ATTACHMENT E - GEOLOGIC HAZARDS REPORT

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GEOLOGIC HAZARDS REVIEW
PROPOSED TOWN OF VAIL
PUBLIC WORKS FACILITY DEVELOPMENT
1309 ELKHORN DRIVE, VAIL
EAGLE COUNTY, COLORADO

PROJECT NO. 18-7-606

NOVEMBER 6, 2018

PREPARED FOR:

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TABLE OF CONTENTS

PURPOSE AND SCOPE OF STUDY

This report presents the findings of a geologic hazards review of the proposed development of the Town of Vail Public Works Facility, 1309 Elkhorn Drive, Vail, Eagle County, Colorado. The purpose of our study was to assess the potential impacts of geologic hazards on the proposed development at the project site. The study was conducted in accordance with our proposal for geological engineering services to Victor Mark Donaldson Architects dated September 26, 2018.

A field reconnaissance of the project site was made on October 3, 2018 to observe the geologic conditions and collect information on the potential geologic hazards present at the project site. In addition, we have reviewed relevant published geologic information and looked at aerial photographs of the project area. Colorado Rockfall Simulation Program (CRSP) analysis was performed to assess potential rockfall paths, velocities, energies, and bounce heights for mitigation design. This report summarizes the information developed by this study, describes our evaluations, and presents our findings.

PROPOSED DEVELOPMENT

The proposed development is in the preliminary design phase. Our understanding is that the existing Town of Vail Public Works facility will be remodeled and additions made to the north side of the building. It is proposed that the existing cut slope on the north side of the parking/drive area to the north of the existing building will be modified and the cut extended into the hillside to create additional space in the parking area. The existing snow dump area is proposed to be expanded to the west.

SITE CONDITIONS

The project site consists of developed and vacant land located at 1301 Elkhorn Drive, north of Interstate 70, at the southern base of the Vail valley side. The project site is made up of two parcels of land covering a combined area of 20.96 acres. The White River National Forest borders the site to the north. The site is just north of Interstate 70 as shown on Figure 1 and about 1 mile east-northeast of Vail Town Center. Elkhorn Drive ends within the property. Steep slopes of the Vail valley side rise to the north. An old ditch/berm feature and un-maintained two-track road follows the north property line above the existing cut slope.

The site lies mostly on gently sloping terrain down to the south at the transition to the higher elevation south-facing, steep valley side. The proposed development site lies at an elevation of between around 8,260 and 8,340 feet. The source zones of potential rockfall at the site lie at an elevation of between around 8,630 and 8,860 feet. The source zones of potential rockfall are within the White River National Forest boundary. The existing topography is depicted by the three-dimensional surface on Figure 2. The slope across the proposed development site is about 2 to 5 percent in the lower parking and existing building area and around 50 percent in the existing cut slope area. To the north of the project site, directly above the proposed development area, the south-facing valley side has a fairly uniform slope of about 65 percent. Vegetation on the south-facing valley side is native grass, cactus, and scrub oak. Vegetation in the debris fan area consists of native grass and weeds with scattered scrub oak, and scattered sage brush.

The old ditch/berm feature does not appear to be maintained. The ditch/berm structure is currently relatively free of debris. Scattered rocks of up to 2½ feet in diameter are present along the entire ditch/berm.

PROJECT AREA GEOLOGY

The main geologic features in the project area are shown on Figure 3. This map is based on regional mapping by Kellogg and Others (2003) published by the United States Geological Survey.

The project site lies along the axis of the Laramide-age north-south trending Spraddle Creek Fold. Formation rock in the area consists of the Pennsylvanian-age Minturn Formation middle member (Pmm), the Robinson Limestone Member (Pmr), and the lower member (Pml). The lower member consists of arkosic conglomerate, sandstone, siltstone, and shale that is pinkish-gray to grayish-brown. The Robinson Limestone Member is a fossiliferous medium to thick bedded marine limestone interbedded with light tan arkosic pebbly sandstones, siltstones, and shales. The middle member consists of arkosic conglomerate, sandstone, siltstone, and shale that is pinkish-gray to grayish-brown. The bedding dip of the formation rock in the vicinity of the project site is variable and ranges from around 20 to 25 degrees toward the east to 40 to 60 degrees toward the west (Kellogg and Others, 2003).

Surficial deposits in the area include upper Pleistocene-age Pinedale glacial till (Qtp), middle Pleistocene-age Bull Lake glacial till (Qtb), and recent landslide deposits (Qlsy). The Pinedale glacial till consists of sub-angular to sub-rounded gneiss cobbles and boulders in a light tan sandy matrix that is unsorted and unstratified. The Bull Lake glacial till consists of material similar to that of the Pinedale till but also contains sandstone, conglomerate, or limestone cobbles and boulders derived from the Minturn Formation. The recent landslide deposits consist of debris deposited by recent landslides that is unstratified and unsorted. The landslide to the northeast of the project site is active and is a deep rotational slide with shallow soil slumping near the surface (Kellogg and Others, 2003).

Kellogg and Others (2003) also state that rockfall is a geologic hazard in portions of the quadrangle, especially in areas below steep slopes and cliffs formed by the Robinson Limestone Member of the Minturn Formation.

The recognized rockfall deposits described by Kellogg and Others (2003) can be observed on this site. The slopes above the property where these processes initiate have measured slope angles ranging from 60 to 100 percent. Heavy rains at this location can be accompanied by rockfall. Rockfall deposits were observed adjacent to and on the property.

GEOLOGIC HAZARDS ASSESSMENT

Geologic hazards potentially impacting the project site consist of rockfall, debris flow and potentially unstable slopes. Rockfall from the outcrops above the site on the valley side appears to be moderate to high risk. There is a small debris basin and associated channel upslope of the east part of the proposed development, north of the existing berm. The existing berm/channel outlets along the western edge of the existing Public Works office building. The potential for unstable slopes appears to be low to moderate and mainly at the existing cut slope to the north of the existing parking/roadway area. We should review the grading plans for the project once they have been developed and perform additional stability and rockfall analyses as needed for the areas of proposed new development.

RECOGNITION

There is evidence of a rockfall hazard at the property. This hazard involves loose rocks along the slope rising above the property to the north and fractured blocks of Minturn Formation exposed in cliff faces and ridges above the site. Evidence of the extent of the hazard within the property may have been obscured by the existing development. We reviewed historic aerial photographs of the property dating back to 1999, the oldest aerial photographs readily available for the site.

Several rocks were found in the area along the existing berm and un-maintained two-track road to the north of the existing cut slope. These rocks ranged in size from around 1 to 4 feet in all dimensions and mainly consisted of angular limestones and sandstones of the Minturn Formation.

IDENTIFICATION

The majority of the rockfall evident adjacent to the property comes from rolling and bounding loose rock. The initiation force may be a combination of loss of support for the loose rock due to precipitation events, freeze thaw cycles, chemical weathering (disintegration of the rock mass), and plant and animal influences. Wind also may be a contributing factor. Other rockfall may result from planer or toppling failures within the large rock masses with open fractures. Based upon the apparent erosion of soil supporting loose rock during heavy rainfall, destabilization of the loose rock could occur during times of high precipitation.

EVALUATION

Evaluation of the project site for rockfall included field observations, terrain analysis, aerial photograph interpretation, and rockfall simulation modeling using the Colorado Rockfall Simulation Program (Crsp3D version 2012.12.12.23.37). The evaluation focused on three zones defined within the area. These included:

1. Rockfall Source Zone
2. Rockfall Paths
3. Rockfall Runout Zone

A map showing potential rockfall hazard areas is presented in Figure 2. The potential hazard consists of a rockfall source zone, a rockfall runout zone, and an area of potential rockfall paths between the source zone and the runout zone. The project site is located in the potential runout zone as shown on Figure 1.

Rockfall Source Zone

The majority of rocks presently posing a hazard to the proposed development are located at the rock outcrop located approximately 560 feet up the slope and along the ridge to the northwest of the proposed development area about 400 to 1000 feet up the slope. The source zones are primarily intact sandstone, conglomerate, and limestone that exhibit varying degrees of weathering and fractures.

There are loose rocks littering the slope below the outcrops that have rolled to their present location. In our opinion, most of these lower, loose rocks do not pose a significant rockfall hazard. This is due to their lower location on the slope. It is unlikely that these lower, loose rocks will develop significant kinetic energy should they roll down the slope. The exception to this is the loose rocks in the vicinity of the outcrops that can be dislodged and are higher up on the slope. There is one very large boulder above the middle of the proposed development at around elevation 8,436 feet that appears currently stable.

Rockfall Paths

The mechanism of rockfall at this location involves rolling, toppling, and/or sliding of loose rock from the source zone. Once moving, the rock rolls and bounces through the rockfall path zone until it stops in the rockfall runout zone. The rockfall path zone above the proposed development area extends from the base of the slope to the ridge and outcrop above. Rocks roll, topple, and/or slide varying distances from the source zone. Some rocks are stopped in the source zone after initial movement. Other rocks stop varying distances down the slope. The rocks that stop movement in the source zone and on the slope lose speed and kinetic energy through contact with the ground surface, other rocks, vegetation, or a combination of these. It is likely that some rocks have rolled and bounced through the rockfall path zone, impacting the flatter ground at the base of the slope. We are unaware of direct evidence that rocks have impacted the existing facility, however, the grading north of the west end of the facility has cut into the deposit formed in part by falling rock.

Rockfall Runout Zone

The rockfall runout zone evaluated for this study is defined as the area of ground at the ditch/berm and two-track road and south into the area of the proposed development. This area has been impacted by falling rock in the past as can be observed by the boulders adjacent to the ditch/berm. In our opinion, the existing ditch/berm feature should not be considered effective rockfall mitigation for the proposed development.

Rockfalls will decelerate, lose kinetic energy, and eventually stop in this zone. Velocities of potential rockfalls are decreasing significantly at this location. This has significant advantages when considering mitigation options. These options are discussed in following sections.

CRSP MODELING

The Colorado Rockfall Simulation Program (Crsp3D version 2012.12.12.23.37) was used to assist in our assessment of the potential rockfall risk to the proposed project and to develop rockfall dynamic information that may be used to assess the feasibility of rockfall mitigation. Crsp3D is a computer program that simulates rockfall tumbling down a slope and predicts the probability distribution of rockfall runout, velocity, bounce height, and kinetic energy. The program takes into account slope profile, rebound and frictional characteristics of the slope, and rotational energy of the rocks. The program was not designed to identify rockfall hazard but to determine mitigation techniques where the hazard has been identified. The program is a tool commonly used in analysis and mitigation of rockfall hazards.

We have simulated rockfall at the project site using Crsp3D. Our calibration of the model to site conditions began with observations of rockfall conditions at the site as described in previous sections of this report. We created a model that reflects the types of rocks found adjacent to the property that we believe resulted from rockfall events. The model was further refined by measurements of the slope and of loose rocks found within the rockfall source zones, rockfall path zones, and rockfall runout zones. Our model was back-calculated from the conditions at the site. The conditions at the property provide reasonable criteria for generating rockfall models that we believe represent the actual rockfall conditions.

The purpose of modeling the rockfall events at the site is to evaluate engineering properties of the rockfall events that can be used in developing alternatives for mitigation of the potential rockfall hazard. These properties include velocity, bounce height, and kinetic energy of the rocks. Feasibility of rockfall mitigation concepts can be evaluated from these properties.

Model Input Information

A surface derived from a 2018 LiDAR survey of the area was used to input terrain information into Crsp3D. Model output probability distributions were calculated based on 99 independent rockfall trials of sphere-shaped rocks, randomly varied between a 3.10 and 8.00-foot diameter. These blocks are similar to rocks ranging from a 2,500-pound rock that is approximately a cube with a side length of 2.5 feet and a 44,000-pound rock that is approximately a cube with a side length of 6.44 feet. The rock block sizes are based on observations of rocks found in the runout zone at the project site and the approximate spacing of fractures in the source zone.

Model Output Information

The results are presented in Table 1. We analyzed the results of our rockfall model at one point, the crest of the ditch/berm and along the lower edge of the two-track trail above the proposed development area, see Figure 4. We also calculated the rockfall dynamic probability distribution at this location. The engineering results of the modeling are given in the following table for a 2% exceedance probability. The bounce height is to the centroid of the rock block. The rockfall dynamic probability distribution may be used to assess the feasibility of rockfall mitigation.

Table 1

Engineering Results from CRSP

Point Evaluated	Velocity ft/s (m/s)	Bounce Hight ft (m)	Kinetic Energy ft-lb (kJ)
Point 1	22 (6.7)	2.5 (0.8)	350,000 (470)

ROCKFALL RISK EVALUATION

Rockfall is an active geologic process in the lower part of the Vail valley side to the north of the project site. Without long term observations, it is not possible to develop recurrence probabilities for rockfalls from the source zones at the project site with high levels of confidence but seems reasonable to infer that rockfalls from these source zones are infrequent. The Crsp3D modeling shows that if a rockfall were to occur during a reasonable exposure time for the proposed development, it is possible that the rockfall would reach the proposed development areas shown on Figures 2, 3, and 4.

Based on our current understanding of the rockfall potential, we characterize the risk that a rockfall will reach the proposed building areas to be moderate to high. If a rockfall were to hit the proposed buildings, the consequence would likely be severe and could cause major structural damage and harm the building occupants, and the feasibility of rockfall mitigation should be evaluated.

ROCKFALL MITIGATION CONCEPTS

There are three approaches to rockfall mitigation that are typically used within the area.

1. Meshing, bolting, and/or shotcreting of the entire rock outcrop in the source zone.
2. Stabilization or scaling of individual rock blocks in the source zone.
3. Installation of a rockfall barrier/catchment area (rigid MSE wall, soil berm, or flexible fence) in the runout zone.

The rockfall source areas are beyond the property boundary to the north. We do not know if the White River National Forest would allow mitigation of the loose rocks within the property. Stabilization methods for the entire outcrop could include anchored mesh and/or shotcrete stabilization. Stabilization methods for individual rock blocks in the source zone could include cable lashing, bolting, and scaling.

Stabilizing the entire rock outcrop in the source zone would likely be the most intrusive and expensive option. The shotcrete and/or mesh would be highly visible from below, and would require a large amount of stabilization material. Due to the large area of outcropping rock in the source zone, this option does not appear to be feasible.

Stabilization of individual rock blocks is more cost effective than stabilizing the entire rock outcrop. This option mitigates the release of large rocks from the source zone but does not mitigate the release of smaller rocks due to severe weather, animal traffic, or rodent undermining. Due to ongoing natural erosion and animal traffic, this mitigation would need to be evaluated annually to adapt to the natural changing conditions. Individual stabilization typically costs between 5% and 50% of the cost of stabilizing the entire rock outcrop based on the amount of individual rocks needing to be stabilized. Based on our field observations it is estimated that the cost of initial individual rock block stabilization at this site will be between around $400,000 to $800,000.

Rock scaling at this site does not seem feasible due to the existing development (including Interstate 70) downslope from the source zone.

In our opinion, a practical protection method would be an MSE wall or a flexible rockfall barrier and catchment area extending above the proposed development, in the area of the existing ditch/berm and two-track road, just to the north of the proposed cut-slope. This protection method would be around 1,000 to 1,500 linear feet. MSE walls typically cost between $35 and $40 per square foot of wall (length x height), or between around $210,000 and $360,000 for this site. A soil berm could be constructed with imported and/or on-site excavated material with a near vertical up slope face such as stacked boulders. The cost of the soil berm would depend on excavation costs and the availability of on-site material.

A flexible rockfall barrier can be located approximately at the northern property boundary which should not impact the property to the north. The installation cost of a flexible barrier is typically around $110 per linear foot or between around $110,000 and $165,000 plus material and grading costs for this site. The flexible fence option will provide better protection from large and small rocks for the proposed buildings than stabilization of individual rock blocks, and will likely remain relatively maintenance free for several years after installation. The flexible barrier will likely be visible from the proposed development, but much less from the surrounding community. A range of colors of flexible barrier are available to help minimize the visual impact of the fence.

RECOMMENDATIONS

Based on the CRSP analysis and our observations at the site, rockfall mitigation is recommended. In our opinion, a flexible rockfall barrier (Option 1) or MSE wall/soil berm (Option 2) with a catchment area uphill of it located in the area of the existing ditch/berm and two-track trail will be an effective mitigation. A flexible rockfall barrier will have the lower amount of visual impact and will require a limited amount of space to construct. The modeled energies and bounce heights for a 2% exceedance probability from the source zone are around 350,000 foot-pounds (470 kJ) and 2.5 feet (0.76 m), respectively. The modeled energies and bounce heights associated with rockfalls from these zones are presented above in Table 1. Based on these modeled energies and bounce heights, the barrier would need to be around 7 feet (2.11m) tall with a strength of 420,000 ft-lb (570 kilojoules). We recommend that a 3 meter (9.9 foot) tall Geobrugg GBE-1000A-R system (or equivalent) or suitable MSE wall or soil berm with catchment area designed by a qualified civil engineer be installed along the existing two-track road, for mitigation of the potential rockfall at the site. A soil berm with catchment area may also reduce the risk of damage due to debris flow at the subject site. If a flexible barrier option is chosen, the existing berm should be extended by approximately 200 feet to the west to intercept possible debris flow paths and the outlet improved so as to not direct flow toward the existing public works office building or existing employee housing building. This berm should be designed by a qualified Civil Engineer to account for design debris flow volumes and velocities.

LIMITATIONS

This study was conducted according to generally accepted geotechnical and engineering geology principles and practices in this area at this time. We make no warranty either express or implied. The conclusions and recommendations submitted in this report are based on our field observations, aerial photograph interpretations, published regional geology information, the currently proposed development plan, and our experience in the area. Our analysis was conducted to model a reasonably accurate indication of rockfall behavior at this location. The results are thought to be representative of conditions observed at the property and the slope and ridge above. Variations in the model resulting from additional observations and information should be expected. This report has been prepared exclusively for our client and is an evaluation of the geologic hazards and their potential influence on the proposed development. We are not responsible for technical interpretations by others of our information.

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Reviewed by:

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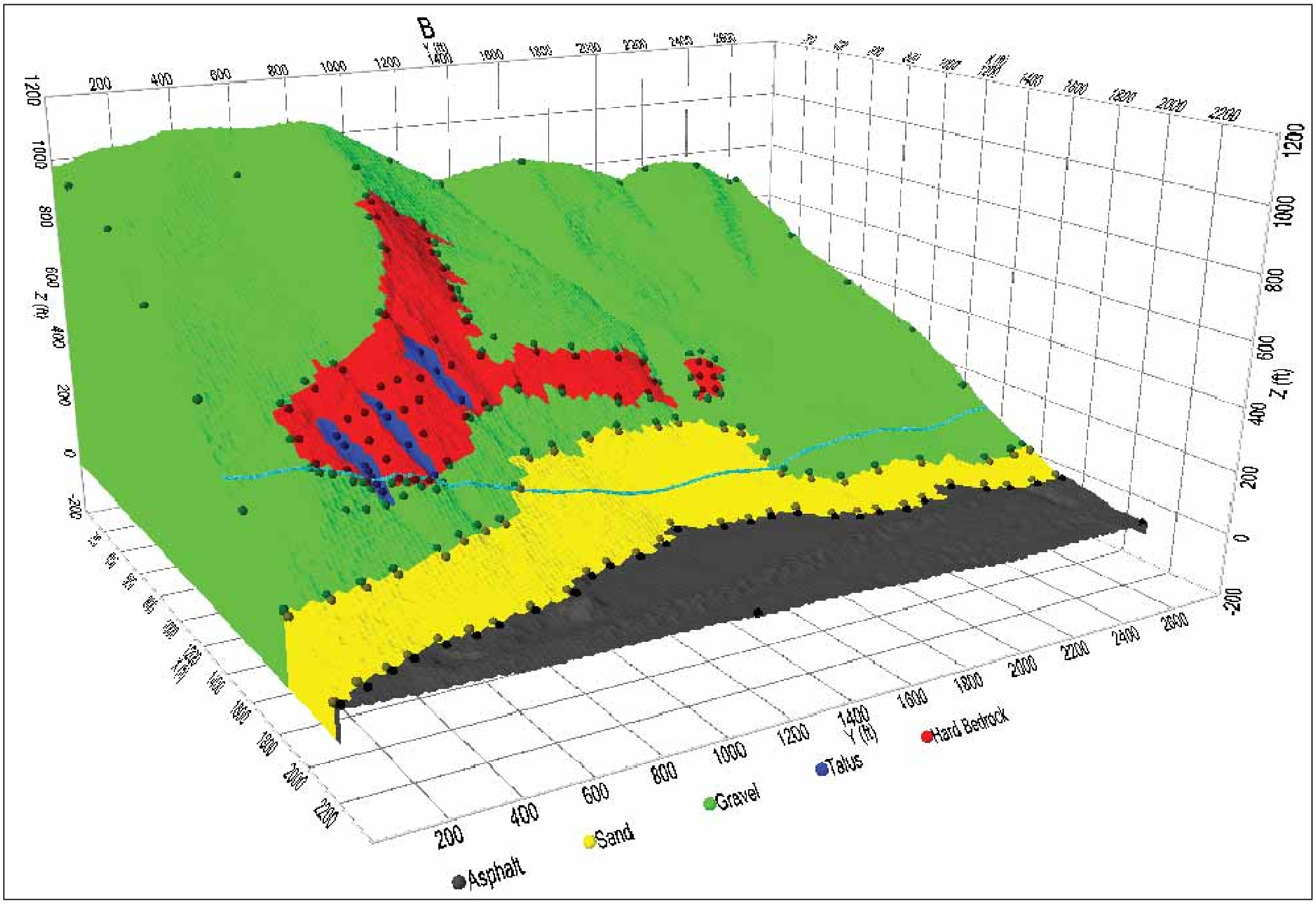
18-7-606	Kumar & Associates	Project Site Location	Figure 1

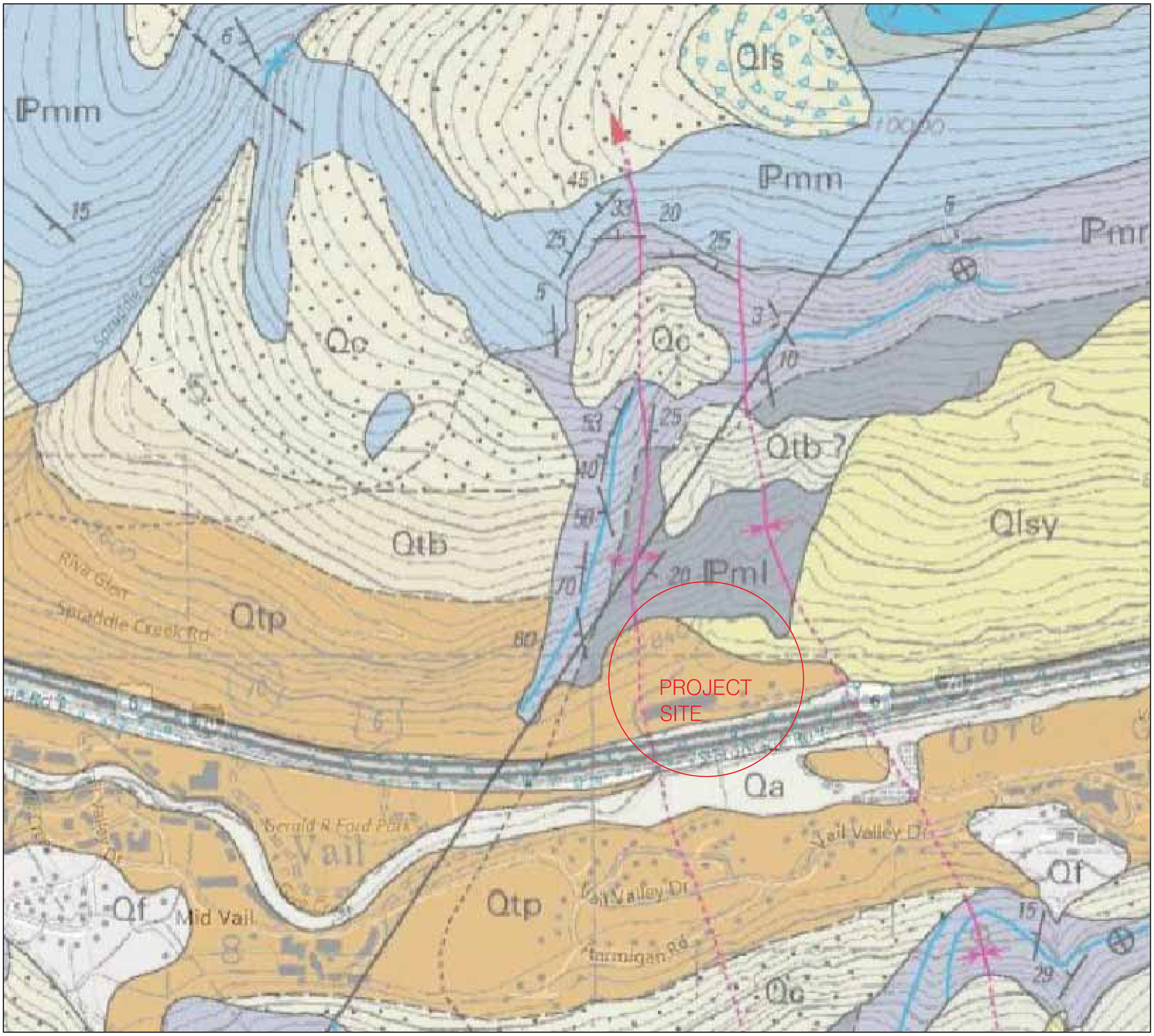


Source

(Upper) Paths

(Lower) Runout

18-7-606	H-P KUMAR Geotechnical Engineering | Engineering Geology Materials Testing | Environmental	ROCKFALL MATERIALS AND ZONES	Figure 2



APPROXIMATELY $\frac{1}{2}$ MILE

Qa - Alluvium
Qc - Colluvium
Qf - Fan Deposits
Qtp - Pinedale Till
Qtb - Bull Lake Till
Qlsy - Recent Landslide Deposits
Qls - Landslide Deposits
Pml - Lower Member Minturn Formation
Pmr - Robinson Limestone Member Minturn Formation
Pmm - Middle Member Minturn Formation

18-7-606	H-P KUMAR Geotechnical Engineering | Engineering Geology Materials Testing | Environmental	PROJECT AREA GEOLOGY	Figure 3

18-7-606	Kumar & Associates	Site Plan	Figure 4