail has 100-foot tall cliffs about starting about 600 vertical feet above the planned trail alignment. Existing buildings shown in Figure 2 are set back from the steep slopes varying distances, but many lie within the range of debris flows, rockfall and snow avalanches. The entire planned trail extension and re-alignments are within these mapped hazard zones.

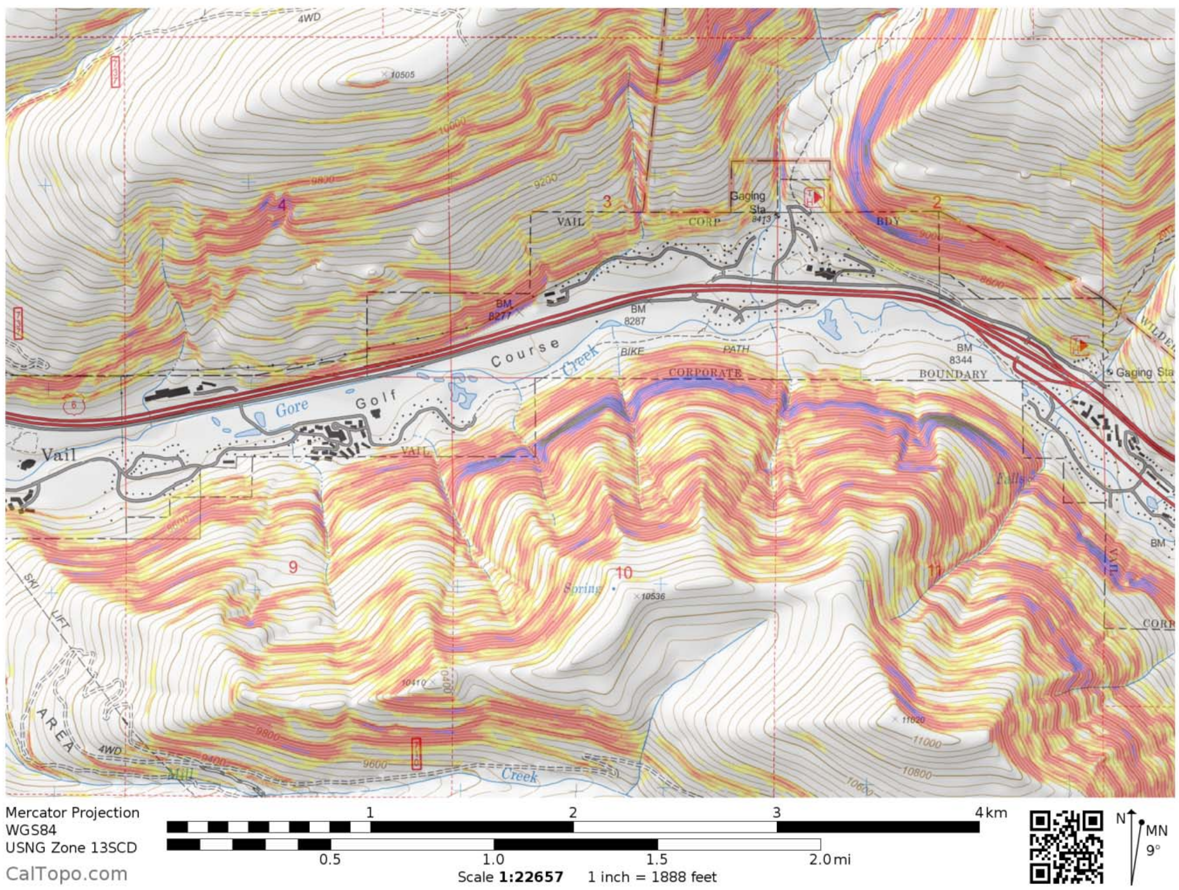

Figure 2 – Trail Alignment and Buildings on CalTopo Slope Shaded Topographic Map

Geology

Figure 3 shows a geologic map of the south side of the Vail Valley and the planned trail location. The Vail Valley exhibits the classic U-shape caused by alpine glaciation that originated in the Gore Range to the northeast. The glaciers retreated from the valley about 15,000 years ago at the end of the Pinedale glaciation. Since that time other slope and channel erosion processes have altered the terrain. Those processes include both minor and major slope movements and landslides, as well as alluvial, colluvial, debris flow and snow and debris avalanches.

The small steep drainages incised into the north-facing glaciated slopes have formed classic conical shaped alluvial or debris fans. The rates of erosion and fan deposition have probably decreased over time, but the processes are still active. The dominant processes in forming the debris fans appears to be debris flows and debris avalanches, but snow avalanches also contribute some material.

Most of the terrain above the planned trail consists of gently dipping Pennsylvanian Minturn formation. The Minturn formation consists of interbedded sandstone, shale, conglomerates, isolated limestone beds and bioherms. Local dip is to the northeast. A large rockslide in this formation closed westbound lanes of I-70 west of Vail in 1989. Claystone beds within the Minturn form failure zones in earthflow type landslides near Dowds Junction (Ref. 1).

At the west end of the project the upper slopes include glacial till (Qtb in Figure 3) along with old and young landslide deposits above Fan 3.

Most of the trail alignment is on post-glacial deposits of either colluvium (unconsolidated soil and rock derived from local gravity transport of uphill materials) or alluvial/debris fan deposits. Additional information about the Vail Valley geology is described in References 2 and 3.

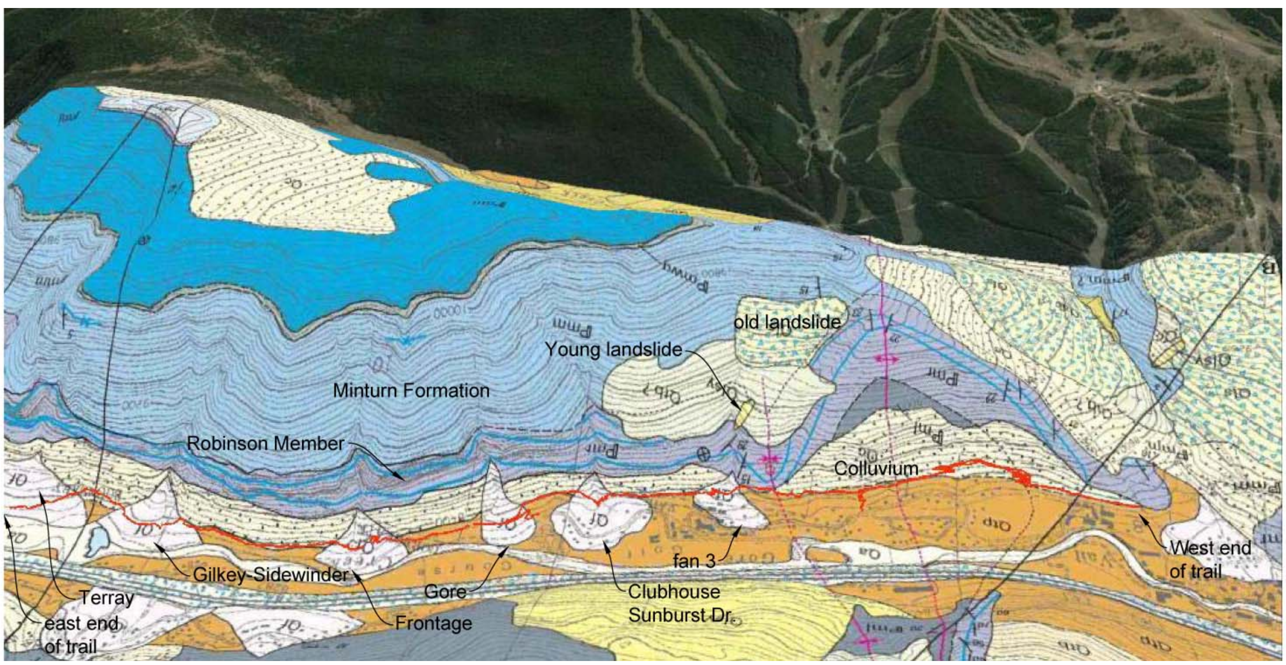

Figure 3 –Aerial view of Trail and Geologic Map Draped on 30m Digital Elevation Model (The view is looking south and the map source is modified from Ref.2)

Surface and Vegetation

Slopes above the planned trail are vegetated with aspen and spruce, fir and pine forests. Mountain shrub and willows also are present. Many linear clearings with the forests are visible on aerial photos on steep slopes. The drought period that peaked in 2002 stressed much of the vegetation in Colorado, including the Vail Valley.

Geologic Hazards

The town of Vail has official planning maps for sensitive geologic areas, including Avalanche, Debris Flow/Debris Avalanche and Rockfall Hazard Maps. These maps have guided development and hazard mitigation since adoption of each map. The maps are based on a variety of studies listed including those listed in the References of this report.

Rockfall

The official Vail Rockfall hazard map is based on a 1984 detailed study (Reference 4). The 1984 study identified medium and high severity rockfall Hazard Zones. Table 1 summarizes their distribution for the new, re-aligned and existing trail sections between re-alignments.

Table 1 – Rockfall Hazard along Trail

Rockfall Hazard	Description	Trail distance (ft)	percent
med.	re-aligned trail	943	7%
not rated	re-aligned trail	899	7%
high	new trail	11,813	87%
	TOTAL	13,655	100%

Avalanche Hazard

The official Vail Avalanche hazard map is based on multiple studies, including but not limited References 5 and 6. The Official Avalanche Hazard Map includes categories of High Avalanche Hazard, Moderate Avalanche Hazard and Potential Avalanche Influence Zone. Table 2 summarizes their distribution for the new, re-aligned and existing trail sections between re-alignments.

Table 2 – Avalanche Hazard along Trail

Avalanche Hazard	Description	Trail distance (ft)	percent
high	new trail	5,230	38%
moderate	new trail	1,785	13%
not rated	new trail	1,762	13%
poss. Infl zone	new trail	3,036	22%
not rated	re-aligned trail	1,091	8%
poss. Infl zone	re-aligned trail	751	5%
	TOTAL	13,655	100%

Debris Flows/Debris Avalanches

The official Vail Debris Flow and Debris Avalanche hazard map is based on a 1984 Study (Reference 7). Table 3 summarizes hazard distribution for the new, re-aligned and existing trail sections between re-alignments.

Table 3 – Debris Flow/Debris Avalanche Hazard along Trail

Debris Flow/Avalanche Hazard	Description	Trail distance (ft)	percent
High Debris Avalanche	new trail	6,775	50%
High Debris Flow	new trail	677	5%
Moderate Debris Flow	new trail	2,949	22%
not rated	new trail	1,412	10%
High Debris Avalanche	re-aligned trail	1,046	8%
Moderate Debris Flow	re-aligned trail	156	1%
not rated	re-aligned trail	640	5%
	TOTAL	13,655	100%

Methods

Previous Reports

The geologic hazards of the Vail Valley have been described in many studies. We reviewed those listed in the References of this report. Additional unpublished studies also exist, but we do not have access to these report.

Historic Events

We interviewed the town's Chief Building Official Martin Haeberle and Senior Building Inspector, JR Mondragon, regarding building or property damage within the project area caused by geologic hazards. They reported that the major events within Vail have been outside of the project area. The most significant event within the project area was a snow avalanche that ran onto the Clubhouse fan, but did not reach the developed area along Sunburst Drive. They were uncertain of the month or year of this event.

Terrain Analysis

The town of Vail has excellent topographic mapping of the project area with 2 foot contours. These maps were used to characterize slopes and landforms including debris fans, landslide areas, channel incision and other characteristics that can be used to evaluate geologic processes.

Aerial Photo Analysis

We analyzed aerial photos taken in 1962, 1998, 2004 and 2008 to evaluate vegetation and visible surface conditions for the project area.

Modeling

We applied the 2-dimensional rockfall model CRSP Version 4 (Ref. 8) to quantify the effects of the planned 4-foot wide trail on rockfall energy and bounce heights above critical areas. We analyzed the probability of rocks bouncing at the trail location and the energies and bounce heights of rocks with trajectories and energy losses due to trail impacts. Table 1 summarized the results and model geometry. The model results indicate that a soft surface trail with a flat or uphill cross slope cause the greatest energy dissipation and hazard reduction for downhill resources.

Table 4 – CRSP Rockfall Model Results Summary

Case	Rock Size (ft)	Rock shape	% reach trail	%reach bldgs.	avg. vel. near bldgs. (ft/s)	avg trail bounce (ft)	avg bounce near bldgs. (ft)
no trail	3	sphere	100	100	52	0.41	0.73
flat hard trail	3	sphere	100	100	42	0.26	0.52
soft flat	3	sphere	100	100	40	0.18	0.52
soft slope UH 8%	3	sphere	100	100	38	0.17	0.39
soft slope DH 8%	3	sphere	100	100	42	0.20	0.41

Field Observations

Field observations are scheduled for late spring after the snow has melted from the project area.

Trail Segments

We divided the trail sections into two categories, based on landforms. For description purposes, segments are classified as either *colluvium slopes* or *debris fans*. Both landforms can be impacted by all types of geologic hazards, but some general distinctions can be made. For example, colluvium slopes tend to be steeper and will have higher rockfall energies and bounce heights than debris fans, assuming similar sources of rockfall. Large high speed long runout avalanches with a powder component are limited to debris fans below channelized basins that extent 1500 to 2800 feet above the valley floor. Smaller, slow-moving wet avalanches occur on colluvium slopes between the debris fans with relatively high frequencies (1 to 5 year return periods). Much larger wet avalanches can also occur in the larger basins, but these will usually stop before reaching the debris fans. Also debris avalanches of snow, soil, vegetation occur on colluvial slopes. Some large wet avalanches can also reach the fans after starting in upper slopes. Fan 3 and Clubhouse are recent examples.

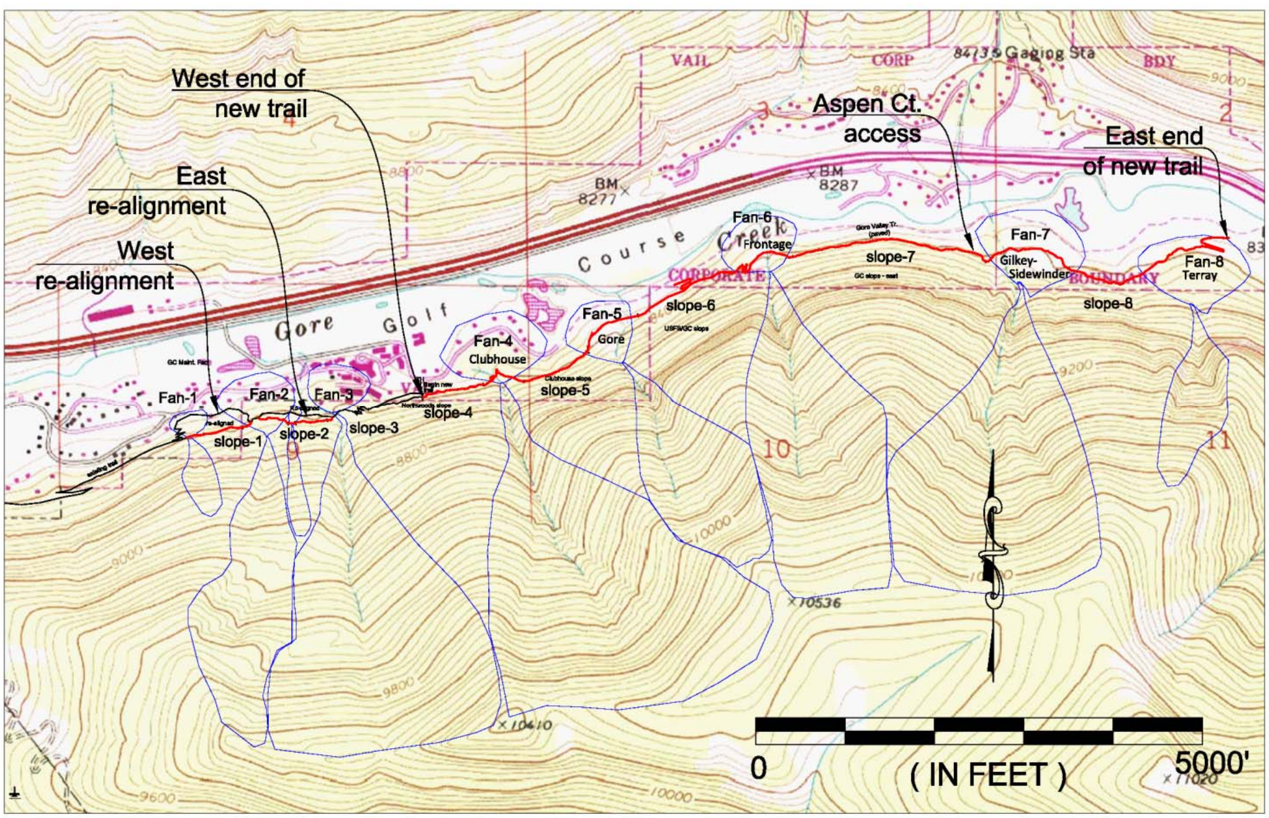

Figure 4 –Trail Segments

Existing Trail West End

Fan 1 Re-alignment

Fan 1 is the smallest debris fan with the smallest basin in the project area. The proposed trail realignment would move the trail from the lower part of the fan to near the apex of the fan. Vegetation patterns (Figure 5) and topography indicate that the new portion of the fan will be subject to greater erosion and deposition at the new location than the existing location.

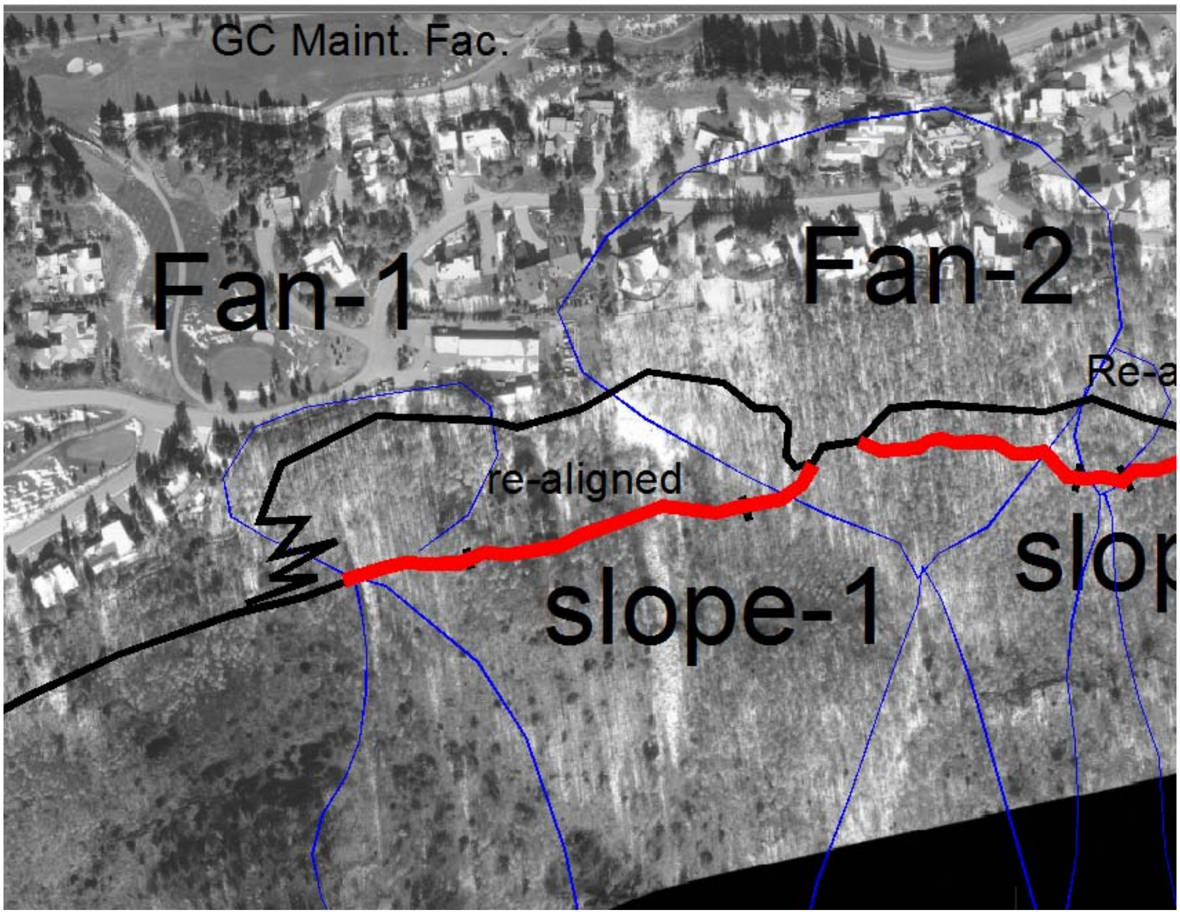

Figure 5 – 1998 Aerial from Debris Fan 1 to Debris Fan 2

Slope 1 Re-alignment

Vegetation clearings shown in Figure 5 indicate that the realignment to higher on the slope will result in more frequent debris and snow avalanche processes crossing this segment of trail.

Debris Fan 2 Re-alignment

The drainage basin for Fan 2 contains ancient and recent landslide deposits that could be subject to reactivation in a series of wet years and produce debris flows and debris avalanches. Aerial photography from 1998, 2004 and 2008 suggest that Fan 2 has been relatively inactive in recent decades.

Colluvium Slope 2 Re-alignment

Colluvium Slope 2 is a relatively narrow slope without cliff outcrops or significant forest clearings.

Debris Fan 3 Golf Terrace

Debris fan 3 appears to be a relatively active fan based on vegetative indicators and fan geometry. The channel has an abrupt 45 degree left bend near the fan apex and is incised about 20 feet deep. The existing trail crosses the channel below the deep incision.

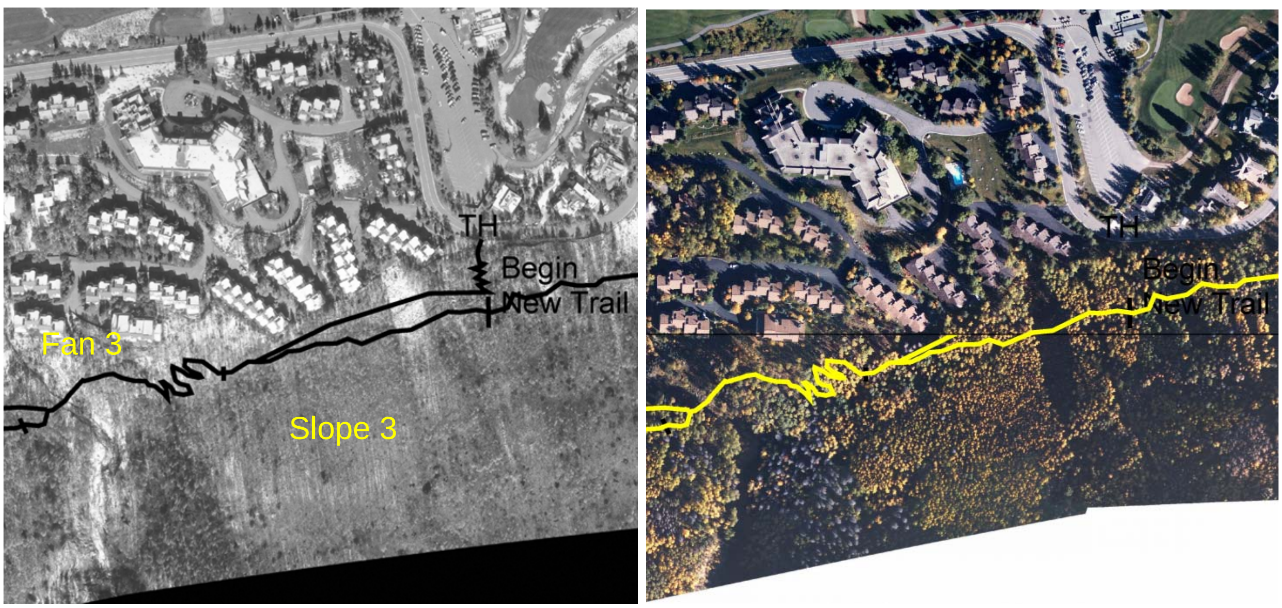

Figure 6 – 1998 & 2004 Aerials of Slope 3 and Debris Fan 3

Slopes 3 and 4

Slopes 3 and 4 are adjacent and continuous slopes above Golf Lane. Slope 3 is above the existing trail and exhibits forest clearings that indicate frequent debris and/or snow avalanche activity (Figure 6). Slope 4 is above the existing eastern trailhead for the Vail Trail. Slopes 3 and 4 can produce snow and/or debris slides and rockfall above or within the colluvium. All begin at or below the prominent Minturn Formation ~ 400-500 feet above the valley. Many observations in 1984 indicated the debris slides were mixed snow and debris including entrained vegetation including aspen trees and their root systems. They often began as soil slips 1-3 feet deep, rarely as deeper rotational failures within the colluvium. In some cases they were triggered by a combination of infiltration directly from the overlying, unusually deep snowpack and piping to the surface soil at boundaries in the bedrock. No events were observed but probably reached maximum speeds of <10m/s and stopped quickly when ground slopes were less than 10 degrees. Rockfall is also a potential hazard from these slopes although some boulders at the valley bottom may also be glacial till.

Fan 4 Clubhouse/Sunburst Dr.

The Clubhouse avalanche path can reach Fan 4 in the Sunburst Drive area. This fan is exposed to low frequency high energy snow avalanches and debris flows. It was studied in 1972 by Borland (Ref. 6). He reported that the Clubhouse avalanche path has a starting zone of about 40 acres and a total vertical fall of about 1600 feet. In 1972, aspen trees in the runout zone on the alluvial fan were about 30 years old, based to tree coring. The estimated return period to the alluvial fan was 30 to 100 years.

Borland described at least six wet slides at the south end of the Clubhouse property with vertical falls of 50 to 300 feet and frequencies of 2 to 5 years.

We applied the Swiss avalanche dynamics model, RAMMS (Ref. 9) to the Clubhouse avalanche path to evaluate the effect of 3-dimension terrain on flow paths. Figure 7 shows the model predicted runout and maximum velocities for a cold dry avalanche with an estimated return period of about 30 years.

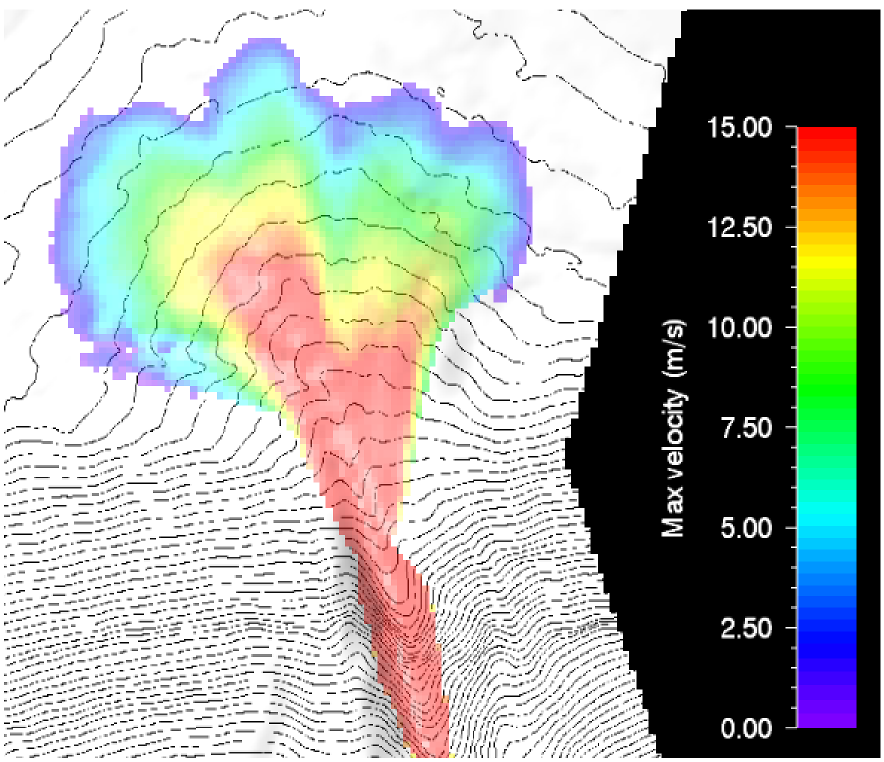

Figure 7 – RAMMS Avalanche Model Runout Prediction for 30-year Event

Figure 8 – 1962 & 2006 Aerials of Clubhouse Debris Fan

West End – Fan 5 Frontage to Fan 7 Terray

East of the Clubhouse debris fan, the proposed new trail crosses four additional debris fans and four colluvial slopes. Terrain and photo analyses indicate that the most active geologic processes are wet avalanches and debris avalanches, especially towards the east end of Colluvium Slope 7. Cliff bands above the planned trail could produce rockfall along this entire section of trail.

Resources at Risk

Within the project area, there are permanent and temporary resources exposed to geologic hazards. The permanent resources consist of buildings, roads and other infrastructure. Temporary resources consist of trail users and residents and visitors outside of buildings. The risk of these two categories differs due to exposure time and vulnerability and was assessed separately.

Buildings

Table 5 lists the number of existing buildings along the trail alignment that are within existing geologic hazard zones based on the adopted Town of Vail Official hazard maps. The level of risk for each building is determined by the frequency and severity of the hazard and the vulnerability (strength, width, orientation, etc.) of each building. The proposed trail construction and realignment could affect the frequency and magnitude of geologic hazard events, either adversely or positively. The factors and effects of trail construction on risk are described in the Conclusions and Recommendations of this report.

Table 5 – Resources Exposed to Geologic Hazards

Slope/fan number	Description	Buildings in Avalanche Zones	Buildings in Debris Flow Zones	Buildings in Rockfall Zones
Slope 1	W end re-align	2 pot.	1 high	2 med.
Slope 2	W Golf Terrace re-align	0	0	0
Slope 3	E Golf Terrace re-align	0	0	0
Slope 4a	Northwoods exist tr.	2 pot.	4 high	5 high
Slope 4b	Northwoods new tr.	0	0	3 high
Slope 5	Clubhouse	1 pot.	3 high	1 high
Slope 6	USFS/Golf Course	0	0	0
Slope 7	E Golf Course	0	0	0
Slope 8	E end new tr.	0	0	0
Fan 1	W end small fan	0	0	0
Fan 2	Vail Valley Dr.	1 pot.	4 mod.	2 med.
Fan 3	Golf Terrace	0	0	3 med 1 high
Fan 4	Clubhouse	13 pot.	13 mod.	14 high
Fan 5	Gore	0	0	0
Fan 6	Gilkey-Sidewinder	0	0	0
Fan 7	Terray	0	0	0

Trail Users

Trail users and persons outside of buildings will also be exposed to geologic hazards described in this report. In general, the frequency of rockfall, avalanches and debris flows/avalanches will be low compared to the total time that persons are exposed to those hazards. The level of risk to trail users will be similar to many established trails within mountainous areas in Colorado.

Findings & Conclusions

Based on the analyses described in this report, we draw the following conclusions:

1. The proposed construction of a new 4-foot wide soft surface trail will have a very small effect on the geologic processes that pose a threat to existing homes in proximity to the trail.
2. The proposed trail will cause a reduction in velocities and energy levels for debris flows, debris avalanches and rockfall events. This reduced energy level will result in a decrease in the hazard to down-gradient resources, including buildings, roads and other infrastructure.
3. The proposed trail may affect rockfall bounce heights. The trail geometry, orientation and construction details could alter natural rockfall trajectories, velocities and bounce heights. Trail design and construction details described below can be implemented to cause rockfall energy dissipation and reduced runout and thereby

reduce rockfall risk to down-gradient resources, including buildings and town streets.

4. The risk to trail users of injury or death caused by rockfall, debris flow, debris avalanche or snow avalanche is similar to many other trails on public lands in mountainous terrain.[2]
5. The largest concentration of resources exposed to geologic hazards along the trail alignment is from Debris Fan 1 through the Clubhouse fan (Debris Fan 4). The planned new trail in this area, if designed and constructed following the recommendations below, will improve the safety for downhill resources, including buildings, streets and other infrastructure.

Recommendations

The following recommendations for the design and construction of the proposed extension and realignment of the Vail Trail are intended to prevent any increase in geologic hazards to existing resources currently exposed to geologic hazards. The recommendations will result in either a negligible change or a slight reduction in the geologic hazards for existing resources.

1. The trail construction should consist of either fill or combined cut/fill such that the trail hardness is less than the natural ground. This condition is recommended to provide energy dissipation to rockfall. The trail materials and construction specifications should be determined by a qualified geotechnical engineer.
2. In areas with the greatest concentration of resources exposed to geologic hazards (from Debris Fan 1 to Debris Fan 4 on Figure 4), we recommend a trail cross slope into the hill between 5 and 10 percent to achieve a high level of energy dissipation for rockfall impacts.
3. The longitudinal grade of the trail should be less than ten percent (10%) to prevent diversion of debris flows and wet avalanches from their natural trajectories and to decrease flow velocities at the trail location.
4. Trail signage should be installed at trailheads informing trail users of geologic hazards and the conditions that make hazards more likely. Signage could include site-specific signage at the locations most prone to impacts by geologic hazard events. Signage could be interpretive and educational and describe the various types of hazards, historic events and conditions that cause hazards to become elevated such as sustained or heavy rain or snowfall, freeze-thaw cycles, and rapid warming that result in melting of snow and soil saturation, especially during deep snowpack years.

[2] A nearby example of a more serious snow avalanche hazard exists in the East Vail Chutes east of the project. According to the Midwinter 2015 issue of Vail-Beaver Creek Magazine, seven people have died in East Vail avalanches in 24 years.

5. The town may want to issue temporary closures or advisories during high avalanche danger and during rare conditions such as those that caused the debris flow events in May 1984 and other years. Determining thresholds for closures is difficult without monitoring precipitation and soil moisture instrumentation and without substantial data from historic events. As a result of these challenges, closures would be subjective and well-qualified persons might disagree on the need and timing of closures.
6. The town and affected neighborhoods should consider forestry and erosion control measures in areas above the trail that would lead to long-term reductions in the frequency and magnitude of geologic hazard events. Colluvium Slopes 3 and 4 shown in Figure 6 might be suitable sites for this type of mitigation. The feasibility, effectiveness and cost of these measures would require additional site-specific studies. Such measures would like require permission and cooperation of the White River National Forest, the Town of Vail and residents.

References

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