Map Series 42

Colorado Springs Landslide Susceptibility Map, El Paso County, Colorado

By Jonathan L. White and T.C. Wait

Colorado Geological Survey
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Foreword

In the late 1990s several landslides occurred in the City of Colorado Springs. These landslides alarmed many people and were widely reported in the press.

Since 1996, the Colorado Geological Survey (CGS) has provided technical reviews of geologic hazards at the request of the city planning office as a part of their plan-approval process for land-use development applications. CGS has also provided risk assessments and validations for those homes impacted by the 1999 landslides whose owners applied for a buy-out from the Federal Emergency Management Administration (FEMA). This program was part of the FEMA response when a Presidential Disaster Declaration was proclaimed for Colorado Springs and El Paso County after heavy spring flooding.

The CGS, as well as other consulting geologists in the area, has noted that landslides occur in specific geologic, geomorphic, and topographic terrains in the city. This specific terrain is widespread in the western parts of Colorado Springs. As such, these areas may be at some undefined potential risk of landslide activation of which many homeowners or property owners may be unaware. The heightened attention to this susceptibility by state geologists, city staff, and policy managers resulted in funding in 2001 for hazard assessment and mapping.

The purpose of this publication is to provide a map for the public that identifies city areas where landslide-susceptibility potential has been determined, based on terrain similarities and conditions comparable to previous landslides.

Funding for this project was provided by FEMA, the City of Colorado Springs, and the Colorado Department of Natural Resources Severance Tax Operational Account. Severance taxes are derived from the production of gas, oil, coal, and minerals.

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Acknowledgments

Funding for this study was provided by FEMA (administered by the Colorado Water Conservation Board), the Development Review Unit of the City of Colorado Spring Planning Agency, and through the CGS Critical Hazards Program funded by the Department of Natural Resources Severance Tax Operational Account. Severance Taxes are derived from the production of gas, oil, coal, and minerals in Colorado. Colorado Springs Utilities, by licensed agreement, provided digital data, Facilities Information Management System (FIMS) and orthorectified air photos used during this project. The Colorado Springs City Planning Agency also provided a Geographic Information Systems (GIS) workstation for use in Colorado Springs. Copies of the 1966 aerial photography were obtained from the Pikes Peak Library District Photo Archives.

The authors would like to acknowledge and thank Phil Friesen, Senior GIS Analyst for the City of Colorado Springs Planning Agency, for his valuable help with the generation of certain GIS coverages and general project assistance. Certain landslide mapping data were taken from private consulting reports submitted to the City, CGS, or El Paso County as part of development land use application and are in the public record. John Himmelreich provided additional landslide data and allowed the CGS to review and digitize certain proprietary, unpublished maps. These various sources are not included in the references, but are enumerated on the map. They can be queried from the map table and landslide table in Appendix A for development name, consultant, their job number, and CGS review number if applicable. Jason Wilson (CGS) provided the base map compilation, some of the graphics, and digital cartography of the map plates. Chris Redman formatted the book and Cheryl Brchan edited the book and text.

The authors would like to extend their appreciation to David Noe (CGS); Thomas Terry (CTL/Thompson); John Himmelreich, Jr. (Himmelreich and Associates); Tom Huber, University of Colorado at Colorado Springs (UCCS); Pat Rogers (CGS); and Scott Anderson, Federal Highway Administration (FHWA) for their technical review of this map and publication. Their thoughtful insights were incorporated into the final publication.

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Introduction

Landslides are one of the most costly natural hazards in the United States, threatening every state. A recent estimate by the U.S. Geological Survey (USGS) states that 25 to 50 deaths and damage exceeding $2 billion occur every year in the U.S. (Spiker and Gori, 2000). Landslides are the result of the force of gravity acting on a slope where the soil/rock strength is sufficiently weak enough that the slope-forming materials shear against each other and begin to move, flow, or slide downhill. These movements can range from very rapid, singular events, such as rockfalls or debris flows, to very slow ground movements that are only perceptible over months or years. Structures not designed for earth movements generally do not survive landslide movements. The tremendous earth forces will shift, shear, crack, remove, or bury buildings. Once initiated, landslide movements often continue until the damage is such that the structure is completely destroyed or the distress makes the structure unusable, requiring demolition and/or costly remedial design and repair. Critical facilities such as highways are similarly affected. When these structures are residential structures, they become dangerous and unlivable, requiring condemnation and loss of the home or even entire neighborhoods.

The City of Colorado Springs lies at the boundary between the Great Plains and the Front Range of the Southern Rocky Mountains (Figure 1). The western part of the city occupies a series of foothills and bench-like pediment remnants underlain by weak, overconsolidated Cretaceous claystones and shales, which are prone to landslides (Brooker and Peck, 1993) (Figure 2). Whereas most early growth generally avoided the foothills, these areas have become increasingly built upon during the 1980s, 1990s, and continuing today. This is fueled by premium land prices for infill and view lots. Many of these areas have previously been mapped as landslide deposits (or susceptible to landslides) by Scott and Wobus (1973), Cochran (1977a-e), and Trimble and Machette (1979). More recently, geologic hazard land-use reviews (see Appendix A) and geologic mapping by the Colorado Geological Survey (CGS) have verified the occurrences of landslides within the Colorado Springs city limits (Carroll and Crawford, 2000; Thorson and others, 2001; Rowley and others, in publication; Keller and others, in preparation; and Morgan and others, in preparation).

Several areas in the city have experienced various degrees of damage from landslide movements during the 1990s. During the spring months of 1995, 1997 (to a lesser extent), and 1999, corresponding with wet winters or long-duration spring rainstorms, there were numerous incidents of ground movement, many of which became well publicized in the local media. Human-caused factors such as slope modification and lawn irrigation appear to have played a part in several of these episodes (Noe and White, unpublished).

Flooding and landsliding resulting from severe storms in 1999 caused widespread and significant damage to Colorado Springs. Subsequently, a Presidential Disaster Declaration was issued for Colorado Springs and El Paso County that made federal relief available. Media attention to the landslide problems grew in 1999 and 2000 during the flood/landslide disaster response by FEMA. Part of that federal response was that the Federal Emergency Management Agency (FEMA) provided Colorado Springs with over $4.8 million in funds, under the Unmet Needs program, to acquire landslide-affected properties. The total cost of this program as of the end of 2002 was $6.35 million, including city and homeowner cost-share contributions (Squire, M., oral communication, 2002). Including this program cost with other damages, investigations, remedial work, maintenance costs, and residential damage not divulged by owners, the total to the city for all landslide damage from 1999 was likely in the tens of millions of dollars.

PURPOSE AND NEED

Since the mid 1990s, it has become increasingly apparent to CGS geologists, Colorado Springs staff and elected officials, and private-sector professionals that significant segments of the public in Colorado Springs are not aware that they reside in areas of

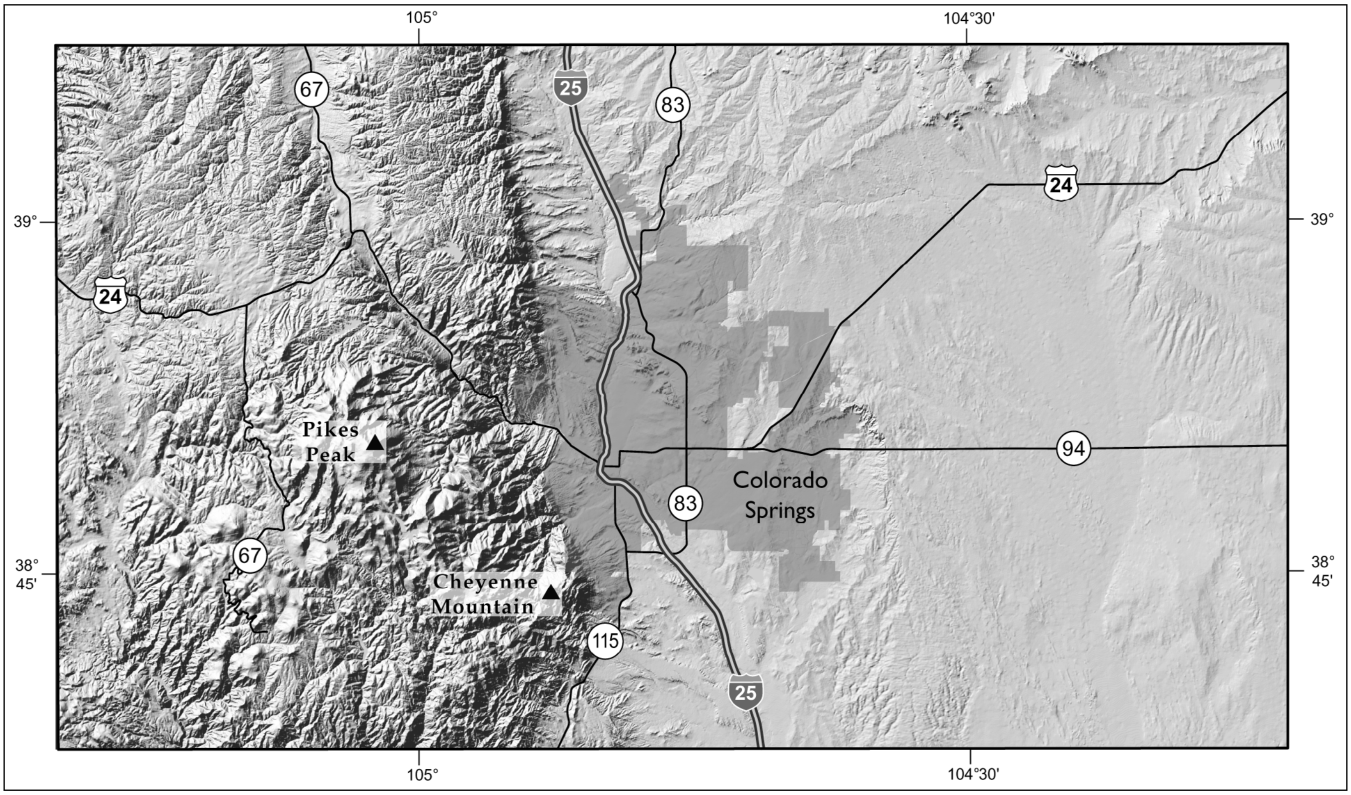

Figure 1. Colorado Springs vicinity shaded relief-map and city boundaries.

landslide potential, and are exposed to the inherent risks and possible liabilities associated with living in such terrain. This perception continues even though some disclosures have been made in public forums.

An aspect of the 1999 federal disaster relief was that certain FEMA Unmet Needs funds became available for hazard delineation purposes. This publication and map were partially funded through that FEMA program and by additional funding from the City of Colorado Springs Development Planning Department. Concurrent with this landslide hazard-mapping, a variety of geology-related land use issues in Colorado Springs prompted the CGS to begin a comprehensive geologic mapping program of El Paso County, centered on the City of Colorado Springs.

The purpose of this publication is to provide a map showing areas of Colorado Springs where landslides have been identified, and to show areas that are judged to be more susceptible to deep-seated landslides than others. This delineation of potential hazards areas is based on existing mapped landslides and specific geologic, topographic, and hydrologic conditions.

SCOPE OF PROJECT

The three map plates included in this publication (Map Plates 1-3) show areas of landslide susceptibility and outlines of landslides mapped within the city limits of Colorado Springs. This map is not intended for site-specific determinations of ground stability or assigning risk, nor does it imply that any property that lies within zone boundaries is necessarily currently unstable. The intent is to provide map coverages that will aid ongoing city planning, allow for general-public information disclosure and education, and prompt a future level of geological and geotechnical investigation that is appropriate for the hazards and potential risks present.

The project methodology applied a modified heuristic or qualitative method using a basic inventory of landslides, published and non-published geologic maps of the area, known engineering characteristics of bedrock and derived soils, and digital information, both image-based and calculated from precise photogrammetry (Soeters and van Western, 1996). Previous landslide susceptibility studies and projects (Ahmad and McCalpin, 1999; Wegmann and Walsh, 2001) and earlier Colorado Springs-specific land use/zoning and hazard reports and maps (Hill,

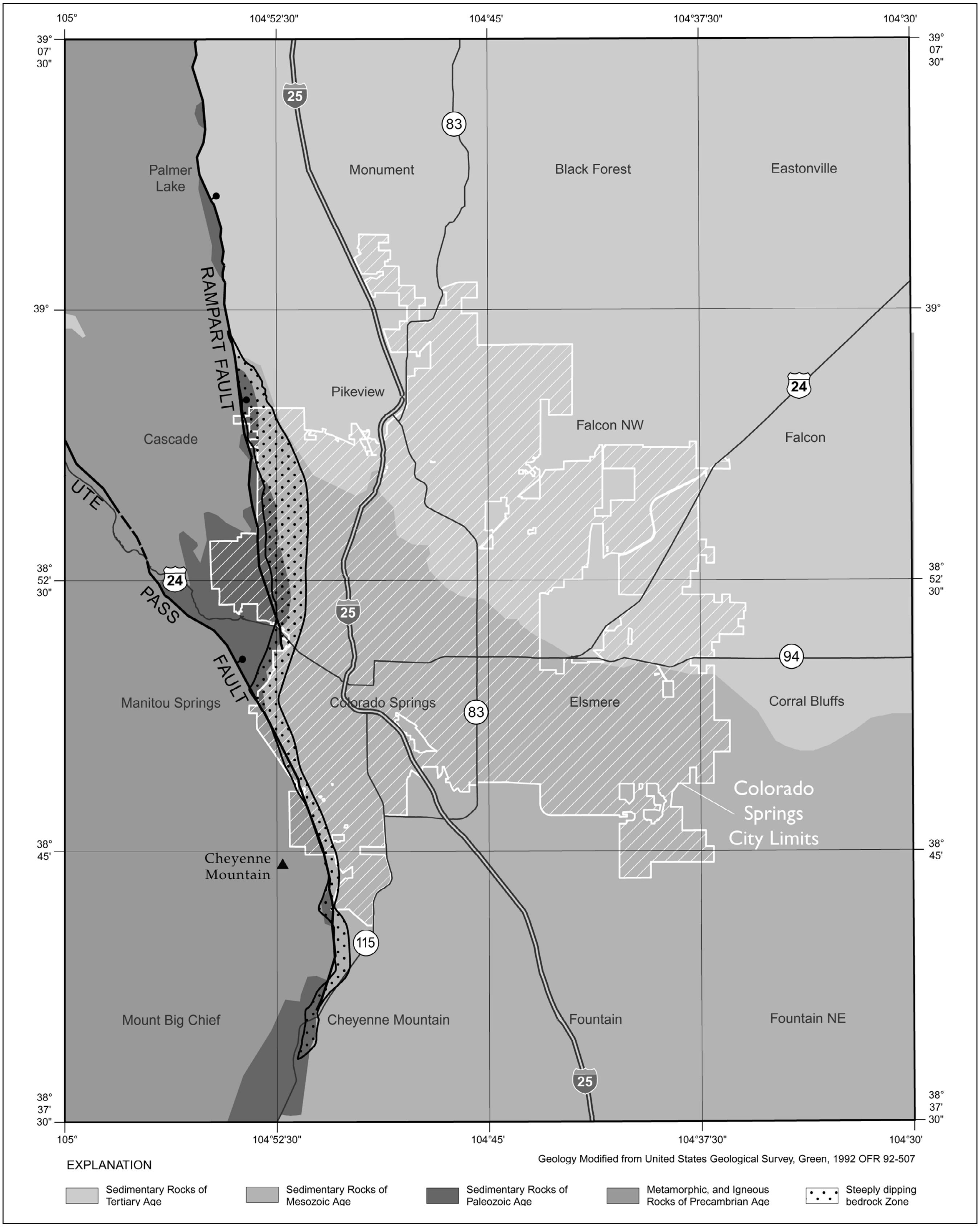

Figure 2. Generalized geologic map of the Colorado Springs area showing the steeply dipping bedrock zone and major faults.

1974; Gruntfest and Huber, 1985) were reviewed for this project. Other data were derived from various consultant reports, GIS data sources, aerial photo interpretations, and field checking by CGS engineering geologists.

Certain forms of ground movements were not included in the scope of this project. They include: slow, shallow creep; ground subsidence from collapsible soils or mine subsidence; swelling and heaving from expansive soil and bedrock; and rapid forms of mass movements such as rockfalls, rockslides, and debris flows. These types of geologic hazards, while still significant in Colorado Springs, are not included or mapped for this specific publication.

Geology and Landslide Background

To understand landslide susceptibility and the risks inherent to such ground movements, some additional background information is needed. The following sections briefly describe the local geologic conditions of Colorado Springs, generalized landslide hazards, the most common method to analyze slopes for instability, and a recent history of landslides and the damage they have caused in Colorado Springs.

GEOLOGY OF THE COLORADO SPRINGS AREA

The City of Colorado Springs straddles the Colorado Piedmont portion of the High Plains and Rocky Mountains physiographic provinces. East of Interstate 25, the city lies on the rolling hills of the High Plains. West of Interstate 25, the city rises in elevation towards Cheyenne Mountain, Pikes Peak and the Rampart Range that border the city to the west. Within the city limits, ground elevations vary from 5,720 to 9,212 feet above sea level, an elevation change of 3,492 feet. Figures 1 and 2 show the physiography and generalized geology of the Colorado Springs area.

Two high angle reverse fault zones, the Rampart Range and Ute Pass faults, mark the eastern edge of the Front Range in the Colorado Springs area. These faults were active during the Cenozoic Laramide Orogeny that uplift the Front Range and have shown continued movements into the Quaternary Period. While uncommon, low-level seismic activity still occurs, and rare felt events have been historically reported (Widmann and others, 2002). Complex geologic structures are found where the faults converge around the Garden of the Gods and Manitou Springs. Tilted, steeply dipping, even vertical and overturned rock formations formed by uplift and thrust-fault drag are found in the late Paleozoic and Mesozoic rock formations in the foothills of the mountain front. Younger Cretaceous and Cenozoic strata become gradually less tilted to the east.

Cretaceous claystone- and shale-rich formations, such as the Pierre Shale, dominate much of the landslide-susceptible terrain along the foothills west of Interstate 25. These formations are overconsolidated, meaning that they were once covered by thousands of feet of sediment and rock that have since been eroded away. The large-scale unloading of this overburden has resulted in a bedrock fabric that is sensitive to changes in overburden pressure, such as the eroding or cutting of slopes. Where local unloading occurs, these overconsolidated formations may become unstable as the fabric undergoes rebound and relaxation.

Tertiary and Pleistocene erosion and deposition processes in the Colorado Piedmont eroded basement rock from the Front Range, moved sediment from the mountains, and deposited sand and gravel on pediment surfaces that cap the claystone bedrock. Late Pleistocene and Holocene erosional downcutting has incised these pediments and underlying bedrock, forming high gravel-capped mesas from the pediment remnants that overlie weak claystone. Deposition of alluvial and debris flow sediment continues to occur along the mountain front. All of these processes have combined to create the modern foothills seen today (Figure 3). The steep slopes along the margins of the mesas are prone to mass wasting processes, such as landsliding. This is a natural erosional process for many of the clay-rich colluvial and bedrock slopes in the Colorado Springs area.

LANDSLIDE HAZARDS

In general, the term "landslide" is used to describe the mass movement of rock or earth material down a slope. Gravity acts on a slope that is oversteepened with respect to the inherent internal strength of the rock or soil materials that compose that slope. This general description also includes debris flows, rockfall, and slope creep. The landslides described in this publication are deep-seated, involving more than shallow surficial material movements that are more indicative of soil creep. They may also be large-scale landslides that cover significant areas. The landslide movement can be described as being rotational (following a curved failure surface), translational (following a planar failure surface), earth

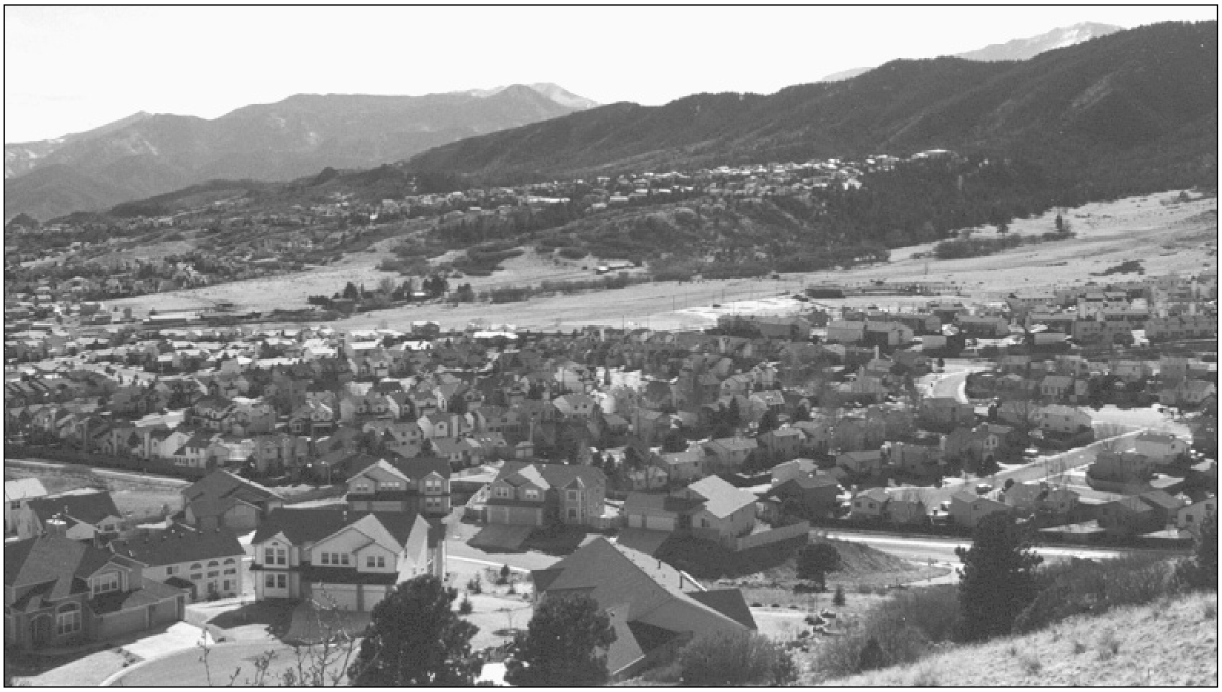

Figure 3. Overview photo showing the northwestern foothills area of Colorado Springs along Centennial Boulevard in 2001. Photo by J. White.

flow, or a complex combination of all of these movements. For example, the head (upper portion) of the landslide may behave as a rotational slide, the middle portion more translational as the shear zone glides along a weak bedding plane, and the toe may behave like an earth flow where the landslide deposit is more disturbed and often very wet.

The main factors that affect whether a landslide will occur are topography, geology, and hydrology. These factors influence the inherent strength of the rock or soil materials that comprise the slope, the forces bearing on the slope, and, accordingly, the slope stability. Very strong, massive rock can hold a vertical slope without failure. Very weak rock and soil materials can only hold a low or moderate slope without experiencing shear failure and lateral ground movements.

Landslides are "caused" or triggered when some critical slope-stability threshold is exceeded. This may occur when the internal strength is lowered as a result of natural processes (e.g., precipitation, weathering, erosion, or earthquakes) or from human influences (e.g., water introduction or adverse ground modification). Ground modifications that contribute to unstable-slope conditions include ground removal or loss of lateral support (e.g., excavation or erosion into the lower portions of the slope, called the toe), increased pore-water pressures (e.g., from water introduction), and/or the addition of weight, or loading (e.g., artificial fills, structures, water loading, or natural sediment deposition on the upper portions of the slope).

Reduced or low shear strengths that affect slope stability can result from naturally weak soil, or certain rock conditions such as lithology (rock type) and discontinuities (partings in the rockmass) that weakens the rock or results in zones of weakness (e.g., joints, fractures, bedding planes, lithology changes). Reduced or low rock and soil shear strengths can also result from weakening by chemical or mechanical weathering processes, or increased subsurface water content. The presence of water contributes by increasing the pore-water pressure between soil grains or within rock structures, creating a hydraulic "lifting" effect and loss of material (shear) strength. A slope that may be stable under dry or moist conditions can suddenly become unstable with increased moisture.

In the Colorado Springs area, weak rock masses, and the soils derived from them, are generally clay-rich materials. Several sedimentary formations contain these weak bedrock materials, including the Glen Eyrie Shale Member of the Fountain Formation, the Graneros and Carlile shales of the Benton Group, the Pierre Shale, the upper part of the Laramie Formation, and the lower part of the Dawson Formation. Most of these formations are overconsolidated Cretaceous shales with pronounced zones of weakness (having low or only residual shear strengths) and possible displacement shears along bedding planes (such as those described in Brooker and Peck, 1993). Derived products include in-situ weathered and disturbed claystones, and residual and colluvial clayey soil deposits. Areas in Colorado Springs where these formations have weak soil and rock zones and sufficient slope grades may be susceptible to landslides.

Landslide deposits have distinct morphology (Figure 4). Most landslides have a scarp at the top and a mounded toe or nose at the bottom of the slope. The ground surface that has moved within the landslide often appears crumpled or is described as having a hummocky topography. Commonly, intermediate scarps and depressions may form above rotated blocks or retrogressive rotational complexes, creating a "step-and-bench" morphology. Often, there is evidence of water influence, seen as seeps and/or vegetation indicative of moist ground, along landslide margins or in susceptible areas at risk. On landslide-prone or potentially unstable slopes that are in the beginning stages of a landslide, ground cracks can sometimes be seen that show subsurface strain (e.g., extensional movements); such tension cracks are the visible precursor of a landslide (Figure 5). Cracks that show any vertical offset are considered scarps. In some cases, the slope may in fact be moving but the soil materials stretch or compress rather than break or tear, and slope movement can only be determined by detailed surface surveys and/or subsurface monitoring devices. This type of behavior in landslides generally occurs only briefly at onset of movement before displacement is evident and seen at surface. In cases where shallow soils and weak rock move and remold without defined slide planes, the movement is generally considered to be creep.

Surface expressions of large scale and/or more geologically recent landslides can be determined by stereoscopic aerial photographic analyses and field checking. However, small rotational and translational slumps are often unrecognizable by these means, as older landslides can be modified by erosion, erasing their distinct morphology, and/or they often become covered with colluvial soils washed in from above. These covered, or "stealth" landslides are generally not recognized in drill borings and can usually only be discerned or observed in road cuts, trenches, and deeper excavations. An excellent

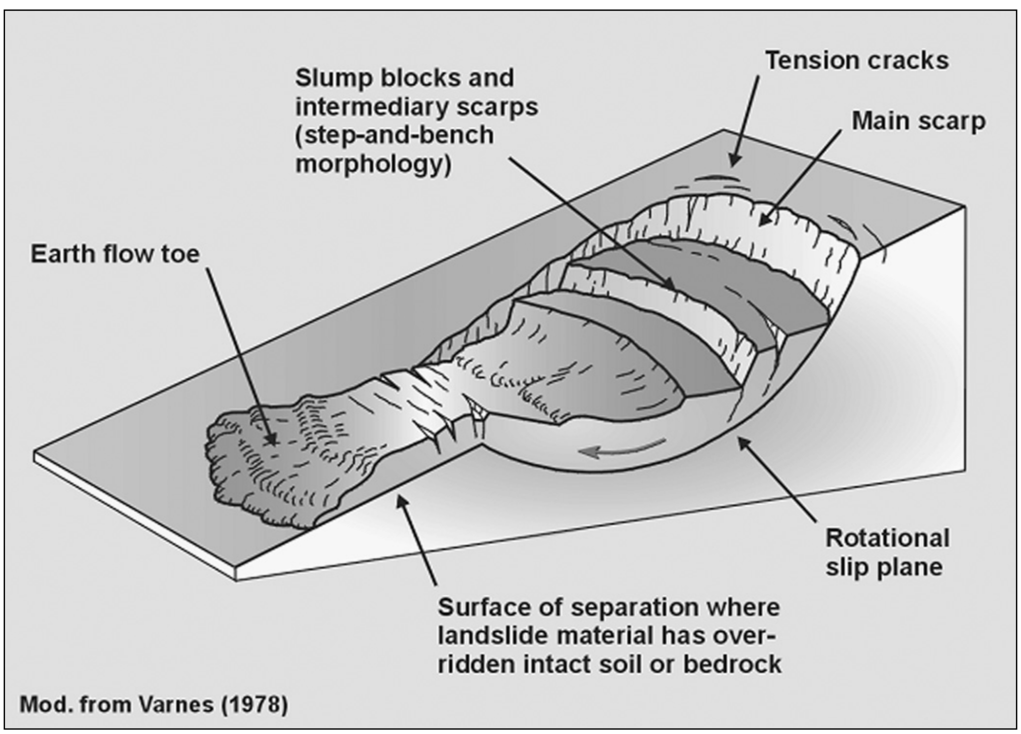

Figure 4. Block diagram of a typical rotational landslide.

Figure 5. Ground crack and beginning of landslide scarp in the Broadmoor area in 1998. Note hat for scale. Photo by J. White.

example was described at the Uintah Street road cut between Wilhelmia and Superior Streets (Figure 6) where a rotational slump has offset Verdos Alluvium and underlying Pierre Shale, and has subsequently been completely buried by colluvial slope wash (Noe, 1996). CGS geologists and other consultant geologists (J.W. Himmelreich, oral communication, 2002) have seen evidence of "stealth" landslides in other parts of Colorado Springs within the landslide-susceptible areas while observing trench and foundation excavations. This suggests that many other landslides have no surface expression, and that these landslides may not be identified with the borings typically drilled for investigations for residential development.

SLOPE STABILITY ANALYSIS

Geotechnical engineers and engineering geologists often use stability analyses in attempts to evaluate the stability of a slope. There are a number of different analytical methods, including limit-equilibrium and finite-element methods. Most limit-equilibrium methods use what is known as the "method of slices" to derive a Factor of Safety (FS)—a ratio of the driving forces (acting to move the slope material downhill) to the resisting forces (acting to keep the slope material in place). An FS of 1.0 indicates the slope is at "limit equilibrium"—a state of incipient failure. An FS of less than 1.0 indicates a slope that is failing; greater than 1.0 indicates a slope that is not moving (stable) and has more strength than required for equilibrium, under the modeled conditions.

Prevailing practice indicates that slopes with an FS greater than 1.25–1.5 can be considered stable. However, the acceptable "safe" FS level depends on the assumptions and conditions used during the analysis, the confidence of the correct characterization of the subsurface and loading conditions, and the type of land use that is proposed. The Federal Highway Administration (FHWA) generally only requires an FS of 1.25 when mitigation design plans are created for a landslide on highways. Some agencies require the use of a design FS of 1.5 because of the inherent uncertainty and assumptions that are involved in slope stability analysis with few investigative borings in native heterogeneous, anisotropic, soil and bedrock. Sensitivity analyses, using variable water levels, subsurface geometries, and material strength parameters, should be undertaken

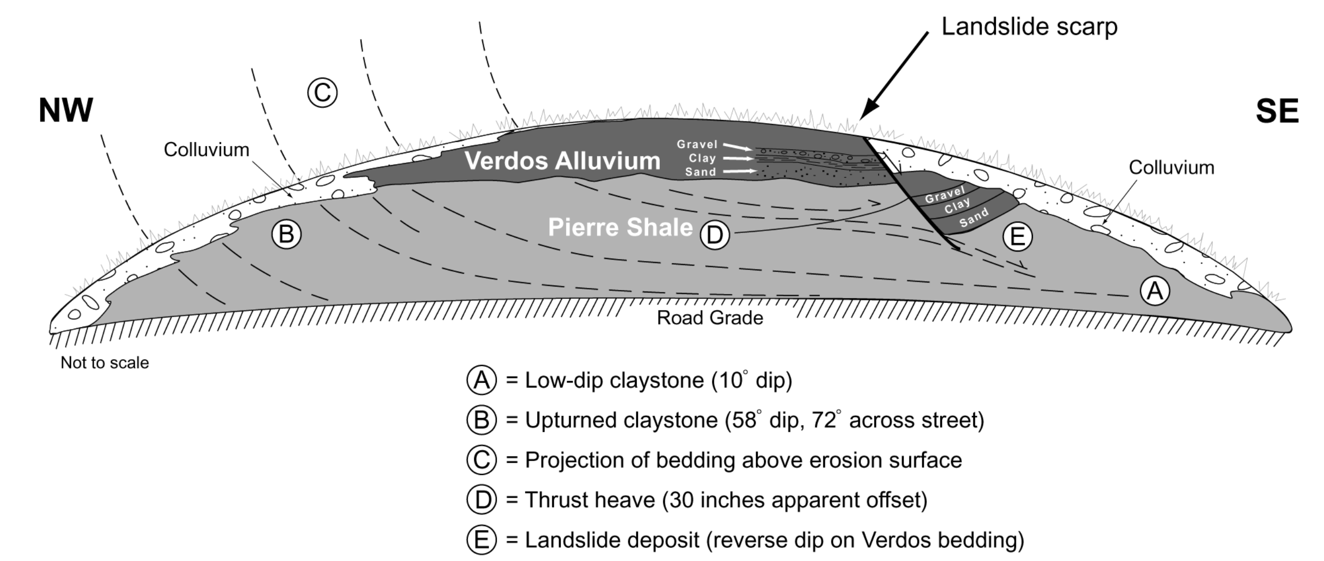

Figure 6. Schematic cross-section of a road cut along Uintah Street, showing a covered or "stealth" landslide (at right) that is not evident at the original ground surface (Noe, 1996).

to test the subsurface assumptions and conditions, and to assess potential future changes in conditions. If ground conditions are uncertain, unclear, or suspect, a wider variability in range of values for these parameters is needed or the acceptable FS should be increased.

There are differences in approaches used for analyzing slope stability for slopes that have failed verses unfailed slopes. In the case of failed slopes, many of the equation variables are known or can be reasonably approximated (e.g., the landslide geometry) or quickly ascertained (e.g., subsurface water conditions). Using a FS of 1.0 for a recently failed slope, it is possible to back calculate the soil strength values. For potentially unstable, but unfailed native slopes, there are many potential combinations of factors that could result in a slope failure. This requires the use of sensitivity analyses to account for the additional complexity and the largely unknown nature of the soil, rock, and water conditions, and potential landslide geometries.

Brooker and Peck (1993) and Hart (2000) commented that when slopes are incised into strata that include highly plastic, relatively flat-lying, overconsolidated clay shales, it is prudent to assume that bedding-plane shears are present and that the FS has approached equilibrium (1.0). Similar circumstances may also occur where flatter rock formations transition into the steeply dipping bedrock zone in Colorado Springs (Himmelreich and Noe, 1999) and the weaker bedding planes in the claystone have sheared against each other to accommodate the folding in the rock, much like bending a deck of cards.

Brooker and Peck (1993) also illustrated the difficulty in analyzing stability, or even determining failure surfaces for seemingly intact overconsolidated Cretaceous clay shales. Landslide gliding along bedding planes can involve extremely thin (only millimeters in thickness) shear zones that are impossible to detect in normal geotechnical auger drilling, and are difficult to detect in core samples from rock core drilling and in excavations. These bedding-plane shears can be nearly horizontal.

Bedding-plane shear deformation, defined by Booker and Peck (1993) and Hart (2000), occurs as a function of the overburden thickness and the reduction of confining stresses (lateral support) near the eroded-slope ground surface, while high lateral stresses due to the overconsolidation still occur at some distance into the formational material from the bank or slope. Bedding-plane shear deformation from rebound can occur without escarpments, or any other geomorphic evidence of landsliding forming at the ground surface. Shale slopes, where long-term incision and lateral unloading have occurred, should be considered as having bedding shears near the slope base, and should be analyzed at residual rock- and soil-strength parameters. Such slopes are exceedingly sensitive to disturbance, either from natural means or human modifications.

LANDSLIDE HISTORY IN COLORADO SPRINGS

Landslide hazards in certain areas of Colorado Springs have been known by some of the engineering and geological community for over three decades, although most residents in those areas may not be aware of the risks. Landslides were mapped in regional studies by Scott and Wobus (1973), Cochran (1977), and Trimble and Machette (1979) prior to the development of many of the more problematic areas. These and other landslides have been mapped during the CGS 1:24,000-scale geologic mapping program by Carroll and Crawford (2000), Thorson and others (2001), Rowley and others (in publication), Keller and others (in preparation), and Morgan and others (in preparation). The published landslide boundaries from all of these published maps are identified by letter on Map Plates 1-3 for this study.

Landslide susceptibilities in Colorado Springs, especially for areas underlain by the Pierre Shale, have also been understood by some for nearly three decades. Hill (1974) discussed the nature of the Pierre Shale and recognized the potential for landslide problems under certain circumstances, even on very gentle slopes. Cochran's (1977) maps included discussion on relative susceptibility and identified potentially unstable slopes. Additionally, Gruntfest and Huber (1985) from the University of Colorado at Colorado Springs (UCCS) prepared a very small-scale (1:171,480) map of potential landslide areas for inclusion in their report on Environmental Hazards of Colorado Springs, prepared for the City Local Affairs office in 1985. Their mapping was based on both Hill (1974) and Cochran (1977).

New landslides and reactivations of older, existing landslides occurred during the wet spring of 1995 (e.g., Broadmoor Mountain Golf Course and Regency Drive); see Figures 7, 8, and 9. A brief flurry of media attention occurred after the landslides of that wet spring. Shortly thereafter, in 1996, the Colorado Springs implemented a geologic hazard statute in their planning review process (City of Colorado Springs, 1996 and 1999), and areas of susceptibility were briefly discussed in a field trip guide book (Himmelreich, 1996) and visited during a CGS-sponsored geological hazards conference in Colorado Springs. In 1998, CGS began planning their mapping program of 1:24,000-scale geologic quadrangle maps of the Colorado Springs and El Paso County area. See the index map in Plates 1–3 for the key to the completed, current, and proposed geologic mapping in this program.

In 1999, another spring of heavy precipitation triggered flooding, caused renewed landslide movement, and activated additional landslides (Noe and White, unpublished). This resulted in El Paso County, including the City of Colorado Springs, to be declared a Presidential National Disaster Area.

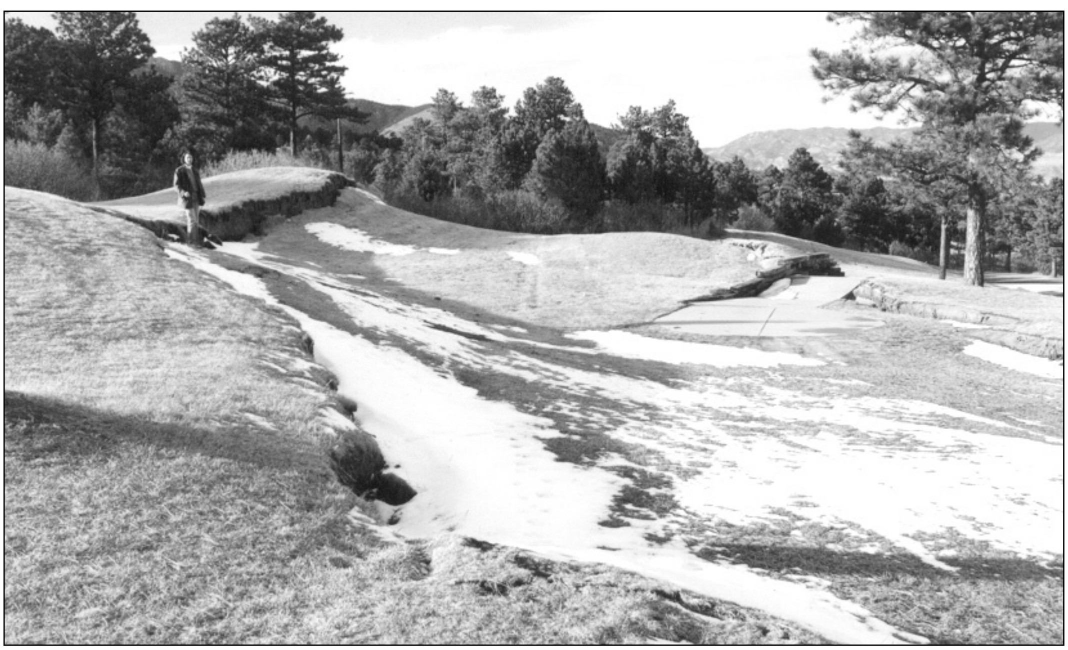

Figure 7. Landslide scarps at Broadmoor Valley Golf Course in 1996. Photo by J. White.

Figure 8. Regency Landslide in the Broadmoor area. White arrows delineate landslide boundary. Hollow arrow points in the movement direction. One home near head scarp that is shown below was condemned and demolished before this photo was taken, only broken foundation and driveway from cul-de-sac show on this photo. Note landslide toe formation in small field near lower road. Photo taken in 1999 by M. Squire.

Figure 9. Catastrophic home damage near head scarp of Regency Landslide in 1995. This home was subsequently demolished. Photo by J. White.

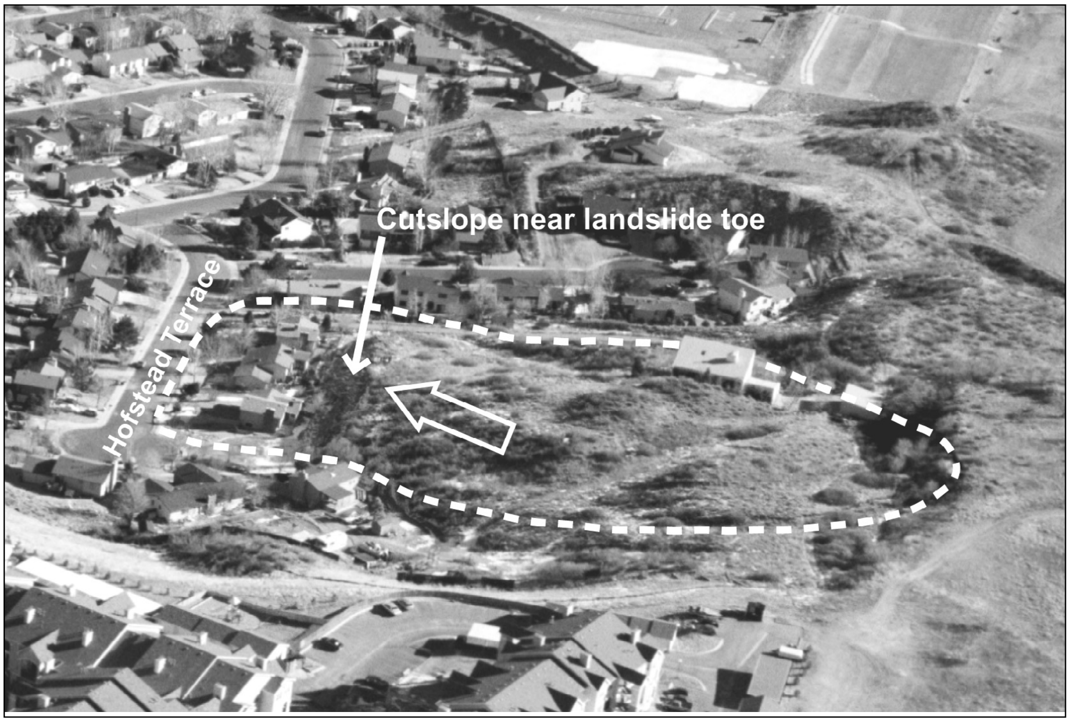

Figure 10. Oblique aerial view eastward of Hofstead Landslide on the flank of "The Mesa." This site was a pre-existing landslide that re-activated in 1999. Note improper excavation at toe of landslide for residential development. Dashed line shows extent of re-activation and hollow arrow shows movement direction. The residence shown at lower left corner of landslide shows extreme distress by the landslide movement, note the perceptible tilt in the back half of the home near the cutslope. These homes have been subsequently demolished. Photo by M. Squire.

Figure 11. Ground movement caused this interior damage of a residence in the Hofstead Landslide in 1999. This home was condemned and later demolished. Photos courtesy of Hofstead Emergency Landslide Protection (HELP) Coalition and M. Squire.

Ground movements impacted several neighborhoods west of Interstate 25 and many homes and properties were threatened, damaged, destroyed, or condemned. Although all of these neighborhoods lie within landslide-susceptible areas, many had no history of landslide activity prior to the 1999 events, and homeowners had no knowledge of the hazard to which they were exposed. Many of the homes and properties impacted were over 20 years old and apparently had no previous problems with lateral earth movements.

Forensic geologic investigations by CGS and others showed that a number of adverse building practices had occurred in the 1999 landslide areas. Grading in some areas undermined existing landslides or potentially unstable slopes. In other areas, fill was placed improperly and proved to be unstable. Some home lots were also located in easily discernable landslide areas (Noe and White, unpublished); see Figures 10, 11, and 12. As of February 2002, 26 homes have been bought by FEMA at a cost of $6.35 million (Squire, M., oral communication, 2003). These homeowners were fortunate that the Presidential Disaster Declaration was made and the FEMA buy-out program was initiated. Normal homeowners insurance does not cover damages from ground-movement hazards related to swelling soils, rockfall, subsidence, or landslides.

Figure 12. Damage to Hofstead Terrace roadway pavement, sidewalk, and driveway by lateral movement of landslide toe at Hofstead Landslide in 1999. Photo by J. White.

Map Methodology and Usage

The following sections concern the methodology that was used to construct the landslide susceptibility coverage shown on the Map Plates 1–3 of this publication and the types of information and data that were examined. It also includes an important discussion on the authors' suggested usage of the maps and certain inherent limitations for the use of this susceptibility coverage.

DATA COMPILATION AND MAPPING

The data used in making this series of maps included historic information, and observations of geomorphology, geology, topography, and water conditions. Colorado Spring Utilities, using their Facilities Information Management System (FIMS) data, provided the initial digital project data, including city and park boundaries, photogrammetric 2-foot contours, street centerlines, and orthorectified air photos from 1995 and 1998. Base-map data coverages, generated by the City Planning GIS Manager from the FIMS data, included a 5-foot pixel DEM, slope gradient grid, and slope aspect grid. Digital CGS geologic maps of the Pikeview, Colorado Springs, Cheyenne Mountain, Cascade, and Manitou Springs quadrangles, geo-referenced scans of USGS geologic maps (Trimble and Machette, 1979), and digitized El Paso County 1041 Geologic Hazards Maps (Cochran, 1977) were provided by the CGS.

The authors compiled digital data coverages using the above base coverages in ArcView 3.2a at a 1 in = 800 ft (1:9,600) scale. Map publication was completed by reducing the scale to 1:24,000 and reprojecting the GIS-based data to USGS topographic base maps. The project methodology is simplified as a flow chart in Figure 13, and is explained in the following paragraphs.

HISTORIC LANDSLIDES

Historic landslide data were collected from published maps and reports, consultant reports from CGS and Colorado Springs land-use review files, news articles, and independent consultants. These sources are also noted by number on Map Plates 1–3 and in Appendix A of this report.

The landslide boundaries shown on the plates are not a complete or verified inventory of the landslides in the area; rather, they are a compilation of mapped landslide locations from various sources that were found given the limited research budget, and are used as an aid to determine areas that may be susceptible to landslides. Areas with a history of past slope stability problems may be prone to future failure, and can also indicate factors that contributed to landslide occurrence. Many of these mapped landslide sites are sensitive to disturbance by human activity and modification. Landslides have been mapped or documented along the flanks of The Mesa, in the Broadmoor area below Cheyenne Mountain, and in the Mountain Shadows and Cedar Heights neighborhoods. Some of the landslides were located in areas where slope conditions had changed, through grading and slope-angle reduction, to the point that they were no longer considered to have stability concerns and were subsequently eliminated from the susceptibility coverage.

GEOMORPHIC FEATURES

Geomorphic features can indicate the presence of landslides and give a relative age based on the amount of landform erosion that has occurred since the slope failure. Geomorphic landslide features become “smoothed” with time and much subtler to discern with age (see earlier discussion of covered landslides). As Figure 4 shows, landslide landforms include scarps or slope breaks, mounded toe morphology, back-tilted or rotated blocks, side shears and offsets, and other compression or tension features. Classic terrain such as “step-and-bench,” “hummocky,” or “lobate” features can indicate landslide deposits. Shifted or offset drainage channels often indicate areas that have been affected by landslides. The digital elevation model (DEM) and air photos were examined for geomorphic evidence of landslide deposits. Follow-up field checking and stereo aerial photographic analyses either confirmed

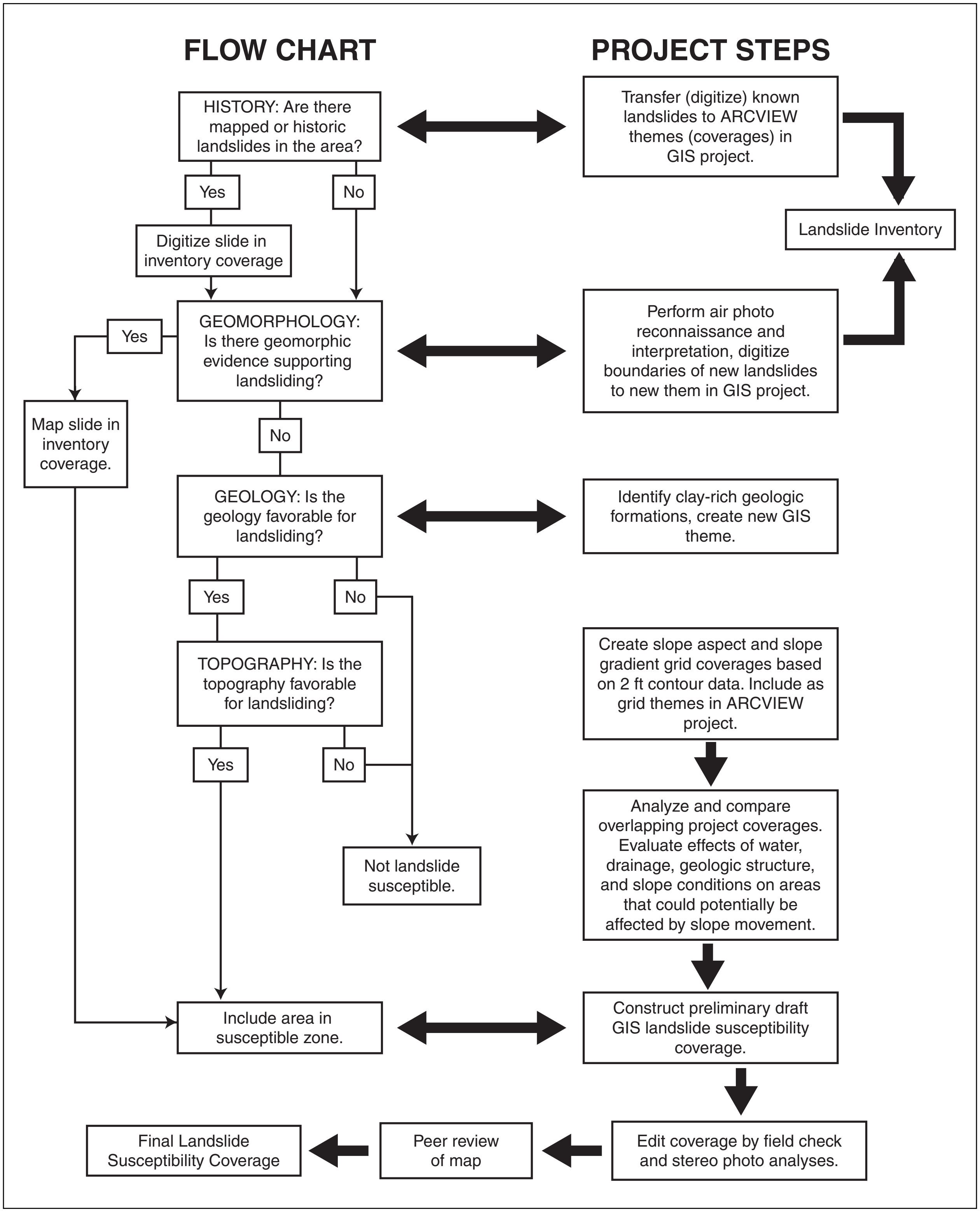

Figure 13. Project flow chart.

or eliminated the area as a landslide or landslide-susceptible area.

GEOLOGY

Geology, including the formational-material composition (or rock type) and geologic structure, is one of the major influences to slope stability. Clay-rich formations are often associated with landslide-prone areas. Overconsolidated claystone or clayshales, bentonite seams, historic failure surfaces, and weathering zones all exhibit adverse physical properties for development associated with weak rock or soil: low peak shear strength, and strength lowered further to residual values on slopes or bedding planes that have previously failed (sheared). High bentonite content and actual thin bentonite beds in the claystone, derived from ashfall from volcanic eruptions into the Cretaceous shallow seas, are known for exceptionally low peak and residual shear strengths.

Geologic structure, such as the orientation of bedding and jointing or fracturing, can also adversely affect slope stability. Bedding planes and other discontinuity surfaces can have much weaker shear strengths than the 'intact' rock. If the dip direction is the same as the slope direction, large translational sheet-like (or block) failures can occur - especially if the bedding dip angle is less than the slope angle. The ground slope will then cross (be steeper than) the bedding planes, and "daylight" the bedding. This can result in slope instability if the shear strength of the bedding plane is sufficiently low, or if other factors are introduced to trigger sliding.

Jointed or fractured rock allows more water to infiltrate, and can result in increased pore pressure and accelerated weathering that softens and weakens the rock mass. In the field, these weakened areas can sometimes be identified by the presence of seeps or vegetation changes along slopes. Rock masses that have been upturned (Himmelreich and Noe, 1999) are typically highly fractured and weathered and are susceptible to water infiltration and weathering. As areas with these characteristics were identified, they were further evaluated to determine whether slope conditions were favorable for landsliding.

Particular attention was given to the following clay-rich bedrock units. Most of these formations have been known previously to be prone to instability in steeper slope terrains in the Colorado Springs area (Scott and Wobus, 1973; Hill, 1974; Cochran, 1977; Himmelreich, 1996; and Noe and White, unpublished). They are listed from the oldest to the youngest formations.

Glen Eyrie Shale Member of the Fountain Formation, Permian to Pennsylvanian Period

The Fountain Formation is most noticeable toward the town of Manitou Springs on Highway 24 and at Garden of the Gods where the resistant, bright red to maroon colored, tilted, sandstone layers outcrop. Interbedded with these hard sandstone beds are thin reddish-brown shales and mudstones. These weak units have caused instability to these tilted beds of red sandstone and resulted in smaller block landslides and rockfall problems around the town of Manitou Springs. The Glen Eyrie Shale Member is a prominent, thicker, and problematic shale at the base of the Fountain Formation. A few areas within the city limits of Colorado Springs are underlain by the Fountain Formation, including the Garden of the Gods and areas to the west that are still within the city limits. The Glen Eyrie Shale has been responsible for instability and landslides in the Cedar Heights neighborhood, where eastward tilting Fountain Formation beds are undermined and daylighted by the downward erosion of Black Canyon.

Benton Group (Graneros Shale, Greenhorn Limestone, and Carlile Shale), Upper Cretaceous Period

The Benton Group occupies a relatively narrow strip of ground along the western margin of the city limits where formational bedding is steeply tilted. These formations are located between the Dakota Sandstone and Niobrara Limestone, which form hard resistant ridges of tilted bedrock called hogbacks. Confined by resistant beds, ground stability concerns within these rocks, and the soils derived from them, are limited to steeper slopes. Side slopes of water gaps, where small creeks have cut through the hogbacks and the steepened slopes are capped by more-resistant sand and gravel pediment alluvium, are areas that may experience stability problems.

Pierre Shale, Upper Cretaceous Period

The Pierre Shale is the most problem-prone bedrock for stability concerns in Colorado Springs. This formation is very thick, about 4,500 feet in this area (Carroll and Crawford, 2000). Generally a dark gray shale in an unweathered state, the Pierre becomes a much softer, olive-green to gray claystone as it weathers. Pierre Shale weathers easily and is characteristically very weak in its weathered state. Bentonitic layers within the formation are weaker still. This formation underlies about 88 square miles within the Colorado Springs city limits, mostly covered by variable thicknesses of recent alluvial, colluvial, and windblown sediments. Bedding inclination (dip) is variable within the city limits, and ranges from steeply dipping and vertical in the western part of the city, along the steeply dipping bedrock zone (Himmel-reich and Noe, 1999), to flatter-lying to the east, with about a 10 degree dip (see Figure 5). The flatter-lying areas, however, prove to be very problematic, especially west of Interstate 25, where gravel-capped hills and mesas form.

The Pierre Shale underlies most of the landslides in Colorado Springs, specifically in the Broadmoor area, along the flanks of The Mesa, and in the Mountain Shadows and the Peregrine areas. The Pierre Shale is well known for its potential instability on even low to moderate slopes where erosion has downcut through formation strata, and is responsible for slope stability problems in the High Plains from Colorado to Canada (Brooker and Peck, 1993).

Upper Part of Laramie Formation, Upper Cretaceous Period

The upper part of the Laramie Formation contains clay-rich shales and shaley sandstones. These materials are brownish to gray and relatively soft (Thorson and others, 2001). They are underlain by a sandstone unit in the middle part of the Laramie Formation and overlain by andesitic claystones of the Dawson Formation. Because of their soft nature, the clay-rich materials of this unit can present slope stability problems.

The area of Colorado Springs that is underlain by the upper part of the Laramie Formation is relatively small; only a band about 400 feet wide through the Woodman Valley area and several parts of the Rockrimmon and Austin Bluffs areas is exposed. Problems with slope stability from this unit can coincide with problems from the overlying Dawson Formation claystones. In select areas, such as the steep slopes of the Popes Bluff area, the underlying sandstone of the middle part of the Laramie Formation also contains interbedded shales that have presented stability problems and landslides.

Lower Part of the Dawson Formation, Upper Cretaceous Period

The lower part of the Dawson Formation contains a greenish-gray to olive-brown sandstone member that has a high andesitic (volcanic) composition (Thorson and others, 2001). Andesitic siltstone and claystone (derived from volcanic ash) layers are often interbedded with this sandstone. Geologists and geotechnical engineers practicing in the area sometimes referred to this unit colloquially as the "green slime." Slope failures have occurred in this unit in the Rockrimmon area, around the UCCS campus, and Austin Bluffs areas. The "green slime" can be undercut by weathering of the underlying Laramie Formation claystones, weakening the resisting forces and allowing slope failure to occur. Areas most prone to failures in these claystones are the hillsides east of Interstate 25 near Pulpit Rock, Austin Bluffs, and Palmer Park. The Woodman Valley and Popes Bluffs areas have also experienced slope failures in the Dawson Formation, ranging from deep-seated landsliding to large-scale ravel and shallow colluvial landslides.

TOPOGRAPHY

Topography is a major factor in landslide susceptibility. As slope grades increase, gravity has a greater driving force contribution and lowers the FS. In the Colorado Springs area, slopes with grades greater than 12 percent (7°) and having geologic factors favorable for landsliding (such as colluvial slopes underlain by Pierre Shale) were considered for inclusion in the susceptible coverage. Twelve percent (7°) was used as a criterion based on past studies (Scott and Wobus, 1973; Hill, 1974; Gruntfest and Huber, 1985), mapped landslides, and reported residual shear strength properties found in the Pierre Shale and other bentonitic shales (Wylie and Norrish, 1996). Slopes that are already inherently weak, weathered, or within existing landslides can fail at low-angle grades.

Slope aspect (the direction a slope face is orientated) can also be a factor, as was discussed earlier. Northeast aspects are more critical in that they typically have slopes in the same directions as the predominant dip of bedrock along the flank of the mountain front, a situation that is conducive to daylighting of the bedding planes. Aspect also affects the amount of seasonal moisture in the soils of a slope; shaded slopes (north- and east-facing slopes) will remain wetter than sun-facing (south and west) slopes.

Basic mechanics of landslides were used in generation of the susceptibility coverage. "Margin zones" that fall outside of the above-defined slope gradients at the top and bottom of slopes were also included in the susceptibility coverage to account for common behavior of landslides. The head scarp of a landslide on a mesa flank and retrogressive rotational and translational complexes commonly encroach laterally onto a mesa top. Similarly, a landslide earthflow-type toe can move out onto relatively flat terrain beyond the base of the steeper slope (see Figure 3). Such circumstances are frequently seen in landslide-susceptible areas of Colorado Springs, where highly disturbed claystone in the toe of a landslide is observed overlying colluvial or alluvial gravelly soils. At times, erroneous characterizations of the site geology are made when such landslide deposits of displaced claystone are wrongly identified as intact bedrock. Such errors can be serious, as proper follow-up investigations for slope stability may not be conducted based on the faulty geologic conclusion.

The preliminary susceptibility boundaries were created by tracing a zone that includes areas of landslide-prone geology, mapped landslides, and at defined slope gradients and slope aspects. A more-accurate landslide susceptible boundary was then refined by the inclusions of margin zones (see previous paragraph) and photo-interpretations of stereo aerial photographs. The final susceptibility area was then field checked and revised as necessary. Figure 14 illustrates some of the digital steps that were taken for "The Mesa" area to prepare the digital project files that were used for this publication. The mapped susceptibility areas of this publication compare favorably with those shown in Gruntfest and Huber (1985).

HOW TO USE THIS MAP

A digital version of the landslide susceptibility map will likely be used as a Landslide Special Study Area for land use planning by the City of Colorado Springs. The digital map will ultimately be viewable on the "El Paso County Natural Hazards Clearinghouse" Web site, hosted by the University of Colorado at Colorado Springs. The URL address for this Web site is: http://www.uccs. edu/geogenvs/Hazards/.

The map included with this publication is divided into three areas at a 1:24000 scale on USGS topographic base maps (Map Plates 1–3). The map shows two basic types of information: areas that may be susceptible to landslides; and approximate boundaries of mapped landslides that were used in this study. The map is not intended to give site-specific information as to slope stability; rather, it serves as a tool for determining areas where slope stability issues may occur. Land use or ownership was not a factor that was given any weight in the generation of the susceptible area, except where large-scale ground disturbances by excavation were noted.

The susceptible areas were mapped based on the methods described in the above sections. These zones should be considered areas that have geomorphic, geologic, and topographic conditions similar to areas of known landslides, but may not presently show evidence of movement. It is possible that many of these areas may not, in fact, experience slope instability under current conditions, but may under certain future conditions (e.g., heavy precipitation, adverse slope modifications, formational weathering, etc.). Areas located within the susceptibility zone should be further evaluated for ground stability and presence of landslide deposits during further development, renovations, ground alterations, road alignments, and residential resale. Geologic and geotechnical investigations including slope-stability analysis should be conducted for new development within the susceptible area. Such investigations should include consideration of site conditions not only within the property boundaries, but how development will impact the vicinity that may also, or may not, lie within the susceptibility area.

It may be necessary to implement mitigation measures such as grading, slope drainage, or engineered ground retaining and/or support systems, or avoid the area completely if the risks are judged as being too high. In cases of in-fill lots within landslides or susceptible areas, it may not be economically feasible or physically possible to mitigate the risks of a potential landslide on a single lot.

Consideration should be given to the formation of special bond districts, called Geologic Hazard Abatement Districts (GHADs), in these larger areas to reduce the financial risks on an area-wide or neighborhood basis. Prospective buyers of existing homes and other real estate that lie within the susceptibility areas may want to consider retaining an experienced professional geologist or geotechnical engineering for a site-specific evaluation of the property, similar to a standard building inspection report that is generally recommended before closing.

The susceptible area boundaries are not absolute. However, based on the inventory and a

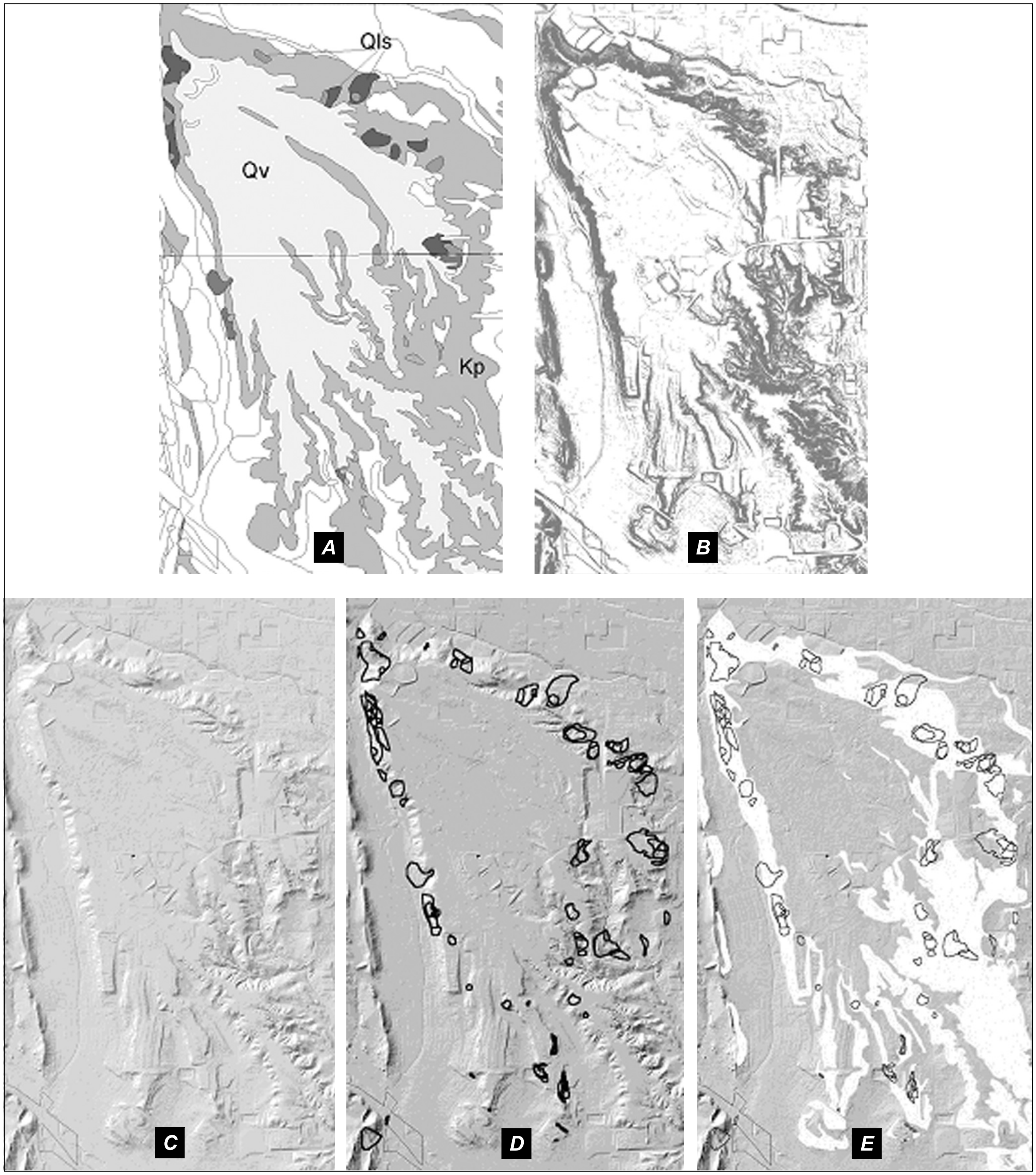

Figure 14. GIS imagery of "The Mesa" area to illustrate map development. Images shown are: (A) geology and published landslides; (B) slope grade; (C) shaded relief DEM; (D) DEM with landslide inventory; and then (E) DEM with landslide boundaries and landslide susceptibility coverage.

consistent assessment of the other factors, an overwhelming majority of the landslide-prone ground in Colorado Springs should lie within the susceptible area as defined for this study. A particular area within the susceptible boundary may not be experiencing problems today, but future conditions involving natural events such as continued weathering and weakening of the slope material or periods of high precipitation, and/or human activities such as wetting, cutting the toe, or loading a headscarp could result in slope movement.

The map plates distinguish three categories of mapped landslides: (1) those from published sources; (2) those from consultant work; and (3) those interpreted through air photos and fieldwork during the course of the project. Some of the landslide boundaries from consultant reports are oddly shaped, with sharp angles or truncated borders; this simply reflects the property boundary of that particular investigation. In these instances, the actual landslide boundary extends outside of the shown outline.

Additionally, in several areas, multiple sources have mapped the same landslide features, resulting in overlapping boundary lines such that several outlines on the map may actually include just one landslide complex. In particular, the hillside areas south of the Broadmoor Hotel have been the subject of multiple mapping programs by various consultants for development purposes. The mapped landslide boundaries in this area appear quite chaotic on the map. In an effort to help the map user identify specific studies, Appendix B includes an enlarged portion of the area near the Cheyenne Mountain Elementary School that will help outline a mapped landslide boundary from a specific study.

The mapped landslides include those with recent movement (e.g., those from the CGS FEMA study) and older landslides that have not had documented movement. Some of the large-scale landslides (e.g., Scott and Wobus' "Qrof" area) are Mid-Pleistocene in age. During that time, climatic conditions were much wetter, and earthquake return intervals along the Ute Pass and Rampart fault systems were likely more frequent than that of the present day (Widmann and others, 2002). Some of the inventoried landslides have since been stabilized through grading or mitigative processes and are not included in the susceptibility area. Other landslides, especially the larger and older landslides, may have stabilized since their original movements, but may have had localized, more-recent re-activations within their boundaries. Such landslides cannot be eliminated from the susceptible area because there has not been regional study done to demonstrate overall stability.

Small, naturally occurring landslides could occur outside of the susceptible area within the city boundary. This possibility is not very likely, provided that significant land use or grading changes do not occur. However, discrete and sporadic clay-rich lenses are known to exist in several of the geologic formations in the Colorado Springs area where steeper slopes are present. There are also shallow but steep stream banks within Colorado Springs, some of which fall outside of the three map plates, that are also susceptible to streamside slumping. Care should be used when siting structures near these slopes. Disturbances of flatter slopes or higher-strength bedrock can also induce instability if excavations are not properly designed or completed, or they are exposed to earthquake seismic ground accelerations and vibrations.

General Information

LIMITATIONS

These data were constructed qualitatively using the available data sources mentioned above and the experience of the authors in the area. The authors have not reviewed all relevant geotechnical, geologic-hazards, and engineering-geology reports in landslide-susceptible areas of Colorado Springs, as many of these reports are proprietary, confidential, or simply lost and unknown. Quantitative approaches, such as deterministic analyses and statistical and probabilistic risk modeling, were beyond the scope of this project.

Because of the uncertainties inherent to geologic science (i.e., subsurface geology and geometry, geologic structure, and water conditions) that are only assumed for most locations, no levels of risk assessment were made within the susceptible zone. For locations that lie within the susceptible area, this designation does not imply that landslides will occur during the life of a residential structure, only that a higher risk exists compared to areas not mapped as susceptible. Appropriate study and, if necessary, mitigation should be conducted, and disclosure should be made to prospective land buyers. It should be noted again that extreme natural or human activity (e.g., earthquakes or poorly designed excavations) may trigger slope instability and landslides in areas that are not included in the susceptible area.

Other types of slope failure and mass wasting can occur that were not within the scope of this project. Rockfall can occur in non-clay bearing material if jointing or other discontinuities sufficiently weaken the rock so that weathering forces can mechanically move a rock to fall, bounce, or roll down a slope. This process should be considered potentially serious in areas of very steep slopes and bedrock cliffs, and it should be considered in development design.

Raveling is another type of mass wasting not considered for this publication. Certain granular soils and highly erodible, weakly cemented sandstones are susceptible to raveling where they are undercut or excavated. Raveling is the particle-by-particle erosion of granular soil at a ground surface that is steeper than the angle of repose (a less-steep slope angle where the loose soil then becomes stable) of the material. It is not a deep-seated stability problem, but more of a nuisance and aesthetic concern. Raveling can migrate up the slope, leaving an ugly scar that is difficult to revegetate, as the soil material tries to find its angle of repose.

Ground failures and earth movements such as creep, debris flows, hydrocompaction, subsidence, and swelling soil were not included in the scope of this project; however, they pose hazards for many areas of Colorado Springs and should be addressed and considered for future investigations and land use planning.

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APPENDIX A

Mapped Landslide Reference

Consultant work reviewed by CGS for this study. Note that some reports listed are draft reports, and others were submitted multiple times during the review process. This list does not reflect all the consultant work done in the area. Reports including maps of landslides have been given a map ID number and are shown on the map plates.

CGS FILE	MAP ID	SUBDIV. NAME	CONSULTANT	REPORT TITLE	DATE	JOB NO.	AUTHOR	REGISTRATION
EP-03-0009	46	EaglePointe	Entech Engineering, Inc.	Geologic Hazard Study Eaglepointe Condominiums Delmonico Drive and Saddle Mountain Road, Colorado Springs, CO	6/24/02	47872	Kristen Andrew Hoeser	PG
EP-02-0017	48	Fillmore Heights Subdivision, Filing 2	John Himmelreich & Associates	Geologic Hazards Evaluation Summary Report	9/18/01	01-145	John Himmelreich, Jr.	PG
EP-02-0045	39	Indian Mesa	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazard Evaluation and Preliminary Geotechnical Investigation Indian Mesa Subdivision Filing No. 1, Colorado Springs, CO	12/14/01	CS-11796	Thomas Terry	PG, PE
EP-02-0049	40	Madison Ridge	Entech Engineering, Inc.	Geologic Hazard Study Madison Ridge A Replat of a Portion of Stepping Stones West Subdivision Colorado Springs, CO	1/9/02	28661	Kristen Andrew Hoeser	PG
EP-02-0058	41 42	Van Buren Townhomes	Kumar & Associates, Inc.	Geologic Hazard Study Proposed Van Buren Square Development, Colorado Springs, CO	3/5/02	012-223 012-223A	Peter Sturdivant	PG
EP-02-0059	43	Centennial Glen	Entech Engineering, Inc.	Geologic Hazard Study Centennial Station, Colorado Springs, CO	8/1/02	36221	Kristen Andrew Hoeser	PG
EP-02-0061	44	Monte Villas	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazard Evaluation and Preliminary Geotechnical Investigation Monte Villas, Filing No. 1 and 2 Orchard Valley Road and Centennial Boulevard, Colorado Springs, CO	2/28/02	CS-11541	Thomas Terry	PG, PE
EP-02-0075	45	Woodmen Point	CTL/Thompson, Inc. Consulting Engineers	Preliminary Geologic Hazards Evaluation Woodmen Point, Woodman Road and Austin Bluffs Parkway, Colorado Springs, CO	12/14/01	CS-11786	Damon Runyan	PG
EP-01-0002	35	Broadmoor Oaks Lots 1,2&4	Entech Engineering, Inc.	Geologic Hazard Study Broadmoor Oaks Subdivision Filing No. 2 Lots 1, 2 and 4 Farthing Drive Colorado Springs, CO	7/5/00	85890	Kristen Andrew Hoeser	PG
EP-01-0011	36	Broadmoor Glen South No 9	Terracon	Geologic Hazards Study (revised) Proposed Residential Development Broadmoor Glen South Filing No. 9 Lots 1 and 2 Colorado Springs, CO	5/12/00	23985047	Richard Webb	PE
EP-01-0012		Broadmoor No 1 Lot 6	John Himmelreich & Associates	Geologic Hazard Report	4/10/00	00-119	John Himmelreich, Jr.	PG
EP-01-0025		Panorama Estates	John Himmelreich & Associates	Revised Summary Report of Geologic Hazards and Slope Stability Analysis lots 1-6, Panorama Estates Filing No. 4	2/6/01	99-149	John Himmelreich, Jr.	PG
EP-01-0028		Broadmoor Glen S Lots 1&2	Terracon	Geologic Hazard Study Residential Development Proposed Broadmoor Glen South Lots 1 and 2, filing No. 10 Colorado Springs, CO	8/21/00	23985078	Richard Webb	PE
EP-01-0030	37	Maytag Sub #5	Entech Engineering, Inc.	Geologic Hazard Study Maytag Sub-division, Filing No. 5 Colorado Springs, CO	9/12/00	86230	Kristen Andrew Hoeser	PG

CGS File	Map ID	Subdiv. Name	Consultant	Report Title	Date	Job No.	Author	Registration
EP-01-0045		360 Roxbury Cr.	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazard Evaluation 3 60 Roxbury Circle Lot 31, Roxbury Park Subdivision Colorado Springs, CO	11/30/00	CS-10973	Jonathan Lovekin	PG
EP-01-0069	38	Renaissance Academy	Terracon	Geologic Hazards Study The Renaissance Academy Filing No. 1 West of Fieldstone Road and Braeburn Way Colorado Springs, CO	8/23/01	23005067	L. Daniel Israel	PE
EP-00-0002	28	Maytag Acres	Entech Engineering, Inc.	Geologic Hazard Study Maytag Acres, Colorado Springs, CO	6/24/99	43098.1	Kristen Andrew Hoeser/ Paul Hoskins	PE
EP-00-0011	29	Staghorn at Peregrine	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards Investigation Staghorn at Peregrine, Colorado Springs, CO	7/16/99	CS-6886	David Glater	PE, CPG
EP-00-0041	31	Stonecliff No. 6 & 6A	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards and Preliminary Geotechnical Investigation Stonecliff FilingNo. 6 and 6A Colorado Springs, CO	11/5/99	CS-9036	Jonathan Lovekin	PG
EP-00-0056	32	Stonecliff No. 6 & 6A	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards and Preliminary Geotechnical Investigation Stonecliff Filing No. 6 and 6A Colorado Springs, CO	3/17/00	CS-9036	Jonathan Lovekin	PG
EP-00-0065	34	Broadmoor Park	Terracon	Geologic Hazards Study, 33-acre Site Northwest Corner of Broadmoor Bluffs Drive and Academy Boulevard Colorado Springs, CO	6/7/99	23995040	Richard Webb	PE
EP-00-0066		Rockrimmon Vista No. 2	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards Evaluation Rockrimmon Vista Rockrimmon Drive South East of Fence Post Drive Colorado Springs, CO	3/22/99	CS-9202	Jonathan Lovekin	PG
EP-00-0073		Victoria Heights PUD	RMG Engineers	Geologic Hazards Investigation Victorian Heights Subdivision Willhelmia & Willamette Ave. Colorado Springs, CO	2/10/99	41404	Craig Wieden/ Michael Grackle	PE
EP-00-0080	33	Stonecliff No. 6 & 6A	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards and Preliminary Geotechnical Investigation Stonecliff Filing No. 6 and 6A Colorado Springs, CO	6/2/00	CS-9036	Jonathan Lovekin	PG
EP-99-0022		Village at Stone Manor	Terracon	Geologic Hazards Report Village at Stone Manor, Broadmoor Resort Community, Colorado Springs, CO	9/3/98	23975014	Richard Webb	PE
EP-99-0023	30	Staghorn at Peregrine	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards Investigation Staghorn at Peregrine, Colorado Springs, CO	8/21/98	CS-6886	David Glater	PE, CPG
EP-99-0029	26	Broadmoor Glen South	Terracon	Geologic Hazards Study Proposed Residential Development Broadmoor Glen South Phases 1, 2, 3 and 4 DFOZ Amended Development Plan, Colorado Springs, CO	9/29/98	23985078	Richard Webb	PE
EP-99-0041	8	Enclave Estates	Terracon	Geologic Hazards Report Enclave Estates Filing No. 1, Colorado Springs, CO	11/18/98	23985068	Richard Webb	PE
EP-99-0042	10	Broadmoor Village	Terracon	Preliminary Geologic Hazards Assessment Property M-2 Southwest Corner of Star Ranch and Broadmoor Valley Roads, Colorado Springs, CO	8/21/98	23985037	Richard Webb	PE
EP-99-0050	27	Broadmoor Glen South Filing 9	Terracon	Geologic Hazards Study Proposed Residential Development Broadmoor Glen South Filing No. 4, lots 1 and 2, Colorado Springs, CO	7/22/98	23985047	Richard Webb	PE
EP-99-0064	9	Enclave Estates Filing #1 Resubmittal	Terracon	Geologic Hazards Study Enclave Estates Filing No. 1, Colorado Springs, CO	2/9/99	23985068	Richard Webb	PE
EP-99-0064	9	Cheyenne Moun-tain Landslide	Chen and Associates	Ranch Landslide Investigation, Colorado Springs, CO	7/31/87	2-222-87	Ralph Mock	

CGS File	Map ID	Subdiv. Name	Consultant	Report Title	Date	Job No.	Author	Registration
EP-99-0079		Enclave Estates change of condition	Terracon	Geologic Hazards Study Enclave Estates Filing No. 1, Colorado Springs, CO	4/21/99	23985068	Richard Webb	PE
EP-98-0016	18	Physicians Network Filing 1	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards Investigation Physicians Network Filing No. 1 North-west of Broadmoor Bluffs and Farthing Drives, Colorado Springs, CO	7/31/97	CS-7792	John Himmelreich, Jr.	PG
EP-98-0017	17	Mahogany Vale at Peregrine #3	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards and Geotechnical Investigation Mahogany Vale at Peregrine Subdivision Filings 3 and 4, Colorado Springs, CO	6/20/97	CS-7304	John Himmelreich, Jr.	PG
EP-98-0036		Reserve at Broadmoor Filing 7 Filing 7	Entech Engineering, Inc.	Geotechnical Engineering and Geologic Hazard Study Reserve at Broadmoor Glen Filing No. 7, El Paso County, CO	10/14/97	19727	Kristen Andrew Hoeser/ Joseph Goode, Jr.	PE
EP-98-0037		Connors Corner	Entech Engineering, Inc.	Geologic Hazard Study Woodman Plaza East, Colorado Springs, CO	8/22/97	23707	Kristen Andrew Hoeser/ Joseph Goode, Jr.	PE
EP-98-0037		Connors Corner	Entech Engineering, Inc.	Subsurface Soil Investigation Sam's Club Connor's Corner, Colorado Springs, CO	9/8/97	25107.1	Paul Hoskins/ Joseph Goode, Jr.	PE/PE
EP-98-0037		Connors Corner	Entech Engineering, Inc.	Preliminary Subsurface Soil Investigation Connor's Corner, Colorado Springs, CO	10/1/97	23707.1	Paul Hoskins/ Joseph Goode, Jr.	PE/PE
EP-98-0055	16	The Pines at Peregrine #5	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards Investigation The Pines at Peregrine Filing No. 1, Colorado Springs, CO	12/12/97	CS-6886	David Glater	PE, CPG
EP-98-0064		Reserve at Broadmoor Glen Filing 8	Entech Engineering, Inc.	Geologic Hazard Study The Reserve at Broadmoor Glen #8, Colorado Springs, CO	2/5/98	31128.1	Kristen Andrew Hoeser/ Joseph Goode, Jr.	PE
EP-98-0066	15	Broadmoor Subdivision	Lincoln Devore, Inc. Geotechnical Consultants	Broadmoor Village Geologic Hazard Study	2/17/98	98-3969-C	Richard Morris	PE
EP-98-0070	14	Boulders Broadmoor Filing 2	CTL/Thompson, Inc. Consulting Engineers	Preliminary Geologic Hazards Investigation The Boulders Broadmoor Phase II, Colorado Springs, CO	3/15/96	CS-6155A	John Himmelreich, Jr.	PG
EP-98-0070	14	Boulders Broadmoor Filing 2	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards and Preliminary Geotechnical Investigaiton Boulders Broadmoor, Filing No. 2 West of Broadmoor Bluffs Drive, North of Norad Entry Road, Colorado Springs, CO	2/24/98	CS-7748	William Hoffmann, Jr.	PE
EP-98-0075	11	Estate at Log Hollow and Village at Stone Manor	Terracon	Geologic Hazards Report Estates at Log Hollow, Villas at Log Hollow No. 4, Village at Stone Manor, Broadmoor Resort Community, Colorado Springs, CO	2/20/98	23975014	Richard Webb	PE
EP-97-0002	21	The Boulders at Broadmoor Bluffs	CTL/Thompson, Inc. Consulting Engineers	Preliminary Geologic Hazards Investigation The Boulders Broadmoor Filing No. 1 and 1A Jarman and Stanwell Streets, Colorado Springs, CO	5/6/96	CS-6438	John Himmelreich, Jr./ William Hoffmann, Jr.	PG/PE
EP-97-0002	21	The Boulders at Broadmoor Bluffs	CTL/Thompson, Inc. Consulting Engineers	Preliminary Geotechnical Investigation The Boulders Broadmoor Filing No. 1 and 1A Jarman and Stanwell Streets, Colorado Springs, CO	5/6/96	CS-6155	John Himmelreich, Jr./ William Hoffmann, Jr.	PG/PE
EP-97-0022	12	Lot 9 Broadmoor Residential Resort	CTL/Thompson, Inc. Consulting Engineers	Stability Analysis Lot 9, Broadmoor Residential Community 4475 Stone Manor Heights, Colorado Springs, CO	10/9/96	CS-6870	William Hoffmann, Jr.	PE
EP-97-0024		The Boulders at Broadmoor Bluffs	CTL/Thompson, Inc. Consulting Engineers	Supplemental Geotechnical Investigation The Boulders Broadmoor Filing Nos. 1 and 1A, Colorado Springs, CO	10/16/96	CS-6438	William Hoffmann, Jr.	PE
EP-97-0025	23	Barons Ridge at the Broadmoor	CTL/Thompson, Inc. Consulting	Geotechnical Hazards Risk Evaluation and Mitigation Report Barons Ridge	10/23/96	CS-7037	William Hoffmann, Jr.	PE

CGS File	Map ID	Subdiv. Name	Consultant	Report Title	Date	Job No.	Author	Registration
			Engineers	Cluster Home Development Charles Grove Cul-de-sac, East of Stone Manor Heights, Colorado Springs, CO				
EP-97-0063	13	Broadmoor Residential Resort Phase I	CTL/Thompson, Inc. Consulting Engineers	Landslide Hazard Evaluation Portions of Broadmoor Residential Resort Community Phase I, Including Barons Ridge, Phases II and III Villas at Log Hollow, Estates Lot 9, Colorado Springs, CO	4/11/97	CS-7322	William Hoffmann, Jr.	PE
EP-97-0064	20	Broadmoor Oaks Filing #4	Entech Engineering, Inc.	Geologic Hazard Study Broadmoor Oaks #4, Colorado Springs, CO	3/31/97	96426.1	Kristen Andrew Hoeser/Joseph Goode, Jr.	PE
EP-97-0073	19	Mountain Shadows Master Plan	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards and Preliminary Geotechnical Investigation Mountain Shadows Centennial Corridor Master Plan, Colorado Springs, CO	3/20/97	CS-7280	John Himmelreich, Jr.	PG
EP-96-0028	24	Broadmoor Phase I PUD	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazard Mitigation Broadmoor Phase I PUDDevelopment Plan, Colorado Springs, CO	10/31/95	CS-5807A	William Hoffman, Jr.	PE
EP-96-0059	25	Broadmoor Glen South	Kumar & Associates, Inc.	Engineering Geology and Preliminary Geotechnical Engineering Study Proposed Broadmoor Glen Development, Colorado Springs, CO	4/17/96	96-109	Marcus Pardi/ Thomas Allen	PE/PE
EP-96-0066	22	Broadmoor Villas, Phase I	CTL/Thompson, Inc. Consulting Engineers	Geologic Hazards Mitigation The Villas at Log Hollow, Colorado Springs, CO	4/24/96	CS-5807B	William Hoffmann, Jr.	PE
N/A	3	Cedar Heights Phase II	CTL/Thompson, Inc. Consulting Engineers	Preliminary Geologic Hazards Investigation Cedar Heights Subdivision, Phase II, Colorado Springs, CO	2/28/94	CS-3708	John Himmelreich, Jr.	PG
N/A	47	Cedar Heights	Shepherd Miller Inc.	Geologic Map, Cedar Heights	2/1/00	100059	N/A	
N/A	49	Myron Stratton Project	Chen and Associates, Inc.	Preliminary Soil and Foundation Investigation for the Myron Stratton Project south of Colorado Springs, CO	8/30/68	3300	Robert W. Thompson	PE
N/A	1	JL Ranch	CTL/Thompson, Inc. Consulting Engineers	Map of Potential Geologic Hazards and Surficial Deposits, JL Ranch, Colorado Springs, CO	unk.	CS-8884	Jonathan Lovekin	PG

Appendix B

Non–Published Reference Sources for Boxed Area Shown on Plate 3

Figure boundary corresponds to box outline shown on Plate 3.

EXPLANATION

- 2
- 4
- 8, 9
- 18
- 25
- 25, 26, 27
- 34
- 35
- 36
- 49

How to read this figure:

Each report source(s) is represented by an uniquely–shaded or textured polygon.

Polygon areas with additional overlapping or enclosed polygons indicate multiple report sources.

Explanation numbers correspond to ID number shown in blue table of Non–Published Sources on Plate 3.

Published Reference Sources for Boxed Area Shown on Plate 3

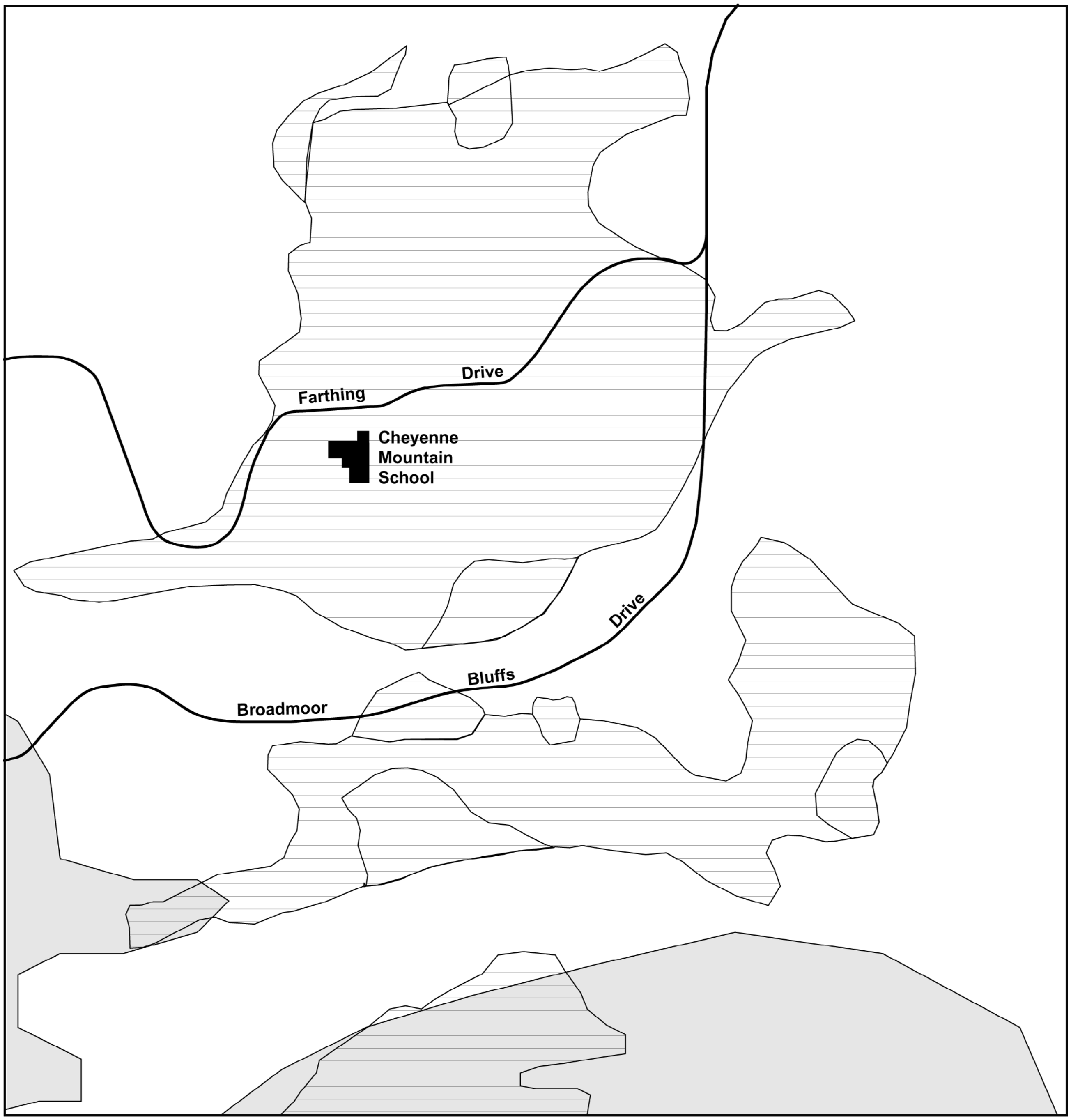

Figure boundary corresponds to box outline shown on Plate 3.

EXPLANATION

B

C

How to read this figure:

Each report source is represented by an uniquely–shaded or textured polygon.

Polygon areas with additional overlapping or enclosed polygons indicate multiple report sources.

Explanation letters correspond to ID letter shown in green table of Published References on Plate 3.

COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

Potential Areas of Landslide Susceptibility in Colorado Springs, El Paso County, Colorado

By Jonathan L. White and T.C. Wait

2003

MAP SERIES 42
PLATE 1 OF 3
2003

ID	NON-PUBLISHED SOURCE	CONSULTANT JOB NUMBER	CGS LUR FILE*
5	Himmelreich, 1999	Unpublished maps	NA
6	Himmelreich, 1996	CGS 1996	NA
45	CTL/Thompson, Inc., 2002	CS–11786	EP–02–0075

*The CGS land use review (LUR) unique number is used by the State archival file system.

Note: It was not possible for the authors to review all relevant geotechnical, geologic hazards, and engineering geology reports in landslide susceptible areas of Colorado Springs, as many of these reports are proprietary, confidential, or simply lost and unknown. Many landslides in the inventory list lie in private property and were not field verified. Some mapped landslide boundaries were changed or omitted in subsequent revisions of consultant reports; those revisions may not be shown in the inventory. Locations of potentially unstable slopes (PUS) and other non-landslide features that may still indicate potential ground movement or instability are not shown in the inventory.

USE OF THIS MAP AND LIMITATIONS

This map is intended to show areas that have geologic, topographic, and geomorphic characteristics that indicate potential landslide susceptibility in the City of Colorado Springs. Susceptibility assessments were made based on site conditions that are similar to areas where landslides have previously occurred. Users of this map should refer to the accompanying report for important information regarding the assessment methodology used and discussion of results. The mapped susceptibility areas may not exhibit evidence of landslide movement or experience slope instability under current conditions, but may under certain future conditions (e.g., heavy precipitation, adverse slope modifications, formational weathering, etc.). For locations that lie within the susceptible area, this designation does not imply that landslides will occur during the life of a residential structure, only that a higher risk exists compared to areas not mapped as susceptible.

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EXPLANATION

DESCRIPTION OF MAP UNITS

Landslide Susceptible Areas—The orange-shaded map zones have been determined to have a level of susceptibility and related risk higher than other areas within the City for landslides or deep-seated, lateral ground movements. This designation is based on bedrock and surficial geology, geologic structure, slope grade and aspect, geomorphology, and landslide history as of 2002. Mapped landslide boundaries lie within the extent of the susceptible areas unless field evidence or site grading indicates otherwise. Other areas shown to be susceptible have terrain and ground conditions similar to where mapped landslides have occurred.

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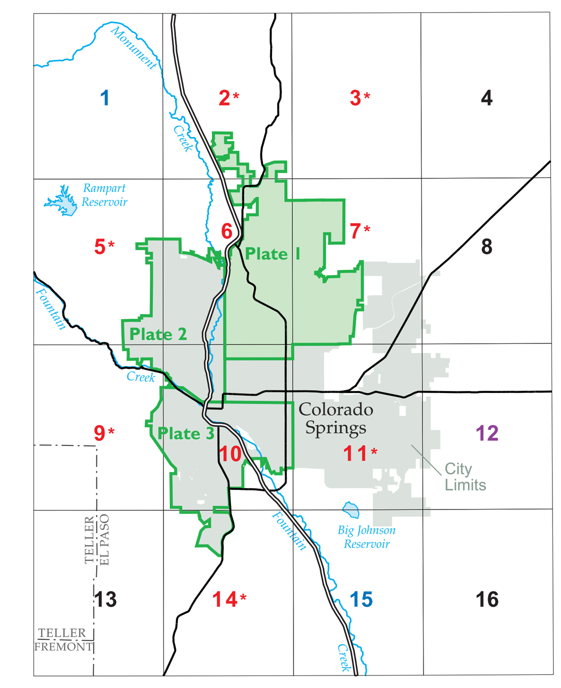
Interpreted Landslides—This purple-colored line shows landslides that were mapped for this project by the authors, using geomorphic interpretation. Stereo aerial photography and high-resolution topographic data were used to determine the locations of areas having landslide geomorphology. The boundaries were mapped and then field verified. These landslides are not indexed. See the accompanying publication booklet for more information on the geomorphology of landslides.

COLORADO INDEX MAP

MAP INDEX

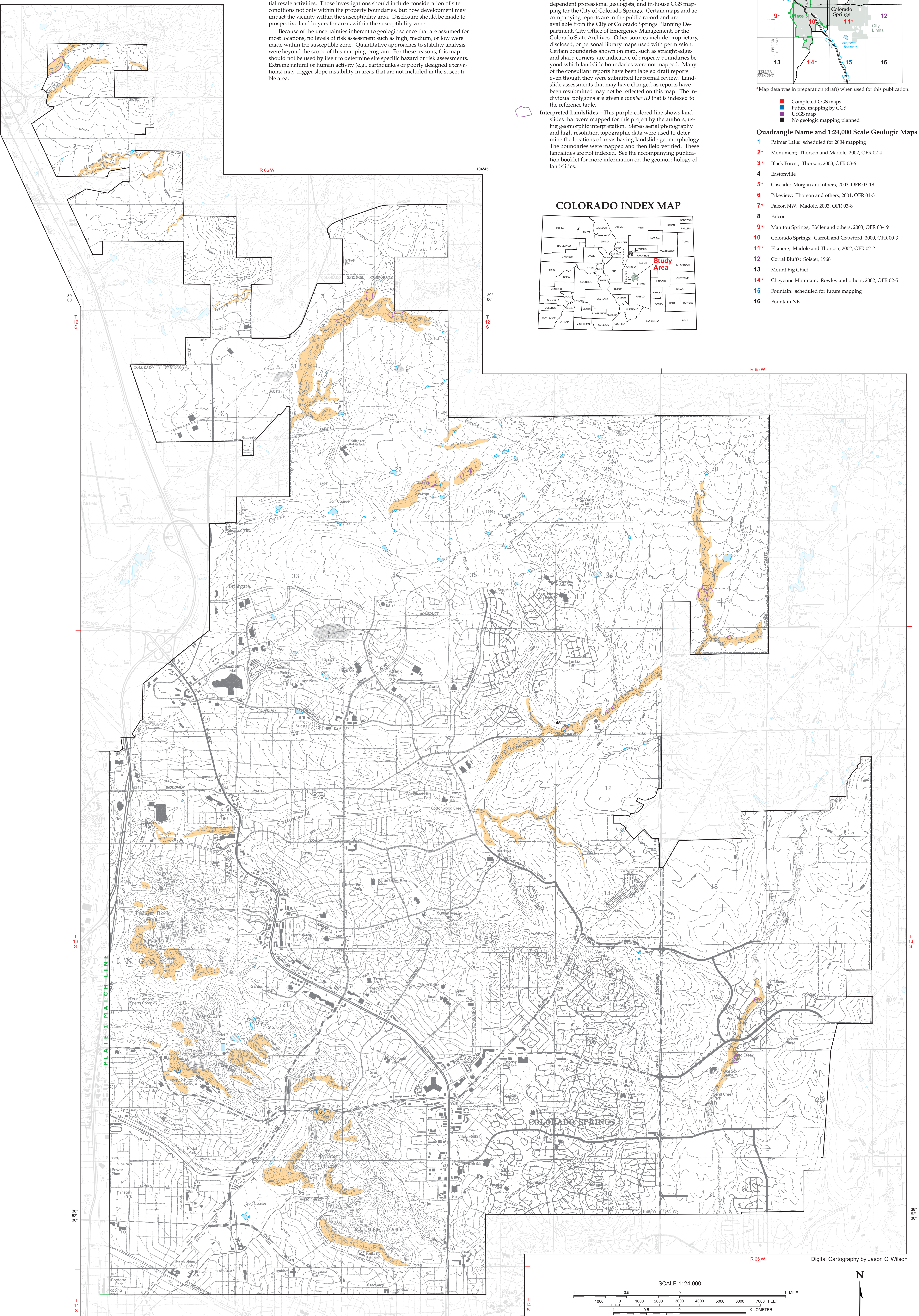


*Map data was in preparation (draft) when used for this publication.

- Completed CGS maps
- Future mapping by CGS
- USGS map
- No geologic mapping planned

Quadrangle Name and 1:24,000 Scale Geologic Maps

1 Palmer Lake; scheduled for 2004 mapping
2* Monument; Thorson and Madole, 2002, OFR 02-4
3* Black Forest; Thorson, 2003, OFR 03-6
4 Eastonville
5* Cascade; Morgan and others, 2003, OFR 03-18
6 Pikeview; Thorson and others, 2001, OFR 01-3
7* Falcon NW; Madole, 2003, OFR 03-8
8 Falcon
9* Manitou Springs; Keller and others, 2003, OFR 03-19
10 Colorado Springs; Carroll and Crawford, 2000, OFR 00-3
11* Elsmere; Madole and Thorson, 2002, OFR 02-2
12 Corral Bluffs; Soister, 1968
13 Mount Big Chief
14* Cheyenne Mountain; Rowley and others, 2002, OFR 02-5
15 Fountain; scheduled for future mapping
16 Fountain NE



Base map compiled from USGS 7.5 minute topographic quadrangle maps; Colorado Springs, Elsmere, Falcon NW, Monument, and Pikeview

Digital Cartography by Jason C. Wilson

SCALE 1: 24,000

Bill Owens, Governor, State of Colorado

Greg Walcher, Executive Director, Department of Natural Resources

Ronald W. Cattany, Director Division of Minerals and Geology

COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

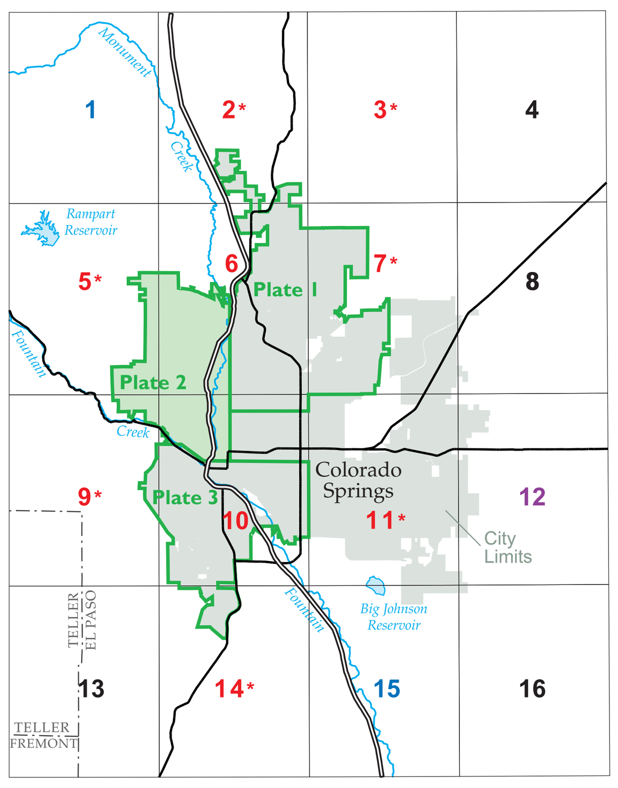
Potential Areas of Landslide Susceptibility in Colorado Springs, El Paso County, Colorado

By Jonathan L. White and T.C. Wait

2003

MAP SERIES 42
PLATE 2 OF 3
2003

MAP INDEX



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4 Eastonville
5* Cascade; Morgan and others, 2003, OFR 03-18
6 Pikeview; Thorson and others, 2001, OFR 01-3
7* Falcon NW; Madole, 2003, OFR 03-8
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9* Manitou Springs; Keller and others, 2003, OFR 03-19
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13 Mount Big Chief
14* Cheyenne Mountain; Rowley and others, 2002, OFR 02-5
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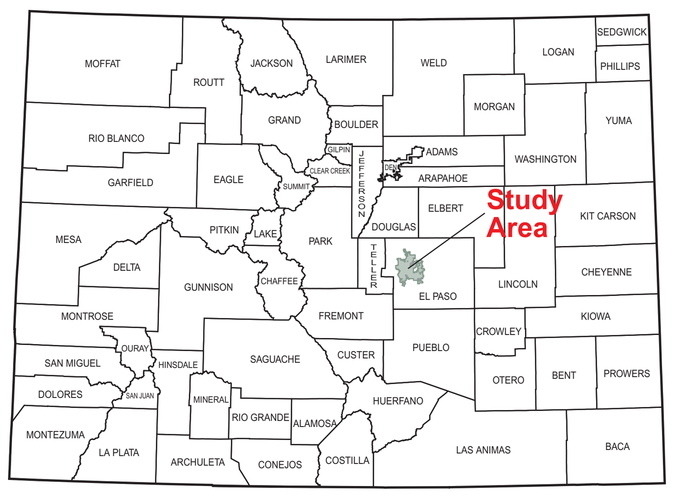
16 Fountain NE

COLORADO INDEX MAP



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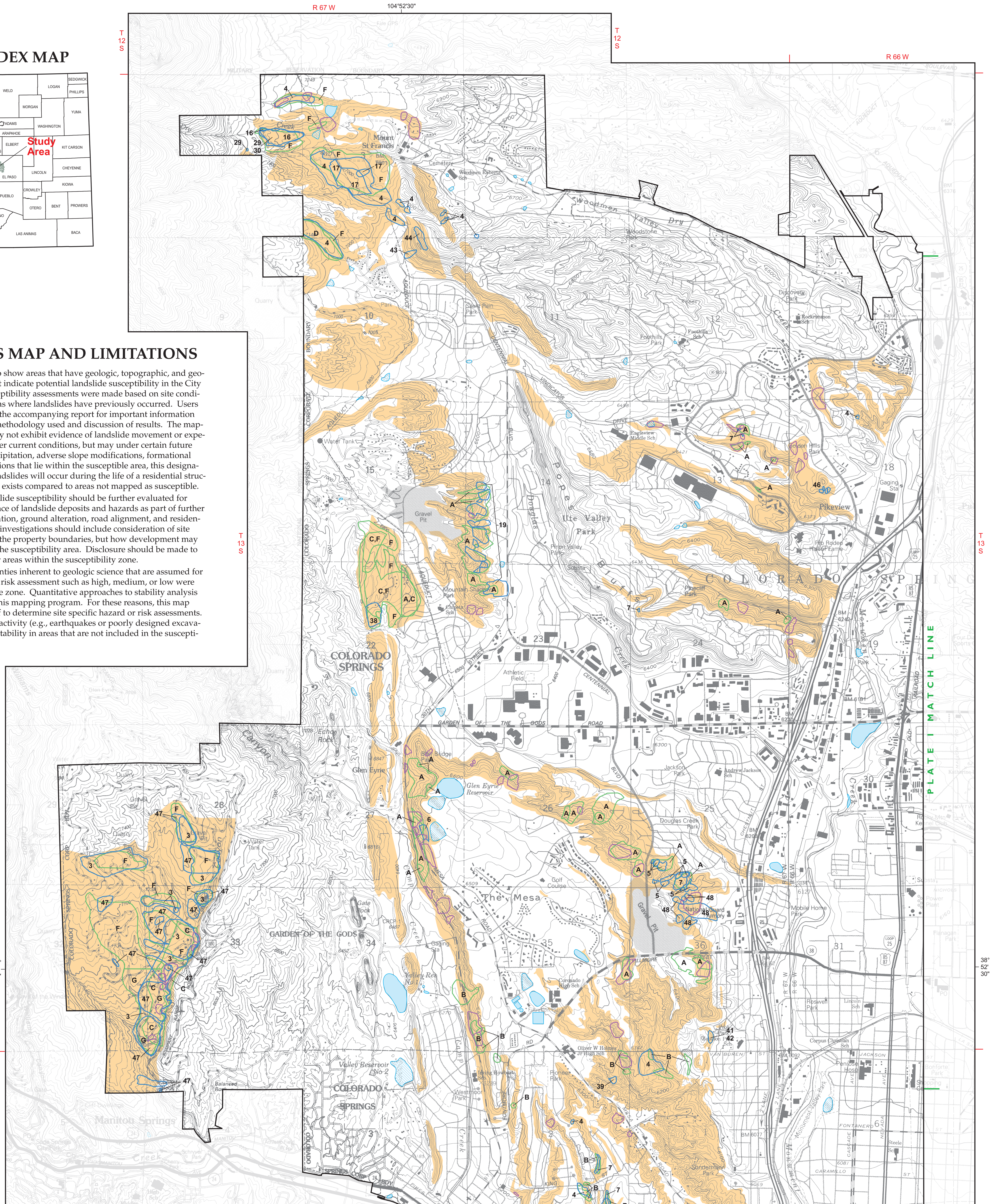

Base map compiled from USGS 7.5 minute topographic quadrangle maps; Cascade, Colorado Springs, Manitou Springs, and Pikeview

EXPLANATION

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ID	NON-PUBLISHED SOURCE	CONSULTANT JOB NUMBER	CGS LUR FILE*
3	CTL/Thompson, Inc., 1994	CS–3708	NA
4	Himmelreich, 2001	Unpublished maps	NA
5	Himmelreich, 1999	Unpublished maps	NA
6	Himmelreich, 1996	CGS 1996	NA
7	Noe and White, 2000	City OEM file – FEMA	NA
16	CTL/Thompson, Inc., 1997	CS–6886	EP–98–0055
17	CTL/Thompson, Inc., 1997	CS–7304	EP–98–0017
19	CTL/Thompson, Inc., 1997	CS–7280	EP–97–0073
29	CTL/Thompson, Inc., 1999	CS–6886	EP–00–0011
30	CTL/Thompson, Inc., 1998	CS–6886	EP–99–0023
38	Terracon, 2001	23005067	EP–01–0069
39	CTL/Thompson, Inc., 2001	CS–11796	EP–02–0045
40	Entech Engineering, Inc., 2002	28661	EP–02–0049
41	Kumar and Associates, 2002	012–223	EP–02–0058
42	Kumar and Associates, 2002	012–223A	EP–02–0058
43	Entech Engineering, Inc., 2002	36221	EP–02–0059
44	CTL/Thompson, Inc., 2002	CS–11541	EP–02–0061
46	Entech Engineering, Inc., 2002	47872	EP–03–0009
47	Shepherd Miller, Inc., 2000	100059	NA
48	Himmelreich and Associates, 2002	01145	EP–02–0017

*The CGS land use review (LUR) unique number is used by the State archival file system.

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ID	PUBLISHED REFERENCE
A	Thorson, J.P., Carroll, C.J., and Morgan, M.L., 2001, Geologic map of the Pikeview quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open File Report 01-3, scale 1:24,000
B	Carroll, C.J. and Crawford, T.A., 2000, Geologic map of the Colorado Springs quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open File Report 00-3, scale 1:24000
C	Trimble, D.E. and Machette, M.N., 1979, Geologic map of the Colorado Springs-Castle Rock area, Front Range Urban Corridor, Colorado: United States Geological Survey Map I-857-F, scale 1:100000
D	Scott, G.R. and Wobus, R.A., 1973, Reconnaissance geologic map of Colorado Springs and vicinity, Colorado: United States Geological Survey MF-482, scale 1:62500
F	Morgan, M.L., Rowley, P.D., Siddoway, C.S., Temple, J., Keller, J.W., Archuleta, B.H., and Himmelreich, J.W., in preparation, Geologic Map of the Cascade quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open File Report 03-18, scale 1:24,000
G	Keller, J.W., Morgan, M.L., Siddoway, C.S., Route, E.E., Grozzell, M.T., Sacerdoti, R., and Stevenson, A., in preparation, Geologic map of the Manitou Springs quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open File Report 03-19, scale 1:24,000

N

SCALE 1: 24,000

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

Digital Cartography by Jason C. Wilson

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DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

Potential Areas of Landslide Susceptibility in Colorado Springs, El Paso County, Colorado

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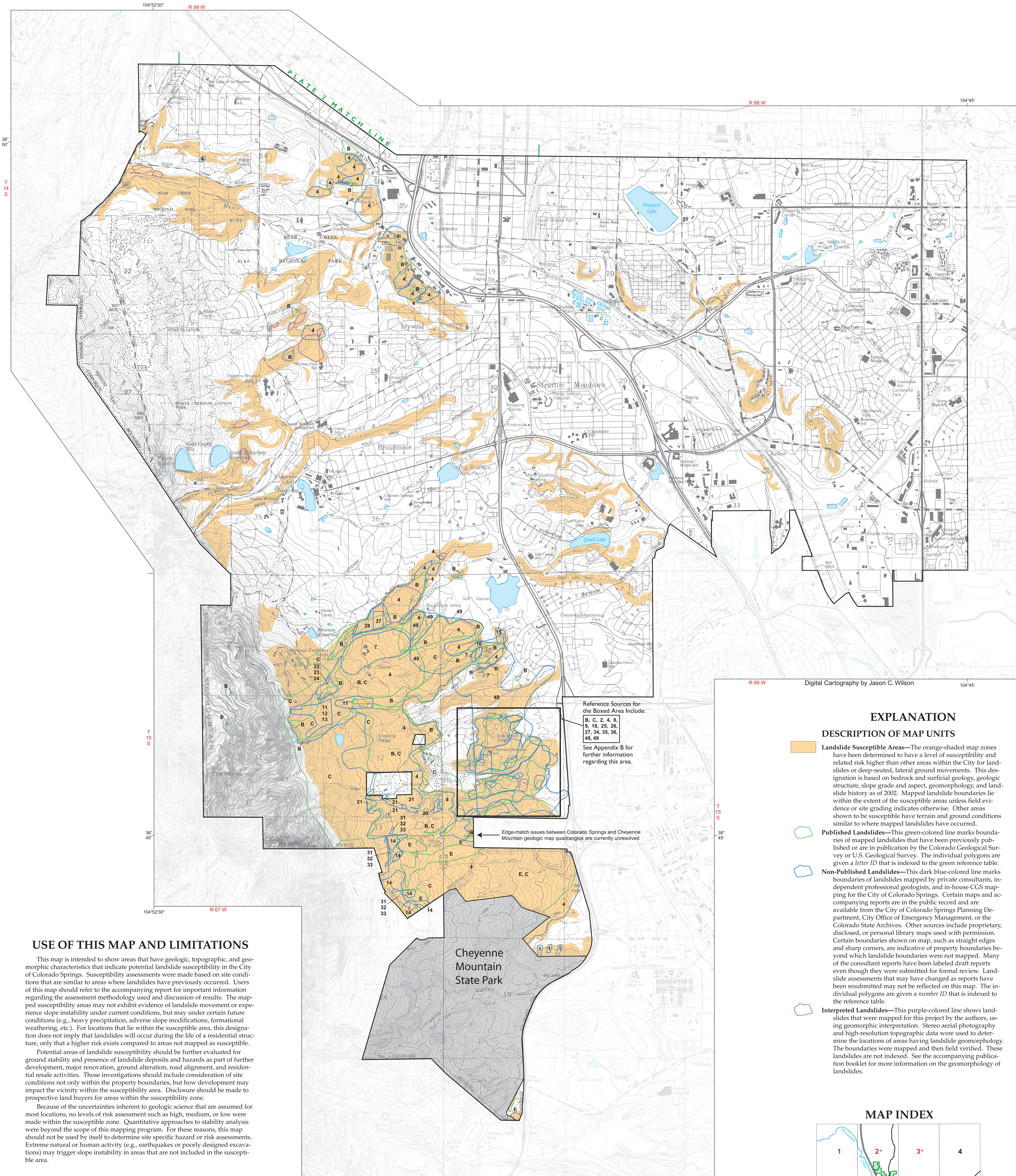
2003

MAP SERIES 42
PLATE 3 OF 3
2003



Digital Cartography by Jason C. Wilson

Base map compiled from USGS 7.5 minute topographic quadrangle maps; Cheyenne Mountain, Colorado Springs, Elsmere, and Manitou Springs

SCALE 1: 24,000

USE OF THIS MAP AND LIMITATIONS

This map is intended to show areas that have geologic, topographic, and geomorphic characteristics that indicate potential landslide susceptibility in the City of Colorado Springs. Susceptibility assessments were made based on site conditions that are similar to areas where landslides have previously occurred. Users of this map should refer to the accompanying report for important information regarding the assessment methodology used and discussion of results. The mapped susceptibility areas may not exhibit evidence of landslide movement or experience slope instability under current conditions, but may under certain future conditions (e.g., heavy precipitation, adverse slope modifications, formational weathering, etc.). For locations that lie within the susceptible area, this designation does not imply that landslides will occur during the life of a residential structure, only that a higher risk exists compared to areas not mapped as susceptible.

Potential areas of landslide susceptibility should be further evaluated for ground stability and presence of landslide deposits and hazards as part of further development, major renovation, ground alteration, road alignment, and residential resale activities. Those investigations should include consideration of site conditions not only within the property boundaries, but how development may impact the vicinity within the susceptibility area. Disclosure should be made to prospective land buyers for areas within the susceptibility zone.

Because of the uncertainties inherent to geologic science that are assumed for most locations, no levels of risk assessment such as high, medium, or low were made within the susceptible zone. Quantitative approaches to stability analysis were beyond the scope of this mapping program. For these reasons, this map should not be used by itself to determine site specific hazard or risk assessments. Extreme natural or human activity (e.g., earthquakes or poorly designed excavations) may trigger slope instability in areas that are not included in the susceptible area.

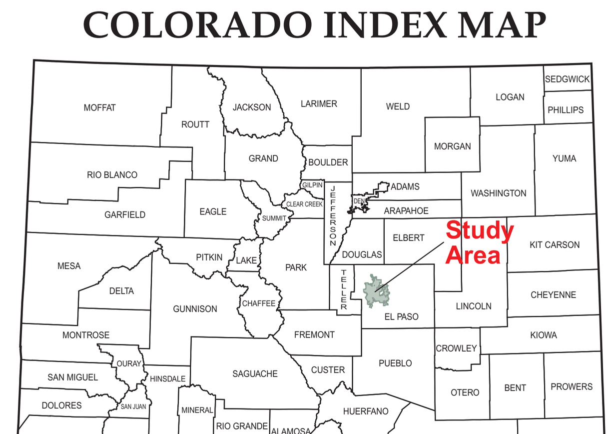
ID	NON-PUBLISHED SOURCE	CONSULTANT JOB NUMBER	CGS LUR FILE*
1	CTL/Thompson, Inc.	CS–8884	NA
2	Entech Engineering, Inc. (proprietary)	Unknown	NA
4	Himmelreich, 2001	Unpublished maps	NA
7	Noe and White, 2000	City OEM file – FEMA	NA
8	Terracon, 1998	23985068	EP–99–0041
9	Terracon, 1999/Chen and Associates, 1987	23985068/2–222–87	EP–99–0064
10	Terracon, 1998	23985037	EP–99–0042
11	Terracon, 1998	23975014	EP–98–0075
12	CTL/Thompson, Inc., 1996	CS–6870	EP–97–0022
13	CTL/Thompson, Inc., 1997	CS–7322	EP–97–0063
14	CTL/Thompson, Inc., 1996	CS–6155A	EP–98–0070
15	Lincoln Devore, 1998	98–3969–C	EP–98–0066
18	CTL/Thompson, Inc., 1997	CS–7792	EP–98–0016
20	Entech Engineering, Inc., 1997	96426.1	EP–97–0064
21	CTL/Thompson, Inc., 1996	CS–6438	EP–97–0002
22	CTL/Thompson, Inc., 1996	CS–5807B	EP–96–0066
23	CTL/Thompson, Inc., 1996	CS–7037	EP–97–0025
24	CTL/Thompson, Inc., 1995	CS–5807A	EP–96–0028
25	Kumar and Associates, 1996	96–109	EP–96–0059
26	Terracon, 1998	23985078	EP–99–0029
27	Terracon, 1998	23985047	EP–99–0050
28	Entech Engineering, Inc., 1999	43098.1	EP–00–0002
31	CTL/Thompson, Inc., 1999	CS–9036	EP–00–0041
32	CTL/Thompson, Inc., 1999	CS–9036	EP–00–0056
33	CTL/Thompson, Inc., 2000	CS–9036	EP–00–0080
34	Terracon, 1999	23995040	EP–00–0065
35	Entech Engineering, Inc., 2000	85890	EP–01–0002
36	Terracon, 2000	23985047	EP–01–0011
37	Entech Engineering, Inc., 2000	86230	EP–01–0030
48	John Himmelreich and Associates, 2001	01–145	EP–02–0017
49	Chen and Associates, Inc., 1968	3300	NA

*The CGS land use review (LUR) unique number is used by the State archival file system.

Note: It was not possible for the authors to review all relevant geotechnical, geologic hazards, and engineering geology reports in landslide susceptible areas of Colorado Springs, as many of these reports are proprietary, confidential, or simply lost and unknown. Many landslides in the inventory list lie in private property and were not field verified. Some mapped landslide boundaries were changed or omitted in subsequent revisions of consultant reports; those revisions may not be shown in the inventory. Locations of potentially unstable slopes (PUS) and other non-landslide features that may still indicate potential ground movement or instability are not shown in the inventory.

ID	PUBLISHED REFERENCE
B	Carroll, C.J. and Crawford, T.A., 2000, Geologic map of the Colorado Springs quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open File Report 00-3, scale 1:24000
C	Trimble, D.E. and Machette, M.N., 1979, Geologic map of the Colorado Springs-Castle Rock area, Front Range Urban Corridor, Colorado: United States Geological Survey Map I-857-F, scale 1:100000
E	Rowley, P.D., Himmelreich, J.W., Kupfer, D.H., and Siddoway, C.S., in publication, Geologic map of the Cheyenne Mountain quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open File Report 02-5, scale 1:24000

COLORADO INDEX MAP



EXPLANATION

DESCRIPTION OF MAP UNITS

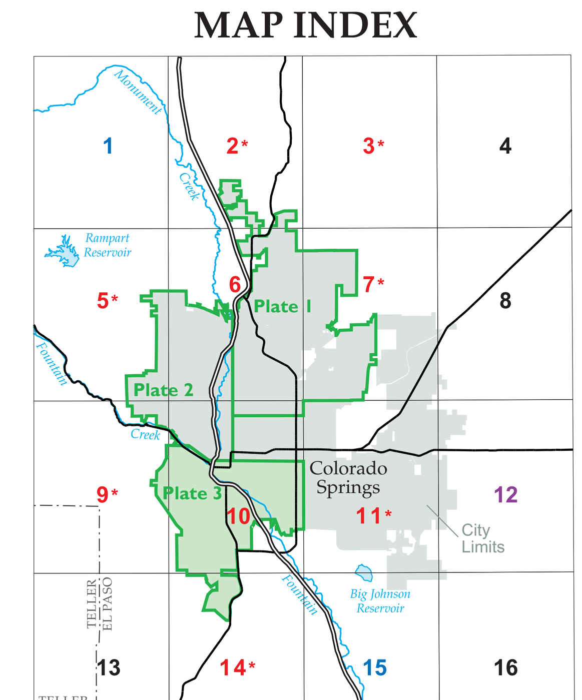
Landslide Susceptible Areas—The orange-shaded map zones have been determined to have a level of susceptibility and related risk higher than other areas within the City for landslides or deep-seated, lateral ground movements. This designation is based on bedrock and surficial geology, geologic structure, slope grade and aspect, geomorphology, and landslide history as of 2002. Mapped landslide boundaries lie within the extent of the susceptible areas unless field evidence or site grading indicates otherwise. Other areas shown to be susceptible have terrain and ground conditions similar to where mapped landslides have occurred.

Published Landslides—This green-colored line marks boundaries of mapped landslides that have been previously published or are in publication by the Colorado Geological Survey or U.S. Geological Survey. The individual polygons are given a *letter ID* that is indexed to the green reference table.

Non-Published Landslides—This dark blue-colored line marks boundaries of landslides mapped by private consultants, independent professional geologists, and in-house CGS mapping for the City of Colorado Springs. Certain maps and accompanying reports are in the public record and are available from the City of Colorado Springs Planning Department, City Office of Emergency Management, or the Colorado State Archives. Other sources include proprietary, disclosed, or personal library maps used with permission. Certain boundaries shown on map, such as straight edges and sharp corners, are indicative of property boundaries beyond which landslide boundaries were not mapped. Many of the consultant reports have been labeled draft reports even though they were submitted for formal review. Landslide assessments that may have changed as reports have been resubmitted may not be reflected on this map. The individual polygons are given a *number ID* that is indexed to the reference table.

Interpreted Landslides—This purple-colored line shows landslides that were mapped for this project by the authors, using geomorphic interpretation. Stereo aerial photography and high-resolution topographic data were used to determine the locations of areas having landslide geomorphology. The boundaries were mapped and then field verified. These landslides are not indexed. See the accompanying publication booklet for more information on the geomorphology of landslides.

MAP INDEX



*Map data was in preparation (draft) when used for this publication.

- Completed CGS maps
- Future mapping by CGS
- USGS map
- No geologic mapping planned

Quadrangle Name and 1:24,000 Scale Geologic Maps

1 Palmer Lake; scheduled for 2004 mapping
2* Monument; Thorson and Madole, 2002, OFR 02-4
3* Black Forest; Thorson, 2003, OFR 03-6
4 Eastonville
5* Cascade; Morgan and others, 2003, OFR 03-18
6 Pikeview; Thorson and others, 2001, OFR 01-3
7* Falcon NW; Madole, 2003, OFR 03-8
8 Falcon
9* Manitou Springs; Keller and others, 2003, OFR 03-19
10 Colorado Springs; Carroll and Crawford, 2000, OFR 00-3
11* Elsmere; Madole and Thorson, 2002, OFR 02-2
12 Corral Bluffs; Soister, 1968
13 Mount Big Chief
14* Cheyenne Mountain; Rowley and others, 2002, OFR 02-5
15 Fountain; scheduled for future mapping
16 Fountain NE

Bill Owens, Governor, State of Colorado

Greg Walcher, Executive Director, Department of Natural Resources

Ronald W. Cattany, Director Division of Minerals and Geology