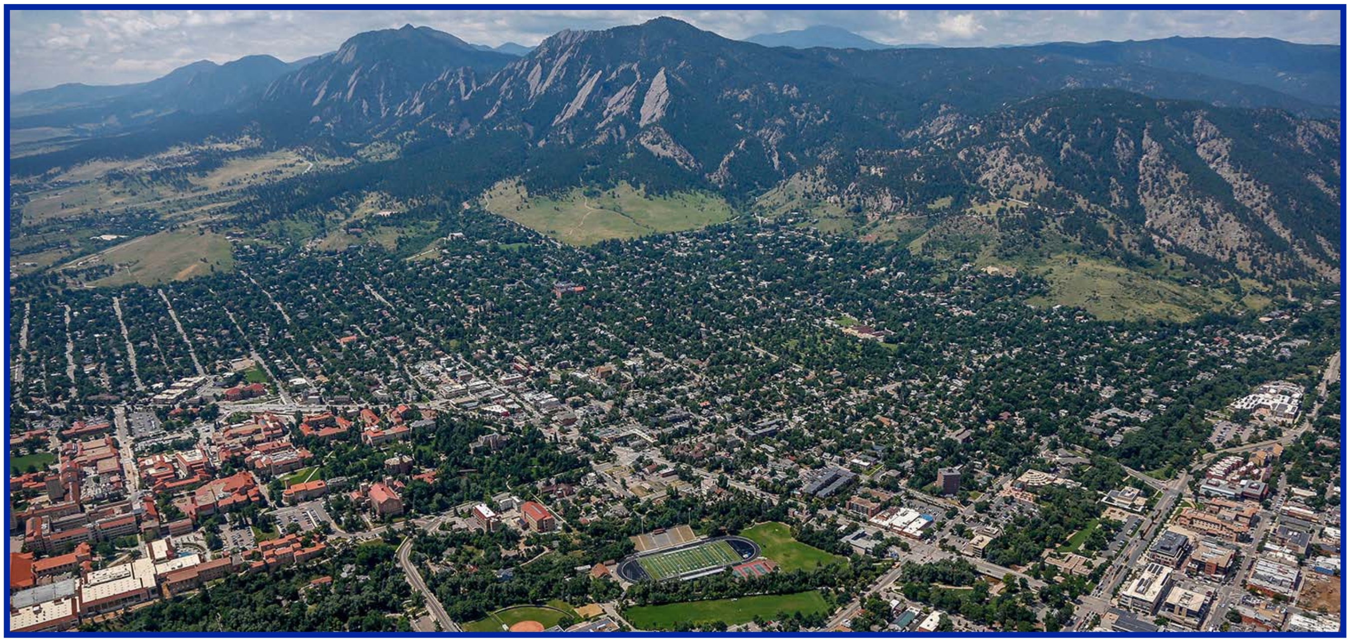
CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

GEOLOGIC HAZARD STUDY

Boulder County, Colorado



Report Prepared for:

Boulder County

Ms. Nicole Wobus, Long Range Planning and Policy Manager
Boulder County Land Use Department
2045 13th Street
Boulder, CO 80302

Project No. 16.3097
March 31, 2017

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Report Prepared by:

Julia M. Frazier, P.G.
Senior Geologist

EXECUTIVE SUMMARY

Cesare, Inc., (Cesare) has partnered with Boulder County Land Use Department to assist in consultation, awareness, education, and characterization of geotechnical and geological hazard conditions impacting Boulder County, Colorado. This study was completed in part due to the impacts of the September 2013 extreme rain and flood event and made possible through funding from a Community Development Block Grant-Disaster Recovery (CDBG-DR) Resiliency Planning and Capacity Building grant. The goals of the services provided by Cesare included characterization of geologic hazards on a countywide scale, prioritization of significant geologic hazards, and geological and geotechnical consultation services for the Development Review Team (DRT). Cesare provided an educational workshop for Boulder County planners, as well as mapping and policy support services.

The first task of this study consisted of research, data compilation and review, and outreach to determine the available information and to also become aware of overlapping or related studies which had already been completed, were occurring concurrently or were planned for the near future by others. Appendices A, B, and C provide outreach contacts and lists of available information and resources. Based on the results of this initial research phase, the project evolved such that characterizing the landslide hazard across Boulder County became a high priority. Mapping efforts were targeted to characterize the landslide potential for Boulder County, as well as the steeply dipping heaving bedrock hazard. Additionally, Cesare provided ongoing consultation with DRT, reviewing cases with geologic or geotechnical aspects and offering feedback and recommendations. Cesare also provided an educational geologic hazard workshop tailored for planners.

The Geology Element of the Boulder County Comprehensive Plan was last updated in 1984 and included a description of the geological and geotechnical background of the County. The Geology Element describes physiography, soils, groundwater, and economic geology, and is a good reference for Boulder County planners, geologists, engineers, and the public. The Geology Element also describes geotechnical considerations related to geologic hazards, such as snow avalanches, expansive soils, flooding, groundwater degradation, landslides, rockfall, soil creep, and ground subsidence. The Geology Element includes a Geologic Hazard and Constraint Area map to be used in partnership with a geotechnical land use guidelines table to help guide planners in determining appropriate site specific study recommendations. Based on conversations and feedback, Cesare determined that Boulder County could benefit from a more layered approach to the geologic hazard map that would more clearly delineate individual hazards, rather than ranking areas of the County based on the number of hazards in a certain area.

Cesare partnered with TerraCognito, a geospatial analysis firm, to compile a map package of available mapping and global information system (GIS) data, as well as, new data created for this study. The components of this map package are intended to be used as informational and planning tools by Boulder County to assist in land use decisions and prioritizations. These maps are not intended to replace site specific studies into the geotechnical or geologic hazard aspects of existing or proposed development areas. Maps which were newly created for this study include a robust light detection and ranging (LiDAR) terrain model with countywide coverage, landslide inventory map, landslide potential map, steeply dipping heaving bedrock map, as well as maps depicting tree height, tree density, and tree root strength index. Maps created through GIS transformation, modification, or combination include geology (1:100,000 scale), bedrock strike and dip orientation, bedrock foliation orientation, surficial soils, swelling soils and bedrock (Hart, 1974), undermined area map (Roberts and others, 2001).

The map package is intended to be used in partnership with an updated geological and geotechnical land use guidelines table. Also integrated here are guidelines and site study recommendations for flood zones and fluvial hazard zone, which are being mapped by others concurrently and in the near future. Guidelines for flood zones and fluvial hazard zones will be determined by others.

The map package components are intended to be used by planners to help guide recommendations for site specific studies, as well as, to inform on surface and subsurface conditions which may have impacts on short and long range planning decisions. The use of third-party reviewers for geologic hazard and geotechnical reports is recommended. Cesare also recommends that the geologic hazard map package be updated regularly and supplemented with additional useful information as it becomes available. The bibliography and list of additional resources included as Appendices B and C should be considered meaningful reference lists for planners. A consideration for the future would also include field verification of the landslide inventory and the steeply dipping heaving bedrock maps.

Similar to the geo-event database maintained by the Colorado Department of Transportation for their roadway corridors, Cesare recommends that Boulder County begin an inventory of rockfall and landslide events along roadway corridors and elsewhere across Boulder County where possible. Cesare also recommends taking a proactive approach to debris flow monitoring and alarms and that Boulder County take an active partnership role with the Office of Emergency Management and other entities that are working toward slope failure early warning systems.

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1. INTRODUCTION AND PURPOSE

Cesare, Inc. (Cesare) has partnered with Boulder County Land Use Department to assist in education, awareness, and characterization of geologic hazards that impact Boulder County (County), Colorado. Based on recent natural disasters, such as wildfires and the extreme rain and flood event of September 2013, natural conditions across Boulder County have been altered and impacted. A component of this study was to update and inform planners on the current conditions and related geologic hazards within Boulder County. Other goals of this study were to provide development review teams with tools and guidance to make decisions related to geologic hazard remediation requirements, as well as to provide the expertise to identify, delineate, and evaluate geologic hazards with the potential to adversely impact current County residents and future development. This study was made possible through funding from a Community Development Block Grant-Disaster Recovery (CDBG-DR) Resiliency Planning and Capacity Building grant.

Cesare's scope consisted of multiple phases and responsibilities. The timeline for this project was from mid-November 2016 to end of March 2017. Task I consisted of research and data compilation of available literature and online information, including but not limited to, published engineering geologic and geologic hazard literature, consultant reports, geologic and geologic hazard maps, aerial photographs, and any other available data or information which would benefit the study. Phase I also included outreach to various local, state, and federal entities in search of information that was not publicly available and to get insight into concurrent or upcoming studies. Refer to Appendix A for a list of outreach avenues explored. Based on the results of Phase I, Cesare determined focus areas for the remainder of the study.

Task II consisted of working with the Boulder County Development Review Team (DRT) on an ongoing basis to assist with case studies with geologic and geotechnical aspects. This included weekly review of DRT meeting agenda items, attendance at weekly DRT meetings, when necessary, and addressing those cases requiring geologic or geotechnical expertise. As part of Task II, Cesare conducted an educational workshop to discuss geologic and geologic hazards within Boulder County and to introduce planners to the maps they would be receiving at the culmination of this study.

Task III consisted of mapping and policy support. Cesare partnered with TerraCognito, a geospatial analysis firm, to compile a map package comprised of available mapping and global information system (GIS) data, as well as new data created for this study. The components of this map package are intended to be used as tools by Boulder County to assist in land use decisions and prioritizations. These maps are not intended to replace site specific studies into the geotechnical, geological or geologic hazard aspects of existing or proposed development areas.

Task IV consisted of a final presentation for Boulder County Land Use and the production of this final report document which describes the results of Tasks I through III, recommended future studies, and any other information related to the project.

Cesare maintained an open line of communication with Boulder County throughout all phases of this project. Cesare regularly updated the Land Use Department on progress, and was continuously available to DRT members to provide advice or recommendations related to geology, geologic hazards, or geotechnical issues.

2. BOULDER COUNTY COMPREHENSIVE PLAN

2.1 THE GEOLOGY ELEMENT

The Boulder County Comprehensive Plan (BCCP) currently includes a Geology Element which was last updated in September 1984 and describes the geological and geotechnical background and characteristic of Boulder County. The Geology Element also describes physiography, soils, groundwater, and economic geology, and is a good reference for County planners, geologists, engineers, and the public. The Geology Element discusses geotechnical considerations related to geologic hazards, such as snow avalanches, expansive soils, flooding, groundwater degradation, landslides, rockfall, soil creep, and ground subsidence. The Geology Element provides geotechnical land use guidelines to aid planners in determining land use capabilities.

Boulder County can be divided into four subprovinces (Figure 1). From east to west these are the Piedmont, Foothills, Montane, and Alpine/Subalpine Subprovinces. These divisions are determined by distinct geomorphic and geologic trends across Boulder County and are referenced throughout this report.

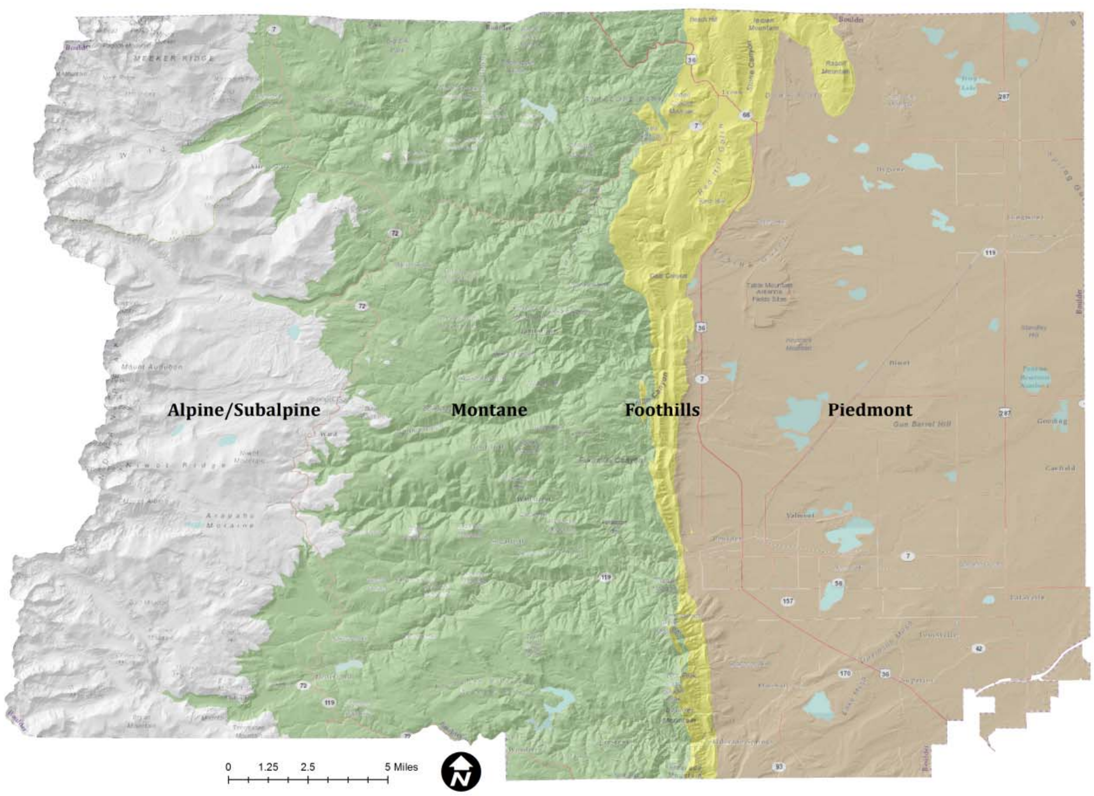


FIGURE 1. Physiographic Subprovinces of Boulder County

The Piedmont Subprovince comprises about one-third of Boulder County and is characterized primarily by gently rolling topography with flat topped mesas divided by broad stream channels and floodplains. The Piedmont Subprovince is divided from the Foothills Subprovince based primarily on slope angle. The Foothills Subprovince predominantly has ground surface slopes exceeding 20%. This region is characterized by steeply dipping sedimentary bedrock units tilted up along the Front Range of the Rocky Mountains. The steeply oriented units form north-south trending hogback landforms which are interrupted at intervals by east-west trending creeks which drain from the higher elevations to the west. The steep topography of this subprovince makes this region susceptible to landslides and soil slumps. Figure 2 shows those slopes which are 25 degrees or greater.

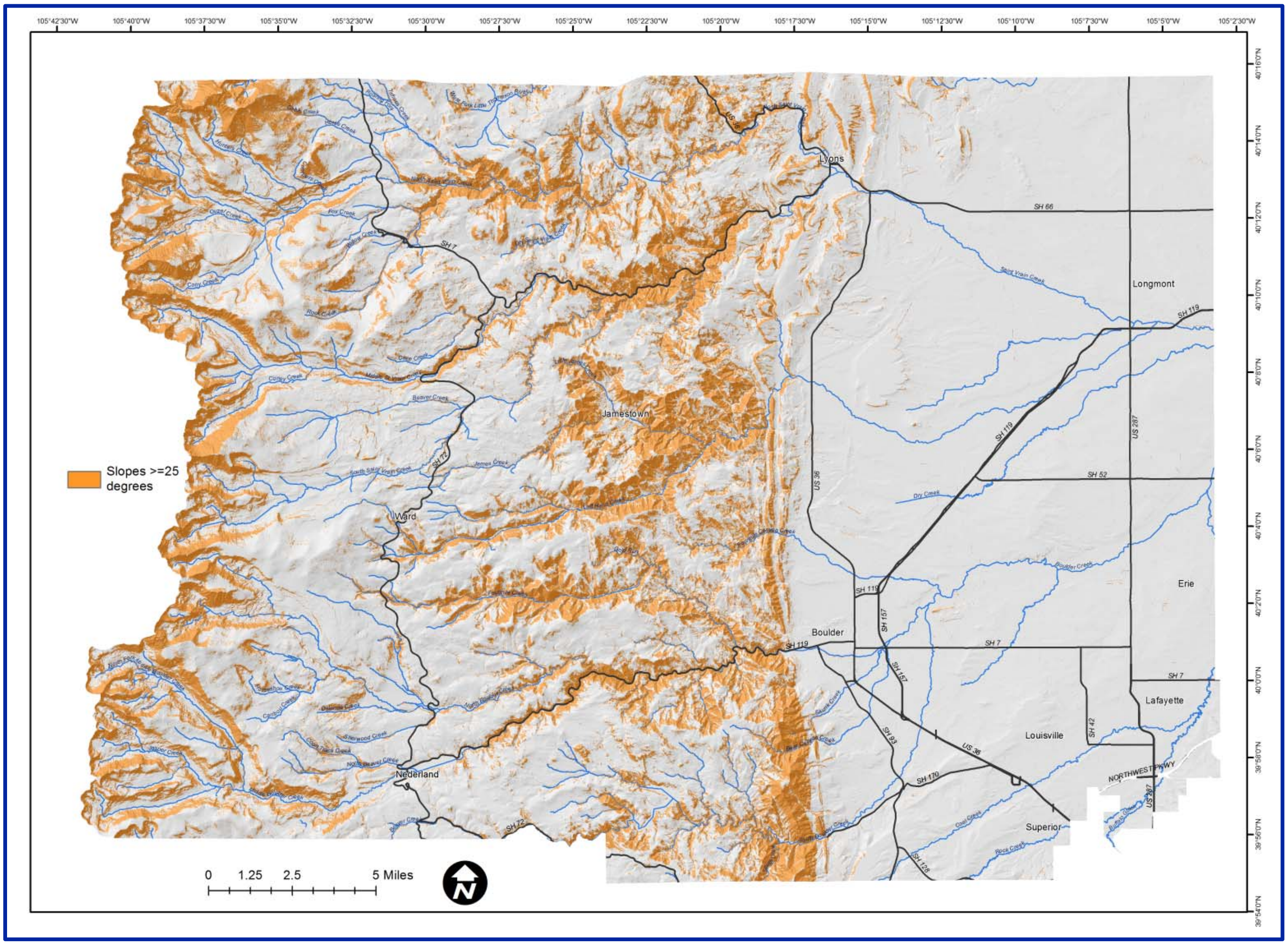


FIGURE 2. Slopes Exceeding 25 Degrees in Boulder County

The division between the Foothills and Montane Subprovinces is based on the geologic contact between the sedimentary Fountain Formation and the granitic and metamorphic basement rocks that comprise the western two-thirds of the County. See Figure 3 for a cross section through Boulder County. The Montane Subprovince has elevations ranging from roughly 7,000 to 9,000 feet. The rocks in the Montane Subprovince have previously undergone extensive erosion and were subsequently uplifted. Remnants of this erosional surface are visible in certain parts of the County. Currently, these rocks are undergoing another stage of erosion driven by stream channels which deeply incise and cut through the granitic and metamorphic rocks, creating sharp and well defined landforms in the eastern part of the Montane Subprovince. The western part of the

Montane Subprovince exhibits slightly more subdued topography, similar to the ancient pre-uplift surface.

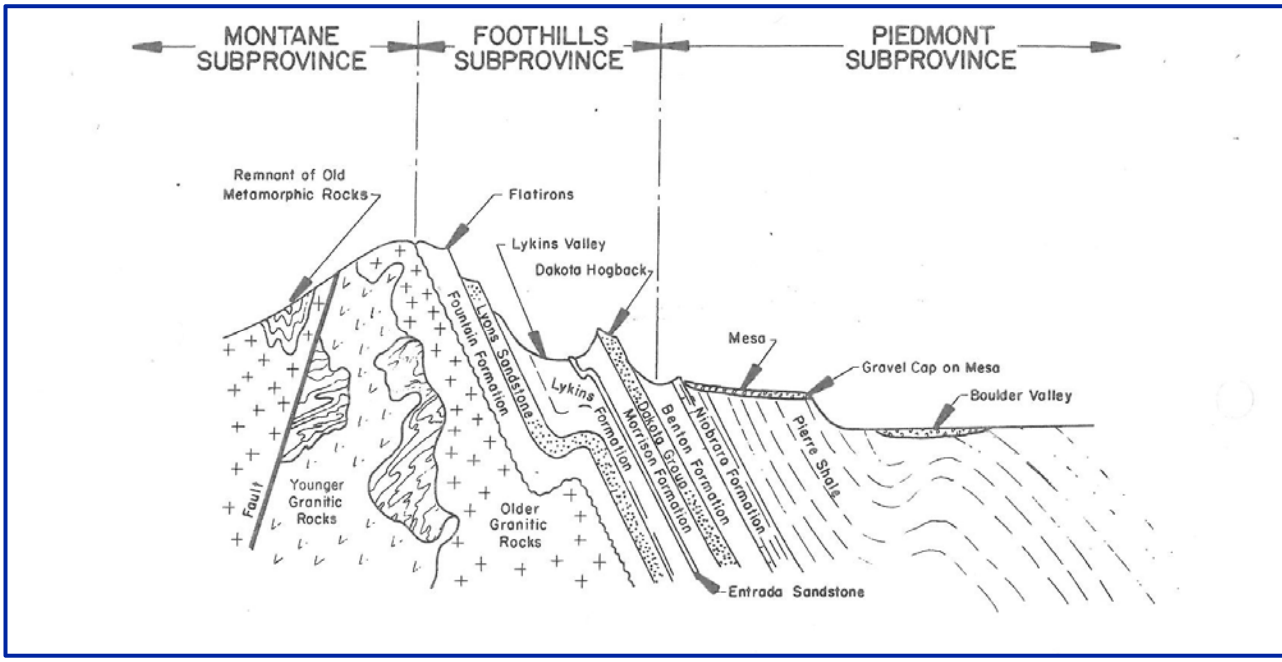


FIGURE 3. Generalized Geologic Cross Section in the Area of Boulder County

(Source: Figure 2-8 of the "Geology Element of the Boulder County Comprehensive Plan".)

The Alpine/Subalpine Subprovince comprises the western side of Boulder County and ranges in elevation from about 9,000 to 14,250 feet. The topography of this region has been shaped by alpine and valley glaciation and is distinctly different from the rest of the County. Glacial and periglacial landforms such as cirques, arêtes, serrated ridges, horns, rock glaciers, and moraines are common.

2.2 GEOLOGIC HAZARD AND CONSTRAINT MAP

The BCCP includes a Geologic Hazard and Constraint Area Map which delineates and rates hazard and constraint zones across Boulder County. See Plate 1 for the Geologic Hazard and Constraint Area Map for Boulder County. According to the BCCP:

> *"Geologic hazard shall mean a geologic condition or geologic process which poses a significant threat to health, life, limb, or property.*
>
> *Geologic constraint shall mean a geologic condition which does not pose a significant threat to life or limb, but which can cause intolerable damage to structures."*

In descending order of hazard level, the rankings on the Geologic Hazard and Constraint Map are as follows:

- **Major Hazard**
  An area where geologic conditions may cause extensive geotechnical problems and there is a high risk related to intensive land uses.

- **Moderate Hazard**
  An area where geologic conditions may cause significant geotechnical problems with provisional risk related to intensive land uses.
- **Moderate Constraint**
  An area where geologic conditions may cause moderate geotechnical problems with provisional risk related to intensive land uses.
- **Minor Constraint**
  An area where geologic conditions may cause few geotechnical problems and there is nominal to no risk related to intensive land uses.

Based on the BCCP, Boulder County discourages intensive land uses in Major and Moderate Hazard Areas, and directs land use toward Constraint Areas over Hazard Areas. Section GE 1.05 of the BCCP states:

> *"The county shall require the evaluation of all geologic hazard and constraints where such hazards or constraints may exist in unincorporated areas of the county as related to new intensive uses. Such evaluations shall be conducted by a professional practitioner having expertise in the subject matter. Such evaluations should incorporate analytical methods representing current, generally accepted, professional principles and practice."*

It is unclear exactly how the geologic hazard ratings were determined for the Geologic Hazard and Constraint Area Map. In general, it would appear that the more geologic hazards present in a certain area, the higher the rating. For instance, areas with three or four geologic hazards are mapped as Hazard Areas, whereas areas with one or two hazards are mapped as Constraint Areas.

Major Hazard Areas are identified along the western edge of the County in the Alpine Subprovince (avalanche, rockfall, soil creep, and landslide), along the Foothills (landslide, rockfall, soil creep, and expansive soil/claystone), and in some areas in the southeast corner of the County (subsidence, landslide, expansive soil/claystone, and flooding). Prominent drainage channels throughout the Montane Subprovince are mapped as Major Hazard Areas due to flash flooding. The rest of the Montane Subprovince is mapped as Moderate Constraint Areas (rockfall, soil creep, and landslide). Moderate Hazard zones are mapped along the Foothills (rockfall, soil creep, and landslide) and along major creek corridors east of the Foothills (flooding and expansive soil/claystone). The areas between major creek corridors in the Piedmont subprovince are mapped as Moderate and Minor Constraint Areas (expansive soil/claystone and landslide).

The Geologic Hazard and Constraint Area Map is a helpful tool for Boulder County planners. Part of the goal of this current study is to improve the level of information that is communicated through mapping of geology and geologic hazards in Boulder County. Based on conversations with DRT members and others, Cesare understands Boulder County could benefit from a layered map package which delineates individual geologic hazards where possible.

3. RESEARCH AND DATA COMPILATION

Cesare performed an extensive review and compilation of available literature and data. Cesare searched through and reviewed documents stored at the Boulder County Land Use Department. A majority of documents retained at the Land Use Department were not related to geologic site conditions, although there were soil reports for a number of properties. These soil reports were not reviewed in their entirety, due to the scope and short timeline for this study, however, they may be good sources of information for future studies. City and County land use and planning departments are, in some cases, a great source for site specific geotechnical information, but those queries are time consuming.

Cesare reviewed published geology and geologic hazard maps and reports comprised mainly of extensive online research. Cesare conducted outreach to municipalities and other sources across the County, at state and federal levels, and through other avenues, to acquire available data and information. The purpose was to compile a collection of available data and information to assess where the greatest needs and gaps existed across the County. Appendix A includes a list of outreach sources of information used for this study. Cesare met or corresponded with a number of these contacts throughout the course of this project.

3.1 COMPILED DATA AND INFORMATION

Available data consisted of published maps and reports (United States Geological Survey, Colorado Geological Survey, and other authors), GIS data, Light Detection and Ranging (LiDAR) data, reports and information collected from online research and direct outreach with various entities, and research documents stored at the Boulder County Land Use Department and through personal communications. Table 1 lists available data that was of direct value for this study. Some of the data listed was modified or transformed for use in this study. For instance, the LiDAR point data was processed for creation of a usable terrain model and a GIS digital image processing tool was used to transform the available geologic maps into layers for landslide potential analysis. Also refer to Appendices B and C for references and resources.

Geologic maps of Boulder County are available at multiple scales and with varying coverage. Complete County coverage of geologic maps with scales from 1:250,000 to 1:100,000 exist. Geologic maps at the 1:24,000 quadrangle scales are available for about 75% of the County. Figure 4 shows the 1:24,000 quadrangles for the County. Refer to the bibliography included in Appendix B for a list of published maps for Boulder County.

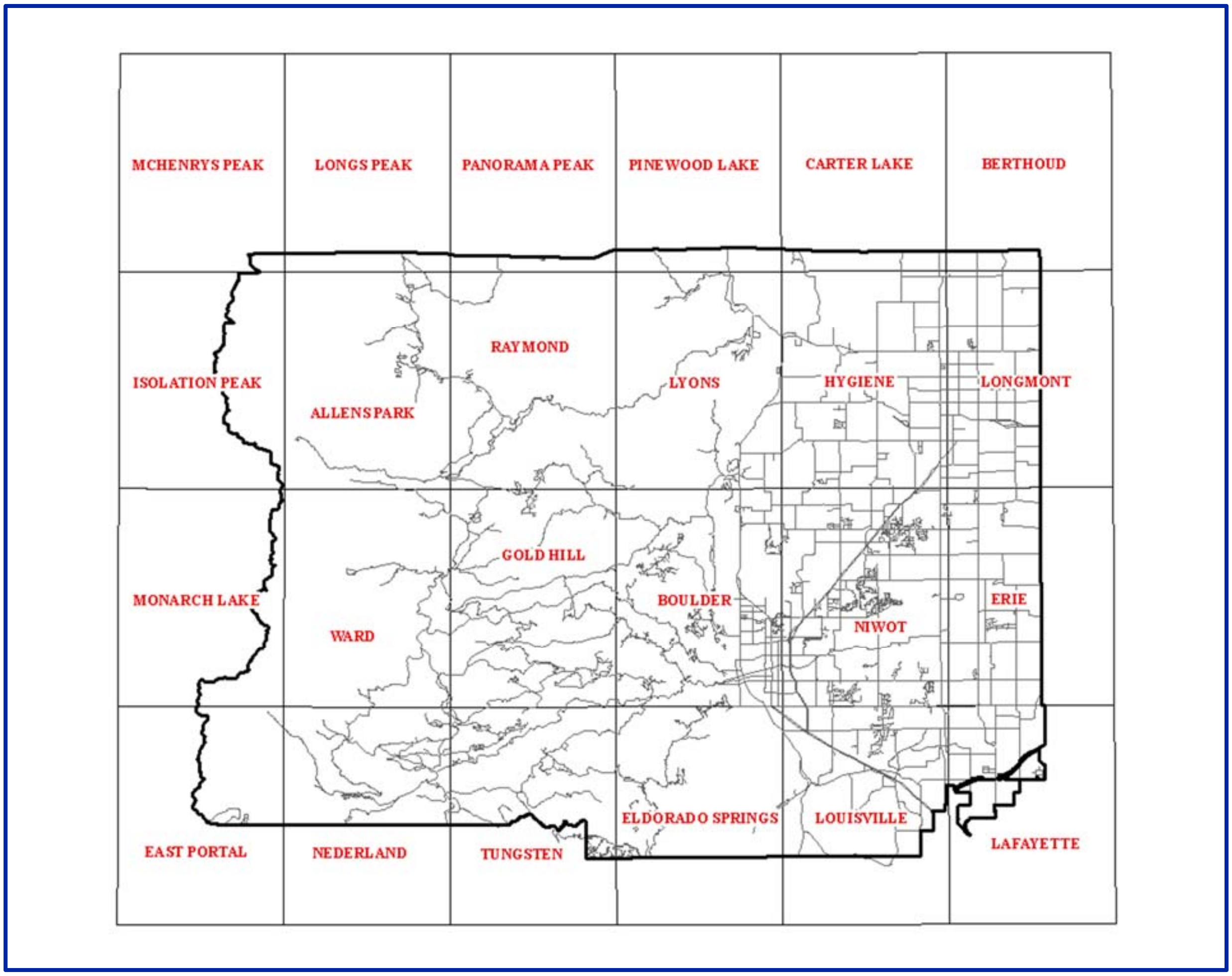


FIGURE 4. Map Showing the 1:24,000 Quadrangles for Boulder County

Table 1 lists available data and information of particular value to this study. Refer to Appendices B and C for a compiled list of data and information reviewed. In addition to what is listed in Table 1, floodplain remapping is currently being conducted by the Colorado Water Conservation Board in collaboration with others. Updates are currently available through the Colorado Hazard and Risk MAP Portal (CHAMP) accessed at http://coloradohazardmapping.com/. Cesare understands that the Town of Lyons will be completing a Hazard Identification and Risk Assessment (HIRA), similar to the one completed for the Town of Jamestown.

TABLE 1. Available Data and Information

Data/Information	Type	Source	Modified or Transformed for this Study
Geology maps, various scales from 1:24,000 to 1:250,000.	PDF, GeoTIFF	USGS, CGS	Yes
Aerial imagery	Imagery	Boulder County, Pictometry International	No
Aerial imagery	Imagery	Denver Regional Aerial Photography Project (DRAPP)	No
Published landslides, various scales.	GIS map, PDF, GeoTIFF	Various sources	Yes
LiDAR data	Raw point data	CWCB, FEMA, CU	Yes
Soils, countywide	GIS spatial and tabular data	National Resources Conservation Services	Yes
Lakes and reservoirs	GIS spatial data	Boulder County	No
Streams and ditches	GIS spatial data	Boulder County	No
Precipitation		NOAA	Yes
Vegetation, parks, and open space only	GIS spatial data	Boulder County	No
Inundated areas, September 2013 flood	GIS spatial data	Boulder County	No
Surface change in creek planning areas, September 2013 flood	GIS spatial data	Watershed Coalitions	No
Wildfire burn history	GIS spatial data	Boulder County	No
Wildfire hazard rating	GIS spatial data	Boulder County	No
Swelling soils and bedrock, Front Range corridor	PDF	Hart (1974)	Yes
Debris flow potential map, foothill and mountainous areas of Boulder County	GIS spatial data	Morgan and others (2015)	No
Landslide scarp locations, September 2013 flood	GIS spatial and tabular data	USGS	No
Rockfall and landslide event locations	GIS spatial and tabular data	CDOT	No
Hazard identification and risk assessment	Report	Town of Jamestown	No
Creek restoration reports and documents	Multiple reports	various	No
Fourmile area debris flow probability and volume	Report, GIS spatial data	USGS	No
Statewide historic underground coal mines	Online map	CGS	No
Annotated bibliography of subsidence studies above abandoned coal mines	Report	Carlson and others (2010)	No
Abandoned mine land inventory	GIS database, online	US Forest Service	No
Undermined Areas Maps	PDF	various	Yes

4. DEVELOPMENT REVIEW TEAM

4.1 CASE STUDY SUPPORT

Cesare collaborated with the DRT throughout the project. Ongoing tasks included review of case studies with geologic or geotechnical issues, participation in weekly DRT meetings requiring background research and correspondence, and creation of a memorandum on geologic hazards. Cesare provided comments and recommendations for sites with steep slopes, potential rockfall, steeply dipping bedrock with the potential for differential heaving of claystone layers, swelling soils and bedrock, subsidence due to abandoned coal mines, and identified locations and other details on documented and undocumented lode mineral mine workings, debris flow channels, and properties in or near fluvial hazard zones related to main, active drainage channels. Examples of a number of these case study memos and write-ups are included for reference in Appendix D.

4.2 EDUCATIONAL WORKSHOP

Cesare conducted an educational workshop for County planners on February 17, 2017. This workshop was a discussion session aimed at prominent geologic hazards within the County, as well as an introduction to the geologic and geologic hazard map package the County will be receiving from Cesare at the culmination of this study. The PowerPoint slides from this workshop are included in Appendix E.

5. GEOLOGIC SETTING OF BOULDER COUNTY

5.1 TOPOGRAPHY AND PHYSIOGRAPHY

Boulder County is roughly rectangular in shape and approximately 750 square miles in size, with the western boundary marked by the Continental Divide. The County spans diverse geomorphic, geologic, and hydrologic terrains. The western two-thirds of the County lies within the Southern Rocky Mountain physiographic province and is characterized by high relief alpine and mountainous terrain, narrow-crested ridges, deeply incised canyons, and a few high elevation, open valleys (Crosby, 1978). It also includes the prominent hogback features along the Front Range, which are alternating ridges and valleys comprised of resistant sandstone and weak shale, respectively. The eastern one-third of the County is within the Colorado Piedmont section of the Great Plains physiographic province, characterized by river valleys that divide the land surface and widen toward the east. Elevations across the County vary from about 14,255 feet at Long's Peak in Rocky Mountain National Park down to about 4,900 feet in St. Vrain Creek in the northeast part of the County.

5.2 GEOLOGY OF BOULDER COUNTY - A BRIEF HISTORY

The geologic history of rocks exposed in Boulder County stretches as far back as the Precambrian, over 1.7 billion years ago. See Plate 2 for a geology map of Boulder County. Intrusive rocks in Boulder County generally include granite, monzogranite, granodiorite, gabbro, diorite, aplite, and metamorphic rocks generally include biotite gneiss, granitic gneiss, amphibolite, schist, and quartzite. The metamorphic rocks began as sedimentary claystones and sandstones and have been altered by heat and pressure. The Boulder Creek Granodiorite (1.7 billion years before present) and the Silver Plume Granite (1.4 billion years before present) are examples of Precambrian igneous intrusions exposed in the Boulder County area. These Precambrian igneous and metamorphic rocks underwent an extensive period of erosion from the Cambrian all the way through the Mississippian Period (about 541 to 323 million years before present).

About 300 million years ago (mya) during the Pennsylvanian Period, the Ancestral Rocky Mountains rose up and were subsequently eroded. Sediment from erosion of the Ancestral Rockies was transported in all directions, accumulating in sedimentary basins which deepened and down warped under the pressure and weight of accumulating sediments. It was during this time that the sands and gravels of the Fountain Formation were deposited by river and stream systems (fluvial deposition). The uplift of the Ancestral Rockies continued for about 20 million years into the Permian Period. The Lyons Formation was deposited during the Permian Period and is comprised of windblown sand dunes. The Ingleside Formation was also deposited during the Permian Period and is only exposed in the northern part of Boulder County.

By about 250 mya, the Ancestral Rockies had significantly eroded down, and the Boulder County area had very little topographic relief. The area was characterized by relatively low relief through the Triassic Period. The weak slope and valley-forming sediments comprising the Lykins Formation were deposited during this time between the Permian and Triassic Periods.

During the Jurassic and Cretaceous Periods, the continent was occupied by an inland sea with multiple cycles of inundation. This seaway is responsible for depositing over 10,000 to 14,000 feet of sediment in the Denver Basin area. The Morrison Formation was deposited by meandering rivers and streams during the earlier seaway occupations, which were less extensive than the later Cretaceous inundations. During the Cretaceous Period, sandstone and shale of the durable Dakota Group, and shale, sandstone, and limestone of the Benton, Niobrara, Pierre Shale, Fox Hills, and Laramie Formations were deposited.

Near the end of the Cretaceous Period, about 65 mya, saw the final retreat of the great inland sea that occupied Colorado. The Fox Hills and Laramie Formations record a combination of marine and fluvial deposition as evidence of this retreat. Also occurring near the end of the Cretaceous Period was the mountain building event known as the Laramide orogeny which began to form the modern Rocky Mountains. This mountain building event caused uplift and massive erosion of sediment into the Denver Basin. Thick sequences of the previously deposited and lithified sedimentary layers were uplifted and steeply tilted along the Front Range (Figures 3 and 5). The time period after the Laramide orogeny was marked by weathering, erosion, and deterioration of the basement rock surface. Intrusion of molten magma and movement of hot, mineral rich water through cracks and weaknesses in the Precambrian basement rocks also occurred. Glacial processes have more recently shaped the mountainous regions of Boulder County, and the erosive power of glaciers and streams has sculpted the landscape into its current form.

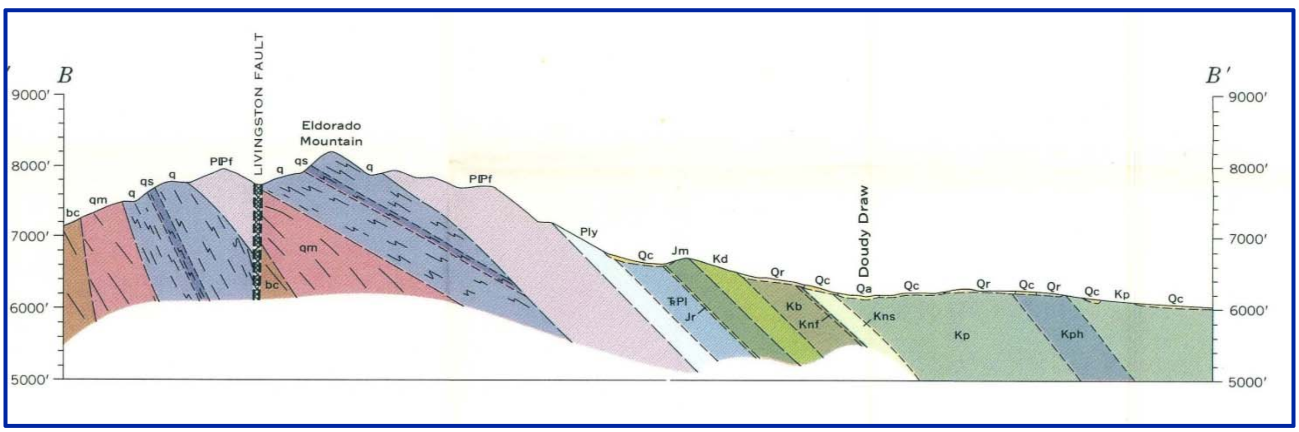


FIGURE 5. Cross Section near the Southern Border of Boulder County

(Excerpted From: Wells, J.D., 1967, Geologic Map and Sections of the Eldorado Springs Quadrangle, Boulder and Jefferson Counties: United States Geological Survey, Bulletin 1221-D.)

The sedimentary bedrock units exposed in Boulder County, listed from oldest to youngest (Pennsylvanian to Cretaceous, from about 300 to 65 mya), are summarized below. References for these descriptions were combined from available geologic maps, listed in Appendix B.

- **Fountain Formation**
  Reddish arkosic sandstone, conglomerate, and claystone. About 1,160 feet thick. Fluvial deposition.
- **Ingleside Formation**
  Pinkish, coarse grained, quartz rich sandstone. Present in northern part of Boulder County only. About 200 feet thick. Eolian and fluvial deposition.
- **Lyons Formation**
  Reddish pink to gray, fine grained, quartz rich sandstone, cemented. About 250 feet thick. Eolian deposition.
- **Lykins Formation**
  Brick red claystone and sandstone, with limestone and dolostone layers. About 600 feet thick. Partly sabkha (salt flat) deposition.
    - Forelle Limestone Member – crinkly texture, stromatolites. About 20 feet thick.
- **Sundance Formation**
  Massively bedded sandstone, weathers white to light gray. Present in northern part of Boulder County only. About 100 feet thick. Fluvial deposition.
- **Morrison Formation**
  Gray, gray green, gray -maroon silty sandstone, with some freshwater limestones. About 345 feet thick. Deposited by lakes and meandering rivers and streams.
- **Dakota Group**
  Sandstone. About 350 feet thick. Fluvial deposition.
    - Lower Dakota – lower part is light colored sandstone with pebble conglomerate at base, and upper part is quartz rich, fine grained, cross bedded, with interbedded shale. About 80 feet thick.
    - Middle Dakota - shale interbedded with sandstone, thickens to the north. About 220 feet thick.
    - Upper Dakota – tan brown sandstone with cross bedding, thins to the north. About 50 feet thick.
- **Benton Formation**
  Dark gray, platy, fissile shale, with fossiliferous limestone layers. About 450 feet thick. Marine deposition (Cretaceous Seaway).
    - Graneros Shale Member – shale.
    - Greenhorn Limestone Member – limestone.
    - Codelle Sandstone Member – sandstone, calcareous in upper part.
- **Niobrara Formation**
  Calcareous shale and limestone, fossiliferous. About 390 feet thick. Marine deposition (Cretaceous Seaway).
    - Fort Hays Member – light gray limestone, inoceramid clams. Forms low hogback. About 20 feet thick.
    - Smoky Hill Shale Member – gray, platy, calcareous shale with thin limestone layers, fossiliferous. About 370 feet thick.
- **Pierre Shale**
  Shale, with sandstone layers. About 8,000 feet thick. Deep marine deposition (Cretaceous Seaway).
    - Hygiene Sandstone Member – sandstone.

- **Fox Hills Sandstone**
  Light gray, tan, fine to medium grained, well sorted, cross bedded sandstone with iron stained concretions. About 300 feet thick. Beach to marine delta deposition.
- **Laramie Formation**
  Gray, brown, stratified sandstone with coal beds, fossiliferous. About 800 feet thick. Marginal marine deposition.

An unconformity, or a gap in the geologic record, separates the Laramie Formation from overlying deposits. Surficial deposits across Boulder County can be grouped into the following categories:

- **Alluvium**
  Material deposited by river and stream systems, varying grain size distribution and thickness.
- **Colluvium**
  Includes talus and slopewash.
- **Terrace Gravels**
  Comprised of older alluvial deposits.
- **Glacial Deposits**
  Includes moraines, glacial tills, and rock glacier deposits.

Boulder County is situated near the northwestern extent of the Denver Basin, a structurally down-warped region characterized by multiple aquifer systems (Figure 6). The outer edge of the Denver Basin underlies the southeastern area of Boulder County. The steeply dipping sedimentary units along the Front Range corridor are interrupted by faults and folds, particularly in the northern part of Boulder County in the area of the Lyons and Hygiene quadrangles, where stratigraphic units are folded and offset. Refer to Figure 7 for a generalized geology and geologic structure map of the northern part of Boulder County (Cole and Braddock, 2009). In general, the steeply tilted orientation of the Foothills sedimentary units decreases to the north of Boulder County. Numerous faults are mapped in the area of the Boulder-Weld Coal Field in the southeastern part of Boulder County. The faults in the Boulder-Weld Coal Field have been mapped in great detail due to the extensive underground mine workings in that area. Other unmapped faults exist in other areas of Boulder County which have not been mapped in such detail. The Precambrian basement rocks underlying the Alpine/Subalpine and Montane Subprovinces are also highly faulted and folded, with numerous igneous intrusions and hydrothermal vein deposits.

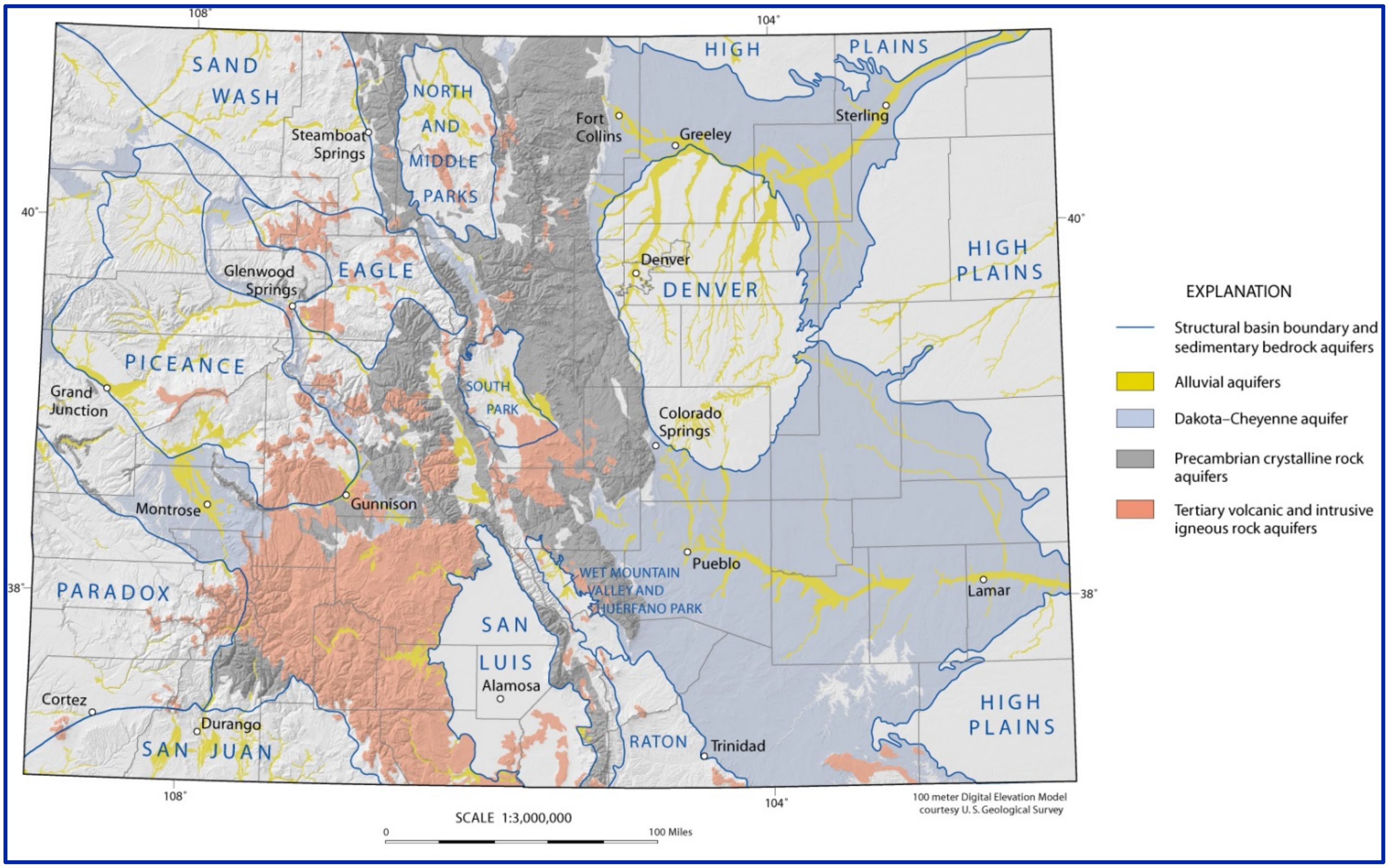


FIGURE 6. Principal Aquifers and Structural Basins of Colorado

(Source: Topper and others, 2003.)

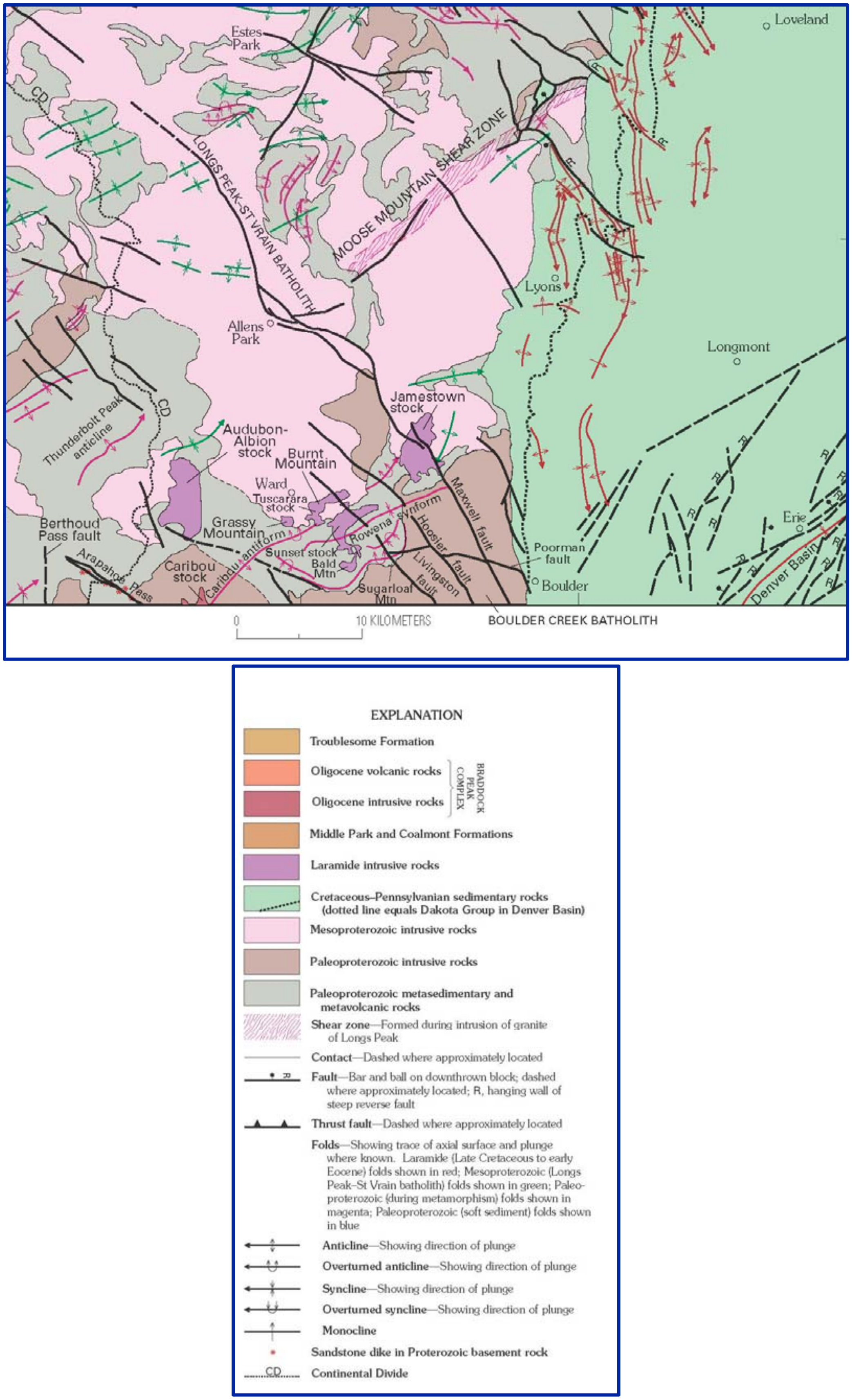


FIGURE 7. Generalized Geologic Map of the Northern Part of Boulder County, including Legend

(Source: Cole and Braddock, 2009.)

6. GEOLOGIC HAZARDS

This study focuses on those critical geologic hazards which are directly exacerbated by rain and flood events and are significant enough to be considered a risk to human safety, property, or the environment. In addition, this study is primarily focused on those geologic hazards which were previously poorly characterized on a countywide scale and which substantially impact current Boulder County residents, future property owners and those which impact planning decisions. This study does not cover all the geologic hazards impacting Boulder County. Through the process of outreach, research, and data collection, the study evolved such that characterizing the landslide hazard became a top priority.

Mapping of the debris flow, flooding, and fluvial hazard zones has either been completed or is concurrently being addressed by others. Debris flow susceptibility has been addressed by the CGS (Morgan and others, 2015). Remapping of the floodplains is currently being completed by the Colorado Water Conservation Board (CWCB) in coordination with other groups. Mapping of fluvial hazard zones is also being completed by the CWCB and should be complete around early 2018 (personal communication, Ms. Stephanie DiBettito).

The following sections briefly describe geologic hazards, including those related to slope stability, swelling soils and bedrock, mines, and fluvial processes (or channel migration).

6.1 LANDSLIDES

A landslide is the downslope movement of rock or soil, or both, which occurs on a rupture surface. The rupture surface is either curved or planar and the material which is mobilized moves as a coherent or partially coherent mass. The basic types of mass movement categories include falls, topples, slides, spreads, and flows. Landslides in Boulder County span varying geologic and geomorphic settings, with differing size, surface expression, and causative factors. Some landslides appear to be ancient with little to no signs of recent movement. Others display signs of ongoing and recent sliding. Some involve only the upper few feet of soil where others are deep-seated or comprised of large blocks of bedrock which have slid downslope. Some have moved downslope in a fast-moving, short-duration event, whereas others move slowly and creep downhill. Refer to Figure 8 for an illustration showing the anatomy of a landslide and to Figure 9 for illustrations of common landslides types. The following is a list of types of mass movements with brief descriptions:

- **Rotational Landslide**
  A landslide in which the surface of rupture/sliding is curved upward and the slide movement is predominantly rotational about an axis, which is parallel to the contour of the ground surface slope. The head of the slide can move vertically downward and the top of the slide mass can tilt backward toward the scarp.
- **Translational Landslide**
  A landslide in which the slide mass moves out, or down and out, along a relatively planar slide surface with limited rotation or backward tilting. Translational slides commonly occur along discontinuities such as faults, fractures, bedding planes, or at the contact between soil and rock.

- **Lateral spread**
  Usually occurs on very gentle to almost flatly lying slopes. Typically involves a stronger upper rock or soil layer that undergoes extension and moves above underlying softer, weaker material. The harder upper layer extends and fractures, pulling apart and moving over the weaker underlying layer without necessarily forming a recognizable failure surface. Generally includes subsidence of the ground surface into the underlying weaker material. In some cases, the weaker underlying layer squeezes upward through cracks and gaps in the overlying harder layer.
- **Creep**
  Imperceptibly slow downward movement, or creep, of soil or rock on a slope. Creep can be seasonal, continuous, or progressive (slope is developing into another type of mass movement).
- **Earthflow**
  An earthflow mobilizes as a plastic or viscous flow with strong internal deformation. Can occur on gentle to moderate slopes, generally in fine grained soil or highly weathered claystone bedrock.
- **Debris Avalanche**
  Large, rapidly moving flow caused by failure of an unstable slope resulting in debris rapidly transported down/away from the slope.
- **Debris Flow**
  A rapid mass movement in which loose soil, rock, and possibly organic matter combine with water to form a slurry that flows downslope. A rotational or translational landslide may evolve into a debris flow.
- **Rockfall**
  Abrupt, downward movement of rock that has detached from a steep slope or cliff. The falling rock or rock mass may break apart upon impact, or may begin rolling and bouncing down the steep slope, stopping when the rock hits a barrier or the terrain flattens.
- **Rock Topple**
  Forward rotation out of a slope around a point or axis below the center of gravity of the displaced rock. Toppling can be driven by gravity of the mass of material upslope from the failure, or due to water or ice in cracks and fissures in the rock.
- **Rock Avalanche**
  A rapid, massive failure involving fragmented rock, mobilized from a large rockslide or rockfall.

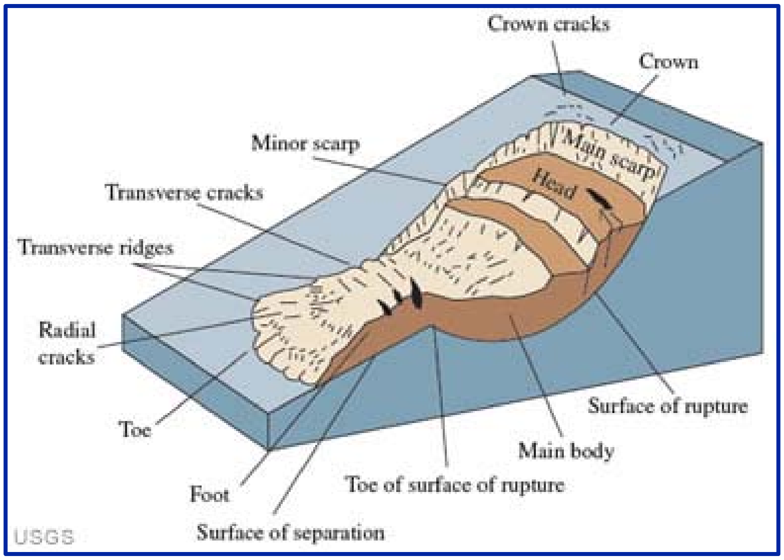


FIGURE 8. Anatomy of a Landslide

(Source: USGS Fact Sheet 2004-3072.)

There are many different potential causes of landslides, including physical triggering mechanisms and natural and human induced causes. Examples of physical triggers include (Highland, 2008):

- intense, long duration precipitation,
- flooding,
- snowmelt, and
- freeze-thaw activity.

Natural causes of landslides include, but are not limited to:

- weak, weathered, sheared, or fractured material,
- adversely oriented discontinuities (faults, fractures, foliations, bedding planes, or other contacts),
- contrasting material properties (e.g., permeability, stiffness),
- erosion of the toe of a slope,
- loading at the top of the slope, or
- vegetation removal by wildfire or drought.

Human induced causes for landslides can include many different activities, such as:

- excavation at the toe of the slope,
- loading of the top of the slope,
- excessive irrigation in the area of a potentially unstable slope, or
- water leakage from utility lines.

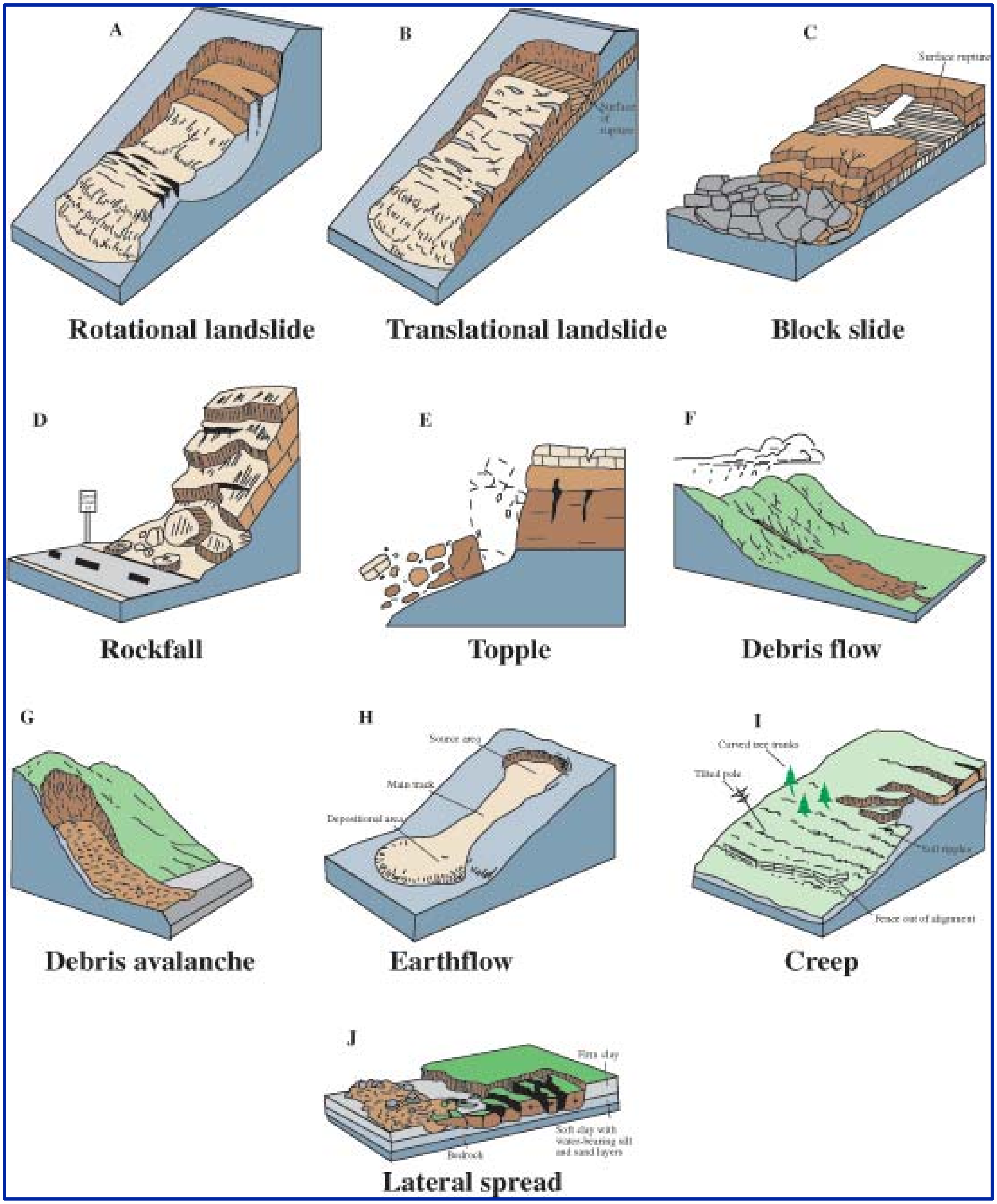


FIGURE 9. Types of Landslides

(Source: USGS Fact Sheet 2004-3072.)

For further reading on landslide hazards, refer to:

Godt, J.W., Coe, J.A., Kean, J.W., Baum, R.L., Jones, E.S., Harp, E.L., Staley, D.M., and Barnhart, W.D., 2014, Landslides in the Northern Colorado Front Range Caused by Rainfall, September 11-13, 2013: united States Geological Survey, Fact Sheet 2013-3114.

Highland, L.M., 2008, The Landslide Handbook – A Guide to Understanding Landslides: United States Geological Survey, Circular 1325.

Highland, L.M., 2012, Landslides in Colorado, USA: Impacts and Loss Estimation for the Year 2010: United States Geological Survey, Open-File Report 2012-1204.

Jochim, C.L., Rogers, W.P, Truby, J.O., Wold, Jr., R.L., Weber, G., and Brown, S.P., 1988, Colorado Landslide Hazard Mitigation Plan: Colorado Geological Survey, Bulletin 48.

6.1.1 Debris Flows

Debris flows are rapidly moving, hyper concentrated slope movements comprised of entrained sediment, rocks, and debris that have been eroded from a slope (Figure 10). Conditions which are conducive to debris flows include steep, channelized slopes, loose material available for downslope transport, and sufficient amounts of water. Initiation of debris flow events usually involve intense rainfall, saturated ground conditions, rapid and erosive surface flows, and shallow soil-slip landslides which can evolve into debris flows. In some cases, multiple soil slip landslides will coalesce into one destructive, erosive debris flow. Debris flows can vary from thin, nuisance level flows to catastrophic events which entrain large boulders and debris. Areas which have experienced removal of vegetation due to wildfires are especially susceptible to debris flows. In recent years, notable wildfires have included the Overland Fire (2003), the Fourmile Canyon Fire (2010), and the Cold Springs Fire (2016). Figure 11 is a map of recent wildfires, available from Boulder County.

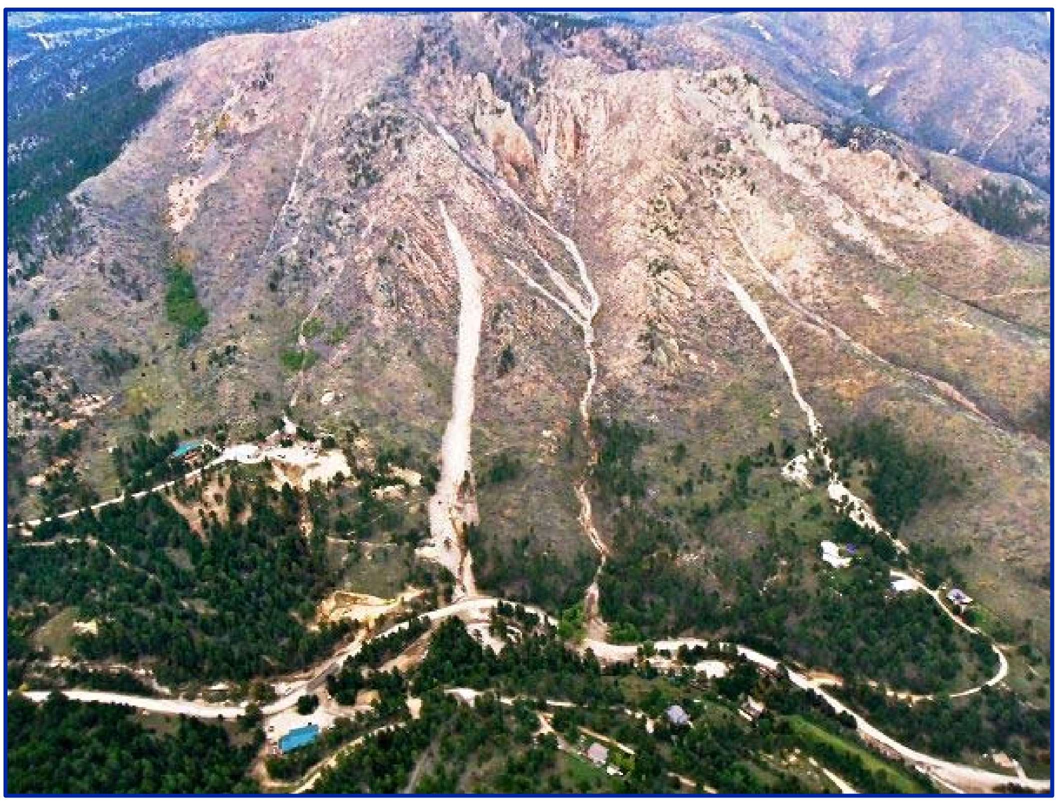


FIGURE 10. Aerial View of Multiple Debris Flows on Porphyry Mountain West of Jamestown, Colorado

(Source: criticalzone.org, photo by Nate Rock, October 3, 2013.)

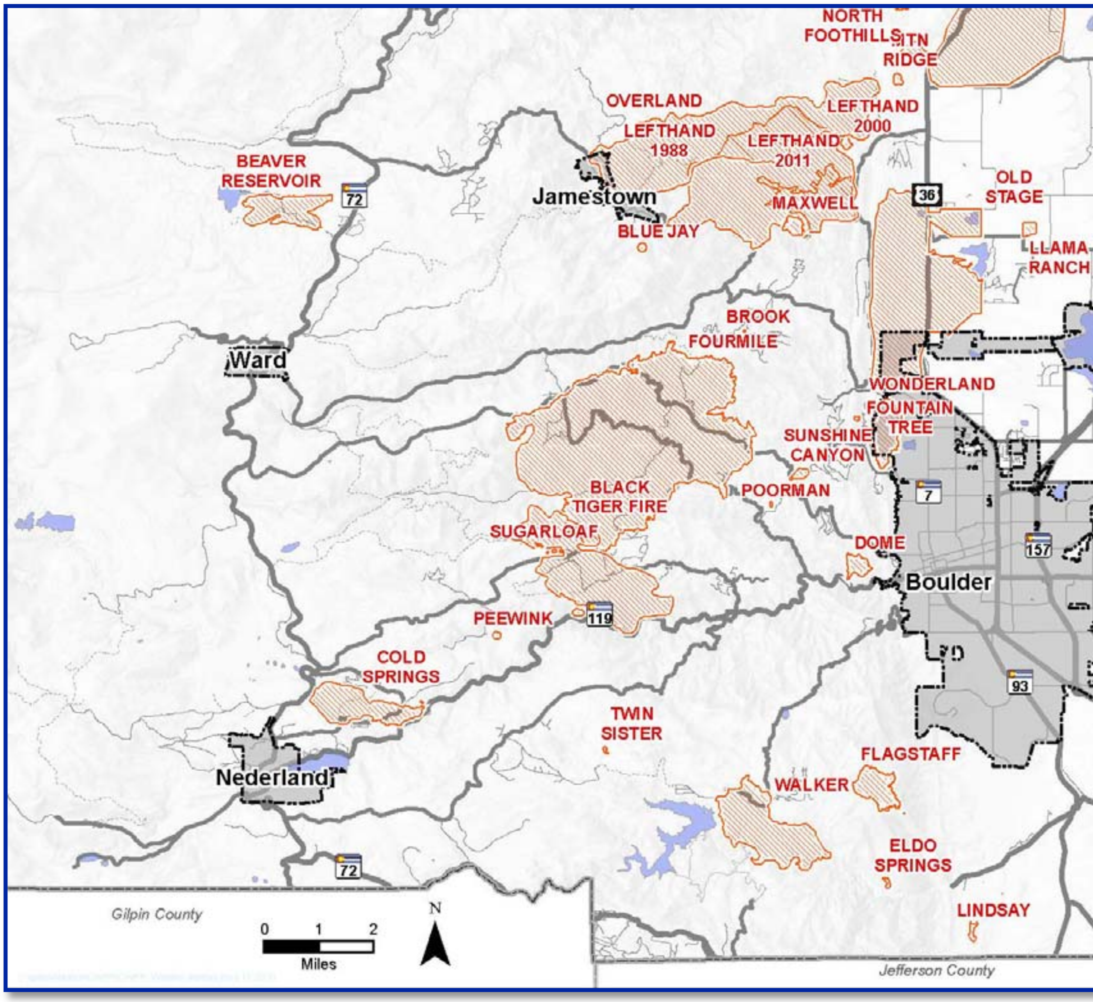


FIGURE 11. Map of Some of the Wildfire Burn Areas in Boulder County

(Source: bouldercounty.org)

The CGS has completed debris flow mapping for Boulder County (Morgan and others, 2014). Refer to Figure 12. This map is available in GIS format and is currently being utilized by the Boulder County Land Use Department. Additionally, the CGS has issued draft maps of debris flow susceptibility for the Gold Run and Ingram Gulch areas in Boulder County (McCoy, 2016). These maps show those areas of Boulder County which are susceptible to debris flows. The debris flow susceptibility for a given drainage after a debris flow is generally considered to be the same as before the event – the susceptibility of a debris flow at that location does not generally decrease after an event. Debris flow susceptibility increases for several years following a wildfire, even for normal, small scale precipitation events.

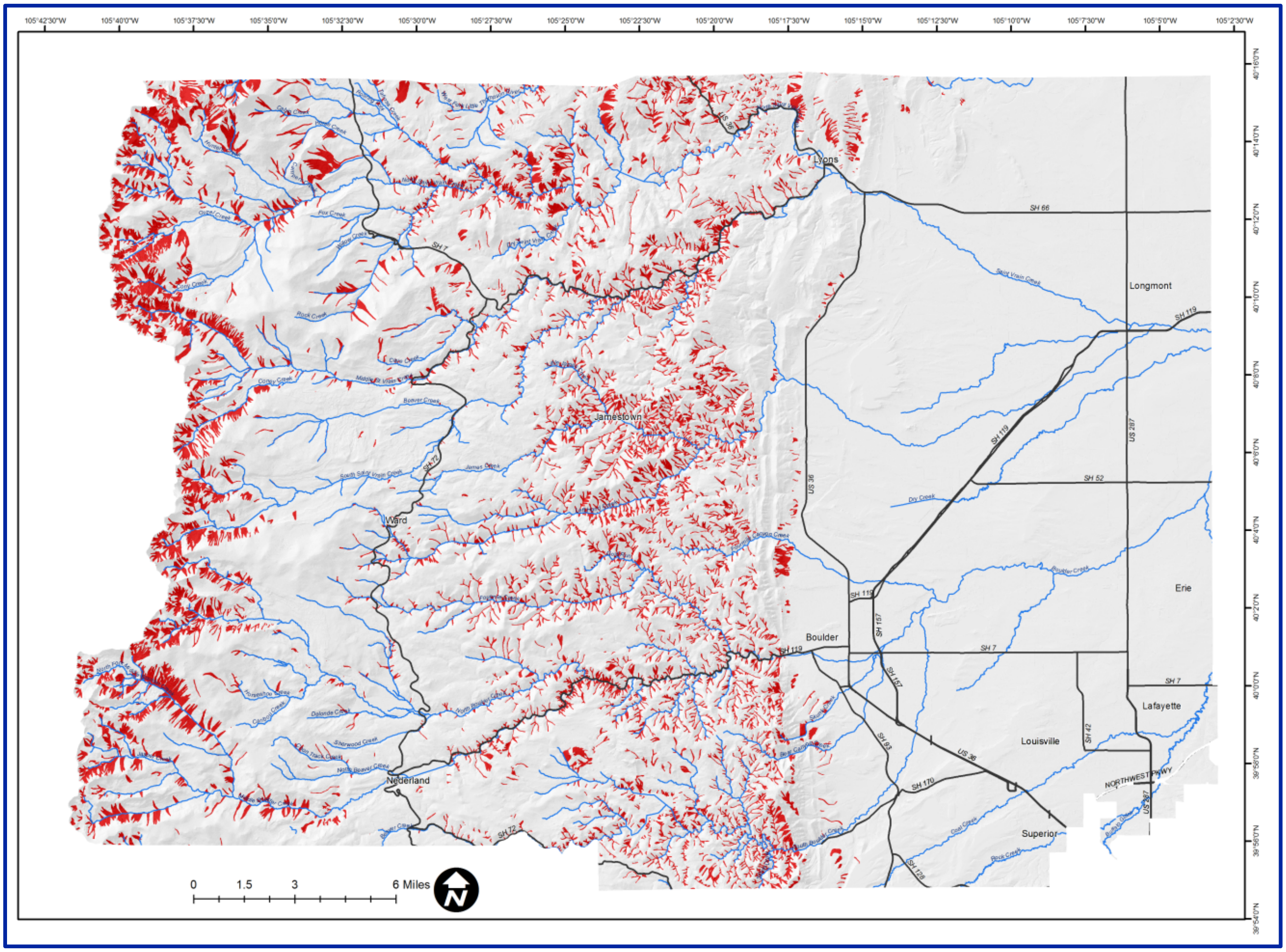


FIGURE 12. Debris Flow Susceptibility Map for Boulder County

(Source: Morgan and others, 2014.)

For further reading on debris flow hazards, refer to:

Anderson, S.W., Anderson, S.P., and Anderson, R.S., 2015, Exhumation by Debris Flows in the 2013 Colorado Front Range Storm: Geology, v. 43, no. 5, pp. 391-394.

Coe, J.A., Kean, J.W., Godt, J.W., Baum, R.L., Gochis, D.J., and Anderson, G.S., 2014, New Insights into Debri-Flow Hazards from an Extraordinary Event in the Colorado Front Range: GSA Today, v. 24, no. 10, pp. 4-10.

Ebel, B.A., Rengers, F.K., and Tucker, G.E., 2015, Aspect-Dependent Soil Saturation and Insight into Debris-Flow Initiation During Extreme Rainfall in the Colorado Front Range: Geology, v. 43, no. 8, pp. 659-662.

McCoy, K.M., 2016, Debris Flow Susceptibility Mapping in the Gold Run and Ingram Gulch Areas, Boulder County, Colorado: Colorado Geological Survey.

Morgan, M.L., White, J.L., Fitzgerald, F.S., Berry, K.A., and Hart, S.S., 2014, Foothill and Mountainous Regions in Boulder County, Colorado that may be Susceptible to Earth and Debris/Mud Flows During Extreme Precipitation Events: Colorado Geological Survey, Open-file Report 14-02.

Rengers, F.K., McGuire, L.A., Coe, J.A., Kean, J.W, Baum, R.L., Staley, D.M., and Godt, J.W., 2016, The Influence of Vegetation on Debris-Flow Initiation During Extreme Rainfall in the

Northern Colorado Front Range: The Geological Society of America, v. 44, no.10, pp. 823-826.

Ruddy, B.C., Stevens, M.R., Verdin, K.L., and Elliot, J.G., 2010, Probability and Volume of Potential Postwildfire Debris Flows in the 2010 Fourmile Burn Area, Boulder County, Colorado: United States Geological Survey, Open-File Report 2010-1244.

6.1.2 Rockfall

Rockfall is the falling of newly detached rock from a cliff or the downslope mobilization of a rock or rock mass. Rockfalls, rock topples, rock avalanches, and rock slides are fast moving, gravity driven landslides that often have overlapping characteristics. These types of landslides commonly grade into each other. These failures are largely related to the type of rock, height, angle and surface of the slope, type and nature of discontinuities in the rock, freeze-thaw activity, precipitation, and other factors. Rockfalls are caused by detachment from a larger rock mass or removal of support from underneath due to ice wedging, root growth, ground shaking, or erosion or chemical weathering.

Excavations for roads and other structures aggravate the rockfall hazard in many areas. In some places, repeated rockfall events occur and require regular attention from roadway maintenance crews (Figure 13). Potential rockfall areas are commonly those areas where steep or barren cliffs rise above less steep talus or colluvial slopes. Areas such as these are common across Boulder County.

FIGURE 13. Rockfall on Highway 119 in Boulder Canyon in Boulder, Colorado

(Source: denver.cbslocal.com, May 7, 2012.)

6.2 SWELLING SOILS AND STEEPLY DIPPING, HEAVING BEDROCK

Swelling soils and bedrock have been mapped across the Piedmont area of Boulder County by Hart (1974). Refer to Plate 3 for a map of swelling soils and bedrock for the Front Range area. Swelling soils contain clay minerals that can attract and absorb water, swelling in volume when wet and shrinking when dry. The swell potential of subsurface materials is characterized through site specific sampling and laboratory testing. Sedimentary layers containing claystone with high swell potential underlie most of the area in Boulder County east of the Front Range. Hart (1974) categorizes swelling soils and bedrock into the following divisions:

> *"VERY HIGH SWELL POTENTIAL: This category includes only bedrock or weathered bedrock. The precautions listed below under "high swell potential" must be utilized. Although construction in these areas is often unavoidable, alternate non-construction uses might be considered for such areas.*
>
> *HIGH SWELL POTENTIAL: This category generally includes only bedrock, weathered bedrock, and colluvium. Careful site investigation, special foundation design, and proper post-construction landscaping and maintenance are required to prevent or minimize damage.*
>
> *MODERATE SWELL POTENTIAL: This category includes several bedrock formations and a few surficial deposits of variable thickness. Special foundation designs are generally ncessary [sic] to prevent damage.*
>
> *LOW SWELL POTENTIAL: This category includes several bedrock formations and many surficial deposits. The thickness of the surficial deposits may be variable, therefore, bedrock with higher swell potential may locally be less than 10 ft below the surface.*
>
> *WINDBLOWN SAND OR SILT: Although this material generally has low swell potential, the upper 9 inches to 12 inches may locally have moderate swell potential. Windblown material may be subject to severe settlement or hydrocompaction when water is allowed to saturate the deposits. The thickness of windblown material may be very variable, therefore, bedrock with higher swell potential may locally be less than 10 ft below the surface."*

Bedrock in a majority of the Piedmont Subprovince is gently dipping. Alternately, bedrock along the Foothills Subprovince is steeply tilted, resulting in a distinct geologic hazard called steeply dipping heaving bedrock. Figure 14 shows the steeply dipping bedrock units exposed along a roadcut for I-70 near Golden, Colorado. Figure 15 depicts a series of cross sectional diagrams which illustrate the steeply dipping heaving bedrock hazard. The steeply dipping heaving bedrock hazard, if not properly remediated, can result in substantial amounts of differential foundation movement. The steeply dipping heaving bedrock condition can also result in a deeper depth of wetting in developed areas, increasing the amount of claystone exposed to swelling and increasing the hazard.

FIGURE 14. Photograph of Steeply Dipping Bedrock in a Roadcut for I-70 along the Front Range in the area of Golden, Colorado

(Photo Source: GEOExPro.com)

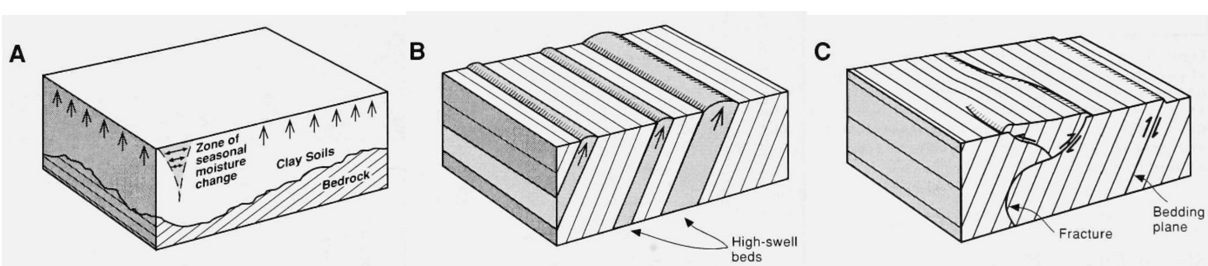


FIGURE 15. Diagrams of the Hazard related to Steeply Dipping Heaving Bedrock

(Modified from: Noe and Dodson, 1999.)

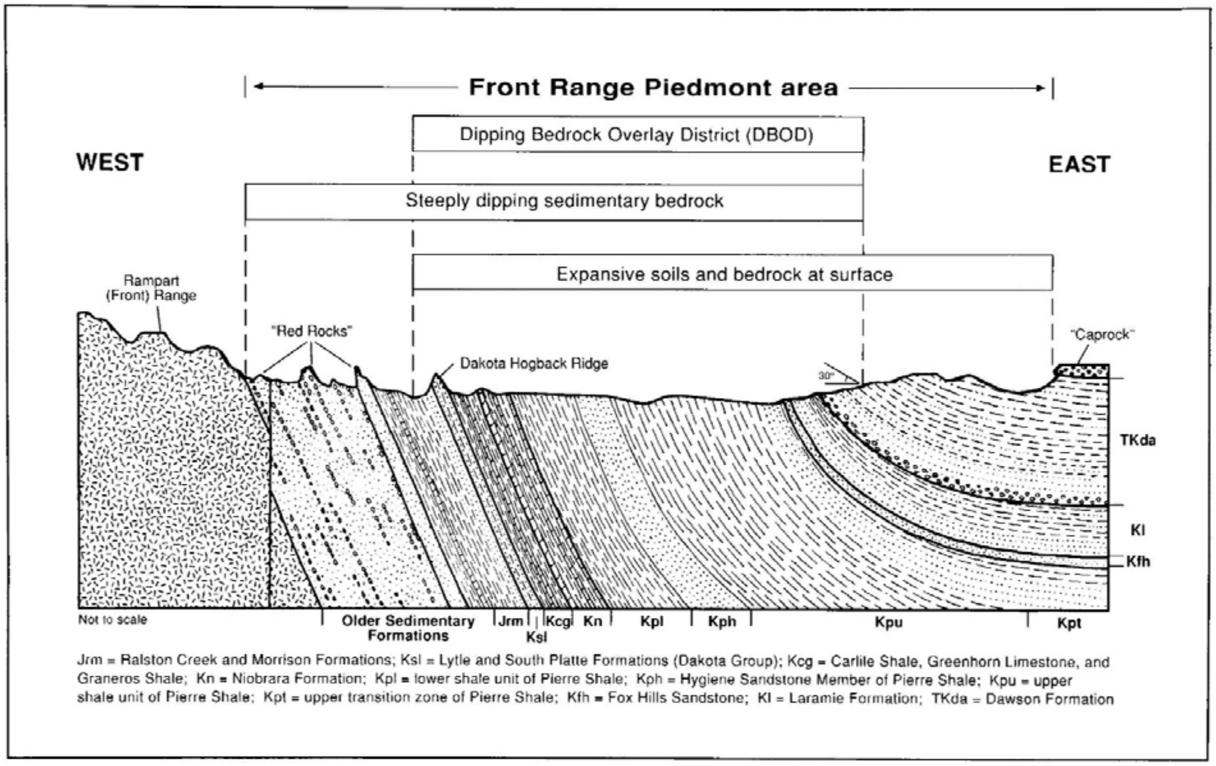


FIGURE 16. Cross Section illustrating Steeply Dipping Heaving Bedrock Hazard in Douglas County

(Source: Noe and Dodson, 1999.)

Both Jefferson and Douglas Counties have delineated zones impacted by the steeply dipping heaving bedrock hazard, and have developed associated regulations and standards. Douglas County delineates a "dipping bedrock overlay district" (DBOD) which is outlined in Noe and Dodson (1999). A cross section through Douglas County is shown in Figure 16. Jefferson County defines a "designated dipping bedrock area" (DDBA) developed by the Jefferson County Expansive Soils Task Force in 1994 and shown in Figure 17. Particular considerations for site investigations and evaluations, development design, construction quality control, and maintenance are warranted in the steeply dipping, heaving bedrock zone (Appendix F). The western boundary of the DDBA is defined as the contact between the Graneros Shale member of the Benton Formation and the underlying Dakota Sandstone, and the eastern boundary corresponds with the eastern extent of where bedrock dips exceed 30 degrees from horizontal. The geologic units considered in the Jefferson County DDBA include, from west to east:

- Graneros Shale
- Greenhorn Limestone
- Carlile Shale
- Niobrara Formation
- Pierre Shale
- Fox-Hills Sandstone
- Laramie Formation
- Parts of the Arapahoe, Denver, and Dawson Formations

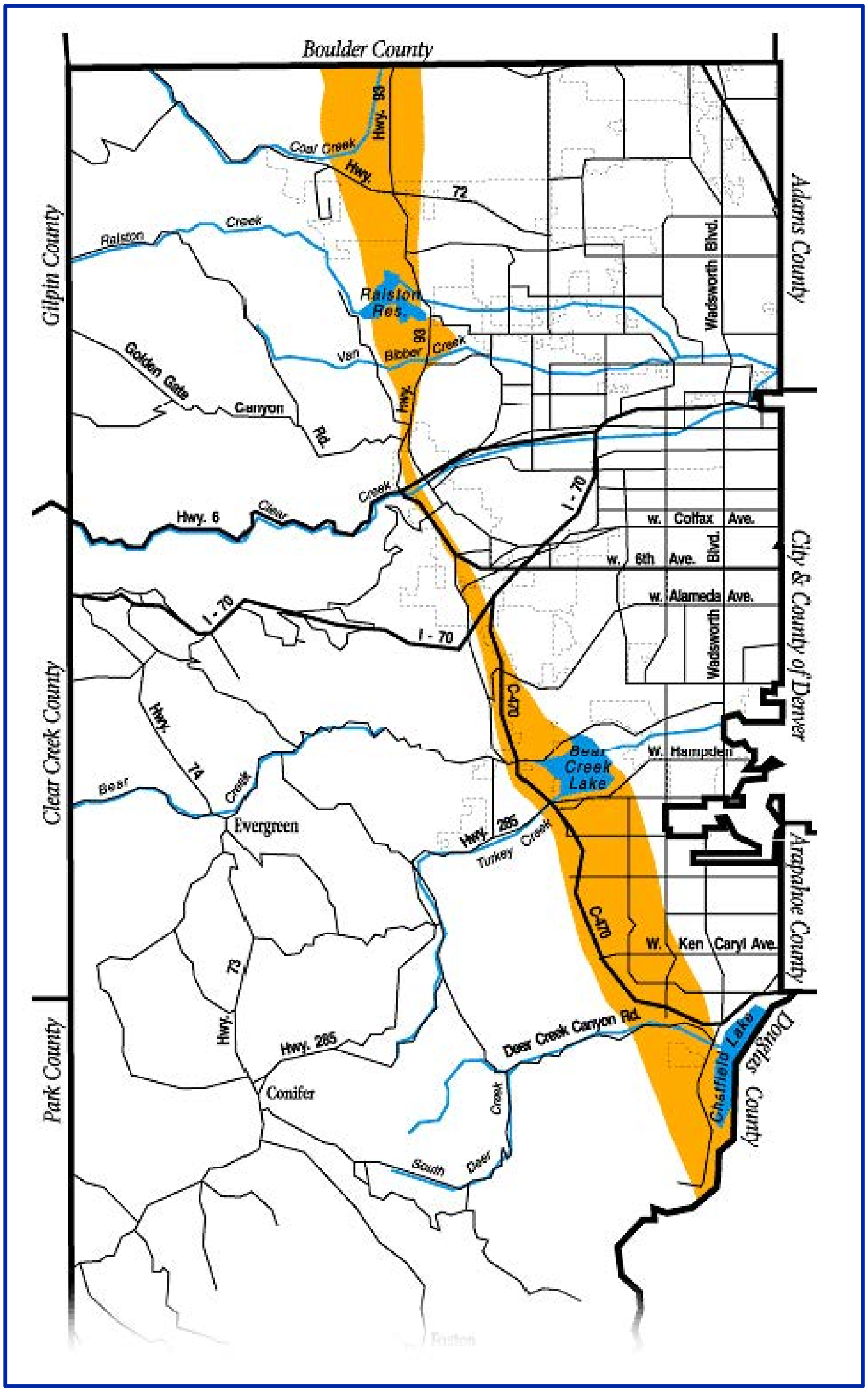


FIGURE 17. Jefferson County Designated Dipping Bedrock Area
(Source: Designated Dipping Bedrock Area Guide, accessed from jeffco.us)

For further reading on hazards related to swelling soils and steeply dipping, heaving bedrock hazards, refer to:

Hart, S.S., 1974, Potentially Swelling Soil and Rock in the Front Range Urban Corridor, Colorado: Colorado Geological Survey, Environmental Geology 7.

Noe, D.C., and Dodson, M.D., 1999, Heaving-Bedrock Hazards Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado: Colorado Geological Survey, Special Publication 42

Noe, D.C., Higgins, J.D., and Olsen, H.W., 2007, Steeply Dipping Heaving Bedrock, Colorado: Part I – Heave Features and Physical Geological Framework: Environmental and Engineering Geoscience, v. XIII, no. 4, pp. 289-308.

Noe, D.C., Higgins, J.D., and Olsen, H.W., 2007, Steeply Dipping Heaving Bedrock, Colorado: Part 2 – Mineralogical and Engineering Properties: Environmental and Engineering Geoscience, v. XIII, no. 4, pp. 309-324.

Noe, D.C., Higgins, J.D., and Olsen, H.W., 2007, Steeply Dipping Heaving Bedrock, Colorado: Part 3 – Environmental Controls and Heaving Processes: Environmental and Engineering Geoscience, vol. XIII, no. 4, pp. 325-344.

Noe, D.C., Jochim, C.L, and Rogers, W.P., 2007, A Guide to Swelling Soil for Colorado Homebuyers and Homeowners: Colorado Geological Survey, Special Publication 43.

6.3 MINE HAZARD

Boulder County has a long history of mining activity within its boundaries. The Boulder-Weld Coal Field occupies the southeastern area of Boulder County. Refer to Figure 18 for the extents of the Boulder-Weld Coal Field. In addition, Plates 4 and 5 show undermined areas and depth of cover maps for this area (Roberts and others, 2001). The Subsidence Study by Dames and Moore (1986) is a comprehensive resource for undermined areas related to coal mining in Boulder County. Other available undermined area maps include those by Amuedo and Ivey (1975) and those available on the websites of the Colorado Division of Reclamation Mining and Safety (DRMS) and the CGS. Carlson and others (2010) have issued a useful annotated bibliography for subsidence studies above inactive coal mines in Colorado. The mine subsidence hazard is related to removal of underground support by mining activities, causing depression, collapse, and subsidence of the ground surface (Figure 19). In addition to the coal mining common in some areas east of the Front Range in Colorado, the mountainous areas of Boulder County have hundreds of hard rock mine workings and exploratory features.

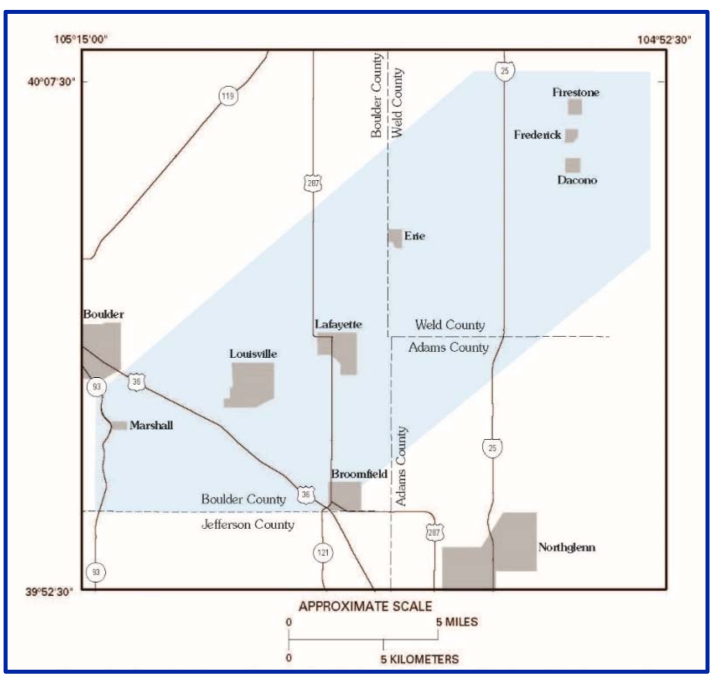


FIGURE 18. Extent of the Boulder-Weld Coal Field (shaded blue area)
(Source: Roberts and others, 2001.)

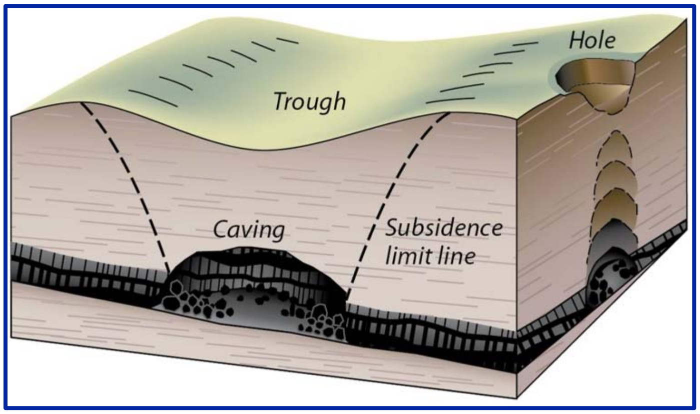


FIGURE 19. Diagram of Mine Subsidence Hazard
(Source: coloradogeologicalsurvey.org).

Characterizing the mine subsidence hazard is made complicated by the fact that many undermined areas have incomplete, incorrect, or nonexistent records or maps. Thus, a thorough review of available information and site specific characterization by a qualified professional is highly recommended for those areas with the potential for mine subsidence. Mine related hazards also include safety and environmental issues, both of which are not addressed in this study. The DRMS and CGS are useful resources for up-to-date mine related information and details.

For further reading on hazards related to coal mine subsidence, refer to:

Amuedo and Ivey, 1975, Coal Mine Subsidence and Land Use in the Boulder-Weld Coalfield, Boulder and Weld Counties, Colorado: Colorado Geological Survey, Environmental Geology 9.

Carlson, J., Hannu, B., and Wait, TC., 2010, Annotated Bibliography of Subsidence Studies over Abandoned Coal Mines in Colorado: Colorado Geological Survey Information Series 22 (originally compiled by Tom Hatton and JE Turney).

Dames and Moore, 1986, Boulder County Subsidence Investigation, prepared for the State of Colorado, Department of Natural Resources, Mined Land Reclamation Division.

Hynes, J.L., 1984, Tri-Towns Subsidence Investigation, Weld County, Colorado, A Community-wide Approach to Hazard Evaluation and Land Use in Undermined Areas.

Spencer, F.D., 1986, Coal Geology and Coal, Oil, and Gas Resources of the Erie and Frederick Quadrangles, Boulder and Weld Counties, Colorado: United States Geological Survey, Bulletin 1619.

Turney, J.E., 1985, Subsidence Above Inactive Coal Mines, Information for the Homeowner: Colorado Geological Survey, Special Publication 26.

6.4 FLUVIAL HAZARD ZONES

During the September 2013 flood event, flood related impacts outside the 100 year FEMA floodplain were experienced throughout Colorado. FEMA's National Flood Insurance Program maps are based on elevation and delineate flood inundation hazard zones by applying a water surface elevation based standard. There are inherent uncertainties embedded in this method which are related to topography, geomorphology, and complex, dynamic flood conditions (Jagt and others, 2016). Boulder County's narrow, steep valleys are greatly influenced by debris flows and hillslope erosion which change stream drainage dynamics during flood events. Figure 20 shows the destruction of a roadway near Jamestown, Colorado, an area which was heavily impacted by damage from the September 2013 rain event.

To further define river corridor hazards, fluvial hazard zones are being delineated and characterized. A fluvial hazard zone (i.e., channel migration zone) is the area a stream has occupied in recent history, could occupy, or could physically influence as it stores and transports sediment and debris during flood events. The Colorado Water Conservation Board, along with others, is currently in the planning phases for mapping of fluvial hazard zones across Colorado. This delineation and mapping will provide land use and floodplain managers insight into the likely long-term behavior of streams and serve as additional flood hazard information. The combination of floodplain and fluvial hazard zone maps will provide a more complete picture of the active river corridor hazard. Fluvial hazards are mentioned in this report because of their relationship with the stability of the slopes that border active drainage channels. Erosion of the toe of a slope due to flooding or severe channel migration and avulsion may lead to slope failures.

FIGURE 20. Aerial View of Roadway near Jamestown, Colorado after the Deluge of September 2013

(Source: 4gwar.wordpress.com, photo by U.S. Air National Guard, Staff Sgt. Nicole Manzanares.)

7. GEOLOGIC HAZARD MAP PACKAGE

Cesare considers the Boulder County geologic hazard map package to include previously existing maps/data, maps/data created for this current study, and maps/data that will be produced by others in the future. The components of this map package are described in the following sections.

7.1 AVAILABLE DATA AND MAPS

Cesare gathered available data and maps for the Boulder County GIS team to begin using as a tool for short and long range planning decisions. Some of these maps are publicly available, some are available by direct request, and some datasets will need to be routinely updated (as is the case for the rockfall and landslide event inventory provided by the Colorado Department of Transportation). The compilation of available maps includes:

1. **Geology Map**
   Compiled from multiple 1:100,000 scale maps covering Boulder County. This map was created using a GIS procedure to extract the unit boundaries from the multiple published maps to create one 1:100,000 scale map of the entire county. This is an improvement from the previously available GIS geology map for Boulder County. Also available from the USGS website are 1:24,000 scale geology maps in GeoTIFF format ready for download (https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl).
2. **Published Landslides Map**
   Landslides compiled from maps with scales varying from 1:250,000 to 1:24,000 (CGS compiled).
3. **Debris Flow Maps**
   3.1. Debris flow potential in foothill and mountainous areas, CGS (Morgan and others, 2015).
   3.2. Fourmile Burn Area Debris Flow Probability and Volume, USGS (Ruddy and others, 2010).
4. **Scarp Locations Map**
   Scarp locations for 841 shallow soil creep events directly related to the September 2013 extreme rain event, provided by the USGS.
5. **Swelling Soils and Bedrock Map**
   This map has been geospatially referenced and transformed into GIS spatial data format (Hart, 1974).
6. **Geo-Event Map**
   This is an inventory of rockfall and landslide events along Colorado State transportation corridors, provided by CDOT.
7. **Undermined Area Map**
   Published Boulder-Weld Coal Field map (Roberts and others, 2001), geospatially referenced and transformed into GIS spatial data format.

7.2 LIDAR DATA PROCESSING

After an in-depth review of the digital elevation model (DEM) provided by Boulder County, it was found that the preliminary nature of the data was causing pervasive errors which would prohibit the use of that data as a terrain model base layer. TerraCognito acquired raw LiDAR point data from multiple sources in order to create a robust terrain model. The sources for the LiDAR data include:

- 2013 LiDAR: FEMA
- 2011 LiDAR: Colorado Water Conservation Board
- 2010 LiDAR: Anderson, S.P., Qinghua, G., and Parrish, E.G., 2012, Snow-on and snow-off Lidar point cloud data and digital elevation models for study of topography, snow, ecosystems and environmental change at Boulder Creek Critical Zone Observatory, Colorado: Boulder Creek CZO, INSTAAR, University of Colorado at Boulder, digital media.
- USGS 30m DEM: Used to fill in gaps in the available LiDAR data in the area of Longs Peak.

7.3 LANDSLIDE INVENTORY

As part of the landslide inventory mapping effort, Cesare verified the location, extents, and type of published landslides across Boulder County compiled from maps of varying scales. Cesare mapped 184 landslides within Boulder County using the DEM created by TerraCognito, published geology maps, and aerial images from various sources. Refer to Plate 6 for mapped landslide locations. Cesare provides tabular data for each mapped landslide, including type, geomorphic evidence, and the level of confidence for that particular mass movement (low, moderate, high).

Landslides were determined using characteristics related to geomorphic, geologic, topographic, and vegetative expressions and patterns. Landslides were mapped at varying scales and using multiple Hillshade maps with varying sun heights and angles to emphasize landforms and landslide features. Cesare's mapped landslides were categorized as either slide or rockfall. The slide category includes rotational, translational, and complex landslides and slumps. The rockfall category encompasses rockfall, rock avalanche, and large rock glacier deposits. Debris flows and fans were not mapped for this study. Cesare considers the debris flow susceptibility mapping produced by the CGS (Morgan and others, 2015) to cover this type of slope failure at a countywide scale.

Shallow slides and near surface failures typically do not appear on the LiDAR images, even at high resolutions. Cesare considers the scarps mapped by the USGS after the September 2013 rain event to constitute most of the shallow slide category of this inventory related to that precipitation event. Shallow slides in addition to those identified by the USGS 2013 scarp locations were not mapped for this study.

The landslide inventory created for this study should not be considered a complete inventory of mass movements for Boulder County. Landslide deposits will exist outside of the areas mapped by Cesare and other authors. The surface expression of older landslides can be smoothed by erosional processes, making it difficult to identify on the LiDAR maps or in the historical aerial images. Cesare's inspection was on a countywide scale and thus did not identify landslides with minimal surface expression based on size, type, age of last slope movement, or other factors.

The Piedmont Subprovince of Boulder County has numerous mesas with colluvium covered flanks that are susceptible to slope failure. These flanks are subject to erosion and slope failures and are also frequently underlain by Pierre Shale, a sedimentary bedrock unit which is prone to slope instability. Many mesas have scalloped ridge tops with visible scarps, bowl shaped depressions, and toe bulges, indications of landslide activity.

The Foothills Subprovince of Boulder County is especially prone to landslides. The sedimentary bedrock layers in this area are tilted up at steep angles, increasing the landslide susceptibility in areas where the bedrock is oriented with a similar dip angle and dip direction as the ground surface. Landslides along the hogbacks commonly include loose mixture of clay, silt, and sand, with large blocks of sedimentary bedrock. The units most commonly involved are Dakota Group, Fountain Formation, and Lyons Formation (Cole and Braddock, 2009). The Dakota Group is historically prone to bedding plane slips along the first sandstone member of the South Platte Formation, where large block glides slid downslope/downdip and rode over younger geologic formations to the east. These block glide landslides were primarily gravity driven detachments along stratigraphic zones of weakness.

Several landslide deposits have been identified in the mountainous regions within and to the west of Boulder County which involve masses of Proterozoic crystalline basement rock (Cole and Braddock, 2009). Glacial deposits have the potential for slope failure, as well as gneissic rocks with preferential foliation orientations making them prone to slope instability. Other mass movement deposits in the Alpine/Subalpine Subprovince include talus deposited on steep slopes and rock glacier deposits.

7.4 USGS SCARP LOCATIONS

Landslide scarp locations for 841 slope failure events in Boulder County which were directly caused by the September 2013 rain event were provided by the USGS (Jonathan Godt, USGS Landslide Hazards Program). For this dataset, the USGS Landslide Hazards Group mapped landslide extents between September 13 and September 26, 2013 (Plate 6). Debris flows were the most common type of landslide observed, initiating on a diverse range of geologic units from Pennsylvanian and Cretaceous age sedimentary units in the east to Precambrian granite and gneiss in the west. A common thread among mapped debris flows in this dataset was that most appeared to have initiated as a discrete sliding mass.

Cesare compared the USGS landslide scarp locations to other countywide datasets such as geology, soils, slope aspect, and slope angle. There is an outstanding correlation between 2013 scarp locations and soils characterized as colluvium and/or residuum derived from igneous and metamorphic rock. Little to no correlation was identified between landslide scarp location and slope aspect.

7.5 LANDSLIDE POTENTIAL MAP

The Landslide Potential Map created for this study (Plate 7) included those areas susceptible to slope movement based on ranking of certain criteria and the estimated significance and level of contribution of different causative factors related to instability. The Landslide Potential Map was developed by using multiple layers of statistically robust contributing factors, leveraging countywide data sets that were both freely available and newly created for this study. Landslides mapped by Cesare for this study, the scarps mapped by the USGS following the September 2013 flood event, and several decades of rockfall events tracked by CDOT were statistically analyzed and used to help guide the criteria for development of the Landslide Potential Map. A list of some of the potential contributing factors for creating landslide potential maps:

- Geology
- Slope angle
- Slope aspect
- Bedrock bedding plane and foliation orientation
- Fractures, folds, faults
- Curvature - plan and profile
- Surface water flow accumulation
- Soil - type, internal angle of friction, thickness, and drainage
- Vegetation - tree density, tree height, and root strength index
- Distance to main, active drainage channels
- Distance to roads
- Wildfire history
- Groundwater levels
- Land use
- Precipitation
- Elevation
- Relief

All of the above listed factors were considered in one way or another for this study. A number of these were directly used for creation of the Landslide Potential Map (Figure 21). Based on statistical analysis of available data, the contributing factors considered in development of the Landslide Potential Map include the internal friction angle of surficial soils as it relates to the slope angle of the ground surface, relative hazard ranking of surficial and bedrock geologic units, internal structure (bedding and foliation) as it relates to the slope and aspect of the ground surface, and the influence of tree root strength on slope stability. A logistic regression analysis was performed using the USGS 2013 landslides as the dependent variable and other explanatory variables in order to identify the most important drivers of slope failure, especially with shallow, rain-triggered landslides. The knowledge gained in the logistic regression analysis informed our general landslide model which includes shallow and deep landslides as well as rockfall hazards.

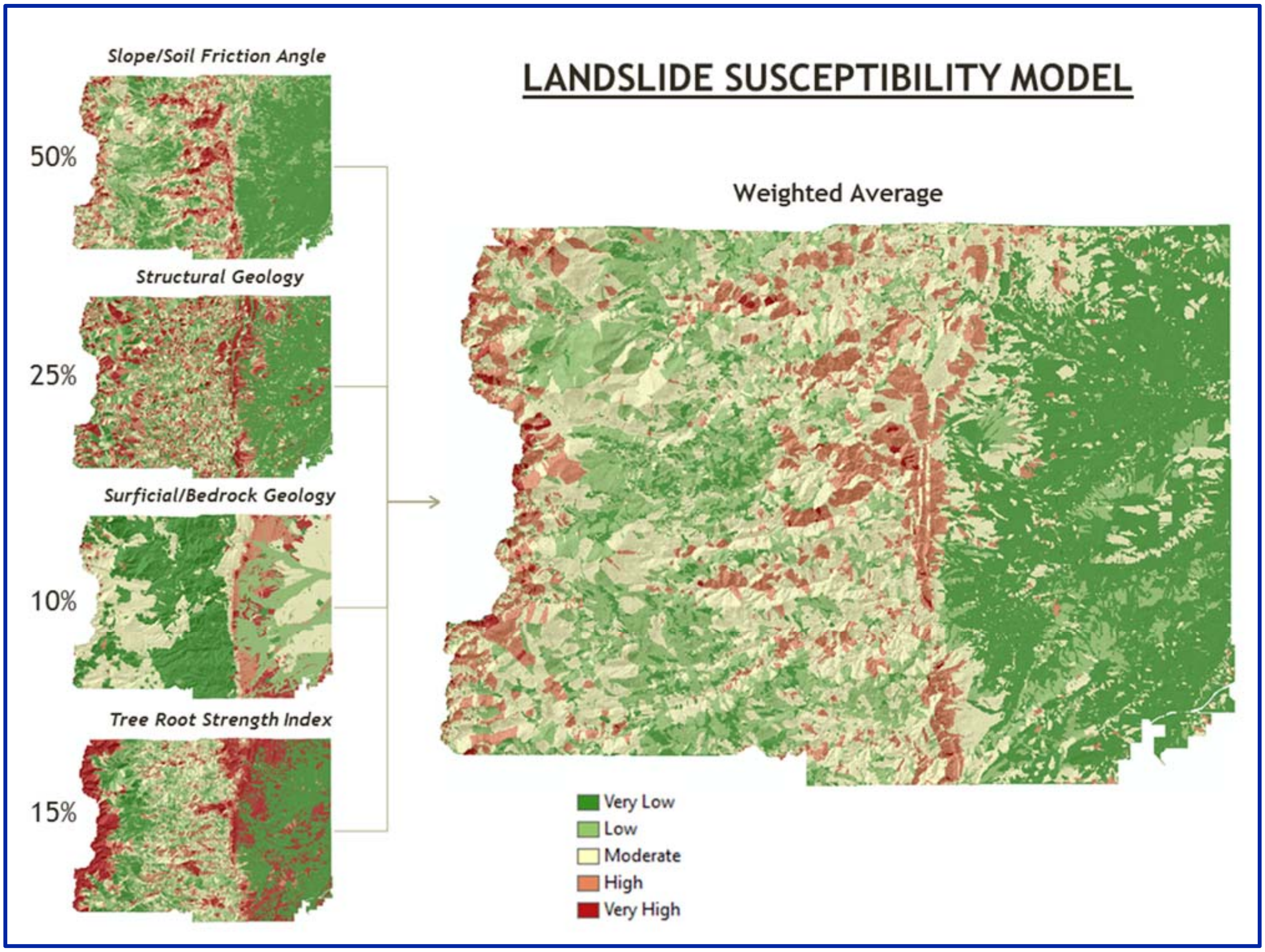


FIGURE 21. Contributing Factors for Landslide Susceptibility Model

A countywide map of surficial soils was obtained from the United States Department of Agriculture, Natural Resources Conservation Service website (nrcs.usda.gov). The surficial soil datasets were combined and transformed for use in the GIS analysis. Soil internal friction angles are a dominant control on soil slope stability. An internal friction angle was estimated for each soil type based on taxonomic, geomorphic depositional setting, published engineering properties for that soil type (Unified Soil Classification System), where available, and Cesare's experience with similar materials. A map was generated that compares the estimated soil friction angle to the slope angle of the ground surface. When this map is compared to the USGS 2013 rain event scarp locations, it appears that the majority of slide events involved soils with an estimated friction angle of 35 degrees. These soils were predominantly comprised of colluvium and residuum derived from igneous and metamorphic rocks. The mean slope angle value for the 841 USGS scarp locations is 34.4 degrees. This result suggests that shallow landslides from the 2013 rain event were strongly driven by soil strength which can be approximated using internal friction angles.

The type of underlying geologic unit is a strong contributing factor for determination of slope stability. Geologic units were ranked based on relative slope stability using the units included in the compiled 1:100,000 scale geology maps. The western two-thirds of Boulder County is generally underlain by granite and metamorphic gneiss, while the eastern one-third is underlain by stratified sedimentary units which are steeply tilted along the Front Range and generally flat lying in the Piedmont region. Generally speaking, igneous and metamorphic rocks are less prone to landsliding than sedimentary rocks, and were thus assigned a lower landslide potential ranking. Sedimentary units comprised of shale and claystone were assigned a higher landslide hazard rating than cemented sandstone units.

The internal structure of the bedrock was considered as a contributing factor for this study. This included bedding planes in sedimentary rocks and foliation orientation for igneous and metamorphic rocks. The bedding and foliation dips, compiled from published maps, were compared with the surface slope orientation to determine if the bedrock was either in-phase or out-of-phase with the ground surface (Figure 22). In-phase relationships where the internal structure is more closely parallel to the ground surface orientation would be considered less stable than out-of-phase relationships.

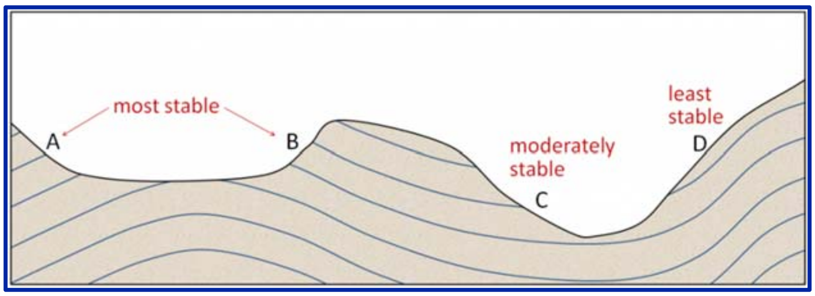


FIGURE 22. Relative Stability of Slopes as a Function of the Orientation of Bedding Planes Relative to Slope Orientation

(Source: Physical Geology by Steven Earle used under a CC-BY 4.0 international license.)

Tree height and tree density were determined through analysis of the high resolution LiDAR point data. The root strength index was then determined using these data sets. The root strength index captures the slope stabilizing effects of tree roots, as a function of tree height and density (iwahashi and others, 2014). Cesare considers this to be a more direct approach to vegetation driven slope stability compared to the commonly used aspect consideration. The tree root strength index is defined as the product of the estimated tree height and the square root of the estimated tree density:

$$RST = H \times \sqrt{D}$$

where RST=root strength index, H=estimated tree height, and D=estimated tree density.

Precipitation was also a consideration in the development of the Landslide Potential Map. This information was acquired by NOAA, Earth System Research Laboratory, Physical Science Division, Climate Analysis Branch, and taken from that webpage titled "Boulder Area Flood of September 2013: Precipitation". This information is from the Advanced Hydrological Prediction Service. The URL for this page is http://www.esrl.noaa.gov/psd/boulder/flood2013/precipplots/

Landslide susceptibility was evaluated for each topographic unit in the study area. Topographic or "slope" units are landscape partitions that have similar slope angle and slope direction characteristics (Figure 23). The basic concept is as follows: if a landslide were to initiate on a given slope unit, it would be contained by that slope unit. This approach circumvents potential spatial autocorrelation problems related to the statistical analysis of landslide causative factors, but more importantly provides planners and landowners with a better understanding of the land area that would likely be affected by a potential landslide event. Here, parcels can be evaluated not only by the landslide susceptibility values within their property boundaries, but more importantly by the susceptible slope units that impact the property.

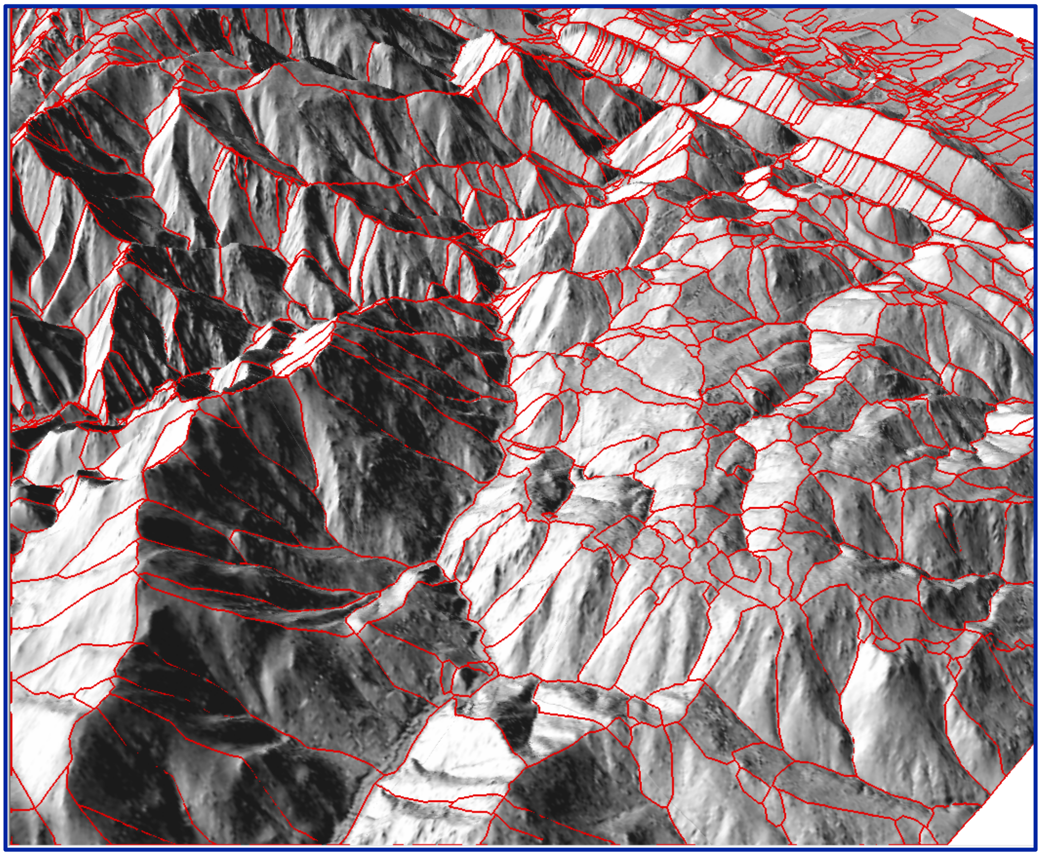


FIGURE 23. Depiction of Slope Unit Divisions

7.6 STEEPLY DIPPING HEAVING BEDROCK MAP

The steeply dipping heaving bedrock hazard zone is characterized by the areas underlain by bedrock units with the following criteria:

1. Sedimentary layers with high swell potential comprise a significant percentage of the unit.
2. Dip at an angle of 30 degrees or more.

The steeply dipping heaving bedrock map for Boulder County produced for this study is shown on Plate 8. The steeply dipping heaving bedrock map created for this study is considered preliminary pending additional fieldwork for collection of bedrock orientations to supplement those on published geology maps and for verification and refinement of the actual boundary limits. Development in these areas may be impacted by differential ground heave where expansive layers of bedrock are present at shallow depths. Cesare recommends that if a proposed development is within or near this zone, that additional information be provided by the developer or landowner to show that the hazard does not exist, or demonstrate that the hazard is being adequately remediated and reduced.

The actual heaving bedrock hazard varies widely across Boulder County, and this map does not take into account those areas where thick surficial soils cover the bedrock surface. A thick, low swell potential, surficial soil cover will significantly reduce the heave related hazard. The amount of overburden with low swell potential required is typically 10 to 16 feet based on current industry standards. The actual amount of surficial soil cover in this zone should be determined by site specific subsurface investigation to characterize the depth to bedrock and engineering properties of potentially expansive claystone.

The western boundary of this zone was generally considered to be the contact between the Dakota and Graneros Shale Member of the Benton Formation. This determination is based on published literature and existing regulatory boundaries in Jefferson and Douglas Counties. The eastern boundary was primarily estimated using dip orientations of problematic units from available geology maps of varying scales (see Appendix B). The sedimentary units along the Front Range in the northern part of Boulder County are folded and faulted (Figure 24), and the steeply dipping heaving bedrock zone is variable in this area. The boundary in this northern area was determined through interpretation of the geology and structure of the area. Figure 25 shows a cross section excerpted from the Hygiene Geologic Quadrangle (1:24,000 scale) and illustrates the structural and stratigraphic condition of this area of Boulder County.

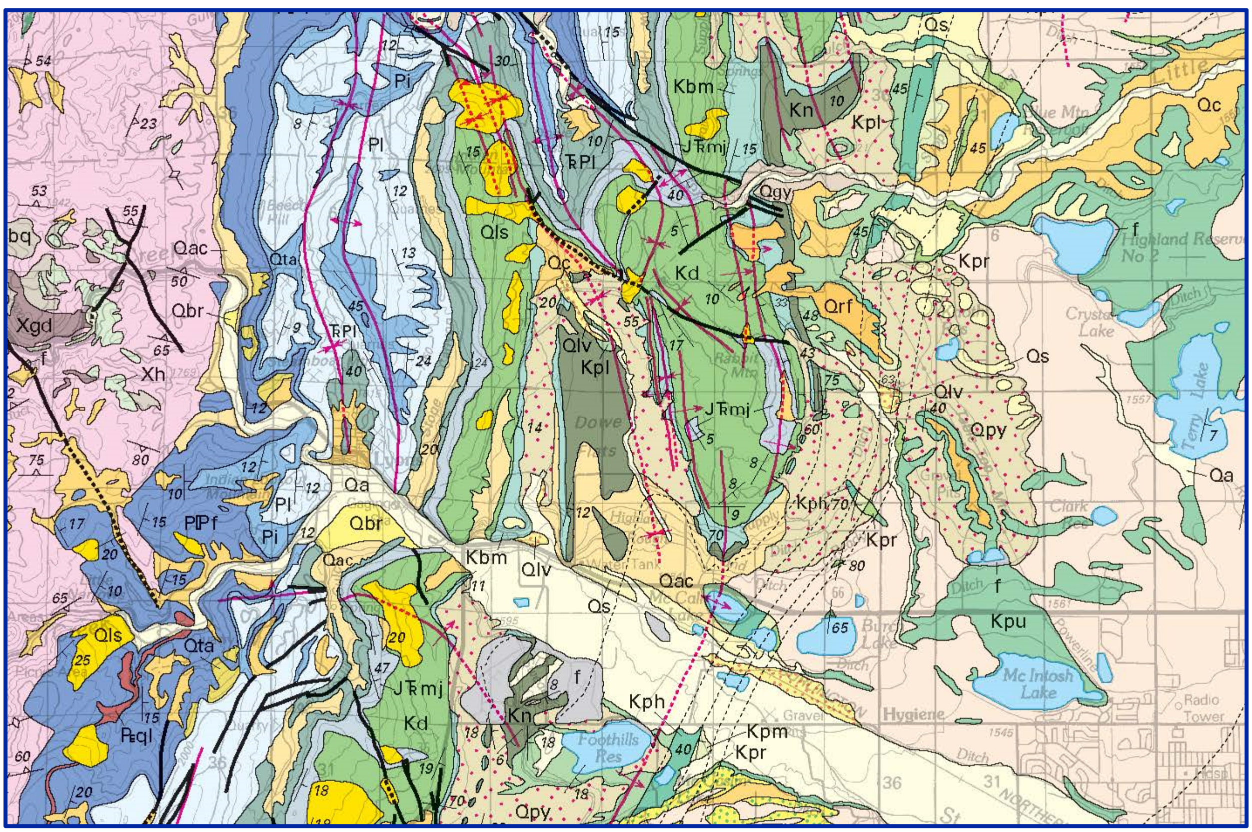


FIGURE 24. Geology Map of the Northern Part of Boulder County, Hygiene Area

(Map Source: Cole and Braddock, 2009.)

Geologic units shown include steeply dipping sedimentary units (blue and green colors) offset by faults (thick black lines) and folds (thick red lines). Also shown in the left part of the map are igneous and metamorphic basement rocks (pink). Surficial deposits (alluvium, colluvium, landslide) are also shown (yellow and orange).

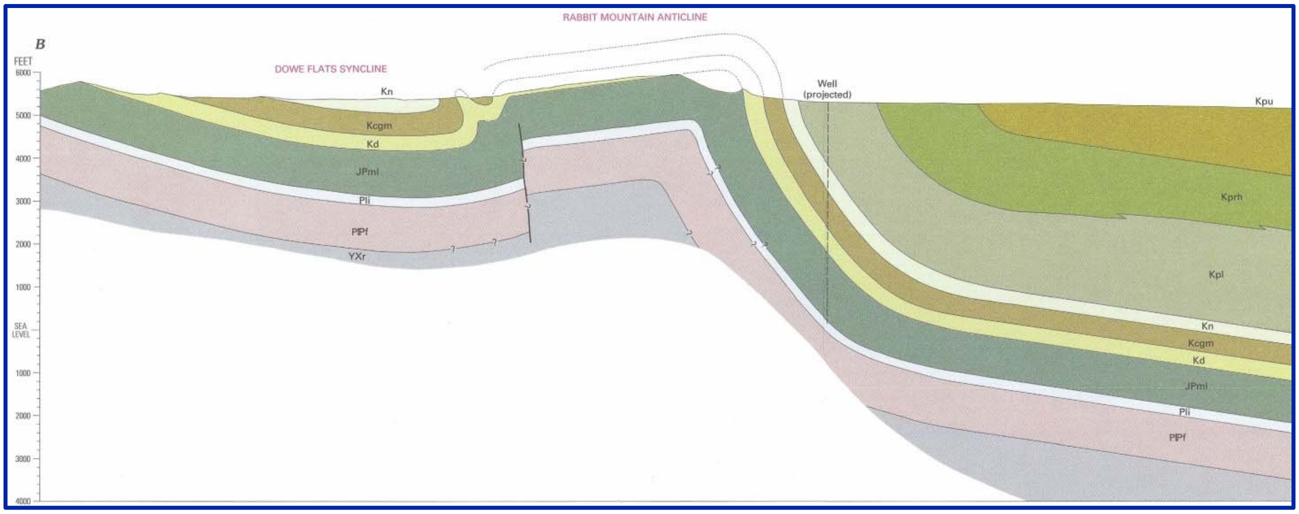


FIGURE 25. Cross Section of the Northern Part of the Hygiene Quadrangle
Shows steeply dipping bedrock along the eastern limb of the Rabbit Mountain Anticline.
(Map Source: Madole and others, 1998.)

Sedimentary bedrock in the southeast part of Boulder County is oriented with variable, and in places, very steep dips which exceed 30 degrees (as shown on published geology maps and undermined area maps for that area). This area of Boulder County was mapped in greater detail than other parts of the County due to the extent of underground mining in the Boulder-Weld Coal Field. Other areas of Boulder County may have heavily faulted bedrock with highly variable dip angles, some of which exceed 30 degrees. The Boulder-Weld Coal Field area, as well as other locations with individual steep-dip-outliers, were not included in the steeply dipping heaving bedrock zone for this study.

7.7 OTHER COMPONENTS OF THE GIS MAP PACKAGE

Other components of the GIS map package deliverable which Boulder County may utilize include slope, tree height, tree density, and root strength index maps. The slope map depicts those slopes in Boulder County which exceed 25 degrees, and is a general way to view potentially problematic slopes in the County (Figure 2). During development of the Landslide Potential Map, tree height, tree density, and root strength index were developed through analysis of the LiDAR point data.

8. HOW TO USE THE GEOLOGIC HAZARD MAPS

8.1 HOW TO USE THE DEBRIS FLOW SUSCEPTIBILITY MAP (CGS)

The debris flow susceptibility map delineates areas which may be susceptible to debris flows during future rain events. The debris flow map was created on a large scale and is not meant to replace site specific investigations quantifying the debris flow hazard. Where debris flow susceptible areas are mapped within or near proposed development, structures should either be sited to completely avoid those areas or remediation solutions presented which would adequately control and/or reduce the debris flow hazard. When remediating a debris flow hazard, attention should be given to how the remediation method impacts adjoining properties.

8.2 HOW TO USE THE LANDSLIDE POTENTIAL MAP

The Landslide Potential Map delineates those areas across Boulder County which may be susceptible to slope failure. This map was created for use by the Boulder County Land Use Department and other County entities for informational and planning purposes. This map does not assign a level of risk nor is it meant to replace site specific studies. If a property is located within or adjacent to a landslide potential zone, additional information related to site specific characterization may be required. When remediating a landslide hazard, attention should be given to how the remediation method impacts adjoining properties.

Site specific characterization of landslides typically includes determination of the type of landslide, mapping and characterizing the extent of the landslide (scarp, toe, and lateral extents), subsurface conditions (depth to bedrock, depth to groundwater, depth to failure plane, and engineering properties of subsurface materials), rate of movement, and other causative factors.

8.3 HOW TO USE THE STEEPLY DIPPING, HEAVING BEDROCK MAP

The Steeply Dipping Heaving Bedrock Map delineates those areas in Boulder County which are underlain by bedrock which is both problematic with relation to swelling claystone and is dipping greater than 30 degrees. The purpose of this map is to outline those areas of Boulder County where these two criteria are met.

It is up to the results of the site specific study to show whether or not there is enough natural, low swell potential overburden soil overlying the bedrock to buffer the hazard. If there is not a sufficient amount of existing overburden between the proposed foundation level of the structure and the bedrock surface, over-excavation and replacement with fill material or deep foundations and structurally supported floor systems may be required to reduce the hazard to an acceptable level. A geotechnical study should be performed for the proposed development.

8.4 HOW TO USE THE SWELLING SOILS AND BEDROCK MAP (HART, 1974)

The Swelling Soils and Bedrock Map by Hart (1974) has been converted into a GIS spatial database (Plate 3). This map covers the area east of the Front Range and categorizes soils and bedrock by swell potential, ranking those materials from low to very high. This map should be used for informational purposes and to help determine if a geotechnical study should be performed for the proposed development. In areas with moderate to high swell potential soils and/or bedrock, particular foundation recommendations or ground improvement such as over-excavation may be necessary.

8.5 HOW TO USE THE PUBLISHED UNDERMINED AREA MAPS

There are multiple published maps of undermined areas associated with the Boulder-Weld coal field located in the southeast area of Boulder County. These published maps should be used as an informational tool to guide the decision for site specific studies. For development within or near areas identified to be undermined, a site specific subsidence investigation should be completed. The Geology Element of the BCCP recommends that long range land use planning in subsidence risk areas be non-structural in nature (e.g., agriculture, wildlife habitats, open space, open storage areas, parking lots, mineral extraction, or certain parts of outdoor recreational facilities). The

Division of Reclamation, Mining, and Safety and the CGS should both be used as ongoing resources for mine-related hazards and information.

8.6 HOW TO USE THE GEOLOGY MAPS

The geology maps that were georeferenced for this study (1:100,000 scale), as well as those 1:24,000 scale maps available for download through the USGS website (already georeferenced), can be used to determine the geology of the site under consideration. In addition to showing bedrock and surficial soil information, these maps also contain information such as topography, geologic structure (faults, folds, foliations, shear zones, etc.), groundwater seeps, oil, gas, and water well locations, and mine workings.

9. GEOLOGICAL AND GEOTECHNICAL LAND USE GUIDELINES

The Geology Element of the BCCP includes a table outlining geotechnical land use guidelines to accompany the Geologic Hazard and Constraint Map. This table lists land use guidelines and recommended reports for each symbol included on the map. Table 2 is a modification of this table, tailored to work with the geologic map package elements compiled and created for this study. Table 2 represents Cesare's recommendations for land use guidelines and consultant reports as related to previously published geologic hazard information, maps created for this study, and those maps and hazard zone delineations concurrently being completed.

TABLE 2. Recommended Geological and Geotechnical Land Use Guidelines

Geologic Hazard or Constraint	Land Use Guidelines	Recommended Study				
		Geotechnical	Geologic Hazard	Subsidence	Flooding	Fluvial Hazard
Landslide	Developable subject to results of recommended site specific study. Development should be guided away from those areas with landslide potential. The impact of landslides on foundations, slope stability, grading plans, retaining walls, and septic drain fields should be carefully studied.	X	X			
Debris Flow	Developable subject to results of recommended site specific study. Development should be guided away from areas with debris flow susceptibility. Where avoidance is not possible, remediation options must be presented which adequately manage and reduce the hazard and which do not adversely impact or increase the hazard on neighboring properties.	X	X			
Rockfall	Developable subject to results of recommended site specific study. Development should be guided away from those areas with rockfall hazard. In the cases where the proposed development cannot avoid the hazard, rockfall mitigation options must be presented which will adequately reduce the hazard and which do not adversely impact or increase the rockfall hazard on neighboring properties.	X	X			
Expansive Soil and Bedrock	Developable subject to results of recommended site specific study. Design of foundations must be appropriate to address the swell potential of subsurface materials.	X				
Steeply Dipping Heaving Bedrock	Developable subject to results of recommended site specific study. It must be shown that steeply dipping heaving bedrock hazard does not exist at the site, or if it does exist, present remediation methodology.	X	X			
Undermined Area	Areas identified to be undermined by abandoned coal mines should be considered for non-structural land use, unless it can be shown that the subsidence hazard does not exist for the proposed development. In the event a proposed structure is sited within or near an undermined area, site should be considered developable subject to the results of the site specific subsidence study.	X	X	X		
Flood	Developable subject to results of recommended site specific study and the rules and regulations of governing entities pertaining to flood zones.	X			X	
Fluvial Hazard	Developable subject to results of recommended site specific study. [Guideline to be determined by others after mapping of fluvial hazard zones is complete.]	X				X

10. RECOMMENDED GUIDELINES FOR GEOLOGIC HAZARD REPORTS

There are resources available which outline and describe guidelines for geotechnical and geologic hazard reports. Colorado Geological Survey Special Publication 12 (Shelton and Prouty, 1979) is one such resource (refer to pages 61-67 of that report). Refer to Appendix G for a fact sheet prepared by the CGS which summarizes engineering geology report guidelines. In addition, Jefferson County has detailed criteria for geotechnical and geologic hazard reports, outlined in Land Development Regulation Section 25, also included in Appendix G. Providing report standards helps support the goal of ensuring proposed development is focused in areas that are free of geologic hazards or adverse ground conditions or that appropriate remediation is implemented to reduce the hazard to an acceptable level.

A geotechnical report must be signed by a qualified professional engineer, registered in the state of Colorado and qualified in the field of geotechnical engineering. A geologic hazard report must be signed by a qualified professional geologist as defined in C.R.S. 34-1- 201(3).

On a basic level, a geologic hazard report includes:

- Project description
- Scope of the project
- Site location description
  - Topography
  - Physiography
  - Regional and site specific geologic setting
    - Surficial deposits
    - Bedrock lithology
    - Bedrock structure
    - Geomorphology
    - Seismicity
    - Groundwater
    - Surface water
  - Geologic hazards
- Investigations
  - Subsurface investigation
  - Geologic mapping
  - Geologic hazard mapping
  - Geophysical investigation
  - Field testing
  - Laboratory testing
- Analysis
  - Describe methodologies and results of analyses performed (e.g., slope stability, rockfall, and subsidence).
- Conclusions and recommendations
  - Address whether the proposed development is feasible with the geologic conditions and geologic hazards identified.
  - Discuss critical development aspects as they relate to geology and geologic hazards at the site and provide recommendations for each.
  - Discuss potential mitigation options, providing construction and maintenance plans.
  - Provide recommendations for additional studies or mitigation needs.

Geologic hazard reports also typically include the following supporting figures and tables:

- Site location map.
- Map depicting location of borings, exploratory pits, trenches, or other excavations.
- Logs of borings, exploratory pits, or trenches.
- Geology map.
- Map(s) depicting nature and extent of geologic hazards.

- Cross sections.
- Figures to illustrate results of geophysical investigation, if performed.
- Any other appropriate illustrations or photographs.
- Tables summarizing results of the laboratory testing and analyses.

11. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations have been brought together from research, data compilation and analysis, and from multiple conversations with Boulder County personnel conducted for this study. Recent natural disasters such as wildfires and the extreme rain event of September 2013 resulted in an increased awareness of the importance of geological and geotechnical characterization on countywide and site specific scales. Wildfires have denuded slopes in areas of Boulder County, making them more susceptible to debris flows during even normal, small scale precipitation events in the few years following the fire. Severe channel migration during the September 2013 flood has resulted in a change in condition and location of major creeks.

One outcome of the initial research and outreach phase of this study was recognizing the need to characterize in more detail the landslide potential and steeply dipping heaving bedrock hazard across Boulder County. Prioritization was set on determining the landslide potential on a countywide scale, starting a landslide inventory, and delineating the steeply dipping heaving bedrock hazard. Refer to Plate 9 for a compilation of available and newly developed geologic hazard data for Boulder County.

A landslide inventory database was created for Boulder County using published and newly mapped landslide deposits (Plate 6). Also included in this inventory are landslide events compiled by the USGS after the September 2013 rain event and rockfall and landslides recorded by CDOT along transportation corridors. Plate 7 shows the Landslide Potential Map for Boulder County with defined slope units ranked by level of landslide susceptibility, ranging from very low to very high. Table 3 summarizes the percentages of each rating for the four Boulder County subprovince divisions. The Foothills Subprovince displays the highest level of landslide susceptibility, ranking mostly in the moderate to high susceptibility levels. The Piedmont Subprovince ranks mostly in the low to moderate susceptibility range. A majority of the Montane and Alpine/Subalpine Subprovince areas rank within the low to high susceptibility categories.

TABLE 3. Landslide Susceptibility Ratings

Geologic Subprovince	Landslide Susceptibility Rating				
	Very Low	*Low*	*Moderate*	*High*	*Very High*
Piedmont	*0.2%*	*37.6%*	*55.6%*	*6.4%*	*0.2%*
Foothills	*0.0%*	*5.3%*	*48.5%*	*43.9%*	*2.2%*
Montane	*0.7%*	*28.1%*	*51.0%*	*19.8%*	*0.4%*
Alpine/Subalpine	*0.6%*	*23.9%*	*51.2%*	*22.3%*	*1.9%*

The steeply dipping heaving bedrock zone is largely associated with the Foothills Subprovince and the steeply tilted sedimentary units along the Front Range. In the south part of Boulder County this zone connects with the area delineated for Jefferson County and continues northward along the Front Range, becoming a relatively thin band west and north of Boulder. The hazard zone is not present in the area west of Table Mountain. In the northern part of Boulder County, the zone is irregular in shape due to the variability of the bedrock structure and orientation in the area of Hygiene and Lyons. This steeply dipping heaving bedrock map approximates those areas susceptible to this particular hazard, delineating a zone not previously characterized. Delineating this zone will help direct planners and property owners toward the appropriate site specific study to determine subsurface conditions for site development and foundation recommendations.

Recommendations and future considerations include:

1. Cesare recommends using the components of the geologic hazard map package to assist in short and long range planning decisions and prioritizations. We encourage the consideration of the geologic and geotechnical aspects of each site location during planning and development review stages. These maps are intended to be used for informational and planning purposes, and are not intended to be used for site specific characterization. The intent is for these maps to be used together as a package to determine the appropriate course of action for development review or for other land use and planning decisions. We recommend urging development away from geologic hazard areas or requiring provision of remediation options in circumstances where avoidance is not possible.
2. Cesare recommends the use of third party review of submitted geotechnical or geologic hazard reports, when necessary. This will help ensure the geotechnical and geologic hazard issues are being properly addressed, and appropriate remediation options presented, where appropriate. The CGS commonly serves as a third party reviewer for local governments across Colorado.
3. Cesare recommends regularly updating geologic hazard data and maps when new information or data becomes available. The floodplain and fluvial hazard zone maps will need to be added to the geologic hazard map package upon completion of those studies. The rockfall and landslide event data set obtained from CDOT will need to be updated. Keeping up to date on studies performed by the USGS and CGS is highly recommended. A bibliography and list of potential resources is included as Appendices B and C.
4. The tree root strength maps are computed from tree height and tree density. Additional applications for this data include the use of tree height for determination of forest age and the use of tree density for fire hazard and fire behavior modeling.
5. The bibliography and list of resources (Appendices B and C) attached to this report should be considered meaningful reference lists should Boulder County personnel require additional or more detailed information on any topic covered in this report. Should Boulder County or others have questions regarding any aspect of this report, from the geologic history of Boulder County to the details of the methodologies employed for creation of the Landslide Potential Map, the primary contacts listed in the beginning of this report should be utilized.
6. Similar to what CDOT has implemented, we recommend Boulder County begin maintaining an inventory of rockfall, landslide, and debris flow events that impact transportation corridors. This task would require an initial review of historical road maintenance records for extraction of pertinent information related to slope failure

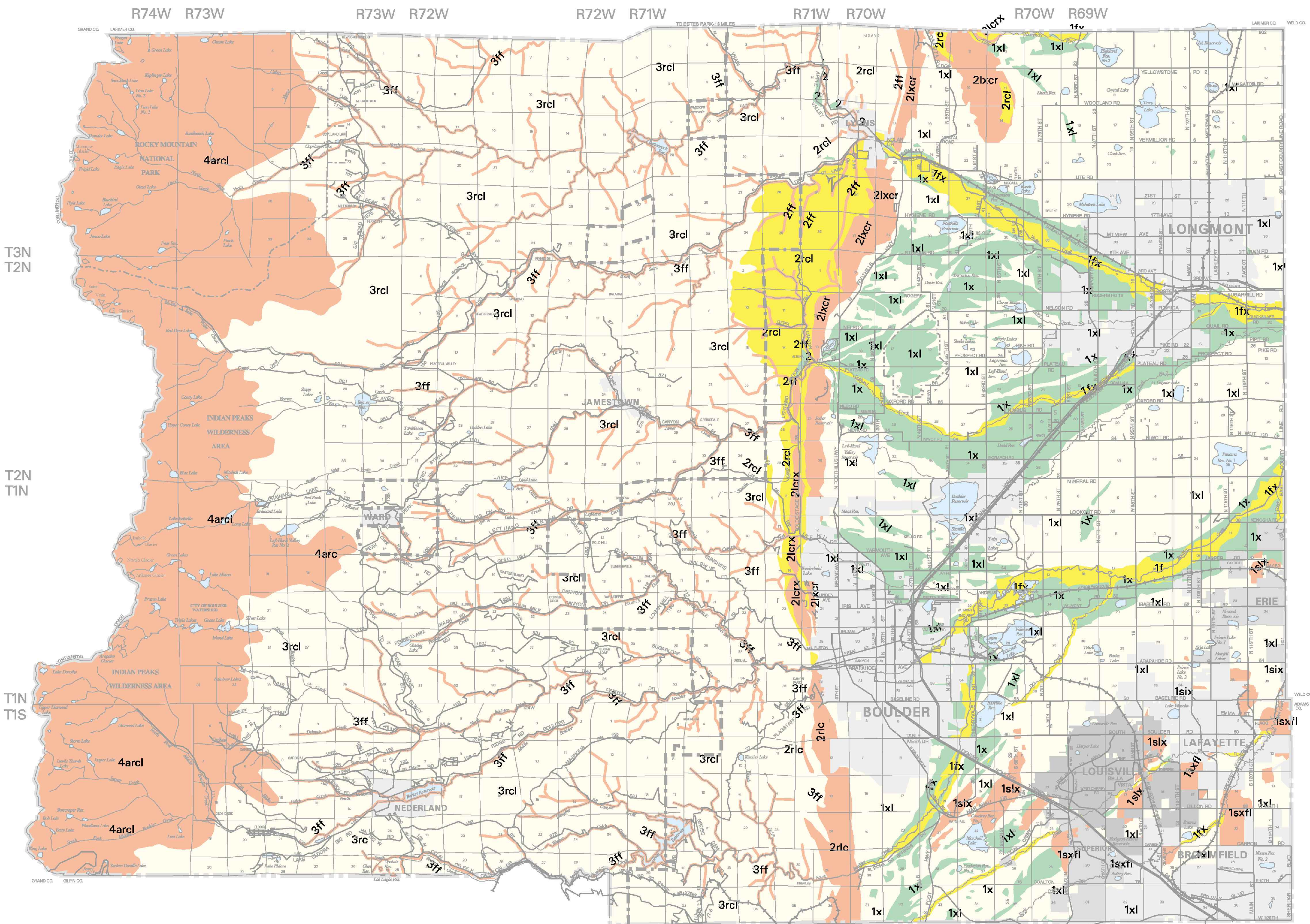
events. Moving forward, Boulder County Transportation Department would need to start recording details of slope failure events during site visits in response to road damage. Integrating police traffic reports is also a component of this inventory. Police reports include details of the level of severity of the accident caused by debris in the road, giving some indication as to the size of rockfall or slope failure.

7. Cesare recommends taking the geo-event inventory one step further and include slope failures outside of transportation corridors (i.e., in residential, commercial, and open space areas). The landslide inventory created for this study does not capture all the landslides in Boulder County. Maintaining a database or record of known slope failure events as that information becomes available would be beneficial to understanding and characterizing the landslide hazard across Boulder County. One option is to make reporting of slope failure events possible for residents to do on the Boulder County website, or by other means.
8. Cesare recommends taking a proactive approach to debris flow monitoring and alarms. We understand that the Boulder Office of Emergency Management (OEM) may be considering some sort of early warning system for some areas of Boulder County. It is strongly encouraged that Boulder County takes an active partnership role with the OEM or other entities that are working toward slope failure early warning systems.
9. With regards to providing applicants with information related to geologic and geotechnical studies, Boulder County may choose to utilize geotechnical consultant company lists provided by the American Council of Engineering Companies (ACEC). http://www.acec.org/
10. A consideration for the future would also include field verification of the landslide inventory and the steeply dipping heaving bedrock maps. Landslides mapped by Cesare and others should be confirmed and the extents modified accordingly based on field observations. Additional landslides should be mapped and added to the inventory. The steeply dipping heaving bedrock map would also benefit from field verification to collect additional bedrock orientations in areas where available data is sparse and in the northern part of Boulder County where the bedrock structure is relatively variable and interrupted by multiple faults and folds.

12. LIMITATIONS

The professional judgments expressed in this report meet the standard of care for our profession. This geologic hazard study is intended to provide a characterization of geologic and geologic hazard conditions with the potential to impact areas within Boulder County, Colorado during extreme rain and flood events. This report does not address all geologic hazards with the potential to impact Boulder County. This report is based on review of available data and information, meetings and correspondence with Boulder County personnel and personnel from other entities and stakeholder groups, and our general understanding and knowledge of the area. Variations in surface and subsurface conditions will occur which are not indicated by available data, literature, or geologic mapping. These variations are sometimes sufficient to necessitate modifications in opinions and recommendations. If unexpected conditions are encountered after issuance of this report, or if additional data is discovered and made available, Cesare should be notified to review our opinions.

W:\2016\Frederick Projects\16.3000\16.3097.G Boulder County Geotechnical-Geohazard Services\ACAD\Final Plates\Boulder County Geologic Hazards Map PLATE 1.dwg 3/31/2017 2:55 PM



Geologic Hazard & Constraint Areas

Geology

Legend

RELATIVE GEOTECHNICAL RATING: GEOLOGIC HAZARD AREAS

Decreasing Geotechnical Problems →

- **Major** Extensive Problems High Risk
- **Moderate** Significant Problems Provisional Risk

GEOLOGIC CONSTRAINT AREAS

- **Moderate** Significant Problems Provisional Risk
- **Minor** Few Problems Nominal Risk
- Incorporated Areas *(As of April 20, 1999)*

MAP SYMBOL DEFINITIONS

First Number Indicates Subprovince

1 Piedmont
2 Foothills
3 Montane
4 Alpine

Subsequent Placed Letters Indicate Geologic Hazard or Constraint in Order of Impact *(See Example Given)*

a Snow Avalanche
c Soil Creep
f Flooding
ff Flash Flooding Corridors and Associated alluvial (Debris) Fans
l Landslides, Mudslides, Mudfalls, Debris Fans
r Rockfalls, Rock Avalanches
s Subsidence (Abandoned Coal Mines)
x Expansive Soil or Claystone

EXAMPLE:

Subprovince — Most Impact → Least Impact

2 l c x r

Notes

Refer to the Colorado Inactive Mine Reclamation Plan completed in February, 1982 by the State of Colorado Department of Natural Resources, Mined Land Reclamation Division, for additional information on sites of environmental hazards resulting from past metal and coal mining activity. (Planning Commission - November 10, 1982, Board of County Commissioners - December 20, 1982).

Map scale and reproduction method limit precision in physical features and boundary locations.
PRINTED - APRIL 22, 1999

Revisions

Adopted - Planning Commission - March 22, 1978

Approved - County Commissioners - April 6, 1978

0 MILES 1 2 3 4 5

Boulder County

COMPREHENSIVE PLAN MAP

North

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Geotechnical Engineers & Construction Materials Consultants

PLATE 1
Boulder County Geologic Hazard and Constraint Area Map

PROJECT NO:	16.3097
PROJECT NAME:	Boulder County Geologic Hazard Study
DRAWN BY:	RAB
CHECKED BY:	JMF
DWG DATE:	03.31.17
REV. DATE:	--

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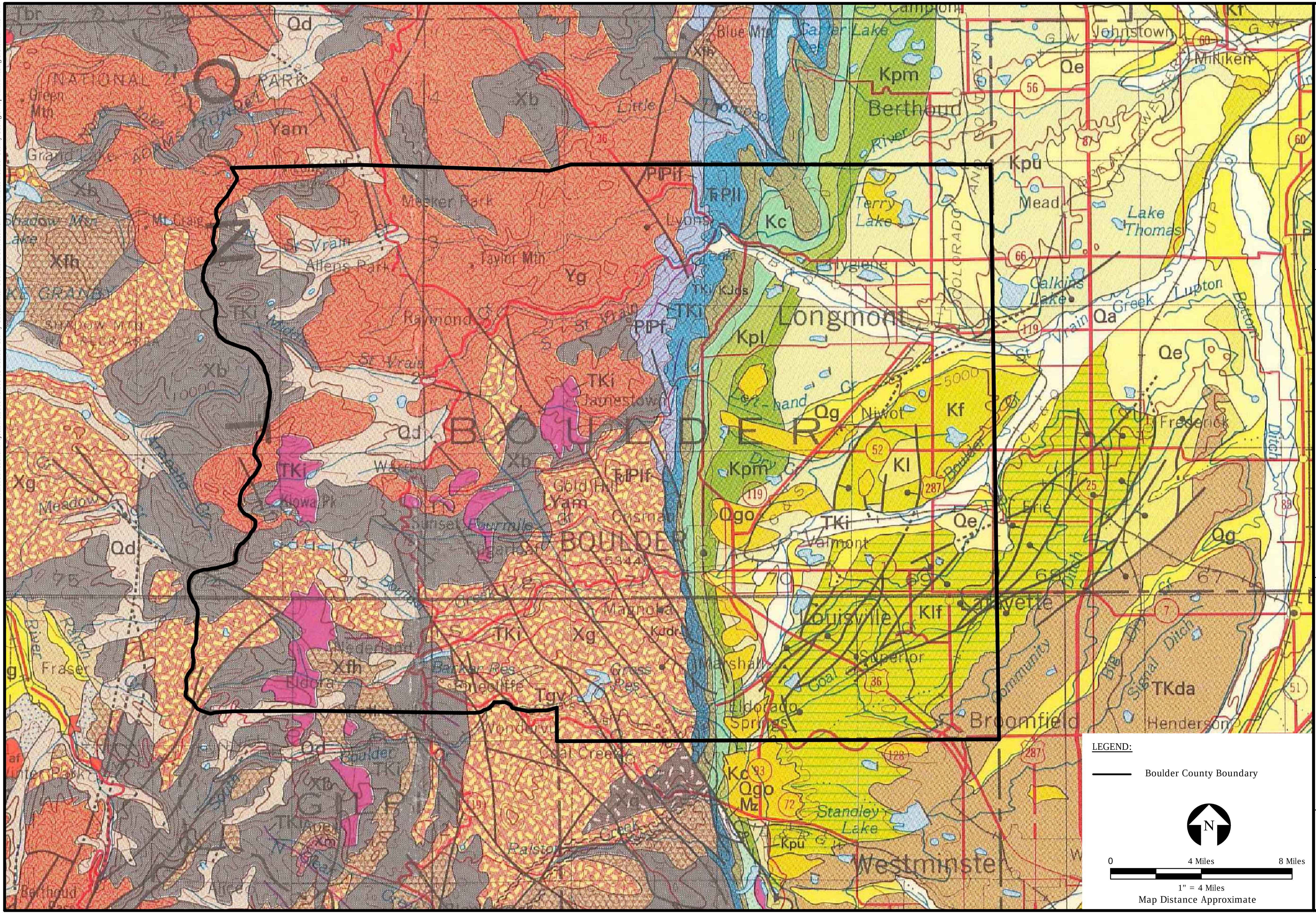

PLATE 2
Boulder County Geology Map
(Tweto, 1979)

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PROJECT NO: 16.3097
PROJECT NAME: Boulder County Geologic Hazard Study
DRAWN BY: RAB
CHECKED BY: JMF
DWG DATE: 03.31.17
REV. DATE: --

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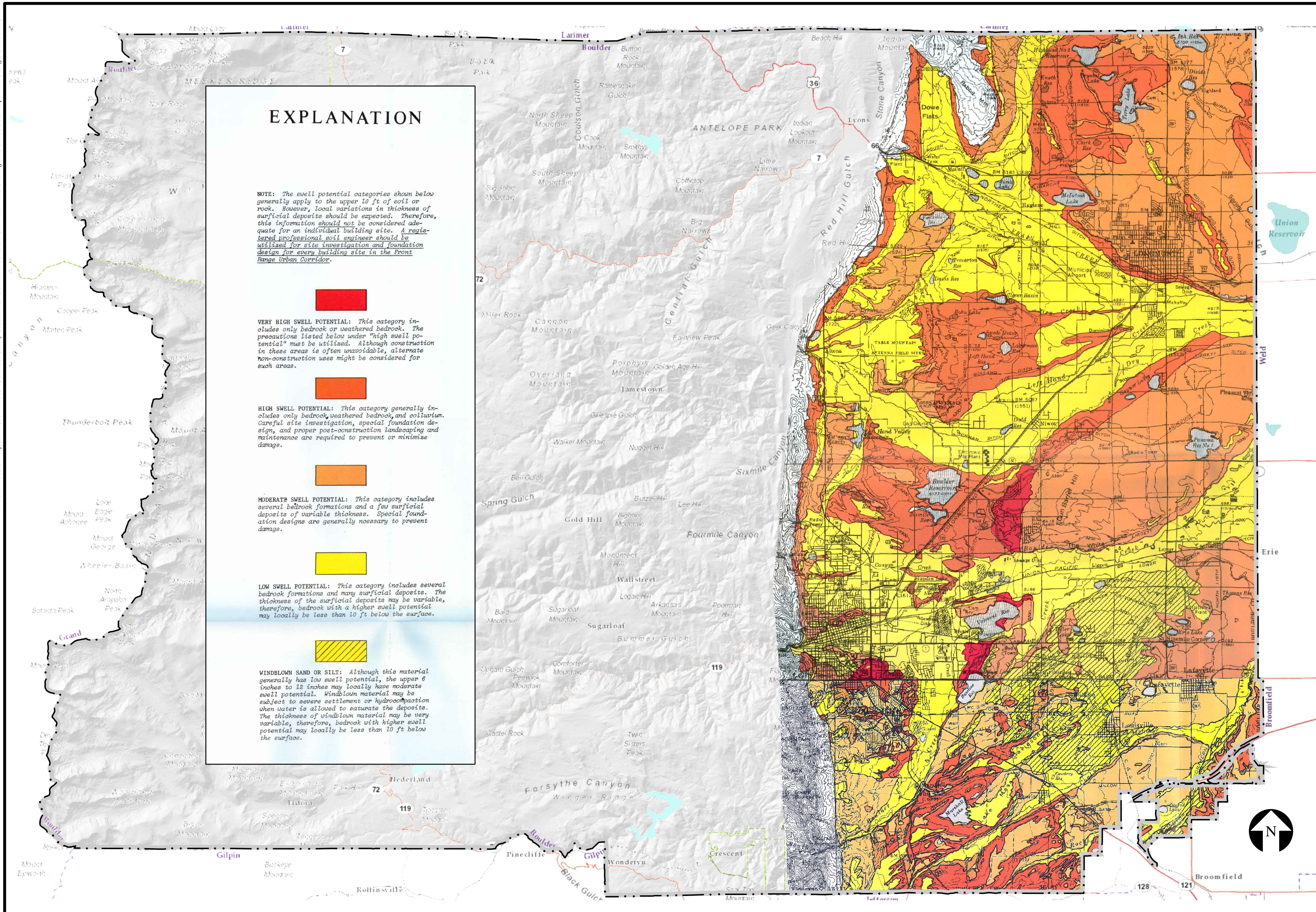

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PLATE 3
Swelling Soils and Bedrock Map
(Hart, 1974)

PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geologic Hazard Study		
DRAWN BY:	RAB	CHECKED BY:	JMF
DWG DATE:	03.31.17	REV. DATE:	--

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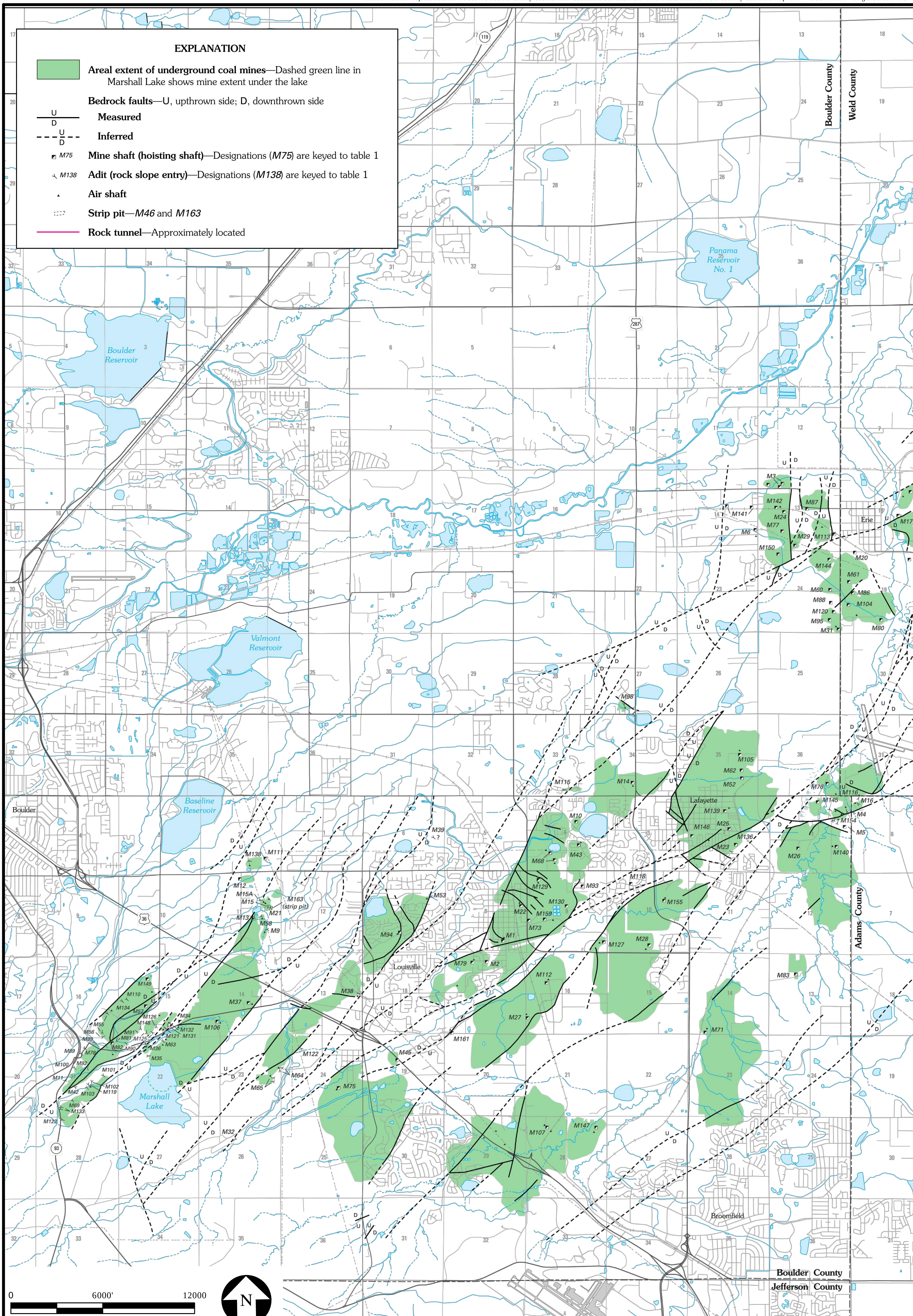

PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geologic Hazard Study		
DRAWN BY:	RAB	CHECKED BY:	JMF
DWG DATE:	03.31.17	REV. DATE:	--

PLATE 4
Boulder-Weld Coal Field - Extents of Abandoned Coal Mines
(Roberts and others, 2001)

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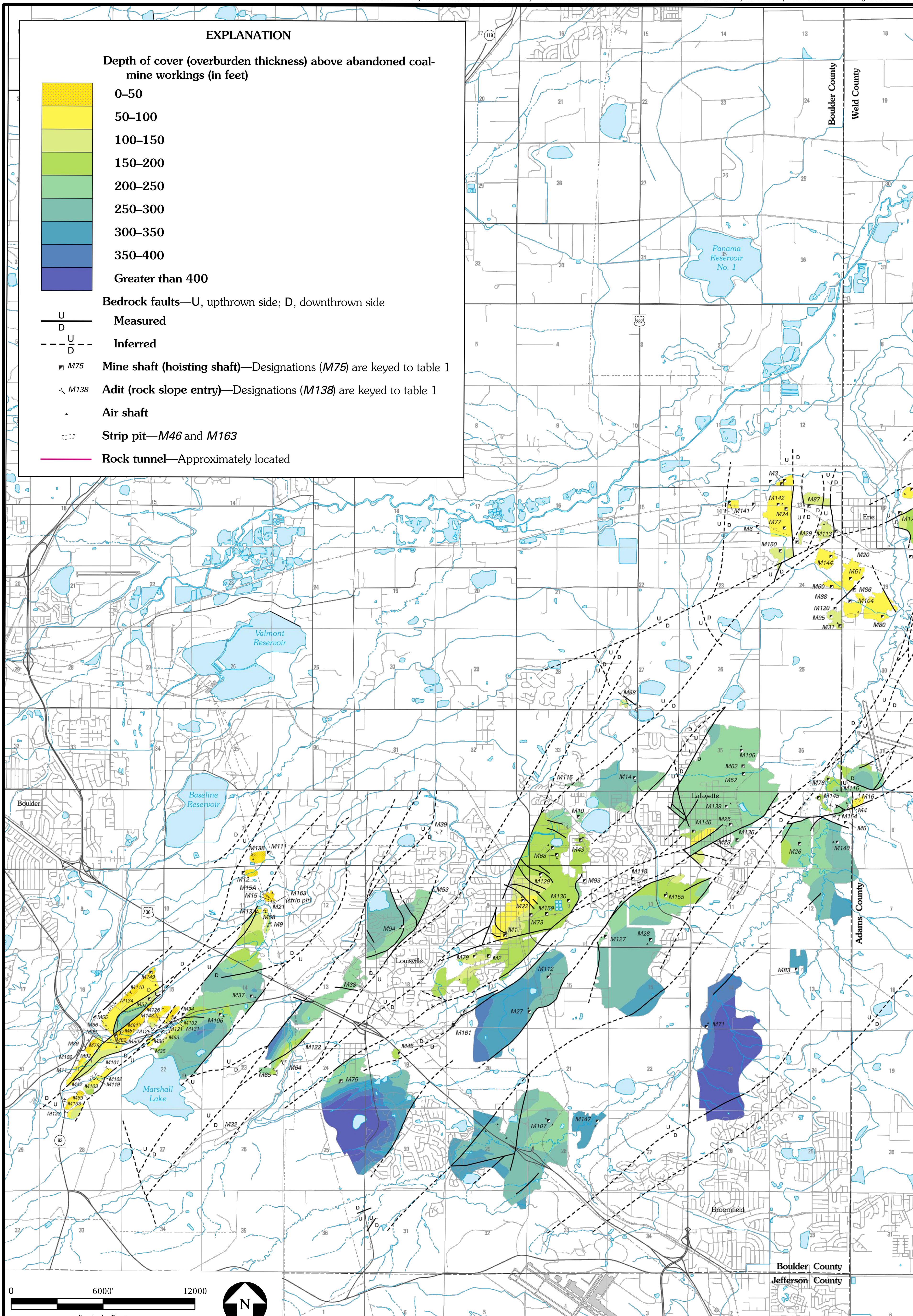
W:\2016\Frederick Projects\16.3000\16.3097.G Boulder County Geotechnical-Geohazard Services\ACAD\Final Plates\Boulder Weld Counnty Coal Field Map B PDF version PLATE 5.dwg 3/31/2017 2:58 PM



PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geologic Hazard Study		
DRAWN BY:	RAB	CHECKED BY:	JMF
DWG DATE:	03.31.17	REV. DATE:	--

PLATE 5
Boulder-Weld Coal Field -Depth Of Overburden
Roberts and others, 2001

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

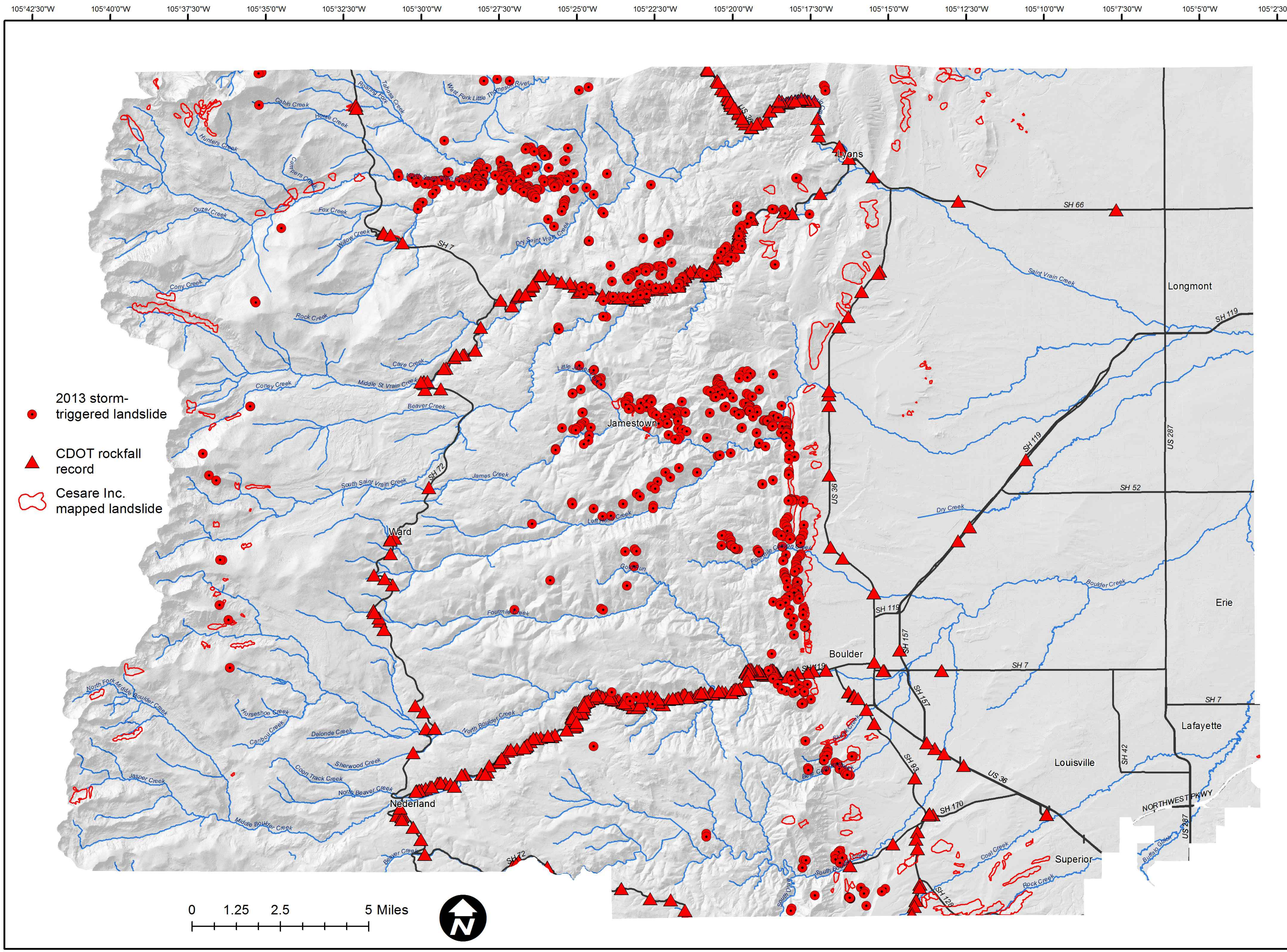


PLATE 6
Landslide Inventory Map

TerraCognitoGIS
Spatial Analysis | 3D Visualization | Decision Support

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

PROJECT NO:	16.3097
PROJECT NAME:	Boulder County Geologic Hazard Study
DRAWN BY:	RAB
CHECKED BY:	JMF
DWG DATE:	03.31.17
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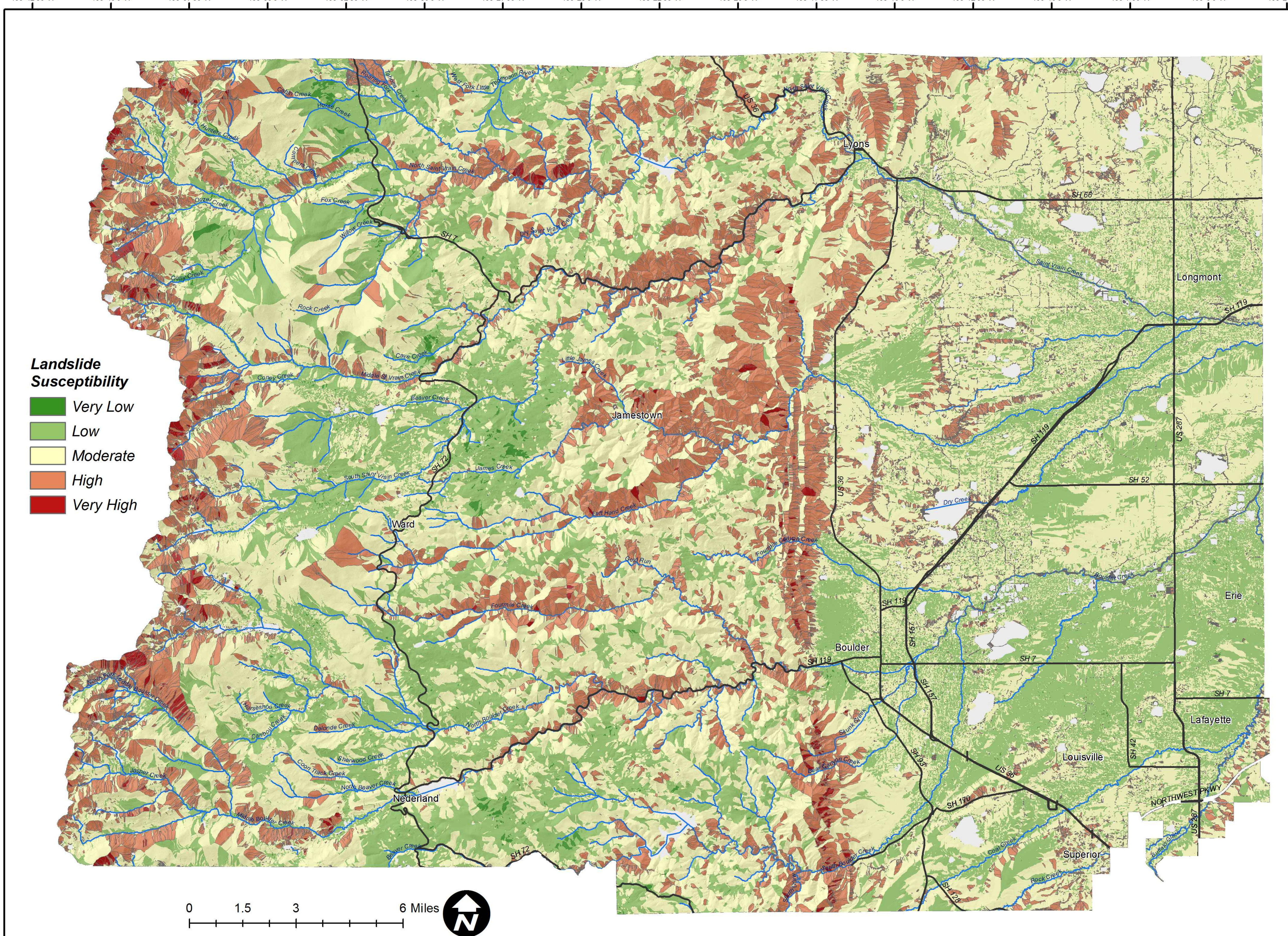

TerraCognitoGIS
Spatial Analysis | 3D Visualization | Decision Support

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

PLATE 7
Landslide Potential Map with Slope Units

PROJECT NO:	16.3097
PROJECT NAME:	Boulder County Geologic Hazard Study
DRAWN BY:	RAB
CHECKED BY:	JMF
DWG DATE:	03.31.17
REV. DATE:	--

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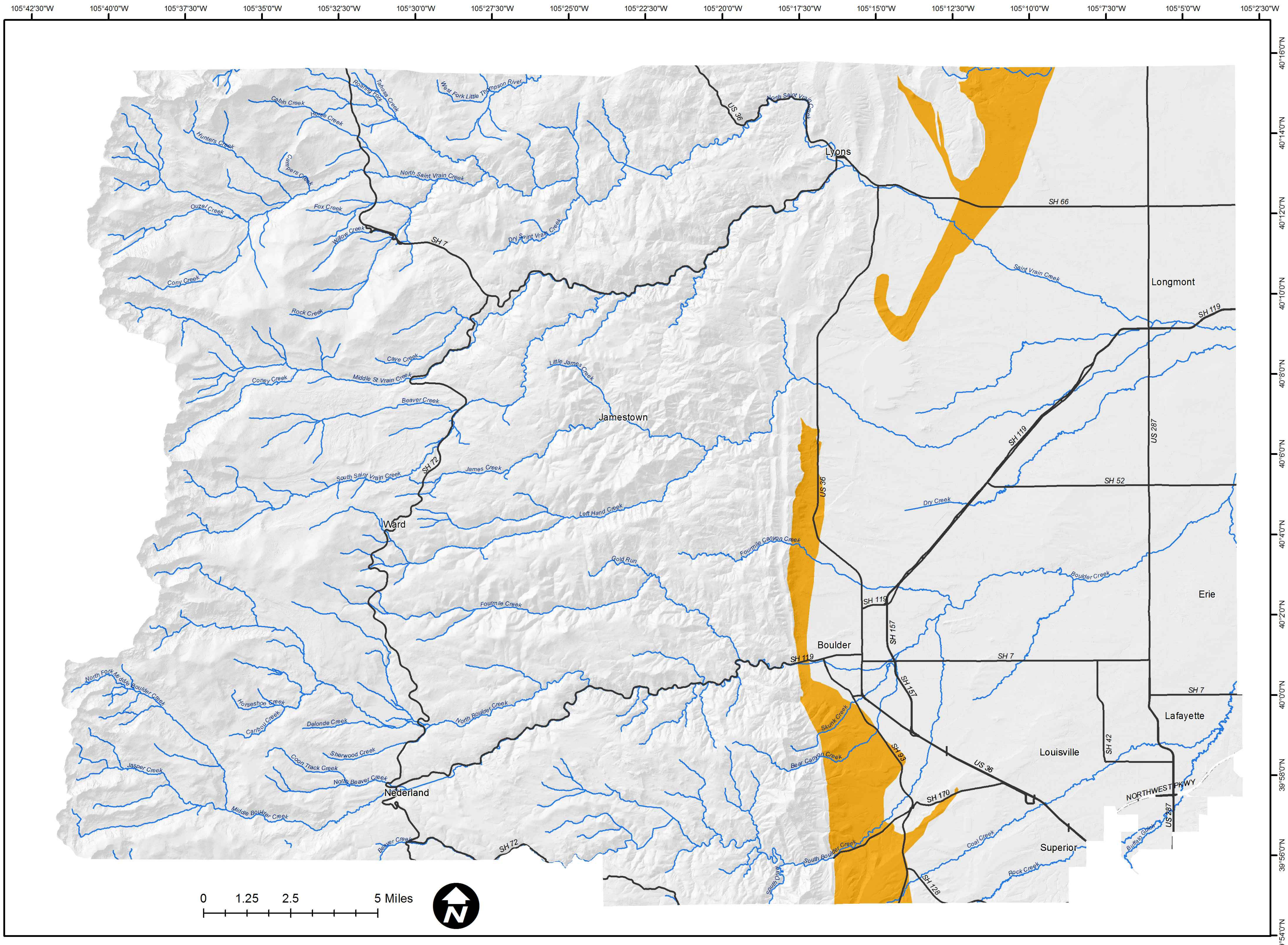
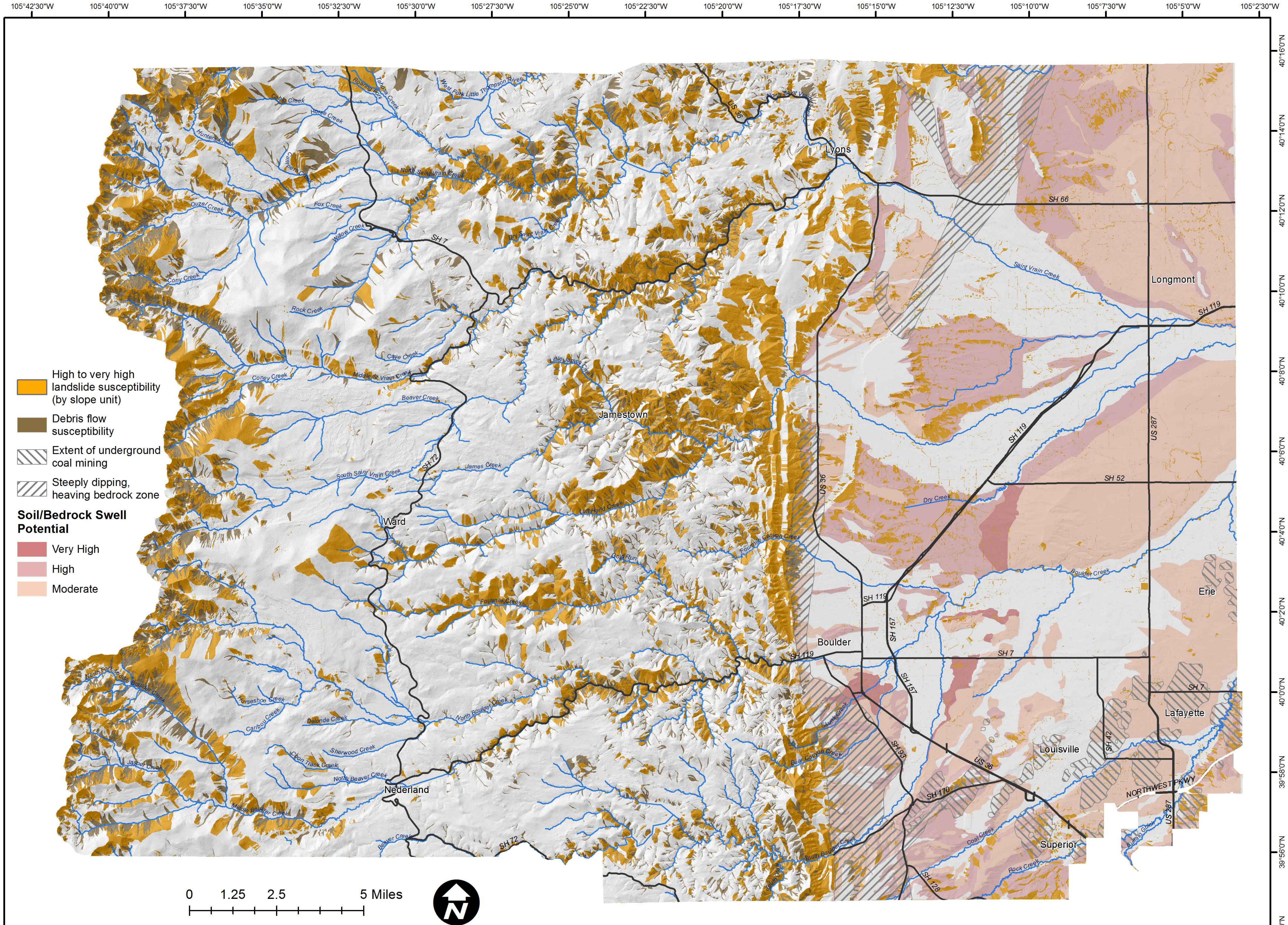


TerraCognitoGIS
Spatial Analysis | 3D Visualization | Decision Support

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

PLATE 8
Steeply Dipping Heaving Bedrock Map

PROJECT NO:	16.3097
PROJECT NAME:	Boulder County Geologic Hazard Study
DRAWN BY:	RAB
CHECKED BY:	JMF
DWG DATE:	03.30.17
REV. DATE:	--



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TerraCognitoGIS
Spatial Analysis | 3D Visualization | Decision Support

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

PLATE 9
Boulder County Geologic Hazards Map

PROJECT NO:	16.3097
PROJECT NAME:	Boulder County Geologic Hazard Study
DRAWN BY:	RAB
CHECKED BY:	JMF
DWG DATE:	03.31.17
REV. DATE:	--

APPENDIX A

List of Outreach Contacts

CESARE, INC.

Table A-1. Outreach and Contact List

Boulder County Geologic Hazard Study

Project Number 16.3097

Boulder County

Group	Contact	Contact Info		Notes
Planning	Nicole Wobus, Long Range Policy and Planning Manager	office 720) 564-2298 cell 303) 995-7318	nwobus@bouldercounty.org	ongoing interaction throughout
	Denise Grimm, Senior Planner	office 720)564-2611	dgrimm@bouldercounty.org	mtgs and correspondence
	Dale Case, Chief Planner			correspondence
Development Review Team (DRT) / Case Studies	Michelle McNamara - primary contact for DRT		mmcnamara@bouldercounty.org	ongoing interaction throughout
	Summer Frederick	720) 564-2603	sfrederick@bouldercounty.org	ongoing interaction throughout
	Matt Thompson		mthompson@bouldercounty.org	correspondence
	Lindsay Schumacher		lschumacher@bouldercounty.org	ongoing interaction throughout
	Christian Martin		cmartin@bouldercounty.org	correspondence
	Rob Haigh	720) 564-2636	rhaigh@bouldercounty.org	correspondence
				correspondence with others
Wildfire Mitigation	Kyle McCatty, Wildfire Mitigation Specialist	720) 564-2625	kmccatty@bouldercounty.org	kyle introduced us to Rob Addington
GIS Team	David Haines		dhaines@bouldercounty.org	mtg 11.29.16; ongoing correspondence throughout
	Molly Molter, primary GIS contact		mmolter@bouldercounty.org	ongoing interaction throughout
Floodplain (Transportation Depart)	Varda Blum	720)564-2659	vblum@bouldercounty.org	mtg 11/29/16; mtg 2/2/17
Watershed/Creek Restoration	Julie McKay, Boulder County Transportation Planning Manager	720) 564-2662	jmckay@bouldercounty.org	email and phone correspondence: phone convo 12/21/16
Transportation Engineering and Planning	Brian Graham, Flood Recovery Coordinator	303) 441-3900	bgraham@bouldercounty.org	email correspondence 12/28/16
	Dave Watson, Transporation GIS	303) 441-3850	dwatson@bouldercounty.org	
Road Maintenance BoCo	Ted Plank	303) 441-3962	tplank@bouldercounty.org	Email and phone correspondence; phone convo 1/13/17; mtg 1/26/17
Parks and Open Space	Janis Whisman, Real Estate Division Manager	303) 678-6200	jwhisman@bouldercounty.org	Email correspondence in Nov 2016
	Doug Laiho			
Parks and Open Space GIS	Kristi VanDenBosch, GIS Supervisor	303) 678-3108	kvandenbosch@bouldercounty.org	Molly in contact with Kristi re: GIS data
	Meredith Dutlinger	303) 678-6356		

Municipalities

Boulder	Chris Meschuck, Sr. Planner	O: 303) 441-4293 C: 303) 386-5143	meschuck@bouldercolorado.gov	sent email on 12/22/16
Jamestown	Millissa Berry, Planner	(303) 449-1806	millissa.berry@jamestownco.org	in-person meeting 12/1/2016; large HIRA study completed 12/2015
Nederland	Chris Pelletier, Public Works Manager	303-570-6039	chrisp@nederlandco.org	No geo-hazard studies recently, indentified ongoing hazards as flooding, fires, and mine spills
Ward				contacts not easily available, not a good source of additional information
Lyons	Matt Manley, Planner	303) 823-6622 ext. 49	mmanley@townoflyons.com	HIRA for Town of Lyons planned to be complete by April 2017.
Niwot				contacts not easily available
Longmont	Monica Bortolini, Public Works Dept	303-651-8411	monica.bortolini@longmontcolorado.gov	no additional information relative to what BoCo already has
Lafayette	Paul Rayl	303-665-5588 (ex 1269)	paulr@cityoflafayette.com	no additional information relative to what BoCo already has
Louisville	Kristin Dean, Principal Planner		kdean@louisvilleco.gov	no additional information relative to what BoCo already has
	Cameron Fowlkes, Public Works		cameronf@louisvilleco.gov	
	Ember Brignull, Open Space		emberb@louisvilleco.gov	
Broomfield	John Hilgers, Planning Director	303) 438-6284	jhilgers@broomfield.org	
Superior	Steven Williams, Associate Planner		stevenw@superiorcolorado.gov	no additional information relative to what BoCo already has
Erie	Planners: Deborah Bachelder	303) 926-2775	dbachelder@erieco.gov	
	Todd Bjerkaas	303)926-2773	tbjerkaas@erieco.gov	
	Hannah Hippely	303)926-2774	hhippely@erieco.gov	

Other Groups

Urban Drainage and Flood Control (UDFC)				website has GIS data, interactive map
Colorado Water Conservation Board (CWCB)	Stephanie DiBetitto	office: 303) 866-3441 ext 3221 cell: 303) 656-0136	stephanie.debettito@state.co.us	involved in Pilot Studies related to channel migration and erosion, beginning in early 2017
	Kevin Houck, Watershed and Flood Protection Section Chief	303) 866-3441 ext. 3219		will also have details on erosion zone mapping status
Colorado Emergency Watershed Protection Program (EWP)				
Boulder County Housing Authority	Ian Swallow	303) 413-7030	iswallow@bouldercounty.org	
Nature Conservancy	Rob Addington	970) 449-2049	raddington@tnc.org	wildfire hazard
Colorado Geological Survey	Karen Berry, State Geologist	303-384-2640	kaberry@mines.edu	email and phone correspondence; mtg on 12/7/16; phone convo on 1/10/17
	Scot Fitzgerald, Hazards Analyst	303-384-2644	ffitzger@mines.edu	
	Jill Carlson, Land Use Review	303-384-2643	jcarlson@mines.edu	phone convo on 1/6/17
	Kevin McCoy, Land Use Review	303-384-2632	kmccoy@mines.edu	
	Dave Noe, CGS retired			Phone convo on 1/9/17
US Geological Survey	Jonathan Godt, Landslide Hazards Program	303) 273-8626	jgodt@usgs.gov	correspondence, shared scarp location data and landslide mapping protocol publication
Division of Mining, Reclamation and Safety (DRMS)	Jeff Graeves or Erica Crosby	303) 866-3567 ext 8122 (Jeff) ext 8115 (Erica)		email correspondence in Dec 2016; phone convo
Colorado School of Mines	Paul Santi	303) 273-3108	psanti@mines.edu	personal communication
Office of Emergency Management (OEM)	Mike Chard	303) 441-3390	mchard@bouldercounty.org	email and phone correspondence
Colorado Department of Transportation	Ty Ortiz		ty.ortiz@state.co.us	email and phone correspondence; phone convo on 1/6/17
	Dave Thomas		david.thomas@state.co.us	included in phone call on 1/6/17
	Nicole Oester		nicole.oester@state.co.us	included in phone call on 1/6/17

Watershed Coalitions

Fourmile Creek (includes Fourmile Creek, Gold Run and others)	Maya MacHamer, Fourmile Watershed Coalition Coordinator	cell: 303) 817-2261 office: 303) 449-3333	fourmilewatershed@gmail.com	correspondence; phone convo on 1/24/17;
	Lauren Duncan, with Trout Unlimited, Abandoned Mine Restoration Project Manager	720-276-3889	lduncan@tu.org	email correspondence, phone convo on 2/6/17;
	Jason Willis, with Trout Unlimited		jwillis@tu.org	email correspondence, phone convo on 2/6/17;
Wagonwheel Gap Road Reconstruction	Andrew Barth, communications; Mohammed Said, project engineer	303) 441-1032		A larger project in which Fourmile Canyon Creek Restoration is a part of.
Fourmile Canyon Creek	Boulder County, Community Development Block Grant - Disaster Relief (CDBG-DR) through the Colorado Watershed Resilience Planning Grant Program, EWP			
Upper Fourmile Creek	no watershed coalition			
Lower Fourmile Creek	no watershed coalition			
Boulder Creek	Urban Drainage and Flood Control District and Boulder County			
Coal Creek (lower) and Rock Creek	David Delagarza, P.E., CFM	(303) 757-3655	david.delagarza@respec.com	
Coal Creek (upper) - CCCWP	Cindy Pieropan	303-875-0629	cpincolo@gmail.com	Website: http://www.cccwp.org/watershed/
St. Vrain Creek - St. Vrain Creek Coalition (SVCC)	Cecily Mui	303-774-4514	cmui.svcc@gmail.com	phone convo on 1/9/17
	Erica, assistant watershed coalition coordinator, manages website	303)774-4513		
Lefthand Creek - Lefthand Watershed Oversight Group (LWOG)	Jessica J. Olson	303-530-4200	lefthandwatershed@gmail.com	www.lwog.org
Little Thompson River - Little Thompson Watershed Restoration Coalition (LTWRC)	Erin Cooper	970-821-5604	erin@ltwrc.org	www.ltwrc.org
South Boulder Creek	Urban Drainage and Flood Control District and the City of Boulder			
James Creek	no watershed coalition			

APPENDIX B

Bibliography

Reports and Publications Reviewed
Published Maps

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APPENDIX C

Additional Resources

Hazard Mitigation Plans
Guideline Documents and Resources
Additional Data and Information

RESOURCES

1. HAZARD MITIGATION PLANS

Flood Hazard Mitigation Plan for Colorado, November 2013, prepared for Colorado Water Conservation Board.

Hazard Mitigation Plan, Boulder County, effective dates 2014-2019.

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- https://bouldercolorado.gov/public-works/multi-hazard-mitigation-plan

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2. GUIDELINE DOCUMENTS AND RESOURCES

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House Bill 1574 (1973)-6 : definition of a "professional geologist."

3. ADDITIONAL DATA AND INFORMATION

3.1 COLORADO DEPARTMENT OF TRANSPORTATION (CDOT)

1. Geo-Event tracking along transportation corridors - a GIS database of slope movement events, acquired by request. Contact: Ty Ortiz

3.2 COLORADO DIVISION OF RECLAMATION, MINING, AND SAFETY (DRMS)

1. Map showing mine locations, interactive map and gis data: http://mining.state.co.us/Reports/Pages/GISData.aspx

3.3 COLORADO GEOLOGICAL SURVEY (CGS)

1. Undermined Areas, GIS map viewer and pdf maps: http://coloradogeologicalsurvey.org/geologic-hazards/subsidence-mine/maps/
2. Debris Flows, Preliminary Survey after September 2013 Flood, GIS data: http://www.arcgis.com/home/item.html?id=39e6c721635f40c8add90112c9d1a646
3. Debris Flows countywide, Susceptible Areas, GIS data: http://www.arcgis.com/home/item.html?id=e93ab396314d4bd3966e87ea62bd799f
4. Debris Flows, Ingram Gulch and Gold Run Areas, Report and GIS data.
5. File titled "Boulder Final Debris Flows", dated November 20, 2013, GIS data: http://www.arcgis.com/home/item.html?id=7cf67064ad72447490eaf38c23fffb64
6. McCoy, K., March 9, 2016, County-Scale Debris-/Mud-Flow Susceptibility Mapping, PowerPoint presentation.

3.4 COLORADO WATER CONSERVATION BOARD

1. Mapping and analysis of channel migration zones, or fluvial hazard zones, for major waterways throughout Colorado, planned for 2017-2018.

3.5 COLORADO HAZARD MAPPING PROGRAM (CHAMP)

1. Website is an interactive portal which posts maps, announcements, and documents related to debris flow maps and ongoing floodplain and fluvial hazard mapping.

3.6 LIDAR DATA (OTHER THAN BOULDER COUNTY)

1. Boulder Creek Critical Zone Laboratory, DEM for Boulder Creek area (2010), available at: http://criticalzone.org/boulder/data/dataset/2915/
2. ColoradoView
3. City of Boulder
   - Classified LiDAR point cloud covering 133 square miles including the City of Boulder and surrounding open space. High resolution data with a point density of 16-24 points per meter squared, vertical accuracy of .34 ft, and a horizontal accuracy of .6 ft. Available at: https://bouldercolorado.gov/open-data?p=2
4. Open Topography website, DEM for Boulder Creek area (2010), available at: http://opentopo.sdsc.edu/datasets?loc=Colorado

3.7 OFFICE OF EMERGENCY MANAGEMENT (OEM)

1. Hazard Mitigation Plan, referenced in Bibliography, Appendix A.
2. Landslide Early Warning System - planning and discussion stages. Contact: Mike Chard.

3.8 UNITED STATES GEOLOGICAL SURVEY (USGS)

1. USGS Landslide Hazards Group: https://landslides.usgs.gov
2. Landslide Susceptibility, Conterminous United States, available at: https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=b3fa4e3c494040b491485dbb7d038c8a
3. Radbruch-Hall, D.H., Colton, R.B., Davies, W.E., Lucchitta, I., Skipp, B.A., and Varnes, D.J., 1978, Landslide Overview Map of the Conterminous United States: United States Geological Survey, Professional Paper 1183, Plate 1. Digital compilation including GIS data available at: http://landslides.usgs.gov/hazards/nationalmap/
4. Stoeser, D.B, Green, G.N., Morath, L.C., Heran, W.D., Wilson, A.B., Moore, D.W., and Van Gosen, B.S., 2005, Preliminary Integrated Geologic Map Databases for the United States Central States: Montana, Wyoming, Colorado, New Mexico, Kansas, Oklahoma, Texas, Missouri, Arkansas, and Louisiana - The State of Colorado: United States Geological Survey Open-File Report 2005-1351.
5. GIS data (including statewide geology, faults, and dikes based on Tweto (1979), scale 1:500,000) available at: https://pubs.usgs.gov/of/2005/1351/

3.9 URBAN DRAINAGE AND FLOOD CONTROL DISTRICT (UDFCD)

GIS data available for download on UDFCD website:

- UDFCD Boundary
- Streams
- Watershed delineation
- Master planned improvements
- Maintenance eligible reaches
- Routine maintenance reaches
- Project reaches

- Master planning studies
- ALERT stations
- Survey monuments

3.10 WATERSHED RESTORATION MASTER PLANS

Watershed	Digital Data Utilized	Study Included
Little Thompson Creek	Aerial Imagery GIS • Geology map of watershed (Stoeser et al., 2007) • Soils map Topography Land Use and Ownership	• Watershed evaluation • Post-flood site assessments • Restoration recommendations and conceptual design strategies • Implementation
St. Vrain Creek	GIS • Post-flood damages • Post-flood stream channel • Post-flood inundation areas • Flood debris • Recovery berms • Recovery planning areas • FEMA FIRM • CWCB floodplains • Pre- and post-flood LiDAR • Pre- and post-flood orthoimagery • Roadways and setbacks • Wetlands • Stream habitat connectors	• Ecological assessment • Geomorphic assessment • Alternatives analysis report • Summary of flood and debris flow impacts at Camp St. Malo • Hydraulics • Guidance for hydrologic and hydraulic analyses • Resource for management of woody debris
Fourmile Creek	Existing hydrologic/hydraulic analyses Topography GIS • Post-flood damages • Post-flood stream channel • Post-flood inundation areas • Flood debris • Recovery berms • Recovery planning areas • FEMA FIRM • CWCB floodplains • Parcels • Pre- and post-flood topography • Pre- and post-flood orthoimagery • Roadways and setbacks • Wetlands • Mine locations	• Restoration recommendations and conceptual design strategies • Prioritization and implementation • Review of previous hydrologic analyses • Ecological assessment • Geomorphic assessment • Hydraulic analysis and flood risk mapping • Resource for management of woody debris • Guidance for hydrologic and hydraulic analyses

	• Historic structures • Stream habitat connectors	
Left Hand Creek	Aerial Imagery GIS • Geology map of watershed (USGS Mineral Resources, State geologic maps, 2005) • Hydrography • Land cover (NLCD 2011) • Fire history • Post-flood road damage • Post-flood structural damage • Inundation zone • DEM of difference • River styles	• Watershed description • Flood risk assessment • Geomorphic risk assessment • Ecosystem assessment • Recommendations, prioritization, and implementation
Upper Coal Creek	• Topography • Aerial photography	• Hydrology • Hydraulics • Geomorphology • Ecological and riparian assessment • Risk identification and alternatives • Recommendations, prioritization, and implementation • Channel morphology report

3.11 ADDITIONAL WATERSHED INFORMATION

1. **St. Vrain Creek**
   - Technical Memo, Geomorphic Assessment of St. Vrain Creek System, July 2014.
   - Field Survey Project Narrative, Technical Support Data Notebook for St. Vrain Watershed (Boulder County), Colorado, December 2015.
   - Hydrologic Data Development, Technical Support Data Notebook for St. Vrain Watershed (Boulder County), Colorado, March 2016.
   - Colorado Hazard Mapping Program Hydrologic Analysis, Technical Support Data Notebook for the St. Vrain Watershed, March 2016.
2. **Fourmile Canyon Creek**
   - Repair design plans and documents.
3. **Fourmile Creek**
   - Final Drainage Report, Salina Junction - TO5, April 2015. Includes drainage design criteria, hydrologic and hydraulic analyses, and erosion control recommendations.
   - Stream restoration projects along Upper Fourmile, Lower Fourmile, and Gold Run.
4. **Boulder Creek**
   - State of the Watershed: Water Quality of Boulder Creek, Colorado: United States Geological Survey Circular 1284.
5. **South Boulder Creek**

- Final South Boulder Creek Major Drainageway Plan - Alternatives Analysis Report (August, 2015). Provides conceptual design recommendations and builds on previous reports (Climatology and Hydrology Report (2007), Hydraulic Modeling Report (2008), and Risk Assessment Report, 2009)).

6. Coal and Rock Creek

- Hydrology Report, September 2012.
- Final Alternatives Report, December 2013.
- Coal Creek and Rock Creek Flood Hazard Area Delineation, April 2014. Provides updated hydrologic and hydraulic information for Coal Creek and Rock Creek watersheds.

APPENDIX D

Example Geologic Hazard Memorandums to Boulder County DRT

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

MEMO

To:	Boulder County Development Review Team
Project Name:	Boulder County Geotechnical and Geohazard Consultation Services
Project No.	16.3097
From:	Julia M. Frazier, P.G. and Darin R. Duran, P.E.
Date:	January 5, 2017
Subject:	Geologic Hazards-Explanation and Preliminary Recommendations

The purpose of this memo is to briefly explain select geologic hazards impacting Boulder County, Colorado and to provide recommendations for potential mitigation and site specific studies. Additional discussions and descriptions are anticipated to follow in meetings with Boulder County. Geologic hazards which have the potential to impact development decisions include, but are not limited to, unstable slopes, rockfall, heaving bedrock hazards associated with expansive, steeply dipping bedrock, swelling soils and bedrock, and subsidence related to abandoned mine workings. Other geologic hazards have significant impacts on development in Boulder County and will be addressed, as necessary, in subsequent memorandums or communications.

1. UNSTABLE SLOPES

Unstable slopes include landslide, shallow soil creep, and debris flows. Landslide is the mass movement of soil and rock downslope. Landslides can be massive or may incorporate only a small amount of material. Landslides can mobilize repeatedly in the same location. Soil creep is a shallow, slow moving earth movement, primarily impacting the surficial soil. Debris flow is a hyper-concentrated, channel-confined slope failure, involving the rapid transport of fluidized debris initiated by focused surface water runoff in drainages and swales. The severe rain event of 2013 resulted in hundreds of shallow soil creep occurrences across Boulder County and initiated landslides and fast moving debris flows.

Slope stability is dependent on any one of (or combination of) such natural conditions as soil/bedrock strength, slope angle, depth of groundwater, drainage, bedrock orientation, amount and type of vegetative cover, recent wildfire events, distance to waterways, and precipitation. Development in areas with the potential for slope instability must consider the current status and future impacts to the natural condition. Examples of adverse ground conditions include a bedrock surface or layer orientation dipping out of the slope at a problematic angle, soil and/or bedrock material properties conducive to slope instability, and shallow groundwater. Mitigation strategies for slope instability (including rockfall) will reduce but not completely eliminate the hazard.

1.1 INFLUENCING FACTORS

1. Slope characteristics.
   - Geomorphology.
     - Height of slope (influences volume mobilized and runout characteristics).
     - Steepness of slope (>30 degrees tends to be most problematic, although

landslides can occur on slopes as gentle as 5 degrees).
    - Vegetative cover (type and density of coverage). Non-vegetated slopes tend to be more prone to erosion than densely vegetated slopes, however, trees also have the potential to threaten slope stability.
    - Ground composition (infiltration vs. runoff). Type of material comprising the slope determines if precipitation infiltrates or runs off downslope. This can be correlated to the type of slope failure (e.g. concentrated surface water runoff within drainages and swales can lead to debris flows).
    - Toe of the slope. Erosion of the toe or removal of material at the base of a potentially unstable slope due to human activities (e.g., roadcuts, excavation for homes or driveways) may result in slope failure.
  - Geology and groundwater. Subsurface materials and depth to groundwater play important roles in slope stability. Certain geologic materials are more prone to slope failure than others. Soil moisture, groundwater pressures play a key role in stability.
2. Environment.
  - Intensity and duration of rainfall. Slope failures most commonly associated with intense, long periods of rain.
  - Type of precipitation (snow vs. rain).
  - Antecedent precipitation conditions.
3. Land development/human impacts.
  - Human induced modifications to the natural condition of the slope. Removing material from the base or overloading the top of a potentially unstable slope may result in slope failure.
  - Grading, removal of vegetation, changing drainage patterns.
  - Changes on one property may impact stability on another, either upslope or downslope.

1.2 RECOMMENDED STUDIES

The impacts of the proposed development on the natural condition must be analyzed through completion of a site specific geotechnical study and slope stability analysis by a licensed engineer with consideration for:

- What is the current stability of the slope?
- How will the proposed development impact the stability of the slope?
- If the proposed development impacts the stability in an adverse and unacceptable way, what are the engineered mitigation methodologies and specifications required to stabilize the slope? (i.e. acceptable factor of safety).

1.3 COMMONLY IMPLEMENTED MITIGATION STRATEGIES

1. Avoid.
2. Protect - contain and/or divert the slope failure.
  - Walls, fences, berms, ditches, and catchments.
  - Maintenance programs (and associated costs).
3. Maintain and monitor.
  - Regular slope observation and assessment.

   - Installation of monitoring devices (water levels, movement, deformation)
4. Stabilize - counter the failure mechanism.
   - Butresses.
   - Benched slopes.
   - Retaining systems.
   - Drainage improvements.

2. ROCKFALL

Rockfall is a type of gravity driven earth movement and is common in mountainous areas with broken, faulted, jointed rock, on steep slopes with cobbly, bouldery soil cover, or where cliffs and ledges are undercut by natural erosion or human activity. Rockfall events can be difficult to predict. There are rockfall modeling programs which transportation departments and geotechnical consultants use to estimate rockfall on certain slopes and to aid in design of catchment structures.

2.1 INFLUENCING FACTORS

1. Rock type, height.
2. Rock structure (fracture and joint patterns).
3. Freeze-thaw cycles, frost wedging.
4. Slope characteristics.
5. Vegetation.
6. Earthquakes.
7. Distance to roads, structures, and waterways, etc.

2.2 RECOMMENDED STUDIES

Recommended studies for sites with rockfall hazard include completion of a site specific geologic hazard study with a focus on rockfall. This may include the use of rockfall modeling software, such as the Colorado Rockfall Simulation Program (CRSP). With regards to rockfall, the geologic hazard study should include, but not be limited to:

1. Rockfall modeling to determine bounce height, velocity, kinetic energy, and rollout distance along the slope.
2. Potential mitigation structures (type, height, and location).
   - Passive (catchment).
   - Active (rock bolts, netting).

2.3 COMMONLY IMPLEMENTED MITIGATION STRATEGIES

1. Avoid.
2. Protect - contain and/or divert the slope failure.
   - Walls, fences, berms, ditches, and catchments.
3. Maintenance programs (and associated costs).
4. Stabilize - improve the condition.
   - Rock scaling operations.
   - Rock anchors.
   - Anchored mesh drapes.

3. HEAVING BEDROCK HAZARDS ASSOCIATED WITH EXPANSIVE, STEEPLY DIPPING BEDROCK

A north-south oriented zone of steeply dipping bedrock is located along the eastern edge of the Front Range, traversing through the middle of Boulder County. Other counties in Colorado, including Douglas and Jefferson Counties, have defined areas designated as having unique hazard potential related to expansive, steeply dipping bedrock. Douglas County defines the zone as the Dipping Bedrock Overlay District (DBOD) and Jefferson County calls it the Designated Dipping Bedrock Area (DDBA). The Douglas and Jefferson Counties steeply dipping bedrock zones are generally contiguous with minor differences.

3.1 INFLUENCING FACTORS

The primary hazards associated with steeply dipping bedrock zones are those related to:

1. The potential for differential heave between expansive and non-expansive layers within the geologic units. These can be relatively thin layers that can be present within the foundation footprint of a single structure, resulting in large differential movements across the structure.
2. An increase in the depth of wetting in steeply dipping bedrock zones. An increase in the depth of wetting (or the depth of water infiltration) increases the amount of bedrock exposed to water and increases the potential heave to a structure. Increasing the swell potential of underlying materials increases the potential for foundation distress.

Based on published literature (Noe and Dodson, 1999), criteria for areas with heave potential associated with expansive, steeply dipping bedrock consists of:

1. Bedrock dip angle of greater than 30 degrees from horizontal.
2. Expansive claystone in all or sections of the formation.

Areas are designated to be within the steeply dipping hazard zone when both of the above criteria are met. The steeply dipping hazard zone does not encompass all areas of steeply dipping bedrock, nor does it encompass all areas underlain by expansive claystone. The steeply dipping hazard zone in Douglas and Jefferson Counties is delineated by a relatively narrow belt along the Front Range, and is similar in Boulder County. The effects of this hazard can be erratic and a home may exhibit structural damage where surrounding structures do not.

Locally occurring geologic factors that impact the hazard potential include:

1. Thickness of the surficial deposits overlying the bedrock.
2. The sections of the formation comprised of non-expansive bedrock.
3. Initial moisture content.

3.2 RECOMMENDED STUDIES

For new development, significant structural additions or remedial work within designated steeply dipping bedrock zones, detailed geotechnical and geological studies should be required.

3.3 COMMONLY IMPLEMENTED MITIGATION STRATEGIES

1. Avoid.

2. At least 10 feet of low to non-swelling overburden or structural fill beneath the base of the foundation (overexcavation).
3. Positive drainage away from foundation.

4. SWELLING SOILS AND BEDROCK

Swelling soils and bedrock are a commonly recognized hazard in Colorado, causing severe damage to concrete flatwork, roadways, basement walls and slabs, buried utilities, and foundations. Swelling soils and bedrock contain clay minerals that attract and absorb water, causing shrink and swell characteristics. They can swell up to 20 percent in volume when wetted and exert pressures in excess of 30,000 pounds per square foot.

4.1 INFLUENCING FACTORS

1. Presence of clays and claystone with significant swell potential. Bentonite and montmorillonite derived from weathered volcanic ash are the primary "bad actor" constituents.
2. Subsurface moisture.
3. Depth of wetting.
4. Drainage.

4.2 RECOMMENDED STUDIES

A geotechnical study is recommended for sites underlain by soils and bedrock with swell potential. A site specific study to include a subsurface investigation and laboratory analysis of samples collected from borings or trenches. Published mapping of swelling soils and bedrock by Hart (1974) is a commonly used reference and covers much of the Front Range of Colorado.

4.3 COMMONLY IMPLEMENTED MITIGATION STRATEGIES

1. Reduce, control the infiltration of water to the subsurface.
   - Specialized landscaping.
   - Limited irrigation.
   - Surface drainage.
   - Subsurface drainage systems.
2. Specialized design and construction methods.
   - Overexcavation.
   - Deep foundations (i.e., drilled piers).
   - Structurally supported floors.
3. Quality control during construction.

5. SUBSIDENCE

Areas underlain by abandoned mine workings are present throughout Boulder County. Documentation and maps of undermined areas and mine workings exist, however, in some cases the records are questionable and may not be complete. Caution is recommended when citing and designing structures in undermined areas. For properties with mapped mine workings and/or evidence of subsidence (e.g., sinkholes, sags, troughs, and depressions) within or near the property boundaries, a subsidence study should be conducted prior to development.

5.1 INFLUENCING FACTORS

1. Type of mining operations.
2. Timing of mine operations and closure.
3. Depth and extent of mining.
4. Types of mine workings within and around the site (e.g., adits, shafts, and pits).
5. Accuracy of records and maps.

5.2 RECOMMENDED STUDIES

In areas where mine openings, underground mine workings, and/or evidence of subsidence have been documented or identified, the requirement should be to conduct a detailed, site specific geologic characterization and subsidence study. Must include a site reconnaissance to identify mine openings, workings, and evidence of subsidence, and a thorough review of available literature, maps, publications, and historical aerial photographs.

5.3 COMMONLY IMPLEMENTED MITIGATION STRATEGIES

1. Avoid.
2. Specialized design and construction methodologies.
   - Deep foundations.
   - Void fill grouting.
   - Geotextiles.

6. RESOURCES

The Colorado Geological Survey (CGS) and United States Geological Survey (USGS) websites are resources of geologic and geologic hazard information and data. The CGS reviews geologic reports issued for new development in unincorporated parts of the counties in Colorado and for new school construction or critical facilities that may be impacted by geological hazards. The Colorado Department of Transportation (CDOT), Geotechnical and Geohazards Teams also deal with geotechnical and geohazard issues along transportation corridors. Dames and Moore (1986) completed a subsidence investigation for Boulder County. The CGS and the Colorado Division of Reclamation, Mining and Safety are also resources for undermined areas.

Select resources are listed below. A thorough list of available and useful references and resources will be included in Cesare's final report.

1. Colorado Landslide Viewer - coloradogeologicalsurvey.org/geologic-hazards/landslides-2/colorado-landslide-inventory.
2. Dames & Moore, 1986, Boulder County Subsidence Investigation, issued to: State of Colorado, Department of Natural Resources, Mined Land Reclamation Division.
3. Hart, S.S., 1974, Potentially Swelling Soil and Rock in the Front Range Urban Corridor, Colorado: Colorado Geological Survey, Department of Natural Resources, Environmental Geology 7.
4. Highland, L.M., and Bobrowsky, Peter, 2008, The landslide handbook—A guide to understanding landslides: Reston, Virginia, U.S. Geological Survey Circular 1325, 129 p.
5. Jochim, C.L., Rogers, W.P., Truby, J.O., Wold, Jr., R.L., Weber, G., and Brown, S.P., 1988, Colorado Landslide Hazard Mitigation Plan: Colorado Geological Survey, Bulletin

48.

6. Morgan, M.L., White, J.L., Fitzgerald, F.S., Berry, K.A., Hart, S.S., 2014, Foothill and Mountainous Regions in Boulder County, Colorado that may be Susceptible to Debris/Mud Flows During Extreme Precipitation Events: Colorado Geological Survey, Open-File Report 14-02.
7. Noe, D.C., Jochim, C.L., and Rogers, W.P., 1997, A Guide to Swelling Soils for Colorado Homebuyers and Homeowners: Colorado Geological Survey, Department of Natural Resources, Special Publication 43.
8. Noe, D.C., and Dodson, M.D., 1999, Heaving-Bedrock Hazards Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado: Colorado Geological Survey, Special Publication 42.
9. Roberts, S.B., Hynes, J.L., and Woodward, C.L., 2001, Maps Showing the Extent of Mining, Locations of Mine Shafts, Adits, Air Shafts, and Bedrock Faults, and Thickness of Overburden Above Abandoned Coal Mines in the Boulder-Weld Coal Field, Boulder, Weld, and Adams Counties, Colorado: United States Geological Survey, Geologic Investigations Series Map I-2735.
10. Turney, J.E., 1985, Subsidence Above Inactive Coal Mines: Information for the Homeowner: Colorado Geological Survey and Colorado Mined Land Reclamation Division Inactive Mine Reclamation Program, Denver, Colorado, Department of Natural Resources, Special Publication 26.

MEMO

Project Name:	Boulder County Geotechnical and Geologic Hazard Consultation Services
Project No.	16.3097
From:	Julia M. Frazier, P.G.
Date:	February 3, 2017
Subject:	Case Study Review 225 Boulder View Lane, Boulder, Colorado

The purpose of this memo is to summarize Cesare, Inc.'s (Cesare) opinions and recommendations related to geologic conditions which have the potential to impact certain properties currently or historically under review by the Boulder County (BoCo) Development Review Team (DRT) and to provide recommendations for future work toward developing criteria for geologic hazard related studies. Cesare's goal is to briefly discuss potential geologic hazards based on available information and to provide potential site study recommendations.

225 BOULDER VIEW LANE, BOULDER, COLORADO

Pinebrook Hills Subdivision
Foothills Subprovince
BoCo Designation: Moderate Geologic Hazard Area

Maps:
Wrucke, C.T., and Wilson, R.F., 1967, Geologic Map of the Boulder Quadrangle, Boulder County, Colorado: United States Geological Survey, Open-File Report 67-281.

PRIMARY GEOLOGIC HAZARDS POTENTIALLY IMPACTING THE SITE:

1. Slope stability – landslide, creep, and rockfall.
2. Steeply dipping heaving bedrock.

SITE CONDITIONS

The site is rectangle in shape and located on a steep, west facing slope with bedrock outcrops exposed at the surface to the east and upslope of the site. The property is located on the western flank of a hogback, a spiney ridge formed by steeply dipping bedrock along the Front Range of the Rocky Mountains. There is an existing residential structure situated in the southern part of the site, nearest to Boulder View Lane. According to the Boulder County Geologic Hazard and Constraint Map used for land use applications, the entire site is within a "moderate geologic hazard area" with debris flow susceptibility areas identified offsite to the east and west (Colorado Geological Survey). Based on published geologic mapping (Wrucke and Wilson, 1967), the site is underlain by bedrock comprised of steeply dipping Dakota Group (comprised of Dakota, South Platte, and Lytle Formations) and Morrison Formation. Bedrock dips range from about 70 degrees east to vertical, and are overturned in some areas. Surficial deposits comprised of colluvium cover the majority of the site. The southern end of a northwest trending fault is mapped about 800 feet west of the site, at closest approach. The geologic map shows that this fault offsets strata west of the site, however, it is not considered active.

Slope stability concerns for this site are related to steep, colluvium-covered slopes, and possibly rockfall from the bedrock outcrops upslope from the structure. Cesare is aware that the existing structure shows signs of foundation distress. It is unclear based on the available information what is causing the foundation movement in the existing structure. It is also unknown at this time what type of foundation was constructed.

The Dakota Group and Morrison Formation underlying the site are steeply dipping sedimentary bedrock units. According to Noe and Dodson (1999), these units are considered to have the following heaving bedrock potential associated with expansive, steeply dipping bedrock:

- Dakota Group - low hazard potential.
- Morrison Formation - high hazard potential.

The contact of two distinctly different bedrock units underlies the site - sandstone of the lower part of the Dakota Group and siltstone-claystone-limestone of the upper part of the Morrison Formation. The risk of differential movement is increased when contacts between different material types underlie a site, particularly when one or more units have heave potential. The exact location of the bedrock contact with relation to the structure is difficult to determine with available maps. The potential for differential foundation movement due to differing material types underlying the building footprint should be a consideration during site development.

RECOMMENDATIONS

If proposed improvements involve constructing a new structure on another part of the property, Cesare's recommendation would be to complete a geotechnical and geologic hazard study for the site, with specific attention to slope stability and swelling soils/bedrock. The geologic hazard study should be performed by a professional geologist and potential mitigation options provided by a qualified geotechnical engineer. The report should include detailed geologic site characterization through site reconnaissance and review of available literature, maps, and data, characterization of all potential geologic hazards which may impact the site and thus be considered during development. Additionally, the report should provide recommendations and options for those hazards requiring mitigation. If a geologic hazard study was previously completed for the original construction, an addendum report may be warranted if additions or redevelopment are significant enough to change conclusions and recommendations.

Depending on the details of the proposed addition/new structure and the steepness of the slope at that location, the site may require a slope stability analysis. This would include recommendations and mitigation options and require a subsurface investigation (such as borings, exploratory pits, etc.) to characterize the nature and geometries of subsurface materials, groundwater, and other factors for stability analyses. Critical sections should be analyzed.

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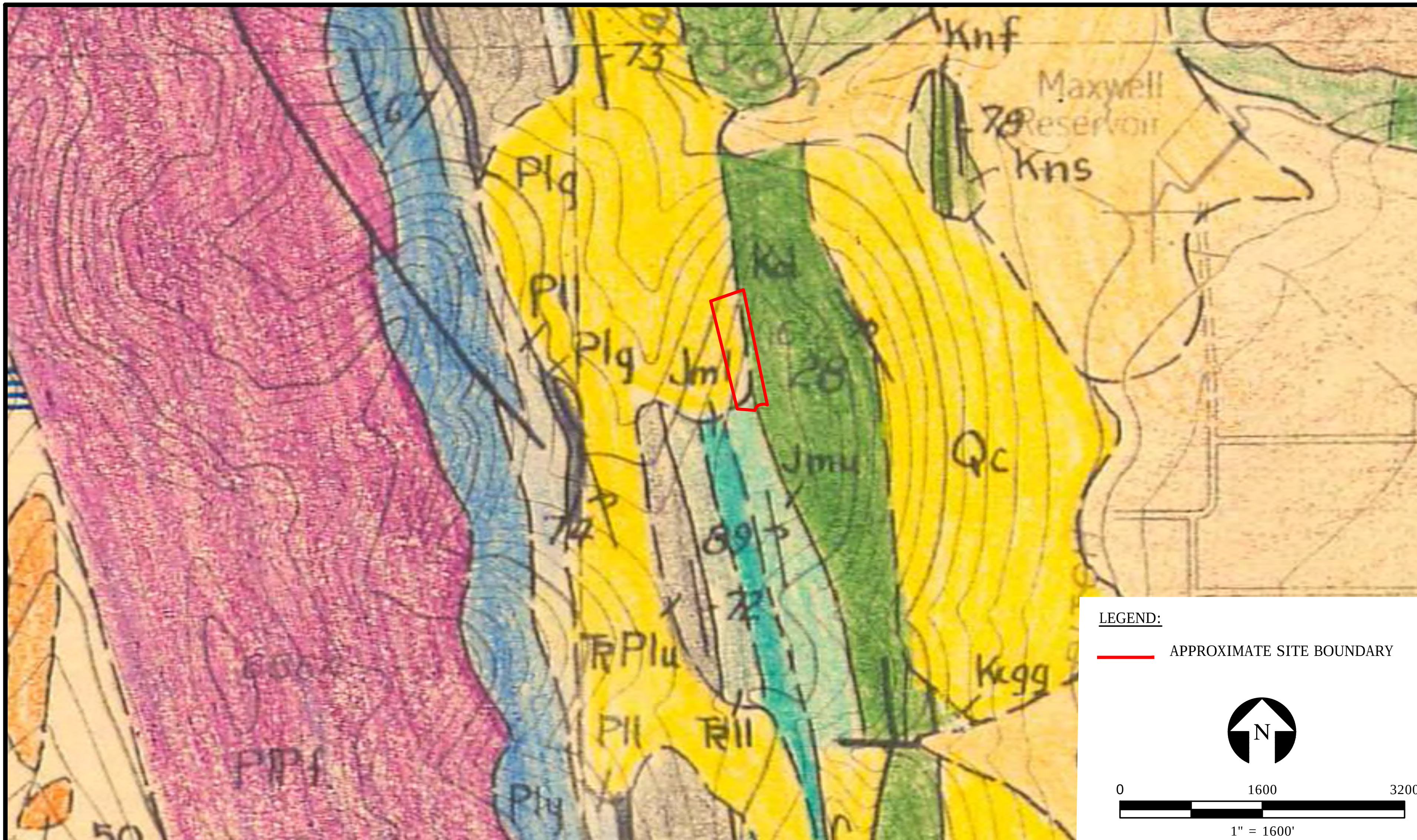

PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
DRAWN BY:	RAB	CHECKED BY:	JMF
DWG DATE:	02.23.17	REV. DATE:	--

FIGURE 1
Geology Map - 225 Boulder View

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

Qal

Alluvium
Gravel and sand. Includes Piney Creek Alluvium east of the mountains except along Boulder Creek and Lefthand Creek

Qaf

Alluvial fan deposits
Angular fragments in a sandy matrix

Qc

Colluvium
Locally derived rock debris and soil

Qls

Landslide deposits
Rock slides of Dakota Group along hogback north of Boulder Canyon and of Fountain Formation south of Boulder Canyon

Qp

Piney Creek Alluvium
Dark-gray humic silt, sand, and pebbles; a younger soil occurs in upper part. Locally includes alluvium of Wisconsin age, which commonly underlies Piney Creek Alluvium

Qw

Alluvium of Wisconsin age
Gray to reddish-brown stratified silt, sand, and pebbles. Includes some overlying Piney Creek Alluvium locally. As much as 20 feet thick

Qs

Slocum Alluvium
Reddish-brown sand and gravel in clayey matrix. Contains partly decomposed pebbles, cobbles, and boulders of igneous, sedimentary, and metamorphic rocks. Caps pediment. As much as 30 feet thick

Qv

Verdos Alluvium
Brown sand and gravel on highest pediment in quadrangle. Contains clayey matrix and partly decomposed pebbles, cobbles, and boulders of igneous, sedimentary, and metamorphic rocks. As much as 30 feet thick

Tb

Bostonite porphyry
Grayish-reddish-purple; contains orthoclase phenocrysts in aphanitic groundmass; forms dikes

Tas

Alkali syenite
Pale-brownish-gray, medium-grained; contains orthoclase microperthite and minor quartz; forms dikes

Tql

Quartz latite porphyry
Light- to medium-gray; contains biotite, feldspar, and quartz phenocrysts in aphanitic groundmass; locally intensely altered; forms dikes

Tqm

Quartz monzonite
Fine- to medium-grained, biotitic and hornblendic; forms small irregular bodies and stocks

TKd

Diabase
Black, fine-grained; forms dikes

Kpu
Kph
Kpl

Pierre Shale
Kpu, upper member; chiefly olive-gray noncalcareous clayey to sandy siltstone and beds of limestone concretions; only part of the 5,700-foot total thickness of the member exposed in quadrangle
Kph, Hygiene Sandstone Member; olive-gray to light-olive-gray silty to fine-grained sandstone, carbonaceous in part; contains prominent olive-gray clayey siltstone 40 feet thick beginning 210 feet above base; forms low ridge; about 500 feet thick
Kpl, lower member; medium- to dark-gray and olive-gray claystone and clayey siltstone; contains subordinate layers and concretions of ironstone, and beds of limestone concretions and calcareous claystone; about 1,650 feet thick

Kns
Knf

Niobrara Formation
Kns, Smoky Hill Shale Member; olive-gray to light-olive-gray calcarenite to calcareous siltstone interstratified with olive-gray to dark-gray siltstone and calcareous siltstone; olive-gray silty calcarenite 23 feet thick at top of member. Weathers to prominent grayish orange; 370 feet thick
Knf, Fort Hays Limestone Member; light-olive-gray to medium-gray calcarenite and microcrystalline limestone; forms low hogback; 15 to 18 feet thick

Kcgg

Carlile Shale, Greenhorn Limestone, and Graneros Shale
Upper part: olive-gray silty claystone, sandy siltstone, and silty sandstone of Carlile Shale, about 75 feet thick; middle part: interlayered dark-gray microcrystalline and bioclastic limestone and calcarenite and olive-gray silty claystone and clayey to calcareous siltstone of the Greenhorn Limestone, about 260 feet thick; lower part: dark-gray to grayish-black siltstone and claystone of the Graneros Shale, about 160 feet thick

Kd

Dakota Group
Upper part: light-gray to grayish-orange well-sorted fine-grained cross-stratified and ripple-laminated sandstone and subordinate horizontally stratified sandy siltstone of South Platte Formation, about 225 feet thick; lower part: white, pinkish-gray, and greenish-gray generally well sorted fine- to medium-grained sandstone of Lytle Formation, about 50 feet thick

Jmu
Jml

Morrison Formation
Jmu, upper member; greenish-gray to pale-reddish-brown clayey siltstone and claystone and subordinate olive-gray limestone; 170-220 feet thick
Jml, lower member; light-brownish-gray to pinkish-gray fine-grained cross-stratified sandstone interbedded with greenish-gray to greenish-red sandy to clayey siltstone and subordinate limestone; 80-100 feet thick. Includes at base greenish-gray siltstone and sandstone and gray limestone, 5 to 20 feet thick, provisionally assigned to Ralston Creek Formation of Late Jurassic age

Js

Sandstone equivalent to Sundance Formation
Very light gray to yellowish-gray fine-grained, in part cross-laminated sandstone equivalent to the Canyon Springs Sandstone Member; 0-37 feet thick. Pinkish-gray very fine grained sandstone at base near northern border of quadrangle may be Jelm Formation of Late Triassic age

R̄Pl
R̄ll
R̄Plu
Plg
Pll

Lykins Formation
R̄ll, ledge-forming member; light-brown to pale-reddish-brown silty fine-grained sandstone and siltstone; 72-153 feet thick
R̄Plu, upper slope-forming member; pale-reddish-brown siltstone and sandy siltstone; poorly exposed; 320 feet thick
Plg, Glennon Limestone Member of Le Roy (1946); pale-red dolomitic siltstone to silty dolomite; has wavy to contorted laminae; 8-16 feet thick
Pll, lower ledge-forming member; pale-reddish-brown to moderate-reddish-brown siltstone and subordinate sandstone; small gypsum nodules locally; 100-150 feet thick

Ply

Lyons Sandstone
Moderate-orange-pink to pinkish-gray fine- to medium-grained well-sorted cross-stratified quartzose sandstone; about 250 feet thick

PPf

Fountain Formation
Pale-red poorly sorted arkosic sandstone and conglomeratic sandstone interstratified with pale-reddish-brown feldspathic sandstone in the upper 550 feet and with pale-reddish-brown siltstone in the lower 400 feet; about 900-950 feet thick

pa

Pegmatite and aplite

hbl

Hornblende-biotite lamprophyre
Greenish-black or greenish-black mottled with pale red, fine- to medium-grained; chiefly hornblende, biotite, and microcline, but may contain quartz and plagioclase; forms dikes. Includes some dark-gray fine-grained quartz monzonite

spe
spp

Silver Plume Granite
spe, pale-grayish-orange to pale-reddish-gray equigranular fine- to medium-grained biotite-muscovite quartz monzonite
spp, gray to tan medium- to coarse-grained seriate porphyritic quartz monzonite that contains tabular microcline phenocrysts; commonly shows trachytoid flow structure

qm

Quartz monzonite
Light- to medium-gray fine-grained biotite quartz monzonite; massive to weakly foliated

bc

Boulder Creek Granodiorite
Light-gray medium-grained granodiorite to quartz monzonite; locally seriate porphyritic with microcline phenocrysts; contains abundant biotite in small aggregates; locally hornblende bearing; weakly to strongly foliated

d

Diorite
Dark-gray fine- to medium-grained diorite and quartz diorite; chiefly biotite, hornblende, cummingtonite, and labradorite. Probably represents metamorphosed gabbro

ba

Biotitic amphibolite
Dark-gray biotite- and quartz-bearing fine-grained amphibolite; forms small irregular bodies

bg

Biotite gneiss
Light- to dark-gray migmatitic, locally sillimanitic, biotite-quartz-plagioclase gneiss and subordinate quartz-microcline-plagioclase gneiss and calc-silicate gneiss; contains well-developed foliation and lineation

PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
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FIGURE 2
Geology Map Legend- 225 Boulder View

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

MEMO

Project Name: Boulder County Geotechnical and Geologic Hazard Consultation Services
Project No. 16.3097
From: Julia M. Frazier, P.G.
Date: February 3, 2017
Subject: Case Study Review
342 South Cedar Brook Road, Boulder, Colorado

The purpose of this memo is to summarize Cesare, Inc.'s (Cesare) opinions and recommendations related to geologic conditions which have the potential to impact certain properties currently or historically under review by the Boulder County (BoCo) Development Review Team (DRT) and to provide recommendations for future work toward developing criteria for geologic hazard related studies. Cesare's goal is to briefly discuss potential geologic hazards based on available information and to provide potential site study recommendations.

342 SOUTH CEDAR BROOK ROAD, BOULDER, COLORADO

Pinebrook Hills Subdivision.
Foothills Subprovince.
BoCo Designation: Major Geologic Hazard Area.

Maps:
Wrucke, C.T., and Wilson, R.F., 1967, Geologic Map of the Boulder Quadrangle, Boulder County, Colorado: United States Geological Survey, Open-File Report 67-281.

PRIMARY GEOLOGIC HAZARDS POTENTIALLY IMPACTING THE SITE

1. Debris flow.
2. Slope stability – landslide, creep, and rockfall.
3. Steeply dipping heaving bedrock.

SITE CONDITIONS

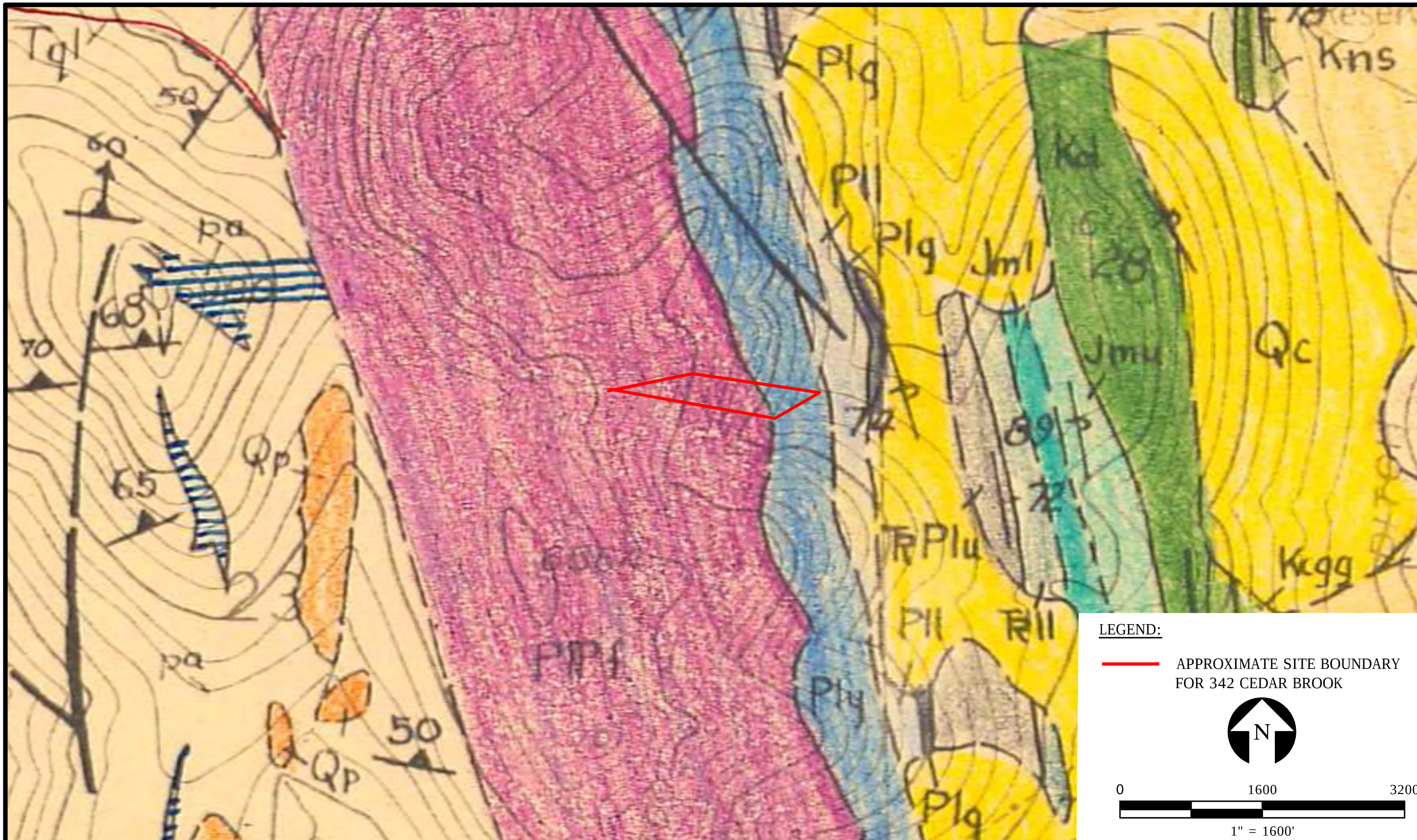
The site is elongate in shape and located on a steep, northeast facing slope with bedrock outcrops exposed at the surface. Based on the Boulder County Geologic Hazards and Constraint Map, there is an intermittent stream traversing the site along the southeast side which is associated with a debris flow channel. The entire site is within a "major geologic hazard area" and debris flow susceptibility areas are identified along the southeast and northern ends of the property boundary (Colorado Geological Survey). Based on published geologic mapping (Wrucke and Wilson, 1967), the site is underlain by steeply dipping Fountain and Lyons Formations. Bedrock dips for the bedrock units range from about 50 to 70 degrees east in the site area. The southern end of a northwest trending fault is mapped about 200 feet northeast of the site, at closest approach. The geologic map shows that this fault offsets the Fountain and Lyons Formations north of the site, however, is not considered active.

A significant geologic hazard impacting the site is a debris flow channel which traverses the property along the southeast side, near the location where the site will be accessed from Cedar Brook Road. There is also a debris flow susceptible area in the north part of the site, based on CGS mapping of the post-2013 flood condition in Boulder County. Access to the site is limited, requires traverse through other lots, and (likely) requires crossing the debris flow channel along the southern end of the property. From site photographs included in the Boulder County project folder, the debris flow channel appears deeply incised with steep channel slopes and large accumulations of sediment, boulders, and vegetative debris. The debris flow channel was identified by the Colorado Geological Survey in their mapping of post-flood debris flow deposits and susceptibility. This debris flow channel feature is a significant controlling factor on development within the site boundaries. Complete avoidance would be the best method of mitigating the hazard, however, there are other engineered remediation options available depending on the intended development. The debris flow channel at this site represents a significant hazard and risk to property and human life. The debris flow hazard and applicable mitigation strategies should be addressed appropriately by a qualified professional geologist and licensed geotechnical engineer.

Slope stability issues related to steep, colluvium covered slopes and rockfall from the bedrock outcrops upslope from the proposed structure location, are also a concern for the site. Although the site is underlain by steeply dipping sedimentary bedrock, the Fountain and Lyons Formations are not considered “bad actors” in terms of heave potential and differential movement of foundations. Sedimentary units to the east, including but not limited to, the Pierre Shale and Morrison and Laramie Formations have higher potential for heave and differential movement. The claystone layers within these formations have high swell potential when wetted.

RECOMMENDATIONS

Cesare recommends completion of geotechnical and geologic hazard studies for the site, with specific attention to debris flow and slope stability. The geologic hazard study should be performed by a professional geologist, and potential remediation options provided by a geotechnical engineer. Studies should include characterization of subsurface materials, detailed geologic site characterization through site reconnaissance and review of available literature, maps, and data, and characterization of all potential geologic hazards which may impact the site and thus be considered during development. Additionally, reports should provide recommendations and mitigation options. Depending on exact location of the proposed structure and the steepness of the slope at that location, the site may require a slope stability analysis (this is most conveniently completed after development design has been decided and requires a subsurface investigation to determine material properties for stability analyses).



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PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
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DWG DATE:	02.23.17	REV. DATE:	--

FIGURE 1
Geology Map - 342 Cedar Brook

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

Qal

Alluvium

Gravel and sand. Includes Piney Creek Alluvium east of the mountains except along Boulder Creek and Lefthand Creek

Qaf

Alluvial fan deposits

Angular fragments in a sandy matrix

Qc

Colluvium

Locally derived rock debris and soil

Qls

Landslide deposits

Rock slides of Dakota Group along hogback north of Boulder Canyon and of Fountain Formation south of Boulder Canyon

Qp

Piney Creek Alluvium

Dark-gray humic silt, sand, and pebbles; a younger soil occurs in upper part. Locally includes alluvium of Wisconsin age, which commonly underlies Piney Creek Alluvium

Qw

Alluvium of Wisconsin age

Gray to reddish-brown stratified silt, sand, and pebbles. Includes some overlying Piney Creek Alluvium locally. As much as 20 feet thick

Qs

Slocum Alluvium

Reddish-brown sand and gravel in clayey matrix. Contains partly decomposed pebbles, cobbles, and boulders of igneous, sedimentary, and metamorphic rocks. Caps pediment. As much as 30 feet thick

Qv

Verdos Alluvium

Brown sand and gravel on highest pediment in quadrangle. Contains clayey matrix and partly decomposed pebbles, cobbles, and boulders of igneous, sedimentary, and metamorphic rocks. As much as 30 feet thick

Tb

Bostonite porphyry

Grayish-reddish-purple; contains orthoclase phenocrysts in aphanitic groundmass; forms dikes

Tas

Alkali syenite

Pale-brownish-gray, medium-grained; contains orthoclase microperthite and minor quartz; forms dikes

Tql

Quartz latite porphyry

Light- to medium-gray; contains biotite, feldspar, and quartz phenocrysts in aphanitic groundmass; locally intensely altered; forms dikes

Tqm

Quartz monzonite

Fine- to medium-grained, biotitic and hornblendic; forms small irregular bodies and stocks

TKd

Diabase

Black, fine-grained; forms dikes

Kpu
Kph
Kpl

Pierre Shale

Kpu, upper member; chiefly olive-gray noncalcareous clayey to sandy siltstone and beds of limestone concretions; only part of the 5,700-foot total thickness of the member exposed in quadrangle

Kph, Hygiene Sandstone Member; olive-gray to light-olive-gray silty to fine-grained sandstone, carbonaceous in part; contains prominent olive-gray clayey siltstone 40 feet thick beginning 210 feet above base; forms low ridge; about 500 feet thick

Kpl, lower member; medium- to dark-gray and olive-gray claystone and clayey siltstone; contains subordinate layers and concretions of ironstone, and beds of limestone concretions and calcareous claystone; about 1,650 feet thick

Kns
Knf

Niobrara Formation

Kns, Smoky Hill Shale Member; olive-gray to light-olive-gray calcarenite to calcareous siltstone interstratified with olive-gray to dark-gray siltstone and calcareous siltstone; olive-gray silty calcarenite 23 feet thick at top of member. Weathers to prominent grayish orange; 370 feet thick

Knf, Fort Hays Limestone Member; light-olive-gray to medium-gray calcarenite and microcrystalline limestone; forms low hogback; 15 to 18 feet thick

Kcgg

Carlile Shale, Greenhorn Limestone, and Graneros Shale

Upper part: olive-gray silty claystone, sandy siltstone, and silty sandstone of Carlile Shale, about 75 feet thick; middle part: interlayered dark-gray microcrystalline and bioclastic limestone and calcarenite and olive-gray silty claystone and clayey to calcareous siltstone of the Greenhorn Limestone, about 260 feet thick; lower part: dark-gray to grayish-black siltstone and claystone of the Graneros Shale, about 160 feet thick

Kd

Dakota Group

Upper part: light-gray to grayish-orange well-sorted fine-grained cross-stratified and ripple-laminated sandstone and subordinate horizontally stratified sandy siltstone of South Platte Formation, about 225 feet thick; lower part: white, pinkish-gray, and greenish-gray generally well sorted fine- to medium-grained sandstone of Lytle Formation, about 50 feet thick

Jmu
Jml

Morrison Formation

Jmu, upper member; greenish-gray to pale-reddish-brown clayey siltstone and claystone and subordinate olive-gray limestone; 170-220 feet thick

Jml, lower member; light-brownish-gray to pinkish-gray fine-grained cross-stratified sandstone interbedded with greenish-gray to greenish-red sandy to clayey siltstone and subordinate limestone; 80-100 feet thick. Includes at base greenish-gray siltstone and sandstone and gray limestone, 5 to 20 feet thick, provisionally assigned to Ralston Creek Formation of Late Jurassic age

Js

Sandstone equivalent to Sundance Formation

Very light gray to yellowish-gray fine-grained, in part cross-laminated sandstone equivalent to the Canyon Springs Sandstone Member; 0-37 feet thick. Pinkish-gray very fine grained sandstone at base near northern border of quadrangle may be Jelm Formation of Late Triassic age

ℜPl
ℜll
ℜPlu
Plg
Pll

Lykins Formation

ℜll, ledge-forming member; light-brown to pale-reddish-brown silty fine-grained sandstone and siltstone; 72-153 feet thick

ℜPlu, upper slope-forming member; pale-reddish-brown siltstone and sandy siltstone; poorly exposed; 320 feet thick

Plg, Glennon Limestone Member of Le Roy (1946); pale-red dolomitic siltstone to silty dolomite; has wavy to contorted laminae; 8-16 feet thick

Pll, lower ledge-forming member; pale-reddish-brown to moderate-reddish-brown siltstone and subordinate sandstone; small gypsum nodules locally; 100-150 feet thick

Ply

Lyons Sandstone

Moderate-orange-pink to pinkish-gray fine- to medium-grained well-sorted cross-stratified quartzose sandstone; about 250 feet thick

PPf

Fountain Formation

Pale-red poorly sorted arkosic sandstone and conglomeratic sandstone interstratified with pale-reddish-brown feldspathic sandstone in the upper 550 feet and with pale-reddish-brown siltstone in the lower 400 feet; about 900-950 feet thick

pa

Pegmatite and aplite

hbl

Hornblende-biotite lamprophyre

Greenish-black or greenish-black mottled with pale red, fine- to medium-grained; chiefly hornblende, biotite, and microcline, but may contain quartz and plagioclase; forms dikes. Includes some dark-gray fine-grained quartz monzonite

spe
spp

Silver Plume Granite

spe, pale-grayish-orange to pale-reddish-gray equigranular fine- to medium-grained biotite-muscovite quartz monzonite

spp, gray to tan medium- to coarse-grained seriate porphyritic quartz monzonite that contains tabular microcline phenocrysts; commonly shows trachytoid flow structure

qm

Quartz monzonite

Light- to medium-gray fine-grained biotite quartz monzonite; massive to weakly foliated

bc

Boulder Creek Granodiorite

Light-gray medium-grained granodiorite to quartz monzonite; locally seriate porphyritic with microcline phenocrysts; contains abundant biotite in small aggregates; locally hornblende bearing; weakly to strongly foliated

d

Diorite

Dark-gray fine- to medium-grained diorite and quartz diorite; chiefly biotite, hornblende, cummingtonite, and labradorite. Probably represents metamorphosed gabbro

ba

Biotitic amphibolite

Dark-gray biotite- and quartz-bearing fine-grained amphibolite; forms small irregular bodies

bg

Biotite gneiss

Light- to dark-gray migmatitic, locally sillimanitic, biotite-quartz-plagioclase gneiss and subordinate quartz-microcline-plagioclase gneiss and calc-silicate gneiss; contains well-developed foliation and lineation

PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
DRAWN BY:	RAB	CHECKED BY:	JMF
DWG DATE:	02.23.17	REV. DATE:	--

FIGURE 2

Geology Map Legend- 342 Cedar Brook

CESARE, INC.

Geotechnical Engineers & Construction Materials Consultants

MEMO

Project Name: Boulder County Geotechnical and Geologic Hazard Consultation Services
Project No. 16.3097
From: Julia Frazier, P.G.
Date: February 3, 2017
Subject: Case Study Review - 6126 Magnolia Drive, Nederland

The purpose of this memo is to summarize Cesare's opinions and recommendations related to geologic conditions which have the potential to impact certain properties currently or historically under review by the Boulder County (BoCo) Development Review Team (DRT) and to provide recommendations for future work toward developing criteria for geologic hazard related studies. Cesare's goal is to briefly discuss potential geologic hazards based on available information and to provide potential site study recommendations.

6126 MAGNOLIA DRIVE, NEDERLAND

Montane Subprovince
BoCo Designation: Moderate Constraint Area

Maps:
Gable, D.J., 1972, Geologic Map of the Tungsten Quadrangle, Boulder, Gilpin, and Jefferson Counties, Colorado: United States Geological Survey, GQ-978.

Gable, D.J., 1973, Map Showing Rock Fractures and Veins in the Tungsten Quadrangle, Boulder, Gilpin, and Jefferson Counties, Colorado: United States Geological Survey, Map I-792-A.

PRIMARY GEOLOGIC HAZARDS POTENTIALLY IMPACTING THE SITE:

1. Slope stability – landslide, creep

The site is rectangle in shape and located on a moderately steep slope north of Magnolia Drive. The site is currently undeveloped and generally surrounded by sparsely developed land. According to the Boulder County Geologic Hazard and Constraint Area overlay used for land use applications, the majority of the site is categorized as "moderate geologic constraint area". The Legend for the Boulder County Geologic Hazard and Constraint Area map indicates this is due to rockfall, soil creep, and landslides/mudslides/mudfalls/debris fans. Based on published geologic mapping of the Tungsten quadrangle (Gable, 1972), the site is underlain by Precambrian age intrusive bedrock comprised of Boulder Creek Granodiorite and Quartz Monzonite. The northwest trending Rogers Fault is mapped through the center of the site and is characterized by a thick zone of shattered, altered, commonly siliceous rock. Other unnamed faults (some with shattered, siliceous zones) and mineralized veins are mapped in the site area and trend in the same northwest-southeast direction as the Rogers Fault. These faults are not considered active. Surficial deposits comprised of

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Phone 303-220-0300 • Fax 303-220-0442

colluvium cover the majority of the site.

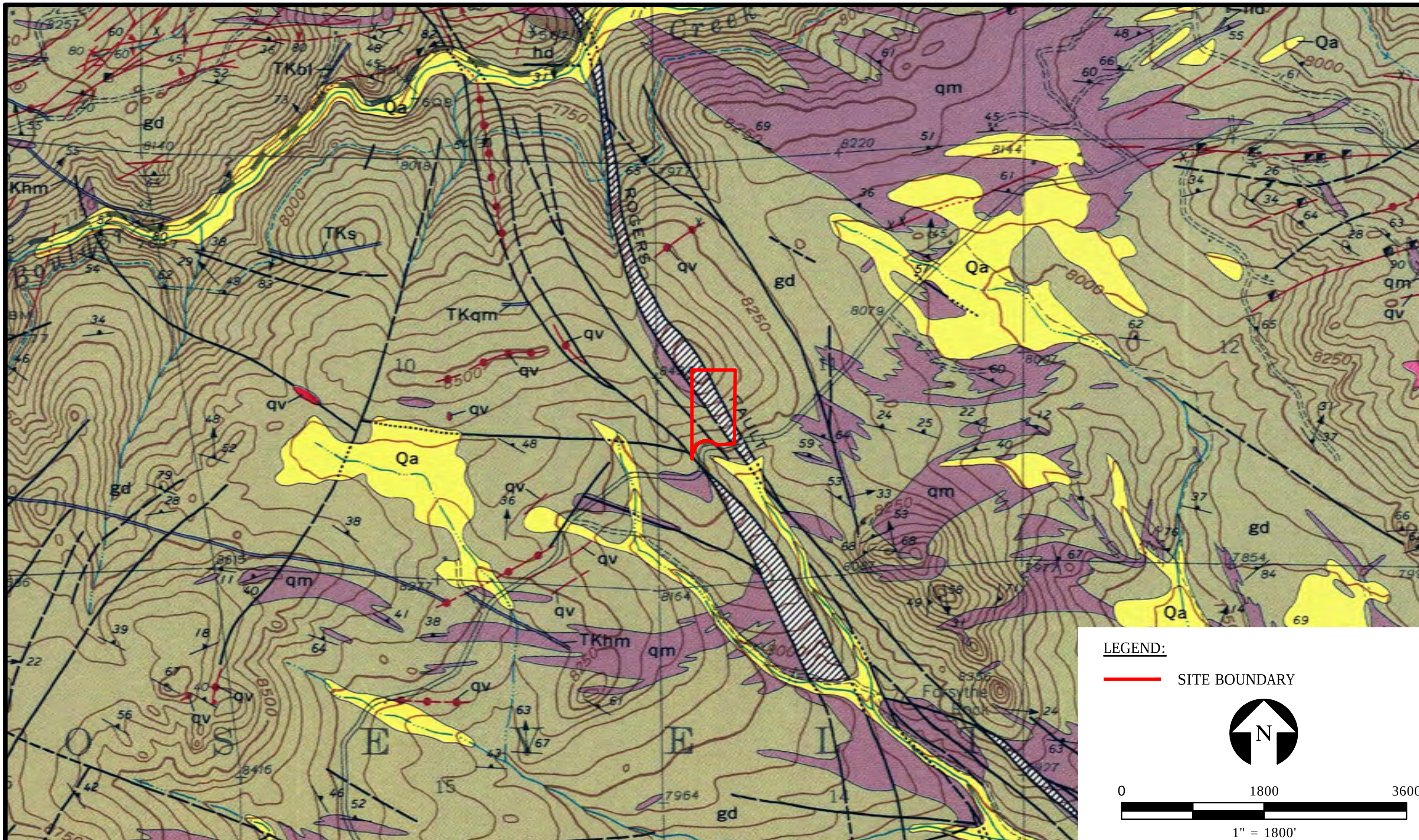
Based on site grading plans by Scott, Cox & Associates (dated August 9, 2016), it is apparent that maximum cuts and fills associated with driveway construction are on the scale of about 5 to 7 feet feet. Site grading associated with the main structure includes cut slopes on the order of about 8 to 10 feet on the north and east sides, and fill slopes on the order of about 6 to 12 feet along the southern side. A two-tiered retaining wall is proposed along the southern part of the building pad.

The Rogers Fault zone trending northwest-southeast through the site may be relatively resistant and may be difficult to excavate. The proposed building footprint may be underlain completely or in part by the Rogers Fault zone.

RECOMMENDATIONS

Cesare recommends, if it has not already been completed, that a geotechnical study be completed for the proposed development. The study should address the stability of the proposed cut and fill slopes. Cesare would also recommend the foundation and wall excavations be observed and verified by a qualified geotechnical engineer, particularly in the area of the mapped fault zones where fractured, altered rock will be exposed.

W:\2016\Frederick Projects\16.3000\16.3097.G Boulder County Geotechnical-Geohazard Services\ACAD\3.1.17\Geologic Map - 6126 Magnolia.dwg 3/28/2017 12:41 PM



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PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
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FIGURE 1
Geology Map - 6126 Magnolia

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

Qa

Alluvium and colluvium

Stream deposits, talus, and solifluction debris

Qg

Glacial till

INTRUSIVE ROCKS

TKlp

Limburgite porphyry

Almost black moderately fine grained dike rock that weathers medium brown. Consists mainly of augite, olivine, and iron oxides in an isotropic groundmass. Olivine extensively altered to carbonate and chlorite or iddingsite

TKlg

Rhyolite porphyry

Pinkish to lilac colored dense porphyritic rock consisting almost entirely of quartz, feldspar, and iron oxides. Chemically it is an alkalic granite

TKhm TKqm

Hornblende monzonite porphyry and monzonite porphyry

TKhm, *hornblende monzonite porphyry: mottled light-buff and gray. Phenocrysts of plagioclase and variable amounts of hornblende occur in a gray fine-grained predominantly feldspathic groundmass*

TKqm, *monzonite porphyry: resembles porphyry above* (TKhm) *but lacks hornblende. May contain quartz*

TKd TKdi

Diabase porphyry and diabase

TKd, *dark-gray dense fine- to medium-grained diabase porphyry that contains phenocrysts of black augite and gray labradorite. Some olivine and apatite also present. The phenocrysts are in a diabasic groundmass of augite, plagioclase, and iron oxides*

TKdi, *dark-brown dense extremely fractured fine-grained diabase. Weathered surfaces show flecks of whitish altered plagioclase. Same chemical composition as diabase porphyry*

TKbl

Biotite-pyroxene-hornblende latite porphyry

Very dark gray fine-grained porphyritic dike that contains abundant small phenocrysts of biotite, hornblende, and pyroxene, light-gray feldspar, and quartz. On fresh fracture, the dark minerals glisten. Phenocrysts of plagioclase, biotite, hornblende, augite(?), and some quartz constitute half to two-thirds of the volume; a nearly isotropic groundmass constitutes the remainder

TKs

Syenite

Grayish-green medium-grained equigranular rock mottled with pinkish feldspars. The plagioclase and potassium feldspar are associated with augite and iron oxides

TKg

Gabbro

Black or greenish-black medium-grained equigranular rock that weathers rusty brown and is well jointed. Labradorite, augite(?), iron oxides, and brown hornblende are the principal minerals. Augite(?) and brown hornblende are partially replaced by chlorite and green hornblede

sp

Silver Plume Quartz Monzonite

Pinkish-gray to light-tan fine- to medium-grained equigranular quartz monzonite, composed of potassium feldspar, oligoclase, quartz, and subordinate biotite and muscovite

gd

Boulder Creek Granodiorite

Gray fine- to medium-grained intrusive rocks. Consists mainly of quartz, potassium feldspar, plagioclase, and biotite, and locally of hornblende. Contains abundant pegmatite. Nearly massive, but somewhat foliated adjacent to quartz monzonite and to many of the faults. Map symbol queried where identification uncertain

qm

Quartz monzonite and associated rocks

Gray, weathering pinkish gray, weakly to strongly foliated rock consisting mainly of quartz, potassium feldspar, plagioclase, biotite, and subordinate amounts of muscovite. Locally pegmatitic or aplitic

hd hd

Hornblende diorite, melasyenodiorite, and hornblendite

Black or mottled black and white medium- to coarse-grained massive to well-foliated intrusive rocks. The diorite locally contains conspicuous quartz, biotite, and potassium feldspar

METASEDIMENTARY ROCKS

Order does not reflect age

gnc q gnb

Biotite gneiss and quartzite

Gray fine- to medium-grained migmatitic biotite gneiss and impure quartzite

gnb, *dominantly sillimanitic biotite-quartz gneiss with interlayers of biotite-quartz-plagioclase gneiss, and biotite-quartz gneiss*

gnc, *garnet- and cordierite-bearing lenses of sillimanitic biotite-quartz gneiss; grades into sillimanitic biotite-quartz gneiss*

q, *white, gray, and black fine- to medium-grained foliated impure quartzite*

86

Contact showing dip, approximately located

Dashed where inferred or gradational; dotted where concealed; queried where doubtful

60

Fault, showing dip and fault zone

Fault occupied by vein

Zones of shattered rock; many of them are siliceous, most of them are altered. Dashed where approximately located; short dashed where inferred; dotted where concealed; queried where doubtful

71

Minor drag fold, showing plunge

13 Inclined — Vertical — 9 Crenulated

Strike and dip of foliation

21

Bearing and plunge of mineral lineation

21

Bearing and plunge of fault grooves, striations, or slickensides

48 49

Strike and dip of foliation and bearing and plunge of lineation

65 90

Mineralized vein, showing dip

Dashed where inferred; dotted where concealed

qv

Quartz vein

Dashed where inferred; dotted where concealed; queried where doubtful

Mine or shaft

Name indicated locally

73

Shaft

Showing angle of inclination

Prospect pit

Portal of adit or tunnel

Trench

PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
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DWG DATE:	02.22.17	REV. DATE:	--

FIGURE 2

Geology Map Legend - 6126 Magnolia

CESARE, INC.

Geotechnical Engineers & Construction Materials Consultants

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

MEMO

Project Name: Boulder County Geotechnical and Geologic Hazard Consultation Services
Project No. 16.3097
From: Julia M. Frazier, P.G.
Date: February 3, 2017
Subject: Case Study Review
7010 South Boulder Road, Boulder, Colorado

The purpose of this memo is to summarize Cesare, Inc.'s (Cesare) opinions and recommendations related to geologic conditions which have the potential to impact certain properties currently or historically under review by the Boulder County (BoCo) Development Review Team (DRT) and to provide recommendations for future work toward developing criteria for geologic hazard related studies. Cesare's goal is to briefly discuss potential geologic hazards identified for each site based on available information and to provide potential site study recommendations.

7010 SOUTH BOULDER ROAD, BOULDER, COLORADO

Piedmont Subprovince
BoCo Designation: Moderate and Major Geologic Hazard Area

Maps:

Amuedo and Ivey, Inc., 1975, Coal Mine Subsidence and Land Use in the Boulder-Weld Coalfield, Boulder and Weld Counties, Colorado: Colorado Geological Survey, Environmental Geology No. 9.

Hart, S.S., 1974, Potentially Swelling Soil and Rock in the Front Range Urban Corridor, Colorado: Colorado Geological Survey, Environmental Geology 7.

Malde, H.E., 1955, Surficial Geology of the Louisville Quadrangle, Colorado: U.S., Geological Survey, Bulletin 996-E.

Roberts, S.B., Hynes, J.L., and Woodward, C.L., 2001, Maps Showing the Extent of Mining, Locations of Mine Shafts, Adits, Air Shafts, and Bedrock Faults, and Thickness of Overburden Above Abandoned Coal Mines in the Boulder-Weld Coal Field, Boulder, Weld, and Adams Counties, Colorado: United States Geological Survey, Geologic Investigations Series I-2735.

Spencer, F.D., 1961, Bedrock Geology of the Louisville Quadrangle, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-151.

Spencer, F.D., 1986, Coal Geology and Coal, Oil, and Gas Resources of the Erie and Frederick Quadrangles, Boulder, and Weld Counties, Colorado: United States Geological Survey, Bulletin 1619.

Turney, J.E., and Murray-Williams, L., 1983, Colorado Front Range Inactive Coal Mine Data and Subsidence Information, Boulder County: Colorado Geological Survey.

PRIMARY GEOLOGIC HAZARDS POTENTIALLY IMPACTING THE SITE

1. Mine subsidence.

2. Swelling Soils.

SITE CONDITIONS

The site is rectangle in shape and located in a generally flat lying and moderately developed area. The property is located near the northwestern extents of the mapped Boulder-Weld Coal Field. There are existing structures in the northern part of the property, with the remainder used for livestock and agricultural purposes. A drainage ditch traverses the center of the site going east-west. According to the Boulder County Geologic Hazard and Constraint Area map, part of the site and areas to the west and northwest are categorized as “major geologic hazard areas”. Based on published geologic mapping of the Louisville quadrangle (Malde, 1955; Spencer, 1961), the site is underlain by bedrock comprised of the Laramie Formation (claystone, shale, sandy shale, sandstone, and lignite). Bedrock dips are generally low lying in this area.

Based on the swelling soils map by Hart (1974), the site is underlain by soils and bedrock with high to very high swell potential. These categories are defined as:

“VERY HIGH SWELL POTENTIAL: This category includes only bedrock or weathered bedrock. The precautions listed below under “high swell potential” must be utilized. Although construction in these areas is often unavoidable, alternate non-construction uses might be considered for such areas.

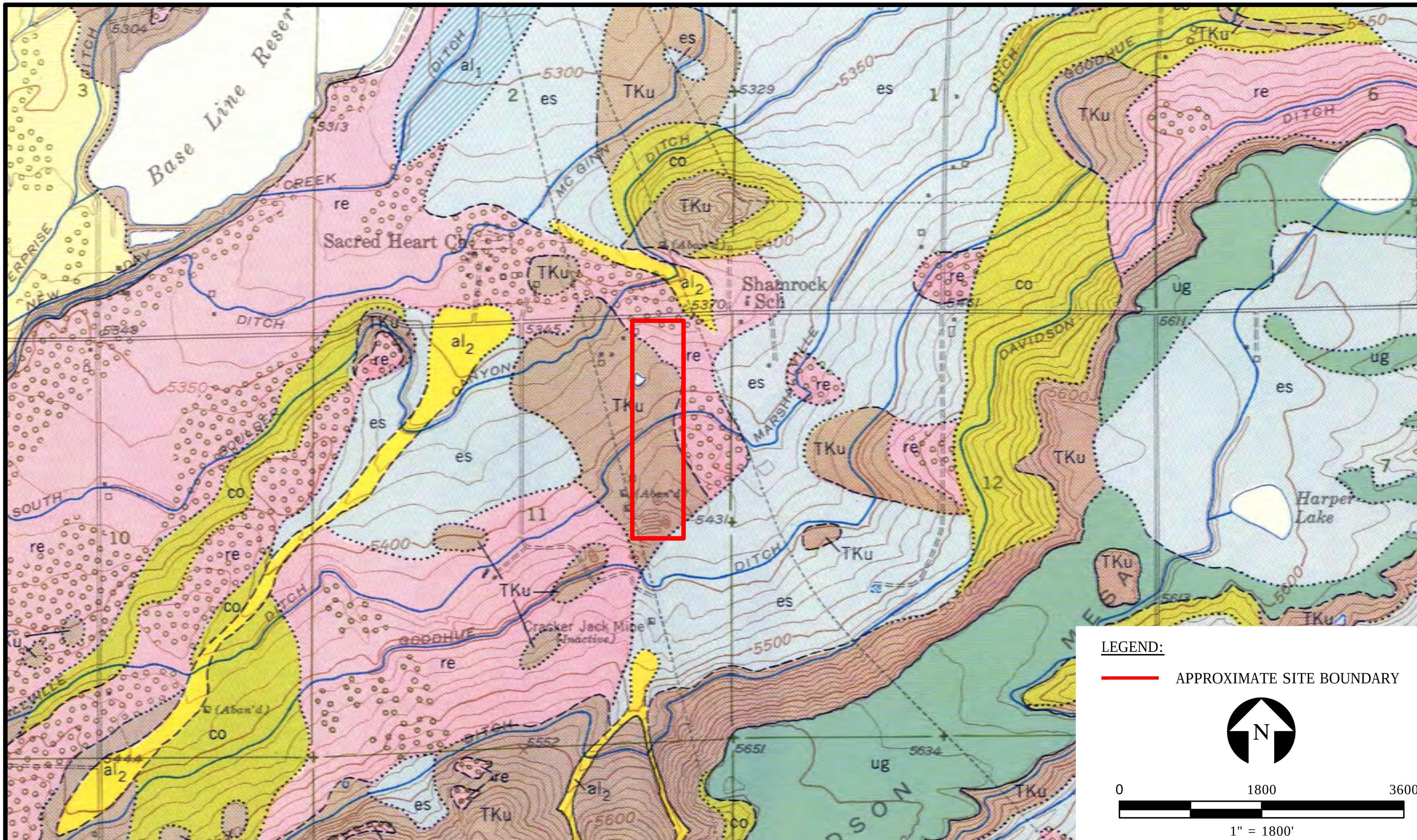
HIGH SWELL POTENTIAL: This category generally includes only bedrock, weathered bedrock and colluvium. Careful site investigation, special foundation design, and proper post-construction landscaping and maintenance are required to prevent or minimize damage.”

Based on available data, a significant part of the site is underlain by mine workings, with surface structures, such as adits, shafts, and a strip pit (located in the southern part of the property). Abandoned mine workings appear to be concentrated predominantly in the southern part of the property, however, undermined areas are also mapped to the northwest and some may underlie other portions of the site. Based on available data, including Amuedo and Ivey (1975), Turney and Murray-Williams (1983), Roberts and others (2001), and the Colorado Historic Coal Mine interactive map accessed from the CGS website, there is reason to suspect that other areas, besides just the southern part of the site, are underlain by mine workings.

RECOMMENDATIONS

Cesare recommends completion of geotechnical and subsidence hazard studies for the site. The potential for swelling soils at the site warrants a geotechnical study. Further characterization of the nature and extents of the potential subsidence hazard due to abandoned coal mines is especially warranted based on the brief review of available published data, which shows that the undermined areas at the site are not well defined and need to be characterized and delineated on a site specific basis. The subsidence hazard study should include review of historical maps and data, aerial photograph review, detailed surface mapping of mine related structures and subsidence features, proposed structure location alternatives with defined “no-build” zones, and potential remediation options.

W:\2016\Frederick Projects\16.3000\16.3097.G Boulder County Geotechnical-Geohazard Services\ACAD\3.1.17\Geologic Map - 7010 S Boulder Road.dwg 3/28/2017 12:37 PM



PROJECT NO:	16.3097		
PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
DRAWN BY:	RAB	CHECKED BY:	JMF
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FIGURE 1
Geology Map - 7010 S Boulder Road

CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

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EXPLANATION

f

Artificial fill
Fill at coal mines and along roadways not mapped. Outlined only at larger damsites

al_3

Post-Piney Creek alluvium
Reworked gravel (shown by pattern) locally overlain by 1 to 3 feet of noncalcareous sand and silt, which, along South Boulder Creek, is divisible into two units. Mapped only in flood plain of main streams

al_2

Piney Creek alluvium
Light to dark gray, slightly calcareous clay, silt, sand, and gravel prominent in upland valleys, along Coal Creek, and on fans at mouths of small valleys tributary to South Boulder Creek. Commonly more than 10 feet thick, even in small valleys

co

Colluvium
Ranges from stony to clayey, depending upon source material immediately upslope. Rarely more than 3 feet thick on gentle slopes

alg

Gravel fill
Cobble and pebble gravel containing scattered boulders. Chiefly confined to main valleys. Well rounded and granitic along South Boulder Creek; poorly rounded and quartzitic elsewhere. Brown and clayey horizon at top grades downward into moderately calcareous zone

al_1

Alluvial fill
Stratified clay, silt, and sand with gravel lenses. As much as 7 feet thick east of Base Line Reservoir. Brown clayey prismatic layer at top grades downward into a grayish-buff loamy calcareous layer

es

Eolian silt and sand
Largely structureless. Thickness exceeds 10 feet in northeast part of quadrangle. Distinctive soil profile developed on this deposit is correlated with the mid-Wisconsin soil of Nebraska and Kansas

cg

Cobble gravel
Coarse gravel along and partly under flood plain of South Boulder Creek. Rich in red sandstone from nearby foothills. Encrusted and partly cemented by calcium carbonate below a depth of 12 to 18 inches

re

Undifferentiated upland deposits
Strongly weathered alluvial, colluvial, and eolian deposits residual upon valley walls and lower interfluves. Gravelly areas shown by pattern. Impregnated with calcium carbonate below a red-brown clayey layer which is only locally preserved

tg

Terrace gravel
Strongly weathered gravel on terraces 150 feet or more above valley bottoms and related to present integrated drainage. The deposit reaches a maximum of 10 feet in thickness and locally contains much sand and silt. Calcium carbonate-impregnated layer is usually at the surface but is locally buried by residuum (re)

ug

Upland gravel
Strongly weathered gravel on Davidson Mesa, Lake Mesa, and pediment remnants (probably correlative) below Rocky Flats. Southern part reworked from older surficial deposits; northern part chiefly derived from source rocks in the mountains. Low-lime-content facies (shown by pattern) grades downslope into caliche facies

rf

Gravel on Rocky Flats
Pediment gravel; boulders and cobbles near mountain front, and cobbles and pebbles with sand lenses at eastern remnants. Strongly weathered. Ranges in thickness from less than 1 foot to about 50 feet on dissected, steeply dipping bedrock; average thickness is about 10 feet. Low-lime-content facies (shown by pattern) grades downslope into caliche facies

og

Old gravel
Boulder and cobble gravel on bedrock knob standing 40 feet above Rocky Flats. May once have been continuous with gravel on bench about 100 feet above Rocky Flats, 1 1/3 miles to the NNW. (In Eldorado Springs quadrangle)

TKu

Undifferentiated bedrock
Cretaceous Pierre shale, Fox Hills sandstone, Laramie and Arapahoe formations, and probably lower part of Denver formation on east border of quadrangle at the boundary of Boulder and Jefferson Counties. Paleocene strata may be present under Rocky Flats east of the Capitol mine

Contact located within 100 feet

Contact located within 300 feet

Contact obscure

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FIGURE 2
Geology Map Legend - 7010 S Boulder Road

CESARE, INC.
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W:\2016\Frederick Projects\16.3000\16.3097.G Boulder County Geotechnical-Geohazard Services\ACAD\3.28.17\Coal Undermine Map A - 7010 S Boulder Road.dwg 3/29/2017 3:49 PM

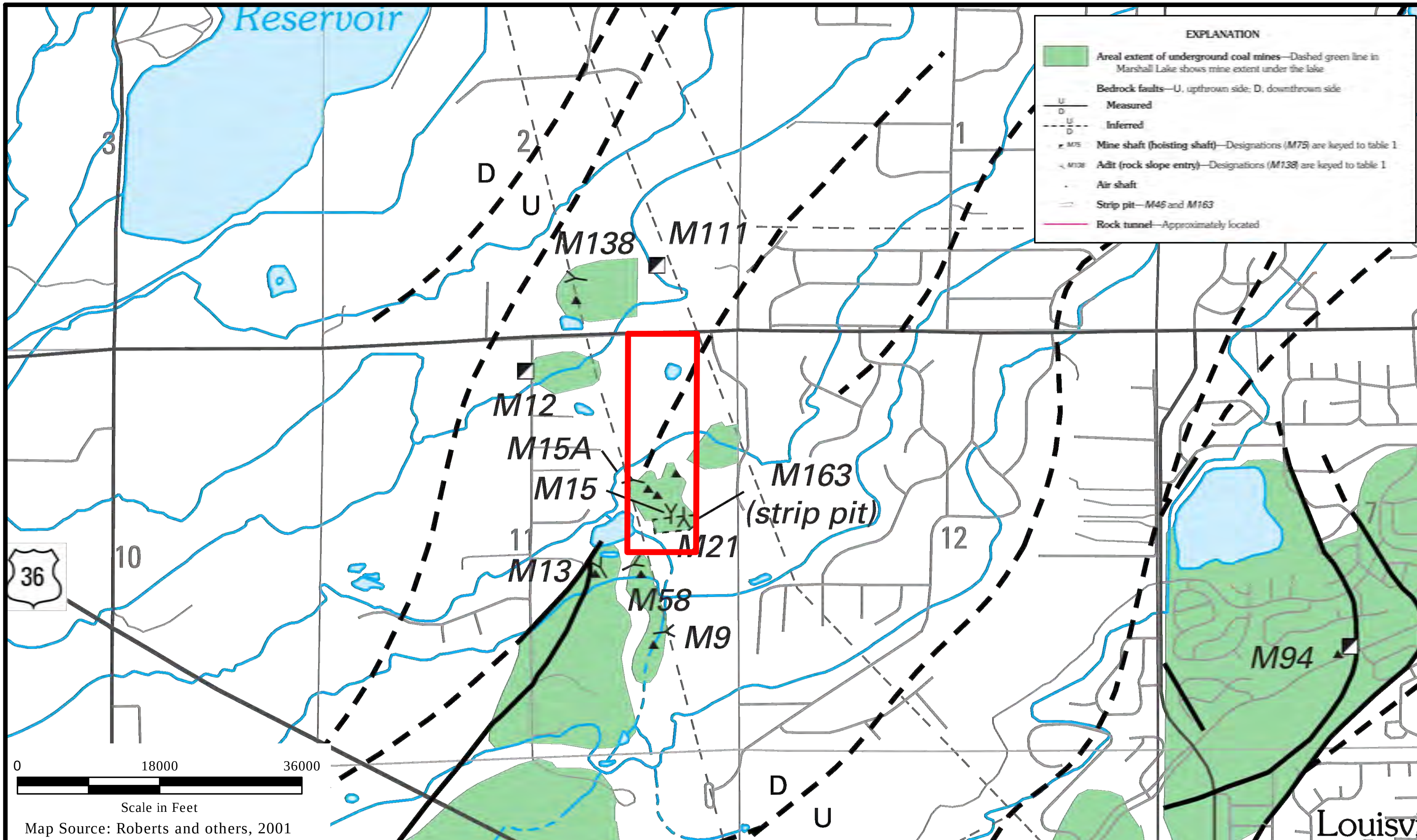

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FIGURE 3
Undermined Area Map- 7010 S Boulder Road

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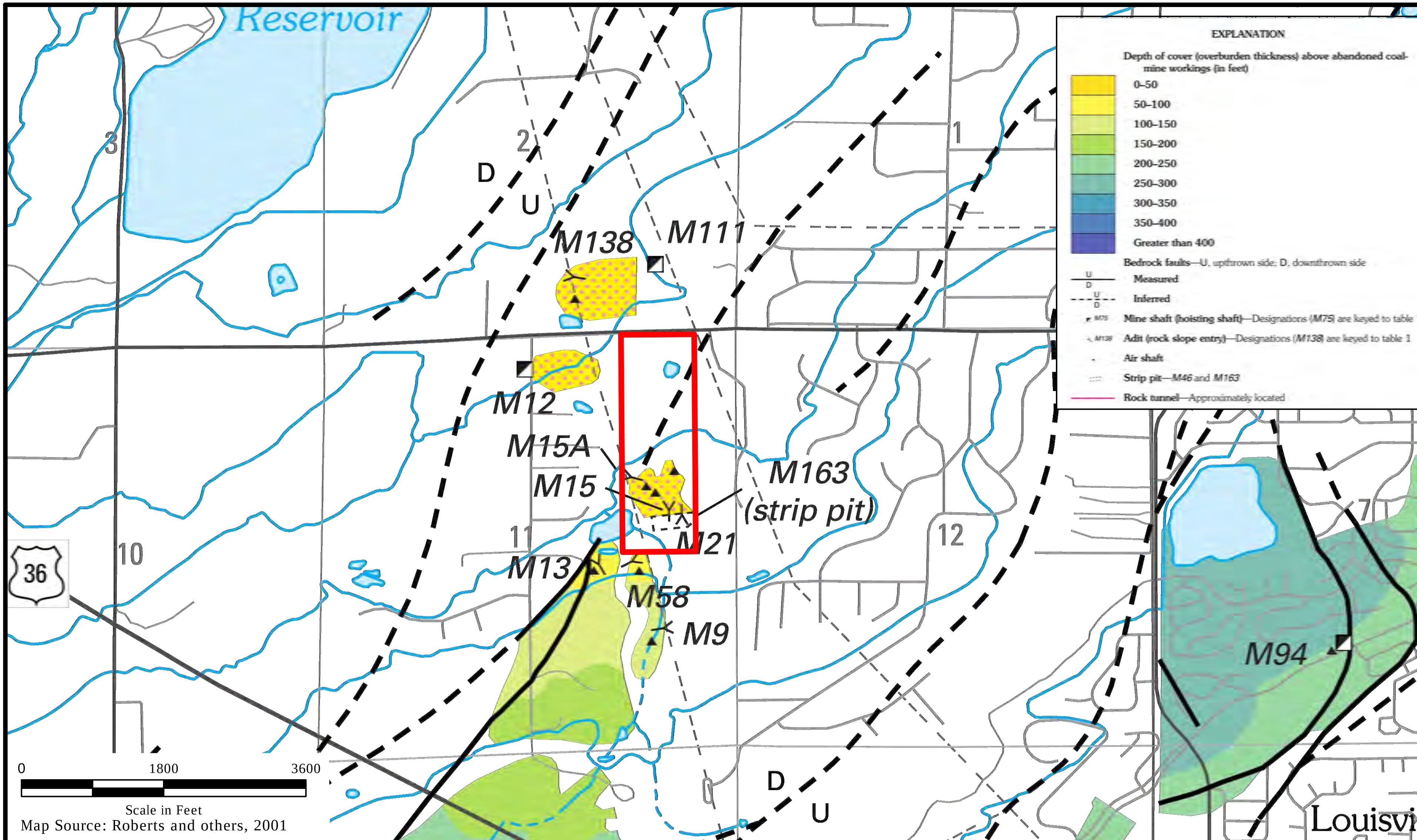

Map Source: Roberts and others, 2001

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PROJECT NAME:	Boulder County Geotechnical-Geohazard Services		
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FIGURE 4
Depth of Overburden - 7010 S Boulder Road

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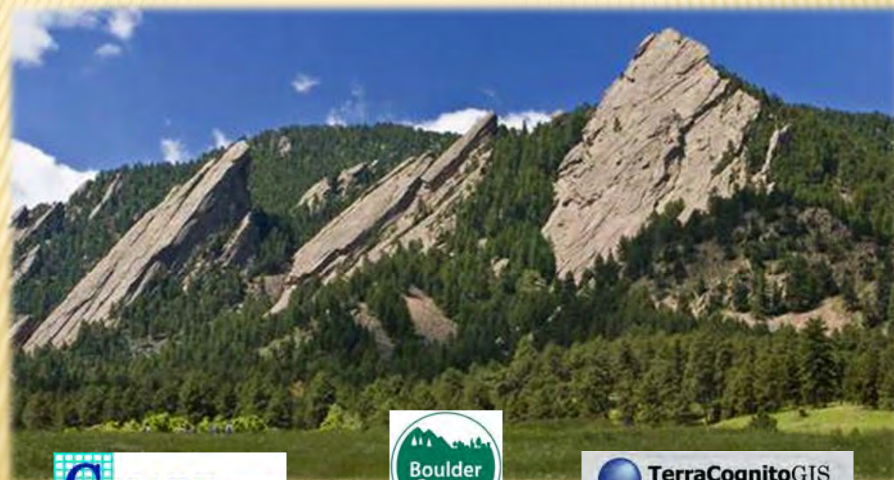
APPENDIX E

PowerPoint Slides from Cesare Workshop on February 7, 2017

BOULDER COUNTY GEOLOGIC HAZARDS



CESARE, INC.
Geotechnical Engineers & Construction Materials Consultants

Boulder County

TerraCognitoGIS
Spatial Analysis | 3D Visualization | Decision Support

AGENDA

- Geology and Geologic Hazards
- Geotechnical Land Use Guidelines
- Case Studies
- Geologic Hazard Mapping

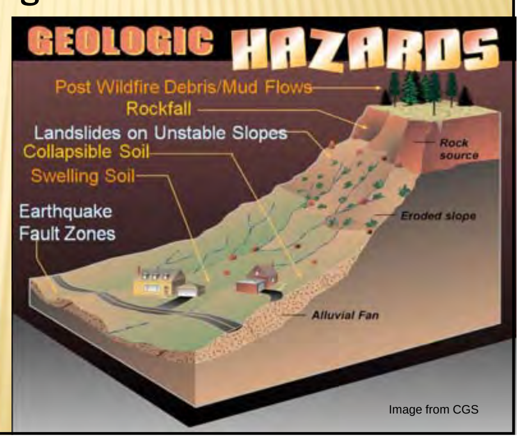
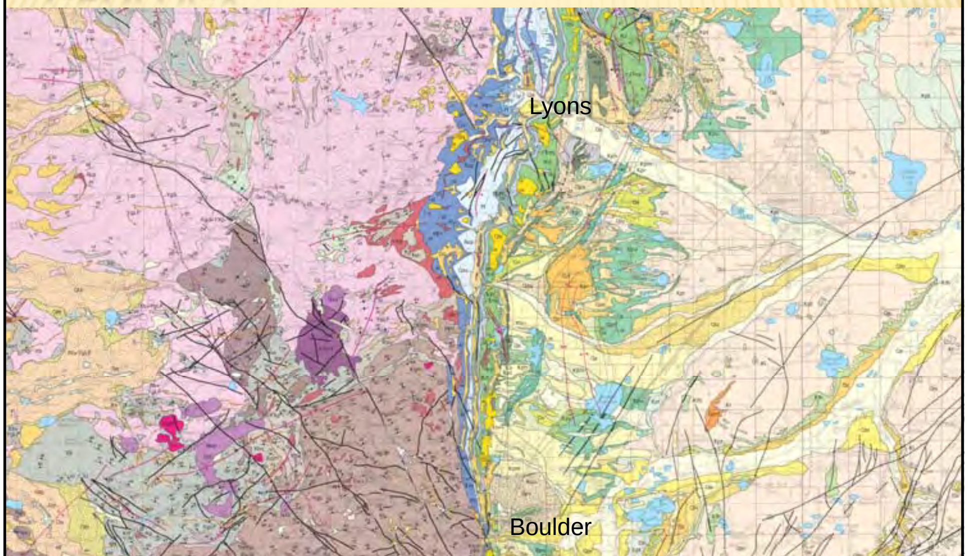


Image from CGS

GEOLOGY

Geology of Boulder County is diverse. The western two thirds is generally comprised of igneous and metamorphic basement rocks while the eastern one third is comprised of gently to steeply dipping sedimentary units (claystone, siltstone, sandstone, conglomerate) overlain by surficial deposits (alluvium, colluvium, landslide).

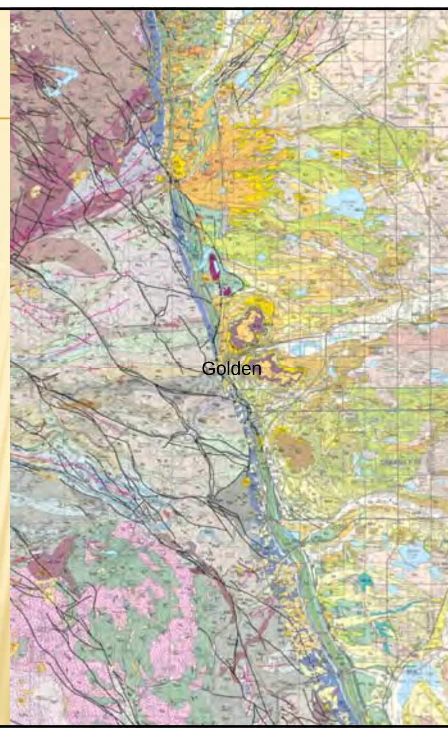


Cole and Braddock, 2009)

GEOLOGY

A view of the geologic diversity in Jefferson County, directly south of Boulder County. The steeply dipping sedimentary units which comprise the Front Range show up as the banded blue and green color units on the geology map. To the east of the front Range, these sedimentary units are generally more gently dipping and overlain by surficial deposits (yellow and orange on the map).

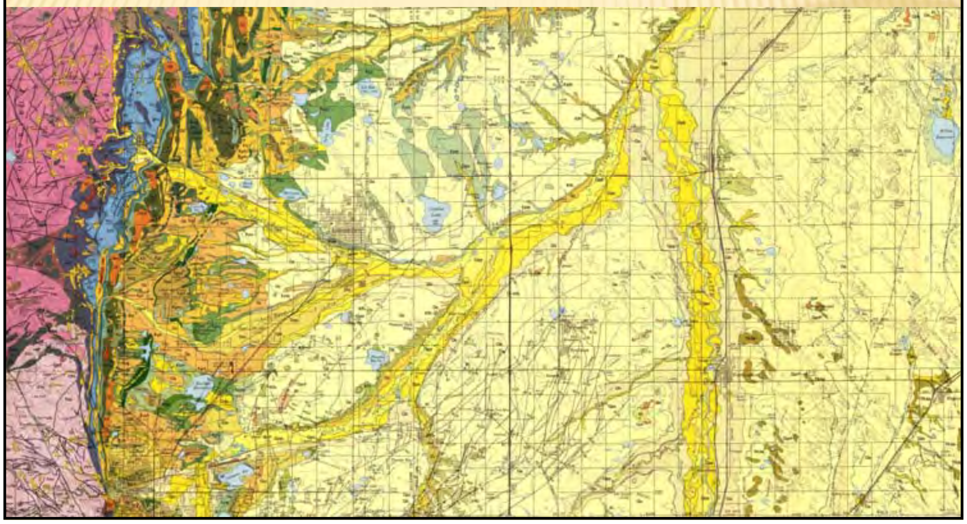
The igneous and metamorphic basement rocks west of the Front Range show as pink and purple colors on the map. The thick black lines depict faults (not active) in the Precambrian basement rocks. Folds appear as red lines on the map.



Cole and Braddock, 2009)

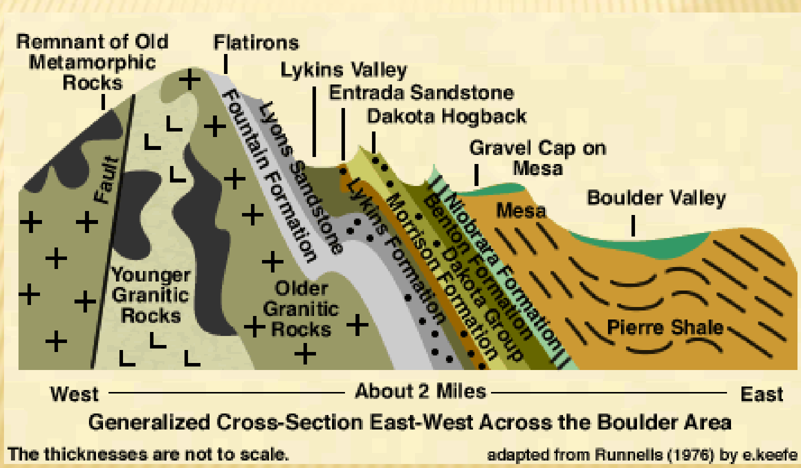
GEOLOGY

Another map depicting the Boulder County area. The City of Boulder is located in the bottom left corner. Notable in this map is the way the steeply tilted Front Range sedimentary units are interrupted and deformed by faults and folds in the Boulder County area. Also notable is how the eastern Piedmont area of Boulder County is predominantly covered in surficial soils (alluvium, colluvium, windblown deposits, landslides). The Boulder-Weld Coal Field area east of Boulder displays more mapped faults than other areas of the County, largely due to the level of detail this area was mapped due to the extent of mining.



GEOLOGY

Typical schematic cross section through Boulder County. Notice how the sedimentary strata of the Fountain Formation, Lyons Sandstone, Lykins Formation, and so on, is steeply tilted against the crystalline basement rocks. The Pierre Shale underlies a majority of the eastern part of Boulder County, and is generally gently to moderately dipping.



GEOLOGY

Boulder County is located near the northwestern edge of the administratively defined Denver Basin aquifer system. The Denver Basin is a structurally down-warped area comprised of a series of hydrogeologic units. This map depicts the extents of the Denver Basin aquifer system, with Boulder County in the northwest area.

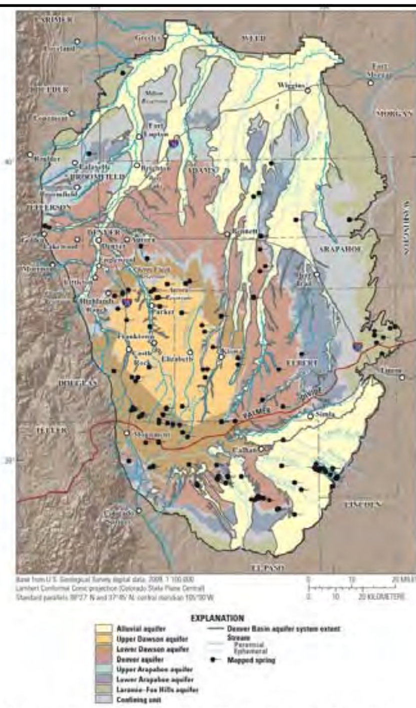


Figure A11. Location of springs and extent of Denver Basin aquifers and confining units.

GEOLOGIC HAZARDS IN BOULDER COUNTY

There are multiple geologic hazards impacting Boulder County, some of which include:

- **Landslides**
- **Rockfall**
- **Debris Flows and Fans**
- **Channel erosion, avulsion, and migration due to flooding**
- **Abandoned Mines and Undermined Areas**
- **Swelling Soils and Bedrock**
- **Steeply Dipping Heaving Bedrock**

West Salt Creek Landslide, Mesa County, CO

One example of a large scale and complex landslide in Colorado. Multiple failure modes are present.

LANDSLIDES

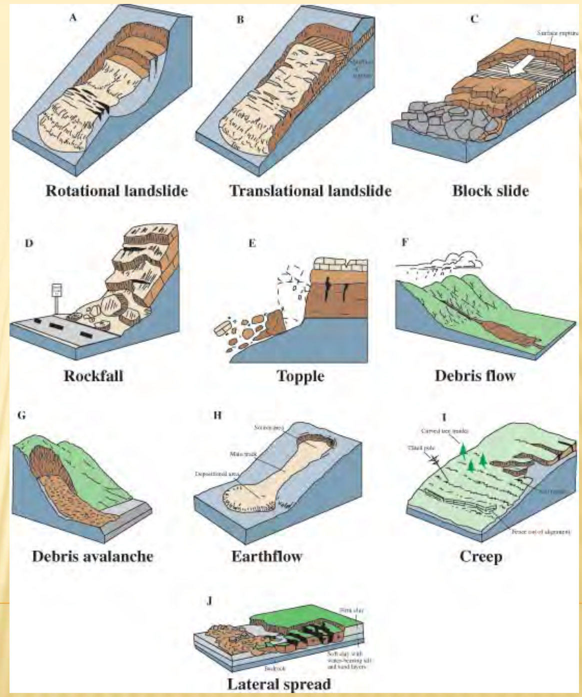
Photo from Critical Zone Laboratories

Caption reads:

Fig. 6. Fresh landslides were triggered during and after the flood along the foothills near Boulder. These are believed to be translational landslides that evolved into debris flows (J. Godt, pers. comm.). (Photo credit Nate Rock, Oct. 3, 2013).

LANDSLIDES

Landslide is a somewhat broad term which actually includes many different types of slope failures and mass movements. Some are depicted in this figure.



LANDSLIDES

LANDSLIDE CAUSES

There are many causes of landslides.
One of the primary causes is water related.

Landslides are closely related to flooding, precipitation, snowmelt, runoff, and saturation of water into the ground and subsurface materials.

Key **water-related** contributors to slope instability:

- Intense, long duration rainfall
- High levels of snowmelt
- Water level changes – groundwater, coastline, earthen dams, lakes, reservoirs, canals, rivers
- Broken utility lines

LANDSLIDE CAUSES

Other Landslide Causes Include:

1. Geology

- Weak or slide-prone materials
- Weathered materials prone to sliding
- Sheared, jointed, or fissured materials
- Adversely oriented discontinuities (bedding, contacts, foliation, faulting, unconformity between units, etc.)
- Contrast in material properties (permeability and/or stiffness)

2. Geomorphology

- Tectonic or volcanic
- Glacial rebound
- Fluvial, wave, or glacial erosion
- Subsurface erosion (solution, piping)
- Sediment deposition which loads the slope or crest
- Vegetation removal (wildfire, drought)
- Thawing
- Freeze-thaw action
- Shrink-swell action

LANDSLIDE CAUSES

3. Human causes

- Excavation of slope or landslide toe
- Loading of slope or crest
- Broken utilities
- Drawdown of reservoirs
- Deforestation
- Irrigation
- Mining
- Artificial vibration

LANDSLIDES

Advice for Homeowners
(adapted from the U.S. Geological Survey website)

1. Do not build near:
   - Steep slopes.
   - Close to mountain edges.
   - Near drainage ways.
   - Near natural erosion valleys.
   - Areas known to have slope instability in the past.

2. Assess the ground conditions and slope stability of your property.

3. Contact local officials, state geological surveys or departments of natural resources, and university departments of geology. Landslides occur where they have before, and in identifiable hazard locations. Ask for information on landslides in your area, specific information on areas vulnerable to landslides, and request a professional referral for a very detailed site analysis of your property, and corrective measures you can take, if necessary.

LANDSLIDES

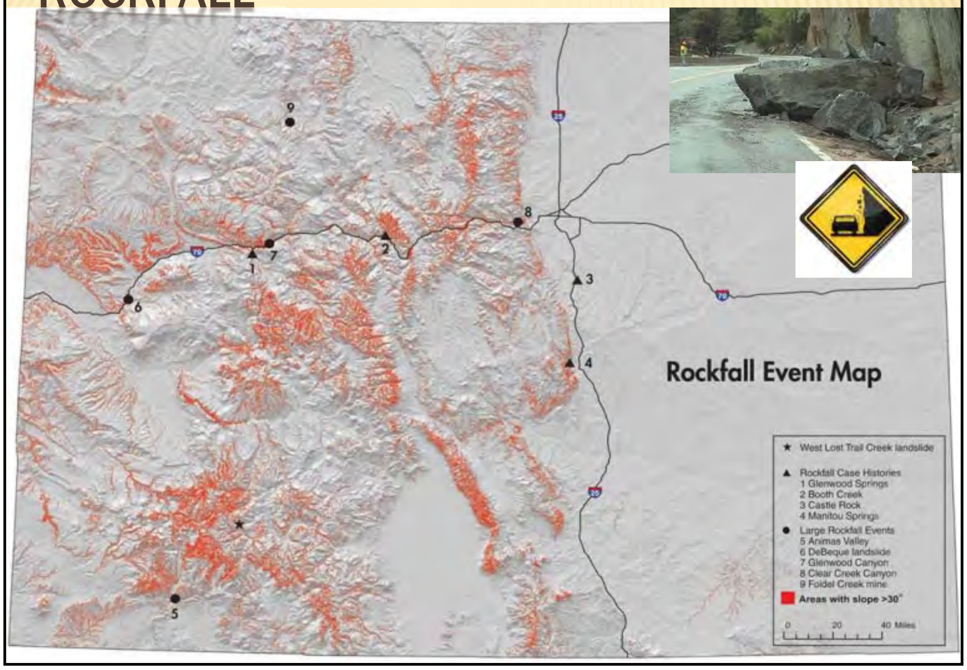
Advice for Homeowners (cont.)
(adapted from the U.S. Geological Survey website)

4. Watch the patterns of storm-water drainage near your home, and note the places where runoff water converges, increasing flow in channels. These are areas to avoid during a storm.

5. Learn about the emergency-response and evacuation plans for your area. Develop your own emergency plan for your family or business.

6. Minimize hazards to your home:
   - Flexible pipe fittings to avoid gas or water leaks - flexible fittings are more resistant to breakage.
   - Plant ground cover on slopes.
   - Build retaining walls.
   - In mudflow areas, build channels or deflection walls to direct the flow around buildings.
   - *Remember*: If you build walls to divert debris flow and the flow lands on a neighbor's property, you may be liable for damages.

ROCKFALL



DEBRIS FLOWS/FANS

Photo from Critical Zone Laboratories. Caption Reads:
Fig. 11. Aerial view of debris flows on Porphyry Mountain west of Jamestown, Colorado. Porphyry Mountain is a quartz monzonite porphyry intrusion into heavily faulted PreCambrian rocks (Photo by Nate Rock, Oct. 3, 2013).

Debris flows are hyperconcentrated, often channelized, mass movements of loose soil, rock and possibly vegetation which are mixed with water to form a slurry that flows rapidly downslope. Rotational or translational landslides may evolve into a debris flow.

CHANNEL EROSION

Channel erosion
Channel avulsion
Channel migration

The Colorado Water Conservation Board is currently in the planning phases of mapping Fluvial Hazard Zones (FHZ) across Colorado. The FHZ is closely linked to hydrologic and geomorphic factors.

The FHZ defines:
- Active river corridors
- Erosion hazard areas
- Avulsion hazard areas
- Alluvial fans

Caption reads: The floods have taken out huge portions of James Canyon Drive east and west of Jamestown, CO on September 15, 2013. (Photo By Helen H. Richardson/ The Denver Post)

CHANNEL EROSION

This image depicts how alluvial fans appear and can be identified using LiDAR imagery. Deeply incised drainages are associated with each of the three alluvial fans identified with red arrows.

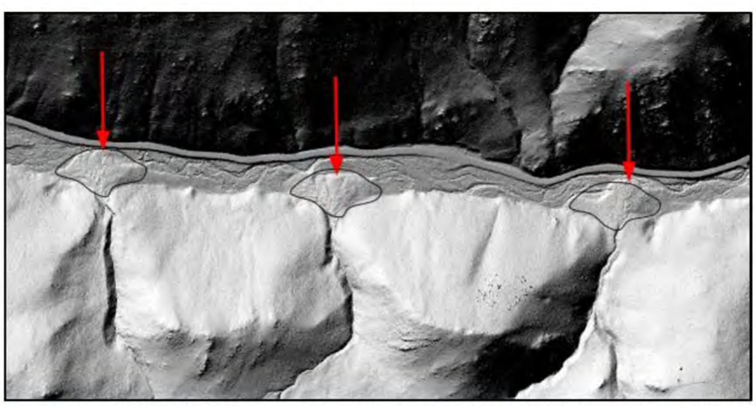
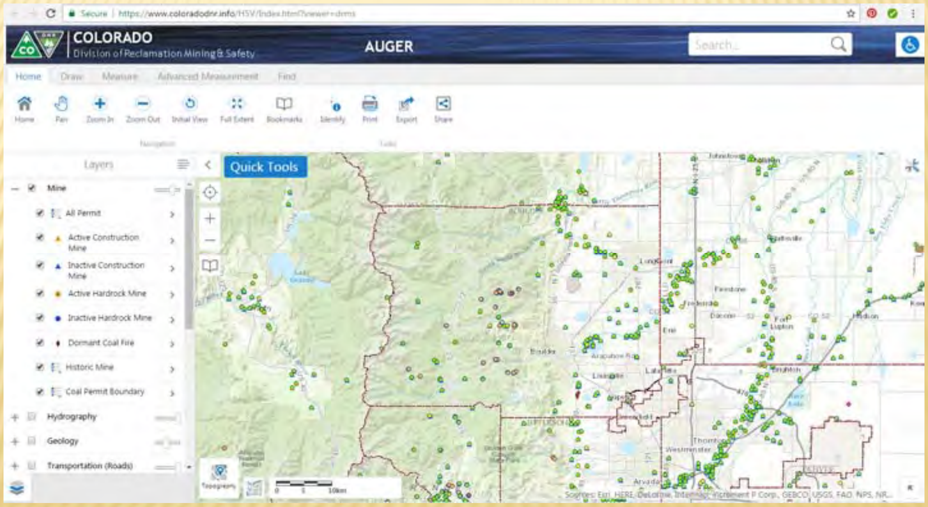


Figure 9: Alluvial fans or debris cones (red arrows) formed at the mouth of small side drainages as they enter the active river corridor of Colorado's Lefthand Creek.

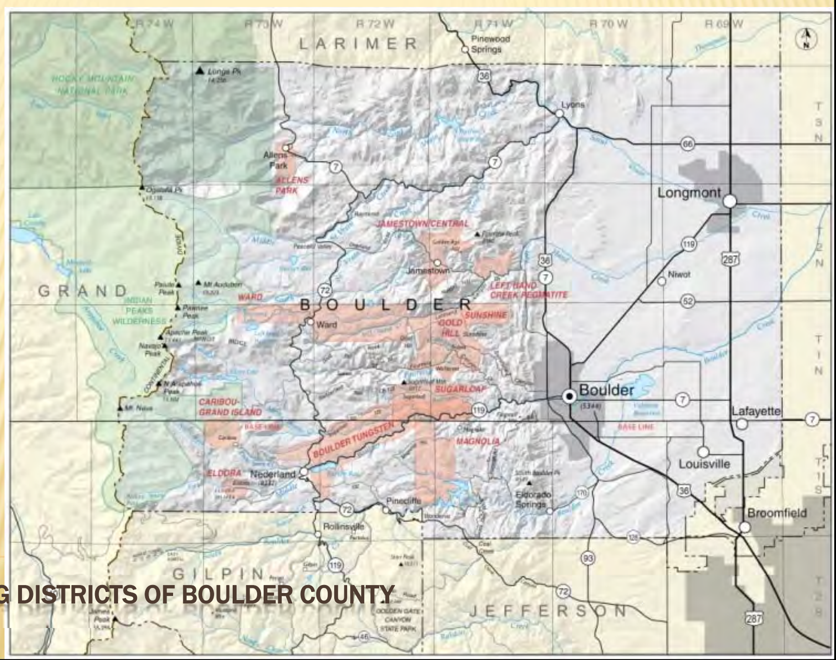
From Jagt et al, 2016, Fluvial Hazard Zone Delineation, A Framework for Mapping Channel Migration and Erosion Hazard Areas in Colorado (accessed from CHAMP website)

MINES

Division of Reclamation Mining & Safety online mine map.
This is one tool to use to quickly check the site for mine-related information.



Hard rock mining districts in Boulder County appear in pink.

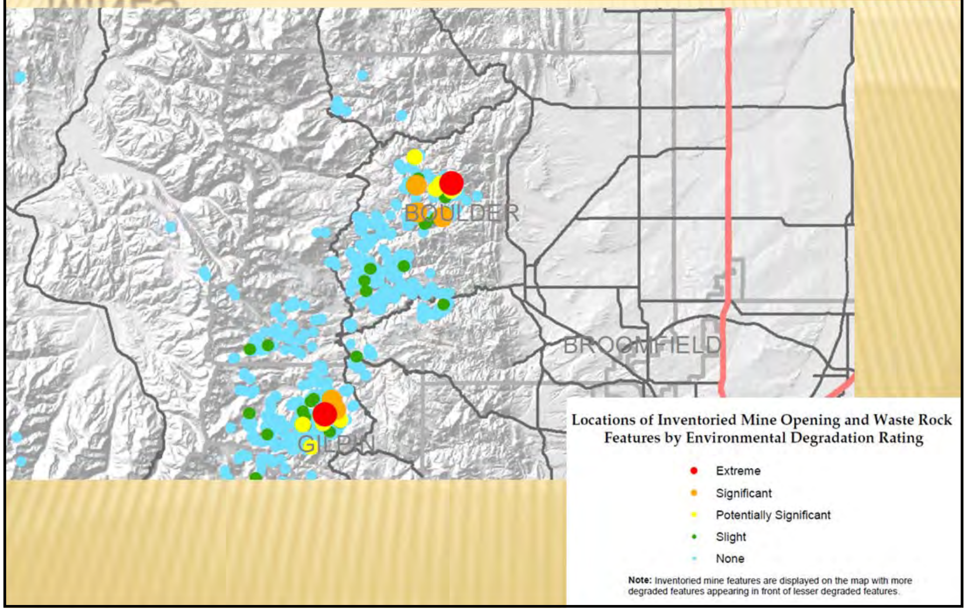


MINING DISTRICTS OF BOULDER COUNTY

MINES

US Forest Service Abandoned Mine Lands Inventory - Mine opening features

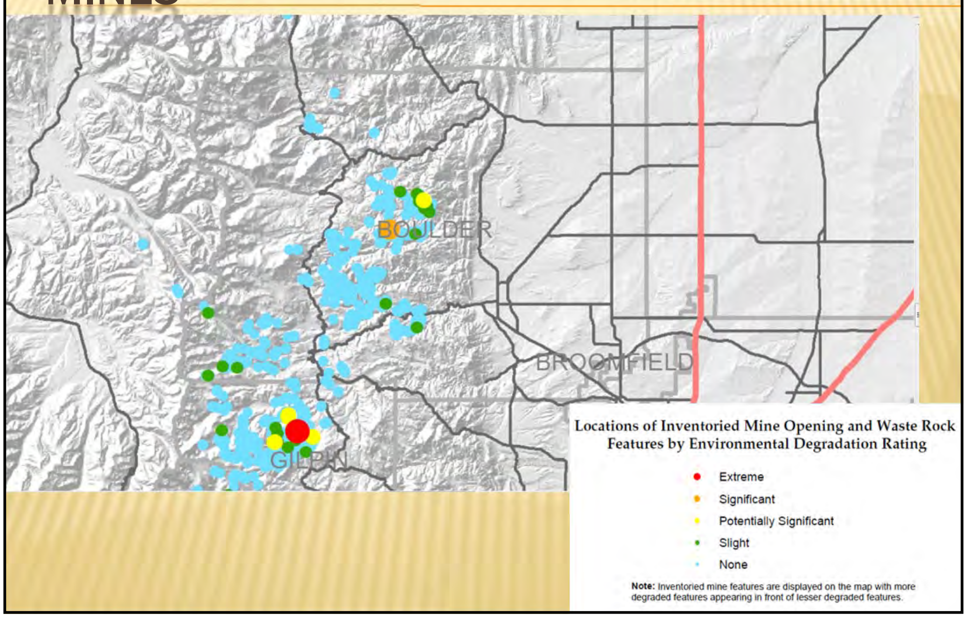
Another resource for information.



MINES

US Forest Service Abandoned Mine Lands Inventory - Mine waste rock features

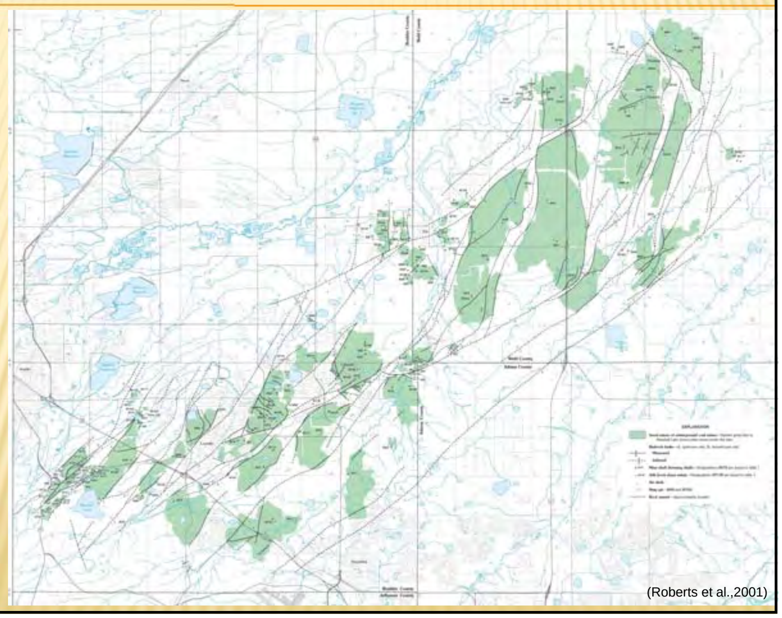
Another resource for information.



MINES

Extent of Abandoned Coal Mine Workings and Locations of Mine Shafts, Adits, Air Shafts, and Faults

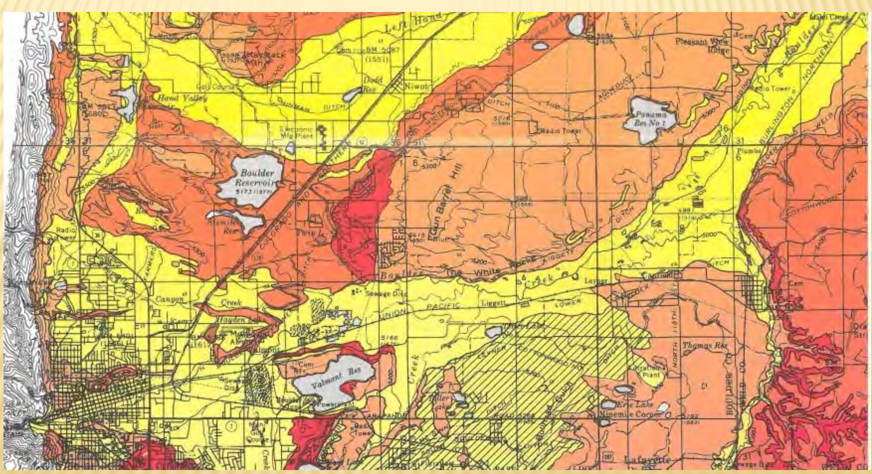
It is important that all available information on mine extents is reviewed and assessed for proposed development within and near areas with underground mine workings. Various maps may exist for one area, and all need to be considered. Maps may be incomplete, incorrect, or not exist at all for a certain area. Site specific study by a qualified professional is recommended for potentially undermined areas.



(Roberts et al.,2001)

SWELLING SOILS AND BEDROCK

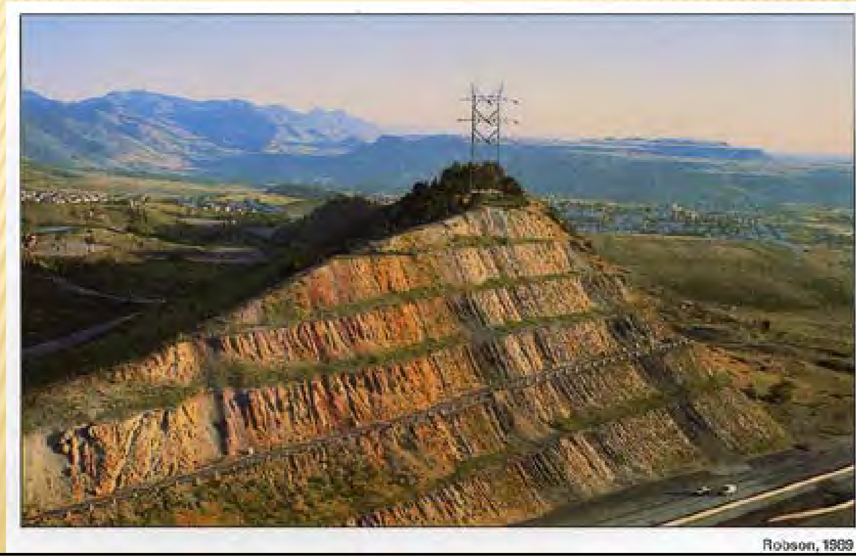
Swelling soils and bedrock has been well-mapped for the area of Boulder County east of the Front Range. The hazard related to this geologic condition is considered low to non-existent in the mountainous areas west of the Front Range. Areas underlain by swelling soils and bedrock with moderate to very high swell potential rankings would require a site specific geotechnical study.



(Hart, 1974)

STEEPLY DIPPING HEAVING BEDROCK

Steeply dipping bedrock units exposed in a roadcut along I-70 in the area of Golden, Colorado. Stratigraphic layers with high swell potential can cause problematic and highly destructive differential foundation heave.

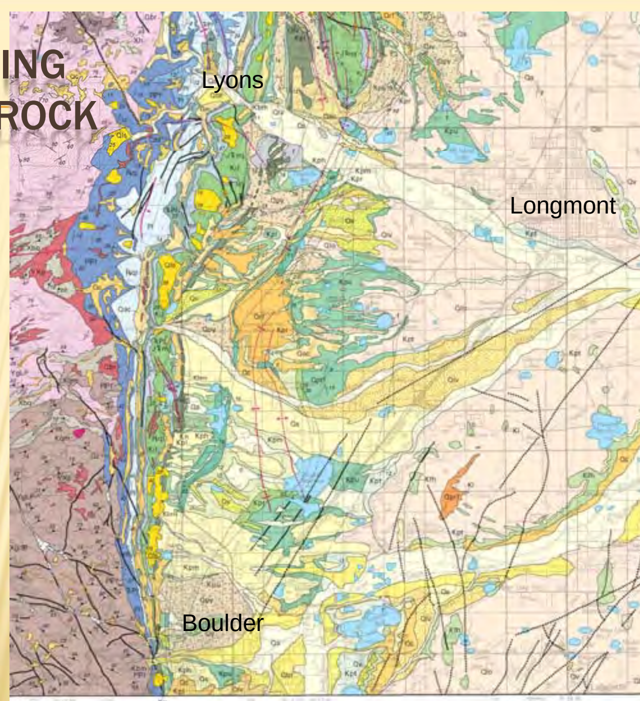


STEEPLY DIPPING HEAVING BEDROCK

The geology map shows the steeply dipping bedrock units as thin bands along the Front Range (blue and green colors). The hazard is also present in areas to the east where bedrock is steeply dipping but is covered with surficial soils of varying thickness. It is up to the results of the site specific study to determine whether there is sufficient amount of low swell potential surficial soil cover or if the development plans will require overexcavation or deep foundation recommendations.

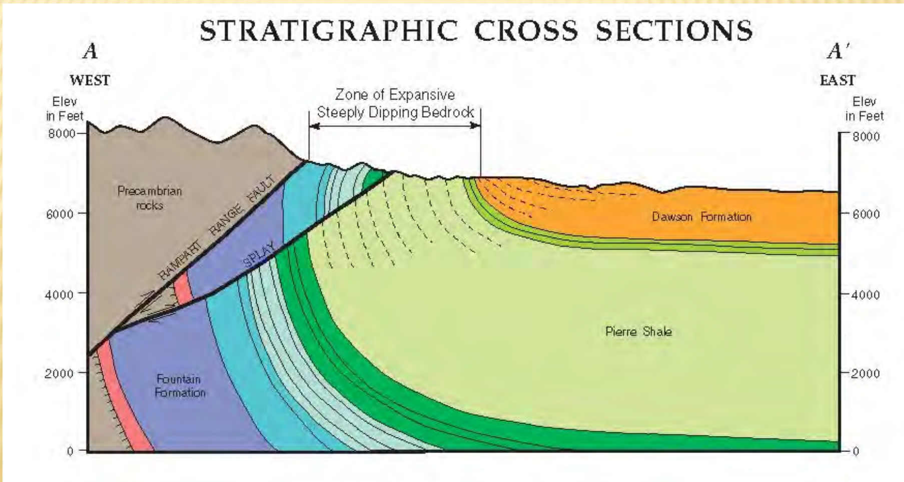
The steeply dipping heaving bedrock hazard zone is defined as those areas that meet the following criteria:

1. Sedimentary layers with high swell potential comprise a significant percentage of the unit which underlies the area.
2. Dip angle is 30 degrees or steeper.



STEEPLY DIPPING HEAVING BEDROCK

Cross section shows steeply dipping units in the area of Colorado Springs. Shows how the sedimentary units are abruptly and steeply tilted near the mountains and become gently dipping toward the east.



(Himmelreich and Noe, 1999)

STEEPLY DIPPING HEAVING BEDROCK

This figure shows areas in Jefferson, Douglas and El Paso Counties with historically documented locations where the destructive forces of steeply dipping heaving bedrock have been recorded.

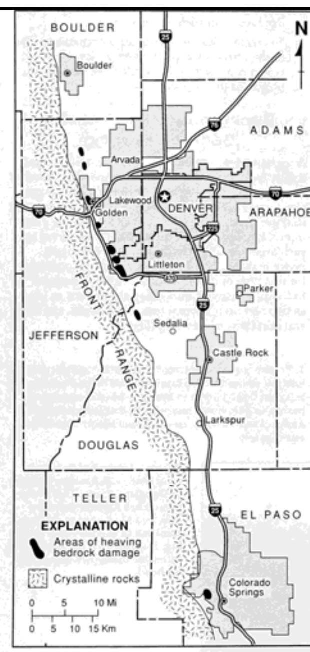


Figure 2. Index map of the Front Range piedmont in Jefferson, Douglas and El Paso Counties, Colorado, showing generalized areas where heaving bedrock damage has occurred.

(Noe et al, 2007)

STEEPLY DIPPING HEAVING BEDROCK

A useful stratigraphic column showing the bedrock units exposed in Douglas County (also exposed in Boulder County). The figure shows the units which meet the two criteria for the steeply dipping heaving bedrock hazard.

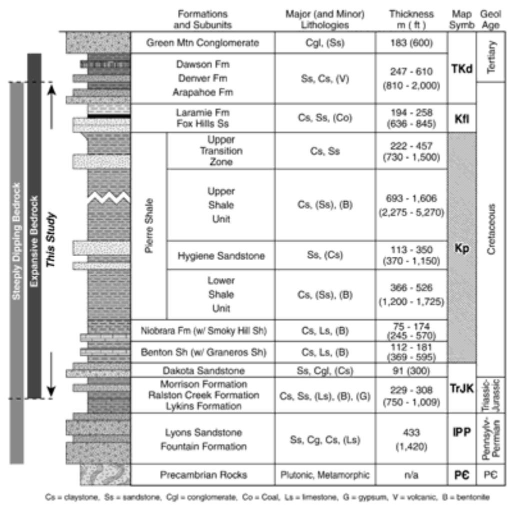
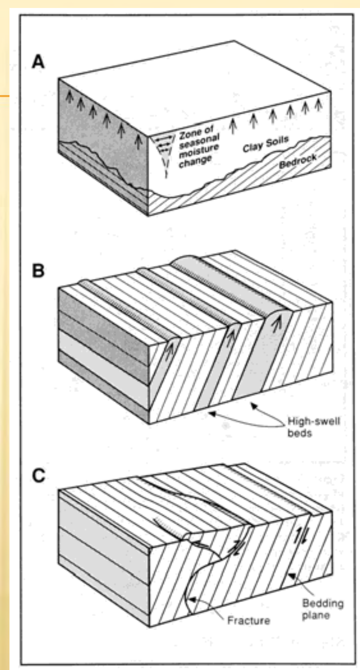


Figure 6. Stratigraphic section and geological characteristics of sedimentary formations in the study area. See Figure 1 for related geologic map. The Kp interval (shaded) is of marine origin; all of the other intervals are mostly non-marine. Figure was modified from LeRoy (1955) and LeRoy and LeRoy (1978).

(Noe et al, 2007)

STEEPLY DIPPING HEAVING BEDROCK

Photograph shows the potentially disruptive nature of this hazard on public roadways. The block diagrams to the right help visualize the hazard and how the high swell potential layers act when wetted.



(Noe et al, 2007)

STEEPLY DIPPING HEAVING BEDROCK

Figure 8. Photograph of a basement excavation in the steeply dipping Morrison Formation at site RD. Several distinct layers of claystone and siltstone (dark- to light-gray tones) and sandstone (white) underlie this house site. Image is from Noe and Dodson (1999); used by permission.

(Noe et al, 2007)

GEOTECHNICAL LAND USE GUIDELINES

Existing geotechnical land use guideline table from the Geology Element of the Boulder County Comprehensive Plan.

GEOTECHNICAL LAND USE GUIDELINES

TABLE 2.5 GEOTECHNICAL LAND USE GUIDELINES

GEOTECHNICAL LAND USE GUIDELINES

Subprovince	Geologic Hazard or Constraint	Map Symbol	Land Use Guidelines	Recommended Reports: Soil	Geology	Subsidence	Flooding
Piedmont	Landslides, expansive soil	1xl	Developable subject to recommended reports.	x	x		
	Flooding, expansive soil	1fx		x	x		x
	Landslides, subsidence, expansive soil	1slx	Strongly recommend non-structural land use unless subsidence hazard can be clearly shown to be non-existent.	x	x	x	
	Flooding, subsidence, expansive soil	1sxfl		x	x	x	x
Foothills	Landslides, expansive soil	?	Developable subject to recommended reports.	x	x		
	Flash flooding	2ff	These stream channels and associated floodways are subject to flash flooding and mountain torrent scouring. See the section on "Flash Floods or Mountain Torrents" for interim land use guidelines.	x	x		x
	Soil creep, landslides, rock-falls, expansive soil	21crx & 21xcr	Excluding those areas subject to subsidence risk and mountain torrents, these areas are the most critical with respect to urban or suburban development. The impact of geologic hazards on foundations, slope stability, grading plans, retaining walls, and septic drain fields should be carefully appraised.	x	x		
	Soil creep, landslides, rockfalls	2rlc	These areas have geologic hazards similar to 21crx and 21xcr except that, in general, the expansion indices of the soil or rock should be non-critical.	x	x		
Montane	Flash flooding	3ff	These stream channels and associated floodways are subject to flash flooding and mountain torrent scouring. See the section on "Flash Floods or Mountain Torrents" for interim land use guidelines.	x	x		x
	Soil creep, landslides,	3rcl	Developable subject to recommended reports. Recommended minimum horizontal spacing between wells and septic drain fields is 250 feet.	x	x		
Alpine	Avalanches, soil creep, land-slides, rockfalls	4erc	Developable subject to recommended reports. Recommended minimum spacing between wells and septic drain fields is 250 feet.	x	x		

2-39

GEOTECHNICAL LAND USE GUIDELINES

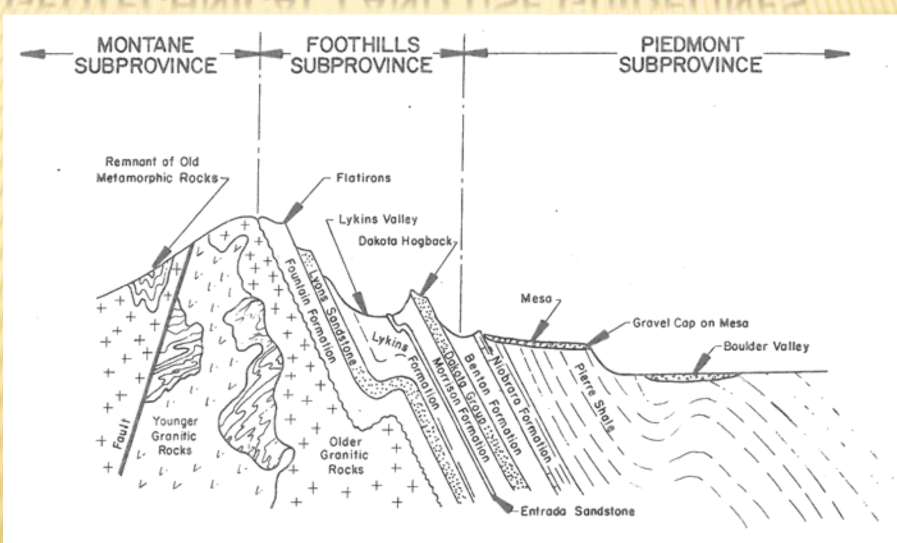


Figure 2C Generalized Geologic Cross-Section From Geology Element of BCCP (1983)

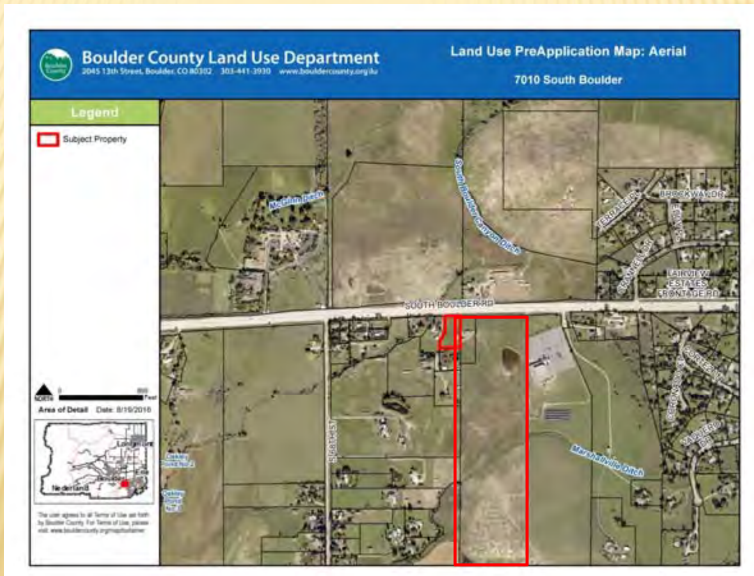
CASE STUDIES

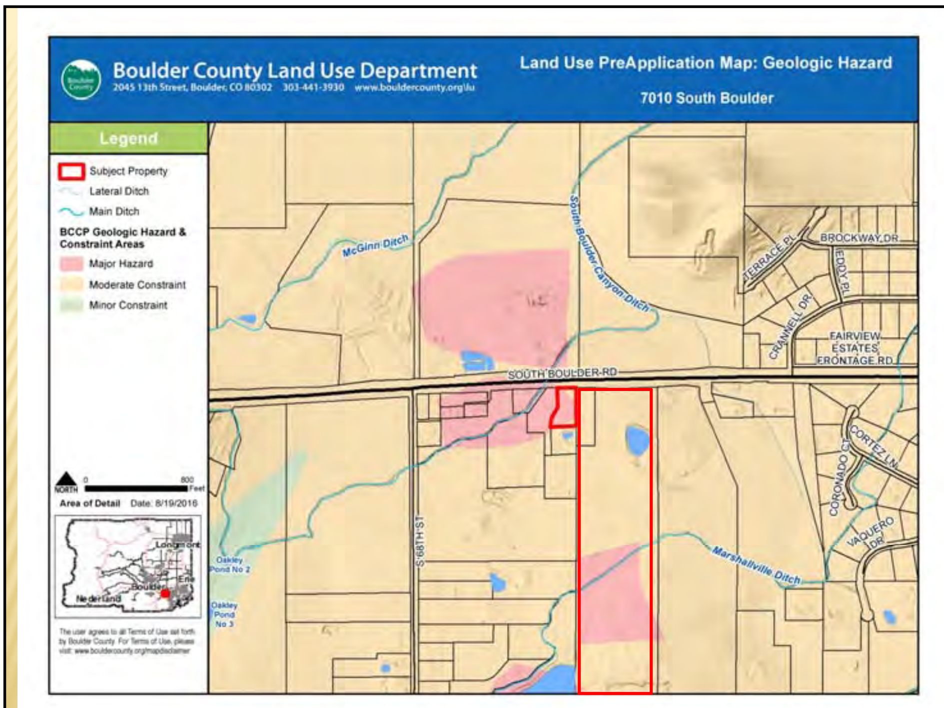
CASE STUDY 1

7010 South Boulder Road, Boulder
Piedmont Subprovince – east of the foothills
Southeast of Baseline Reservoir

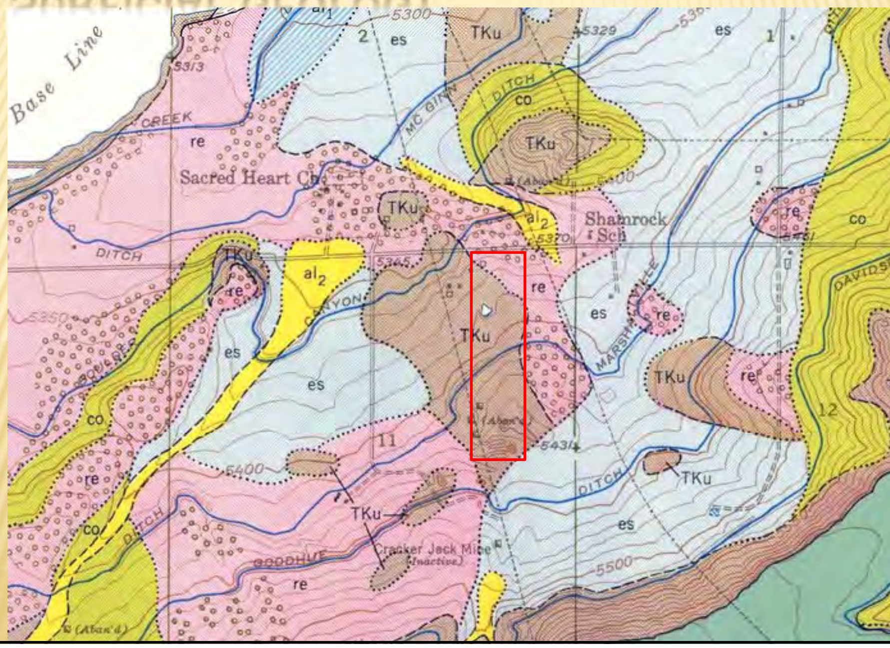
Geohazard Concerns:
Undermined area
Visible sinkholes onsite
Swelling soils

CASE STUDY 1


Boulder County Land Use Department
Land Use PreApplication Map: Aerial
7010 South Boulder
Legend
Subject Property
SOUTH BOULDER RD
McGinn Ditch
Marshallville Ditch

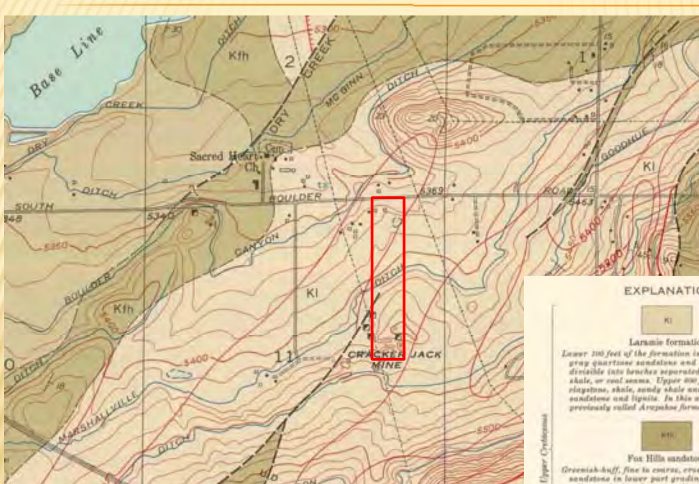

Boulder County Land Use Department
2045 13th Street, Boulder, CO 80302 303-441-3930 www.bouldercounty.org/lu
Land Use PreApplication Map: Geologic Hazard
7010 South Boulder
Legend
Subject Property
Lateral Ditch
Main Ditch
BCCP Geologic Hazard & Constraint Areas
Major Hazard
Moderate Constraint
Minor Constraint
Area of Detail Date: 8/19/2016
McGinn Ditch
South Boulder Canyon Ditch
SOUTH BOULDER RD
BROCKWAY DR
TERRACE PL
EDDY PL
CRANNELL DR
FAIRVIEW ESTATES FRONTAGE RD
CORTEZ LN
CORONADO CT
VAQUERO DR
Marshallville Ditch
S 68TH ST
Oakley Pond No 2
Oakley Pond No 3
Longmont
Boulder
Nederland
Erie

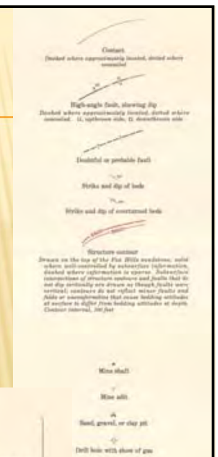
SURFICIAL GEOLOGY

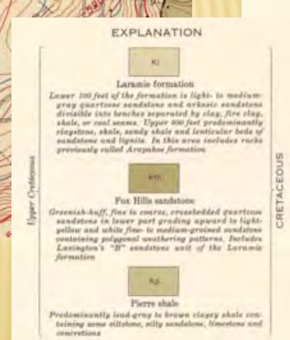


BEDROCK GEOLOGY

Geology maps often display other useful information besides just geology, including mine workings.

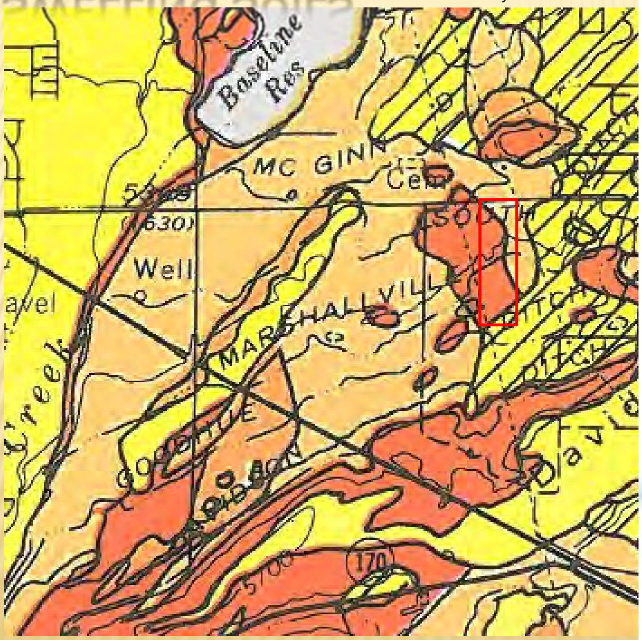


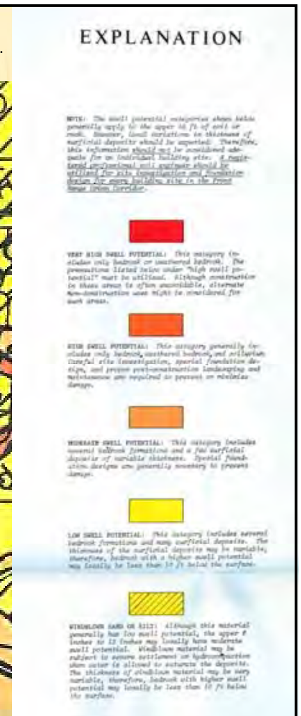




SWELLING SOILS

Site is underlain by soils/bedrock with high to very high swell potential. Geotechnical Study recommended.

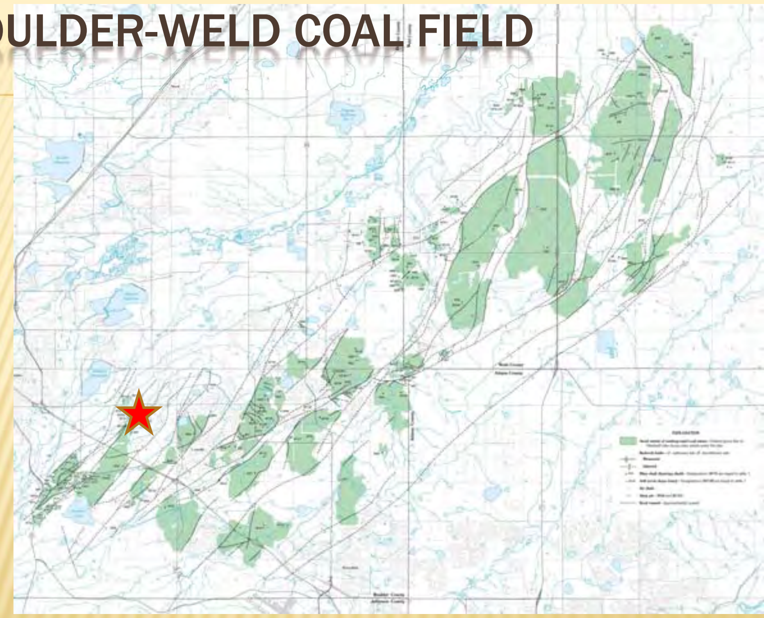




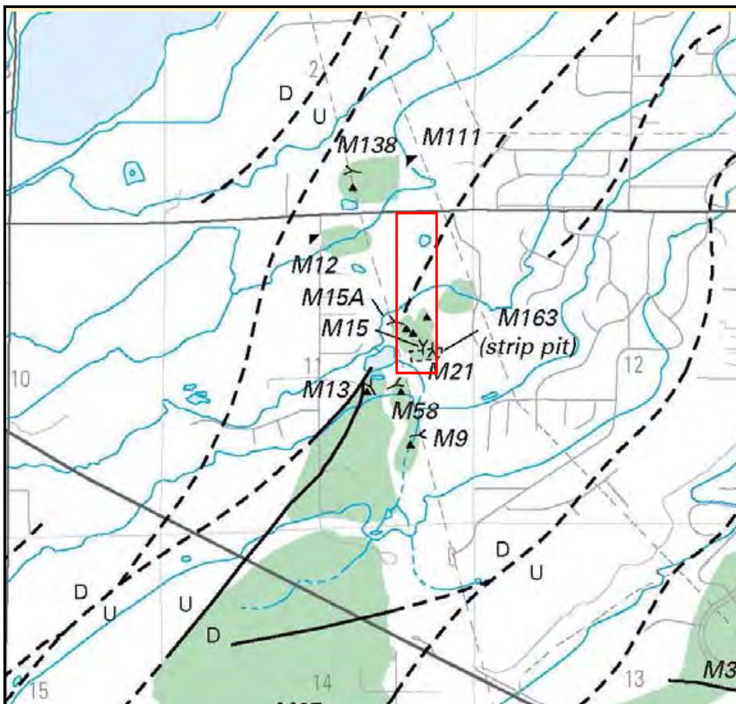
CASE STUDY 1

Photograph taken during site meet with property owner. One example of a sinkhole feature near the southern part of the property.

BOULDER-WELD COAL FIELD

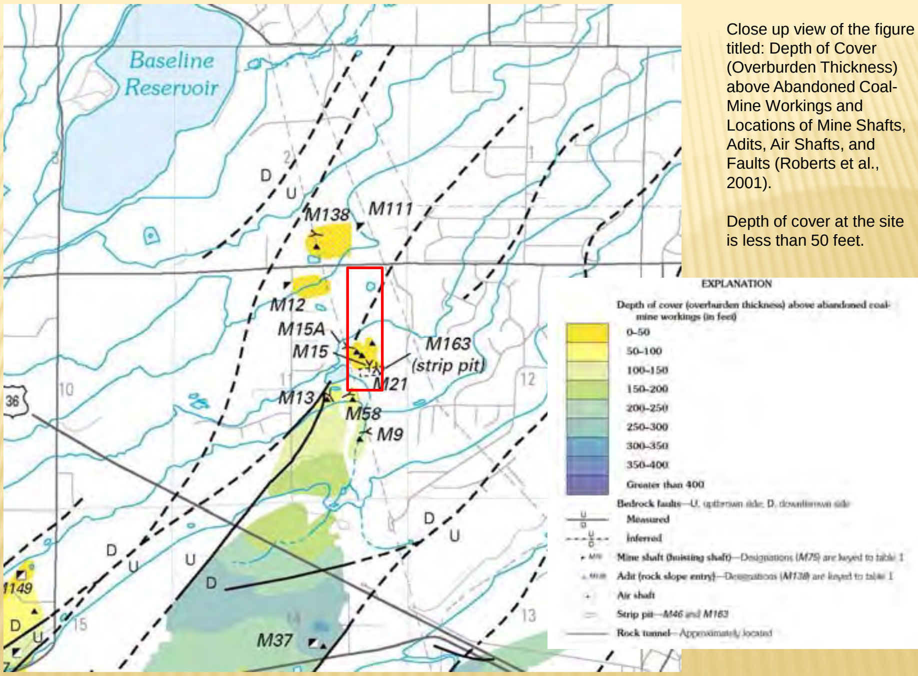


Extent of Abandoned Coal-Mine Workings and Locations of Mine Shafts, Adits, Air Shafts, and Faults (Roberts et al., 2001)



Close up view of the figure titled: Extent of Abandoned Coal-Mine Workings and Locations of Mine Shafts, Adits, Air Shafts, and Faults (Roberts et al., 2001).

Undermined areas and mine workings are mapped in the southern part of the property, and to the south, northwest and east. Faults are also mapped in the area and within the site boundaries (not active).

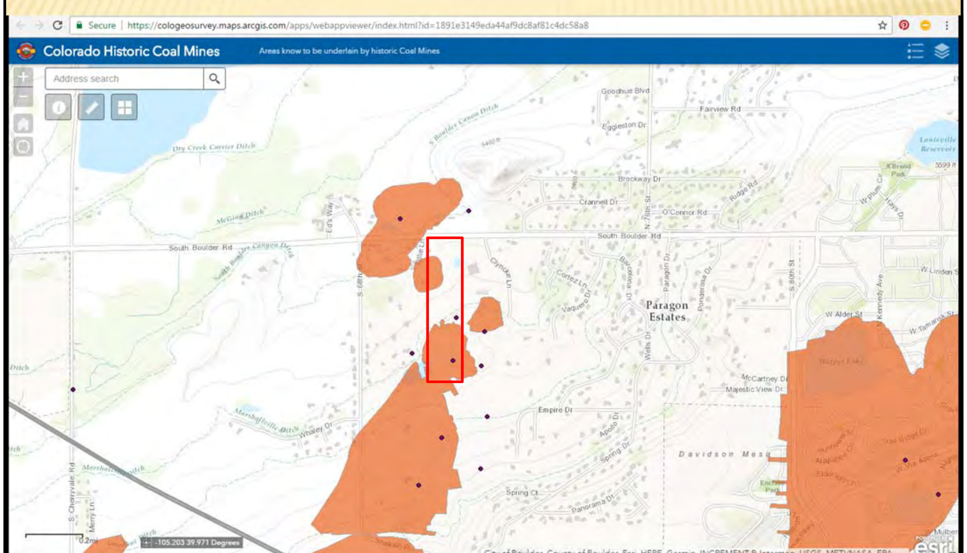


Close up view of the figure titled: Depth of Cover (Overburden Thickness) above Abandoned Coal-Mine Workings and Locations of Mine Shafts, Adits, Air Shafts, and Faults (Roberts et al., 2001).

Depth of cover at the site is less than 50 feet.

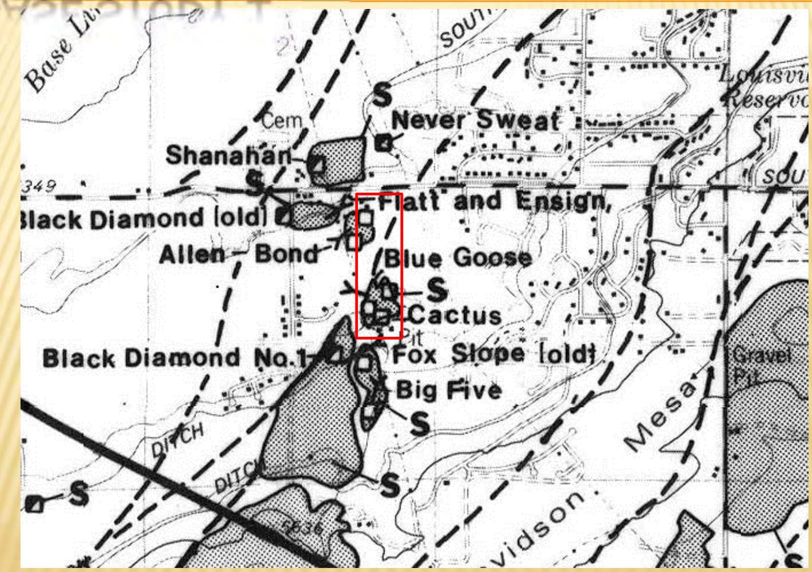
CASE STUDY 1

Colorado Historic Coal Mines – online map portal on the CGS website. Orange areas depict undermined area extents and red dots indicate a mine opening.



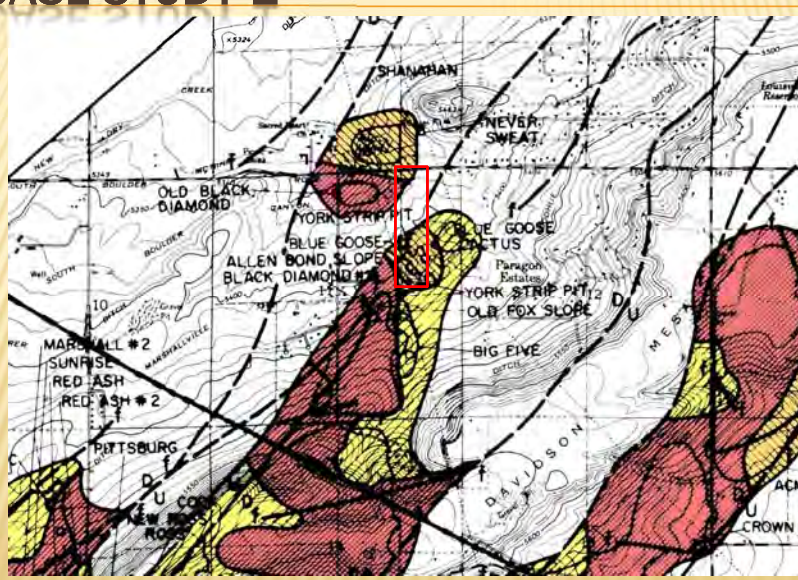
CASE STUDY 1

Another published mine map:
Turney, J.E., and Murray-Williams, 1983, Colorado front Range Inactive Coal Mine Data and Subsidence Information, Boulder County: Colorado Geological Survey



CASE STUDY 1

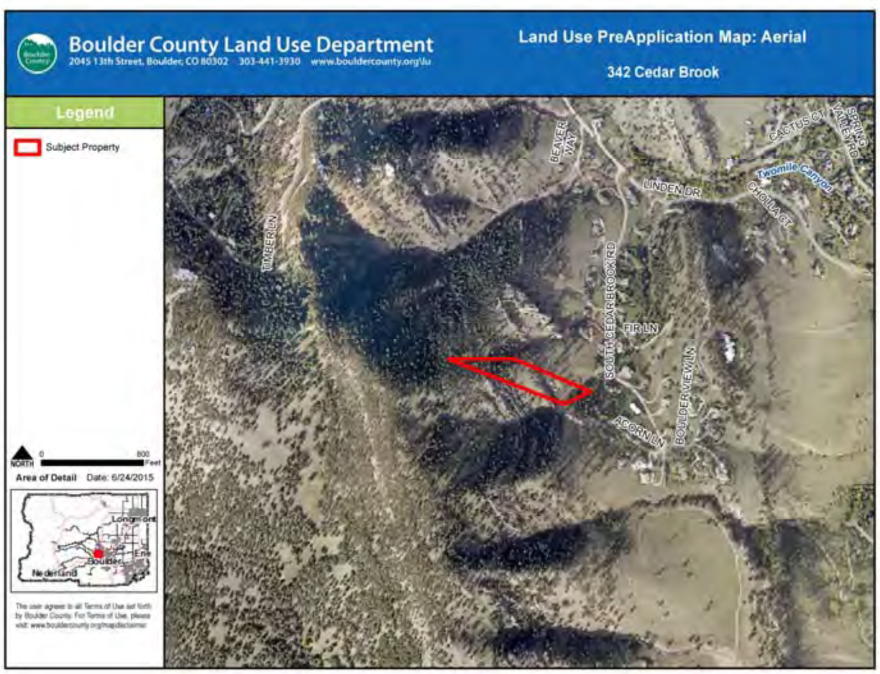
Another published mine map:
Amuedo and Ivey, 1975, Coal Mine Subsidence and Land Use in the Boulder-Weld Coalfield, Boulder and Weld Counties, Colorado: Colorado Geological Survey, Environmental Geology 9.

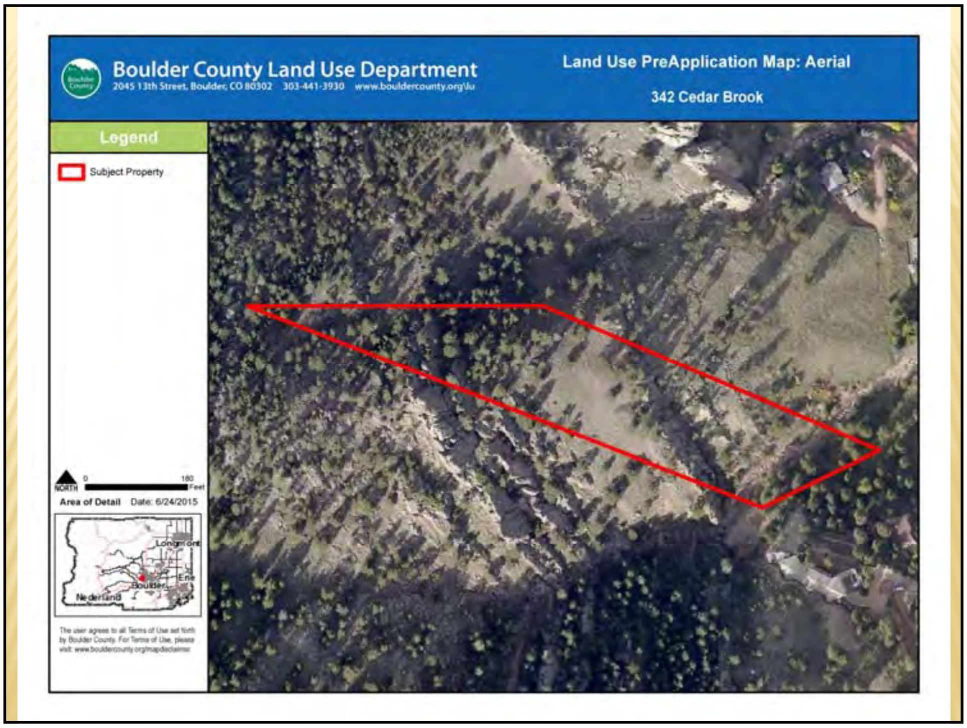


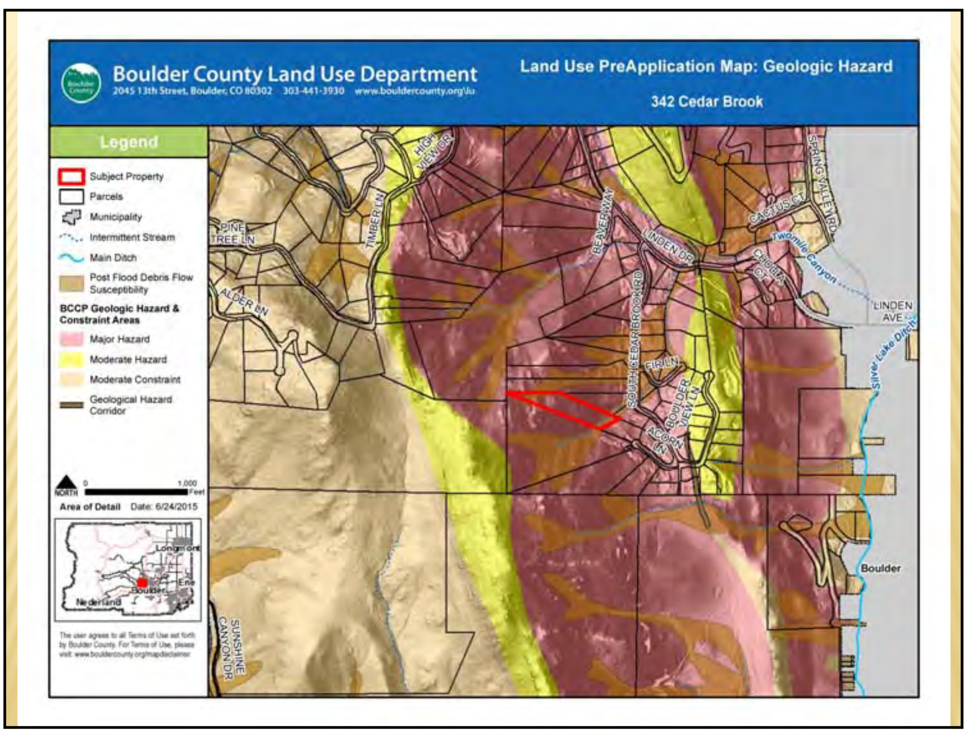
CASE STUDY 2

342 South Cedar Brook Road, Boulder
Pinebrook Hills Subdivision

Geohazard Concerns:
Steep slopes
Exposed bedrock, potential rockfall hazard
Debris flow channels
Steeply dipping heaving bedrock hazard in the area

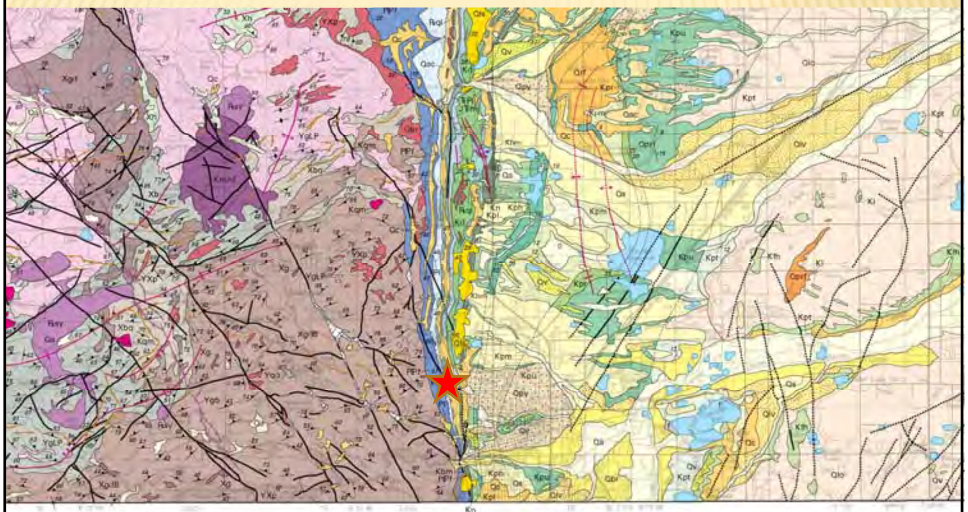



Boulder County Land Use Department
2045 13th Street, Boulder, CO 80302 303-441-3930 www.bouldercounty.org\lu
Land Use PreApplication Map: Aerial
342 Cedar Brook
Legend
Subject Property
Area of Detail Date: 6/24/2015
Longmont
Boulder
Erie
Nederland


Boulder County Land Use Department
2045 13th Street, Boulder, CO 80302 303-441-3930 www.bouldercounty.org\lu
Land Use PreApplication Map: Geologic Hazard
342 Cedar Brook
Legend
Subject Property
Parcels
Municipality
Intermittent Stream
Main Ditch
Post Flood Debris Flow Susceptibility
BCCP Geologic Hazard & Constraint Areas
Major Hazard
Moderate Hazard
Moderate Constraint
Geological Hazard Corridor
Area of Detail Date: 6/24/2015
Longmont
Boulder
Erie
Nederland
SPRING VALLEY RD
CACTUS CT
LINDEN DR
BEAVER WAY
SOUTH CEDAR BROOK RD
FIR LN
BOULDER VIEW LN
ACORN LN
TIMBER LN
PINE TREE LN
ALDER LN
SUNSHINE CANYON DR
LINDEN AVE
Twomile Canyon
Silver Lake Ditch
Boulder

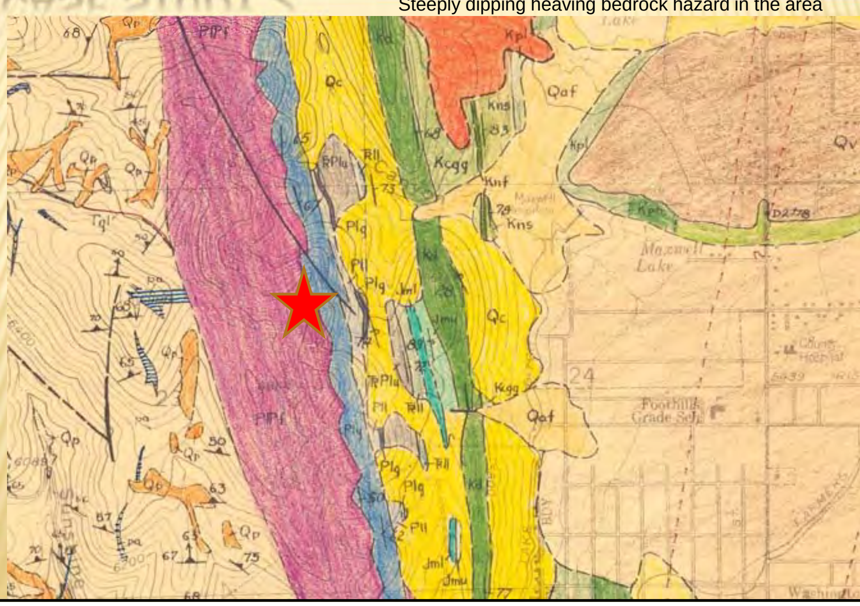
CASE STUDY 2

Geohazard Concerns:
Steep slopes
Exposed bedrock, potential rockfall hazard
Debris flow channels
Steeply dipping heaving bedrock hazard in the area

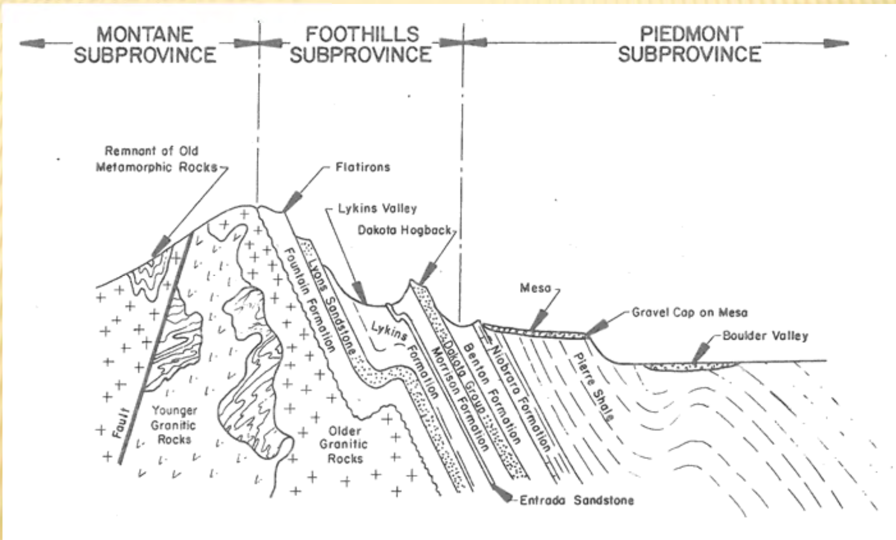


CASE STUDY 2

Geohazard Concerns:
Steep slopes
Exposed bedrock, potential rockfall hazard
Debris flow channels
Steeply dipping heaving bedrock hazard in the area



CASE STUDY 2



CASE STUDY 3

Area of Fourmile Canyon Drive and Switzerland Trail

Geohazard Concerns:
Flood Hazards
Debris Flows
Fluvial hazard in mapped Quaternary alluvium areas

CASE STUDY 3

Geohazard Concerns:
Flood Hazards
Debris Flows
Fluvial hazard in mapped Quaternary alluvium areas

CASE STUDY 3

Geohazard Concerns:
Flood Hazards
Debris Flows
Fluvial hazard in mapped Quaternary alluvium areas

CASE STUDY 3

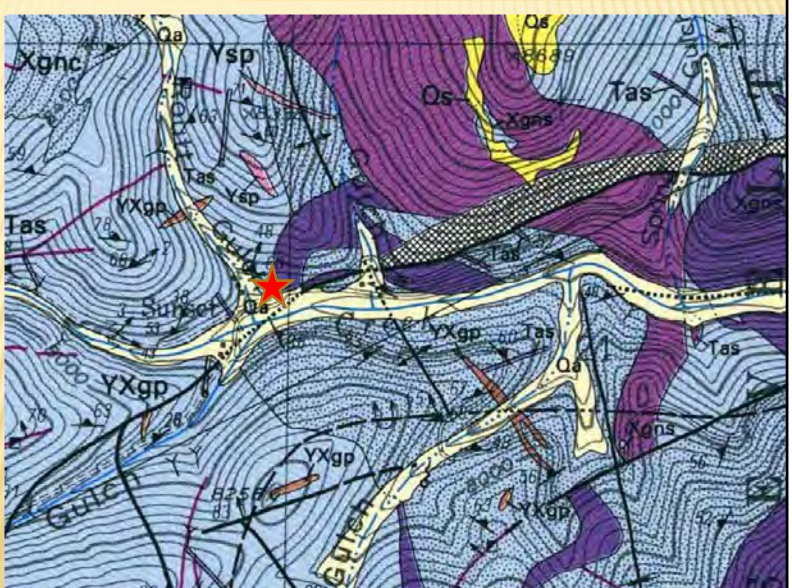
Geohazard Concerns:
Flood Hazards
Debris Flows
Fluvial hazard in mapped Quaternary alluvium areas

From CHAMP

CASE STUDY 3

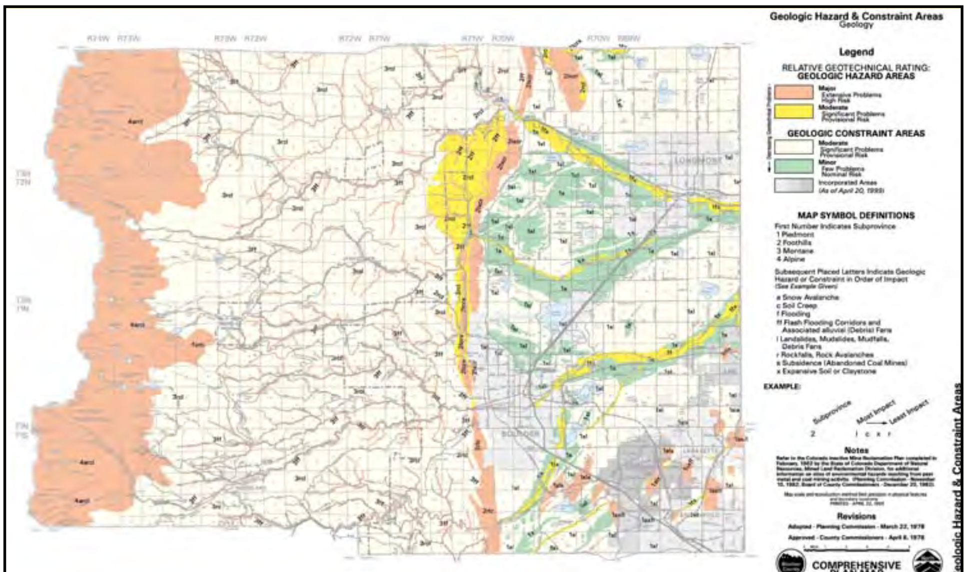
Geohazard Concerns:
Flood Hazards
Debris Flows
Fluvial hazard in mapped Quaternary alluvium areas

Concern: Areas available for development along stream corridors and at the mouths of drainage channels with mapped debris flows or debris flow susceptibility. Areas also potentially susceptible to flood and fluvial hazards.



What to Expect

GEOLOGIC HAZARD MAPPING



GEOLOGIC HAZARD & CONSTRAINT MAP

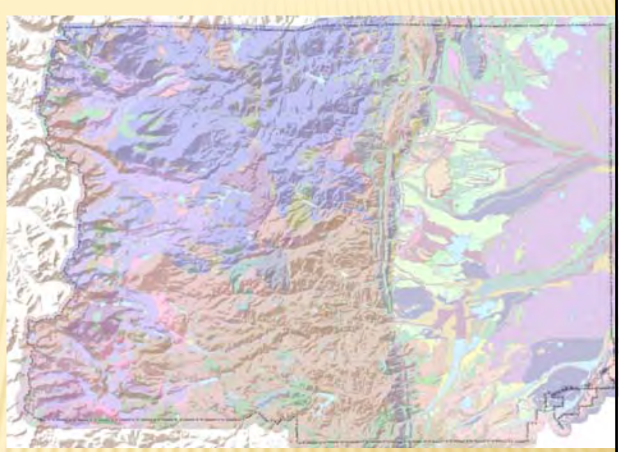
Ultimate Goal -
The Boulder County Geologic Hazard Map Package
(GIS databases for individual geologic hazards)

Geology
Landslides
Debris Flows
Rockfall
Swelling Soils and Bedrock
Steeply Dipping Heaving Bedrock
Undermined Areas
Flood Zones
Fluvial Hazard Zones
And others…

GEOLOGIC HAZARD & CONSTRAINT MAP

Geology Map:

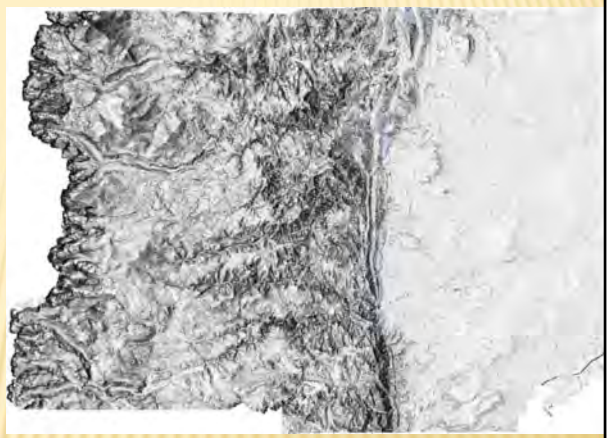
- Compiled from published mapping.
- 1:100,000 scale covering the entire county.
- Georeferenced spatial database.



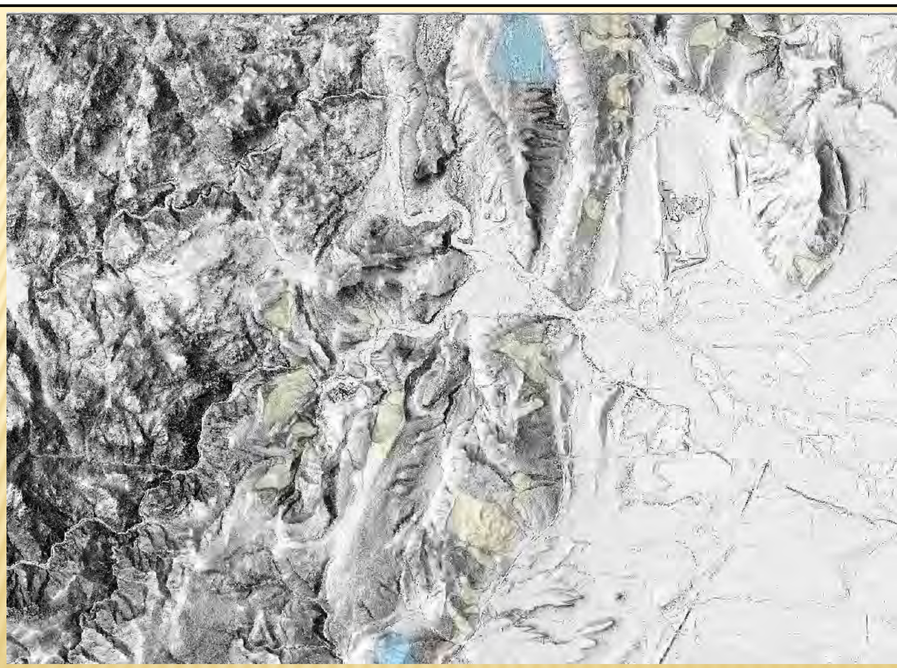
GEOLOGY MAP

Landslides inferred from:

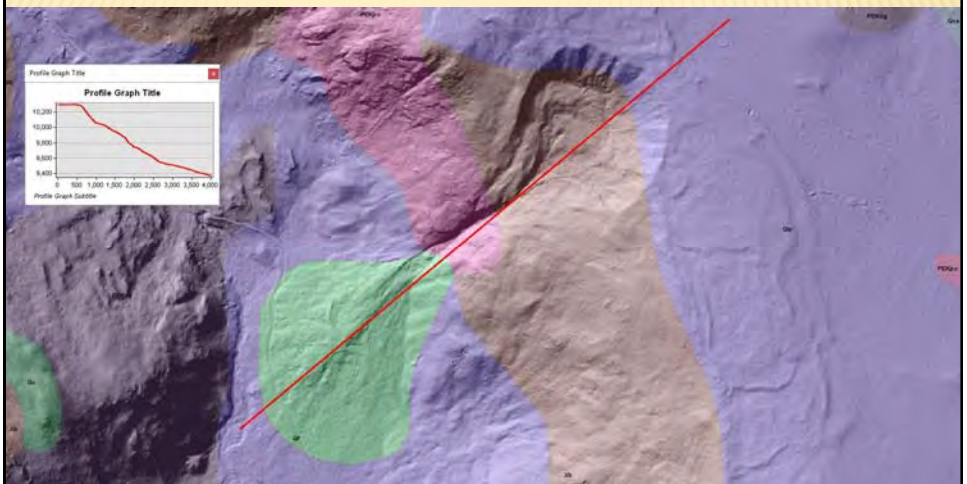
- Geology maps
- Geomorphic expression
- Aerial photography
- Hillshade maps
- Digital terrain model
- Personal communication with county and state
- Limited site reconnaissance.



LANDSLIDE MAPPING



Mapped Landslides – in progress. Landslides shown in yellow and blue on the hillshade map.

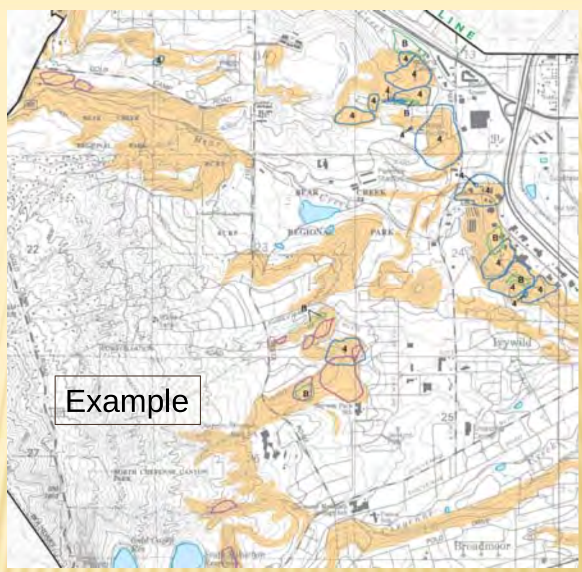


Alpine Subprovince

Landslide susceptible areas derived from multiple contributing factors which are ranked according to their contribution to slope instability.

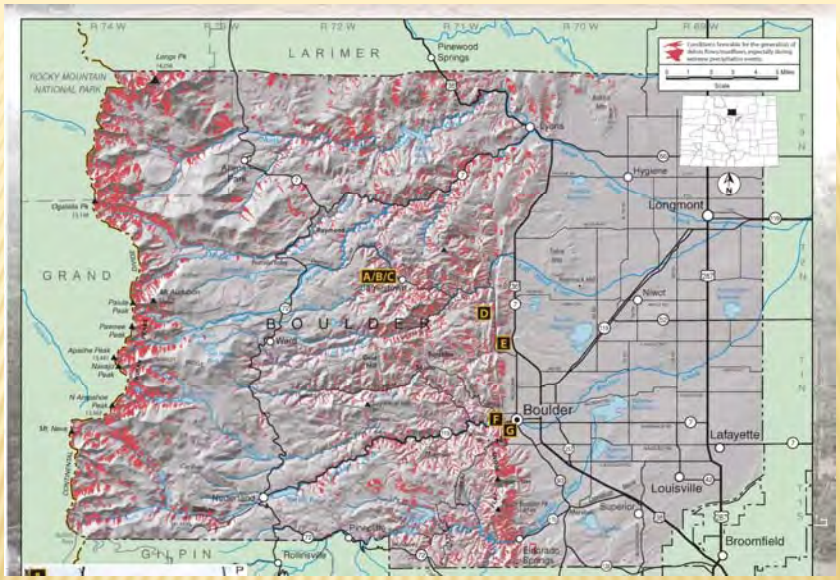
Data leveraged includes:

Elevation
Slope
Aspect
Curvature
Precipitation
Geology
Surficial soils
Wildfire history
Vegetative cover

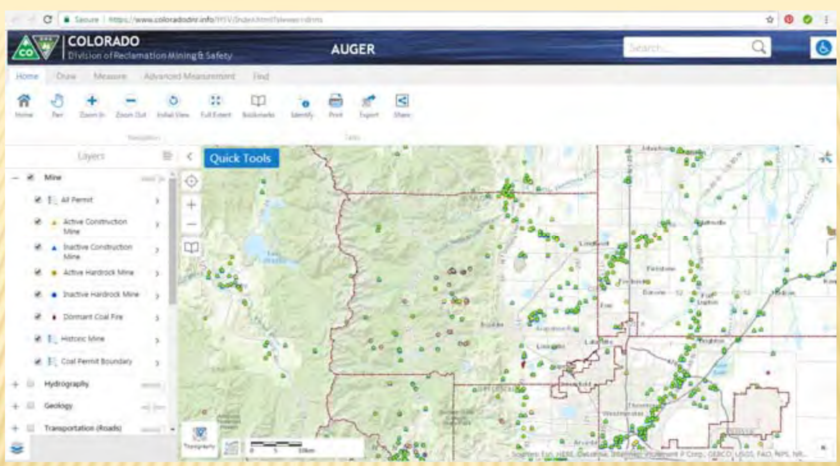


excerpted from Colorado Springs Landslide Susceptibility Map (White and Wait, 2003)

LANDSLIDE SUSCEPTIBILITY MAP



DEBRIS FLOW SUSCEPTIBILITY MAP – BY CGS

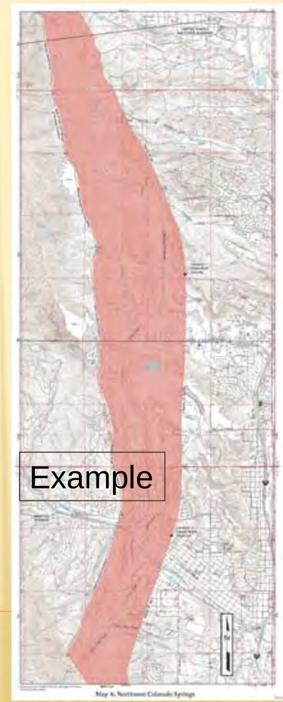


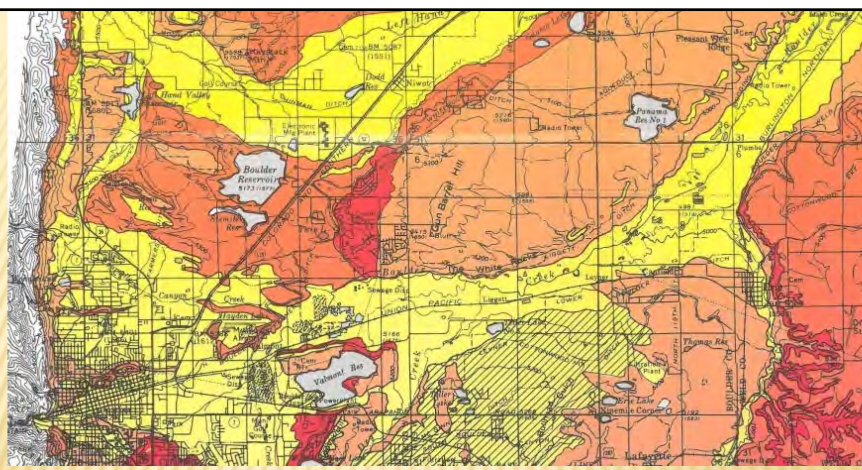
ABANDONED MINES MAP AND INVENTORY – BY CGS, DRMS

A corridor along the Front Range is underlain by steeply dipping bedrock with the potential to heave.

Jefferson County, Douglas County, and others have delineated this zone.

STEEPLY DIPPING HEAVING BEDROCK MAP





A published map depicting levels of severity of swelling potential of soils and bedrock.

Generally covers the area east of the Front Range.

SWELLING SOILS AND BEDROCK MAP

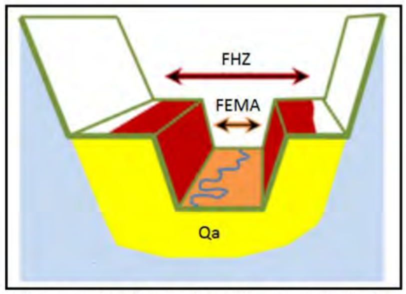


Figure 1: Example diagram depicting a semi-confined valley with quaternary alluvium (Qa) deposits where there would be a wider "fluvial hazard zone" (FMZ) compared to the FEMA regulated 100-year floodplain (adapted from Olson et al., 2014).

FLUVIAL HAZARD ZONE MAPPING – BY CWCB

From Jagt et al, 2016, Fluvial Hazard Zone Delineation, A Framework for Mapping Channel Migration and Erosion Hazard Areas in Colorado (accessed from CHAMP website)

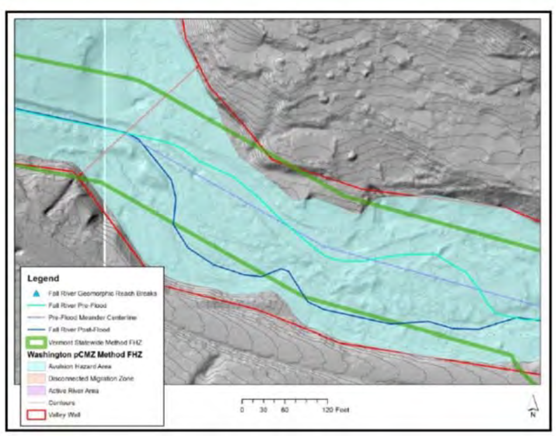


Figure 10: Fall River, Estes Park. Comparison of pre-flood and post-flood channel location and FHZ delineations using the VT and WA planning-level delineation methods. An avulsion that occurred during the 2013 flood fell outside of the belt-width delineated with pre-flood channel alignment. (Note: Additional buffers for delineation of Erosion Hazard setbacks are not depicted).

FLUVIAL HAZARD ZONE MAPPING – BY CWCB

From Jagt et al, 2016, Fluvial Hazard Zone Delineation, A Framework for Mapping Channel Migration and Erosion Hazard Areas in Colorado (accessed from CHAMP website)

The *erosion hazard area* is defined primarily in three ways across the nation:
1) A specified and consistent setback from the stream centerline, ordinary high water mark, or top of bank (e.g., Town of Estes Park, CO 50' setback from ordinary high water mark for new development).
2) A range of buffer widths from the active river corridor manually assigned. These widths range from as small as half of a channel width for very resistant or mild hillslopes to a full meander belt width for highly erodible and susceptible hillslopes and terraces (e.g., Washington CMZ protocol).
3) A buffer width from the *active river corridor* toe that is determined by extending a sloped plane out at a specified angle until it intersects the hillslope or floodplain surface. This method relies on estimating the maximum depth of incision a channel may obtain as the base of this buffer. The angle of this plane generally ranges from 3:1 to 6:1 (H:V) and depends on properties of the hillslope or terrace material and vegetation, slope, channel width, meander amplitude, and relative likelihood of the channel encountering the valley wall (e.g., City of Austin, TX).

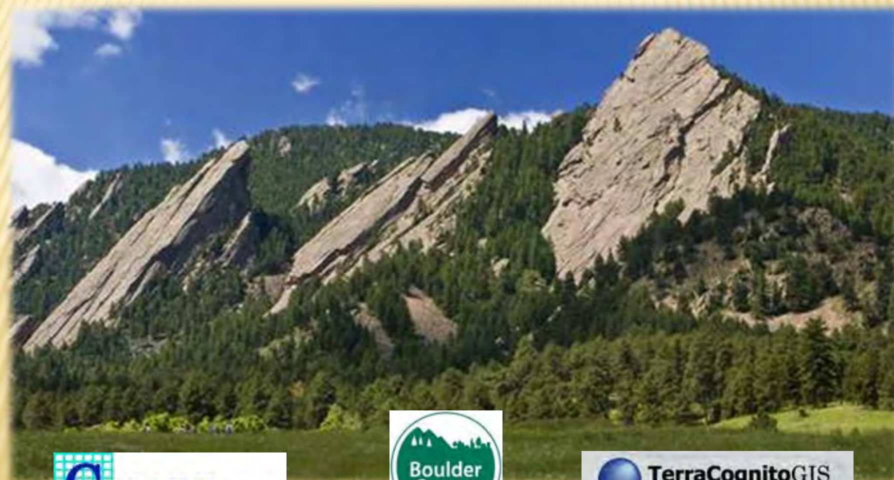
From Jagt et al, 2016, Fluvial Hazard Zone Delineation, A Framework for Mapping Channel Migration and Erosion Hazard Areas in Colorado (accessed from CHAMP website)

FLUVIAL HAZARD ZONE MAPPING – BY CWCB

RESOURCES

- Colorado Geological Survey
- United States Geological Survey
- Colorado Water Conservation Board
- Watershed Coalition groups
- Colorado Division of Reclamation, Mining, and Safety
- Colorado Division of Natural Resources
- Colorado Department of Transportation
- Colorado School of Mines
- And others

THANK YOU!



CESARE, INC.
Boulder County
TerraCognitoGIS

APPENDIX F

Jefferson County Designated Dipping Bedrock Area Guide

Designated Dipping Bedrock Area Guide

Map of an Area of Potential Heaving Bedrock Associated with Expansive, Steeply Dipping Bedrock in Jefferson County, Colorado is at the end of this document

The Designated Dipping Bedrock Area (DDBA) defines an area of Jefferson County where heaving bedrock is possible under certain geological and human-influenced conditions. The conditions warrant special consideration in all phases of development, including site exploration and evaluation, facilities, design, construction, and subsequent maintenance. In some areas, avoidance may be the best mitigation method.

Heaving Bedrock Geological Hazard

Historically, a high rate of damage to roads, utilities and lightly loaded structures has occurred where steeply dipping beds of expansive claystone bedrock are found near the ground surface. In such areas, ridges of "heaving bedrock," as large as two feet high, several tens of feet wide, and several hundreds of feet long have been mapped. The ridges form where adjacent, dipping layers of bedrock, each possessing a different potential for expansion, are exposed to water. We see damage from heaving bedrock typically within ten years after development and ground deformations may continue for years or decades. This geological hazard is responsible for tens of millions of dollars in excess maintenance costs to County taxpayers and homeowners. Compared to damage caused by flat-lying expansive soils and bedrock, which are found to the east over much of the Denver metropolitan area, heaving bedrock problems are more complex in nature and difficult to predict, and the resulting damage is often more localized and destructive.

Considerations for Proposed and Existing Subdivisions

The DDBA contains many areas where geological conditions are favorable for development and where satisfactory performance of homes and other facilities has occurred. Developers and builders should conduct detailed geological/ geotechnical investigations for proposed developments within the DDBA to delineate areas where favorable conditions occur, such as thick alluvial soils or layers of nonexpansive bedrock are encountered. These are summarized as follows:

- For all inhabited structures, at least ten feet of overburden soil or structural fill beneath the bottom of the foundation.
- Minimum foundation design requirements that are part of the Building Code.
- Subsurface groundwater collection systems, which must have positive drainage and daylight points.

Minimum design requirements for water, sewer and subsurface groundwater collection system.

Existing subdivisions are not subject to most of the overlay district regulations. However, large additions or remedial, structural repair work may be subject to minimum foundation-design standards and special review of the Building Department. Potential home buyers should be aware that the distribution of areas of damage within the DDBA may be erratic. A home that exhibits structural damage may be next to other homes that have no damage. When purchasing an existing home within the map area, or any other expansive soil area, the buyer may want to have an engineer conduct a detailed evaluation of the home to ensure that it is structurally sound.

Geology and Boundaries

The DDBA contains eight sedimentary formations of Cretaceous age, including the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and Laramie Formation and parts of the Arapahoe/Denver/Dawson Formations. The western boundary corresponds to the contact between the Graneros Shale and underlying Dakota Sandstone on the eastern dip slope of the Hogback ridge or near Golden where these units are missing due to faulting, to the mapped location of the Golden Fault. The eastern boundary corresponds roughly to the eastern extent of the bedrock which dips at greater than 30 degrees from horizontal. Bedrock layers underlying the DDBA dip to the east or northeast at 30 to 90 degrees from horizontal. The map does not show internal contacts between different bedrock formations, nor attempts to delineate areas of natural alluvial deposits that may cover and significantly reduce the heaving potential of the bedrock.

Submittal Requirements Special to the DDBA

Zoning

1. Detailed grading plans shall be submitted which show overburden soil or fill at least ten (10) feet thick beneath the anticipated level of the bottom of the structure foundation(s) and the top of bedrock. If deep (pier) foundations are proposed, the Zoning Administrator may require review of such plans by the Engineering Advisory Board.

or

If ten (10) feet of overburden or fill are not proposed, detailed engineering plans shall be submitted to the Engineering Advisory Board. The alternate mitigation plans shall contain the information necessary to determine that potential hazards can be adequately mitigated by other methods.

2. The rezoning application shall include geologic and soils/geotechnical reports prepared according to Section 25 of the Land Development Regulation. The geologic report includes a contour map of the top of the bedrock surface and may require trenching to expose the claystone bedrock for detailed geologic mapping. The geotechnical investigation requires test borings be drilled every 250,000 square feet to a minimum depth of 25 feet. One of the objectives of the geotechnical investigation is to establish the depth to bedrock across the site.

Preliminary Platting

1. Detailed grading plans shall be submitted which show overburden soil or fill at least ten (10) feet thick beneath the anticipated level of the bottom of the structure foundation(s) and the top of bedrock. If deep (pier) foundations are proposed, the Zoning Administrator may require review of such plans by the Engineering Advisory Board.

or

If ten (10) feet of overburden or fill are not proposed, detailed engineering plans shall be submitted to the Engineering Advisory Board. The alternate mitigation plans shall contain the information necessary to determine that other methods can adequately mitigate potential hazards.

2. The platting application shall include geologic and soils/geotechnical reports prepared according to Section 25 of the Land Development Regulation.

3. Subsurface groundwater collection system plans designated according to Section 19 of the Land Development Regulation.

Final Plat

1. Detailed grading plans shall be submitted which show overburden soil or fill at least ten (10) feet thick beneath the anticipated level of the bottom of the structure foundation(s) and the top of bedrock. If deep (pier) foundations are proposed, the Zoning Administrator may require review of such plans by the Engineering Advisory Board.

or

If ten (10) feet of overburden or fill are not proposed, detailed engineering plans shall be submitted to the Engineering Advisory Board. The alternate mitigation plans shall contain the information necessary to determine that other methods can adequately mitigate potential hazards.

2. The plat application shall include geologic and soils/geotechnical reports prepared according to Section 25 of the Land Development Regulation.

3. Subsurface groundwater collection system design and maintenance plans in accordance with Section 19 of the Land Development Regulation.

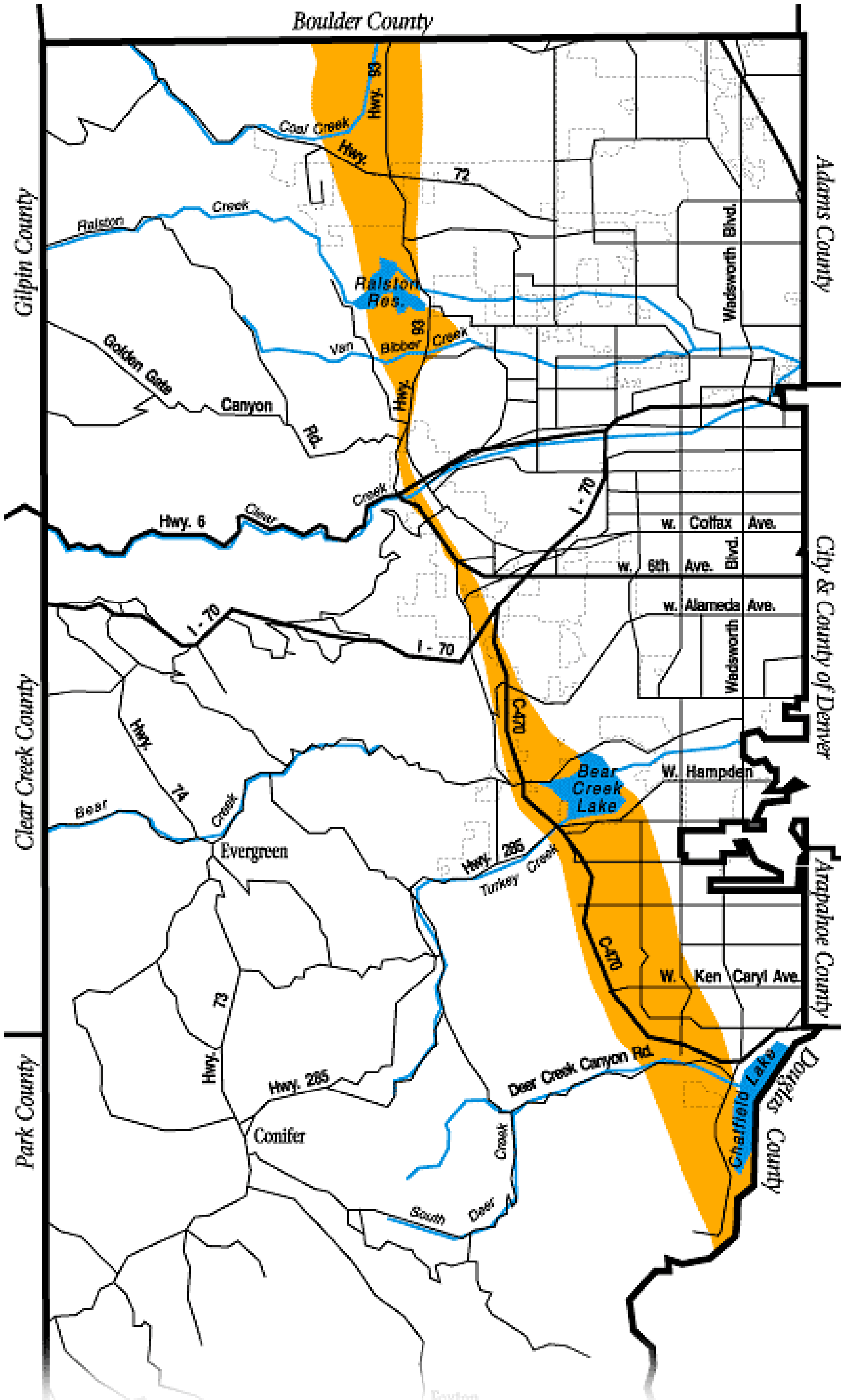
4. Central Water System plans designated according to Section 21 of the Land Development Regulation.

5. Central wastewater collection system plans designated according to Section 22 of the Land Development Regulation.

6. Grading plans designed according to Section 17 of the Land Development Regulation. These regulations establish excavation and fill construction specifications including test methods and frequencies.

Building Permit

Meet the minimum foundation design requirements for piers, foundation walls and drainage and grading. These requirements may be found in the Jefferson County Supplement to the Uniform Building Code and are available from the Building Department.



Boulder County
Gilpin County
Adams County
Clear Creek County
City & County of Denver
Arapahoe County
Park County
Douglas County
Coal Creek
Hwy. 93
Hwy. 72
Ralston Creek
Ralston Res.
Wadsworth Blvd.
Golden Gate Canyon Rd.
Van Bibber Creek
Hwy. 93
Clear Creek
Hwy. 6
I - 70
W. Colfax Ave.
W. 6th Ave.
Blvd.
W. Alameda Ave.
Wadsworth
C-470
Bear Creek Lake
W. Hampden
Hwy. 74
Bear Creek
Evergreen
Hwy. 285
Turkey Creek
C-470
W. Ken Caryl Ave.
Hwy. 73
Hwy. 285
Deer Creek Canyon Rd.
Chatfield Lake
Conifer
Creek
South Deer

APPENDIX G

Engineering Geology Report Guidelines

Engineering Geology Report Guidelines (CGS)
Jefferson County Land Development Regulation Section 25

Geology and Soil Suitability Reports

Engineering Geology Report Guidelines

REVIEW REQUIREMENTS

Counties are required to send subdivision applications to CGS for review. Applications must include reports about soil suitability and geologic conditions. Cities and counties can adopt more stringent requirements. Please contact your city or county for more information on local rules. (CRS 30-28-136)

GEOLOGY REPORTS

All reports must be prepared by a Professional Geologist as defined by Colorado law. Geologists must have special education and experience. (CRS 34-1-201)

SOIL SUITABILITY REPORTS

Engineers preparing soil suitability reports must have specialized knowledge and experience in mitigation of natural hazards and must consult with geologists, planners, and other professionals. See http://www.dora.state.co.us/aes/Policies-PEPLS.pdf

The guidelines that follow are a general outline what should be included in an engineering geology or soil suitability report. Each report should be site-specific, and identify all known or potential geologic hazards or soil conditions that may affect the property, proposed land uses, and public safety.

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This is a general list of information commonly required in geologic and soil investigations for a land use application. Report authors and applicants should be thoroughly familiar with all federal, state, and local land-use codes, policies, and regulations, especially those pertaining to geologic hazards and soil suitability. These vary widely across Colorado and it is the responsibility of each geologist, engineer, and applicant to become familiar with all applicable codes, policies, and regulations.

Basic Information

PROJECT DESCRIPTION

- Describe present zoning, land-use proposed and structure(s) anticipated.
- Indicate size and relationship of the project to the surrounding area.

LOCATION

- Specify the project location in terms of section, township and range, and county.
- Depict the project location on an index map of appropriate scale like USGS 7.5-minute quadrangle map.

PURPOSE

- Clearly state the uses for which the report was prepared. Indicate the commissioning person or organization.

SCOPE

- State the objective(s) and level of investigation for the study.
- Cite previous published or unpublished geologic and geotechnical reports in the subject area and indicate the author(s), firm, and dates of each report.
- List all the methods of investigation as well as professional firm(s) and individuals who participated.

Basic Data

REGIONAL SETTING

- Describe the general physiographic setting of the project and its relationship to local topographic features.
- Describe the general geologic setting of the project and indicate any lithologic, seismotectonic, geomorphic, or soils problems specific to the area. Include the size, frequency, duration and location of historic earthquakes.

SUBSURFACE TESTING FREQUENCY

Subsurface testing is often done during a soil suitability study. Testing and sampling must be done at a frequency that provides a clear indication of soil and bedrock properties. Some cities and counties have specific standards that must be followed. A good example of subsurface testing standards is found in the Jefferson County Land Development Regulations. (http://www.jeffco.us/jeffco/planning_uploads/regulations/ldr/25.pdf)

HOW MANY REPORTS ARE REQUIRED?

Land-use applications should contain both a geology report and a soil suitability report. They can be combined or submitted as two separate reports. Geology reports or sections of a report must be done by a Professional Geologist.

- Describe the general surface and ground water conditions and their relationship to the project area.
- Describe the mineral resources in the general and project area.

Evaluation Techniques

TOPOGRAPHIC MAPPING

- State the extent and method of surface and subsurface geologic studies.
- Indicate the type and accuracy of topographic maps; include the date of the topographic survey and who conducted the survey.

GEOLOGIC MAPPING

- Prepare geologic map(s) on the project topographic map to show important details commensurate with the purpose of the investigation.
- Show the abundance and distribution of earth materials and structural elements exposed or inferred in the subject area. Observed and inferred features or relationships should be so designated on the geologic map.
- Depict significant three dimensional relationships on appropriately positioned cross sections.
- Portray all geologic information at the same scale as the project plans.
- Indicate the geologic base map used, date, and significant additions and modifications to previous work.

REMOTE-SENSING IMAGES

- Describe type(s) of photographs or images including instrumentation, processing techniques, and final product.
- Describe the source, date and scale of photographs or imagery used in the investigation.
- Indicate general relationships observed on the images.

GEOPHYSICAL INVESTIGATIONS

- State type, techniques and objectives of any geophysical investigation(s), quality of the data, and limitations of the geophysical techniques.
- Describe the information used to correlate the geophysical data and known geologic conditions.
- Display the geophysical data on the topographic/geologic maps and cross sections and show cultural features which affect the data.

DRILL-HOLE DATA

- State the specific investigative methods, tests conducted, drilling equipment, and date of investigation.
- Show the location of all borings on the topographic and geologic map.
- Show boring logs, geophysical logs, or profiles obtained in the investigation.
- On boring logs, show depths, type of samples; soil descriptions according to the unified soil classification; lithologic descriptions using standard geologic terminology; critical soil or geologic contacts; and ground-water levels.

TEST PITS AND TRENCHES

- Describe the location and general dimensions of all pits and trenches and date of investigation.
- Indicate the location of all excavations on topographic and geologic maps.
- Provide a large scale descriptive log with sufficient detail commensurate with the features observed.
- Show sample locations and depths if laboratory tests were conducted.

FIELD AND LABORATORY TESTS

- Describe the type and objectives of any tests conducted in the field or laboratory.
- Describe the sample method and test procedures. Show the test results on boring log, data work sheets and in summary tables.
- Describe the type, objectives, and location of all monitoring programs in the subject area

WHAT IS A GEOLOGIC HAZARD?

Colorado statutes define geologic hazards as a "geologic phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property." (CRS 24-65.1-101)

Geologic and natural hazards include:

- Avalanches
- Landslides
- Rockfalls
- Mudflows & Debris Fans
- Unstable Slopes
- Potentially Unstable Slopes
- Seismic Effects
- Radioactivity
- Ground Subsidence
- Expansive Soil and Rock
- Corrosive Soil
- Floodplains
- Wildland Fire
- Siltation
- Dry Wash Channels

- State the monitoring period and frequency, and who is responsible for monitoring and collection of data.

Geologic Descriptions

BEDROCK

- Describe and map sedimentary, igneous, and metamorphic rock types and units.
- Describe and map rock types bedding orientation.
- Describe age of and correlation with recognized formations.
- Describe and map dimensional characteristics such as thickness and extent.
- Describe and show on logs distribution and extent of the weathered zone.
- Describe physical and chemical characteristics.
- Describe response of bedrock materials to natural processes and proposed land uses.
- Describe and map mineral occurrences.

SURFICIAL DEPOSITS

- Describe and map fluvial, colluvial, glacial, eolian, mass wasting, and man-made deposits
- Identify, describe and map material types and sources
- Describe and map dimensional characteristics such as thickness and extent
- Describe surface expression and relationships with present topography
- Describe physical and chemical characteristics
- Describe and map altered zones
- Describe response of surficial materials to natural processes and proposed land uses.
- Describe and map mineral occurrences

GEOMORPHIC FEATURES

- Describe and map landslides, earthflows, debris flows, mudflows, rockfalls, debris avalanches, fault scarps, soil creep, erosion scarps, avalanche paths, and subsidence phenomenon.
- Describe dimensional characteristics
- Describe and map age of feature and history of activity
- Describe recurrence interval for geomorphic process
- Describe physical characteristics including depth, flow velocities, and impact pressures

STRUCTURAL FEATURES

- Describe and map joints, faults, shear zones, folds, schistocity, and foliation
- Describe occurrence, distribution, and proximity to site.
- Describe dimensional and displacement characteristics of faults
- Describe orientation and changes in orientation of all structural features
- Describe and map physical characteristics such as brecciation, slickensides, gouge zones, sand boils, sag ponds, spring alignment, disrupted drainages, or ground water barriers
- Describe and map nature of offset(s) and timing of movement(s)
- Describe absolute or relative age of latest movement
- Describe and map location of seismic events, including size, frequency, duration and their association with faults or fault systems

SURFACE WATER

- Describe and map rivers, streams, ditches, dams, ponds, canals, creeks, wetlands, and draws
- Describe relation to topography (drainage patterns)
- Describe relation to geologic features
- Describe source, permanence, and variation in amount of surface water
- Describe and map earlier occurrence of water at localities now dry
- Estimate peak flows and physiographic flood plain of drainages
- Describe and map probable maximum or 100-year flood limits, including flash and debris floods
- Describe water use and quality

MINERAL RESOURCES

In many counties, Colorado law requires CGS to review subdivision plans for potential land use conflicts with extraction of commercial mineral deposits. (CRS 34-1-304, as amended)

ENGINEERED STRUCTURES

Plans for mitigation involving engineered structures shall be prepared and signed by a professional engineer, registered in the State of Colorado, and qualified in the field of natural hazard mitigation. Plans should assure that soil and geologic factors affecting the planning, design, construction, operation, and maintenance of structures are recognized, adequately interpreted, and presented for use in engineering practice.

GROUND WATER

- Describe and map hydraulic gradients, and aquifer characteristics for confined and unconfined aquifers
- Describe and map saturated zones, depth to ground water, and seasonal fluctuations
- Describe relation to geomorphology, geologic features, recharge and discharge areas
- Describe and map potential for perched ground-water and where the chemical content of water poses engineering concerns
- Describe how on-site sewage disposal impacts water quality and quantity, and geologic hazards

MINERAL RESOURCES

- Describe and map mineral resources, especially commercial mineral deposits.
- Describe past and current mineral production, mineral rights and agreements
- Describe how past and current mineral production impacts existing and proposed land uses and geologic hazards

Geologic Interpretation

GEOLOGIC HAZARDS

- Describe and map landslides, avalanches, rockfall, mudflows, debris flows, radioactivity, expansive soil or rock, potentially unstable slopes, unstable slopes, soil creep, hydrocompaction, shallow bedrock, erosion and siltation.
- Describe and map earthquake hazards, including the potential for surface rupture (sense and amount of displacement); estimated ground motion, duration, and response variability; potential subsidence or uplift from regional tectonic deformation
- Describe and map potential secondary hazards associated with earthquake or wildland fire induced landslides, liquefaction, rockfall, flooding, mudlfows, or debris flows.
- Describe and map soil, geologic, geomorphic, structural and man-induced hazards near or in project area
- Describe and map age and activity of hazards and correlation with formations and land uses.
- Describe how natural and man-induced features and processes affect hazards.
- Describe potential impact and risk of hazards to project area, existing and proposed land use and to public safety.
- Describe amenability of adverse conditions and hazards for adequate mitigation
- Describe long-term lateral and vertical stability of earth and man-made materials

Recommendations

- State whether the proposed land uses are compatible with existing or potential geologic hazards and if mitigation measures are needed
- Discuss critical planning and construction aspects including waste disposal, the stability of earth materials, grading plans, avoidance of hazards, static and dynamic parameters for the design of structures, the extraction of mineral resources, allowable and excluded land uses
- Clearly state the basis for all recommendations and conclusions
- Discuss mitigation measures and procedures needed to mitigate or abate geologic hazards, adverse conditions, or mineral resource conflicts, Each hazard, adverse condition, or mineral resource conflict must be addressed.
- Provide detailed construction and maintenance plans for each mitigation measure.
- Include recommendations for any additional hazard studies or mitigation plans
- All recommendations, mitigation measures, and plans must ensure the long-term stability and adequate performance of the project, protect public safety, and be compatible with existing and proposed land use.

Section 25 - Geologic and Geotechnical

A. Standards

The following standards were adopted to protect lots, tracts and structures from geologic hazards, including, but not limited to, Dipping Bedrock, Rockfall, Potentially Unstable Slopes, Swelling Soils, and Subsidence. (orig. 10-25-05)

1. Buildable areas within lots, tracts, and areas designated for streets/roads and drainage improvements shall be: (am. 10-25-05)
    a. Reasonably free from geologic hazards or adequately mitigated from geologic hazards. (orig. 10-25-05)
    b. Free of adverse soil conditions, constructed away from adverse soil conditions, or constructed in areas where adverse soil conditions have been abated. (orig. 10-25-05)
2. All areas which fall within the Dipping Bedrock Overlay District shall be subject to the restrictions in the Dipping Bedrock Overlay District of the Jefferson County Zoning Resolution. (am. 10-25-05)

B. Geologic Report

1. Preparation
    a. The Geologic Report shall be prepared and signed by a qualified professional geologist (as defined in 34-1-201 C.R.S, as amended) and shall be in substantial conformance with the content requirements of this section. If the development in the Dipping Bedrock Overlay District, the geologist shall have extensive first hand knowledge of and experience with the geology of eastern Jefferson County. (reloc. 7-12-05; am. 10-25-05)
    b. The Geologic Report and the Geotechnical Report may be combined in a single report, or may be two seperate Reports. (orig. 10-25-05)
2. Content
    a. Bedrock Geology
        (1) Rock types present, including formation names and ages, if possible. (reloc. 7-12-05)
        (2) Bedrock characteristics including, but not limited to the following: (reloc. 7-12-05)
            (a) Degree of weathering, including depth of weathering, presence of expansive claystones. (reloc. 7-12-05)
            (b) Erodibility, including the range of normal angles of slopes. (reloc. 7-12-05)
            (c) Aquifer characteristics, including moisture content and permeability. (reloc. 7-12-05)
            (d) Shrink-swell potential, potential differential heave and range of swelling pressures. (reloc. 7-12-05)
            (e) Potential response to seismic activity. (reloc. 7-12-05)
            (f) Radioactivity (naturally occurring and man-made). (reloc. 7-12-05)

(g) Slope stability in natural and excavated states, including mudflows, rockfall, creep, subsidence, settlement and slumping. (reloc. 7-12-05)

(h) Strike and dip of bedding planes, foliation, joints and faults and the frequency and distribution of any such features. (reloc. 7-12-05)

(i) Well and Individual Sewage Disposal System suitability. (reloc. 7-12-05; am. 10-25-05)

(j) Detailed description of the bedrock surface topography. (reloc. 7-12-05)

(3) The following items may be required if any portion of the proposed development is located in the Dipping Bedrock Overlay District, and the plans do not conform to the provisions of the Dipping Bedrock Section of the Jefferson County Zoning Resolution: (am. 7-12-05; am. 10-25-05)

(a) Trenching or other test methods to determine attitudes of bedding planes, depth to bedrock, detailed bedrock stratigraphy and to determine the interface between weathered claystone and clay. Where claystone or weathered claystone is present, the evaluation shall include a detailed description of discrete or zones of highly expansive claystone and/or bentonite beds and a detailed description of filled or open fractures. (reloc. 7-12-05)

(b) Cross-sections, which show subsurface bedrock relationships including depth to bedrock, dip of beds and detailed stratigraphy of the bedrock may be required. Frequency and distribution of joints and faults should be noted on the cross-sections using drawings or written descriptions. (reloc. 7-12-05)

b. Surficial Geology

(1) Location and description of all surficial materials present, including artificial fill, utilizing unit names and ages, if possible. (reloc. 7-12-05)

(2) A discussion of the thickness and distribution of surficial materials. (reloc. 7-12-05)

(3) Surficial material characteristics including, but not limited to the following: (reloc. 7-12-05)

(a) Erodibility. (reloc. 7-12-05)

(b) Degree of weathering, including types of clay minerals. (reloc. 7-12-05)

(c) Aquifer characteristics, including permeability and soil moisture. (reloc. 7-12-05)

(d) Shrink-swell potential and the potential for differential heave. (reloc. 7-12-05)

(e) Potential response to all seismic activity. (reloc. 7-12-05)

(f) Radioactivity (naturally occurring and man-made). (reloc. 7-12-05)

(g) Slope stability in natural and excavated states, including mudflows, rockfall, creep, subsidence, settlement and slumping. (reloc. 7-12-05)

(h) Well and Individual Sewage Disposal System suitability. (reloc. 7-12-05; am. 10-25-05)

(i) Discussion and evaluation of the suitability of structure foundations. (reloc. 7-12-05)

(j) If any portion of the proposed development is within the Dipping Bedrock Overlay District, a description and map of the general condition and performance of existing roads and structures. Descriptions shall include degree of driveway, flatwork and road damage and/or repair, and any other evidence of ground deformation or movement such as linear heave trends. Areas of investigation shall include the site plus an outlying adjoining area of at least 1/2-mile from the site boundaries in the direction of regional strike and perpendicular to the strike. The map of the area outside the proposed development may be a separate map at a scale of one (1) inch equals 1,000 feet. (reloc. 7-12-05; am. 10-25-05)

(4) A description of the surficial geomorphology. (reloc. 7-12-05)

(5) Cross-sections which show bedrock/surficial material relationships may be required in order to illustrate the depth to bedrock and any structural features such as faulting. (reloc. 7-12-05)

c. Hydrology

(1) Depth to groundwater, utilizing isopach map. (reloc. 7-12-05)

(2) Perched water tables, including existing conditions and potential post-development perched water table conditions. (reloc. 7-12-05)

(3) Expected seasonal variations in groundwater. (reloc. 7-12-05)

(4) A description of the possible effects of surface water on structure performance, including the potential for erosion and flooding. (reloc. 7-12-05)

d. Mineral Resources

(1) Amount and quality of any mineral resources, including, but not limited to sand and gravel, quarry aggregate, coal, limestone, mineral fuels (e.g., oil, gas, uranium), metallic resources (e.g., gold, copper), and nonmetallic resources (e.g., clay). (reloc. 7-12-05)

(2) Existing mining site or prospects. (reloc. 7-12-05)

e. Geologic Map

(1) Preparation

The Geologic Map shall be legible at a suitable scale not greater than 1:24,000.(reloc. 7-12-05; am. 10-25-05)

(2) Content

(a) The boundaries of the proposed developmentl, including lots, tracts and street/road alignments or the area to be rezoned. (reloc. 7-12-05; am. 10-25-05)

(b) The natural and proposed final topography as shown by contour lines. (reloc. 7-12-05)

(c) Location of borings, pits, trenches, seismic traverses, etc. (reloc. 7-12-05)

(d) Bedrock geology conditions, including the following where applicable: (am. 7-12-05; am. 10-25-05)

(d-1) Test holes, trenches or test pits used in the investigation. (am. 7-12-05; am. 10-25-05) (d-2) Sites of special geologic interest (e.g., fossil beds or unusual mineral formations). (reloc. 7-12-05)

(d-3) Geologic Hazard Overlay Zone. (reloc. 7-12-05)

(e) Surficial geology conditions. (am. 7-12-05; am. 10-25-05)

(f) Groundwater hydrology conditions. (am. 7-12-05)

(g) Mineral resource conditions. (am. 7-12-05; am. 10-25-05)

(h) Formation contacts. (reloc. 7-12-05; am. 10-25-05)

(i) Outcrops. (reloc. 7-12-05)

(j) Isopach map showing the thickness and distribution of surficial materials (unconsolidated natural soils and artificial fill). (reloc. 7-12-05)

(k) An elevation contour map of the top of the bedrock surface for areas of the proposed development which fall within the Dipping Bedrock Overlay District. For areas which contain claystone, the top of the weathered claystone shall be considered as the top of the bedrock. (reloc. 7-12-05; am. 10-25-05)

f. The date of all fieldwork performed and a list of references and other supportive data used. (orig. 10-25-05)

3. Approval

The Geologic Report shall be approved by the County Engineering Geologist prior to the proposed development's approval. (orig. 10-25-05)

C. Geologic Plans

1. Preparation

a. The Geologic Plan(s) (excluding plans for engineered structures) shall be prepared and signed by a qualified professional geologist (as defined in 34-1-201 C.R.S, as amended). If the proposed development is in the Dipping Bedrock Overlay District, the geologist shall have extensive first hand knowledge of and experience with the geology of eastern Jefferson County. (reloc. 7-12-05; am. 10-25-05)

b. Plans for engineered structures shall be prepared and signed by a professional engineer, registered in the State of Colorado, and qualified in the field of civil engineering. (reloc. 7-12-05)

c. Geologic Plan(s) shall assure that geologic factors affecting the planning, design, construction, operation, and maintenance of engineered structures are recognized, adequately interpreted, and presented for use in engineering practice. (am. 7-12-05; am. 10-25-05)

2. Content

a. The geologic processes, constraints, and hazards which will or could affect proposed structures or the intended uses of the site. Recommendations for additional site exploration, testing, development which are necessary to assure adequate performance of mitigation methods. (reloc. 7-12-05)

b. Methods to mitigate adverse geologic conditions on proposed structures. (reloc. 7-12-05)

c. Mineral resource recovery, if applicable, in accordance with the Jefferson County Mineral Extraction Policy Plan. (reloc. 7-12-05)

d. The entity/entities that will implement the mitigation recommendations, construct required improvements, and be responsible for the maintenance of the improvements and appropriate easements, if any. (reloc. 7-12-05)

3. Approval

a. The Geologic Plans shall be approved by County Engineering Geologist prior to the proposed development's approval. (reloc. 7-12-05; am. 10-25-05)

b. Plans for engineered structures shall be approved by Planning and Zoning prior to the proposed development's approval. (reloc. 7-12-05; am. 10-25-05)

D. Geotechnical Report

1. Preparation

a. Any Geotechnical Report shall be prepared and signed by a qualified professional engineer, registered in the Sate of Colorado and qualified in the field of geotechnical engineering and shall be in substantial conformance with the content requirements of this section. (orig. 10-25-05)

b. The Geologic and Geotechnical Reports may be combined in a single report, or may be two separate Reports. (orig. 10-25-05)

2. Content

a. Geotechnical Investigation Standards

(1) All sites shall be investigated to evaluate the potential impacts of adverse soil and bedrock conditions on proposed structures, pavements, drainage structures, and utilities. The objectives of this investigation shall be to establish the depth to bedrock across the site with respect to the proposed final grades and foundation elevations of proposed structures and to develop recommendations to mitigate the impacts of adverse soils and bedrock conditions and/or the impacts of steeply dipping bedrock on the proposed development. (reloc. 7-12-05; am. 10-25-05)

(2) Dipping Bedrock Overlay District

(a) At least one (1) exploratory boring shall be drilled every 250,000 square feet to a minimum depth of 35 feet, or to 25 feet provided bedrock is found. A minimum of 4 borings shall be drilled. (reloc. 7-12-05)

(b) If bedrock is not found within 15 feet of anticipated foundation levels (after site grading), the site or portions of the site may be exempted from further requirements for special investigation requirements, such as increased testing upon approval by the Engineering Geologist. In order to qualify for this exemption, the geotechnical engineer shall submit findings to the Engineering Geologist in a letter requesting exemption. The letter shall include a plan showing existing site topography and location of borings, and graphical logs of the borings. If grading plans are available, they shall also be provided. The anticipated cut/fill shall be indicated on the boring logs. The Engineering Geologist shall respond to this request in writing within 14 calendar days. If grading plans are not provided, exemption granted for all or a portion of a site will be subject to review upon review of grading plans by the Engineering Geologist. The Engineering Geologist may refer an exemption request to the Colorado Geological Survey for review and comment. (reloc. 7-12-05; am. 10-25-05)

(3) All Other Areas in the Plains: At least one (1) exploratory boring shall be drilled every 250,000 square feet to a minimum depth of 25 feet. A minimum of 4 borings shall be drilled. (reloc. 7-12-05)

(4) On comparatively small sites (less than 5 acres) a minimum of 4 borings is required. Boring locations and elevations shall be accurately located and shown on the soils and bedrock map. All borings shall be sampled at approximately 5-foot intervals using a modified California sampler (nominal 2 inch inside diameter) or similar device to obtain relatively undisturbed samples. The minimum depth of all boring shall be 25 feet unless drilling refusal in bedrock is encountered. If deep cuts (in excess of 15 feet) are anticipated during site grading, the borings in cut areas shall extend at least 25 feet below the anticipated cut. The depth of free groundwater shall be measured in each boring at the time of drilling and at least 48 hours after drilling. If rain or snow melt occurs between time of drilling and subsequent measurements, these occurrences shall be noted. (reloc. 7-12-05)

(5) Laboratory testing of soil and bedrock shall be conducted to verify field classifications and provide indications of soil and bedrock material properties. Tests shall include the following: (reloc. 7-12-05)

(a) Moisture content and a dry density profile for all intervals sampled on at least four borings. (reloc. 7-12-05)

(b) Atterberg Limits and percent passing the No. 200 sieve on representative samples of each clay or claystone strata. (reloc. 7-12-05)

(c) Percent passing the No. 200 sieve from representative samples of each sand or sandstone strata. (reloc. 7-12-05)

(d) One dimensional swell-consolidation tests and/or soil suction tests on representative samples of each clay or claystone strata. Swell tests may be performed using a surcharge of 500 psf, 1000 psf, or the anticipated overburden pressure after site grading. Swell tests are not required for non-expansive strata provided other laboratory tests are performed to confirm classification. (reloc. 7-12-05)

(6) For sites where sub-excavation of bedrock and construction of fill is planned, bulk samples of the cut materials shall be obtained, preferably from exploratory test pits excavated with a backhoe. Standard Proctor tests (ASTM D698) shall be performed on each of the materials. Atterberg Limits and percent passing the No. 200 sieve tests shall be performed for each sample. The proposed fill materials shall be tested for swell using samples compacted to 95 to 98 percent of maximum dry density as determined using ASTM D698 at molding moisture contents of approximately 2 percent below optimum moisture, optimum moisture, 2 percent above optimum moisture, and 4 percent above optimum moisture. These tests shall be performed using a surcharge of 500 psf or 1000 psf. The remolded swell moisture and density data points shall be indicated on the corresponding Proctor Curve. (reloc. 7-12-05)

(7) Required test frequency per type of material sample is set forth in the following table: (reloc. 7-12-05)

REQUIRED TEST FREQUENCY PER TYPE OF MATERIAL SAMPLED						
Unified Soil Classification or Equivalent Soil Classification	Moisture Content ASTM D2216-80	Dry Density	Atterberg Limits ASTM D424-59 D423-66	Passing #200 Sieve ASTM D1140-54	Hydrometer	One Dimensional Swell/Consolid-ation or Soil Suction
Sand, clean to silty (SM, SW & SP)	X			X		
Sand, clayey (SC)	X	X	X	X		X
Clay (ML, CL, MH, & CH), Weathered Claystone	X	X	X	X	X	X
Sandstone, clean to silty (SM, SW & SP)	X	(where possible)		X		
Sandstone, clayey (SC)	X	X	X	X		
Claystone (ML, CL, MH, & CH)	X	X	X	X	X	X
Dipping Bedrock Overlay District - A minimum of 2 test series per strata sampled for every 4 borings, except for hydrometer tests which are required at a minimum rate of one (1) test per strata sampled for every 4 borings. All Other Areas In the Plains - A minimum of one (1) test series per strata sampled for every four (4) borings and hydrometer tests are not required. However, in areas of highly expansive clays, additional testing may be required.						

b. Geotehnical Investigation Findings

(1) A description of the site including existing vegetation, evidence of previous construction, nearby water sources, and the slope of the existing site. (reloc. 7-12-05)

(2) A description of the proposed construction, including site grading, anticipated maximum cut and fill depths, the types of structures planned, and any anticipated sources of water such as detention or retention ponds, lakes and water features. (reloc. 7-12-05)

(3) Results of field and laboratory investigations and tests. (reloc. 7-12-05; am. 10-25-05)

(4) Graphical logs of the exploratory borings. All measurements of moisture content, dry density, Atterberg Limits, percent passing the No. 200 sieve, and measured percent swell of relatively undisturbed samples shall be summarized on the graphical logs. Boring logs shall indicate exisitng surface elevations, proposed surface elevations, foundation limits and bearing elevation limits of over-excavation if applicable. (reloc. 7-12-05; am. 10-25-05)

(5) Results of laboratory tests in graphic or tabular form. (reloc. 7-12-05)

(6) If applicable, discussion of dipping bedrock on the proposed development and the methods recommended to mitigate these impacts. If sub-excavation of bedrock and replacement by compacted fill is recommended, the recommended compaction and moisture contents for the fill shall be in accordance with the Compaction procedures in Excavation and Grading Section. (am. 7-12-05)

c. Geotechnical Map

(1) Preparation

The Geotechnical Map shall be a legible map of the area of investigation, at a suitable scale not greater that 1:24,000. (orig. 10-25-05)

(2) Content

(a) The proposed development's boundary, including lots, tracts, and street/road alignments. (reloc. 7-12-05; am. 10-25-05)

(b) The existing site topography based upon a topographic survey performed by a professional land surveyor. (am. 7-12-05; am. 10-25-05)

(c) The surface elevation of the bedrock beneath the site in the form of a contour map if not already included in the geologic reports. (am. 7-12-05; am. 10-25-05)

(d) Delineation and designation of soil types present. (reloc. 7-12-05)

(e) Natural and artificial soil hazard areas. (reloc. 7-12-05)

d. The date of all fieldwork was performed and a list of references and other supportive data used. (orig. 10-25-05)

3. Approval

The Geotechnical Report shall be approved by the County Engineering Geologist prior to the proposed development's approval. (orig. 10-25-05)

E. Geotechnical Plans

1. Preparation

a. The Geotechnical Plans shall be prepared and signed by a qualified professional engineer, registered in the Sate of Colorado, and qualified in the field of geotechnical engineering. (reloc. 7-12-05; am. 10-25-05)

b. Plans for engineered structures shall be prepared and signed by a professional engineer, registered in the State of Colorado, and qualified in the field of civil engineering. (reloc. 7-12-05)

c. Plans shall assure that soil and bedrock factors affecting the planning, design, construction, operation, and maintenance are recognized, adequately interpreted, and presented for use in engineering practice.(am. 7-12-05; am. 10-25-05)

2. Content

a. Alternative and solutions to abate and/or minimize the adverse soil and bedrock conditions on structures. (reloc. 7-12-05)

b. The entity/entities that will implement the plan, construct required improvements, and be responsible for the maintenance of the improvements and appropriate easements, if any. (reloc. 7-12-05)

3. Approvals

The Geotechnical Plan(s) shall be approved by the County Engineering Geologist prior to the proposed development's approval. (reloc. 7-12-05; am. 10-25-05)