OPEN-FILE REPORT 03-02

GEOLOGIC HAZARDS OF THE GEORGETOWN, IDAHO SPRINGS, AND SQUAW PASS QUADRANGLES, CLEAR CREEK COUNTY, COLORADO

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Denver, Colorado
2002

FOREWORD

The purpose of Colorado Geological Survey Open File Report 03-02, Geologic Hazards of the Georgetown, Idaho Springs, and Squaw Pass quadrangles, Clear Creek County, Colorado is to describe and map geological hazards within this part of Clear Creek County. This report includes a CD-ROM with digital shapefiles, a text booklet that defines and describes the various types of geological hazards, and two map plates (1:24,000-scale) that show the distribution of hazards in the project area. Some of the shapefiles on the CD-ROM include geologic hazards by type, geology, topography, slope inclination, stream channels, and a series of shaded relief maps.

The objective of this publication is to provide geological hazard information to government planners, resource and real estate developers, consultants, and interested citizens. Funding for this project came from the Colorado Department of Natural Resources Severance Tax Operational Fund and the Clear Creek County Planning Office. Severance taxes are derived from the production of gas, oil, coal, and minerals.

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INTRODUCTION

This report describes the geologic hazards of the Georgetown, Idaho Springs, and Squaw Pass quadrangles in Clear Creek County (Fig. 1). It was prepared to assist Clear Creek County in future planning and land-use management decisions. The report was prepared on the basis of 1:24,000-scale mapping and is recommended for initial land-use planning only. It is not intended for use in project or site-specific planning.

The report consists of a text booklet, digital shapefiles, and two maps (Plates 1 and 2) that describe and depict geologic hazards such as landslides, rockfalls, debris flows, and unstable slopes in the project area. Potential snow-avalanche and debris-flow paths, shallow groundwater and potential flood areas, major fault zones, and mine waste sites are also addressed herein. Some of the shapefiles include geologic hazards by type, geology, topography, slope inclination, stream channels, and a series of shaded relief maps.

Geologic hazards were outlined on the basis of previous studies, field work, and careful examination of 1:6,000- and 1:24,000-scale color aerial photographs. Geologic hazards in the towns of Idaho Springs and Georgetown were previously mapped by Soule (1975, 1999). Two masters theses from the Colorado School of Mines describe in detail some of the geologic hazards and engineering constraints throughout much of the Squaw Pass quadrangle (Montazer, 1978; Pelizza, 1978). Potential flood areas were outlined on the basis of geomorphic flood plains and Clear Creek County Flood Insurance Rate Maps (Federal Emergency Management Agency, 1980). The stream channel shapefile included in this report depicts streams on the basis of order as defined by the U.S. Geological Survey. First order streams are those in which stream flow originates, typically along steep tributary channels. These steep channels flow into lesser gradient second order streams, which in turn flow into third order streams, and so on. Clear Creek is a fourth order stream. The geology of the Georgetown and Idaho Springs quadrangles was mapped by Widmann and Miersemann (2001) and Widmann and others (2000), respectively. The geology of the Squaw Pass quadrangle was mapped by Sheridan and Marsh (1976). The slope shapefile was created using 30 m digital elevation models and the following slope classifications: 0 to 15 percent (0° to 6.75°), 15 to 30 percent (6.75° to 12.5°), 30 to 50 percent (12.5° to 22.5°), 50 to 70 percent (22.5° to 31.5°), 70 to 100 percent (31.5° to 45°), and greater than 100 percent (greater than 45°).

These maps are intended to show geologic conditions on a regional scale. Charts on each of the two map plates show applicability of the potential hazards to a variety of common land uses. Site-specific investigations by qualified professional engineering geologists will be necessary to accurately characterize the geologic conditions of any particular tract of land for development. Avoidance can be the optimal way to prevent conflicts between surface development and geologic hazards. Unfortunately, with strong development pressures affecting much of Colorado, avoidance may not always be an acceptable option. Engineered hazard mitigation may provide an acceptable alternative that enables selective development, or even full development, in areas subject to adverse geologic conditions. However, careful engineering geology studies and recommendations should precede engineering mitigation to allow for proper problem recognition and effective solutions.

GEOLOGIC SETTING

The project area is located in the central and eastern part of Clear Creek County in the Colorado Front Range west of Denver (Figure 1). The Interstate 70 (I-70) transportation corridor and the historic mining towns of Idaho Springs, Georgetown, and Silver Plume are located in the northern part of the project area. The area is characterized by rugged terrain ranging in elevation from just under 7,000 ft in the Squaw Pass quadrangle to over 12,800 ft in the Georgetown quadrangle. Parts of five historic precious- and base-metal mining districts lie within the area. They include the Idaho Springs, Freeland-Lamartine, Chicago Creek, Georgetown, and Silver Plume mining districts. The principal ore metals mined were gold, silver, lead, zinc, and copper, listed in order of decreasing importance (Streufert and Cappa, 1994). Active mining occurred generally from 1859 to 1942 and has been sporadic ever since.

The predominant rock types in the county are Precambrian metasedimentary, metavolcanic, and granitic rocks. There are several Precambrian faults in the area, many of which may have been reactivated during the late Cretaceous – early Tertiary Laramide orogeny (Tweto and Sims, 1963), and a few as recently as Miocene-Pliocene time (Scott, 1975; Kirkham and Rogers, 1981). Pleistocene-age glaciers in the Chicago Creek, West Chicago Creek, South Clear Creek, Leavenworth Creek, Clear Creek, and Bard Creek drainages carved out steep valley walls and deposited abundant glacial material throughout much of the Georgetown and Idaho Springs quadrangles.

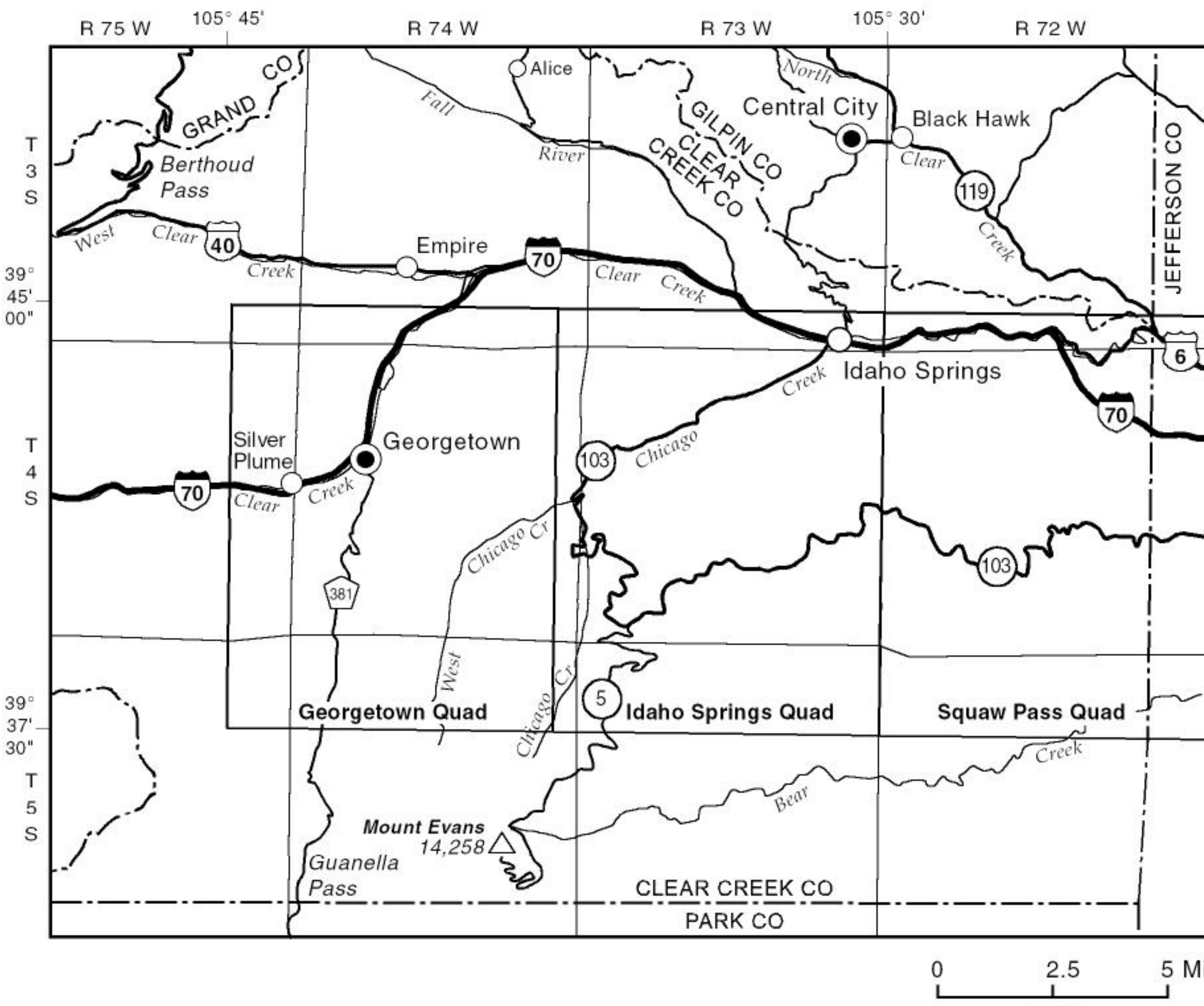

Figure 1: Map showing location of project area in the eastern part of Clear Creek County.

GEOLOGIC HAZARDS

A geologic hazard is a condition that poses, has posed, or has the potential to pose a threat to life, property, roads, utilities, and other works of man. Geologic hazards mapped in Clear Creek County were chosen for the propensity of geologic conditions and processes to cause problems for development and human activities. The units and their definitions are consistent with those described in House Bill 1041 (1974) and the Colorado Geological Survey's "Guidelines and Criteria for Identification and Land-Use Controls of Geologic Hazard and Mineral Resource Areas" (Rogers and others, 1974).

The occurrence and severity of geologic hazards is commonly associated with, but not entirely dependant upon, increased slope inclination and aspect. The topography in Clear Creek County area becomes much more extreme from east to west, and the abundance of geologic hazards similarly increases from the Squaw Pass quadrangle to the Georgetown quadrangle. The three most significant geologic hazards in the project area are rockfall areas, landslides, and debris flows. Rockfall is the most pervasive geologic hazard and is a particular problem along the I-70 corridor, U.S. Highway 6 (US-6), Colorado State Highway 103 (C-103) along West Chicago Creek, and County Road 381 (CR-381) to Guanella Pass. Major landslide complexes are located along CR-381, and along I-70 at the north end of Georgetown and south of Silver Plume. There are only a few small landslides on the Squaw Pass and Idaho Springs quadrangles, but two relatively small, active landslides in the northeastern part of the quadrangle affect I-70 and the area near the junction of US-6 and C-119. Debris flows are most prevalent at the base of the steep valley walls along the I-70 corridor, South Clear Creek, and West Chicago Creek, where tributary streams discharge a mixture of rock, debris, and floodwaters onto the main valley floor. Other hazards described herein include unstable and potentially unstable slopes, potential snow-avalanche paths, shallow groundwater and potential flood areas, major fault zones, mine waste, and artificial fill.

Rockfall Areas

Rockfall areas are defined as being subject to deposition of "relatively large fragments of rock [that] become detached [from their source area] and by means of free-fall, rolling, bounding or rapid sliding, or a combination of these methods, move rapidly down a very steep slope under the force of gravity" (Rogers and others, 1974, p. 30). Three zones typically define most rockfall hazards areas (Soule, 1976). They include: 1) the *source zone*, such as an exposed cliff, from which material is derived; 2) the *acceleration zone*, which is the area immediately below the source and is the path or debris chute down which the dislodged rock fragments travel, and 3) the *runout zone*, where slope inclination decreases and rock fragments are deposited. The boundaries between these zones are often gradational and difficult to delineate, and there was no attempt to map the zones separately in this report. The degree of risk associated with mapped rockfall areas should be assessed on a site-by-site basis by an engineering geologist with particular attention to the less obvious runout zone at the downslope edge of rockfall areas.

Source and accelerations zones in rockfall areas are characterized by slopes generally greater than about 50 percent. Moving rocks in these zones have high momentum and will travel a similar distance within the acceleration zone, fairly independently of size and shape. Within the runout zone, however, most smaller rocks will come to rest near the upper margin of this zone, and the larger rocks will travel farther. Similarly, equidimensional rocks will travel a greater distance than irregular or flat rocks. Other factors such as slope and surface conditions will also affect how far a moving rock will ultimately travel. Rocks of all sizes will lose momentum and be deposited more readily on slopes with low inclinations, such as exists on valley foot slopes and valley floors. However, rocks will travel farther on a runout surface that is wet and clayey or frozen, and a lack of vegetation or the presence of hard-pack snow may contribute to lengthened travel paths (Soule, 1976). The lower limit of the runout zone is therefore not easily defined on a reconnaissance scale, and it is strongly recommended that sites below mapped rockfall hazards also be studied by a qualified engineering geologist to ensure proper delineation of the maximum limits of the rockfall hazard. Inherent risks in rockfall areas include loss of life and damage to structures, roads, vehicles, and utilities. Therefore, development in and below these areas should be avoided unless site-specific analyses, such as detailed field studies and computerized rockfall simulation profiles (Jones and others, 2000), indicate that avoidance or engineering solutions will effectively mitigate the hazard.

Rockfall in Clear Creek County (Plate 2) is most prevalent in moderately jointed or foliated bedrock and is generally the result of exposure to repeated freeze-thaw cycles. These cycles occur most frequently during the spring and fall seasons, and accordingly, these are the times when rockfall events are most numerous (Andrew, 1994). Rockfall may also occur in more competent bedrock where steep cliffs are undercut due to erosion of less resistant underlying material, or where fractured by excavation or blasting activities. Local herds of bighorn sheep and mountain goats frequently graze along the west side of I-70 between Idaho Springs and Silver Plume, often starting small rockfalls as they scale the steep slopes. Vibrations from heavy vehicular traffic along I-70 may, over time, loosen or dislodge unstable rock fragments.

Most of the rock types in the Georgetown, Idaho Springs, and Squaw Pass quadrangles are prone to rockfall. Rockfall is less severe where metasedimentary rocks are particularly schistose, or contain high percentages of biotite. This rock type is the least resistant to weathering and therefore less likely to be cliff-forming. Foliation and jointing also play a significant role in the development of rockfall hazards. Where foliation and joints dip away from steep valley walls or road cuts, rockfall is less severe and slopes tend to be more stable. However, rockfall is more pronounced where foliation and joints dip toward valley walls and road cuts. Rockfall hazards are greatest along the steep-sided valley walls of glaciated drainages such as Clear Creek, South Clear Creek, and Chicago Creek, where slopes exceed 70 percent (approximately 30° or more). Areas prone to rockfall hazards were primarily identified based on the presence of existing rockfall debris. Other indicators of rockfall hazards include historic reports and rockfall tracks, freshly exposed faces in cliffs, and disturbed vegetation.

The Colorado Department of Transportation (CDOT) has systematically evaluated rockfall hazards along all state-maintained transportation corridors throughout the state (Andrew, 1994). Roadways studied by CDOT within the Clear Creek County project area include I-70, US-6, and C-103. Several factors such as geology, slope, drainage, rockfall history, and other physical aspects were considered to evaluate rockfall potential. At each site, the severity of each factor was rated and assigned a series of points ranging from 3 (least hazard potential) to 81 (greatest hazard potential). The total points calculated for all factors at a given site indicates the degree of rockfall potential. Sites receiving ratings of 550 or higher are considered priority sites for mitigation.

Along I-70, the rockfall hazard increases in severity from east to west. The slopes between the I-70/US-6 exchange and Idaho Springs received an average of about 250 points, whereas the rockfall areas between Idaho Springs and Silver Plume received and average of more than 420 points. The 3rd and 6th highest rated rockfall areas in the state are located just east of Silver Plume along the Georgetown Incline, both sites having earned more than 600 points. Several motorist fatalities caused by rockfalls have occurred here. The section of US-6 between the Clear Creek/Jefferson County line and the I-70/US-6 exchange averaged about 265 points, and C-103 from West Chicago Creek to South Chicago Creek had an average rating of 255 points.

Debris-Flow Deposition Areas

Areas subject to mass movement and deposition of over-saturated soil and rock debris and sediment-laden flooding during heavy rainfall or snowmelt runoff events are mapped as debris-flow areas. A debris flow is a viscous, flowing mixture of water, mud, boulders, other granular material, and organic debris. Debris flows typically originate in basins above the valley floor where considerable soil and debris is available for mobilization. Once dislodged and incorporated into the flow, material is funneled down steep debris chutes and either deposited in a fan-shaped area at the foot of the slope or incorporated into the flow of a higher order stream along the valley floor. Debris incorporated into a stream channel may then be deposited in a similar fan-shaped area where that stream intersects another drainage. These depositional areas are typically referred to as debris fans and are often considered prime sites for development because of easy access and scenic views offered by being elevated above the main valley floor. However, the lower reaches of debris chutes feeding the debris fans are high-hazard areas because of the tendency towards high velocity and thick flows. The sediment deposits from a single debris flow event may be several tens of feet thick.

Debris flows can be very destructive and life-threatening. Large boulders in debris flows can cause severe damage on impact, and shear and lift forces are capable of pulling poorly anchored structures from their foundations. Serious structural damage can result from debris-flow inundation of homes, particularly those with below-grade living, storage, and utility spaces. Damage to landscaping may prove costly as well, because the debris-flow material must be removed and disposed of and the site re-graded before re-vegetation can begin. In 1899, Brownville, a small settlement west of Silver Plume, was completely destroyed by a series of major debris flows carrying rock, mine tailings, and mud (oral communication, Silver Plume Historical Society).

The largest and most numerous debris fans in the county (Plate 1) are found along the I-70 corridor and South Clear Creek. A report by Coe and Godt (1997) indicates there are about

44 fans along the I-70 corridor between the Floyd Hill area and Georgetown. In addition, there are numerous small, roughly parallel debris chutes in the mapped area that create coalescing debris-flow deposition areas. Large areas of Idaho Springs, Georgetown, and Silver Plume are built on debris fans. Skyline Road in Georgetown passes over a large debris fan at the north end of town. Historical records indicate numerous depositional events on debris fans, many of which are coalescing, along the north and west sides of I-70 between the I-70 and US-6 interchange and the Georgetown incline. Recurrence intervals range from tens of years to thousand of years. Conversely, the last major phase of deposition on debris fans on the south and east sides of the highway generally occurred between 750 to 950 years ago (Coe and others, 1998), and recurrence intervals are on the order of hundreds of years to thousands of years (oral communication, J.Coe, 2000). This due in part to the fact that south-facing slopes in the area tend to be more sparsely vegetated than north-facing slopes, which leaves exposed soil and debris at greater risk for mobilization. South-facing slopes also experience more frequent and more pronounced freeze-thaw cycles, which may be partially responsible for manufacturing a greater abundance of debris-flow source material than on north-facing slopes. There are several smaller fans in many other prominent drainages such as Chicago Creek, West Chicago Creek, Leavenworth Creek, and Bard Creek.

Landslide Areas

Two different types of landslides are recognized in the project area (Plate 1). Most are characterized by curvilinear scarps parallel to the drainage, hummocky terrain, large rock fragments, and massive toreva blocks, which are essentially intact slabs of bedrock hundreds of feet in size that have been incorporated into the slide mass, moved downhill, and are frequently tilted backwards. In many cases, this process was probably initiated during glacial time when glaciers carved and over-steepened the valley walls of South Clear Creek, Clear Creek to just east of Georgetown, and Bard Creek. When glacial ice retreated, the valley walls were left without the support of the thick ice and subsequently began to fail. Foliation of the bedrock in these areas tends to be very steep (generally greater than 65°), which allows for multiple planes of weakness, thus promoting the landslide process. Release joints adjacent to lower valley walls and sackungen along ridge crests parallel to glaciated valleys are associated with many of the larger landslide complexes in the area. Major landslide complexes of this type occur on both sides of the South Clear Creek drainage, along the south side of I-70 near Silver Plume and the east side of I-70 near the Georgetown reservoir, and on the northern flank of Sherman and Republican mountains.

East of Georgetown, landslide activity is greatly reduced and landslides that do occur tend to be much smaller. This second type of landslide is characterized by material that is generally less than 10 ft in diameter but may range to several tens of feet in diameter. Three such landslides near the Georgetown reservoir have a fairly distinctive tear-drop morphology with an arcuate head scarp and a bulge of material at the toe of the landslide. Landslides on the Idaho Springs and Squaw Pass quadrangles occur on lesser slopes and have a less distinct morphology, but are comprised of similar-sized material.

The U.S. Geological Survey, Colorado Geological Survey, and Colorado Department of Transportation have worked together to install and monitor benchmark points on certain landslides and rockfall source areas along the I-70 corridor from Golden to the Eisenhower Tunnel. Within the project area of Clear Creek County, there are multiple GPS monitoring stations at five sites: 1) a rockfall slope just east of the town of Silver Plume, 2) an unstable slope on the west side of I-70 at Empire Pass, 3) the Floyd Hill landslide on the southwest side of I-70, 4) the I-70 fill landslide southeast of the I-70/US-6 exchange at the base of Floyd Hill, and 5) the Clear Creek Forks landslide at the junction of US-6 and Colorado State Highway 119 (C-119). Data and images of these sites can be viewed at http://landslides.usgs.gov/html_files/landslides/oueb2/landslide.htm.

The Clear Creek Forks landslide occurs at the US-6/C-119 junction in the northeastern-most part of the quadrangle. It is somewhat different than other slides in the area in that it appears to be a significant translational slide, which occurs when a large block of material slides downslope along a moderately-dipping plane of weakness, such as a foliation plane, under the force of gravity. In this case, the rocks are strongly foliated and have a foliation plane that dips towards the valley. This has led to the deformation of highway structures and the continuous release of debris onto the highway. Movement history of this landslide was monitored between 1951 and 1998. The landslide was reported to have moved 0.6 m/yr during the first two years it was monitored, 0.04 m/yr from 1952-1975, and less than 0.03 m/yr from 1987-1998 (Savage and others, 1998).

The Floyd Hill landslide has moved about 10 cm since last monitored in 1997. Rates of movement at the other three monitoring sites are minimal but no data have been published (written communication, R. Mock, 2000).

Landslide areas are recognized by their surface morphology, prominent head scarps, hummocky terrain, and disrupted drainage patterns. They may be in a state of quasi-equilibrium, but human-made disturbances such as road construction, placement of fills, cutting of slopes, irrigation, and septic systems can affect the stability of landslides and instigate renewed activity (Cruden and Varnes, 1996). Shallow groundwater areas or seeps may be present. Landslide areas may be subject to future movement, which can pose significant hazards to residences, roads, septic systems, utilities, and other improvements. Rockfall hazards are coincident with many landslide areas. Some landslide deposits may be prone to renewed movement or settlement when loaded or wetted.

Snow-Avalanche Paths

Avalanches involve the release of large masses of snow and accompanying debris that travel at high velocity down avalanche chutes. Like rockfall areas, avalanche paths are often characterized by three zones: 1) an accumulation or starting zone, 2) an acceleration zone, and 3) a runout zone. Avalanches typically begin on slopes ranging between 30° and 50° (greater than 70 percent) where there have been large accumulations of snow (Mears, 1992). In general, north-facing slopes are more susceptible to snow failure due to greater snow accumulations and colder snow conditions. The greater the mass of snow and debris released, and the greater the velocity of the turbulent mass, the greater the risk of fatalities and catastrophic damage to structures, roads, and utilities. There are numerous factors, such as slope angle and aspect, and snow moisture that determine how far an avalanche will travel downslope before losing its momentum and coming to rest. High-velocity avalanches traveling down steep slopes will be able to overcome the impeding effects of a highly vegetated or rough, irregular channel. Avalanches are likely to maintain momentum even on lesser slopes when the avalanche path is free of vegetation, underlain by a smooth surface such as hard pack snow or ice, or is relatively straight. Depending on the type and energy of the avalanche, snow and debris may reach as far as the valley floor and may even travel a considerable distance up the opposing valley wall before finally coming to rest. Avalanche runout zones are often coincident with debris-flow fans, as the same steep tributary channels often serve as paths for both types of events.

Clear Creek County is ranked 3rd in the state for avalanche fatalities, having recorded 20 within the past 50 years (written communication, D. Atkins, 2000). Avalanche-prone slopes occur most frequently on the Georgetown quadrangle (Plate 1), particularly along the I-70 corridor and CR-381 to Guanella Pass (Martinelli and Leaf, 1999). One of the most disastrous historic events in the area occurred in 1899 when an avalanche released from Williham and Cherokee Gulches swept through the town of Silver Plume and killed ten miners. Although avalanches were more frequent during the mid-1800s to the early 1900s (Atkins, 1998; Martinelli and Leaf, 1999) when mining activities had denuded the local hill slopes of vegetation, avalanche potential remains significant, especially north and south of Silver Plume.

Modern research on avalanche paths has been focused primarily near developed areas and important transportation corridors such as I-70. The avalanche paths shown herein are from publications by Mears (1979; 1992), Atkins (1998), and Martinelli and Leaf (1999), and reflect the focus of studies in the Silver Plume and Georgetown areas. *There have been no detailed studies of potential avalanche paths in the backcountry areas of eastern Clear Creek County, and no attempt was made to map potential paths in these areas during this project*. However, it is important to remember that most steep slopes may be susceptible to snow avalanches given extraordinary weather conditions. Therefore, careful consideration should be given to all debris chutes on steep slopes and beneath areas where large accumulations of snow may occur. For more information on avalanche hazard analysis, refer to Mears (1979; 1992) or visit the Colorado Avalanche Information Center website at www.caic.state.co.us.

Debris Chutes

Debris chutes are steep-gradient, entrenched, or v-shaped channels that serve to focus surface water and debris mobilized during storm events and spring snowmelt. Debris chutes may also act as rockfall and snow-avalanche acceleration zones. Most of the debris-flow deposition areas in the project area are located at the base of one or more debris chutes (Plate 1). Although not all debris chutes in the area have generated definitive debris fans, the area at the base or mouth of any of these steep gradient channels should be considered a potential hazard area. Debris chutes were mapped herein, first by tracing sharp "v" patterns in topography and all steep channels associated with debris fans. Chutes with a less-pronounced channel that exhibited signs of fresh scouring or were vegetated by plant life of a younger age or different type than surrounding areas were also included. The areas along the path of or at the base of these chutes are subject to all the same risks to life and property inherent to debris-flow, snow-avalanche, and rockfall hazards, and should be evaluated carefully on a site-by site basis.

Unstable Slopes

Unstable slopes are those that have a high potential for life- or property-threatening failure. These areas are particularly susceptible to rockfall, landslide, debris-flow hazards, and potential snow-avalanches and may be subject to all the same risks to life and property previously described for each of these hazards. Unstable slopes were mapped herein partly on the basis of slope inclination (generally more than about 70 percent), proximity to known landslide or rockfall areas, and presence of debris chutes. Other determining factors included rock structure, soil moisture content, and type of material comprising the slope. Where bedrock is highly competent, some steeper slopes may be fairly stable, and some lesser slopes may fail where bedrock is strongly jointed or foliated, particularly where joint and foliation surfaces dip towards principal valleys where there are transportation routes and development. Similarly, unconsolidated surficial material is prone to landsliding or creep and is considered unstable on slopes that exhibit features such as high soil moisture, seeps and water-loving plants, tension cracks, ridges or swales, or tilted or bent trees. Increased soil moisture conditions decrease slope stability, particularly when there is shallow bedrock or frozen substratum. Surficial material in steep basins above debris chutes and some first-order streams are prone to mobilization during heavy precipitation and may contribute significantly to debris-flow events. Above tree line, these deposits are typically less than five to seven feet thick; elsewhere the deposits may be several tens of feet thick.

The engineering and mitigation techniques required to build on unstable slopes frequently makes it cost prohibitive to develop these areas. Failure in the form of landsliding, rockfall, debris-flow, or accelerated creep can be initiated by natural causes such as increased precipitation, weathering, erosion, and earthquakes, and human-induced causes such as cut-and-fill activities, disruption of natural drainages, and blasting. Careful on-site investigations, siting, and mitigation are necessary in these areas to minimize the hazard.

Unstable slopes are prevalent along the I-70 corridor and become more pronounced from east to west (Plate 2). The steepest and most unstable slopes are in the Georgetown-Silver Plume area and the South Clear Creek drainage. Other areas of significant concern are US-6 east of the I-70/US-6 interchange, and C-103 along Chicago Creek.

Potentially Unstable Slopes

Potentially unstable slopes (Plate 2) were also mapped in part on the basis of geologic similarity to known rockfall and landslide areas and slope inclination (generally between 30 percent and 70 percent). Potentially unstable slopes differ from unstable slopes in that they are in a state of quasi-equilibrium and do not show signs of active failure. However, these slopes have the potential to generate life- and property-threatening hazards when disturbed by cut-and-fill activities, blasting, or disruption of natural drainages. Failure in the form of landsliding, rockfall, mudflow, or accelerated creep (particularly in surficial deposits) can also be initiated by natural causes such as increased precipitation, weathering, erosion, and earthquakes. Potentially unstable slopes are primarily susceptible to rockfall, landslide, and debris-flow hazards and are subject to all the same risks to life and property previously described for each of these hazards. Slopes underlain by competent rock may prove to be fairly stable, even on steep slopes, whereas lesser slopes underlain by strongly jointed or foliated rock or unconsolidated surficial deposits may be at risk for future slope failure. Slopes underlain by unconsolidated surficial deposits may be subject to sediment deposition and downslope movement of material by gravity, precipitation or snow-melt water, creep, or freeze-thaw action. In high alpine areas, these deposits are typically less than five to seven feet thick; elsewhere the deposits may be several tens of feet thick. Careful on-site investigations, siting, and mitigation are necessary in these areas to minimize the hazard.

Deposits Resulting from Human Activities

<u>Mine Waste and Selected Mine Openings</u>

The Georgetown-Silver Plume and Idaho Springs mining districts are part of the Central City-Clear Creek Superfund Study Area, defined by the U.S. Environmental Protection Agency (EPA). At the request of the U.S. Forest Service, the Colorado Geological Survey evaluated the physical and environmental hazard potential of numerous abandoned mine sites in ranger districts throughout the state. Sites occurring on Forest Service land were rated on a scale of 1 to

5, with 1 being extreme hazard potential and 5 being no hazard potential. Physical hazards include but are not limited to open vertical shafts, unstable adits, extremely tall highwalls, and collapsed stopes. Physical hazards of this nature near roads or towns (i.e., reasonably accessible to the public) may pose extreme danger to persons or property. Progressive development may increase public access to some mines that were previously considered lower risk because of their remoteness, thus increasing risk potential of those mines. Environmental hazards generally focus on the potential of mine sites to contaminate nearby streams or groundwater through influx of sulfide minerals, which may lead to acid drainage and elevated heavy metal content. For more information on the guidelines used to assign hazard potential ratings, see Sares and others (1993).

The Georgetown, Idaho Springs, and Squaw Pass quadrangles are all within the Clear Creek Ranger District, which was evaluated in 1993 (Sares and others, 1993). Roughly 155 abandoned mines on Forest Service land within the Georgetown, Idaho Springs, and Squaw Pass quadrangles were evaluated for physical hazards. Most of these sites received a rating of 3 or higher. However, 17 sites received a rating of 2 (Plate 1), and six of these are among the ten most significant mine hazard sites in the district (Table 1).

The Colorado Geological Survey recommended that all sites with a physical hazard rating of 1 or 2 be capped, filled, or closed in some way. These high-hazard mine sites are shown on Plate 1 and the GIS shapefile accompanying this report. *Mine sites not occurring on U.S. Forest Land were not evaluated during this study and should be examined by a professional geologist to determine the potential of physical hazard to life or property*.

	Rank	Rating	Site Name	Quadrangle	Location
Physical	3	2	West Gold Upper Tunnel	Idaho Springs	NW sec. 2, T. 4 S., R. 73 W.
	5	2	Golden Glen	Idaho Springs	E ½ sec. 8, T. 4 S., R. 73 W.
	6	2	Upper Warren Gulch	Idaho Springs	SW,SW sec. 12, T. 4 S., R. 73 W.
	7	2	Little Richard Mine	Idaho Springs	C-E ½ sec. 12, T. 4 S., R. 73 W.
	8	2	Lower Ute Creek	Idaho Springs	SE sec. 7, T. 4 S., R. 73 W.
	10	2	Sidney Tunnel	Georgetown	NW sec. 36, T. 4 S., R. 75 W.
Environ-mental					
	1	2	Little Bear Creek*	Idaho Springs	SE,NW sec. 12, T. 4 S., R. 73 W.
	5	3	West Gold Upper Tunnel	Idaho Springs	NW sec. 2, T. 4 S., R. 73 W.

*Site reclaimed in 1999.

Table 1. Abandoned mine sites ranked among the ten most hazardous (rank of 1 is the worst) in the Clear Creek Ranger District for potential physical and environmental hazards.

Just over 100 mines within the Georgetown, Idaho Springs, and Squaw Pass quadrangles were evaluated for environmental hazards. Most of the sites evaluated were rated 4 or 5. However, two sites ranked among the top ten environmentally degraded sites in the district (Table 1). One of these sites, Little Bear Creek, south of Idaho Springs, was listed as the most significantly environmentally degraded site in the district. The mine opening was draining very poor quality water that had low pH (3.85) and high conductivity (1500 μS). The waste pile associated with the mine was up to 35 ft thick, had an estimated volume of 7,000 cubic yards, and contained heavy metals including arsenic, cadmium, and lead (written communication, Armstrong Data Services, EPA contractor, 1999). The site was reclaimed in 1999 in a cooperative effort by the U.S. Forest Service, Colorado Department of Public Health and Environment, and the EPA. Additionally, the Black Eagle mill tailings located southwest of Idaho Springs, and the Big Five tunnel mine waste pile located near the U.S. Forest Service office in Idaho Springs, were graded and re-seeded in 1994 and 2000, respectively. Once reclaimed, environmental hazards at these sites were greatly reduced.

The Colorado Geological Survey recommended that all abandoned mines earning an environmental hazard rating of 1 or 2 be reclaimed in some fashion. All sites within the Georgetown, Idaho Springs, and Squaw Pass quadrangles that were evaluated for environmental degradation received a rating of 3 or higher, except for the Little Bear Creek site, which received a rating of 2. Although Plate 1 shows abandoned mine sites rated 1 or 2, the Little Bear Creek site is not shown because it has been reclaimed. *Sites not occurring on U.S. Forest Land were not evaluated during this project and should be examined by a professional geologist to determine environmental hazard potential.*

Artificial Fill

Artificial fill is used in the construction of roads, dams, and other human facilities and may be susceptible to settlement if not properly engineered and constructed. The majority of the artificial fill in the project area is associated with the I-70 corridor and numerous reservoirs, particularly along South Clear Creek. Most fill areas associated with town sites, homes, and commercial sites were not mapped during this project.

Landfill

Municipal and household refuse landfill sites may pose physical and environmental risks. Municipal trash placed in landfills is susceptible to severe settlement and can contaminate local water resources. Also, waste products may generate biogenic methane gas as organic materials decay, which can create fire and explosion hazards. The Soda Creek landfill south of Idaho Springs is the only one within the project area that is considered active. The landfill near the cemetery in Silver Plume has been inactive for about 20 years, and a reclaimed landfill site near the present-day Silver Queen apartments in Georgetown has not been used for more than 30 years (oral communication, Clear Creek County Archivist, C. Bradley, 2000). Only the Soda Creek landfill is shown on the map that accompanies this report.

Geomorphic Floodplains

Geomorphic floodplains are herein delineated on the basis of stream bed morphology and distribution of young alluvium (Plate 1). *They do not necessarily reflect hydrogeologic potential, statistical recurrence intervals, or flood magnitude for a given stream.* Areas up to roughly 15 feet above the bank full stage, which represents, in a general way, the mean annual flood level, are herein considered subject to potential seasonal or storm-event flooding, ponding of water, and alluvial deposition. Structures, roads, and utilities located near active stream channels may be damaged or destroyed during high-water or flood events. Areas where the water table is at or very close to the land surface, either seasonally or year-round, will likely interfere with normal construction techniques and may pose problems for below-grade construction and septic systems.

Flooding often occurs along Clear Creek and its tributaries during the spring due to rapid snowmelt, and during the summer due to intense localized rainfall events (Colorado Water Conservation Board, 1998). The worst-case scenarios occur when heavy rainfall coincides with rapid snowmelt. On the Georgetown and Idaho Springs quadrangles, geomorphic floodplains generally coincide with areas mapped by Widmann and others (2000) and Widmann and Miersemann (2001) as Quaternary alluvium (Qa). On the Squaw Pass quadrangle, geomorphic floodplains coincide in part with areas mapped by Sheridan and Marsh (1976) as Piney Creek or Post-Piney Creek alluvium (Qpp, Qp, and Qal).

Any area on or adjacent to stream channels may be flood-prone. To assess the flood potential in a specific area or site, consult the Clear Creek County Flood Insurance Rate Map (Federal Emergency Management Agency, 1980), Floodplain Information Report (Colorado Water Conservation Board, 1998), and Flood Insurance Study (U.S. Department of Housing and Urban Development, 1978). Additionally, a report by the Environmental Protection Agency and Colorado Department of Public Health and Environment describes many aspects of the Clear Creek watershed in great detail (Fliniau and Norbeck, 1997).

Sackungen and Lineaments

Sackungen are linear features or trough-like structures occurring on high mountain ridges that indicate deep-seated rock creep, ridge spreading movements, and slope failure. In the Georgetown quadrangle there are several such lineaments on Republican Mountain, Pendleton Mountain, the Sugarloaf Peak ridge, and the ridge line east of Hells Hole (Plate 1). These features are generally parallel to the ridge-crest lines and have probably developed in response to gradual gravitational spreading of rock masses into adjacent valleys after glacial ice retreated, leaving over-steepened valley walls and upper slopes without the support of the thick ice. Foliation of the bedrock in these areas tends to be roughly parallel and to dip steeply (generally greater than 65°) toward adjacent valleys, which further enhances sackungen development. Many of these features have a close spatial relationship to major landslide complexes along South Clear Creek, Clear Creek, and Bard Creek. Furthermore, many of these landslides appear to have originated along sackung features and may have resulted in part from sackungen that failed completely, suggesting the potential for continued or future landslide activity wherever these features are present.

Several linear features also occur on Otter Mountain, at the southwest corner of the map. These lineaments may be related to ridge spreading, but they differ somewhat from typical sackungen features in that they are oblique to the ridge crest and cut across Otter Mountain. Furthermore, they happen to be parallel to two northwest-striking faults that occurr in saddles immediately west of Otter Mountain, suggesting a possible fault-related origin. Subsequent gravitational spreading may be responsible for accentuating these features.

Although sackungen are mostly in high and remote areas and appear to be in a state of quasi-equilibrium, natural processes such as freeze-thaw cycles, heavy precipitation events, and gravitational stresses may accelerate ridge spreading and may trigger large-scale, potentially catastrophic landsliding. Mapped landslide deposits in the area show many cases where significant slope failures have descended into and across major valleys. Similarly, disturbance of valley walls adjacent to these features by significant human activities such as road construction, placement of fills, cutting of slopes, irrigation, and installation of septic systems may cause serious slope failure.

Faults and Fault Zones

A fault is a break, or series of breaks, in the earth's surface along which there has been movement of one side relative to the other. The vibrations from these movements are called earthquakes. Large earthquakes result in ground-surface rupture along the causative fault. Aside from the obvious threat to structures due to a surface rupture, a great deal of structural damage is often sustained as a result of violent shaking of the earth's surface during a nearby earthquake. During moderate and large earthquakes, violent shaking of the ground can occur many miles away from the causative fault. In addition to ground displacement and ground shaking, other potential hazards such as landsliding and rockfall may occur. The Floyd Hill fault and the Kennedy Gulch fault have been defined as late Cenozoic structures (less than 23.7 million years old), and have some undetermined, but probably low potential for future surface rupture (Widmann and others, 2002). Present knowledge of seismic potential in the area does not allow for determination of rupture potential for other faults in Clear Creek County. Therefore, a professional engineering geologist should carefully analyze any site on a fault or within a fault zone where critical structures such as hospitals, schools, emergency-response facilities, dams, and power plants are proposed.

The majority of the faults mapped on the Georgetown, Idaho Springs, and Squaw Pass quadrangles cut through crystalline rocks such as granite and gneiss. Some of these faults exhibit only minor displacement. The rocks adjacent to these faults are typically only minimally affected and the fault zone is considered thin or narrow. However, some of the faults are characterized by wide zones (several tens to hundreds of feet) of fractured and pulverized rock. In some cases, these zones of shattered rock may adversely affect development potential in that they may be conduits for or barriers to surface or groundwater flow, may have low bearing strength, and may be susceptible to collapse or compaction. Where exposed on steep slopes, material from these zones is prone to rockfall and landsliding. For example, landslide deposits along the I-70 corridor in the eastern part of the project area are derived from highly fractured rock associated with the Floyd Hill fault. Usually, careful planning will allow for mitigation of these potential hazards.

GEOLOGIC CONSTRAINTS

A geologic constraint is a condition that may require special engineering design considerations, which may translate to added cost in development, but does not ordinarily present a serious threat to life or property. One of the principal building constraints in the area is shallow crystalline bedrock. In many places, hard granite or gneissic rock is at or very near the surface. Development in these areas may require blasting for foundations, roads, and utility trenches. Furthermore, areas of solid bedrock usually hinder construction of or interfere with the proper functioning of septic systems. Shallow crystalline bedrock is not shown on either of the map plates accompanying this report; consult the GIS geologic map layers included on the CD-ROM to locate these areas (mapped as Precambrian rock). Another potential development constraint involves areas where the groundwater table is at or very near the ground surface, either seasonally or year-round. This includes areas adjacent to many stream channels and wetland areas such as Doolittle Ranch and Echo Lake. A shallow groundwater table interferes with normal construction techniques and may pose problems for below-grade construction and septic systems.

ACKNOWLEDGEMENTS

This project was funded jointly by the Clear Creek County Planning Office and the Colorado Geological Survey's Department of Natural Resources Severance Tax Operational Funds. Many thanks are extended to David Noe, Jon White, Vince Matthews, and Jim Soule, Colorado Geological Survey, for their professional guidance and reviews. Map plates were completed with the greatly appreciated assistance of Jason Wilson.

REFERENCES

Andrew, R.D., 1994, Colorado rockfall hazard rating system: Colorado Department of Transportation, Report No. CTI-CDOT-2-94, prepared in cooperation with the Colorado Geological survey and the Colorado Transportation Institute, 457 p.

Atkins, D., 1998, Colorado Department of Transportation, Region I Avalanche Atlas: unpublished report prepared for the Colorado Department of Transportation, October 7, 1998, unpaginated.

Coe, J.A., and Godt, J.W., 1997, Characteristics of alluvial fans from tributaries of Clear Creek, Floyd Hill to Georgetown, Colorado: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A-316.

Coe, J.A., Godt, J.W., and Parise, M., 1998, Evaluation of stream and debris flow hazards on small fans along the Interstate-70 Highway corridor, Central Colorado, U.S.A.: 23rd General Assembly, European Geophysical Society, Nice, France, April, 1998, Annales Geophysicae, v. 16, Supplement IV, p. C1215.

Colorado Water Conservation Board, 1998, Floodplain Information Report, Clear Creek County, Colorado: Colorado Water Conservation Board, Department of Natural Resources, Denver, Colorado, 6 p.

Cruden, D.M., and Varnes, D.J., 1996, Landslide types and processes, in Landslides, Investigation and Mitigation: Transportation Research Board Special Report 247, Washington, D.C., National Academy Press, p. 36-75.

Federal Emergency Management Agency, 1980, Flood Insurance Rate Map, Clear Creek County, Colorado: Federal Emergency Management Agency, Washington.

Fliniau, H., and Norbeck, C., 1997, State of the watershed report – 1997, Clear Creek, Colorado: Environmental Protection Agency and Colorado Department of Public Health and Environment, 41 p.

Jones, C.L., Higgins, J.D., and Andrew, R.D., 2000, Colorado rockfall simulation program, v. 4.0: Colorado Geological Survey Miscellaneous Investigations 66, CD-ROM.

Kirkham, R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: Colorado Geological Survey Bulletin 43, 171 p.

Martinelli, M., J., and Leaf, C.F., 1999, Historic avalanches in the northern Front Range and the central and northern mountains of Colorado: U.S. Forest Service General Technical Report RMRS-GTR-38.

Mears, A.I., 1979, Colorado snow-avalanche area studies and guidelines for avalanche-hazard planning: Colorado Geological Survey Special Publication 7, 124 p.

Mears, A.I., 1992, Snow-avalanche hazard analysis for land-use planning and engineering: Colorado Geological Survey Bulletin 49, 55 p.

Montazer, P.M., 1978, Engineering geology of upper Bear Creek area, Clear Creek County, Colorado: Golden, Colorado, Colorado School of Mines, Masters thesis T-1909, 229 p.

Pelizza, M.S., 1978, Environmental and surficial geology in east central Clear Creek County, Colorado: Golden, Colorado, Colorado School of Mines, Masters thesis T-1895, 102 p.

Rogers, W.P., Ladwig, L.R., Hornbaker, A.L., Schwochow, S.D., Hart, S.S., Shelton, D.C., Scroggs, D.L., and Soule, J.M., 1974, Guidelines and criteria for identification and land-use controls of geologic hazard and mineral resource areas: Colorado Geological Survey Special Publication 6, 146 p.

Sares, M.A., Phillips, R.C., and Streufert, R.K., 1993, USFS abandoned mine land inventory, Clear Creek Ranger District: unpublished report prepared by the Colorado Geological Survey under cooperative agreement with U.S. Forest Region 2, CD-ROM.

Savage, W.Z., Coe, J.A., Varnes, D.J., Godt, J.W., and Streufert, R.K., 1998, Movement history of the Clear Creek Forks landslide, Clear Creek County, Colorado, in Moore, D., and Hungr, O., eds., Proceedings of the Eighth International Congress, September 21-25, 1998: International Association for Engineering Geology and the Environment, p. 1683-1687.

Scott, G.R., 1975, Cenozoic surfaces and deposits in the southern Rocky Mountains, in Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 227-248.

Sheridan, D.M., and Marsh, S.P., 1976, Geologic map of the Squaw Pass quadrangle, Clear Creek, Jefferson, and Gilpin Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1337.

Soule, J.M., 1975, Idaho Springs, Clear Creek County, Colorado, area geologic hazards map: Colorado Geological Survey Open-File Report 75-5.

Soule, J.M., 1976, Geologic hazards in the Crested Butte – Gunnison area, Gunnison County, Colorado: Colorado Geological Survey Information Series 5, 34 p.

Soule, J.M., 1999, Active surficial-geologic processes and related geologic hazards in Georgetown, Clear Creek County, Colorado: Colorado Geological Survey Open-File Report 99-13, 6 p.

Tweto, Ogden, and Sims, P.K., 1963, Precambrian ancestry of the Colorado mineral belt: Geological Society of America Bulletin, v. 74, p. 991-1014.

U.S. Department of Housing and Urban Develoment, 1978, Flood Insurance Study, City of Idaho Springs, Colorado, Clear Creek County: U.S. Department of Housing and Urban Development, Federal Insurance Administration, Denver, Colorado, 10 p.

Widmann, B.L., Kirkham, R.M., Beach, S.T., 2000, Geologic map of the Idaho Springs quadrangle, Clear Creek County, Colorado: Colorado Geological Survey Open-File Report 00-2, 22 p, scale 1:24,000.

Widmann, B.L., Kirkham, R.M., Morgan, M.L, and Rogers, W.P., *with contributions by* Crone, A.J., Personius, S.F., and Kelson, K.I., *and GIS/Web design by* Morgan, K.S., Pattyn, G.R., and Phillips, R.C., 2002, Colorado Late Cenozoic fault and fold database and internet map server: Colorado Geological Survey Bulletin 64a, http://geosurvey.state.co.us/pubs/ceno/index.htm

Widmann, B.L., and Miersemann, Ulrike, 2001, Geologic map of the Georgetown quadrangle, Clear Creek County, Colorado: Colorado Geological Survey Open-File Report 01-05, scale 1:24,000.