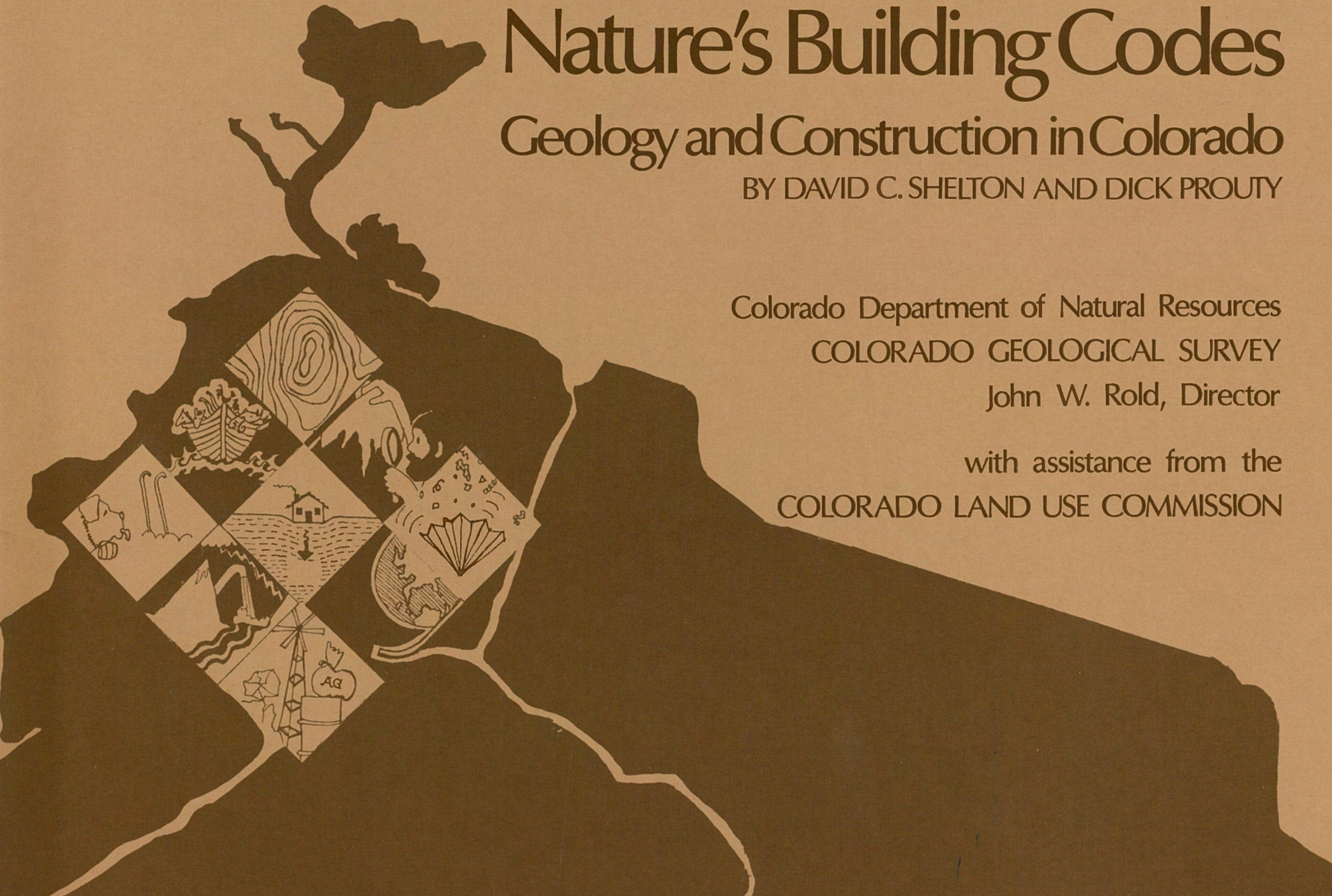
Special Publication 12
1979



Nature's Building Codes

Geology and Construction in Colorado

BY DAVID C. SHELTON AND DICK PROUTY

Colorado Department of Natural Resources
COLORADO GEOLOGICAL SURVEY
John W. Rold, Director

with assistance from the
COLORADO LAND USE COMMISSION

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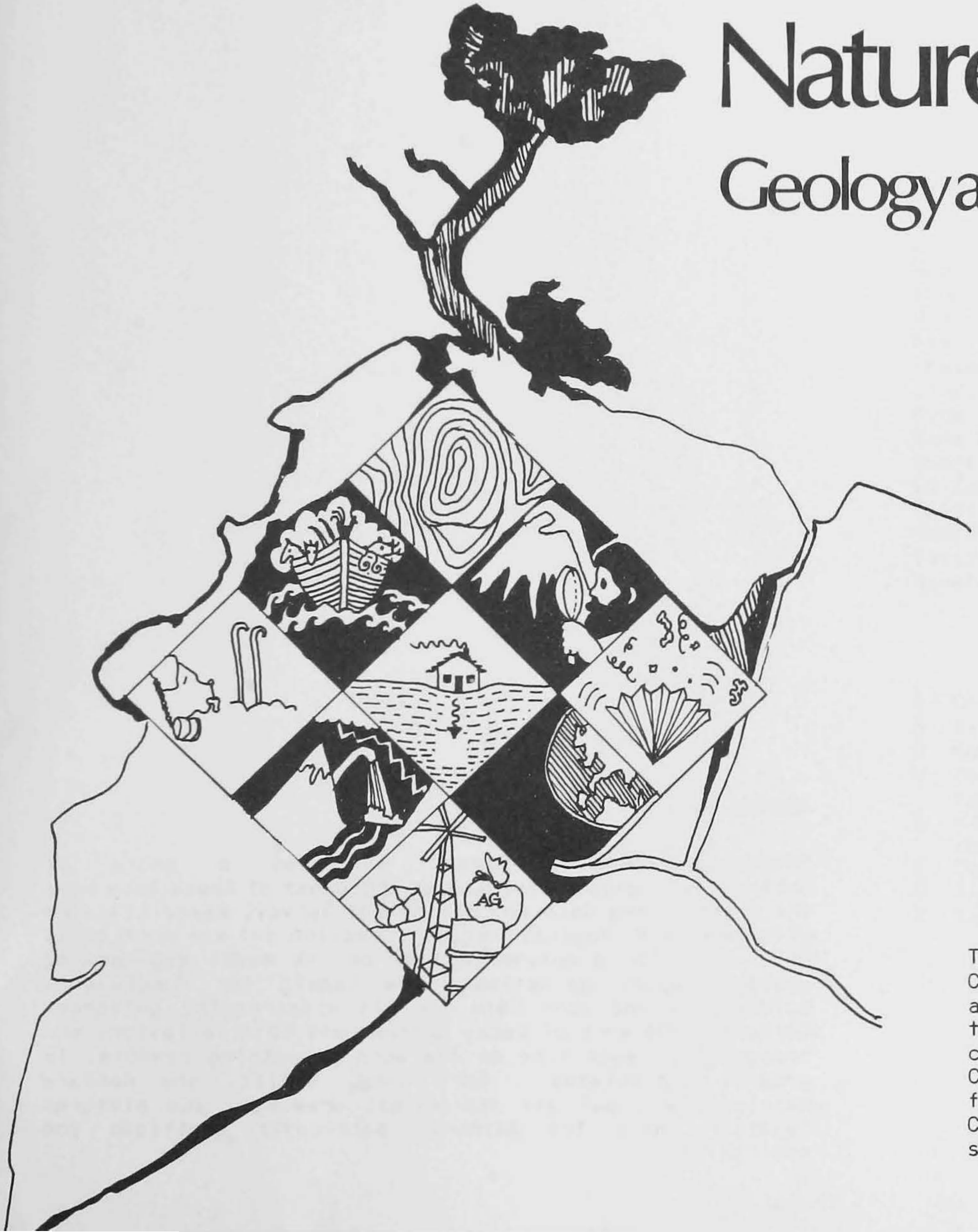

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DOI: https://doi.org/10.58783/cgs.sp12.noze1077

The preparation of this report was financed in part through a Comprehensive Planning grant from the Department of Housing and Urban Development, under the provisions of Section 701 of the Housing Act of 1954, as amended. The report was completed in August of 1979 and was administered through the Colorado Division of Planning. Additional assistance in funding of the report was provided by the Colorado Land Use Commission. The planning area involved covers the entire state of Colorado.

ACKNOWLEDGMENT

"Nature's Building Codes" has had a cadre of behind-the-scenes contributors. Foremost of these have been the staff of the Colorado Geological Survey, especially the efforts of W.P. Rogers, for his direction and wry critiques, Rahe Junge for a monumental job on the model engineering geology report guidelines, Lew Ladwig for Homebuyer's Guidelines, and John Rold for his wide-ranging guidance. Certainly the work of Becky Andrews and Valerie Taylor, who "wanged" out each line on the word processing console, is greatly appreciated. Kara Lang, artist, and Barbara Neyrinck, who put all the words, drawings, and pictures together, have the authors' particular gratitude and admiration.

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Introduction

Americans sustain more than $1 billion in damages annually from landslides, mudflows, subsidence, avalanches, and other common earth movements. The cost figures do not include earthquakes or loss of life. While no similar figures have been compiled for Colorado, the price tag is in the millions of dollars. In California, where geologic hazards and improper construction practices associated with them also abound, planning officials project $300 million annually in damages and related geologic hazard costs--nearly $3 billion in a decade.

At the same time the planners believe the losses "could be reduced 90 percent or more by a combination of measures involving adequate geologic interpretations, good engineering practice, and effective enforcement of legal restraints on land use and disturbance."[1]

The situation is put further into perspective by the conclusion that "although slope failures generally are not so spectacular or costly as certain other natural catastrophes such as earthquakes, major floods, and tornadoes, they are more widespread and the total financial loss due to slope failures (landslides, etc.) is probably greater than that for any other geologic hazard to mankind."[1]

Another national study of nine natural hazards estimated the losses in the tens of billions of dollars. It forecast accelerated property damage and deaths unless mitigation measures are initiated. It categorically predicted marked reductions of losses (up to 85 percent) by implementing geologic investigations, building and siting requirements that acknowledge and compensate for known hazard areas.[2]

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[1] Landslides: Analysis and Control, Special Report 176, Robert L. Schuster and Raymond J. Krizek, editors; National Academy of Sciences, 1978; 234 p.

[2] "Natural Hazards--Earthquake, Landslide, Expansive Soil Loss Models," John H. Wiggins, James E. Slosson, James P. Krohn; and "Building Losses from Natural Hazards: Yesterday, Today and Tomorrow," Daniel H. Baer; J.H. Wiggins Company, 1650 South Pacific Highway, Redondo Beach, CA, 90277; December 1978.

Geo~logic

This is what this "geo-logic" volume is about--using land wisely and saving money with sound construction and common sense on Colorado's prairies, peaks and plateaus. It contains some of the rules that are not subject to appeals or variances. These are "nature's building codes"--common, everyday, ongoing geologic processes and conditions. They will prevail regardless of zoning regulations, master plans, construction standards, and other societal mechanisms that may or may not take them into consideration. These are normal, natural processes and conditions that have existed through geologic time. They only become hazardous when man's activities interact adversely with them.

The time to think about geology related to development and construction is <u>before</u> option or purchase of land. Some questions to be asked might include: Will unrecognized geologic factors mean the developer goes back to the drawing boards on his proposal? Will lending institutions qualify their loans based upon geologic factors? Will county officials require special measures to be taken to keep the county and the taxpayers from being stuck with unwanted consequences of development? If a foreseeable geologic circumstance causes damage or loss of life will there be legal liability?

The answers to some of these questions are available through the county planning departments, the county geologist or the Colorado Geological Survey. Often there are maps of geologic hazards--flood plains, unstable slopes and other features of which the developer and investor should be aware from the outset.

"Nature's Building Codes" is intended for builders, homebuyers, rulemakers, planners, bankers, developers, realtors, school teachers, legislators, and community leaders on commissions and councils.

Colorado Losses

Repeatedly, Colorado roads, utilities, and buildings are constructed in places and in ways that the land's movement (up, down, sideways) will damage or destroy them. The Colorado Geological Survey estimates that $16 million a year in damages occur to taxpayer financed structures alone--roads, bridges, buildings--from just one phenomenon, swelling soils. Of course, Dick and Jane Taxpayer pick up the bill, and the bill is getting bigger as Colorado grows and develops. Colorado taxpayers also pay for the cleanup and rehabilitation of privately owned property damaged by a natural occurrence, a cost that could have been avoided, or at least minimized, by observing nature's building codes. These natural processes do not stop at property lines or with changes in surface land use. Adjacent and future landowners may be affected by poorly conceived development and construction which later triggers earth and water movements.

Heeding common earth behavior patterns, many of them beyond man's control, can have short and long term economic benefits to construction and land development projects. These include marketability, maintenance costs, insurability, and the continuing value of homes, buildings, roads, utility installations, and other improvements. In other words, the bottom line on nature's building codes is money in or out of your pocket, depending upon whether or not they are followed or ignored. Nature has written on the face of the land what she has done, is doing, and will do. If we will read it, understand it, and act upon it, a significant amount of damage and human misery can be averted.

Engineering Geologist

Finding out which seemingly stable soils will collapse, which hillsides will move, and where the earth will expand with tremendous force is the job of the engineering geologist. An engineering geologist is trained in a specialized area of geology, just a neurologist or surgeon is trained in a particular aspect of medicine. He "reads" the work of nature in the rocks, soils, and water, and interprets how nature and proposed developments and construction are going to affect each other. Working with soils engineers, architects, contractors, financiers, and local planners and officials, he can assemble a "diagnosis" of the land's behavior and recommend what can be done to get the maximum benefits with minimum adverse effects.

The lack of geologic investigation, non-recognition of the natural and geologic principles and the subsequent failure to take steps to compensate for them has lead to increasing levels of property damage, and, in some instances, losses of human life. Consequently, federal, state, county, and local governments have become involved in land use and construction decisions. This has occurred, in part, because the public treasuries have been saddled repeatedly with the damage and cleanup costs of both public and private property subjected to natural hazards. Colorado and some other states have passed laws intended to benefit the private as well as the public interest. In Colorado, bills enacted into law include Senate Bill 35 and House Bills 1041, 1529, and 1034 and 1574. They are summarized in the appendix.

In addition, city and county governments have imposed specific measures relating to construction standards. With Colorado's rapid growth it is becoming increasingly common for a government authority to tell a landowner or a contractor what he cannot do--or shouldn't have done--because of a geologic hazard. In one instance, the governor ordered a halt to construction of apartment buildings on a flood plain in Boulder after city efforts to stop it failed.

The builder of a $120,000 home in Jefferson County was sued because the house was built on swelling soils. The unhappy owner of the home wants the house, repairs, and damages from the contractors because of their alleged negligence!

It is the intent of this volume to foster awareness of natural conditions so as to minimize the direct, as well as the indirect legal consequences of not complying with nature's building codes.

The information presented is by no means all inclusive. Such a great variety of conditions, alone and in combination, interact with each other and with human activities in such a way that a substantial volume would be necessary to outline the majority of them. Indeed, for each of the chapters a virtual library exists on the technical aspects and historical incidents.

Colorado's Growth

The extraction and processing of energy fuels--oil, gas, coal, uranium, oil shale--and basic metals such as molybdenum, tin, lead, zinc, gold, and silver are a $1.5 billion a year business in the state. Tourism, skiing, and other recreation are a $2 billion factor in Colorado economy.[3] These two driving forces compete for the state's resources and both produce impacts such as new subdivisions, industrial and building complexes, roads, and other facilities, all of which are subject to natural constraints.

The timeliness and need to recognize "nature's building codes" is evidenced in the surging population growth and record development resulting from the international appeal of Colorado mineral and recreational resources and the state's desirability as a place to live.

Today's growth and development offers an unprecedented opportunity to use ingenious technology and sophisticated methods to alleviate and prevent losses from floods, landslides, contaminated water, and other natural perils. Although we all too often are building in areas by-passed by our forefathers as undesirable, it also is evident we are "recycling" the land. Virtually abandoned mining centers are now ski and convention resorts. Pastures that became sand and gravel pits, and then dumps, are now shopping centers and subdivisions. This pattern is called multiple sequential land use.

Who, a generation ago, would have thought that Denver's splendid Windsor Hotel, the magnificent Tabor Opera House, and scores of mansions, all of them byproducts of the state's early mineral development, would be demolished in little more than one man's lifetime so the land could be put to another use?

Who anticipated in Colorado's 19th century vitality that most of the narrow gauge railroads, many of the mountain pass roads and tunnels, the extensive water developments serving the 430 mining districts would be useful for only a few decades? And who today, in the midst of this multiple sequential land use, is anticipating future land uses, some of which may be non-development?

Impact of Water

There is a common denominator in the natural processes described in "Nature's Building Codes." This common factor is water, a moving force on, in, and under the land we are using. It is everywhere, and as such warrants special consideration. There are few geologic constraints to land use and construction that are not in some way associated with water.

Because water knows no political or property boundaries, it forces examination of land use and development impacts on a broad basis geographically and governmentally. Indeed, the most sophisticated land and water management measures are of little significance or value if limited to a man-made boundary line. A specific site can be subject to processes on adjacent lands, just as events on the site affect other properties. It becomes clear that proper construction and wise land use in one location can be negated by improper land use and/or construction practices across the boundary line.

The lessons of nature are all around us. Only a few have been included here as case histories. These sometimes tragic situations in a state that is spectacularly scenic and delightfully diverse offer profitable lessons upon which to plan wisely.

As the eminent American Ralph Waldo Emerson observed: "The use of history is to give value to the present hour and its duty." In short, we can learn and profit from experience.

Nature has provided us with a history of the earth--it is up to us to understand its value and build Colorado in harmony with her ways.

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[3] The Colorado Excitement. The First National Bank of

Flooding

FLOODING is the overflowing of water onto land that is normally dry. It is a natural event that has occurred periodically throughout geologic time. Flood plains are the land areas adjacent to streams that flood waters cover.

Characteristics

Flooding is a common, often seasonal occurrence. When soils become saturated from prolonged rains or snowmelt, the water accumulates faster than it can be absorbed or carried away in stream channels. Stream levels gradually rise over several hours or days so that some notice can be given of impending high waters--a distinct contrast to a mountain torrent or flash flood which happens so fast that little warning can be given. Accidental or forced releases from reservoirs also can cause floods. The mainstream of a flood (floodway) is swift and forcefully destructive. The overflow onto the flood plain (flood fringe) is less forceful but still destructive. Flood waters are loaded with sediment and debris which in themselves become agents of destruction in addition to the water itself. A stream may change its course during a flood, cutting a new channel within the flood plain.

Consequences

Flood damage is caused by the force of the water itself, the saturation of land and property, the erosive nature of the water and deposition of mud and debris. Homes, trailers, trees, signs, and other items swept away by the flood waters are jammed against bridges, fences, buildings, utility poles, and other structures, resulting in "backwater" damage that the flood waters alone would not cause. Crops and livestock often are drowned and swept away. The swirling waters, their erosive capability increased by sediments and debris, undermine bridges, buildings, and other improvements. As the flood waters recede, the sediments and debris cover the inundated areas. Sewer and water lines may be ruptured and utility lines downed. There is a wide range of havoc generated directly and indirectly. The loss of human life is a real possibility in any flood.

These apartment houses are within the flood plain of Bear Creek in the Denver metropolitan area. A flood control dam has been placed upstream of this development.

Aggravating Circumstances

The frequency, extent, and the degree of damage of flooding are directly related to land use. Natural features such as open land, trees and grasses are replaced with paving, buildings, and other improvements which instead of absorbing or holding back water and slowing down its movement increase the amount and rate of runoff. Drainageways are filled with trash, channels are narrowed with landfills for construction, streams are straightened and their rough bottoms covered with concrete. A variety of structures from billboards to homes erected in flood plains are not designed to withstand floods and not only are damaged or destroyed, but often become debris and an aggravating factor in increasing damage to other property.

The mere failure to keep drainageways and stream channels free from development and trash results in the rising waters lodging debris against culverts and bridges, effectively damming a watercourse and forcing flood waters into the areas that might not be affected otherwise.

The greatest cause of flood damage is man's choice to build on flood plains. Flooding is a natural process which has only become a hazard to man since he has built and developed in flood-prone areas. Man also creates new and enlarged floodplains. As communities grow, storm runoff from new development often is channelled through older areas. The additional water that is generated cannot be handled in the historic manner and flooding of previously flood-free areas results.

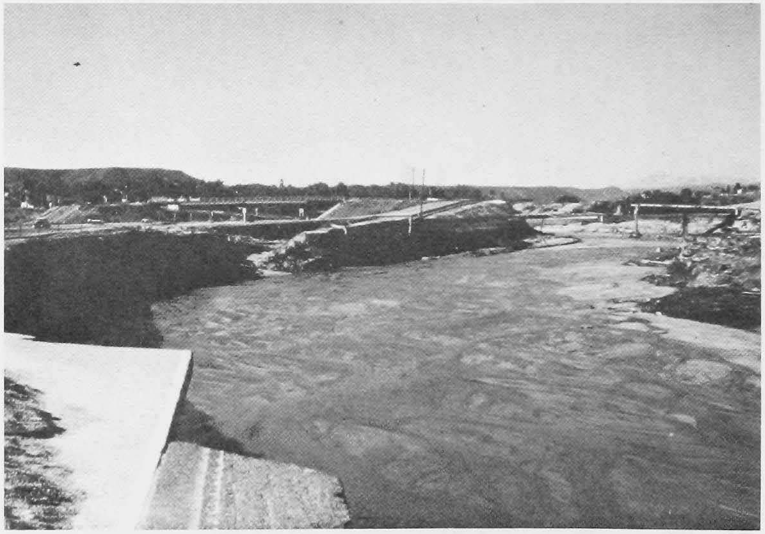
Mitigation

Land use controls and minimizing of flood damage are interdependent. One serves the other. The least costly way of minimizing flood damage is to avoid intense development on flood plains. Essential improvements such as highways, bridges, and utility lines can be designed to withstand floods.

Preservation of natural drainageways as open space in developed areas permits land to serve more than one beneficial use.

In developing areas, detention basins can effectively store and slow down the velocity of high water, lessening the likelihood of flood damage. Detention basins are bowl shaped holding areas where runoff waters can accumulate and drain

Little Dry Creek flooded a wide area in south metropolitan Denver during May, 1973.



Bridge washouts near Castle Rock were caused by severe flooding in 1965.

off later through normal channels at lower volumes and velocities. Parks, playgrounds and parking areas can be useful in this way and they can be cleaned up relatively easily after a flood. Storm sewers, drop structures, channelization, and irrigation ditches are used to dissipate floodwater energy and to direct high water away from or through developed areas to another location. Floods usually subject several governmental jurisdictions to a natural, though man-aggravated, hazard. Consequently, flood control, drainage and land use programs and policies must be on a regional or river basin basis if damage from floods is to be minimized. Otherwise, one area might be protected at the expense of another. Where structures must be built in areas subject to flooding, specialized designs and construction methods can be implemented. The effect of these structures on the rest of the flood plain must be understood in order to prevent increased flood damage to adjacent properties. Keeping natural and manmade drainageways open and free of debris and keeping lowlying areas undeveloped helps minimize the damage from high water.

Land Use

Keeping flood-prone areas undeveloped except as parking areas, parks, and playgrounds, for example, avoids unnecessary damage. Farming, livestock grazing, woodlands, and sand and gravel mining are other possible uses. Fringes of drainageways can double as hiking and bicycle paths and garden areas.

Case History

"The Flood of '65" caused $508 million in damage and took the lives of six people as the South Platte River and some of its southern tributaries roared into the pages of Colorado history on June 16, 1965. The unprecedented flooding was followed a few days later by a similar flood on the Arkansas River, the tremendous impact of which was virtually drowned by the public attention on the South Platte's surging waters and their aftermath.

A combination of tornadoes and violent thunderstorms was climaxed by the opening of the rain-choked clouds over Plum Creek and its tributaries southwest of Castle Rock, south of Denver. In a matter of minutes the peaceful creek became a roaring torrent, out of its banks, cutting new channels, sweeping away trees, houses, bridges, cars, livestock, and portions of Interstate-25 as it raced to its confluence with the South Platte. The accompanying erosion and mudslides

Citizens clean out the first floor of a building in Ouray after a flood early in this century.

Harmlessly, flooding sweeps through a park in Denver in May, 1973. Open space uses like this can add to the attractiveness of an area and minimize damage during high water.

were awesome, according to witnesses.

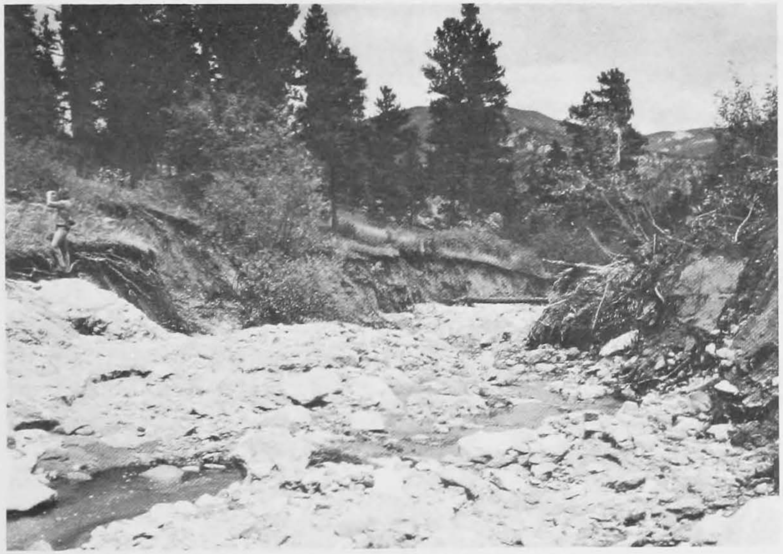
Another storm cell dumped its water upon the upper reaches of Cherry Creek, southeast of Denver. That flood also swept away bridges, buildings, and other structures in its path before being stopped by Cherry Creek Dam. Other storm cells, plus rain in Denver and its environs soon had local drainage channels choked with water and debris.

By late afternoon, flood warnings were out as frightening reports came in from upstream on the South Platte and Plum Creek. The flood crest moved on. By nightfall it was washing away bridges, homes, trailers, cars, and taking human lives in Denver and its suburbs. Shortly before midnight the flood crest was well out of the river banks and sweeping across the low-lying business and industrial districts. It moved through a startled, disbelieving city, as major bridges seemed to dissolve into the water as it lapped at the main spans. For the next several hours the flood's irresistible power churned its way downstream with slowly diminishing havoc, leaving behind a soggy, mud-choked scene of wreckage and human misery.

In retrospect, the flood was a predictable natural event. The property damage was entirely due to human activities and construction in geologically and hydrologically definable hazard areas. Since the flood, Chatfield Dam has been built at the confluence of the South Platte River and Plum Creek south of Denver. It is designed to hold back flood waters, should a similar incident occur. However, it will not protect property upstream. Bear Creek Dam, on a principal stream feeding into the South Platte River in the Denver metropolitan area, also has been built to provide protection to the developed downstream flood plains.

Mountain Torrents & Flash Floods

MOUNTAIN TORRENTS and FLASH FLOODS are local, sudden, and sometimes catastrophic and short-lived floods of relatively great volume and velocity. They frequently occur in dry or intermittent stream channels where they move immense loads of mud, rock fragments and other debris. Ordinarily, they are caused by brief but heavy rainfall over a relatively small, steeply sloping drainage basin. Most small and steep-gradient watersheds in Colorado are subject to flash floods.



These two photos of very similar small tributaries to the Big Thompson River could almost be "before and after" views. In 1976, one flooded, the other did not. If you were evaluating a peaceful looking stream valley for a house site, would you expect the violent flooding as evidenced in the photo which can affect these small tributaries?

Characteristics

The characteristics of a mountain torrent or flash flood differ from the mainstream low-gradient flooding described in the chapter on flooding. The extremely rapid rise of water, its very high velocity as it rushes down mountainsides and across open areas and the extremely high percentage of sediment and debris carried in the water makes flash floods especially destructive and dangerous. Where the gradient of the stream is steep, tremendous erosive powers act on the stream channel and banks, transporting and destroying almost everything in the way. This material then is deposited downstream where the gradient decreases. (See debris fan.) Flash flooding of smaller basins can occur either with major mainstream flooding or as small, isolated events.

There is seldom much time to warn people or evacuate the areas threatened by mountain torrents. Because many streams are periodically dry or contain only intermittent flows, there is a danger of underestimating the potential hazard. Many channels which contain a small, peaceful stream can become raging torrents within minutes after a cloudburst.

Consequences

The tremendous destructive power of the mountain torrent and flash flood process can destroy essentially all works of man within the flood path. Erosion can undercut buildings that are above the flood, causing them to fall into the torrent.

Dam failures can also cause flash floods. They are often catastrophic in loss of life and property because of development below them. The levels of flood waters often exceed any that would occur naturally had the dam not existed.

Aggravating Circumstances

Excessive logging, overgrazing and forest fires reduce the land's capacity to absorb water and slow down runoff.

Mitigation

If property damage and loss of life are to be avoided, the only economically reasonable and physically safe mitigation is complete avoidance of areas subject to mountain torrent and flash flood processes.

Monitoring of dams can give warning of impending failure so repairs can be made or people evacuated. In some cases inundation maps prepared in advance can precisely detail the route and depth of a flood in case of dam failure.

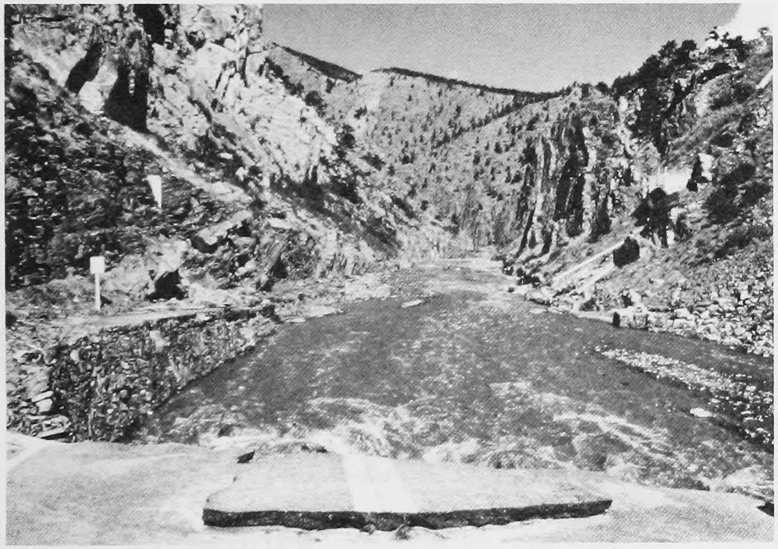
This house was totally destroyed by the 1976 Big Thompson flood. Note debris and sediment piled around the trees and the house.

Land Use

The only potential land use which is 'safe' is open space.

Case History

On the late evening and night of July 31-August 1, 1976, one of the worst natural disasters in Colorado history roared savagely down the narrow canyon of the Big Thompson River east of Rocky Mountain National Park. Spawned by 10 to 12 inches of rainfall from a violent cloudburst, the mountain torrent rapidly demolished nearly everything in its path including the canyon highway, bridges, homes, cabins, and commercial buildings. At least 135 men, women, and children perished. The velocity of the foaming, surging walls of muddy, debris-laden water combined with the fading light and then darkness to thwart effective warnings. Dozens of people barely escaped with their lives. Property damage and reconstruction costs were estimated to be in excess of $50 million over the score of miles most impacted by the torrent.



The Big Thompson River Canyon from just west of Loveland is pictured after the flood of July 31-August 1, 1976. The flood water was 20 feet deep through this section and had sufficient force to completely remove any evidence of what was a major road to Estes Park.

Erosion/ Deposition

EROSION is the removal and simultaneous transportation of earth materials from one location to another by water, wind, waves, or moving ice. DEPOSITION is the placing of the eroded material in a new location. All material which is eroded is later deposited in another location.

Characteristics

Erosion and deposition are occurring continually at varying rates over the earth's surface. Swiftly moving flood waters cause rapid local erosion as the water carries away earth materials. Deposition occurs where flood waters slow down, pool or lose energy in other ways and the materials settle out. Similarly, wind erosion can occur from exposed areas such as fields, tailings and desert areas when the wind is strong and the materials are deposited when the wind diminishes. Another factor which controls the amount of erosion is the ease with which material can be dislodged. Hard granites erode very slowly while soft silts and sands erode very quickly. Vegetation which holds soils in place can decrease significantly the rates of erosion from water and wind.

Consequences

Erosion can result in minor inconveniences or total destruction. Severe erosion removes the earth from beneath bridges, roads, and foundations of structures adjacent to streams. By undercutting it can lead to increased rockfall and landslide hazard. The deposition of material can block culverts, aggravate flooding, destroy crops and lawns by burying them, and reduce the capacity of water reservoirs as the deposited materials displace water.

Severe erosion from man-made alterations of the natural drainage systems resulted in a large gully in Douglas County. Note man standing in the center of the picture.

Housing development and drainage alterations caused this accelerated erosion near Golden.

Aggravating Circumstances

Man's activities greatly influence the rate and extent of erosion and deposition. Stripping the land surface of vegetation, altering natural drainages, and rearranging the earth through construction of highways, subdivision development, farm land preparation, and modification of drainage channels for water control projects are significant factors in increased erosion and deposition. All the geologic processes which make available more material for erosion and deposition tend to increase the rates of each process. This is particularly true for landslides, mudflows, debris flows, earthflows, rockfalls, and physical and chemical weathering. These processes also involve erosion and deposition while frequently making more material vulnerable to erosion.

Mitigation

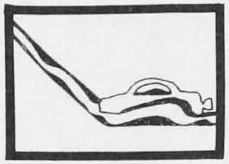
The processes of erosion and deposition cannot be stopped totally. They can be reduced and controlled by surface drainage management, revegetation of disturbed lands, controlling stream-carried eroded materials in sediment catchment basins, and riprapping of erosion-prone stream banks, especially adjacent to structures. Understanding these processes and taking preventative action can lead to development and land-use methods which minimize losses.

Land Use

Ordinarily, erosion and deposition do not curtail land use, especially if efforts are made to minimize them.

Case History

Near Larkspur in Douglas County an access road and shallow borrow ditch were cut to serve an airport runway uphill from the access road. During construction of the road and borrow pit a large area was stripped of vegetation. Heavy water runoff from above the runway and the runway itself was channelled down the borrow ditch. There were no control features to slow the velocity of the water or retard erosion. Within five years the borrow ditch was eight feet deep. Properly designed and installed water control structures, revegetation of the graded area, detention ponds, drop structures, and other measures would have paid for themselves in later maintenance and repair costs.



Mud Flow/ Debris Flow

A MUD FLOW is a mass of water and fine-grained earth materials that flows down a stream, ravine, canyon, arroyo or gulch. If more than half of the solids in the mass are larger than sand grains--rocks, stones, boulders-- the event is called a DEBRIS FLOW.

Characteristics

Debris and mud flows are a combination of fast moving water and a great volume of sediment and debris that surges down slope with tremendous force. The consistency is like that of pancake batter. They are similar to flash floods and can occur suddenly without time for adequate warning. When the drainage channel eventually becomes less steep, the liquid mass spreads out and slows down to form a part of a debris fan or a mud flow deposit. In the steep channel itself, erosion is the dominant process as the flow picks up more solid material. A drainage may have several mud flows a year, or none for several years or decades. They are common events in the steep terrain of Colorado and vary widely in size and destructiveness. Cloudbursts provide the usual source of water for a mudflow in Colorado.

Consequences

Mud/debris flows ruin substantial improvements with the force of the flow itself and the burying or erosion of them by mud and debris. The heavy mass pushes in walls, removes buildings from foundations, fills in basements and excavations and sweeps away cars, trucks, heavy equipment and other substantial objects. Boulders and trees swept along by the muddy mass demolish buildings, flatten fences and utility poles. In mountain areas, portions of valleys have been eroded to a depth of several feet by the flow process.

Aggravating Circumstances

The likelihood of mud flows and mud flow damage is increased by actions which increase the amount of water or soils

Mud and debris flows at Slate Creek near Marble lodged mud and boulders high in the trees, indicating a flow depth of at least 10 feet higher than the present ground level. This was a relatively minor event such as occurs on Slate Creek about every five years.

involved. Removal of vegetation on steep slopes, dumping debris and fill in a mud flow path and improper road building or earth moving can contribute to a mud flow. The failure of a dam, irrigation ditch or other water management structure can initiate mud/debris flow if the escaping water can swiftly accumulate a large volume of soil materials. Similarly, a landslide which temporarily blocks a stream may cause or contribute to a debris flow.

Mitigation

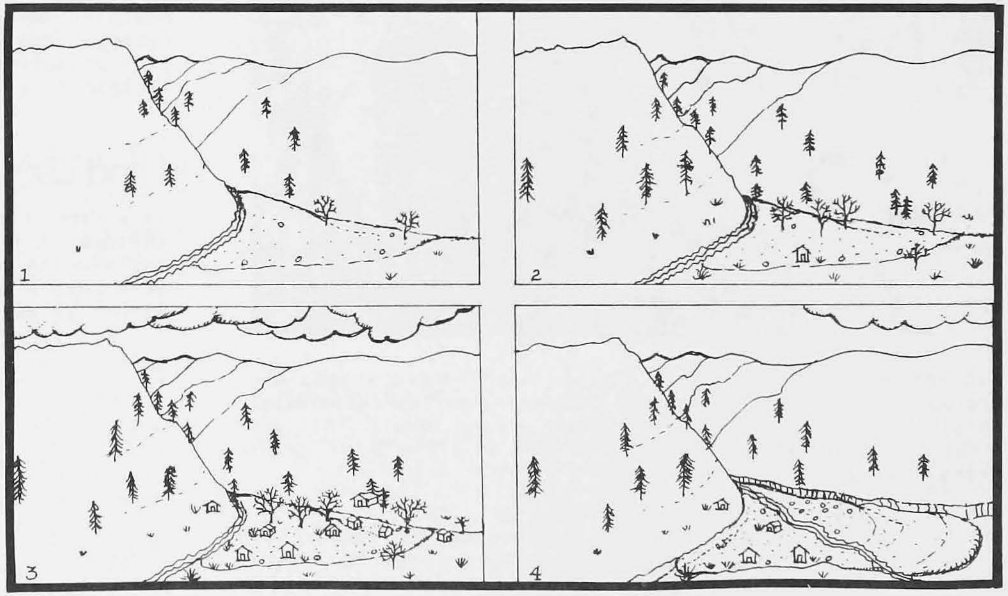
In most instances very little can be done to mitigate the mud flow process in the channel itself. Property damage can be prevented by recognizing natural mud flow areas and avoiding them. In some cases unstable slopes can be revegetated or reinforced to reduce the effect of large volumes of moving water upon them. A series of check dams or other storm drainage management practices may be considered in some cases. Geologic investigations can identify areas of mud flow potential and serve as a guideline for development of mitigation plans.

Land Use

To prevent loss of life and property damage, areas subject to mud/debris flows should not be developed. In some cases engineering geologic investigations may define the dynamics of a severe mud/debris flow and allow steps to be taken to direct it away from buildings and other improvements.

Debris Fan

A DEBRIS FAN is a sloping, wedge-shaped deposit of loose rock, earth and vegetative debris near or at the junction of a smaller stream with a larger stream valley, or where the gradient of a stream abruptly decreases. It is created by debris flows--the downstream/downslope propulsion of rocks, vegetative matter, junk and other material in a watery, muddy slurry. The stream which deposited the fan normally traverses or runs along one of the edges of the fan.



Debris/mud flow fans frequently offer scenic building sites in mountain valleys. This case illustrates the following sequence. 1) A time in the past, shortly after a debris flow that removed many of the trees and left the channel on one side of the fan. 2) Some years later the soil and vegetation have recovered and the fan shows little evidence of past debris flow events. 3) Man develops the fan area with housing. 4) An intense cloudburst causes a debris flow which destroys structures and vegetation and moves the channel to a new location until the next event.

Characteristics

In many stream valleys, the debris fans, built up over the centuries at the mouth of the small tributaries, offer attractive places for development. Frequently, in an effort to avoid mainstream flooding, the debris fans are built upon without the realization that they, too, are subject to periodic debris flows and flooding. Depending on the climate and geology, the fans may recover quickly from the destructive effects of a debris flow event, offering little visual evidence of the active processes. In general, the existing channel on a debris fan cannot accomodate the next large debris flow. It cannot be assumed to be the only hazardous location on a debris fan. The land form is built up over the years as debris flows periodically deposit materials across the entire debris fan or portions of it. During a large flow a new channel may result from plugging of the existing channel with debris. Usually, the destructive forces of the debris flow decrease as one moves from the narrow, steep apex of the fan to the broader, gentler slopes down gradient. Correspondingly, the size of the material deposited decreases as the debris flow moves across the fan. Debris fans often are vegetated with cottonwood or aspen trees, grasses and shrubs in a distinct contrast to adjacent plant growth. Some debris fans in the high mountains also are subject to avalanches.

Consequences

Structures and improvements on the apex of the fan may be destroyed or badly damaged while improvements farther down on the fan may only experience water and mud damage. Erosion and deposition on an active fan by successive debris flows is to be expected.

Aggravating Circumstances

Man's activities which could increase the natural hazards are similar to those cited under debris flow and mud flow. In addition, however, significant, short-term alterations to the debris fan land form can increase the hazard on particular areas on the fan. Massive earth moving on the fan could create an artificial diversion or channel which would cause temporary preferential flow directions during a debris flow.

Mitigation

The best form of mitigation is based upon an understanding of the natural processes of a debris fan and locating and constructing improvements accordingly. Given the condition of a developed debris fan, measures that can be taken to decrease the hazard include building massive earth structures on the uphill side of houses or other improvements to divert the flow to one side or the other, planting a dense row of trees, erecting retaining walls, and channelling the stream. These measures should be considered only after a complete understanding of the process is obtained because in many instances they could be of little benefit and could even increase the hazard to other developed areas.

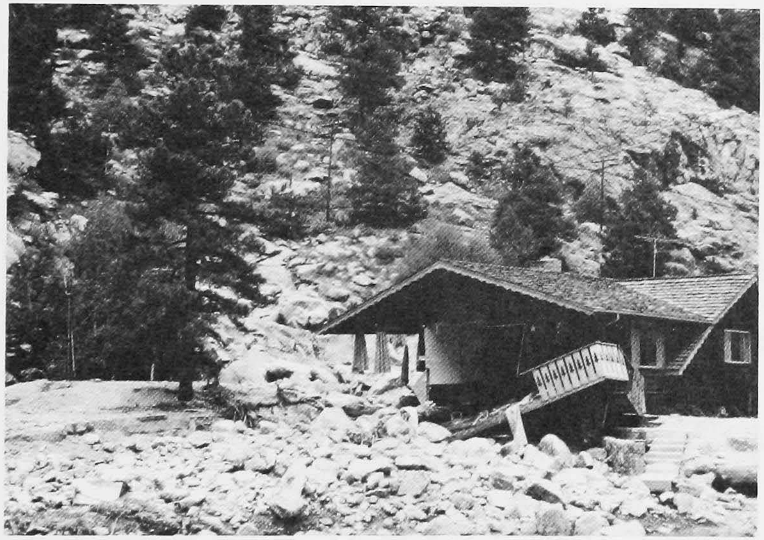
Land Use

Land uses on debris fans range from open space to relatively intensive use. Intensive use may be appropriate after a thorough geologic study and understanding of the debris fan is obtained. Some fans have very deeply entrenched channels, indicating that during recent geologic time, the dominant process has been erosion on the fan rather than deposition. Such a debris fan may be safe for development. Until determined otherwise, however, building on a debris fan should be considered hazardous.

A debris flow smashed into this Glenwood Springs home in 1977. The house is a part of a residential development placed on a debris fan which had been built up over the years. Note the height of the flow as indicated by the water/mud mark at second floor level.

Case History

On July 24, 1977, an intense rainstorm drenched Glenwood Springs and the steep slopes above the town. It generated debris flows that caused a reported $2 million in damage in the southern part of the city. Remarkably, there were no reported injuries as tons of red rock and other material, loosened by the rainfall, swept down the scenic mountainside into homes and other buildings, severely damaging them. The financial loss, much of it borne by city and Garfield County taxpayers, could have been averted with proper development planning on a known debris fan and its periphery.



This house was located on a debris fan of a small tributary to the Big Thompson River. The house was not damaged by mainstream flooding on the Big Thompson, but by the debris flow from the small ravine behind the house.

Case History

Debris flows were a significant factor in the July 31-August 1, 1976, natural disaster in the Big Thompson River Canyon that claimed 135 lives and caused an estimated $50 million in property damage. Besides the flash flood itself, heavy debris flows were initiated in the side canyons and ravines of the main stream by the rains. In several instances property up away from the mainstream torrent was not damaged until the debris flows swept across their historic debris fans, destroying most structures. These separate geologic phenomena combined to constitute one of the most devastating nights in Colorado history. (See the Mountain Torrents chapter.)

Deposits on a debris fan on Sweetwater Creek in Eagle County occurred ten days after the Big Thompson flood in 1976.

Case History

"One street leads through Marble, Colorado, after the recent flood that struck there a week ago last Friday, August 8 (1941) and many of the homes that were struck by the full force of the flood will never be dug out of the mud or repaired. 'Main Street' in Marble is still under 6 to 8 feet of mud and rock, much of which will probably never be removed...

"Marble...was all but swept away in a flood and rock and mud slide... in some localities in the town, during the peak of the storm and tragedy, the mud, rock and water level reached 20 feet. Later it subsided to 6 to 10 feet as it remains today.

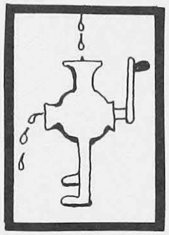
"The flood and slide came down Carbonate Creek and struck at about 3:30 o'clock in the afternoon...just before the flood struck, a severe lightning storm was prevalent and all the children and women had gone indoors.

"The flood came rushing down upon the town and before most people realized what had happened it had removed 1 1/2 blocks of houses and buildings, as well as the entire water main and electric supply for the community. The furnishings of many homes were washed out of the buildings and down the creek, being carried about 500 feet by the speed of the water when it struck a home.

"Homes that were not torn from their bases, turned over or set sailing on the flood waters were badly damaged by mud and water that ran in from doorways and windows, filling rooms to a level of from one to three feet. The mud and rock slide was well over a thousand feet wide and the debris that rode on the crest of the moving mass was responsible for taking out several bridges and causing much of the damage.

"The flood that struck two weeks ago was the worst in the past 20 years. Marble has been subjected to periodic inundations..."

The Glenwood Post
August 21, 1941

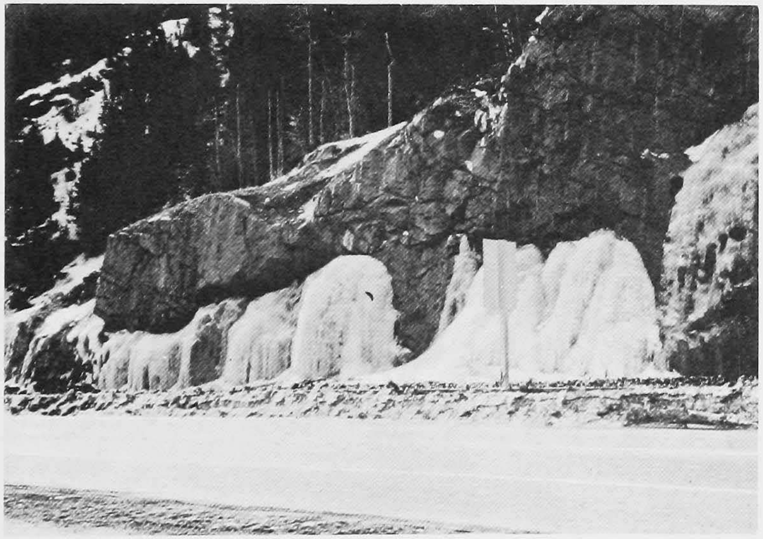


Ground Water

Introduction

Because of its importance ground water is treated in three sections: quantity, quality, and its relationships to construction.

While water occurs in varying amounts in all earth materials, ground water is the subsurface water that saturates certain underground formations. It occurs in definable formations called aquifers. Some aquifers (unconfined), are closely associated with the surface of the ground through infiltration or at streams, springs, or ponds while other aquifers (confined), are virtually isolated from the surface by overlying impermeable bedrock. A single aquifer may underlie many square miles of land and when tapped by wells can be a principal source of water for domestic, industrial or agricultural use.



The pathways of groundwater movement through fractures in crystalline rocks in Clear Creek County are vividly shown by the formation of ice from seeping ground water at joints in the rock.

Some ground water supplies are renewed rapidly by natural processes. These unconfined aquifers are "recharged" with water seeping into them from precipitation, streams, lakes, drainageways, swamps and other sources on the surface of the ground. Confined deep aquifers generally have no way to quickly replace water pumped from them. In most cases, ground water flows through the rocks and soils of aquifers at rates ranging from a few inches to hundreds of feet per year. The underground water can move slowly through the aquifers for many miles. Some aquifers are mapped in detail and their characteristics have been determined as the result of extensive use and testing. In general, however, many aquifers are poorly understood, making management and conservation of this valuable resource difficult.

The ground water aquifers closest to the surface are of primary concern to land development and construction projects because they most frequently affect the availability of supply, water quality and affect other geologic phenomena such as landslides, subsidence and collapsing soils. They also are most vulnerable to man-caused pollution. Indirectly, ground water affects the value of property and the improvements on it.

Quantity

Characteristics

Different kinds of rocks and soils store and yield water in varying amounts. Shales and other rock formations composed of fine particles yield very little water because water cannot move easily through them. Sand and gravel formations, on the other hand, may yield as much as 2,000 gallons of water per minute because vast amounts of water lie between the sand and grains and pebbles. Crystalline rocks, like granite, appear to have no available water when an individual rock is examined. Yet, moderate amounts of water can be contained in fractures interlacing an extensive rock mass.

Because of great hydrologic variation in rocks and soils, and the differences in the rates at which aquifers recharge, there is a great range in the amount of water available from location to location, season to season, and year to year. Ground water aquifers may provide a sustained yield of less than a gallon to several thousand gallons of water per minute.

Aggravating Circumstances & Consequences

If water is pumped out of an aquifer faster than it is recharged, the water level in the aquifer--the ground water table--is said to drop. Seasonal fluctuations from irrigation or changes in recharge are quite common. If the excessive withdrawal of water continues over an extended period of time and the natural recharge does not offset the total amount of water extracted, it is said the ground water is being "mined."

There is evidence that once vast amounts of water are withdrawn from deep aquifers at rates exceeding recharge, the aquifers never again can be recharged with the original volume of water. Consolidation and subsidence processes can fill in the space once occupied by water. Efforts to artificially recharge underground aquifers have met with limited success.

Human activities greatly affect the availability of ground water in some areas. Widespread and excessive pumping of underground waters can lower the ground water table under many square miles. This is the situation in some irrigated farming areas in eastern Colorado. In many areas wells have had to be deepened to obtain sufficient water as a ground water table drops. The lower the ground water table, the more it costs to drill a well and to pump the water to the surface. It eventually may cost more to pump water than the water is worth, especially for agricultural and industrial applications using large volumes of water.

Paving large areas, altering or removing vegetation, grading, sand and gravel mining, diverting storm runoff away from established channels and other manipulation of the land and surface hydrology can change recharge rates in the immediate vicinity, thus altering ground water levels.

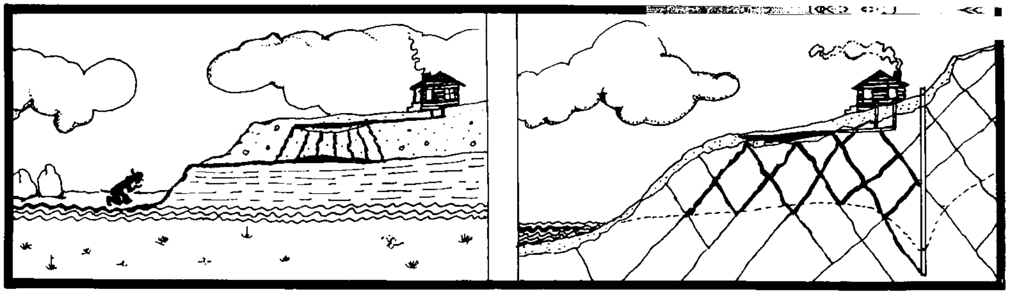
Mitigation

An adequate understanding of the ground water system is the best measure of protection from property damage and devaluation from a reduction or loss of water supply. By using such knowledge, construction and property development can be accomplished without encountering unexpected ground water situations. Hydrogeologic investigations can reveal not only specific characteristics, but the interrelationships between and among human endeavors and natural factors. Knowledge of the amount of water withdrawn per year, the recharge rates and other facts may require the amount of water withdrawn annually from wells to be restricted and the number of wells limited to keep the wells from drying up. Restrictions on land development may be needed to preserve recharge from natural sources and thus maintain the ground water supply and protect land investments.

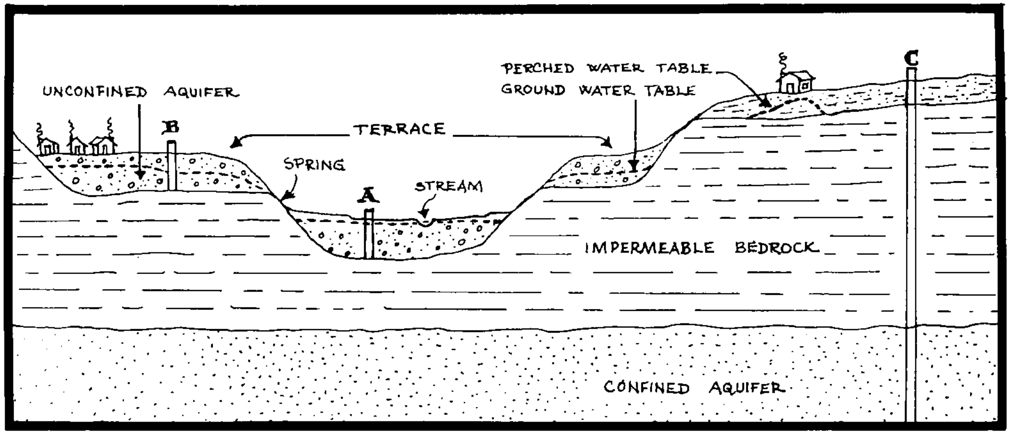
Land Use

In semi-arid Colorado ground water considerations are increasingly considered in making land use decisions. Normally land uses are not restricted, although they may entail construction modifications to protect or enhance ground water supply and related property values. Too much or too little ground water, year around or seasonally, can be compensated for ordinarily through geologic investigation and responsive planning.

Developments which rely on ground water should be permitted only after it is established that sufficient water exists and that the necessary amounts can be withdrawn indefinitely without jeopardizing the supply.



Individual sewage disposal systems, if improperly located, designed, or maintained, can cause contamination of ground and surface waters. In both of the cases illustrated, insufficiently treated household effluent is contaminating waters used locally. On the left, the effluent reaches a stream due to thin, permeable gravels lying over impermeable shale. On the right, a homeowner unknowingly is polluting his own well water due to the flow of contaminated water from the septic system through the rock fractures.



This diagrammatic sketch shows common ground water conditions found in Colorado. Well "A", located near a stream penetrates the water saturated sands and gravel. The ground water is recharged primarily by the stream and irrigation if the area is agricultural. Water yields from this unconfined aquifer can be as great as 2,000 gallons per minute and the ground water table may be only a couple of feet below the ground surface. Well "B" is located in older sand and gravel on a stream terrace above the present stream. The ground water levels and recharge are primarily the result of precipitation, runoff, and lawn irrigation in the subdivision. Notice the mounding of the ground water table under the houses. Yields from this well will be less than from "A" because of a smaller saturated thickness and lower permeability of the aquifer.

Well "C" is located on an upland surface characterized by several feet of weathered bedrock at the surface. The well penetrated this slightly more permeable layer before passing through the impermeable shale bedrock into a confined sandstone aquifer. The ground water in the sandstone may be recharged many miles away and thus is susceptible to overutilization without the ability to fully recover. The water may be artesian, which means it will rise in the well above the top of the aquifer. Yields from this type of aquifer are highly variable.

Quality

Characteristics

There is a tremendous range of ground water quality because of the chemical characteristics of recharge water and the geologic formations through which ground water travels. Some ground water aquifers yield water nearly as pure as distilled water. Others may be saltier than seawater and still others may be naturally radioactive or characterized by some particular chemical constituent or combination of them. Differences in ground water quality are often predictable from geologic and geochemical knowledge.

Aggravating Circumstances & Consequences

In Colorado the most common natural water quality problems are hardness and salinity because of minerals dissolved in the water. Hard water can be softened with chemical treatment. The second most prevalent situation, and an increasingly serious one as the state's limited water supplies are called upon to meet the demands of growth, is the contamination of good ground water with sewage, industrial and agricultural chemicals and other wastes.

Malfunctioning sewage disposal systems, seepage from dumps and landfills, improper waste disposal methods, mineral exploration and production are jeopardizing drinkable water supplies and increasing the cost of treating them before they can be used. Depending upon the type and volume of contaminants, rehabilitation of a polluted ground water supply may take several years or an undetermined amount of time--if it can be achieved at all.

Mitigation

A thorough understanding of the ground water system and its relationship to human activities is the first step in protecting water quality, minimizing treatment costs and providing people with safe water for drinking and growing food.

Proper construction, operation and maintenance of sewage disposal systems, neutralizing or isolating harmful chemicals prior to disposal and revised manufacturing processes are basic protective measures.

Land Use

While land uses which contaminate ground water will always exist, hydrogeologic investigations are fundamental to managing both land and water and ensuring their value.

Case History

In the 1940's and 50's, the U.S. Rocky Mountain Arsenal in western Adams County deposited a complex mixture of chemical wastes from the manufacture of pesticides, herbicides, and some chemical warfare agents into unlined holding ponds. It also injected wastes into subsurface zones through a deep disposal well. More than 30 square miles of a shallow fresh water aquifer were contaminated by toxic substances (aldrin and dieldrin) in the vicinity of the ponds.

Losses from this disposal of toxic wastes over a permeable ground water zone exceeded $2,165,000, including payments to ranchers and farmers for well contamination and crop losses. Adequate geological investigations could have anticipated the problem and lining of the disposal ponds could have prevented seepage contamination.

Wastes also were injected into the subsurface zones through a deep disposal well. Mild earthquakes recorded in the vicinity of the well were attributed to deep well injections. The earth tremors were not experienced prior to injection and gradually ceased after injection disposal was terminated.

In June, 1978, a U.S. Senate subcommittee approved $6.5 million to continue cleanup work at the arsenal.

Ground Water & Construction

Characteristics

Ground water can be one of the most costly--even ruinous--factors in construction and land development if it is not understood and taken into consideration in the planning phases of a project. Water is the primary cause of the ground moving--up, down or laterally--because of its capability of changing the chemical and physical nature of rocks and soils. Water activates swelling and hydrocompacting (collapsing) soils and is a major factor in slope instability.

The value of any development is affected, directly and indirectly, by the long term impacts of ground water. The lack of it or the over abundance of it is one of the most prevalent and fundamental reasons for financial distress in the building and land development businesses. Its significance is evidenced by outright losses, delays, lawsuits, improper or inadequate use of a site and post construction corrective measures.

Aggravating Circumstances & Consequences

Elementary practices such as roof and pavement storm runoff, sewage treatment, landscaping and land grading can upset the existing natural ground water regimen and create new situations that did not exist prior to development. Basements may flood, foundations sink or be pushed upward to affect an entire structure and underground utilities as well. Pavements may bulge or cave in as ground water is affected by land-use changes on the surface of the ground. Planning projects with knowledge of the pre-development ground water conditions and analysis of anticipated post-development conditions may indicate the desirability of mitigation measures before full development. The cost of prevention is ordinarily far cheaper than trying to correct and repair damage from ground water related causes.

High ground water tables limit land use and may require special construction methods. Lowering the water table by draining low-lying areas and then filling them with soil is a common practice which frequently alters local ground water conditions.

Mitigation

Ground water is an area-wide matter which can be managed to the short and long term benefit of surface lands. It is to the advantage of contractors and developers to know in advance what their project will do to ground water and what ground water may do to it.

Case History

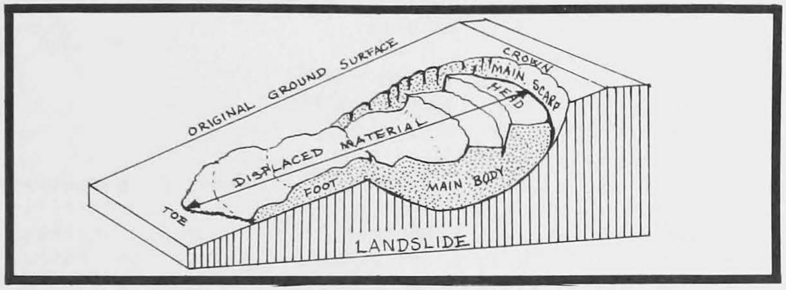
A southern Aurora subdivision was developed in the early 1970's when the groundwater table was 20 feet below the surface. Piecemeal development, changing of drainage patterns during development, and excessive lawn watering over the sandy soils raised the water table and caused chronic basement flooding. Many homeowners put in sump pumps and shallow lawn-watering wells. Damage is estimated at $1,000 to $4,000 each to several hundred homes. Integrated surface drainage, non-basement homes, and an area-wide dewatering system could have prevented such high water table damage. The city estimated residents were sprinkling 45 inches of water on their lawns annually, thus contributing to the problem.

Landslides

LANDSLIDES are the downward and outward movement of a slopes composed of natural rock, soils, artificial fills, or combinations thereof. Common names for landslide types include slump, rock slide, debris slide, lateral spreading, debris avalanche, earth flow, and soil creep.

Characteristics

Landslides move by falling, sliding, and flowing along surfaces marked by differences in soil or rock characteristics. A landslide is the result of either a decrease in resisting forces that hold the earth mass in place and/or an increase in the driving forces that



Common nomenclature used for describing components of a landslide.

Soil creep is common on a steep slope with a thin soil cover over bedrock. Such patterns are frequently mistaken for animal trails. Soil creep can be an indicator of more serious failures in the future, especially if the area is disturbed.

This landslide near Breckenridge occurred in an area proposed for development. The land "failed" as a result of water saturating the slope. The slide moved so rapidly and with such force that trees were uprooted with the tops falling uphill.

facilitate its movement. The rates of movement for landslides vary from tens of feet per second to fractions of inches per year. Landslides can occur as reactivated old slides or as new slides in areas not previously experiencing them. Areas of past or active landsliding can be recognized by their topographic and physical appearance. Areas susceptible to landslides but not previously active can frequently be identified by the similarity of geologic materials and conditions to areas of known landslide activity.

Consequences

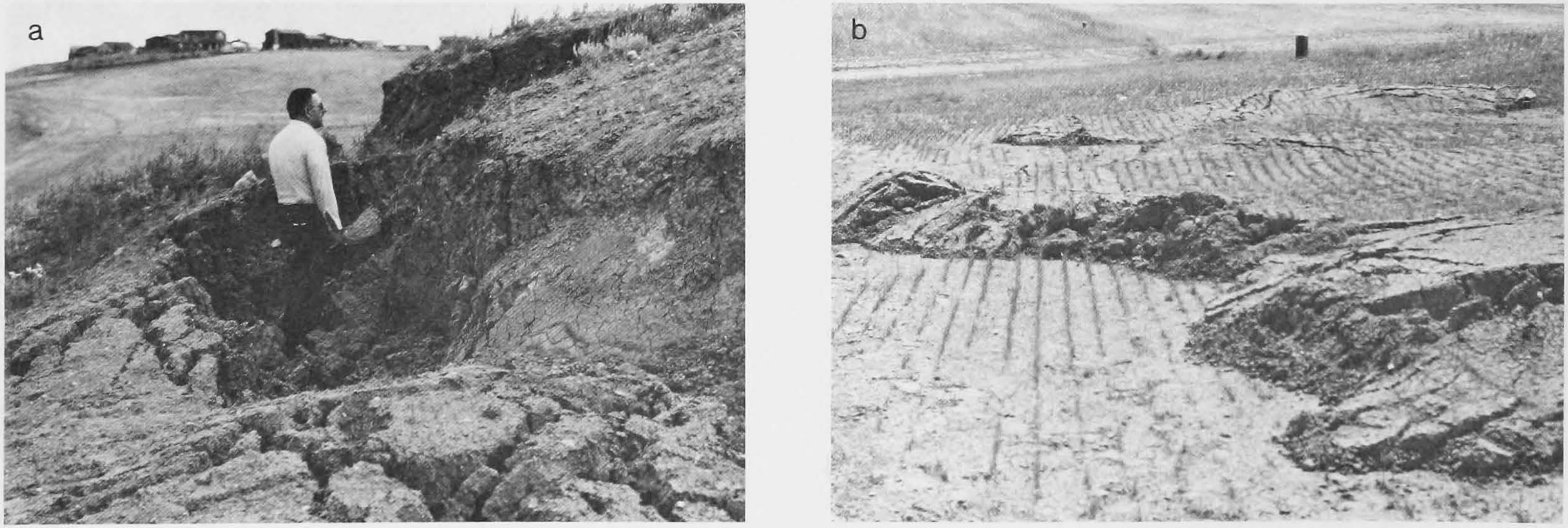
Landslides in the U.S. are estimated to cause more than $1 billion a year in property damage, according to the Transportation Research Board of the National Academy of Sciences. Railroads, highways, homes, and entire communities are lost to landslides which demolish and/or bury them. In Colorado the 19th century mining camp of Brownsville just west of Silver Plume is buried beneath a rain triggered landslide that became a debris flow. It is now under Interstate 70. Landslides occur commonly throughout Colorado, and the annual damage is estimated to exceed three million dollars to buildings alone.

Aggravating Circumstances

Landslides are one of the primary natural processes shaping the land. Man's activities that frequently cause significant increases in landslide activity include:

1) excavation of a steep slope or the toe of an existing landslide, thus removing support of the upslope mass,
2) addition of material to the head (top) of a landslide which pushes the slide material downslope,
3) addition of moisture to the landslide mass, increasing the weight and decreasing the strength.

The activities which tend to increase landslide potential include excavation for highways and houses, and earth fills for highways and houses, lawn watering or surface drainage diversions, and changes in water infiltration rates. Alteration of surface land use such as roadcuts and water impoundments, which allows more water into the subsurface of a slide-prone slope, is a major contributing factor in landslides.



These two photos show the headscarp (a) and toe (b) of a landslide in a residential subdivision south of Denver. Fortunately, this slide occurred during utility placement and lot grading prior to construction of homes. Geologic investigations resulted in alterations in the development plan to prevent future damage. Note the very gentle slopes at the toe of the slide. Such earth movements are common in Colorado.

Mitigation

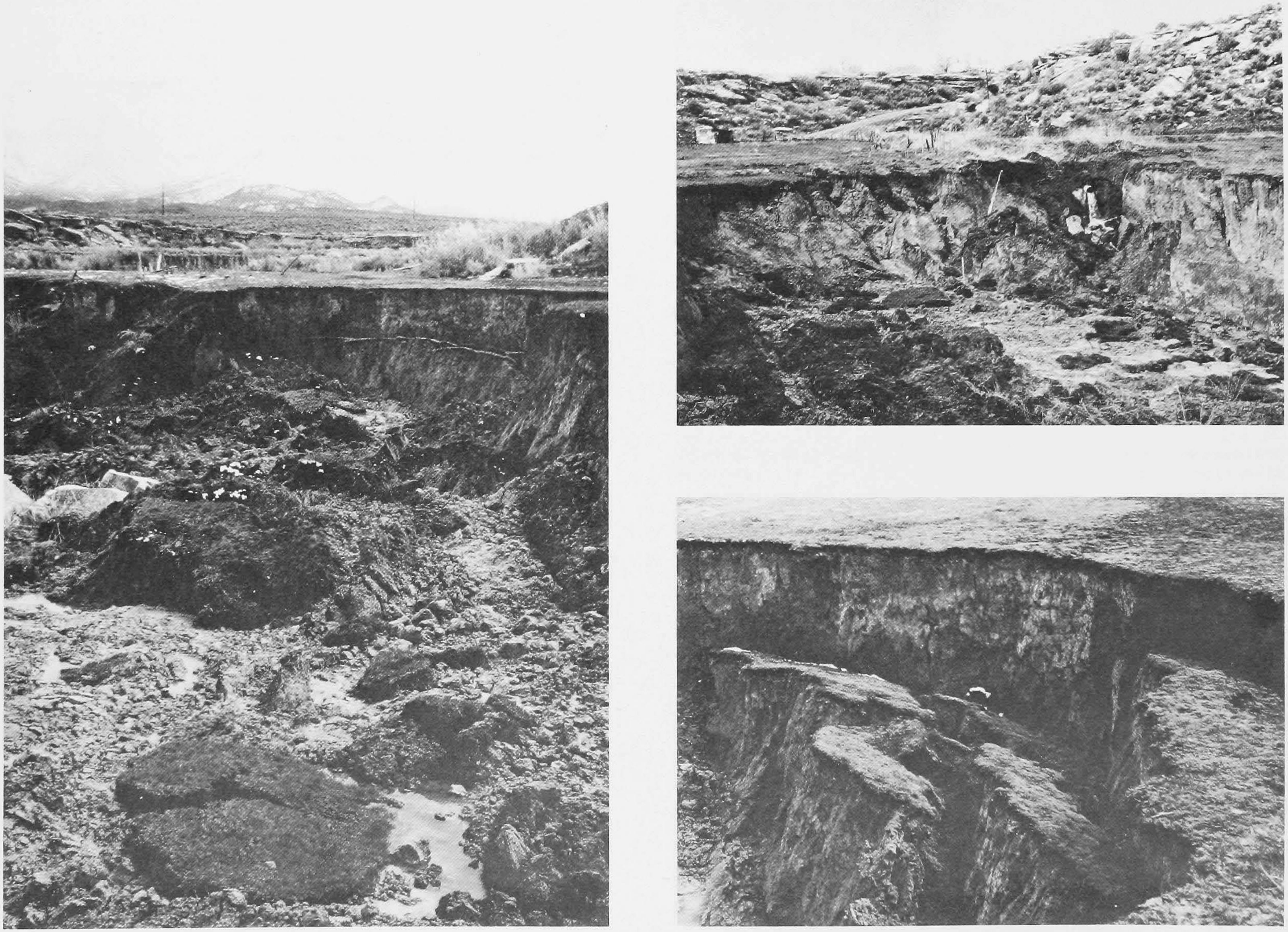
Many methods of mitigation can be designed for active or potentially active landslide areas. These generally fall into four categories: 1) change of slope shape, 2) drainage management, 3) retaining structures, and 4) special treatments. Change of slope shape methods include excavating the entire slide, benching, excavating the upper part of the slide, increasing the weight and resistance to movement of the lower part of the slide (loading), and a combination of excavation and loading.

Drainage methods include changes of surface drainage through diversions and increasing subsurface drainage with various construction practices. Retaining structures used to control landslides include buttresses, piles, walls, and anchors. Special treatments for slide control include freezing, grouting, blasting and vegetative plantings or other surface cover for water and erosion management.

A landslide on the edge of a subdivision west of Denver is destined to "shrink" backyards unless stabilization measures are taken.

Land Use

The above mitigation techniques can be quite costly, particularly for large landslide areas, and are often used only as a last resort or to protect expensive structures. Even then they may be temporary and in the long run ineffective. In general, recognition and avoidance of landslide areas with all structural land uses is desirable. Significant earth moving or structural use of the land nearly always justifies a thorough analysis of the landslide potential prior to construction. In some situations, such as highway construction, landslide-prone areas are unavoidable and mitigation measures must be utilized to fit the circumstances.



Significant landsliding can occur on almost flat terrain due to a very weak layer of material. These scenes are near Cortez in Montezuma County.

Case History

In June, 1977, a residential subdivision developer in Jefferson County dug a utility trench half way up a 100 foot long slope contrary to the recommendations of an engineering geology report. Surface water collected in the improperly located and constructed trench causing a landslide 100 feet across, 50 feet long and up to 6 feet deep. It is not known if the costly remedial measures will prevent additional sliding and damage to property in the subdivision.

Case History

A school in Eagle County was proposed for the toe of an old landslide. A geologic examination revealed natural hazards and the location of the multi-story school, football field and grandstand area was moved to a safe site. The estimated savings: $3.5 million.

Case History

An area being planned as a subdivision in Summit County was engulfed in a matter or minutes by a mudslide caused by saturated soils below the Town of Breckenridge water reservoir and a beaver pond. Geologic investigation showed several similar slides had occurred previously. The property lost its prime value and extensive regrading and mitigation work was required. No structures were involved. Rerouting drainage, drying out the slope, regrading and preventive construction measures should mitigate future damage as the area is developed.

Case History

During heavy spring snowmelt in 1972, the municipal sewage disposal plant for the city of Cortez was threatened by sudden and massive "erosion" eating away at the bench upon which the plant was located. Emergency action by City of Cortez employees prevented impending severe damage to the plant and appurtenant facilities.

A geological study of the site during the crisis showed that the actual cause was not normal erosion, as had been originally supposed, but was a type of landsliding known as lateral spreading. A build up of groundwater developed during the runoff caused a weak soil at a depth of about 20 feet to liquefy. Outflow of the liquefied weak soil at depth caused collapse of overlying firm clays and the entire mixture of firm clay, liquefied soil, and water was washed down the stream course by runoff waters, allowing the process to continue.

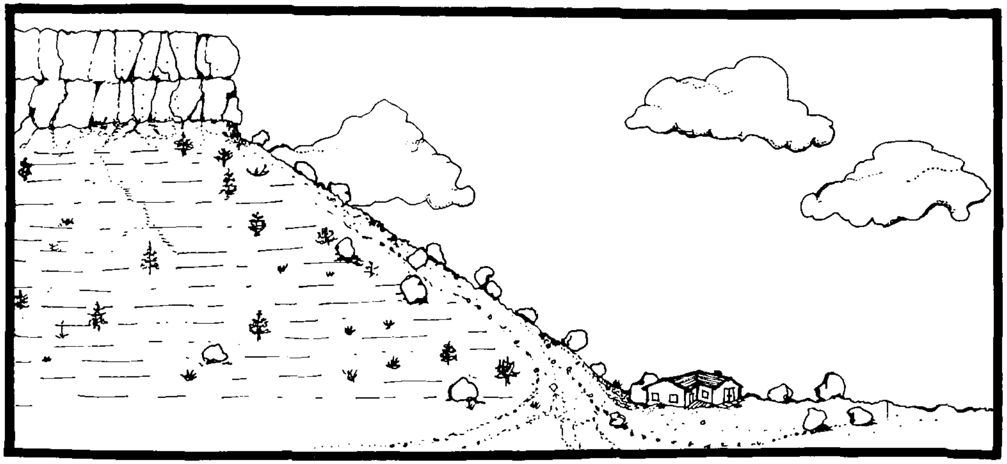
Proposed reconstruction and enlargement of the facility recognizes the potentially serious geologic problems and it is being engineered to minimize the hazard. An eventual savings in excess of a million dollars may be realized.

Rockfall

ROCKFALL is the falling of a newly detached mass of rock from a cliff or down a very steep slope. Rocks in a rockfall can be of any dimension, from the size of baseballs to houses.

Characteristics

Rockfalls are the fastest type of landslide and occur most frequently in mountains or other steep areas during early spring when there is abundant moisture and repeated freezing and thawing. The rocks may freefall or carom down in an erratic sequence of tumbling, rolling and sliding. When a large number of rocks plummet downward at high velocity, it is called a rock avalanche.



Scenic western settings often are subject to rockfalls and landslides. Here, a weak, erodible rock such as shale forms the slope below the sandstone or volcanic caprock. As the shale erodes from beneath, the caprock is a continuing source of rockfall as detached blocks topple and roll down the slope.

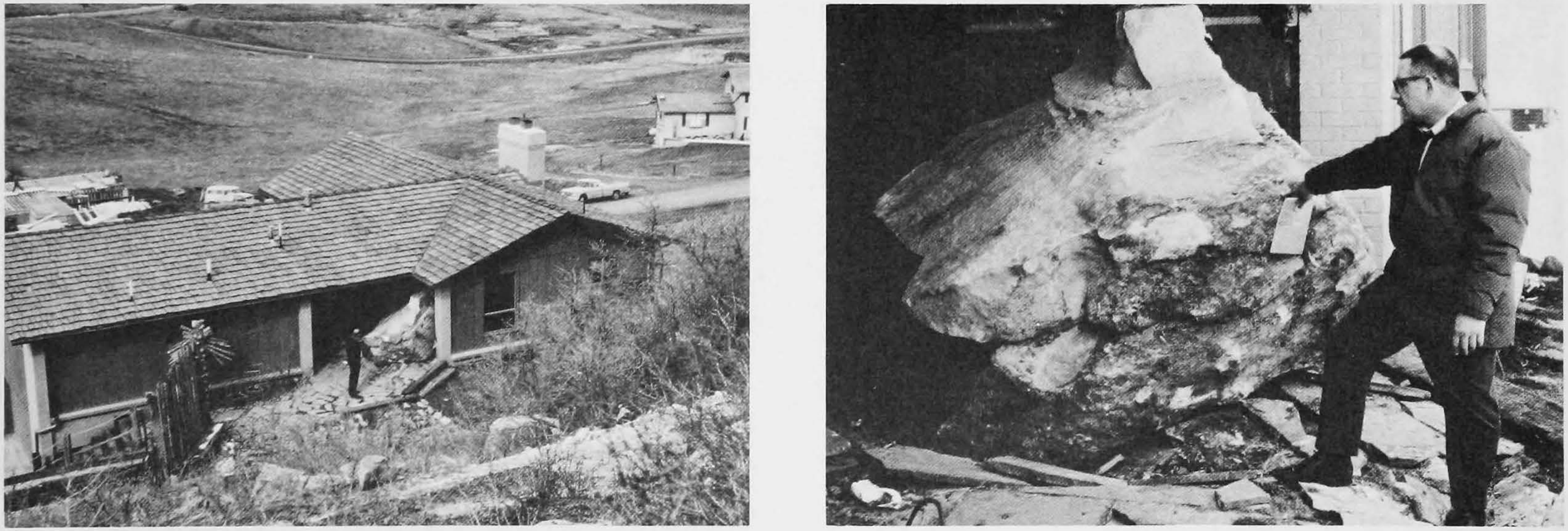
Rockfalls are caused by the loss of support from underneath or detachment from a larger rock mass. The fall may be started by ice wedging, root growth, or ground shaking, as well as a loss of support through erosion or chemical weathering.

Consequences

Rockfalls can demolish structures and kill people. Rocks falling on highways may strike vehicles, block traffic, cause accidents, and sometimes damage the road. A minor but costly consequence is the work of clearing highways and borrow ditches in rockfall areas. Any structure in the path of a large rockfall is subject to damage or destruction.

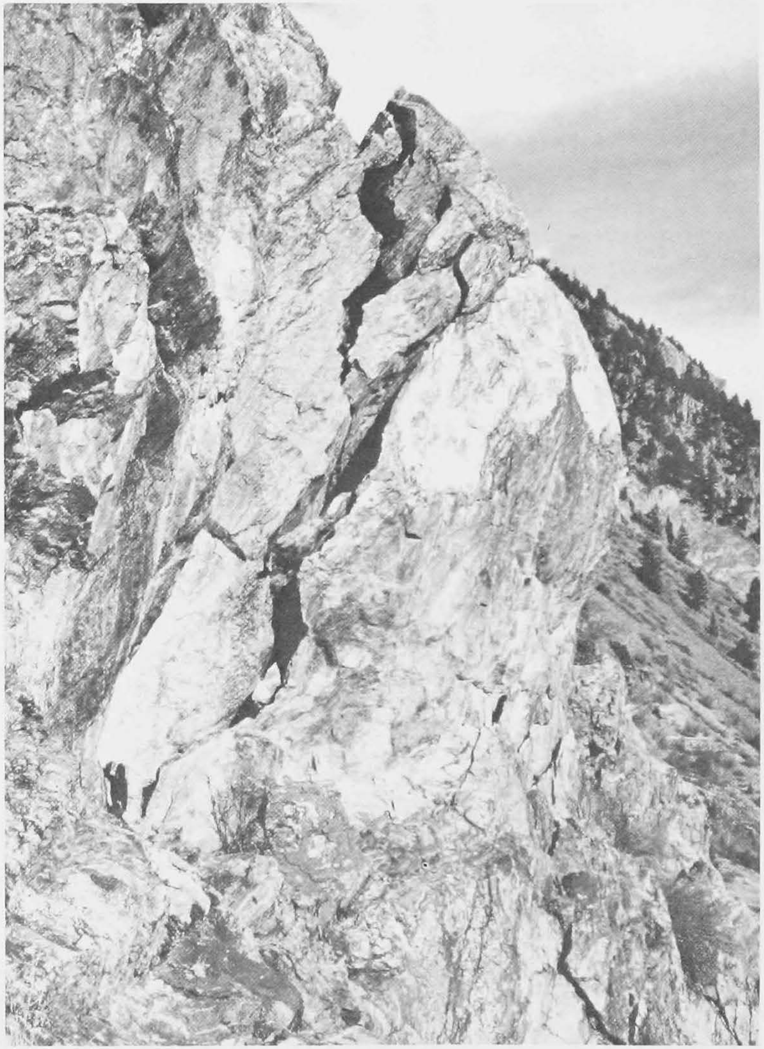
Aggravating Circumstances

Man's activities often cause rocks to fall sooner than they would naturally. Excavations into hill and mountainsides for highways and buildings frequently aggravate rockfalls. Vibrations from passing trains or blasting can trigger them, as can changes in surface and ground water conditions. Rockfalls have been attributed to earthquakes and sonic booms.



This set of photos shows where a rock the size of a small car came to rest after rolling down a hogback southwest of Denver. Rockfalls and slides are a factor in mountainside development.

A typical rockfall hazard area on the steep west side of a hogback south of Denver. The massive sandstone blocks exposed at the top of the hogback can roll to the base of the hogback.



A very large mass of crystalline rock destined to fall looms above the town of Silver Plume. It is about 40 feet high and weighs about 2,000 tons. It is one of two such hazards to the community.

Mitigation

The best way of dealing with rockfalls is to stay out of areas where rockfalls are naturally prevalent. If highways or other activities put people in rockfall areas, expensive methods can be utilized to decrease the likelihood and severity of rockfall damage. Some methods are removing unstable rocks, securing rocks to the slope so they will not fall and sheltering the improvements with earthen berms, fences, or other structural protection. In some instances of existing development, monitoring devices can be installed to warn approaching traffic of a rockfall. This measure could save lives, but will not protect property.

Land Use

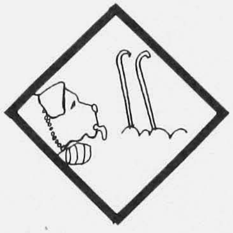
The most appropriate land use in rockfall hazard areas is open space. Land development beneath or within rockfall areas should include evaluation of the hazards during the planning stage so structures can be located where rockfall damage is minimized. Unstable rocks can be removed or stabilized at considerable cost. In many cases periodic rock removal is necessary.

Case History

Two large rock masses loom precariously on the mountainside above the town of Silver Plume. One imperils the post office; the other a saloon; and anyone or anything in their path. Natural processes are at work and eventually both of the rock slabs will fall. Mitigation measures could include moving objects in their paths or deliberately initiating the falls to avoid loss of life. The town has been notified of the hazards and is contemplating the solutions.

Case History

In March, 1974, a boulder the size of a small car hurtled down the steep west side of the Lyons hogback in Jefferson County. It bounced into a new subdivision and stopped after penetrating a wall in the back of an expensive home. No one was injured. Property damage was about $10,000, including the cost of measures to prevent similar incidents at that site in the immediate future. The incident could have been prevented easily in the subdivision development stage but it was not recognized.



Snow Avalanches

A SNOW AVALANCHE is a mass of snow, ice, and debris, flowing and sliding rapidly down a steep slope.

Characteristics

Snow avalanches occur in the high mountains of Colorado during the winter as the result of heavy snow accumulations on steep slopes. When the snow pack becomes unstable, it suddenly releases and rapidly descends downslope either over a wide area or concentrated in an avalanche track. Avalanches reach speeds of up to 200 miles an hour and can exert forces great enough to destroy structures and uproot or snap off large trees. It may be preceded by an "air blast" which also is capable of damaging buildings.

Avalanche paths consist of a starting zone, a track, and a runout zone. In general the runout zone is the critical area for land use decisions because of its otherwise attractive setting for development. Avalanche-prone lands may pass many winters or even decades without a serious avalanche. Only part of an avalanche starting zone may run, or several parts or all of an avalanche may release at once. Lack of vegetation or a predominance of quick-growing aspen and low shrubs often characterize active portions of an avalanche track and the runout zone, readily identifying the seasonal peril. Hundreds of snow avalanches happen each winter, most of them in remote places.

Consequences

Avalanches are extremely destructive due to the great impact forces of the rapidly moving snow and debris and the burial of areas in the runout zone. Structures not specifically designed to withstand the impacts are generally totally destroyed. Where avalanches cross highways, passing vehicles can be swept away, demolished and their occupants killed. Cross country skiers, downhill skiers, and snowmobilers also are imperiled by snow avalanches and several of the back country visitors perish each winter. Residences planned or erected in avalanche runout zones may not qualify for financing or insurance.

Aggravating Circumstances

Man's activities frequently trigger avalanches and certainly man's activities create the hazard. The process only becomes a hazard when man interacts adversely with it. Where no structures exist or no recreational activity occurs, avalanches occur with no damage to structures or lives being lost. Building construction in an avalanche path eventually may result in the destruction of property and the loss of life. Although most snow slides are initiated by natural causes, skiers frequently trigger the smaller avalanches which take their lives by breaking the snow surface while crossing an area prone to "run". Avalanches can also be triggered by sounds from shouts, machine noises, and sonic booms.

Mitigation

The cheapest and safest way to prevent property damage and save lives is to stay out of avalanche paths and runout zones in winter. Methods of avalanche control include directional control of blowing and drifting snow by erecting snow fences to keep it away from the starting zone; planned release of small snowslides with explosives before the snow accumulation increases their destructive potential to unmanageable proportions; building snow sheds over particularly dangerous sections of railroad and highways. Sometimes diversion structures can divide an avalanche and minimize its impact. Avalanche warnings are common in Colorado, but they do not remove the peril, only alert one to it.

Land Use

In general, land use within an avalanche area should not include buildings intended for winter and early spring occupancy. Ordinarily, use of avalanche areas in the summer and fall constitute no hazard. In some cases, other hazards,

Avalanche paths on the east side of Berthoud Pass cross Highway 40 in two locations (center, bottom). Note the lack of trees in each of the paths, indicating the frequency of avalanche activity.

such as debris flows, occupy the same area. Non-occupancy structures which are placed in avalanche paths and runout zones should be designed for expected impacts even if some other preventative measures are implemented. Portions of powerlines, highways, railroads and other facilities often have to be built to withstand avalanches.

Case History

Seven persons sleeping in their beds were swept to a frigid doom in a predawn avalanche at Twin Lakes, Colorado, on January 21, 1962. Two persons and a spotted puppy miraculously survived.

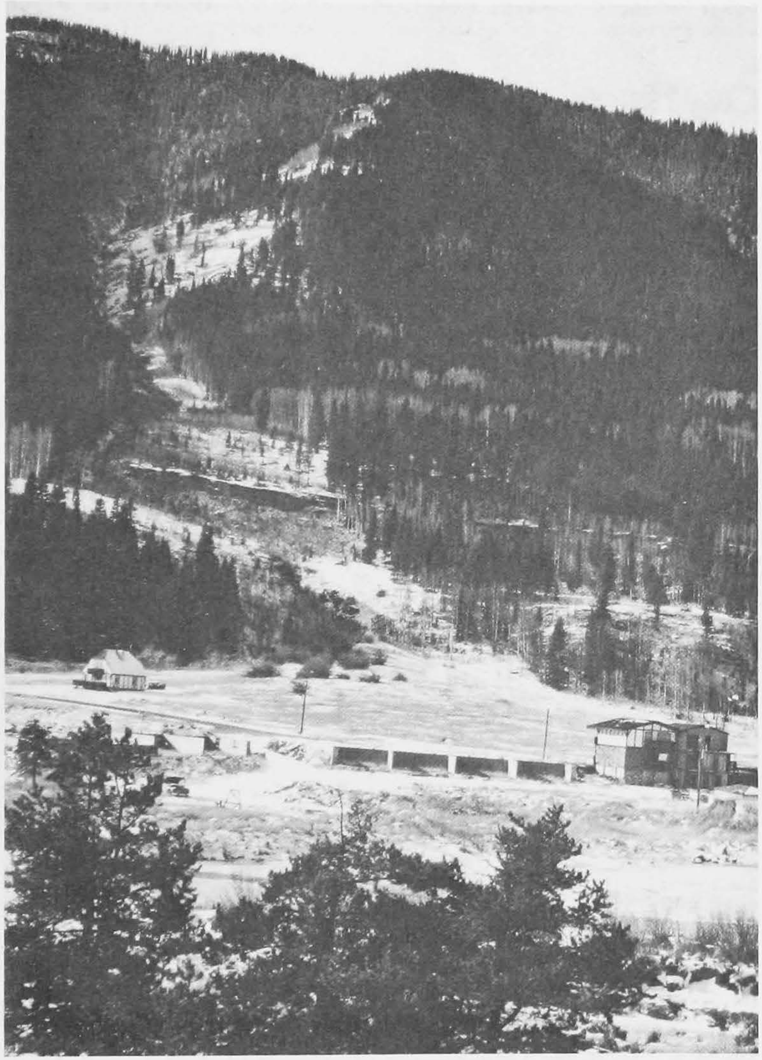
The avalanche raced down Gordon Gulch on 12,676 foot high Perry Peak, traveling some 9,000 feet at very high speed over 2,800 vertical feet. It topped a 100 foot high natural barrier and demolished everything in its path including seven buildings and a house trailer. The remains of one house were found 500 feet from the foundation. Two cars, three trucks, two pickup trucks and other equipment were crumpled. State highway 82 was under 8 feet of packed snow and power and telephone lines were ripped out for 1,000 feet.

Many of the victims were still wrapped in their blankets on their mattresses and were buried alive under as much as 12 feet of snow. The injured survivors were buried more than four hours before rescue. They were sheltered by debris although still trapped under the snow. Rescuers found hard snow slabs 3 feet across and 18 inches thick that had survived the high speed trip from near the summit of the peak. The snow was 10 feet deep where it broke away. Enroute it launched two other slides from adjacent tracks. It was later determined that avalanches had topped the 100 foot high glacial moraine at least twice before (in 1899 and 1916), a fact confirmed by counting tree growth rings on large 70-year-old aspen which had been snapped off and carried along by the snow.

While the moraine ordinarily had sheltered the village on the northwest side of Twin Lakes Reservoir, it was inadequate for this very large avalanche. The site of the tragedy is still evident, although nature has begun healing the scars with new vegetation.

Case History

On the afternoon of February 23, 1961, two women left the groomed ski slopes at Aspen to ski in unblemished snow of a small basin near the main ski run. The avalanche hazard was high and warnings had been published and posted.



An avalanche path near Vail. Note the foundations of condominium units abandoned because of the hazard.

The experienced skiers whisked out onto the slope and down, intent on skiing toward and then through a small stand of timber. When the first skier reached the bottom of the slope, her companion had vanished. Less than an hour later the missing skier was found suffocated under three feet of snow from a small avalanche that ran only 90 feet.

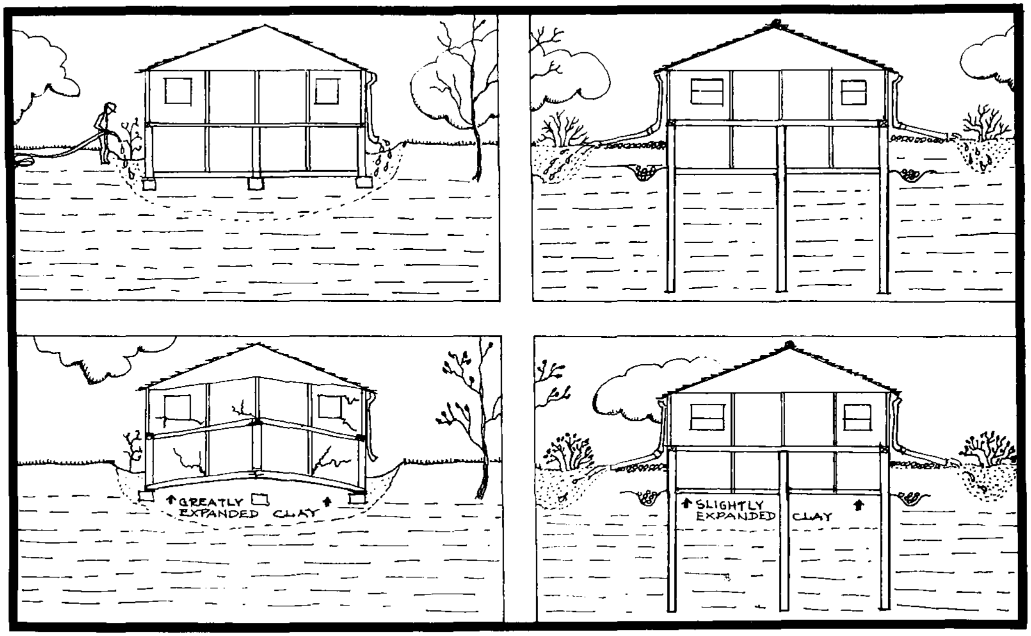
Note
These examples are from "The Snowy Torrents, Avalanche Accidents in the United States, 1910-1966," published by the Alta Avalanche Study Center, U.S. Forest Service.

Case History

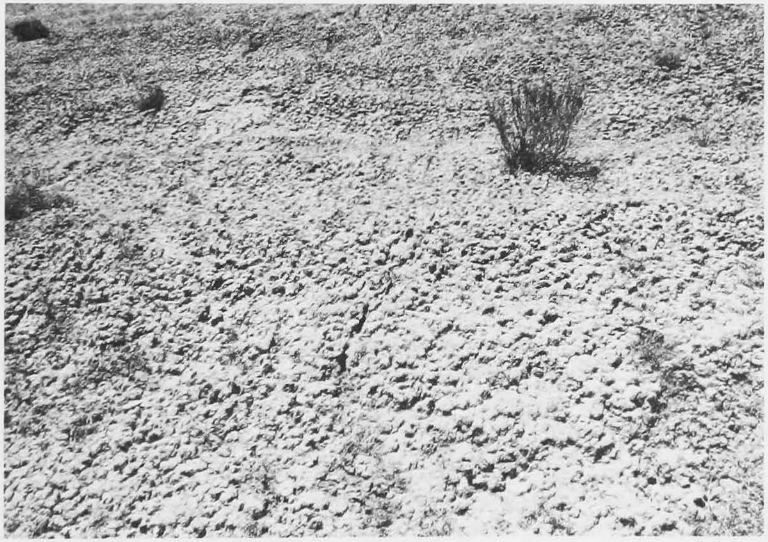
In 1972 a subdivision near Vail was allowed in an avalanche path not far from the ski area and construction began on condominiums. The builder was stopped after financial institutions withdrew money from the project on learning it was in an avalanche path and mudflow zone. Today the development is but a concrete foundation--a monument that property damage can be prevented and lives saved by responsible action. The geologically hazardous area is not zoned for open space. The case is a landmark example of what can happen when land-use regulations are legally circumvented and the builder's and the public's best interests are ignored.

Swelling Soils

SWELLING SOILS are soils or soft bedrock which increase in volume as they get wet and shrink as they dry out. They are also commonly known as bentonite, expansive, or montmorillinitic soils.



The two drawings on the left illustrate improper design, construction, landscaping, and maintenance on swelling soils with the resulting damage to the house. On the right, no damage is experienced from swelling soils. Even with proper methods, some movement of the floating floor slabs should be anticipated as shown because of natural increases in moisture under the structure. The positive surface drainage, landscaping, impermeable barriers, subsurface drains and other measures will act to minimize the movement of the floating slab.



When they are dry, swelling soils often can be recognized by their "popcorn" appearance.

Characteristics

Swelling soils contain a high percentage of certain kinds of clay particles which are capable of absorbing large quantities of water. Soil volume may expand 10 percent or more as the clay becomes wet. The powerful force of expansion is capable of exerting pressures of 20,000 psf or greater on foundations, slabs or other confining structures. Subsurface Colorado swelling soils tend to remain at a constant moisture content in their natural state and are usually relatively dry at the outset of disturbance for construction on them. Exposure to natural or man-caused water sources during or after development results in swelling. In many instances the soils do not regain their original dryness after construction, but remain somewhat moist and expanded due to the changed environment.

Consequences

Swelling soils are one of the nation's most prevalent causes of damage to buildings and construction. Annual losses are estimated in the range of $2 billion. The losses include severe structural damage, cracked driveways, sidewalks and basement floors, heaving of roads and highway structures, condemnation of buildings, and disruption of pipelines and sewer lines. The destructive forces may be upward, horizontal, or both.

Aggravating Circumstances

Design and construction of structures while unaware of the existence and behavior of swelling soils can worsen a readily manageable situation. Where swelling soils are not recognized, improper building or structure design, faulty construction, inappropriate landscaping and long term maintenance practices unsuited to the specific soil conditions can become a continuing, costly problem. Design problems might include improper foundation loading, improper depth or diameter of drilled piers. insufficient reinforcing steel, and insufficient attention to surface and underground water. Miscalculating the severity of the problem for a particular clay soil can result in damage although some mitigating measures were taken.

Construction problems related to swelling soils include lack of reinforcing steel, insufficient or improperly placed reinforcing steel, mushroom-topped drilled piers, and inadequate void space between soils and grade beams. Allowing clays to dry excessively before pouring concrete and permitting the ponding of water near a foundation during and after construction also are contributing factors in swelling-soil related construction problems. Building without allowance for basement or ground floor movement in known swelling soils areas is a very common source of property damage. Improper landscaping problems include inadequate management of surface drainage and planting vegetation next to the foundation so irrigation water enters the soil.

Mitigation

Methods for building in and on swelling soils are well developed and some of them are highly sophisticated. Although more costly initially, there is usually no reason to avoid construction <u>provided the appropriate mitigation measures are taken.</u> Corrective measures to prevent or at least minimize damage and recurring problems include:

-- Identifying soil problems

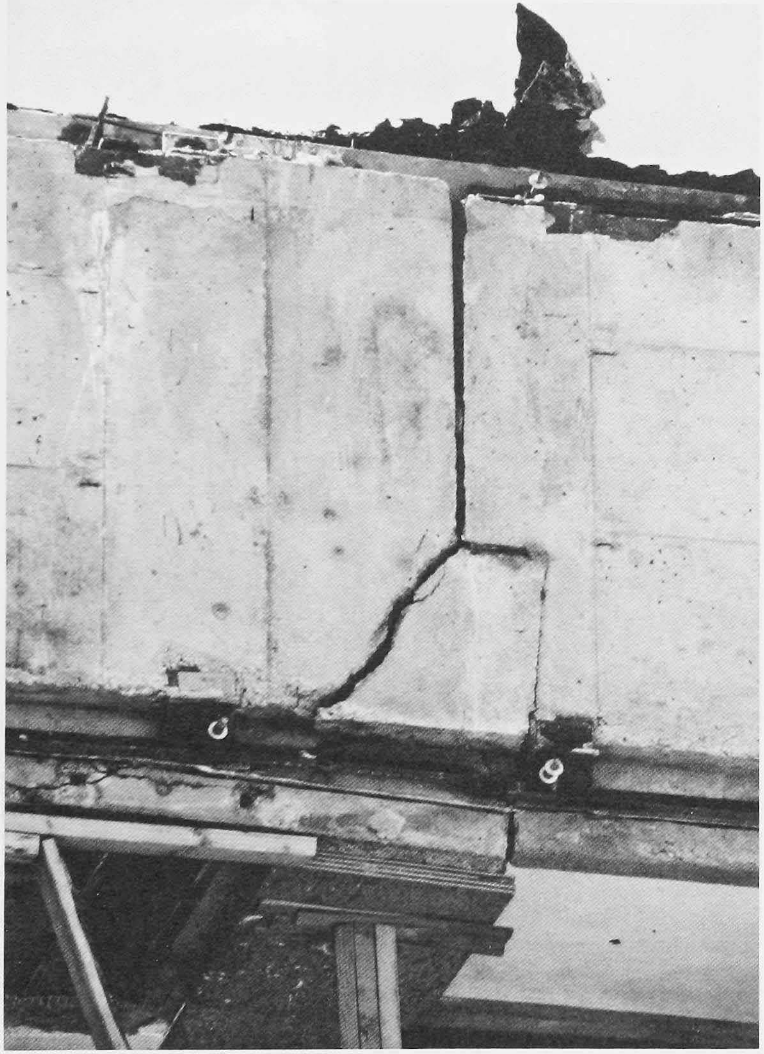
-- Testing of soils to determine their physical characteristics

-- Designing structures to withstand the "worst possible" changing soil conditions as indicated by testing.

-- Constructing the properly engineered design in a workmanlike fashion

-- Educating building owners/ occupants about the soil situation and its potential significance, especially relative to the role of water.

Swelling soils damaged this basement slab so severely that the concrete was removed. The photo shows the basement floor before it was hauled away.



Swelling soil damaged the Life Sciences Building at the Southern Colorado State College campus near Pueblo.

Land Use

Swelling soils are not a geologic factor that by itself should dictate land use patterns. As a soils engineering and foundation design challenge, swelling soils can be managed adequately so as to be secondary to other geologic/construction considerations. Despite this available knowledge and technical capability, swelling soils damage in Colorado costs approximately $16 million annually in public facility damage alone.

Case History

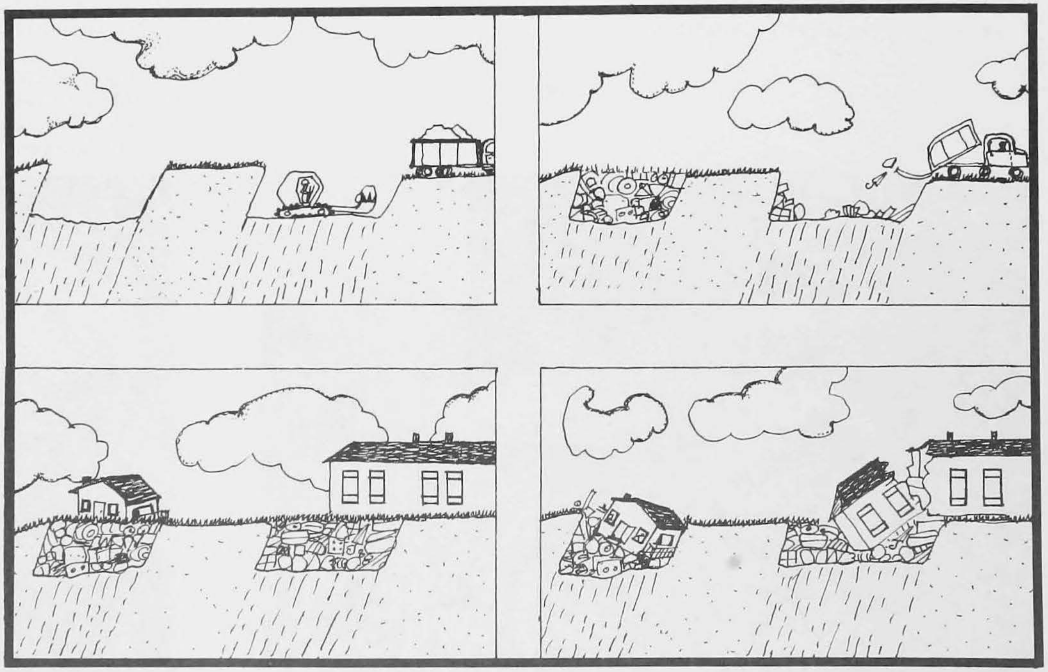
Several structures on the Southern Colorado State University Campus northeast of Pueblo have been damaged because swelling soils were not recognized or compensated for adequately in design, construction and maintenance of buildings, sidewalks, driveways, and water lines. Water percolating into dry soils exposed by construction excavation caused the clays to expand, exerting tremendous upward pressures. Floors, walls, ceilings, sidewalks, water lines, driveways, and other improvements have sustained an estimated $1.5 million in damages.

Case History

In 1976 at the site of the new maximum security facility for the Colorado State Prison in Fremont County, swelling soils and bedrock were shown on geologic maps. Field investigations and soils tests resulted in a remedial plan by the geologic and soils engineers, architect, builder and others on foundation design, drainage and landscaping. Millions of dollars in potential damages were avoided.

Collapsing Soils

COLLAPSING and settling soils are relatively low density materials which shrink in volume when they become wet, and/or are subjected to great weight such as from a building or road fill. The process of collapse with the addition of water is also known as hydrocompaction.



Successful multiple sequential land-use of mined areas requires planning and engineering from the beginning. As illustrated here, filling a clay pit with trash and placing structures on the fill may not be successful due to the settlement of fill as it decomposes. Controlled placement of fill and/or drilled pier foundations can often create stable conditions for structures in similar situations. Other situations may require an open space use of land.

Characteristics

Collapsing and settling soils have considerable strength when dry and generally are not a problem to structures and improvements. When they become wet, they are subject to rapid collapse and can be reduced in volume as much as 10 to 15 percent. Surface ground displacement of several feet can result. Similar processes frequently affect old landfills or poorly placed earth fills.

Consequences

The large ground displacements caused by collapsing soils can totally destroy roads and structures and alter surface drainage. Minor cracking and distress may result as the improvements respond to small adjustments in the ground beneath them.

Hydrocompaction of soils caused by a ruptured water line in Boulder County.

Aggravating Circumstance

Man's activities are definitely the cause of most soils collapsing. These activities include watering grass and shrubs, failing to repair leaking water lines in utility trenches, impounding water, blocking drainages by highways, loading excessive weight upon collapsible soils, and any activity which increases subsurface moisture in soils prone to collapse.

Man-made and/or man-placed materials frequently are subject to collapse and settlement. The filling of mined out areas, natural depressions and swamps with trash and debris is a common practice. Eventually the site is put to another use. Decomposition and compaction at landfill dumps also can result in generation of explosive methane and poisonous hydrogen sulfide gases, as well as pollution of subsurface water with carbolic acid or other chemicals. These problems, in addition to settling, occur despite compaction during the landfill operation.

Damage to structures erected on landfills is common if proper construction methods are not used to counteract settling and other problems. Dangerous methane can seep into basements and crawl spaces and explode, demolishing the structure.

These soils in Garfield County collapsed from wetting.

Mitigation

Construction in areas susceptible to collapse is difficult. Some soils will collapse under their own weight if wetted. Two construction techniques are possible in this case: 1) prevent wetting of the soils for the lifetime of the structure, or 2) precollapse the soils prior to construction by deep soaking of the area. Soils which will collapse with the addition of heavy structures alone might be developed successfully with light weight improvements. In some cases the problem soil may be shallow enough to excavate, or the building foundation may be placed below the troublesome soil in more suitable material. Any technique of development is effective only after careful analysis of the conditions and a thorough understanding of the process is gained. Corrective techniques can be costly. Given no other choice, this may be less expensive than continual repair or rebuilding of the structure. Geologic investigations and testing can reveal collapsing soils as well as sites subject to to settlement for natural or man-caused reasons.

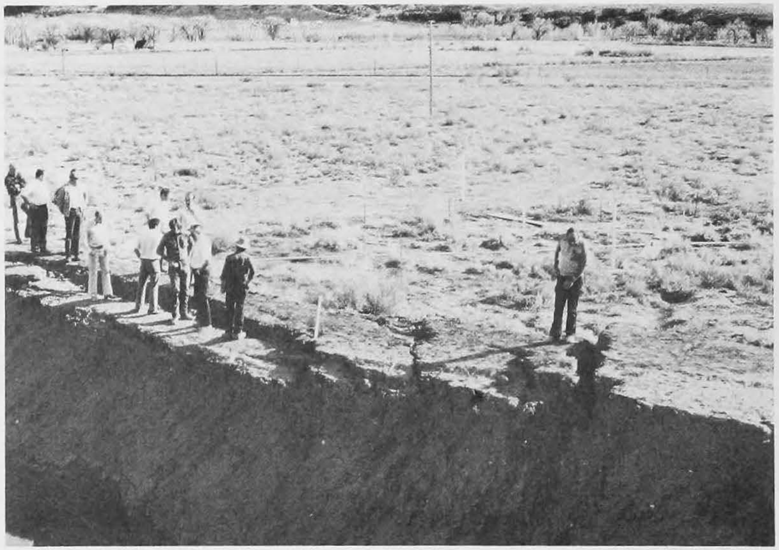
These two photos show hydrocompaction of soils along the proposed Interstate 70 alignment near Rifle. Note concentric rings around the pond and through a test road embankment.

Land Use

The only land uses which create no-risk situations are agricultural and open space. Land uses that involve structural improvement on the land surface may generate costly maintenance and even destruction of the development. Minimum structural development, such as a storage yard, constitutes a relatively safe use of land subject to collapse or settlement.

Case History

A Carbondale, Colorado, rancher's stock watering pond excavated in a pasture collapsed because of hydrocompaction. A bowl-shaped depression 60 feet across and 8 feet deep resulted when he attempted to pond water in his field. The soils were so permeable that the pond would not hold water, and the wetted soils under the pond collapsed. Many roads and other improvements in the vicinity have been destroyed or damaged by soaking of collapsible, low density soils.



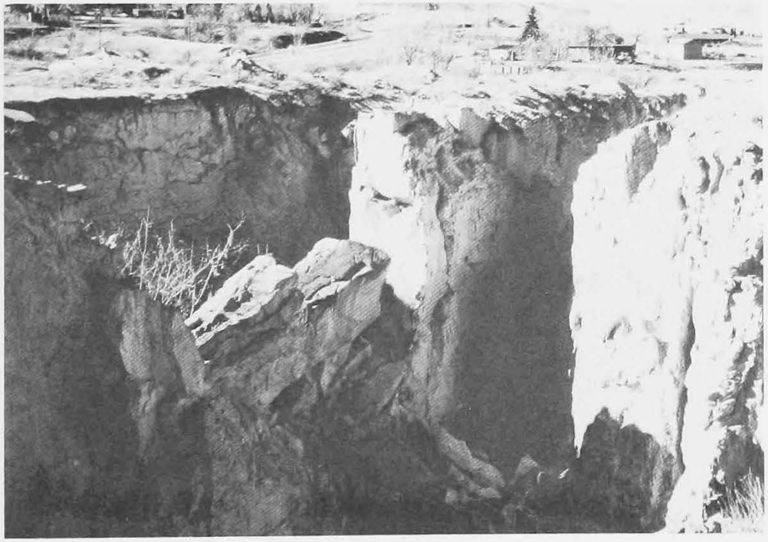
Tests permitted proper highway design and construction, avoiding future repairs.

Case History

The Colorado Highway Department, recognizing that severe hydrocompaction along a highway alignment could totally destroy a road, investigated the potential for hydrocompaction along the alignment of I-70 from Rifle to Debeque. Water was impounded in a small pond and a road fill was placed beside the pond as a model of probable future conditions. The result of the test was that the ground surface sank three feet in one month. The test provided design information to prevent the possible future total failure of a portion of the highway. The engineering geologic investigation may have saved taxpayers millions of dollars.

Case History

At Golden, abandoned clay pits were used as a refuse dump. In the 1960's after the pits were "filled", a residential housing complex was built on sites for the Colorado School of Mines. Sidewalks, streets, and two story buildings have sustained substantial damage from settlement. The problem continues despite repeated repairs and some corrective work.



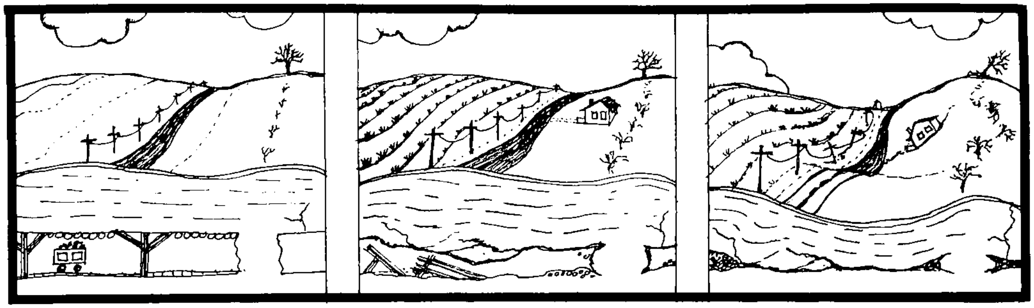
These clay pits near Golden are similar to those over which married student housing at the Colorado School of Mines was built. These pits, when filled with organic and uncompacted debris, became man-made sources of collapsing soils.

Subsidence

Ground SUBSIDENCE is the sinking of the land over man-made or natural underground voids. In Colorado, the type of subsidence of greatest concern is the settling of the ground over abandoned mine workings.

Characteristics

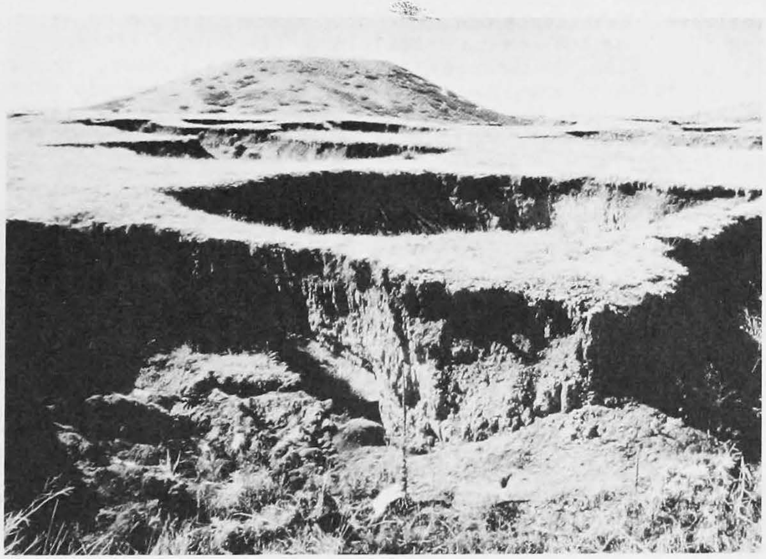
Subsidence may occur abruptly--virtually instantly--or gradually over many years. It may occur uniformly over a wide area as local depressions or pits separated by areas which have not visibly subsided. In Colorado, it is most common in the sedimentary rocks over abandoned coal and clay mines. The crystalline rocks in which most metals are mined have greater strength and are less likely to settle or collapse. Subsidence can also occur where underground water has dissolved subsurface materials or has been withdrawn by wells. Although serious in other western states, these latter types of subsidence are less common in Colorado than sinking caused by the caving in of underground mine workings. Subsidence caused by collapsing soils is discussed under the heading Collapsing Soils.



This cutaway view of an underground coal mine shows the progression of subsidence with time and its affect on the surface topography and improvements. During operation, the mine roof in the working areas is supported to protect the miners. After abandonment, the underground voids may suddenly or slowly collapse or fill with rubble as the roof caves. This in turn can cause subsidence at the surface.

Consequences

Subsidence can result in serious structural damage to buildings, roads, irrigation ditches, underground utilities and pipelines. It can disrupt and alter the flow of surface or underground water. Surface depressions created by subsidence may be filled in, only to sink further because the underground void has not been completely closed. Areas may appear to be free of subsidence for many years and then undergo renewed gradual or even drastic subsidence.



This "moonscape" in Douglas County shows subsidence over abandoned underground clay workings.

Aggravating Circumstances

Weight, including surface developments such as roads, reservoirs, and buildings, and man-made vibrations from such activities as blasting, heavy truck or train traffic can accelerate the natural processes of subsidence. Fluctuations in the level of underground waters caused by pumping or by injecting fluids into the earth can initiate sinking to fill the empty space previously occupied by water or soluble minerals.

Subsidence pit in a trailer park at Lafayette. This 25 ft x 25 ft hole, 30 ft deep resulted from collapse of the overlying materials into an inclined mine shaft.

Mitigation

Recognition of past subsurface mining activity, including the study of mine maps, can help identify potential problem areas so precautions can be taken to prevent or minimize property damage on the surface of the ground. The surest way to avoid structural damage is not to build above underground voids. Also, detailed engineering geologic analyses may show that some areas over an underground mine may be stable because of previous subsidence or because the specific site was not mined out. Sometimes special structural designs can compensate for future ground movement. Backfilling of the voids before construction can stabilize the surface, but usually at prohibitive cost.

Subsidence is characteristic of some lands underlain by formations containing soluble rocks (for example, the Eagle Valley evaporite, which contains rock salt and gypsum). It is usually very difficult to accurately predict the exact location or time of any future subsidence from this cause because of the many variables.

Land Use

Unless property damage can be prevented or alleviated, subsidence-prone lands are best used for farming, open space, land fills, open storage areas or surface mineral extraction. Special construction methods can be used for roads and pipelines spanning subsidence-prone land. Corrective measures after subsidence has occurred are usually very expensive. Sometimes maps of underground mines are helpful in relating subsidence-prone areas with proposed surface development. Most problems can be solved using a combination of geologic knowledge and special engineering design and construction methods. Investigations and special engineering designs are costly. In many cases avoidance or selective land use is the only economic and safe solution.

Case History

One evening in 1974 a Lafayette, Colorado, trailer park resident noticed a two foot hole in his front yard. By morning the hole was 10 feet deep and 10 feet across. The trailer was moved as the hole continued to grow until it was about 25 feet deep and 25 feet in diameter. The sidewalk, a telephone pole, a concrete pad and a fence had to be replaced after the hole was filled. Fortunately a gas line exposed by subsidence did not rupture. The property owner backfilled the hole, acknowledging the site had previously subsided and had been filled. The site is underlain by an inclined shaft to an old coal mine. The workings were abandoned more than 50 years ago.

Case History

Interstate Highway 25 crosses several abandoned coal mines in Weld County. Roadway settlement of more than two feet near Erie has taken place in patterns that can be closely correlated to subsidence over coal mine workings 350 to 400 feet below the surface. Much of the severely damaged road is now below original grade, resulting in a mild roller coaster like ride. Estimates for repair of the 3/4 mile section damaged by subsidence are about $1 million.

Case History

Friday, April 13, 1979, was a lucky day for a group of Colorado Highway Department workers and passersby. Maintenance crews found a 500 foot deep airshaft to the abandoned Klondike coal mine had been reopened by surface subsidence into the mine. A crater about 20 to 25 feet across opened like a funnel into the shaft just off the pavement on the northeast corner of the Interstate-70 Woodmen Park Road interchange near Colorado Springs. The shaft had previously been capped, but the slow deterioration of the surface plug finally caused this reopening. Proper filling and capping of this shaft can prevent future incidents.

Radioactivity

RADIOACTIVITY is the spontaneous decay of unstable atoms of certain elements into new and different atoms. Eventually the decay process leads to the point that the materials are no longer radioactive. Decay of a radioactive substance to a nonradioactive state may take a few minutes or millions of years, depending upon the element.

Characteristics

Traces of radioactive materials naturally occur in the rocks, soils, and waters of Colorado as they do throughout the world. Many common rocks in Colorado, such as granite, some sandstones and volcanic materials, contain higher than average amounts of radioactive minerals so that the natural radiation background levels in the state are measurably higher than in many other states. Some of the elements, such as uranium, are mined and processed. Processing natural radioactive ores for medical, industrial, or energy uses redistributes the radioactive materials into artificial compounds and wastes such as uranium mill tailings. Some man-modified radioactive materials emit radiation into the environment in amounts and concentrations in excess of those found in nature.

Consequences

The consequences of prolonged exposure to low levels of radiation are not fully understood. The high levels of radiation from radium or plutonium and other substances is very harmful even in minute amounts. Permanent tissue damage and death can result. Cell changes caused by radiation are linked with several diseases, some of them eventually fatal.

Aggravating Circumstances

Disposal of man-made radioactive wastes is a national as well as local concern. In Colorado, a major radium and uranium production and processing state since the early 1900's, it has become a multi-million dollar problem due to the high cost of stabilizing and monitoring waste disposal and mill tailings sites. Before the seriousness of the problem was realized thousands of tons of radioactive wastes were abandoned at dozens of locations. In the intervening years large quantities of radioactive mill tailings were used in construction of homes, schools, offices, industrial buildings, and roads. In many cases costly removal of the tailings and repair work has been done. More than $7 million has been spent in the Grand Junction area alone to protect occupants of buildings from radiation from radioactive mill tailings used in their construction. In the Denver area several former uranium and radium processing sites, now being used for other purposes, are being evaluated for radiation levels and their significance to health. Development of radioactive ground water while being unaware of its natural contamination, has been a problem in the Pueblo area. The contamination of good water with radioactive materials from mineral processing or disposal operations also has affected some areas.

Mitigation

Containment of radioactive wastes and avoidance of construction in the areas of concentrated radiation are methods of mitigation. Areas of higher than normal radiation sometimes can be used if proper stabilization, shielding and other measures are undertaken to decrease their potential effect on human and other life in an area. Areas of tailings impoundments are being stabilized and reclaimed for limited use. The Colorado State Department of Health, in cooperation with other federal, state, and local agencies, oversees radiation health matters in the state.

Land Use

Although all rocks in Colorado contain some radioactive materials, naturally occurring radioactive concentrations ordinarily are not sufficient to warrant land-use restrictions. In areas where natural radioactive materials are known to exist in concentrated levels, radiation surveys should be completed prior to development to determine the possible significance to human health. Land use controls must be very strict in areas with manmade concentrations of radioactive substances to protect public health.

Livestock utilizing radioactive water and plants grown in radioactive soils can absorb some radiation into their tissues. Thus grazing and other agricultural use of reclaimed radioactive lands is not always advisable.

Case History

One of the results of uranium mining and milling is the creation of great volumes of low-level radioactive wastes. The unwanted leftovers from milling (mill tailings) are often tempting for use as a source of fine aggregate or fill in construction. Unfortunately, the tailings are radioactive and their continuing decay produces harmful radiation and radioactive gases.

In the mid 1960's, public health officials became concerned about large amounts of tailings being used in land fill and construction. In the Grand Junction area, particularly, the tailings were used for concrete in building foundations, floors, pavements, patios, and as fill around foundations, in utility trenches, and even in children's sand boxes. A door to door survey turned up their use at 6,000 locations in houses, offices, schools, factories, gardens, lawns, and playgrounds, as state, local, and federal officials acted to determine the extent and seriousness of the situation.

Congress in 1972 moved to provide federal funds for remedial measures. To date, more than $7 million of the $12.5 million authorized to minimize or eliminate the radiation exposure has been spent on about 350 of the 600 homes, schools, and businesses identified as having potentially dangerous levels of radiation.

Costs of remedial measures for industrial and commercial establishments are expected to average more than $40,000 each and several will cost more than double that amount. In February, 1979, a progress report to Congress was made on the Grand Junction Remedial Action Program. It will be several years before the project is completed.

Seismicity

Background

Much of Colorado is at lofty elevations consisting of high mountains and intervening parks or structural basins. A generation ago most geologists thought them to be a result of ancient mountain building and that the forces that created them dissipated millions of years ago. Now geologists recognize that many of the state's mountain ranges and basins are geologically youthful and that the faults associated with them continue to move and have the potential for generating earthquakes.

In the 120 years that modern man has occupied Colorado, hundreds of earthquakes have been noted. In the early years there were "felt reports." In the last few decades earth movements have been detected by seismographic instruments. Most of the earthquakes were quite small, but several exceeded Richter magnitude 5 and caused severe ground shaking locally. A plot of known earthquakes has the same general distribution as the potentially active faults. This suggests that Colorado is a moderately active earthquake area and in time larger earthquakes than have yet been experienced can occur. Other indications that the state has a significant level of seismicity are derived from the "manmade earthquakes" triggered by fluid injections into the earth at the Rocky Mountain Arsenal near Denver and near Rangely in northwestern Colorado.

Probably the largest quake ever felt in Colorado occurred in November of 1882. It was felt throughout Colorado and in several adjacent states. Accounts of the earthquake suggest it was centered north of Denver near present day Broomfield or Louisville. Although there were widespread but scattered reports of violent ground shaking, relatively little property damage apparently resulted. This is probably due to the sparseness of development and prevailing one or two story frame construction of the time. A similar earthquake today would very possibly result in millions of dollars of property damage and perhaps loss of lives. A recent study conducted by the J.H. Wiggins Co., under sponsorship of the National Science Foundation, shows Colorado to be third among all states in the value of expected annualized building losses from earthquakes between 1980 and the year 2000.

Characteristics

Earthquakes are caused by fault movements within the earth that produce vibrational waves which are transmitted through the ground. Interaction of these earthquake vibrations with the nearby surface and with the works of man results in the damage and destruction that often accompanies moderate and larger-sized earthquakes. The adverse effects may include severe ground shaking in the epicentral region, possible ground rupture and displacement in the fault zone, and in cases of adverse conditions--ground failure--such as landslides, soil settlement, soil liquefaction and ground cracking. Indirect effects which can occur include dam failure and accompanying flooding, fires from ruptured gas lines, uncontrolled fires due to failure of water distribution systems, and health problems from dysfunction or loss of sanitary facilities.

Mitigation

When the location of active faults of an area is well known and surface rupture and displacement are known to accompany earthquakes, building near faults should be avoided completely except in cases where there is no alternative, such as for certain transportation and utility corridors. However, the potentially active faults in Colorado have not been studied in detail and ground breakage has not been documented for historic earthquakes.

Mitigation of earthquake damage for Colorado must deal primarily with the broader effects of ground shaking on actual structures and on preventing associated effects such as landslides through careful and conservative engineering designs and building codes that are consistent with the actual seismic hazard. Since the study of seismicity of Colorado is at an early stage, there is still much to do in the way of additional earthquake studies, public awareness, improved governmental coordination and implementation of seismically appropriate building codes, land use controls, and policies. Special attention should be given to seismic safety of institutional buildings such as schools, hospitals, prisons, and other facilities where large numbers of citizens are assembled.

Another special category consists of development activities and structures that have the potential for severe offsite impacts. Such facilities must receive careful seismic analyses and conservative engineering designs consistent with the earthquake risk of their locations. Included in this category are nuclear facilities, large tailings impoundments, large reservoirs, hazardous waste storage and handling facilities, deep fluid disposal wells, and any other activity where a malfunction due to an earthquake could cause serious adverse effects to adjacent lands.

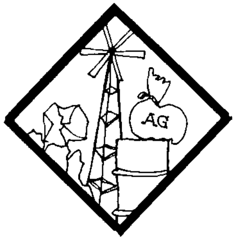
Land Use

Land use policies for areas of Colorado that are subject to earthquakes and their effects are just beginning to emerge since the recent completion of the cooperative study of potentially active faults of Colorado by the Colorado Geological Survey and the U.S. Geological Survey. Already major projects whose failure could cause hazard to adjacent residents are receiving special attention including the use of earthquake-resistent dam designs where it is found proper. It is anticipated that as more detailed knowledge of the seismic environment of the state emerges and as current knowledge becomes better known, building regulations and general land use policies should and will be revised.

Case History

At 6:30 p.m. on November 7, 1882, a moderate-sized earthquake shook Colorado and parts of the adjacent states. Study of reports included in newspaper articles which describe the earthquake suggest the earthquake centered in the Denver-Broomfield area. The walls of the Boulder County railroad depot cracked. Plaster fell from walls at the University of Colorado. Inmates at the jail in Golden supposedly demanded immediate release. Several clocks were stopped by the violent ground shaking. Reports of falling plaster and other similar damage came from as far away as Rawlins, Wyoming.

A curious aspect of this earthquake was that it occurred just after the close of the polls for the state elections. Several newspapers suggested the earthquake was nature's way of protesting the outcome of the elections.



Mineral Resources

The geologic processes which created Colorado endowed it with mineral riches which have been a dominant factor in the state's heritage, its growth and its cultural and economic vitality.

In 1979 the extraction and processing of Colorado minerals is a growth--if not booming--industry. Production of the metallic and energy fuels resources from the prairies, plateaus, and mountains is expected to exceed $1.5 billion this year as some 64,000 men and women earn their livelihood from mineral related activities.

The accompanying table shows Colorado mineral production in 1977. In the same year the mineral industries paid nearly $50 million in state and local taxes. An additional $22.4 million in royalties, bonuses and lease revenues from minerals extracted from federal lands in Colorado was deposited in the state treasury. A like amount ($22.4 million) went to the U.S. Treasury Department.

Colorado has dozens of mineral resources including the energy fuels of oil, gas, uranium, coal, and oil shale. Among the economically significant non-energy minerals are molybdenum, copper, clay, tin, lead, zinc, sand, and gravel. Also there are deposits of feldspar, marble, pumice, perlite, mica, lime, turquoise, bentonite, salt, gypsum, diatomaceous earth, and others.

No list would be complete without gold and silver, the two metals which spurred Colorado settlement beginning in 1859. The two metals seem to have cast a special aura of the Old West over the mining industry. The legends of lucky strikes, awesome feats of threading narrow gauge railroads through and around the Colorado Rockies, fortunes gained and lost and regained, and booms and busts tend to obscure the dynamic reality of a much different industry today.

This great history seems to have left such a strong impression with many people that it constitutes the image of mining in 1979 as well. Instead, sophisticated technology, environmental protection, safety measures and, above all, new attitudes about social and economic impacts and long term land use, today are integral aspects of underground and surface mining and mineral processing.

Mineral operations planned today are a far cry from the frontier days when the consequences of mining to air, land, water, and people were ignored in the rush for riches. Treatment and holding of water to protect quality and quantity, air pollution control devices, sequential use of reclaimed mined lands, provisions for schools, homes, recreation, and other community facilities, and the protection of wildlife and scenery have truly revolutionized the minerals extraction and processing industries. Mining does create major changes, such as the filling of valleys with mine and milling wastes. The disposal, however, is planned so the tailings piles can be used later and in the meantime they are often screened from public view and stabilized to protect off-site property and lives. Today a mining company operates on an enormous scale where, a century ago a score of separate, small mines would have been in operation.

The "olden days" also tend to obscure some of the fundamentals about mineral deposits and extraction. Among the basic precepts are:

1. Mines and oil/gas wells have to be where the economic concentrations of the minerals are. Unlike a factory, there's little choice as to where a mineral operation can be located.

2. Economically recoverable minerals are increasingly more difficult to find and extract. The "easy" to get higher grade ores, for the most part, have been developed.

3. The oil, gas, and minerals that remain are generally deeper in the earth and are in lower concentra-

tions. As a result, they cost more to extract and often cost more to process.

4. Sooner or later, by today's economic standards, recoverable mineral deposits will be exhausted or cost more to obtain than the consumer is willing to pay.

5. New mining and processing methods sometimes make it possible to extract valuable minerals by reprocessing the discards of earlier operations, from previously inaccessible places and from lowgrade deposits previously bypassed.

6. Often, more than one mineral commodity is obtained from a single operation.

7. As lower grade ores are utilized, the volume of wastes to be disposed of increases.

8. Oil, gas, and mining operations are temporary uses of the land. After operations cease, the land can and should be "recycled" for another use.

9. Mining operations frequently use enormous amounts of energy for drilling, crushing, hauling, separation, and processing.

10. The greatest and most enduring impacts from mineral operations are not from the operations themselves, but from the secondary and tertiary aspects: new towns, roads, railroads, water project development, utility corridors, and increased numbers of people.

In urbanized society it is sometimes forgotten that the extraction of minerals is one of the three basic sources of new wealth--a non-inflationary asset that previously wasn't part of the economy. Minerals, products from the forest and farm and from the sea provide the basics upon which other

Table 1
1977 COLORADO PRODUCTION OF
METALS, NONMETALLICS, MINERAL FUELS*

Metallics	
Molybdenum	$276,538,944
Uranium	33,411,581
Vanadium	25,041,601
Zinc	20,292,427
Silver	18,560,061
Tungsten	15,544,678
Lead	10,181,349
Gold	8,528,605
Copper	2,001,737
Tin	749,306
Cadmium	387,771
Iron	309,764
Total Metallic Mineral Production	$411,547,824
Nonmetallics	
Sand & Gravel	$ 47,050,426
Cement	24,732,653
Limestone	5,532,666
Stone	3,864,872
Clay	995,457
Dolomite	502,656
Volcanic Scoria	252,000
Peat Moss	111,500
Gypsum	----
Mica, Feldspar	----
Perlite	----
Oil Shale	----
Miscellaneous Nonmetallics	----
Total Nonmetallic Mineral Production	$ 83,145,589
Mineral Fuels	
Crude Oil	$374,132,765
Coal	197,284,436
Gas	133,223,995
Total Mineral Fuel Production	$704,641,196
TOTAL COLORADO MINERAL PRODUCTION	$1,199,334,609

*Colorado Department of Natural Resources, Division of Mines businesses, in the final analysis, depend. Manufacturing, agriculture, trade, and the service segments of society are dependent upon earth resources.

Colorado's history documents this fact. When the mines closed, people moved away, thriving communities became ghost towns, railroads were abandoned, and only the land remained to be used again. Aspen, Crested Butte, Telluride, and Breckenridge are "born again" towns with a change in land use from mining to skiing and other recreation/tourism activities based upon hunting, fishing, camping, hiking, and sightseeing and cultural events.

One common Colorado resource is often overlooked. It is natural hot spring water for which Steamboat Springs, Pagosa Springs, Waunita Springs, and Glenwood Springs are named. In some locales the hot water from the earth is used to heat public and private facilities. Elsewhere, such as in the San Luis Valley and near Mount Princeton, the geothermal resources are being evaluated as a source of thermal energy for generating electrical power.

Clearly, Colorado's past and present well being are inseparable from mineral development. The challenge for the people of Colorado, then, is to direct growth and development in a way that will minimize the potential conflicts between mineral resource development and other uses. No home owner wants a large strip mine 100 ft from his house. Nor can we afford to prevent extraction of needed mineral deposits by pre-empting the land for other uses. For this reason, the Colorado Legislature passed House Bill 1529 (1973) and House Bill 1041 (1974), which are summarized in the Appendix.

These conflicts can be greatly diminished by designing mining operations with the potential problems in mind. In combination with this, local governments and property owners can schedule the development of areas to avoid many of the conflicts.

We can never know exactly where all future mining will occur, but using past activity and geologic information as a guide, the potential for land-use conflicts can be greatly reduced.

Appendix A

Character and Behavior of Earth Materials

The earth's surface is characterized by great variety of form and features. This derives from a combination of different physical properties, behavior, climate, and earth processes. These conditions, in turn, influence our lives in many ways, including construction projects, resource development, and recreational activities.

In general, earth materials may be divided into three groups: 1) crystalline rock, 2) sedimentary rock, and 3) unconsolidated material (soil).

Crystalline rocks, like granite, basalt, gneiss, and schist, are usually hard, erode slowly, are difficult to excavate, yield water only from fractures, may contain metallic mineral resources, and make excellent foundations. Crystalline rocks frequently form the core of mountain ranges. They are rocks which have formed by crystallization either from a molten liquid or under conditions of hign temperature pressure. Crystalline rocks, if not exposed at the earth's surface, are always found at some depth because they form the "basement"--and majority--of the earth's crust.

Sedimentary rocks are those rocks which have been formed by deposits in water (fresh or salt) or on land (by wind, ice, or gravity) and have since been solidified by processes such as cementation, consolidation, or precipitation. Sedimentary rocks include sandstones, conglomerates, and limestone, which can behave much like crystalline rocks in their strength, hardness, and erodability. Shale, coal, and evaporites in contrast are frequently soft, weak, and erode quickly. The variability of physical properties is the only reasonable generalization which can be made. Their properties and effect on man are dependent on such things as mineralogy, grain size, and consolidation, water content, bedding, and jointing. Many of our mineral and energy resources come from sedimentary rock including coal, oil shale, oil, gas, cement, clay, salt, uranium, and some metals. Major ground water resources are found in the sandstones and limestones of Colorado.

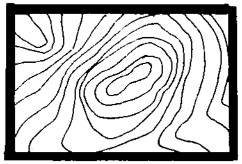
In general, sandstones, conglomerates, and limestones form ridges, mesas, and mountains, while shale, evaporites, and other weak sedimentary rocks form valleys and low areas.

Unconsolidated materials are the youngest (except for recent volcanics) in Colorado and, as the name implies, are weak enough to be shoveled by hand. They are composed of fragments of the crystalline or sedimentary rocks from which they are derived. They are classified by origin (alluvial, fluvial, colluvial, glacial, eolian, residual, landslide, or debris fan) or by type and particles size distribution (clay, silt, sand, pebble, boulder, organic, and combination of these).

Included in these unconsolidated materials are "soils." Different professionals and disciplines use "soil" to mean different things: To many engineers, soils are any material which can be excavated with normal power equipment; to the agricultural community, soil is any natural medium that will support the growth of land plants; to geologists and engineering geologists, soils may be either similar to that of agronomists or may be all unconsolidated material above bedrock. These differences become even more confusing when soils are described and classified by different systems. These systems may be based on the origin of the soil material, the soil forming process, or the physical properties. The engineering geologist and soils engineer will define physical and chemical properties such as size, gradation, organic content, specific gravity, moisture, optimum water content, permeability, elasticity, plasticity, cohesion, shearing strength, soluble salts, consolidation, swell, and frost susceptibility. In construction, it is these physical and chemical properties which, when confined with the geologic processes, are the key to sound geotechnical development.

These unconsolidated materials then, form the thin skin which mantles most of the crystalline and sedimentary rocks in Colorado. They are the soils, stream sands and gravels, debris fans, slope wash, and wind blown sands and silts. They are the major source of aggregate for concrete and contain the most easily accessible ground water. They are indeed the source of our food. They also, when not understood, can cause the worst harm to man's work as they rapidly erode, deposit, swell, shrink, collapse, and move downslope.

The character and behavior of earth materials to an engineering geologist is a natural outgrowth of the combination of geologic and engineering knowledge. Understanding their geologic origin and history provides an excellent framework from which to predict character and future behavior of earth materials as they interact with man and continuing natural processes. The complexity and variability of the natural world leads to a necessary degree of uncertainty when extrapolating detailed information from a small sample to the side of a mountain or a square mile of the plains. Geologic understanding can help to bridge this gap between the detailed physical parameters and the real world of dynamic earth processes and heterogeneity.



Appendix B

Topographic Maps and Contours

A major element of any subdivision plan or master plan is a topographic map. The distinguishing characteristic of a topographic map is its ability to portray the position, both horizontal and vertical, as well as size, shape, and elevation of features in the area. The contour lines of a topographic map are imaginary lines on the land surface at the same elevation above sea level. The contour interval is the vertical difference between contours and it varies according to the amount of relief and the detail needed for a particular map's purpose. A map made or used to depict or support a particular land use activity should be of sufficient scale, contour interval, and detail to show all pertinent topographic and cultural features related to that development.

Using a contour map, it is possible to determine the average slope angle and gradient at any location. The closer the contour lines are together, the steeper the slope being represented. By measuring the elevation change over a measured horizontal distance, the average gradient or slope angle can be determined. In construction plans, slopes are frequently designated by a ratio
instance the 2 means two feet horizontal distance to one foot of vertical measurement. The relationship of these ratios to percent slope and angle of slope are shown in the diagram.

The importance of topography, both natural and man-made, to development in Colorado cannot be overemphasized. An understanding of rock types, vegetation, drainage, climate, and active earth processes in relationship to topography is one of the keys to successful development. Some of the planning elements affected directly by topography include: 1) road layout, 2) access to individual lots, 3) need for cut and fill, 4) sewage disposal system feasibility, 5) surface drainage control and pattern, 6) slope stability, 7) lot layout, 8) density of units, 9) need for building envelopes, 10) visual impact, and 11) wildfire hazard.

Clearly an essential component of any subdivision plan is an adequate topographic map which shows the shape and character of the land surface proposed for development. Superimposing the proposed development on a topographic map can reveal unsuspected relationships that are not evident when considered individually. The developer/builder then can take advantage of desirable natural features and avoid problem areas, especially if a geologic investigation provides data on subsurface characteristics of a site.

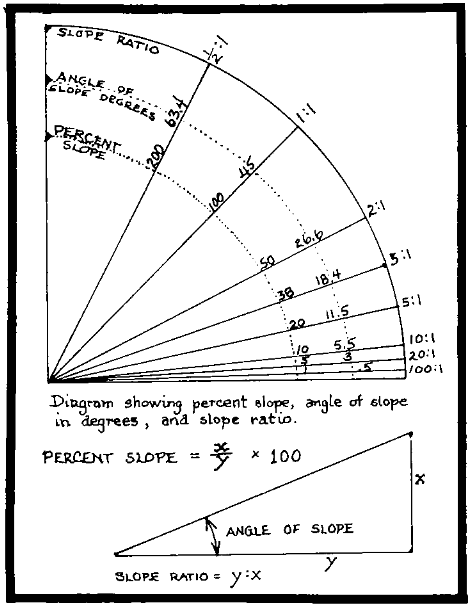


Diagram showing percent slope, angle of slope in degrees, and slope ratio.

The severe constraints associated with the development of steep slopes include: 1) Subdivision roads with steep gradients which are hazardous under icy conditions, 2) Large cuts and fills which may be unstable, 3) Access roads to lots with even steeper gradients, which may not be accessible, 4) Some lots may have no reasonable access through a large cut or fill on the main subdivision road, 5) Interception of steep hillside drainages.

Appendix C

Homebuyer's Guide

Introduction

Every house has imperfections, some of them serious. The purpose of this guide is to alert the buyer to basic geologic considerations affecting the value, serviceability and long term maintenance of a house or building. Structural flaws can have many causes. They may be of geologic, design, construction, or material origin, or a combination of them. A crack in concrete, for example, may be caused by geologic conditions, improper concrete mixing, lack of reinforcing steel or inadequate soil or base.

Basic lot locations relative to flood potential, unstable soils or other geologic hazards often can be checked with city, county or regional planning offices. In some instances maps of the hazard areas are available. In cases where examination of a structure indicates potential serious problems, experts can be retained to evaluate the situation. Such a consulting service can be inexpensive insurance for a major investment.

This guide is not intended to make all homebuyers into geotechnical experts. It can, however, be used by anyone to give a property a first screening.

Homebuyer's Geotechnical Inspection Guide

Look at OUTSIDE	Observation	Significance	Action
Onsite lot grading.	Lot slopes toward structure; water ponds next to foundation.	Roof runoff and precipitation will flow toward foundation adding water to subsoils which in turn cause wet basements, and aggravate potential swelling and collapsing soil problems which can cause foundation movement.	Regrade lot so the grade slopes away from the structure in all directions at least 6" in the first 10'.
	Lot has low areas with thick vegetation.	Possible high water table, surface drainage insufficient to remove runoff.	Determine if house is above water table or has functioning dewatering system.
	Steep slopes	Potential areas for rapid erosion and/or instability.	Control of surface drainage and do not overwater area. If severe, regrading may be required.
Landscaping	Vegetation planted close to structure and foundation.	Heavy irrigation may cause the same problem cited under "lot grading."	Control irrigation to prevent application of excess water; landscape and move vegetation.

Look at	Observation	Significance	
Water well and sewage disposal systems.	Close proximity of well and sewage disposal area (either on lot or adjacent lot).	Potential for contamination of water supply.	Have water quality checked by local health department.
	Well water tastes, looks or smells peculiarly.	Possibly poor water quality.	As above
	Well water yield unreliable.	Well may need maintenance or replacement. Some areas cannot yield sufficient water.	Repair or drill new well.
	Old septic-tank leach field-system. Sewage system backing up; effluent surfacing at leach field.	Malfunctioning system may cause surface or subsurface water contamination.	Septic tank may need to be pumped and/or leach field relocated.
Adjacent land	Surface water will drain onto property.	Could cause drainage problems such as ponding, erosion, or deposition on lot.	Create positive drainage control.
	Steep slopes	An unstable slope could generate rockfall, debris flow, landslide.	Investigate to determine if adverse effects are possible
	Low areas with heavy grass or other plant growth; standing water.	High groundwater table.	Investigate to determine if adverse effects are possible.
	Structure and lot close to drainageway.	It could mean part of the property is in flood prone area or susceptible to severe erosion; may be hazardous or just a maintenance nuisance.	If serious, check with local planning officials; initiate channelization measures.
Flat work (patio, driveway, sidewalks, garage floors).	Hairline cracks - no significant offset.	Minor settlement and/or shrinkage.	No problem - observe over long term.
	Cracks with offsets.	Major settlement or heaving unsightly but harmless.	If caused by poor drainage - drainage control may arrest process.
	Deteriorating concrete.	Old concrete or chemical deterioration due to sulfates in soil.	Replace with sulfate resistant concrete.

Look at OUTSIDE/ INSIDE	Observation	Significance	Action
Foundation and basement walls.	Vertical or near-vertical cracks open at the top or bottom.	If clay soils, foundation movement caused by swelling soils. If silts and sands, settlement is the probable cause of movement. If severe, can cause damage to rest of structure.	Keep surface and subsurface water away from foundation. Investigate for structural damage.
	Cracks open on inside but not on outside.	Indicates inward movement of foundation or basement wall caused by external pressure. Could be minor backfill problem or major slope instability.	Determine cause and correct: remove and replace backfill or stabilize slope.
Exterior walls (Brick, block, stucco).	Cracks in masonry walls, along joints and across bricks and blocks. Windows and doors may not operate properly.	Probable foundation movement caused by swelling and settling soils.	As noted above for foundation movement.
(Wood)	Movement may only show around windows and doors due to flexibility of structure.		
Fireplace and chimney.	Cracks in masonry.	Differential settlement of foundation can cause openings in flue liner increasing fire hazard and/or pulling of chimney away from structure.	Check structural integrity for fire safety.
	Masonry intact but chimney pulling away from structure.	Fireplace foundation rotating away from structure and/or foundation.	Jack back into place or rebuild.
Look at INSIDE			
Basement floors	Cracks across slab or parallel to wall so floor shows upward movement. Check furnace duct work and interior partition walls for distress.	Swelling soils causing heave of slab. If basement is unfinished, may be only cosmetic problem unless furnace and utilities are affected. If basement is finished, problem may be serious causing major damage to walls, doors, and windows.	Determine if corrective or structural damage. Repair may be very costly.
Sumps, drains, sump pumps in basement and around foundation.	If these dewatering systems exist, look for evidence of past wet or flooded basement.	Indicates high or perched groundwater conditions are possible. Pumps require maintenance. Drains may plug. If malfunctioning, basement or crawl space may then become wet or flooded.	Check for proper operation and ascertain past history.
Interior walls, doors, and ceilings.	Cracks with offsets in plaster, drywall, wallpaper, often most noticeable around door and window panes.	May only indicate shrinkage or of wood frame. Can also indicate foundation or basement slab movement from swelling or collapsing soils.	Determine cause. May require structural repair or cosmetic attention.

Appendix D

How to Find Out About Geology and Land Use in Colorado

Several organizations exist to help the homebuyer, contractor, developer, banker, or other land user find out about the natural conditions prevailing at a particular location. Many Colorado cities and most counties have planning and building departments and some staff geologists particularly familiar with local situations. In some parts of Colorado several counties have banded together to form Councils of Governments (COG) to provide these services. Also, there are special districts in addition to state and federal agencies and professional organizations.

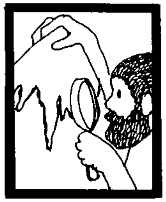
The organizations cited here are starting points and the list is by no means all inclusive. It is intended as a place to begin an inquiry into the fascinating interrelationships between man and nature in continuing wise use of the land.

Organizations	Types of Information
American Institute of Professional Geologists (AIPG) 622 Gardenia Street Golden, CO 80401 Phone: 279-0026	List of geologist members Monthly meetings Continuing education Professional ethics
Association of Engineering Geologists (AEG) 7391 W. 38th Avenue Wheat Ridge, CO 80033 Phone: 424-5564	List of engineering geologist members Monthly meetings Continuing education
Consulting Engineers of Colorado 1111 S. Colorado Blvd., Suite 305 Denver, CO 80222 Phone: 757-3379	List of member engineers Monthly meetings Professional ethics
Rocky Mountain Association of Geologists (RMAG) 1615 California Street, Suite 217 Denver, CO 80202 Phone: 573-8621	List of geologist members Weekly meetings Continuing education

Colorado State Agencies	
Colorado Geological Survey 1313 Sherman Street Denver, CO 80203 Phone: 839-2611	General information on Colorado geology. Engineering and resources. Special mapping projects.
Colorado Health Department Water Pollution Control Commission 4210 E. 11th Avenue Denver, CO 80220 Phone: 320-8333	Regulatory agency for water pollution control.
Colorado Health Department Radiation and Hazardous Wastes Division 4210 E. 11th Avenue Denver, CO 80220 Phone: 320-8333	Regulatory agency for radioactive material management and disposal.
Colorado Land Use Commission 1313 Sherman Street Denver, CO 80203 Phone: 839-2778	Major land-use issues and information. Commission has investigative and regulatory powers.
Colorado Division of Planning 1313 Sherman Street Denver, CO 80203 Phone: 839-2351	Assistance for local planning and State planning.
Colorado Division of Mines 1313 Sherman Street Denver, CO 80203 Phone: 839-3401	Mine maps of coal mines and most other mines.
Colorado Water Conservation Board 1313 Sherman Street Denver, CO 80203 Phone: 839-3441	Flood plain information.
Colorado Division of Water Resources 1313 Sherman Street Denver, CO 80203 Phone: 839-3581	Administration of groundwater resources, dam safety.

United States Agencies	Types of Information
U.S. Geological Survey Box 25286 Denver Federal Center, Building 41 Denver, CO 80225 Phone: 234-3832	Map sales
U.S. Geological Survey Public Inquiries Office 1961 Stout Street, Room 169 Denver, CO 80294 Phone: 837-4169	Map and publication sales.
U.S. Bureau of Mines Mine Map Repository Denver Federal Center, Building 20 Denver, CO 80225 Phone: 234-4161	Microfilm collection of mine maps.

Other	Types of Information
Urban Drainage and Flood Control District 2480 W. 26th Avenue Denver, CO 80228 Phone: 455-6277	Flood control projects and flood plain maps for the Denver Metro area.



Appendix E

A Guide for the Preparation of Engineering Geology Reports in Colorado

An engineering geology report furnishes both technical and non-technical persons with information related to subdivision development, public works construction, mineral extraction, and other uses. It describes clearly all important geologic conditions, interprets correctly their impact on proposed development activities, and makes recommendations regarding the mitigation of adverse conditions or mineral resource conflicts. The report provides persons involved in the planning, design, construction, finance or review process with geologic information so that technical decisions can be made.

The guide is intended as a framework for many types of geotechnical investigations. However, it is designed specifically as a description of the type of geologic information and analysis that usually is included in engineering geology reports for residential and commercial subdivisions. The guide also lists geology-related investigations including flooding and water resources, that may be reviewed by governmental agencies other than the Colorado Geological Survey. These investigations usually are discussed as a part of the geotechnical report so that project feasibility can be evaluated in the early planning stages.

The size and geologic complexity of a project requiring engineering geology reports vary greatly. This variability necessitates reports different from one another in scope, length, and organization. Because of this wide variation, the geologic investigations and reports should be flexible and tailored to the specific geologic conditions and intended land-use. Additionally, certain geologic interpretations and report recommendations may not be firm or complete in the initial planning stages of a project and supplemental information or detailed reports may be necessary during later stages of development. Regardless of the project size, stage, or geologic complexity, all pertinent data, interpetations, and recommendations regarding geologic hazards, constraints, or resource conflicts should be presented clearly in the engineering geology report.

Geologic studies of hazardous or mineral resource areas are required by certain Colorado Statutes. Senate Bill 35 (C.R.S. 1973, 30-28-101, 110(3)-(5), 133-137) and House Bills 1041 (C.R.S. 1973, 24-65.1-101, et seq.) and 1529 (C.R.S. 1973, 34-1-301, et seq.) require that geologic hazards and mineral resources be considered prior to development activities. Geologic hazard is defined in HB 1041 as "a geologic phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property." A mineral resource area is defined in this same bill as "an area in which minerals are located in in sufficient concentration in veins, deposits, bodies, beds, seams, fields, pools, or otherwise, as to be capable of economic recovery..." Local governments are empowered to regulate development in these hazard or resource areas by Senate Bill 35, House Bill 1041, and by House Bill 1034 (C.R.S. 1973, 29-20-101, et seq.). Regardless of the legal requirements it is in the best interest of the designer, developer and builder and financial institutions to obtain a report on the geologic conditions before a project is begun so that the results of a geologic investigation can be incorporated into the project planning. Geologic information can be used to save development and construction costs or, perhaps, liabilities and legal costs by acquainting the developer or contractor with adverse geologic conditions and their impact on the proposed project. Ultimately, the use of information contained in the report also could save local and state governments, and the taxpayers from excessive expense resulting from failure to recognize and cope with natural hazards. Private property owners benefit by preventing foreseeable devaluation of their holdings.

All engineering geology reports should be prepared and signed by a Professional Geologist as defined by Colorado law, House Bill 1574 (C.R.S. 1973, 34-1-20, et seq.). To prepare a complete and accurate report, the geologist must have special education and experience in the field of engineering and environmental geology. The geologist who does not have this general training and experience should refrain from doing engineering geology studies or should work under supervision of a geologist who is experienced in this field. The report should be prepared in accordance with the highest prevailing standards of the profession realizing that omissions of significant data are as serious an error as giving misinformation.

General Content of Engineering Geology Reports

Engineering geology reports generally contain three distinct and essential elements: 1) data, 2) interpretation of the data, and 3) conclusions and recommendations.

Data: Report data are facts used as the basis for interpretations, discussions, and conclusions. These facts are the cornerstone of the report and are obtained from published documents, surface and subsurface investigations, and field and laboratory tests. Surface studies generally include topographic surveys, geologic mapping, and the review of aerial photographs or other remote-sensing imagery. Subsurface investigations can include geophysical surveys, drill holes, test pits, and trenches. Field and laboratory tests may cover the analysis of various factors involving soils engineering, sewage leach fields, water quality, or mineral resources.

Geologic conditions which should be described in the report include bedrock units, surficial deposits, geomorphic features, structural features, surface drainage, ground-water conditions, and mineral resources. Description of the conditions will differ markedly in their degree of detail and specificity depending on the particular method or technique used in gathering data. The limitations of the method or techniques used and the quality of the data should be discussed. Where interpretations are added to the recording of direct observations, the basis for interpretations must be clearly stated.

Interpretation: After the geologic data has been presented, it is analyzed with regard to geologic hazards and geologic constraints, mineral resources, and water conditions. Geologic hazards are conditions that eventually will affect the safety of persons and property by instability of the ground surface or inundation of the surface by debris, mud, snow, or water. Instability or inundation may be caused by either natural or man-induced processes such as landslides, debris flows, mudflows, flooding, faulting, avalanches, rockfall, and subsidence over underground mines. Paramount in the analysis of geologic hazards and constraints is the recognition and evaluation of natural processes as well as an estimation of the recurrence interval for a specific size and kind of event. Colorado Geological Survey Special Publication 6 (Rogers and others, 1974) offers detailed descriptions of these processes. It defines the processes, gives the criteria for recognition, and anticipating the consequences of improper utilization. It also suggests mitigation procedures.

Geologic constraints are conditions that probably will not result in the loss of life but could cause significant added construction expense or property damage. These constraints may be controlled by by proper design and construction. The lack of proper design or construction could initiate or aggravate specific geologic processes and escalate construction and maintenance costs. These costs could determine project feasibility, especially if they are not recognized and incorporated into project plans. Geologic constraints can affect road and foundation stability, sewage disposal feasibility, cut and fill stability, and other construction activities. These include factors such as potentially unstable slopes, expansive soils, hydrocompaction, high ground-water levels, ground subsidence, shallow bedrock, erosion, and soil creep.

Mineral resources usually do not affect safety of individuals or the stability of structures but they may impact the long-term economic well-being of citizens within the county and state. Mineral resources should be evaluated, administered, and protected to permit the wisest use of our limited resources. Mineral resources including occurrences of construction materials and industrial minerals at the surface and metallic and mineral fuel deposits within the subsurface, should be evaluated and described in the report.

These resources, such as oil, gas, coal, sand and gravel, uranium, and precious metals, should not only be economically evaluated but also should be evaluated with regard to multiple sequential land-use. This program considers the analysis of mineral extraction followed by use of the land for other activities. Colorado Geological Survey Special Publication 6 (Rogers and others, 1974) and Special Publication 8 (Shelton, 1977) should be consulted for detailed descriptions of mineral resources and resource factors.

Water resources, including surface and ground waters, are similar to mineral resources in that they usually do not adversely affect the safety of individuals or the stability of structures. However, water resources must be analyzed with regard to location, quality, and quantity so that possible pollution, recharge, or depletion can be determined.

The analysis of geologic hazards, geologic constraints, mineral resources, and water conditions constitutes the major part of an engineering geology report. The analysis, supported directly from geologic data and information, should identify and interpret adverse geologic processes and important mineral and water resources. It should evaluate (1) the effects of geologic processes or resources on the proposed construction and (2) the effect of the proposed project on the future geologic processes or resources in the area.

Conclusions and Recommendations: Report conclusions and recommendations vary greatly from report to report because of variable geologic conditions and different project criteria. Regardless of these variations, the data necessary for safe construction, long-term viability of the project, and adequate protection of mineral and water resources must be contained in the engineering geology report. It is equally important that this report be used in the planning process; e.g., the preparation of the preliminary plat. Geologic factors are incorporated most easily before submittal of the report to reviewing agencies.

Report conclusions and recommendations should be stated in ordinary and unambiguous language and should first identify the critical geologic aspects of all elements of the project. The geologic feasibility of the project should be determined and mitigation measures or design changes recommended to minimize or abate any adverse conditions. Further studies should be recommended if needed.

Engineering Geology Report Guidelines

The guidelines that follow are a general outline of the materials usually included in an engineering geology report. Items discussed in the outline were compiled from a variety of sources, especially the California Division of Mines and Geology, Ventura County and the City of San Jose, California, and from publications of the Association of Engineering Geologists. Specific references used in this compilation are cited at the end of this appendix and should be consulted for additional details.

These guidelines are not intended as a rigid framework of requirements, a specific format for all reports, or report procedures for all geotechnical investigations. Particular items or investigations listed may be deleted or may require emphasis because of local geologic conditions or type of project proposed. This outline should be considered as a general list of geotechnical information commonly evaluated and provided in an engineering geologic investigation.

I. BASIC INFORMATION

A. PROJECT DESCRIPTION

1. Describe present zoning, land-use proposed and structure(s) anticipated.

2. Indicate size and relationship of the project to the surrounding area.

B. LOCATION

1. Specify the project location in terms of section, township and

range, and county.

2. Depict the project location on an index map of appropriate scale, usually U.S. Geological Survey 7.5-minute quadrangle map.

C. PURPOSE

1. Clearly state the uses for which the report was prepared. Excluded uses also may be described.

2. Indicate the commissioning person or organization.

D. SCOPE

1. State the objective(s) and level of investigation for the study.

2. Cite previous published or unpublished geologic reports in the subject area and indicate the author(s), firm, and dates of each report.

3. List all the methods of investigation as well as professional firm(s) and individuals who participated.

4. If the level of investigation varies within the subject area, describe in the text and show on the maps areas of concentration or exclusion.

5. Indicate the approximate time spent in the field investigation and by whom.

II. <u>BASIC DATA</u>

A. REGIONAL SETTING

1. Describe the general physiographic setting of the project and its relationship to local topographic features.

2. Describe the general geologic setting of the project and indicate any lithologic, tectonic, geomorphic, or soils problems specific to the area.

3. Describe the general surface and ground water conditions and their relationship to the project area.

4. Describe the mineral resources in the general area.

B. SITE EVALUATION TECHNIQUES

1. State the extent and method of surface and subsurface geologic studies.

2. Topographic Mapping

    a. Indicate the type and accuracy of topographic maps in the area.

    b. State the date of the topographic survey and firm or individuals who conducted the survey.

3. Geologic Mapping

    a. Prepare geologic map(s) on the project topographic map to show important details commensurate with the purpose of the investigation.

    b. Show the abundance and distribution of earth materials and structural elements exposed or inferred in the subject area. Observed and inferred features or relationships should be so designated on the geologic map.

    c. Depict significant three dimensional relationships on appropriately positioned cross sections.

    d. Portray all geologic information at the <u>same scale</u> as the project plans. Use "tie-points" between the geologic map, topographic map, and project plans.

    e. Indicate the geologic base map used, date, and significant additions and modifications to previous work.

4. Aerial Photographs and Remote-Sensing Imagery

    a. Describe type(s) of photographs or images including instrumentation, processing techniques, and final product.

    b. Indicate data and scale of photographs or imagery used in the investigation.

    c. Describe the source of photographs and photographic identification numbers.

    d. Indicate usefulness and general relationships observed on the images.

5. Geophysical Investigations

    a. State type and objectives of the geophysical investigation(s) (if any), quality of the data, and limitations of the geophysical techniques.

    b. Describe the information used to correlate the geophysical data and known geologic conditions.

    c. Display the geophysical data on the topographic/geologic maps and cross sections and show cultural features which affect the data.

6. Drill-Hole Data

    a. State the specific investigative methods, tests conducted, drilling equipment, and date of investigation.

b. Show the location of all borings on the topographic or geologic map.

c. Show boring logs, geophysical logs, or profiles obtained in the investigation. This information generally includes location and type of samples; soil descriptions according to the unified soil classification; lithologic descriptions using standard geologic terminology; critical soil or geologic contacts; and groundwater levels.

7. Test Pits and Trenches

   a. Describe the location and general dimensions of all pits and trenches and date of investigation.

   b. Indicate the location of all excavations on the topographic/geologic map and profiles.

   c. Provide a large scale descriptive log with sufficient detail commensurate with the features observed. Insets may be used if necessary.

   d. Show sample locations if supplemental laboratory tests were conducted.

8. Field and Laboratory Tests

   a. Describe the type and objectives of any tests conducted in the field or laboratory.

   b. Describe the sample method and test procedures.

   c. Show the test results on data work sheets or on summary tables.

9. Monitoring Programs

   a. Describe the type, objectives, and location of all monitoring programs in the subject area.

   b. State the monitoring period, the firm(s) or individuals responsible for the care and disposal of the installations.

III. GEOLOGIC DESCRIPTIONS

A. BEDROCK UNITS: sedimentary, igneous, and metamorphic rock types.

1. Rock type and bedding orientation.

2. Age of and correlation with recognized formations.

3. Dimensional characteristics such as thickness and extent.

4. Distribution and extent of the weathered zone.

5. Physical and chemical characteristics.

6. Distribution and extent of weathered zone.

7. Response of bedrock materials to natural processes.

8. Mineral occurrences.

B. SURFICIAL DEPOSITS: fluvial, colluvial, glacial, eolian, mass wasting, and man-made deposits

1. Distribution, occurrence, and age

2. Identification of material types and sources

3. Dimensional characteristics such as thickness and extent

4. Surface expression and relationships with present topography

5. Physical and chemical characteristics

6. Distribution and extent of altered zones

7. Response of surficial materials to natural processes

8. Mineral occurrences

C. GEOMORPHIC FEATURES: landslides, earthflows, debris flows, mudflows, rockfalls, debris avalanches, fault scarps, soil creep, erosion scarps, avalanche paths, and subsidence phenomenon.

1. Location and distribution

2. Dimensional characteristics

3. Age of feature and history of activity

4. Recurrence interval for geomorphic process

5. Physical characteristics including depth, flow velocities, and impact pressures

D. STRUCTURAL FEATURES: joints, faults, shear zones, folds, schistocity, and foliation

1. Occurrence, distribution, and proximity to site

2. Dimensional and displacement characteristics of faults

3. Orientation and changes in orientation

4. Physical characteristics such as brecciation, slickensides, gouge zones, sand boils, sag ponds, spring alignment, disrupted drainages, or ground-water barriers

5. Nature of offset(s) and timing of movement(s)

6. Absolute or relative age of latest movement

7. Location and magnitude of seismic events and their association with faults or fault systems

E. SURFACE DRAINAGE: rivers, streams, creeks, and draws

1. Distribution and occurrence

2. Relation to topography (drainage patterns)

3. Relation to geologic features

4. Source, permanence, and variation in amount of surface water

5. Evidence of earlier occurrence of water at localities now dry

6. Estimated peak flows and physiographic flood plain of drainages

7. Probable maximum or 100-year flood limits, including flash and debris floods

8. Water quality

9. Use of surface waters

F. GROUND WATER: confined and unconfined

1. Distribution and occurrence

2. Hydraulic gradients

3. Recharge areas for aquifers

4. Relation to topography

5. Relation to geologic features

6. Seasonal variations

7. Water quality

8. Use of ground waters

9. Aquifer characteristics

G. Mineral resources: metallics, mineral fuels, and non-metallics

1. Distribution and occurrence

2. Abundance and past production

3. Mineral rights and agreements

IV. GEOLOGIC INTERPRETATION

A. GEOLOGIC HAZARDS (landslides, avalanches, rockfall, mudflows, debris flows, radioactivity)

1. Geomorphic and structural features/processes present in the area

2. Man-induced features/processes

3. Age and activity of the features/processes

4. Natural conditions affecting the features/processes

5. Susceptibility to man-induced changes

6. Potential impact of hazard(s) and risk to project

7. Amenability of adverse conditions for adequate mitigation

8. Long-term lateral and vertical stability of earth materials

9. Impact of project on materials stability

B. GEOLOGIC CONSTRAINTS (expansive soil or rock, potentially unstable slopes, high ground-water levels, soil creep, hydrocompaction, shallow bedrock, erosion)

1. Soil, surface and ground water, and geomorphic conditions

2. Man-induced conditions

3. Activity of conditions

4. Effect of natural or man-induced changes

5. Potential impact of conditions and risk to project

6. Amenability of adverse conditions for adequate mitigation

7. Impact of project on long-term project stability

C. WATER RESOURCES

1. Quantity of surface or ground water available to project

2. Long-term water availability

3. Impact of waste disposal on water quality

4. Effect of project on ground water recharge

5. Potential for development of perched ground-water conditions

6. Impact of project, especially of on-site sewage disposal, on quality and quantity of water resources

D. MINERAL RESOURCES

1. Type of resource

2. Mineral economic parameters

3. Economic potential of the deposit(s)

4. Impact of the project on mineral resources

V. CONCLUSIONS

A. STATE WHETHER THE INTENDED USE OF THE LAND IS COMPATIBLE WITH

POTENTIAL GEOLOGIC HAZARDS, CONSTRAINTS, AND MINERAL RESOURCES AND IF MITIGATION MEASURES ARE NECESSARY.

B. DISCUSS THE CRITICAL PLANNING AND CONSTRUCTION ASPECTS INCLUDING SEWAGE OR SOLID WASTE DISPOSAL, THE STABILITY OF EARTH MATERIALS, GRADING PLANS, AVAILABILITY AND QUALITY OF SURFACE OR GROUND WATER, THE NEED FOR SELECTIVE LOCATION OF PROJECT FACILITIES, STATIC AND DYNAMIC PARAMETERS FOR THE DESIGN OF STRUCTURES, AND METALLIC AND NON-METALLIC MINERAL EXTRACTION.

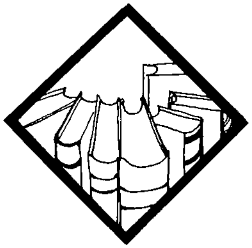
C. CLEARLY STATE THE GEOLOGIC BASIS FOR ALL CONCLUSIONS.

VI. RECOMMENDATIONS

A. DISCUSS THE DEVELOPMENT OF MITIGATION PROCEDURES OR DESIGN CHANGES NECESSARY TO MINIMIZE OR ABATE ANY ADVERSE CONDITIONS OR MINERAL RESOURCE CONFLICTS. EACH HAZARDOUS CONDITION OR MINERAL RESOURCE REQUIRES A RECOMMENDATION

B. STATE THE RECOMMENDATIONS IN ORDINARY AND UNAMBIGUOUS LANGUAGE, ESPECIALLY FOR NON-GEOTECHNICAL PERSONNEL. THE RECOMMENDATION SHOULD INSURE THE LONG-TERM STABILITY AND SAFETY OF THE PROPOSED PROJECT.

C. INCLUDE ANY SUGGESTIONS FOR ADDITIONAL GEOTECHNICAL STUDIES NEEDED TO DETERMINE THE IMPACT OF KNOWN OR INFERRED FEATURES IN THE SUBJECT AREA.



Appendix F

Suggested Readings for More Detailed Information

Proceedings of the Governor's First Conference on Environmental Geology, Association of Engineering Geologists and American Institute of Professional Geologists, 1970, Colorado Geological Survey Special Publication 1, 78 p., 13 papers dealing with application of geology to urban growth and planning, mineral conservation and engineering problems.

Guidelines and criteria for identification and land-use controls of geologic hazard and mineral resource areas, W.P. Rogers and others, 1974, Colorado Geological Survey Special Publication 6, Land use planning guide for H.B. 1041. Definition, identification and mitigation for avalanches, landslides and rockfalls. Identification and classification of mineral resource areas. Glossary and model geologic hazard area regulations.

Natural hazards, earthquake, landslide expansive soil loss models, John H. Wiggins, James E. Slosson, James P. Krohn; J.H. Wiggins Co., 1650 South Pacific Coast Highway, Redondo Beach, CA, 90277; December 1978.

Building losses from natural hazards: yesterday, today, and tomorrow, Daniel H. Baer; J.H. Wiggins Co., 1650 South Pacific Coast Highway, Redondo Beach, CA, 90277; December 1978.

Proceedings Governor's Third Conference on Environmental Geology--Geologic Factors in Land Use Planning, D.C. Shelton, editor, 1977, Colorado Geological Survey Special Publication 8, 17 papers dealing with geologic hazards, mineral resources: case studies in county planning, land use regulation and legal aspects.

Prairie, peak and plateau--a guide to the geology of Colorado, John and Halka Chronic, 1972, Colorado Geological Survey Bulletin 32. A layman's guide to the geology of Colorado.

Geological map of Colorado, U.S. Geological Survey, 1935: reprint Colorado Geological Survey, 1975. At present it is the only colored geologic map of the State of Colorado at a scale of 1:500,000. The U.S.G.S. has a revised version in

preparation.

Earth-science information in land-use planning--guidelines for earth scientists and planners, U.S. Geological Survey, 1976, U.S.G.S. Circular 721.

Geologic aspects of soil and related foundation problems Denver metropolitan area, Colorado, J.L. Hamilton and W. G. Owens, 1972, Colorado Geological Survey Environmental Geology 1. Bedrock and surface geology soil and stability problems, rock unit engineering characteristics, foundation design criteria. Includes engineering soils and geology/depth to bedrock maps.

"Nature to be commanded...," earth science maps applied to land and water management, G.D. Robinson and A.M. Spieker, editors, 1978, U.S. Geological Survey Professional Paper 950. Case histories of geology used in land and water management.

Flooding

Floodplain management, flood control and flood disaster programs--Manual for local governments, Colorado Water Conservation Board, June 1976. Discusses legislation, identification and regulation, control, and emergency and disaster programs.

Flood plain--Handle with care!, Department of the Army Corps. of Engineers, March 1975, EP1105-2-4. A case history approach to flood hazard mitigation.

Mountain Torrent-Flash Flood

Geologic hazards, geomorphic features and land-use implications in the area of the 1976 Big Thompson Flood, Larimer County, Colorado, J.M. Soule, W.P. Rogers, and D.C. Shelton, 1976. Colorado Geological Survey Environmental Geology 10. Present and potential geologic hazard areas, debris fans, landslides, rockfalls, unstable slopes, flood hazards, flood discharges, and descriptive text.

Debris/Mud Flow and Fan

Debris-flow hazard analysis and mitigation--an example from Glenwood Springs, A.I. Mears, 1977, Colorado Geological Survey Information Series 8. Characteristic dynamics, and probability debris flows; measures for protecting buildings from debris flow impact.

Ground Water

Bibliography of hydrogeologic reports in Colorado, R.H. Pearl, 1971. Colorado Geological Survey Bulletin 33. Compilation of published and unpublished reports on ground water conditions through 1970, with subject index.

Geologic control of supply and quality of water in the mountainous part of Jefferson County, Colorado, W.E. Hofstra and D.C. Hall, 1975. Colorado Geological Survey Bulletin 36. General geology, soils and water resources; chemical quality of surface and ground water; environmental factors influencing water quality; water-management problems and alternatives. Includes graphs and tables of water quality data.

Geology of ground water resources in Colorado--an introduction, R.H. Pearl, 1974. Colorado Geological Survey Special Publication 4. Occurrence, quality, and movement of ground water. Outline of resources in seven regions, stratigraphic chart showing water-bearing formations. Extensive bibliography.

Manual of Septic Tank Practice, U.S. Department of Health, Education, and Welfare, 1967. DHEW Publication #(HSM)72-10020.

National interim primary drinking water regulations, 1976, U.S. Environmental Protection Agency, Office of Water Supply, EPA-570/9-76-003. Maximum contaminent levels, monitoring and analytical requirements and background information.

Manual of water well construction practices, 1975, U.S. Environmental Protection Agency, Office of Water Supply, EPA-570/9-75-001. Technical standards, construction, casing, grouting, screen and perforations, and development.

Landslide-Rockfall

Landslides--analysis and control, R.L. Schuster, and R.J. Krizek, editors, 1978. Transportation Research Board, National Academy of Sciences, Special Report 176. A comprehensive resource document covering all aspects of slope instability. Discussions of slope movement types and processes, recognition and identification, field investigation, instrumentation, strength properties and their measurement, methods of stability analysis, design and construction of soils slopes, engineering of rock slopes.

Avalanche

Snow avalanche sites--their identification and evaluation, M. Martinelli, Jr., 1974. U.S. Forest Service Agricultural Information Bulletin 360. General guidelines for the identification and evaluation of snow avalanche areas.

Colorado snow avalanche area studies and guidelines for avalanche hazard planning, A.I. Mears, 1979. Colorado

Geological Survey Special Publication 7. Includes avalanche area studies for 15 areas in Colorado. Text includes general descriptions and individual path statistics for each area and guidelines for land-use planning in avalanche hazard areas.

Guidelines and methods for detailed snow avalanche hazard investigations in Colorado, A.I. Mears, 1976. Colorado Geological Survey Bulletin 38. Land-use planning guide for hazard quantification and avoidance. Avalanche mechanics and frequency, topographic limitations. Runout determination, flow dynamics equations, impacts, frequency predictions, mitigation and defense measures.

Swelling Soils

Potentially swelling soil and rock in the Front Range Urban Corridor, Colorado, S.S. Hart, 1974, Colorado Geological Survey Environmental Geology #7. Definition and recognition of swelling soil, geology of hazardous areas, extensive bibliography, glossary, estimate of swell potential. Colored maps of the Front Range Urban Corridor.

Home construction on shrinking and swelling soils, W.G. Holtz and S.S. Hart, 1978. Prepared under a grant from the National Science Foundation. Distributed by Colorado Geological Survey. Basic construction techniques and swelling soil areas.

Collapsing Soils

Hydrocompacting soils on the Interstate 70 route near Grand Valley, Colorado, D.C. Shelton, and others, 1977, in Proceedings of 15th Annual Engineering Geology and Soils Engineering Symposium, Idaho. A case history of the identification and evaluation of hydrocompacting soils on a proposed major highway route.

Review of collapsing soils, J.H. Dudley, 1970. American Society of Civil Engineers Journal of Soil Mechanics and Foundation Division, v. 96, no. 3, p. 925-947. A general review of the mechanisms involved in collapsing soils.

Ground Subsidence

Ground subsidence and land use considerations over coal mines in the Boulder-Weld Coal Field, Colorado, Amuedo and Ivey, geologic consultants, 1975, Colorado Geological Survey Environmental Geology 9. Explanatory text and six plates, including extent of mining, depth of cover, mine colors, probable thickness of extracted coal, subsidence inventory, and subsidence hazard.

Site investigations in areas of mining subsidence, F.G. Bell, editor, 1975, Newness-Butterworth's, publishers. Presents detailed methods for investigation of areas prone to subsidence due to past mining.

Seismicity

Earthquake potential in Colorado, R.M. Kirkham and W.P. Rogers, 1978, Colorado Geological Survey Open-file 78-3. Three maps showing potentially active faults of Colorado and earthquakes from 1870 to 1975. Text discussing the earthquake potential in Colorado.

Natural hazards, earthquake, landslide expansive soil loss models, John H. Wiggins, James E. Slosson, James P. Krohn; J.H. Wiggins Co., 1650 Pacific Coast Highway, Redondo Beach, CA, 90277; December 1978.

Radiation

Administrator's guide for siting and operation of uranium mining and milling facilities, Stone and Webster Engineering Corporation, Denver, Colorado, 1978. Prepared under contract to United States Environmental Protection Agency. Pages 4-39 through 4-54. This publication provides a general discussion of uranium mining and milling. The pages noted give a good summary of radiological hazards associated with radioactive materials.

Basic radiation protection criteria, National Council on Radiation Protection, NCRP Report No. 39, 1971.

Mineral Resources

Articles contained in Special Publication 6 and Special Publication 8 listed under "General" contain discussions concerning mineral resources and land-use planning.

Legislation

The law of planning and land-use regulations in Colorado, T.W. Dorsey and F. Salek, 1975, Colorado Chapter, American Institute of Planners. A summary of Colorado legislation relating to land-use regulation in Colorado. Includes the statutes and discussions.

Colorado revised statutes, 1973. This set of volumes contains the laws of Colorado.

Character and Behavior of Earth Materials

Earth manual, a Water Resources Technical Publication, 2nd edition, U.S. Department of the Interior, Bureau of Reclamation, 1974. This book provides a comprehensive discussion of all aspects of earth materials and foundations with an emphasis on dam construction. The principles contained therein, however, apply to all types of construction.

Topography

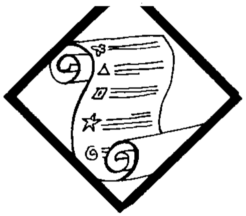
Topographic maps, U.S. Geological Survey, 1969. This free pamphlet describes what topographic maps are and the symbols used on them.

Topographic maps, tools for planning, U.S. Geological Survey, 1971. This pamphlet describes uses of topographic mapping for planning.

Glossary

Glossary of geology, M . Gary and others, editors, American Geological Institute, 1972.

Dictionary of geological terms, American Geological Institute, 1962, Dolphin Books.



Appendix G

Glossary

Selected terms from "Nature's Building Codes" with definitions not readily found in a standard dictionary.

Air blast - A fast-moving mass of air compressed by the sudden movement of a wall of snow in an avalanche. It may precede the avalanche down the mountain.

Backfilling - Replacing material (fill) in a ditch or other excavation from which material has been taken previously.

Cuts and fills - Areas where earth material has been excavated (cut) or placed deliberately (fill) to alter the ground surface configuration.

Engineering geology - The science and study of the behavior of land and and water as they affect developments and structures, and vice versa.

Epicenter - That point on the earth directly above the focus or earthquake center from whence the first earthquake waves originate within the earth.

Fault - A surface or zone of rock fracture along which movement or displacement of the rocks on either side is parallel to the zone or surface.

Field investigation - An on-site examination.

Floating slab - A slab of concrete poured between walls but not under them so that it can rise and fall without affecting the structure, i.e., a basement floor.

Foliation - Banding or lamination of metamorphic rocks as contrasted with stratification of sediments. Generally they are planes of weakness.

Geo - Pertaining to the earth.

Geologic investigation - Examination of the earth and earth processes on site.

Gradient - A measure of slope.

Hogback - A sharp ridge with steep sloping sides.

Hydrocompaction - The property of some dry, unconsolidated earth materials to compact, settle, and crack when wetted.

Hydrogeologic investigation - Examination of water and earth interactions.

Jointing - A fracture or parting in the rock mass along which little movement has occurred.

Milling - Physical and/or chemical processing of ore to extract the valuable elements.

Montmorillinite - A clay type characterized by expansion upon wetting and shrinkage upon drying.

Open space - Land essentially lacking structural improvements.

Piers (drilled) - Holes bored in the earth or rock and filled with reinforced concrete to make solid posts upon which to build.

Professional geologist - A professional geologist is defined by Colorado State Statutes as " A graduate of an institution of higher education..., with a minimum of 30 semester (45 quarter) hours of undergraduate or graduate work in a field of geology and whose post-baccalaureate training has been in the field of geology with a specific record of an additional five years of geologic experience to include no more than two years of graduate work."

psf - Pounds per square foot, a measure of pressure or stress.

Richter magnitude - A measure of the strength of an earthquake or the strain energy released by it as determined by standardized seismographic observations and calculations.

Runout zone - The area where an avalanche decreases velocity and stops on gentler slopes at the bottom of the path.

Shrink-swell soils - Soils that change in volume with changes in moisture.

Soil failure - The collapsing or downslope movement of soil.

Soil strength - The soil's ability to support a load and stay in place on a steep slope.

Starting zone - Where an avalanche begins.

Tailings - Waste materials remaining after the processing of ores.

Topography - The configuration of the land surface including its relief and the position of its natural and man-made features.

Appendix H

Geologically Related Land-Use Legislation

In recent years some of the geologic aspects of Colorado land-use regulations have been formalized by five major laws. A summary of each statute and its legal citation relative to land planning and development follows.

Senate Bill 35 (1972): C.R.S. 1973, 30-28-101, 110 (3) - (5), 133-137 is the major land subdivision legislation passed by the Colorado General Assembly. It is widely referred to as Senate Bill 35. It requires that all proposed developments of land in unincorporated areas, dividing property into two or more parcels shall be accompanied by reports on the geologic characteristics significantly affecting the proposed land use. The reports also are to determine the impact of such characteristics on proposed subdivisions. The reports, plans, and other supporting documents for the proposed development shall be submitted to the Colorado Geological Survey for an evaluation of the geologic factors which would have a significant impact on the proposed use of the land.

The law also requires 1) reports concerning streams, lakes, topography, and vegetation, 2) evaluations of potential radiation hazards, and 3) maps and tables concerning the suitability of types of soil in a proposed subdivision, 4) adequate evidence that a water supply that is sufficient in terms of quality, quantity, and dependability will be available to insure an adequate supply of water for the type of subdivision proposed, and 5) evidence of adequate sewage disposal conditions.

House Bill 1574 (1974): C.R.S. 1973, 34-1-20, et seq. requires that all geologic reports prepared for governmental review must be prepared by a professonal geologist. A professional geologist is defined as an individual with at least 30 semester hours of geologic education and five years of experience.

House Bill 1529 (1973): C.R.S. 1973, 34-1-301, et seq. is commonly known as the "Sand and Gravel Bill." It states that "After July 1, 1973, no board of county commissioners, governing body, or any city and county, city or town, or other governmental authority which has control over zoning, shall, by zoning, rezoning, granting of variance or other commercially feasible and regarding which it can be demonstrated by geologic, mineralogic, or other scientific data that such deposit has significant economic or strategic value to the area, state, or nation."

The law applies to any county or city or city and county having a population of 65,000 inhabitants or more according to the latest federal decennial census. It also requires local government to adopt a master plan for the extraction of commercial mineral deposits.

House Bill 1034 (1974): C.R.S. 1973, 29-20-101, et seq. is known as the "Local Government Land Use Control Enabling Act of 1974." It specifically authorizes local government to oversee the use of land by "regulating development and activities in hazardous areas." This statute is perhaps the broadest statement of local government's authority to control development in geologically hazardous areas.

House Bill 1041 (1974): C.R.S. 1973, 24-65.1-101, et seq. states that "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 admininistration thereof." Included as items of state interest are geologic hazards including avalanches, landslides, rockfalls, mudflows, and debris fans, unstable or potentially unstable slopes, seismic effects, radioacitivity, ground subsidence, and expansive soil and rocks.

The law requires the Colorado Geological Survey to assist local governments in identifying, designating, and adopting guidelines for the administration of such areas of state interest. The law states that "In geologic hazard areas all development shall be engineered and administered in a manner that will minimize significant hazard to public health and safety or to property due to geologic hazards." Similarly, "Mineral resource areas...shall be protected and administered in such a manner as to permit the extraction and exploration of minerals thereform unless extraction and exploration would cause significant danger to public health and safety."