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January 24, 2017

A.G. Wassenaar, Inc.
Attn: Kathleen A. Noonan, P.E.
2180 S. Ivanhoe, Suite 5
Denver, CO 80222

SUBJECT: Geologic Hazard Assessment, ~360-Acre Red Rocks Centre Residential Development in Morrison, Colorado, Jefferson County, Colorado, MWWAI Project No. 161302

Dear Ms. Noonan:

As requested, we have completed a geologic hazard assessment for the proposed Red Rocks Centre residential development area located in Jefferson County, Colorado directly east of Highway C-470 near Red Rocks Amphitheater. We understand that potential future development will generally include construction of several single family detached, single family attached (townhomes and duplexes), and multi-family residential dwellings, flatwork of parking lots and sidewalks, and landscaping. A.G. Wassenaar, Inc. (AGW) is concurrently conducting a preliminary geotechnical assessment for the site; we have reviewed AGW's draft boring logs and laboratory data in preparing this report.

The Red Rocks Centre property is irregularly-shaped and largely undeveloped. The property is bounded by Highway C-470 to the west, Morrison Road and sparsely developed land to the south, a church and residential development to the east, and a residential development and undeveloped land to the north. Rooney Gulch bisects the site in a NW/SE orientation, drains to the southeast, and forms a small valley with relatively steep slopes, up to 2:1 (H:V), in the southern half of the property. Relatively flat, high-lying alluvial surfaces exist on either side of the valley formed by the gulch. More gentle slopes are present in the northern half of the property. The elevation of the property ranges from approximately 5,820 feet above sea level at the pediment surfaces to approximately 5,670 feet where Rooney Gulch exits the property to the south, creating a total relief of 150 feet.

According to published geologic mapping (Scott, 1972), the property is underlain by steeply-dipping bedrock of the Pierre Shale throughout the majority of the site. The Fox Hill Sandstone and the Laramie Formation underlie the site near the northeast corner. All three members of the Pierre Shale are present at the site: the lower member, Hygiene Sandstone member, and upper transition member. The lower member is described as blocky, weathered siltstone and claystone containing thin bentonite beds, limestone concretions, and iron concretions. The Hygiene Sandstone member is described as a yellowish-gray or olive-brown sandstone. The upper transition member is described as an olive-gray shale with interbedded fine sandstone layers containing sandstone concretions and interbedded silty sandstone and sandy shale containing limestone.

Various types of unconsolidated, surficial deposits commonly mantle the underlying bedrock. Recent alluvium consisting of dark-gray to reddish-brown clayey silt and sand with pebbles, is present within and adjacent to Rooney Gulch. Older alluvial deposits of the Slocum alluvium cap the pediment surface in the southern half of the property and are also present towards the eastern boundary and northeast corner of the property. The Slocum alluvium consists of reddish-brown pebbly silt and clay interlayered with gravel, cobbles, and boulders.

The project site is situated within the Designated Dipping Bedrock Area (DDBA), as defined by the Jefferson County Planning and Zoning Division. Jefferson County Land Development Regulations (July 24, 1978, amended July 12, 2005) state that at least one exploratory boring must be drilled every 250,000 square feet to a minimum depth of 35 feet, or 25 feet provided bedrock is found. The regulations also state that site locations where bedrock is not found within 15 feet of anticipated foundation levels (after site grading) may be exempt from additional special investigation requirements with a written application and approval from the Jefferson County Engineering Geologist (July 24, 1978, amended October 25, 2005). Further discussion regarding the potential impact of steeply dipping bedrock to site development is provided in this report.

OBJECTIVES AND SCOPE

The objectives of our geologic hazard assessment were to characterize geologic conditions and hazards at the proposed ~360 acre Red Rocks Centre residential development site and assess the potential impact of those conditions and hazards. The scope of work for this project included:

1. Completion of a geologic hazard assessment for the project site in accordance with Jefferson County Land Development Regulations which entailed: (a) review of existing published information pertaining to geologic conditions and hazards at the site; (b) site reconnaissance of geologic conditions and hazards; (c) site reconnaissance of surrounding roadways and structures with respect to heaving bedrock per section 25.B.2.b.3.j of the Jefferson County Land Development Regulations; and (d) preparation of a map showing surficial geology and geologic hazards within the project site.

2. Development of geologic descriptions for geomorphologic landforms, surface and subsurface drainage, bedrock stratigraphy, bedrock structures, surficial deposits, and other geologic features of significance.

3. Preparation of a written report describing our literature review and site reconnaissance findings, our conclusions regarding geologic hazard risks, and our mitigation recommendations.

SITE LOCATION AND GEOMORPHOLOGY

The project site encompasses approximately 360 acres and is located within the majority of Section 36, Township 4 South, Range 70 West of the Morrison Quadrangle in Jefferson County, Colorado. The site, irregularly-shaped and currently undeveloped, is bounded by Highway C-470 to the west, Morrison Road to the south, Indiana Street to the east, and Yale Street to the north. In the southeastern portion of the site there are two dry ponds, a vehicle parking area, a cow pen and grazing area, and a hay baling area. The West Metro Fire Protection building is roughly located in the middle of the southern site boundary. South of the West Metro Fire Protection building, there is an approximately 4-foot wide canal that roughly follows Morrison Road. We believe its purpose is to redirect surface water to minimize erosion and potential flooding in the area. Immediately outside of the site to the east, there are the Tamarisk and Summit Glen neighborhoods, a soccer field, and Red Rocks Baptist Church. To the northeast is the Coyote Gulch neighborhood, and to the north are two additional neighborhoods – Rooney Valley and Solterra. The Bandimere Speedway drag strip is located to the west of the site on the western side of Highway C-470. **Figure A.1** defines the boundary of the site area and shows a topographic overlay provided by the United States Geological Survey (USGS) (2016).

The elevation of the site ranges from 5,680 to 5,800 feet above mean sea level, and the topography is non-uniform. A small stream named Rooney Gulch flows from the northwest to the southeast though the middle of the site and exhibits a dendritic drainage pattern. It possesses modern stream-cut terraces and over-steepened banks in the southeastern portion of the site where it is most developed. Drainages that empty into Rooney Gulch in the northern portion of the site are primarily responsible for the varied site topography. There are three isolated high areas at the site, two in the southern region of the site on either side of Rooney Gulch and one along the northern site boundary. The site's topographic lows are concentrated in the southeastern region of the site and generally follow Rooney Gulch. Also in this region are minor cut and fill features up to 5 feet tall. These earth-worked areas can be found along both asphalt and dirt roads, near the West Metro Fire Protection building, near the cow pen and grazing area, and around both aforementioned ponds. An area where soils have been stockpiled exists within the westernmost portion of the project site, east of Highway C-470. A variety of grasses dominate the vegetation at the site, but trees, Yucca plants, shrubs, and cacti are also present.

SITE GEOLOGY

Bedrock

The *Geologic Map of the Morrison Quadrangle, Jefferson County, Colorado* (Scott, 1972) indicates that the Pierre Shale is the predominant rock formation underlying the site. The Arapahoe Formation, the Laramie Formation, and the Fox Hills Sandstone are present in the northeastern corner of the site while a relatively small portion of the Niobrara Smoky Hill Shale member exists along the western-most site boundary. Our site reconnaissance confirmed these general conditions. Bedrock geology at the site is illustrated in **Figure A.2**. The bedrock descriptions provided below are in order from oldest to youngest and incorporate descriptions from reviewed published mapping (Miller and Bryant, 1976; Scott, 1972; and Smith, 1964), information from AGW's draft boring logs, and MWWAI's site reconnaissance observations.

Arapahoe Formation (Ka, upper Cretaceous): The upper part of this unit consists of a coarse- and fine-grained sandstone, siltstone, and claystone with thin pebble beds while the lower part is dominated by coarse-grained sandstone and poorly-sorted pebble and cobble conglomerate. The conglomerate contains large shale and sandstone blocks. Together, both parts have a 400-foot thickness.

Niobrara Formation – Smoky Hill Shale Member (Kns, upper Cretaceous): This is the upper member of the Niobrara Formation, a thinly-bedded calcareous shale interbedded with thin layers of limestone. There are three ridge-forming beds within this member: yellowish-orange chalk at the top, yellowish-grey chalky limestone in the middle, and grey soft limestone in the lower third. Bentonite beds are frequently found within this yellowish-brown 410-foot thick member.

Pierre Shale: The Pierre Shale, the thickest geologic formation throughout the Morrison Quadrangle, reaches 6,200 feet in thickness. It is generally easily eroded and poorly exposed at the ground surface. The following text describes the three members that make up the Pierre Shale.

Pierre Shale – Lower part (Kpl, upper Cretaceous): This olive-grey non-calcareous to slightly calcareous fissile shale possesses both ironstone and limestone concretions as well as few thin beds of interbedded bentonite. Illite (generally low swell potential) is dominant in the shale while montmorillonite (generally high to very high swell potential) is present in small amounts but is dominant in the bentonite beds. Miller and Bryant (1976) state the unit material is firm, but becomes friable in near-surface weathered zones. Smith (1964) describes the lower-most

100 feet of the Pierre Shale as calcareous shale and states that it grades into the underlying Niobrara Formation.

This unit was observed at an exposure along Rooney Gulch in the southeastern portion of the site. The thinly-bedded shale was extremely friable and heavily iron-stained. The frequently-spaced discontinuities had a maximum aperture of 3 millimeters, were slightly rough to smooth, had no infilling, and were highly weathered. Metamorphism warped the bedding in a localized section of the exposure.

Pierre Shale – Hygiene Sandstone Member (Kph, upper Cretaceous): This member is a yellowish-grey or olive-brown sandstone. Locally, it forms a hogback.

Pierre Shale – Upper transition Member (Kpu, upper Cretaceous): This member is an olive-grey shale and brown fine-grained sandstone containing hard 4-foot sandstone concretions and interbedded silty sandstone and sandy shale with limestone and ironstone concretions. An underlying olive-grey claystone with limestone and ironstone concretions lays on top of large limestone masses and a thin sandstone bed which transitions into the Hygiene Sandstone member.

This unit was observed along Rooney Gulch in the middle and southeastern portions of the site. Nearly-perpendicular jointing was observed throughout the grey fine-grained sandstone. The discontinuities were spaced 5 inches apart on average, were a maximum of 0.5 meters in length, and displayed a variety of aperture conditions ranging from no aperture to a 5 millimeter wide aperture with soft clayey infilling. The sandstone beds were stronger, more abundant, and slightly thicker than the shale. The dark-grey thinly-bedded shale (~1/4 inch thick on average) was weathered enough to chip away using a fingernail. Large iron concretions up to 6 inches in length were frequently scattered throughout the unit. Iron and calcium carbonate staining covered large portions of the exposures. In some cases, local metamorphism was observed.

Fox Hills Sandstone (Kf, upper Cretaceous): The Fox Hills Sandstone can generally be characterized by thick-bedded sandstone. The upper 105 feet of this formation is silty shale and interbedded, wavy-banded micaceous sandstone. Within the shale are grey limestone concretions up to 12 inches in diameter. The lower 75 feet consist of thinly-bedded to massive sandstone and interbedded dark olive-grey shale and claystone. The sandstone within this lower portion of the formation is yellowish-orange, locally cross-bedded, fine-grained, friable, and ridge-forming. Shale beds dominate the base of the Fox Hills Sandstone. The total thickness of this unit is 180 feet.

Laramie Formation (Kl, upper Cretaceous): The Laramie Formation is a highly interbedded and irregular unit reaching 550 feet in thickness. Light-grey micaceous siltstone, silty claystone, lignitic claystone, friable ridge-forming sandstone, and thin pebbly sedimentary conglomerate layers compose the upper part of this formation. The lower part is primarily made-up of friable sandstone composed of quartz, biotite mica, and kaolinized feldspar. The base consists of a 110-foot thick grey sandstone with grey shale chips. Subbituminous coal beds up to 8-feet thick are present within the 200-foot thickness above the base.

AGW boring logs show claystone as the dominate rock type onsite, and the majority of borings contain about one foot of topsoil overburden. Other logged units include clay, clayey sand and gravel, silty sand and gravel, sandstone, and interbedded claystone and sandstone where the clay and sand and gravel typically overlie bedrock material. The majority of logged sandstone is located in the northeastern portion of the site.

Bedrock Structure

Descriptions provided below are based on reviewed published mapping (Smith, 1964) and MWWAI's site reconnaissance observations.

The *Geology of the Sedimentary Rocks of the Morrison Quadrangle, Colorado* (Smith, 1964) shows three mapped bedding attitudes within the site dipping 38, 60, and 54 degrees to the general northeast direction in the southwestern, mid-western, and southeastern regions of the site, respectively. Other bedding attitudes closely surrounding the site (within 0.3 miles) show dips ranging from 45 to 77 degrees, all in the general northeast directions. During site reconnaissance, exposed Pierre Shale upper transition member bedding was measured in two different locations. An exposure along Rooney Gulch near the West Metro Fire Protection building displayed an attitude of 328/50 while an exposure along Rooney Gulch in the middle of the site displayed an attitude of 336/58. In some instances, small-scale metamorphism was observed with respect to the entire exposure.

The Golden fault and an adjacent splay run through a large portion of the proposed development area in a northwest-southeast orientation as indicated by the red dotted lines in **Figure A.2**. The Golden fault, a complex reverse-thrust fault dipping 45 degrees or more in the general westward direction, is the result of the Laramide Orogeny. It displays dip-slip movement and includes wedges of sedimentary rock.

Surficial Deposits

Surficial deposits, also illustrated on **Figure A.2**, are described below in order from oldest to youngest based on published mapping (Scott, 1972) and information from AGW's draft boring logs.

Slocum Alluvium (Qs, Pleistocene – Sangamon Interglaciation): This ~15-foot thick alluvium consists of reddish-brown pebbly silt and clay interlayered with calcium carbonate-coated gravel. A brown soil with a high swell potential has developed on top of the upper overbank silts.

Upper Slocum Alluvium (Qs1): This describes the lower of two terraces within the Slocum Alluvium that lies 100 feet above the modern stream.

Lower Slocum Alluvium (Qs2): This is the older upper terrace that sits 120 feet above the modern stream.

Colluvium (Qc, upper Holocene to Pleistocene): This dark-grey to reddish-brown material is a bouldery to sandy silt and clay found on mountain slopes and plains. It is typically thicker than 5 feet and contains soil in the upper part and some alluvium throughout.

Piney Creek Alluvium (Qp, upper Holocene): Piney Creek Alluvium is present along modern stream channels and consists of organic, dark-gray to dark-brown micaceous sandy silt or silty sand. The deposits are well-graded, and the clasts are commonly subrounded. The unit is relatively thin at the site with a thickness ranging from 5 to 20 feet throughout the Morrison Quadrangle.

Post-Piney Creek Alluvium (Qpp, upper Holocene): This organic-rich sandy to gravelly alluvium is found along major streams where it forms either a flood plain or terrace 10 feet above stream level. The unit is relatively thin at the site with a thickness ranging from 5 to 15 feet throughout the Morrison Quadrangle.

Artificial Fill (a1 – a4): This unit encompasses pond berms, cut slopes, top soil stockpiles, and aggregate stockpiles.

The most common surficial deposit found in AGW's borings is stiff to very stiff clay. This material was identified directly underneath topsoil for 49 out of all 65 borings drilled by AGW. The thickness of surficial stiff to very stiff clay is highly variable, ranging from 1 ft to 18.5 ft. For the other 16 borings, the most common surficial deposit is sand and gravel.

ENGINEERING GEOLOGY

Bedrock and Surficial Deposits

Simpson and Hart (1980) prepared an engineering geological map of the Morrison Quadrangle. The engineering geological units shown on their map are *"…differentiated solely on the basis of texture and composition, whereas map units on basic geologic maps are differentiated chiefly on the basis of geologic age as well as texture and composition"*. Each engineering geological unit has a description for the following categories: 1) Dominant texture; 2) Equivalent geologic map units or parts of units; 3) Lithologic character of the engineering geologic map unit; 4) Topographic expression; 5) Weathering and weathering effects; 6) Workability; 7) Surface drainage and erodibility; 8) Groundwater characteristics; 9) Suitability for waste disposal; 10) Foundation stability; 11) Slope stability; 12) Probable earthquake stability; and 13) Known, reported, and possible uses of material. **Figure A.3** displays the engineering geological map within the project site. **Table B.1** is adapted from the report associated with the *Preliminary Engineering Geologic Map of the Morrison Quadrangle, Jefferson County, Colorado* (Simpson and Hart, 1980) and provides descriptions of those engineering geological units found within the project site. These units include *Smb (surficial)* – silty sand or gravel with some boulders; *Smo (surficial)* – organic silty sand and gravel; *Cm (surficial)* – silty clay with stones; *ss-cs (bedrock)* – sandstone and claystone; *ms-cs (bedrock)* – siltstone and claystone; *cs-ms (bedrock)* – claystone and siltstone, *ms-ss (bedrock)* – siltstone and sandstone; *cs-sh (bedrock)* – claystone and shale; *cs-ms (bedrock)* – claystone-siltstone; and *ms-cs (bedrock)* – siltstone-claystone.

Soils

Information for soils on site was acquired from the USDA Soil Survey of the Golden Area, Colorado, Parts of Denver, Douglas, Jefferson, and Park Counties CO641. **Figure A.4** is a soil map of the project site generated using the USDA Web Soil Survey website. **Table B.2** provides various soil characteristic ratings for each unit present within the project site. The characteristics considered for this assessment are: 1) Erodibility; 2) Aquifer characteristics; 3) Shrink-swell potential; 4) Well and individual sewage disposal system suitability; and 5) Foundation suitability.

HYDROLOGY

According to the *Depth to the Water Table (1976-1977) in the Greater Denver Area, Front Range Urban Corridor, Colorado* by Hillier et al. (1983), the project site is located in an area where localized water table aquifers occur in: 1) unconsolidated alluvial deposits 5 to 10 feet bgs; 2) unconsolidated alluvial deposits that are not perennially saturated 5 to 20 feet bgs; 3) the Denver Aquifer 20 to greater than 100 feet bgs; 4) the Arapahoe Aquifer 20 to greater than 100 feet bgs; and 5) colluvial and fractured/weathered sedimentary rocks near the surface 5 to 20 feet bgs.

Free water was encountered in 36 of AGW's preliminary borings. The average depth to groundwater is 22.5 ft. Boring 60 shows a relatively deep groundwater level of 74 ft below ground surface (bgs). The northwestern and northeastern portions of the site generally display a relatively shallow depth to groundwater (5 to 25 ft bgs) while the southeastern and southwestern portions of the site have a generally deeper depth to groundwater (14 to 46 ft bgs excluding boring 60). Groundwater levels are subject to vary with development.

Free-flowing water was observed in multiple drainages during our site reconnaissance. In other cases, drainages contained frozen water, stagnant water, or soggy and damp areas. Pooling and seepage was not observed anywhere other than in Rooney Gulch or related drainages.

MINERAL RESOURCES

Bedrock

See **Table B.1c** for known, reported, and possible uses of material descriptions of Simpson and Hart's (1980) engineering geological units.

Soils

The USDA Soil Survey of the Golden Area, Colorado, Parts of Denver, Douglas, Jefferson, and Park Counties CO641 presents the suitability of a soil to act as a construction material source. **Figure A.4** can be used as a reference in conjunction with **Table B.3** which provides the construction material source ratings for all soils present within the project site. The construction material sources considered for this assessment are gravel, roadfill, sand, reclamation material, and top soil. In addition, see **Table B.1c** for known, reported, and possible uses of material descriptions of Simpson and Hart's (1980) engineering geological units.

GEOLOGIC HAZARDS DISCUSSION

Based on published literature, our site observations, and our general experience in the area, potential geologic hazards and associated risk at the proposed development area are discussed below:

Slope Stability – We consider the project site to have a moderate slope stability risk.

According to the *Map Showing Landslides and Areas Susceptible to Landsliding in the Morrison Quadrangle, Jefferson County, Colorado* (Scott, 1972), the proposed development area does not contain any landslide (earthflow) deposits of at least three generations on steep slopes, active landslides, potential rockfall zones, or areas susceptible to sliding. The dip-slope hogbacks approximately 0.5 miles to the west of the proposed development area are depicted as the closest landslide hazard (area susceptible to sliding).

The topography at the site is moderately steep and irregular. The severity of slope movement observed during site reconnaissance ranged from slope creep to landsliding. Slope creep, continuous slope movement which generally advances less than a foot per decade (Cruden and Varnes, 1996), creates a stair-step pattern at the ground surface. It is likely that observed linear stair-step features onsite are well-defined wild game and cattle trails and are not indicative of slope creep. **Figure A.5** shows photos taken at the site and aerial satellite images which clearly display this ground surface pattern.

The majority of over-steepened slopes are located in the southeastern portion of the site where Rooney Gulch is most developed and incised. Scarp traces from past landslides were observed during site reconnaissance along the banks in this area. While some slopes were completely covered with grasses, others showed fresh exposures with partial revegetation indicating both older, more stable slides and relatively recent slides are present. **Figure A.6** shows a landslide where the scarp trace can be identified, but the majority of the exposure has been revegetated with grasses and shrubs. Because erosion has considerably modified the scarp and its flanks, this landslide is most likely *'dormant'* based on Wieczorek's landslide inventory hazard evaluation guide (1984). **Figure A.7** depicts an exposure that is much less vegetated than that displayed in **Figure A.6**. Although bedrock is freshly exposed and bedding is discernible, cracks are no longer visible above the main scarp and the scarp's flanks are highly vegetated. According to Wieczorek (1984), this landslide would be classified as *'questionably dormant'*. One other exposure exhibiting similar characteristics to those shown in **Figure A.7** was observed of Rooney Gulch in between the two onsite topographic high points.

The exposures described above are very shallow-seated landslides with essentially no scarp height. They formed from the toppling and sloughing of soils and weathered rock due to over-steepening. A deeper-seated rotational landslide was observed near the culvert where it passes under Morrison Road in the southwestern portion of the site. This landslide, shown in **Figure A.8**, has a ~2-foot tall, freshly exposed head scarp composed of soil, gravel, and cobbles, an ~8 foot width, and a ~12 foot length from scarp to toe. The scarp flanks and body of the landslide are highly overgrown with grass and reeds, respectively. Due to the high degree of vegetative cover, this landslide is believed to be *'dormant'*, although it is possible that surrounding grasses obscured related tension cracks above the scarp. Unlike the toppling and sloughing processes associated with the previously described shallow-seated landslides, this landslide failed along a subsurface rupture plane with low shear strength.

Tension cracks in surficial soils were infrequently observed within relatively steep drainage slopes. Because Rooney Gulch and associated steep drainage slopes will be avoided during construction, we believe slope movement associated with these tension cracks poses little threat to future development.

Due to the presence of over-steepened slopes and fresh landslide exposures, there is a moderate risk of slope instability at the site. Significant cuts/fills or excavations during development should be designed to address potential short- and long-term slope instability. Sliding or toppling of bedrock along bedding planes out of cut slopes and into excavations is possible, especially where excavations in bedrock are oriented parallel or nearly parallel to the strike of the bedrock. With proper attention to slope stability in engineering design and site grading, the majority of slope stability issues should be avoided.

Expansive Soils and Bedrock – Based on previous geologic mapping and AGW's preliminary borings and laboratory data, we consider the bedrock and surficial material at the project site to have a high to very high swell potential.

Scott (1964) assigns swell potential to the following units: 1) Slocum Alluvium (Qs) – *"The B (clay-enriched) horizon of this soil commonly has a high swell potential."*; 2) Pierre Shale (Kp) – *"Shale and bentonite beds have potential of swelling when wetted and shrinking when dried."*; and 3) Niobrara Formation (Kns) – *"Contains many bentonite beds."* In addition, other units containing clay, namely montmorillonite, and/or shale, likely have the tendency to swell when in contact with water.

According to the *Map Showing Areas Containing Swelling Clay in the Morrison Quadrangle, Jefferson County, Colorado* (Scott, 1972), the proposed development area is, in essence, entirely underlain by geologic units that contain swelling clays. As shown in **Figure A.9**, the majority of the middle and northeastern portions of the proposed development area are underlain by geologic units that contain clays with swelling pressures higher than 2,500 psf. Geologic units that contain clays with swelling pressures higher than 2,500 psf are also present throughout the bulk of the western and southeastern portions of the proposed development area but are covered by 5 or more feet of non-swelling surficial deposits.

We reviewed swell/consolidation laboratory results for bedrock and soil samples collected during AGW's preliminary geotechnical study. The swell potential of bedrock and soil ranges from low to very high based on the Slab Performance Risk Category (CAGE, 1996). Claystone produced a minimum swell of -4.1%, a maximum swell of 14.8% (the overall maximum swell for all material types), and an average swell of 3.6% while clay soil produced a minimum swell of -0.4%, a maximum swell of 11.9%, and an average swell of 2.4%.

The swell potential of the bedrock and surficial material at the project site should be addressed by the project geotechnical and structural engineer during foundation design.

Steeply-dipping Bedrock – The underlying bedrock at the site consists of the Arapahoe Formation, Laramie Formation, Fox Hills Sandstone, Pierre Shale, and Niobrara Formation. These units dip as steeply as 77 degrees towards the northeast based on published geologic mapping (Smith, 1964) and MWWAI's strike and dip measurements. According to the Noe and Dodson (1999), "*the Dipping Bedrock Overlay District is based on the coincidence of steeply-dipping (tilted or upturned) layers of sedimentary bedrock having dip angles of greater than 30 degrees from horizontal…*". Therefore, it is appropriate to classify onsite bedrock units as steeply-dipping.

Heaving Bedrock – We consider the site to have a significant heaving bedrock risk. "Heaving bedrock" refers to steeply-dipping bedrock that exhibits some degree of swell potential. The combination of steeply-dipping beds and swelling clays allows a unit to expand vertically, or heave, when wetted.

Within a zone of steeply dipping bedrock, high swell potential layers can create "heave ridges" oriented along the strike of the bedrock. We did not observe direct evidence of heaving bedrock on site. This is not remarkable as the site has not been developed and thus, has not experienced significant deviations from natural wetting conditions. The increased wetting that is typically associated with residential development should be expected to promote heaving if the site is developed in the future.

The area within ½ mile from the site boundary in the direction of regional strike was observed for evidence of ground deformation due to heaving bedrock in accordance with 23.B.2.b.3.j of the Jefferson County Land Regulations. Some unevenness to the pavement was observed in Morrison Road directly south of the site, and some sidewalk distress was observed along Morrison Road. Both of these features are likely a product of heaving bedrock. Elsewhere over the vast majority of the evaluated area we observed no significant damage to structures or pavement. The developments to the north of the site are relatively new, and in some places, construction is ongoing, and therefore not enough time has transpired for distress related to ground heave to be visible. Minor swales in the road in the Tamarisk neighborhood were not linearly aligned with the strike of bedrock and could not be specifically attributed to heaving bedrock over utility trench settlement or road fill settlement. The road pavement in Bear Creek Lake Park south of the site looked new and showed no signs of distress.

Differential heave along steeply-dipping beds can result in a deep propagation of surface water along bedding planes and thus, a potentially greater depth of heave. The Pierre Shale underlies the majority of the project site and has been known to cause significant distress to structural foundations and pavement flatwork throughout Colorado due to the high to very high differential swell potential of its bentonite beds.

Collapsible Soils – We reviewed swell/consolidation laboratory results for bedrock and soil samples collected during AGW's preliminary geotechnical study. Only a small fraction of lab tests resulted in compression upon wetting at an applied stress. Of those samples that compressed, the percent compression was generally less than one. We believe the risk of collapsible soils at the site to be low for native soils and bedrock.

The potential for collapse and settlement of subsurface materials at the project site, including man-made fill material, should be addressed by the project geotechnical and structural engineer during foundation design.

Erosion – The claystone and siltstone exposures on site are extremely weathered and highly jointed while the sandstone exposures are moderately to very weathered and moderately to very jointed. Both weathered and unweathered claystone and siltstone bedrock are erodible when exposed to wind and water. Plant roots increase shear strength of surficial soils on top of bedrock and help prevent erosion, but vegetation can be difficult to re-establish in the Pierre Shale on slopes exceeding 36 percent (Simpson and Hart, 1980). The potential erodibility of shale is moderate to high where cuts expose the material for extended periods of time. Due to the contrast in strength between the shale and sandstone bedrock present in the upper transition member of the Pierre Shale, the potential erodibility of sandstone is low to moderate.

Erosion control measures and/or landscaping elements should be placed over exposed bedrock material to lessen the potential for erosion. The drainage and erosion plans for the project should address the erosion potential of bedrock materials at the site.

Areas where vegetation density is sparse, especially steep slopes with surficial slope instabilities, prominent drainages, regions modified for the construction of roads, and heavily grazed areas, have a moderate to high soil erosion susceptibility.

See **Table B.1b** for erodibility descriptions of Simpson and Hart's (1980) engineering geological units.

Flooding – A moderate risk of natural flooding exists at the project site. McCain and Hotchkiss (1975) prepared the *Map Showing Flood-Prone Areas, Greater Denver Area, Front Range Urban Corridor, Colorado* which shows a *Flood-prone area along principal stream based on study by USGS* along Rooney Gulch and a *Flood-prone area along principal stream based on study by U.S. Army Corps of Engineers* along Pioneer Union Ditch, although this area only slightly overlaps with the project site in the southeastern corner (**Figure A.10**).

Shallow Groundwater – Groundwater levels are known to fluctuate over time, with development, and seasonally. Perched groundwater tables can develop due to increases in irrigation and infiltration that will occur once the site is developed. See **Table B.1b** for groundwater characteristic descriptions of Simpson and Hart's (1980) engineering geological units. Refer to the Hydrology section of this report for more information.

Excavatibility – We expect that the majority of the surficial materials can be excavated using heavy construction equipment. Excavation may become difficult if light backhoes and/or trenchers are used due to the abundance of large cobbles and boulders found in the alluvial deposits on site. Please note that the high plasticity of swelling soils on site allows clays to adhere to equipment when wet. Weathered shale and weathered sandstone bedrock is also expected to be easily excavated using most heavy construction equipment. If excavations are cut into less weathered bedrock, which may be within 5 feet of the surface in some areas, ripping, or even blasting, may be required. See **Table B.1b** for excavatibility descriptions of Simpson and Hart's (1980) engineering geological units.

Seismic Risk – A 10% probability exists that a 0.033 g peak horizontal ground acceleration associated with an earthquake will be exceeded in 50 years and that a 0.053 g peak horizontal ground acceleration will be exceeded in 100 years at the project site (USGS, 2008). According to the most recent earthquake rate and probability models made available by the USGS (2009), the project site has a low probability (≈1% in 50 years, ≈3% in 100 years) of experiencing a $M \geq 5.0$ earthquake within 50 km. See **Table B.1c** for probable earthquake stability descriptions of Simpson and Hunt's (1980) engineering geological units.

The Golden fault runs through the middle of the project site (see red dotted lines, **Figure A.2**), but no evidence of Holocene faulting (<10,000 years before present) was observed during site reconnaissance. According to the USGS Quaternary Fault and Fold Database, the Golden fault is classified as a *Class B Quaternary-age fault*, meaning that geologic evidence demonstrates the existence of a fault or suggests it has experienced Quaternary deformation. However, evidence does not exist to classify the fault as either *Class A* (a Quaternary fault of tectonic origin) or *Class C* (a fault with insufficient evidence to prove Quaternary deformation has occurred). The nearest Quaternary-age (<1.6 million years) fault is part of the Ute Pass fault zone approximately 27 miles south of the site. The Ute Pass fault is not considered an earthquake causative-fault by current criteria.

Based on this information, seismic risk is low at the project site. The structural engineer should address the potential for seismic activity with respect to Jefferson County building codes.

Radon – According to the Colorado Geological Survey's (CGS) Open-File Report 91-4 (1991), the average state-wide radon gas levels for the bedrock units underlying the project site are as follows:

Soil or Bedrock Name as Reported by CGS	Average Radon Levels (pCi/l)	No. of Samples Collected for Analysis
Older Gravels and Alluvium (Pre-Bull Lake) (Qgo)	5.23	58
Modern Alluvium (Piney Creek Alluvium) (Qa)	3.57	122
Unclassified Surficial Deposits (QTsa)	2.51	26
Denver and Arapahoe Formations (TKda)	6.17	113
Laramie Formation (Kl)	3.96	18
Laramie Formation/Fox Hills Sandstone (Klf)	2.96	27
Pierre Shale – upper transition member (Kpu)	4.88	46
Pierre Shale – Hygiene Sandstone member (Kpm)	6.29	42
Pierre Shale – lower member (Kpl)	6.31	113
Niobrara Formation (Kns)	7.06	60

In their report *A Citizen's Guide to Radon* (EPA 402-K02-006, revised September 2005), the Environmental Protection Agency (EPA) recommends that radon levels greater than or equal to 4.0 picocuries per liter (pCi/l) be reduced for health and safety reasons. As seen in the table above, the majority of soil and bedrock on site exceeds this maximum radon level suggestion. The risk associated with naturally occurring radon gas at the site is moderate to high and can be mitigated by radon-resistant construction techniques, including the provision of ventilation of basement and crawl-space areas. Notably in the CGS (1991) study, structures with basements, cellars, and/or garden levels statistically displayed higher levels of radon gas than structures without them. The EPA recommends that every new home be tested for radon after occupancy.

Mine Subsidence – The project site including a half-mile buffer zone around the site was evaluated for the presence of abandoned mines. The considered area lies within the Foothills Coal Mining District of Colorado (Bucknam, 1982). Coal mining started in the 1890's in the foothills, and since mining operations have been replaced with housing developments, surface subsidence has been a continuing problem. According to the *Subsidence Inventory Map, Morrison Quadrangle* (USGS, 1978), there are four mines within the buffer zone. **Figure A.11** shows the location of these mines with respect to the project site. The South South Chieftain surface clay mine is located along Yale Street on the northern bound of the site. It has an estimated 70-foot thickness of extracted clay, an estimated 30-foot maximum depth of mining, and an estimated vertical dip of mine workings. The Mann underground coal mine is located just east of the eastern site boundary near Indiana Street.

The *Subsidence Hazard Map, Morrison Quadrangle* (USGS, 1978) shows subsidence areas associated with both mines described above (**Figure A.11**). The two mines located on the slopes of the hogback west of Highway C-470 are too far away to cause surface subsidence at the site. The South South Chieftain clay mine subsidence area occupies a portion of the site while the subsidence area associated with the Mann mine is in close proximity to the eastern site boundary.

We believe the risk of subsidence of abandoned mine workings for the site to be low based on published mapping and our site reconnaissance. Site development plans should consider the previous existence of the surface clay mine at the northernmost portion of the site as additional investigation of this area may be warranted.

Environmental Risk – We did not conduct an environmental assessment of the property. Accordingly, this report does not address hazards or risks associated with environmental contamination from previous land uses.

RECOMMENDATIONS

1. Foundation design should be guided by a qualified geotechnical engineer experienced in the design and construction of lightly-loaded foundations within bedrock and soil units that may possess one or more of the following: slope instability, steeply-dipping beds, high potential to swell, heave, settle, or collapse.

2. If grading plans involve significant excavations and/or cut/fill slopes, the short- and long-term stability of these slopes should be evaluated by the project engineer. Increased wetting can destabilize shale slopes.

3. Verification of geological/geotechnical subsurface conditions should be completed on a lot-specific basis to determine if settlement- and collapse-prone soils are present and to help develop appropriate foundation design and construction criteria. The physical extent of settlement- and collapse-prone deposits and the potential for settlement/collapse to occur should be addressed by the project geotechnical and structural engineer during the development of foundation design.

4. Due to the influential uplift processes associated with the Golden fault, the strike and dip of bedrock is not consistent throughout the site. Special investigations may be necessary to determine underlying stratigraphic properties, including the location of bentonite beds, and the dip of bedrock. We would be pleased to assist you if further geological investigations are warranted. The site may be exempt from further special investigations if clearance between bedrock and foundation elements is at least 10 feet, and a written request is made to the Jefferson County Engineering Geologist.

5. Grading and drainage plans should address the erodibility of site materials and risk of localized flooding.

6. The EPA recommends that every new home be tested for radon after occupancy. The risk due to natural occurrence of radon gas can be mitigated by radon-resistant construction techniques, possibly including ventilation of basements and crawl spaces.

GENERAL INFORMATION

Information presented in this report is intended to provide an assessment of geological conditions for the proposed residential development of the Red Rocks Centre in Jefferson County, Colorado; no other use is intended or authorized. The report is based on review of geological literature, a site reconnaissance, our general understanding of geological processes in the project area, and past experience with similar conditions. Variations can and do occur in geological materials, and departures from conditions portrayed in this report are possible. The conclusions and recommendations presented in this report are subject to the limitations and explanations contained herein. The economic and technical performance of the project cannot be guaranteed in any respect.

We have enjoyed working with you on this interesting project. If you have any questions, or if we may be of further assistance, please do not hesitate to call.

Very truly yours,

MICHAEL W. WEST & ASSOCIATES, INC.

By: Emma L. Bradford, E.I.T.
Staff Engineering Geologist

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Figure Area Evaluated by MWWAI (after USGS, 2016)	BY: ELB	DATE: 12/1/16
Project Red Rocks Centre Location Morrison, CO	PROJ: 161302	FIGURE: A.1

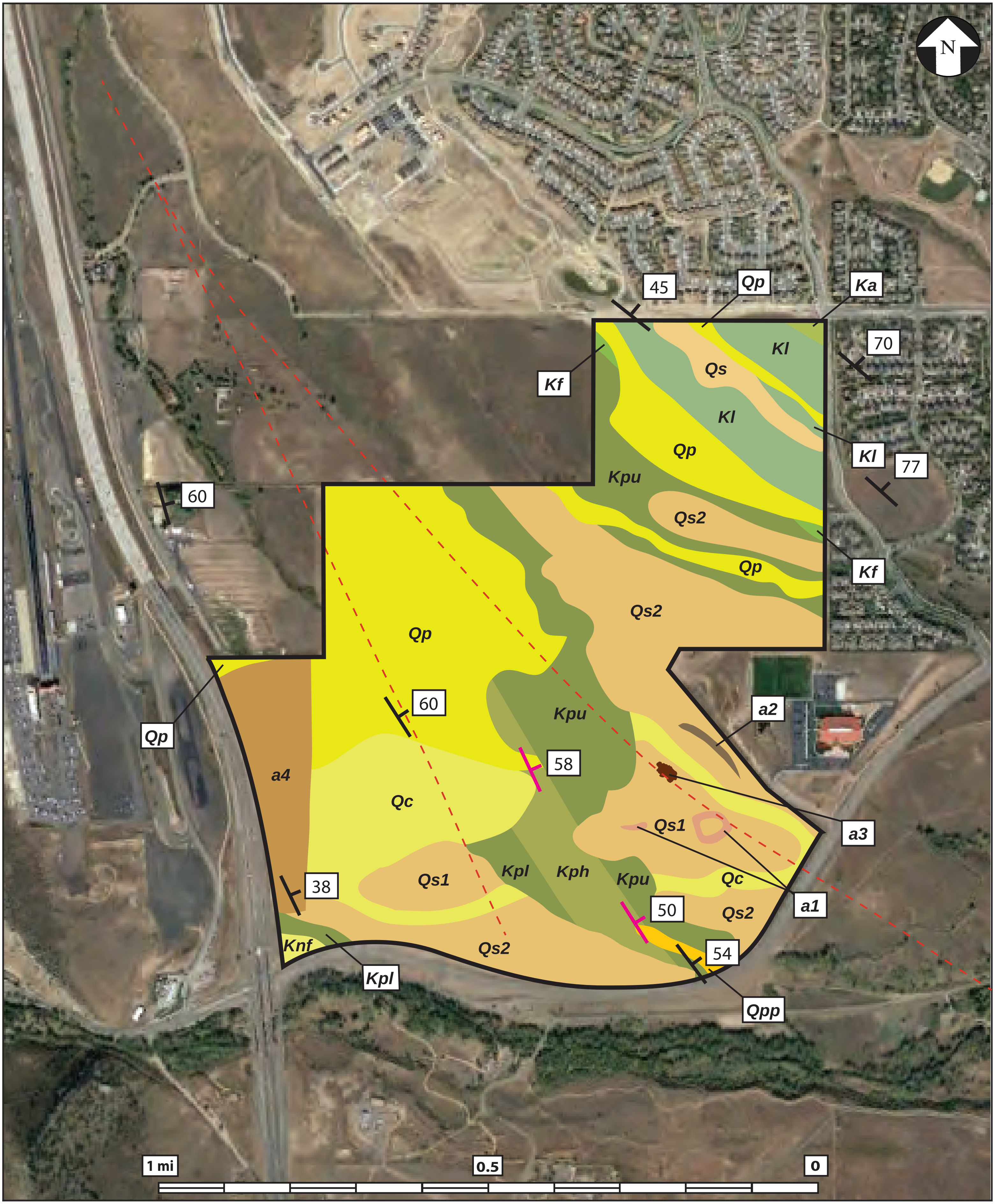

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Figure Site Geology (after Scott, 1972)		BY: ELB	DATE: 12/1/16
Project Red Rocks Centre	Location Morrison, CO	PROJ: 161302	FIGURE: A.2a

SURFICIAL DEPOSITS

a1 POND BERM: Built up native soils around ponds on site.

a2 CUT SLOPE: 20ft tall slope.

a3 TOP SOIL STOCKPILE: A collection of top soil mounds.

a4 STOCKPILE AREA: Privately owned land with a variety of aggregate piles.

Qpp POST-PINEY CREEK ALLUVIUM (UPPER HOLOCENE): Dark-grey humic sandy to gravelly alluvium containing sticks and roots. Only along major streams where it forms flood plain and one or rarely two terraces less than ten feet above stream level. Lies within channels cut into Piney Creek Alluvium along arroyos and valleys, but overlies Piney Creek Alluvium where arroyos are not cut. Underlain by older gravelly alluvium along large valleys. Thickness about 5-15 feet. Most seasonal floods cover this unit.

Qp PINEY CREEK ALLUVIUM (UPPER HOLOCENE): Dark-gray to reddish brown humic clayey silt and sand containing layers of pebbles, generally in lower part. Underlaln by older gravelly alluvium or bedrock. Grades upslope into colluvium. Contains upper Holocene weak brown soil in upper part. Thickness 5-20 feet. Terrace is 10-20 feet above modern streams. Generally not covered by seasonal floods.

Qc COLLUVIUM (UPPER HOLOCENE TO PLEISTOCENE): Dark-gray to reddish brown bouldery to sandy silt and clay on slopes of mountains and plains where it was deposited by gravity and sheet wash. Grades downslope into Piney Creek Alluvium. Locally contains some alluvium. Generally thicker than 5 feet. Ranges in age from Holocene to pre Bull Lake, most is Piney Creek or Louviers. Contams soil in upper part.

Qs SLOCUM ALLUVIUM (PLEISTOCENE - SANGAMON INTERGLACIATION) OR ILLINOIAN GLACIATION: Moderate reddish brown pebbly silt and clay interlayered with gravel. Gravel contains larger and more abundant boulders near mountains than to east. Stones are altered by weathermg and are coated by calcium carbonate. Thickness probably averages about 15 feet. Contains fossil mollusks. Upper part of most deposits is overbank silt on which a very strong brown soil of pre-Bull Lake (Sangamon?) age is developed. The B (clay-enriched) horizon of this soil commonly has a high swell potential.

Qs1 Lower of two terraces or pediments lies about l00 feet above modern stream.

Qs2 Upper terrace or pediment lies about 120 feet above modern stream.

BEDROCK GEOLOGY

Ka ARAPAHOE FORMATION (UPPER CRETACEOUS): Coarse- and fine-grained sandstone, siltstone, claystone, and thin pebble beds in upper park, white, yellowish-grey, and yellowish-orange coarse-grained sandstone and poorly sorted pebble and cobble conglomerate in lower part. Stones from sedimentary rocks make up about 60 percent and igneous and metamorphic rocks about 40 percent of basal conglomerate, but proportions reverse upward. Thickness 400 ft.

Kl LARAMIE FORMATION (UPPER CRETACEOUS): Upper part is light-grey micaceous siltstone stained yellowish-orange light olive-, and pinkish gray. Silty claystone grayish brown humic claystone, minor white and yellowish orange friable ridge-forming sandstone, and near top, thin layers of conglomerate composed of pebbles of sedimentary rocks. Yellowish sandy ironstone concretions. Lower part is almost entirely yellowish-grey iron-stained and white “salt-and-pepper” friable sandstone composed of quartz, biotite mica, and kaolinized feldspar. Gray sandstone contains gray shale chips. Contains thin ironstone layers and shale layers near base. Subbituminous coal beds as thick as 8 feet in the lower 200 feet above basal sandstone. Abandoned cool mines are areas of potential subsidence, as the valley south of Alameda Parkway. Thickness 55O feet.

Kf FOX HILLS SANDSTONE (UPPER CRETACEOUS): Upper 105 feet is olive gray to dark yellowish brown silty shale and interbedded wavy banded friable micaceous sandstone. Shale contains flattened gray limestone concretions 12 inches in diameter. Lower 75 feet is yellowish-orange, massive to thin bedded locally interbedded friablc fine-grained ridge-forming sandstone and interbedded dark-olive-gray shale and claystone. Contains large reddish brown hard calcareous iron-stained sandstone concretions about 6S feet above base. Shale beds are abundant near base. Contains large flow casts about 20 feet above base. Contains fossil pelecypods in lower part of upper shale and at top of lower sandstone. Thickness 180 feet.

Kp PIERRE SHALE (UPPER CRETACEOUS): Thin bentonite (clay) layers common in formation. Shale and bentonititc beds have potential of swelling when wetted and shrinking when dried. Thickness 6,200 feet.

Kpu Upper transition member: Olive-grey shale fine-grained brown sandstone layers containing hard 4 foot brown sandstone concretions and interbedded yellowish brown to olive gray silty sandstone and sandy shale containing limestone and ironstone concretions. Underlying olive-gray claystone contains ironstone and limestone concretions, large limestone masses called Tepee Butte limestone. Thin sandstone bed in zone of *Didymoceras cheyennense*. At base is sandy siltstone.

Kph Hygiene Sandstone Member: Yellowish-gray or olive brown sandstone.

Kpl Lower part: Olive gray clayey shale containing ironstone and limestone concretions.

NIOBRARA FORMATION (UPPER CRETACEOUS):

Kns Smoky Hill Shale Member: Pale to yellowish brown soft thin bedded calcareous shale and interbedded thin layers of limestone. Three ridge-forming beds yellowish-orange chalk at top, yellowish gray chalky limestone in middle, and gray soft limestone in lower third. Contains many bentonite beds. Contains many fossils. Thickness 410 feet.

SYMBOLS

60 Strike and dip measured by Smith (1964)

60 Strike and dip measured by MWWAI

Golden Fault

MICHAEL W. WEST & ASSOCIATES, INC. 2 Inverness Dr. East, Suite 106 Englewood, CO 80112–5508	Figure: Site Geology Legend (after Scott, 1972)	BY: ELB	DATE: 12/1/16
	Project: Red Rocks Centre Location: Morrison, CO	PROJ: 161302	FIGURE: A.2b

Map Unit Label	Map Unit Description
Smb (surficial)	silty sand or gravel with some boulders
Smo (surficial)	organic silty sand and gravel
Cm (surficial)	silty clay with stones
ss-cs (bedrock)	sandstone and claystone
ms-cs (bedrock)	siltstone and claystone
cs-ms (bedrock)	claystone and siltstone
ms-ss (bedrock)	siltstone and sandstone
cs-sh (bedrock)	claystone and shale
cs-ms (bedrock)	claystone-siltstone
ms-cs (bedrock)	siltstone-claystone

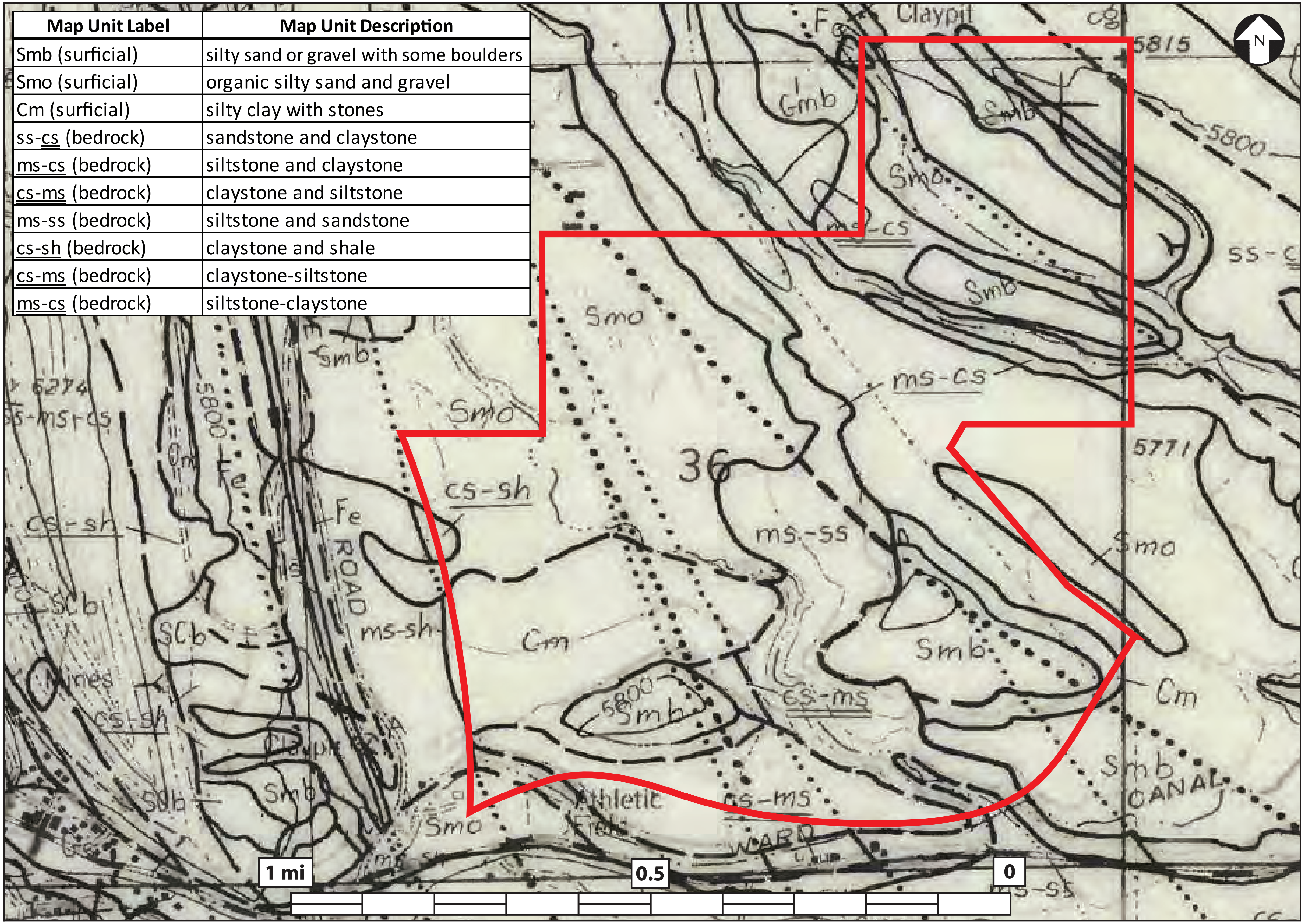

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Figure Engineering Geological Map (adapted from Simpson and Hart, 1980)	*BY:* ELB
Project Red Rocks Centre	*DATE:* 11-30-16
Location Morrison, Colorado	*PROJ:* 161302
	FIGURE: A.3

Map Unit Label	Map Unit Name
4	Argiustolls
25	Denver clay loam
26	Denver clay loam
28	Demver cobbly clay loam
42	Englewood clay loam
60	Haverson loam
74	Lebsack clay loam
80	Layden-Priment-Standley cobbly clay loam
91	Manzanola clay loam
93	Manzanola clay loam
96	Manzanola-Renohill-Stoneham complex
110	Clay pits
111	Gravel pits
132	Renohill loam
160	Ulm clay loam
162	Ulm-Urban land complex

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Figure Soil Map (after USDA Soil Survey CO641)
Project Red Rocks Centre
Location Morrison, Colorado

BY: ELB
DATE: 11-30-16
PROJ: 161302
FIGURE: A.4

DSCN6868 – Slope to the north of drainage ditch north of southeastern topographic high point.

DSCN6897 – Western stream bank ~150 feet south from intersection of main stream and drainage ditch directly north of southeastern topographic high point.

DSCN6946 – Southern slope of the topographic high point northeast of the stream in the southeastern portion of the site.

DSCN7071 – Southeastern slope of the topographic high point northeast of the stream in the southeastern portion of the site.

Figure A.5a

DSCN7028 – Southern slope of ridge located directly north of culvert under Morrison Rd.

DSCN7107 – Northeastern slope of hill along McIntyre St. across from road to church parking lot.

DSCN7270 – Southeastern slope near electrical towers located in the middle portion of the side.

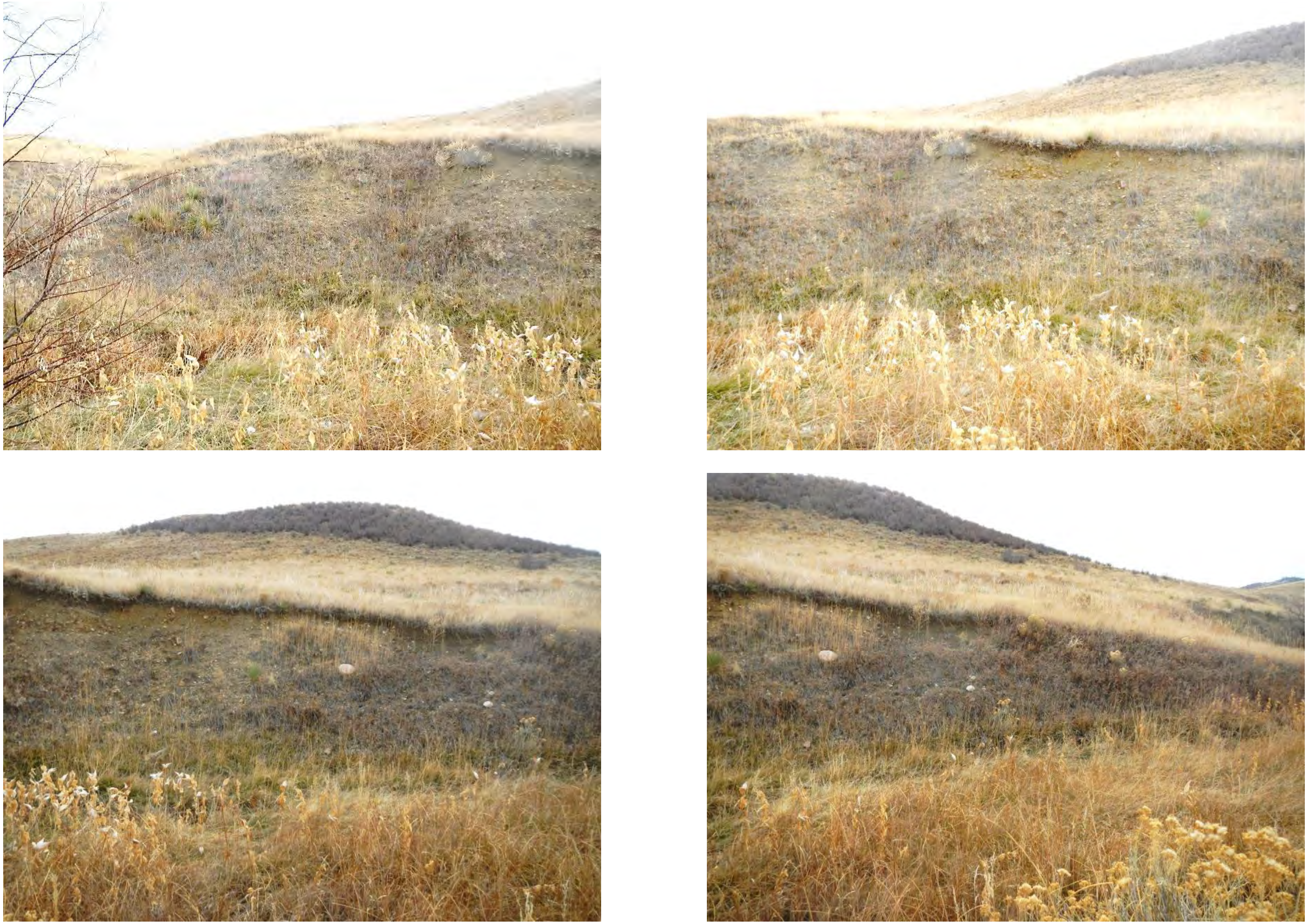
DSCN7309 – Slope on southern side of drainage ditch ~800 feet north of soccer field.

Figure A.5b

Figure A.5c: Aerial photo shows linear ground surface features (after GoogleEarth, 2016).

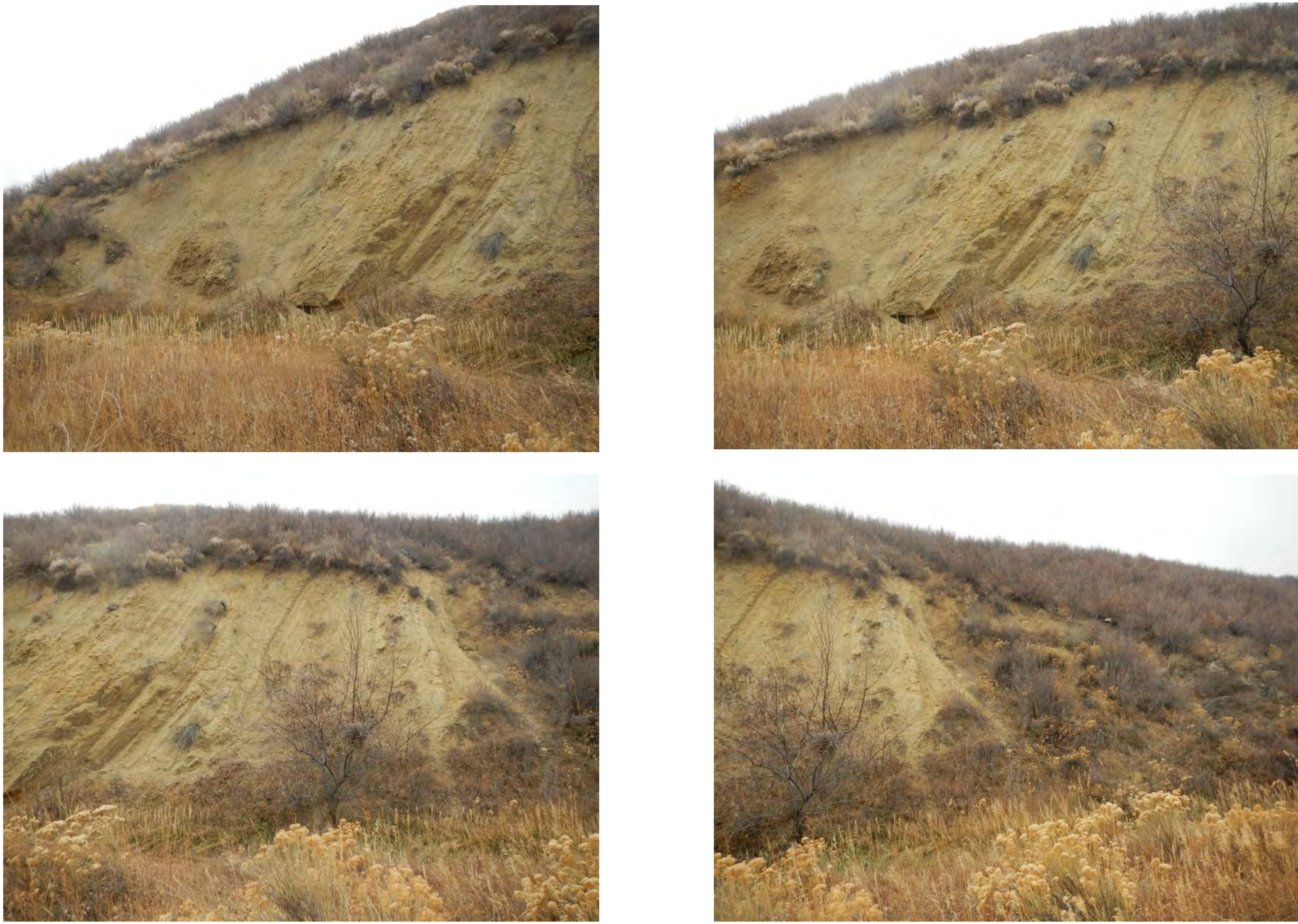
Figure A.5d: Aerial photo highlights linear features on northwestern slope of the topographic high point to the west of Rooney Gulch (after GoogleEarth, 2016).

Figure A.5e: Aerial photo highlights linear features of the northeastern hillslope along McIntyre St. across from road to church parking lot (after GoogleEarth, 2016).



DSCN6882 – DSCN6885 - Eastern stream bank ~150 feet south from intersection of main stream and drainage ditch directly north of southeastern topographic high point.

Figure A.6



DSCN6966 – DSCN6969 - Northern over-steepened stream bank ~420 feet north of West Metro Fire Protection Building.

Figure A.7




DSCN7046, DSCN7048, DSCN7050 – DSCN7051 – Rotational landslide with ~2-foot tall head scarp in southwestern portion of site.

Figure A.8

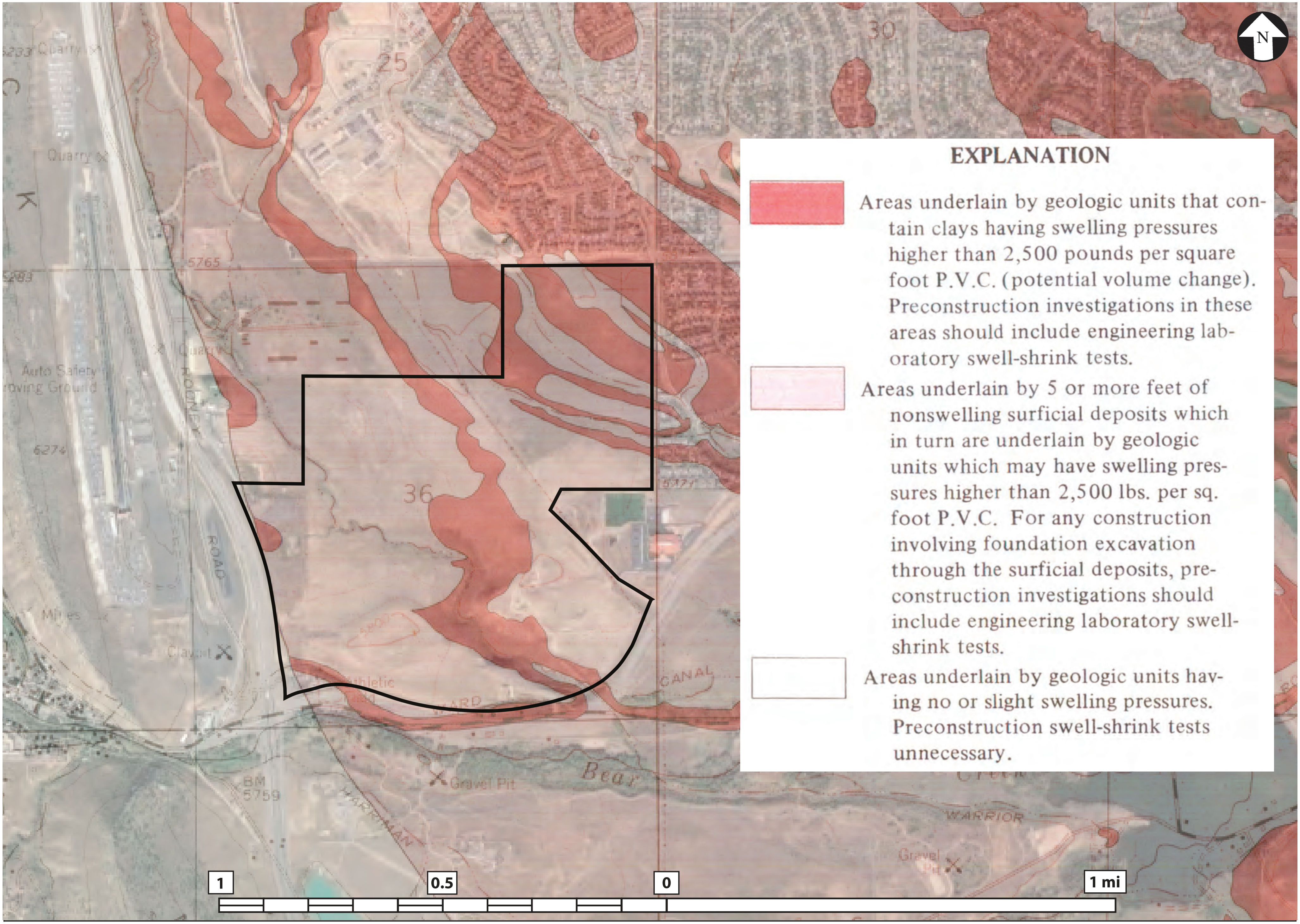


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Figure Site Swelling Soils (after Scott, 1972)
Project Red Rocks Centre
Location Morrison, Colorado

BY: ELB
DATE: 12-09-16
PROJ: 161302
FIGURE: A.9

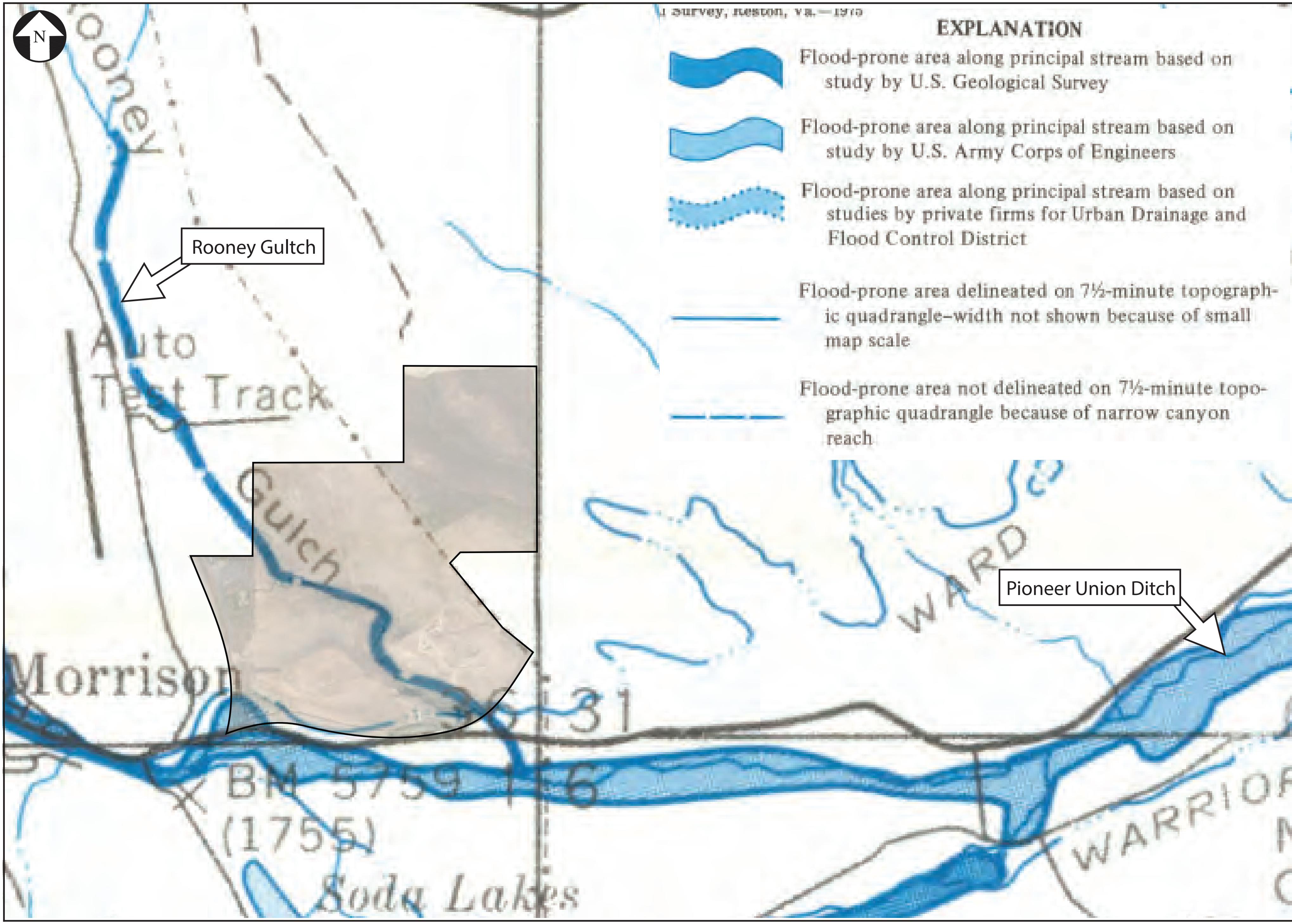

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Figure Flood-prone Areas (after McCain and Hotchkiss, 1975)		BY: ELB	DATE: 12-06-16
Project Red Rocks Centre			
Location Morrison, Colorado		PROJ: 161302	FIGURE: A.10

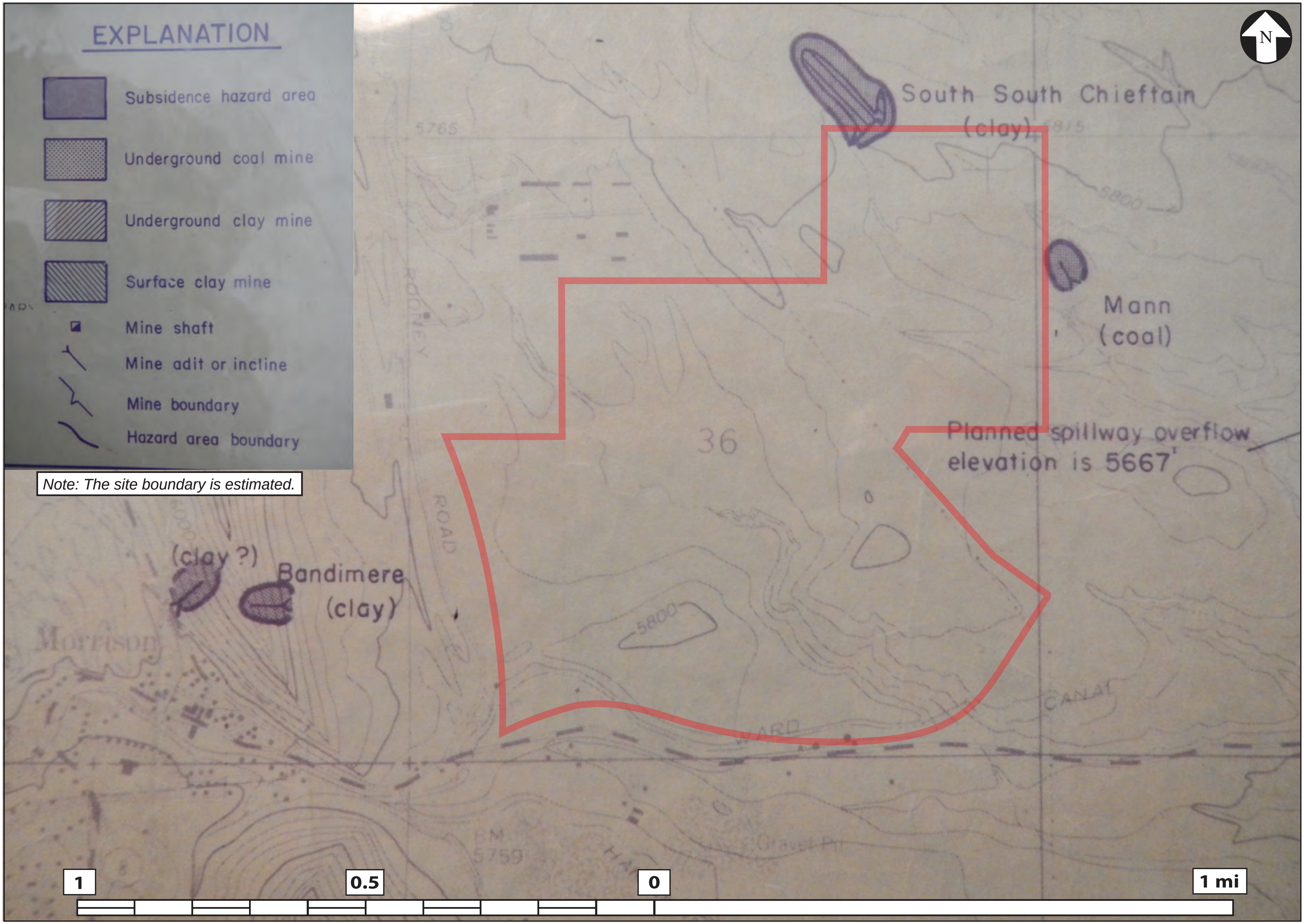

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Figure: Abandoned Coal Mines WRT Site (after USGS, 1978)
Project: Red Rocks Centre
Location: Morrison, Colorado

BY: ELB	DATE: 12-15-16
PROJ: 161302	FIGURE: A.11

APPENDIX B: TABLES

Table B.1a (to be used in conjunction with Figure A.3)
(after Simpson and Hart, 1980)

Engineering geologic map unit symbols	1. Dominant texture	2. Equivalent geologic map units or parts of units	3. Lithologic charcter of the engineering geologic map unit
Smb (surficial) - silty sand or gravel, some boulders	sand	Nussbaum(?), Alluvium, Rocky Flats Alluvium. Verdos Alluvium. Slocum Alluvium. Louviers Alluvium (in part). Broadway Alluvium. Post-Piney Creek Alluvium (in part). Eolian (windblown) sand.	Clayey to silty, pebbly to bouldery, sand and bouldery sand and gravel (SM, GM, SP, SC, some CL, GW), a little silt, a little volcanic ash. Thickness: from 3-35 ft. Beds from 1-5 ft thick, discontinuous, nearly level; boundaries uneven, distinct; loose to very dense; noncoherent to friable; generally well graded. Mainly derived from metamorphic and igneous rocks, in part from sedimentary rocks. Stones present locally, angular to subrounded, from 1-6 ft diameter, average diameter 6 in. Unit generally in 2 parts: Upper: clayey to pebbly silt, commonly 1-4 ft thick (soil); dark gray to reddish or yellowish brown. Lower: sand and gravel, uppermost 1-7 ft weakly to strongly cemented by calcium carbonate (caliche). Unit toward west mainly silty sand with boulders (Smb) or silty sand and gravel, with scattered boulders (Gmb); grade eastward into sand lacking boulders (Sm). Unit attitude: nearly level. Jointing: absent. Contacts: abrupt to gradational, even to uneven.
Smo (surficial) - organic silty sand and gravel	sand	Piney Creek Alluvium.	Organic, clayey to silty sand (SM, SC), some silty gravel (GM), some pebbly to cobbly sand and gravel (GW). Thickness: from 3-20 ft, average 6 ft. Beds from 1 in.-2 ft thick, dip gently to moderately; discontinuous; boundaries even to uneven, distinct. Material loose to medium density; noncoherent to friable; well graded; coarse fraction mainly of metamorphic and igneous origin; stones subround, nearly equidimensional, maximum diameter 10 in. Generally two parts. Upper: humus-rich silt (ML, OL) (soil), from 1 to 5 ft thick; dark gray to reddish brown. Lower: sand and gravel, thickness from 2-18 ft. Unit attitude: level to moderate dip. Jointing; rare. Contacts: distinct to gradational, uneven to very uneven.
Cm (surficial) - silty clay with stones	clay	Colluvium (in part).	Silty to sandy, pebbly to cobbly, clay (CL—CH, some SC). Thickness: from 2-18 ft, average 6 ft. Bedding generally absent; discontinuous, even to uneven, boundaries gradational where present. Material stiff to very stiff, generally well graded; derived mainly from sedimentary rock upslope. Clay minerals varied, mainly illite, mixed-layer illite-montraorillonite, some montmorillonite; stones angular to subrounded, mainly from other surficial deposits and sedimentary bedrock (Is, ss-ms-cs) PVC rating 0.8-5.4: noncritical to critical; swell index 800-4300 psf; dark gray to reddish brown. Unit attitude: gently to moderately inclined. Jointing: absent. Contacts: gradational even to uneven.
ss-cs (bedrock) - sandstone and claystone	sandstone-claystone	Laramie Formation. Fox Hills Sandstone.	Lithology: clayey to silty sandstone and sandy to silty claystone; some coal, mainly near middle. Thickness: from 750-1200 ft; apparent thickness greater due to dip. General character: beds from several inches to 25 ft thick, persistent to discontinuous, boundaries even and distinct; overconsolidated. Sandstone: medium density where weathered to very dense where nonweathered; locally crossbedded; moderately graded; sand grains subangular to rounded, mainly quartz and chert; light gray to reddish brown. Claystone: very soft where weathered to hard where nonweathered; poorly graded; clay minerals mainly montniorillonite in basal and upper-middle part of map unit, kaolinite dominant elsewhere, some illite present throughout unit PVC rating 0.8-7.7, noncritical to very critical, swell pressure from 800-6200 psf, swelling clays most abundant in upper 75 percent of unit in beds associated with coal. Coal: lignite to subbituminous; 2-5 beds from 6 in.-4 ft thick, discontinuous along strike and down dip. Attitude: strike generally a little west of north, dip from 45° eastward to 76° westward (overturned). Jointing: Sandstone: conspicuous, extensive, somewhat regular, ordered, numerous; consists of three nearly perpendicular sets. Claystone: inconspicuous, short, irregular, random, few.
ms-cs (bedrock) - siltstone and claystone	siltstone-claystone	Pierre Shale (Upper transition member downward through the Baculites grandis Zone).	Lithology: clayey to very sandy siltstone, silty claystone; a little fine-grained sandstone. Thickness: from 1-1500 ft; locally thinned by ancient faulting; apparent thickness greater because of dip. General character: beds several inches to several feet thick, persistent, boundaries even, gradational; soft where weathered, hard where nonweathered; overconsolidated; contains scattered lenses of hard, brittle, calcareous ironstone concretions as much as 2 ft in diameter; clay minerals mainly montmorillonite and mixed-layer illite-montmorillonite; poorly graded; grains mainly quartz, some feldspar, a little calcite and dolomite. Siltstone and sandstone: PVC rating 0.4-3.4, noncritical to marginal, swell index 500-2800 psf; mainly very fine silt to fine sand, grains include some gypsum; yellowish brown to reddish brown. Claystone: PVC rating 2.0-4.2, marginal to critical, swell index 1700-3300 psf; olive gray to dark gray. Attitude: strike varies from northwest to slightly west of north, dip from 45° eastward to 70° westward (overturned). Jointing: inconspicuous, random, short, irregular, numerous. Contacts: gradational with map unit cs-ms below (west) and ss-cs above (east), distinct with any overlying surficial units; even.
cs-ms (bedrock) - claystone and siltstone	claystone-siltstone	Pierre Shale: (includes two parts: (1) from the base of the Baculites grandis Zone down to top of Hygiene Sandstone Member, and (2) from base of Hygiene Sandstone Member down through Basperiformis Zone).	Lithology: silty claystone, and clayey to sandy siltstone; a little sandstone. Subunits: two (separated by map unit ms-ss). Eastern subunit mainly claystone, siltstone dominant at base; western subunit mainly claystone. Thickness: eastern subunit from 1 to 2600 ft, western subunit from 1 to 800 ft; locally thinned by ancient faulting; apparent thickness greater because of dip. General character: beds persistent, boundaries even, distinct; overconsolidated; contains numerous layers of many hard, brittle, calcareous concretions of ironstone as large as 3 ft in diameter; poorly graded; clay minerals mainly montmorillonite and mixedlayer illite-montmorillonite; silt and sand grains mainly quartz and calcite, some feldspar, dolomite, and gypsum. Claystone: beds from 1 in. to several feet thick; medium consistency where weathered to hard where nonweathered; PVC rating 1.2-5.0, noncritical to critical, swell index 1070-3590 psf; olive gray to mottled medium gray to black. Siltstone and sandstone: beds generally less than 2 ft thick; soft where weathered to very stiff where nonweathered; PVC rating 0.5-2.9, noncritical to marginal, swell index 550-2400 psf; cemented, partly by calcium carbonate, partly by clay; yellowish brown to dark olive gray. Attitude: strike varies, consistently west of north, dip 54°-60° eastward. Jointing: inconspicuous, random, short, irregular, numerous. Contacts: gradational with map unit ms-ss below (west) and map unit ms-cs above (east), and with map unit ms-ss between the subunits; distinct with any overlying surficial units; even.
ms-ss (bedrock) - siltstone and sandstone	siltstone-sandstone	Pierre Shale (Hygiene Sandstone Member only).	Lithology: clayey silts tone and silty claystone; some clayey sandstone (dominant near top of unit). Thickness: from 1 to 900 ft; locally thinned by ancient faulting; apparent thickness greater because of dip. General character: beds from several inches to 2 ft thick, persistent, boundaries even to uneven, distinct to gradational; overconsolidated. Siltstone and sandstone: medium consistency where weathered to dense where nonweathered; silt- to fine-sand-size grains mainly quartz and mica, some glauconite and iron oxides, a little organic material; light gray to yellowish brown. Claystone: soft where weathered to hard where nonweathered; clay mineral mainly illite, some mixed-layer illite-montmorillonite, PVC rating 0.3-1.7, non-critical, swell index 400-1450 psf; light to dark gray. Attitude: strike varies, generally a little west of north; dip from 54° to 60° eastward. Jointing: inconspicuous, random, short, irregular, numerous. Contacts: gradational with map unit cs-sh below (west) and cs-ms above (east); distinct with any overlying surficial units; uneven.
cs-sh (bedrock) - claystone and shale	claystone-shale	Pierre Shale (from base of Baculites asperiformis to Zone downward base of lower transition member). Graneros Shale and Greenhorn Limestone.	Lithology: silty claystone, locally silty shale, some sandy limestone, and a little calcareous sandstone. Subunits: two (separated by map units Is and ms-sh). Eastern subunit mainly silty claystone, calcareous sandstone at base; western subunit mainly silty shale in basal two-thirds, sandy limestone in upper 1/3. Thickness: eastern subunit from 1-650 ft, western subunit from 1-280 ft; locally thinned by ancient faulting, apparent thickness greater because of dip. General character: beds from 1 in. to several feet thick, persistent, boundaries even, gradational, overconsolidated; poorly graded; clay minerals mainly mixed-layer illite-montmorillonite, some illite and kaolinite; contains scattered layers 0.25-1.0 in. thick of montmorillonite (bentonite), silt grains mainly quartz. Claystone: soft where weathered to hard where nonweathered; PVC rating 2.5-3.1, marginal, swell index 2100-2500 psf; light gray to dark brown. Shale: stiff where weathered to very hard where nonweathered; PVC rating 0.8-1.8, noncritical, swell index 800-1550 psf; mottled gray to black. Limestone: thin-bedded; hard. Sandstone: thinbedded, dense, sand grains mainly quartz; cemented by calcium carbonate. Attitude: strike varies, consistently west of north, dip from 35° eastward to 52° westward (overturned). Jointing: random, irregular, short, numerous.

Table B.1b (to be used in conjunction with Figure A.3)
(after Simpson and Hart, 1980)

Engineering geologic map unit symbols	4. Topographic expression	5. Weathering and weathering effects	6. Workability	7. Surface drainage and erodibility	8. Groundwater characteristics
Smb (surficial) - silty sand or gravel, some boulders	Underlies broad, nearly flat, stream-dissected, mesalike remnants of formerly extensive landforms, and terracelike features that slope eastward about 50-600 ft/mi. Unit also underlies small, concave upward surfaces along lower sides of some mountain valleys, and forms small alluvial-fan deposits at mouths of some intermittent mountain streams.	Ancient zonal soil profile on deposits 25 ft and more above nearby stream moderately to well developed. Both humus-rich A horizon and clay-rich B horizon generally 6 in.-2.5 ft thick, but locally removed by erosion. Underlying calcium carbonate-rich C horizon generally 1-4 ft thick. Stones of metamorphic and basaltic composition near top of unit generally decomposed ("rotted") more than granitic stones; all stones in upper part at some localities coated with calcium carbonate. Ancient soil profile lacking on deposits less than 25 ft above nearby stream, but upper 1-2.5 ft can be humus rich.	Excavation: generally easy to moderately easy with power equipment; moderately difficult for light backhoes and trenchers within 1 mi of the mountain front because of numerous large boulders; these decrease in frequency and diameter eastward. Compaction: moderately easy to moderately difficult; vibratory compactors and rubber-tire rollers commonly used; compaction easier if boulders removed. Drilling: moderately difficult where cobbles and boulders numerous; moderately easy elsewhere.	Infiltration: generally moderately rapid to rapid; very rapid where clay-rich B horizon absent. Runoff: slow; tier may puddle temporarily in shallow depressions underlain by clay- rich B horizon; susceptible to flooding adjacent to streams. Erodibility: moderately resistant where gravel content high; moderately easy by gullying, sheetwash, and stream scour where sandy.	Permeability: moderate to high Water table: 2-20 ft or more; estimated average 9 ft. Yield to wells: 1-30 gal/min; estimated average 14 gal/min. Quality: generally highly mineralized: very hard; calcium and sodium content high, sulfate content locally very high. Use: stock, domestic, some commercial.
Smo (surficial) - organic silty sand and gravel	Underlies nearly flat floors of most valleys, and terrace surfaces 10-20 ft above nearby stream. Toward valley sides surfaces slope upward, and grade into map units Cm and Scb; locally overlies map units Sm and Gs.	Ancient zonal soil profile underlies surface, is weakly developed and locally removed by erosion. Humus-rich A horizon and clay-enriched B horizon generally 6 in.-1 ft thick, grayish brown; underlying C horizon 1-3 ft thick is sandy to pebbly silt containing pinhead-size spots of white calcium carbonate.	Excavation: easy with power equipment. Compaction: moderately easy; vibratory compactors and sheepsfoot rollers commonly used; adheres when wet. A horizon of soil, if more than 10 percent humus by volume, should be removed before excavation for use elsewhere, or before placement of fill material. Drilling: easy.	Infiltration: moderate. Runoff: moderate; susceptible to flooding near adjacent stream; not covered by most seasonal floods, might be covered by 50- to 100-year flood. Erodibility: moderately easy by gullying, sheetwash, and stream scour where sandy; easy where organic content high.	Permeability: moderate. Water table: 1-12 ft, estimated average 12 ft. Yield to wells: 3 gal/min reported from 1 spring, generally less; less yield to wells. Quality: highly mineralized, hard to very hard; iron content locally very high. Use: stock, domestic, some commercial.
Cm (surficial) - silty clay with stones	Underlies gently rolling terrain in eastern half of quadrangle; slopes generally < 10 degrees.	Ancient zonal soil profile weakly to strongly developed; locally removed by erosion. Reddishbrown, iron-stained B horizon or calcium carbonate rich C horizon developed in upper 1-3 ft of deposit.	Excavation: easy with most power equipment; adheres when wet. Compaction: easy; sheepsfoot and smooth-tire rollers suggested; adheres when wet. Drilling: easy; may tend to clog toothed bits.	Infiltration: negligible to slow. Runoff: generally rapid but water can temporarily puddle in surface depressions. Erodibility: very easy by gullying; slopewash, and stream scour; upper few inches to feet subject to slow downhill soil-creep and soilflow; rate of flow increases with increasing slope and moisture content. Moderately easy by wind deflation where dry and loosened by activity on surface.	Permeability: negligible to low. Water table: depth varies, deeper under steeper slopes; ground water can move in thin zone at top of underlying bedrock surface. Yield to wells: undeveloped. Quality: unknown. Use: unknown.
ss-cs (bedrock) - sandstone and claystone	Underlies moderately rolling surface generally mantled by alluvium and colluvium; locally forms low ridge east of Dakota Hogback; slopes as steep as 45°; exposures mainly in claypits in unit, a few natural exposures along the ridge.	Sandstone: commonly case-hardened where naturally exposed. Claystone: two horizons formed by weathering downward from the eroded surface of the unit. Upper horizon yellowish-gray clay (CL, CH, MH, some ML) from 1-3 ft thick. Lower horizon yellowish-brown to gray claystone, broken into angular fragments 0.25-1.5 in. in diameter that increase in size with depth; from 4-8 ft thick. Claystone weathers more rapidly than sandstone.	Excavation: easy with most power equipment to base of weathered fractured material; increasingly difficult with depth; adheres when wet. Moderately difficult in most sandstone with heavy rippers and scrapers; blasting may be required locally. Compaction: easy for claystone, earthmoving equipment and sheepsfoot and smooth-tired rollers suggested; moderately difficult for sandstone, steel-wheeled rollers suggested; coal may compress and rebound. Drilling: easy in claystone to moderately difficult in sandstone; claystone tends to clog toothed bits.	Infiltration: negligible into claystone, moderate into sandstone; rapid through fractures. Runoff: rapid on claystone, moderate on sandstone. Erodibility: moderately resistant to resistant to gully and sheetwash and stream scour. Difficult to reestablish vegetation on slopes steeper than 25° (47 percent).	Permeability: moderate to high in sandstone, negligible in claystone; high through fractures. Water table: varies greatly from place to place; artesian pressure causes rise of water level in most wells, pressure gradient slopes eastward from area of outcrop. Yield to wells: average 53 gpm; maximum reported as much as 100 gpm. Quality: moderately mineralized; soft; sodium content high in some wells. Use: domestic, commercial, irrigation, and livestock use.
ms-cs (bedrock) - siltstone and claystone	Underlies nearly flat to gently rolling surface generally mantled by alluvium and colluvium; slopes as steep as 22° (40 percent). Exposures mainly in roadcuts and valley walls.	Two horizons formed by weathering of the exposed cross section of the unit. Upper horizon yellowish-brown clay and silt (CH, CL, MH, ML, some SM) from 1 to 3 ft thick, commonly eroded. Lower horizon yellowish-gray stained claystone and siltstone broken into angular fragments 0.5-1.5 in. in diameter, that increase in size with depth; from 3 to 6 ft thick. Claystone weathers somewhat more rapidly than siltstone. Where basal 200 ft of unit is exposed at ground surface, weathering yields gypsum crystals.	Excavation: easy to base of weathered, fractured material with most power equipment including tractor-drawn scrapers and backhoes; increasingly difficult with depth, requiring heavy equipment where nonweathered. Difficult in siltstone and sandstone beds, and in concretion horizons. Adheres when wet. Compaction: easy for claystone and most siltstone, moderately easy for some siltstone and sandstone; sheepsfoot and rubber-tired rollers suggested; adheres when wet. Drilling; easy generally, may be moderately difficult drilling through concretion horizons; clay component tends to clog bits.	Infiltration: negligible through rock, negligible to slow through fractures. Runoff: generally rapid; water may accumulate in scattered shallow depressions for as long as a week. Erodibility: easily eroded by gully- and sheetwash, and by stream scour; moderately easily eroded by wind where loosened by plowing or construction; difficult to reestablish vegetation on slopes steeper than 20° (36 percent).	Permeability: negligible to very slow in clays tone and siltstone; slow in sandstone beds; rapid through fractures. Water table: varies greatly from place to place. Yield to wells: not reported, probably small; better yield probably from base of overlying surficial material. Quality: very highly mineralized, very hard; calcium, magnesium and sulfate content very high; may react with some types of concrete, and corrode iron pipe. Use: single reported well used for domestic supply.
cs-ms (bedrock) - claystone and siltstone	Underlies nearly flat to gently rolling surface mantled by alluvium and colluvium; hillside slopes as steep as 22° (40 percent).	Two horizons formed by weathering of the exposed cross section of the unit. Upper horizon brown to gray, structureless, clay and silt (CH, MH, CL, some ML), from 1-3 ft thick, commonly eroded. Lower horizon olive-gray to mottled gray and black claystone and siltstone broken into fragments from 0.5 to 1.5 in. in diameter that increase in size with depth, generally from 3-8 ft thick. Claystone weathers more rapidly than siltstone. Gypsum crystals develop on weathering in basal 100 ft of western subunit.	Excavation; same as map unit ms-cs above. Compaction: same as map unit ms-cs above. Drilling: same as map unit ms-cs above.	Infiltration: same as map unit ms-cs above. Runoff: same as map unit ms-cs above. Erodibility: same as map unit ms-cs above.	Permeability: negligible through rock, negligible to slow through fractures. Water table: varies greatly from place to place. Yield to wells: no wells reported; very small amounts may be available from rock fractures and sandy beds; better yield may be from base of overlying surficial material. Quality: highly mineralized; iron and sulfate content high; locally may react with some concrete and corrode iron pipe. Use: may be useful for domestic or livestock needs.
ms-ss (bedrock) - siltstone and sandstone	Underlies gently rolling alluvium and colluvium mantled plains; slopes as steep as 19° (34 percent) on low hills south of Turkey Creek. Exposures scattered, mainly in valley walls and roadcuts.	Surface of sandstone case—hardened in natural exposures. Rock weakened where weathered. Siltstone more resistant than claystone; claystone weathers rapidly to yield clayey silty sand (SM, SC) to depth of about 2 ft.	Excavation: easy in claystone, moderately easy in siltstone and sandstone with heavy equipment, increasingly difficult with depth. Adheres when wet. Compaction: moderately easy with sheepsfoot and rubbertired rollers. Adheres when wet. Drilling: easy to moderately easy, tends to clog bit.	Infiltration: moderate to slow in siltstone, slow to negligible in claystone; slow to moderate through fractures in either. Runoff: Generally moderate to rapid. Erodibility: moderately resistant to gully and sheetwash, moderately easy by stream scour; vegetation difficult to reestablish on cut slopes steeper than about 19° (35 percent).	Permeability: same as map unit cs-ms above. Water table: same as map unit cs-ms above. Yield to wells: same as map unit cs-ms above. Quality: same as map unit cs-ms above. Use: same as map unit cs-ms above.
cs-sh (bedrock) - claystone and shale	Underlies gently rolling surface at base of east flank of Dakota Hogback, locally underlies that flank. Exposures mainly scattered along roadcuts and drainageways.	Two horizons formed by weathering of the exposed cross section of the unit. Upper horizon light-gray clay (CL, CH, MH) from 2-4 ft thick, commonly eroded away. Lower horizon brown to black claystone and shale broken into irregular angular fragments from 0.5-6 in. in diameter that increase in size with depth; from 2-8 ft thick. Claystone weathers more rapidly than sandstone or limestone.	Excavation: easy, to base of weathered, fractured material with most power equipment including tractor-drawn scrapers and backhoes; moderately difficult where nonweathered, or in limestone or sandstone beds; these require heavy equipment including heavy rippers and scrapers. Compaction: same as map unit cs-ms above. Drilling: same as map unit cs-ms above.	Infiltration: same as map unit cs-ms above. Runoff: same as map unit cs-ms above. Erodibility: same as map unit cs-ms above.	Permeability: low in limestone and sandstone, egligible in claystone and shale, high through fractures. Water table: as shallow as 6 ft locally, but varies greatly from place to place. Yield to wells: a single reported well yields 9 gpm, with artesian flow during winter. Quality: hard to very hard; iron content high. Use: single reported well used for domestic needs.

Table B.1c (to be used in conjunction with Figure A.3)
(after Simpson and Hart, 1980)

Engineering geologic map unit symbols	9. Suitability for waste disposal	10. Foundation stability	11. Slope stability	12. Probable earthquake stability	13. Known, reported, and possible uses of material
Smb (surficial) - silty sand or gravel, some boulders	Septic systems: generally satisfactory; locally unsatisfactory as percolation too rapid in gravels or too slow in clay-rich zone of ancient soil; great risk of pollution of both ground- and surfacewater. Dump sites: generally unsatisfactory owing to great risk of polluting both ground and surface water.	Generally good below clay-rich B horizon of soil, which may swell on wetting and shrink on drying.	Fair, newly cut vertical slopes as much as 10 ft high commonly stand for months in borrow pits, but ravel or slump to about 30° (55 percent) slope on wetting and drying over period of several years, or if below water table. Slopes higher than 10 ft may be stable at about 33° (66 percent) where subsoil is well drained.	Fair, poor on or near steeper slopes or near margin of deep excavation.	Source of poor to good quality road metal and embankment fill.
Smo (surficial) - organic silty sand and gravel	Septic systems: generally satisfactory; locally unsatisfactory as percolation too rapid in gravels or too slow in clay-rich zone of ancient soil; great risk of pollution of both ground- and surfacewater. Dump sites: generally unsatisfactory owing to great risk of polluting both ground and surface water.	Generally good below humus-rich A horizon of soil, unit can compress under load if humus content high, or when moisture content increases. Foundation investigation recommended before construction.	Fair, newly cut vertical slopes as much as 10 ft high commonly stand for months in borrow pits, but ravel or slump to about 30° (55 percent) slope on wetting and drying over period of several years, or if below water table. Slopes higher than 10 ft may be stable at about 33° (66 percent) where subsoil is well drained.	Fair, poor on or near steeper slopes or near margin of deep excavation.	Humus-rich A horizon of soil a source of topsoil for landscaping if pebbles removed.
Cm (surficial) - silty clay with stones	Septic systems: generally unsatisfactory because of slow percolation; can increase risk of landsliding of adjacent slopes. Dump sites: moderately good; excavation easy, and moderately low risk of polluting ground water.	Poor to fair, can expand excessively above, and exert high pressure on wetting; can shrink on drying; swell pressure generally a little less than that of parent material. Heavy structures can settle unevenly. Foundation investigation recommended before construction.	Poor to good, poor to fair on slopes steeper than about 11° (20 percent). Stability investigation recommended before grading. Good on slopes of less than about 11° (20 percent).	Generally good.	Source of poor-quality embankment fill, except good where source of impermeable core material for earthfill dams if large stones absent or removed.
ss-cs (bedrock) - sandstone and claystone	Septic fields: generally unsatisfactory; rate of percolation in claystone too slow; in sandstone, risk of pollution of ground-water supply moderate to high, and excavation is difficult. Dump sites: poor in sandstone as difficult to excavate and risk of pollution of ground-water supply moderate to high; good in claystone provided all sandstone layers are sealed off before use.	Claystone: good to poor, as some beds swell excessively and exert high pressure when wetted, and shrink when dried. Sandstone: excellent to good. High risk of differential swelling or settlement if foundation is placed on differing rock types. Clay beds excavated, then refilled with trash or earth materials, have high risk of differential or excessive settlement. Foundation investigation recommended before building.	Generally good, poor to very poor in cuts higher than 20 ft and on slopes steeper than 45° (100 percent) or where bedding surfaces dip into cut; very poor in claypits with steep cuts, or faces formed by sandstone beds. Stability investigations recommended before building.	Generally good, poor at top of high cuts and on steep hillsides.	Source of good clay for brick and tile, fair source of lichencovered landscape rock. Formerly a major source of coal; at least nine mines are reported to have operated formerly in the quadrangle.
ms-cs (bedrock) - siltstone and claystone	Septic fields: generally unsatisfactory as percolation too slow, and may pollute any water supply present. Dump sites: generally excellent except in sandstone beds and concretionary beds where excavation may be moderately difficult, and risk of ground-water pollution is moderate.	Generally fair to poor. Locally expands excessively and exerts moderate swelling pressure on wetting, and shrinks on drying; siltstone and sandstone least affected; high risk of differential swelling or settlement if foundation placed on differing rock types. Foundation investigation recommended before building.	Generally good, locally poor to very poor where cuts are more than 20 ft high, or where beds dip downward into excavations, or where cuts are steeper than about one horizontal to one vertical. Stability investigations recommended before building.	Generally good, locally poor at top of high cuts and on steep hillsides.	Possible source of claystone for manufacture of lightweight aggregate, and of impervious fill or binder material that is poor to very poor because of swelling potential.
cs-ms (bedrock) - claystone and siltstone	Septic fields: same as map unit ms-cs above. Dump sites: generally excellent as excavation easy, but may pollute any water supply present unless sandstone beds sealed.	Very poor to fair, locally clay expands excessively and exerts high swelling pressure when wetted, and shrinks on drying. Differential expansion, and differential settlement, likely if foundation is placed on differing rock types.	Same as map unit ms—cs above.	Same as map unit ms—cs above.	Same as map unit ms—cs above.
ms-ss (bedrock) - siltstone and sandstone	Septic systems: generally unsatisfactory as percolation rate low to marginal, locally satisfactory where deeply and well weathered; risk of pollution of ground-water supply moderate. Dump sites: fair, as excavation moderately easy, excavated material can be used for cover; however, risk of pollution of ground-water supply moderate.	Generally fair, locally poor where foundation rests on two or more distinctly different kinds of rock because of risk of differential settlement or heaving.	Generally good, may be poor if beds dip downward into opencut or excavation; stability investigation recommended.	Good to fair on gentle slopes; poor on steep hillsides and at top of high cuts.	Reported source of olive-gray landscape rock.
cs-sh (bedrock) - claystone and shale	Septic fields: same as map unit cs-ms above. Dump sites: generally excellent except where risk of ground-water pollution is moderate, as in some limestone and sandstone beds.	Poor to fair. Locally clay expands excessively and exerts high swelling pressure when wetted, and shrinks on drying. Differential swell or settlement likely if foundation is placed on differing rock types. Foundation investigations recommended before building.	Same as map unit cs-ms above.	Same as map unit cs-ms above.	Same as map unit cs-ms above.

Table B.2 Characteristic Descriptions
(USDA Web Soil Survey, 2016)

The following characteristic descriptions have been excerpted directly from the USDA Web Soil Survey website:

Erodibility – Factor K: Erosion factor K indicates the susceptibility of a soil to sheet and rill erosion by water. Factor K is one of six factors used in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. The estimates are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (Ksat). Values of K range from 0.02 to 0.69. Other factors being equal, the higher the value, the more susceptible the soil is to sheet and rill erosion by water. "Erosion factor K_w (whole soil)" indicates the erodibility of the whole soil. The estimates are modified by the presence of rock fragments.

Erodibility – Wind Erodibility Group: A wind erodibility group (WEG) consists of soils that have similar properties affecting their susceptibility to wind erosion in cultivated areas. The soils assigned to group 1 are the most susceptible to wind erosion, and those assigned to group 8 are the least susceptible.

Aquifer Characteristics – Available Water Capacity: Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in centimeters of water per centimeter of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments.

Aquifer Characteristics – Depth to Water Table: "Water table" refers to a saturated zone in the soil. It occurs during specified months. Estimates of the upper limit are based mainly on observations of the water table at selected sites and on evidence of a saturated zone, namely grayish colors (redoximorphic features) in the soil. A saturated zone that lasts for less than a month is not considered a water table.

Shrink-Swell Potential – Linear Extensibility: Linear extensibility refers to the change in length of an unconfined clod as moisture content is decreased from a moist to a dry state. It is an expression of the volume change between the water content of the clod at 1/3- or 1/10-bar tension (33kPa or 10kPa tension) and oven dryness. The volume change is reported as percent change for the whole soil. The amount and type of clay minerals in the soil influence volume change.

Shrink-Swell Potential – Percent Clay: Clay as a soil separate consists of mineral soil particles that are less than 0.002 millimeter in diameter. The estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.

Well and Individual Sewage Disposal System Suitability – Septic Tank Absorption Fields: Septic tank absorption fields are areas in which effluent from a septic tank is distributed into the soil through subsurface tiles or perforated pipe. Only that part of the soil between depths of 24 and 60 inches is evaluated. The ratings are based on the soil properties that affect absorption of the effluent, construction and maintenance of the system, and public health. Stones and boulders, ice, and bedrock or a cemented pan interfere with installation. Subsidence interferes with installation and maintenance. Excessive slope may cause lateral seepage and surfacing of the effluent in downslope areas.

Some soils are underlain by loose sand and gravel or fractured bedrock at a depth of less than 4 feet below the distribution lines. In these soils the absorption field may not adequately filter the effluent, particularly when the system is new. As a result, the ground water may become contaminated.

Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect the specified use. "Not limited" indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. "Somewhat limited" indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected. Onsite investigation may be needed to validate these interpretations and to confirm the identity of the soil on a given site.

Foundation Suitability – Dwellings with Basements: Dwellings are single-family houses of three stories or less. For dwellings with basements, the foundation is assumed to consist of spread footings of reinforced concrete built on undisturbed soil at a depth of about 7 feet.

The ratings for dwellings are based on the soil properties that affect the capacity of the soil to support a load without movement and on the properties that affect excavation and construction costs. The properties that affect the load-supporting capacity include depth to a water table, ponding, flooding, subsidence, linear extensibility (shrink-swell potential), and compressibility. The properties that affect the ease and amount of excavation include depth to a water table, ponding, flooding, slope, depth to bedrock or a cemented pan, hardness of bedrock or a cemented pan, and the amount and size of rock fragments.

Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect the specified use. "Not limited" indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. "Somewhat limited" indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected. Onsite investigation may be needed to validate these interpretations and to confirm the identity of the soil on a given site.

Table B.2a (to be used in conjunction with Figure A.4) (USDA Web Soil Survey, 2016)			
Map Unit Label	**Map Unit Name**	**Erodibility - K Factor, Whole Soil (dominant condition)**	**Erodibility - Wind Erodibility Group (dominant condition)**
4	Argiustolls	0.05	5
25	Denver clay loam	0.24	6
26	Denver clay loam	0.24	6
28	Demver cobbly clay loam	0.1	7
42	Englewood clay loam	0.2	6
60	Haverson loam	0.28	6
74	Lebsack clay loam	0.24	4
80	Layden-Priment-Standley cobbly clay loam	0.1	7
91	Manzanola clay loam	0.28	6
93	Manzanola clay loam	0.28	6
96	Manzanola-Renohill-Stoneham complex	0.32	6
110	Clay pits		8
111	Gravel pits	0.02	8
132	Renohill loam	0.32	6
160	Ulm clay loam	0.24	6
162	Ulm-Urban land complex	0.24	6

Table B.2b (to be used in conjunction with Figure A.4) (USDA Web Soil Survey, 2016)			
Map Unit Label	**Aquifer Characteristics - Available Water Capacity (centimeters per centimeter, weighted average of all layers)**	**Aquifer Characteristics - Depth to Water Table (centimeters, weighted average)**	**Shrink-Swell Potential - Linear Extensibility (percent, weighted average of all layers)**
4	0.13	>200	1.5
25	0.17	>200	7.2
26	0.17	>200	7.2
28	0.15	>200	5.8
42	0.16	>200	6
60	0.12	>200	1.5
74	0.14	168	7.2
80	0.14	>200	4
91	0.16	>200	3.9
93	0.16	>200	3.9
96	0.17	>200	3.4
110	0	>200	
111	0.02	>200	1.5
132	0.17	>200	3.9
160	0.18	>200	6.4
162	0.13	>200	6.4

Table B.2c (to be used in conjunction with Figure A.4) (USDA Web Soil Survey, 2016)			
Map Unit Label	**Shrink-Swell Potential - Percent Clay (percent, weighted average of all layers)**	**Well and Individual Sewage Disposal System Suitability - Septic Tank Absorption Fields**	**Foundation Suitability - Dwellings With Basements (dominant condition)**
4	21.1	very limited	very limited
25	47.1	very limited	very limited
26	47.1	very limited	very limited
28	45.3	very limited	somewhat limited
42	39.1	very limited	very limited
60	20.5	somewhat limited	very limited
74	42.8	very limited	very limited
80	39.7	very limited	very limited
91	35.1	very limited	somewhat limited
93	35.1	very limited	somewhat limited
96	32	very limited	somewhat limited
110			
111	0.5		
132	33.9	very limited	somewhat limited
160	40.5	very limited	very limited
162	40.5	very limited	very limited

Table B.3 Mineral Resource Descriptions
(USDA Web Soil Survey, 2016)

The following construction material source descriptions have been excerpted directly from the USDA Web Soil Survey website:

Gravel Source: Gravel consists of natural aggregates (2 to 75 millimeters in diameter) suitable for commercial use with a minimum of processing. Only the probability of finding material in suitable quantity is evaluated. The suitability of the material for specific purposes is not evaluated, nor are factors that affect excavation of the material.

The properties used to evaluate the soil as a source of gravel are gradation of grain sizes (as indicated by the Unified classification of the soil), the thickness of suitable material, and the content of rock fragments. If the bottom layer of the soil contains gravel, the soil is considered a likely source regardless of thickness. The assumption is that the gravel layer below the depth of observation exceeds the minimum thickness. The ratings are for the whole soil, from the surface to a depth of about 6 feet. Coarse fragments of soft bedrock, such as shale and siltstone, are not considered to be gravel.

The soils are rated "good," "fair," or "poor" as potential sources of gravel. A rating of "good" or "fair" means that the source material is likely to be in or below the soil. The bottom layer and the thickest layer of the soils are assigned numerical ratings. These ratings indicate the likelihood that the layer is a source of gravel.

Roadfill Source: Roadfill is soil material that is excavated in one place and used in road embankments in another place. The soils are rated as a source of roadfill for low embankments, generally less than 6 feet high and less exacting in design than higher embankments. The ratings are for the whole soil, from the surface to a depth of about 5 feet. It is assumed that soil layers will be mixed when the soil material is excavated and spread.

The soils are rated "good," "fair," or "poor" as potential sources of roadfill. The ratings are based on the amount of suitable material and on soil properties that affect the ease of excavation and the performance of the material after it is in place. The thickness of the suitable material is a major consideration. The ease of excavation is affected by large stones, depth to a water table, and slope. How well the soil performs in place after it has been compacted and drained is determined by its strength (as inferred from the AASHTO classification of the soil) and linear extensibility (shrink-swell potential). Normal compaction, minor processing, and other standard construction practices are assumed.

Sand Source: Sand is a natural aggregate (0.05 millimeter to 2 millimeters in diameter) suitable for commercial use with a minimum of processing. It is used in many kinds of construction. Specifications for each use vary widely. Only the probability of finding material in suitable quantity is evaluated. The suitability of the material for specific purposes is not evaluated, nor are factors that affect excavation of the material.

The properties used to evaluate the soil as a source of sand are gradation of grain sizes (as indicated by the Unified classification of the soil), the thickness of suitable material, and the content of rock fragments. If the bottom layer of the soil contains sand, the soil is considered a likely source regardless of thickness. The assumption is that the sand layer below the depth of observation exceeds the minimum thickness. The ratings are for the whole soil, from the surface to a depth of about 6 feet.

The soils are rated "good," "fair," or "poor" as potential sources of sand. A rating of "good" or "fair" means that sand is likely to be in or below the soil. The bottom layer and the thickest layer of the soil are assigned numerical ratings. These ratings indicate the likelihood that the layer is a source of sand.

Source of Reclamation Material: Reclamation material is used in areas that have been drastically disturbed by surface mining or similar activities. When these areas are reclaimed, layers of soil material or unconsolidated geological material, or both, are replaced in a vertical sequence. The reconstructed soil favors plant growth. The ratings do not apply to quarries or other mined areas that require an offsite source of reconstruction material. The ratings are based on the soil properties that affect erosion and stability of the surface and the productive potential of the reclaimed soil. These properties include the content of sodium, salts, and calcium carbonate; reaction; available water capacity; erodibility; texture; content of rock fragments; and content of organic matter and other features that affect fertility.

The soils are rated "good," "fair," or "poor" as potential sources of reclamation material. The ratings are based on the amount of suitable material and on soil properties that affect the ease of excavation and the performance of the material after it is in place. The thickness of the suitable material is a major consideration. The ease of excavation is affected by large stones, depth to a water table, and slope. How well the soil performs in place after it has been compacted and drained is determined by its strength (as inferred from the AASHTO classification of the soil) and linear extensibility (shrink-swell potential). Normal compaction, minor processing, and other standard construction practices are assumed.

When the material is properly used in reclamation, a rating of "good" means that establishing and maintaining vegetation are relatively easy, that the surface is stable and resists erosion, and that the reclaimed soil has good potential productivity. A rating of "fair" means that vegetation can be established and maintained and the soil can be stabilized through modification of one or more properties. For satisfactory performance, it may be necessary to topdress with better suited material or add soil amendments. A rating of "poor" means that revegetation and stabilization are very difficult and costly. To establish and maintain vegetation, it is necessary to topdress with better suited material.

Topsoil Source: Topsoil is used to cover an area so that vegetation can be established and maintained. The surface layer of most soils is generally preferred for topsoil because of its content of organic matter. Organic matter greatly increases the absorption and retention of moisture and nutrients for plant growth.

The upper 40 inches of a soil is evaluated for use as topsoil. Also evaluated is the reclamation potential of the borrow area. Normal compaction, minor processing, and other standard construction practices are assumed.

The soils are rated "good," "fair," or "poor" as potential sources of topsoil. The ratings are based on the soil properties that affect plant growth; the ease of excavating, loading, and spreading the material; and reclamation of the borrow area. Toxic substances, soil reaction, and the properties that are inferred from soil texture, such as available water capacity and fertility, affect plant growth. The ease of excavating, loading, and spreading is affected by rock fragments, slope, depth to a water table, soil texture, and thickness of suitable material. Reclamation of the borrow area is affected by slope, depth to a water table, rock fragments, depth to bedrock or a cemented pan, and toxic material.

Table B.3 (to be used in conjunction with Figure A.4) (USDA Web Soil Survey, 2016)						
Map Unit Label	**Map Unit Name**	**Gravel Source**	**Roadfill Source**	**Sand Source**	**Source of Reclamation Material**	**Topsoil Source**
4	Argiustolls	poor	poor	fair	fair	poor
25	Denver clay loam	poor	poor	poor	poor	poor
26	Denver clay loam	poor	poor	poor	poor	poor
28	Demver cobbly clay loam	poor	fair	poor	poor	fair
42	Englewood clay loam	poor	poor	poor	poor	fair
60	Haverson loam	fair	fair	fair	fair	fair
74	Lebsack clay loam	poor	poor	poor	poor	poor
80	Layden-Priment-Standley cobbly clay loam	poor	poor	poor	poor	poor
91	Manzanola clay loam	poor	fair	poor	fair	fair
93	Manzanola clay loam	poor	fair	poor	fair	fair
96	Manzanola-Renohill-Stoneham complex	poor		poor	fair	fair
110	Clay pits					
111	Gravel pits					
132	Renohill loam	poor	poor	poor	fair	fair
160	Ulm clay loam	poor	poor	poor	poor	poor
162	Ulm-Urban land complex	poor	poor	poor	poor	poor