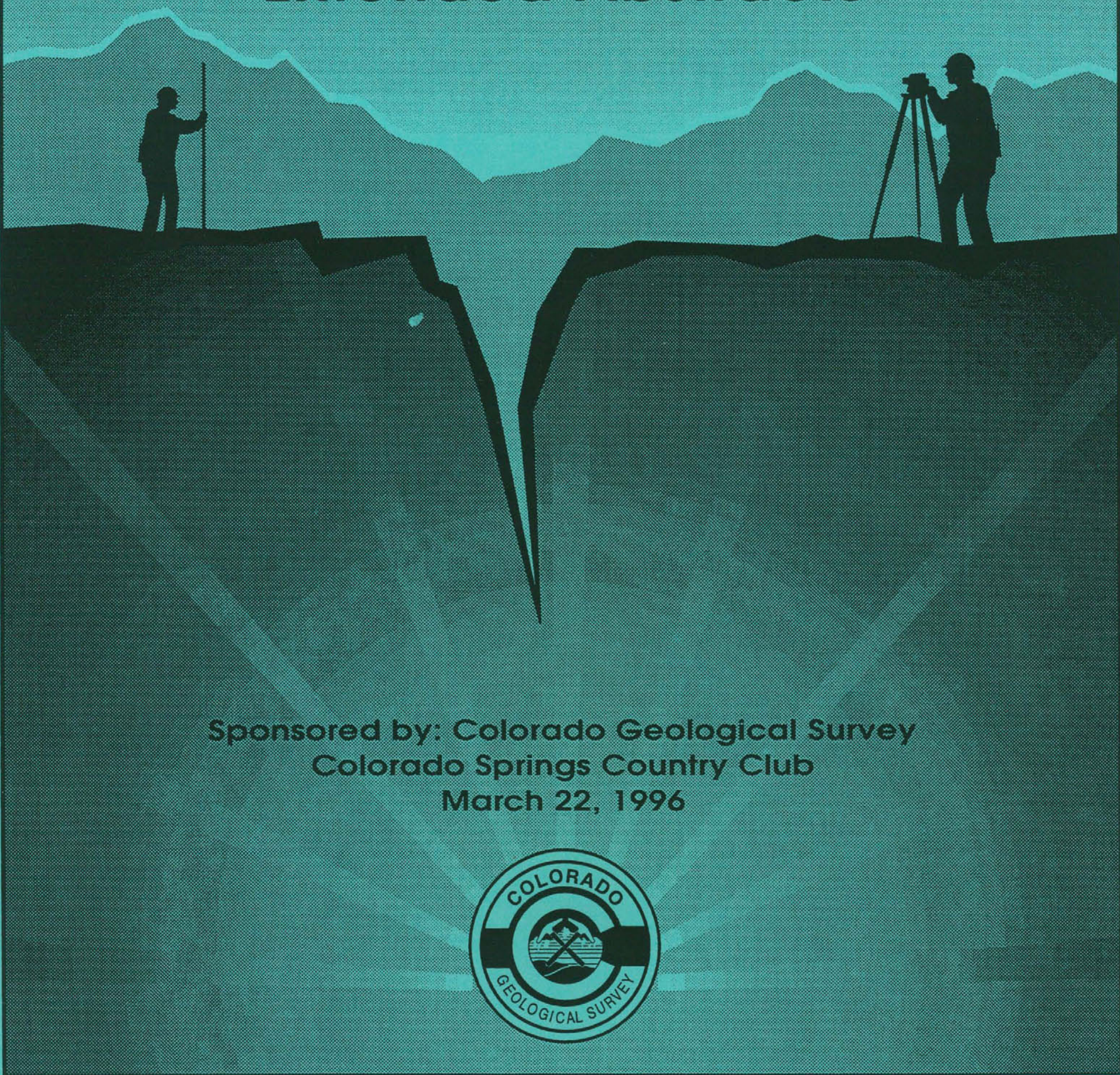
GEOLOGIC HAZARDS AND ENGINEERING PRACTICES IN COLORADO

Extended Abstracts



Sponsored by: Colorado Geological Survey
Colorado Springs Country Club
March 22, 1996

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado / 1996

Geologic Hazards and Engineering Practices in Colorado

EXTENDED ABSTRACTS

with a Section on
Key Laws Related to Geologic Hazards and Land Use in Colorado

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Colorado Geological Survey
"Geologic Hazards and Engineering Practices in Colorado" Conference

March 22, 1996

Purpose of Seminar

Prepared by: Robert T. Bates, PE
Soils Task Force Chairman

In May, 1994, State Senator Bill Schroeder met with representatives of engineering organizations and outlined concerns regarding performance of residences constructed on expansive soils and bedrock in Colorado. In response to Senator Schroeder, the Colorado Board of Registration for Professional Engineers and Professional Land Surveyors helped form a Soils Task Force. The purpose of the Task Force was to make recommendations to the Board relative to the practice of engineering and the design of structures and infrastructures in expansive soils found throughout Colorado and steeply dipping expansive bedrock found along the eastern flank of the Hogback along the Front Range.

The Task Force met numerous times for several months. Early in the process, the Task Force defined the perceived problem to include, among several factors, lack of education of the public and transfer of technology to design professionals. The members of the Task Force believed that professionals involved in the design of structures and infrastructure in areas of natural hazards, such as expansive soils and bedrock, would benefit from increased:

1. education regarding current design methodologies,
2. knowledge of successful performance of structures and infrastructure and,
3. awareness of development and construction risks.

The Task Force went on to conclude that knowledge of natural hazards should be demonstrated by attendance at courses on natural hazards sponsored by professional societies, universities and government organizations including the State Geological Survey.

Thus, the purpose of this Conference is offer an opportunity to engineers, and other professionals such as planners and architects, to possess the necessary knowledge for the planning and design of structures and infrastructure, and to become more aware of the development and construction risks, in areas of natural hazards.

HEAVE PREDICTION AS A DESIGN CONSIDERATION

Robert W. Thompson

Clients are no longer satisfied with qualitative description of expansive soil characteristics as a basis for design. There is need for more quantitative determination of potential movements of expansive soils to allow rational evaluation of design alternatives. Measurement of distortion caused by expansive soil or expansive bedrock in several structures in Colorado is compared with geotechnical data from design and remedial investigations. The case histories indicate a need for more complete subsurface design study to quantify the movement potential. Field observations indicate reasonable quantification can be achieved with relatively inexpensive swell tests or soil suction tests. Some of the limitations of predictive methods are identified.

Swelling Soils
Engineering Practice in Colorado Springs / Pueblo

by Joseph C. Goode, Jr., P.E. [1]

Introduction

Expansive soils are prevalent along the entire front range corridor of Colorado. Colorado Springs, the second largest metropolitan area along the front range, is greatly impacted by the costs and constraints associated with construction on expansive soils. Expansive soils are also encountered in many areas of Pueblo.

Recognition of problems with expansive soils in foundation designs began in the late 1950's and early 1960's. Drilled pier foundations were developed for expansive soil sites in the Denver area. The lack of caisson drilling equipment in the Colorado Springs and Pueblo area and the costs associated with mobilizing from Denver created the need to develop alternatives to drilled piers.

Voided foundation designs were used for many years in Colorado Springs and Pueblo. The voided foundation typically consists of a stemwall-on-grade foundation with voids placed along wall lines to increase contact pressures and balance the building loads. The overexcavation/replacement approach was also developed.

Engineering practice and foundation design in areas with expansive soils has evolved to standards of practices that are effective in minimizing damage to structures. Although design approaches have not changed significantly over the past twenty years, the design criteria have been refined.

Identification of Expansive Soils

The clay soils in the Colorado Springs and Pueblo areas are typically expansive to some degree. The Pierre Shale formation and the claystone of the Dawson formation can usually be expected to have moderate to very high swelling potential. Residually weathered clays, colluvial clays, and clays encountered in various alluviums are also expansive. Visual identification of expansive clay soils is relatively easy. Estimating the degree of expansion, however, is sometimes difficult. The magnitude of swelling will be affected by the clay content, moisture conditions, and density of the soil. Numerous tests are available to determine the swell potential of a soil. Direct methods of measurement of swell potential are most useful for geotechnical engineers.

Measurement of Swell Potential

The FHA swell test and the Denver Swell / Consolidation Test are the primary tests used in Colorado Springs and Pueblo to determine the expansive properties of clay soils. The FHA Swell Test (Potential Volume Change Meter) was developed for the Federal Housing Administration in 1960. The test was created to determine a swell index and swell category to classify expansive soils. The Denver Swell / Consolidation Test (ASTM D-4546) is a one-dimensional swell test. To date, a correlation between the two tests has not been established, and it is the author's opinion that a correlation can not be developed due to the inherent differences in the tests.

The FHA Swell Test involves a remolded sample which is compacted in a one inch ring at natural moisture content (many firms will compact the sample at drier conditions). The sample is then wetted and allowed to swell

[1] President and Owner of Entech Engineering, Inc.

against a proving ring. The test was originally intended to give a "Swell Index". The swell pressures measured in the test were not intended to be used for actual design values. The swell pressure recorded in the test has been used to determine design balance pressures for voided foundation designs. Today, the FHA swell test is generally used to classify the soils into a swell category. FHA swell pressure ranges and typical foundation recommendations corresponding with the pressures are presented in Table 1.

Table 1
FHA Swell Test

Swell Pressure (psf)	Swell Classification	Foundation Types
0 - 1000	low	footing, stemwall-on-grade (1)
1000 - 1500	moderate	footing, stemwall-on-grade, voided stemwalls (2)
1500 - 2000	moderate to high	footing, stemwall-on-grade, overexcavation, voided stemwalls(2)
2000 - 3000	high	3 foot overexcavation, drilled piers
> 3000	very high	3 to 5 foot overexcavation, drilled piers

(1) Footing sizes or types will depend on soils bearing capacity and building loads
(2) Voided foundations are very common in Pueblo with limited use in Colorado Springs.

The Denver Swell / Consolidation Test is also widely used to measure soils' expansive characteristics. The Denver Swell / Consolidation Test allows for testing an "undisturbed" sample from a California Sampler. Many believe that the test more accurately represents field conditions. The sample is placed in a consolidation frame and allowed to swell under a 500 or 1000 psf load. The test is typically run in the Colorado Springs area with a 1000 psf load. After swelling, the soil is then compressed to its original height by applying loads. The test yields a percent swell and a swell pressure. The swell pressure is recorded as the pressure required to compress the sample to its original height. The percent swell is the change in volume of the sample under constant load upon wetting. Table 2 shows the Denver Swell / Consolidation Test result ranges, swell classification and typical foundation recommendations.

Table 2
Denver Swell / Consolidation Test

Percent Swell	Swell Classification	Foundation Recommendations
0 - 1	low	footing, stemwall-on-grade
1 - 2½	low to moderate	footing, stemwall-on-grade, voided stemwalls (1)
2½ - 4	moderate to high	drilled pier/ overexcavation, voided stemwalls (1)
4 - 6	high	drill pier/ overexcavation
> 6	very high	drilled piers/extensive overexcavation

(1) Voided stemwalls are used in Pueblo with very limited use in Colorado Springs.

Foundation Recommendations

Recommended foundations on highly expansive soils typically consist of footing or stemwall-on-grade in conjunction with overexcavation or a drilled pier foundation system. Voided stemwalls are also commonly used in the Pueblo area. Voided stemwall designs were used extensively in Colorado Springs in the 1970's and 1980's. Presently their use is very limited in Colorado Springs. A voided footing design has been used by some engineers on moderately expansive soils. The foundation type for a given swell range can vary based on site conditions as shown in Tables 1 and 2. Post tensioned slabs are an alternative which is not widely used in the Colorado Springs/Pueblo area.

The overexcavation/replacement approach generally involves excavation of a minimum of 3 feet below foundation members and extends 3 feet beyond the perimeter of the foundation, being replaced with non-expansive structural fill. In many instances, the overexcavation depth is increased to 4 or 5 feet depending on the expansive characteristics of the soils. The advantage of the overexcavation approach is the protection it provides to the basement floor slab. The overexcavation/replacement approach has been used very successfully in the Colorado Springs area since the 1960's, but is not used as frequently in the Pueblo area.

Drilled pier foundations typically consist of 10 or 12 inch diameter concrete piers drilled into bedrock. Bedrock penetration depths of 4 to 6 feet are typical. Minimum length of drilled piers are typically on the order of 15 to 20 feet depending on the engineer. The drilled pier approach provides a very stable foundation system for the structure; however, the floor slab may still be placed on the expansive soils if the subgrade is not overexcavated. Generally, the slab's performance is acceptable in areas with 2-3% swells. Floor slabs-on-grade are not recommended for areas with swells of 4% or greater using the Denver Swell / Consolidation Test. In these areas, structural floors are recommended for basement levels.

Post tensioned slabs are currently being used on multifamily and apartment projects. Post tensioned slabs are slabs-on-grade with thickened edges and cross beams. Post tensioned slabs are typically not cost effective for highly expansive clays due to the extreme lifting conditions required in the design. Post tensioned slab contractors are not readily available in the Colorado Springs area. The desire for basements also affects the use of post tensioned slabs in single family residential construction. Generally post tensioned slabs are only cost effective on larger projects.

Floor Slabs and Structural Wood Floors

The use of concrete slabs-on-grade for basement floors is acceptable in areas where swells measured by the Denver Swell / Consolidation Test are up to 2½ to 3 percent. Concrete slabs in these areas will experience movement and cracking; however, with properly voided partition walls, slab movement should not cause structural distress to the building. Control joints should be installed in slabs to attempt to limit the cracking.

In areas of highly expansive soils, Denver swells greater than 4 percent, or FHA swells greater than 4500 psf, the use of a structural wood floor system in basement levels is commonly recommended. Structural wood floors require deeper foundation walls to provide an adequate crawlspace to lower the basement level. Although structural wood floors add to the cost of the structure, they eliminate the possibility of slab movement and significant structural damage caused by extreme slab movements. Structural floors also add to the deadloads along grade beams and drilled piers.

Subsurface Perimeter Drains

Subsurface perimeter drains are generally recommended for all structures with usable space below grade in the Colorado Springs area. In areas where expansive soils are encountered, engineers typically recommend perimeter drains for the entire structure. On occasion, some engineers still only drain the basement level. The perimeter drain around structures constructed on expansive soils is generally intended to intercept water which infiltrates into the backfill zone and to minimize the infiltration or seepage of water below the foundation. Many are of the opinion that the perimeter drain's function is to remove excess water from the excavation and prevent water from seeping into the basement, and it is not intended to prevent moisture increases in the subgrade soils. An improperly installed drain, however, can cause significant distress to a structure. Irrespective of the reason for the perimeter drain, most engineers are in agreement that perimeter drains should be installed around structures built on expansive soils.

Voided Partition Walls

Voided partition walls have been recommended in the Colorado Springs area since the late 1970's on lots with expansive soils. Today, voided partition walls are generally installed as a rule of thumb. Typically, a minimum void height of 1½ inches is recommended. A newer trend is to recommend larger void heights in areas of highly expansive clays. Void heights of up to 3 inches have been recommended. The 3 inch void height can create some constraints with respect to trimming finished basements. A common problem associated with finished basements when walls are voided is the lack of voiding of drywall, door jambs and trim. Significant distress can be caused by drywall when it is nailed to framed partition walls. A typical void detail is shown in Figure 1.

Landscaping and Surface Drainage

Proper surface drainage and landscaping is critical to foundation and slab performance where expansive soils are present. Engineers are constantly emphasizing the need to adhere to surface grading, drainage and landscape recommendations. Maintenance of positive slope away from the foundation is a common problem. Proper installation and maintenance of gutter downspouts is also a common problem. Roof gutter downspouts can discharge large quantities of water into the subgrade soils. A positive slope of 5 percent in the first ten feet adjacent to foundations is typically recommended.

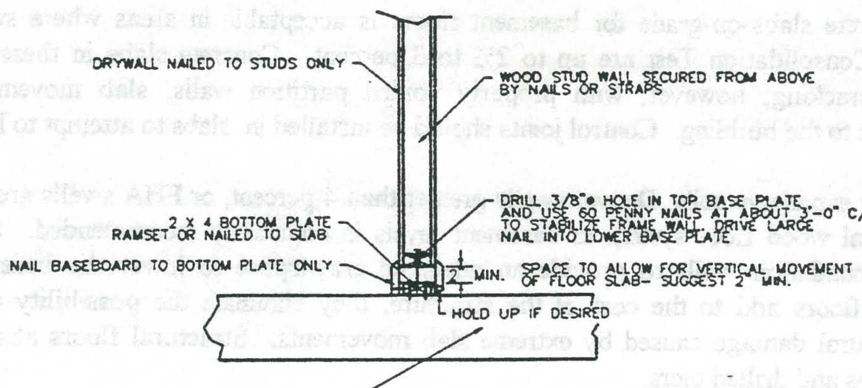

Figure 1 - Partition Void Detail

Landscaping adjacent to the foundation should consist of rock or other material placed on landscape fabric. Plastic membranes as weed barriers are not recommended. Irrigation adjacent to the foundation, if any, should only consist of drip irrigation of shrubs. Sprinkler systems should be designed to have a separate zone for the drip irrigation.

Remedial Measures

Even with the requirements for designs and inspections, some structures experience distress. The majority of remedial work is with houses constructed prior to the recent policy changes. Remedial measures required depend on the extent of movement and distress. Remedial measures may include drainage improvements, isolation of slabs, adjustment of beams, lateral bracing or underpinning.

The majority of the problems associated with structures on expansive soils are related to slab movements, improper isolation of the slab and improper installation of non-bearing partition on basement levels. Generally these problems can be corrected by recreating void space on non-bearing partition walls and adjusting doors.

When foundation movement occurs, several alternatives are available for stabilizing the foundation system. In some circumstances, the use of pads beneath the grade beams may be effective in increasing contact stresses. Generally, major foundation movement can be corrected by underpinning the foundation. Underpinning can be performed with drilled piers which are installed with a portable rig. Piers are usually placed adjacent to the foundation walls and a concrete haunch is placed to support the wall.

A relatively new underpinning approach being used in the Colorado Springs/Pueblo area involves the use of helical screws. The helical screws are drilled with a hydraulic drive to refusal. The screws are then fastened to the foundation walls with steel brackets. Although the helical screw system has been around for many years, it has only been used recently for underpinning of structures. Equipment required to install helical screws can often reach areas inaccessible to pier drilling equipment.

A new problem with lateral movement of foundations has been created by the recent trend towards 9 and 10-foot high basement walls. To increase basement heights, many builders are stacking plates on top of the foundation wall. The restraint provided by the floor system in these areas is significantly reduced. In most instances, the foundations have been designed with some restraint provided at the main floor level.

Remedial measures associated with repairing lateral displacement of foundations may involve steel angles and brackets or buttresses and counterforts. Steel angles can generally be utilized to provide additional lateral resistance if significant movement has not occurred. If significant lateral movement has occurred, the use of buttresses or counterforts may be required. To realign a foundation wall which has experienced lateral movement, generally excavation along the entire wall is required.

On numerous occasions, movements within structures can be minimized when irrigation practices are corrected and surface drainage around a structure is improved to prevent ponding of water adjacent to foundations. A fairly common statement from engineers when dealing with structures on expansive soils is that the surface drainage and landscape around the structure should be corrected to adhere to original recommendations. The fact remains that the increased moisture content of expansive clay soil will cause expansion of the soil.

Summary

In general, the engineering approach for sites with expansive soils has not changed significantly over the years. Engineering practice in the Colorado Springs/Pueblo area with respect to expansive soils has progressed due to past problems with structures on expansive soils. Changes in policies by Regional Building Department that require individual foundation designs for each structure in El Paso County is also believed to have an impact on building performance and failure rates. Soil testing is also performed on a higher percentage of lots and building sites than in the past, allowing for a better determination of expansive soil characteristics for each structure. The design of foundations has also progressed over the past few years with improvements in reinforcing, lateral bracing and field inspection.

In all cases, when expansive soils are encountered, the best approach to minimizing problems is to properly construct a foundation in accordance with the design recommendations, correctly install the perimeter drain, have positive surface drainage away from the structure and minimize irrigation immediately adjacent to foundation walls. The guidelines discussed in this report with respect to swell potentials and foundation recommendations are intended as general guidelines and should not be interpreted as rules for engineering design. Recommendations for specific structures should be provided by a registered professional engineer who practices geotechnical engineering and is familiar with the conditions of the area.

HEAVING BEDROCK: NEW JEFFERSON COUNTY REGULATIONS AND CONSIDERATIONS FOR SIMILAR GEOLOGICAL SETTINGS

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INTRODUCTION

Heaving bedrock is a potentially destructive geological hazard in Colorado. It is responsible for tens of millions of dollars in damage to structures, roads, and utilities along Colorado's Front Range piedmont. The term refers to highly localized, linear to curvilinear ground deformations that result from the differential movement (heaving) of near-surface, expansive bedrock deposits. Heaving bedrock may be distinguished from expansive soils by one or more of the following characteristics:

1. The localized, and sometimes highly abrupt character of individual heave features;
2. Upturned, or steeply dipping bedding (in many cases);
3. Heterogeneous composition of adjacent rock layers or zones;
4. Heterogeneous subsurface moisture distribution along fractures (conduits) and bentonite beds (aquitards); and
5. A pronounced lateral component of heaving.

The heave features begin forming shortly after site construction, and may grow to more than two feet high and to several hundreds of feet long.

HEAVE MORPHOLOGY AND MECHANICS

Distinct, symmetrical to highly asymmetrical morphologies are recognized in surface-deformation features caused by heaving bedrock. Symmetrical heave features typically form where a discrete bed (such as a bentonite seam) is bounded by beds having lower swell potentials (Fig. 1A). The potential height of the feature in this case depends on the swell potential contrast between beds. Highly asymmetrical heave features typically form as a result of shear-slip movement between adjacent blocks of expansive bedrock (Fig. 1B). The shear surfaces may be located along bedding planes, within discrete bentonite seams, or along low- to high-angle, thrust-type "faults" that cut across bedding. All of the heave features mentioned above may occur in areas where the bedrock is inclined greater than 30 degrees from horizontal (i.e., areas of steeply dipping bedrock). However, asymmetrical heave features associated with "fault" deformation may occur regardless of the bedding dip. Significant "fault"-type heave features were documented in South Dakota in nearly flat-lying Pierre Shale (see Nichols, 1992).

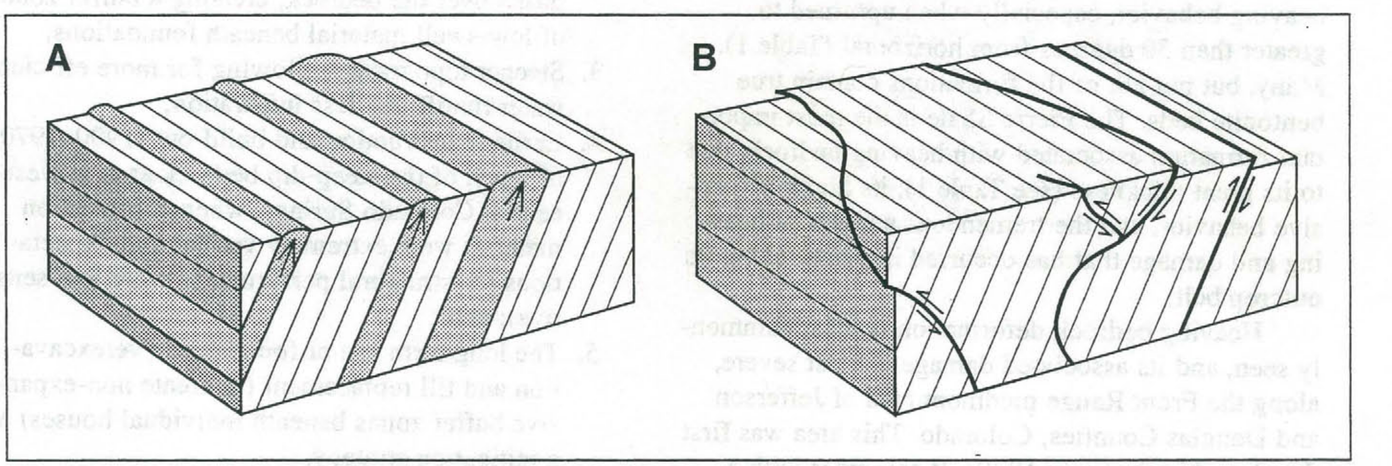

Figure 1. Block diagrams of heave features from steeply dipping bedrock (from Noe and Dodson, 1995): (A) near-symmetrical heave caused by differential expansion between highly expansive clay layers (e.g., bentonite) and adjacent, less-expansive layers; (B) highly asymmetrical heave caused by shear-slip between bedding planes and/or fault-like surfaces.

The mechanics of heaving bedrock are poorly understood, but are undoubtedly more complex than those assumed for expansive soils (see Noe and Dodson, 1995). One likely mechanism is hydration and expansion of bedrock layers having dissimilar swell potentials, in response to an increase in subsurface moisture. Discrete bentonite layers are capable of causing significant deformation and damage in this manner (e.g., Gill et al, in prep.). Infiltrating water can penetrate and circulate through fractures and permeable rock layers. Thompson (1992) demonstrated that post-construction moisture penetration (and, by inference, the depth of potential clay hydration and heaving) occurs to depths of 25 feet or more in areas underlain by expansive, steeply dipping bedrock. In some cases, lateral moisture flow may be interrupted by a bedrock layer (most notably bentonites) and/or a shear surface. Such damming effects may result in differential accumulation of moisture and a greater magnitude of heaving on one side of the layer/surface. Another potential heaving bedrock mechanism is the elastic rebound of overconsolidated shale (shale that was over-loaded in past geologic time, as compared with present loading; see Nichols, 1992). Rebound, in the form of differential shear-slip type movements, may occur in response to excavation and unloading in cut areas.

DISTRIBUTION OF HEAVING BEDROCK

At least nine sedimentary formations along the central and southern Front Range piedmont area contain expansive claystone and may exhibit differential heaving behavior, especially when upturned to greater than 30 degrees from horizontal (Table 1). Many, but not all, of the formations contain true bentonite beds. The Pierre Shale is the most important formation associated with heaving bedrock, due to its great thickness (see Table 1), its highly expansive behavior, and the tremendous amount of heaving and damage that has occurred in places along its outcrop belt.

Heaving bedrock deformation is most commonly seen, and its associated damage is most severe, along the Front Range piedmont area of Jefferson and Douglas Counties, Colorado. This area was first developed in the early 1970s. It coincides with a .25-to-2 mile wide belt of faulted and steeply dipping bedrock between Golden and Roxborough Park (Fig. 2A) where outcrops of the Fox Hills Sandstone, Laramie Formation, Pierre Shale, and older sedimentary rocks are markedly narrow. North of Golden, the Pierre and Fox Hills/Laramie outcrops widen in response to a general flattening of bedrock dip angles. Accordingly, the intensity of heaving bedrock damage in Boulder is much diminished, and is relegated to the western-most parts of town where the bedrock dip is steep. Heaving bedrock deformation is recognized in areas underlain by the Arapahoe/Denver/Dawson formations where they are upturned along the margin of the Golden-to-Roxborough Park outcrop belt, but is largely absent in parts of the Denver metropolitan area where these formations are flat-lying.

The Colorado Springs area in El Paso County appears to be relatively unaffected by heaving bedrock, even though a large part of the city is underlain by the Pierre Shale (Fig. 2B). Most of Colorado Springs is underlain by flat or low-dip bedrock except for its extreme western edge, much like Boulder. Heaving bedrock damage is relegated to the zone of steeply dipping bedrock (with the notable exception of two asymmetrical, shear-plane featuress in flat-lying Pierre Shale at a memorial park in southeast Colorado Springs; J. Himmelreich, personal communication). The number of heave features and severity of deformation and damage is notably diminished in Colorado Springs as compared to the southwest Denver metropolitan area. There may be several reasons for this, including:

1. The presence of more sandy and silty zones in the Pierre Shale, reducing the overall swell potential of those zones;
2. The presence of thick, extensive surficial deposits over the bedrock, creating a buffer zone of low-swell material beneath foundations;
3. Steeper topography, allowing for more efficient water runoff and less infiltration;
4. Earlier construction and build-out (1900–1970) of much of the steep-dip bedrock area in west-central Colorado Springs, when construction methods were extremely varied (and expectations for structural performance were less sensitive); and
5. The long-term use of foundation overexcavation and fill replacement (to create non-expansive buffer zones beneath individual houses) as a mitigation strategy.

Other areas along the southern Front Range piedmont have outcrops of steeply dipping, expansive bedrock that may be prone to differential heave,

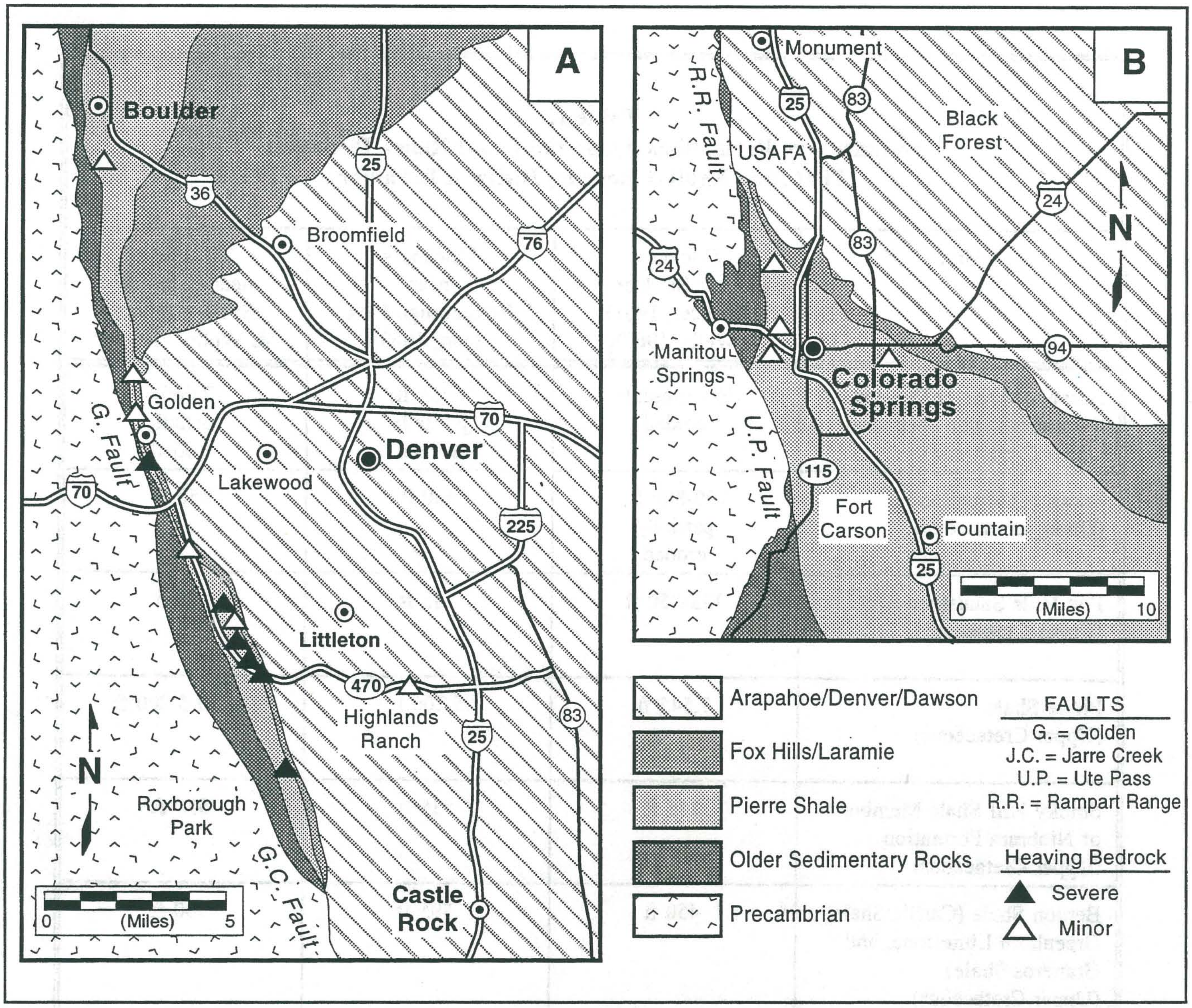

Figure 2. General geologic maps of (A) Denver metropolitan area and (B) Colorado Springs, showing bedrock geology and locations where heaving bedrock deformation is recognized (modified from Tweto, 1979; Noe and Dodson, 1995).

most notably the Perry Park (Douglas County) and Canon City (Fremont County) areas. The Pueblo area (Pueblo County) is underlain by low-dip outcrops of the Pierre Shale and Niobrara Formation and is expected to be relatively free of differentially heaving bedrock, although occasional and isolated shear-plane type heave features are possible.

JEFFERSON COUNTY REGULATIONS

In April, 1995, Jefferson County enacted new zoning and land use regulations that deal specifically with the heaving bedrock hazard. These regulations were written by a task force comprised of engineering geologists, geotechnical/civil/structural engineers, builders, developers, warranty insurers, realtors, and county officials. The task force addressed engineering issues and developed criteria for geological and geotechnical investigations, foundation, roadway, and utility designs, remediation of existing problems, and delineation of an "overlay" area called the Designated Dipping Bedrock Area (DDBA). The regulations recognize that some areas of the DDBA may be underlain by thick surficial deposits or non-expansive bedrock, and that no special investigations or building techniques are required in those areas. However, detailed initial

Table 1.
Sedimentary Formations Along the Front Range Piedmont That May Exhibit Heaving Bedrock Behavior

Unit	Thickness near Boulder (Spencer, 1961)$_1$ (Wells, 1967)$_2$	Thickness near Roxborough Park (Scott, 1963)$_3$	Thickness near Colorado Springs (Scott & Wobus, 1973)$_4$
Arapahoe/Denver/Dawson Formations (Paleocene and Upper Cretaceous)	Not present; eroded	1,450 ft; partially eroded	2,000; partially eroded
Laramie Formation (Upper Cretaceous)	700-800 ft; partially eroded	660 ft	250 ft
Fox Hills Sandstone (Upper Cretaceous)	133-250 ft	185 ft	250 ft
Pierre Shale (Upper Cretaceous)	7,545 ft	5,200 ft	3,750-5,200 ft
Smoky Hill Shale Member of Niobrara Formation (Upper Cretaceous)	215 ft	535 ft	530 ft
Benton Shale (Carlile Shale, Greenhorn Limestone, and Graneros Shale) (Upper Cretaceous)	450 ft	595 ft	300 ft
Morrison Formation (Upper Jurassic)	325-345 ft	320-380 ft	225 ft
Ralston Creek Formation (Upper Jurassic)	34 ft	48-100 ft	20 ft
Lykins Formation (Triassic? and Permian)	550 ft	387 ft	180 ft
Glen Eyrie Shale Member of Fountain Formation (Pennsylvanian)	Not Recognized	Not Recognized	100 ft

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1. Bedrock geology of the Louisville quadrangle, Colorado: USGS Map GQ-151.
2. Geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: USGS Bulletin 1121-D.
3. Bedrock geology of the Kassler quadrangle, Colorado: USGS Professional Paper 421-B.
4. Reconnaissance geologic map of Colorado Springs and vicinity, Colorado: USGS Map MF-482.

investigations are required where expansive, steeply dipping bedrock is encountered at shallow depths. Such investigations involve bedrock trenching in addition to conventional borehole surveys. Foundation overexcavation and fill replacement is named as the preferred building technology for areas where the potential for differential bedrock heaving is found to be significant.

Douglas County is expected to follow Jefferson County in adopting regulations that require more extensive investigations and problem-specific building techniques in areas of potentially heaving bedrock. The adoption of specific regulations for heaving bedrock may not be necessary in other areas such as Boulder, Colorado Springs, and Canon City. Geological conditions may be such that the extent and severity of potentially heaving bedrock is diminished in those areas. Nevertheless, workers in any area along the Front Range piedmont should be aware of geological conditions that are conducive for heaving bedrock, and should design their projects accordingly.

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LANDSLIDES: CLASSIFICATION, PRINCIPLES, AND RECOGNITION

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The Landslide Hazard

Landsliding is a natural geologic process that occurs and recurs in common sets of geologic settings and natural conditions. In the United States, landslides typically cause between $1 and $2 billion in economic losses and 25 to 50 deaths each year (NRC, 1985). Landsliding is widely distributed and occurs in many different physiographic and climatic regions. In much of the US, it is a dominant process of landscape alteration. Landslides may occur as isolated phenomena or in conjunction with heavy rains, earthquakes or volcanic eruptions. According to the NRC report approximately 1/3 of the annual landslide loss is associated with major catastrophic events. Landslides are also common along river banks and underwater. The process may occur on slopes ranging from extremely gentle to steep.

The number of damaging landslides has increased in the past two decades. The increase appears to be due to continuing expansion of the population into the vicinity of difficult terrain (steeply sloping terrain and/or low strength soils and bedrock). The expansion includes residential and commercial buildings, infrastructure corridors, and development of irrigated landscape, all of which alter the hillslope configuration and upset the equilibrium conditions. This may compound the natural instability of many slopes and may reactivate older landslides.

Much of the Rocky Mountain region is characterized by unstable slopes. Population growth and increasing use of large areas for recreation in the region most likely will increase landslide-related losses in the near future. In Colorado landslides occupy about 8 percent of the area of the state. Annual landslide damage to buildings is estimated to exceed $3 million and damage to transportation corridors is estimated at several times that amount (NRC, 1985).

This presentation will focus upon the geologic and geotechnical aspects of recognition of landslide prone areas and identification of factors that contribute to slope instability. Recognition of a potential landslide problem is the first step in avoiding damage.

Landslide Hazard Reduction

Landslide losses can be reduced in two ways. First, the occurrence of landslides can be reduced by requiring that excavation, grading, landscaping, and construction be carried out in ways that do not contribute to slope instability. Second, damage can be minimized when landslides do occur by either restricting development in landslide-prone terrain and/or by protecting structures from landslide damage by damage resistant design or construction of diversion barriers. To accomplish either of these loss-reduction methods, first the potential hazard must be recognized.

Classification and Recognition of Landslides

A landslide is the perceptible movement of earth materials (rock, debris, or earth) down a slope (Table 1). The materials may move as falls, topples, slides, flows or spreads. Complex slides may occur that include a combination of these types of movements (Figure 1). A landslide may vary considerably in rate of movement (Table 2) and in water content (Table 3). A classification of landslides that is useful in engineering practice was developed by Varnes (1978) and recently modified by Cruden and Varnes (1996), which is shown in Table 4. The classification is based primarily on the type of movement (or combinations of movement and type of material. The landslide name can be modified depending on velocity, moisture content, and other factors (Table 5).

Causes of Landslides

The processes involved in landsliding comprise a continuous series of events from cause to effect. A landslide most likely can't be attributed to a single cause, but rather a number of causes exist simultaneously. All landslides involve the failure of earth materials; therefore, the initiation of the landslide process can be examined according to the factors that contribute to increased shear stress, to low or reduced shear strength, or a combination of the two (Varnes, 1978). Table 6 is a list of factors that may cause landslides. Any engineering project should consider how these potential causes may affect shear stress and shear strength of the slope forming materials.

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Table 1. Definition of Landslide Materials (Cruden and Varnes, 1996).

Term	Definition
Rock	A hard or firm mass that was intact and in its natural place before the initiation of movement.
Soil	An aggregate of solid particles, generally of minerals and rocks, that has either been transported or formed by the weathering of rock in place. Gases or liquids filling the pores of the soil form part of the soil.
Debris	Contains a significant proportion of coarse material; 20 to 80 percent of the particles are larger than 2 mm, the remainder are less than 2 mm.
Earth	Material in which 80 percent or more of the particles are smaller than 2 mm.

Table 2. Landslide Velocity Classes (Cruden and Varnes, 1996)

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity
7	Extremely Rapid		
		5×10^{3}	5 m/sec
6	Very Rapid		
		5×10^{1}	3 m/min
5	Rapid		
		5×10^{-1}	1.8 m/hr
4	Moderate		
		5×10^{-3}	13 m/month
3	Slow		
		5×10^{-5}	1.6 m/year
2	Very Slow		
		5×10^{-7}	16 mm/year
1	Extremely Slow		

Table 3. Water Content of Landslides (Cruden and Varnes, 1996)

Term	Definition
Dry	No moisture visible.
Moist	Contains some water but no free water. The material may behave as a plastic solid but does not flow.
Wet	Contains enough water to behave in part as a liquid, has water flowing from it, or supports significant bodies of standing water.
Very Wet	Contains enough water to flow as a liquid under low gradients.

Table 4. Classification of Slope Movements (Cruden and Varnes, 1996)

TYPE OF MOVEMENT	TYPE OF MATERIAL		
	BEDROCK	ENGINEERING SOILS	
		Predominantly Coarse	Predominantly Fine
FALLS	Rock Fall	Debris Fall	Earth Fall
TOPPLES	Rock Topple	Debris Topple	Earth Topple
SLIDES	Rock Slide	Debris Slide	Earth Slide
SPREADS	Rock Spread	Debris Spread	Earth Spread
FLOWS	Rock Flow	Debris Flow	Earth Flow

Table 5. A Glossary for Forming Names of Landslides (Cruden and Varnes, 1996)

The second movement table can be used to describe subsequent movements in complex landslides and lower movements in composite landslides.

Activity:

State of Activity	Distribution of Activity	Style of Activity
Active Reactivated Suspended Inactive : Dormant : Abandoned : Stabilized : Relict	Advancing Retrogressive Enlarging Widening Moving Confined Diminishing	Complex Composite Multiple Successive Single

Description of First Movement:

Rate of Movement	Water Content	Material	Type
Extremely rapid Very rapid Rapid Moderate Slow Very slow Extremely slow	Dry Moist Wet Very Wet	Rock Soil : Earth : Debris	Fall Topple Slide Spread Flow

Description of Second Movement:

Rate of Movement	Water Content	Material	Type
Extremely rapid Very rapid Rapid Moderate Slow Very slow Extremely slow	Dry Moist Wet Very Wet	Rock Soil : Earth : Debris	Fall Topple Slide Spread Flow

Subsequent movements may be described by repeating the above description of movement tabulation as many times as necessary.

Table 6. Landslide Causes (Cruden and Varnes, 1996)

1. Ground causes
   1) Weak materials
   2) Sensitive materials
   3) Weathered materials
   4) Sheared material
   5) Jointed or fissured material
   6) Adversely oriented mass discontinuity (bedding, schistosity etc.)
   7) Adversely oriented structural discontinuity (fault, unconformity, contact etc.)
   8) Contrast in permeability
   9) Contrast in stiffness (stiff, dense material over plastic materials)

2. Morphological causes
   1) Tectonic or volcanic uplift
   2) Glacial rebound
   3) Fluvial erosion of the slope toe
   4) Wave erosion of the slope toe
   5) Glacial erosion of the slope toe
   6) Erosion of the lateral margins
   7) Subterranean erosion (solution, piping)
   8) Deposition loading the slope or its crest
   9) Vegetation removal (by forest fire, drought)

3. Physical causes
   1) Intense rainfall
   2) Rapid snow melt
   3) Prolonged exceptional precipitation
   4) Rapid drawdown (of floods and tides)
   5) Earthquake
   6) Volcanic eruption
   7) Thawing
   8) Freeze and thaw weathering
   9) Shrink and swell weathering

4. Man made causes
   1) Excavation of the slope or its toe
   2) Loading of the slope or its crest
   3) Drawdown (of reservoirs)
   4) Deforestation
   5) Irrigation
   6) Mining
   7) Artificial vibration
   8) Water leakage from utilities

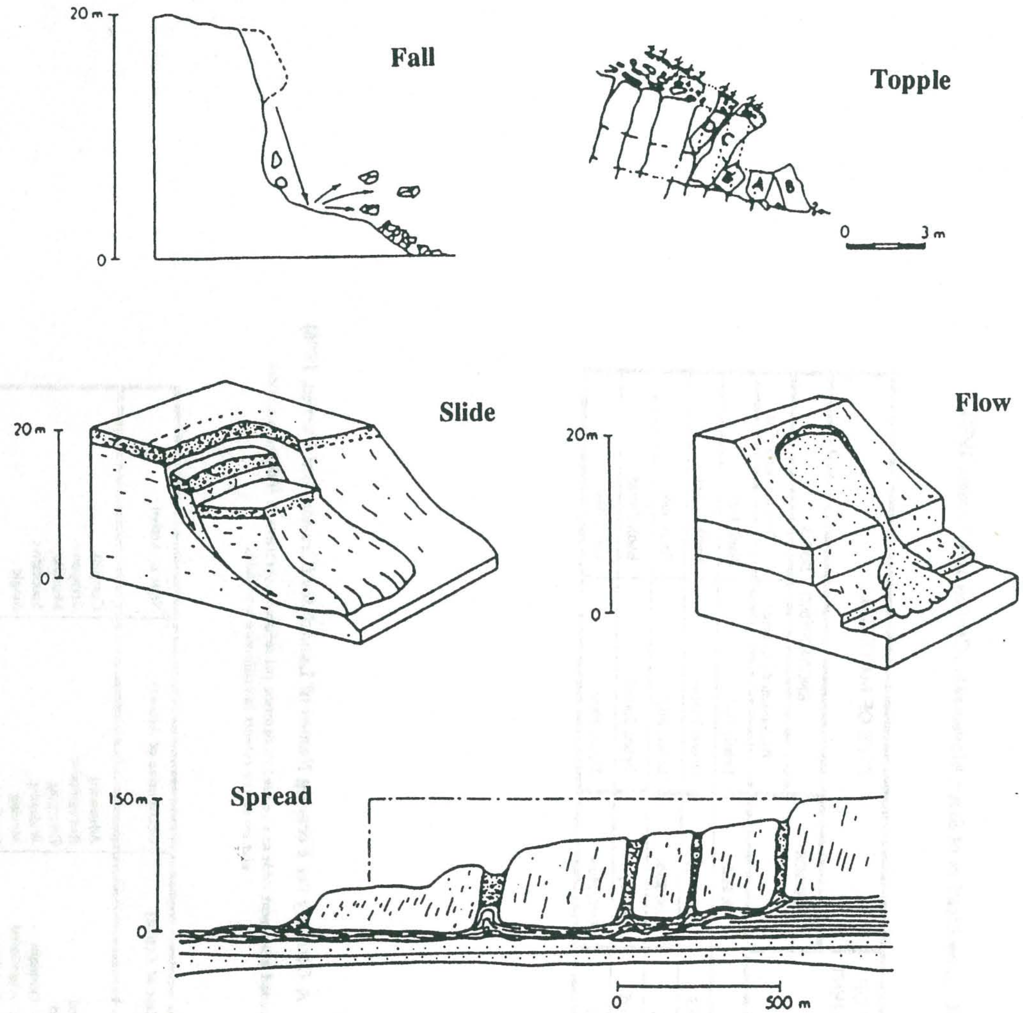

Figure 1. Types of landslides. Broken lines indicate the original ground surfaces, arrows show portions of the trajectories of individual particles of the displaced mass (Cruden and Varnes, 1996).

LANDSLIDES: ANALYSIS AND MITIGATION

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Introduction

Landslide engineering is a geotechnical discipline that deals with slope stabilization or stability improvements of landslides. Landslide engineering techniques typically employ analytical methods to evaluate whether a landslide can be stabilized and determine the cost of mitigation.

Landslide engineering has made significant progress during the last decades. The progress is important in the computerized analytical methods that enable fast and reliable analyses for a variety of the slip planes and for a variety of stabilizing methods. Significant progress has also been made in development of slope retaining structures that are relatively inexpensive and have been used in stabilizing large landslides only recently.

Methods of landslide engineering might be worthless if they are applied without the knowledge of the landslide type, mechanism, and current stability conditions. Any landslide analysis and stabilization design should be preceded by appropriate engineering geological studies, geotechnical mapping, drilling, field instrumentation and testing.

Addressing the condition of landslides is very important in states such as Colorado, where, in the mountainous parts of the state, landslides cover significant areas that are being developed or considered for future development.

Landslide Analyses

Computerized methods of slope stability analysis are abundant and they enable a geotechnical professional to precisely model the geologic conditions, various landslide slip planes, and the groundwater conditions. Each of these conditions have a far-reaching effect on the accuracy of the analyses. Without a correct input, the analyses may be meaningless.

Figure 1 illustrates a case history of a landslide in Northern California where a landslide developed, probably as a result of construction of a road fill, on a steep and marginally unstable slope underlain by weathered and altered rocks of the Franciscan formation. To obtain data on the landslide slip plane and the groundwater conditions, four sets of inclinometers and piezometers were installed in one section, the section considered most critical for the stability.

Accurate estimation of the landslide slip plane and of the piezometric levels provides a basis for the analyses. Shear strength along the landslide slip plane was estimated from a condition that the landslide had a factor of safety equal to unity at the time of the failure. Using the PC-STABLE and XSTABLE methods, a series of potential stabilizing measures has been analyzed. The mitigating measures included the following techniques:

- Removal of the road fill and shifting the road further into the slope
- Replacing the conventional road fill with a light-weight fill
- Dewatering
- Retaining the landslide by means of a tieback structure consisting of vertical soldier piles anchored into the rock below the landslide slip plane

These techniques are considered to be applicable, with minor variations, for the analyses of most landslides encountered in a variety of geologic conditions.

Landslide Mitigation Methods

Mitigation methods most commonly used in landslide engineering can be divided into following groups:

- Living with a landslide
- Landslide regrading
- Landslide dewatering
- Landslide stabilization with a structure

Living with a Landslide

An important number of landslides in Colorado and in the other parts of the United States are of such dimensions that their stabilization is technically and economically not feasible. The costs of the stabilization increase considerably with the size of the landslide and with its volume. Landslides with a volume exceeding

1,000,000 cubic yards are very rarely stabilized or the stabilization is limited to slight increases in stability, such as the improvements of the surface water drainage. Living with such features is often the only option if any development has to be undertaken on the surface of such large landslide.

There are tens of large landslides in state of Colorado that are too large to be stabilized and across which numerous highways, pipelines, dams or other structures had to be constructed. Since large landslides usually provide a very favorable topography for ski areas, at least three large Colorado ski areas have been developed on the surface of very large landslides (Vail, Buttermilk and Snowmass ski areas near Aspen).

Interstate I-70 traverses a number of similar landslides near Vail. US Hwy 139, between Loma and Rangely in Colorado's western slope, traverses a number of large landslides that have repeatedly caused the loss of the highway. US Hwy 133 near Paonia has been seriously influenced by the Muddy Creek landslide--one of the largest landslides in the United States.

Stabilization of significant landslides is not economically feasible and the owners or operators of any facilities within such topographical features are only able to maintain them to their best ability. Many significantly sized landslides are ancient, have been stable for hundreds of years, and do not endanger the construction on or across them. Many of landslide areas, however, have been experiencing deformations for years and they often have a significant impact on any man-made facilities or structures. The activity of such landslides usually depends on the climatic conditions, precipitation, snow cover, and the rate of snowmelt.

Figure 2 illustrates a railroad (originally Denver & Rio Grande Railroad) and a natural gas pipeline located in the Eagle River Valley, between Minturn and Leadville. Both facilities are routed in the same ancient landslide that has been experiencing minor deformations through the present time. The railroad owner has had to occasionally rectify the alignment and elevation of the tracks; the natural gas pipeline is subject to deformations which can cause pipeline rupture. Public Service Company, the owner of the pipeline, has been using a monitoring system to determine the pipeline strains and stresses caused by the landslide deformations and periodically releases the accumulated stresses using temporary excavation methods. A similar system has been successfully used for decades at tens of other landslides across the state of Colorado.

Landslide Regrading

Landslide regrading is one of the oldest and relatively inexpensive methods of stabilization. It relies on the unloading of the landslide's upper section (reducing the landslide driving forces), or on loading the landslide's lower section (increasing the landslide resisting forces) to increase the stability. A buttress at the landslide's toe is a typical, often-used method of stabilization. To achieve a satisfactory increase in the factor of safety, the volume of the soil or rock mass has to be quite significant (as a rule of thumb, about one third of the landslide volume). This is often not feasible and many buttresses have failed because they were simply too small.

Landslide Dewatering

Stabilization of landslides by dewatering is by far the most popular and most frequently used mitigation method. Lowering groundwater levels within the landslide mass may result in a decrease of the driving forces and/or an increase of the resisting forces to achieve a corresponding increase in safety factors. If the groundwater levels can be lowered below the landslide slip plane, the strength of the landslide slip plane material can be increased but this is not always a necessary condition for a successful stabilization.

Stability analyses commonly demonstrate that the increase of factors of safety may be significant even if the groundwater levels have been decreased only by a small amount. Efficient dewatering may also prevent sudden increases of groundwater levels during seasonal periods, significant precipitation events, or a fast snowmelt.

Methods of dewatering vary widely between simple modifications of the surface runoff to complex systems of subsurface dewatering using the drainage tunnels or a combination of vertical shafts and blanket drains between them.

French drains, are basically trenches excavated from the surface and filled with pervious material. French drains are the oldest commonly used dewatering method, and were often used during railroad construction in the last century to mitigate unstable railroad cuts. French drains have been frequently until the present. French drain applications are limited by the depth of the trenches and by the potential stability problems of the trench walls. The only improvement in their construction , compared to the original drains, is the addition of a geotextile filter around the drain, and, often, the addition of a perforated plastic pipe at the drain bottom, as an additional drainage improvement. If the drains can be excavated deep enough below the landslide slip plane, they can further increase the stability as they may function as a "shear key."

Horizontal drains are the most widely used method of dewatering. The main reason for their popularity is the relatively inexpensive per foot cost and the ease of the application. They are functional in decreasing the groundwater levels when the soil or rock is reasonably permeable; they are less effective in low permeability materials such as the clay or clay soils.

Figure 3 shows an exceptionally functional dewatering of a landslide that developed in the sedimentary Minturn formation west of Vail Pass, during the construction of the I-70 in early 1970s. The dewatering scheme appears to be a successful stabilization method.

Landslide Stabilization with a Structure

Stabilizing a landslide with a structure is a method which is usually more expensive than the methods discussed earlier in this abstract. For this reason, it was used in the past only to mitigate landslides of a limited extent and volume.

Methods of Slope Retention and Use of Structures. During the last several decades, numerous innovate slope retaining structures have been developed. The cost of them is often much lower than the cost of traditional slope retaining structures such as *gravitational retaining walls.* Such structures include reinforced earth, soil nailing, micropiles, tieback structures, and other methods.

Methods of slope retention that *enable installation from the top of the structure down* most likely comprise some of the most important progress in slope stability engineering. They enable the installation of retaining forces without significant undercutting of the unstable slope. Undercutting is typically necessary for the installation of a retaining structure, such as the gravity wall or a reinforced earth structure.

Soil nailing or installations using slope retaining anchors or bolts are a typical example of the structures that can be installed from the top down. The excavation needed to install soil nails or anchors can be limited to only several feet.

Figure 4 illustrates the recent (1995) stabilization of a large landslide on Colorado State Highway 93 near Golden, Colorado using high-capacity tendons. This project, performed by the Colorado Department of Transportation (CDOT), is a noteworthy example of landslide stabilization methods and structures because of the size of the landslide stabilized and because of the advanced monitoring system used with the remote transfer of data. The high-capacity tendons were installed in the centers of large precast concrete panels. Dewatering was also used in this slope stability project.

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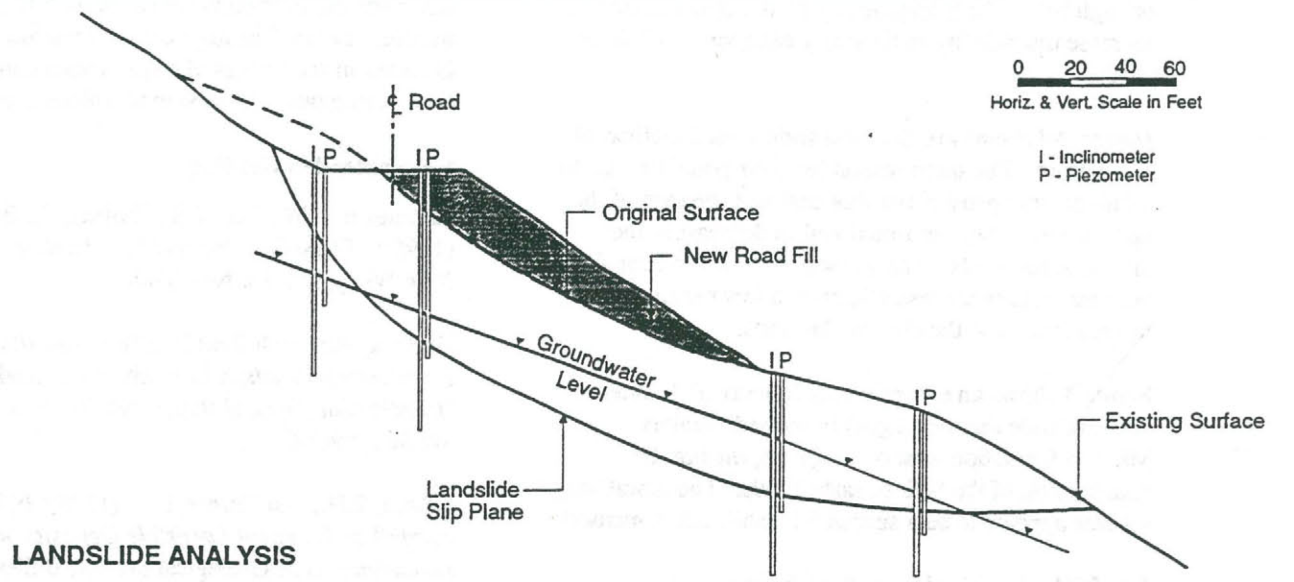
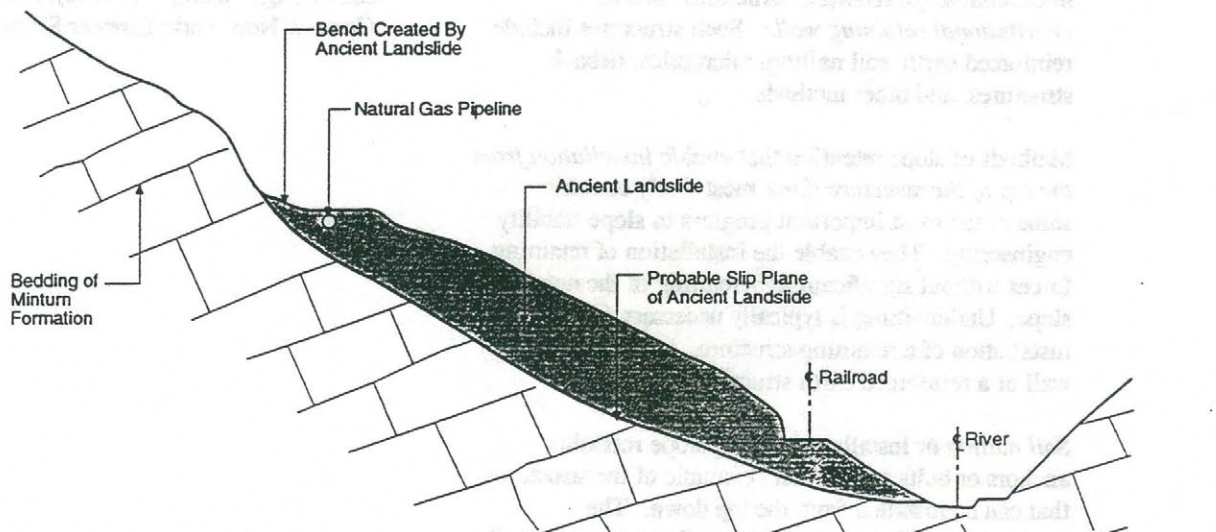


LANDSLIDE ANALYSIS

1. Investigate the Slip Plane Depth by Inclinometers
2. Install Piezometers to Investigate Groundwater
3. Test Shear Strength
4. Verify Shear Strength by Backanalysis Assuming F.S. = 1.0
5. Analyze Increase of F.S. for Various Stabilization Methods

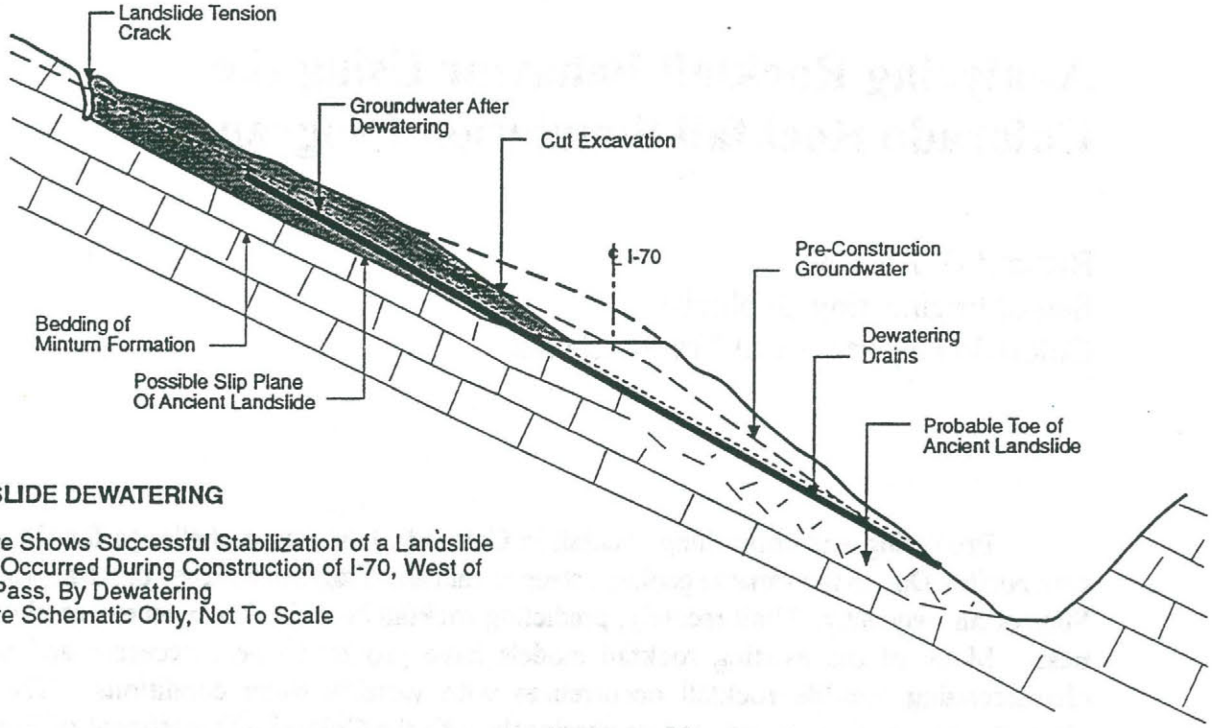
Figure 1
Landslide Analysis



LANDSLIDE TO LIVE WITH

1. Figure Shows the Construction of a Railroad and of a Natural Gas Pipeline in a Very Large, Ancient Landslide in the Eagle Valley, Close to Camp Hale
2. Figure Schematic Only, Not to Scale, Vertical Drop Between the Pipeline and the Railroad is Several Hundred Feet
3. The Landslide is Marginally Stable. It Would Deform During Periods of Unfavorable Climatic Conditions

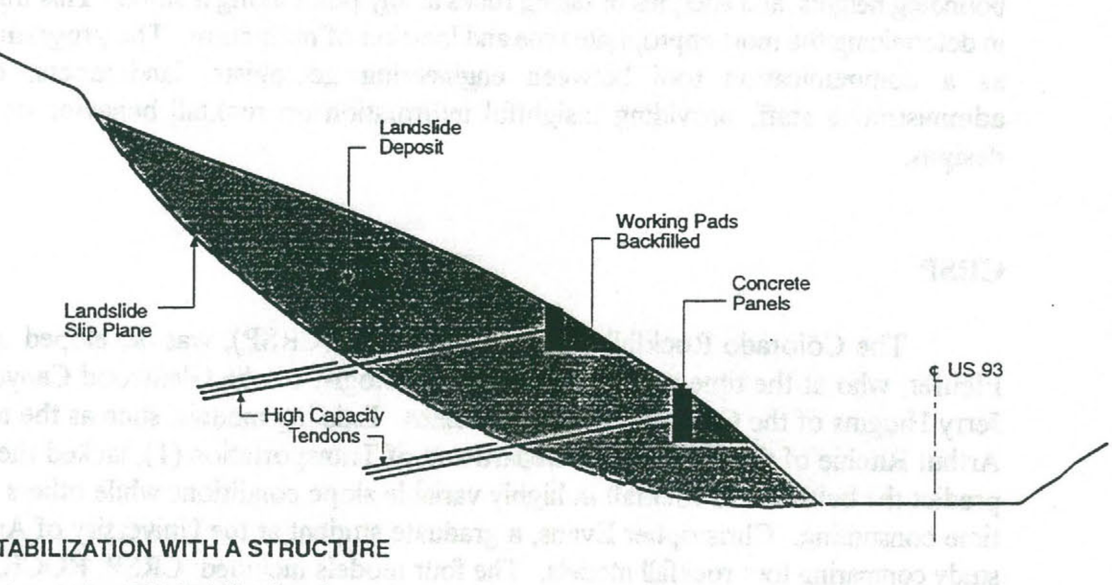
Figure 2
Landslide To Live With



LANDSLIDE DEWATERING

1. Figure Shows Successful Stabilization of a Landslide That Occurred During Construction of I-70, West of Vail Pass, By Dewatering
2. Figure Schematic Only, Not To Scale

Figure 3
Landslide Dewatering



LANDSLIDE STABILIZATION WITH A STRUCTURE

1. Figure is a Scheme of a 1995 Stabilization of a Landslide at US 93 in Golden, Colorado
2. Landslide Stabilization Has Been Achieved By Installing Two Tiers of High Capacity Tendons
3. Tendons Have Been Installed in Centers of Square Concrete Panels
4. Working Pads For Tendon Installation Have Been Backfilled So That the Structure is Totally Hidden
5. Figure Not To Scale

Figure 4
Landslide Stabilization With a Structure

Analyzing Rockfall Behavior Using the Colorado Rockfall Simulation Program

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Predicting and controlling rockfall in Colorado has been a challenge for the geotechnical community. Due to the variable geology, steep terrain and irregular weather patterns, rockfalls in the State occur frequently. Until recently, predicting rockfall behavior has been extremely subjective at best. Many of the existing rockfall models have proven to be inaccurate and unrealistic in characterizing real-life rockfall occurrences with variable slope conditions. The inability to characterize a rock in motion led professionals with the Colorado Department of Transportation, Colorado School of Mines and the Colorado Geological Survey to develop the Colorado Rockfall Simulation Program. Since its first release, the program has been used to analyze a number of hazardous rockfall areas throughout the State and across the country.

The program models varying slope conditions and provides information on the velocities, bounding heights, and energies of falling rocks at any point along a slope. This information is critical in determining the most appropriate type and location of mitigation. The program has also been vital as a communication tool between engineering geologists, landscapers, designers and the administrative staff, providing insightful information on rockfall behavior on proposed grading designs.

CRSP

The Colorado Rockfall Simulation Program (CRSP), was developed in 1987 by Timothy Pfeiffer, who at the time was an engineering geologist on the Glenwood Canyon Project, and Dr. Jerry Higgins of the Colorado School of Mines. Existing models, such as the model developed by Arthur Ritchie of the Washington Department of Transportation (1), lacked the ability to correctly predict the behavior of rockfall in highly variable slope conditions while others were awkward and time consuming. Christopher Evans, a graduate student at the University of Arizona, conducted a study comparing four rockfall models. The four models included: CRSP, ROCKSIM (developed by the North Carolina Department of Transportation), Evert Hoek's Rockfall Program (from Golder Associates), and Arthur Ritchie's ditch design criteria. Evans compared the results from eight different slopes for a total of 260 rockfall events. He concluded that CRSP was the most consistent in predicting rockfall behavior and recommended its use in designing rockfall catch benches in surface mining (2).

INPUT PARAMETERS

CRSP was designed to provide bounding heights and velocities of a rock in motion and the amount of kinetic energy the rock possesses at any given location along the slope. This information is necessary in designing the most effective and economical mitigation system.

The model is achieved by converting the physical characteristics of the slope and the properties of the predicted rockfall into a numerical data file. The interaction of these characteristics or factors, as they are referred to by Pfeiffer and Higgins, are varied with each rockfall event. This is done to depict the irregularities along the slope and accounts for the randomness of every event.

The most important aspect in predicting rockfall behavior is that of slope geometry. Ritchie documented that velocity is related to slope length and angle, while bounding height is related to slope irregularities (1). CRSP models slope geometry by converting slope survey data into a cartesian coordinate system, where a change in the slope angle is represented by a different line segment or cell (3,4).

Another slope geometry factor that greatly influences rockfall behavior is surface roughness. Surface roughness is defined as the maximum probable variation in the slope with respect to rock size (4,5). Variations in the slope can significantly alter the angle at which the rock impacts the surface. CRSP randomly alters this impact angle within the constraints set by the maximum slope variation and the size of the rock. Changes in surface roughness along the slope will also be represented by a discreet cell for each zone.

Other characteristics that affect rockfall behavior are vegetation, soil and rock composition and bedrock properties (3,4,5). The values for these characteristics are empirically derived and quantified as the normal coefficient of restitution and the tangential coefficient of frictional resistance. The normal coefficient of restitution represents the resistance perpendicular to the surface, while the tangential direction is parallel to the surface (1,3,4).

The final factors that influence rockfall behavior are the geometry and material properties of the rock in motion. These factors are determined through extensive observations made in the field. A range of rock sizes and types should be used to analyze the rockfall behavior on a slope. Normally the maximum rock size from an event will result in a fairly conservative form of mitigation. However, in some conditions, smaller rocks will tend to have higher bounding heights and may clear a barrier designed for something larger. The program will accurately model these different interactions, but it should be noted that the accuracy of the results is dependent on the quality of the input data.

DATA OUTPUT

CRSP uses the input data to produce a model which represents the slope and rock interaction. Equations of gravitational acceleration and conservation of energy are applied to the model to describe this interaction (3,4). Information regarding the behavior of the rock along the slope includes maximum and average bounce heights, maximum and average velocities, a graphical representation of the slope profile and the position of the simulated rock every tenth of a second along the slope (Figure 1). Total kinetic energy may also be obtained at any location along the slope.

CRSP provides objective information on rock behavior. Slopes that appear fairly consistent in terms of gradient variations, may in fact, have very distinct zones of acceleration and deceleration or variations in bounding heights. CRSP models these slope variations and accurately predicts their effect on rockfall behavior.

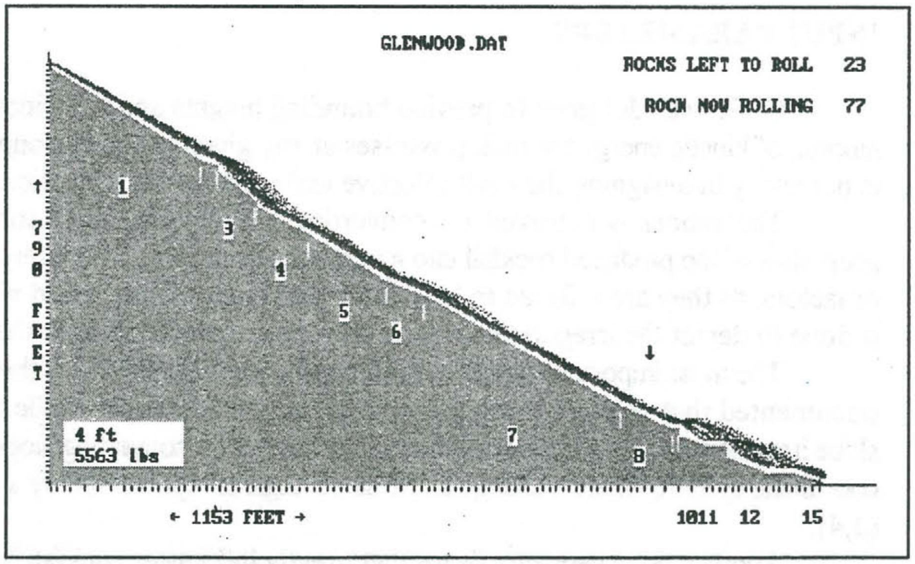

Figure 1. Typical CRSP Slope Profile.

APPLICATION

For years, geologists with the Colorado Department of Transportation and the Colorado Geological Survey have been monitoring rockfall events along the State's highways. A database was established which reflected the areas that received the highest incidence of rockfall. It was this data, in addition to extensive field review, that led geologists to prioritize the rockfall prone areas. CRSP is used to analyze these areas and to assist in determining the most suitable mitigation systems. As a result of this study, a formal program has been adopted by CDOT to mitigate the highest rated rockfall sites. The program has also been used in land use review to determine the effect of rockfall hazards on proposed areas of development.

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ROCKFALL MITIGATION

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INTRODUCTION

Rockfall is a geologic hazard that is catastrophic in nature. For the most part it is viewed as a nuisance by highway maintenance personnel who are required to clean the debris off the roadway and periodically clean out the fallen rocks within the roadside ditches. When rockfall occurs in populated areas or areas frequented by people, lethal accidents can occur.

In general, rockfall occurs where there is source of rock and a slope. Within the rock mass, discontinuities (bedding planes, joints, fractures, etc.) are locations where rock is prone to move, and ultimately, fail. Depending on the spatial orientation of these planes of weakness, failures occur when the driving forces, those forces that cause movement, exceed the resisting forces. The slope must have a gradient steep enough that rocks, once detached from bedrock, can move and accelerate down the slope by sliding, falling, rolling, and/or bouncing. Where the frequency of natural rockfall events are considered unacceptable for an area of proposed or current use, and avoidance is not an option, there are techniques of mitigation that are available to either reduce rockfall rates and prevent rocks from falling, or to protect structures or areas of use from the threat.

There have been important technological advancements in rockfall analysis and mitigation techniques in the last several years. They include rockfall simulation software, rock mechanics software, and research and development in new, innovative mitigation techniques. This paper emphasizes mitigation techniques.

There are many factors that influence a selection and design of a mitigation system to reduce or eliminate a rockfall hazard. They include:

1. The rock source (lithology, strength, structure, and weatherability) and expected resultant fallen rock geometry (size and shape);
2. Slope geometry (topography);
3. Slope material characteristics (slope surface roughness, softness, whether vegetated or barren);
4. Proximity of the structure requiring protection to source area and rockfall run-out zone;
5. Level of required rockfall protection (the acceptable degree of risk);
6. Cost of the various mitigation options (construction, project management, and design);
7. Constructability (mobilization difficulties, equipment access, and other constraints);
8. Future maintenance costs.

For any public or private land use proposal, in steep sloping areas, the geologic hazard investigation should initially recognize those physical factors listed above. If rockfall has been identified as a hazard then a detailed rockfall hazard analysis is warranted. The conclusion of such analyses, in addition to the determination of the factors above, must include:

1. An accurate determination of anticipated risk and frequency of rockfall at the location of the proposed land use, and;
2. Site specific calculations of the velocities, bounding heights, and impact forces for the range of anticipated rockfall events.

Once all physical characteristics and calculated falling rock dynamics are determined then the appropriate engineering and design can be completed for mitigation of the rockfall threat.

ROCKFALL MITIGATION TECHNIQUES

The available techniques in effective prevention and mitigation of rockfall, fall into two categories. One is stabilization of the rock mass at the source to prevent or reduce rockfall occurrences. The other is the acceptance that hazardous rockfall will occur, but with the placement of protective devices to shield structures, or public areas, from the threat of impact. There is a third category that, while not a form of mitigation, is a method that can diminish the catastrophic nature of rockfall. It is rockfall warning and instrumentation systems. Systems, electrical and mechanical, that either will indicate that a rockfall event is imminent, or has just occurred.

Stabilization and Reinforcement

Techniques that require in-situ or surficial treatments of the slope to induce additional stability to the exposed rock mass are termed rock and/or slope stabilization and reinforcement. Stabilization can be accomplished by any combination of the following: removing unstable rock features, reducing the driving forces that contribute to instability and ultimate failure, and/or increasing the resisting forces (friction or shear strength).

1. **Scaling (hand scaling, mechanical scaling, and trim blasting).** Scaling is the removal of loose and potentially unstable rock from a slope. On slopes of poor rock conditions scaling is generally viewed as a continual maintenance procedure because the loose rock removed exposes the rock underneath to further weathering.
2. **Reduce slope grade.** Laying a slope back can prevent rocks from falling from a source area.
3. **Dewater or drain rock slope to reduce water pore pressures.** The installation of drainage holes in rock can reduce the pore pressure in rock fractures—one of the driving forces mentioned above.
4. **Rock dowels.** Rock dowels are steel rods that are grouted in holes drilled in rock, generally across a joint or fracture in the rock of unfavorable orientation. It is a passive system in which loading or stressing of the dowel occurs only if the rock moves (slides) along the joint plane. (See Figure 1.)
5. **Rockbolts.** Rockbolts are installed much like dowels but are usually loaded or stressed, which imparts a compressive force on the rock. The loading of the steel rod during the installation increases the shear strength of the joint or fracture and prevents movement, reinforcing the exposed rock mass. There are wide varieties of rockbolts, including mechanical, grouted, and binary epoxy resin systems.
6. **Steel strapping.** Steel strapping, also called mine strapping, is a strip of steel that bridges between offset rockbolts or dowels to support the rock mass between them.
7. **Anchored wire mesh or cable nets.** Fence wire or, depending on loading criteria, cable nets are draped on a rock slope and anchored to the rock mass by the bearing plates of rock dowels or rock bolts. The anchor pattern is set so that the wire mesh or cable nets are in continuous contact with the rock face so that there is complete confinement of the loose rock material. (See Figure 2.)

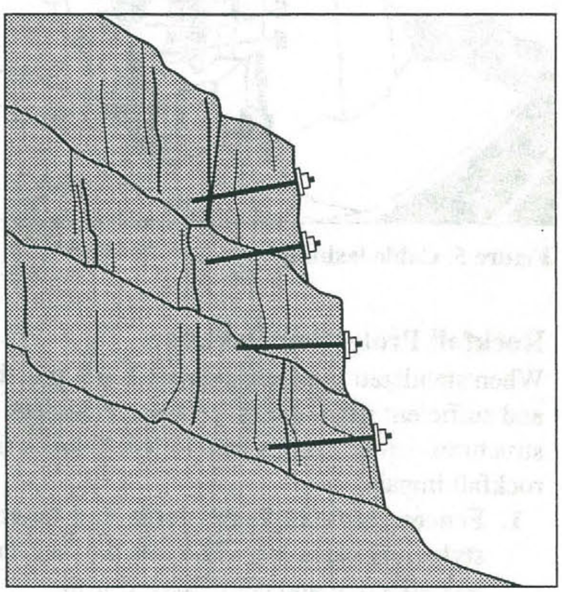

Figure 1. Rockbolts and dowels.

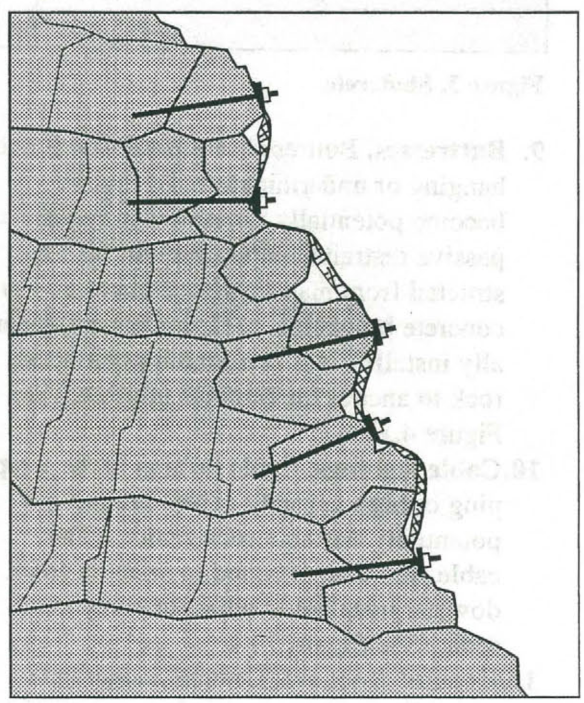

Figure 2. Anchored mesh or nets.

8. **Shotcrete.** Shotcrete is the sprayed application by compressed air of concrete on rock or rocky soil slopes for reinforcement and containment. Shotcrete applications can be strengthened by the addition of nylon or steel fibers to the concrete mixture, or the placement of a wire grid on the rock slope prior to application. Weep holes are usually drilled into the shotcrete to ensure that the contained material is free draining. (See Figure 3.)

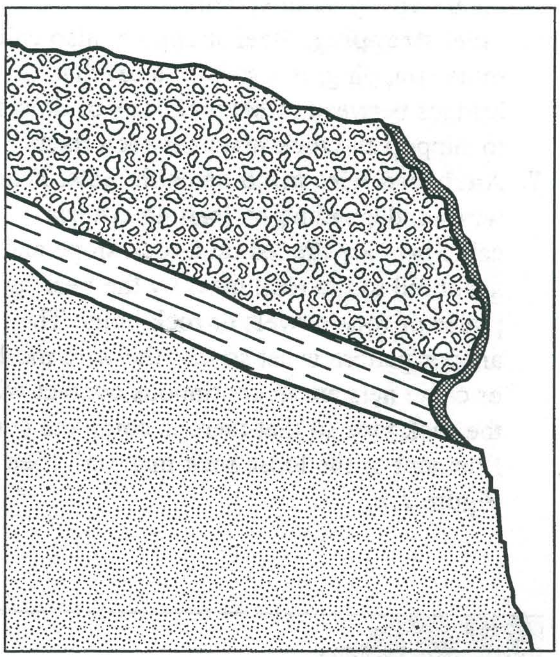

Figure 3. Shotcrete.

9. **Buttresses.** Buttresses are used where overhanging or undermined rock features become potentially unstable and require passive restraint. Buttresses can be constructed from many types of material. For concrete buttresses, rock dowels are generally installed into surrounding competent rock to anchor the buttress in place. (See Figure 4.)
10. **Cable lashings.** Cable lashing is the wrapping of high capacity cables around a potentially unstable rock feature. The cables are then attached to anchors (rock dowels) installed in adjacent competent rock. (See Figure 5.)
11. **Ground Anchors.** Ground anchors are generally used to prevent large, potential landslide-type failures in heavily weathered, fractured rock and rocky soils. Their installation requires the drilling of deep holes and the grouting of thick bundles of high-strength wire strand, which are attached to large load-bearing panels and then stressed (pulled) to a desired tensional load and locked off.

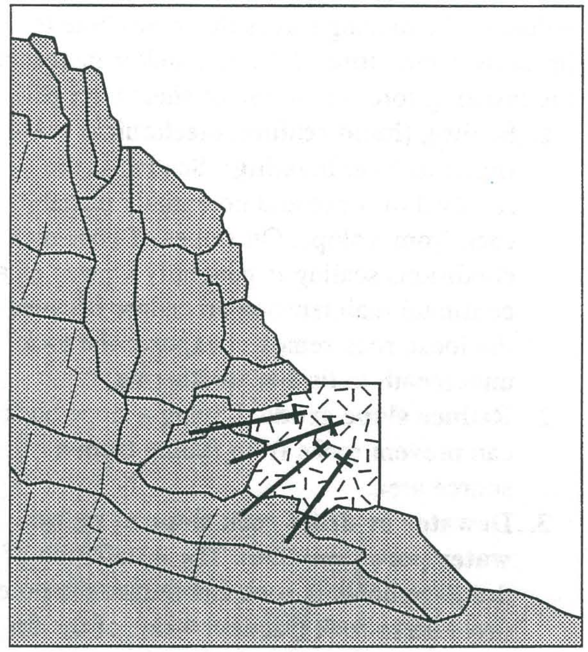

Figure 4. Anchored concrete buttress.

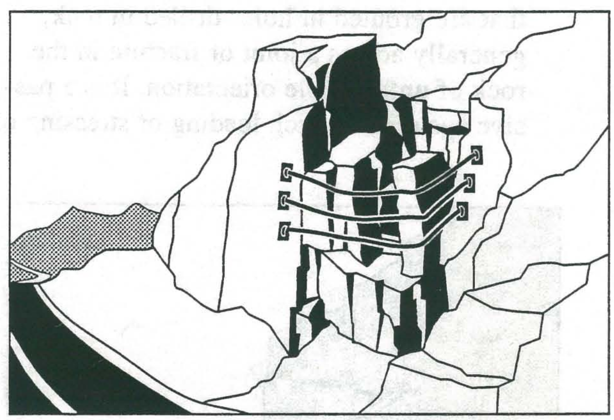

Figure 5. Cable lashing.

Rockfall Protection Devices

When stabilization of rock slopes is not practical and sufficient room exists, protective devices or structures can be constructed to shield areas from rockfall impact.

1. **Fences.** Rockfall fences come in a variety of styles and capacities. They tend to become less effective and are damaged if not destroyed by larger rockfall events. (See Figure 6.)

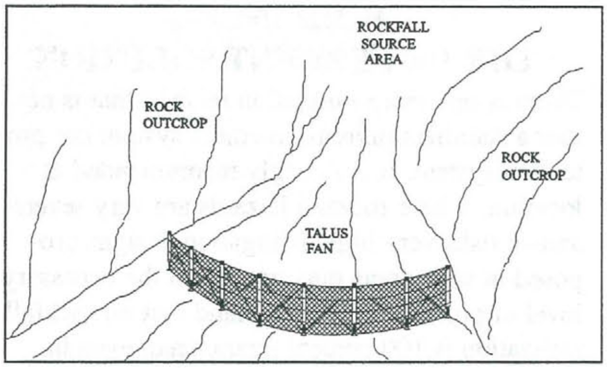

Figure 6. Rockfall fence.

2. **Ditches.** Ditches excavated into slopes can provide excellent rockfall protection. Care is needed in analysis and design to insure that bounding rocks cannot span the ditch width. (See Figure 7.)
3. **Impact barriers and walls.** Impact barrier and walls can be made from many types of material, from fill mechanically stabilized by geotextiles, rock gabion baskets, timber, steel, concrete, or even haybales. Highway departments commonly use Jersey barriers on roadsides to contain smaller falling rock in the ditch. The inertial systems, able to absorb the forces of momentum of the moving rock, have higher capacities, without costly impact damage, compared to more rigid systems. (See Figure 8.)
4. **Earthen berms.** Berms are elongated mounds of fill, commonly used in association with ditches to increase the effective height and catchment of the protection device. (See Figure 7.)
5. **Hanging fences, nets, and other attenuation devices.** In well-defined rockfall chutes in steeper rock slope areas it is possible to anchor cables to span the chute and hang fence mesh, cable netting, or rock attenuation elements. Rocks that roll and bounce down the chute impact these devices, which attenuates (reduces) the rock velocity. (See Figure 9.)

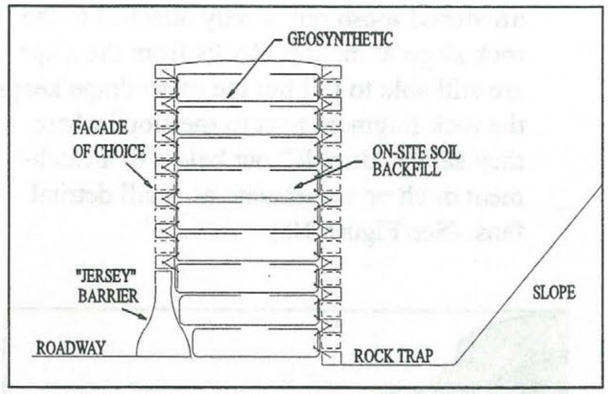

Figure 8. Mechanically stabilized backfill barrier.

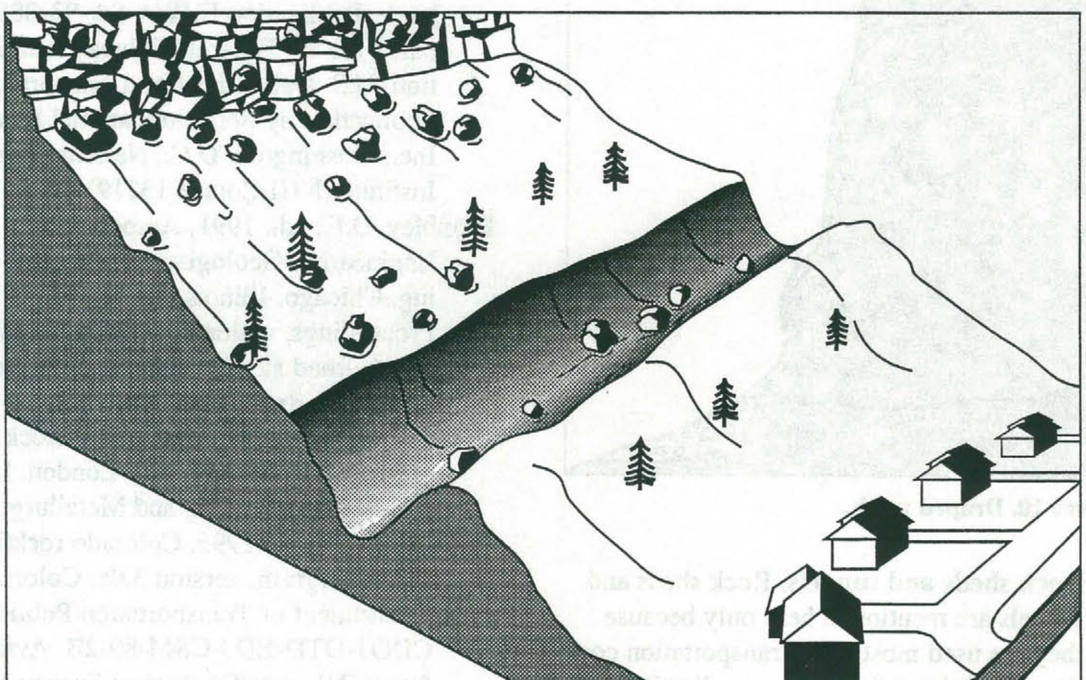

Figure 7. Rockfall ditch and berm.

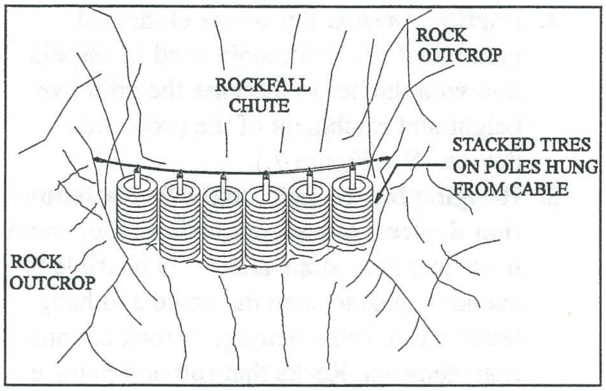

Figure 9. Tire impact attenuator.

6. **Draped mesh or netting.** Draped mesh is similar to the stabilization technique **anchored mesh** but is only attached to the rock slope at the top. Rocks from the slope are still able to fail but the mesh drape keeps the rock fragment next to the slope where they safely "dribble" out below to a catchment ditch or accumulate as small detrital fans. (See Figure 10.)

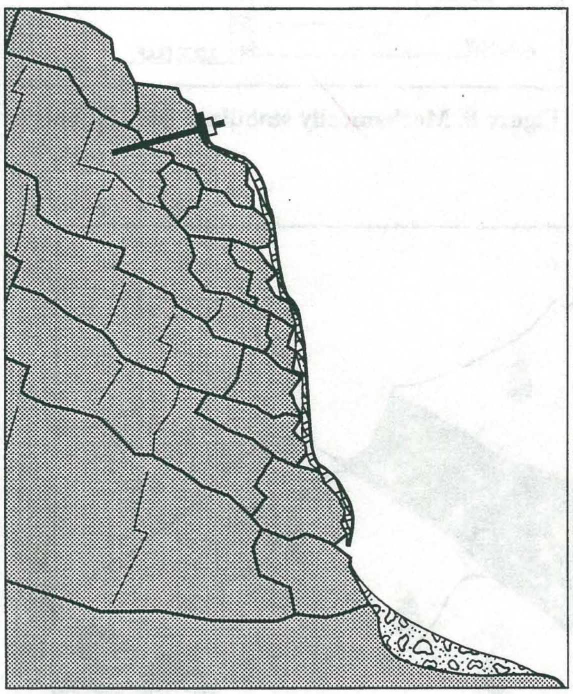

Figure 10. Draped mesh.

7. **Rock sheds and tunnels.** Rock sheds and tunnels are mentioned here only because they are used mostly for transportation corridors. They have little or no application in most types of land use.

AVOIDANCE— THE 100 PERCENT SOLUTION

There is one more mitigation method that is neither a stabilization/reinforcement system nor protection system. It is strongly recommended at locations where rockfall hazards are very severe, and/or risks very high. Mitigation designs proposed in such areas may not afford the necessary level of protection. Bear in mind that no rockfall mitigation is 100 percent guaranteed, even in mild rockfall hazard zones. **Avoidance** is excellent mitigation and must be considered where circumstances warrant. Any professional in rockfall analysis and mitigation (as with any geologic hazard) must, at times, inform developers, planners, and the public that a proposed land use is incompatible with the site conditions.

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HYDROCOMPACTION: MECHANICS AND MITIGATION

by Harold W. Olsen

Hydrocompaction is the decrease in bulk volume of a soil in response to an increase in its water content, commonly caused by applying water for irrigation. Other terms that are used to describe this process include collapse, collapsing soil, near surface subsidence, subsidence, and hydroconsolidation. Hydrocompacting soils differ from expansive soils in that the latter increase in volume when their moisture content increases.

In recent decades, hydrocompacting soils have become widely recognized as a geologic hazard to transportation, water supply, and urban facilities throughout the world. An extensive and growing literature documents problems with these soils throughout the Southwestern United States, and also in many other countries including China, Australia, Israel, India, Europe, Canada, and Africa.

Although damage resulting from hydrocompacting soils does not generally result in loss of life or large costs for any single event as an earthquake would, the cumulative costs are substantial (Prokopovich and Marriott 1988). The cost of remedial measures required to repair structures at a cement plant in central Utah located on collapsible soils was more than $20,000,000 (Hepworth and Langfelder 1989). Collapse-related damage to houses in a small community north of Santa Fe, NM was so extensive that the governor declared it a disaster area (Shaw and Johnpeer 1985). Although these examples are rather dramatic, the majority of damage attributable to collapsible soils likely involves much less visible low-rise buildings and homes for which damage costs are rarely summarized (Rollins and Rogers, 1994). Economical yet reliable mitigation measures are required to provide satisfactory support for small structures located on these materials.

In Colorado, this hazard is prevalent in the Western Slope valleys, especially in colluvial slopes derived from the Eagle and Wasatch Formations, which are known to create highway and other infrastructure problems in Eagle, Pitkin Garfield, Rio Blanco, and Mesa Counties. On the East side of the Continental divide, this hazard occurs in the extensive Loess deposits on the Eastern Plains of Colorado. These deposits are common in the Colorado Springs Metropolitan Area, primarily to the East of Interstate I-25.

Hydrocompacting soils have a loose structure (low density and high void ratio) and a moisture content less than saturation. The geologic sources of hydrocompacting soils are diverse, including soil deposits that were loessial, aeolian, subaerial, colluvial, mud flow, alluvial, residual, and man-made fills. Furthermore, the collapse potential can vary widely within any of these deposits. Laboratory analyses on undisturbed samples are commonly used to evaluate the collapse potential of soil at any given site. Extensive research has and is being conducted to clarify the physical and chemical factors governing the collapse potential of soils.

Regarding mitigation measures, a recent paper by Rollins and Rogers (1994) describes an experimental study designed to compare the advantages and limitations of five methods, as summarized in the following table.

Advantages	Limitations
Prewetting with water	
Low cost Ease of application	Excessive settlement without preloading Failure to densify surface layers Differential settlement likely
Prewetting with sodium silicate	
Dramatic reduction in collapse settlement Development of permanent cementation Reduction in hydraulic conductivity Significant reduction in creep settlement Potential for use as a remedial measure	Higher cost ($8-$12 / cu yd) Limited experience base Treatment depth limited to less than 2 m
Partial excavation and replacement with fill	
Relatively low cost ($4-$8 / cu yd) Ease of application Extensive contractor experience with this method Reduction of induced stress on collapsible soil Minimal settlement for small volumes of water Minimization of differential settlement	Treatment of surface zones only Excessive settlement following wetting of deep zones
Dynamic compaction at natural moisture content	
Dramatic reduction in collapse settlement Decrease in hydraulic conductivity Improvement to significant depths (>5m)	Higher cost ($8-$10 / cu yd) Potential for damage due to vibrations Non uniformity of treatment Less contractor experience with this method
Dynamic compaction after prewetting	
Significant decrease in collapse settlement Increased compaction efficiency prior to liquefaction Reduction in level of vibrations Greater uniformity of densification Decrease in hydraulic conductivity Improvement to significant depths	Higher cost ($9-$11 cu yd) Increase in creep (long term) settlement Potential for liquefaction when water content is high Difficult to withdraw weight after drop Drying time following treatment may be excessive Less contractor experience with method Difficult to measure improvement

An extensive literature has been accumulating concerning the occurrence of hydrocompacting soils, criteria for evaluating their collapse potential, and procedures for mitigating this hazard for major infrastructure facilities and commercial structures, and also for low-rise commercial and residential developments. This literature is widely scattered, and not readily available to planners, developers, regulators, and others in either the public or private sectors. The following bibliography is a selection of this literature aimed at making it more accessible to attendees of this conference.

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Mine Hazards-Subsidence and Hazardous Openings

Jeff Hynes-Colorado Geological Survey
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Bruce Stover-Colorado Division of Minerals & Geology

SUBSIDENCE EVALUATIONS

The potentially adverse impacts of mine hazards on development in Colorado have been exacerbated by rapid population growth with its attendant community expansion. This has driven development pressure into subsidence-prone areas heretofore avoided or relegated to lower order uses such as open space, agriculture or storage.

The consequences of unrecognized or improperly managed mine hazards are much more serious where burgeoning urban and suburban land use patterns are supplanting the previous surface uses related to grazing, farming or recreational open space.

This evolution and escalation of land use over old, abandoned mines has become a consideration requiring the cooperative attention and expertise of geologists, engineers, architects and planners in a multi-disciplinary approach.

As required by State Subdivision Regulations and Land Use Laws, most notably SB-35 and HB 1041, subsidence is defined as a geologic hazard and, as such, must be addressed as part of the County review process. While incorporated areas are exempt from SB-35 obligation, most of the impacted cities participate voluntarily in the evaluation of subsidence impacts within their jurisdiction. Mortgage lenders, including FHA, have also developed an interest in the risk to the asset.

Risk management is the ultimate objective; but risk is a complex relationship between the physical impacts produced by the phenomenon, the probability of occurrence and the presence of man and his works and their sensitivity to the impacts. To properly evaluate this relationship, data pertaining to the mine workings and the overlying development plan must be considered simultaneously.

The development plan is readily available and amenable to changes if required but the mining parameters are fixed and, are usually poorly known at the outset. Records kept during mining operations are not likely to provide the necessary information without interpretation and new data. Factors such as accuracy, completeness, veracity and relevance of the available records are beyond the control of the current investigator. The design and implementation of a detailed investigation must address, to the extent possible, any shortcomings in the historical data.

At a minimum all acceptable investigations must include: 1.) acquisition and proper fitting of the best available mine map to overlay the proposed development plan; 2.) careful planning of the need, number, type and location of drill holes; 3.) appropriate use of down-hole logging techniques, including geophysics; 4.) determination of the need for sampling and testing of relevant materials; 5.) a survey of the site and adjacent area for evidence of previous or on-going subsidence; and 6.) development and demonstration of the adequacy and appropriateness of the method or methods used to evaluate the site with respect to the hazard and degree of risk associated with the proposed use.

The outcome of this investigation then becomes a valid basis with which to determine the suitability of, or need for alteration or mitigation of, the development plan.

The ultimate land use decision can range from total avoidance of the site, prohibition for residential use, mitigation such as shaft or void filling, specified building orientation, architectural measures or to no mitigation actions required.

HAZARDOUS OPENINGS

The boom years of mining in Colorado have left a legacy of colorful history and events. They also left a legacy of physical hazards which in many areas have been or are just now beginning to be encroached upon by the current boom in growth and development.

Suburban growth in both the northern Front Range and Colorado Springs areas has encroached into the coal fields which were mined from the late 1870's through the 1970's by underground room-and-pillar methods. Mine subsidence and abandoned, haphazardly filled shafts can pose significant hazards to structures and the public through their potential for settlement, or sudden collapse.

The issue of mine subsidence damage to homes built prior to February 1989 can be addressed through the Colorado Mine Subsidence Protection Program (MSPP). The MSPP is being required by some lenders as a means of safeguarding their investment. There is no such protection available for structures built over mined areas after that date. Techniques are available, however, to identify the locations of high potential subsidence, and partially filled, abandoned shafts or chimney collapse features. Methods have been developed to stabilize abandoned vertical shafts, chimney collapsed features, and horizontal workings using various grouting techniques. Information to assist local governments, property owners, and developers in designing an appropriate stabilization strategy is available through the Colorado Division of Minerals and Geology, and the Colorado Geological Survey.

Numerous historic mountain hardrock mining districts are now undergoing rapid development and seeing an increase in tourist visitation. Towns such as Central City, Boulder, Breckenridge, Cripple Creek, Aspen and Telluride have all experienced a major land use change to tourism and resort/second-home development. Much of the growth in these areas is occurring on the old mining claims, as they represent a large part of the scarce, privately owned property in these mountain areas. New structures and people are thus potentially exposed to hazardous open mine shafts, adits, and stopes, as well as to the potential environmental problems associated with mill and mine wastes, and acidic, metal-laden discharges and groundwater contamination. For example, at least 27 unknown shafts and stopes have suddenly collapsed during construction activity in Central City, over the last few years.

The Colorado Division of Minerals and Geology has been engaged in stabilizing, sealing, and safeguarding both coal and hardrock inactive mine openings for 16 years, through its Inactive Mine Reclamation Program. Numerous techniques, designs, and methods have been developed through this program, and are available to local governments, developers, and private property owners for use in addressing hazardous mine openings.

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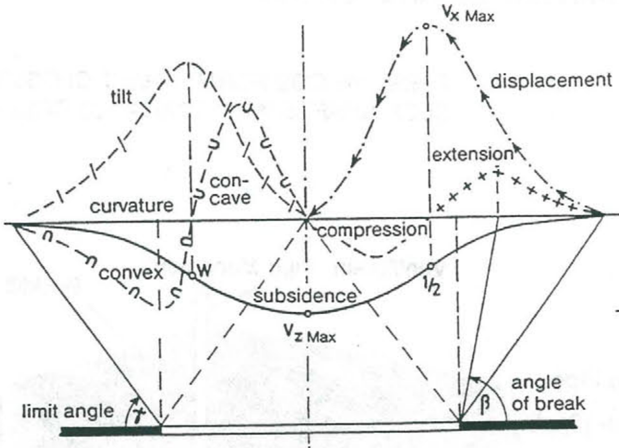
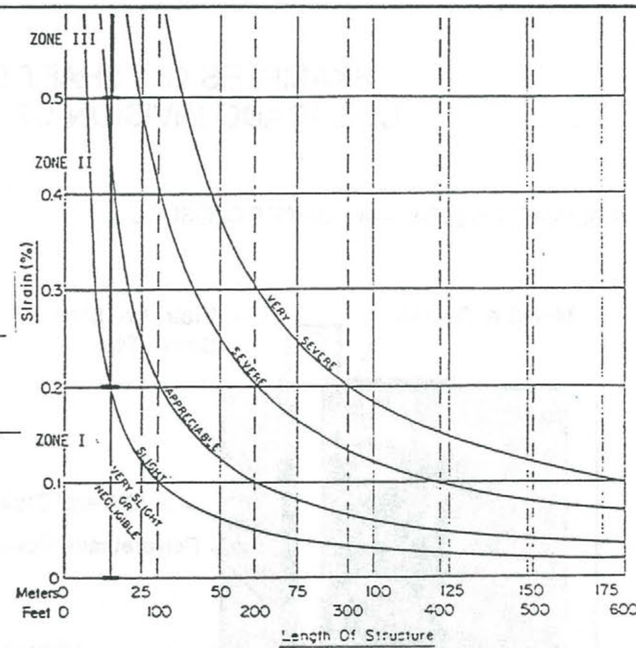
Mine Subsidence and Hazardous Openings

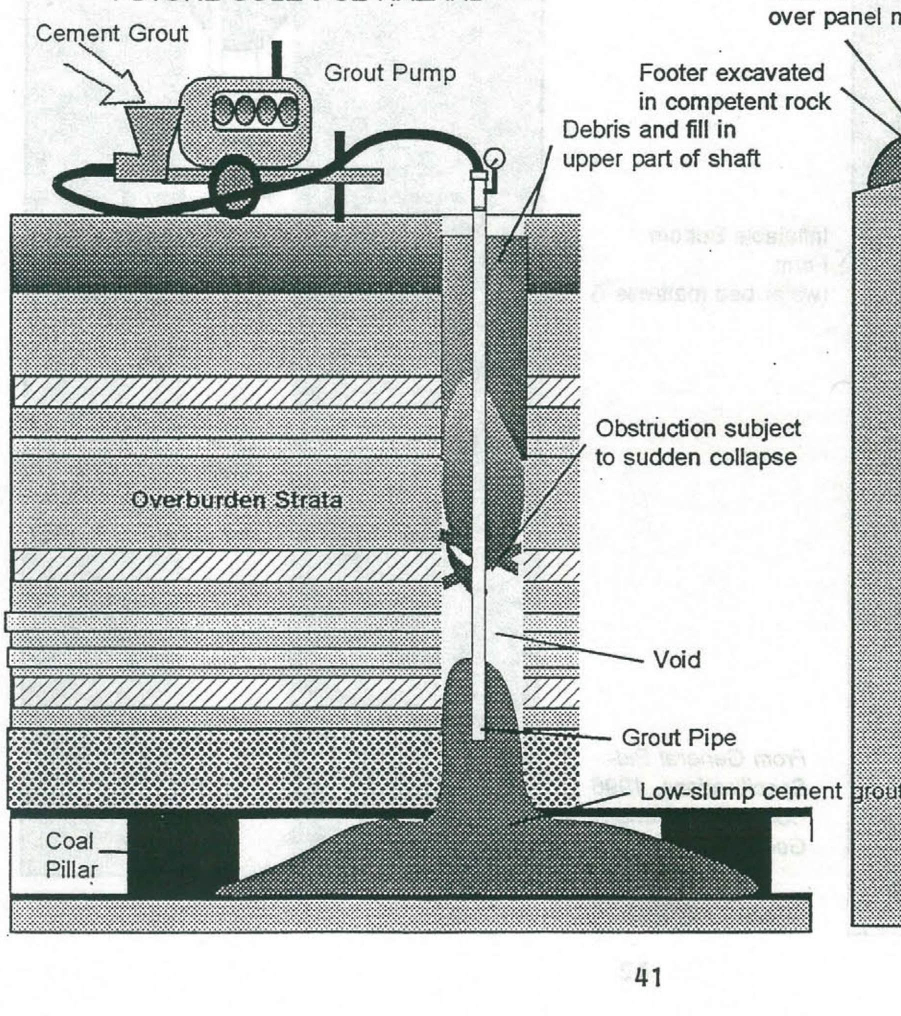


The components of ground movement over a critical area of extraction. Left half of profile:vertical components. Right half: horizontal components.
From H. Kratzch, Mining Subsidence Eingineering

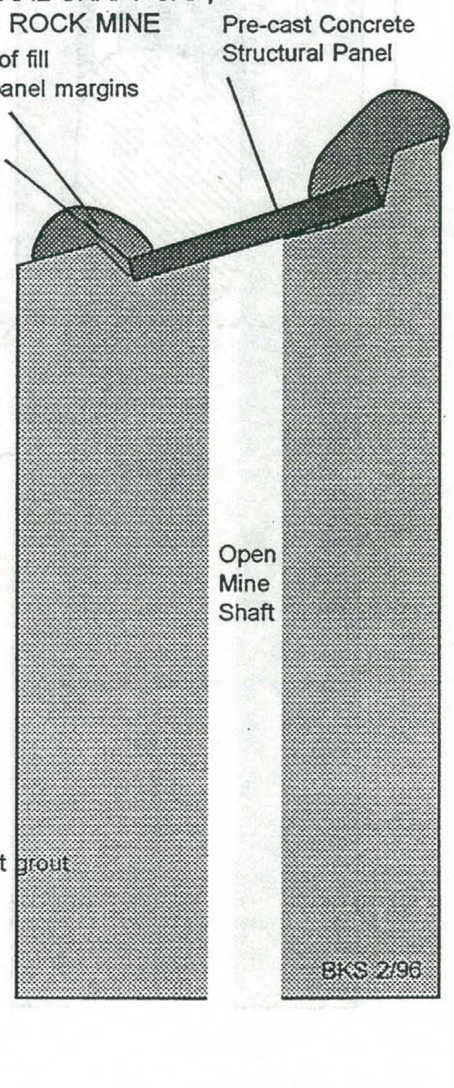


Relationship of damage to length of structure and horizontal ground strain zones in category 4
From British National Coal Board

GROUTING PARTIALLY FILLED COAL MINE SHAFT TO PREVENT FUTURE COLLAPSE HAZARD

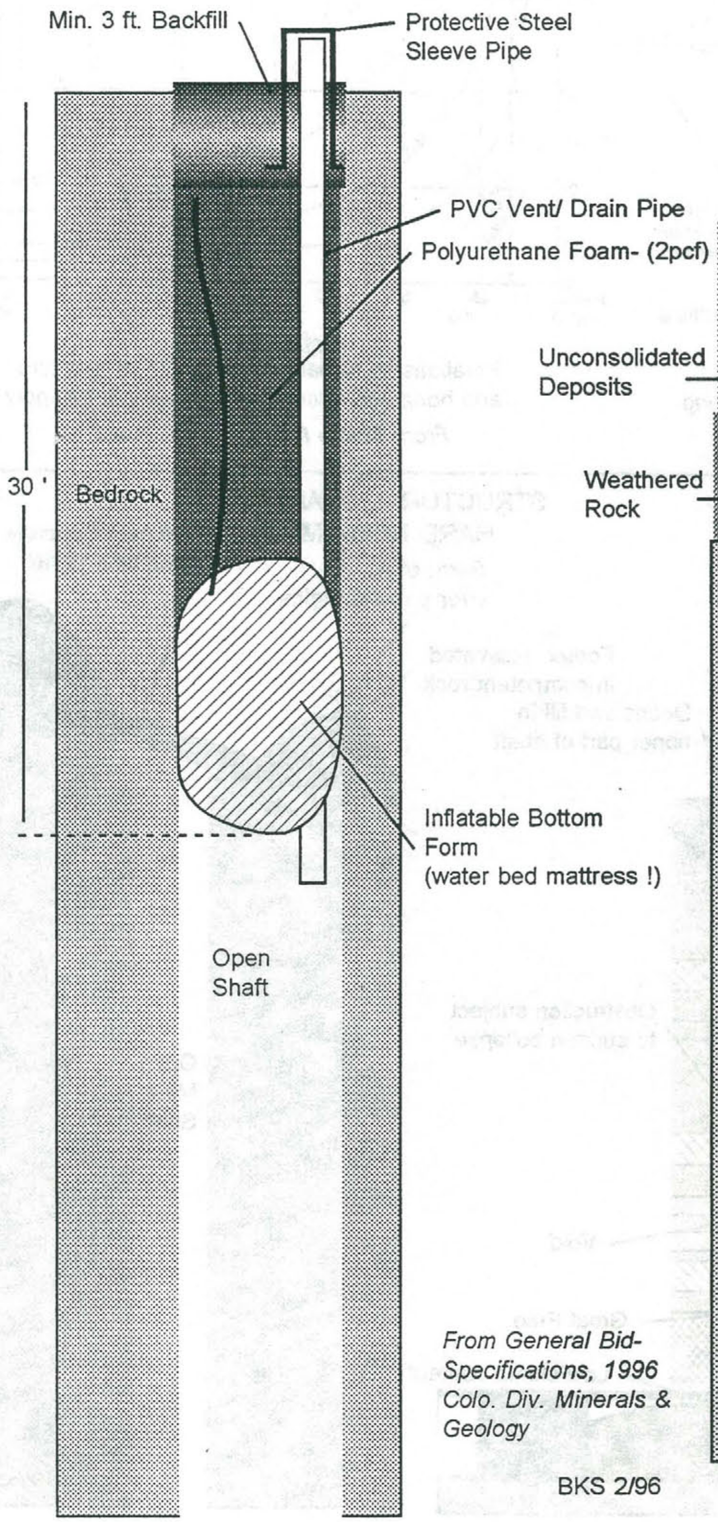


STRUCTURAL SHAFT CAP, HARD ROCK MINE

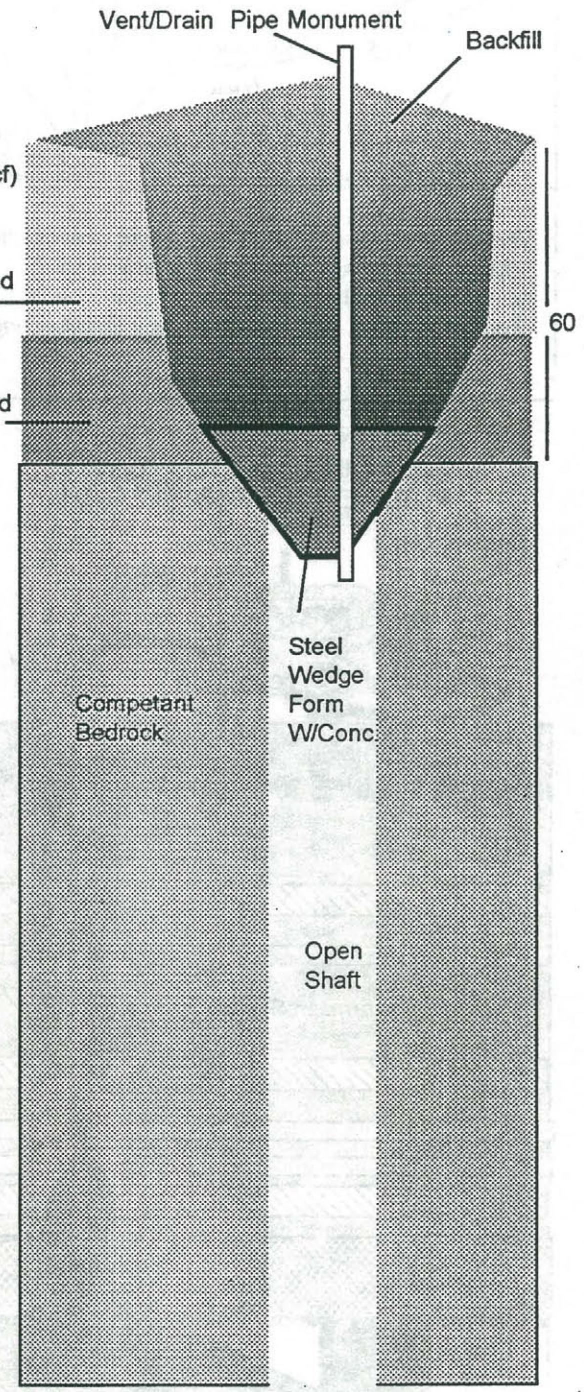


EXAMPLES OF SHAFT CLOSURE TECHNIQUES, COLORADO DIVISION OF MINERALS AND GEOLOGY

POLYURETHANE-FOAM SHAFT CLOSURE



STEEL WEDGE FORM SHAFT CLOSURE, DEEP SHAFTS WITH UNSTABLE COLLARS



From General Bid-Specifications, 1996 Colo. Div. Minerals & Geology

BKS 2/96

RADON OCCURRENCE, HEALTH HAZARDS, ANALYSIS, AND MITIGATION

Milton Lammering, PhD, Director Toxics Program, US Environmental Protection Agency Region VIII, Denver, CO 80202

AND

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ABSTRACT

Radioactive materials can be classified into two broad categories: man-made and naturally occurring radioactive materials (NORM). Man-made radionuclides are produced by splitting (fission) or combining atoms (fusion) in private and research nuclear reactors or by bombarding atoms with subatomic particles utilizing accelerators, research reactors, and other devices. NORM occurring radionuclides are classified as primordial, signifying those isotopes which were present at the time of formation, possess sufficient abundance in the earth's crust to be of interest to mineral processing concerns, and have long radiological half-lives. Principal NORM radionuclides contained in rocks and minerals are headed by uranium (U-238 series), actinium (U-235 series), thorium (Th-232 series), and plutonium (Pu-241 series). At background concentrations the three principal contributors from the terrestrial radiation field to human radiation exposure are the radionuclides in the thorium and the uranium series (Th-232 and U-238) and K-40. Estimated average annual population radiation dose from various natural background sources are shown in Table 1. The subject of this presentation concerns the radiological exposures and potential hazards from the uranium series, minerals containing U-238, Ra-226, and Rn-222.

Colorado has long been known to have high natural-background radioactivity. Uranium soil concentrations across the state typically range from 0.5 to 3.4 pCi/g whereas radon concentrations in the United States range between 100 to 1000 pCi/L per ppm of uranium (NCRP 45, 1975). Most of the uranium milled over the years by the mining industry has been found in geologic formations that include sandstone, claystone, siltstone, shale, and limestone deposits. The area considered to have the highest hazards associated with Ra-226 and Rn-222 includes all the Front Range of Colorado, from Pueblo north to the Colorado-Wyoming state line. The Wyoming Basin Province consists of elevated semiarid basins containing rocks and soils having uranium contents greater than 2.5 mg/kg and host a number of uranium occurrences. The Souther Rocky Mountain Province is underlain by igneous and metamorphic rocks with uranium contents also generally exceeding the upper continental crustal average.

Table 1. Estimated average annual dose equivalent (mrem/yr) from various sources of natural background radiation in the United States.

SOURCE	GONADS	LUNGS	BONE MARROW	OTHER TISSUES
COSMIC RADIATION	28	28	28	28
COSMOGENIC RADIONUCL.	0.2	0.1	0.4	0.3
EXTERNAL TERRESTRIAL	26	26	26	26
INHALED	--------	200	------	------
RADIONUCL. IN BODY	27	24	24	24
TOTALS (ROUNDED)	80	280	80	80

1-NCRP 45. Natural background in the United States, National Council on Radiation Protection and Measurements, November 15, 1975.
2-NCRP 93. Ionizing Radiation Exposure of the Population of the United States, National Council on Radiation Protection and Measurements, September 1, 1987.

The Front Range Mineral Belt west of Denver hosts a number of uranium occurrences and inactive uranium mines.

The decay products or daughter products of U-238, Ra-226 and Rn-222, are of the greatest interest in assessing hazards from radiological exposure primarily because of the solubility of Ra-226 in water and the mobility of noble gas Rn-222. Radon is the direct daughter (decay product) of Ra-226, meaning that for each atom of Ra-226 that disintegrates, one atom of Rn-222 is formed. And since Rn-222 is a noble gas, it does not undergo chemical reaction in the environment. Thus, Rn-222 can diffuse through materials to the extent allowed by its radiological half-life of 3.8 days, porosity of the medium, changes in barometric pressure in the pore spaces of the medium, and soil moisture content. Therefore, only Rn-222 produced near the surface of a solid (usually in the top few meters of soil) diffuse to the medium's surface is of a health concern to the population. For soils, the fraction escaping into the air through soil pore spaces may reach upwards of 0.6. This high emanating fraction usually occurs in clays due to the larger surface area and smaller particle sizes. When the Rn-222 atom decays, it forms a particulate daughter product, Po-218, Pb-214, Bi-214, and Po-210 which may be trapped and adsorbed onto the diffusing medium and carried downwind contributing to the external terrestrial radiation exposure.

The hazards and associated risks of Rn-222 were first realized in the US after discoveries of high Rn-222 levels in eastern Pennsylvania and increased lung cancers found in chronically exposed Uranium underground miners. Various health agencies to include the National Cancer Institute, National Institutes of Health, Biological Effects of Ionizing Radiations Board on Radiation Effects Research, Public Health Service, and EPA have modeled and estimated that of the projected annual 150,000 lung cancer deaths, approximately 10% (range of 7,000 to 30,000 deaths) each year may be attributable to radon. Since 1988, EPA has been directed by the "Indoor Radon Abatement Act of 1988, Public Law 100-551" to establish guidance for radon and radon decay products in homes with a "targeted long-term national goal of achieving Rn-222 levels in buildings at the ambient air levels outside of buildings (less than 1 pCi/L)". Radon standards and guidelines around the world are shown in Table 2.

Radon and radon decay product measurements most commonly used are small passive detectors that utilize a tiered approach in monitoring Rn-222 in homes. First, a short term 48 hours to 90 days screening measurement is conducted. If the home exceeds the annual guideline value of 4 pCi/L in the screening test, a followup long term measurement study over 3 to 12 months is conducted. Less commonly used in home monitoring measurements are active air monitoring systems such as continuous air pumps, grab samples, or continuous working level monitors.

If home measurements have shown that the 4 pCi/L guideline value is exceeded, there are steps which can be taken to reduce the exposure from increased Rn-222 air concentrations. These mitigation steps can either be taken through passive or active engineering systems.

Table 2. International Radon Guidelines.

COUNTRY	EXISTING DWELLINGS	NEW CONSTRUCTION
US	4 pC/L	4 pC/L
GERMANY	7 pC/L	7 pC/L
SWEDEN	11 pC/L	4 pC/L
U.K.	5.4 pC/L	5.4 pC/L

Passive steps include sealing off potential entry routes into the home such as cracks and holes in concrete walls and floors; cover exposed soil or crawl spaces with concrete or gas proof liners; cover basement sumps or vent them to the outdoors; build passive sub-slab soil ventilation systems.

Examples of active radon reduction techniques include the use of mechanical fans, ventilators, or heating recovery systems. These or other methods which increase the air exchange rates in homes or enclosed buildings will reduce the risks associated with increased Rn-222 levels.

In summary, soils containing naturally occurring radioactive materials contribute to the normal background radiation exposure observed in Colorado. The uranium series radionuclides are of most interest in Colorado due to the mineralogical mining and milling history, mobility, and potential health hazards associated with Ra-226 and Rn-222. Normally, in outdoor settings, neither Ra-226 or Rn-222 are known to be of human health concerns at average soil and air concentrations. However, various agencies have recently shown that Rn-222 presents unacceptable health risks indoors, in enclosed areas, or underground mines as evidenced by increased lung cancers in various occupationally exposed workers. These elevated Rn-222 levels, especially in homes, can be measured and cost-effectively reduced either through passive or active Rn-222 reduction techniques.

REFERENCES

1. Exposure of the Population of the United States and Canada from Natural Background Radiation. NCRP Report 45 and 94. November, 1975 and December 1987.

2. "A Citizens Guide to Radon: What it is and What to do about it", U.S. Environmental Protection Agency, OPA-86-004, August, 1986.

3. Radon and Lung Cancer Risk: A Joint Analysis of 11 Underground Miners Studies. J. Lubin et al. U.S. Dept. of Health and Human Services, Public Health Service, National Institutes of Health, NIH Publication No. 94-3644, 1994.

4. The USGS/EPA Radon Potential Assessments: An Introduction, L.C.S. Gundersen et al., USGS Open File Report 93-292, September 1993. EPA Region 8 Geologic Radon Potential Summary, R.R. Schumann et al., USGS Open File Report 93-202-H, September, 1993.

5. Health Risks of Radon and Other Internally Deposited Alpha Emitters. BIER IV. Committee on the Biological Effects of Ionizing Radiations, Board on Radiation Effects Research Commission on Life Sciences, National Research Council. National Academy Press, 1988.

BOARD NEWS -- JULY 1995 -- COLORADO STATE BOARD OF REGISTRATION

THE BOARD ADDRESSES ENGINEERING IN NATURAL HAZARD AREAS

Soils Task Force Report

In May 1994, Senator Bill Schroeder met with representatives of the engineering community and outlined concerns regarding performance of residences constructed on expansive soils and bedrock in Colorado. In response, the Colorado Board for Registration for Professional Engineers Professional Land Surveyors ("Board") helped to form a Soils Task Force. The purpose of the Task Force was to make recommendations to the Board pertaining to the practice of engineering and the design and review of structures in expansive soils found throughout Colorado, and steeply dipping bedrock found along the eastern flank of the Front Range. The Task Force was formed last summer and met periodically from September 1994 to January 1995. The efforts of the Task Force are summarized here.

During the early meetings, the Task Force attempted to define the perceived problem to include: 1) lack, and timing, of proper disclosure of soil hazards during all phases of property development from zoning through construction and subsequent property transfers; 2) lack of proper education of the public regarding risks associated with expansive soils; 3) lack of standard practice and quality of investigations; and 4) lack of land use planning and design which considers, soils risks and site and off-site drainage. Our discussions then focused on the development of standards with less emphasis on the other problem components which are not within the authority of the Board. We discovered existing legislation, C.R.S. 24-65.1-202 (2), which identifies soils hazards as one category of natural hazards. Our subsequent discussions dealt with natural geologic hazards.

The Task Force acknowledges that professional engineers practicing in the design of foundations, grading and drainage, buried utilities, streets and remedial repairs in areas of natural hazards should demonstrate knowledge of the design and construction methods used to mitigate the effects of such hazards, and the investigations necessary to evaluate impacts of hazards on existing and proposed construction. We considered many possible solutions, including Task Force development of statewide standards of practice, which was rejected because such standards are too much of a moving target, do not reflect area-specific practice, and would require far more numerous standards than the Task Force can effectively develop. Specialty registration for engineers was also considered and rejected because many different engineering specialties are involved, it would require modification of the engineering practice law, would be slow and divisive for the engineering community, and has not proven to be effective in reducing problems in other states where specialty registration exists.

The Task Force recommended to the Board that they consider measures to guide engineers practicing in hazard areas by establishing a Board policy regarding such work. Disciplinary action could then be based upon C.R.S. 12-25-108 (1) (a) regarding failure to meet generally accepted standards of engineering practice.

As a result of these discussions, the Task Force recommended that the Board adopt Policy Statement 15 - Engineering in Designated Natural Hazard Areas, which the Board did at its February 20, 1995 meeting. The text of that policy is found in this newsletter in the section on "Recently Adopted Policies."

Policy Statement 15 -- Engineering in Designated Natural Hazard Areas

In areas designated as "Natural Hazards" in accordance with section 24-65.1-202 (2), C.R.S., engineers performing soils (Geotechnical) investigations, construction observation, and design of structures including foundations, grading and drainage, buried utilities, streets and pavements, and remedial work to these improvements shall demonstrate knowledge and incorporate knowledge of and expertise in: 1) methods used to mitigate such hazards and, 2) investigation, design and construction guidelines adopted by local governments pursuant to their authority established in section 24-65.1-202 (2), C.R.S. It is the opinion of the Board that this policy statement should be implemented by the following guidelines:

1. Recognition and Mitigation of Natural Hazards

   Registrants should be thoroughly familiar with applicable natural hazard legislation (section 24-65.1-202 (2), C.R.S., etc.) and local government policies and regulations for mitigation of effects of natural hazards. Local government policies and regulations may vary. It is the responsibility of each registrant to become familiar with applicable policies and regulations. Local government polices and regulations, or lack thereof, concerning natural hazards do not relieve the registrant of and engineering practice in the recognition and mitigation of natural hazards.

2. Multi-disciplinary Approach

   Registrants should recognize and acknowledge that the mitigation of effects from natural hazards requires a multi-disciplinary approach encompassing the fields of engineering, geology, hydrology, architecture, and land-use planning. It is incumbent on the registrant that these fields are adequately represented in the mitigation of natural hazards through demonstrated knowledge and experience. In general, the Board believes that individual registrants are unlikely to possess the necessary knowledge and expertise to deal with all natural hazards in all cases.

3. Education

Knowledge of natural hazards should be demonstrated by attendance at courses on natural hazards sponsored by the Colorado Geological Survey, Universities, local government, or professional societies. Registrants should be prepared to demonstrate appropriate knowledge and expertise.

4. Disclosure

Registrants should be open and forthright about the existence of natural hazards, risks to their clients and the public, methods mitigation and of the chances of success in mitigation. This applies to all stages of the design process, from feasibility through final design and construction. Registrants should not knowingly take part in remedial work in natural hazard areas where the intent is to disguise either the hazards or existing damage.

Adopted February 20, 1995)

Some Key Laws Related to Geologic Hazards and Land Use in Colorado

1. House Bill 1034 (1974), C.R.S., 29-20-101, et seq.—*Local Government Land Use Control Enabling Act.*

2. House Bill 1041 (1974), C.R.S. 24-65.1-101, et seq.—*Areas and Activities of State Interest* (including natural hazards).

3. Senate Bill 35 (1972), C.R.S. 30-28-101, et seq.—*County Planning and Building Codes.* (Only the title page and sections 133 through 137 are reprinted because they deal with subdivision regulations and referral and review requirements.)

4. Senate Bill 13 (1984), C.R.S. 6-6.5-101, *Soil and Hazard Analyses of Residential Construction—Disclusure to Purchaser.*

29-15-109. No action maintainable. No action or proceeding, at law or in equity, to review any act or proceeding, or to question the validity or enjoin the performance of any act or the issuance of any tax anticipation notes authorized by this article, or to obtain any other relief against any acts or proceedings done or had under this article, whether based upon irregularities or jurisdictional defects, shall be maintained unless such action or proceeding is commenced within thirty days after the performance of the act or the effective date of the legislative act complained of; otherwise, it shall be thereafter perpetually barred.

Source: L. 85, p. 1056, § 1.

29-15-110. Independent authority. The authority granted by this article shall constitute separate and independent authority for the powers granted in this article and shall be effective without reference to the powers or limitations contained in any other law, and the provisions of this article shall not be deemed to constitute limitations on the powers granted to public bodies under any other law.

Source: L. 85, p. 1056, § 1.

29-15-111. Application ... intent of the general assembly that ... ply to home rule municipalities ... uperseded by their charters or any ... charters and also shall apply to special ... es.

Source: L. 85, p. ...

LAND USE CONTROL AND CONSERVATION

ARTICLE 20

Local Government Land Use Control Enabling Act

29-20-101. Short title. This article shall be known and may be cited as the "Local Government Land Use Control Enabling Act of 1974".

Source: L. 74, p. 353, § 1.

Law reviews. For article, "Cumulative Impact Assessment of Western Energy Development: Will it Happen?", see 51 U. Colo. L. Rev. 551 (1980).

29-20-102. Legislative declaration. The general assembly hereby finds and declares that in order to provide for planned and orderly development within Colorado and a balancing of basic human needs of a changing population with legitimate environmental concerns, the policy of this state is to clarify and provide broad authority to local governments to plan for and regulate the use of land within their respective jurisdictions. Nothing in this article shall serve to diminish the planning functions of the state or the duties of the division of planning.

Source: L. 74, p. 353, § 1.

Applied in City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981); Theobald v. Board of County Comm'rs, 644 P.2d 942 (Colo. 1982).

29-20-103. Definitions. As used in this article, unless the context otherwise requires:

(1) "Local government" means a county, home rule or statutory city, town, territorial charter city, or city and county.

Source: L. 74, p. 353, § 1.

29-20-104. Powers of local governments. (1) Without limiting or superseding any power or authority presently exercised or previously granted, each local government within its respective jurisdiction has the authority to plan for and regulate the use of land by:

(a) Regulating development and activities in hazardous areas;

(b) Protecting lands from activities which would cause immediate or foreseeable material danger to significant wildlife habitat and would endanger a wildlife species;

(c) Preserving areas of historical and archaeological importance;

(d) Regulating, with respect to the establishment of, roads on public lands administered by the federal government; this authority includes authority to prohibit, set conditions for, or require a permit for the establishment of any road authorized under the general right-of-way granted to the public by 43 U.S.C. 932 (R.S. 2477) but does not include authority to prohibit, set conditions for, or require a permit for the establishment of any road authorized for mining claim purposes by 30 U.S.C. 21 et seq., or under any specific permit or lease granted by the federal government;

(e) Regulating the location of activities and developments which may result in significant changes in population density;

(f) Providing for phased development of services and facilities;

(g) Regulating the use of land on the basis of the impact thereof on the community or surrounding areas; and

(h) Otherwise planning for and regulating the use of land so as to provide planned and orderly use of land and protection of the environment in a manner consistent with constitutional rights.

Source: L. 74, p. 353, § 1.

Law reviews. For comment, "Regionalism or Parochialism: The Land Use Planner's Dilemma", see 48 U. Colo. L. Rev. 575 (1977).

No authority to adopt "subdivision" definition contrary to § 30-28-101. Sections 29-20-101 to 29-20-107 do not confer the authority upon a county to adopt a definition of "subdivision" in its regulations which is contrary to the express statutory definition found in § 30-28-101 (10). Pennobscot, Inc. v. Board of County Comm'rs, 642 P.2d 915 (Colo. 1982).

Or to adopt regulations covering land specifically excluded. Section 29-20-101 to 29-20-107 do not confer the authority to adopt subdivision regulations covering parcels of land which are specifically excluded from the provisions of § 30-28-101 (10). Pennobscot, Inc. v. Board of County Comm'rs, 642 P.2d 915 (Colo. 1982).

Applied in Theobald v. Board of County Comm'rs, 644 P.2d 942 (Colo. 1982).

29-20-105. Intergovernmental cooperation. Without limiting or superseding any power or authority presently exercised or previously granted, local governments are authorized and encouraged to cooperate or contract with other units of government pursuant to part 2 of article 1 of this title for the purposes of planning or regulating the development of land, including but not limited to the joint exercise of planning, zoning, subdivision, building, and related regulations.

Source: L. 74, p. 354, § 1.

29-20-106. Receipt of funds. Without limiting or superseding any authority presently exercised or previously granted, local governments are hereby authorized to receive and expend funds from other governmental and private sources for the purposes of planning for or regulating the use of land within their respective jurisdictions.

Source: L. 74, p. 354, § 1.

29-20-107. Compliance with other requirements. Where other procedural or substantive requirements for the planning for or regulation of the use of land are provided by law, such requirements shall control.

Source: L. 74, p. 354, § 1.

ARTICLE 21

Conservation Trust Funds

29-21-101. Conservation trust funds. (1) As used in this article, unless the context otherwise requires:

(a) "County" includes a city and county.

(b) "Eligible entity" means a county, municipality, or special district which has created a conservation trust fund pursuant to this section and which has certified to the department of local affairs that it has created such fund.

(c) "Interests in land and water" means any and all rights and interests in land or water, or both, including fee interests and less than full fee interests

(d) The names of school districts, if any which ... the state treasurer pursuant to ... graph (f) of ...

AMENDMENTS TO ARTICLE 20 IN THE 1994 SUPPLEMENT

... Octo-

LAND USE CONTROL AND CONSERVATION

ARTICLE 20

Local Government Land Use Control Enabling Act

Law reviews: For article, "Vested Property Rights in Colorado: The Legislature Rushes in Where ...", see Den. U. L. Rev. 31 (1988).

29-20-104. Powers of local governments.

This section does not confer upon counties the authority to impose conditions for granting permits for exploratory oil well operation when such authority was granted exclusively to state oil and gas conservation commission under "Oil and Gas Conservation Act". Oborne v. County Comm'rs of Douglas Cty., 764 P.2d 397 (Colo. App. 1988), cert. denied, 778 P.2d 1370 (Colo. 1989).

Applied in Board of County Comm'rs v. Bowen/Edwards Assoc., 830 P.2d 1045 (Colo. 1992).

29-20-105. Intergovernmental cooperation. (1) Local governments are authorized and encouraged to cooperate or contract with other units of government pursuant to part 2 of article 1 of this title for the purposes of planning or regulating the development of land including, but not limited to, the joint exercise of planning, zoning, subdivision, building, and related regulations.

(2) (a) Without limiting the ability of local governments to cooperate or contract with each other pursuant to the provisions of this article or any other provision of law, local governments may provide through intergovernmental agreements for the joint adoption by the governing bodies, after notice and hearing, of mutually binding and enforceable comprehensive development plans for areas within their jurisdictions. This section shall not affect the validity of any intergovernmental agreement entered into prior to April 23, 1989.

(b) A comprehensive development plan may contain master plans, zoning plans, subdivision regulations, and building code, permit, and other land use standards, which, if set out in specific detail, may be in lieu of such regulations or ordinances of the local governments.

(c) Notwithstanding any other statutory provisions of article 28 of title 30, C.R.S., review of comprehensive development plans by the planning commissions of the local governments shall be discretionary, unless otherwise required by local ordinance. This subsection (2) shall not apply to the requirements of sections 30-28-110 and 30-28-127, C.R.S.

(d) An intergovernmental agreement providing for a comprehensive development plan may contain a provision that the plan may be amended only by the mutual agreement of the governing bodies of the local governments who are parties to the plan.

(e) In the event that a plan is silent as to a specific land use matter, existing local land use regulations shall control.

(f) An intergovernmental agreement may contain a provision that a comprehensive development plan shall continue to control a particular land area even though the land area is annexed or jurisdiction over the land area is otherwise transferred pursuant to law between the local governmental entities who are parties to the agreement.

(g) Each governing body that is a party to an intergovernmental agreement adopting a comprehensive development plan shall have standing in district court to enforce the terms of the agreement and the plan, including specific performance and injunctive relief. The district court shall schedule all actions to enforce an intergovernmental agreement and comprehensive development plan for expedited hearing.

(h) Local governments may, pursuant to an intergovernmental agreement, provide for revenue-sharing.

(i) Local governments shall not be required to enter into intergovernmental agreements or comprehensive development plans pursuant to this section.

Source: L. 89: Entire section amended, p. 1268, § 1, effective April 23.

29-20-107. Compliance with other requirements. Except as provided in section 29-20-105 (2), where other procedural or substantive requirements for the planning for or regulation of the use of land are provided by law, such requirements shall control.

Source: L. 89: Entire section amended, p. 1269, § 2, effective April 23.

ARTICLE 21

Conservation Trust Funds

29-21-101. Conservation trust funds. (1) (g) "Special district" means:

(I) A special district organized under article 1 of title 32, C.R.S., which provides park or recreation facilities or programs pursuant to the district's service plan, which facilities or programs are open to public use; or

HB 1041 (1974)

24-65-106. Commission staff to assist countie[illegible] [illegible] unicipalities. The commission, within available appropri[illegible] n full-time professional staff members to a[illegible] es in the program established unde[illegible] or progress in the same. No later [illegible] ll issue its report to the general a[illegible] rogram and shall include in its re[illegible] -105 (2) (b) and (2) (c).

Source: L. 74, p[illegible]

ARTICLE 65.1

Areas and Activities of State Interest

PART 1

GENERAL PROVISIONS

24-65.1-101. Legislative declaration. (1) In addition to the legislative declaration contained in section 24-65-102 (1), the general assembly further finds and declares that:

(a) The protection of the utility, value, and future of all lands within the state, including the public domain as well as privately owned land, is a matter of public interest;

(b) Adequate information on land use and systematic methods of definition, classification, and utilization thereof are either lacking or not readily available to land use decision makers; and

(c) It is the intent of the general assembly that land use, land use planning, and quality of development are matters in which the state has responsibility for the health, welfare, and safety of the people of the state and for the protection of the environment of the state.

(2) It is the purpose of this article that:

(a) The general assembly shall describe areas which may be of state interest and activities which may be of state interest and establish criteria for the administration of such areas and activities;

(b) Local governments shall be encouraged to designate areas and activities of state interest and, after such designation, shall administer such areas and activities of state interest and promulgate guidelines for the administration thereof; and

(c) Appropriate state agencies shall assist local governments to identify, designate, and adopt guidelines for administration of matters of state interest.

Source: L. 74, p. 335, § 1.

Law reviews. For article, "Synthetic Fuels — Policy and Regulation", see 51 U. Colo. L. Rev. 465 (1980). For article, "Cumulative Impact Assessment of Western Energy Development: Will it Happen?", see 51 U. Colo. L. Rev. 551 (1980). For article, "The Emerging Relationship Between Environmental Regulations and Colorado Water Law", see 53 U. Colo. L. Rev. 597 (1982). For article, "Quality Versus Quantity: The Continued Right to Appropriate — Part I", see 15 Colo. Law. 1035 (1986).

Land use controls to bear rational relationship to community's health, safety, and welfare. The exercise of the police power, be it in the enactment of land use controls or in decisions enforcing those regulations, must bear a rational relationship to the health, safety, and welfare of the community. Tri-State Generation & Transmission Ass'n v. Board of County Comm'rs , 42 Colo. App. 479, 600 P.2d 103 (1979).

Court may interfere only when exercise of police power capricious and arbitrary. It is axiomatic that every exercise of the police power applying land use regulations is apt to affect adversely someone's property interests and that a reviewing court should intervene only when such power is exercised capriciously and arbitrarily. Tri-State Generation & Transmission Ass'n v. Board of County Comm'rs, 42 Colo. App. 479, 600 P.2d 103 (1979).

Counties are delegated power to supervise land use involving "state interest". This article delegates to the counties power to supervise land use with regard to areas and activities of "state interest", i.e., which may have an impact on the people of the state beyond the immediate scope of the project. City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981).

Applied in Board of County Comm'rs v. District Court, 623 P.2d 1017 (Colo. 1981).

24-65.1-102. General definitions. As used in this article, unless the context otherwise requires:

(1) "Development" means any construction or activity which changes the basic character or the use of the land on which the construction or activity occurs.

(2) "Local government" means a municipality or county.

(3) "Local permit authority" means the governing body of a local government with which an application for development in an area of state interest or for conduct of an activity of state interest must be filed, or the designee thereof.

(4) "Matter of state interest" means an area of state interest or an activity of state interest or both.

(5) "Municipality" means a home rule or statutory city, town, or city and county or a territorial charter city.

(6) "Person" means any individual, partnership, corporation, association, company, or other public or corporate body, including the federal government, and includes any political subdivision, agency, instrumentality, or corporation of the state.

Source: L. 74, p. 336, § 1.

24-65.1-103. Definitions pertaining to natural hazards. As used in this article, unless the context otherwise requires:

(1) "Aspect" means the cardinal direction the land surface faces, characterized by north-facing slopes generally having heavier vegetation cover.

(2) "Avalanche" means a mass of snow or ice and other material which may become incorporated therein as such mass moves rapidly down a mountain slope.

(3) "Corrosive soil" means soil which contains soluble salts which may produce serious detrimental effects in concrete, metal, or other substances that are in contact with such soil.

(4) "Debris-fan floodplain" means a floodplain which is located at the mouth of a mountain valley tributary stream as such stream enters the valley floor.

(5) "Dry wash channel and dry wash floodplain" means a small watershed with a very high percentage of runoff after torrential rainfall.

(6) "Expansive soil and rock" means soil and rock which contains clay and which expands to a significant degree upon wetting and shrinks upon drying.

(7) "Floodplain" means an area adjacent to a stream, which area is subject to flooding as the result of the occurrence of an intermediate regional flood and which area thus is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property. The term includes but is not limited to:

(a) Mainstream floodplains;

(b) Debris-fan floodplains; and

(c) Dry wash channels and dry wash floodplains.

(8) "Geologic hazard" means a geologic phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a

significant hazard to public health and safety or to property. The term includes but is not limited to:

(a) Avalanches, landslides, rock falls, mudflows, and unstable or potentially unstable slopes;

(b) Seismic effects;

(c) Radioactivity; and

(d) Ground subsidence.

(9) "Geologic hazard area" means an area which contains or is directly affected by a geologic hazard.

(10) "Ground subsidence" means a process characterized by the downward displacement of surface material caused by natural phenomena such as removal of underground fluids, natural consolidation, or dissolution of underground minerals or by man-made phenomena such as underground mining.

(11) "Mainstream floodplain" means an area adjacent to a perennial stream, which area is subject to periodic flooding.

(12) "Mudflow" means the downward movement of mud in a mountain watershed because of peculiar characteristics of extremely high sediment yield and occasional high runoff.

(13) "Natural hazard" means a geologic hazard, a wildfire hazard, or a flood.

(14) "Natural hazard area" means an area containing or directly affected by a natural hazard.

(15) "Radioactivity" means a condition related to various types of radiation emitted by natural radioactive minerals that occur in natural deposits of rock, soil, and water.

(16) "Seismic effects" means direct and indirect effects caused by an earthquake or an underground nuclear detonation.

(17) "Siltation" means a process which results in an excessive rate of removal of soil and rock materials from one location and rapid deposit thereof in adjacent areas.

(18) "Slope" means the gradient of the ground surface which is definable by degree or percent.

(19) "Unstable or potentially unstable slope" means an area susceptible to a landslide, a mudflow, a rock fall, or accelerated creep of slope-forming materials.

(20) "Wildfire behavior" means the predictable action of a wildfire under given conditions of slope, aspect, and weather.

(21) "Wildfire hazard" means a wildfire phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property. The term includes but is not limited to:

(a) Slope and aspect;

(b) Wildfire behavior characteristics; and

(c) Existing vegetation types.

(22) "Wildfire hazard area" means an area containing or directly affected by a wildfire hazard.

Source: L. 74, p. 336, § 1.

24-65.1-104. Definitions pertaining to other areas and activities of state interest. As used in this article, unless the context otherwise requires:

(1) "Airport" means any municipal or county airport or airport under the jurisdiction of an airport authority.

(2) "Area around a key facility" means an area immediately and directly affected by a key facility.

(3) "Arterial highway" means any limited-access highway which is part of the federal-aid interstate system or any limited-access highway constructed under the supervision of the state department of highways.

(4) "Collector highway" means a major thoroughfare serving as a corridor or link between municipalities, unincorporated population centers or recreation areas, or industrial centers and constructed under guidelines and standards established by, or under the supervision of, the state department of highways. "Collector highway" does not include a city street or local service road or a county road designed for local service and constructed under the supervision of local government.

(5) "Domestic water and sewage treatment system" means a wastewater treatment plant, water supply system, or water treatment plant, as defined in section 25-9-102 (5), (6), and (7), C.R.S., and any system of pipes, structures, and facilities through which wastewater is collected for treatment.

(6) "Historical or archaeological resources of statewide importance" means resources which have been officially included in the national register of historic places, designated by statute, or included in an established list of places compiled by the state historical society.

(7) "Key facilities" means:

(a) Airports;

(b) Major facilities of a public utility;

(c) Interchanges involving arterial highways;

(d) Rapid or mass transit terminals, stations, and fixed guideways.

(8) "Major facilities of a public utility" means:

(a) Central office buildings of telephone utilities;

(b) Transmission lines, power plants, and substations of electrical utilities; and

(c) Pipelines and storage areas of utilities providing natural gas or other petroleum derivatives.

(9) "Mass transit" means a coordinated system of transit modes providing transportation for use by the general public.

(10) "Mineral" means an inanimate constituent of the earth, in solid, liquid, or gaseous state, which, when extracted from the earth, is usable in its natural form or is capable of conversion into usable form as a metal, a metallic compound, a chemical, an energy source, a raw material for manufacturing, or a construction material. "Mineral" does not include surface or groundwater subject to appropriation for domestic, agricultural, or industrial purposes, nor does it include geothermal resources.

(11) "Mineral resource area" means an area in which minerals are located in sufficient concentration in veins, deposits, bodies, beds, seams, fields, pools, or otherwise as to be capable of economic recovery. "Mineral resource area" includes but is not limited to any area in which there has been significant mining activity in the past, there is significant mining activity in the present, mining development is planned or in progress, or mineral rights

are held by mineral patent or valid mining claim with the intention of mining.

(12) "Natural resources of statewide importance" is limited to shorelands of major, publicly owned reservoirs and significant wildlife habitats in which the wildlife species, as identified by the division of wildlife of the department of natural resources, in a proposed area could be endangered.

(13) "New communities" means the major revitalization of existing municipalities or the establishment of urbanized growth centers in unincorporated areas.

(14) "Rapid transit" means the element of a mass transit system involving a mechanical conveyance on an exclusive lane or guideway constructed solely for that purpose.

Source: L. 74, p. 338, § 1.

24-65.1-105. Effect of article - public utilities. (1) With regard to public utilities, nothing in this article shall be construed as enhancing or diminishing the power and authority of municipalities, counties, or the public utilities commission. Any order, rule, or directive issued by any governmental agency pursuant to this article shall not be inconsistent with or in contravention of any decision, order, or finding of the public utilities commission with respect to public convenience and necessity. The public utilities commission and public utilities shall take into consideration and, when feasible, foster compliance with adopted land use master plans of local governments, regions, and the state.

(2) Nothing in this article shall be construed as enhancing or diminishing the rights and procedures with respect to the power of a public utility to acquire property and rights-of-way by eminent domain to serve public need in the most economical and expedient manner.

Source: L. 74, p. 339, § 1.

Exemption inapplicable to municipal utilities serving outside boundaries. The exemption conferred by this section does not apply to municipal utilities serving outside their territorial boundaries. City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981).

24-65.1-106. Effect of article - rights of property owners - water rights. (1) Nothing in this article shall be construed as:

(a) Enhancing or diminishing the rights of owners of property as provided by the state constitution or the constitution of the United States;

(b) Modifying or amending existing laws or court decrees with respect to the determination and administration of water rights.

Source: L. 74, p. 340, § 1.

Law reviews. For article, "The Emerging Relationship Between Environmental Regulations and Colorado Water Law", see 53 U. Colo. L. Rev. 597 (1982).

Applied in City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981).

24-65.1-107. Effect of article - developments in areas of state interest and activities of state interest meeting certain conditions. (1) This article shall not apply to any development in an area of state interest or any activity of state interest which meets any one of the following conditions as of May 17, 1974:

(a) The development or activity is covered by a current building permit issued by the appropriate local government; or

(b) The development or activity has been approved by the electorate; or

(c) The development or activity is to be on land:

(I) Which has been conditionally or finally approved by the appropriate local government for planned unit development or for a use substantially the same as planned unit development; or

(II) Which has been zoned by the appropriate local government for the use contemplated by such development or activity; or

(III) With respect to which a development plan has been conditionally or finally approved by the appropriate governmental authority.

Source: L. 74, p. 340, § 1.

"Electorate", as used in subsection (1)(b), refers to the appropriate local electorate which is affected by the approval of a project and which accepts, by its approval, the consequences of a exemption from land use control under this article. City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981).

24-65.1-108. Effect of article - state agency or commission responses. (1) Whenever any person desiring to carry out development as defined in section 24-65.1-102 (1) is required to obtain a permit, to be issued by any state agency or commission for the purpose of authorizing or allowing such development, pursuant to this or any other statute or regulation promulgated thereunder, such agency or commission shall establish a reasonable time period, which shall not exceed sixty days following receipt of such permit application, within which such agency or commission must respond in writing to the applicant, granting or denying said permit or specifying all reasonable additional information necessary for the agency or commission to respond. If additional information is required, said agency or commission shall set a reasonable time period for response following the receipt of such information.

(2) Whenever a state agency or commission denies a permit, the denial must specify:

(a) The regulations, guidelines, and criteria or standards used in evaluating the application;

(b) The reasons for denial and the regulations, guidelines, and criteria or standards the application fails to satisfy; and

(c) The action that the applicant would have to take to satisfy the state agency's or commission's permit requirements.

(3) Whenever an application for a permit, as provided under this section, contains a statement describing the proposed nature, uses, and activities in conceptual terms for the development intended to be accomplished and is not accompanied with all additional information, including, without limitation, engineering studies, detailed plans and specifications, and zoning approval, or, whenever a hearing is required by the statutes, regulations, rules, ordinances, or resolutions thereof prior to the issuance of the requested permit, the agency or commission shall, within the time provided in this

section for response, indicate its acceptance or denial of the permit on the basis of the concept expressed in the statement of the proposed uses and activities contained in the application. Such conceptual approval shall be made subject to the applicant filing and completing all prerequisite detailed additional information in accordance with the usual filing requirements of the agency or commission within a reasonable period of time.

(4) All agencies and commissions authorized or required to issue permits for development shall adopt rules and regulations, or amend existing rules and regulations, so as to require that such agencies and commissions respond in the time and manner required in this section.

(5) Nothing in this section shall shorten the time allowed for responses provided by federal statute dealing with, or having a bearing on, the subject of any such application for permit.

(6) The provisions of this section shall not apply to applications approved, denied, or processed by a unit of local government.

Source: L. 74, p. 340, § 1.

PART 2

AREAS AND ACTIVITIES DESCRIBED - CRITERIA FOR ADMINISTRATION

24-65.1-201. Areas of state interest as determined by local governments. (1) Subject to the procedures set forth in part 4 of this article, a local government may designate certain areas of state interest from among the following:

(a) Mineral resource areas;

(b) Natural hazard areas;

(c) Areas containing, or having a significant impact upon, historical, natural, or archaeological resources of statewide importance; and

(d) Areas around key facilities in which development may have a material effect upon the key facility or the surrounding community.

Source: L. 74, p. 341, § 1.

Law reviews. For article, "Synthetic Fuels — Policy and Regulation", see 51 U. Colo. L. Rev. 465 (1980). For article, "Cumulative Impact Assessment of Western Energy Development: Will it Happen?", see 51 U. Colo. L. Rev. 551 (1980).

24-65.1-202. Criteria for administration of areas of state interest. (1) (a) Mineral resource areas designated as areas of state interest shall be protected and administered in such a manner as to permit the extraction and exploration of minerals therefrom, unless extraction and exploration would cause significant danger to public health and safety. If the local government having jurisdiction, after weighing sufficient technical or other evidence, finds that the economic value of the minerals present therein is less than the value of another existing or requested use, such other use should be given preference; however, other uses which would not interfere with the extraction and exploration of minerals may be permitted in such areas of state interest.

(b) Areas containing only sand, gravel, quarry aggregate, or limestone used for construction purposes shall be administered as provided by part 3 of article 1 of title 34, C.R.S.

(c) The extraction and exploration of minerals from any area shall be accomplished in a manner which causes the least practicable environmental disturbance, and surface areas disturbed thereby shall be reclaimed in accordance with the provisions of article 32 of title 34, C.R.S.

(d) Unless an activity of state interest has been designated or identified or unless it includes part or all of another area of state interest, an area of oil and gas or geothermal resource development shall not be designated as an area of state interest unless the state oil and gas conservation commission identifies such area for designation.

(2) (a) Natural hazard areas shall be administered as follows:

(I) Floodplains shall be administered so as to minimize significant hazards to public health and safety or to property. The Colorado water conservation board shall promulgate a model floodplain regulation no later than September 30, 1974. Open space activities such as agriculture, recreation, and mineral extraction shall be encouraged in the floodplains. Any combination of these activities shall be conducted in a mutually compatible manner. Building of structures in the floodplain shall be designed in terms of the availability of flood protection devices, proposed intensity of use, effects on the acceleration of floodwaters, potential significant hazards to public health and safety or to property, and other impact of such development on downstream communities such as the creation of obstructions during floods. Activities shall be discouraged which, in time of flooding, would create significant hazards to public health and safety or to property. Shallow wells, solid waste disposal sites, and septic tanks and sewage disposal systems shall be protected from inundation by floodwaters. Unless an activity of state interest is to be conducted therein, an area of corrosive soil, expansive soil and rock, or siltation shall not be designated as an area of state interest unless the Colorado soil conservation board, through the local soil conservation district, identifies such area for designation.

(II) Wildfire hazard areas in which residential activity is to take place shall be administered so as to minimize significant hazards to public health and safety or to property. The Colorado state forest service shall promulgate a model wildfire hazard area control regulation no later than September 30, 1974. If development is to take place, roads shall be adequate for service by fire trucks and other safety equipment. Firebreaks and other means of reducing conditions conducive to fire shall be required for wildfire hazard areas in which development is authorized.

(III) In geologic hazard areas all developments shall be engineered and administered in a manner that will minimize significant hazards to public health and safety or to property due to a geologic hazard. The Colorado geological survey shall promulgate a model geologic hazard area control regulation no later than September 30, 1974.

(b) After promulgation of guidelines for land use in natural hazard areas by the Colorado water conservation board, the Colorado soil conservation board through the soil conservation districts, the Colorado state forest service, and the Colorado geological survey, natural hazard areas shall be administered by local government in a manner which is consistent with the guidelines for land use in each of the natural hazard areas.

(3) Areas containing, or having a significant impact upon, historical, natural, or archaeological resources of statewide importance, as determined by the state historical society, the department of natural resources, and the appropriate local government, shall be administered by the appropriate state agency in conjunction with the appropriate local government in a manner that will allow man to function in harmony with, rather than be destructive to, these resources. Consideration is to be given to the protection of those areas essential for wildlife habitat. Development in areas containing historical, archaeological, or natural resources shall be conducted in a manner which will minimize damage to those resources for future use.

(4) The following criteria shall be applicable to areas around key facilities:

(a) If the operation of a key facility may cause a danger to public health and safety or to property, as determined by local government, the area around the key facility shall be designated and administered so as to minimize such danger; and

(b) Areas around key facilities shall be developed in a manner that will discourage traffic congestion, incompatible uses, and expansion of the demand for government services beyond the reasonable capacity of the community or region to provide such services as determined by local government. Compatibility with nonmotorized traffic shall be encouraged. A development that imposes burdens or deprivation on the communities of a region cannot be justified on the basis of local benefit alone.

(5) In addition to the criteria described in subsection (4) of this section, the following criteria shall be applicable to areas around particular key facilities:

(a) Areas around airports shall be administered so as to:

(I) Encourage land use patterns for housing and other local government needs that will separate uncontrollable noise sources from residential and other noise-sensitive areas; and

(II) Avoid danger to public safety and health or to property due to aircraft crashes.

(b) Areas around major facilities of a public utility shall be administered so as to:

(I) Minimize disruption of the service provided by the public utility; and

(II) Preserve desirable existing community patterns.

(c) Areas around interchanges involving arterial highways shall be administered so as to:

(I) Encourage the smooth flow of motorized and nonmotorized traffic;

(II) Foster the development of such areas in a manner calculated to preserve the smooth flow of such traffic; and

(III) Preserve desirable existing community patterns.

(d) Areas around rapid or mass transit terminals, stations, or guideways shall be developed in conformance with the applicable municipal master plan adopted pursuant to section 31-23-206, C.R.S., or any applicable master plan adopted pursuant to section 30-28-108, C.R.S. If no such master plan has been adopted, such areas shall be developed in a manner designed to minimize congestion in the streets; to secure safety from fire, floodwaters, and other dangers; to promote health and general welfare; to provide adequate light and air; to prevent the overcrowding of land; to avoid undue concentration of population; and to facilitate the adequate provision of transportation, water, sewerage, schools, parks, and other public requirements. Such development in such areas shall be made with reasonable consideration, among other things, as to the character of the area and its peculiar suitability for particular uses and with a view to conserving the value of buildings and encouraging the most appropriate use of land throughout the jurisdiction of the applicable local government.

Source: L. 74, p. 341, § 1; L. 75, p. 1270, § 4; L. 88, p. 1436, § 34.

24-65.1-203. Activities of state interest as determined by local governments. (1) Subject to the procedures set forth in part 4 of this article, a local government may designate certain activities of state interest from among the following:

(a) Site selection and construction of major new domestic water and sewage treatment systems and major extension of existing domestic water and sewage treatment systems;

(b) Site selection and development of solid waste disposal sites except those sites specified in section 25-11-203 (1), C.R.S., sites designated pursuant to part 3 of article 11 of title 25, C.R.S., and hazardous waste disposal sites, as defined in section 25-15-200.3, C.R.S.;

(c) Site selection of airports;

(d) Site selection of rapid or mass transit terminals, stations, and fixed guideways;

(e) Site selection of arterial highways and interchanges and collector highways;

(f) Site selection and construction of major facilities of a public utility;

(g) Site selection and development of new communities;

(h) Efficient utilization of municipal and industrial water projects; and

(i) Conduct of nuclear detonations.

Source: L. 74, p. 344, § 1; L. 79, pp. 1067, 1070, § § 9, 2; L. 83, p. 1105, § 26.

Law reviews. For article, "Synthetic Fuels — Policy and Regulation", see 51 U. Colo. L. Rev. 465 (1980). For article, "The Emerging Relationship Between Environmental Regulations and Colorado Water Law", see 53 U. Colo. L. Rev. 597 (1982). For article, "Quality Versus Quantity: The Continued Right to Appropriate — Part I", see 15 Colo. Law. 1035 (1986).

24-65.1-204. Criteria for administration of activities of state interest. (1) (a) New domestic water and sewage treatment systems shall be constructed in areas which will result in the proper utilization of existing treatment plants and the orderly development of domestic water and sewage treatment systems of adjacent communities.

(b) Major extensions of domestic water and sewage treatment systems shall be permitted in those areas in which the anticipated growth and development that may occur as a result of such extension can be accommodated within the financial and environmental capacity of the area to sustain such growth and development.

(2) Major solid waste disposal sites shall be developed in accordance with sound conservation practices and shall emphasize, where feasible, the recycling of waste materials. Consideration shall be given to longevity and subsequent use of waste disposal sites, soil and wind conditions, the potential problems of pollution inherent in the proposed site, and the impact on adjacent property owners, compared with alternate locations.

(3) Airports shall be located or expanded in a manner which will minimize disruption to the environment of existing communities, minimize the impact on existing community services, and complement the economic and transportation needs of the state and the area.

(4) (a) Rapid or mass transit terminals, stations, or guideways shall be located in conformance with the applicable municipal master plan adopted pursuant to section 31-23-206, C.R.S., or any applicable master plan adopted pursuant to section 30-28-108, C.R.S. If no such master plan has been adopted, such areas shall be developed in a manner designed to minimize congestion in the streets; to secure safety from fire, floodwaters, and other dangers; to promote health and general welfare; to provide adequate light and air; to prevent the overcrowding of land; to avoid undue concentration of population; and to facilitate the adequate provision of transportation, water, sewerage, schools, parks, and other public requirements. Activities shall be conducted with reasonable consideration, among other things, as to the character of the area and its peculiar suitability for particular uses and with a view to conserving the value of buildings and encouraging the most appropriate use of land throughout the jurisdiction of the applicable local government.

(b) Proposed locations of rapid or mass transit terminals, stations, and fixed guideways which will not require the demolition of residences or businesses shall be given preferred consideration over competing alternatives.

(c) A proposed location of a rapid or mass transit terminal, station, or fixed guideway that imposes a burden or deprivation on a local government cannot be justified on the basis of local benefit alone, nor shall a permit for such a location be denied solely because the location places a burden or deprivation on one local government.

(5) Arterial highways and interchanges and collector highways shall be located so that:

(a) Community traffic needs are met;

(b) Desirable community patterns are not disrupted; and

(c) Direct conflicts with adopted local government, regional, and state master plans are avoided.

(6) Where feasible, major facilities of public utilities shall be located so as to avoid direct conflict with adopted local government, regional, and state master plans.

(7) When applicable, or as may otherwise be provided by law, a new community design shall, at a minimum, provide for transportation, waste disposal, schools, and other governmental services in a manner that will not overload facilities of existing communities of the region. Priority shall be given to the development of total communities which provide for commercial and industrial activity, as well as residences, and for internal transportation and circulation patterns.

(8) Municipal and industrial water projects shall emphasize the most efficient use of water, including, to the extent permissible under existing law,

the recycling and reuse of water. Urban development, population densities, and site layout and design of storm water and sanitation systems shall be accomplished in a manner that will prevent the pollution of aquifer recharge areas.

(9) Nuclear detonations shall be conducted so as to present no material danger to public health and safety. Any danger to property shall not be disproportionate to the benefits to be derived from a detonation.

Source: L. 74, p. 344, § 1; L. 75, p. 1270, § 5.

Law reviews. For article, "The Emerging Relationship Between Environmental Regulations and Colorado Water Law", see 53 U. Colo. L. Rev. 597 (1982).

PART 3

LEVELS OF GOVERNMENT INVOLVED AND THEIR FUNCTIONS

24-65.1-301. Functions of local government. (1) Pursuant to this article, it is the function of local government to:

(a) Designate matters of state interest after public hearing, taking into consideration:

(I) The intensity of current and foreseeable development pressures; and

(II) Applicable guidelines for designation issued by the applicable state agencies;

(b) Hold hearings on applications for permits for development in areas of state interest and for activities of state interest;

(c) Grant or deny applications for permits for development in areas of state interest and for activities of state interest;

(d) Receive recommendations from state agencies and other local governments relating to matters of state interest;

(e) Send recommendations to other local governments and the Colorado land use commission relating to matters of state interest; and

(f) Act, upon request of the Colorado land use commission, with regard to specific matters of state interest.

Source: L. 74, p. 346, § 1.

24-65.1-302. Functions of other state agencies. (1) Pursuant to this article, it is the function of other state agencies to:

(a) Send recommendations to local governments and the Colorado land use commission relating to designation of matters of state interest on the basis of current and developing information; and

(b) Provide technical assistance to local governments concerning designation of and guidelines for matters of state interest.

(2) Primary responsibility for the recommendation and provision of technical assistance functions described in subsection (1) of this section is upon:

(a) The Colorado water conservation board, acting in cooperation with the Colorado soil conservation board, with regard to floodplains;

(b) The Colorado state forest service, with regard to wildfire hazard areas;

(c) The Colorado geological survey, with regard to geologic hazard areas, geologic reports, and the identification of mineral resource areas;

(d) The Colorado division of mines, with regard to mineral extraction and the reclamation of land disturbed thereby;

(e) The Colorado soil conservation board and soil conservation districts, with regard to resource data inventories, soils, soil suitability, erosion and sedimentation, floodwater problems, and watershed protection; and

(f) The division of wildlife of the department of natural resources, with regard to significant wildlife habitats.

(3) Pursuant to section 24-65.1-202 (1) (d), the oil and gas conservation commission of the state of Colorado may identify an area of oil and gas development for designation by local government as an area of state interest.

Source: L. 74, p. 346, § 1.

PART 4

DESIGNATION OF MATTERS OF STATE INTEREST - GUIDELINES FOR ADMINISTRATION

24-65.1-401. Designation of matters of state interest. (1) After public hearing, a local government may designate matters of state interest within its jurisdiction, taking into consideration:

(a) The intensity of current and foreseeable development pressures; and

(b) Applicable guidelines for designation issued by the Colorado land use commission after recommendation from other state agencies, if appropriate. In adopting such guidelines, the Colorado land use commission shall be guided by the standards set forth in this article applicable to local governments.

(2) A designation shall:

(a) Specify the boundaries of the proposed area; and

(b) State reasons why the particular area or activity is of state interest, the dangers that would result from uncontrolled development of any such area or uncontrolled conduct of such activity, and the advantages of development of such area or conduct of such activity in a coordinated manner.

Source: L. 74, p. 347, § 1.

24-65.1-402. Guidelines - regulations. (1) The local government shall develop guidelines for administration of the designated matters of state interest. The content of such guidelines shall be such as to facilitate administration of matters of state interest consistent with sections 24-65.1-202 and 24-65.1-204.

(2) A local government may adopt regulations interpreting and applying its adopted guidelines in relation to specific developments in areas of state interest and to specific activities of state interest.

(3) No provision in this article shall be construed as prohibiting a local government from adopting guidelines or regulations containing requirements

which are more stringent than the requirements of the criteria listed in sections 24-65.1-202 and 24-65.1-204.

Source: L. 74, p. 347, § 1.

24-65.1-403. Technical and financial assistance. (1) Appropriate state agencies shall provide technical assistance to local governments in order to assist local governments in designating matters of state interest and adopting guidelines for the administration thereof.

(2) (a) The department of local affairs shall oversee and coordinate the provision of technical assistance and provide financial assistance as may be authorized by law.

(b) The department of local affairs shall determine whether technical or financial assistance or both are to be given to a local government on the basis of the local government's:

(I) Showing that current or reasonably foreseeable development pressures exist within the local government's jurisdiction; and

(II) Plan describing the proposed use of technical assistance and expenditure of financial assistance.

(3) (a) Any local government applying for federal or state financial assistance for floodplain studies shall provide prior notification to the Colorado water conservation board. The board shall coordinate and prescribe the standards for all floodplain studies conducted pursuant to this article, including those conducted by federal, local, or other state agencies, to the end that reasonably uniform standards can be applied to the identification and designation of all floodplains within the state and to minimize duplication of effort.

(b) No floodplains shall be designated by any local government until such designation has been first approved by the Colorado water conservation board as provided in sections 30-28-111 and 31-23-301, C.R.S.

Source: L. 74, p. 347, § 1; L. 77, p. 1241, § 1.

24-65.1-404. Public hearing - designation of an area or activity of state interest and adoption of guidelines by order of local government. (1) The local government shall hold a public hearing before designating an area or activity of state interest and adopting guidelines for administration thereof.

(2) (a) Notice, stating the time and place of the hearing and the place at which materials relating to the matter to be designated and guidelines may be examined, shall be published once at least thirty days and not more than sixty days before the public hearing in a newspaper of general circulation in the county. The local government shall send written notice to the Colorado land use commission of a public hearing to be held for the purpose of designation and adoption of guidelines at least thirty days and not more than sixty days before such hearing.

(b) Any person may request, in writing, that his name and address be placed on a mailing list to receive notice of all hearings held pursuant to this section. If the local government decides to maintain such a mailing list, it shall mail notices to each person paying an annual fee reasonably related to the cost of production, handling, and mailing of such notice. In order to have his name and address retained on said mailing list, the person shall resubmit his name and address and pay such fee before January 31 of each year.

(3) Within thirty days after completion of the public hearing, the local government, by order, may adopt, adopt with modification, or reject the particular designation and guidelines; but the local government, in any case, shall have the duty to designate any matter which has been finally determined to be a matter of state interest and adopt guidelines for the administration thereof.

(4) After a matter of state interest is designated pursuant to this section, no person shall engage in development in such area, and no such activity shall be conducted until the designation and guidelines for such area or activity are finally determined pursuant to this article.

(5) Upon adoption by order, all relevant materials relating to the designation and guidelines shall be forwarded to the Colorado land use commission for review.

Source: L. 74, p. 348, § 1.

Failure to give land use commission notice of hearing minor defect. Failure to give formal notice to the Colorado land use commission, as required by subsection (2)(a), is a minor defect which cannot render otherwise valid regulations void. City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981).

24-65.1-405. Report of local government's progress. (1) Not later than one hundred eighty days after May 17, 1974, each local government shall report to the Colorado land use commission, on a form to be furnished by the Colorado land use commission, the progress made toward designation and adoption of guidelines for administration of matters of state interest.

(2) Upon the basis of the information contained in such reports and any information received pursuant to any other relevant provision of this article, the Colorado land use commission may take appropriate action pursuant to section 24-65-104 (2) (a).

Source: L. 74, p. 348, § 1.

24-65.1-406. Colorado land use commission review of local government order containing designation and guidelines. (1) Not later than thirty days after receipt of a local government order designating a matter of state interest and adopting guidelines for the administration thereof, the Colorado land use commission shall review the contents of such order on the basis of the relevant provisions of part 2 of this article and shall accept the designation and guidelines or recommend modification thereof.

(2) If the Colorado land use commission decides that modification of the designation or guidelines is required, the Colorado land use commission shall, within said thirty-day period, submit to the local government written notification of its recommendations and shall specify in writing the modifications which the Colorado land use commission deems necessary for compliance with the relevant provisions of part 2 of this article.

(3) Not later than thirty days after receipt of the modifications recommended by the Colorado land use commission, a local government shall:

(a) Modify the original order in a manner consistent with the recommendations of the Colorado land use commission and resubmit the order to the Colorado land use commission; or

(b) Notify the Colorado land use commission that the Colorado land use commission's recommendations are rejected.

Source: L. 74, p. 349, § 1.

Applied in Board of County Comm'rs v. District Court, 632 P.2d 1017 (Colo. 1981); City & County of Denver v. Bergland, 517 F. Supp. 155 (D. Colo. 1981).

24-65.1-407. Colorado land use commission may initiate identification, designation, and promulgation of guidelines for matters of state interest. (1) (a) The Colorado land use commission may submit a formal request to a local government to take action with regard to a specific matter which said commission considers to be of state interest within the local government's jurisdiction. Such request shall identify the specific matter and shall set forth the information required in section 24-65.1-401 (2). Not later than thirty days after receipt of such request, the local government shall publish notice and hold a hearing within sixty days, pursuant to the provisions of section 24-65.1-404, and issue its order thereunder.

(b) After receipt by a local government of a request from the Colorado land use commission pursuant to paragraph (a) of this subsection (1), no person shall engage in development in the area or conduct the activity specifically described in said request until the local government has held its hearing and issued its order relating thereto.

(c) If the local government's order fails to designate such matter and adopt guidelines therefor, or, after designation, fails to adopt guidelines therefor pursuant to standards set forth in this article applicable to local governments, the Colorado land use commission may seek judicial review of such order or guidelines by a trial de novo in the district court for the judicial district in which the local government is located. During the pendency of such court proceedings, no person shall engage in development in the area or conduct the activity specifically described in said request except on such terms and conditions as authorized by the court.

Source: L. 74, p. 349, § 1.

Law reviews. For article, "Synthetic Fuels — Policy and Regulation", see 51 U. Colo. L. Rev. 465 (1980). For article, "Cumulative Impact Assessment of Western Energy Development: Will it Happen?", see 51 U. Colo. L. Rev. 551 (1980).

Subsection (1)(c) held constitutional. Colorado Land Use Comm'n v. Board of County Comm'rs, 199 Colo. 7, 604 P.2d 32 (1979).

Court reviews questions of illegality or impropriety on local government's part. Review de novo under this section does not take on the meaning applied in the review of judicial or quasi-judicial proceedings: trial anew on the merits; rather, it constitutes a review of questions of illegality or impropriety on the part of the local government. Colorado Land Use Comm'n v. Board of County Comm'rs, 199 Colo. 7, 604 P.2d 32 (1979).

Applied in Board of County Comm'rs v. District Court, 632 P.2d 1017 (Colo. 1981).

PART 5

PERMITS FOR DEVELOPMENT IN AREAS OF STATE INTEREST AND FOR CONDUCT OF ACTIVITIES OF STATE INTEREST

24-65.1-501. Permit for development in area of state interest or to conduct an activity of state interest required. (1) (a) Any person desiring to engage in development in an area of state interest or to conduct an activity of state interest shall file an application for a permit with the local government in which such development or activity is to take place. The application shall be filed on a form prescribed by the Colorado land use commission. A reasonable fee determined by the local government sufficient to cover the cost of processing the application, including the cost of holding the necessary hearings, shall be paid at the time of filing such application.

(b) The requirement of paragraph (a) of this subsection (1) that a public utility obtain a permit shall not be deemed to waive the requirements of article 5 of title 40, C.R.S., that a public utility obtain a certificate of public convenience and necessity.

(2) (a) Not later than thirty days after receipt of an application for a permit, the local government shall publish notice of a hearing on said application. Such notice shall be published once in a newspaper of general circulation in the county, not less than thirty days nor more than sixty days before the date set for hearing, and shall be given to the Colorado land use commission. The Colorado land use commission may give notice to such other persons as it determines not later than fourteen days before such hearing.

(b) If a person proposes to engage in development in an area of state interest or to conduct an activity of state interest not previously designated and for which guidelines have not been adopted, the local government may hold one hearing for determination of designation and guidelines and granting or denying the permit.

(c) The local government may maintain a mailing list and send notice of hearings relating to permits in a manner similar to that described in section 24-65.1-404 (2) (b).

(3) The local government may approve an application for a permit to engage in development in an area of state interest if the proposed development complies with the local government's guidelines and regulations governing such area. If the proposed development does not comply with the guidelines and regulations, the permit shall be denied.

(4) The local government may approve an application for a permit to conduct an activity of state interest if the proposed activity complies with the local government's regulations and guidelines for conduct of such activity. If the proposed activity does not comply with the guidelines and regulations, the permit shall be denied.

(5) The local government conducting a hearing pursuant to this section shall:

(a) State, in writing, reasons for its decision, and its findings and conclusions; and

(b) Preserve a record of such proceedings.

(6) After May 17, 1974, any person desiring to engage in a development in a designated area of state interest or to conduct a designated activity of

state interest who does not obtain a permit pursuant to this section may be enjoined by the Colorado land use commission or the appropriate local government from engaging in such development or conducting such activity.

Source: L. 74, p. 350, § 1.

Law reviews. For comment, "Regionalism or Parochialism: The Land Use Planner's Dilemma", see 48 U. Colo. L. Rev. 575 (1977).

Applied in C & M Sand & Gravel v. Board of County Comm'rs, 673, P.2d 1013 (Colo. App. 1983).

24-65.1-502. Judicial review. The denial of a permit by a local government agency shall be subject to judicial review in the district court for the judicial district in which the major development or activity is to occur.

Source: L. 74, p. 351, § 1.

Applied in Board of County Comm'rs v. District Court, 632 P.2d 1017 (Colo. 1981).

ARTICLE 66

Planning Aid to Local Governments

24-66-101. Short title. This article shall be known and may be cited as the "Colorado Planning Aid Fund Act".

Source: L. 71, p. 1069, § 1; C.R.S. 1963, § 106-5-1.

24-66-102. Legislative declaration. The general assembly finds and declares that the rapid growth and development of the state has resulted in demands for land use planning not only statewide but also in cities, towns, counties, and regions throughout the state; that certain of these units of local government may not be financially able adequately to plan for the demands of such growth; and that, in order to provide for necessary planning assistance to such units of local government, it is the intention of the general assembly to establish a state-local government planning aid fund.

Source: L. 71, p. 1069, § 1; C.R.S. 1963, § 106-5-2.

24-66-103. Planning aid fund - qualification. (1) There is hereby created in the office of the state treasurer the state-local government planning aid fund. There shall be credited to said fund such moneys as may, from time to time, be appropriated by the general assembly for purposes of this article.

(2) Moneys in the state-local government planning aid fund shall be available to municipalities, counties, and regional planning agencies which:

COUNTY PLANNING AND BUILDING CODES

ARTICLE 28

County Plannin- -

SB 35 (1972) (in part)

Cross references: For t ... e 24.

PART 1

COUNTY PLANNING

30-28-101. Definitions. As used in this part 1, unless the context otherwise requires:

30-28-133. Subdivision regulations. (1) Every county in the state which does not have a county planning commission on July 1, 1971, shall create a county planning commission in accordance with the provisions of section 30-28-103. Every county planning commission in the state shall develop, propose, and recommend subdivision regulations, and the board of county commissioners shall adopt and enforce subdivision regulations for all land within the unincorporated areas of the county in accordance with this section not later than September 1, 1972. Before finally adopting any subdivision regulations, the board of county commissioners shall hold a public hearing thereon, and at least thirty days' notice of the time and place of such hearing shall be given by at least one publication in a newspaper of general circulation in the county. Before adopting any such subdivision regulations, the board of county commissioners may revise, alter, or amend any such subdivision regulations developed, proposed, or recommended by the county planning commission. In the event the board of county commissioners of any county in the state has not adopted subdivision regulations by September 2, 1972, the Colorado land use commission may promulgate such subdivision regulations for such areas of the county for which no subdivision regulations exist. Such subdivision regulations shall be in full force and effect and enforced by the board of county commissioners. If at any time thereafter the board of county commissioners adopts its own subdivision regulations for land within the unincorporated areas of the county, such regulations shall be no less stringent than the regulations promulgated by the Colorado land use commission under this subsection (1). All subdivision regulations, and all amendments thereto, adopted by a board of county commissioners shall be transmitted to the Colorado land use commission.

(2) Prior to the adoption of the regulations referred to in this section, a public hearing shall be held thereupon in the county in which said territory or any part thereof is situated. A copy of such regulations shall be certified by the commission and thereupon filed with the county clerk and recorder of the county in which said territory is situated.

(3) Subdivision regulations adopted by a board of county commissioners pursuant to this section shall require subdividers to submit to the board of county commissioners data, surveys, analyses, studies, plans, and designs, in the form prescribed by the board of county commissioners, of the following items:

(a) Property survey and ownership of the surface and mineral estates including mineral lessees, if any;

(b) Relevant site characteristics and analyses applicable to the proposed subdivision including the following, which shall be submitted by the subdivider with the sketch plan:

(I) Reports concerning streams, lakes, topography, and vegetation;

(II) Reports concerning geologic characteristics of the area significantly affecting the land use and determining the impact of such characteristics on the proposed subdivision;

(III) In areas of potential radiation hazard to the proposed future land use, evaluations of these potential radiation hazards;

(IV) Maps and tables concerning suitability of types of soil in the proposed subdivision, in accordance with any standard soil classifications and procedures therefor, for the proposed use;

(c) A plat and other documentation showing the layout or plan of development, including, where applicable, the following information:

(I) Total development area;

(II) Total number of proposed dwelling units;

(III) Total number of square feet of proposed nonresidential floor space;

(IV) Total number of proposed off-street parking spaces, excluding those associated with single-family residential development;

(V) Estimated total number of gallons per day of water system requirements where a distribution system is proposed;

(VI) Estimated total number of gallons per day of sewage to be treated where a central sewage treatment facility is proposed or sewage disposal means and suitability where no central sewage treatment facility is proposed;

(VII) Estimated construction cost and proposed method of financing of the streets and related facilities, water distribution system, sewage collection system, storm drainage facilities, and such other utilities as may be required of the developer by the county;

(VIII) Maps and plans for facilities to prevent storm waters in excess of historic runoff, caused by the proposed subdivision, from entering, damaging, or being carried by conduits, water supply ditches and appurtenant structures, and other storm drainage facilities;

(d) Adequate evidence that a water supply that is sufficient in terms of quality, quantity, and dependability will be available to ensure an adequate supply of water for the type of subdivision proposed. Such evidence may include, but shall not be limited to:

(I) Evidence of ownership or right of acquisition of or use of existing and proposed water rights;

(II) Historic use and estimated yield of claimed water rights;

(III) Amenability of existing rights to a change in use;

(IV) Evidence that public or private water owners can and will supply water to the proposed subdivision stating the amount of water available for use within the subdivision and the feasibility of extending service to that area;

(V) Evidence concerning the potability of the proposed water supply for the subdivision.

(4) Subdivision regulations adopted by the board of county commissioners pursuant to this section shall also include, as a minimum, provisions governing the following matters:

(a) Sites and land areas for schools and parks when such are reasonably necessary to serve the proposed subdivision and the future residents thereof. Such provisions may include:

(I) Reservation of such sites and land areas, for acquisition by the county;

(II) Dedication of such sites and land areas to the county or to the public or, in lieu thereof, payment of a sum of money not exceeding the full market value of such sites and land areas or a combination of such dedication and such payment; except that the value of such combination shall not exceed the full market value of such sites and land areas. If such sites and land areas are dedicated to the county or the public, the board of county commissioners may, at the request of the affected entity, sell the land. Any such sums, when required, or moneys paid to the board of county commissioners from the sale of such dedicated sites and land areas shall be held by the board of county commissioners:

(A) For the acquisition of reasonably necessary sites and land areas or for other capital outlay purposes for schools or parks;

(B) For the development of said sites and land areas for park purposes; or

(C) For growth-related planning functions by school districts for educational purposes.

(III) Dedication of such sites and land areas for the use and benefit of the owners and future owners in the proposed subdivision.

(b) Standards and technical procedures applicable to storm drainage plans and related designs, in order to ensure proper drainage ways, which may require, in the opinion of the board of county commissioners, detention facilities which may be dedicated to the county or the public, as are deemed necessary to control, as nearly as possible, storm waters generated exclusively within a subdivision from a one hundred year storm which are in excess of the historic runoff volume of storm water from the same land area in its undeveloped and unimproved condition;

(c) Standards and technical procedures applicable to sanitary sewer plans and designs, including soil percolation testing and required percolation rates and site design standards for on-lot sewage disposal systems when applicable;

(d) Standards and technical procedures applicable to water systems.

(4.3) After final approval of a subdivision plan or plat and receipt of dedications of sites and land areas or payments in lieu thereof required pursuant to subparagraph (II) of paragraph (a) of subsection (4) of this section, the board of county commissioners shall give written notification to the appropriate school districts and local government entities. Following such notice, a school district or local government entity may request and shall demonstrate to the board of county commissioners a need for land or moneys for a use authorized by subparagraph (II) of paragraph (a) of subsection (4) of this section. When a board of county commissioners votes to allocate land or moneys for subject project, such land or moneys shall immediately be transferred to the appropriate school district or local government entity.

(4.5) Subdivision regulations adopted by a board of county commissioners may provide for the protection and assurance of access to sunlight for solar energy devices by considering the use of restrictive covenants or solar easements, height restrictions, side yard and setback requirements, street orientation and width requirements, or other permissible forms of land use controls.

(5) No subdivision shall be approved under section 30-28-110 (3) and (4) until such data, surveys, analyses, studies, plans, and designs as may be required by this section and by the county planning commission or the board of county commissioners have been submitted, reviewed, and found to meet all sound planning and engineering requirements of the county contained in its subdivision regulations.

(6) No board of county commissioners shall approve any preliminary plan or final plat for any subdivision located within the county unless the subdivider has provided the following materials as part of the preliminary plan or final plat subdivision submission:

(a) Evidence to establish that definite provision has been made for a water supply that is sufficient in terms of quantity, dependability, and quality to provide an appropriate supply of water for the type of subdivision proposed;

(b) Evidence to establish that, if a public sewage disposal system is proposed, provision has been made for such system and, if other methods of sewage disposal are proposed, evidence that such systems will comply with state and local laws and regulations which are in effect at the time of submission of the preliminary plan or final plat;

(c) Evidence to show that all areas of the proposed subdivision which may involve soil or topographical conditions presenting hazards or requiring special precautions have been identified by the subdivider and that the proposed uses of these areas are compatible with such conditions.

(7) The board of county commissioners shall send a copy of the preliminary plan or final plat submission to the Colorado land use commission upon receipt of said submission.

(8) Upon adoption and transmittal of subdivision regulations by the board of county commissioners in accordance with this section and upon a finding by the Colorado land use commission that such subdivision regulations are in compliance with this section, the provisions of subsection (7) of this section shall no longer apply, and the Colorado land use commission shall so notify the board of county commissioners.

(9) The subdivision regulations adopted under this section may provide that, without a hearing or compliance with any of the submission, referral, or review requirements in this section and section 30-28-136, the board of county commissioners may approve a correction plat if the sole purpose of such correction plat is to correct one or more technical errors in an approved plat and where such correction plat is consistent with an approved preliminary plan.

(10) It is recognized that surface and mineral estates are separate and distinct interests in land and that one may be severed from the other and that the owners of subsurface mineral interests and their lessees, if any, are entitled to the notice specified in section 31-23-215, C.R.S., and shall be recognized by the commission as having the same rights and privileges as surface owners.

(11) The subdivision regulations adopted under this section may provide for the payment of a sum of money or proof of a line of credit or other fees in connection with a subdivision on a per-acre basis, to represent an equitable contribution to the total costs of the drainage facilities in the drainage basin in which the subdivision is located. The subdivision regulations shall provide for the repayment to a subdivider, from any surplus basin funds available, of any costs he incurs because of compliance with the plans for the development of drainage basins in excess of the sum of the drainage fees assessed against his acreage. When the subdivision regulations require such payment, a plan for the development of drainage basins shall be adopted pursuant to section 30-28-106 (3) (d). The provisions of this section shall not apply to any area which is within an existing drainage district organized or created pursuant to law without the approval of such district.

Source: L. 61, p. 592, § 2; CRS 53, § 106-2-35; C.R.S. 1963, § 106-2-34; L. 67, p. 110, § 1; L. 71, p. 1055, § § 1, 2; L. 72, p. 501, § § 6, 7; L. 73, p. 1085, § § 1, 2; L. 75, p. 1001, § 1; L. 77, p. 1453, § 2; L. 79, pp. 1162, 1167, 1169, § § 9, 1, 2, 1; L. 83, p. 1236, § 5; L. 84, pp. 826, 827, § § 1, 1.

Law reviews. For article, "1974 Land Use Legislation in Colorado", see 51 Den. L.J. 467 (1974). For comment, "Pre-Enforcement Judicial Review: CF & I Steel Corp. v. Colorado

Air Pollution Control Commission'', see 58 Den. L.J. 693 (1981). For article, ''Property Tax Incentives for Implementing Soil Conservation Programs Under Constitutional Taxing Limitations'', see 59 Den. L.J. 485 (1982). For note, ''The Permissible Scope of Compulsory Requirements for Land Development in Colorado'', see 54 U. Colo. L. Rev. 447 (1983). For article, ''Subdivision Improvement Requirements and Guarantees in Colorado'', see 14 Colo. Law. 554 (1985).

A landowner must comply with all county as well as state subdivision requirements. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

But county subdivision regulations are of primary importance. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

Land use regulations generally may be applied prospectively only. Board of County Comm'rs v. Goldenrod Corp., 43 Colo. App. 221, 601 P.2d 360 (1979).

Not necessary to pursue administrative remedies where county initiates court action to enforce regulations. Although usually a landowner must first present his objections to land use regulations to the appropriate administrative agency before challenging those regulations in the courts, where a board of county commissioners initiates an action to enforce its subdivision regulations, a landowner is under no obligation to first exhaust available administrative remedies prior to asserting a defense predicated upon allegations of unconstitutionality. Board of County Comm'rs v. Goldenrod Corp., 43 Colo. App. 221, 601 P.2d 360 (1979).

Applied in Stagecoach Property Owners Ass'n v. Young's Ranch, 658 P.2d 1378 (Colo. App. 1982); Winslow v. Morgan County Comm'rs, 697 P.2d 1141 (Colo. App. 1985); Beaver Meadows v. Bd. of County Comm'rs, 709 P.2d 928 (Colo. 1985).

30-28-133.1. Subdivision plan or plat - access to public highways. No person may submit an application for subdivision approval to a local authority unless the subdivision plan or plat provides, pursuant to section 43-2-147, C.R.S., that all lots and parcels created by the subdivision will have access to the state highway system in conformance with the state highway access code.

Source: L. 80, p. 796, § 57; L. 82, p. 626, § 32.

Applied in Beaver Meadows v. Bd. of County Comm'rs, 709 P.2d 928 (Colo. 1985).

30-28-134. Telecommunications research facilities of the United States - inclusions in planning and zoning. Any zoning plan, modification thereof, or variance therefrom adopted or granted under this part 1 on or after April 23, 1969, shall comply with the requirements of part 6 of article 11 of this title.

Source: L. 69, p. 238, § 2; C.R.S. 1963, § 106-2-35.

30-28-135. Safety glazing materials. The board of county commissioners of each county in this state shall adopt standards governing the use of safety glazing materials for hazardous locations in the unincorporated areas of the county. No building permit shall be issued for the construction, reconstruction, or alteration of any structure in the unincorporated area of such county unless such construction, reconstruction, or alteration conforms to the standards adopted pursuant to this section. The county building inspector shall inspect all places to determine whether such places are in compliance with the standards for the use of safety glazing materials.

Source: L. 71, p. 885, § 2; C.R.S. 1963, § 106-2-36; L. 86, p. 501, § 122.

30-28-136. Referral and review requirements. (1) Upon receipt of a complete preliminary plan submission, the board of county commissioners or its authorized representative shall distribute copies of prints of the plan as follows:

(a) To the appropriate school districts;

(b) To each county or municipality within a two-mile radius of any portion of the proposed subdivision;

(c) To any utility, local improvement and service district, or ditch company, when applicable;

(d) To the Colorado state forest service, when applicable;

(e) To the appropriate planning commission;

(f) To the local soil conservation district board within the county for explicit review and recommendations regarding soil suitability, floodwater problems, and watershed protection. Such referral shall be made even though all or part of a proposed subdivision is not located within the boundaries of a conservation district.

(g) When applicable, to the county, district, regional, or state department of health, for its review of the on-lot sewage disposal reports, for review of the adequacy of existing or proposed sewage treatment works to handle the estimated effluent, and for a report on the water quality of the proposed water supply to serve the subdivision. The department of health to which the plan is referred may require the subdivider to submit additional engineering or geological reports or data and to conduct a study of the economic feasibility of a sewage treatment works prior to making its recommendations. No plan shall receive the approval of the board of county commissioners unless the department of health to which the plan is referred has made a favorable recommendation regarding the proposed method of sewage disposal.

(h) (I) To the state engineer for an opinion regarding material injury likely to occur to decreed water rights by virtue of diversion of water necessary or proposed to be used to supply the proposed subdivision and adequacy of proposed water supply to meet requirements of the proposed subdivision. If the state engineer finds such injury or finds inadequacy, he shall express such finding in an opinion in writing to the board of county commissioners, stating the reason for his finding, including, but not limited to, the amount of additional or exchange water that may be required to prevent such injury. In the event the subdivision is approved notwithstanding the state engineer's opinion, the subdivider shall furnish to all potential purchasers a copy of the state engineer's opinion prior to the sale or a synopsis of the opinion; except that the subdivider need not supply the potential purchaser with a copy of such opinion or synopsis if, in the opinion of the board of county commissioners, the subdivider has corrected the injury or inadequacy set forth in the state engineer's finding.

(II) A municipality or quasi-municipality, upon receiving the preliminary plan designating said municipality or quasi-municipality as the source of water for a proposed subdivision, shall file, with the board of county commissioners and the state engineer, a statement documenting the amount of water which can be supplied by said municipality or quasi-municipality to proposed subdivisions without causing injury to existing water rights. The state engineer shall file, with said board of county commissioners, written comments on the report. If, in the judgment of the state engineer, the report is insufficient to issue an opinion, the state engineer shall notify the board of county commissioners to this effect, indicating the deficiencies.

(i) To the Colorado geological survey for an evaluation of those geologic factors which would have a significant impact on the proposed use of the land.

(2) The agencies named in this section shall make recommendations within thirty-five days after the mailing by the county or its authorized representative of such plans unless a necessary extension of not more than thirty days has been consented to by the subdivider and the board of county commissioners of the county in which the subdivision area is located. The failure of any agency to respond within thirty-five days or within the period of an extension shall, for the purpose of the hearing on the plan, be deemed an approval of such plan; except that, where such plan involves twenty or more dwelling units, a school district shall be required to submit within said time limit specific recommendations with respect to the adequacy of school sites and the adequacy of school structures.

(3) The provisions of this part 1 shall not modify the duties or enlarge the authority of the state engineer or the division engineers nor divest the water courts of jurisdiction over actions concerning water right determinations and administration; neither shall any opinion of the state engineer submitted under subsection (1) (h) of this section nor any finding by a board of county commissioners concerning subdivision water supply matters create any presumption concerning injury or noninjury to water rights; and neither the state engineer's opinion nor the finding of the board of county commissioners may be used as evidence in any administrative proceeding or in any judicial proceeding concerning water right determinations or administration.

(4) Each month the board of county commissioners or its appointed representative shall transmit to the Colorado land use commission copies of the notice of filing and a summary of information of each subdivision preliminary plan and plat submitted to them, together with a report of each exemption granted by the board of county commissioners pursuant to section 30-28-101 (10) (d), on such form as may be prescribed by the Colorado land use commission.

Source: L. 72, p. 504, § 8; C.R.S. 1963, § 106-2-37; L. 73, pp. 781, 1087, 1088, § § 2, 1, 1; L. 75, p. 1002, § 1; L. 77, p. 1453, § 3.

Cross references: For duties of the state geologist upon receipt of copies of prints of the plans, see § 34-1-103(4).

Law reviews. For article, "1974 Land Use Legislation in Colorado", see 51 Den. L.J. 467 (1974). For article, "Property Tax Incentives for Implementing Soil Conservation Programs Under Constitutional Taxing Limitations", see 59 Den. L.J. 485 (1982).

Zoning and subdivision regulations are separate and distinct legislation and serve different purposes. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

A subdivider must first meet zoning regulations and then additionally must comply with state and county subdivision regulations. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

This section is designed to allow a planning commission to make a decision on a preliminary plat without waiting indefinitely for agencies' reports. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

Authority to act on reports implicit. If a planning department or a board of county commissioners has no authority to consider and act on reports required by this section, particularly where they indicate a hazard to the public, then the general purpose to be served by enacting the regulations would be vitiated. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

There was no error or violation of petitioner's due process right in a board's consideration of late agency reports. Shoptaugh v. Board of County Comm'rs, 37 Colo. App. 39, 543 P.2d 524 (1975).

30-28-137. Guarantee of public improvements. (1) No final plat shall be recorded until the subdivider has submitted and the board of county commissioners has approved one or a combination of the following:

(a) A subdivision improvements agreement agreeing to construct any required public improvements shown in the final plat documents, together with collateral which is sufficient, in the judgment of said board, to make reasonable provision for the completion of said improvements in accordance with design and time specifications; or

(b) Other agreements or contracts setting forth the plan, method, and parties responsible for the construction of any required public improvements shown in the final plat documents which, in the judgment of said board, will make reasonable provision for completion of said improvements in accordance with design and time specifications.

(2) As improvements are completed, the subdivider may apply to the board of county commissioners for a release of part or all of the collateral deposited with said board. Upon inspection and approval, the board shall release said collateral. If the board determines that any of such improvements are not constructed in substantial compliance with specifications, it shall furnish the subdivider a list of specific deficiencies and shall be entitled to withhold collateral sufficient to ensure such substantial compliance. If the board of county commissioners determines that the subdivider will not construct any or all of the improvements in accordance with all of the specifications, the board of county commissioners may withdraw and employ from the deposit of collateral such funds as may be necessary to construct the improvement in accordance with the specifications.

(3) The board of county commissioners or any purchaser of any lot, lots, tract, or tracts of land subject to a plat restriction which is the security portion of a subdivision improvements agreement shall have the authority to bring an action in any district court to compel the enforcement of any subdivision improvements agreement on the sale, conveyance, or transfer of any such lot, lots, tract, or tracts of land or of any other provision of this part 1. Such authority shall include the right to compel rescission of any sale, conveyance, or transfer of title of any lot, lots, tract, or tracts of land contrary to the provisions of any such restriction set forth on the plat or in any separate recorded instrument, but any such action shall be commenced prior to the issuance of a building permit by any county where so required or otherwise prior to commencement of construction on any such lot, lots, tract, or tracts of land.

Source: L. 72, p. 506, § 8; C.R.S. 1963, § 106-2-38; L. 75, p. 988, § 3.

Law reviews. For article, "1974 Land Use Legislation in Colorado", see 51 Den. L.J. 467 (1974).

Applied in Colorado Nat'l Bank v. Board of County Comm'rs, 634 P.2d 32 (Colo. 1981).

6-6-103. Collections prohibited - penalt... ...der of any unsolicited goods shall mail to any recipient ... goods a bill for such unsolicited goods or an... ...olation of this section shall constitute ... ...nviction thereof, the violator shall be ... ...vo hundred fifty dollars.

SB 13 (1984)

Source: Entire a... ..., § 1, effective July 14; entire section amended, L... ..., effective May 20.

ARTICLE 6.5

Soil and Hazard Analyses of Residential Construction

6-6.5-101. Disclosure to purchaser - penalty. (1) At least fourteen days prior to closing the sale of any new residence for human habitation, every developer or builder or their representatives shall provide the purchaser with a copy of a summary report of the analysis and the site recommendations. For sites in which significant potential for expansive soils is recognized, the builder or his representative shall supply each buyer with a copy of a publication detailing the problems associated with such soils, the building methods to address these problems during construction, and suggestions for care and maintenance to address such problems.

(2) In addition to any other liability or penalty, any builder or developer failing to provide the report or publication required by subsection (1) of this section shall be subject to a civil penalty of five hundred dollars payable to the purchaser.

(3) The requirements of this section shall not apply to any individual constructing a residential structure for his own residence.

Source: Entire article added, L. 84, p. 294, § 1, effective July 1.

Law reviews. For article, "Building on Expansive Soils: Colorado's Legislative Response", see 14 Colo. Law. 379 (1985).

ENERGY CONSERVATION

ARTICLE 7

Residential Building Energy Conservation

PART 1

GENERAL PROVISIONS

FIELD TRIP GUIDEBOOK

GEOLOGIC HAZARDS AND ENGINEERING PRACTICES IN COLORADO

COLORADO SPRINGS, COLORADO
MARCH, 22-23, 1996

About the Cover: View of Pulpit Rock from the south. This prominent sandstone landmark is the resistant bluff- and cliff-forming Arapahoe Formation. Underlying the sandstone at the base of the cliff is the Lower Andesitic Member (lower Dawson Formation of Scott and Wobus, 1973). This photo illustrates one of the less-common geologic hazards in the Colorado Springs area - rockfall - and the most common but more subtle - expansive soil and/or bedrock. Rockfall in the Colorado Springs area is limited mostly to areas along the base of Cheyenne Mountain, the Dakota Hogback, the Fountain Formation, the Laramie Formation and the Arapahoe Formation. The Lower Andesitic Member, forming the gentler slopes below the sandstone cliff, is the most expansive bedrock in the region. It underlies some Rockrimmon neighborhoods, known for expansive soils problems. Below this unit is the Laramie Formation, the primary coal bearing formation along the Front Range. The northwest/southeast trending bluffs of the Arapahoe Formation form a prominent "marker bed" which is used by geologists to locate potential rockfall problems, expansive soils in many areas to the south, and undermined areas in a band south of and parallel to the bluffs. (Photo by John Himmelreich)

FIELD TRIP GUIDEBOOK

GEOLOGIC HAZARDS AND ENGINEERING PRACTICES IN COLORADO

COLORADO SPRINGS, COLORADO
MARCH 22-23, 1996

Edited by:
John Himmelreich, David Noe, and Jonathan White

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CONTENTS

FIELD TRIP ROUTE

The following describes points of interest and stops along the field trip route. The field trip route, stops and points of interest are shown on the accompanying Field Trip Maps 1 - 9. A brief description of the points of interest is provided in the following Table I. Field trip stops are described in the table and in the abstracts included with this guidebook. Additional points of interest described in the abstract, "Expansive Soil and Heaving Bedrock: Uintah Street Road Cut" by David C. Noe are also shown on Field Trip Maps 1 - 9. The following provides a legend for the points of interest and field trip stops shown on the Field Trip Maps.

LEGEND:

2	Field Trip Stops
4	Points of interest and field trip drive-bys
3	Noe's points of interest. See abstract by David C. Noe, Table I.

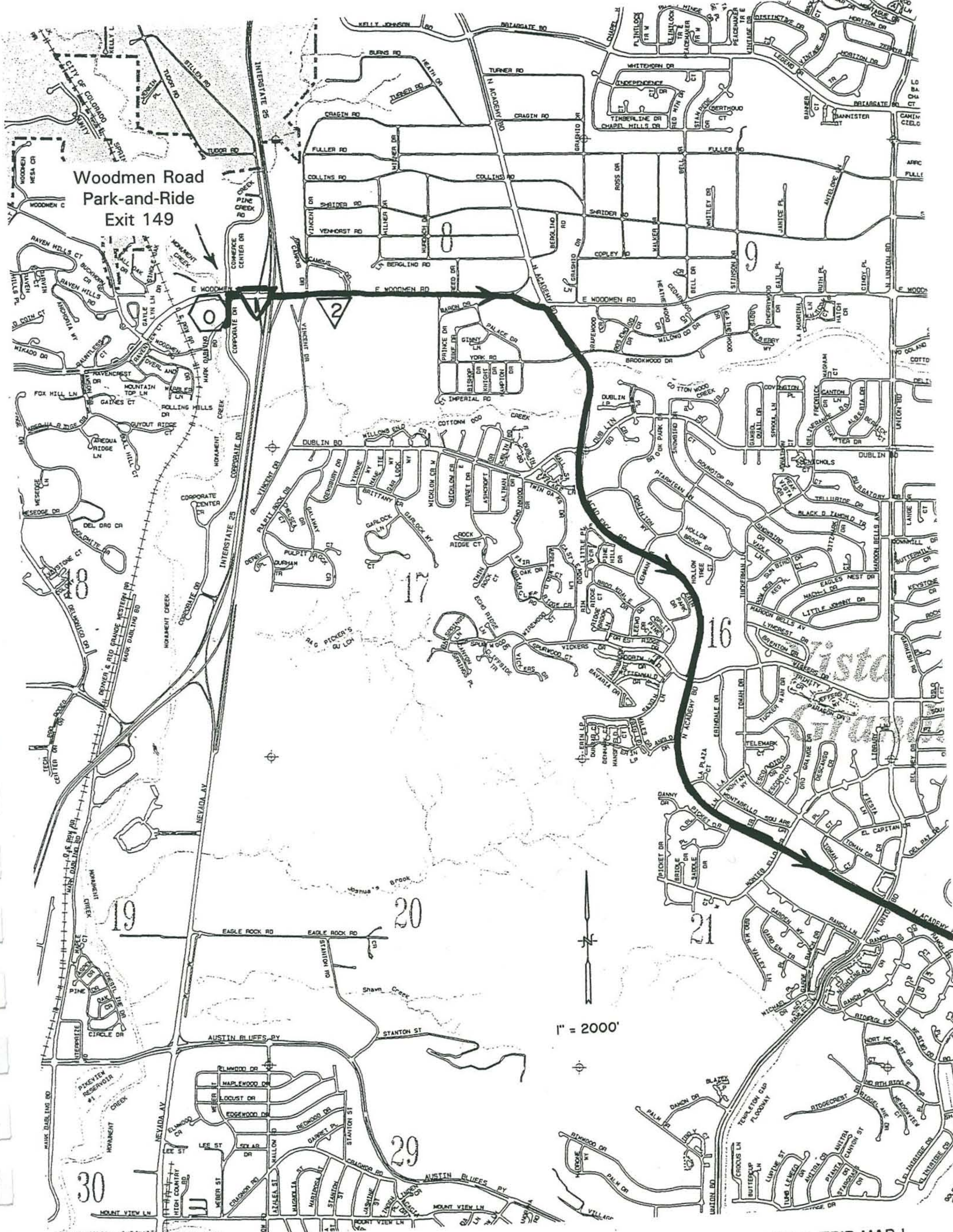
The guidebook has been written such that self-guided tours are also possible. This was done so that the guidebook may be effectively utilized by all conference attendees, whether or not they attend the March 23 field trips. In addition to the regular tour, author David Noe has compiled a separate mini-tour of points of interest where heaving bedrock, steeply dipping bedrock, and exposures of Pierre Shale can be viewed. These mini-tour locations are included on the main field trip maps, and are further outlined in the guidebook section on expansive soil and heaving bedrock.

TABLE I

Number	Description
⬡ 0	Park and Ride - Corporate Drive and Woodmen Road
▽ 1	Exposure of the Lower Dawson Formation of Scott and Wobus, 1973. This claystone is known for its high expansion potential.
▽ 2	Isolated hoodoo marks the bottom of the Arapahoe Formation. These hoodoos are common in Woodmen Valley (to the west) and in Palmer Park and are unique "markers" for this formation.
▽ 3	Cut slope exposes contact between Arapahoe Formation (sandstone) and Lower Dawson Formation. Note the gentle northerly dip. The claystone erodes easily and undermines the more resistant sandstone causing occasional toppling failures. The Arapahoe Formation is similar to, and is often confused with, the Dawson Arkose which underlies the Black Forest area to the north of Colorado Springs.
⬡ 1	Grandview Overlook. This spectacular view provides an unparalleled panorama of Colorado Springs and as far south as a clear day will allow. Several points of interest are shown on Color Plate 3. From this overlook many of the areas geologic features can be viewed. Color Plates 1 and 2 provide a Columnar Section and Geologic Cross-sections of the region. A trip back to this overlook at the end of the field trip provides the viewer an opportunity to put the days geologic points of interest into prospective.
⬡ 2	Portal Park - See abstract on Portal Park by Jeff Hynes.
▽ 4	Pulpit Rock. Prominent landmark in Colorado Springs, see front cover and back of front cover.
▽ 5	Popes Bluff, the prominent ridge of the Pine Cliff Subdivision area, is underlain by the Laramie Formation. The Laramie Formation is the coal bearing formation in the Colorado Springs area and is the lowest member (with the underlying Fox Hills Sandstone) of the Denver Basin Aquifers. The Denver Basin aquifers, used by county subdivisions and the City of Colorado Springs, include from top to bottom the Dawson, Denver, Arapahoe and Laramie/Fox Hills Aquifers.

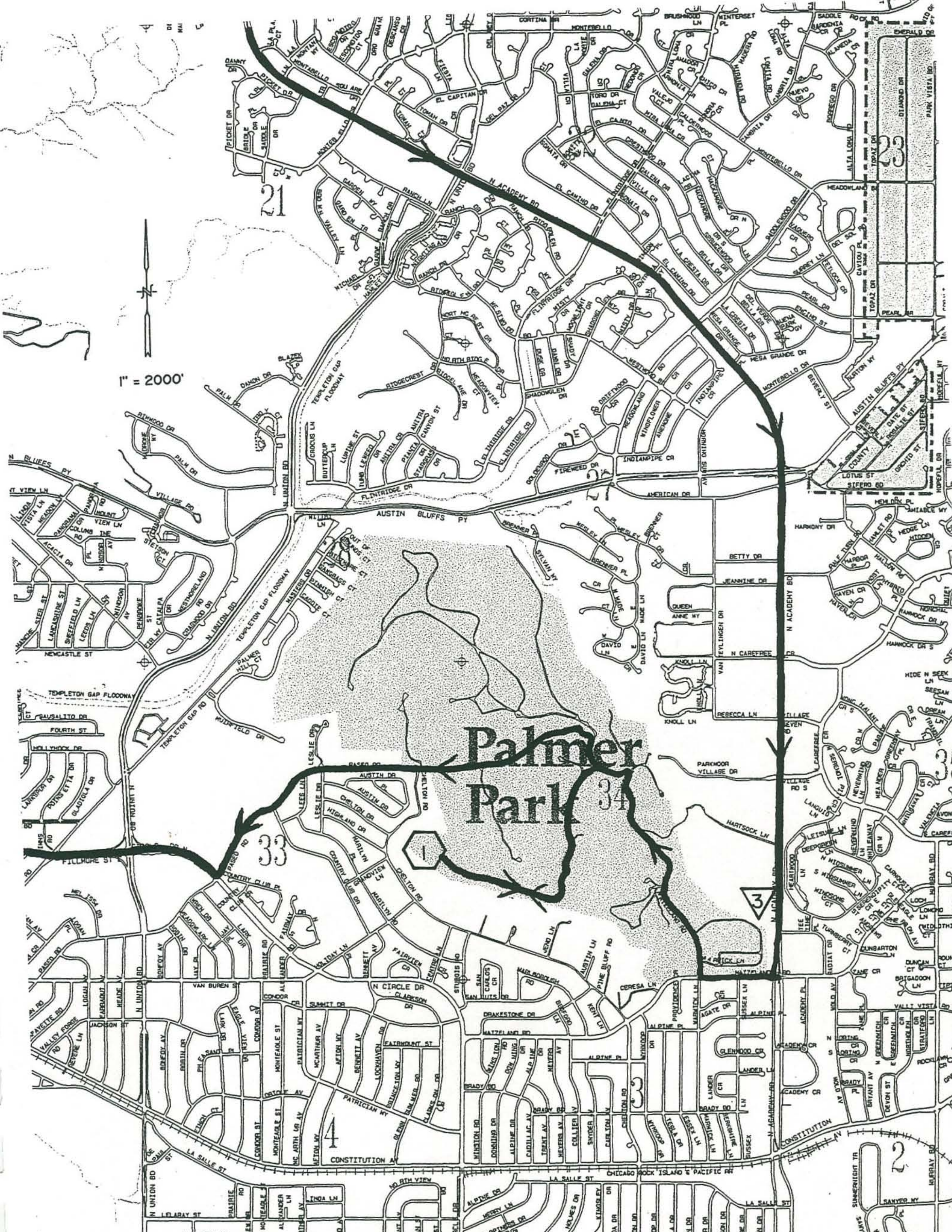
Number	Description
6	The Mesa is underlain by sand and gravel deposits of the Verdos alluvium, glacial outwash sediment which once covered a broad area. Locally, the Verdos alluvium is one of the major sources for road base.
7	The valley that Garden of the Gods Road traverses is underlain by two ancient alluvial (water transported) deposits - The Slocum alluvium and Louviers alluvium. Several glacial and interglacial episodes have affected this region resulting in several pediment and alluvial terrace levels. Note how you "step up" on a higher terrace as you travel east to west along Garden of the Gods Road.
8	Small landslide in cut slope on south side of road. This is in an area of steeply dipping shale.
9	Landslide in the spring of 1995 closed the bike path and temporarily closed Mesa Road, see Color Plate 9.
3	Garden of the Gods Visitors Center. From the Visitors Center, several prominent hogbacks can be seen, along with Queens Canyon Quarry which mined the Manitou Limestone. Concerted efforts over the last several years by Castle Concrete, the City and citizens groups have resulted in enhanced reclamation. The hogbacks are, from east to west, the Fort Hays Limestone, the Dakota Sandstone, and the Lyons Sandstone (Kissing Camels). The Visitors Center is a wonderful place to enjoy and learn more about Garden of the Gods Park.
4	Uintah Street Road Cut; see abstract by David C. Noe.
10	Exposure of upturned and faulted strata near the southern end of the Rampart Range fault.
11	Gently to moderately tilted Fountain Formation provides colorful exposures up Ute Pass through Manitou Springs.
5	View of rockfall source; see abstract by Jonathan White and Color Plate 7.
13	Small landslide in tilted Fountain Formation occurred in the spring of 1995.
12	Houses below rockfall source as described in field trip stop 5.

Number	Description
14	Gold Hill Mesa. Millions of tons of gold ore from Cripple Creek were milled and processed here for gold and silver. The smoke stack marks the mill's location. The eroding "badlands" to the east of the stack are the discarded mill tailings.
15	Downtown Colorado Springs. Founded on deep alluvial sands of the Louviers Alluvium. Note the broad flat terrace formed by the Louviers.
6	Clubhouse Drive near Cheyenne Mountain Conference Resort. This stop provides a view of Cheyenne Mountain and its foothills. Debris flows in the past, from basins draining Cheyenne Mountain, have damaged commercial and private recreation facilities in the area. Mitigation of debris flow hazards is planned for some basins in this area; see abstract by Jim S. O'Brien. This stop also provides a broad view of a large landslide complex mapped by the United States Geological Survey; see abstract by John Himmelreich.



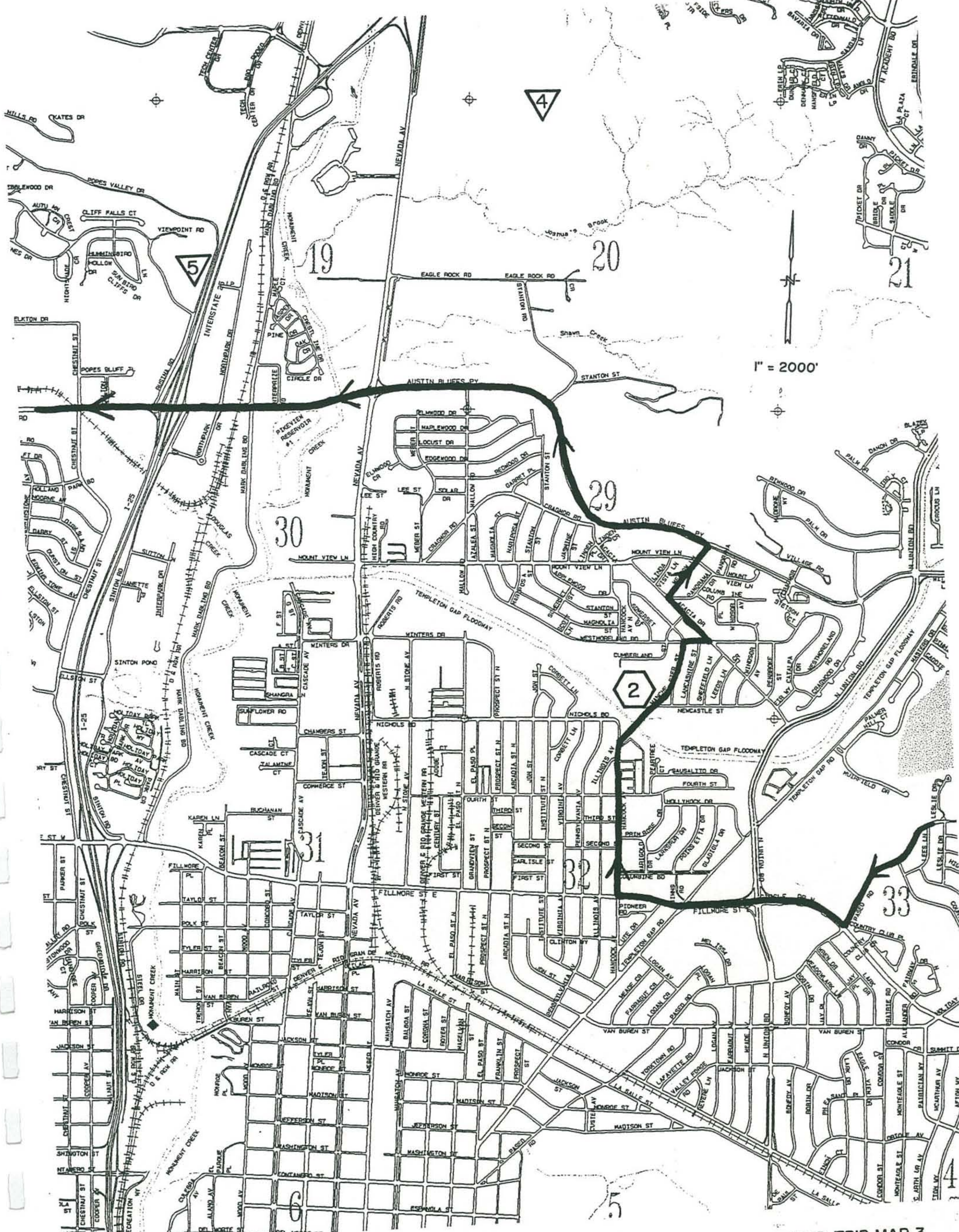
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP I



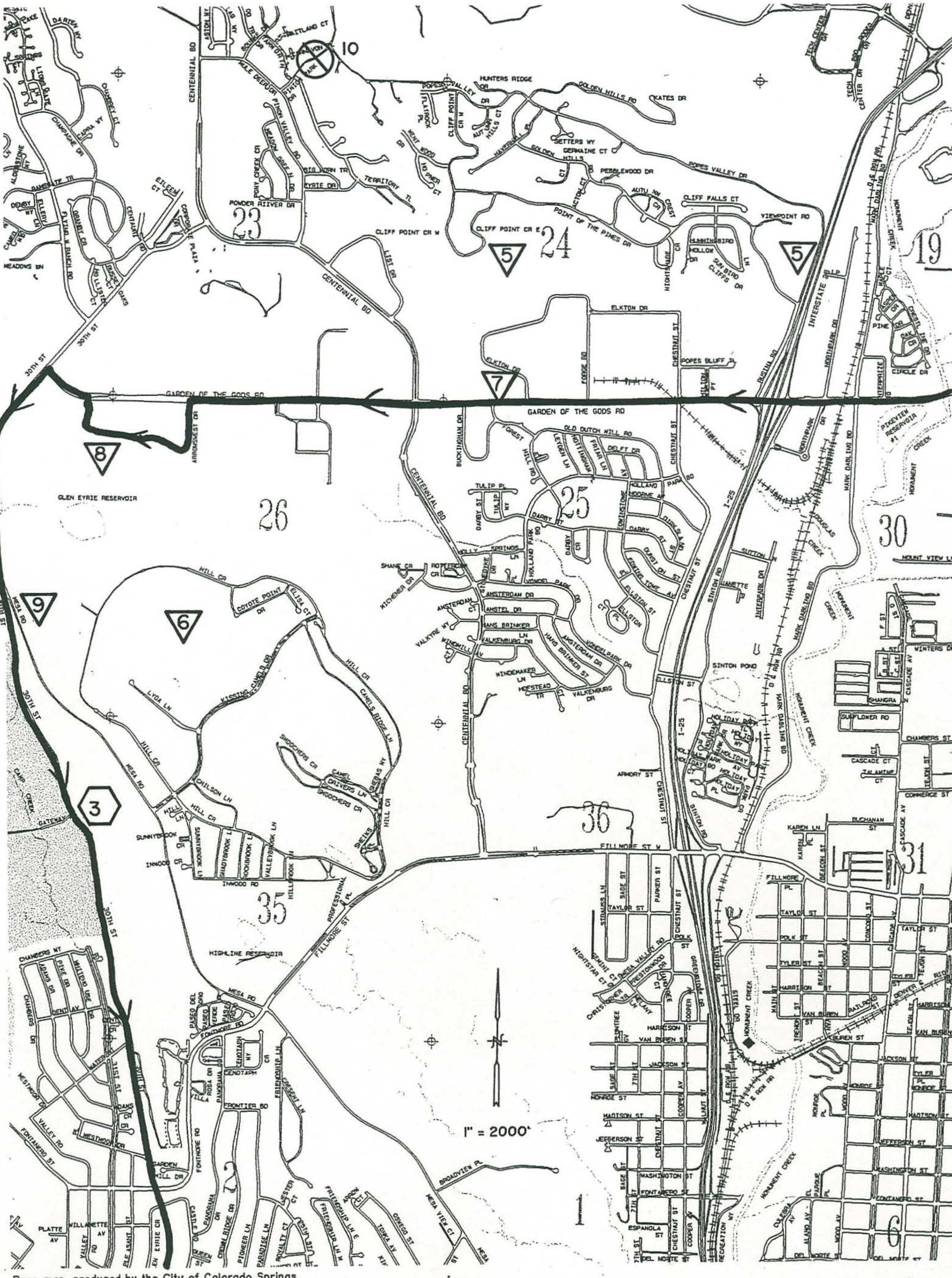
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 2



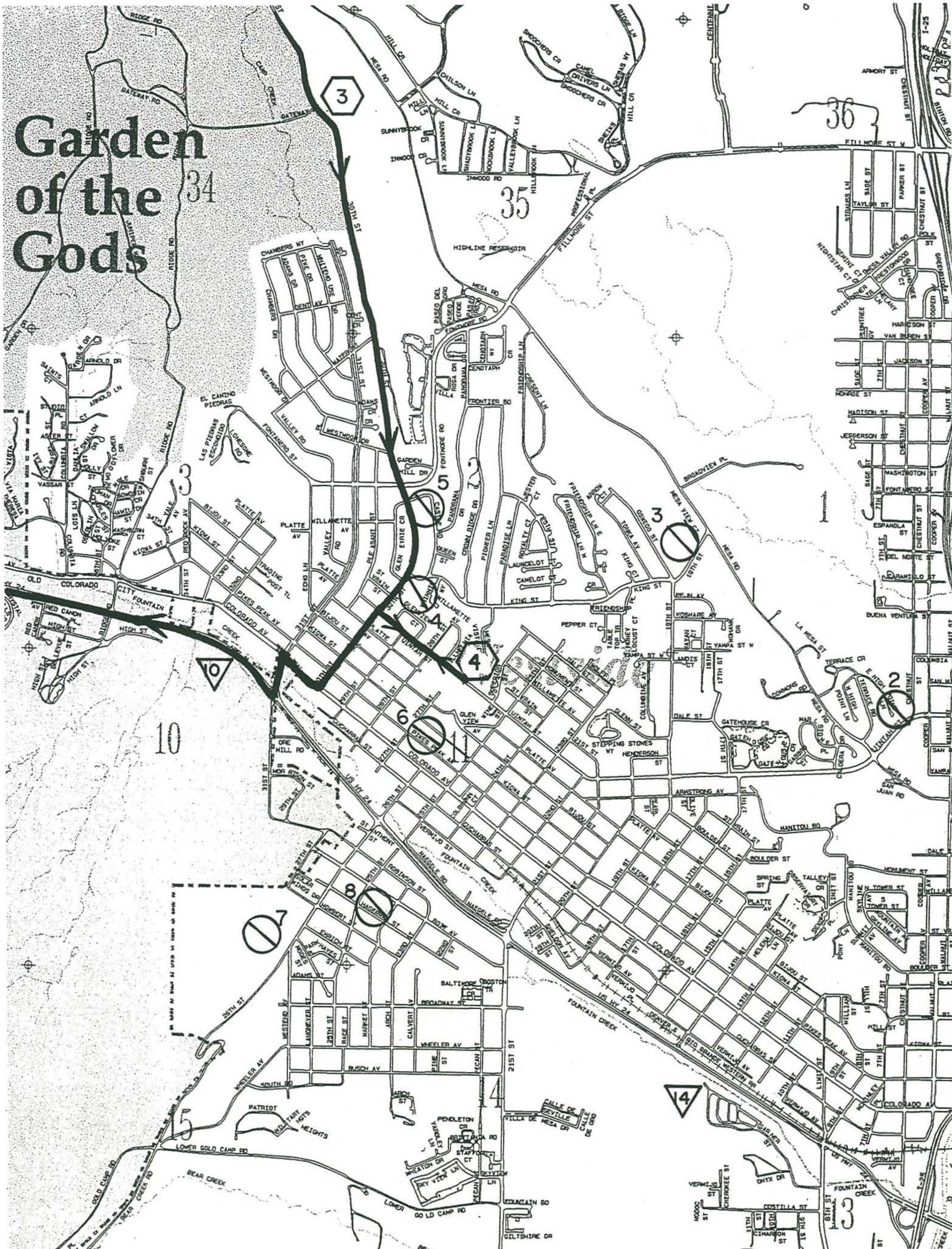
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 3



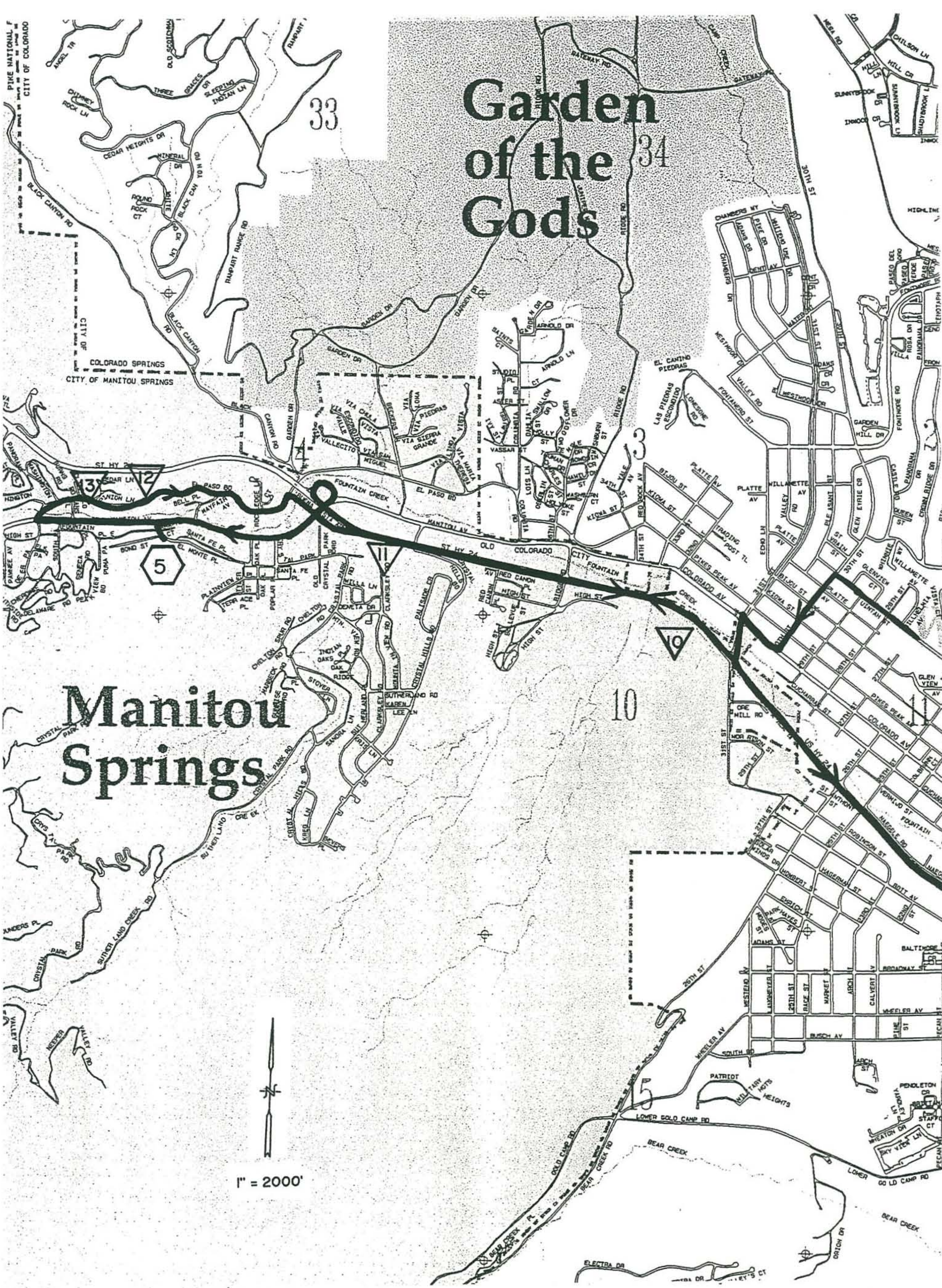
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 4



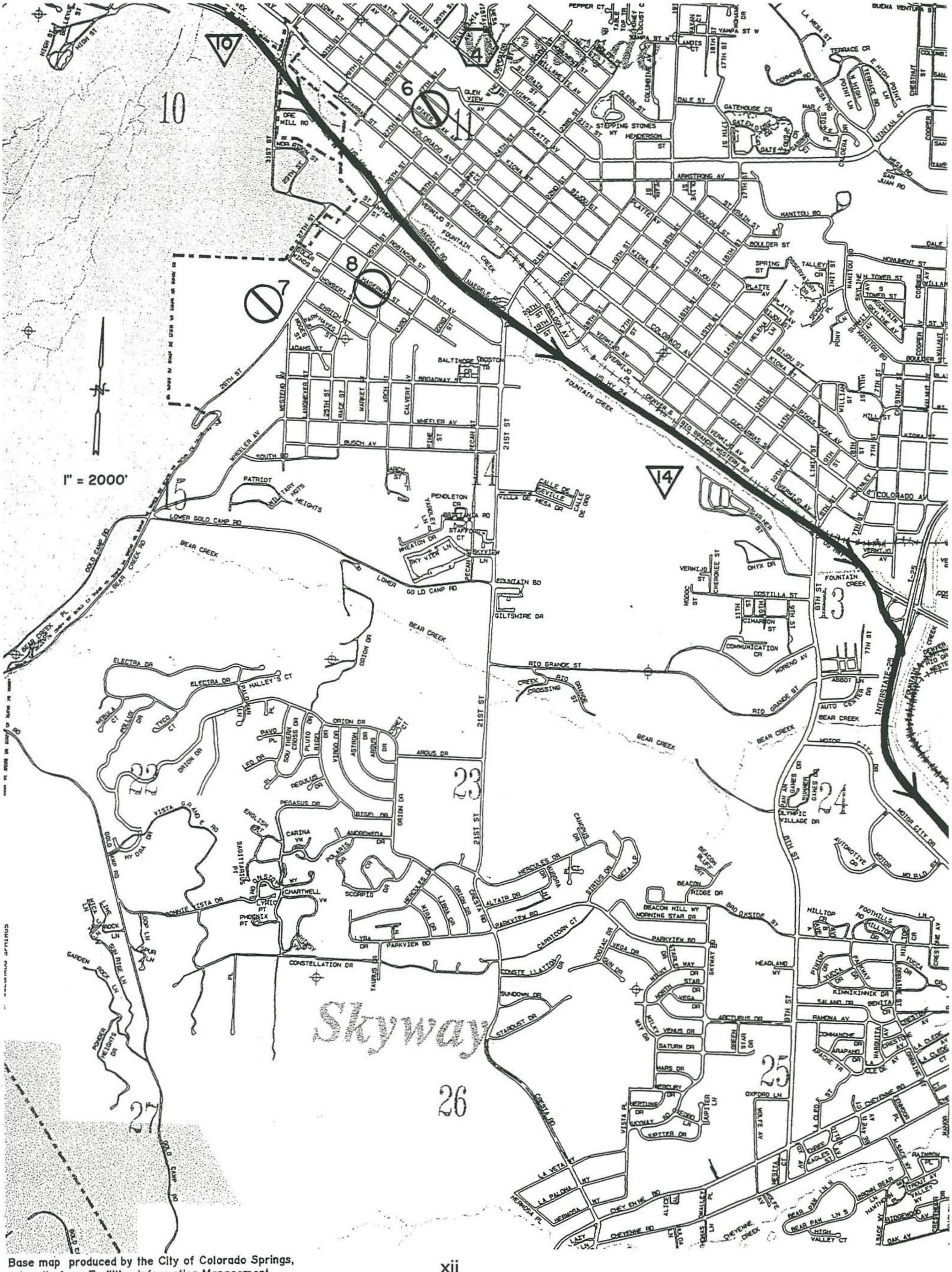
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 5



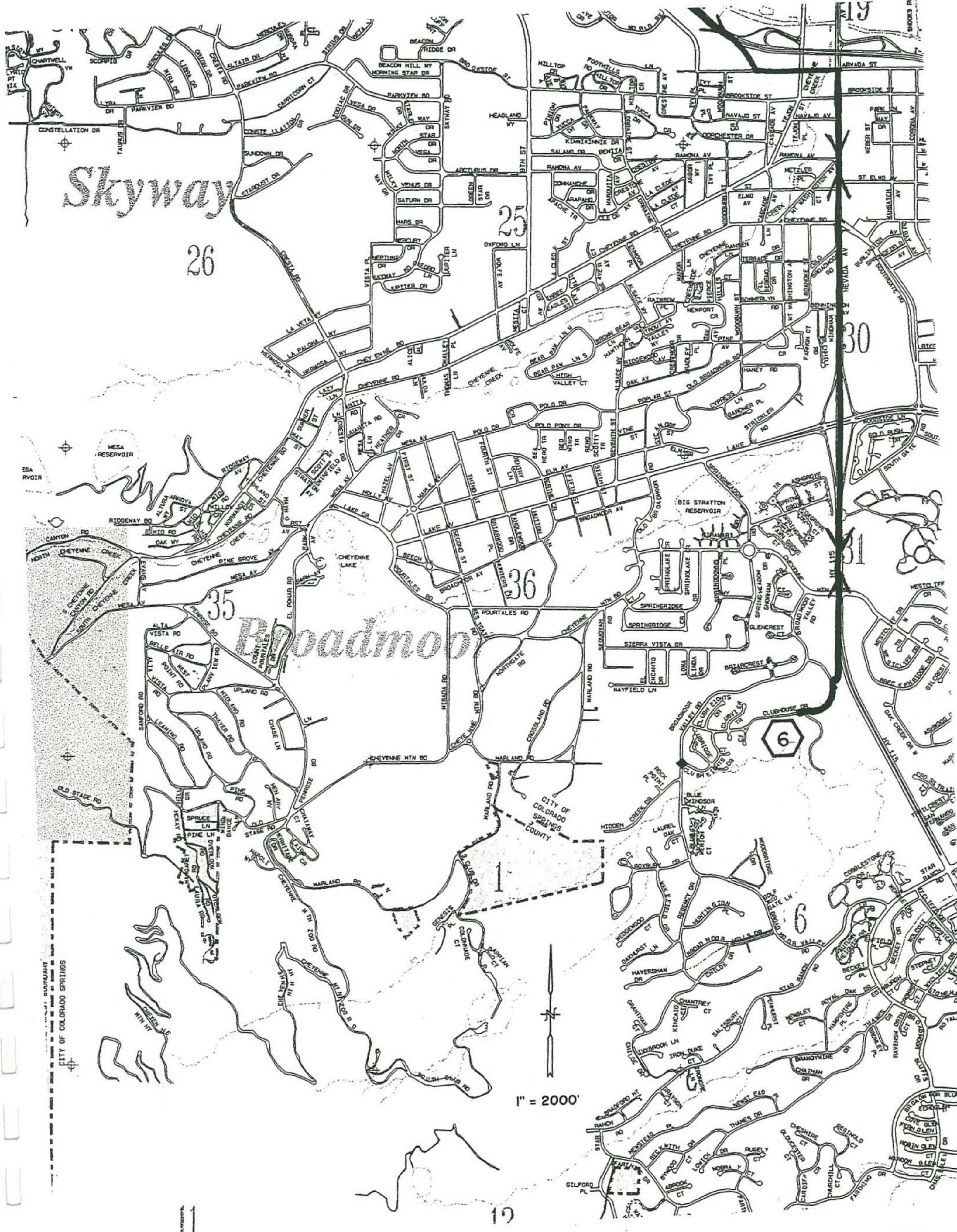
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 6



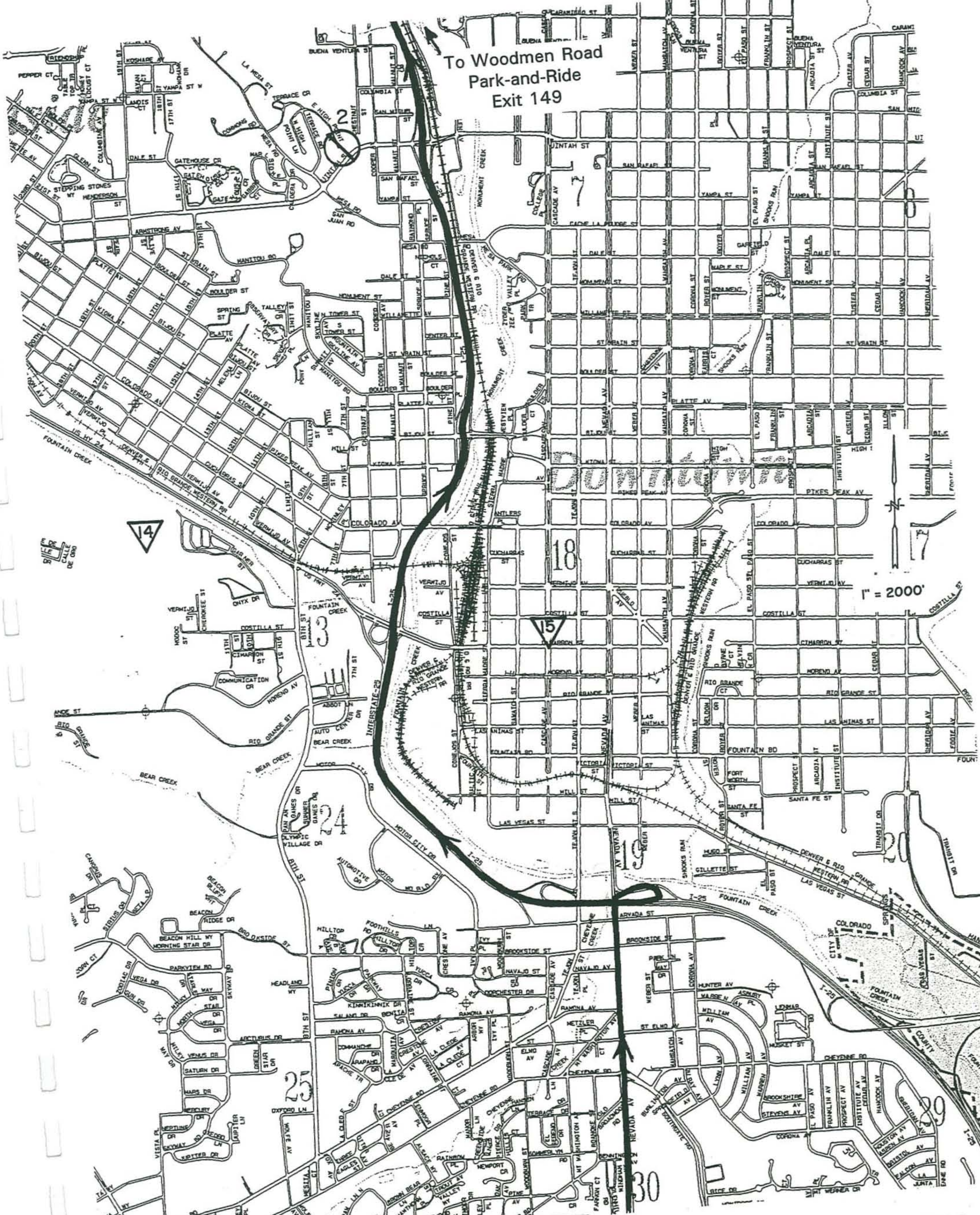
Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 7



Base map produced by the City of Colorado Springs, primarily from Facilities Information Management System's (FIMS) data. Used with permission.

FIELD TRIP MAP 8



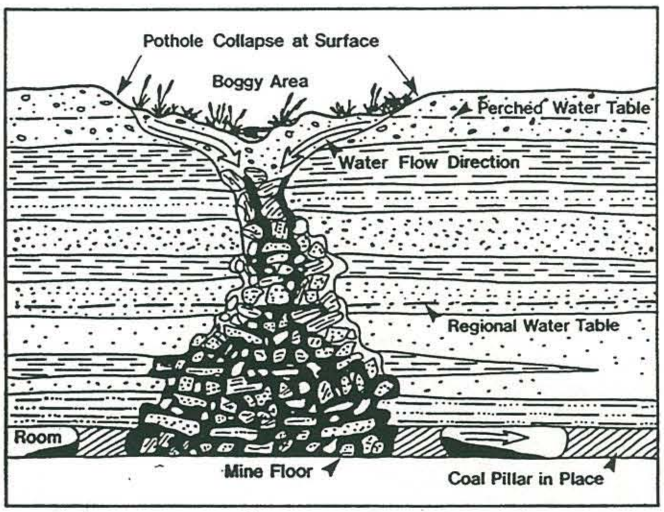
FIELD TRIP MAP 9

Base map produced by the City of Colorado Springs, primarily from Facilities Information Management ... with permission.

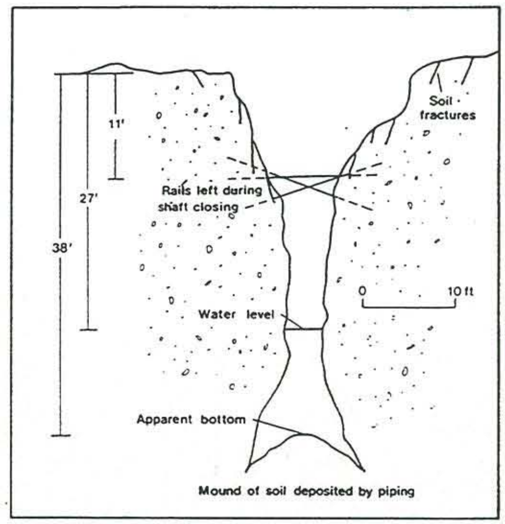
COAL MINE SUBSIDENCE FEATURES: PORTAL PARK

Jeffrey L. Hynes
Colorado Geological Survey

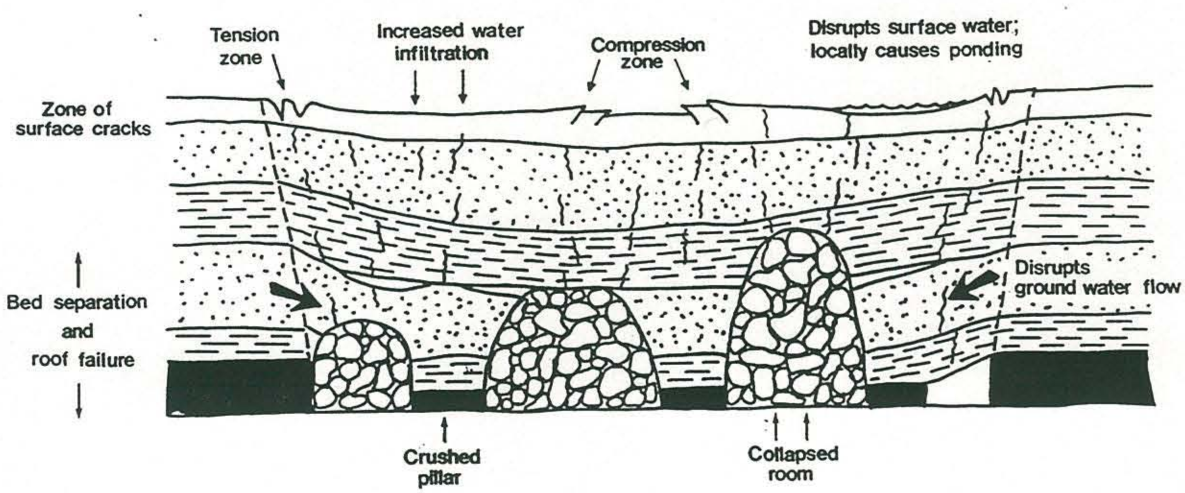
PART I: HOLES, SAGS AND TROUGHS



Cross-sectional view of a subsidence pit.



Cross-sectional view of an air shaft.



A subsidence trough formed over an area where several pillars have collapsed.

PART II: COLORADO SPRINGS SHAFTS (PORTAL PARK) PROJECT
OSM Number (08-101), 6th Construction Grant, January 9, 1990

I. PROJECT OVERVIEW

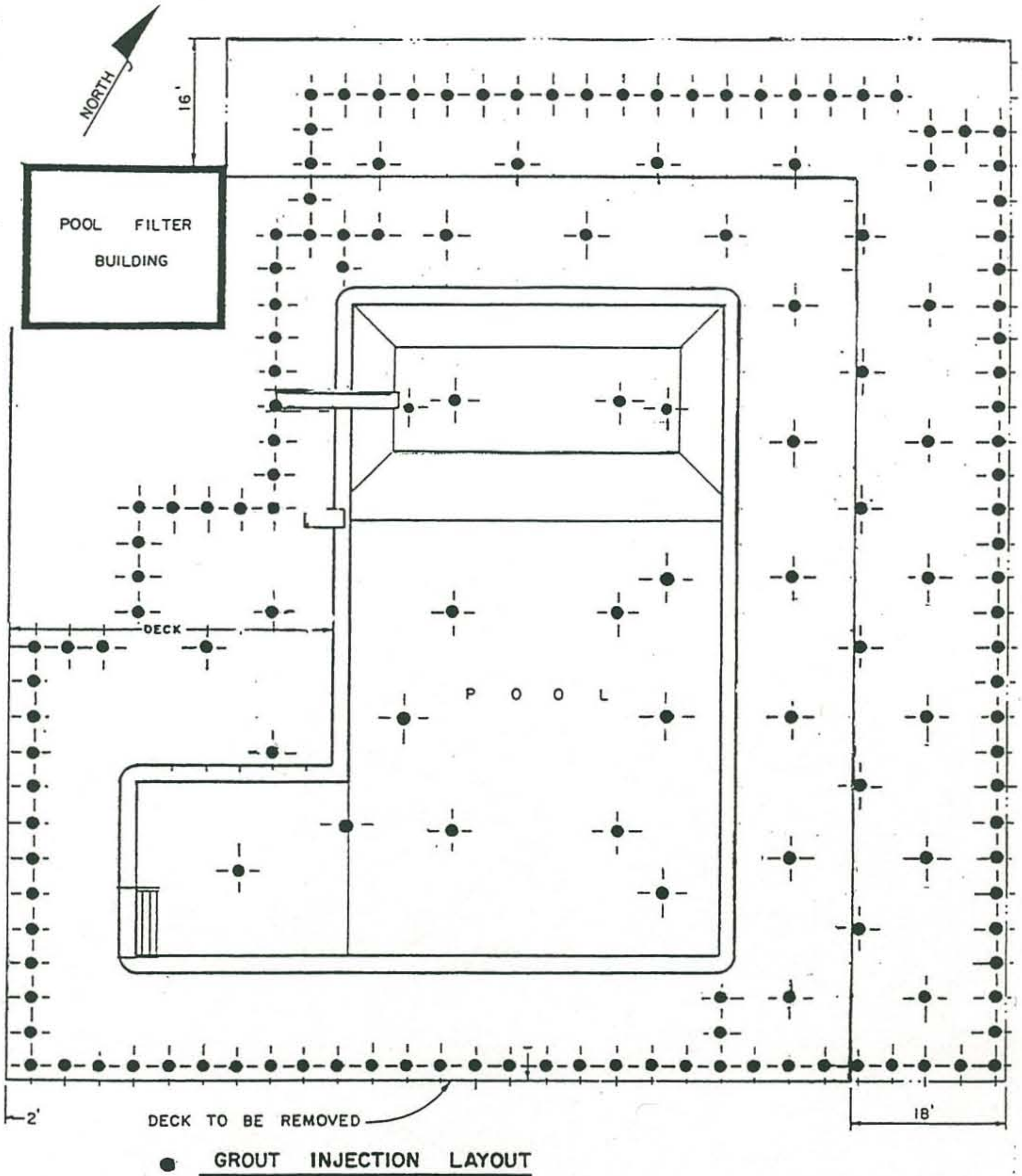
The PORTAL PARK PROJECT is located along the Templeton Gap Floodway in the Cragmoore area of Colorado Springs. The project is located at the Portal Park Swimming pool, a City Recreation Facility, in Sec. 29, Tl3S, R66W, within the Pikeview 7.5 Min. USGS Quadrangle. The Patterson and Busy Bee coal mines were developed in a 15 foot thick seam in the project area in the early 1900's. The "New-slope" entry was driven in the 1920's at the project site location to facilitate room-and-pillar mining operations. Later, as the mine was abandoned, pillar robbing and scavenging operations were conducted through the New Slope, and many rooms were apparently driven directly off it during this period. Mine voids thus exist less than 40 feet below the surface in the project area.

Construction Summary

The project was designed to complete backfilling of mine voids and then densify and compact any loose or disturbed soft areas in the sandy overburden soils above mine level. The first phase was to construct a zero-slump barrier grout curtain to contain the grout-filling materials in the rooms beneath the pool, preventing them from migrating down dip to the north and east. During this initial drilling, it was discovered that the existing mine maps were not accurate. The pillars depicted on the map were never encountered. The entire north end and much of the east side were found to be over mine voids. This required more drilling and zero-slump grout material than was originally anticipated to form the grout curtain, and an extension of time was granted to cover the additional drilling. This encircling grout curtain was completed on 4 ft. centers on November 17. It took 4,526.5 ln. ft. of drilling and 341.2 cubic yards of grout to complete this first phase.

The second Phase consisted of backfilling the mine voids below the pool within the grout-curtain closure. A hig-slump filling mix with a strength of 200 psi @ 28 days was pumped on 16 foot centers in staggered rows 8 ft. apart until either A) 40 cu. yds. of take; B) refusal, or C) ground surface lift or cracking was observed. Holes were cut through the aluminum pool bottom and a portable drill used to advance borings into the mine level in order to directly fill voids beneath the pool itself. This phase proceeded until refusal was achieved and/or the surface was raised or cracked. Another 1,308 ln. ft. of drilling and 333 cu. yds. of grout were required. This phase completed the backfilling of voids beneath the pool by densifying and compacting the sand previously placed by OSM in 1984, and filling the remaining 2 to 3 foot void which we encountered above the sand backfill. It was apparent that no soft or weak zones remained in the overburden due to the fact that surface cracking and ground lift were produced by grouting at 30 to 45 ft. below the surface. These uplift pressures compacted any soft zones in the overburden between the mine level and surface.

Phase 3 involved an attempt at re-leveling the pool as much as was possible without inducing distress or damage to the aluminum pool structure. Unfortunately, only about half of the 4 inches of original settlement could be regained before distress to the thin aluminum bottom of the pool was noted. It might have been more successful if the leveling operation were conducted with the pool filled, however, this was not possible due to the time of year in which the project had to be executed. A section in the southeast corner of the pool floor had to be cut out to allow for removal of grout which forced its way up directly under the aluminum floor, and caused heaving and a loss of depth. A new section of sheet aluminum was rewelded after the grout was removed. The final inspection was held December 15, 1989 with the contractor and city officials both in attendance. Colorado Springs Officials Mike McCauley and Scott Simpson accepted the site, and approved release of the Contractor.



Drilling and grouting pattern at Portal Park pool.

Portal Park Project:

Final Cost $163,086.10
Change Order(s) . . . . 1 (Increased time of completion only, due to extent of unexpected void areas. Pillars shown on mine maps not encountered.

EXPANSIVE SOIL AND HEAVING BEDROCK: UINTAH STREET ROAD CUT

David C. Noe
Colorado Geological Survey

Introduction

On this part of the field trip, we will consider expansive soil and heaving bedrock in the greater Colorado Springs area. There will be a short stop to look at an outstanding road cut of Pierre Shale near the corner of Uintah and Superior Streets. Several excellent exposures of Pierre Shale and/or examples of heaving bedrock deformation are found nearby but cannot be visited due to time constraints; an index map and a table of descriptions is included to allow the reader to visit those sites at his/her convenience.

Expansive Soil and Rock in Colorado Springs

Perhaps the best reference on the occurrence of expansive materials in the Colorado Springs area is Hart's 1974 map, published by the Colorado Geological Survey (Color Plate #5). The map shows the general distribution of soil and bedrock at the ground surface with respect to swell potential and hydrocompaction. The overall pattern is complex and reflects the presence of numerous types of surficial soil deposits and bedrock outcrops. The Hart map does not account for the geology beneath the ground-surface deposits, and there may be significant local variations in swell potential within a single geological deposit. For these reasons, it is important to conduct drillhole tests before a property is developed in order to assess the site-specific swell potential and design accordingly.

Heaving Bedrock in Colorado Springs

Differential ground-surface deformations caused by heaving bedrock are relatively uncommon in Colorado Springs. Most of these heave features are located along the west edge of the city, where the sedimentary bedrock is upturned to angles of greater than 30 degrees from horizontal. The Colorado Springs heave features tend to be less abrupt in terms of short-distance, differential displacements as compared to those in the southwest Denver metropolitan area. The largest concentration of heaving bedrock deformations in Colorado Springs is located in the west-central part of the city, in the vicinity of Old Colorado City. Figure 1 is an index map of this area showing the location of several notable heave features and/or exposures of Pierre Shale. A descriptive summary for each of these locations is provided in Table 1. Figure 1 and Table 1 are set up so that the reader may take a self-guided tour of the area.

Uintah Street Road Cut

The Uintah Street road cut (Fig. 1; location 1) is significant in many ways. It exposes the upwarp axis of the Front Range monocline fold, separating steeply dipping bedrock to the west and gently dipping bedrock to the east (Fig. 2). A thrusted, shear-slip type heaving bedrock surface and a cross-section through an old landslide are also exposed. In all, three remarkable and rarely seen geological features are exposed in the cut.

A schematic cross-section along the north wall of the road cut is shown in Figure 3. This segment of Uintah Street was constructed between 1969 and 1975 (based on USGS topographic maps). The cut is approximately 300 feet long. It bisects a finger-like mesa capped by Quaternary Verdos alluvium and exposes a 30-foot thick section of Cretaceous Pierre Shale. The Pierre Shale is quite clay-rich here, and bedding is readily seen in the form of several thin (1/2- to 3-inch thick) beds of ironstone, siltstone, and/or bentonite within the claystone. The bedrock goes from nearly flat-lying to nearly vertical within a distance of 300 feet. At the east end of the cut, the bedrock dips gently eastward at about 10 degrees (Fig. 3, circle A). The bedrock begins to bend upward near the middle of the cut, and the bedding dip steepens progressively to the west (circle B). The maximum dip measured at the west end of the north side of the cut is 58 degrees east-northeast; the maximum dip on the south side, slightly to the west of the section shown in Figure 3, is 72 degrees east-southeast. The original bedding, as projected over and away from the cut, was probably steeper but has been eroded away (circle C).

The cut has exposed a single, low-angle plane of heaving bedrock running diagonally upward from the center toward the eastern part of the cut (Fig. 3, circle D). A pair of prominent ironstone beds are visually offset by 30 inches across the plane. The direction of offset indicates thrusting shear-slip movement, with the top part moving toward and overriding the lower part. Some parts of this thrust heave may be actively moving. The upper bedrock block exhibits an overhang of 1/4-1 inch relative to the lower block, and some of the shale along the plane looks as if it has been squeezed outward. The heave surface appears to be a place where water accumulates, as evidenced by the preferential occupation along the plane by tree roots. The author has observed several similar thrust heaves in highly expansive shales in the southwest Denver metropolitan area. It appears that many of these features, especially the ones with low-dip planes, do not extend more than 20-25 feet beneath the ground surface. Such thrust heaves appear to be products of the long-term (on the order of tens or hundreds of thousands of years) unloading, weathering, and expansion of the bedrock mass as a whole, rather than deeper-rooted tectonic features. Compressive (thrusting) shear-slip movement along an internal plane is a likely mechanism by which an expansive rock mass may relieve internal pressure when the rock weathers, rebounds, takes on water through fractures, and swells. Heave features with asymmetric, thrust-type morphologies are capable of causing a great deal of localized damage. An outstanding example is seen a few blocks to the northwest of the Uintah Street road cut at a church (location 4, Fig. 1 and Table 1).

Also exposed, at the eastern-most end of the cut, is a small landslide that was partially removed when the cut was constructed (Fig. 3; circle E). Such a cross-sectional exposure is relatively rare. The landslide takes the form of a small, circular-type slump with its failure plane rooted in the Pierre Shale. The failure surface is best exposed in the upper part of the cut, where reddish sand, gravel, and clay layers of Verdos alluvium have slid downward nearly 15 feet. The beds within the slumped block tilt westward with a reverse dip that is characteristic of such slump deposits. The same beds are also seen within the in-place alluvial cap immediately to the west of the failure surface. Colluvium (slope-wash material) has filled in the scarp area at the top of the slump, disguising the slump's presence at the upper ground surface. The lower failure surface is not readily seen. It probably curves tangentially into the bedded shale at its base. Small slumps of this type are quite common along the Front Range piedmont in slopes floored by gently dipping, expansive claystone (G. Scott, USGS retired, personal communication). They are difficult to recognize when covered with colluvium, even using drillhole investigations. Slumps can be reactivated when houses or other facilities encroach onto and disturb the slope. There are numerous examples of this, with varying degrees of subsequent movement and damage, in Colorado Springs.

References

Hart, S.S., 1974, Potentially swelling soil and rock in the Front Range Urban Corridor, Colorado: Colorado Geological Survey, Environmental Geology 7, 23 p., 4 map plates, scale 1:100,000.

Scott, G.R. and Wobus, R.A., 1973, Reconaissance geologic map of Colorado Springs and vicinity, Colorado: U.S. Geological Survey, Map MF-482, scale 1:62,500.

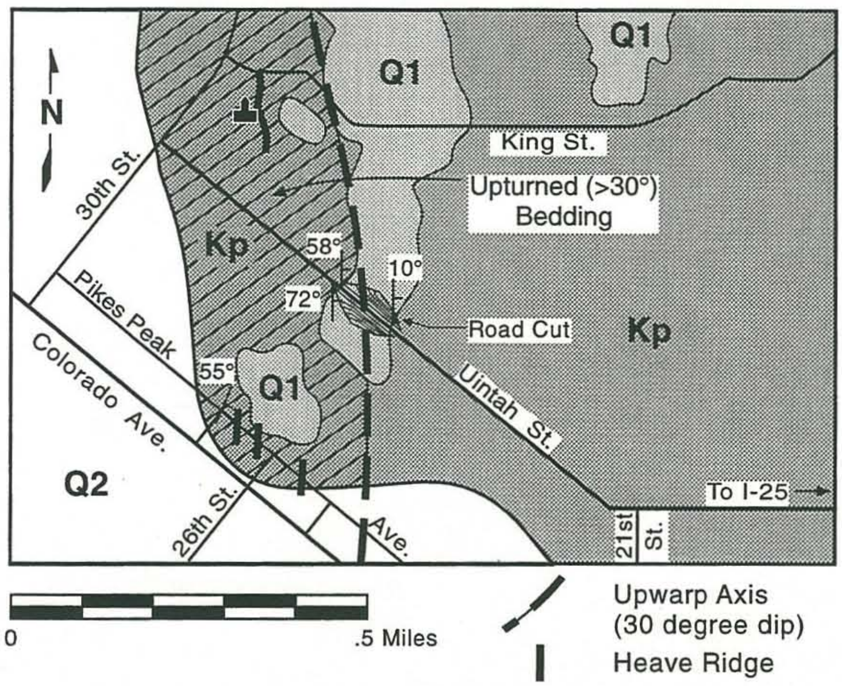


Figure 1. Index geologic map of the west-central Colorado Springs area (modified from Scott and Wobus, 1973), showing the locations of heave deformation features and exposures of the Pierre Shale (see Table 1 for a descriptive summary of locations). Geologic symbols are used for: older Cretaceous and Jurassic formations (KJ); Cretaceous Pierre Shale (Kp); mesa-capping, older Quaternary alluvial deposits (Q1); and valley filling, younger Quaternary alluvial deposits (Q2).

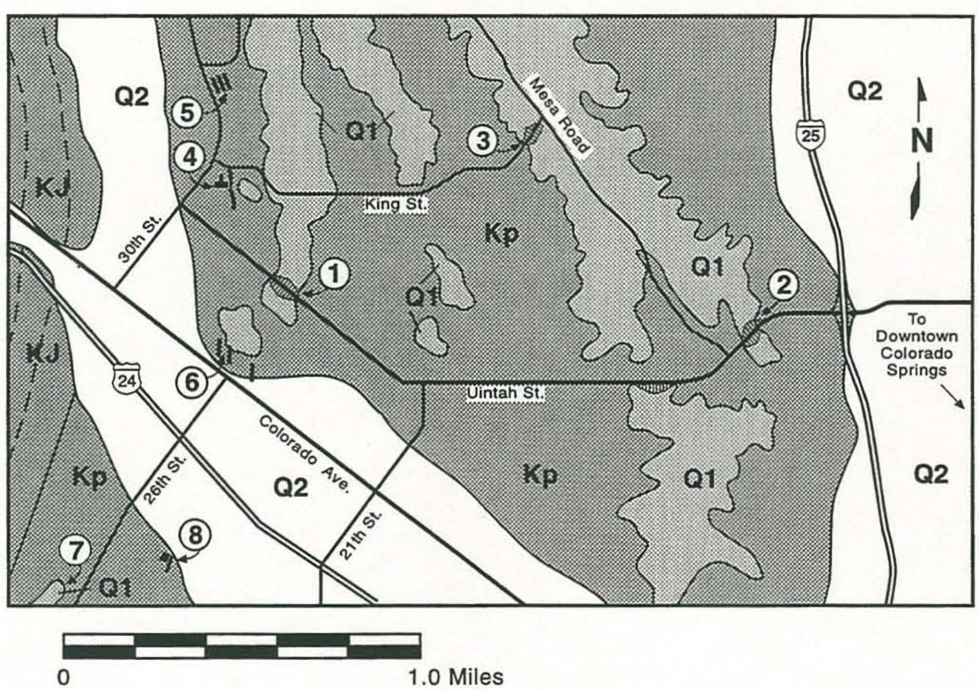
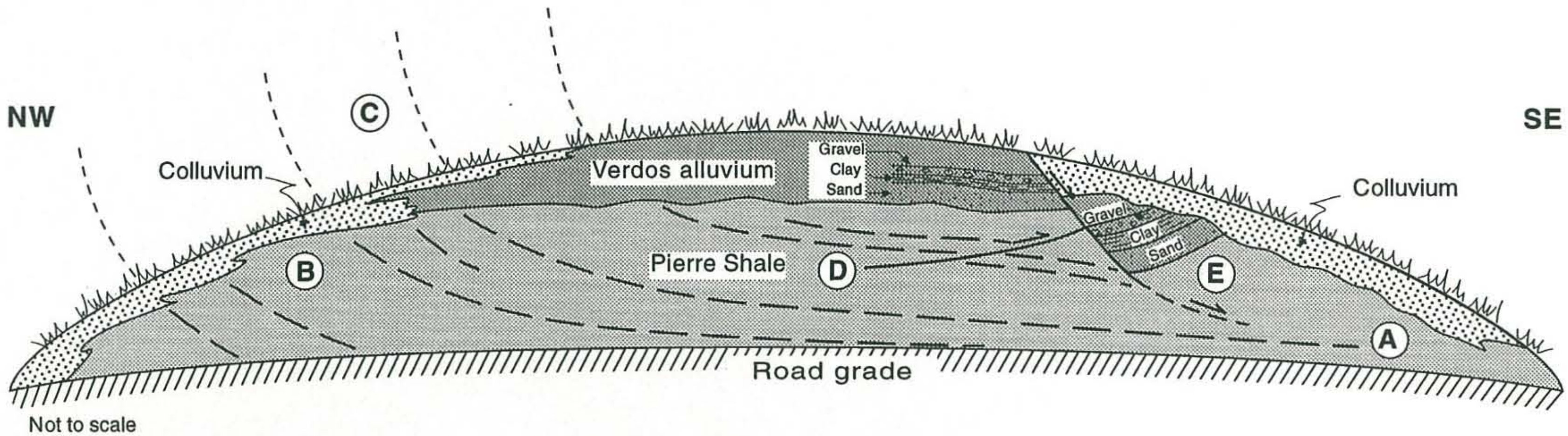


Figure 2. Geologic map (modified from Scott and Wobus, 1973) showing location of the Uintah Street road cut in relation to the upwarp axis of the Front Range monocline fold. Sedimentary bedrock to the west of this axis is upturned and steeply dipping, while bedrock to the east is relatively gently dipping. Note that nearby heave features are preferentially located within the Pierre Shale (Kp) where its bedding is upturned.



(A) = Low-dip claystone (10° dip)

(B) = Upturned claystone (58° dip; 72° across street)

(C) = Projection of bedding above erosion surface

(D) = Thrust heave (30 inches apparent offset)

(E) = Landslide deposit (reverse dip on Verdos bedding)

Figure 3. Schematic cross section of the north side of the Uintah Street road cut. See text for explanation of features.

Table 1. Points of interest for expansive soil and heaving bedrock in west-central Colorado Springs. (* Refer to Fig. 1 for index map.)

No.*	Location	Description
1	Uintah St, W of Superior St	FIELD TRIP STOP (see text). Road cut in Pierre Shale on NE and SW sides of road. The shale strat dips gently (10 degrees E) at the E end, but becomes progressively upturned (to 72 degrees E) to the W. A thrusted shear-slip surface and an exhumed landslide are exposed on the NE cut, at E end.
2	Uintah St, two blocks E of Mesa Rd	Road cut in Pierre Shale on N side of road; best seen from church parking lot on S side of Uintah St. The Pierre Shale is predominantly silty, and contains at least two well-developed, thin sandstone beds that dip eastward at about 15 degrees. The top of the hill at the cut is occupied by the Verdos alluvium, consisting of reddish brown sand. There is an erosional angular unconformity (representing a time gap of nearly 80 million years) between the low-dip Pierre Shale and the flat-lying Verdos alluvium.
3	King St, one block W of Mesa Rd	Road cut in Pierre Shale on N side of road. Here, the Pierre Shale is a thin-bedded sandstone, and not a true shale at all. The bedding is disturbed by bioturbation (the feeding traces of sea creatures 80 million years ago), and dips at approximately 15 degrees E.
4	Church on S side of King St, at Castle Road	Large, asymmetrical, curvilinear heave ridge with vertical displacement of up to 1 ft crosses parking lot southward from King St, and has uplifted and buckled the slabs of two demolished buildings (shown as standing on the 1975 USGS orthophotoquad of Colorado Springs). The ridge can be followed to where it intersects and produces a significant uplift in the N side of a brick veneer building (now a church; formerly a grocery store?). The ridge can then be followed away from the E side of the building to the edge of the bench. Bricks on the E side of the building display striking diagonal cracking and lateral offsets.
5	Castle Road, E of 30th St	At least three low (1/2 ft uplift) heave ridges can be traced across the road by matching heaved sidewalks. The western-most heave may be projected into a heaved porch at the house on the NE corner of Castle/30th. The foundation wall of the house has several large cracks.
6	Pikes Peak Ave, between 25th St and 27th St	At least three heave ridges cross this road segment. The two eastern-most ridges are best seen in the concrete gutters. The western-most ridge is low and subtle; it can be traced from a pair of bentonite beds exposed behind a new house on the N side to a heaved crown in the once-flat roofline of the apartments on the S side. A 14-inch thick, high-dip (55 degrees ESE) bentonite was temporarily exposed in a new house excavation in March, 1996, on the N corner of Pikes Peak/27th.
7	Fairview Cemetery, 26th St at Westend Ave	Pierre Shale exposed in cuts on the north and east sides of a hillock at the south end of the cemetery. Good exposures of cream-colored bentonite beds, dipping 79 degrees ESE, behind the white shop building. No heave features are visible across any of the cemetery roadways along the trend of the bentonite beds.
8	School on Hagerman St, between 24th St and 25th St	One small, broad heave ridge (< 1/2 ft uplift) crosses the street. The old redstone school building has a singular, large crack running vertically up the outside wall where the wall intersects the projected trend of the heave ridge. The crack turns and runs diagonally to the E across the upper story.
(9)	Memorial Gardens Cemetery, Academy Blvd and Airport Rd (to E of map area)	Two asymmetrical heave ridges (1/2 ft and 1 ft uplifts, respectively) across loop road in northeast corner of cemetery. The most prominent ridge crosses the grass and cemetery plots to the east-northeast of the road. This ridge is a thrust-heave along a 60 degree plane that cuts across bedding in low-dip Pierre Shale (J. Himmelreich, personal communication).
(10)	Ute Valley Park, at E end of Pinon Park Dr (to N of Map area)	Walk uphill past gate to road cut through Laramie Formation. This cut exposes the regional monoclinal fold, in a manner similar to that seen at the Uintah St road cut (but more spectacularly). The tightly folded sandstone beds decrease in dip angle from W to E, from 70 degrees ENE to 12 degrees ENE, within a distance of 150 ft. Bedding in the lower, W part of the cut is bent downward as it approaches the ground surface; this is a result of localized slope-creep processes rather than regional folding.
(11)	Allegheny Dr, E of Centennial Blvd (to N of map area)	Road cut through steeply dipping Laramie Formation. Dip is 50 degrees ENE. Note the carbonaceous streaks in the shale. The Laramie Formation contains layers of highly expansive claystone as well as non-expansive bedrock, making it capable of undergoing differential heave where the beds are upturned.

DCNoe, 2/96

ROCKFALL HAZARD AND EMERGENCY MITIGATION AT MANITOU SPRINGS

Jonathan L. White
Colorado Geological Survey

Introduction

Precipitation during the Spring of 1995 was higher than usual for most parts of Colorado. Rocky slopes, by becoming saturated with moisture, created conditions that resulted in numerous rock mass failures, which generated rockfall throughout Colorado at rates higher than normal. Unfortunately, falling rocks the spring of 1995 resulted in fatalities in other parts of the state. The rockfall hazard that occurred in Manitou Springs was unusual because the rock feature that was moving and dangerously unstable was discovered prior to ultimate failure. This was very fortunate because of the rock size and immediate proximity to homes below. There is no doubt that, were this rock to roll down the slope, home(s) would be destroyed and any occupants inside probably killed.

Regional Setting

Manitou Springs occupies a relatively narrow valley where Fountain Creek emerges from the Front Range Foothills. It lies within a complex geologic region where a tilted terrane of sedimentary rock is pinched between the termination of the Rampart Range Thrust Fault from the north and the southeast trending Ute Pass Thrust Fault. Red sandstone bluffs of the Fountain Formation comprise the valley slopes, most prevalent on the steeper north side. The valley bottom is narrow enough, and developed enough, that an improvement of Highway 24 to a modern four lane roadway required a realignment to a location further up onto the bluffs, north of town.

The Fountain Formation in the immediate vicinity of Manitou Springs has a relatively gentle dip of 13° in the southeast direction. This formation is composed of sequences of interbedded sandstone, conglomerate, silt(mud)stone, and shale. The sandstone beds tend to be the most resistant to weathering. The hills to the north of town are characterized by series of benches, where rock is resistant, and slopes, where rock is soft and erodes easily. The softer strata easily weathers to mud and clay that when wetted, become slick to the point that blocks of harder rock can begin to slide on the contact between the sandstone and mudstone. Typically, the softer mudstone and claystone beds can erode out from under the more massive sandstone benches. The sandstone is then undermined and, dependant on jointing or fracturing, can slump. The slumping can and eventually does lead to toppling failures. **See Color Plate #7**. Such is the condition that exists above El Paso Boulevard in Manitou Springs.

The Rockfall Hazard

Two beds of hard sandstone exists on a slope below Highway 24 and above El Paso Boulevard. The slope gradient from El Paso Boulevard towards these rock outcrops steepens quickly enough that only one row of homes could be built along the road. The top stratum is a 12 foot thick, massive, well cemented, coarse grained sandstone. The bottom four feet is comprised of pebbly conglomerate. The hardness of this sandstone has created a 'caprock' where softer material has eroded away from above in an area from the rim of the outcrop to Highway 24, leaving the ground relatively flat (tilted at 11°, approximating the dip of the rock formation as a whole). Below this massive sandstone bed is a 2 foot layer of mudstone and siltstone, and below that, 14 feet of hard, medium to thickly interbedded sandstone. A view of the sandstone ledge reveals two prominent joint sets which are essentially vertical and intersect at 100°, almost at right angles. Rectangular blocks, defined by the joint sets, occur at the ledge. Those joint surfaces defining the rock blocks nearest the edge have opened and in-filled with soil. Once this occurs, successive moisture saturation and freeze-thaw cycles very slowly push the rock block away from the open joint, along the slippery claystone.

The rock hazard was a 14 by 12 by 6 foot, 70 ton, block in this prominent ledge of sandstone. Over time the block had slid 2.5 feet from the joint face of the ledge. Soil had completely filled this 2.5 foot wide void. Concurrently, this rock had also been partially undercut at the weak layers of mudstone and conglomeratic sandstone. During the extremely wet conditions of the spring of 1995, the block slid an additional 3 feet and tilted on a 32° incline within the sheared, weaker, conglomeratic sandstone and weathered mudstone. **See Photo #1, Color Plate #7**. Fortunately, relatively soon after this slumping occurred, the tilted block was discovered and city authorities were notified.

An emergency response team was formed to evaluate the hazard and determine the best approach for mitigation. The occupants of the homes directly below the perched rock block were evacuated and El Paso Boulevard was closed. The block movement was monitored while a rockfall mitigation construction crew was being mobilized. Additional slump movements totaling two inches were measured. The tilted block movement stopped when it "ground" through the weathered mudstone onto the top of the hard sandstone bench below. As more rock surface area bore onto the lower bench the weight and friction caused movement to slow and eventually stop, leaving the rock block in a precarious tilted orientation, perched on the lower sandstone bench and isolated from the surrounding ledge. **See Color Plate #7.**

Mitigation

Upon evaluation of the hazard it was determined that the quickest and safest approach to stabilize the rock was a cable sling system. Removal of the hazard was considered but not done because of the requirement for continued occupant evacuation and of the probable damage of unknown severity to the homes below (As mentioned earlier the homes are placed immediately below, 100 vertical feet, from the rock ledge). There is no room for a run-out zone for falling rocks and no way to mobilize heavy equipment to the site. Yenter Companies, specialists in construction of rock slope stabilization and rockfall protection systems, was hired by the city to mitigate the hazard.

Worked commenced on May 23, 1995 and six initial cables were wrapped around the front of the block and anchored into competent rock of the ledge on May 26, 1995. Once this minimum stabilization was in place, people were then allowed to re-occupy their homes before the Memorial Day weekend. The next week, once the risk of the rock falling was removed, anchors were drilled into the rock itself and seven additional cables were strung to opposite anchor points in stable rock on the slope. **See Photo 3, Color Plate #7**.

Conclusions

Careful land use planning, as used today, would have correctly identified the area below this prominent ledge along El Paso Boulevard as a geologic hazard zone. If investigated prior to home construction, the zone could have been effectively mitigated from rockfall events by merely having them removed or stabilized with no risk. As with most geologic hazards, when the hazard is determined after homes or other structures have been placed, effective mitigation can be expensive and difficult, if not impossible. The City of Manitou Springs was lucky that this particular hazard was spotted prior to failure and they only had to respond by implementing an emergency mitigation project, not to a fatal catastrophe. Most times rockfall hazards are investigated after the fact. The conditions that formed this hazard are present elsewhere in the area. **See Photo #2, Color Plate #7**. While mobilized, Yenter Companies was directed to stabilize other rock blocks in the immediate vicinity that would have failed the same way. The Colorado Geological Survey has installed movement gauges across joints that separate the rock blocks on this sandstone ledge above El Paso Boulevard. The locations were determined where blocks have moved and are slightly undermined but are not currently a danger.

Mitigation of Debris Flows on Cheyenne Mountain, Colorado Springs

J.S. O'Brien, FLO Engineering, Inc.

Introduction

In recent geologic history, a number of large debris flows created a series of coalescing alluvial fans with large boulder levees on the eastern face of Cheyenne Mountain (Color Plate #8, Photo 1). The major debris flows were probably associated with post-glacial runoff. In July 1965, a high intensity thunderstorm generated destructive debris flows in the steep mountain basins. Prior to 1965, there was no evidence to indicate that any major debris flows had occurred in the previous 50 years. Mud and debris flows associated with the 1965 event and other small storms have left deposits in existing channelways and reduced flood conveyance (Color Plate #8, Photo 2).

Prediction of Design Flood Events

There was no data available from the 1965 flooding to estimate rainfall intensity, debris volumes, sediment concentration, peak discharge or hydraulic variables (velocity and depth). In the absence of the historic data, FEMA and local drainage criteria require that the 100-year rainfall-runoff constitute the design storm for mitigation planning.

Since there are no stream gages in the project watersheds, it was necessary to estimate rainfall-runoff with Corps of Engineers HEC-1 hydrologic model and hydrologic criteria from the City of Colorado Springs Drainage Criteria Manual. Precipitation records for five local rain gage stations were analyzed and the 2-hr, 100-year storm was selected as the design rainstorm. The HEC-1 hydrologic parameters were calibrated using a small gaged basin (Rock Creek) whose headwaters were contiguous to the study basins. Two historic storms were calibrated for peak flow and volume using both the SCS curve number and the Green-Ampt infiltration methods for computing runoff. The calibrated SCS curve numbers correlated well with the curve numbers used in other local hydrology studies. Flood hydrographs were computed with HEC-1 at the various fan apices and peak discharges ranged form 15 cfs to 560 cfs with unit runoff ranging from 1,030 to 1,440 cfs/mi^2. The unit runoff values compared well with those reported in other studies. The design storm hydrographs at the fan apices were bulked with sediment for mud and debris flow routing.

The 100-year storm generally will have so much water volume that a very viscous mudflow with a large debris frontal wave is unlikely to be sustained very far down-fan of the apex. During large flood events, a slow moving debris frontal wave may develop, but on the fan surface the faster traveling watery peak discharge will overtake and dilute the frontal wave. Mud and debris flows are more commonly associated with 10-year or 25-year return period flood events. The mudflow during these smaller rainfalls is usually initiated by hillslope or bank failure. A very erosive watershed with an unlimited supply of sediment might produce mudflows during any storm, but in most cases, the basin channels need to be charged with boulders and debris from previous storms.

The 100-year water flood and mudflow hydraulics for the basin channels downstream of the fan apex were computed using the FLO-2D two-dimensional flood routing model. It can be applied for hyperconcentrated sediment flows such as mud and debris flows as well as water flooding. FLO-2D is a finite difference model that predicts the flow depth and velocity using a diffusive wave approximation to the full dynamic wave momentum equation. The model was developed by FLO Engineering. A description of the model is presented in O'Brien et al., 1992.

To simulate the Cheyenne Mountain debris flows, the 100-year HEC-1 flood hydrograph at the fan apex was bulked with sediment. A maximum sediment concentration of 47% by volume assigned to the frontal wave with the peak discharge sediment concentration of 45% by volume. The rest of the discretized hydrograph decreased uniformly to 20% concentration by volume using five minute timesteps. This assumed sediment concentration is conservatively high. For example, a mudflow with a fluid matrix concentration in excess of 50% by volume would ooze down the mountainside and cease flowing at the first break in slope. The peak sediment concentration of 47% by volume preserves fluid behavior while bulking the discharge to create a mudflow event. The mudflow properties of viscosity and yield stress as a function of sediment concentration by volume were conservatively estimated using relationships derived from a laboratory analysis of debris flow deposits (O'Brien and Julien, 1988).

FLO-2D predicted flow depth, velocity, discharge, and sediment concentration for every overland or channel grid element for computed timesteps ranging from 1 to 30 seconds. Maximum flow depths, velocities and discharges were summarized in various output files. The depth and velocity results were imported to the original digitized mapping and plotted as contours. In one of the lower watersheds, the finite difference grid system was comprised of 3,224 grid elements (each element being 50 ft square). Channel flow, overland flow, rill and gully flow, rainfall and infiltration were simulated. The rainfall-runoff on the lower basin diluted the mudflow sediment concentrations.

Debris Flow Mitigation Design

The best alluvial fan flood mitigation is avoidance. Flood hazard mitigation on alluvial fans is possible in most cases but is extremely expensive. There are two principal ways to mitigate debris flow damages on an alluvial fan: 1) Storage of the flood and debris in an upstream detention basin; or 2) Controlled conveyance of the flows off the fan. It is possible to combine the two methods by constructing debris basin while discharging the diluted floodwaters downstream. Debris basins can be designed with fences to trap the debris frontal wave, fill with sediment and then overflow. Another combined mitigation approach is to construct a channelway with floodplain berms which would confine overbank flows and enhance the deposit of boulders and debris on the fan surface. Other mitigation methods include watershed erosion practices, channel stabilization and slope control to reduce the sediment supply to the fan channel. Hydraulic engineers should also be cognizant of channel erosion and debris downstream of the fan apex. Channel riprap can be a source of boulders for down-fan flows.

Watershed channels upstream of the fan apex are generally so steep that debris basins can store only a fraction of the 100-year storm volume. There is also a remote chance that the debris basin may fail when overtopped and together these reasons make upstream storage the less desirable of the two mitigation methods. The preferred method of mitigation of flow conveyance off the fan also has drawbacks which include the potential increase in peak discharge from improved conveyance, the prohibitive cost-associated channel reconstruction, and expensive future channel maintenance. Often the existing downstream channel and conveyance facilities have not been appropriately sized for mudflow events. Concentrating flows in enhanced channels may exacerbate downstream flooding.

Mitigation design on the Cheyenne Mountain alluvial fans focuses on conveyance of the flow off the fans. FLO-2D was applied to compute flow hydraulics to size channels with freeboard. Some overbank flow of mud and debris may be designed to decrease downstream impacts. Floodplain berms will confine the overbank flow and provide the opportunity for debris storage between the berms. The berm height will be five feet higher than the computed mudflow surface. Trees and natural topography between the berms will enhance the potential for debris deposition. Channel drop structures may berequired for energy dissipation. Channel stability is not as critical as the berm stability and the berms will be designed with soil cement facing or embedded concrete walls to protect against potential scour. Mitigation features may include:

- A small debris basin with a debris fence to store the frontal wave.
- Channel straightening, enlargement and excavation.
- Placement of drop structures where necessary.
- Creation of an overbank floodway confined by stable berms.
- Removal of boulders and debris from the floodway.
- Construction of a concrete wall and footer within the berm at critical location.
- Free span channel crossings such as wide box culverts (20 ft wide x 10 ft high).
- Unobstructed and uniformly graded approaches to channel crossings.
- A maintenance program to remove sediment and debris deposits.

These proposed mitigation measures are designed to pass the flood and debris downstream. With sediment bulking [bulking factor=1./(1.-C_v); where C_v = sediment concentration by volume], both the flood peak discharge and volume will be increased. The mitigation analysis must consider potential downstream impacts including inadequate capacity of existing flood facilities and channel crossings, loss of conveyance capacity with sediment and debris deposition, and loss of downstream storage with sediment deposition.

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O'Brien, J.S., P.Y. Julien, and W.T. Fullerton, 1992. "Two-Dimensional Water Flood and Mudflow Simulation," ASCE Journal of Hydraulics, V. 119, No. 2, pp. 244-261.

LANDSLIDES IN COLORADO SPRINGS

John Himmelreich
CTL/Thompson, Inc.

The term landslide is commonly used to describe a wide range of mass movement processes including rockfall, talus, translational and rotational slides, rock slide, block glide, debris slide, avalanche, earth flow, mud flow, quick clay slide, liquefaction slide, slump, etc. In this paper the term landslide is generally limited to slides, slumps and earth flows.

Landslides have not been studied in much detail in the Colorado Springs area, except where active slides have affected structures or the works of man. A landslide inventory of the Colorado Springs area (Robinson, 1977; Trimble and Machette, 1979; Himmelreich, in preparation) indicates mapped landslides primarily occur within, or are associated with, four geologic units or their derived soils: the Pierre Shale, the Fountain Formation, the Lower Dawson Formation of Scott and Wobus (1973), and the east side of the Dakota Hogback.

Pierre Shale

The largest mapped landslide in Colorado Springs occurs along the front of Cheyenne Mountain (Trimble and Machette, 1979a) and covers about 2200 acres. This is a mass wasting complex consisting of rockfall and rock avalanche, slumps, translational and rotational slides, earth flows, and debris flows. The Pierre Shale is the underlying bedrock.

The Ute Pass Fault generally forms the western boundary of this complex and activity on the fault probably triggered landslides in the past. The Ute Pass Fault has truncated the strata along the mountain front and steeply tilted it. It is believed the strata rapidly flattens to a much gentler dip (probably less than 15 degrees) within a quarter to half mile east of the fault. The geologic structure (inclination of the strata) and relatively low strength of materials of the Pierre Shale appear to be the primary causes of landsliding within this unit. Slopes in Pierre Shale of five degrees or more have the potential to fail (Scott and Wobus, 1973; Robinson, 1977). Springs along the Ute Pass Fault, infiltration of precipitation, and occasional flooding provide water to the landslide complex.

Within the last 25 years, development of residences and private recreation facilities have encroached on portions of the landslide complex. Reactivation of portions of the landslide and damage to facilities and residences has occurred within the past five years on this mapped complex.

Other landslides associated with the Pierre Shale are by far the most numerous in the Colorado Springs area and are mapped mainly where the Pierre Shale occurs on slopes. Since the Pierre Shale is not resistant to erosion and does not normally form prominent ridges or highlands, the Pierre occurs on slopes where protected by resistant "caps". In the Colorado Springs area the resistant "cap" is generally the Verdos Alluvium. Many landslides occur along the edge of mesas capped by the Verdos Alluvium and underlain by the Pierre Shale. Since the regional dip of the Shale is easterly, most slides interpreted to result from bedrock failure occur along easterly facing slopes. Landslides on slopes of other orientations (especially north facing slopes) also occur, but are less common (see Color Plate #9, Photos 1-3).

Fountain Formation

The second-largest mapped landslide in Colorado Springs occurs in the Fountain Formation and covers about 75 acres. In this area, the Fountain Formation has been tilted, resulting in an increased potential for landsliding along the shale layers. The Glen Eyrie Shale Member at the base of the Fountain Formation is locally known for its expansive (and weak) shale. The landslide is interpreted to have resulted from undercutting of the tilted strata by erosion along Black Canyon. Smaller landslides associated with the Glen Eyrie Shale have also been recognized in this area. The relatively small outcrop area of this unit limits the number of landslides associated with it.

Lower Dawson Formation

The Lower Dawson Formation consists of andesitic claystones and sandstones which are locally known for their high expansion potential. A few landslides have been mapped within this unit, all being relatively small and recent. Two have occurred in the Rockrimmon area, resulting in damage to multi-family and single-family dwellings. One small slump occurred in the spring of 1995 near Palmer Park (see Color Plate #9, Photo 4). One occurred a few years ago near the campus of UCCS in the Austin Bluffs area. It appears the relatively low strength of materials is the governing factor for most recognized landslides in this unit.

Dakota Hogback

Landslides are common along the east side of the Dakota Hogback throughout the entire Front Range foothills (Colton, 1978; Trimble and Machette, 1979a and 1979b). The Graneros Shale, Greenhorn Limestone, and Carlile Shale (collectively called the Benton Group) occur along the east side of the hogback. Failure of the Benton Group formations on the east side of the tilted and resistant Dakota Sandstone appear to have occurred in times past due to higher moisture conditions.

Landslides along the Dakota Hogback have been mapped in Colorado Springs, and in southern El Paso County along Colorado State Highway 115 and in Fort Carson. The relatively narrow outcrop zone of these formations limits the number of landslides associated with it.

Landslide Problems

Colorado Springs is not without its slope stability problems. Landslides in Colorado Springs within the last 30 years have affected many works of man causing considerable damage. Damage due to active landsliding has affected single-family and multi-family dwellings, Interstate 25 right-of-way on many occasions, Colorado State Highway 115, private and public roads, commercial structures, major drainage improvements, private recreation facilities, and graded subdivision slopes. Many more landslides have also occurred but have not caused appreciable damage. The cost to the public and private sector has been substantial.

The spring of 1995 was an unusually wet one for the area. The increased moisture resulted in several landslides in the spring and early summer (see Color Plate #9).

Over the last few years alone, damage from and mitigation of active landslides has cost millions of dollars. Mitigation measures which have been installed locally to mitigate or slow landslide movement include:

1) Tie-back anchor systems on a slope failure affecting multi-family dwellings.

2) Horizontal drainage systems to aid in dewatering in a private recreation facility.

3) Temporary grading and toe buttress installation along a public roadway.

4) Removal of the landslide mass, installation of subsurface drainage facilities and replacement with a buttress to stabilize a private roadway.

5) Reinforced earth walls to stabilize a public roadway.

The challenge facing the Colorado Springs area today is how to administer the landslide areas already developed, and those where development is proposed.

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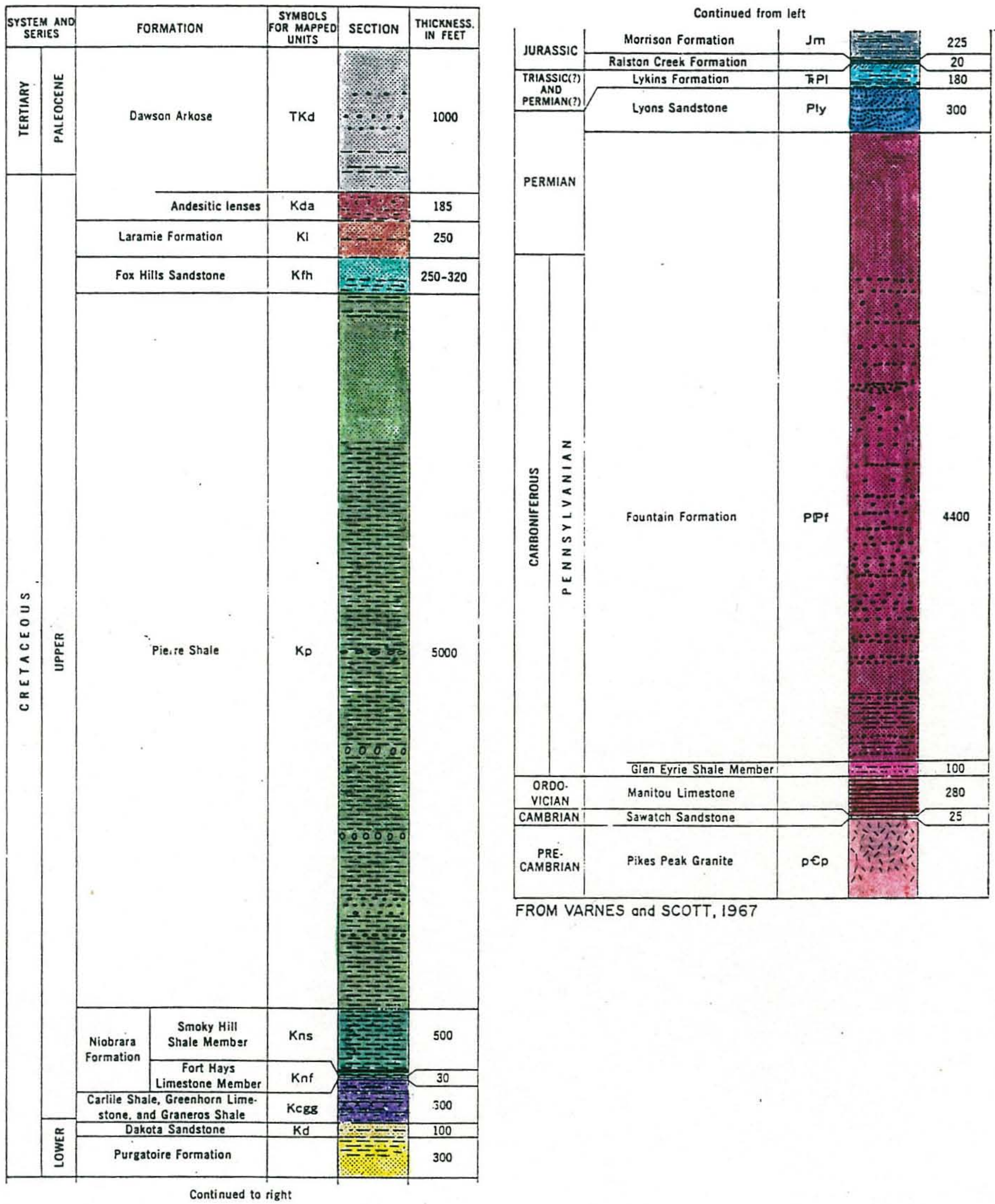
Trimble, D. E. and Machette, M. N., 1979b; Geologic map of the greater Denver area, Front Range urban corridor, Colorado; U. S. Geological Survey, Miscellaneous Investigation Series, Map I-856-H.

COLOR PLATES



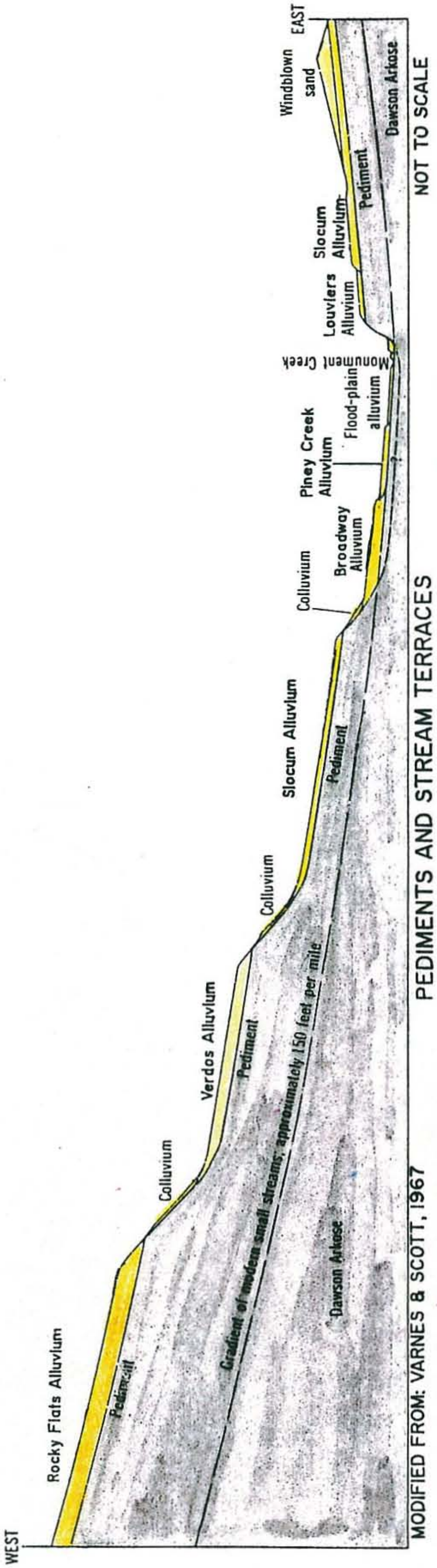
FROM VARNES and SCOTT, 1967

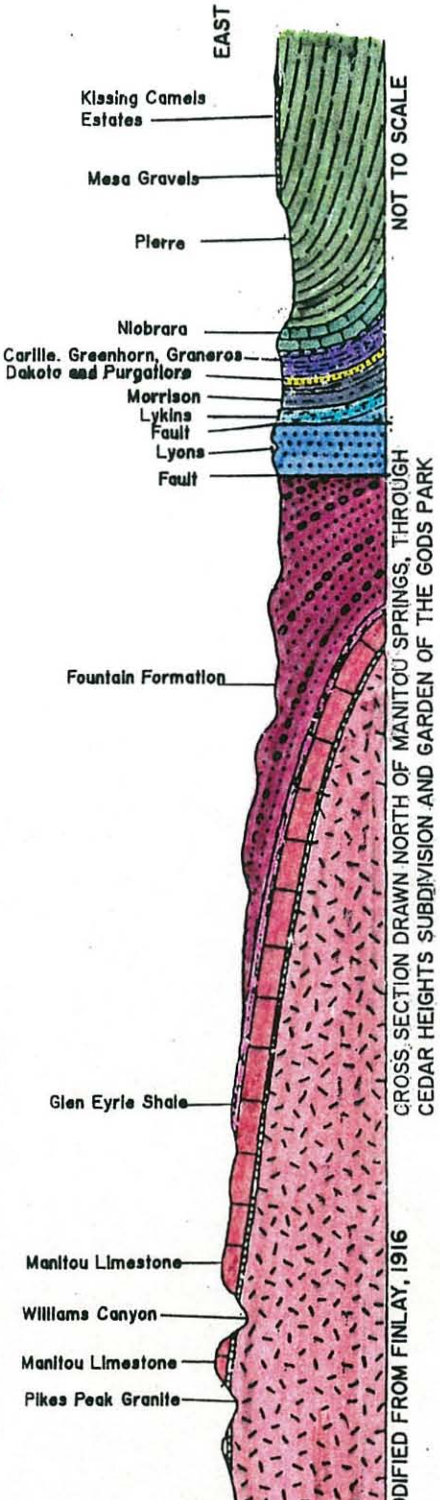
COLUMNAR SECTION OF BEDROCK EXPOSED IN THE COLORADO SPRINGS AREA

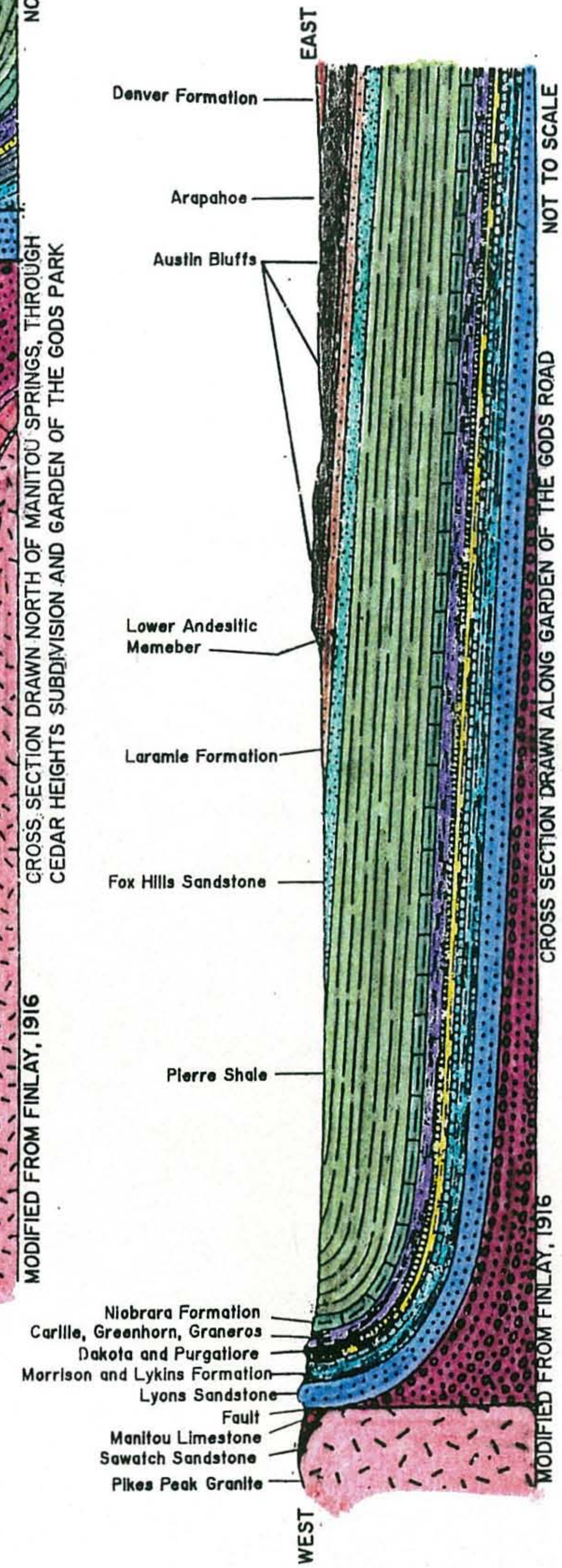
COLOR PLATE 1

GEOLOGIC CROSS SECTIONS

COMPILED BY JOHN HIMMELREICH



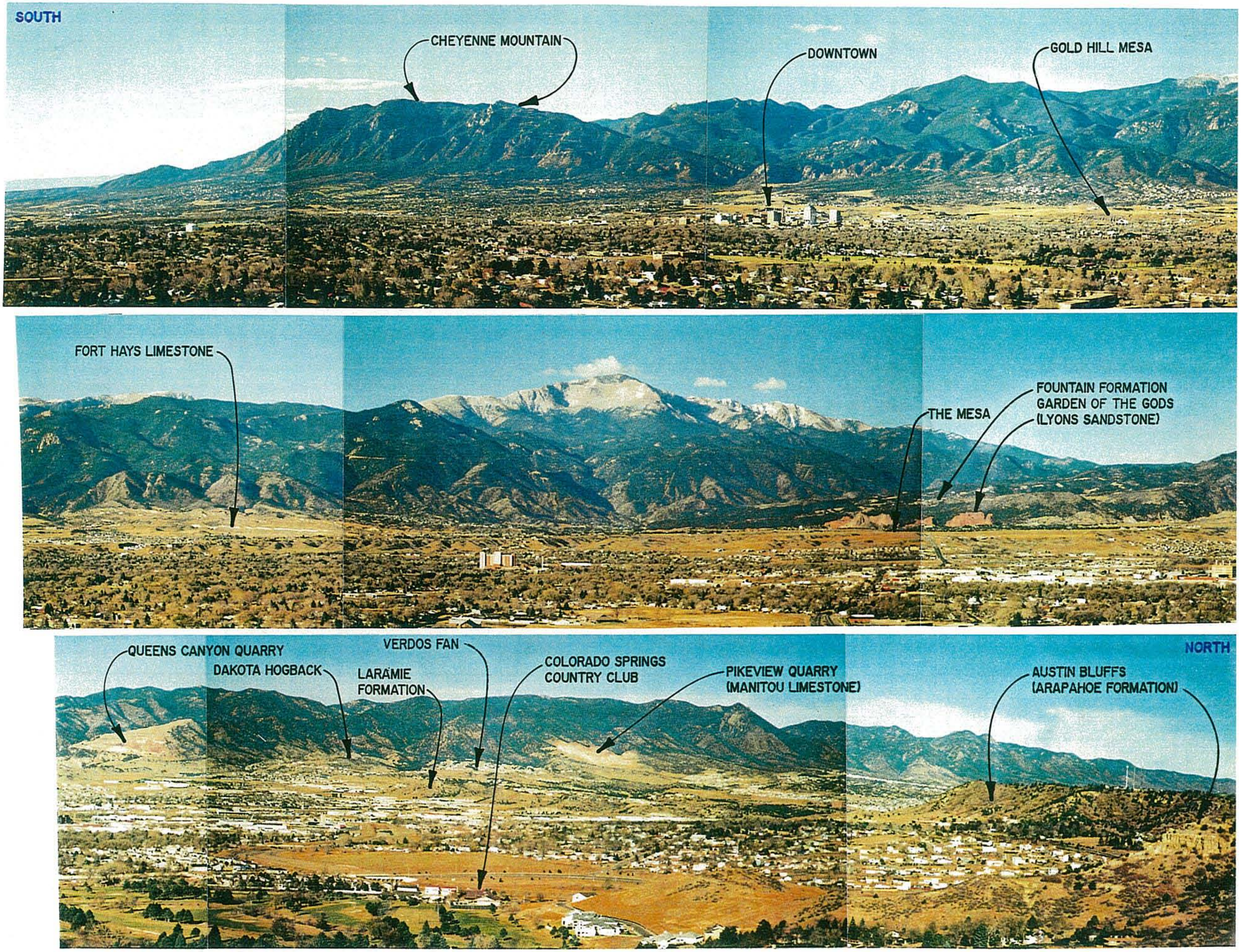




COLOR PLATE 2

PANORAMA FROM GRANDVIEW OVERLOOK

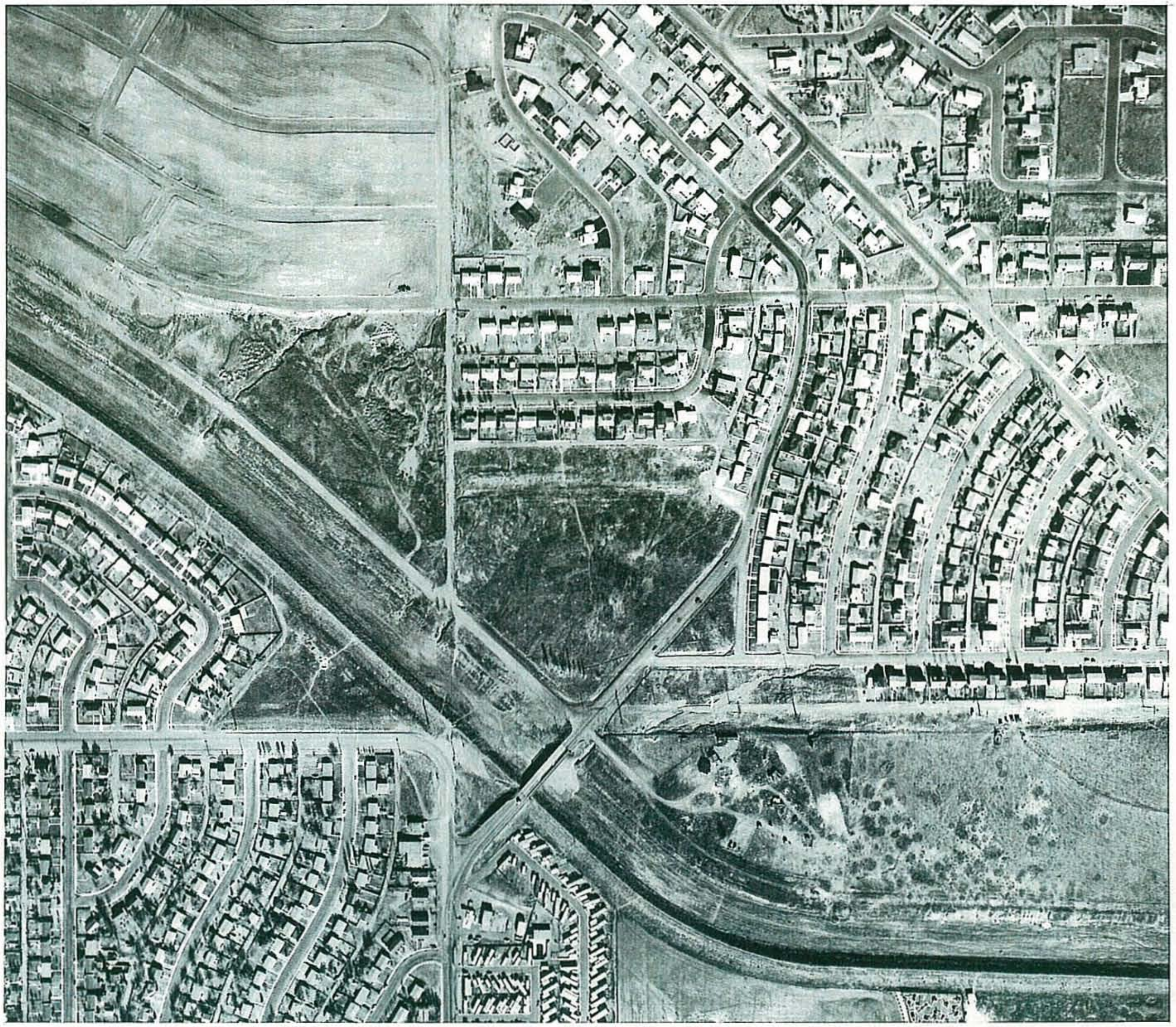
PHOTOS BY JOHN HIMMELREICH



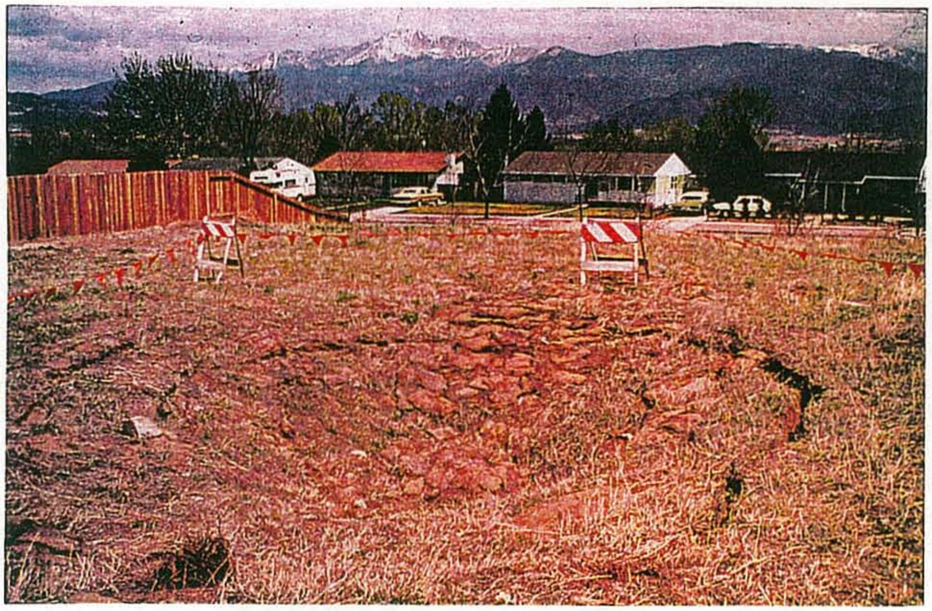
COLOR PLATE 3

PORTAL PARK: THEN...

1966

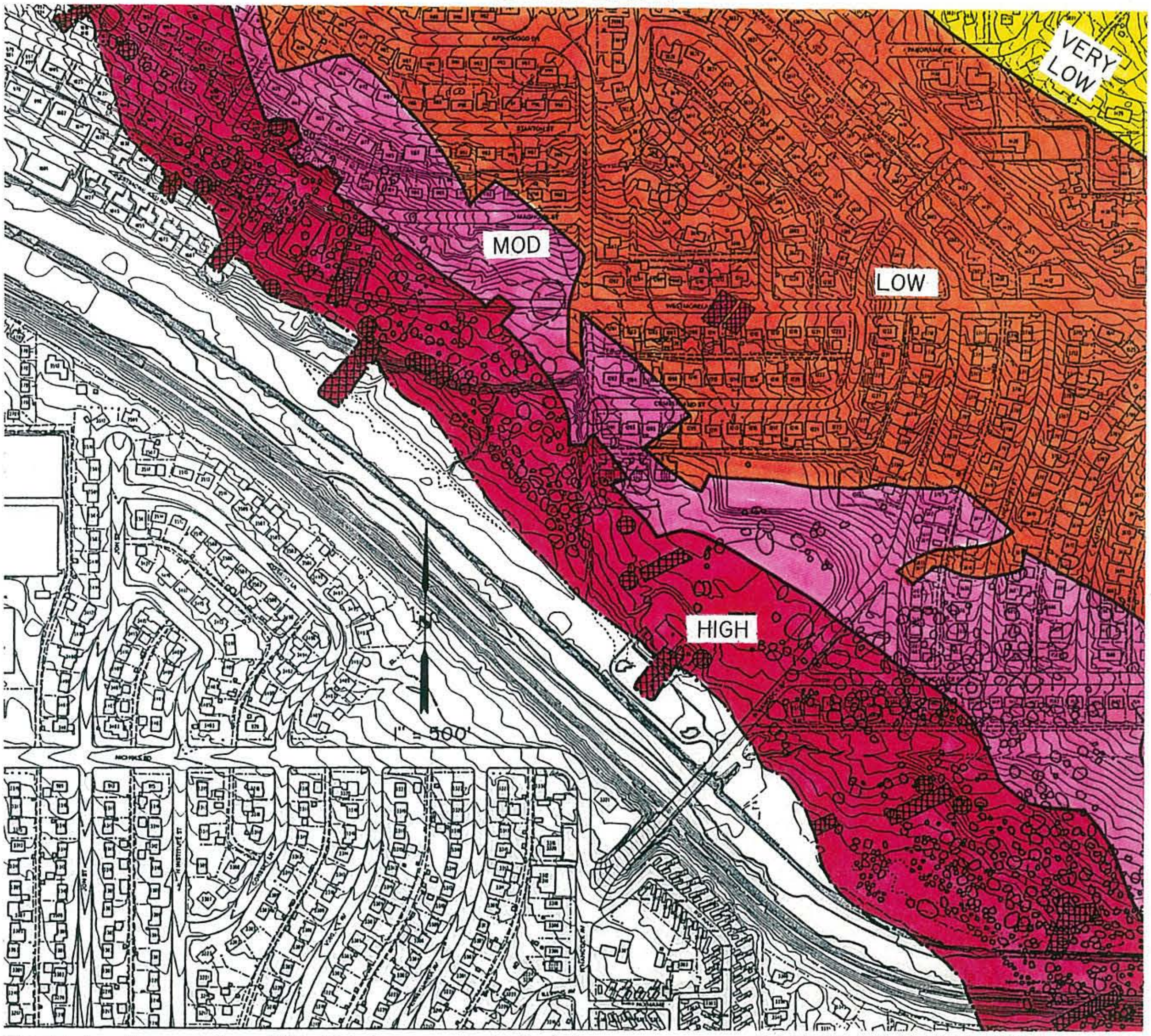


1968



COLOR PLATE 4

...AND NOW



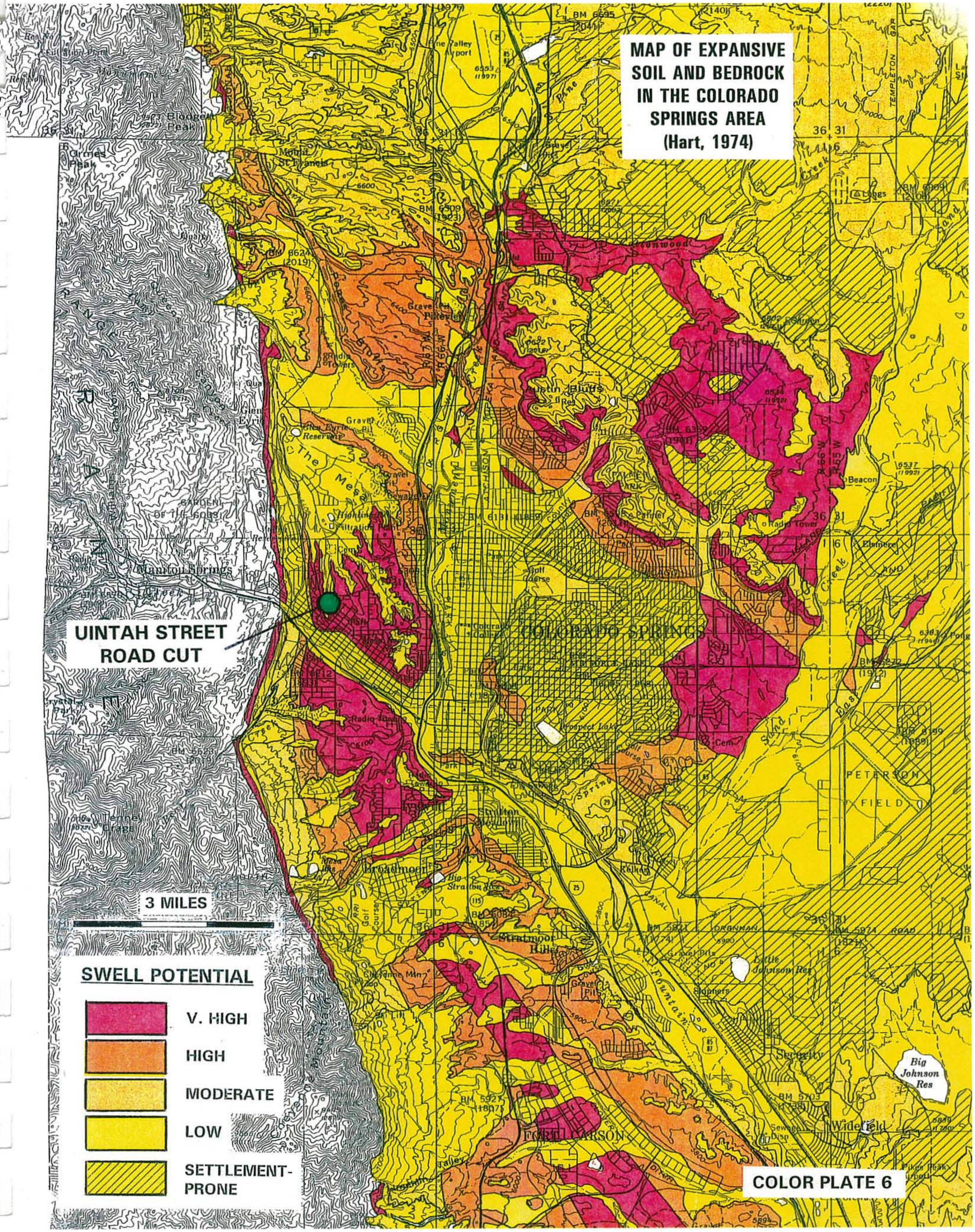
Mine data from Dames and Moore, 1985. All features approximately located.

Base map courtesy of Colorado Springs Utilities, Facilities Information Management System

ILLUSTRATIVE MINE HAZARD MAP

1995

COLOR PLATE 5



COLOR PLATE 6

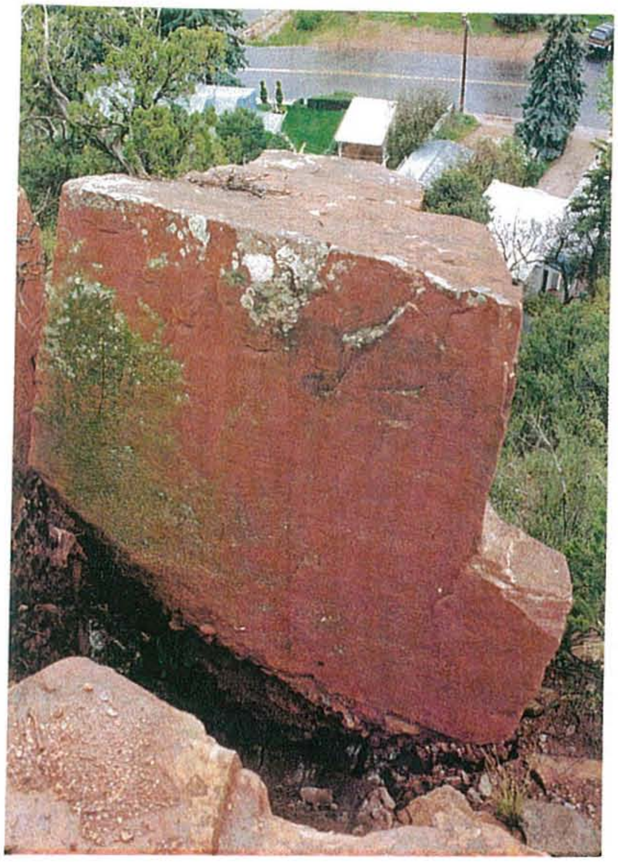


Photo #1. Rock block at time of discovery. Note vicinity of homes below. Street shown is El Paso Boulevard.

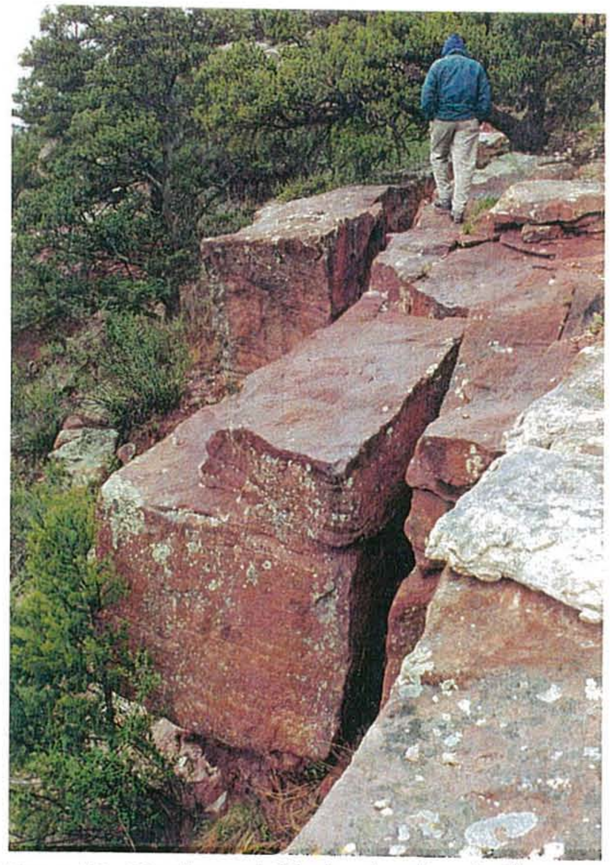


Photo #2. Nearby rock blocks showing similar pre-failure conditions. Note undercutting and open joint surfaces. These blocks were bolted during the emergency mitigation project.

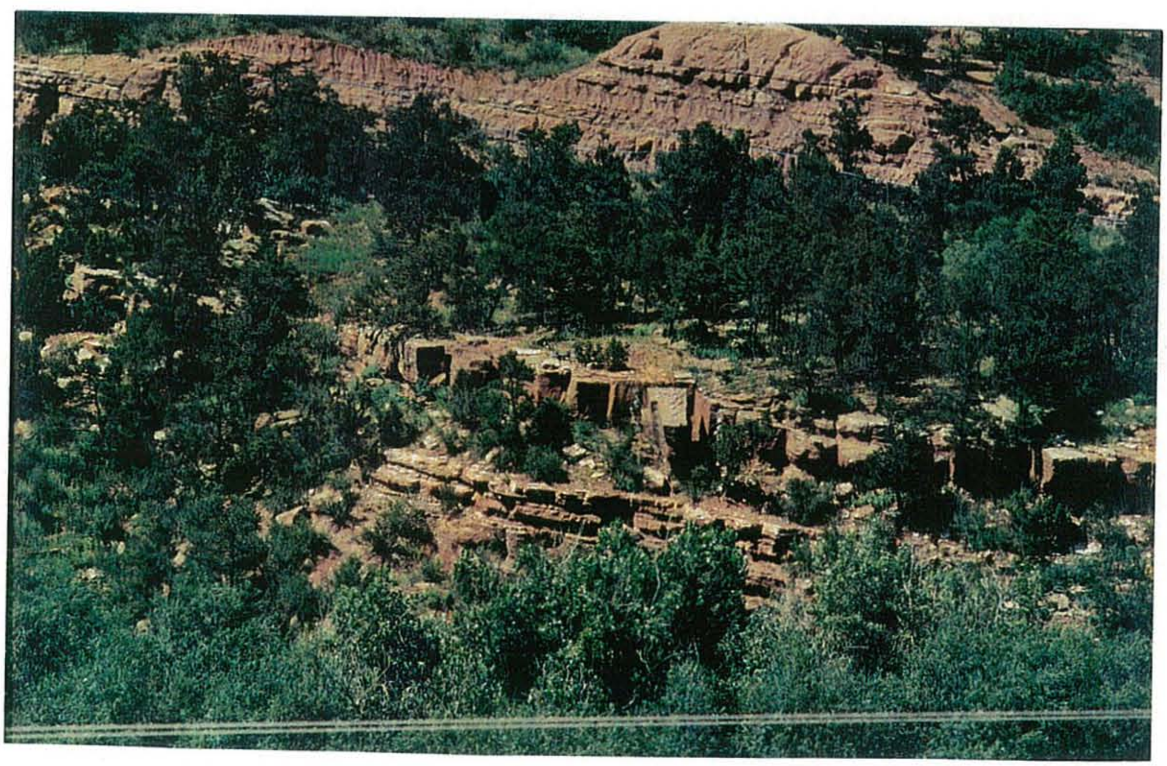


Photo #3. Large rock cut in background is Highway 24. Homes below the slope are obscured by trees in this photograph. Note cables wrapped around and installed in top of tilted rock block, right of photo center. Blocks shown in Photo #2 are prominent to the left of center.

COLOR PLATE 7

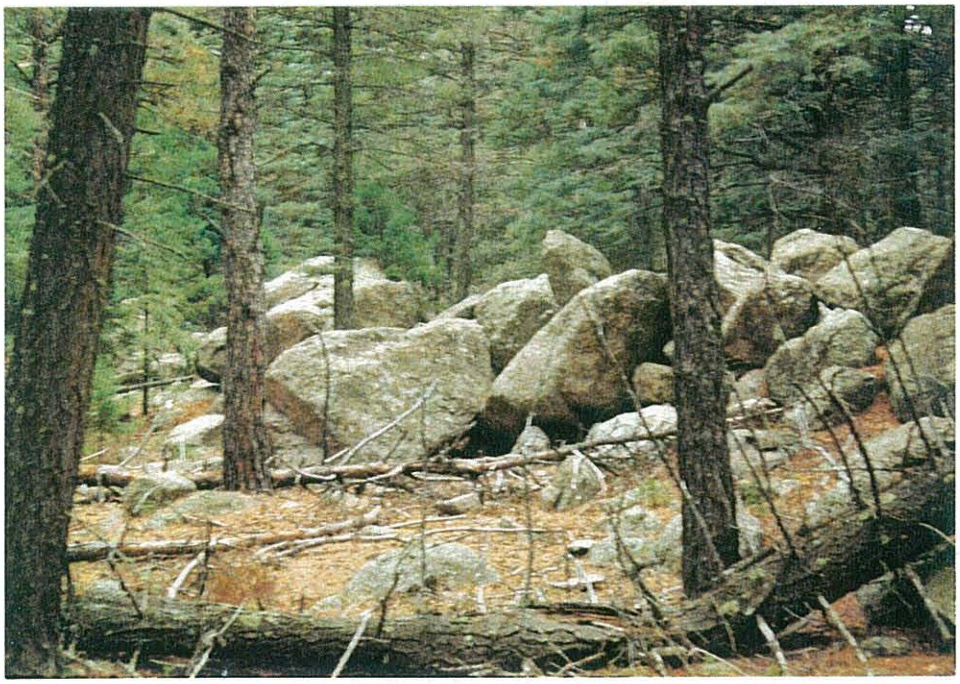


Photo 1. Boulder levees constructed by large post-glacial debris flows.

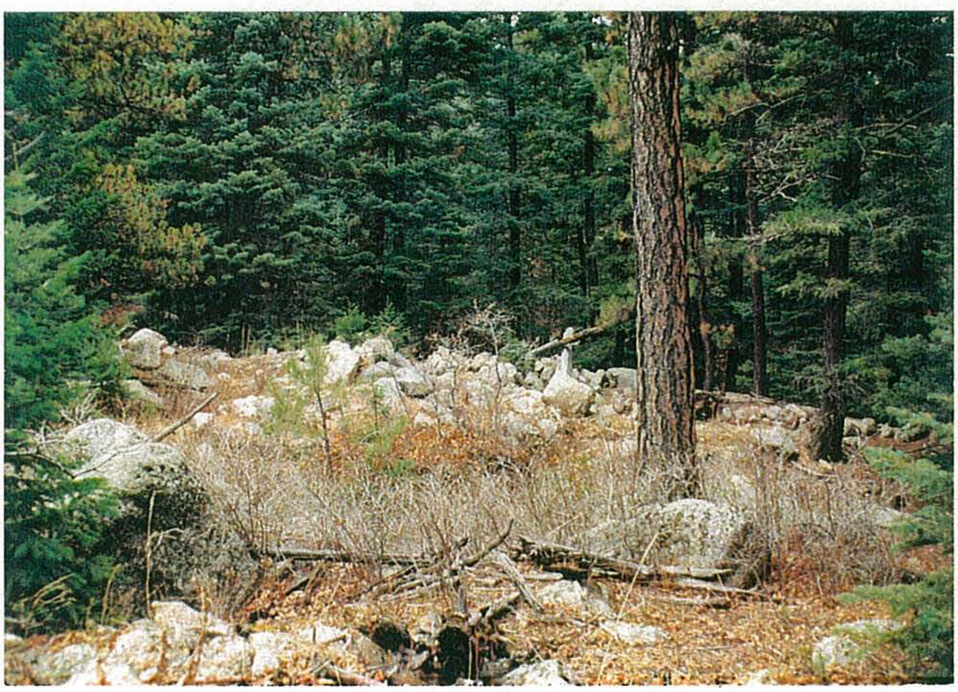


Photo 2. Recent debris flow deposits reduce channel capacity.

Photo 1. Landslide above Mesa Road near 30th Street. Note van (upper right) parked on bike path. Scarp in upper middle part of photo. Toe encroaching on Mesa Road.

Photo 2. Bike path, damaged and offset by landslide, above Mesa Road. Note traffic cones in the background, on top of in-place path.

Photo 3. Toe of landslide encroaching on Mesa Road. Note white stripe on asphalt chunk in toe bulge left of barricade.

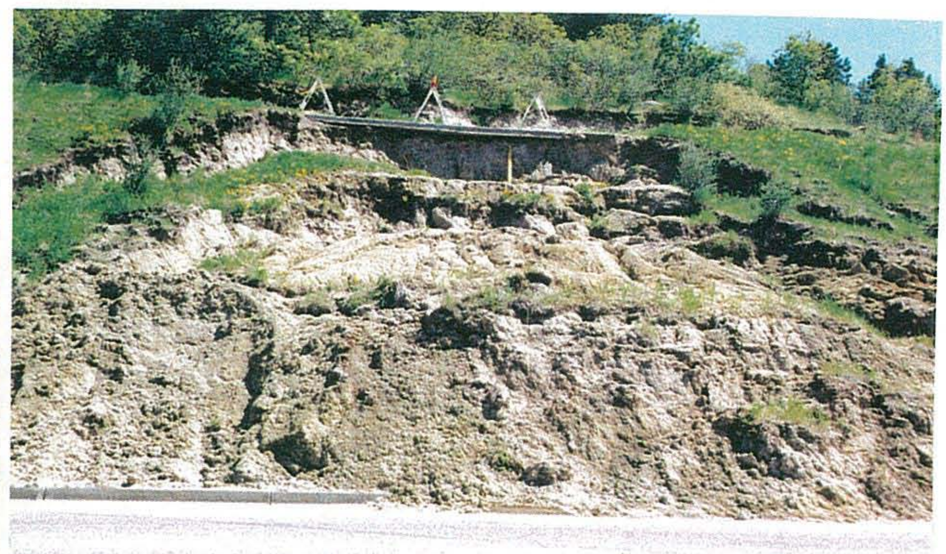


Photo 4. Austin Bluffs Parkway, east of Union Boulevard. Toe of landslide "flowing" over curb, scarp undermining concrete bike path (with barricades).