COLORADO
GEOLOGICAL
SURVEY

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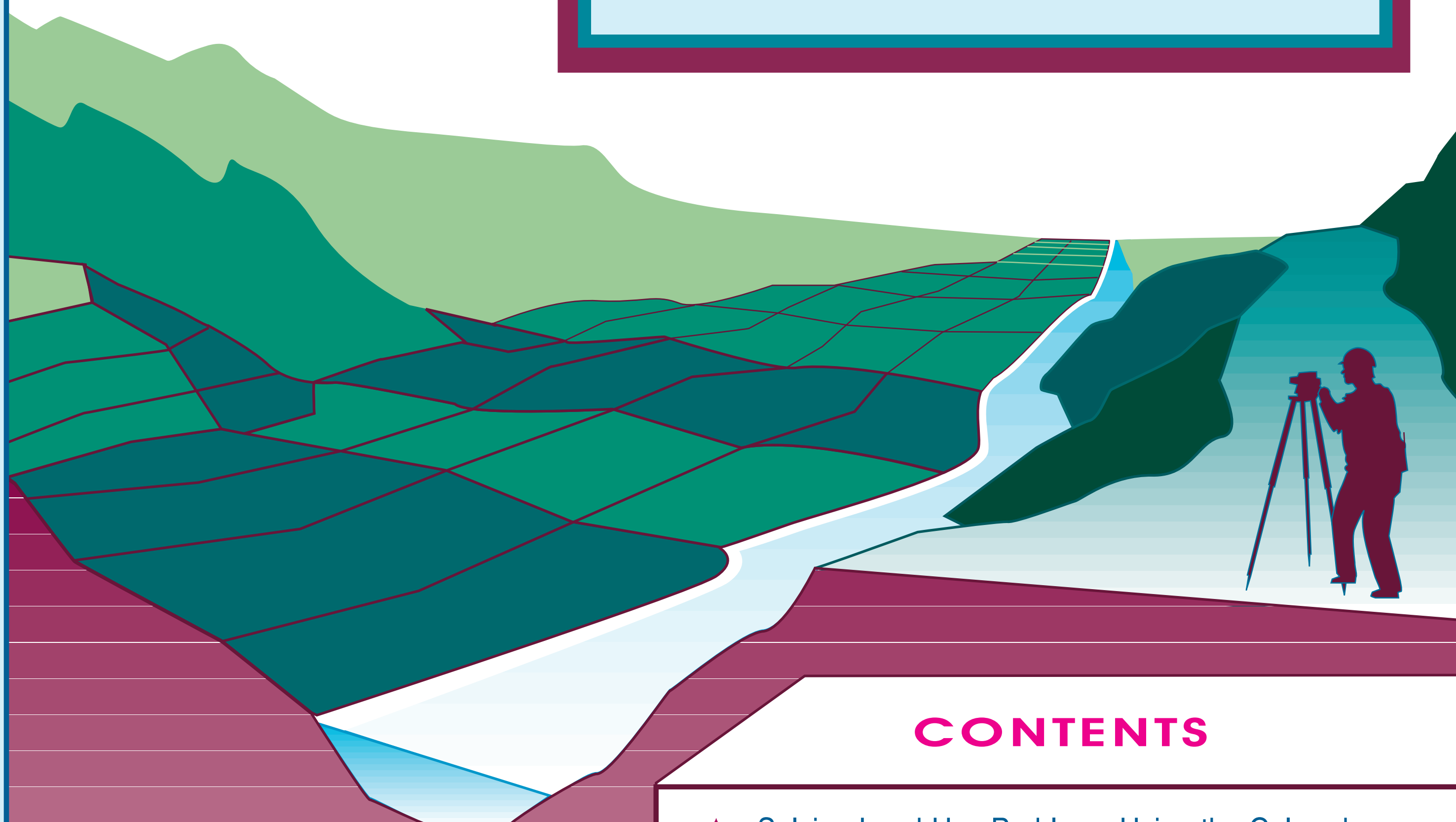
COLORADO GEOLOGICAL SURVEY

Solving Land-Use Problems



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COLORADO
GEOLOGICAL SURVEY

Solving Land-Use Problems Using the Colorado Geological Survey

HISTORY AND EXPERIENCE

For over two decades, the Colorado Geological Survey (CGS) has assisted Colorado county governments with geologic-hazard problems and other geologic concerns related to proposed land-use changes. Initially, most of the cases were for residential subdivisions in unincorporated areas. Senate Bill 35 (1972) directs CGS to review and report on these to the Boards of County Commissioners through their planning departments. In recent years, this function has evolved into a wide range of land-use reviews and environmental studies. These services are also frequently provided, at their request, to municipalities and other entities.

HOUSING

Currently, the services that the CGS offers to Counties usually focus on county planners and, indirectly, building officials who have responsibility for the reasonable safety and feasibility of new housing construction. CGS services include geological and geotechnical reviews of site-investigation documents which are supplied by the developer for a proposed subdivision. The ultimate customers are elected officials who make the actual land-use decisions and policies. The topography, rocks, and soils of our State can present extremely difficult design and construction problems and if these are not considered adequately in planning, engineering, and construction, the citizen homeowner can eventually be presented with maintenance problems for his residence that are costly or even impossible to solve.

INFRASTRUCTURE

The serviceability of the public infrastructure can be drastically affected by adverse geologic conditions too. Road alignments and construction,water-supply and water-treatment facility siting and expansions, school-site acquisition and school-facility construction (H.B. 1045, 1984), and landfill and mine locations are several of the kinds of cases with which the Survey has developed experience over many years.

Sometimes, such cases involve controversy and, by making objective investigations and realistic reviews for public officials, the decisions can be made using relevant geologic facts. This can be important to public confidence in local government even when an adversarial, fractious atmosphere is prevalent, as is frequently the case with gravel pits, mines, quarries, and landfills.

PLANNING

To improve land-use planning, the Survey can conduct topical studies of geologic conditions and processes. Examples of especially problematical and costly-to-mitigate geologic hazards are expansive, heaving, settling, and corrosive soils, rapid mass movements such as rockfalls and debris flows, and large-scale landslides in developing mountainous areas or critical transportation and utility corridors. Interpretive, intermediate- to large-scale geologic mapping and investigations of soils and bedrock, when appropriately formatted, can be used by planners and developers to identify potential geology-related problems early in the process.

The Survey has worked recently with Jefferson and Douglas Counties (see section below titled "Working With Counties. . .") to study soil-related problems which have cost homeowners and local governments millions of dollars. Other recent cases include ongoing studies of landslides at the Dowd's Junction infrastructure-complex corridor west of Vail, assistance to the City of Grand Junction with a subdivision area on a landslide immediately above the Colorado River, monitoring of the continuing debris-flow threats to the I-70 corridor from the 1994 Storm King Mountain burn area, and the Town of Vail with mitigation of severe rockfall hazards near Booth Creek.

ENVIRONMENT

With the advent of new State and Federal environmental laws and regulations, the Survey now works for the Colorado Department of Transportation and other State agencies in site investigations and remediations of underground-storage-tank sites. The U.S. Forest Service is benefiting from the Survey's inventory and assessment of environmental and ground-water degradations and hazardous mine openings caused by past mining and other activities on lands under its jurisdiction.

GEOGRAPHIC INFORMATION SYSTEMS

One of the greatest challenges of land use planning is that of compiling and comparing all relevant information about an area and making an informed decision about how that area should be managed. This requires assembling a variety of dissimilar sets of information and synthesizing them into a usable form.

For the last ten years, CGS has utilized computer-based technologies to help Colorado governments resolve land-use issues which have geologic problems and concerns. More recently, Geographic Information System (GIS) technologies have become available which greatly enhance our ability to provide decision support to county and local governments on these issues. Also, CGS now manages a GIS library of digital geologic and geographic data which, when combined with county and local-government data sets, can be used to better understand the full range of factors affecting an area of concern. This GIS technology allows scientists, in partnership with government decision-makers, to integrate a wide variety of information into a unified form and helps to visualize various combinations of data to gain a better understanding of the potential impacts of land use decisions.

WORKING WITH COUNTIES: RECENT EXAMPLES OF CGS LAND-USE-PLANNING ASSISTANCE

A belt of land along the central Front Range foothills in Colorado is experiencing tremendous population growth, but has been beset with problems due to the post-construction development of a distinctive type of ground heave. The ground deformations assume the form of low, linear mounds and have caused millions of dollars in property damage to houses, commercial buildings, roadways and utility lines. Early attempts to solve the problem using conventional engineering technology were largely unsuccessful.

The Colorado Geological Survey has assumed a leading role in determining that this costly problem is clearly and fundamentally geologic and has undertaken steps to assist planning agencies in Jefferson and Douglas Counties to deal with the problem according to the particular needs of each county.

In Jefferson County, suburban growth in the affected area has occurred for nearly two decades and continues to this day. Based on the high demand for homes in this area, it is unlikely that actual growth will be discouraged. The CGS and Jefferson County have worked cooperatively to study the causes and areal extent of heaving ground at selected research sites in the County. County officials and staff have been informed of the presence, magnitude, and nature of the problem during a series of CGS-led field trips which visited impacted areas. Finally, CGS geologists chaired two subcommittees of the Jefferson County Expansive Soils Task Force in 1994. The Task Force delineated an overlay district of potentially heaving ground and developed a comprehensive set of amendments to the land-development regulations for explicitly recognizing and mitigating problem areas. The overlay-district map was created for the County in digital form by the CGS using a Geographic Information System (GIS) format which is fully compatible with its other existing GIS-mapping and planning functions.

Douglas County, in contrast, has seen only limited development within its Front Range foothills area. However, very costly damage has occurred there and the pressure to develop the area is extreme. The County is in an advantageous position to modify its long-range planning goals for this area because so much land remains unplatted. The CGS was contracted by Douglas County to delineate a geology-specific overlay district map (Special Publication 42), again using a GIS digital format, and to consider recommendations for future prudent land use in the area of potentially heaving bedrock, including creative delineation of areas which may be considered for low-impact use such as open space.

In both counties, the Colorado Geological Survey continues to be active in reviewing proposed subdivisions which are located within the overlay districts to help ensure that future homeowners, and county agencies, will not be exposed to undue financial or safety risks from heaving-ground hazards.

Assessment of Geologic Suitabliity of Colorado Subdivisions—25 Years' Experience

By James M. Soule

ABSTRACT

Since 1972, when the enabling Colorado statute was enacted, the Colorado Geological Survey (CGS) has reviewed required engineering geologic reports for subdivisions prepared for county planning departments by private consultants. These consultants are retained by subdividers of unincorporated land who propose parcels of 35 acres or less. CGS' role is to advise county officials about report adequacy in indicating potentially adverse geologic conditions. Regardless of our findings, the final decision about acceptance of a submitted report is always made by a county government.

The majority of these subdivisions are residential and many are for "recreational homes" in remote, mountainous localities. CGS has been placed in a similar role by municipalities for cases where reviews have been voluntarily requested. Several hundred reviews are done annually statewide. Review activity has reflected mountain development, usually in skiing or all-season resorts, economic and population growth along the Front Range and established smaller communities throughout the State, and energy-resource-development-related growth in western Colorado. During the nineties, virtually all of Colorado has seen economic and population growth and this is reflected in the review activity. Some of the reviews have corroborated consultants' recommendations entirely; others have indicated where additional study and remedial-engineering work needed to be done; and a few have demonstrated the nearly complete technical and/or economic infeasibility of a land-development proposal.

This discussion is about the general background of CGS involvement with geologic hazards in land subdivisions and, mostly without citing specific cases, some of our experiences in evaluating the adequacy of geotechnical reports. In many cases, monetary savings and/or reduction in likelihood of future engineering-performance and safety problems have been realized.

INTRODUCTION

Shortly after its reestablishment in 1969, and coincident with a period of rapid economic and population growth in Colorado, the fledgling Colorado Geological Survey (CGS) became involved with geotechnical problems caused by land development. The earliest, and then very innovative, published work which was used by the CGS to convey geologic information to county land-use planners was that of Gardner and Hart (1971) for the Golden 7.5-minute quadrangle (west Denver metropolitan area-Figure 1, Locality 1). Subsequently, Rogers and Rold (1972) studied the serious and practically insurmountable geologic-hazard problems that could have been caused by proposed development of the, now defunct, destination ski-area complex at Marble, Gunnison County (Locality 2).

This involvement with geologic-hazards continues to the present and was mandated formally by legislation in 1972 (Senate Bill 35). House Bill 1041 (1974) was enacted and the CGS responded with legal definitions of geologic hazards and guidelines for investigation of them (Rogers and others, 1974). This legislation also instructed counties that the geologic hazards defined and discussed therein are "matters of State interest" and to better facilitate safe land development in geologic-hazard areas, mapping of these hazard areas should commence and that the State would offer technical support for the work.

The CGS and several private contractors initiated numerous pilot mapping programs and topical studies to respond to this directive (Amuedo and Ivey, 1975; Kirkham and Rogers, 1981; Mears, 1976; Soule, 1976; Soule, 1978). Some counties, such as Eagle (Vail-Locality 3), contracted with private consultant(s) to undertake hazards-mapping work (Robinson and Associates, 1975). Costa and Bilodeau (1982, p. 309–310) outline the background of engineering-geologic practice in Colorado during that time and scientific, legal and administrative aspects of this law and its implementation are discussed in Shelton (1977). Based mostly on Colorado experiences, Soule (1980) discusses some of the technical problems and semantic pitfalls of engineering-geologic mapping of geologic hazards.

Colorado can be grossly divided into three physiographic provinces (Figure 1), each with characteristic geologic environment(s) and physical properties of its soils and rocks. These provinces are the high plains and piedmont east of the central Rocky Mountains front where Cretaceous and Cenozoic sedimentary rocks and a suite of late Tertiary to Holocene alluviums and eolian deposits predominate; the central Rocky Mountains themselves where Precambrian to Tertiary igneous and metamorphic rocks, Cretaceous to Tertiary sedimentary rocks, and their derived colluviums and alluviums are most common; and the table lands and plateaus of western Colorado where nearly flat-lying, but commonly deeply dissected, Cretaceous to Tertiary sedimentary rocks dominate the terrain. Alpine glacial deposits occur in the higher mountains and large scale mass wasting (landsliding) of many different kinds of materials occurred during the Neogene to late Pleistocene and/or Holocene on the side slopes of many mountains and plateaus.

Unstable slopes (landslides of all types and landslide-prone ground) and expansive soils and rock are probably Colorado's most widespread geologic hazards. Seismic risk in Colorado is low to moderate and is not a major factor in many land-use decisions. However it needs to be evaluated for certain localities and for all critical facilities. According to our statutes, snow avalanching is a geologic hazard, but clear-water flooding is not; both occur in well defined places. Soil settlement and compaction, corrosivity, and erodibility are geologic hazards as is subsidence, either natural or man-caused. Hazardous-material-contamination and environmental issues have

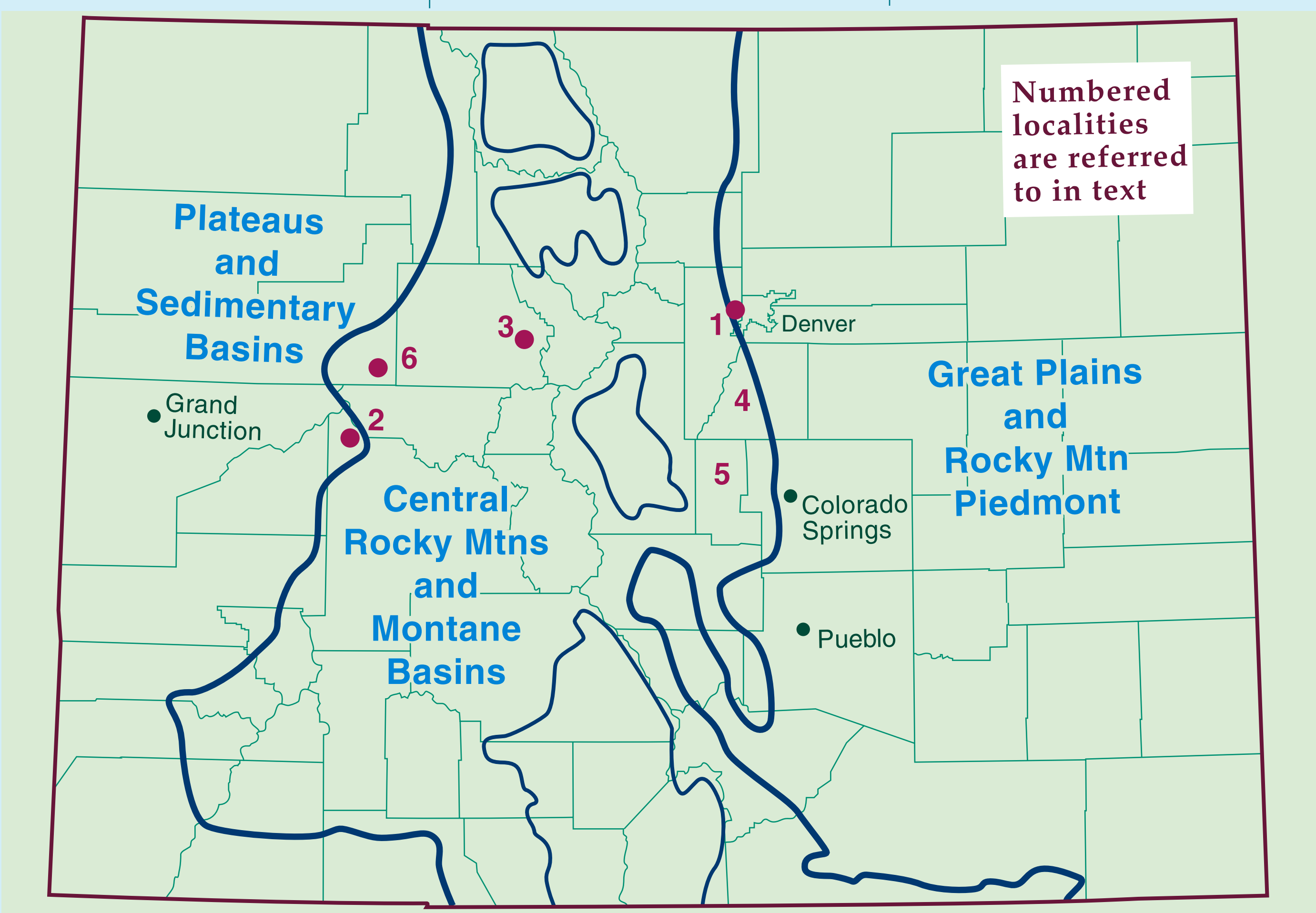

Figure 1. Map of Colorado showing county boundaries, major physiographic regions, and localities.

been addressed in our reviews in recent years as dictated by the geologic aspects of Federal and State laws and policies. As indicated below, interaction(s) between human activities and geologic conditions or environments, and how they are addressed in reports have become the primary focus of geotechnical-investigation evaluations made in our reviews.

INVESTIGATIONS OF GEOLOGIC HAZARDS IN SUBDIVISIONS AND CGS-REVIEW EXPERIENCES

Landslides

The fundamental issues which must be addressed in evaluation of landslides of all types and their potential for occurrence in subdivided land are:

1) Have landslides occurred in the subdivision area in the past?
2) Are landslides occurring now and, if so, under what conditions?
3) Are there materials present that could be caused to fail as a result of subdividing and developing this land?

During the process of grading subdivision land and installing improvements, earth is moved, drainage is usually changed, and fills are placed. Structural loads combined with changed ground-moisture conditions resulting from septic-system leach fields and altered water-runoff patterns can render formerly stable to metastable ground unstable, causing damages ranging from minor foundation, utility, and road disturbance to complete structural and facility losses. A geotechnical consultant should determine, after initial field examination of the site, study of the developer's plans, and, if warranted, materials testing and risk modeling, the likelihood of consequent slope-failure. Based on data obtained during investigations, interpretations can be made and remedial work can be recommended. In most cases, long-term maintenance plans, especially for slowing or stopping active landslides, should be provided in the geotechnical report.

Expansive (Swelling) Soils and Rock

From our Colorado experiences, occurrences of expansive soils and rock are nearly always correlative with certain lithologies, especially montmorillonitic shales and their derived residuum, colluvium, and occasionally, alluvium. The expansion potential of weathered, in-place bedrock depends on many factors, according to recent CGS research by David C. Noe, of the CGS and others (see "Working with Counties..."in this booklet). These factors include the primary composition, thickness, and geometry of different bedrock layers, bedding dip (angle of bedding inclination), degree of overconsolidation, thickness of overburden soil deposits over bedrock, water table depth, and the amount of surface water infiltrating the bedrock. Thus, where medium- to large-scale geologic maps or, ideally, maps of expansive-soil areas such as those by Hart (1974) are available, a consultant can usually make a good first approximation of resulting potential problems for building tracts with expansive-soils conditions simply by transferring the map data to a larger-scale subdivision sketch plan. Where such mapping is not available, a quick field check, including inspection of nearby roads, road cuts, and (damaged) buildings, especially in places with drainage problems, often can be helpful.

Following the reconnaissance the site investigation should be much more site-specific. The typical, standardized soils and foundation investigation, especially for "lightly loaded residential structures" has merit, but too often consists of a few, too widely spaced and generally logged drill holes. The material(s) from these dril holes then may be subjected to uniform and simple laboratory tests. These data typically support a "cookbook" commentary about foundation design(s) and maintenance. Few home builders retain a geotechnical engineer to inspect foundation excavations and caisson (drilled-shaft or drilled-pier) holes and/or to ensure quality assurance of foundation construction, as is common practice for commercial and industrial work. Probably because of cost, most home builders have been unwilling to invest in more than an overly simplified soils and foundation investigation. CGS has noticed a fortunate trend away from this attitude in the nineties. In the past, standardized foundation and other structural-concrete designs, the incentive in the marketplace to minimize per-square-foot construction costs, the practice of emphasizing house size over construction quality in real-estate appraisals, and the non-existence (in Colorado) of concrete-flatwork structural-performance, almost assure faster home deterioration and greater long-term maintenance and repair costs for homeowners.

In the opinion of this report reviewer, the issues above should be better addressed and the likelihood of the large monetary losses by the public thus could be significantly reduced. The geotechnical-consulting industry should make a much stronger case to HUD, real-estate lenders and appraisers, local building departments, architects, and home builders for increasing the sophistication and improving the thoroughness of geotechnical work. Municipal building departments should be empowered to enforce compliance by home builders with recommendations made by geotechnical professionals, especially for relatively moderately priced residential construction. Another aspect of the communication problem which this consulting industry should address is public awareness of the seriousness and costs of repair of structural damages. To this end, CGS has produced publications about expansive soils since 1974; the latest one (Noe and others, 1997) is a maintenance and landscaping guide for homebuyers and homeowners. About 150,000 copies of its original (Jochim, 1987) have been sold, mostly to home builders who are required by Colorado law (S.B. 13, 1984) to distribute them at sales closings. The later, updated and expanded version had sold about 69,000 copies by end-of-year 1999.

Seismicity

Colorado has a relatively short history of instrumentally recorded earthquakes but this is reinforced by felt earthquake reports, which extends the period of record to about 140 years. Over 400 earthquakes have been felt or recorded in Colorado since 1867. The strongest earthquakes have been in the range of magnitude 5.5 to 6.5. In November 1882 an earthquake of magnitude 6.5 occurred in Colorado. The epicenter is now believed to have been in the mountains of Larimer County west of Loveland. It was felt throughout Colorado and parts of neighboring states.

Although no complete collapse of structures or deaths have resulted from a Colorado earthquake, numerous instances of minor and moderate damage have occurred. Cracked plaster, cracked walls, cracked and fallen chimneys, broken windows, dishes and other household goods, damaged roof tiles, and similar effects have been reported for many of Colorado's earthquakes.

The CGS characterizes the seismic risk as low-moderate. This should not pose a major problem for **well constructed modern residential construction**, but could pose serious problems for older or poorly constructed buildings, building contents, and infrastructure.

The seismic hazard is sufficient that planning for critical facilities, high occupancy buildings and historic preservation of old buildings, should consider the seismic exposure. CGS favors a building-code approach to planning and mitigation of this hazard, but this has not yet been achieved.

Snow Avalanches

Snow avalanches (see "Avalanche Facts" in this booklet) occur frequently during the winter months in most of the alpine mountains of Colorado; in fact, Colorado has more areas susceptible to them than any other state. Delineation of avalanche starting zones and tracks is a relatively easy task based on well defined parameters as discussed in Mears (1976). Usually, starting zones and tracks do not present hazards for subdivisions as they are in places that are so rugged and steep that they are not developable. However, they can be an extreme hazard to winter-time recreational users of the back country and to persons and vehicles on high mountain roadways that traverse them. For subdivisions, the hazard-assessment problem is usually a determination of frequency of occurrence of events of a given magnitude and type and determination of the runout or "stopping" zone which is usually on lower valley sideslopes, and, in the case of many large events, valley floors. The scientific methods used to study snow movement and to predict when, and under what specific conditions events of a given magnitude will occur have parallels with those for rapid mass movements of earth, e.g. debris flows.

For the geotechnical consultant, geologic-hazards assessment in these areas is a specialized applied science where competence in engineering and design of "defense" structures, an understanding of the rheology and movement dynamics of unstable snow pack and moving snow, and a knowledge of winter weather patterns in the specific area being studied are absolutely critical to an adequate investigation.

Water Flooding

Although not a "geologic hazard" under Colorado law, some kinds of floods, especially "flash" floods in steep mountain drainages, "cloudburst" floods in arid areas, and those caused by extended rainfall and/or rapid snowmelt, occur coincidentally with landsliding and rapid erosion. Because of this, subdivisions that are in these kinds of flood-prone areas, even those in or near small ephemeral drainages, almost always need a drainage-control plan. Most of these areas are outside of a 100-year floodplain. This plan should always address the effects of the subdivision on drainage in nearby subdivisions and undeveloped property that might be developed in the foreseeable future.

Soil Settlement

Soil settlement is a common problem in Colorado where surficial materials are either low density clayey loess, poorly compacted eolian sand, soils containing soluble minerals (e.g., gypsum and halite), or some types of alluvial (stream-originated)and debris-flow deposits. These materials occur in many places in Colorado and are the subject of a topical 1997–1998 study by CGS. The loess, which can range upward to 30 ft or more in thickness, is especially problematical in higher density, urban, residential subdivisions because, after house construction is completed, residents commonly install landscaping irrigation. Soon, moderate to severe settlement can rapidly occur and pavements are damaged. Then, owing to its clay content, the loess may behave indefinitely as expansive soil. In cases where it is especially thick, it also presents expensive foundation-engineering problems as it can initially settle under structural load. Especially long caissons founded in bedrock are frequently necessary for successful drilled-pier and grade-beam foundations.

In older subdivisions or in areas heavily irrigated for agriculture, a perched water table can develop on relatively impermeable materials immediately beneath sand and in some places, loess. If this contact is above normal foundation depth, and depending on the expansivity of the underlying materials, homeowners can experience problems ranging from extreme structural distress to flooded basements.

Commonly these collapsible soils are also prone to piping (underground erosion) which results in voids that can collapse unpredictability with severe consequences for structures built on them.

With appropriate modification to geotechnical-investigation techniques, most of the comments applying to consulting practice in expansive-soil areas also applies to places with soil-settlement conditions.

Corrosive Soils

Corrosive soils are fairly common in Colorado and are most commonly developed on rocks and their erosion products that contain evaporites. (soluble minerals). The usual problems are rapid deterioration of conventional concrete in contact with soil and corrosion of buried, bare metal pipes. In the places where these soils occur, they were poorly understood until relatively recently, and older construction has thereby been seriously damaged if not entirely ruined.

In places where these soils are likely to occur, CGS expects that results of appropriate testing and concrete specifications be included in a consultant's subdivision report.

Erodible Soils and Rock

Although all soils and rocks are to some degree erodible, we have many experiences with two rock units which have accompanied many costly land-development problems in recent years. The deeply weathered Pikes Peak Granite of Douglas (Fig. 1, Locality 4), Teller (Locality 5), and El Paso Counties (Colorado Springs) is very erosion-prone. In many places and especially on steeper slopes, it has a thin to absent pedogenic soil. Naturally, its "soil" and grus (a gravel-like weathering product) support a low-density coniferous forest with a fragile understory of easily damaged, high altitude grasses. This granitic terrane was the source area for the Dawson Formation which consists predominantly of friable arkosic grit with a poorly developed, clayey, residual soil. The Dawson has a widespread outcrop on the Rocky Mountain piedmont in Douglas and El Paso Counties. The surficial environment and erosion characteristics of the Dawson are similar to those of the Pikes Peak Granite although in most places its plant communities are more varied and slopes on it are less steep.

Because of the rapid increase in higher-density subdivisions on the outcrops of these two formations, what was formerly ranch land and, in privately-owned mountain areas, summer camps and homes, is now becoming predominantly "bedroom" communities for Denver and Colorado Springs. Prior to urban development, cattle grazing and other pasturing on the piedmont had severely damaged the range, and an episode of rapid, ephemeral-stream downcutting (gullying) was well underway. Most of the trunk-stream beds had become choked with granular sediment which greatly changed their hydrology and riparian habitat. As geologic hazards, these man-accelerated processes have resulted in not only severe damage to much of the remaining raw land, but also have increased maintenance costs for roads and bridges, increased potential for landsliding and "muddy"-water flooding, and caused damages by deposition of large volumes of sediment in many residential subdivisions.

Addressing and designing mitigation of these adverse effects on residential subdivisions can present difficult challenges for the geotechnical professional. Development plans must be combined with very carefully designed drainage control for roads and runoff from impervious cover(s). (Re)establishment of vegetation that will help reduce sheet flooding and gullying is difficult to do and usually justifies collaboration with botanists and landscape architects. Slope instability can be greatly increased in places adjacent to undercutting streams, and debris avalanches and flows can be the direct result of slope denudation during and after construction.

Ground Subsidence

Colorado ground-subsidence hazards are caused by: collapse of abandoned-underground-mine openings, collapse of solution voids in rock units containing evaporites and limestones, and hydrocompaction of soils and surficial materials caused by dissolution of soluble minerals. Ground subsidence can, for soils, be considered an extreme case of "soil settlement" as discussed above. Mining subsidence is by far the most widespread, and for that reason, the most serious type subsidence hazard in Colorado. Localized areas, primarily in Eagle and Garfield Counties (Fig. 1, Locality 6), have experienced serious property losses caused by subsidence and hydrocompaction over the outcrop of the Eagle Valley Evaporite. Paleokarst-void collapse in Mississippian limestones has been reported but has not resulted in serious damages to date.

Colorado's mining history extends back to 1859 when placer gold was discovered in Douglas County. Placer and lode mining of gold and soon thereafter, silver mining, supported many now famous mining camps, the majority of which still exist as established communities, albeit most with different economies. Very soon after the inception of this mining boom, numerous mountain areas experienced a shortage of wood; what had been there was exploited for construction materials, fuel, and mine timbers. This situation, combined with railroad development and presence of exploitable coal, especially on the Front Range piedmont and in a few mountain areas, rapidly gave rise to an underground-coal-mining industry, which supplied not only the mining camps and railroads, but also the nearby residential- and commercial-fuel markets and many smelters including, eventually, the Colorado Fuel and Iron Corporation steel mills at Pueblo. A legacy of all this mining is that most of these same areas of the State have mine subsidence and related problems. Somewhat ironically, far more land was impacted by coal mining than metal mining, the resulting surface hazards are usually potentially more severe over abandoned coal mines, and much of this affected land is now in populous areas.

It is not possible in this paper to discuss all of the conditions and parameters that should be addressed in a mine-subsidence-hazard investigation for land subdivisions. From our experiences the following considerations appear to be the most relevant:

1) What is the present status of mine collapse? Has the mine collapse gone to completion, and if so, have all of the potentially adverse surface effects taken place?
2) Was the mining deep enough or is the roof rock and overburden competent enough and is the remaining mine void so small that, regardless of the status of mine collapse, the mining will never have significant adverse effects on the surface (or subdivision)?
3) Is the record (mine mapping) of mining accurate? How much of a safety (hazard) zone should be delineated to compensate for possible inaccuracies in mine mapping? How far beyond the actual extent of mining might the surface effects extend, i.e. determination of "angle of draw". How does mining method, e.g. room-and-pillar versus long-wall (for coal mining), influence surface-subsidence timing and patterns.
4) If applicable, was there enough subsurface work, e.g. drilling and geophysics, done in the investigation (and provided in the report)

and is it interpreted competently and reasonably?

5) Are shafts, adits, and dumps and spoils (especially if they have been regraded and/or used for fills) shown accurately on a map of the surface. If they have been back filled or otherwise "reclaimed", have shafts and adits been correctly plugged or sealed off to render their associated hazards minimal?

6) Are the subsidence-hazard-area delineation(s), surface improvements, and cultural features accurately rectified to the subdivision plat?

As for expansive soils, CGS has published a public-information guide to mine-subsidence hazards (Turney, 1985).

Much of the commentary about mine-subsidence investigations also applies to investigation of solution-collapse hazards. Perhaps the most important differences are that there is rarely any relevant subsurface mapping available and that movement and location of ground water, both before and after subdivision development, must be considered. We usually recommend that a consultant map known sinkholes and related features, investigate the subsurface with drilling and shallow geophysical surveys, and determine the hydrologic effects of the subdivision on natural ground-water conditions.

Hydrocompactive materials in Colorado are usually rapidly deposited, low density alluvial-fan and/or sheet-flood deposits derived from rocks containing soluble minerals. The significant difference between them and settling soils as a geologic hazard is that the subsidence can be much greater (upwards to 15 ft in places) and can occur rapidly in a few hours. The most common cause of these movements are drainage changes which divert water onto these deposits, especially relocation of irrigation ditches by unsuspecting farmers and ranchers. For subdivisions and roadways, the most advisable mitigation measure is prewetting and compaction followed by regrading.

'Environmental' Hazards

Although they are not included strictly in Colorado subdivision laws, the kinds of investigations required by the various "environmental cleanup" regulations have made their way into geologic-hazards studies and subdivision reviews. These two examples have been seen often enough Colorado in subdivisions to warrant comment here:

1) Fills of unknown composition and structural characteristics commonly are found in (re)developing urban and urban-fringe areas, in or near transportation corridors, in mining areas, and on land which has been used for many different kinds of refuse dumps. One of the most tragic and difficult to mitigate circumstances is the widespread past use of radioactive uranium mill tailings for fill, especially in the Grand Junction area.

2) Leaking underground storage tanks (UST's) and other sources of soil contamination by hazardous materials, including petroleum products and agricultural and industrial chemicals, have been located in both urban and rural subdivisions. In two cases we have reviewed, one industrial and one residential, the environmental clean-up costs exceeded the value of the undeveloped property.

For the geotechnical professional who is preparing a subdivision report for a private client, extreme care should be taken when discussing possible environmental degradation. We have seen several cases where engineering geologists have disclaimed responsibility for any part of their investigation that might relate to "environmental" matters; others have recommended environmental assessments by specialist firms. The discussions by Gerla and Jehn-Dellaport (1989) are probably as relevant to residential real-estate transfers (i.e.,building-lot sales) as commercial ones.

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Avalanche Facts

By the Colorado Avalanche Information Center

HOW SEVERE IS THE AVALANCHE PROBLEM IN COLORADO?

We estimate that 20,000 avalanches fall in the Colorado mountains in an average winter. Most of these cause no harm whatsoever. However, since 1980, avalanches annually cause on average five deaths, five severe injuries, more than $100,000 in direct property damage, and more than $1 million in economic losses. Additionally, avalanches block highways 100–200 times per winter.

WHICH COUNTIES HAVE AVALANCHE PROBLEMS?

Since 1950, 21 counties have had at least one avalanche death (see Figure 1).

WHAT CAN BE DONE ABOUT AVALANCHES?

Avalanches are forces of nature and cannot be eliminated. However, much can be done to mitigate avalanche hazards and reduce avalanche accidents. In developed areas, avalanches can be controlled— either actively by explosives, or passively by permanent retaining or diverting structures. In backcountry areas, forecasting avalanche dangers and educating recreationalists can reduce accidents.

WHAT IS THE COLORADO AVALANCHE INFORMATION CENTER?

Founded in 1983, the CAIC is a program in the Colorado Geological Survey. Its mission is to promote safety by reducing the impact of avalanches on recreation, industry, and transportation in Colorado.

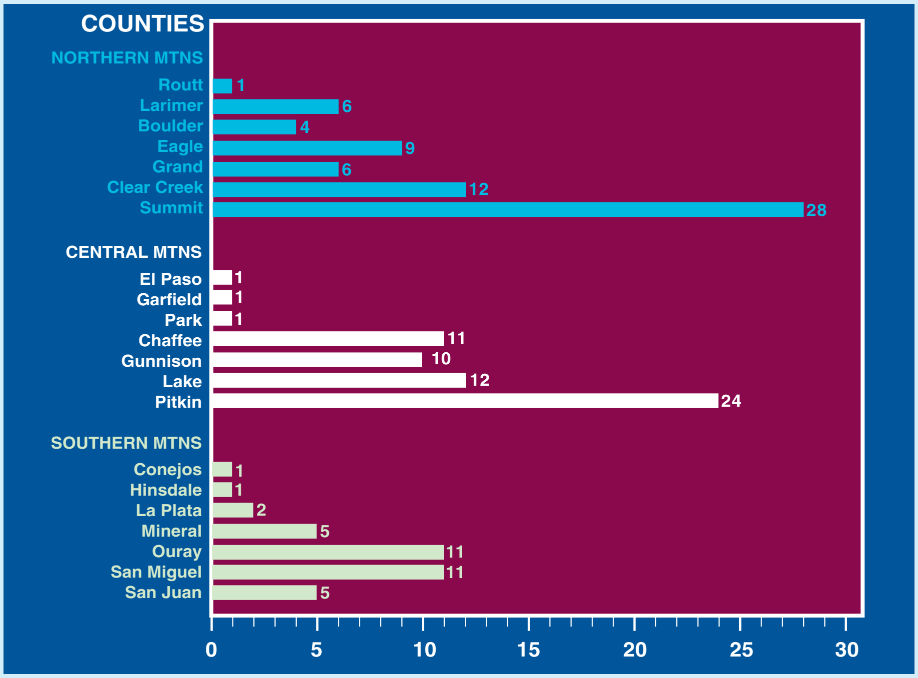

Figure 1. Avalanche fatalities in Colorado since 1950.

HOW IS THE CAIC FUNDED?

The CAIC is entirely cash and federally funded. Grants and donations come from the Colorado Department of Transportation, U.S. Forest Service, local governments including counties and towns, ski industry, hut and trail associations, and foundations. In 1996–97, revenues were approximately $350,000.

WHAT DOES THE CAIC DO?

The CAIC has a staff of 10 avalanche experts to carry out a program of forecasting, training, and consulting.

Forecasting

The CAIC uses a network of 35 observers to provide daily data on weather, snowpack, and avalanches. We provide this information and a forecast to the public via seven hotlines and a computer bulletinboard. Last year there were 126,000 calls to the hotlines, bulletin board, and home page for this information. Additionally, 11 mountain radio stations broadcast our hotlines messages daily.

Training

The CAIC offers avalanche classes that range from a 2-hour lecture to multi-day field courses.

Last year we presented 84 classes to 3,800 people. Additionally, we have produced two educational videos.

Consulting

The CAIC provides avalanche consulting services to the ski industry and CDOT.

WHAT SERVICES CAN THE CAIC PROVIDE COLORADO COUNTIES?

The CAIC can provide the following services:

- Mountain weather forecasts and backcountry avalanche danger ratings for use by the public and by county road maintenance personnel.
- Weather and avalanche forecasts to sheriffs and search-and-rescue teams during rescue missions.
- Avalanche education programs and materials.
- Consultation on avoiding, controlling, or otherwise managing specific avalanche problems.

AVALANCHE HOTLINES

Current information on mountain weather, snow, and avalanche conditions are updated daily.

Denver/Boulder	**(303) 275-5360**
Colorado Springs	**(719) 520-0020**
Fort Collins	**(970) 482-0457**
Summit County	**(970) 668-0600**
Durango	**(970) 247-8187**
Vail	**(970) 827-5687**

FOR MORE INFORMATION CONTACT

Knox Williams, Director
Colorado Avalanche Information Center
325 Broadway, WS1
Boulder, CO 80303-3337
(303) 499-9650
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Coalbed Methane— A Potential Geologic Hazard

By Carol M. Tremain

METHANE OCCURRENCES

Gas seeps in the Pine River, ponds, and some water wells in the Pine River Ranches subdivision (Sec. 14, T. 35 N., R. 7 W.) led La Plata County and Amoco personnel to test 66 homes near the outcrop of the coal-bearing Fruitland Formation for methane gas. Sixteen of the tested homes had detectable levels of methane.

The methane (natural gas believed to have emanated from underlying coal seams) reached explosive levels outside one house in the subdivision (Amoco Pine River Fruitland Outcrop Investigation, Sept. 15, 1994). Methane seeps were mapped by an Amoco subcontractor in portions of a 500 ft wide area in the Pine River Valley directly underlain by the Fruitland Formation.

La Plata County officials reported that another house near a very active historical gas seep in South Texas Creek (a tributary of the Pine River) had explosive levels of probable coal-derived methane in the crawl space and under the kitchen sink (Durango Herald, Sept. 15, 1994).

Historically active gas seeps have been observed in other localities in the County including the Animas River near Durango and the Soda Springs area near Red Mesa. Twenty affidavits attesting to gas seeps which have been active for decades are also on file with La Plata County District Court. Many of these gas seeps occur where the coal-bearing Fruitland or Menefee Formations are exposed (outcrop) or directly underlie surface soils or gravels (subcrop).

Approximately one-third of Colorado is underlain by coal (Fig. 1). Much of the coal is deeply buried, and natural gas generated during the coalification process is trapped in the micropores of the coal at depth. However, coalbed methane gas does escape from shallow coal seams and this gas could present a hazard if trapped in a surface structure. This is particularly true in areas where mines were historically gassy.

Gas has been reported in abandoned coal mines in Las Animas County and was responsible for a mine explosion in an active mine as recently as 1991 (Denver Post, Oct. 1, 1994). Gas is being vented as part of the mining process from operating mines in Rio Blanco, Gunnison, La Plata, Mesa, and Routt Counties. Coalbed methane is being produced from gas wells in Garfield, La Plata, Rio Blanco, and Las Animas Counties, and has been produced to a minor extent in Archuleta and Huerfano Counties.

Although methane gas is colorless, odorless, and non-toxic, it *is* explosive at 5 to 15 percent mixtures in air. Numerous injuries and fatalities in the state's underground coal mines have been attributed to ignition of methane released during mining. Methane can also saturate the ground and deprive plant roots of oxygen and the ability to absorb needed nutrients from the soil.

Although CGS geologists are unaware of any above-ground losses of lives or structures due to coalbed-methane explosions or emissions, the gas occurrences in La Plata County investigated by the Pine River Fruitland Outcrop Investigative Team and the increase in housing development and water-well drilling around the state have prompted the CGS to add coalbed methane to our list of potential geologic hazards.

The CGS began accumulating data about the methane potential of Colorado coals in 1975 with a U.S. Bureau of Mines grant, and has continued this research to the present. Research objectives are to increase mine safety and productivity, and to aid in the development and conservation of this new source of pipeline-quality natural gas.

In 1978, our earliest coalbed methane publication reported mine-gas emissions and explosions around the state. Subsequent gas-content measurements of coal core samples and coal-basin geologic studies revealed that Colorado contained an in-place coalbed methane gas resource in excess of 100 trillion cubic feet. In 1995, 43 percent of the natural gas produced in Colorado was coalbed methane (Colorado Oil and Gas Conservation Commission).

Oil and gas seep naturally to the surface and such seeps led to the discovery of many of the state's oldest oil and gas fields. Where gas is escaping from coals, seeps may be observed in standing or flowing water or in water wells. Proposed construction sites directly overlying coal seams in the Raton and Vermejo Formations in the Raton Coal Region, the Fruitland and Menefee Formations in the San Juan River Region, and the Mesaverde Group in the Uinta and Green River Regions should be checked for visible gas occurrences particularly where the coal is at or very near the surface and not covered by an aquitard.

However, gas seeps may vary seasonally or at much longer climatic cycles; a lack of seeps in the present does not preclude their occurrence in the future. Long-time rural residents, coal miners, water well drillers, or fire safety personnel may provide additional information on the occurrence of methane in an area. Methane concentrations in suspect locations can be measured with combustible gas detectors or alarms; Amoco has provided a number of these to concerned residents in La Plata County. La Plata County will arrange for methane testing when contacted by residents (La Plata County methane health and safety brochure, 1993).

The CGS recommends that jurisdictions that have past or ongoing coal mining (Fig. 2) consult with CGS geologists regarding the potential for methane seeps. For land-use-change proposals, such as housing subdivisions, methane occurrences may need to be addressed as geologic hazards as indicated in S.B. 35 (1972) and H.B. 1041 (1974). Measures to mitigate and monitor methane-related hazards in existing structures (e.g., ventilation of

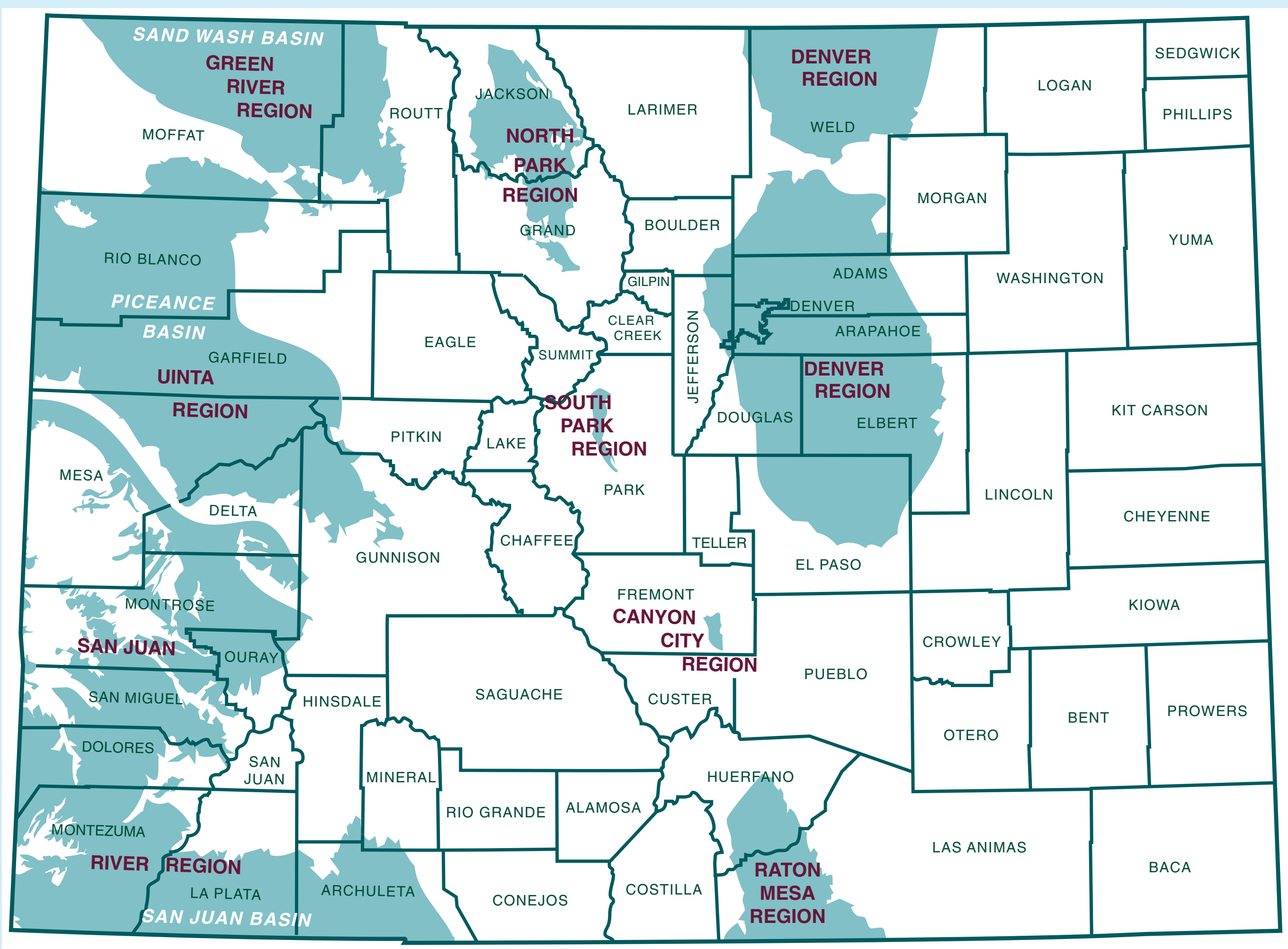

Figure 1. Coal regions and basins of Colorado.

crawl spaces and water wells) do exist. However, prudence dictates site evaluation for potential coalbed-methane hazards prior to construction in coal outcrop and subcrop areas. Published geologic maps and reports on coal and coalbed methane geology should provide developers with general geologic information on proposed development areas. In areas where coals are near surface and historically gassy, a detailed geologic review and possibly soil, structure, or water well testing may be necessary. Due to the relatively recent recognition of this potential hazard, building standards and testing procedures still must be formulated in cooperation with local government authorities.

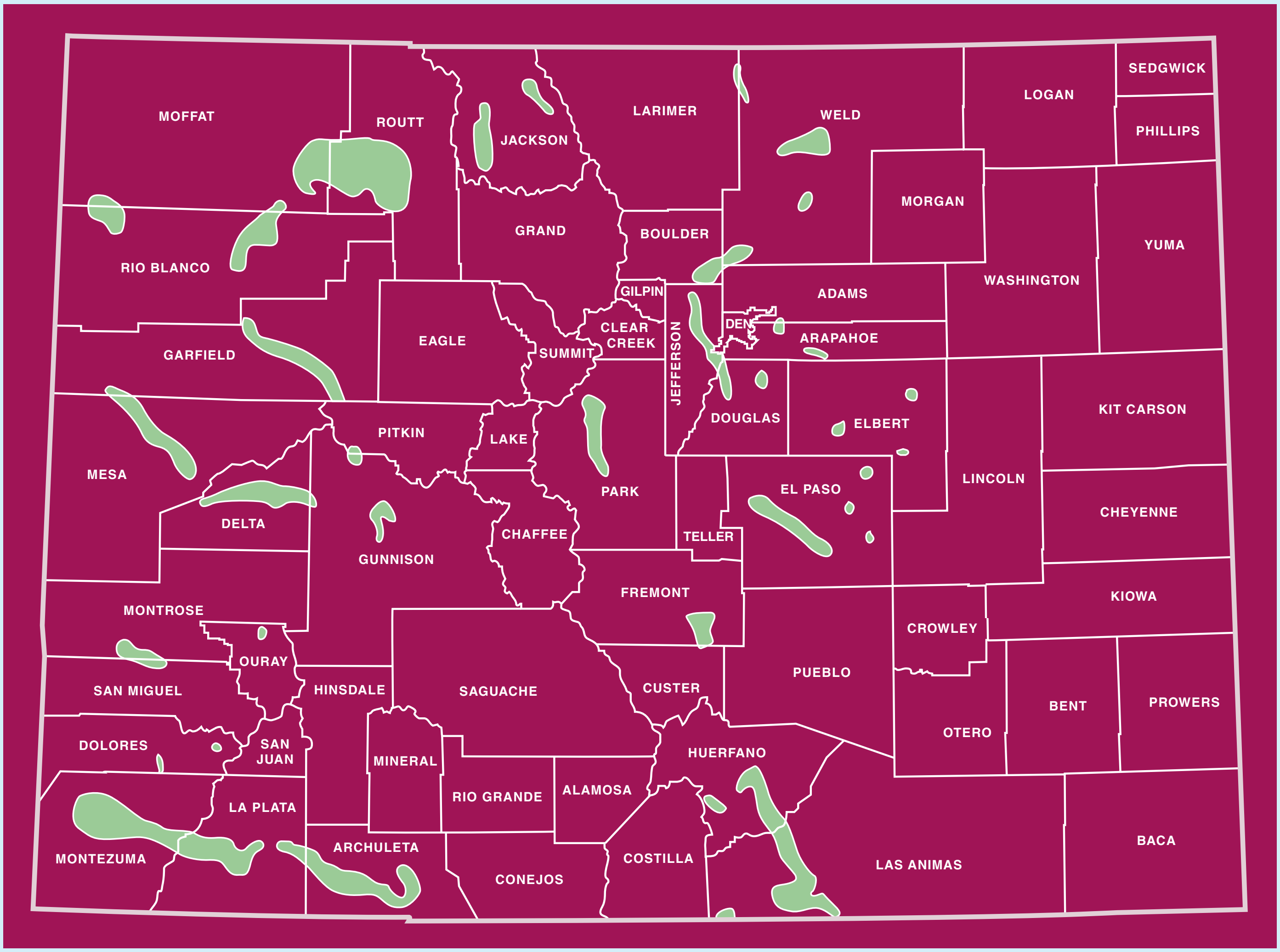

Figure 2. General locations of active and inactive coal mines in Colorado.

Geologic Hazard Reviews Performed by the Colorado Geological Survey

By James M. Soule

REVIEWS

To review is to make a constructive critique and usually means an assessment of the adequacy and appropriateness of (geo)technical investigations and/or applications of geologic principles made by others, mostly professional geotechnical engineers and consulting engineering geologists. CGS reviewers make decisions about whether enough meaningful work was done, if the resulting report proposes reasonable solutions to problems related to the geology of the site, and if it offers a technically competent analysis of natural geologic conditions and their potential impacts on a proposed activity.

The CGS reviews land-use or land-use-change proposals, as required by statute, regulation, or when voluntarily requested by public or quasi-public entities as follows:

REVIEW TYPES

- Subdivision reviews required by S.B. 35 (1972) submitted by county planning departments
- Subdivision reviews voluntarily requested by cities and towns
- School-site reviews required by H.B. 1045 (1984) submitted by School Districts (see addendum at the end of this section)
- Water-quality reviews submitted by engineering firms or other representatives of water and sanitation districts, local governments, and/or various health and sanitation authorities.
- Miscellaneous reviews of:
  - — landfill proposals
  - — utility alignments
  - — transportation alignments
  - — building-lot construction suitability
  - — public-facility construction
  - — major development impacts (e.g., mines, ski areas)
  - — airport sites and improvements

Some counties also request reviews based on the "matters of state interest" provisions of H.B. 1041 (1974) which they have incorporated into their local land-use regulations.

REVIEW PROCESS

The review geologist reads and interprets submitted review materials, does background research and analysis based on file and library materials, and makes a site (field) investigation of the location and/or parcel that is the subject of the review. The reviewer then prepares a letter report to the submitter which discusses the accuracy and adequacy of materials prepared by or for the land-use-change proponent (e.g., land developer or land subdivider) and whether additional and/or more technical or detailed geotechnical work should be done. The reviewer offers advice to the submitter and proponent regarding possible changes in the proposal which might make it more compatible with geologic conditions and geology-related constraints. In extreme (usually infrequent) cases where an activity might become life or property threatening, the reviewer might recommend (rarely) outright denial of a proposal or its major revision. If deemed necessary, the review geologist, planner or other local government official (as appropriate), proponent, and the proponent's geotechnical consultant and, sometimes, his attorney meet or otherwise collaborate to resolve any differences about the geological feasibility of a proposal. The ultimate decision about acceptance of the final proposal is made by local-government officials, most commonly the Board of County Commissioners or other local legal, planning, or regulatory authority.

HAZARDS REVIEWED

The most significant and/or widespread geologic hazards in Colorado, insofar as they threaten public safety and well being or cause economic losses, are as follows. They cannot be ranked by severity unless a specific land use or human activity in a defined (mapped) susceptible area is specified.

- Snow avalanches
- Landslides (There are many

types of such ground movements and they are frequently transitional to one another.)

— rockfalls
— mud and debris flows
— slumps
— rockslides
— rock and debris avalanches
— earthflows
— settlement, subsidence, and lateral spreading (soil collapse)
— man-induced ground failure (which may simulate any of the natural types indicated)

- Seismic (ground-shaking/earthquake) events, bedrock movements, and their effects
- Ground subsidence caused by underground mining, fluid withdrawal, or rock dissolution
- Nuclear radiation (natural and man-caused)
- Soil and rock properties (expansivity, chemistry (corrosivity), and bearing capacity and strength)
- Radioactive and explosive soil and rock gases (radon and methane)
- Hazardous- and deleterious-material contamination of rocks, soils, and water
- Soil- and rock-erosion potential

Note: Clear-water (overbank) flooding and fill failures of dams and canal banks are not legally defined in Colorado as geologic hazards. They are not addressed in geologic-hazards reviews unless they are related to or can be caused by the geologic hazards indicated above..

School Site Reviews Performed by the Colorado Geological Survey

By James M. Soule

INTRODUCTION

The Colorado Geological Survey (CGS) has reviewed proposals and plans for all new real-estate acquisitions and facility construction for all Colorado K-12 school districts since enactment of H.B. 1045 (1984) (C.R.S. 22-32-124 et seq.). This act provided that the *"Board of Education…"*, is directed to consult with CGS about *"…geologic hazards…"* (e.g., expansive soils, slope instability) *"… prior to the acquisition of land for school building sites or construction of any buildings thereon…and to determine the geologic suitability of the site for its proposed use."* Boards of Education were also instructed to participate in local land-use-planning processes and to conform with construction, fire, and safety codes.

UNDEVELOPED (RAW) LAND

The District is considering a land purchase, trade, or dedication—

- School districts usually acquire land by dedication, trade, or outright purchase. There is a tendency of owners to offer land which is marginally suitable for other development purposes. The reviewer assesses the relevant geologic and geology-related conditions for the planned use of the site.
- School districts can thus avoid involvement with real-estate sales resulting from acquisition of land which they cannot use without surmounting serious geology-related development problems.
- Almost all school campuses are a permitted non-conforming use in R-1 or R-2 zones. Unless a district plans to use a site in the foreseeable future for a school, the reviewer considers whether it is more suitable for residential or open-space land use.

NEW CONSTRUCTION, RECONSTRUCTION, AND ADDITIONS

The District is going to build on a new site or modify or add to an existing facility—

- Geotechnical and drainage studies must be relevant to plans and proposed designs. The reviewer evaluates the adequacy of these and indicates to district officials and architects whether additional work is justified.
- A forensic inspection of existing facilities is made to assess their condition and to relate damages or deterioration, if any, to geologic and geology-related (e.g., soils and drainage) conditions. The resulting conclusions are used to support recommendations about possible modifications of site drainage control, repairs to existing facilities, and changes in construction plans to reduce the possibility of similar damages to new construction, rebuilding, and additions as applicable.
- Specific siting of new construction and its appurtenances can greatly affect its long-term servicibility and overall maintenance and repair costs. The reviewer may recommend changes in site plans to avoid problem areas and to avoid places that may be hazardous to pupils (e.g., drainage and irrigation ditches).

EXISTING FACILITIES

The District is Considering Acquisition of Developed Property—

- All of the appropriate considerations made for undeveloped land and construction apply and are considered by the reviewer.

Colorado Geological Survey Standard Fee Schedule for Most Commonly Used Services

Effective July 1, 1994

1. SMALL SUBDIVISION REVIEW

(Those with lots for ten or fewer dwelling units), also major replats of *existing approved subdivisions*, rezonings or sketch plans for twenty acres or less, major activity notice reviews, and water quality application reviews:

Cost = $485.00 prepaid
$510.00 not prepaid

2. MEDIUM AND LARGE SUBDIVISION REVIEW

(Those with lots for more than ten dwelling units), rezonings or sketch plans for more than twenty acres:

Cost = $595.00 prepaid
$620 not prepaid

Although most reviews listed in **1** and **2** above will fall within the estimated time and costs built into the listed standard charges, it is necessary, in fairness to all users, to provide for those cases that will incur excess review costs. The CGS will contact the local planner if it is evident that additional review costs will be requested (See discussion in **3** below).

3. VERY LARGE OR COMPLEX SUBDIVISON, GEOLOGICAL HAZARD REVIEW, MASTER PLAN, OR PUD

These reviews generally require field observation and much more review time. Consequently, cost varies considerably and may exceed $1,200.00 based upon standard fee plus additional review time and travel cost.

Excess time or travel charges

Will be made for those expenditures in excesss of the normal range of review time (maximum 6.75 hours on small reviews or 8.75 hours for large reviews), or for extensive travel related to a particular case:

Extra review time: at hourly fee rate of CGS reviewer

Travel at current state rates:
- Per diem: current state rates
- Vehicle mileage : $0.20/mile; $0.24/mile 4WD

Other travel at actual cost (e.g., auto rental, plane fare, etc.).

4. SCHOOL SITE REVIEW

Single school site: **$855.00**. Multiple submittals from the same district, *submitted at the same time*: (Not to exceed the number of sites that can be reasonably visited in one day.) **$855.00** for the first one, and **$700.00** for each additional one (includes $155.00 reduction for travel.)

5. WRITTEN MINE SUBSIDENCE HAZARD OPINION ON A RESIDENTIAL LOT FOR REAL ESTATE TRANSACTION

These will be done as quickly as possible, but *five to ten days* lead time is needed in most cases. **$135.00** prepaid, **$150.00** otherwise.

As stipulated in C.R.S. 30-28-136, it is the responsibility of the county planners, to submit copies of subdivision plans to the CGS. It should also be noted that the statute has been amended, and now states that reviewing agencies shall make recommendations within twenty-one (21) working days after the mailing by the county, or its representatives. However, reviews are performed as quickly as possible.

ADDITIONAL SERVICES BY CGS REQUIRING AN AGREEMENT AND PRICE ESTIMATE

Price ranges shown here are only suggested for general information. Actual prices will vary according to specific needs, size and complexity of the individual project, staff assignment by us, and amount of travel and follow-up work required. Please contact **Jim Soule (303-866-2611)** to discuss details of review or other project needs. In come cases, a fixed cost may be practical. In others, it will be more practical to use hourly fees plus other direct costs attributable to the work.

PH: (303) 866-2611
FAX: (303) 866-2461

TABLE OF SERVICES AND COSTS

Description of Service	Estimated Cost or Range	Comments
Solid waste disposal application review	Basic review, $1500 to $3500, extra for testimony and travel, if needed	Basis: 30–40 hours professional time
Hydrogeological/water quality problems • Septic tank failures • Brine pit contamination • Old landfill • Methane, radon or other contaminants in water wells • Hydrocarbon leakage from storage facilities		Highly variable—individual project estimate required
Water quality application reviews	Standard fee no.1 $485 if prepaid, otherwise $510	Possible extra charges in some cases
Geological review of new local environmental health regulation	$300 to $700 in most cases	Variable, depending on complexity
Geological hazard studies and reviews Review of detailed geologic hazard reports: mine subsidence, slope instability, dam site and/or active fault studies, mudflow/debris flow mitigation, etc.	Basic reviews $500 to $3,000 plus travel	Recommended individual project estimate
Expert testimony in local goverment of other administrative or judicial forums	Minimum approx. $500 for one day, possibly less if minimal travel	Cost highly variable, includes preparation time, testimony and travel
Geological assistance with planning area studies	Highly variable, depending on time and travel	Based on actual hours
Geological hazard or mineral resource conservation map	Highly variable, depending on size and complexity	Recommend individual project estimate
Site reconnaissance for facilities (sewage treatment plants, public buildings, etc.)	Typical $450 to $650, plus travel	May be more for large project or extensive travel
Mineral resource and/or conservation reviews Master extraction plan for sand, gravel or quarry aggregate	Typical cost: $450 to $800	May be more if issues are complex
Specific mineral resource area evaluation	Typical cost: $450 to $800	May be more if issues are complex
Major quarry aggregate application review, local rezoning, local mining permit, etc.	Typical cost: $1,500 to $3,500	Depends on size and complexity
Small gravel pit or borrow pit application	Standard fee no. 1: $485, if prepaid, $520 otherwise	

Information regarding other services consistent with our statutory duties on request

Additions: 1. Fee for bad checks: $25.00

2. Fee for retrieval of archived documents: $25.00 per file
3. Invoices for services will be directed to the submitting local government unless another address is provided.