GRANITE ENGINEERING GROUP

November 7, 2022 Project No. 222-059

Ms. Kara Swanson, Project Manager, Transportation
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1600 Broadway Street, Suite 800
Denver, CO 80202

Subject: **Memorandum for Geotechnical Engineering Services**
Cottonwood Pass Concept Design
Garfield and Eagle Counties, Colorado

Dear Ms. Swanson:

Granite Engineering Group (GEG) has performed the Cottonwood Pass Feasibility Study from the geologic and geotechnical standpoints for this project. The results of the study are presented in the following sections.

INTRODUCTION AND BACKGROUND

The proposed project is along the existing Cottonwood Pass in Eagle and Garfield Counties in CDOT Region 3. The Cottonwood Pass is an existing county road connecting from Town of Gypsum in Eagle County to State Highway 82 in Garfield County, Colorado. The total length of the study route is approximately 22.83 miles, with approximately 15.1 miles in Eagle County, and approximately 7.73 miles in Garfield County. A total of fourteen (14) areas were identified along the existing alignment for the study and used for the identifications of the extent of the project. Six (6) of these sites are located in Eagle County and identified as Eagle County Site 1 through Site 6. The remaining eight (8) sites are located in Garfield County and are identified as Garfield County Site 1 through 8. These are the sites that were identified as areas where improvements and features of interest are present within the project limits. The project’s fourteen (14) sites are presented in Figure 1.

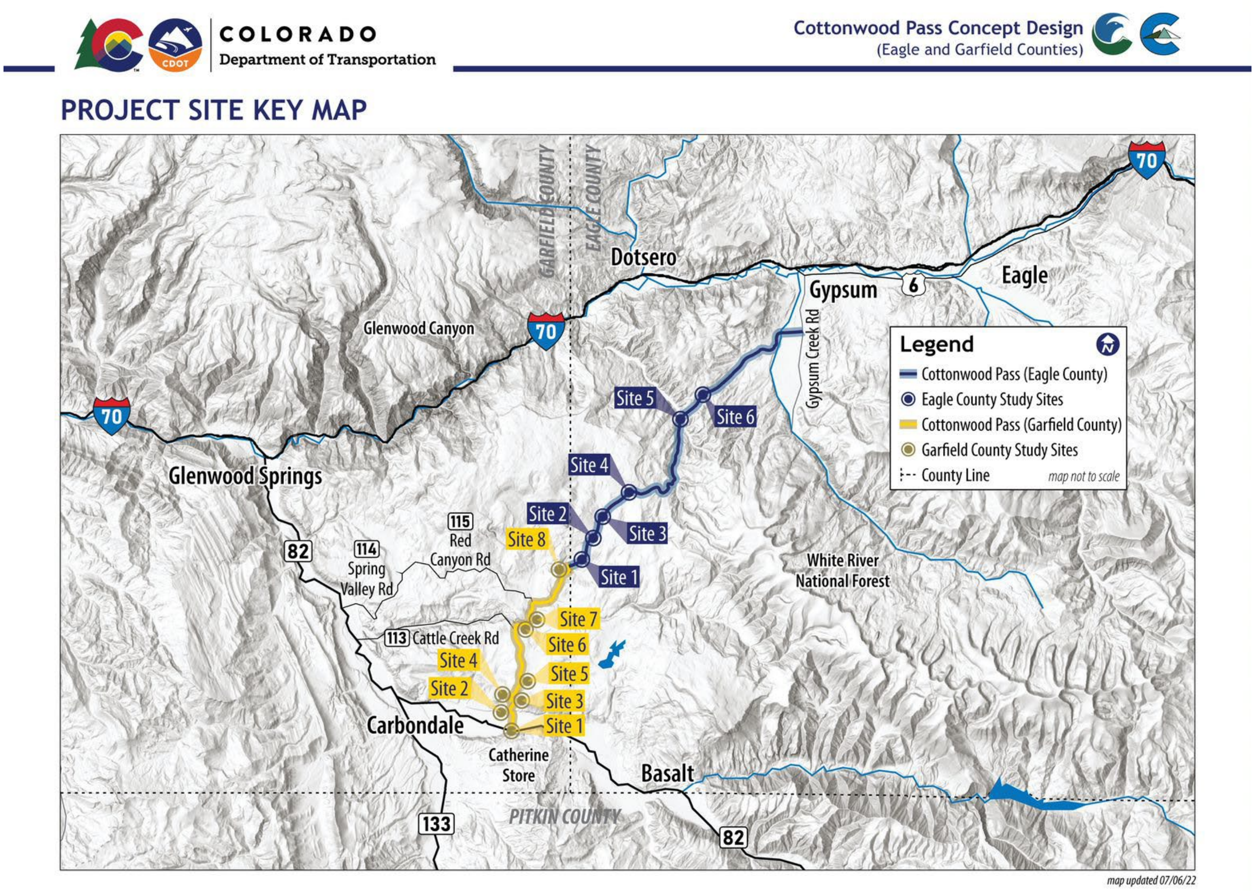


Figure 1. Project 14 Sites

As part of the Cottonwood Pass Concept Design project, this memo is prepared to evaluate the impacts of the existing geohazards and geotechnical features along the roadway for the potential road safety improvements.

METHODOLOGY

Geologic and geotechnical conditions present along the project limits were identified through desktop study using the information from geologic maps, U.S. Geological Survey (USGS) reports and publications, Colorado Geological Survey (CGS) publications, Colorado School of Mines publications, CDOT publications, Light Detention and Ranging (LiDAR) data from Eagle County and Colorado Water Conservation Board. The information obtained from desktop study was field verified for the mapped features in accessible areas. Features observed during the field verification and mapping have also been included in the database.

EXISTING CONDITIONS

This section summarizes the initial evaluation of the geologic and geotechnical features, geologic hazards and soil resources observed along Cottonwood Pass from the Town of Gypsum in Eagle County to SH 82 in Garfield County. The elevation varies between approximately 6,000 and 8,000 feet.

General Geology

The most prominent geologic and geotechnical features along Cottonwood Pass are collapsible soils, evaporite soils and karst, and landslide features. The collapsible soils are due to the dry, low density silty and sandy soils with high void space or air gaps between the soil particles where the soil particle binding agents are highly sensitive to water. The evaporite soils consist primarily of gypsum and anhydrite that were deposited during the cyclic evaporation of shallow seas that existed in central Colorado millions of years ago. The evaporite soils can dissolve in the presence of fresh water and causing caverns, sink holes and subsidence. The landslides described along Cottonwood Pass occur either in the surficial deposits or deeper into bedrock. More detail discussions along with other geological hazards and geotechnical features are presented in the following sections of this memo.

Bedrock Formations

Approximately northern two fifths of the roadway are within the Eagle Valley formation and Eagle Valley Evaporite of Middle Pennsylvanian age. The Eagle Valley Formation consists of interbedded reddish-brown, gray, reddish gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks. The formation represents a stratigraphic interval in which the red beds of the Maroon Formation grade into and intertongues with the predominantly evaporitic rocks of the Eagle Valley Evaporite. It includes rock types of both formations. Strata in the lower part of the Eagle Valley Formation frequently are deformed by dissolution and flowage of underlying evaporite rocks. The Eagle Valley Formation is both conformable and intertonguing with the overlying Maroon Formation and underlying Eagle Valley Evaporite. Contact with the Maroon Formation is placed at the top of the uppermost evaporite bed or light-colored clastic bed. Thickness is variable, ranging from about 500 to 1,000 ft. The formation was deposited in the Eagle Basin in fluvial, eolian, and marine environments on the margin of an evaporite basin.

The Eagle Valley Evaporite is comprised of a sequence of evaporitic rocks consisting mainly of massive to laminated gypsum, anhydrite, and halite, interbedded with light colored mudstone and fine-grained sandstone, thin carbonate beds, and black shale. Strata in the formation commonly are intensely folded, faulted, and ductily deformed by diapirism, flowage, load metamorphism, dissolution, hydration of anhydrite, and regional tectonism. The contact with overlying Eagle Valley Formation is both conformable and intertonguing and is defined as the base of the lowest red bed within the Eagle Valley Formation. Thickness of the formation averages about 1,800 ft, but it varies due to flowage and diapirism.

Approximately southern three-fifths of the roadway are within Basalt flows of Miocene age, with small portion on the northern end within Sedimentary deposits of Miocene age. These Miocene aged formations were underlain by older age Eagle Valley formation and Eagle Valley Evaporite. Basalt flows consist of multiple light- to dark-gray basaltic flows and minor flow breccias. Lenses of slightly indurated tan to light brown sediments locally are intercalated with or underlie the volcanic flows and breccias of the unit. Flow rocks range from slightly to highly vesicular and locally contain amygdules of calcite and iron-rich clay. Petrographically most flows are olivine basalt, many of which are porphyritic. The phenocrysts are chiefly olivine and less commonly plagioclase. The groundmass is predominantly plagioclase and pyroxene, with lesser amounts of olivine, glass, pigeonite, augite, and magnetite. Accessory minerals include apatite, iddingsite and hematite. Some flows contain rare xenocrysts of quartz or xenoliths of quartzite. Individual basaltic flows range in thickness from about 5 to 50 ft. Thickness of the entire sequence of flows averages 20 to 80 ft.

Sedimentary deposits include widespread deposits that underlie basalt flows near and south of Cottonwood Pass, and a thin, localized deposit associated with the basalt on Spruce Ridge.

Deposits near and south of Cottonwood Pass are poorly exposed. Here the unit contains abundant round to subangular pebbles of red sandstone, quartz, and coarse-grained plutonic rocks, with minor amounts of metamorphic and hypabyssal lithologies. The hypabyssal clasts are similar to ones in late Pleistocene Colorado River deposits upstream of Dotsero. East of Cottonwood Pass the unit includes finer grained sandy and clayey silt that is exposed in roadcuts along the Cottonwood Pass Road. Pebbly strata in the unit also underlies a basaltic flow on Spruce Ridge. A channel filled with clast-supported sandy pebble and cobble gravel included in the unit partially cuts out the basaltic flow on Spruce Ridge (Kirkham, Kunk, and others, 2001). These channel deposits also are included in the unit. The clasts in the channel gravel are moderately to very weathered, well rounded to subrounded, and chiefly composed of various types of plutonic granitic rocks, red sandstone, quartzite, quartz, and conglomeratic sandstone. These lithologies are typical of a Colorado River provenance. Deposits of the unit near and south of Cottonwood Pass may attain thicknesses more than 200 ft.

Surficial Deposits (Soils)

Alluvial deposits consist of sediments deposited in stream channels, flood plains, glacial outwash terraces and sheetwash areas. The alluvial deposits are mostly poorly sorted, clast-supported locally boulder, pebble and cobble gravel in a sand and silt matrix.

Mass-wasting deposits consist of sediments on valley sides, valley floors, and hillslopes transported and deposited primarily by gravity. Mass-wasting deposits include various types of landslide deposits, unsorted, unstratified gravel, sand, silt, clay, and rock debris.

Alluvial and mass-wasting deposits consist of sediments in debris fans, stream channels, flood plains, and hillslopes along tributary valleys. The deposits include poorly sorted to moderately well-sorted, matrix- and clast-supported deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and boulder gravel, or moderately well-sorted to well-sorted, stratified, interbedded sand, pebbly sand, and sandy gravel to poorly sorted, unstratified or poorly stratified, clayey, silty sand, boulder sand and sandy silt.

Alluvial, mass-wasting, lacustrine, and deltaic deposits consist of locally derived gravel, sand, silt, and clay deposited in the Missouri Heights-Cottonwood Pass region in alluvial, mass-wasting, and either lacustrine or deltaic environments.

Collapse deposits consist of slightly to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Locally includes large intact blocks of basalt that are lowered by collapse.

Faults and Seismicity

The areas along Cottonwood Pass are not considered to be seismically active. There are faults identified around Garfield County Site 6 area. No other fault was identified within the project limits.

GEOLOGIC HAZARDS AND GEOTECHNICAL FEATURES

Geologic hazards are natural phenomena, or a geologic process, capable of inflicting harm to people or property (USGS, 2017). Geotechnical features are modifications to the geologic setting and have similar effect as geologic hazards. The complex and problematic subsurface conditions along Cottonwood Pass have developed zones of marginally stable conditions, and potential of developing problematic conditions. These developments are the results of natural processes and land use activities, they can pose a risk to public either directly by an encounter with the hazard or indirectly through structures including roadways and buildings. The geologic conditions, precipitation, wind, temperature, seismic, ground modifications and drainage features can directly or indirectly impact the geologic hazards. The severity and risk factors of these geologic hazards can be mitigated through identifications of the potential issues, evaluating the conditions and engineering design. The major geologic hazards and geotechnical features identified along Cottonwood Pass are discussed below.

Collapsible Soils

Collapsible soils are generally found in dry, low density silty and sandy soils with high void ratio in the soil structures. The soil particles are held in place by physical or chemical binding agents. When the soils are exposed to moisture and water, the binding agents break, soften and dissolve in a way that the soil particles rearrange and form a denser and tighter structures. This process causes the volume decrease in soil mass and causes settlement of the ground surface, and sometimes creates subsidence and impacts the natural setting, improvements, and structures. Certain fine-grained soils can also collapse and settle by piping, which is the removal and suspension of soil particles in moving water, creating open soil pipes and voids that eventually cave in (CGS, 2002). The collapse of the soil mass can occur under the weight of the soil itself without any external loading, and it only needs sufficient moisture to occur. Depending on the precipitation, sources of water, the permeability of the settled/compacted surficial soils, and penetration of the moisture in soil mass, the collapsible soils can settle several feet and the process can take years to occur.

Evaporite Soils and Karst

Evaporite soils consist of the common evaporite minerals of gypsum ($CaSO_4$*H2)), anyhydrite ($CaSO_4$) and halite (rock salt – NaCl). The formation also typically consists of thinly interbedded fine sandstone, mudstone, and black shale. The evaporite soils were deposited sediments that were created from evaporation of shallow seas millions of years ago. Evaporite soils and bedrock have two (2) distinctive characteristics. One is that they can flow under certain pressures and temperatures. The other one is that the evaporite minerals in the soils can dissolve in the presence of fresh water, at the proper temperature. The dissolved evaporite mineral will create voids. Karst is a technical term that refers to ground conditions where caverns and open fissures, subterranean drainage, closed depressions, sinkholes and subsidence exist that are underlain by soluble bedrock (CGS 2002). Most of the karst formed in this area occur on flat-lying river terraces or slopes on the valley sides, and rarely in the volcanic lava flows that have collapsed into voids within the underlying evaporite. Sometimes karst could not be observed from the surfaces until the roof of the caverns collapsed under load. This type of collapse can be sudden and catastrophic.

Landslide

Landslide is the movement of mass of rock, debris, or soil down a slope. Landslides include many different kinds of mass movements, including falls, topples, slides, spreads, flows, or a combination of one or more of these movements. Slopes of any angle from gentle slope to steep mountains can fail in a sudden landslide, and the sizes can be very small or very large. Landslides can travel incredibly quickly and may recur multiple times in virtually the same location (CGS). Slope movement occurs when forces/weights of the mass acting downward exceed the strength of the materials. The causes of a landslide can be very complex and typically caused by multiple factors. Factors that increase the downward forces and/or factors that contribute to low or reduced materials strengths are the main causes of landslides. Landslides can be initiated by rainfall, snowmelt, changes in surface and groundwater levels, erosion, earthquake, human activities, or any combination of these factors. Some landslides are ancient landslides that occurred millions of years ago and are currently not active. However, any changes to the ground conditions, or adverse weather events can reactivate these landslides. Landslides can adversely threaten life and infrastructure, therefore it is important to understand how landslides occur, if a landslide mass continues to move, and mitigation to minimize or eliminate the chances of landslide due to human activities such as development.

Rockfall

Colorado experiences many rockfalls due to its mountainous terrain. A rockfall happens when rock loses support, falls, bounces, or rolls from a cliff or down a steep slope. Rockfalls generally start from high outcrops of hard, erosion-resistant rock that become unstable for a variety of reasons. The size of the falling rock depends on the outcrop and geology (bedding thickness, hardness, joint and fracture orientation) and weathering, and the severity of the rockfall is affected by the position of the rock, slope angle, shape and ground covering of the slope. Generally, an individual rockfall has one to only a few rocks, with sizes that vary from cobble to boulders (few inches to five feet or larger in relative diameter). Rockfalls can be very dangerous depending on where they occur, size of the rocks, and how the rocks roll or bounce along the slope face. Rockfalls can cause property loss, personal injury or even loss of life. Rockfalls typically are catastrophic and occurred without warning, so it is difficult to predict how often rockfalls occur. Rockfalls are a common erosional process in mountainous areas near cliffs or steep slopes of broken, faulted, or jointed bedrock, or on steep slopes of rocky materials. When the support is undercut by erosion or human activity, or when external driving force (e.g. heavy rainfalls) occurred, rockfalls can occur.

Steep Slopes

Steep slopes can contribute to slope instability issues ranging from small slumps to large scale landslides. Several slopes along the northern portion of Cottonwood Pass in Eagle County were very steep at approximately 0.75H:1V slope. On-site observation indicates that the slopes were stable, and no obvious slope movement was observed. Further inspection indicated that these steep slopes comprised of evaporite soils where the binding agents strengthen the shear strength of the soils and allow the slopes to stand at steep slopes. These evaporite soils can lose strength and dissolve in the fresh water and under correct conditions, these slopes can become unstable and cause landslide or slope failures.

Bedrock in Cut Sections

Bedrock consisting of sandstone, conglomerate, mudstone, siltstone and shale, thin beds of gray limestone is present along Cottonwood Pass. The bedrock will impact the cut slopes, the excavation methods (e.g. ripping and blasting), suitability and availability of materials for aggregate source, and material processing methods (e.g. crushing).

GEOLOGIC CONDITIONS AND GEOTECHNICAL FEATURES ALONG COTTONWOOD PASS

The project consists of fourteen (14) sites for this feasibility study. The geologic and geotechnical conditions that occur at these sites are summarized in Table 2. The information presented in Table 2 was obtained from results of the desktop study and the field mapping and verification performed by GEG. Detailed maps related to the geologic hazards and geotechnical features are presented in Appendix A.

The risk factors for each identified geologic hazard and geotechnical features are also presented in Table 2.

Table 2. Summary of Geologic Hazard and Geotechnical Features Along Cottonwood Pass

Site I.D.	Collapsible Soils	Evaporite Soils and Karst	Landslide	Rockfall	Steep Slopes	Bedrock in Cut Sections	Descriptions
Garfield County							
Garfield Site 1 to Site 2	High risk factor	High risk factor	Not applicable	Not applicable	Not applicable	Medium risk factor	Site 1 and the alignment to Site 2 are mapped in collapsible soils and evaporite soils. Rock outcrops were observed along the alignment. Bedrock appears to be rippable based on the outcrops observed.
Garfield Site 2 to Site 3	High risk factor	High risk factor	Medium risk factor	Not applicable	Not applicable	Medium risk factor	Site 2 and the alignment to Site 3 are mapped in collapsible soils and evaporite soils. Majority of the site and the alignment are located in the Eagle Valley Evaporite formation. Sinkholes were documented in the area west of the alignment and Site 2. The northern portion of the alignment is located in the landslide mapped based on HB 1401 maps. However, no evidence of slope failure or movement was observed during field investigation. Rock outcrops were observed at Site 2 and along the alignment. Bedrock appears to be rippable based on the outcrops observed.
Garfield Site 3 to Site 4	High risk factor	High risk factor	Medium risk factor	Not applicable	Not applicable	Medium risk factor	Site 3 and the alignment to Site 4 are mapped in collapsible soils and evaporite soils. Majority of the site and alignment are located ib the Eagle Valley Evaporite formation. Site 3 is locate in the landslide mapped based on HB 1401 maps. However, no evidence of slope failure or movement was observed during field investigation. Rock outcrops were observed at Site 3 and along the alignment. Bedrock appears to be rippable based on the outcrops observed.
Garfield Site 4 to Site 5	High risk factor	High risk factor	Medium risk factor	Not applicable	Not applicable	Medium risk factor	Site 4 and the area to Site 5 are mapped in collapsible soils and evaporite soils. Majority of the site and the alignment are located in the Eagle Valley Evaporite formation. Site 4 is located in the landslide mapped based on HB 1401 maps. However, no evidence of slope failure or movement was observed during field verification. Rock outcrops were observed at Site 4 and along the alignment. Bedrock appears to be rippable based on the outcrops observed.
Garfield Site 5 to Site 6	High risk factor	High risk factor	Medium risk factor	Medium risk factor	Not applicable	Medium risk factor	Site 5 and the alignment to Site 6 are mapped in collapsible soils and evaporite soils. Majority of the areas are located in the Collapse deposits that were formed in response to differential collapse resulting from dissolution of underlying evaporite bedrock. Sinkholes were documented near the mid-section of the alignment. Site 5 is located near the edge of the landslide mapped based on HB 1401 maps. However, no evidence of slope failure or movement was observed during field investigation. Rock outcrops were observed at Site 5. Rockfall was not observed during field investigation. However, rockfall analysis and protection may be required if the alignment requires the excavation into the outcrops. Bedrock may require blasting for excavation.

Site I.D.	Collapsible Soils	Evaporite Soils and Karst	Landslide	Rockfall	Steep Slopes	Bedrock in Cut Sections	Descriptions
Garfield Site 6 to Site 7	High risk factor	High risk factor	Medium risk factor	Low risk factor	Not applicable	Medium risk factor	The Site 6 and portion of the alignment are located in the Sediments of Missouri Heights, that occurred in the areas that are topographically lowered by collapse or subsidence related to dissolution or flow of salt deposits in the underlying Eagle Valley Evaporite. These areas are mapped as collapsible soils and evaporite soils areas. A portion of the alignment is mapped as landslide by CGS. No evidence of slope failure or movement was observed during field verification. Further study may be required during the design phase of the project. Rock outcrops were observed in the existing cut section, however, no evidence of rockfall was observed. Rockfall protection and slope stability mitigation may be required if the cut into the existing slope is planned. Bedrock appears to be rippable based on the outcrop observed.
Garfield Site 7 to Site 8	High risk factor	High risk factor	Medium risk factor	Low risk factor	Not applicable	Medium risk factor	The northern portion of the alignment near Site 8 is located in the Eagle Valley formation. Sinkholes were documented in the area east of the alignment. This area is subject to potential of collapsible soils and evaporite soils. An area at the mid-section of the alignment is mapped at the toe of the landslide based on the HB 1401 maps. However, no evidence of slope failure or movement was observed during field verification. Rock outcrops were observed along the existing hill side slopes, majority on the west side of the alignment. Rockfall was not observed during field verification. However, rockfall analysis and protection may be required during design phase due to the height of the slopes. Bedrock appears to be rippable but blasting may be required in selected areas.
Garfield Site 8	High risk factor	High risk factor	Not applicable	Not applicable	Not applicable	Medium risk factor	Site 8 is located in the Eagle Valley formation. Sinkholes were documented to the area south of Site 8. Site 8 is subject to potential of collapsible soils and evaporite soils. Rock outcrops were observed in the existing cut sections. The bedrock appears to be rippable based on the outcrops observed.
Eagle County							
Eagle Site 1 to Site 2	Low risk factor	Not applicable	Not applicable	Not applicable	Not applicable	Low risk factor	Site 1 and the area to the north are located in the Maroon Formation that consists of red beds of sandstone, conglomerate, siltstone, mudstone, and shale with minor thin beds of gray limestone. There is a small portion of the alignment that is mapped as collapsible soils and should be evaluated during the design phase. Rock outcrop was observed in the existing cut sections along the alignment. The bedrock appears to be rippable based on the outcrops observed.
Eagle Site 2 to Site 3	Not applicable	Not applicable	Medium risk factor	Not applicable	Not applicable	Medium risk factor	Site 2 is located within the Landslide Deposits, and it is also mapped near the toe of the landslide mapped by CGS. No evidence of slope failure or movement was observed during the field investigation. Further study may be required during the design phase of the project. Rock outcrop was observed in some of the areas. No evidence of rockfall was observed. Bedrock appears to be rippable based on the outcrops observed.

Site I.D.	Collapsible Soils	Evaporite Soils and Karst	Landslide	Rockfall	Steep Slopes	Bedrock in Cut Sections	Descriptions
Eagle Site 3 to Site 4	Not applicable	Low risk factor	Medium risk factor	Not applicable	Not applicable	Medium risk factor	Site 3 is not mapped as the evaporite soils area. However, sinkholes were documents at approximately 0.5 miles north of Site 3. The site and the area are located in the Sediments of Cottonwood Bowl and Basalt formation. There is a potential for the evaporite soils and karst formation at this area. Site 3 is located at the toe of the landslide mapped by CGS. No evidence of slope failure or movement was observed during field investigation. If the alignment is shifted and cuts into the hillside to the west, large scale slope stability should be evaluated. Rock outcrops were observed in some of the cut areas, however, no evidence of rockfall was observed. Rockfall protection and slope stability may be required if the cut is deeper than 10 feet. Bedrock appears to be rippable but blasting may be required in some of the areas.
Eagle Site 4	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Site 4 appears to be in favorable location with no obvious evidence for geologic hazards or geotechnical features that would adversely impact the design and construction.
Eagle Site 4 to Site 5	High risk factor	Medium to high risk factor	High risk factor	Medium risk factor	Medium risk factor	Medium risk factor	The northern portion of the area between Site 4 and Site 5 is located in hee area mapped for collapsible soils and evaporite soils with karst. Majority of the northern portion of the alignment is located within the Eagle Valley Formation and Eagle Valley Evaporite, Undivided where contact between the formations is not mappable. A sinkhole was documented on the mountain to the east of the alignment. The southern portion of the alignment is located within the sedimentary deposits and Basalt formation that are not mapped as collapsible soils or evaporite soils. A large portion of the alignment at the mid-section is located within the landslide and landslide deposits. The landslide is a large-scale feature, and the alignment is located near the toe of the landslide mass. No evidence of the slope movement was observed in the accessible area and on the road during field investigation. However, further study and continuous monitoring will be required during the design phase of the project. Steep slopes were also observed along the northern portion of the alignment. It is believed that the weak cementation and binding provided the support for the steep slopes but could be impacted by water and moisture. Rock outcrops were observed in the northern portion of the alignment. No evidence of rock fall was observed, however, if the widening cuts into the hillside to the west, rockfall protection and slope stability design may be required. Bedrock appears to be rippable based on the outcrops observed.
Eagle Site 5 to Site 6	Medium to high risk factor	Medium to high risk factor	Medium risk factor	Medium risk factor	Medium to high risk factor	Medium risk factor	Site 5 and the alignment heading north to Site 6 are mapped for both collapsible soils and evaporite soils with karts. The alignment crosses Eagle Valley Evaporite formation, and Site 5 is located in the Young debris-flow deposits and alluvium and colluvium materials. The Young debris-flow deposits were deposited by debris flows and surface water. The alluvium and colluvium materials were deposited by alluvial and colluvial processes. Sinkholes were documented on the mountain southwest of the alignment between Site 5 and Site 6. Site 5 is also located in the unnamed faults. Site 5 and a portion of the alignment between Site 5 and Site 6 were identified as landslide areas by CGS. Steep slopes were common both on the uphill to the east, and downhill to the west of the alignment. No evidence of slope failure or movement was observed during field investigation. Field observation indicates that the soil slopes have weak cementation that is providing the supports for the slope stabilization. Rock outcrops were observed on the hill side and rock sizes smaller than 1 foot in diameter were observed on the side of the road. Rockfall protection and slope stability design will be required. Bedrock appears to be rippable based on the outcrop observed.

Site I.D.	Collapsible Soils	Evaporite Soils and Karst	Landslide	Rockfall	Steep Slopes	Bedrock in Cut Sections	Descriptions
Eagle Site 6 and to the north	Medium to high risk factor	Medium to high risk factor	Medium to high risk factor	Low risk factor	Low risk factor	Medium risk factor	Site 6 is located in the area mapped for collapsible soils and evaporite soils with karst. The Cottonwood Pass alignment crosses Eagle Valley Formation to the north of Site 6 and located in the Eagle Valley Evaporite formation between Site 6 and Site 5. The Eagle Valley Formation comprised of interbedded reddish brown, gray, reddish gray, and tan siltstone, shale, sandstone, gypsum, limestone, and carbonate rocks. The Eagle Valley Evaporite comprised of massive to laminated gypsum, anhydrite, and halite, interbedded with light colored mudstone and fine-grained sandstone, thin carbonate beds, and black shale. These formations are known for collapsible soils and evaporite soils. Sinkholes were identified on the mountains northwest and southeast of Site 6, however, no sinkholes were identified at Site 6. Site 6 was identified as landslide areas by CGS based on the HB1041 Maps. Steep slopes were observed along the alignment to the north and to the south of Site 6. However, no evidence of slope failure or movement was observed during field investigation. Rock outcrops were observed on the hill slope west of the alignment, north of Site 6. No evidence of rockfall was observed, however, if the widening cuts into the hillside to the west, rockfall protection and slope stability design may be required. Bedrock appears to be rippable based on the outcrops observed.

MITIGATION MEASURES AND BEST MANAGEMENT STRATEGIES

Based on the understanding of identified geologic hazards and geotechnical features, and the expected risk factors, the measures and management strategies to mitigate these risks are presented below.

- **Collapsible Soils**
  - Sufficient geotechnical borings should be planned to cover the proposed improvement areas and extended into the areas where drainage features and embankment are planned.
  - Borings should be extended at least twice the embankment height or 25 feet deep. Undisturbed samples should be obtained for laboratory testing.
  - Laboratory testing including 1-Dimensional swell consolidation test should be performed to evaluate the collapse potential of the foundation soils.
  - The extent of the collapsible soils should be established to allow development of the mitigation plans.
  - Collapsible soils can be mitigated by over-excavate collapsible soils and recompact properly to remove the collapsible potential. The over-excavation and recompaction should be performed beyond the depth where surface water could penetrate.
  - Drainage features including water quality pond should be planned far away from roadway and structures.
- **Evaporite Soils and Karst**
  - Sufficient geotechnical borings should be planned to cover the proposed improvement areas and extended into the areas where drainage features and embankment are planned.
  - Geophysical exploration should be considered to better explore the extents of evaporite soils, and the presence of karst.
  - Borings should be extended into the bedrock. If gypsum bed is encountered in the borings, the borings should be extended at least 30 into the gypsum bed.
  - The extent of the evaporite soils and karst should be established to allow development of the mitigation plans.
  - Good drainage system should be provided for the surface drainage and water should be directed away from roadway and structures.
  - Drainage features that can store water including water quality pond should be lined with geosynthetic liners to prevent penetration of water into the subsurface evaporite soils.
  - If karst is encountered, roadway and structure should be shifted to miss the karst especially if the karst is large in size and has the potential for roof collapse.
  - If alignment shifting is not possible, deep foundation should be planned for structures to allow the load to transfer to deeper foundation materials and minimize the risk of movement. Karst that is small in sizes can be mitigated by

providing large footings, such as mat foundation for a box culvert structure to bridge over the karst.

- Chemical stabilizations should be not utilized if the evaporite soils are used as subgrade and embankment.

- **Landslide**
  - It is important to evaluate if the existing landslide is currently still active. LiDAR images, satellite images including DinSAR and SqueeSAR can be used to effectively measure the ground movement over a period of time. When these data paired with the weather, precipitation data, snow melt, and local construction activities, the causes of the ground movement and the stability of the existing slope could be understood on a larger scale.
  - Monitoring equipment including inclinometer should be installed if the existing landslide is determined to be active.
  - Subsurface exploration and laboratory testing should be planned to fully understand the soil shear strength and subsurface conditions including groundwater level so engineering analysis can be performed. In the areas where landslide failure modes and envelopes can be obtained, backcalculation should be performed to better model the subsurface materials engineering properties.
  - The widening and grade changes of the proposed roadway should be carefully planned by not adding additional loads near the top of the landslide mass, or removing resistance forces near the toe of the landslide mass. The Cottonwood Pass route was constructed near the toe of the identified landslides and widening by adding embankment materials can provide additional resistance.
  - Good drainage should be provided by minimizing the ponding or penetration of water into the subsurface materials. Water could increase the driving force that cause ground movement, and can significantly weaken the shear strength of the soils especially the evaporite soils that are very sensitive to the moisture.
  - Localized landslide and slope failure can be mitigated with ground improvement and structures including but not limited to retaining walls, soil nails, anchors and buttress.

- **Rockfall**
  - The rockfall evaluation should be evaluated with Colorado Rockfall Simulation Program or equivalent. The rockfall size, surface and rockfall protection should be selected based on the project design criteria.

- **Steep Slopes**
  - The existing steep slopes appeared to be stable and supported by the weak cementation in the soil mass. The weak cementation can be adversely impacted and weakened by moisture and water. Good drainage should be provided if the slope design includes the weak cementation in the analysis.
  - Since the existing steep slopes appear to be in stable conditions, widening of the roadway should consider widening into the downslope side instead of cutting into the existing slope. The widening into the downslope side can be achieved by constructing retaining wall structures. Retaining wall structures with flexible

facing such as welded wire retaining wall that has higher tolerance to ground movement when compared to more rigid wall structures.

- A wider shoulder should be considered for the catchment of the materials eroded from the existing steep slope if the roadway widening is planned into the downslope side.

- **Bedrock in Cut Sections**
    - Borings paired with field mapping should be performed to understand the structures of the bedrock. The stability of the cut slopes should be planned based on structure analysis (Markland method) and global stability analysis.
    - The rippability of the bedrock should be evaluated based on core samples and joints information. Geophysical exploration using seismic refraction test can provide better evaluation on the rippability of the bedrock.

Detailed maps with identified geologic hazards either from desktop study or field verification are presented on Figures A-1 through A-5 in Appendix A. Photography documentations from field verification are presented in Appendix B.

Limitations

The comments and recommendations presented in this memorandum are based upon the limited site visits and information provided, and other information discussed in this letter.

The letter was prepared in substantial accordance with the generally accepted standards of practice for geotechnical engineering as exist in the site area. No warranties, express or implied, are intended or made.

Respectfully,
GRANITE ENGINEERING GROUP, INC.

Hai Ming Lim, P.E.
Project Manager

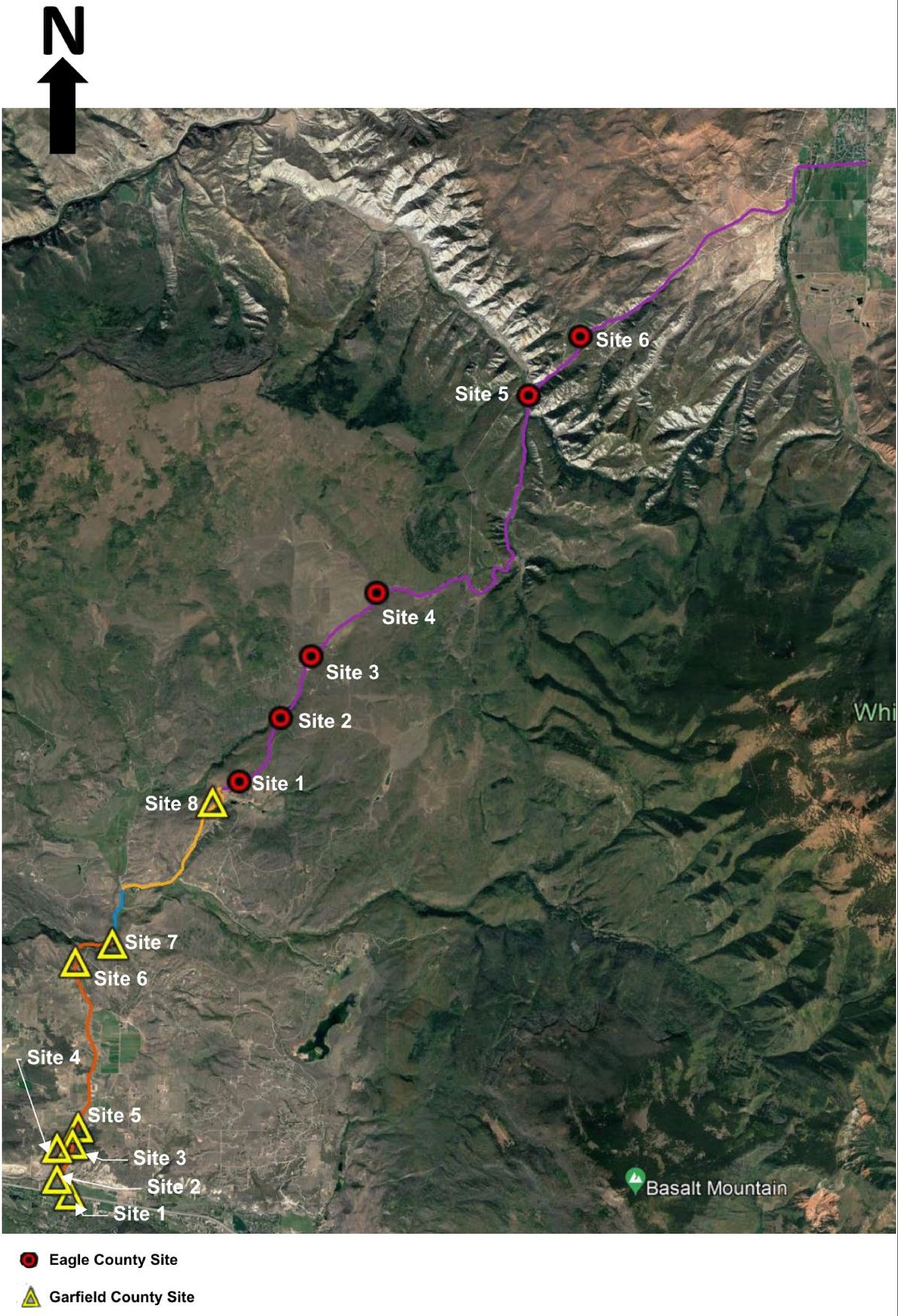
Richard D. Andrew, PG
Technical Specialist

Xuhui Chang
Senior Engineer

Joel Shekoski
Staff Geologist

Attachments: Appendix A: Figures A-1 to A-9
Appendix B: Figures B-1 and B-2
Photography Documentations

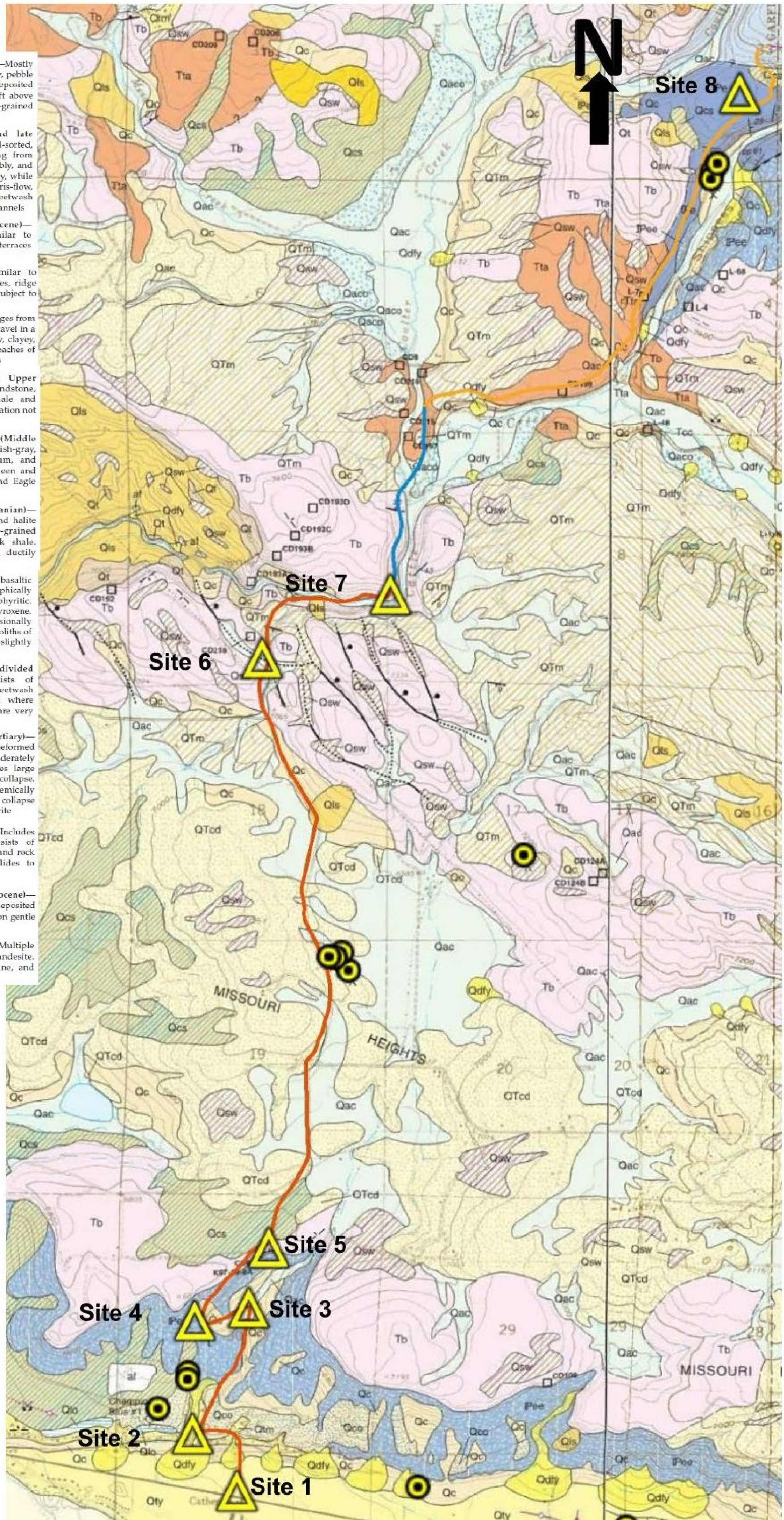
Appendix A



GEG Granite Engineering Group	PROJECT NO. 222-059 DRAWN: DRAWN BY: HML CHECKED BY: RDA FILE NAME:	Alignment and Site Number Cottonwood Pass Feasibility Study Eagle and Garfield Counties, CO	FIGURE A-1

Qty	**Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a sand and silt matrix. Deposited as glacial outwash. Underlies terraces 14–45 ft above modern stream level. May include fine-grained overbank deposits
Qdfy	**Younger debris-flow deposits (Holocene and late Pleistocene)**—Poorly sorted to moderately well-sorted, matrix- and clast-supported deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and bouldery gravel. Fan heads tend to be bouldery, while distal fan areas are finer grained. Includes debris-flow, hyperconcentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels
Qtm	**Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces 55–110 ft above modern streams
Qco	**Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. Generally not subject to future deposition.
Qc	**Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Usually coarser grained in upper reaches of colluvial slopes and finer grained in distal areas
PIPm	**Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone. Top of formation not exposed in quadrangle
IPe	**Eagle Valley Formation (Middle Pennsylvanian)**—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks which are gradational between and intertonguing with the Maroon Formation and Eagle Valley Evaporite
IPee	**Eagle Valley Evaporite (Middle Pennsylvanian)**—Evaporitic sequence of gypsum, anhydrite, and halite interbedded with marine mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed
Tb	**Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. Petrographically most flows are olivine basalt; many are porphyritic. Groundmass predominantly plagioclase and pyroxene. Phenocrysts chiefly olivine and occasionally plagioclase. May contain rare xenocrysts or xenoliths of quartz and quartzite. Locally includes slightly indurated sediments
Qcs	**Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)**—Consists of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are very gradational and difficult to locate
QTcd	**Collapse deposits (Pleistocene and late Tertiary)**—Heterogeneous deposits of slightly to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Locally includes large intact blocks of basalt (Tb) that are lowerd by collapse. Several flows in these blocks were geochemically analyzed. Formed in response to differential collapse resulting from dissolution of underlying evaporite
Qls	**Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris. Ranges from recently active landslides to long-inactive Pleistocene landslides
Qsw	**Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly silty sand, sandy silt, and clayey silt deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, and in basinal areas
Tta	**Trachyandesite undifferentiated (Pliocene)**—Multiple flows of basaltic trachyandesite and trachyandesite. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts

Documented Sinkhole



GRANITE ENGINEERING GROUP

PROJECT NO.	222-059
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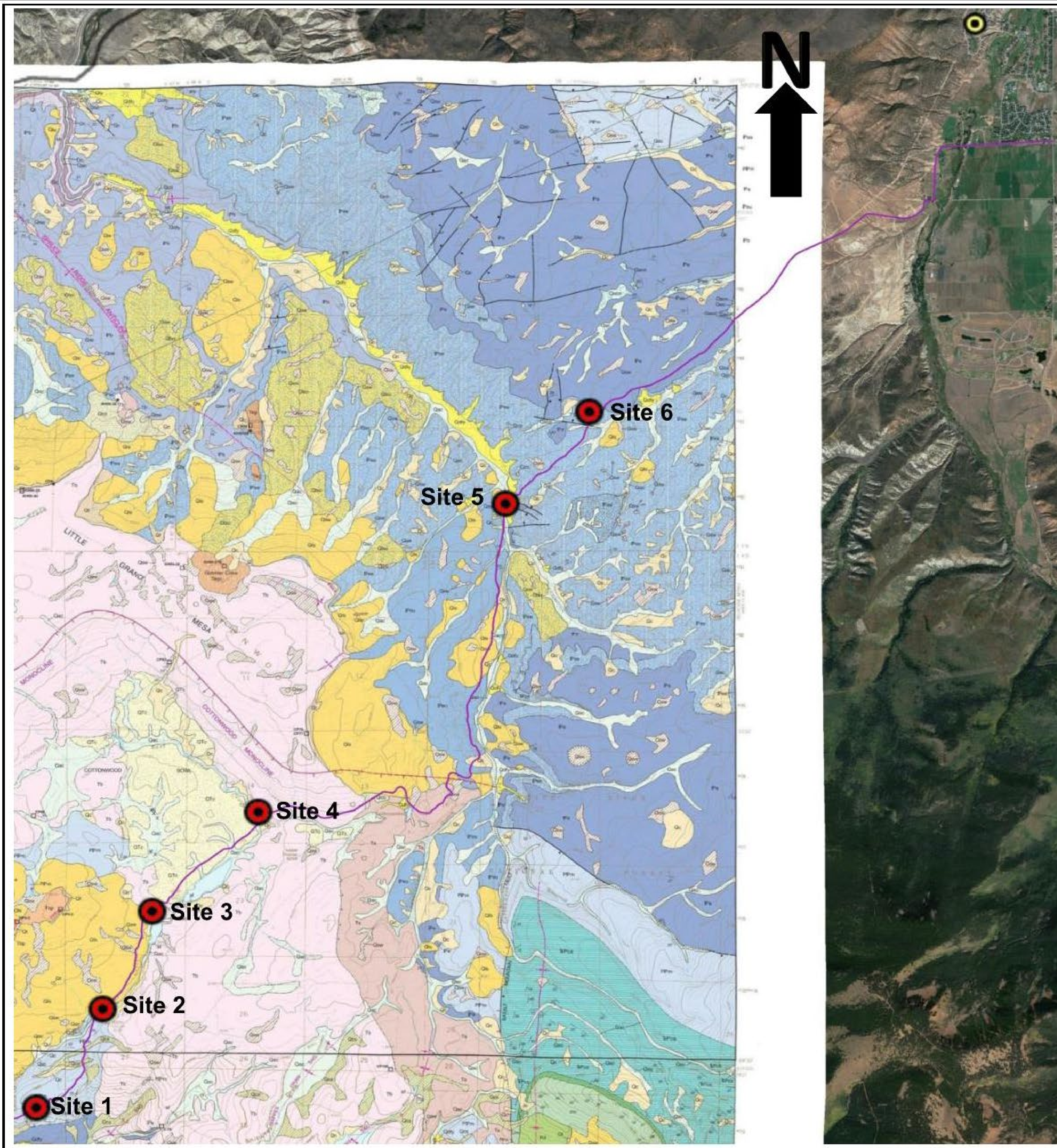
Garfield CO Geologic Map

Cottonwood Pass Feasibility Study
Eagle and Garfield Counties, CO

FIGURE
A-2



Qty	**Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a sand and silt matrix. Deposited as glacial outwash. Underlies terraces 14–45 ft above modern stream level. May include fine-grained overbank deposits
Qdfy	**Younger debris-flow deposits (Holocene and late Pleistocene)**—Poorly sorted to moderately well-sorted, matrix- and clast-supported deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and bouldery gravel. Fan heads tend to be bouldery, while distal fan areas are finer grained. Includes debris-flow, hyperconcentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels
Qtm	**Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces 55–110 ft above modern streams
Qsw	**Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly silty sand, sandy silt, and clayey silt deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, and in basinal areas
Tta	**Trachyandesite undifferentiated (Pliocene)**—Multiple flows of basaltic trachyandesite and trachyandesite. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts
Qls	**Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris. Ranges from recently active landslides to long-inactive Pleistocene landslides
Qco	**Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. Generally not subject to future deposition.
Qc	**Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Usually coarser grained in upper reaches of colluvial slopes and finer grained in distal areas
PPm	**Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone. Top of formation not exposed in quadrangle
Pe	**Eagle Valley Formation (Middle Pennsylvanian)**—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks which are gradational between and intertonguing with the Maroon Formation and Eagle Valley Evaporite
Pee	**Eagle Valley Evaporite (Middle Pennsylvanian)**—Evaporitic sequence of gypsum, anhydrite, and halite interbedded with marine mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed
QTcd	**Collapse deposits (Pleistocene and late Tertiary)**—Heterogeneous deposits of slightly to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Locally includes large intact blocks of basalt (Tb) that are lowerd by collapse. Several flows in these blocks were geochemically analyzed. Formed in response to differential collapse resulting from dissolution of underlying evaporite
Tb	**Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. Petrographically most flows are olivine basalt; many are porphyritic. Groundmass predominantly plagioclase and pyroxene. Phenocrysts chiefly olivine and occasionally plagioclase. May contain rare xenocrysts or xenoliths of quartz and quartzite. Locally includes slightly indurated sediments
Qcs	**Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)**—Consists of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are very gradational and difficult to locate
QTc	**Sediments of Cottonwood Bowl (early Pleistocene and late Tertiary?)**—Locally derived gravel, sand, silt, and clay deposited in and near the topographic bowl in headwaters of East Coulter Creek. Deposits range from sandy and silty pebble, granule, or cobble gravel to gravelly, sandy silt. Deposited in fluvial, sheetwash, and colluvial environments in a large collapse bowl that developed after emplacement of the basalts of Dock Flats
Peu	**Eagle Valley Formation and Eagle Valley Evaporite, undivided (Middle Pennsylvanian)**—Includes Eagle Valley Formation and Eagle Valley Evaporite where contact between the formations is not mappable
Qac	**Alluvium and colluvium, undivided (Holocene and latest Pleistocene)**—Alluvium is typically poorly to well-sorted, stratified, interbedded pebbly sand, sandy silt, and sandy gravel. Colluvium may range to unsorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt. Occurs in tributary valleys of small perennial, intermittent, and ephemeral streams. Deposited by alluvial and colluvial processes

Documented Sinkhole

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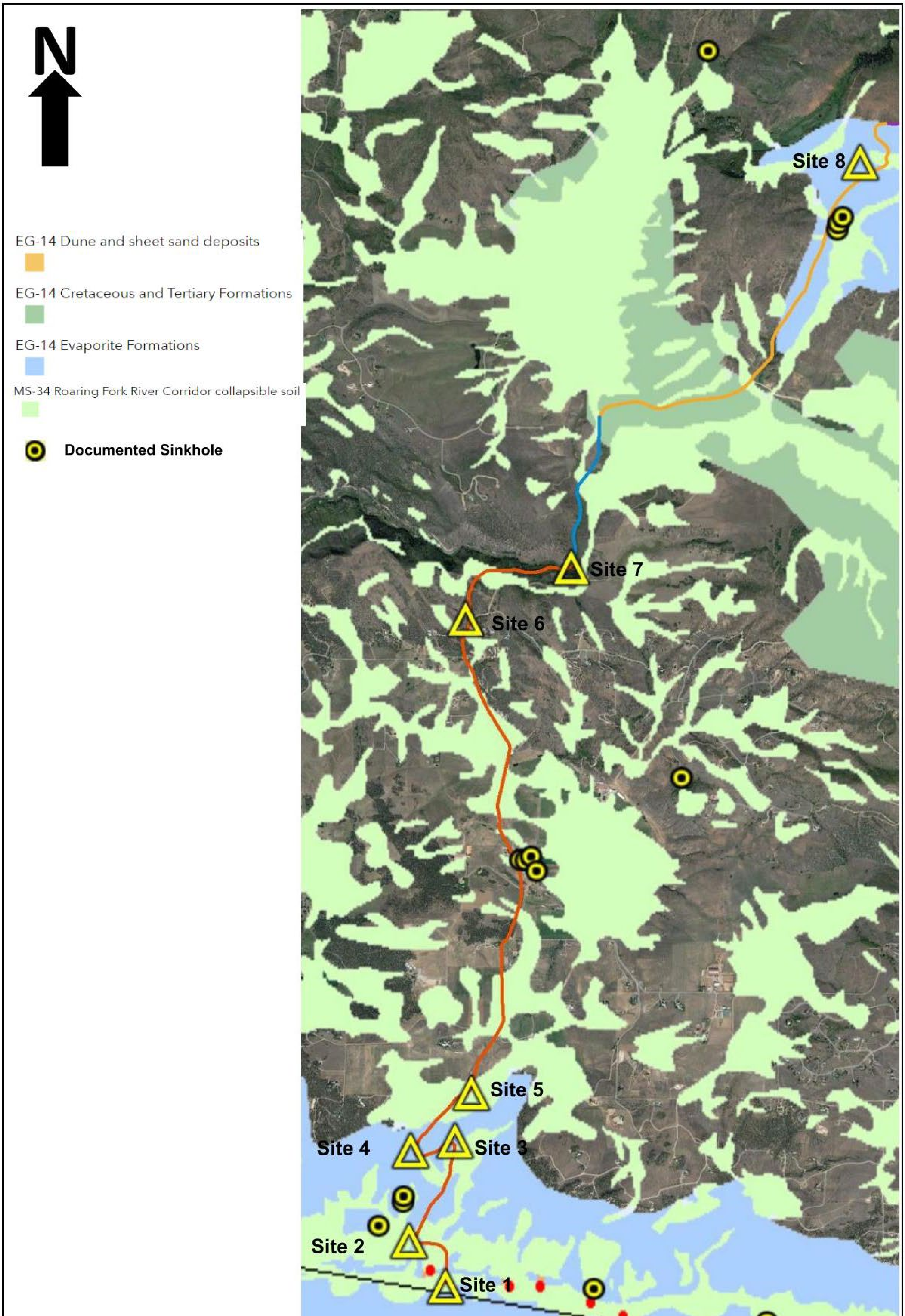
Eagle CO Geologic Map

Cottonwood Pass Feasibility Study
Eagle and Garfield Counties, CO

FIGURE **A-3**



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PROJECT NO.	222-059
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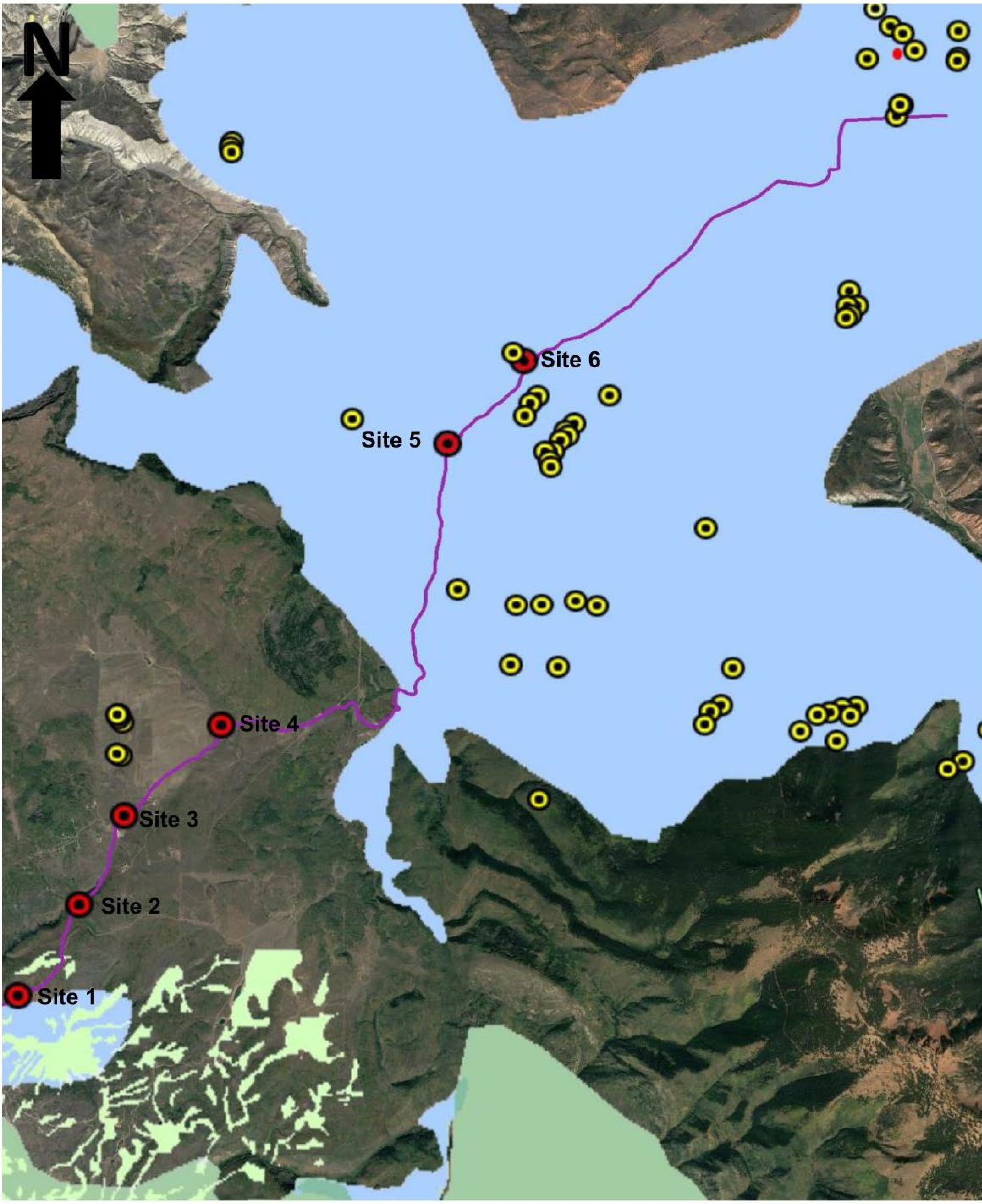
Garfield CO Collapsible Soils

Cottonwood Pass Feasibility Study
Eagle and Garfield Counties, CO

FIGURE
A-4



EG-14 Dune and sheet sand deposits

EG-14 Cretaceous and Tertiary Formations

EG-14 Evaporite Formations

MS-34 Roaring Fork River Corridor collapsible soil

Documented Sinkhole

GEG GRANITE ENGINEERING GROUP	PROJECT NO. 222-059 DRAWN: DRAWN BY: HML CHECKED BY: RDA FILE NAME:	Eagle CO Collapsible Soils Cottonwood Pass Feasibility Study Eagle and Garfield Counties, CO	FIGURE A-5

Surficial deposits. (Holocene to late Quaternary)—Unconsolidated deposits, generally exceeding five feet in thickness, which mantle the ground surface. These deposits include hillside colluvuim, sheet wash deposits, debris-flow deposits, alluvium along tributary and ephemeral streams, and eolian loess. The deposits, generally considered soils in civil and geotechnical engineering terms, varying from uniform loess to coarse gravel in a clay, silt and sand matrix. These soils are geologically recent, are typically loosely packed, porous, dry, and have not been subject to geologically recent saturation by ground water. While some early Holocene to late Pleistocene sediments may have developed soil horizons and limited cementation of the sediment grains, the deposits are mostly younger in age and their pedogenic development is immature. Hazards associated with this unit include potential of soil collapse (hydrocompaction) when wetted and piping collapse of fine-grained deposits in the presence of running water. Risks to structures and infrastructure include
distress from adverse ground settlements and openings of piping voids. Where hachured, the underlying bedrock is Eagle Valley Evaporite or collapse debris, depending on the hachure line color.

Collapse debris (Quaternary and late Tertiary)—Heterogeneous deposits of moderately to severely deformed bedrock overlain by undeformed to moderately deformed surficial deposits north of the Roaring Fork River. Unit formed in response to differential collapse or regional subsidence resulting from dissolution of underlying thick beds of evaporite, primarily halite (rock salt), and/or flow of the evaporitic rocks out from beneath the area. Hazards include surface strain regimens related to subsidence deformation and potential of sinkhole formation. The subsidence deformation hazard is currently poorly understood and it is not presently known whether there is any structural risk.

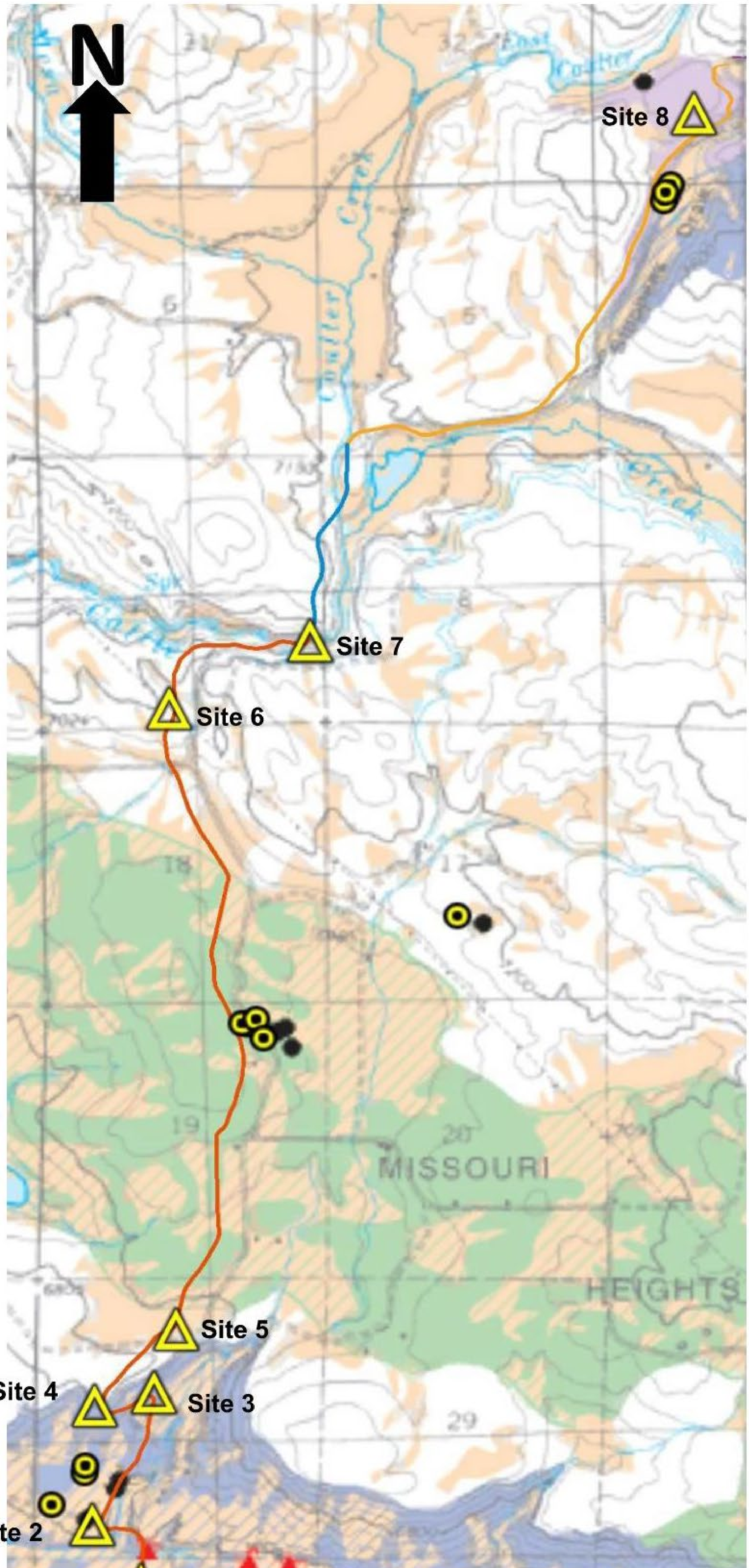
Eagle Valley Formation (Middle? Pennsylvanian)—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks that are gradational between and intertongue with the underlying Eagle Valley Evaporite. Soils derived from the Eagle Valley Formation can have significant gypsum content and are also known to have an elevated potential for hydrocompactive soil hazards.

Eagle Valley Evaporite (Middle Pennsylvanian)—Evaporitic sequence of gypsum, anhydrite, and halite (rock salt) interbedded with mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed. Includes areas overlain by various thin (approximately 50-ft or 15-m thick), surficial deposits. Boundaries are approximate where covered by surfical deposits. Evaporite minerals are soluble; as dissolution of the bedrock occurs, a karst morphology results. Hazards include spontaneous ground openings (sinkholes) and subsidence deformation and settlement near sinkholes and closed depressions. Soils derived from evaporite have high gypsum content and may have high potential for significant collapse upon wetting (hydrocompaction). Potential hazards from regional deformation of the evaporite and risks to structures and infrastructure are undefined. Ground water in this unit typically has a high percentage of total dissolved solids and high salinity.

Sinkholes and subsidence features—Ground depression areas created either by (1) piping or collapse of surficial deposits into dissolution fissures, voids, or caverns within underlying Eagle Valley Evaporite, (2) downward movement of gravel chimneys into deep bedrock voids, (3) dissolution caverns in outcrops of Eagle Valley Evaporite, or (4) large-scale collapse or settlement of low-density surficial deposits. A black dot denotes small sinkholes or clusters of small sinkholes, and closed, hatured lines denote the larger subsidence areas. Many small sinkholes in addition to those shown are probably present where the Eagle Valley Evaporite is shown, but have not been detected or mapped.

Soil-collapse locations—Historical occurrences of soil settlement, damage to structures, and/or collapsible soils verified by soil testing. These data were compiled by CGS as part of the Statewide Collapsible Soil Study (White and Greenman, in prep.). Red triangles show approximate locations of historical occurrences of collapsible soils or damage to a structure as a result of soil collapse and settlement. A Red triangle with black edging denotes approximate locations of historical occurrences of both collapsible soils and sinkholes.

Documented Sinkhole



GRANITE ENGINEERING GROUP			
PROJECT NO. 222-059	Garfield CO Evaporite Soils	FIGURE
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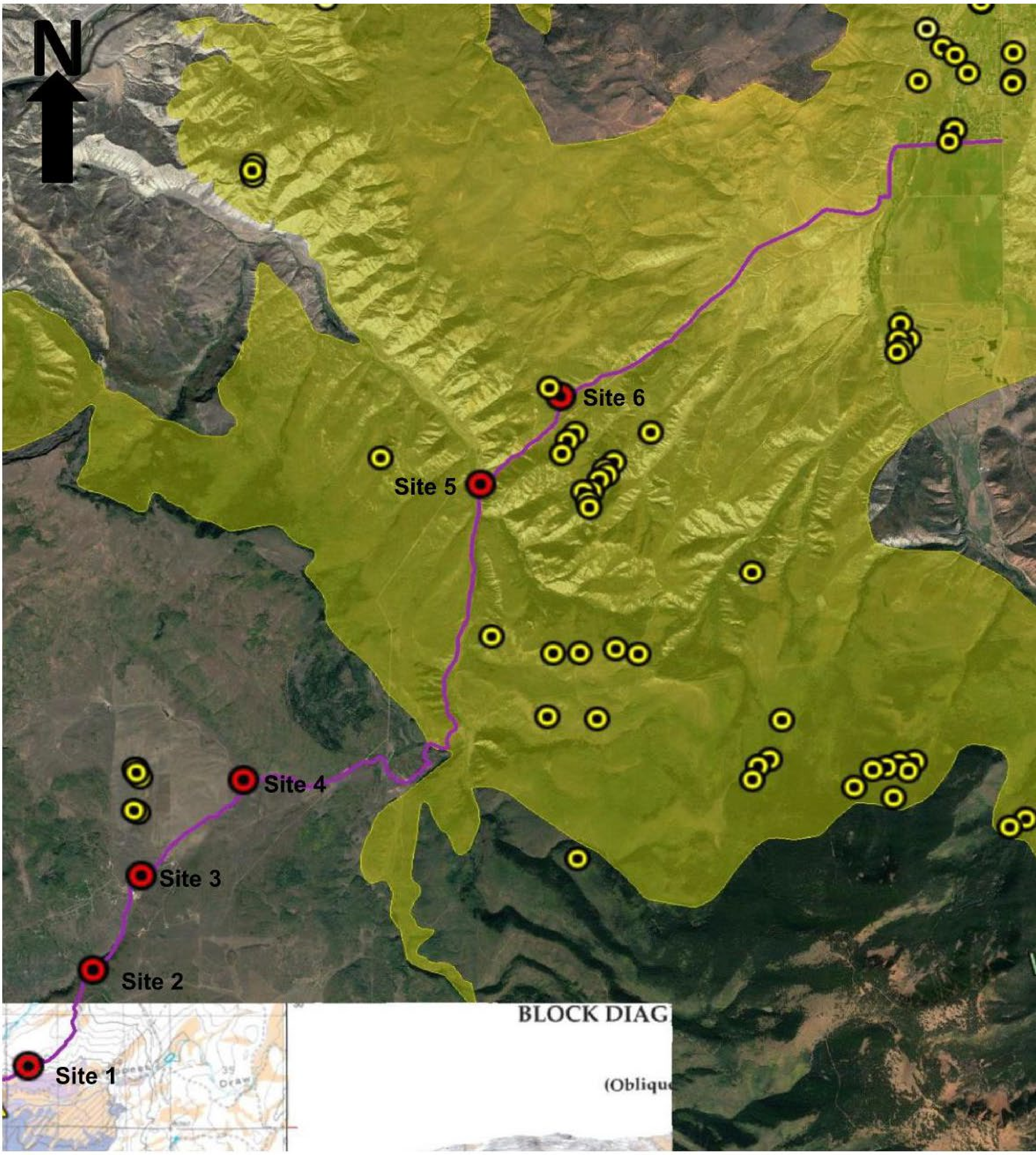
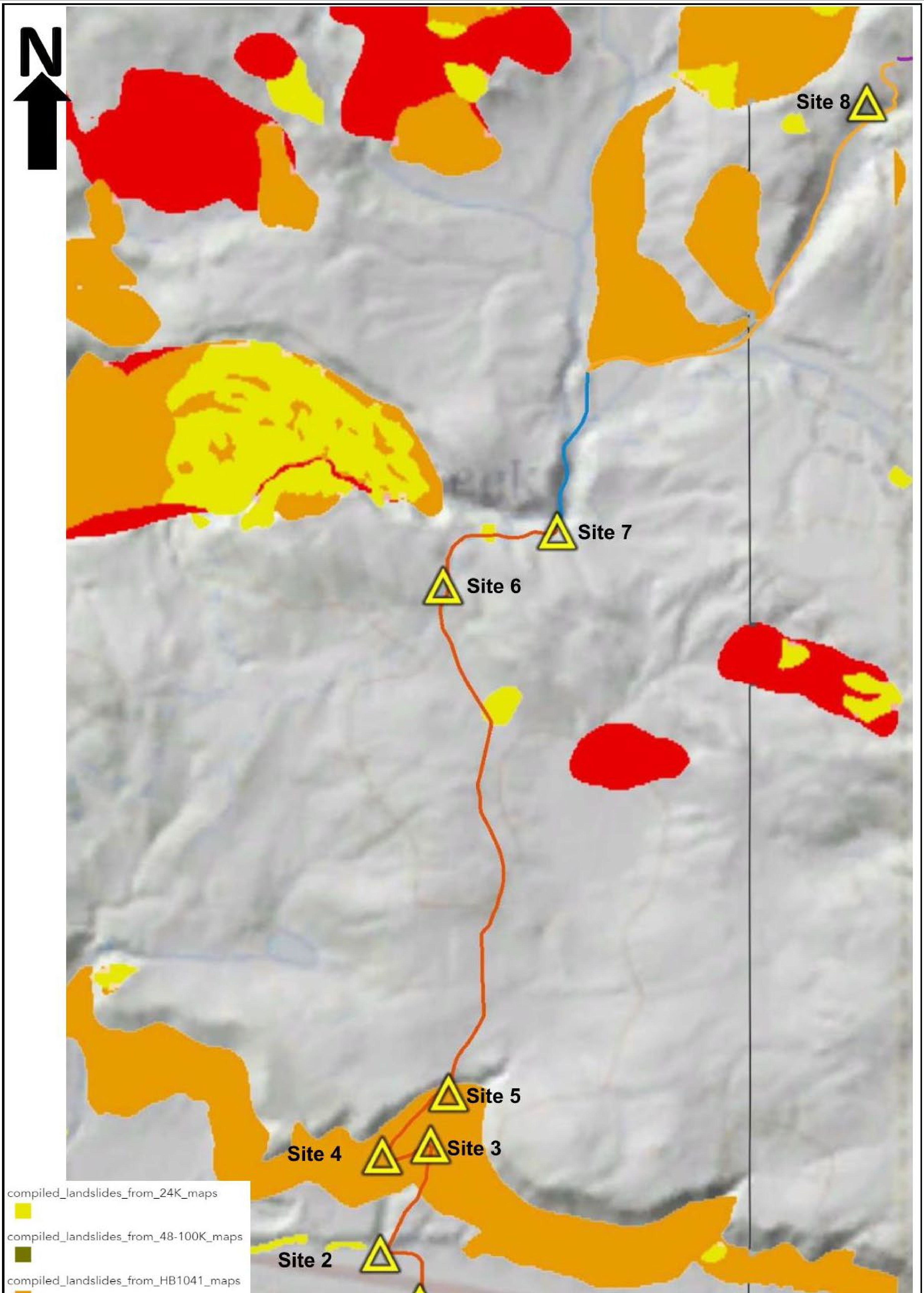
CHECKED BY: RDA	Cottonwood Pass Feasibility Study Eagle and Garfield Counties, CO	
FILE NAME:		



Documented Sinkhole

Evaporite Bedrock

GEG GRANITE ENGINEERING GROUP	PROJECT NO. 222-059 DRAWN: DRAWN BY: HML CHECKED BY: RDA FILE NAME:	Eagle CO Evaporite Soils Cottonwood Pass Feasibility Study Eagle and Garfield Counties, CO	FIGURE A-7



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PROJECT NO.	222-059
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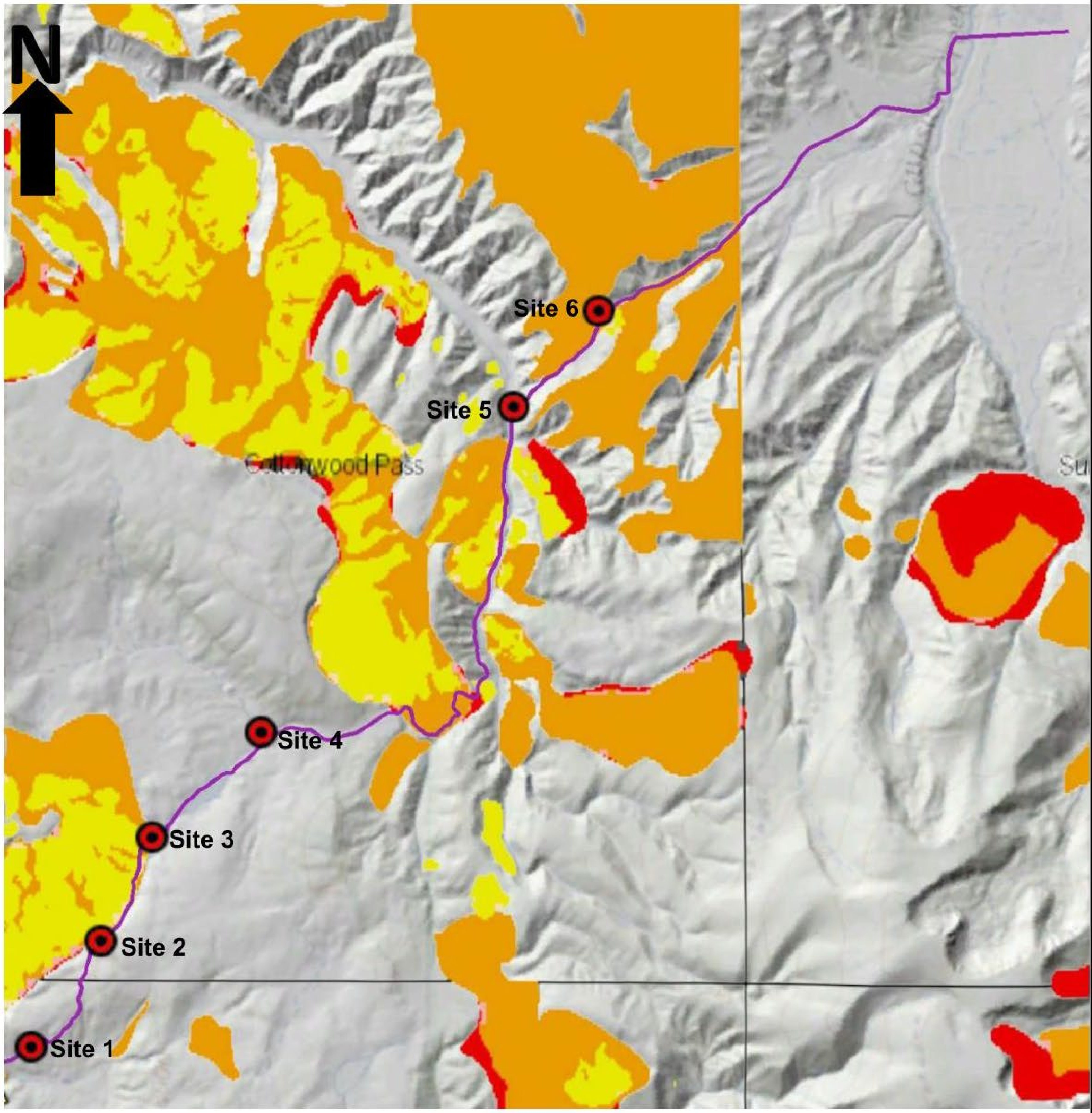
FILE NAME:	

Garfield CO Landslide

Cottonwood Pass Feasibility Study Eagle and Garfield Counties, CO

FIGURE

A-8



compiled_landslides_from_24K_maps

compiled_landslides_from_48-100K_maps

compiled_landslides_from_HB1041_maps

compiled_landslides_from_250K_maps

GEG
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PROJECT NO.	222-059	Eagle CO Landslide	FIGURE A-9
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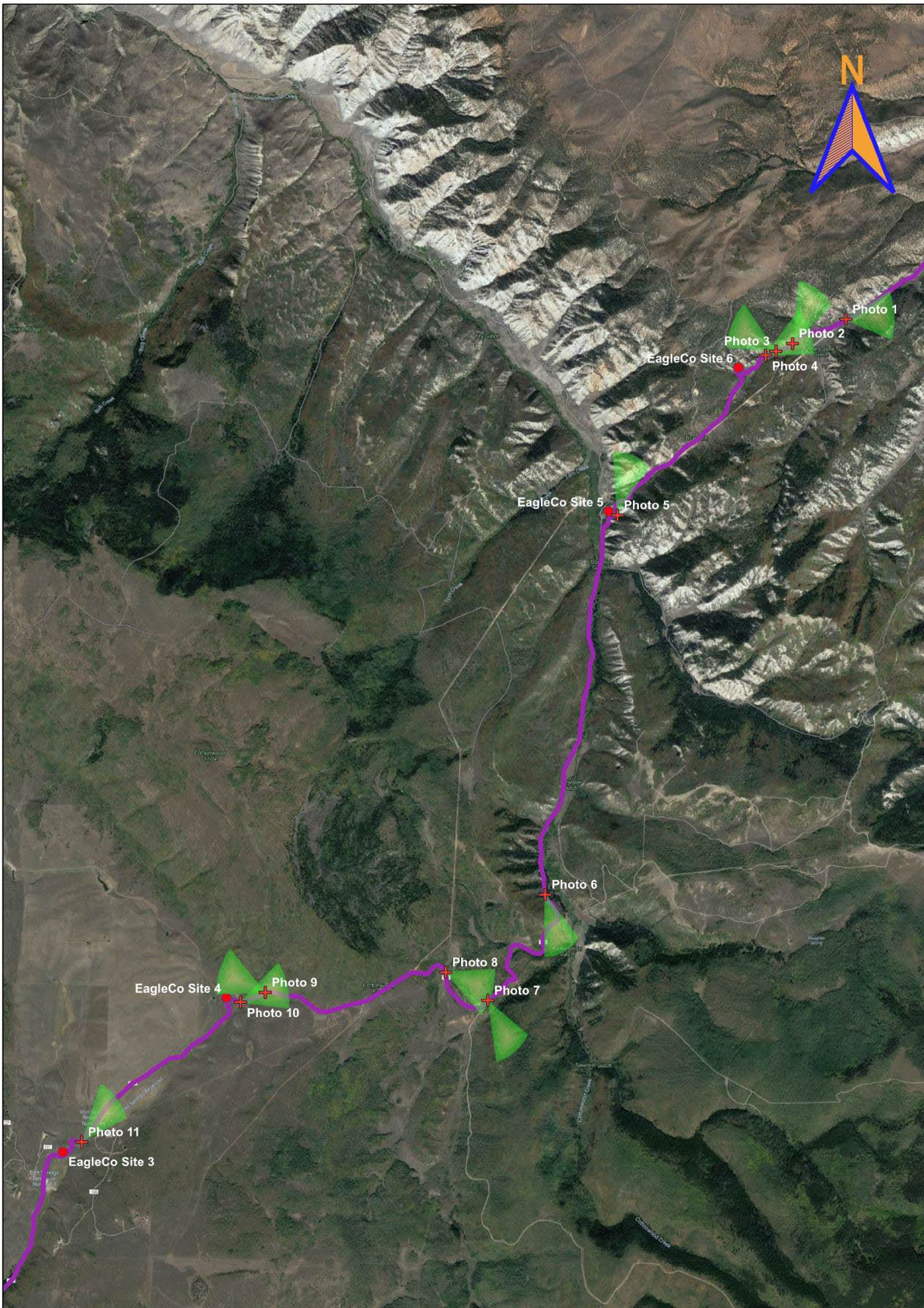
CHECKED BY:	RDA	Cottonwood Pass Feasibility Study Eagle and Garfield Counties, CO	
FILE NAME:			

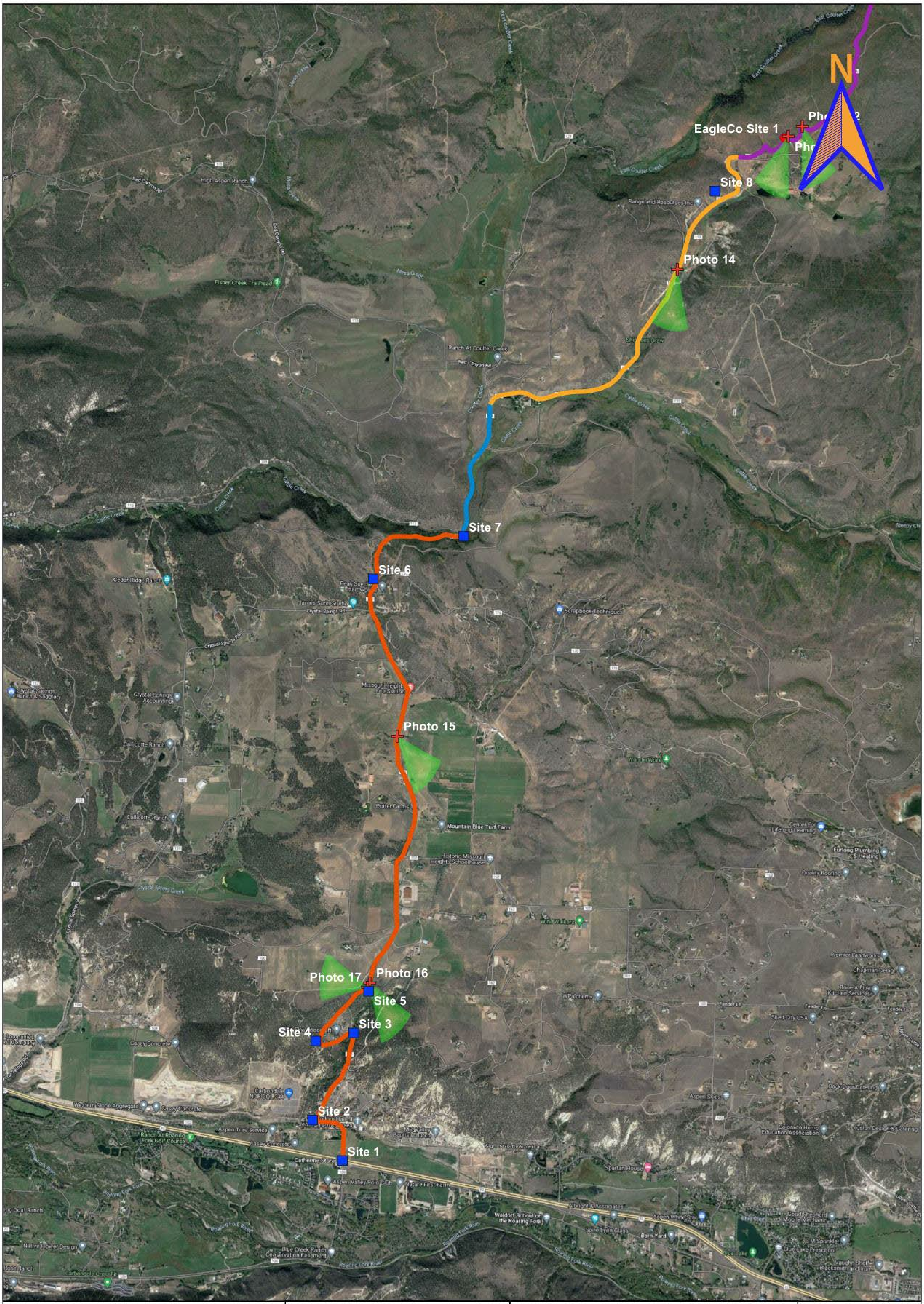
Appendix B

FIGURES B-1 & B-2” PHOTO LOCATION DIAGRAM

PHOTOGRAPHY DOCUMENTATIONS



GEG GRANITE ENGINEERING GROUP	PROJECT NO. 222-059 DRAWN: 9-17-22 DRAWN BY:HML CHECKED BY:RDA	PHOTO LOCATION DIAGRAM Cottonwood Pass Feasibility Study Garfield & Eagle Counties, CO	FIGURE B-1



GEG GRANITE ENGINEERING GROUP	PROJECT NO. 222-059 DRAWN: 9-17-22 DRAWN BY:HML CHECKED BY:RDA	PHOTO LOCATION DIAGRAM Cottonwood Pass Feasibility Study Garfield & Eagle Counties, CO	FIGURE B-2

Photo 1. Existing hillside covered in vegetations

Photo 2. Steep slopes with weakly cemented surficial soils

Photo 3. Rock outcrop

Photo 4. Rock outcrop and weakly cemented surficial soils

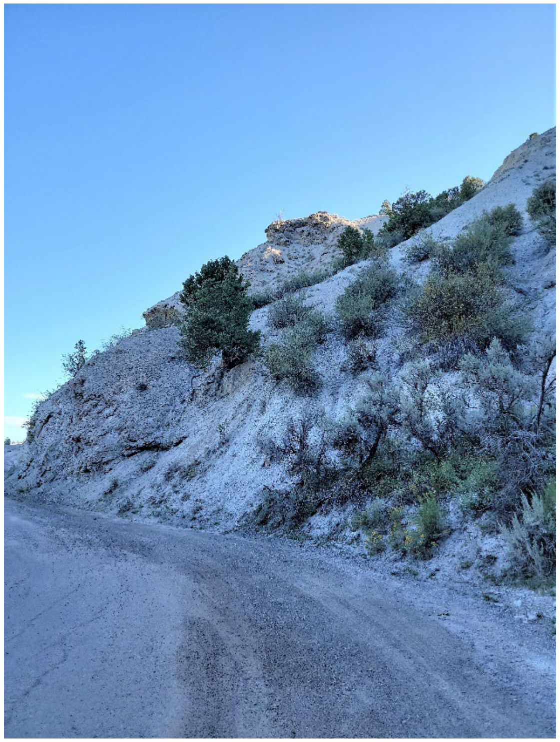


Photo 5. Steep slope with weakly cemented surficial soils

Photo 6. Closer look at steep slope surficial conditions. Note the erosion from surface runoff.

Photo 7. Landslide deposit covered with vegetation

Photo 8. Toe of the landslide mass

Photo 9. Rock outcrop at the top of the slope

Photo 10. A very large scale landslide mass

Photo 11. Rock outcrop in the potential cut section


Photo 12. Structure or embankment to improve alignment


Photo 13. Side slope of the existing roadway


Photo 14. View of the valley


Photo 15. Potential karst in the evaporite soils

Photo 16. Volcanic rock used for embankment

Photo 17. Rock outcrop that will require mitigation