SECTION 2 - HAZARDS

Avalanche

avalanche - is a mass of snow, ice, and debris; flowing and sliding rapidly down a steep slope. Also called snowslides.

SNOW AVALANCHE

It is estimated that 100,000 snow avalanches occur each year, yet only about 10,000 snow avalanches are reported.

Avalanches need a steep slope, snow cover, a weak layer in the snow cover, and a trigger.

In Wellington, Washington in 1910, an avalanche derailed two trains, killing 96 people.

The greatest avalanche threats are in the mountainous areas of the Western United States including Alaska.

Over the past 30 years, on average each year, 144 persons have been trapped; resulting in 14 injured and 14 dead. The number of deaths attributed to avalanches each year is exceeded only by floods, lightning, tornados and extreme heat.

The estimated annual average structure damage is $500,000. The estimated annual impacts and costs of all factors is greater than $5 million.

If conditions are right, avalanche releases can reach maximum velocities of 157 mph.

Avalanches are triggered by natural causes or human actions. Natural causes include earthquakes, thermal changes, and blizzards. Ice slabs falling off cornices may trigger avalanches.

Human activities, such as snowmobiling, snowboarding, skiing, hiking, driving or setting off explosions may trigger an avalanche. Loss of life of backcountry skiers, snowboarders, backpackers, climbers, and snowmobilers due to suffocation is the principal danger.

In Towns like Vail and Telluride, avalanche hazard zones are incorporated in comprehensive plans and and regulations are one of the tools used in evaluating development proposals.

There were 114 reported deaths in Colorado attributed to avalanches from 1985/86-2003/04.

(Sources: FEMA 1997; Mears 1979; Mears 1992; www.caic.state.co.us/facts.html)

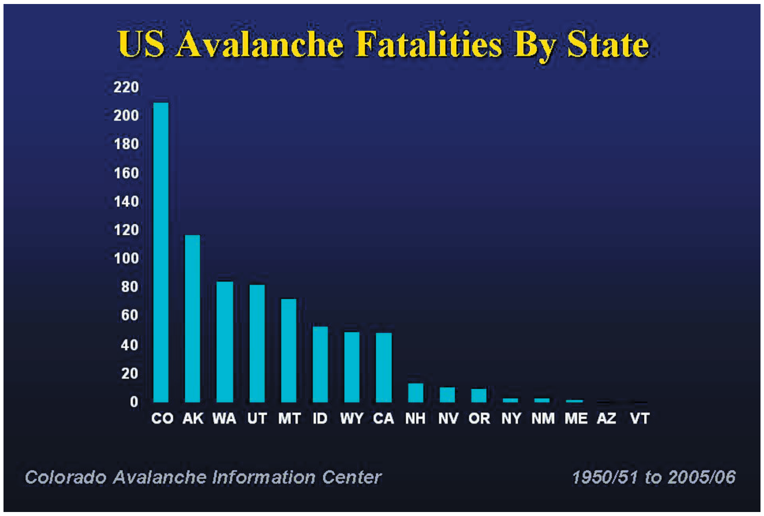
Local emergency managers that responded from the west and northwest regions, when averaged, rated avalanche as a moderate hazard. Other regions, when responses were averaged, ranked it as low. The Colorado Department of Transportation ranked it as a high probability of occurrence and a high cost, especially with respect to highway infrastructure; four other state agencies ranked it as moderate probability and moderate cost with respect to their areas of concern. The Department of Transportation has an avalanche program, as described in the 'State Assessment'. The Colorado Geological Survey & CDOT have the Colorado Avalanche Information Center, as described in the 'State Assessment'.

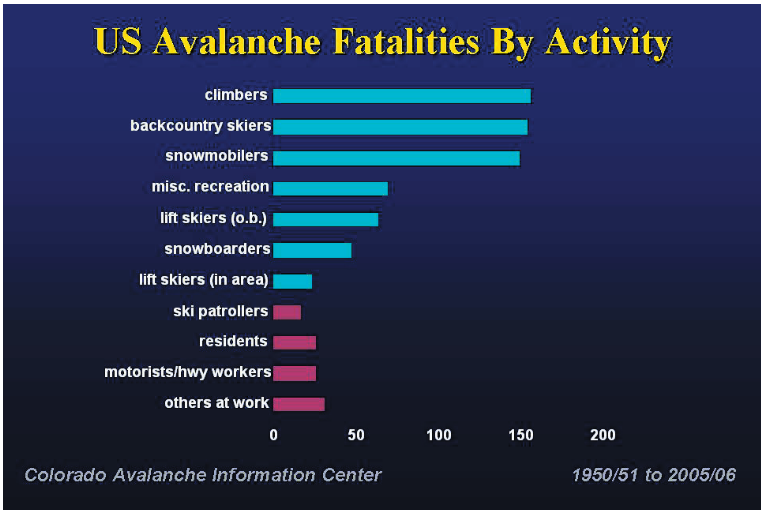
Avalanche mitigation at Arapahoe Basin along Highway 6 just north of Loveland Pass Photo by Marilyn Gally

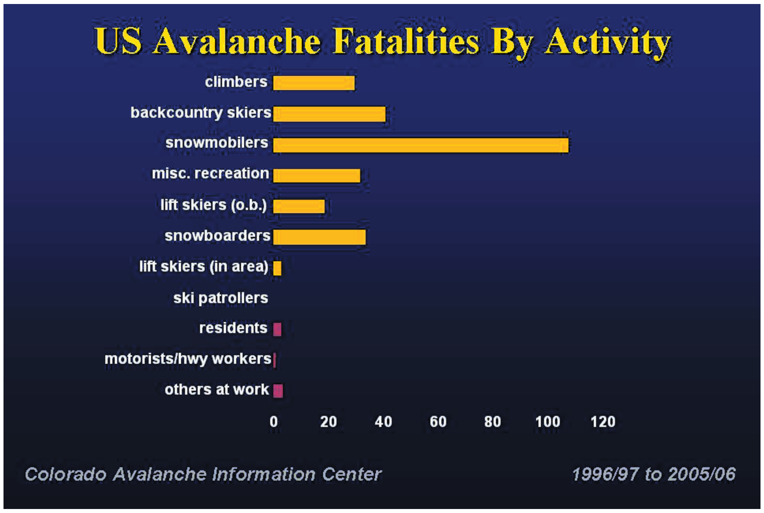
DAMAGE RELATED TO AVALANCHE IMPACT PRESSURES	
IMPACT PRESSURE (lbs/ft^2)	**POTENTIAL DAMAGE**
40-80	Break windows
60-100	Push in doors, damage walls, roofs
200	Severely damage wood frame structures
400-600	Destroy wood-frame structures, break trees
1000-2000	Destroy mature forests
>6000	Move large boulders
Sources: Mears 1992; FEMA 1997	

AVALANCHE HAZARD IN THE UNITED STATES

The following graph depicts the number of avalanche fatalities by state for winter seasons 1950/51 to 2005/06. Colorado leads the country with deaths attributed to avalanches during this time period. As shown in the next graph, statistics show that from 1950/51-2005/06 most deaths occurred during climbing activities. Statistics gathered from 1996/7-2005/6 show that that trend has been altered; most avalanche deaths in the United States in recent years occurred from avalanches while riding a snowmobile. For more information, refer to the Colorado Avalanche Information Center's website at http://avalanche.state.co.us.







SNOW AVALANCHE HAZARD IN COLORADO

The Colorado Geological Survey mapped areas susceptible to avalanche activity. Refer to Special Publication 7, Colorado Avalanche Area Studies and Guidelines for Avalanche-Hazard Planning, published in 1979. Plates are included for the following hazard zones areas:

- Aspen area, Pitkin County
- Camp Bird area, Ouray County
- Crested Butte-Gunnison area, Gunnison County (selected zones)
- Frisco area, Summit County
- Henson Creek area, Hinsdale County
- Independence Pass area, Lake & Pitkin Counties
- Marble area, Gunnison County
- Mt. Zion area, Lake County
- Ophir area, San Miguel County
- Rico area, Dolores County
- Rose Cabin area, Hinsdale County
- Sherman area, Hinsdale County
- Silver Plume area, Clear Creek County
- Twin Lakes area, Lake County
- Vail area, Eagle County

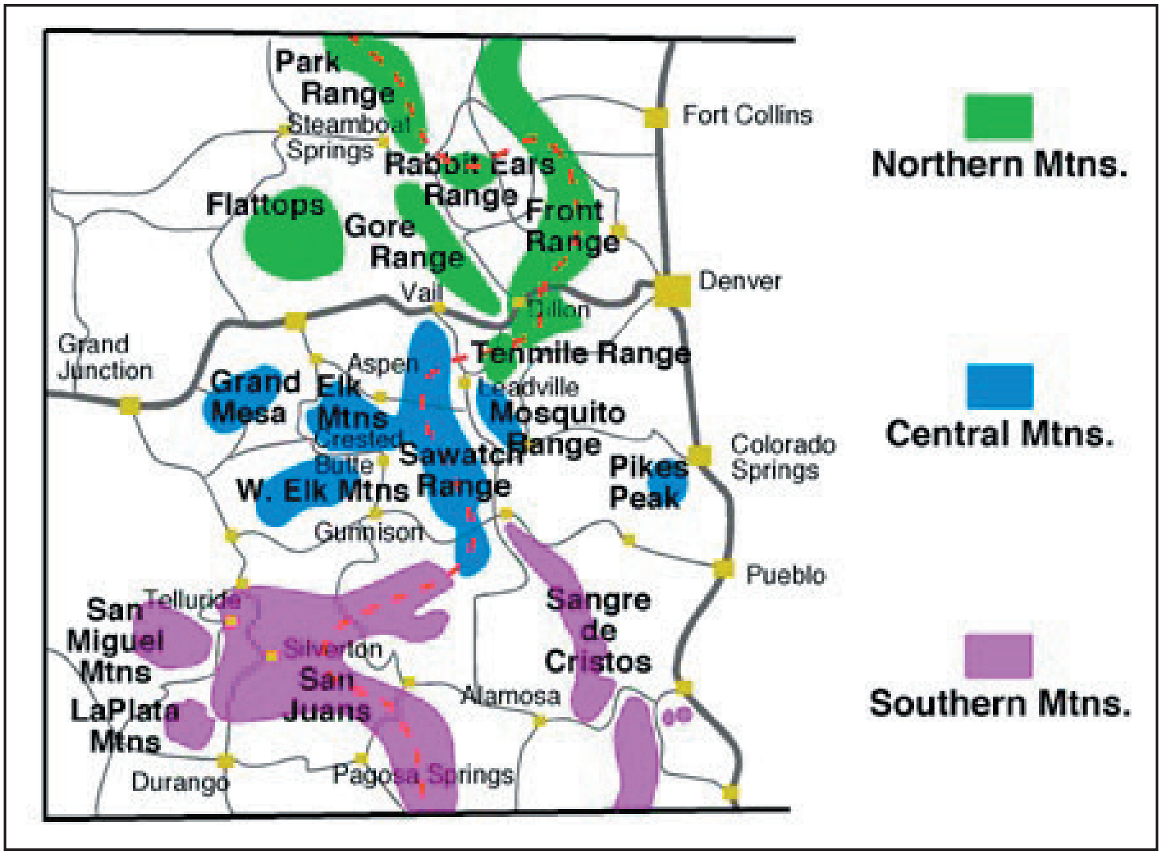
Avalanche Area Warning Sign Photo by David Marlin

> **"... since 1980, avalanches annually cause on average five deaths, five severe injuries, more than $100,000 in direct property damage, and more than $1 million in economic losses. Additionally, avalanches block highways 100-200 times per winter."**
>
> - From "Avalanche Facts" by the Colorado Avalanche Information Center in Solving Land-Use Problems, Colorado Geological Survey 1998

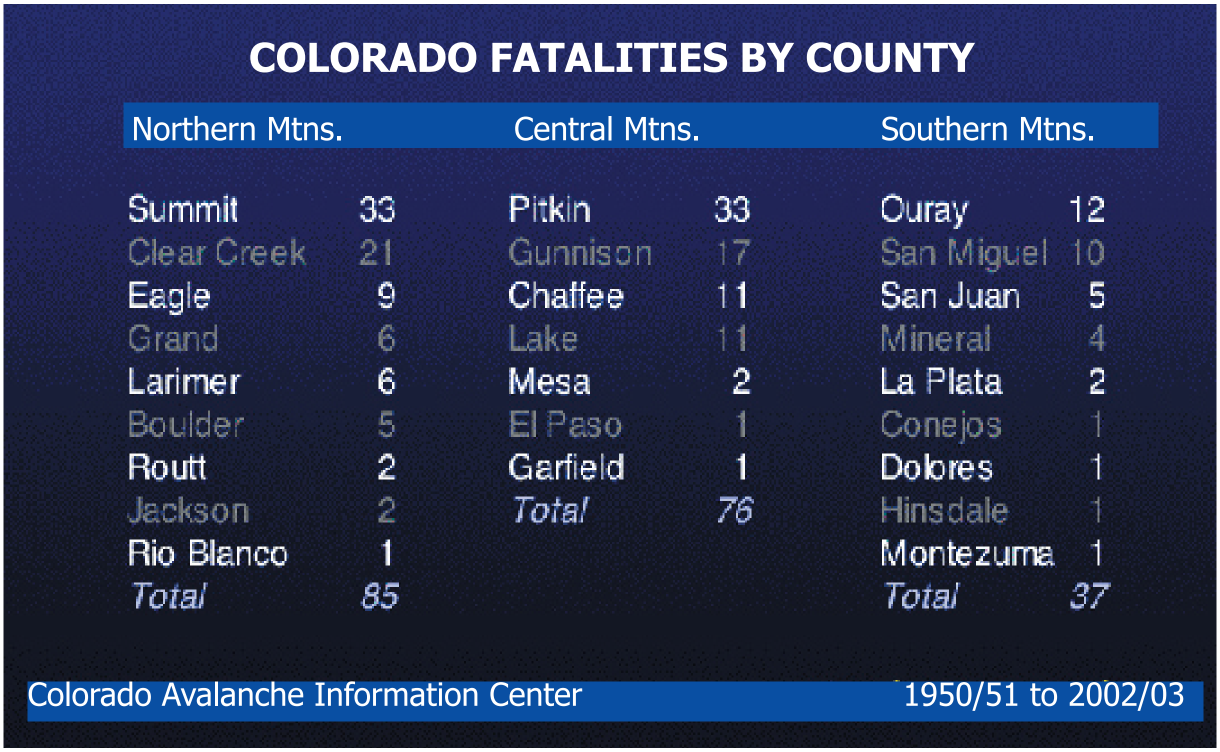
Notable Reported Avalanche Events with Deaths or Damages in Colorado: 1993 - 2006 (does not include injuries)

Date	Description	Deaths	Damage
1993	Heavy snow. Mountains, southwest. Highest snowfall 60.5". Road closures.	0	50,000
1993	Heavy snow. Northern, central, southwest mountains. I-70 avalanche. Cars, truck buried.	0	50,000
1993	Heavy snow to 2'. Mountains, southwest.	0	5,000
1994	Heavy snow (1-5'), high winds. Southwest. 200 hunters lost, stranded.	2	
1995	Heavy snow. Mountains, Front Range. Mountain snow to 8'. Road closures.	2	1.7 million
1996	Heavy snow to 2'. Central, northern, southwest mountains. I-70 20-car pile-up. Roads closed.	1	
1998	Avalanche. San Bernardo Mountain.	1	
1998	Avalanche. Ophir Gulch.	1	
1998	Avalanche. Near Gladstone.	0	75,000
1998	Preseason skier. Telluride Ski Area.	0	500
1999	Two skiers triggered avalanche at Aspen Highlands Ski Area.	1	
1999	Human triggered avalanche on Grand Mesa. Snowmobiler buried.	1	
1999	Cumberland Pass area.	3	
2000	Avalanche. Hurricane Gulch.	1	
2000	Avalanche. Highland Peak.	2	
2000	Diamond Peaks. Backcountry snowboarder buried.	1	
2001	Ohio Pass. Backcountry skier killed.	1	
2001	Farwell Mountain. Backcountry skier.	1	
2001	Crystal Peak, Tenmile Range. Backcountry snowmobiler.	1	
2001	Yankee Doodle Lake. Backcountry skiers.	1	
2002	Aspen Highlands. Skier killed.	1	
2002	Crystal Peak. Backcountry skier.	1	
2002	Miner Basin. Snowmobiler.	1	
2002	Aspen Mountain. Skier.	1	
2002	Ashcroft. Four backcountry skiers.	1	
2002	Telluride. Snowboarders.	1	
2002	Pagoda Peak. Three snowmobilers.	1	
2003	Burro Mountain. Snowmobilers.	1	5,000
2003	Clear Creek County. Damage to Silver Plume water treatment plant's chlorine contact building and tank. I-70 frontage road blocked. Clear Creek dammed up. Utility line down.	0	
2004	Grand Mesa. Crossed Highway 65.		5,000
2004	La Plata Peak. Snowshoers.	1	
2004	Mt. Huron. Snowshoer & skier.	1	
2005	Closure of Red Mountain, Molas and Coal Bank Passes. Front Range Wireless/Verizon Cell building destroyed.	0	200,000
2005	Soda Mountain. Backcountry skier.	1	
2005	Aspen Highlands area. Skier.	1	
2005	Quandary Peak. Climbers.	1	
2005	Grand Mesa. Skier.	1	
2005	Arapahoe Basin. Skier.	1	
2005	Mines Peak. Snowboarder.	1	
2005	Kelso Mountain. Hikers.	1	
2006	Trap Park area. Snowmobilers.	2	
2006	Snowmass. Skier.	1	

http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms; Colorado Avalanche Information Center http://avalanche.state.co.us



"Avalanche Regions" reprinted from http://geosurvey.state.co.us/avalanche/Default.aspx?tabid=1



COLORADO FATALITIES BY COUNTY

Northern Mtns.		Central Mtns.		Southern Mtns.	
Summit	33	Pitkin	33	Ouray	12
Clear Creek	21	Gunnison	17	San Miguel	10
Eagle	9	Chaffee	11	San Juan	5
Grand	6	Lake	11	Mineral	4
Larimer	6	Mesa	2	La Plata	2
Boulder	5	El Paso	1	Conejos	1
Routt	2	Garfield	1	Dolores	1
Jackson	2	*Total*	*76*	Hinsdale	1
Rio Blanco	1			Montezuma	1
Total	*85*			*Total*	*37*

Colorado Avalanche Information Center 1950/51 to 2002/03

From CGS Special Publication 12

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 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.

The Battleship (also known as Arnold) is a large path along US 550 in southwestern Colorado. It is located in the San Juan Mountains about 3.55 miles north of Silverton. The top of the starting zone is at 12,400 feet, and avalanches can fall 2720 feet to Mineral Creek, but very large slab avalanches such as this one can climb the 250 feet from the creek to the highway. This avalanche buried US 550 3 feet X 800 feet on February 28, 1987, Red Mountain Pass, Colorado. Photo by Tim Lane.

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. Snow avalanches also imperil cross-country skiers, downhill skiers, and snowmobilers and several of the backcountry 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 avalanche 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 destruction of property and the loss of life. Although most snow slides are initiated by natural causes, skiers frequently trigger the smaller avalanches that 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, such as debris flows, occupy the same area. Non-occupancy structures that are placed in avalanche paths and runout zones should be designed for expected impacts even if some other preventative measures are implemented. Portions of power lines, 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 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.

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:

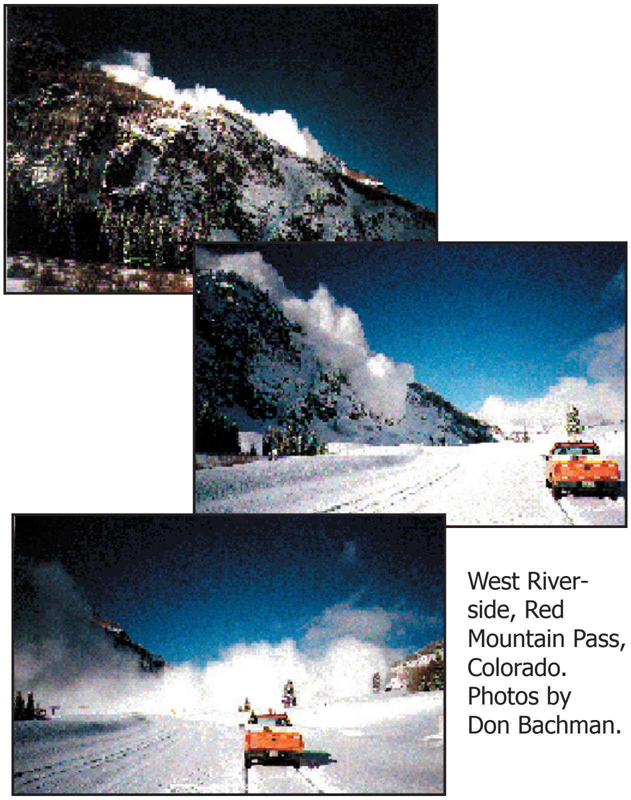
These examples are from "The Snowy Torrents, Avalanche Accidents in the United States, 1910-1966," published by the Alta Avalanche Study Center, U.S. Forest Service.

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 mud flow 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 now 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.

From CGS Special Publication 6
Definitions
Legal definition

H.B. 1041, Part 1, 106-7-103 (2) "Avalanche" means a mass of snow or ice and other material that may become incorporated therein as such mass moves rapidly down a mountain slope.



West Riverside, Red Mountain Pass, Colorado. Photos by Don Bachman.

The West Riverside is a large path along US 550 in southwestern Colorado. It is located in the San Juan Mountains, about 7.7 miles north of Red Mountain Pass. The top of the starting zone is at 11,840 feet. Avalanches can fall 2520 feet to Red Mountain Creek, but large slab avalanches such as this one can climb the 60 feet from the creek to the highway. During the winter of 1931-32 a huge avalanche buried the highway 53 feet X 1000 feet.

Descriptive definition

Snow avalanches are the rapid downslope movement of snow, ice, and associated debris such as rocks and vegetation. "The forces generated by moderate or large avalanches can damage or destroy most manmade structures. The debris from even small avalanches is enough to block a highway or railroad" (Martinelli, 1974, p. 5). Avalanches occur in the mountainous areas of Colorado generally above 8,000 ft. elevation, and most commonly occur from November through April. Avalanche occurrence is directly related to topography, climate, vegetation and aspect* of the area. Much of the information in this report was extracted from "Snow Avalanche Sites – Their Identification and Evaluation" by M. Martinelli, Jr. (1974). Readers with particular interest in avalanches will find that publication quite valuable.

An avalanche site or area is a location with one or more avalanche paths. Avalanche path refers to the specific area where a snow mass moves. A complete path is made up of starting zone(s) at the top where the unstable snow breaks away from the more stable part of the snow cover, runout zone(s) at the bottom where the moving snow and entrained debris stop, and track (s) that run between starting zone, where damage occurs from the turbulent winds that accompany fast-moving powder avalanches. The air blast zone is usually in the vicinity of, but not necessarily continuous with, the lower track or runout zone. In some cases it may even run part way up the slope across the valley from the avalanche path.

Avalanche start most frequently on slopes with average gradients of 30 to 45 degrees. Slopes steeper than 45 degrees usually do not accumulate enough snow to produce very large avalanches in the Rocky Mountain climate. Avalanches may start on slopes of less than 30 degrees if the snow is highly unstable as the result of a prolonged warming trend, heavy snowfall, or unusual wind condition.

These starting zone slope angles are, however, merely the range in which most dangerous avalanches occur; do not assume that slopes outside this range are safe from avalanches.The average gradient for the entire avalanche path will be more gentle than that of the starting zone. Average gradients of 20 degrees to 35 degrees are common for the tracks of Rocky Mountain avalanches while the slopes in the runout zones are often more gentle and sometimes completely flat, and may even extend up the opposite valley side.

Avalanches are not confined to specific terrain features: they may follow narrow gullies or ravines for all or part of their path; they may occur on broad, uniform slopes or even ridges and spurs. Longitudinal profiles of the paths may be concave, convex, or stepped. On stepped paths, small avalanches will often stop on a bench part way down the tract while larger ones run the full length of the path.

Severity of problem

The severity of avalanche hazard increases when the works of man extend into avalanche areas; therefore, the recognition of the potential aerial extents of avalanches is necessary. This recognition is difficult to achieve when man has not had the opportunity to observe avalanche activity in any particular path over a long enough period of time so that a reasonable assessment of runout potential may be made.

The maximum measured impact pressure of an avalanche is 10 ton/ft (2) while 1 ton/ft (2) is more common. A typical range is form 0.5 to 5.0 ton/ft (2). Air blasts from powder avalanches commonly exert a pressure of 100 lb/ft (2) of force (Martinelli, speech November 8, 1973). Pressures of only 20-50 lb/ft (2) are capable of knocking out most windows and doors. Roads, highways, and railroads are blocked for hours, or sometimes days, every year due to avalanches. Many skiers, other winter sportsmen, and travelers have been injured or killed by avalanche activity.

Lack of recognition of avalanche runout potential has resulted in residential building construction within runout zones in Colorado. When the infrequent, large avalanche event occurs, damage to these buildings will occur unless measures are taken to protect existing structures.

Criteria for Recognition

General

By far the most reliable way of locating avalanche areas is to study long-term, detailed records of past events when they are available. Such records are available for many localities in Europe, but unfortunately, compilation is just starting in Colorado.

Usually, data on the location, frequency, or severity of avalanche activity are completely lacking when new areas are considered for highways, winter sports, mining operations, or mountain home sites. Without adequate records of past events, the best alternative is to obtain what data are available, examine the area, map all recognizable paths, estimate the frequency and intensity of the avalanche action, and if possible, start a record of avalanche events.

Active or recently active avalanche paths are most easily identified on air photos or from low-flying airplanes or helicopters. The next best viewpoint is the slope or ridge across the valley from the suspected avalanche area. The entire path should be viewed from such vantage points so that there is less chance of misjudging the size of the path or of overlooking an indistinct or inconspicuous path. Such an overall view makes it possible to spot paths where the aspect of the starting zone and the track are different—an important feature in determining what wind direction causes deposition in the starting zone. Surveys from the valley bottom or lower slopes (the usual road location) are often very misleading. Crooked paths or those with a short, steep pitch in the lower track or runout zone often appear much shorter and smaller than they really are or may not even be recognized as avalanche paths.

Field evidence of avalanche

Summer conditions

Avalanche paths in forested areas usually appear as strips straight down the mountain, characterized by a different type or age of the dominant vegetation. These vertical swaths through the trees can be very dramatic when the change is from natural timber to grasses and small herbs. They are less conspicuous but still obvious to most observers when the change is from conifers to aspen or brush. On the other hand, careful scrutiny and often a distant vantage point are needed to spot the change from mature timber to younger trees of the same species.

In some cases, avalanches run down slopes with only scattered trees or open park-like stands of trees. These paths are hard to see, and only long and complete records will reveal all of them. Suspected areas should be checked carefully for evidence of avalanche activity. Good indicators of avalanche activity are trees with scars or broken limbs on the uphill side, or trees that lean downhill. Leaning trees deserve a second look, however, to be sure avalanches and not snow or soil creep or a landslide causes them.

An accumulation of wood debris on lower slopes or in the valley may mark an avalanche run-out zone, as might a patch of aspen or young trees at the bottom of a likely avalanche path. Patches of downed trees all aligned in the same direction are a good indication of avalanche activity. Do not discount such patches of downed trees because their tops point uphill. They may mark areas of air-blast, or they may be the result of an avalanche that crossed the valley and ran part way up the opposite slope.

Summer identification of avalanche paths in non-forested areas is difficult and uncertain. Slope steepness, aspect, and surface roughness all offer clues but no proof. Other things being equal, avalanches will be more likely:
-On lee slopes than on windward slopes, because of wind loading;
-On grass slopes than on brush-covered slopes, because of lower surface roughness;
-On shaded northern slopes than on sunny southern slopes, because the snow stays loose and unstable longer; and
-On slopes between 30 degrees and 45 degrees than on steeper or gentler slopes because of their ability to accumulate sufficient snow on terrain steep enough to avalanche readily.

Large patches of bare soil surrounded on the sides and above by vegetation, if located on slopes steep enough to avalanche, should be considered possible avalanche starting zones. This lack of vegetation is often due to deep snow accumulation.

Steep rock faces or cliffs that have numerous benches or pockets where snow can accumulate may also be the sources of avalanches in spite of the general statement that very steep slopes usually are not serious avalanche problems.

Many avalanche paths cross both non-forested and forested areas. In the Rocky Mountains, for example, many avalanches start above timberline, their track in the timber. In such cases, the swath through the trees is the most obvious identification feature, but the starting and run-out zones must be given full consideration when establishing size and estimating frequency and intensity of activity.

Winter Conditions

Not all avalanche paths run every year. Many run only once every 5 to 15 years, and others even less frequently. Nor do all avalanches run the full length of their paths every time. Avalanches may stop in the starting zone, track, or run-out zone, depending on the amount and condition of the snow in the path. Field evidence—usually confined to the starting zone—that an avalanche has occurred includes:
A fracture line or fracture face where the unstable snow broke away as a slab avalanche from the remaining snow cover. This is the most frequently observed and perhaps the most important, single, winter identification feature. The continuity of these fracture lines makes even small ones visible for great distances. New snowfall or drifting snow, however, soon obscures shallow fracture lines and makes even large ones much less distinct.

A change in snow depth and in the texture and features of the snow surface, without a distinct fracture face. All of these features, which mark the start of a loose snow avalanche, are quickly erased by snowfall and drifting snow, and may be missed even by a careful observer. Additional evidence of avalanches—features that may be located in the starting zone, track, or run-out zone, and whose size and location in the path are clues to the size of the avalanche – includes:

Mounds of blocks of snow. Major concentrations usually mark the lower end of the avalanche. Lesser amounts may be scattered higher on the path, at breaks in the slopes, or curved in the track. This is the second most important winter identification feature.

Snow dirtier and denser than the surrounding cover. At times, even after avalanche debris has been covered by fresh snow and all surface indications of avalanche debris are lost, a ski tip or pole or a probe rod can detect the harder, denser avalanche snow beneath. In late spring or summer, these deeper and denser snow deposits often persist after the surrounding cover has melted, and they make excellent identification features. It may be difficult, however, to tell if the debris is from one or more avalanches on the same path.

A clean white swath through gray or dust-covered snow in steep terrain. After snow surfaces have become dust covered or modified by weather during long snow-free periods, the removal of these surface layers by avalanches reveals the clean, unmodified snow beneath. The change in color and texture is noticeable, even if the avalanche left little other evidence.

Accumulations of broken trees, limbs, twigs, leaves, and needles. Entire trees may be uprooted, broken off, or bent over and are usually oriented parallel to the down-slope direction. Large amounts of timber in the debris indicate an avalanche that ran larger than usual or took a different route down the mountain.

Snow, mud, rock, or detached tree limbs plastered against uphill side of standing trees or rocks. These signs often help mark the outer edges of the moving snow. They are most noticeable just after an avalanche has run and are quick to disappear.

Deep grooves in the snow and walls of snow; both usually oriented down the fall line. These indicated avalanches in heavy, wet snow. Grooves and sides of walls are usually smooth and icy. These features are more common in spring avalanches than in winter ones.

“Flag trees” with fresh scars or broken limbs on uphill side of standing trees, and brush with healthy limbs confined to the downhill side. Confusion with wind-damaged trees can be avoided by a complete investigation of the site containing such “flag trees.”

After an avalanche path has been located, it is important to know the size and frequency of avalanches on the path. Long-term observation is the best way to establish avalanche frequency and size. These are, however, available for only a few locations in the United States. The next best thing is to systematically observe the destructive effects of avalanches on the terrain during snow-free conditions. Sometimes, evidence may be found of multiple avalanche events of various sizes and ages through a careful analysis of destruction in the avalanche track and through the distribution of debris in the run-out zone. Additional sources of information may come form “old timers” in the area. Highway maintenance crews, power-line crews, ranchers, trappers, hunters, or fishermen should be quizzed. In more remote areas, ski touring, snow mobiling, or winter mountaineering groups may be a better source of information. Newspaper and other written accounts occasionally help in establishing the data of major events, but are selective toward very large avalanches or those that took lives or did extensive damage.

All incomplete records will be selective in one way or another, and must be used with caution. Highway crews will be most concerned with slides across the road and will seldom pay much attention to those that do not reach the road. Sportsmen will be more apt to see the early avalanches that run during hunting season or those that leave large debris cones that persist in the valley well into fishing season. Such accounts are not definitive in establishing avalanche frequency.

Consequence of Improper Utilization

Avalanches are not a hazard until man’s activities and land uses are affected adversely by the avalanches.
Possible conflicting land uses are recreation, residential, transportation, and mining. Examples of this conflict would include property damage, injury, deaths and excessive maintenance costs.

Deaths

Avalanches can cause deaths whenever people are within the area affected by the avalanche. This area is the entire avalanche path including the air-blast zone. Death can be caused by impact and/or suffocation. In Colorado there have been 43-recorded deaths from avalanches since 1950. This averages about two avalanche fatalities per year for the state (Martinelli, 1974, personal communication).

In the late 1800’s and early 1900’s the number of fatalities caused by avalanches in Colorado was far greater due to the extensive mining activity in avalanche-prone areas. It has been reported that 119 people died in 1899 alone while it was not uncommon to have dozens killed each year. Now in the 1970’s, Colorado is again experiencing an increase of human activity in the high mountain area. H.B. 1041 provides government and citizens with the means to protect property and life from future high losses caused by snow avalanches.

Property damage

Property damage can occur throughout the entire avalanche path. Impact (air or snow) damage ranges from minor to major structural damage to any structure within the path. Vehicles and equipment can be moved great distances and damaged. When deposited, the debris associated with the avalanche might cause damage and be expensive to remove. Roads and bridges may be damaged.

Maintenance

Roads, highways and railroads may become blocked by avalanche snow and debris. In addition to delaying highway and rail travel, it is costly to clear the transportation routes. In a few cases, where avalanches threaten access roads to mountaintop radio and microwave communication sites, emergency repairs and maintenance are delayed. In areas where efforts are underway to control avalanches, the maintenance of avalanche control structures and/or explosive control is costly. In summary, man's activities in avalanche-prone areas can be costly in both money and lives. Improper utilization of avalanche areas includes all uses that generate unacceptable costs in lives or property.

Mitigation Procedures

The location, time, and magnitude of avalanche events are difficult to predict. Because potentially destructive avalanches are relatively common in the Colorado mountains, anyone planning new facilities and land uses should avoid avalanche-prone sites, or otherwise provide for acceptable safety and economic feasibility of the proposed use.

Avoidance

The safest and probably the most economic mitigation procedure is to avoid building or any type of development involving winter use in avalanche-prone areas. This implies that all avalanche prone areas can be identified and the avoidance is possible.

Non-conflicting use

Non-conflicting land uses of avalanche-prone area include all uses that will not cause loss of life, property, or excessive maintenance. Agriculture and recreational activities that take place during non-avalanche months are desirable non-conflicting uses. Other uses that could be considered are those that involve no permanent unprotected structures in the avalanche path or those that could be moved or closed down during high avalanche-risk periods.

Engineered design and construction for correction of adverse conditions

The two basic methods of avalanche control are: 1) explosive and 2) structural. Explosive techniques have been used for the deliberate release of avalanches for many years. The theory of this technique is to cause many smaller, controlled avalanches and thus avoid large unpredictable destructive avalanches. The principal methods of charge emplacement are: a) hand delivery, in which charges are placed on or in the snow-pack for immediate firing, and b) projectile delivery, in which charges are fired into the snow-pack by guns. Explosive control has been very effective in areas with easy access to avalanche starting zones and ones that can tolerate many small slides without causing damage. Detailed information on current and past snow-pack and avalanche conditions should be available, for this technique to be safe and effective. This method may be unacceptable in areas where easy access to the starting zones is not available, where projectiles must be fired over occupied buildings, where an occasional large avalanche would be especially destructive, or where manpower and facilities are not available to maintain an up-to-date evaluation of snow cover stability. In general, explosive control is probably unacceptable for areas of human occupancy.

Structures for the control of snow avalanches fall into four categories (for details see Martinelli, 1972):

Supporting structures in the starting zone are built in the upper part of the avalanche path to prevent avalanches from starting, or to retard snow movement before it gains momentum. Some of the first supporting structures were massive earth and stonewalls and terraces intended to interrupt the continuity of the steep slopes and to prevent avalanches. Modern supporting structures in the starting zone may be either rigid or flexible. The rigid ones are made of wood, steel, aluminum, pre-stressed concrete, or a combination of these materials. Flexible supporting structures called "snow nets" are constructed of steel cables or nylon straps and are held up by steel poles.

Deflecting and retarding structures in the run-out zone are massive structures usually made of earth, rock, or concrete located in or near the avalanche track or run-out zone. The purpose of the structures is to keep the moving snow of an avalanche away from critical locations of structures. Structures to confine or deflect moving snow should deflect the avalanche as little as possible from the direction of natural flow. Walls built at sharper angles to the flowing snow will often be overrun by fast-moving masses of dry snow.

Retarding structures are usually earth mounds or large concrete structures called breakers or tripods. They should be built on benches or less steep parts of the path where avalanches slow or stop naturally. The additional roughness and cross currents set up by these structures usually stop all but large, dry snow avalanches. Mounds are inexpensive to install and relatively easy to maintain; however, they have been ineffective on slopes steeper than 20 degrees (35%).

Direct protection structures are built immediately adjacent to the object to be protected, or in a few cases, incorporated in the design of the object itself. The aim is to render complete protection regardless of avalanche size, type, or frequency example. Avalanche sheds are merely roofs over a road or railroad that allows avalanches to cross the road without interrupting or threatening traffic. Avalanche sheds are more effective for railroads or narrow roads than for multilane superhighways currently being built.

In actual practice it is common for many different types of structures to be used on a single path. For example, to protect a village with its homes, schools, churches, and roads, from large avalanches, supporting structures, wind baffles, and snow fences may be used in or near the starting zone. These stabilize the upper part of the avalanche path. Mounds, walls, and concrete tripods may be used farther down the mountain to catch any avalanches that start below the supporting structures. Direct protection structures may also be needed to protect isolated objects such as power-lines or ski-lift towers, mines, or buildings, if any exist in or near the path between the supporting structures and the mounds. In addition, most European avalanche defense systems include reforestation up to the natural tree line.

Obviously, the most desirable and effective protection against avalanches is to locate buildings, roads, and other valuable objects in areas free from avalanches. With ample space and an informed mountain population this is not too difficult. However, as population grows and less desirable sites are considered for development, advanced planning and strictly enforced zoning and construction practices appear the best solutions. In some cases, even these are not adequate to completely eliminate risks for avalanche danger and certain risks must be assumed, especially in the case of roads, power-lines and railroads. These risks can, however, be reduced considerably if appropriate structural controls are employed.

For more information on avalanches please visit the Colorado Avalanche Information Center. From http://geosurvey.state.co.us/pubs/geohazards/docs/avalanche.asp.

For more information on avalanches please visit the Colorado Avalanche Information Center. http://avalanche.state.co.us

Avalanche danger along Highway 6
Photo by Marilyn Gally

Drought

drought - an extended period of dry weather, especially one injurious to crops.

DROUGHT

Ironically, droughts are usually associated with "unusually nice weather," for example, very long periods of warm, dry, sunny days.

High temperatures, prolonged high winds, and low relative humidity can aggravate drought conditions.

Twenty Colorado counties declared drought disasters due to loss of winter wheat and hay for cattle in the 1989-1990 season. Losses to the agricultural community were estimated in the millions of dollars.

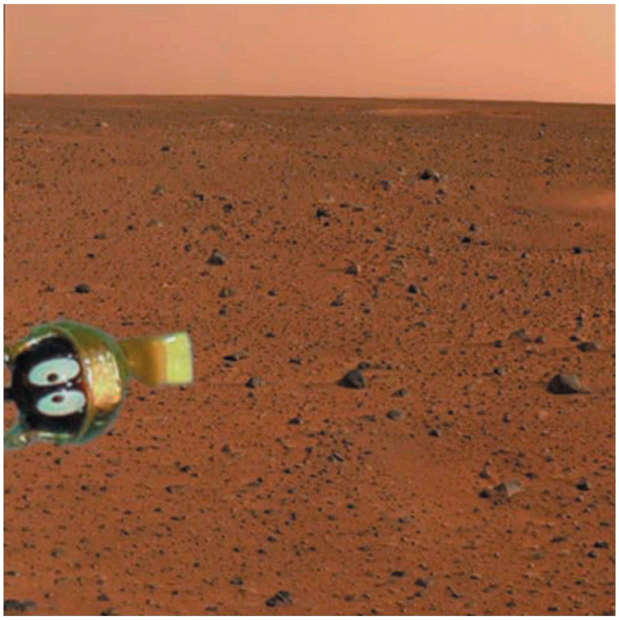
Loss estimates for the 1976-1977 drought in the Great Plains, Upper Midwest, and Western States were up to $15 billion. Losses for the 1987-1989 drought in the Central and Eastern states were $39 billion. In 1998, over $2 billion in property loss was credited to drought in the United States.

Significant impacts, which may affect Colorado during periods of drought, are those that rely heavily on high water usage. Activities affected include agriculture, tourism, wildfire protection, municipal water usage, commerce, recreation, wildlife preservation, electric power generation, and water quality deterioration.

Droughts can lead to economic losses, such as unemployment, decreased land values, and business losses.

USDA and Small Business Administration disaster declarations include drought. These declarations allow small businesses in certain counties that meet the criteria to apply for low interest Economic Injury Disaster Loans.

(Sources: FEMA 1997; Colorado Office of Emergency Management 2000; www.nws.noaa. gov/om/severe_ weather/sum_98.htm)



Drought News ...

"Hot, dry weather has wilted Colorado's wheat harvest, parched pasture land and drained reservoirs, spurring the growth of desperation, fear and despair among ranchers and farmers. ..."

-from "Western Ranchers Fear Crisis," Associated Press Information Services, September 04, 2000

"Just as the Eastern Plains have been scorched by what officials are reluctantly beginning to call a drought, the normally green mountains in Colorado have become parched as well, and residents are beginning to feel the heat. Carbondale officials today are planning to impose watering restrictions, joining a growing list of towns throughout the mountains where rationing is becoming a way of life. Limits on water use are already in place in Kremmling, Basalt, Gypsum, Pinewood Springs and Georgetown."

- from Steve Lipsher, "Heat parches mountains," The Denver Post, August 12, 2000

TYPES OF DROUGHT
Meteorologic: based on degree of dryness; actual precipitation is less than expected average or normal amount.
Hydrologic: based on precipitation shortfall effects on streamflows and reservoir, lake & groundwater levels.
Agricultural: based on soil moisture deficiencies relative to water demands of plant life.
Socioeconomic: occurs when the demand for water is greater than supply due to a weather-related supply shortfall.
Source: FEMA 1997

DROUGHT HAZARD IN THE UNITED STATES

The table below lists 17 significant droughts in the United States, as listed by www.ncdc.noaa.gov/ol/reports/billionz.html.

Notable Drought Events in the United States: 1924-2006

Years	Region
1924-1934	California
1930-1940	Midwest (Dust Bowl)
1942-1956	Southwest
1952-1956	Midcontinent and Southeast
1961-1967	Northeastern States
1976-1977	Great Plains, Upper Midwest, Western States
1980-1981*	Central and Eastern States
1987-1989*	Central and Eastern States
1987-1992	California and Upper Great Plains
1993*	Southeast
1995-1996*	Southern Plains
1998*	Southern States
1999*	Eastern States
2000	Southeastern, Southcentral States
2002	Widespread (30 states)
2005	Midwest (AR, IL, IN, MO, OH, WI)
2006	Great Plains region, south, far west

*Refer to BILLION!! Dollar Disaster Events 1980-2006

Sources: www.ncdc.noaa.gov/ol/reports/billionz.html

According to NOAA, since 1980 there have been 12 drought/heat waves in the U.S. with losses estimated at over $1 billion each. Starting with the most recent:

2006 - Great Plains, parts of the south and far west. Estimated over $6 billion.
2005 - Midwest. Spring-Summer 2005. Estimated $1.0 billion+ in damage/costs, no reported deaths.
2002 - Thirty states, western states, Great Plains, eastern states. Estimated $10.0 billion in damages/costs. No deaths reported.
2000 – Southeastern and southcentral states. Estimated losses $4+ billion and 140 deaths.
1999 – Mainly eastern states. Estimated over $1 billion in losses and 502 deaths.
1998 – Texas/Oklahoma eastward to Carolinas. Estimated losses $6 to 9 billion and 200 deaths.
1995-6 – Southern plains. Estimated $5 billion in losses. No deaths reported.
1993 – Southeast states. Estimated $1 billion in losses and 16 deaths.
1989 – Northern plains. Estimated $1 billion in losses. No deaths reported.
1988 – Central and eastern states. Estimated $40 billion in losses and 5,000 to 10,000 deaths.
1986 - Southeast states. Estimated $1 to $1.5 billion in losses and 100 deaths.
1980 – Central and eastern states. Estimated $20 billion in losses and 10,000 deaths.

The table following demonstrates the amounts of property and crop damage in the United States attributed to drought in recent years.

Summary of Reported Damage Costs for the United States due to Drought: 1996-2006

Year	Property Damage ($ millions)	Crop Damage ($millions)
1996	135.4	504.1
1997	24.0	253.0
1998	40.0	2,142.0
1999	0.1	1,332.9
2000	0.7	2,438.1
2001	0	1,273.9
2002	0	737.6
2003	645.2	572.5
2004	0	1.2
2005	77.4	1,311,1
2006	138.0	2,498.1

Sources: www.nws.noaa.gov/om/severe_weather/

USDA's Federal Crop Insurance Corporation (FCIC) payments alone for drought losses have averaged $462 million annually (33 percent of total FCIC payments) since 1989. More than half of the total $4.1 billion in 2002 crop insurance indemnity payments, or some $2.5 billion, was for drought-related causes. In 2003, those indemnities were approximately $3.2 billion – of this amount about 54 percent is attributable to drought-related losses. (http://www.usda.gov/documents/NewsReleases/2004/05/fs0199.doc).

DROUGHT HAZARD IN COLORADO

"Drought is a natural yet unpredictable occurrence in Colorado. Colorado weather does not provide for a consistent, dependable water supply throughout the year across the state. With Colorado's semiarid and variable climate there will always be concern for water availability within the state" – from The Colorado Drought Mitigation and Response Plan, January 2001. Several times throughout this century, areas of Colorado have experienced conditions of drought. The most dramatic drought periods occurred in the 1930s and 1950s when many states, Colorado included, were affected for several years at a time. The table on the next page, presented by McKee, Doesken and Kleist (1999), shows five multi-year drought periods experienced in Colorado since 1893.

For complete information on drought in Colorado, refer to the *Colorado Drought Mitigation and Response Plan* at www.dola.state.co.us/oem/Publications/droughtplan.402b.pdf.

HISTORICAL DRY AND WET PERIODS IN COLORADO: 1893-1996

YEARS	DRY	WET	DURATION
1893-1905	X		12
1905-1931		X	26
1931-1941	X		10
1941-1951		X	10
1951-1957	X		6
1957-1959		X	2
1963-1965	X		2
1965-1975		X	10
1975-1978	X		3
1979-1996		X	17

Sources: McKee, Doesken and Kleist 1999

USDA Disaster Declarations For Colorado

USDA secretarial disaster designations must be requested by a governor or the governor's authorized representative or by an Indian Tribal Council leader. The secretarial disaster designation is widely used. Damages and losses prompting disaster designations must be due to a natural disaster and a minimum 30-percent production loss of at least one crop in the county must have occurred. The table below lists the most recent USDA Secretarial disaster designations for Colorado. The actual year, not the federal fiscal year, is listed along with the type of hazard, declaration number and primary counties.

USDA SECRETARIAL DISASTER DECLARATIONS: PRIMARY COUNTIES ONLY, 2003 - 2006 UPDATE

YEAR	TYPE	DECLARATION NUMBER AND COUNTIES
2006	Drought	S2480 Sedgwick
2006	Drought	S2382 Jackson, Lincoln, Mesa, Moffat
2006	Heat, high winds, drought	S2351 Eagle, Garfield, Larimer, Logan, Otero, Pitkin, Rio Blanco, Yuma
2006	Heat, high winds, insect pests, late freeze, drought	S2329 Arapahoe, Archuleta, Bent, Boulder, Crowley, Delta, El Paso, Gunnison, Jefferson, Kiowa, La Plata, Montrose, Ouray, Park, Phillips, Teller, Washington
2005-2006	Drought, Fire, High Winds, Heat	S2327 Adams, Alamosa, Baca, Broomfield, Chaffee, Cheyenne, Conejos, Costilla, Custer, Denver, Dolores, Douglas, Elbert, Fremont, Hinsdale, Huerfano, Kit Carson, Lake, Las Animas, Mineral, Montezuma, Morgan, Prowers, Pueblo, Rio Grande, Saguache, San Miguel, Weld
2005-2006	Drought, Crop Diseases, Insect Infestation	S2287 Huerfano, Kiowa, Las Animas, Sedgwick
2005	Drought, Crop Diseases, Insect Infestation	S2217 Logan
2005	Drought, Wind, Heavy Rain, Hail	S2188 Crowley, El Paso, Lincoln, Otero, Park, Phillips, Pueblo, Teller, Washington, Yuma
2005	Drought, Freezing Temperatures	S2160 Delta, Kit Carson
2005	Drought	S2031 Huerfano, Las Animas, Rio Blanco
2004	Drought	S2009 Moffat
2004	Drought, Freeze, Hail	S1947 Baca, Chaffee, Cheyenne, Custer, Eagle, Fremont, Garfield, Grand, Jackson, Kiowa, Kit Carson, Lake, Lincoln, Phillips, Pitkin, Prowers, Pueblo, Routt, Summit, Yuma
2003	Drought	S1890 Cheyenne, Phillips
2003	Drought, Insects	S1843 Alamosa, Archuleta, Chaffee, Conejos, Costilla, Crowley, Custer, Dolores, Fremont, Garfield, Hinsdale, Huerfano, La Plata, Lake, Las Animas, Mesa, Mineral, Moffat, Montezuma, Otero, Pueblo, Rio Blanco, Rio Grande, Routt, Saquache
2003	Drought	S1797 Baca, Bent, Elbert, Kiowa, Lincoln, Prowers

2007 USDA-Colorado Farm Services Agency

DESCRIPTION OF MAPS ON THE FOLLOWING PAGES
The National Climatic Data Center map on the following page shows statewide ranks for the driest and wettest precipitation years on record. In 2002, Colorado had the driest year on record. The subsequent three maps are from the Drought Monitor and Drought Impact Reporter websites.

About the Drought Impact Reporter

(from http://www.drought.unl.edu/dm/monitor.html) The three maps following are downloaded from the Drought Impact Reporter site and the description below is directly taken from the website.

The National Drought Mitigation Center developed the Drought Impact Reporter in response to the need for a national drought impact database for the United States. Drought impacts are inherently hard to quantify, therefore there has not been a comprehensive and consistent methodology for quantifying drought impacts and economic losses in the United States. The Drought Impact Reporter is intended to be the initial step in creating a comprehensive database. The principal goal of the Drought Impact Reporter is to collect, quantify, and map reported drought impacts for the United States and provide access to the reports through interactive search tools.

The need for the Drought Impact Reporter and its comprehensive database becomes clear when one considers that drought is a normal part of the climate for virtually all portions of the United States. In addition, all evidence suggests that the impacts of drought are increasing in magnitude and complexity. A risk management approach to drought management, which strongly emphasizes improved monitoring and preparedness, requires more timely information on the severity and spatial extent of drought and its associated impacts. Improved information on drought impacts will help policy and decision makers identify what types of impacts are occurring and where. In addition, the Drought Impact Reporter will aid them in understanding the magnitude of the impacts by providing access to reported drought impacts. More precise estimates of drought impacts will aid the government in instituting programs before drought occurs, as opposed to incurring high expenditures on post-drought relief.

The Drought Impact Reporter

Information for the impact report database comes from a variety of sources:

- on-line drought-related news stories and scientific publications, reviewed by NDMC staff
- members of the public who visit the website and submit a drought-related impact for their region (see Add A Drought Impact)
- members of the media
- members of government agencies such as National Oceanic and Atmospheric Administration (NOAA) and U.S. Department of Agriculture (USDA).

All impact reports submitted via the website are reviewed by NDMC staff members. After a new entry is reviewed and accepted, its impact report will be posted on the map.

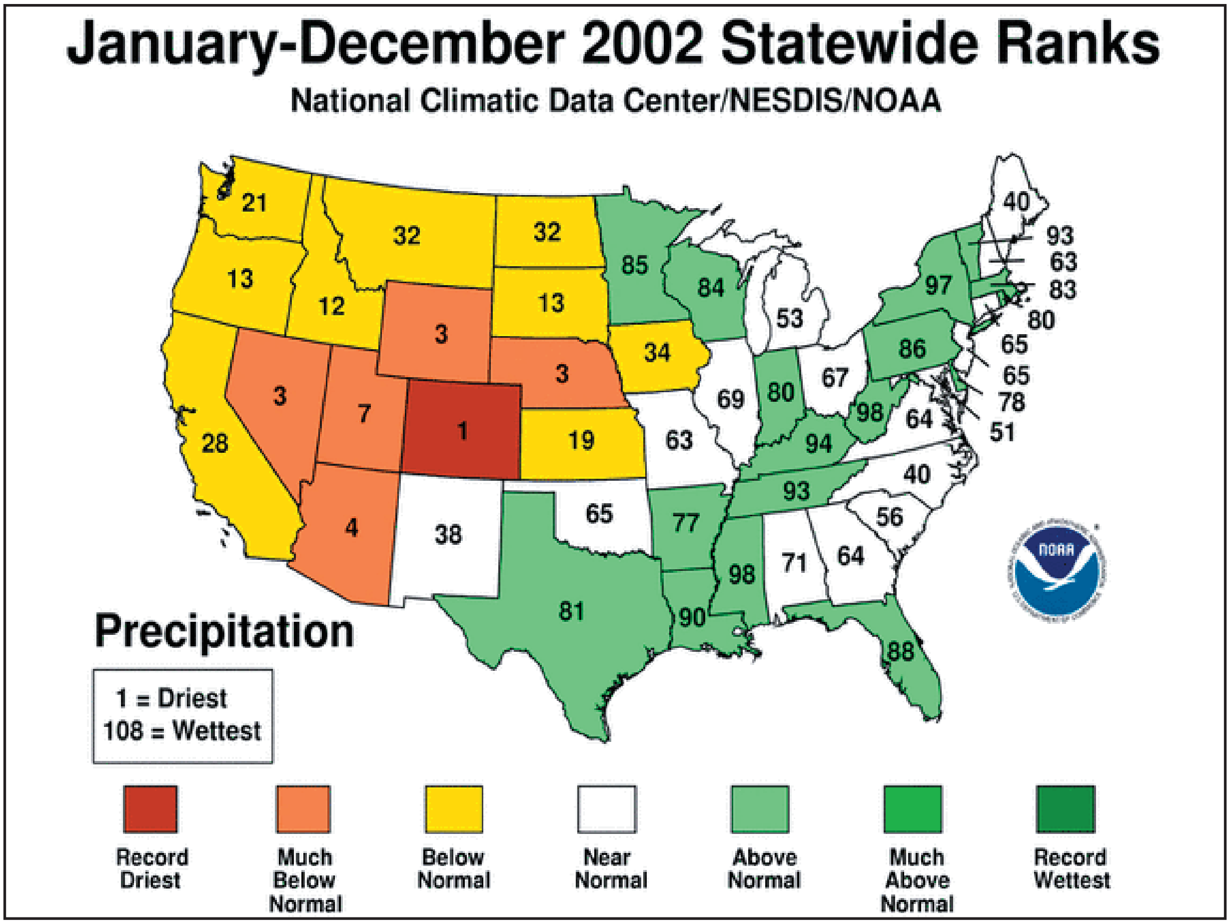
We are in the process of building the impact database, beginning with the most recent impacts (in the past few months) and working back. We appreciate your patience as we continue to populate the database.

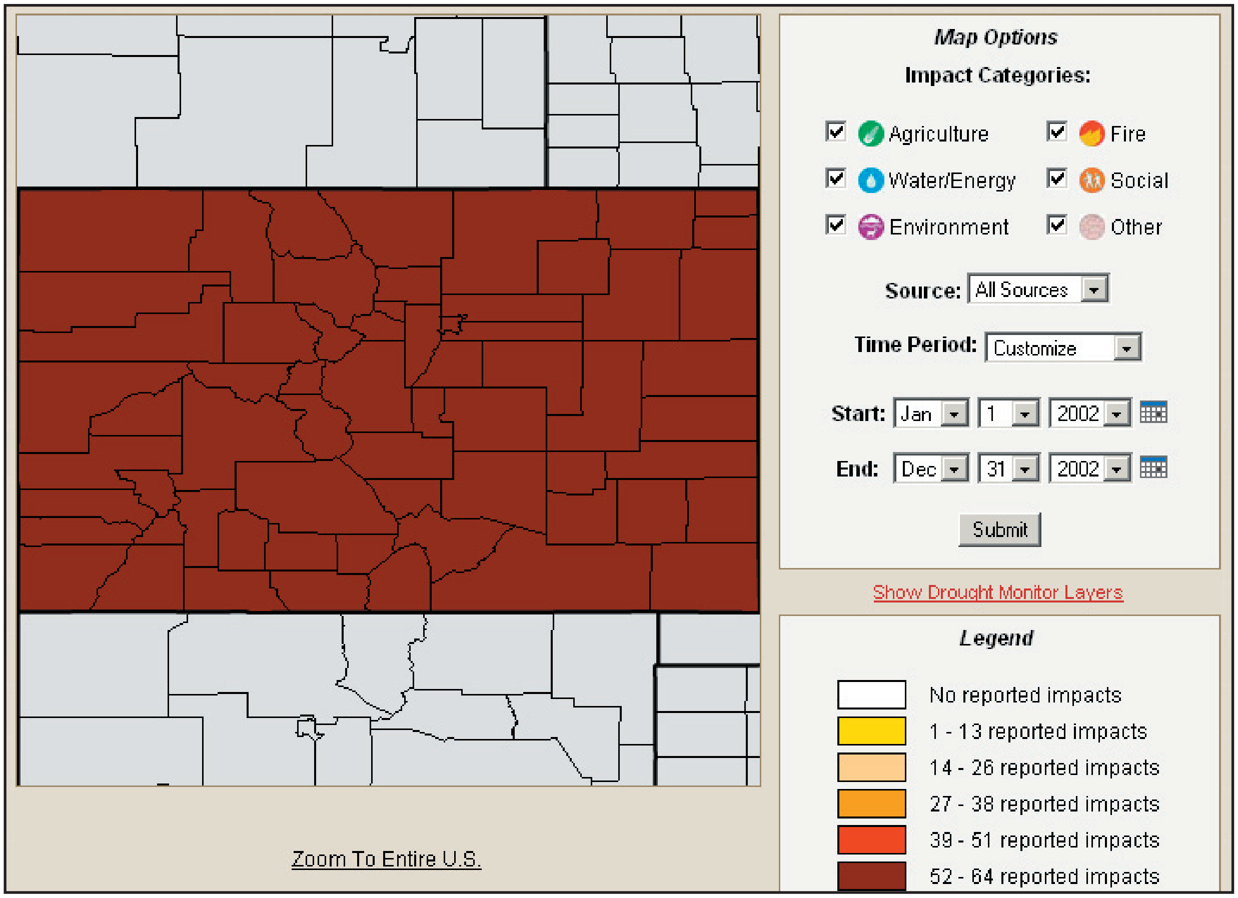
The Drought Impact Reporter Map

The Drought Impact Reporter displays a map that represents the number of reported drought impacts over a specified period of time. The default view displays the reported impacts from all sources and all impact categories for the last month at the national level. At the national level, states are shaded in colors based on the number of reported impacts in each state. To view a state in more detail, click on the state. At the state level, the counties are also shaded in colors based on the number of reported impacts in each county. To the right of the map, several settings can be changed under Map Options. The user can select various impacts to map, change the timeframe for the map, change the reporting source, or turn on the Drought Monitor shapefiles.

The first Drought Impact Reporter Map on the following pages reflects the year 2002, the driest year on record. Every county in the state had over 52 impacts reported. Specific impacts are too numerous to list in this plan; please refer to the website for specific information. The second map shows the drought impacts for this state plan update period, from January 1, 2004 through December 31, 2006. During this time period, reports of impacts ranged from 26 to 42. The following page contains an example of the impacts for the three-year period for Mesa County as reported in the Drought Impact Reporter. The final two maps demonstrate the Drought Monitor maps available online.

The maps below are from the U.S. Drought Monitor website. http://drought.unl.edu/dm/monitor.html





Map Options

Impact Categories:

☑ Agriculture ☑ Fire

☑ Water/Energy ☑ Social

☑ Environment ☑ Other

Source: All Sources

Time Period: Customize

Start: Jan 1 2002

End: Dec 31 2002

Submit

Show Drought Monitor Layers

Legend

⬜ No reported impacts

🟨 1 - 13 reported impacts

🟧 14 - 26 reported impacts

🟧 27 - 38 reported impacts

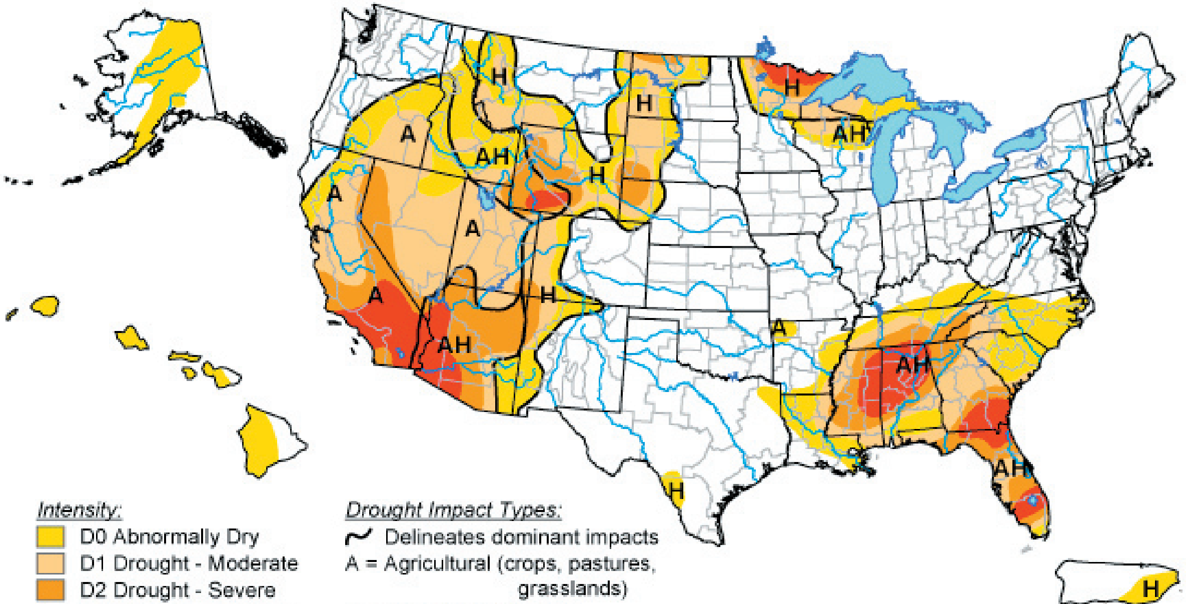
🟥 39 - 51 reported impacts

🟫 52 - 64 reported impacts

Zoom To Entire U.S.

U.S. Drought Monitor

May 8, 2007
Valid 8 a.m. EDT



Intensity:
- 🟨 D0 Abnormally Dry
- 🟧 D1 Drought - Moderate
- 🟧 D2 Drought - Severe
- 🟥 D3 Drought - Extreme
- 🟫 D4 Drought - Exceptional

Drought Impact Types:
- ~ Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm

Released Thursday, May 10, 2007
Author: Brian Fuchs, National Drought Mitigation Center

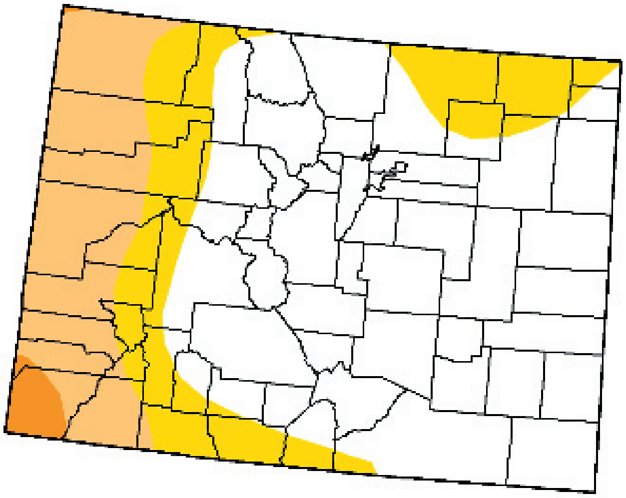
U.S. Drought Monitor

Colorado

May 1, 2007
Valid 7 a.m. EST

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	63.8	36.2	18.3	1.5	0.0	0.0
Last Week (04/24/2007 map)	58.2	41.8	21.0	1.5	0.0	0.0
3 Months Ago (02/06/2007 map)	73.7	26.3	12.3	2.3	0.0	0.0
Start of Calendar Year (01/02/2007 map)	59.5	40.5	15.8	2.2	0.0	0.0
Start of Water Year (10/03/2006 map)	0.0	100.0	36.5	8.6	0.0	0.0
One Year Ago (05/02/2006 map)	24.5	75.5	55.3	23.6	0.5	0.0



Intensity:
- 🟨 D0 Abnormally Dry
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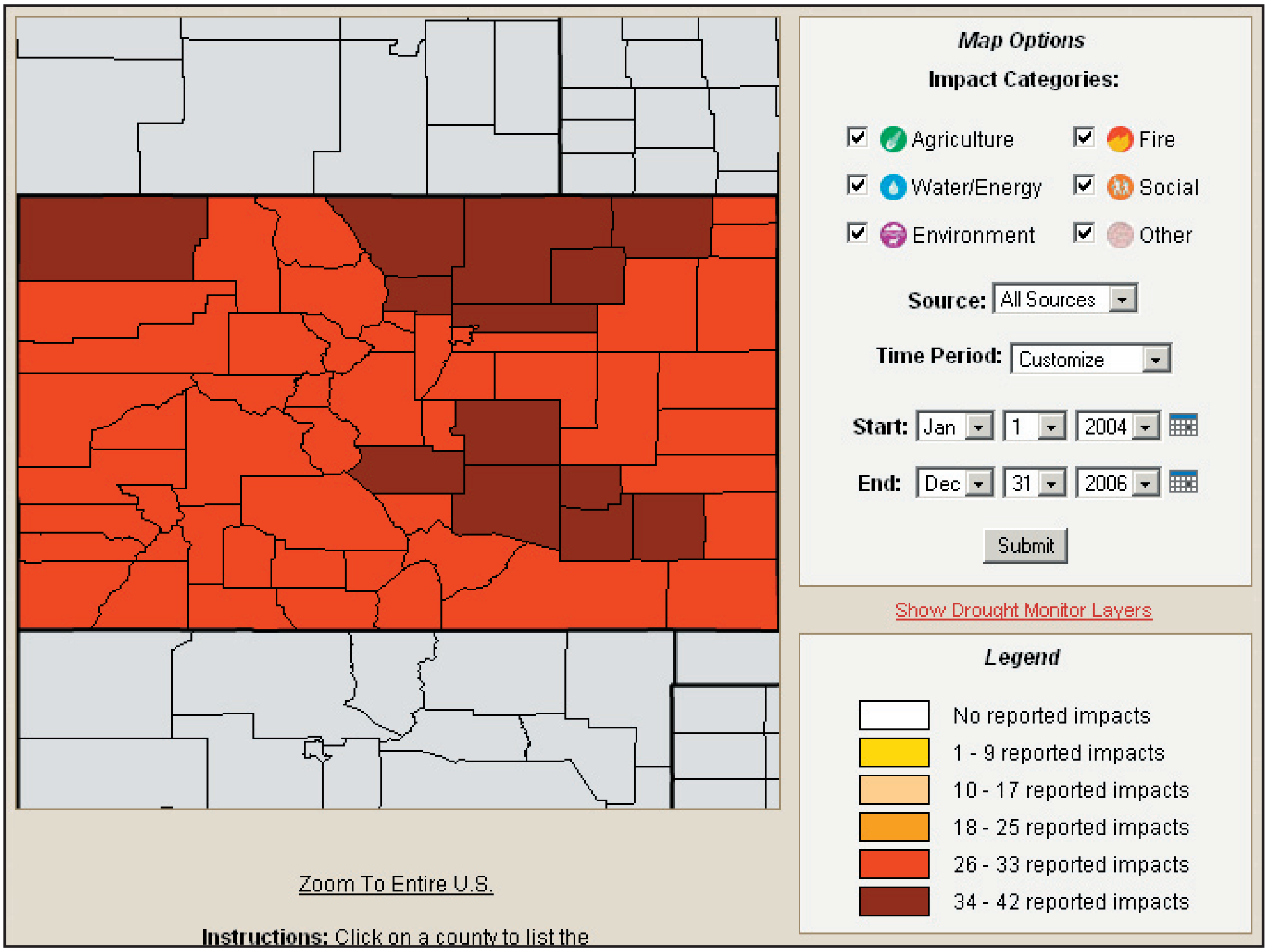
- 🟧 D2 Drought - Severe
- 🟥 D3 Drought - Extreme
- 🟫 D4 Drought - Exceptional

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements

http://drought.unl.edu/dm

Released Thursday, May 3, 2007
Author: Brian Fuchs, National Drought Mitigation Center

The adjacent figure reflects drought impacts information for the 3 update years from January 1, 2004 through December 31, 2006. Based on reports to the National Drought Mitigation Center, all counties recorded 26 or more impacts in the three-year period. The sample below demonstrates how information is presented in the Drought Impact Monitor. It represents a few items for Mesa County in 2006.



Map Options

Impact Categories:

☑ Agriculture ☑ Fire
☑ Water/Energy ☑ Social
☑ Environment ☑ Other

Source: All Sources

Time Period: Customize

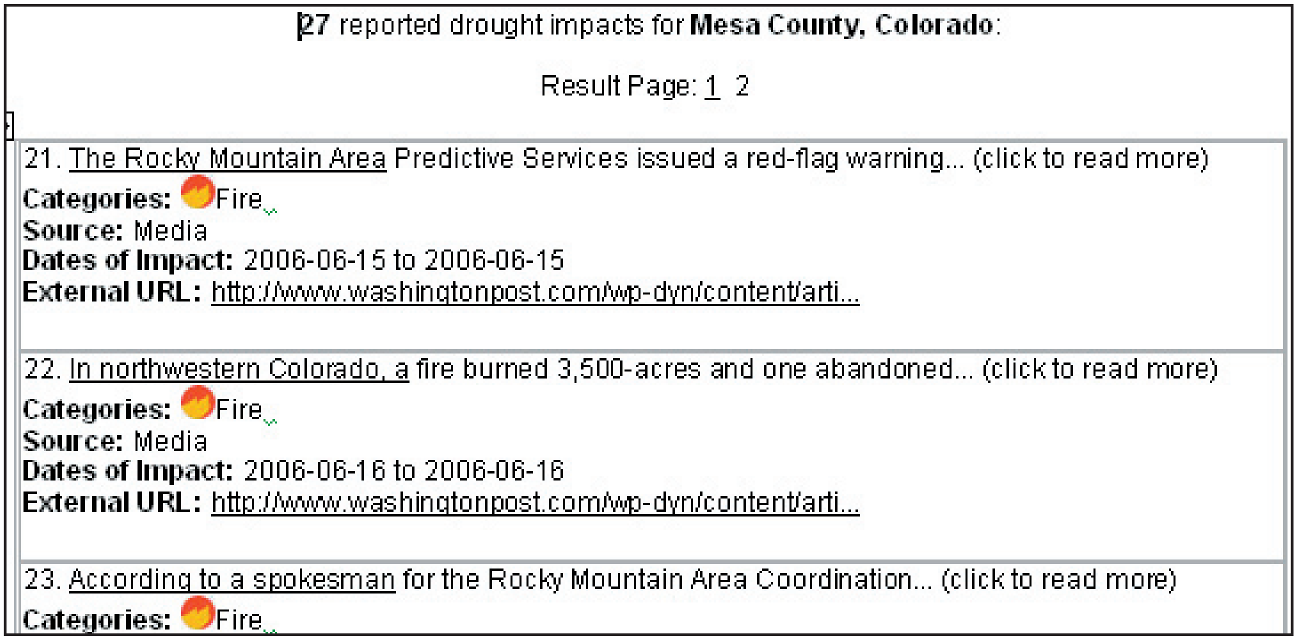
Start: Jan 1 2004

End: Dec 31 2006

Legend

☐ No reported impacts
🟨 1 - 9 reported impacts
🟧 10 - 17 reported impacts
🟧 18 - 25 reported impacts
🟥 26 - 33 reported impacts
🟫 34 - 42 reported impacts

Instructions: Click on a county to list the



27 reported drought impacts for **Mesa County, Colorado**:

Result Page: 1 2

21. The Rocky Mountain Area Predictive Services issued a red-flag warning... (click to read more)
Categories: Fire
Source: Media
Dates of Impact: 2006-06-15 to 2006-06-15
External URL: http://www.washingtonpost.com/wp-dyn/content/arti...

22. In northwestern Colorado, a fire burned 3,500-acres and one abandoned... (click to read more)
Categories: Fire
Source: Media
Dates of Impact: 2006-06-16 to 2006-06-16
External URL: http://www.washingtonpost.com/wp-dyn/content/arti...

23. According to a spokesman for the Rocky Mountain Area Coordination... (click to read more)
Categories: Fire

As stated in the *Updated Information Provided in Support of the 2002 Colorado Drought Mitigation and Response Plan* report, section titled *Identifying Hazards*, "This shows that drought continues to have significant effect on the entire state in all impact categories, including agriculture, water and energy, environment, fire, social, and others." The *Update* continues with "(T)he Agriculture Impact Task Force specifically noted that in Colorado, there are differences between those affected by hydrologic drought than by meteorological drought. Meteorological drought will reduce dryland crop production and will reduce forage on rangeland. (Non-irrigated farmland exists primarily in eastern Colorado and, to a lesser extent, in portions of southwestern Colorado. Northwest Colorado is primarily rangeland.) However, if there is a hydrologic drought (winter snowpack below average), irrigated areas could suffer. (Extensive areas of irrigated cropland can be found in the Platte, Arkansas, Colorado, and Republican River basins, as well as smaller irrigation systems along the North Platte, Yampa/White, and Las Animas Rivers.) The DWSP also included an assessment of impacts on different water users. The greatest impacts identified were: loss of reliable water supply; loss of system flexibility; loss of crop yield; fire damage; and loss of livestock. Again, those sectors that are highly dependent on these water uses would be especially vulnerable to damage or loss.

The DEM took a different approach to reviewing vulnerability this year than in the past by asking the SHMT to review hazards and vulnerability with respect to prevention of the undesired outcomes (leading to the goals). Each SHMT participant was given the opportunity to contribute to this analysis. In reviewing the responses, drought was determined to be a very high priority for preventing economic loss at the residential level, damage to private property, and damage to private nonprofit property. In fact of the 18 hazards reviewed, drought was ranked the second or third highest concern by the SHMT hazard experts.

The table demonstrates drought vulnerability with respect to the undesired outcome. Drought was of high concern in these three; it was of moderate concern with respect to preventing the following outcomes: economic loss at the state level and economic loss at the local level. It was a hazard of low concern with regard to loss of life/sustaining injuries, damage to state critical infrastructure, and damage to local critical infrastructure.

The map to the right represents the local assessment of drought vulnerability by emergency managers. Source: Local Emergency Managers Survey, 2003 and 2007; local hazard mitigation plans.

For complete information on drought in Colorado, refer to the following:

Colorado Drought Mitigation and Response Plan at www.dola.state.co.us/oem/Publications/droughtplan.402b.pdf.

Updated Information Provided in Support of the 2002 Colorado Drought Mitigation and Response Plan report

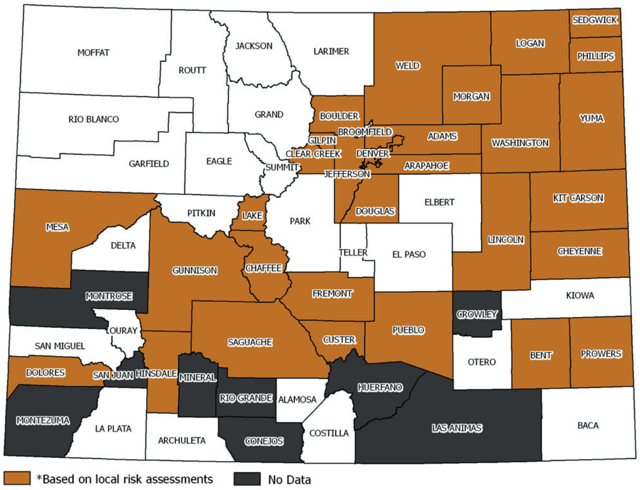
Drought & Water Supply Assessment
http://cwcb.state.co.us/Conservation/Drought/Drought_Water/index_DWSA.html

Guidelines for the Office to Review and Evaluate Drought Mitigation Plans Submitted by Covered Entities and Other State or Governmental Entities
http://cwcb.state.co.us/Conservation/Drought-droughtMitigation.htm

DROUGHT VULNERABILITY WITH RESPECT TO PREVENTION OF UNDESIRED OUTCOMES

Economic loss at the residential level.	2nd
Damage to private property.	3rd
Damage to private nonprofit property.	3rd
Source: SHMT 2007	

Drought: High Risk Counties



Water Availability Task Force

http://cwcb.state.co.us/Conservation/Drought/waterAvailability.htm

Colorado drought planning has been developed through the preparation and implementation of the Colorado Drought Mitigation and Response Plan. The plan consists of four components: monitoring, assessment, mitigation, and response. Monitoring is ongoing and accomplished, at a minimum, by quarterly meetings of the Water Availability Task Force (WATF). Meetings are occasionally held in conjunction with the Colorado Flood Task Force. The WATF is comprised of Colorado's water supply specialists, emergency management professionals, federal land managers, scientists, and experts in climatology and weather forecasting.

Members of the WATF include:
Colorado Water Conservation Board (Co-Chair)
Colorado Division of Water Resources (Co-Chair)
Division of Emergency Management
Office of the State Climatologist
National Weather Service National Oceanic Atmospheric Administration
Natural Resources Conservation Service
United States Geological Survey
Bureau of Land Management
Bureau of Reclamation
Impact Task Force Chairs
John Henz, HDR Engineering

Throughout the water year (October through September) the WATF monitors snowpack, precipitation, reservoir storage, streamflow, and temperatures, and provides a forum for synthesizing and interpreting water availability information. Task force members meet quarterly or monthly to share information.

When the WATF determines drought conditions are reaching significant levels, the Governor's staff and cabinet notifies the Governor and recommends activation of the Colorado Drought Mitigation & Response Plan. When the Plan is activated, the first step is impact assessment. Assessment begins with activation of the relevant Impact Task Forces (ITFs). These task forces convene to determine the impacts of a drought within specific sectors that affect the environment and the economy. They utilize a broad range of information sources to gather and evaluate data when the impact of drought is beyond local capabilities to cope with it. Data Sources Utilized by WATF:
Monthly Water Supply Report
Monthly Climate Report
Historical Norms
Weather Forecasts
Reservoir Levels
Stream Flow Data
Rain Gauge Sites
Snow Course Sites
Monthly Standardized Precipitation Index (SPI)
Surface Water Supply Index (SWSI)
Modified Palmer Drought Index

Tasks for all Impact Task Forces are to identify the drought related problems, and to define and assess societal impacts, severity, loss and costs; evaluate state and local capacity for response: determine residual needs, report findings and action plans.

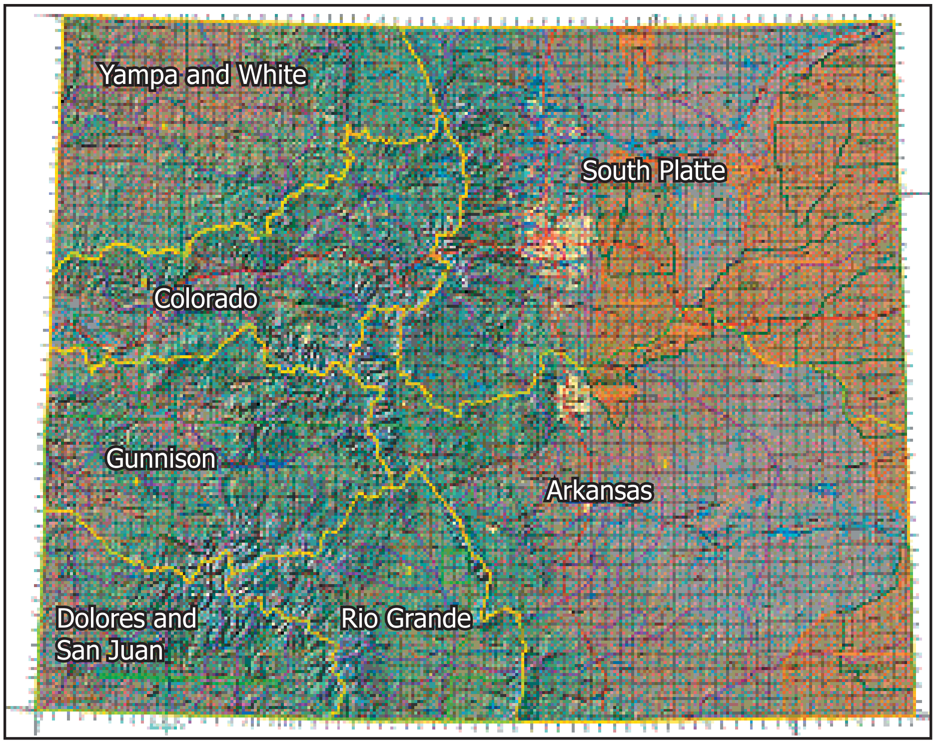
Impact Task Forces (ITFs):

Municipal Water–Assesses municipal impact.
Wildfire Protection–Assesses wildfire risk.
Agricultural Industry–Assesses soil erosion, crop/livestock loss, and insect/pest issues.
Tourism–Assesses the impact of drought upon tourism.
Wildlife–Assesses the impacts of drought upon wildlife (fish, game & non-game).
Economic–Assesses impact of drought on economy.
Health–Assesses impact of drought on health & human services.
Review & Reporting–Reviews all task force assessments & recommends overall drought response.

The impact assessment information coordination is assigned to the Review and Reporting Task Force, which includes chairpersons of the WATF and the Impact Task Forces, the Executive Directors of the Department of Natural Resources (DNR) and the Department of Local Affairs (DOLA). This task force assesses the drought projections, evaluates overall conditions, develops recommendations for drought response and makes timely reports to leadership, the media, and response agencies in times of serious drought conditions.

Summary of Effective Drought and Water Conservation Tools: Municipal/Agricultural/Other Entities
Drought: public education and involvement; lawn and garden watering restrictions; fines and tiered rates for water use; water conservation; cooperative agreements/operating agreements.
Water Conservation: public education and involvement; metering; distribution/transmission system leak detection; fines and tiered rates for water use; alternative irrigation practices (includes alternative crops and planting strategies); lining ditches and canals; conjunctive use of surface and ground water/recycled water
-2004 Drought & Water Supply Assessment, p. V

Map of the Major Water Basins **www.geosurvey.state.co.us**



Drought & Water Supply Assessment: Basin Summaries

Arkansas River Basin

Population in 2000: 811,442
Projected in 2030: 1,293,000
Number of Reservoirs and Dams: 426
Survey Participants: 83
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 98,100 acre-feet

Issues: Growth in the basin is expected to be an issue in the future, as is the pressure to transfer traditional agricultural rights to other uses, primarily municipal, competing with recreation uses, e.g. boating and fishing.

Current water use limitation: About half the water users indicated that current water supply is most limited by the water distribution system losses and availability of in-basin water rights. The most severe limitation is pressurized development on agricultural water rights.

Water Supply Master Plans: 56%
Drought Management Plan: 42%
Tools for Drought: more conjunctive use, more lawn watering fines, more lawn water restrictions, more cooperative agreements, more public education and involvement.

Water Conservation Plans:
Tools utilized: less lining of ditches and canals, more metering, pricing strategies, and public education/information
Best tools: public education/involvement and metering

Drought Impacts from 1999-2003
Loss of reliable water supply
Loss of system flexibility
Loss of crop yield
Loss of operations revenue
Loss of livestock
Raw water quality

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
New or upgraded pipelines
New or deepened wells
New storage for groundwater
New raw water treatment systems

Non-structural drought mitigation projects:
(prioritized for the basin)
Public education and awareness
Improved water conservation methods
Technical support in water supply planning
Technical support in drought & conservation planning
Improved water conservation measurement methods

Colorado River Main Stem Basin

Population in 2000: 259,800
Projected in 2030: 493,000
Number of Reservoirs and Dams: 280
Survey Participants: 60
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 62,100 acre-feet

Issues: Interstate compacts with other basin states define the apportionment of developable water. Currently, in-basin demands are approximately 130,000 acre-feet, and between 450,000 and 600,000 acre-feet is diverted annually to east slope communities via transmountain water projects.

Current water use limitation: About 62% of the water users indicated that current availability of storage most limits current water use. The most severe water use limitation was identified as availability of groundwater recharge.

Water Supply Master Plans: 59%
Drought Management Plan: 29%
Tools for Drought: public education and involvement programs, lawn and garden outdoor watering restrictions, fines for excess water use, dual water systems for irrigation, emergency water supply agreements, and controls on new construction.

Water Conservation Plans: 43%
Tools utilized: leak detection, non-structural water conservation programs
Best tools: metering, water conservation pricing, distribution/conveyance leak detection

Drought Impacts from 1999-2003
Loss of reliable water supply
Loss of crop yield
Loss of system flexibility
Loss of operations revenue
Fire damage

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
Lining of ditches
New or upgraded pipelines
Structural improvement to meet dam safety
New or deepened wells

Non-structural drought mitigation projects:
(prioritized for the basin)
Improved water conservation methods
Public education and awareness
Technical support in drought & conservation planning
Technical support in water supply planning
Improved water conservation measurement methods

Dolores and San Juan Rivers Basin

Population in 2000: 133,282
Projected in 2030: 172,000
Number of Reservoirs and Dams: 92
Survey Participants: 67
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 19,900 acre-feet

Issues: The mainstems are not currently over-appropriated, however, water shortages and scarcities exist under current conditions in various areas; pressures on future water supplies will continue to grow as population increases.

Current water use limitation: Users identified water distribution system losses and availability of in-basin water rights as the factors most limiting current water use. The most severe limitation has been identified as availability of augmentation water, followed by availability of groundwater recharge and reliability of existing in-basin water rights.

Water Supply Master Plans: 43%
Drought Management Plan: 45%
Tools for Drought: more cloud seeding, less pumping of groundwater, fewer lawn water restrictions.

Water Conservation Plans: 38%
Tools utilized: lining of ditches and canals, alternative irrigation practices
Best Tools: lining of ditches and canals, alternative irrigation practices.

Drought Impacts from 1999-2003
Loss of livestock
Loss of reliable water supply
Loss of crop yield
Fire damage
Loss of operations revenue
Loss of system flexibility
Raw water quality

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
Lining of ditches
New or upgraded pipelines
Dredging existing reservoirs
Structural improvements to existing reservoirs

Non-structural drought mitigation projects:
(prioritized for the basin)
Technical support in water supply planning
Improved water conservation measurement methods
Public education and awareness
Technical support in drought & conservation planning
Improved water conservation methods

Gunnison River Basin

Population in 2000: 93,908
Projected in 2030: 161,000
Number of Reservoirs and Dams: 240
Survey Participants: 70
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 15,800 acre-feet

Issues: Growth is not expected to be large in numbers, but large in percentage. Future pressure may be exerted for transmountain diversion, and increased recreational and environmental flows to protect the quality of the watershed in response to public expectations.

Current water use limitation: The users believe that the current availability of storage and the availabililty of in-basin water rights most limits use. Users identified pressurized development on agricultural water rights, and availability of augmentation water and in-basin water rights as the most severe limitations.

Water Supply Master Plans: 42%
Drought Management Plan: 38%
Tools for Drought: more cloud seeding, fewer lawn watering fines, fewer lawn water restrictions, not as much groundwater.

Water Conservation Plans: 43%
Tools utilized: lining of ditches and canals, metering, public information
Best tools: public education/involvement

Drought Impacts from 1999-2003
Loss of crop yield
Loss of reliable water supply
Loss of livestock
Loss of system flexibility
Loss of operations revenue
Fire damage

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
Lining of ditches
Structural improvements to meet dam safety requirements
Rehabilitation or new diversion structures
New or upgraded water distribution systems

Non-structural drought mitigation projects:
(prioritized for the basin)
Improved water conservation methods
Technical support in water supply planning
Technical support in drought & conservation planning
Public education and awareness
Improved water conservation measurement methods

Rio Grande River Basin

Population in 2000: 44,574
Projected in 2030: 63,000
Number of Reservoirs and Dams: 72
Survey Participants: 43
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 4,300 acre-feet

Issues: Growth is not particularly an issue, however, reliable agricultural use and municipal water supply will continue to dominate short and long-term water resources management.

Current water use limitation: Water users indicated that availability of groundwater recharge was the most limitating water use. Availability of in-basin water rights and storage create the most severe limitations.

Water Supply Master Plans: 32%
Drought Management Plan: 26%
Tools for Drought: aquifer storage/recovery, pumping groundwater, some cloud seeding, some emergency water supply agreements, some cooperative agreements, some landscape controls, controls on new construction, and dual water systems for irrigation.

Water Conservation Plans: 44%
Tools utilized: agricultural conservation methods (e.g. dry land farming and canal and ditch sectioning)

Drought Impacts from 1999-2003
Loss of reliable water supply
Loss of crop yield
Loss of system flexibility
Loss of livestock
Loss of operations revenue
Wells went dry or produced sand

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
New or upgraded pipelines
Install water use meters
New or deepened wells
New or upgraded water distribution systems

Non-structural drought mitigation projects:
(prioritized for the basin)
Technical support in water supply planning
Technical support in drought & conservation planning
Improved water conservation methods
Public education and awareness
Improved water conservation measurement methods

South Platte River Basin

Population in 2000: 2.97 million
Projected in 2030: 4.91 million
Number of Reservoirs and Dams: 879
Survey Participants: 154
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 409,500 acre-feet

Issues: The combination of the state's largest population center next to one of the state's largest agricultural business areas creates unique conflicts and challenges. As population increases, conflicts will increase.

Current water use limitation: Water users indicated that current availability of storage most limits and is the severest limitation on current water use. Availability of groundwater recharge was the next severest limitation.

Water Supply Master Plans: 47%
Drought Management Plan: 48%
Tools for Drought: emergency water supply agreements, fines for excess water use, lawn and garden outdoor watering restrictions, substitute water supply plans, operation/cooperative agreements, and landscaping controls.

Water Conservation Plans: 37%
Tools utilized: metering and pricing
Best tools: public education/involvement and water conservation pricing

Drought Impacts from 1999-2003
Loss of reliable water supply
Loss of system flexibility
Loss of crop yield
Loss of operations revenue
Wells went dry or produced sand

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
New storage for groundwater, including aquifer storage recovery systems
New or deepened wells
New or upgraded water distribution systems

Non-structural drought mitigation projects:
(prioritized for the basin)
Improved water conservation methods
Public education and awareness
Technical support in water supply planning
Technical support in drought & conservation planning
Improved water conservation measurement methods

Yampa and White Rivers Basin

Population in 2000: 41,497
Projected in 2030: 61,000
Number of Reservoirs and Dams: 155
Survey Participants: 106
Additional Projected In Basin Municipal/Industrial Water Supply at 2030: 22,300 acre-feet

Issues: Water rights administration has been limited to internally controlled tributaries. This division has both significant agricultural uses of water and supports over 500,000 acre-feet of power generation. Future demand is not expected to increase significantly, but growth will create localized challenges. Water quality issues will increase in areas with construction related to housing, transportation, and recreation.

Current water use limitation: Water users indicated that availability of storage and reliability of existing in-basin water rights most limit current water use. Severity of limitations was most affected by availability of augmentation water and availability of storage.

Water Supply Master Plans: 22%
Drought Management Plan: 33%
Tools for Drought: limited public education, some lawn watering fines, a few lawn watering restrictions, and a few landscape controls.

Water Conservation Plans: 31%
Tools utilized: lining of ditches and canals
Best tool: alternative irrigation practices

Drought Impacts from 1999-2003
Loss of crop yield
Loss of reliable water supply
Loss of operations revenue
Loss of livestock
Loss of system flexibility

Structural projects to mitigate drought impacts:
(prioritized for the basin)
New storage for surface water
Lining of ditches
Structural improvements to meet dam safety requirements
New or upgraded water distribution systems
Rehabilitation or new diversion structures

Non-structural drought mitigation projects:
(prioritized for the basin)
Public education and awareness
Technical support in drought & conservation planning
Improved water conservation methods
Technical support in water supply planning
Improved water conservation measurement methods

Earthquake

earthquake - a vibration or movement of a part of the earth's surface, due to the faulting of rocks, to volcanic forces, etc.

QUAKES

Magnitude and intensity are used to describe seismic activity.

Magnitude (M) is a measure of the total energy released. Each earthquake has one magnitude.

Intensity (I) is used to describe the effects of the earthquake at a particular place. Intensity differs throughout the area.

The Northridge Earthquake of 1994 caused $20 billion in damage.

Many earthquakes in Colorado occur naturally; many are caused by human actions. Humans may trigger earthquakes through different types of activities including oil and gas extraction, reservoir impoundment, fluid injection, or mining.

In the 1960s, earthquakes were triggered as a result of activities at the Rocky Mountain Arsenal.

Recent earthquake activity has been triggered by human activities at Rangely Oilfield, Paradox Basin, and Ridgway Reservoir.

Seismic events may lead to landslides, uneven ground settling, flooding, and damage to homes, dams, levees, buildings, power and telephone lines, roads, tunnels, and railways. Broken natural gas lines may cause fires.

Scientists are constantly studying faults in Colorado to determine future earthquake potential. Faults are cracks in the earth's crust along which movement occurs.

Thousands of faults have been mapped in Colorado, but scientists think only about 90 of these were active in the past 1.6 million years.

An earthquake in 1967 caused more than $1 million in damage in the Denver metro area. It may have been caused by injections of liquid waste deep into the earth at the Rocky Mountain Arsenal.

(Sources: www.dnr.state.co.us/geosurvey/pubs/geohazards/docs/sp12.htm; www.dnr.state.co.us /geo survey/pubs/equake/Eqfactsheet.htm; FEMA 1997; The Denver Business Journal 11/26-12/2/99)

MEASURING EARTHQUAKES

Magnitude and intensity are used to measure earthquakes. A scale commonly used to measure magnitude is the Richter Scale; the Modified Mercalli Scale (MMI) is used for intensity.

MEASURING EARTHQUAKES

Richter Scale	Modified Mercalli	Description
2	I	Felt by only a few people. Detected mostly by instruments.
3	II	Felt by a few people, especially those on upper floors of buildings. Suspended objects may swing.
	III	Felt by people indoors. Standing cars may rock slightly. Vibration similar to the passing of a truck.
4	IV	Felt indoors by many, felt outdoors by a few; at night, some awakened. Dishes, windows, and doors disturbed. Sensation like a heavy truck striking building. Cars rock.
	V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned.
5	VI	Felt by all. Many frightened. Some heavy furniture moved. Some fallen plaster. Damage slight.
6	VII	Many people alarmed. Negligible damage in well built buildings. Considerable damage in poorly built structures.
7	VIII	Damage slight in specially designed structures, great in poorly built ones. Heavy furniture overturned. Chimneys and wall may fall.
	IX	Damage considerable in specially designed buildings; great in substantial buildings. Buildings shift off foundations and crack. Underground pipes broken.
8	X	Some well-built wooden structures destroyed. Most masonry and frame structures destroyed. Rails bent. Ground cracked. Landslides on steep slopes.
	XI	Few, if any, masonry structures remain standing. Rails bent. Bridges destroyed. Broad fissures appear in the ground.
	XII	Damage total. Waves are seen on the ground surface. Objects thrown into the air.

Sources: Colorado Earthquake Project 1999; FEMA 1997

EARTHQUAKE HAZARDS IN COLORADO

The following is from "Colorado Earthquake Information" prepared by the Earthquake Subcommittee of the Colorado Natural Hazards Mitigation Council on November 15, 1999.

Introduction - Colorado is comprised of areas with low to moderate potential for damaging earthquakes, based on research by geologists and geophysicists who specialize in seismology. Several 1000 faults have been mapped in Colorado….Thus far, about 90 potentially active faults have been identified, with documented movement within the last 1.6 million years. Because the occurrence of earthquakes is relatively infrequent in Colorado and the historical earthquake record is short (only about 130 years), it is not possible to accurately estimate the timing or location of future dangerous earthquakes in Colorado. Nevertheless, the available seismic hazard information can provide a basis for a reasoned and prudent approach to seismic safety.

Faulting - Sudden movement on faults is responsible for large earthquakes. By studying the geologic characteristics of faults, geoscientists can often determine when the fault last moved and estimate the magnitude of the earthquake that produced the last movement. In some cases, it is possible to evaluate how frequently large earthquakes occurred on a specific fault during the recent geological past.

Geological studies in Colorado indicate that there are about 90 faults that moved during the Quaternary Period (the last 1.6 million years) and should be considered potentially active. The Sangre de Cristo Fault, which lies at the base of the Sangre de Cristo Mountains along the eastern edge of the San Luis Valley, and the Sawatch Fault, which runs along the eastern margin of the Sawatch Range, are two of the most prominent potentially active faults in Colorado. Not all of Colorado's potentially active faults are in the mountains and some cannot be seen at the earth's surface. For example, the Cheraw Fault, which is in the Great Plains in southeast Colorado, appears to have had movement during the recent geologic past. The Derby Fault near Commerce City lies thousands of feet below the earth's surface but has not been recognized at ground level.

Several potentially active faults in Colorado are thought to be capable of causing earthquakes as large as magnitude 6½ to 7¼. In comparison, California has hundreds of hazardous faults, some of which can cause earthquakes of magnitude 8 or larger. The time interval between large earthquakes on faults in Colorado is generally much longer than on faults in California.

Past and Possible Future Earthquakes - More than 400 earthquake tremors of magnitude 2½ or higher have been recorded in Colorado since 1867. More earthquakes of magnitude 2½ to 3 probably occurred during that time, but were not recorded because of the sparse distribution of population and limited instrumental coverage in much of the state. For comparison, more than 20,500 similar-sized events have been recorded in California during the same time period. The largest known earthquake in Colorado occurred on November 7, 1882 and had an estimated magnitude of 6½. The location of this earthquake, which has been the subject of much debate and controversy over the years, appears to be in the northern Front Range west of Fort Collins.

The table below lists notable events in Colorado. Events are considered notable if the magnitude was greater than 5.0 on the Richter Scale or the intensity was greater than V on the Mercalli Scale.

NOTABLE EARTHQUAKE EVENTS IN COLORADO: 1870 THROUGH 2000

Date	Location	Magnitude (M) and Intensity (I)	
		M	I
12/04/1870	Pueblo-Ft. Reynolds		VI
10/1871	Lily Park, Moffat Co.		VI
09/17/1880	Aspen		VI
11/07/1882	Northcentral Colorado	6.5*	VII
12/1891	Maybell		VI
11/15/1901	Buena Vista		VI
11/11/1913	Ridgway area		VI
09/09/1944	Montrose-Basalt		VI
08/03/1955	Lake City		VI
10/11/1960	Montrose/Ridgway	5.5	V
01/04/1966	Northeast of Denver	5.0	V
01/23/1966	Southern Colorado border (Dulce, NM)	5.5	VII
08/09/1967	Northeast of Denver	5.3	VII
11/27/1967	Northeast of Denver	5.2	VI

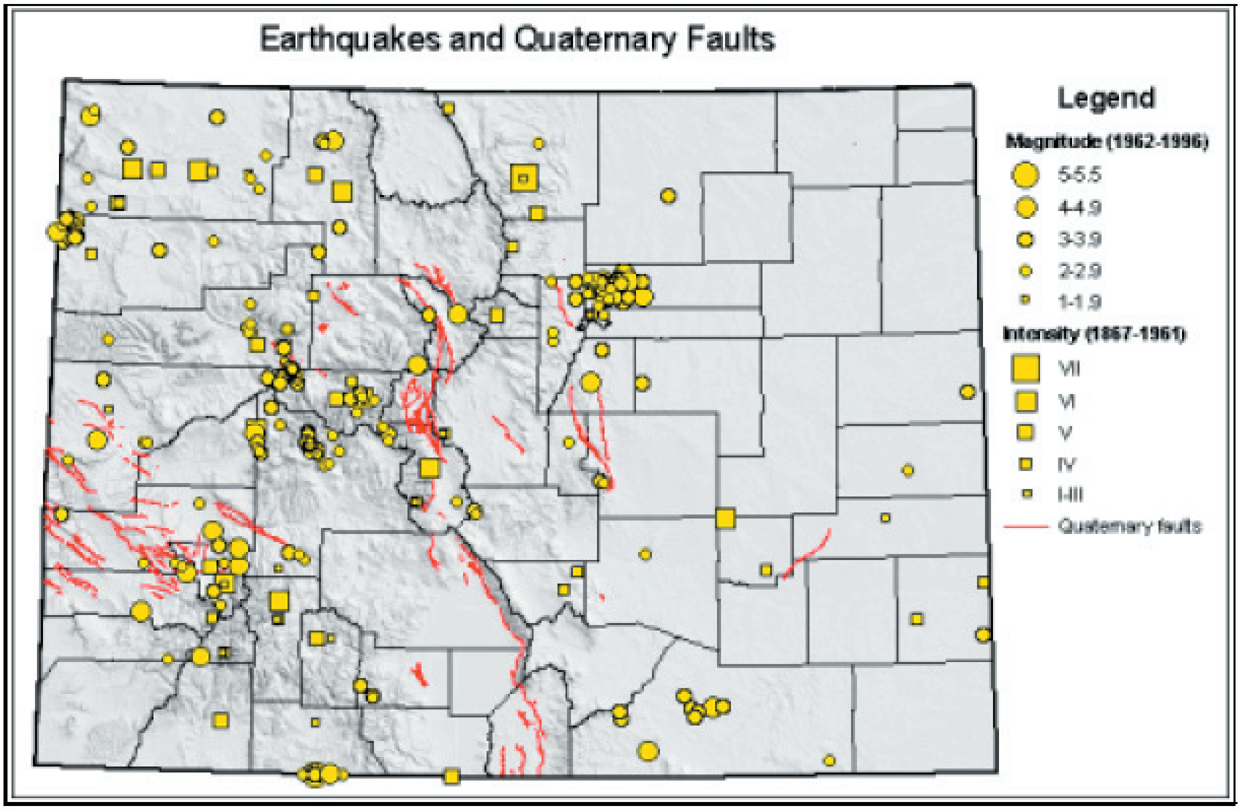
*Estimated, based on historical felt reports.

Sources: Colorado Earthquake Project 1999; www.neic.cr.usgs.gov/neis/states/colorado/colorado_history.html; The Denver Business Journal 11/26-12/2/1999

Although many of Colorado's earthquakes occurred in mountainous regions of the state, some have been located in the western valley and plateau region or east of the mountains. The most economically damaging earthquake in Colorado's history occurred on August 9, 1967 in the northeast Denver metropolitan area. This magnitude 5.3 earthquake, which was centered near Commerce City, caused more than a million dollars damage in Denver and the northern suburbs. This earthquake is believed to have been induced by the deep injection of liquid waste into a borehole at Rocky Mountain Arsenal.

It was followed by an earthquake of magnitude 5.2 three months later in November 1967. Although these events cannot be classified as major earthquakes, they should not be discounted as insignificant. They occurred within Colorado's Front Range Urban Corridor, an area where nearly 75% of Colorado residents and many critical facilities are located. Since March 1971, well after the initial flurry of seismic activity, 15 earthquakes of approximate magnitude 2½ or larger have occurred in the vicinity of the northern Denver suburbs. Relative to other western states, Colorado's earthquake hazard is higher than Kansas or Oklahoma, but lower than Utah, and certainly much lower than Nevada and California. Even though the seismic hazard in Colorado is low to moderate, it is likely that future damaging earthquakes will occur. It is prudent to expect future earthquakes as large as magnitude 6.5, the largest event of record. Calculations based on the historical earthquake record and geological evidence of recent fault activity suggest that an earthquake of magnitude 6 or greater may be expected somewhere in Colorado every several centuries.

Summary and Conclusions - Based on the historical earthquake record and geologic studies in Colorado, an event of magnitude 6½ to 7¼ could occur somewhere in the state. Scientists are unable to accurately predict when the next major earthquake will occur in Colorado, only that one will occur. The major factor preventing the precise identification of the time or location of the next damaging earthquake is the limited knowledge of potentially active faults. Given Colorado's continuing active economic growth and the accompanying expansion of population and infrastructure, it is prudent to continue the study and analysis of earthquake hazards. Existing knowledge should be used to incorporate appropriate levels of seismic safety in building codes and practices. The continued and expanded use of seismic safety provisions in critical and vulnerable structures and in emergency planning statewide is also recommended. Concurrently, we should expand earthquake monitoring, geological and geophysical research, and mitigation planning.



For more information on earthquakes, refer to the Earthquake Evaluation Report.

HAZUS Summary

Colorado's earthquake hazard and risk has historically been rated lower than most knowledgeable scientists in the state consider justified. As a result, local emergency managers are generally unaware of the size and consequences of an earthquake that could occur in the state. HAZUS 99 gave a probabilistic Annualized Earthquake Loss (AEL) of $5.8 million which ranked Colorado 30th in the nation.

The Colorado Geological Survey (CGS) ran a series of deterministic scenarios for selected faults around the state using HAZUS MH. The earthquake magnitudes used for each fault were the "Maximum Credible Earthquake" taken from the USGS Quaternary Fault and Fold Database or from the USGS National Earthquake Hazard Map. The results demonstrate that the probabilistic AEL value of $5.8 million does not begin to convey the size of the loss that would occur in the event of a strong earthquake on any of these faults. For example, a magnitude 6.5 earthquake on the Golden fault is forecast to result in a $22 billion economic loss. Or, consider that a magnitude 6.0 earthquake under the Rocky Mountain Arsenal would result in $3.9 billion economic loss to Adams County alone; and a loss ratio of 17% that would make recovery difficult.

Much additional work is required to more reasonably characterize Colorado's earthquake risk. CGS believes the following areas should receive the highest priority for additional work and mitigation:

1. Training for emergency responders on the consequences of a strong earthquake.
2. Establishment of a comprehensive seismograph network in Colorado.
3. Development of a landslide susceptibility map for Colorado.
4. Better definition of the attenuation factor (Q) for earthquakes in Colorado.
5. Better characterization of Colorado's known Quaternary faults.
6. Better characterization of Colorado's known Neogene faults.
7. Regional investigation for previously undetected Neogene faults.

Background

In 1960 there were no young faults reported in the literature for Colorado and the dogma being taught in Colorado's institutions of higher education were that the faults in Colorado were all dead, and had been so for 40 million years. Therefore, there was no earthquake hazard in the state.

In 1970, the USGS published a paper that reported eight young faults around the state. By 1980, there were 45. By, 1985, there were more than 60. And by 1998, there were more than 90 young faults and folds identified in the state. Clearly, the more we look, the more we find. But, the looking has been dramatically underfunded.

Colorado's earthquake hazard and risk has historically been rated lower than most knowledgeable scientists in the state consider justified. There are a plethora of reasons for this and the reader is referred to the following publications for a comprehensive review:

Matthews, V. 2003, The Challenges of Evaluating Earthquake Hazard in Colorado, in Boyer, D.B, Santi, P.M. Rogers, W.P., Engineering Geology in Colorado-Contributions, Trends, and Case Histories, Association of Engineering Geologists Special Publication No. 15, 22 p.

Matthews, V., 2002, We don't have earthquakes in Colorado do we?: RockTalk, Colorado Geological Survey, v. 5, no.2, 12p. http://geosurvey.state.co.us/pubs/rocktalk/rtv5n2.pdf

Matthews, V., 1973, A reappraisal of the seismic-risk classification of Colorado; Mountain Geologist, V. 10, p. 111-115.

HAZUS is driven primarily by the information in the USGS National Earthquake Hazard Map. Resources have not been adequately devoted to understanding Colorado's earthquake hazard. Consequently, the map probably underestimates Colorado's earthquake hazard. Therefore, a probabilistic analysis of Colorado's risk using HAZUS would also be understated.

Some faults in Colorado have received considerable work on hazards. Many of these investigations were conducted by personnel and consultants for the Bureau of Reclamation as part of their dam safety program. With the exception of investigations on the Cheraw and southern Sangre de Cristo faults, the USGS has conducted very few studies of earthquake hazard in Colorado.

The Colorado Geological Survey, with generally inadequate funding and conflicting priorities, has attempted to categorize the extent of young faulting and earthquakes in the state. Several important publications have resulted:

Kirkham, R.M., and Rogers, W.R., 1999, Colorado earthquake information: 1867-1996: Colorado Geological Survey Bulletin 52, CD-ROM.

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

Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open- Report 98-8, 331 p.

Deterministic HAZUS Analyses

HAZUS can perform either probabilistic or deterministic analyses. The probabilistic analyses attempt to use statistical probability to predict what the "Annualized Earthquake Losses (AEL) are in each part of the state. These are driven by the USGS National Earthquake Hazard Maps. The deterministic analyses provide "what if" scenarios, e.g. what if a magnitude 6.0 earthquake actually did occur under the Rocky Mountain Arsenal (such a possibility can be found in two different scientific papers). What damage would result, and where would it be located?

HAZUS was recently used to evaluate potential damage from an earthquake on a major feature on Colorado's eastern plains. Because the feature was isolated, intuition suggested that a large earthquake on this feature would not cause significant loss and therefore the expenditure of state resources to investigate the feature was not justified. However, a HAZUS deterministic analysis revealed that a large earthquake could cause more than $11 billion in economic loss, including $2.6 billion in the City and County of Denver. Based on this information CGS decided to spend the resources to evaluate the possible earthquake history on the feature.

HAZUS Results

The results of the HAZUS runs are extremely detailed and only the summaries are presented in this document. The full reports are 20 pages and include such things as casualties broken into several categories of severity and calculated at three different times of the day; building damage broken into categories; highway and utility damage; number of people needing shelter; hospitals able to function at 50% capacity one day after the earthquake, seven days after the earthquake, and two weeks after the earthquake; post earthquake fires, and volume of debris to clean up. The following information chart shows the top five losses in several categories: five most damaging faults, 14 highest economic losses, five highest loss ratios for counties, and the five highest calculated potential loss by county.

In the Earthquake Evaluation Report (annex) to this plan are several portrayals of loss. One report shows losses by counties. One table summarizes losses by fault. One map shows the locations and names of the faults analyzed. The other map shows the losses calculated for each fault.

HAZUS Top Fives

Most damaging faults:

1. Rocky Mountain Arsenal
2. Golden
3. Rampart Range
4. Ute Pass
5. Walnut Creek

Total direct economic loss:

1. Rocky Mountain Arsenal M6.5 Counties 150km CEUS – $24.83 Billion
2. Golden M6.5 Counties 150km CEUS - $22.08 Billion
3. Rampart Range M7 Counties 150km CEUS - $18.26 Billion
4. Walnut Creek M6 Counties 150km CEUS - $13.25 Billion
5. Ute Pass M7 Counties 150km CEUS – $12.88 Billion
6. Rocky Mountain Arsenal M6 Counties 150km CEUS - $12.13 Billion
7. Golden M6 Counties 150km CEUS - $11.41 Billion
8. Rampart Range M7 Counties 150km WUS - $11.25 Billion
9. Ute Pass M7 Counties 150km WUS - $9.77 Billion
10. Ute Pass M7 Reverse El Paso County WUS – $9.30 Billion
11. Rampart Range M7 El Paso County WUS - $8.15 Billion
12. Golden M6.5 Jefferson County CEUS - $8.14 Billion
13. Ute Pass M7 El Paso County WUS - $7.92 Billion
14. Rampart M6.5 Counties 150km CEUS - $7.04 Billion

Highest loss ratio:

1. Rocky Mountain Arsenal M6.5 Adams County CEUS – 29.7%
2. Ute Pass M7 Reverse El Paso County WUS – 26.8 %
3. South Sawatch M7.25 Chaffee County WUS – 24.1%
4. Rampart M7 El Paso County WUS – 23.5%
5. Ute Pass M7 El Paso County WUS – 22.9%

Counties at greatest risk (high monetary loss, casualties, and loss ratios):

1. El Paso County
2. Jefferson County
3. Denver County
4. Summit County
5. Chaffee County

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 that 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 floodwaters 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 that 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 that 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.

Aggravating Circumstances

Human 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, farmland preparation, and modification of drainage channels for water control projects are significant factors in increased erosion and deposition. All the geologic processes that make available more material for erosion and deposition tend to increase the rates of each process. This is particularly true for landslides, mud flows, debris flows, earthflows, rock falls, and physical and chemical weathering. These processes also involve erosion and deposition while frequently make more material vulnerable to erosion.

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 channeled 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.

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 that minimize losses.

Land Use

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

For complete information on erosion and deposition mitigation, refer to http://geosurvey.state.co.us.

Expansive Soils

expansive (swelling) soils or rock - "… soils or soft bedrock that increase in volume as they get wet and shrink as they dry out. They are also commonly known as bentonite, expansive, or montmorillinitic soils." (http://geosurvey.state.co.us/pubs/geohazards/docs/sp12.htm).

SWELLING SOIL FACTS

Soils that expand have a high proportion of water-absorbing clay particles.

When wet, some expansive soils may expand more than ten percent.

The resulting pressure can be more than 20,000 pounds per square foot on structures such as basement walls and floors. Pressure can be upward, horizontal, or both.

Many times swelling soils present no problem in their natural state, however, exposure to water sources and drying cycles during or after development results in swelling and shrinking. Swelling and shrinking may occur any number of times for a single soil mass.

Most damage occurs to highways, streets, and structures build on expansive soils. Losses can include damage to structures, driveways, roads, sidewalks, basement floors, gas pipelines, and sewer lines.

Damage from expansive soils is estimated to be $2 billion per year.

Despite knowledge of the problem and technical capability to address it, damages to public facilities in Colorado cost approximately $16 million annually.

Methods for building in and on swelling soils are well developed and some are very sophisticated. Although there are more up front costs, there is usually no reason to avoid construction provided the appropriate mitigation measures are taken.

(Source: http://geosurvey.state.co.us/pubs/geohazards /docs/sp12.htm)

For complete information on swelling soils mitigation, refer to http://geosurvey.state.co.us/pubs /geohazards/docs/sp12.htm.

EXPANSIVE SOIL/ROCK HAZARD IN COLORADO

The following is reprinted from the Colorado Geological Survey website at http://geosurvey.state. co.us/pubs/geohazards/docs/sp12.htm.

Swelling soils are soils or soft bedrock that 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 "roller-coaster road" is the result of uneven swelling and heaving of steeply dipping bedrock layers. Photo by Dave Noe, Colorado Geological Survey

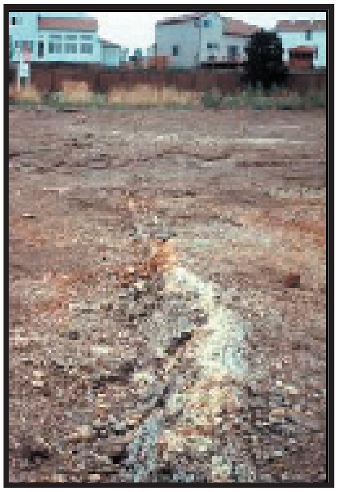
Characteristics

Swelling soils contain a high percentage of certain kinds of clay particles that 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.

As seen in the photo below, the bentonite layer heaved approximately three inches within 24 hours after a rainstorm at this construction site. There is also a hump in the fence aligned with the trend of the bentonite layer. Damage is occurring in the subdivision in the background.



A near-vertical bentonite layer in the Upper Cretaceous Pierre Shale in Jefferson County.
Photo by Dave Noe, Colorado Geological Survey

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 pier, 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 provided the appropriate mitigation measures are taken.

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

Land Use

Swelling soils and rock can be a geologic factor that should be considered in the land use. 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.

Severity of problem

Swelling soils are a nationwide problem, as shown by Jones and Holtz (1973): Each year, shrinking or swelling inflict at least $2.3 billion in damages to houses, buildings, roads, and pipelines – more than twice the damage from floods, hurricanes, tornadoes, and earthquakes…Over 250,000 new homes are built on expansive soils each year. 60 percent will experience only minor damage during their useful lives, but 10 percent will experience significant damage-some beyond repair…one person in 10 is affected by floods; but one in five by expansive soils.

Swelling is generally caused by expansion due to wetting of certain clay minerals in dry soils. Therefore, arid or semi-arid areas such a Colorado with seasonal changes of soil moisture experience a much higher frequency of swelling problems than eastern states that have higher rainfall and more constant soil moisture.

Rocks containing swelling clay are generally softer and less resistant to weathering and erosion than other rocks and therefore, more often occur along the sides of mountain valleys and on the plains than in the mountains. Because the population of Colorado is also concentrated in mountain valleys and on the plains, most of the homes, schools, public and commercial buildings, and roads in the state are located in areas of potentially swelling clay. Swelling clays are, therefore, one of the most significant, widespread, costly, and least publicized geologic hazards in Colorado.

Criteria for Recognition

Although several visual methods for identification of potentially swelling clays exist, only a competent, professional soil engineer and engineering geologist should be relied upon to identify this potential hazard. Some warning signs for swell might include: a) soft, puff, "popcorn" appearance of the surface soil when dry; b) surface soil that is very sticky when wet; c) open cracks (desiccation polygons) in dry surface soils; d) lack of vegetation due to heavy clay soils; e) soils that are very plastic and weak when wet but are "rock-hard" when dry.

Engineering soil tests include index tests and design tests. Rapid, simple index tests are used to determine whether more complex design tests are necessary. Some index properties that may aid in the identification of probable areas of swelling clay include Atterberg limits, plasticity index, grain size determination, activity ratio, dry unit weight, and moisture content (Asphalt Institute, 1964). The primary design tests for swelling soils are the consolidation swell* test for buildings, and the California Bearing Ratio* swell test for roads (Asphalt Institute, 1964).

Consequences of Improper Utilization

Damage from swelling clays can affect, to some extent, virtually every type of structure in Colorado. Some structures, such as downtown Denver's skyscrapers, generally have well engineered foundations that are too heavily loaded for swelling damage to occur. At the opposite extreme are public schools and single family homes, which are generally constructed on a minimal budget and which may have under-designed lightly loaded foundations that are particularly subject to damage from soil movements. Homeowners and public agencies that assume they cannot afford more costly foundations and floor systems often incur the largest percentage of damage and costly repairs from swelling soil.

In 1970, the state of Colorado spent nearly $1/2 million to repair cracked walls, floors, ceilings, and windows caused by swelling-clay damage at a state institution near Denver. In 1972, a state college library in southern Colorado required $170,000 to repair swelling-clay damage. A 6-yr-old, $2 million building on the same campus was closed pending repairs to structural components pulled apart by swelling clay. A college building in western Colorado and a National Guard armory near Denver are among the other state buildings severely damaged by swelling clays. These examples of damage to public buildings do not include the hundreds of thousands of dollars spent for repairs by local school districts. One school district near Denver is attempting to circumvent these expensive repairs by spending an additional $42,000 per school on structural floors. No figures are available for the total damage to homes in Colorado from swelling clays. However, several examples are known where the cost of repairs exceeded the value of the house. Cracked and heaved sidewalks, patios, driveways, and garage and basement floor slabs are very com-mon indicators of swelling clay throughout Colorado.

Highways in some areas of Colorado have required frequent and very expensive reconstruction or maintenance due to damage from swelling clay. As much as one foot of uplift from swelling clay forced the repair of two concrete lanes of interstate highway in eastern Colorado only six months after completion of paving. In the same area, additional right-of-way had to be purchased, and the highway design had to be revised to eliminate cuts and fills in order to prevent similar problems with the two remaining lanes.

Mitigation Procedures

Complete avoidance or non-conflicting use:
In Colorado, swelling clays are so common in urban areas that complete avoidance is generally not feasible. However, all should recognize the widespread distribution of swelling soils, and precautions must be taken to require engineered foundation and floor systems designs and to provide detailed maintenance instructions to owners in affected areas that are to be developed.

Engineered design for correction of adverse conditions: Combinations of four methods – engineered foundation design, well planned site drainage, landscaping to enhance drainage, and careful interior construction details, may minimize swelling clay damage.

Foundation design. In areas of relatively low swell potential, spread footings are commonly used. For slightly high swell pressures, extended bearing walls or pads may be used. In areas containing moderate to highly swelling clay, drilled pier and grade beam foundations are used. The weight of the building is transmitted through bearing walls to horizontal grade beams. These beams rest on cylindrical, reinforced concrete piers that concentrate the weight on a very small area below the zone* of seasonal moisture change. The foundation is thereby founded upon soil that because its moisture content remains constant throughout the year, should not experience a volume change.

With each of these special foundation designs, floating slabs are commonly used for all on-grade floors. These interior concrete floor slabs are completely isolated by joints or void spaces from all structural components. Complete isolation from bearing walls, columns, nonbearing interior partitions, stairs, and utilities allows the slab to move freely without damaging the structural integrity of the building. In the Denver area, swelling soil below the level of the proposed floor slab is sometimes excavated to a depth of several feet and replaced by various kinds of engineered backfill.

Overexcavation where expansive soils and/or bedrock are removed below the foundation and replaced with compacted fill. The mixing of the soil, the addition of moisture to the fill materials and compaction of the fill material reduces the swell potential of the soils. The mixing of the soil also reduces the chances of differential swell within the fill.

Drainage. The Federal Housing Administration recommends slopes of no less than 6 in. of vertical fall in 10 ft (12 in. in 10 ft is safer) around all buildings for drainage water into drainage swales, streets, or storm sewers. Water must not be allowed to stand near foundations in areas of swelling clay due to the potential for wetting foundation soils. All downspouts and splash blocks should be placed so that roof runoff will be carried at least 4 ft from the building. In areas of heavy lawn irrigation, peripheral drains have proven effective in preventing the formation of perched water tables and the resulting downward seepage of the surface water. The clay-tile or perforated plastic peripheral drains completely surround the building just below the level of the floor. The drain is and covered with washed gravel and a geotextile. The drain is normally connected to a main collection line located beneath the sanitary sewer, a sump or a daylight or gravity discharge point.

Landscaping. Proper foundation design and construction will not solve all swelling-clay problems. The owner of a structure is responsible for maintaining proper drainage by careful landscaping. Backfill around foundations is often not properly compacted. Therefore, additional soil may be required on the slope around the structure in order to compensate or settlement of the backfill. This prevents "ponding" and percolation of water around the foundation. Grass, shrubs, and sprinkler systems should be kept a minimum of 5 ft from the foundation. Trees should be planted no nearer than 15 ft from a building. The most critical aspect of landscaping in swelling clay areas is not to flatten a properly designed slope.

Interior finishing. One of the most costly mistakes a homeowner or careless contractor can make is to defeat the design purpose of a floating floor slab. A floating garage or basement floor slab is designed to move freely. Therefore, any furring, paneling, dry wall, or interior partitions added to a basement or garage must maintain this freedom of vertical movement. Any added walls or wall coverings should be suspended from the existing walls or ceiling, and should not be attached to the floor slab. A minimum void space of 3 in. should then be provided just above the floor slab. This void space may be covered with flexible molding, or inflexible molding attached to the floor rather than the wall. Although these recommendations provide for 3 in. of upward swell of the soil beneath the floor slab, more void space may be necessary in areas of highly swelling clay.

Fire

wildfire - "an open fire which spreads unconstrained through the environment. If not quickly controlled, the result can be a firestorm, often termed a 'conflagration,' which destroys large amounts of property and threatens lives." (Colorado State Forest Service 1995)

FIRE FACTS

Topography, fuel, and weather are the three main factors that affect wildfires.
There are four categories of wildfires:
Wildland fire - fuel is mainly natural vegetation;
Interface or intermix fire - urban/wildland fires, both vegetation and manmade fuel;
Firestorm - very intense event, suppression very difficult; and
Prescribed/prescribed natural fire - fire set or natural fire allowed to burn.

Fire in Colorado in 2000 Photo provided by CDEM

Other hazards can produce wildfires or aggravate conditions. High winds can down powerlines, earthquakes may crack gas lines, and volcanoes, lightning, and floods can cause fires. Areas experiencing extreme drought conditions are particularly vulnerable to lightning strikes.

Wildfires destroy vegetation, which can contribute to mudslides, landslides and floods. Large fires can also create very strong winds. Colorado roads and residences have suffered continual damage in recent years from flood and mudslides created in burned scar areas.

The 2002 wildfire season in Colorado was the most expensive in the state's history. The overall estimated cost of the Iron Mountain, Coal Seam, Missionary Ridge and Hayman Fires in Colorado is $70.3 million in insured losses ($78.8 million in 2006 dollars). Companies took in about 1,236 claims for the Hayman and Missionary Ridge Fires at an estimated cost of $56.4 million.

For complete information on wildfire, refer to the Colorado Wildfire Mitigation Plan located online at http://www.colostate.edu/Depts/CSFS/govpage.html

Drought and Stress-Colorado has experienced a multi-year drought recently that has resulted in drier and more flammable fuels. Insect epidemics and forest parasites may be increasing in number and severity due to drought-related stress.

Lightning can cause structural fires as well as wildfires. In 1997 in Denver, a warehouse fire caused by lightning resulted in a $70 million loss.

One of the most noted urban fires is the Great Chicago Fire of 1871. Attributed to this fire were 1,152 deaths, 17,450 burned buildings, and damage estimated at $168 million.

Due to the risk of fire from lightning strikes, it is very dangerous to store flammable liquids in rooftop storage tanks.

Some of the factors used in risk assessment of buildings for lightning events include structure type, construction type, location, topography, occupancy, and contents.

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Catastrophic fires account for 2.3% of insurance losses.

Colorado State Parks has identified 16 parks in the "red zone," an area defined by the Colorado State Forest Service as having a high potential for catastrophic fire events near communities.

(Sources: http://rmiia.org/Catastrophes_and_Statistics/Wildfire.htm; www.nifc.gov/fireinfo/nfnmap.html; www.nifc.gov/stats/wildlandfirestats.html; FEMA 1997); Colorado State Parks: Reducing the Risk of Wildfire on State Parks.

WILDFIRE HAZARD IN THE UNITED STATES

The table below is a summary of the total fires and acres burned in the U.S. from 1990 through 2006. The figures are based on end-of-year reports compiled by wildland fire agencies (Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), USDA Forest Service (USFS) and state lands) after each fire season. Complete information is found at http://www.nifc.gov/stats/wildlandfirestats.html. Total fires and acres burned data goes back to 1960. The table at the bottom shows total suppression costs by year for five federal land management agencies. Three times during the period, the suppression costs surpassed $1 billion. Costs were just under $8 billion for the eleven years.

Total Fires and Acres Burned in the U.S. from 1990-2006

Year	Fires	Acres
2006	96,385	9,873,745
2005	66,552	8,686,753
2004	77,534	6,790,692
2003	85,943	4,918,088
2002	88,458	6,937,584
2001	84,079	3,555,138
2000	122,827	8,422,237
1999	93,702	5,661,976
1998	81,043	2,329,709
1997	89,517	3,672,616
1996	115,025	6,701,390
1995	130,019	2,315,730
1994	114,049	4,724,014
1993	97,031	2,310,420
1992	103,830	2,457,665
1991	116,953	2,237,714
1990	122,763	5,452,874

http://www.nifc.gov/stats/wildlandfirestats.html

Fire Suppression Costs for Federal Agencies (BLM, BIA, USFWS, NPS, USFS) from 1994-2004

Year	Five Agency Total
2004	890,233,000
2003	1,326,138,000
2002	1,661,314,000
2001	917,800,000
2000	1,362,367,000
1999	523,468,000
1998	328,526,000
1997	256,000,000
1996	679,167,600
1995	340,050,000
1994	845,262,000
Total	7,804,187,600

www.nifc.gov/stats/wildlandfirestats.html

WILDFIRE HAZARD IN COLORADO

The table below show statistics provided by the Colorado State Forest Service. In the period from 1990 through 2005, there were a total of 32,790 reported fires on state and private lands. Over 600,000 acres burned.

Fires In Colorado On State and Private Lands by Year from 1990 to 2005

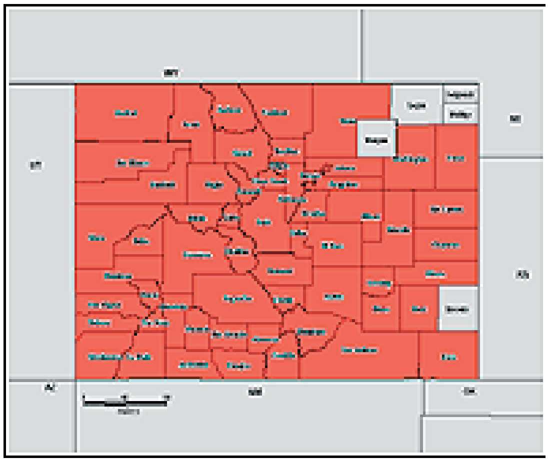
Year	Number	Acres
2005	2,014	14,446
2004	1,826	15,239
2003	2,471	23,308
2002	3,409	244,252
2001	2,966	45,816
2000	2,043	76,288
1999	1,987	33,256
1998	1,349	10,282
1997	1,605	16,703
1996	2,499	49,498
1995	2,224	32,011
1994	3,158	52,125
1993	1,267	3,526
1992	1,048	4,158
1991	1,449	6,576
1990	1,475	9,825
Totals	32,790	637,309

Colorado State Forest Service 2007

Colorado has one Presidential disaster declaration for wildfires in 2002:

Aid For Colorado Wildfires Tops $29.7 Million
Disaster Recovery Update
Release Date: August 21, 2002
Release Number: 1421-39

Summary of Colorado Disaster Statistics
Registrations 2,724
Disaster Housing ($ Approved) $251,275
IFG ($ Approved) $441,041
DUA ($ Disbursed) $46,604
SBA loans ($ Approved) $9,007,300
FMA assistance (advance) $20,000,000
Source:www.fema.gov/news/newsrelease.fema?id=4058



Notable Fire Events in Colorado

Year	Location/Name	Costs/Losses
1937	Roosevelt NF	1 death
1976	Battlement Mesa, Grand Junction	3 deaths, 880 acres
1985	Columbia	1 death
1986	Montrose	4 deaths
1988	Lefthand Canyon, BoulderCo.	2,500 acres
1989	Black Tiger, Boulder Co.	$10,000,000, 44 structures, 1,778 acres
1989	Panorama, Garfield & Eagle Counties	Unknown
1990	Olde Stage, Boulder Co.	10 structures, 3,000 acres
1991	Routt NF	1 death
1992	Glenwood Springs	1 death
1994	Hourglass (Pingree Park)	13 structures, $2,200,000
1994	Wake, Delta Co.	$2,675,000, 3 structures, 4,000 acres
1994	South Canyon, Garfield Co.	14 deaths, 2,115 acres
1994	Roxborough, Jefferson Co.	100 acres
1996	Buffalo Creek, Jefferson Co.	$3,835,000, 10 structures, 12,000 acres
1999	Battlement Mesa	9 structures
2000	Eldorado, Boulder Co.	$2,000,000
2000	Bobcat, Larimer Co.	18 structures, 10,600 acres
2000	Hi Meadow, Jefferson Co.	51 structures, 10,800 acres
2000	Pony Fire	4 structures, 5,240 acres
2000	Eldorado Fire-Walker Ranch	1,061 acres
2000	Bircher (Mesa Verde)	19,709 acres
2001	Larkspur	1 death
2001	Armageddon-Carter Lake	1,216 acres
2002	Snaking Fire	2,590 acres, 2 structures
2002	Cuerno Verde Fire	388 acres, 2 structures, 2 deaths
2002	Black Mountain Fire	200 acres, 1 injury
2002	Schoonover Fire	3,862 acres, 12 structures, 1 bridge, 2 injuries
2002	Iron Mountain Fire	4,440 acres, 200+ structures, 3 injuries
2002	Spring & James John/Fisher (Trinidad Complex)	17,295 acres, 6 injuries
2002	Ute Pass Fire	
2002	Coal Seam Fire	12,209 acres, 99 structures & 14 outbuildings
2002	Hayman Fire	137,760 acres, 5 deaths, 16 injuries, 600 structures
2002	Dierich Creek/Long Canyon (Miracle Complex)	3,951 acres, 1 injury
2002	Missionary Ridge Fire	70,485 acres, 56 structures, 52 injuries, 1 death
2002	Million Fire	9,346 acres, 11 structures
2002	Mt. Zirkel Complex	31,016 acres
2002	Wiley Ridge Fire	1,084.5 acres
2002	Valley Fire	400 acres, a few homes
2002	Burn Canyon Fire	31,300 acres, 9 injuries
2002	Big Elk Fire	4,413 acres, 1 airtanker, 3 deaths
2002	Big Fish	17,056 acres, 1 logde, 7 cabins
2002	Long Mesa	2,601 acres, 3 homes
2002	Panorama Fire	1,700 acres, 4 homes
2003	Brush Mountain	5,292 acres
2003	Overland	3,439 acres, 12 homes
2003	Cherokee Fire	1,200 acres, 2 homes
2004	Picnic Rock	8,908 acres, 1 home
2005	Mason	11,357 acres
2006	Mauricio Canyon	3,825 acres
2006	Yuma County	23,000 acres
2006	Thomas	3,347 acres
2006	Mato Vega	13,820 acres

Sources: Teie & Weatherford 2000, Wildfire Hazard Mitigation Plan 2007

The 2006 Wildfire Season Summary

Three Fire Management Assistance declarations were received during the 2006 Colorado wildfire season: Red Apple, Mato Vega, and Mauricio Canyon. Red Apple, south of Rifle, started on August 31 and was declared September 1. It burned approximately 800 acres. It was human-caused. Local landowners, Natural Resources Conservation Service, Bookcliffs Conservation District and Williams Production had grass seed sown in the burn area from an airplane in the fall. In the Spring of 2007, juniper and pinon trees were planted. The Mato Vega Fire, in the Sangre de Cristo Mountains in southern Colorado burned in June 2006. The fire burned 13,820 acres in grass, timber, and logging debris. The Mauricio Canyon fire, human caused, burned 3,825 acres near Aguilar in Las Animas and Huerfano Counties.

The 2005 Wildfire Season Summary

One Fire Management Assistance declaration was received during 2005 for the Mason Fire, that burned south of Wetmore, in Custer and Pueblo Counties.

NRCS Emergency Watershed Protection Program		
Mason	Pueblo County	$52,200
http://www.co.nrcs.usda.gov/about/2006LegislativeRpts/Salazar06.pdf		

The 2004 Wildfire Season Summary

Two Fire Management Assistance declarations were made during 2004: McGruder Fire and Picnic Rock Fire. Picnic Rock was declared April 1, 2004 and McGruder was declared July 3, 2004. McGruder was near Cedaredge in Delta County.

NRCS Emergency Watershed Protection Program		
Picnic Rock	Larimer County	$137,680
McGruder	Delta County	$18,000
http://www.co.nrcs.usda.gov/about/2004AnnualReport/ewp.pdf		

The 2003 Wildfire Season Summary

According to the "National Report of Wildland Fires and Acres Burned by State," in 2003 Colorado had a total of 2,180 fires reported and 53,412 acres burned. One hundred twenty-two fires were prescription burns for a total of 22,238 acres. Five Fire Management Assistance declarations were received during 2003: Buckhorn Creek, Cherokee Ranch, Overland, Lincoln Fire Complex, and Cloudy Pass.

NRCS Emergency Watershed Protection Program		
Overland Fire	Boulder County	$56,114
http://www.co.nrcs.usda.gov/about/2004AnnualReport/ewp.pdf		

The 2002 Wildfire Season Summary

The 2002 Colorado Wildfire season was the worst on record. It began in April and continued until early Fall with periods when multiple large fires were burning simultaneously. Details of the season are highlighted below:

-Four thousand six hundred and twelve fires burned 619,030 acres during the 2002 season. The ten-year average is 3,119 fires burning 70,000 acres.

-Twenty-two large fires (of which 17 qualified for FEMA assistance) became state responsibility fires with an estimated cost to the state of over $24 million dollars.

-U.S.D.A. released $14 million to the Natural Resources Conservation Service to restore burned watersheds in Colorado at a 75/25 match.

-Thirteen Type I and II Incident Management teams were utilized.

-One hundred forty-two subdivisions were evacuated, displacing 81,435 people.

-384 homes were lost and an additional 624 other structures were destroyed.

-Sixteen-thousand five-hundred firefighters fought Colorado's 2002 incidents. Tragically, nine firefighters were killed. One air tanker and one helicopter were lost killing three people.

-One Presidential disaster declaration and twenty Fire Management Assistance declarations were made: Panorama, Big Elk, Burn Canyon, Again, Grizzly Gulch, Valley, Wiley Ridge, Million, Missionary Ridge, Dierich, Hayman, Coal Seam, Ute Pass, Janes John/Fisher, Spring, Iron Mountain, Schoonover, Black Mountain, Cuerna Verde, and Snaking.

2002 Colorado Wildfire Insurance Costs

Hayman Fire: $38.7 million insured losses
Missionary Ridge Fires: $17.7 million in insured losses
Coal Seam Fire: $6.4 million in insured losses
Iron Mountain Fire: $7.5 million in insured losses

NRCS Emergency Watershed Protection Program		
Coal Seam	Garfield Co.	446,199
Missionary Ridge	La Plata Co.	2,183,904
Hayman	Douglas/Park/Jefferson/Teller	5,627,369
Million	Rio Grande Co.	214,046
Snaking	Park Co.	72,883
Schoonover	Douglas Co.	74,951
Iron Mountain	Fremont Co.	96,298
Dierich	Mesa Co.	38,013
Burn Canyon	San Miguel Co.	232,393
Panorama	Garfield Co.	108,298
Cherry Creek	La Plata Co.	59,484
http://www.co.nrcs.usda.gov/about/2004AnnualReport/ewp.pdf		

Suppression costs for 2002 exceeded $152 million.

While these numbers are dramatic, they are not surprising. A century of aggressive fire suppression, combined with cycles of drought and changing land management practices, has left many of Colorado's forests unnaturally dense and ready to burn. At the same time, the state's record setting growth has driven nearly a million people into the forested foothills of the Front Range and along the West Slope and central mountains – the same landscapes that are at highest risk for large-scale fire. This movement of urban and suburban residents into the wildland-urban interface (WUI) significantly increases the values-at-risk from wildland fire – the most critical of these being human life.

The 2001 Wildfire Season Summary

In October, 2001, a fire management assistance grant was awarded to the State of Colorado to support fire-fighting activities associated with containing the Armageddon Fire. The fire began on October 31, 2001. The fire was in the foothills along the Front Range.

The 2001 fire season in Colorado was not as spectacular as the 2000 fire season. At 4,022, the number of fires that started was above the 2000 year total of 3,698 fires but the acreage burned (72,210) was significantly less than the 249,976 acres burned in 2000. The Armageddon Fire was the only fire that met the criteria for a Fire Management Assistance Grant.

The Armageddon Fire began on October 31, 2001. The fire was located in Larimer County and threatened approximately 100 homes in the Carter Lake area. The fire was human-caused fire. The fire originated on private land and expanded quickly, fanned by high winds. Initial response to the fire focused on evacuation and structure protection. The complexity of the fire led to the order for an Interagency Type 2 Incident Management Team. The fire was returned to local management on November 3, 2001. The final size of the fire was calculated at 1,216 acres, all in private ownership. Like most large fires, the fire was weather driven-wind controlled. The biggest concerns were high winds, light flashy fuels, narrow roads with congested urban traffic and a private dump with unknown material in it. No dwellings were destroyed and no lives were lost or serious injuries reported from any of the fires.

The 2000 Wildfire Season Summary

In June 2000, two fire assistance grants were awarded to the State of Colorado to support fire-fighting activities associated with containing the Bobcat Gulch and Hi Meadow Fires. Both fires began on June 12th, 2000. A third fire assistance grant was awarded to the State for the Eldorado/Walker Ranch (Eldorado) Fire that began on September 15th, 2000. All fires were in the foothills along the Front Range in Colorado. The Bobcat Gulch fire was caused by human error – an escaped campfire. The fire was located in Larimer County approximately one mile north of the Town of Drake with the affected acreage in Township 6 North and Ranges 70 and 71 West. The Bobcat Gulch fire burned in the Arapahoe-Roosevelt National Forest. Fuels included brush, ponderosa pine, spruce-fir, and lodge pole pine at higher elevations of the fire. The fire impacted the Cedar Park Subdivision where a total of 60 homes were evacuated. The fire threatened structures in an area from Eden Valley to Buckhorn Creek. The fire consumed 10,599 acres of grass, brush, and timber and destroyed 18 homes within the wildland interface out of a total of 25 sites where property was reported as destroyed or damaged. An estimated 1500 to 2000 residences were within easy reach.

The Hi Meadow fire also started on June 12th. The Hi Meadow fire began in Jefferson and Park Counties. The location of the fire was about 35 miles southwest of Denver. It was caused by human activity. The Hi Meadow fire affected federal, state, and private lands and resulted in the evacuation of approximately 600 residents from two towns (Pine and Buffalo Creek), and 19 subdivisions in the area. The Hi Meadow Fire had 3000 structures in the interface that could have been affected. The control date for the Hi Meadow fire was on June 25th. A total of 10,800 acres were burned: 5,623 acres on federal land and 5,177 acres were on state or private land. A total of 10,592 acres were in Jefferson County and 208 acres in Park County. A total of 51 residences, six outbuildings, and one commercial building were lost.

The Eldorado fire began on September 15. The fire was located approximately seven miles southwest of the City of Boulder and is suspected to be human caused. It started on county administered open space called Walker Ranch Park. It affected County land, Denver Water Board land, and private lands. The fire burned in mixed Douglas fir and ponderosa pine with interspersed open grasslands and shrubs. The blaze consumed over a thousand acres (1,061). It posed a threat to residents in the Pine Notch, Lake Shores and Juniper Heights subdivisions and forced the evacuation of over 200 residents from 125 homes. No residences or other structures were lost. Besides the homes, utilities, park facilities, historic structures, Denver Water Board lands with significant watersheds, and riparian and fisheries resources were also at risk.

Like most large fires, the three fires were weather driven-wind control. One of the biggest problems was a high fuel load. The areas' steep terrain and high altitude made firefighting difficult. The State also dealt with a limited number of resources.

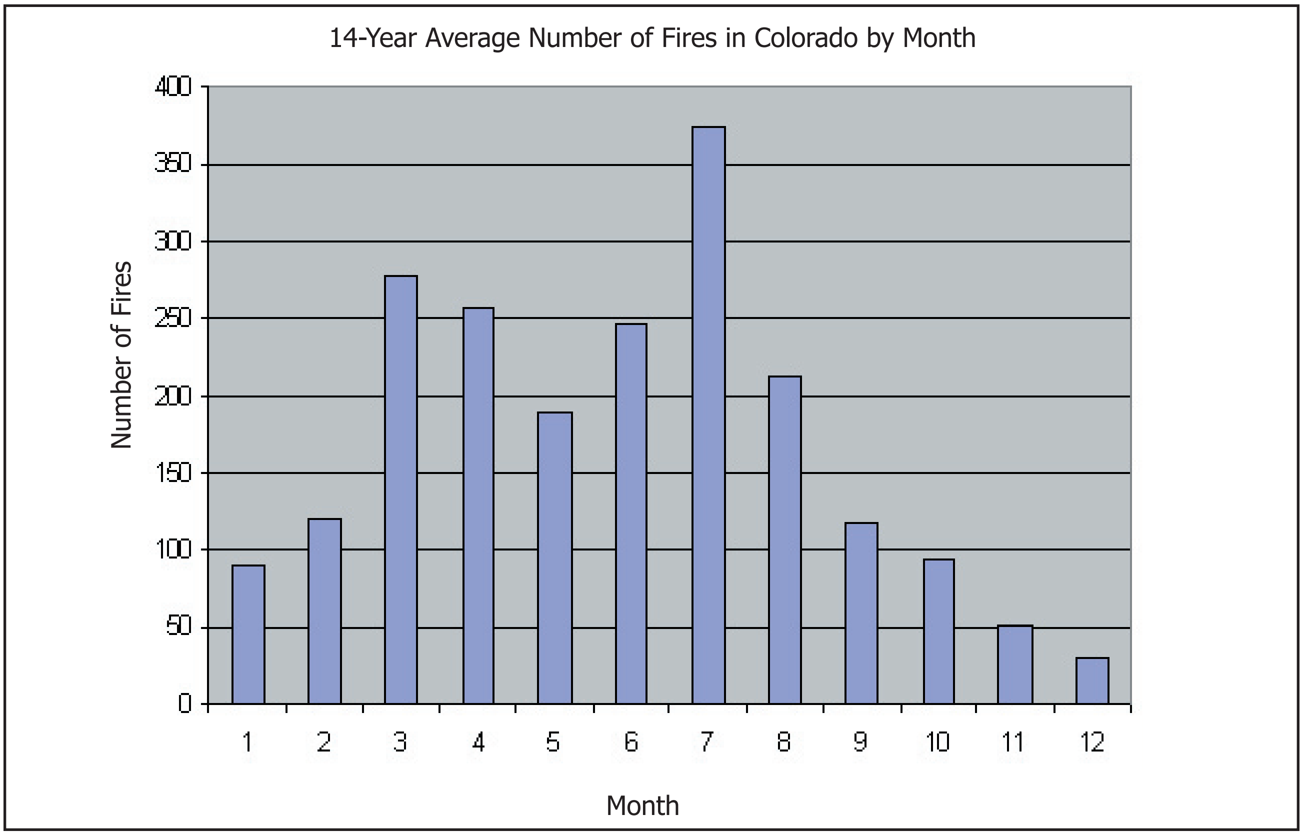
The table and chart at the bottom of the page demonstrate that fires occur every month. The most fires occurred in July seven of the 14 years, followed by March, April, June, August, and May. The 14 year average number of fires per year is 2,059. Over the years, most acreage has burned in May, June, July, and August. Conditions such as drought and beetle kill add to fire risk.

Communities and wildfire mitigation specialists coordinate annually to organize and host the Colorado Mitigation and Wildfire Conference. Federal and state agencies provide staff support and financial assistance. The conference has been held in various communities around the state, to encourage homeowners, politicians, fire fighters, planners, decisionmakers and others to attend.

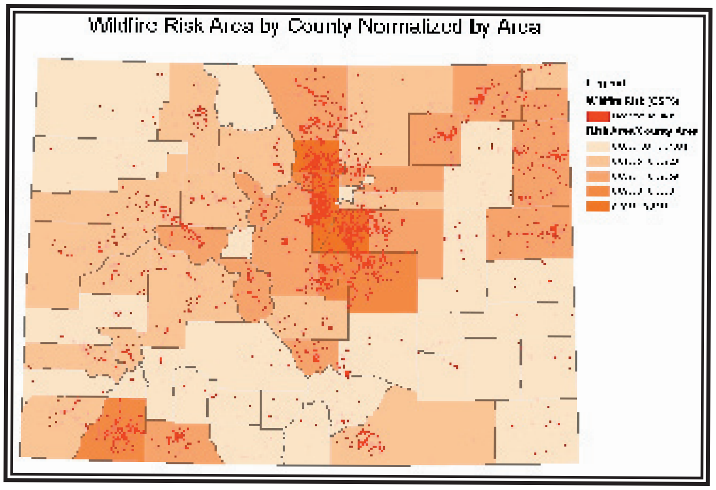
COLORADO STATE AND PRIVATE LAND FIRES: 14-YEAR AVERAGES BY MONTH FROM 1990-2003

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
14-yr average number/ month	90	120	278	257	189	246	374	213	117	94	51	30
14 year average acres/ month	801	1,609	2,874	2,711	4,853	14,164	5,913	6,420	1,809	1,189	826	42

Colorado State Forest Service 2004



Two major risk assessments have been completed in the past. The first was completed by the Colorado State Forest Service and the Colorado Office of Emergency Management in March of 1999 known as the Midlevel Assessment. The table below represents data from that model. The wildfire risk is shown in acres and as the percent of the county with a moderate to high hazard. The layer was combined with the moderate to high hazard risk layer to create the map to the right.



Colorado Counties by Percent of Acres at Risk for Wildfire: 1999*

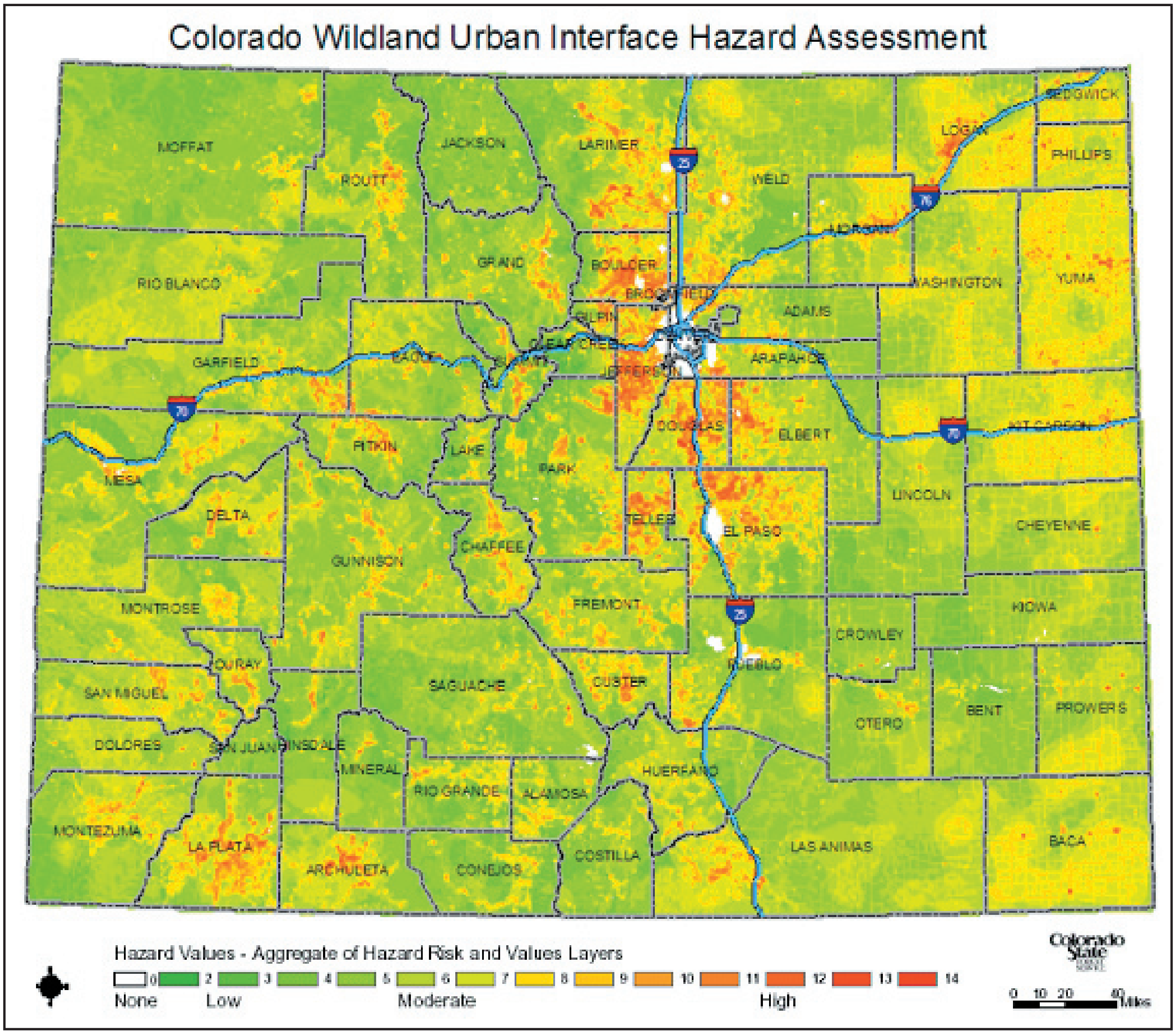
% Area at Risk	County	Moderate to High Hazard (acres)	Total Acres	% Area at Risk	County	Moderate to High Hazard (acres)	Total Acres
0.06	Adams	497.78	768,098.50		Kit Carson		
2.65	Alamosa	12,233.72	462,496.20	9.33	Lake	22,870.38	245,001.80
1.12	Arapahoe	5,748.71	514,107.30	26.46	La Plata	287,983.31	1,088,385.00
26.36	Archuleta	228,558.66	867,207.00	21.91	Larimer	368,957.77	1,684,129.00
	Baca			7.09	Las Animas	216,392.35	3,053,720.00
	Bent				Lincoln		
19.80	Boulder	95,168.25	480,686.40		Logan		
	Broomfield			25.81	Mesa	552,686.56	2,141,740.00
19.80	Chaffee	128,559.50	649,452.80	5.49	Mineral	30,831.46	561,889.90
	Cheyenne			3.80	Moffat	115,639.59	3,042,580.00
29.21	Clear Creek	73,998.63	253,372.60	17.68	Montezuma	230,435.72	1,303,012.00
2.95	Conejos	24,337.81	826,095.90	24.45	Montrose	351,531.89	1,437,765.00
5.99	Costilla	47,137.33	787,009.30		Morgan		
	Crowley				Otero		
19.93	Custer	94,314.40	473,309.80	23.38	Ouray	81,149.07	347,072.30
21.15	Delta	155,555.62	735,609.50	14.47	Park	204,649.50	1,414,525.00
0.01	Denver	8.64	99,617.14		Phillips		
6.60	Dolores	45,495.34	689,285.80	21.01	Pitkin	130,464.21	621,026.90
35.97	Douglas	193,724.18	538,527.30		Prowers		
29.32	Eagle	319,184.56	1,088,545.00	3.07	Pueblo	47,180.53	1,534,410.00
0.80	Elbert	9,411.22	1,182,788.00	9.04	Rio Blanco	186,769.06	2,065,924.00
18.36	El Paso	250,229.55	1,362,591.00	6.03	Rio Grande	35,238.91	584,600.10
33.78	Fremont	331,266.29	980,558.00	17.55	Routt	265,245.90	1,511,680.00
39.93	Garfield	755,612.73	1,892,209.00	14.31	Saguache	290,135.10	2,027,853.00
20.50	Gilpin	19,728.13	96,212.98	0.34	San Juan	841.74	248,753.50
11.47	Grand	137,260.33	1,196,335.00	20.99	San Miguel	173,351.36	826,057.50
22.32	Gunnison	465,280.69	2,084,727.00		Sedgwick		
5.59	Hinsdale	40,199.48	719,278.60	13.10	Summit	51,892.21	396,124.60
15.09	Huerfano	153,756.32	1,019,181.00	32.06	Teller	114,669.95	357,724.60
2.29	Jackson	23,784.72	1,036,872.00		Washington		
56.84	Jefferson	282,540.56	497,076.60	0.05	Weld	1,403.47	2,570,639.00
	Kiowa				Yuma		

Based on the Mid-level wildfire assessment, March 1999 by the Colorado State Forest Service and Office of Emergency Management

The second risk assessment was completed in 2002 by the Colorado State Forest Service. Full details of the risk assessment, including the methodology and digital layers used, are included in the appendices. The map below was generated as a product of the assessment and indicates the wildland urban interface hazard assessment for the state. In reviewing the map, it becomes obvious that every county has some area with at least a moderate interface wildfire hazard.

To determine if your community is designated as a "community at risk" in the "Wildland Urban Interface Communities at High Risk from Wildfire," list, refer to www.stateforesters.org/WUI_list.html.

Home burned in the fire on Battlement Mesa. The fire was human-caused. Photo provided by the Colorado State Forest Service.



Colorado Wildland Urban Interface Hazard Assessment

FRONT RANGE FORESTS REQUIRING FOREST TREATMENT BY COUNTY (acres)

County	Restoration only	Fire risk mitigation only	Both restoration and fire risk mitigation	Total restoration and/or fire risk mitigation	Private land (percent of total)
Boulder	35,978	77,212	51,021	164,211	58%
Clear Creek	833	58,595	7,356	66,784	59%
Douglas	90,807	61,143	40,529	192,479	42%
El Paso	31,169	41,891	57,107	130,167	62%
Gilpin	2,177	42,365	472	45,014	63%
Grand	1,838	94,321	390	96,549	65%
Jefferson	71,157	92,971	88,094	252,222	73%
Larimer	98,856	130,956	42,350	272,162	60%
Park	27,463	122,808	31,377	181,648	57%
Teller	27,211	86,848	23,168	137,227	61%
Total Front Range	387,489	809,110	341,864	1,538,463	60%

Source: Front Range Fuels Treatment Partnership: Living with Fire: Communities and Restoring Forests, May 2006

Many partnerships around the state have started conducting more localized risk assessments. The Front Range Fuels Treatment Partnership is an example of a multi-organization entity conducting a regional risk assessment across jurisdictional boundaries. The partnership split into four task forces, each intent on completing specific tasks within the process. The above chart depicts acres at highest risk for wildfire as defined by that committee. In an effort to reduce devastating results, more and more wildfire mitigation councils and committees and forums have leapt up all over the state. Much of the state legislation in the past five years focuses on wildfire mitigation and suppression activities.

Wildfire mitigation projects are being completed all over the state. The photos to the left are of a Colorado Springs wildfire mitigation project in North Cheyenne Canyon. The city wildfire mitigation team has used many funding sources, including FEMA's Pre-Disaster Mitigation program, to fund fuels mitigation. El Paso County bought a chipper with Hazard Mitigation Grant program funds and did fuel mitigation in several neighborhoods in the Monument-Woodmoore area. Clear Creek County bought a chipper with Project Impact funds and did mitigation throughout the county. Recently, the Colorado State Forest Service, Colorado State Parks, and Colorado Division of Emergency Management pursued funds to continue fuels mitigation in the state park system.

Colorado Springs North Cheyenne Canyon
Photos by Christina Randall

Community Wildfire Protection Plans (CWPPs)

The Colorado State Forest Service keeps track of the communities with wildfire protection plans.

COMMUNITIES WITH COMPLETED CWPPS

COUNTY	COMMUNITY
Alamosa	Zapata Subdivision
Archuleta	Archuleta County
Boulder	Four Mile FPD
Boulder	Gold Hill FPD
Boulder	Boulder Mountain FPD
Boulder	Lefthand FPD
Costilla	Forbes Wagon Creek
Dolores	Dolores County
Douglas	Perry Park
Eagle	Eagle County
Eagle	Cordillera
El Paso	Woodmoore
El Paso	Caroll Lakes
El Paso	Crystal Park HOA
Garfield	Glenwood Springs FPD
Gilpin	Colorado Sierra FPD
Grand	Grand Lake FPD
Grand	Grand County
Gunnison	Arrowhead Subdivision
Jackson	Rand
Jackson	Gould
Jefferson	Elk Creek
Jefferson	Lower North Fork
Jefferson/Douglas	South Platte
Jefferson/Park	Harris Park
La Plata	La Plata County Community
Lake	Lake County
Larimer	East Portal
Larimer	Little Valley HOA
Larimer	Buckskin Heights
Larimer	Larimer County
Larimer	Poudre Fire Authority
Larimer	Crystal Lakes
Las Animas	Sante Fe Trail Ranch
Mesa	Mesa County
Montezuma	Montezuma County
Pueblo	Pueblo County
Routt	Burgess Creek
Routt	Steamboat Pines
San Juan	San Juan County
Saguache	Baca Grande
Summit	Summit County
Teller	Teller County

Source: Colorado State Forest Service 2007

COMMUNITIES WITH CWPPS IN PROGRESS

COUNTY	COMMUNITY
Chaffee	Chaffee County
Conejos	Sheep Creek Landowners Association and Posada Del Rio, LLLP
Custer	Custer County
Custer	Spread Eagle
Delta	Delta Hotchkiss FD
Douglas	Roxborough Park
Douglas	Pine Ridge Subdivision
El Paso	Black Forest FPD
El Paso	Ridgewood HOA
El Paso	Ute Pass (Cascade, Chipeta Park, Green Mountain Falls)
Fremont	Fremont County
Grand	Fraser Valley (Fraser/Winter Park/Sunset Ridge)
Jackson	Jackson County
Jefferson	Inter-Canyon FPD
Jefferson	Indian Hills FPD
Jefferson	West Metro FPD
La Plata	Falls Creek Ranch
La Plata	Edgemont Ranch (unit 1)
La Plata	Los Ranchitos Estates HOA
Larimer	Magic Sky
Larimer	Sambhala Mountain Center
Larimer	Estes Park
Larimer	Ben Delatour Boy Scout Ranch
Larimer	City of Loveland
Larimer	Town of Berthoud
Larimer	Poudre Canyon
Larimer	Rist Canyon
Larimer	Meadowdale Hills
Larimer	Glen Haven
Larimer	Red Feather Lakes
Mesa	Colorado National Monument
Mesa	Glade Park
Montezuma	Cedar Mesa Subdivision
Ouray/ Montrose	Horsefly FP Association (Cornerstone, Eldred Ranch, Powerline, Tyoweh Trail Deerview Estates/V66 Trail, Wildcat Canyon, Mariposa, Government Springs
Park	Park County
Pitkin	Conundrum Area
Pitkin	Starwood Area
Rio Blanco	Rio Blanco County
Saguache	Baca Grande VFD and Kundalini Fire Management
	SW Hwy 115 FPD

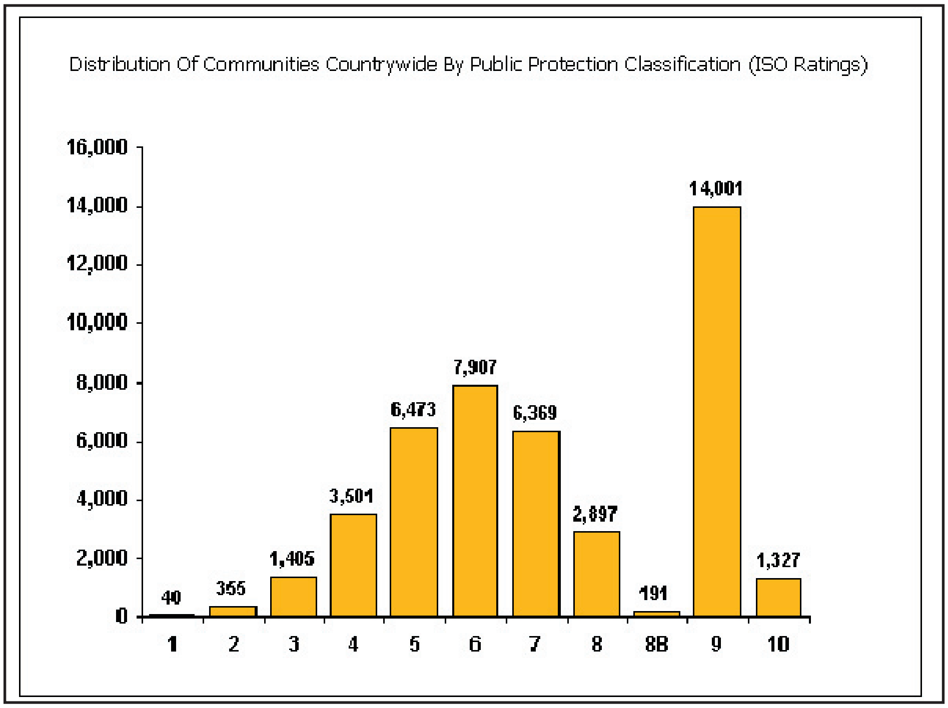
Source: Colorado State Forest Service 2007

ISO RATINGS FOR COMMUNITIES

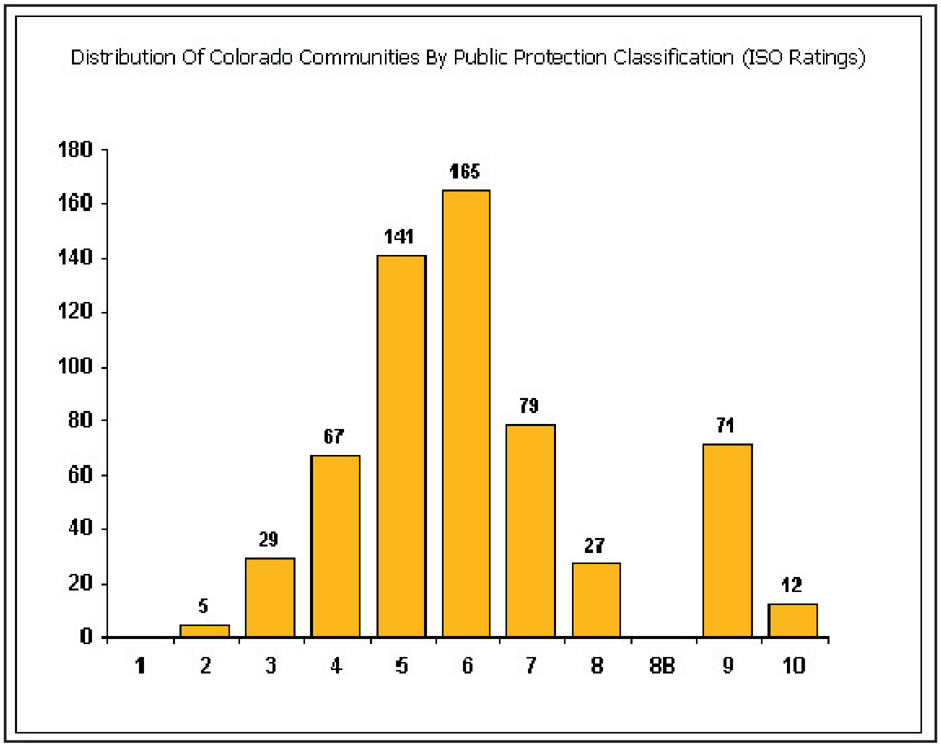
The Insurance Services Office, Inc., commonly known as ISO, is an independent group that serves insurance companies, fire departments, insurance regulators, and others by collecting and analyzing information about municipal fire protection efforts and grading the community with a Public Protection Classification (PPC). The program measures fire-suppression programs in 45,000 fire districts around the country.

The two graphs below are reproduced from the ISO Mitigation Online website and may be found at www.isomitigation.com/fire9.html and www.isomitigation.com/ppcchart/colorado.html. According to the graph, 596 communities are rated in Colorado.

The organization uses the Fire Suppression Rating Schedule manual. Classification ranges from 1 to 10, with Class 1 representing exemplary fire protection and Class 10 indicating that the area's fire suppression program does not meet minimum program criteria. Three factors are used to determine a community's grade: fire alarms (10 percent of grade), fire department (50 percent of grade), and water supply (40 percent of grade).



The fire alarm portion of the grade takes into account how well the fire department receives and dispatches fire alarms, including the number of operators, telephone service and lines, and the listing of emergency numbers in phone books. The fire department part of the grade looks at the number of engine companies and their distribution in the community, training of personnel, response to emergencies, and equipment maintenance and testing. Water supply considerations include sufficiency of water supply, rate of water flow at water mains, and distribution and condition of fire hydrants.



Floods

flooding - accumulation of water within a water body and the overflow of excess water onto adjacent floodplain lands (FEMA 1997).

floodplain - land adjoining the channel of a river, stream, ocean, lake or other watercourse or water body that is susceptible to flooding (FEMA 1997).

FLOOD FACTS

All states and territories are at risk from floods.

Overflow from river channels, flash floods, alluvial fan floods, ice-jam floods, dam breaks, high groundwater levels, debris flows, subsidence and changing lake levels can cause flooding.

Damage estimates from the 1993 floods in the Midwest were $21 billion. Forty-eight deaths were attributed to these storms.

Floodprone areas have been identified in 180 cities and towns and 51 of the 64 counties in Colorado.

It is estimated that over 250,000 people are living in Colorado's floodplains.

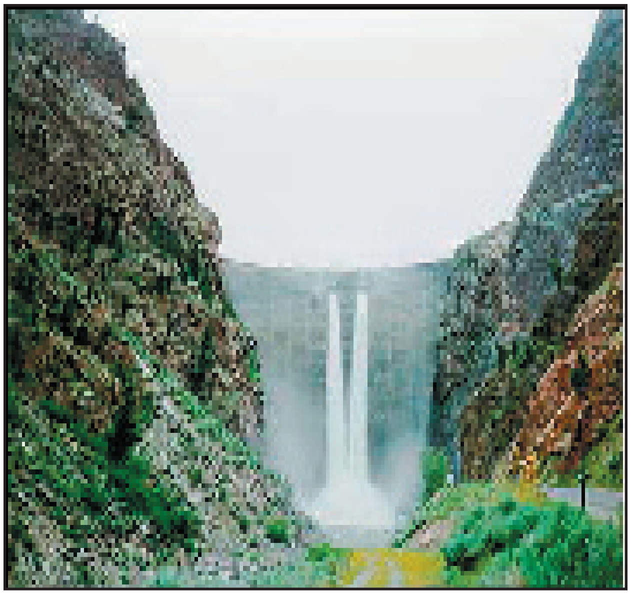
There are estimated to be 65,000 homes and 15,000 commercial, industrial, and business structures in identified floodplains in Colorado.

The value of the property, structures, and contents located in identified floodplains in Colorado is estimated to be over $11 billion.

Colorado has had nine major flood disasters between 1965 and 1999:

1965: 33 Front Range communities
1969: 15 Front Range communities
1970: Southwestern Colorado
1973: 13 Front Range communities
1976: 2 Front Range communities
1982: Larimer County (dam failure)
1984: 15 Western Slope counties
1997: 13 Eastern Colorado counties
1999: 12 counties

One rescue worker lost his life in 2000 attempting to rescue people trapped during a flash flood in the Denver metropolitan area.



Crystal Dam Photo provided by Alan Pearson, DWR

(Sources: www.fema.gov/nfip/flossdp.htm; http://cwcb.state.co.us/flood_watch/floodplain.html; www.fema.gov/nfip/10409912.htm; www.fema.gov/nfip/flossp.htm; FEMA 1997)

FLOOD HAZARD IN THE UNITED STATES

The following table lists reported deaths, injuries, and property and crop damage costs due to flash, river, and small stream/urban flooding in the United States for consecutive years from 1996 through 2006.

Summary of Reported Deaths, Injuries, and Damage Costs due to Flash, River, and Small Stream/Urban Flooding in the United States: 1996-2006

Year	Deaths	Injuries	Property Damage ($million)	Crop Damage ($million)
1996	131	95	2,120.7	414.6
1997	118	525	6,910.6	116.9
1998	136	6,440	2,324.8	318.1
1999	68	301	1,420.7	371.7
2000	38	47	1,255.1	679.3
2001	48	277	1,220.3	43.0
2002	49	88	655.0	82.5
2003	86	70	2,543.1	158.1
2004	82	128	1,696.2	341.4
2005	43	38	1,537.7	104.2
2006	76	23	118,650.4	200.1

Sources: www.nws.noaa.gov/om/severe_weather/

For complete information on floods in Colorado, refer to the Colorado Flood Hazard Mitigation Plan 2007 at http://cwcb.state.co.us.

Every year, flooding causes hundreds of millions of dollars in damage to residences and businesses in the United States. Standard homeowners and commercial property policies do not cover flood losses. To meet the need, the federal government offers the National Flood Insurance Program (NFIP). Some companies, such as Lloyd's of London and Chubbs also offer flood insurance. The NFIP offers flood insurance to communities that comply with standards for floodplain management. A flood does not have to be a declared disaster in order to make a claim on this insurance.

The following statistics are reported on the National Flood Insurance Program website:

In the United States, there are over 4.2 million flood insurance policies in the program.

In Colorado there are over 17,600 policies.

Since January 1, 1978, close to 2,000 losses have been paid to Colorado policy holders; $8 million in payments have been received.

According to the FEMA Disaster Report for Colorado, there are 40 repetitive loss properties. None have been identified as "target" properties.

Source: www.fema.gov/nfip/

Canon City Detention Pond Photo by Bill Archambault
Ordway Detention Pond Photo by Marilyn Gally

The following table shows flood loss statistics by state for the period 1/1/1978 through 07/19/2007.

SUMMARY OF FLOOD LOSS STATISTICS IN THE UNITED STATES: 1/1/1978-07/19/2007

STATE	NUMBER OF LOSSES	TOTAL PAYMENTS ($MILLION)
Alabama	36,057	920.2
Alaska	396	3.8
Arizona	3,675	28.5
Arkansas	4,394	40.0
California	42,983	474.8
Colorado	2,075	8.0
Connecticut	15,374	114.1
Delaware	3,484	50.3
Florida	209,857	3,280.8
Georgia	13,339	192.8
Hawaii	3,790	62.6
Idaho	591	4.7
Illinois	35,882	244.2
Indiana	10,912	84.0
Iowa	7,231	66.5
Kansas	5,921	59.2
Kentucky	16,563	190.0
Louisiana	372,782	1,538.1
Maine	4,079	30.9
Maryland	14,013	234.5
Massachusetts	26,473	269.3
Michigan	9,229	41.8
Minnesota	9,391	108.8
Mississippi	60,167	2,886.9
Missouri	39,759	495.0
Montana		
Nebraska	3,412	21.0
Nevada	1,397	37.3
New Hampshire	3,172	30.6
New Jersey	81,764	744.5
New Mexico	876	8.0
New York	164,642	828.1
North Carolina	62,053	788.7
North Dakota	9,344	133.7
Ohio	20,525	186.9
Oklahoma	17,678	207.3
Oregon	4,843	77.1
Pennsylvania	53,882	731.3
Rhode Island	3,279	32.5
South Carolina	30,871	478.7
South Dakota	1,808	14.4
Tennessee	6,844	62.7
Texas	230,589	4,038.4
Utah	779	5.0
Vermont	1,014	6.7
Virginia	31,078	442.3
Washington	9,344	134.1
West Virginia	23,764	262.0
Wisconsin	6,054	36.9
Wyoming	349	1.4

Source: www.fema.gov/nfip/

FLOOD HAZARD IN COLORADO

Colorado has a history of tragic flood events. The table to the right highlights major flood events in Colorado from 1864 through 2006. Greatest loss of life occurred during the Big Thompson flood of 1976. In 1965, damages in Denver were evaluated at over $2 billion ($2007) due to a South Platte River flood. Dams at Chatfield and Cherry Creek were built as a result.

The table below shows recent U.S.D.A. Natural Resource Conservation Service projects.

NRCS Emergency Watershed Protection Program		
Deadwood Gulch	Dolores County	23,900
Turkey Rock Subdivision	Teller County	135,000
http://www.co.nrcs.usda.gov/about/2004AnnualReport/ewp.pdf		

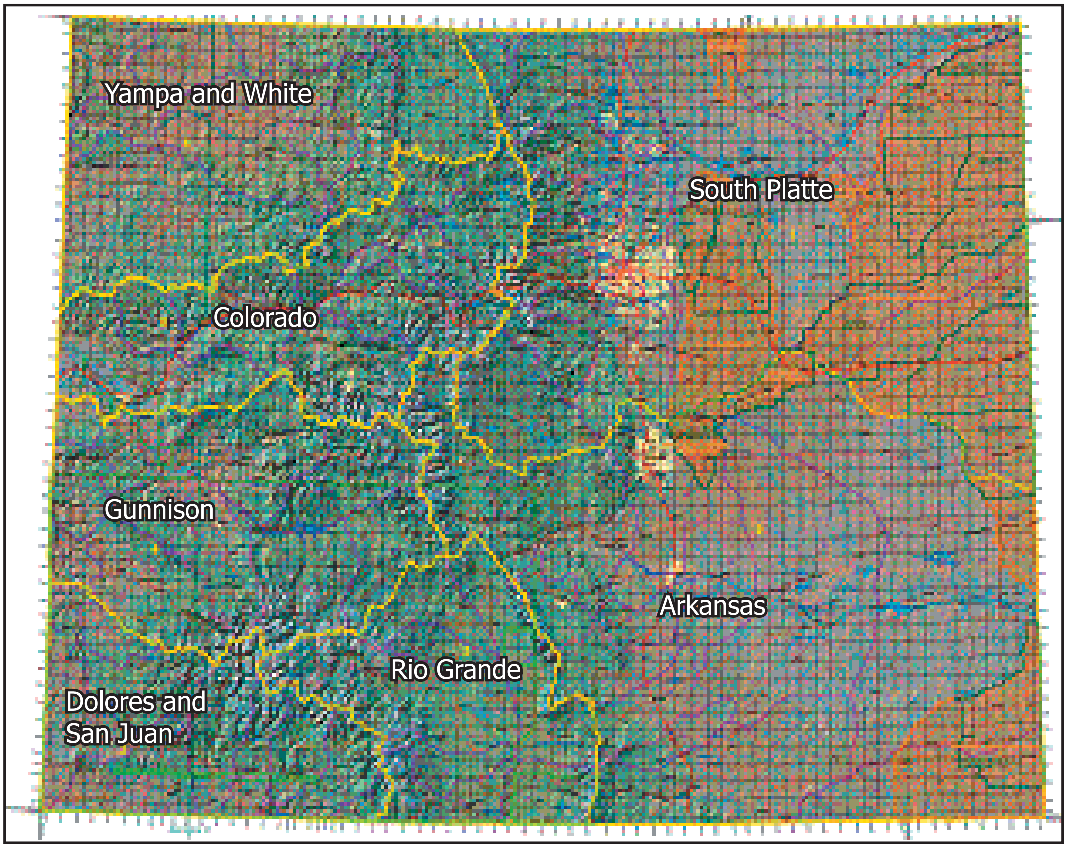
The maps below and on the next page depict the water resources division boundaries for the state. There are seven regions. Resource boundaries are highlighted.

The table to the right is a summary of damage in Colorado due to floods. The period is from January 1, 1978 through December 31, 2006.

NOTABLE FLOOD EVENTS IN COLORADO: 1864-2006

YEAR	LOCATION	DEATHS	DAMAGES (2007 $ MILLIONS)
1864	Cherry Creek (Denver)	0	7
1896	Bear Creek (Morrison)	27	8
1911	San Juan River (by Pagosa Spr.)	2	7
1912	Cherry Creek (Denver)	2	156
1921	Arkansas River (Pueblo)	78	988
1935	Monument Creek (Col. Springs)	18	68
1935	Kiowa Creek near Kiowa	9	20
1942	South Platte River Basin	?	10.8
1955	Purgatorie River (Trinidad)	2	47
1957	Western Colorado	0	23
1965	South Platte River (Denver)	8	2,600
1965	Arkansas River Basin	16	267
1969	South Platte River Basin	0	28
1970	Southwest Colorado	0	17
1973	South Platte River (Denver)	10	505
1976	Big Thompson River (Larimer)	144	110
1982	Fall River (Estes Park)	3	64
1983	North Central Counties	10	34
1984	West & Northwest Counties	2	61
1993	Western Slope	0	2.7
1995	Western Slope & South Platte	21	68
1997	Ft Collins & 13 East Counties	6	220
1999	Col. Springs, 12 East Counties	0	130
2000-6	Statewide various events	5	111
Totals		363	5.5 billion

Source: Colorado Flood Hazard Mitigation Plan 2007



http://water.state.co.us/pubs/gis.asp

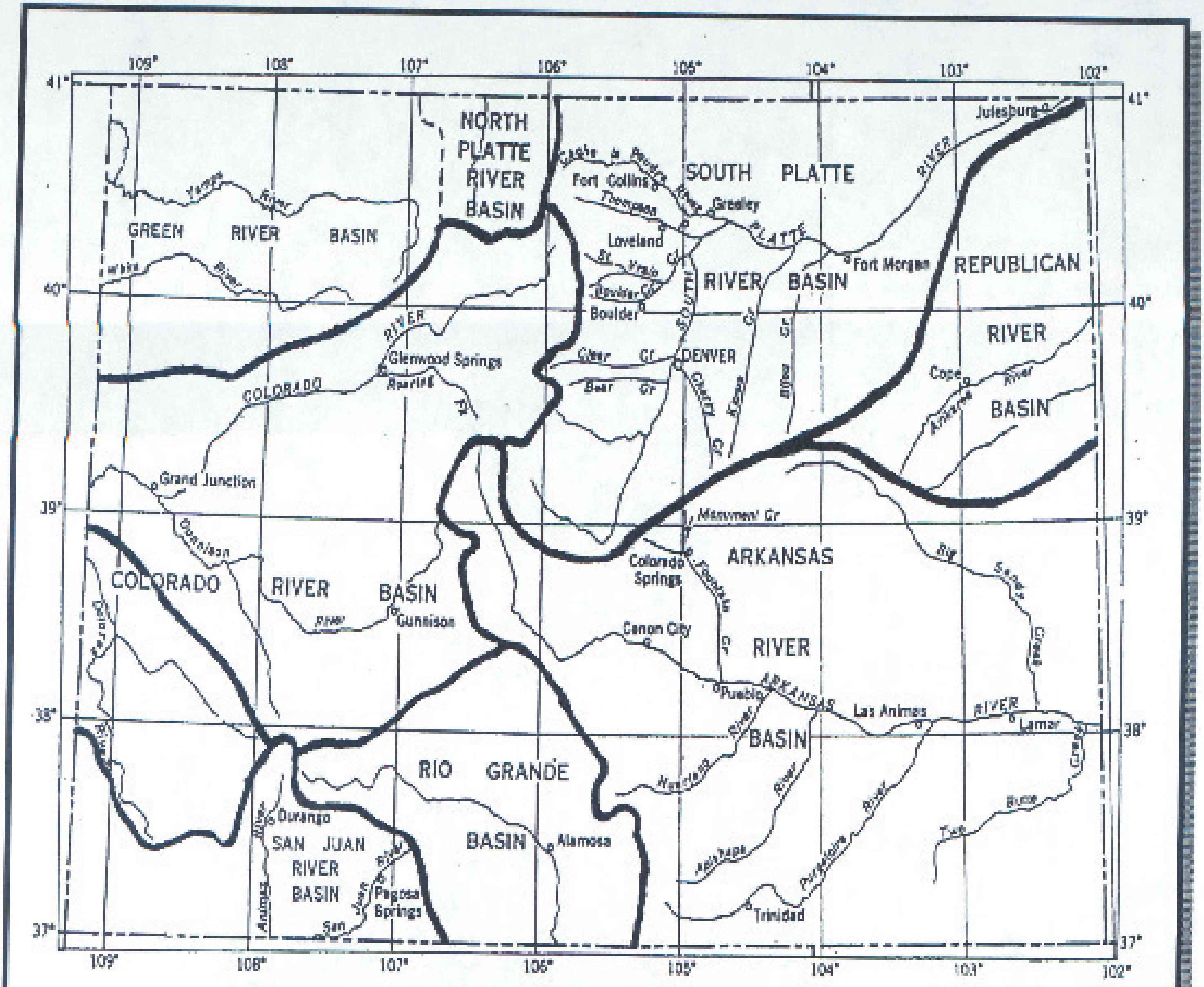

109°
108°
107°
106°
105°
104°
103°
102°
41°
40°
39°
38°
37°
NORTH PLATTE RIVER BASIN
GREEN RIVER BASIN
Yampa River
White River
SOUTH PLATTE RIVER BASIN
Cache la Poudre River
Fort Collins
Greeley
Thompson
Loveland
St Vrain Cr
Boulder Cr
Boulder
PLATTE
SOUTH
Fort Morgan
Julesburg
RIVER
DENVER
Clear Cr
Bear Cr
Cherry Cr
Kiowa Cr
Bijou Cr
REPUBLICAN RIVER BASIN
Cope
Arikaree River
COLORADO RIVER BASIN
RIVER
Glenwood Springs
Roaring Fk
COLORADO
Grand Junction
Gunnison
River
Gunnison
Dolores
River
Monument Cr
Colorado Springs
Fountain Cr
ARKANSAS RIVER BASIN
Canon City
Pueblo
ARKANSAS
Las Animas
RIVER
Lamar
Big Sandy Creek
Creek
Huerfano River
Apishapa
Purgatoire River
Trinidad
Two Butte
RIO GRANDE BASIN
Alamosa
SAN JUAN RIVER BASIN
Durango
Animas
Piedra
Pagosa Springs
San Juan
Florida

Figure 2-2

Home flooded in Otero County in 1999, Photo provided by the Colorado Water Conservation Board

Public Information Sign Photo by David Marlin

The following table reveals the losses and payments to each community participating in the NFIP. This does not include uninsured losses or losses covered by another flood insurance.

SUMMARY OF DAMAGE LOSSES AND PAYMENTS FROM NFIP DUE TO FLOODS IN COLORADO:
1/1/1978-07/19/07

COMMUNITY	LOSSES	PAYMENTS	COMMUNITY	LOSSES	PAYMENTS	COMMUNITY	LOSSES	PAYMENTS
Adams Co.*	20	38,541	Estes Park	35	660,606	Mineral Co.*	1	268
Alamosa Co.*	3	1,215	Federal Heights	2	12,773	Minturn, Town of	1	6,035
Alamosa, City of	14	9,226	Florence	3	17,366	Montezuma Co.*	1	0
Arapahoe Co.*	11	19,929	Fort Collins	41	351,915	Montrose Co.*	1	21,759
Archuleta Co.*	4	1,863	Fort Morgan	1	0	Montrose, City of	2	681
Arvada	48	38,288	Fountain	12	655	Morgan Co.*	5	22,112
Aspen	9	168,271	Frederick	5	10,349	Morrison	2	1,232
Aurora	34	1,010	Fremont Co.*	7	22,040	Northglenn	2	2,785
Basalt	1	3,816	Frisco	5	921	Otero Co.*	85	1,194,844
Bent Co.*	2	2,689	Garfield Co.*	8	5,728	Ouray, City of	6	33,045
Black Hawk	4	8,332	Georgetown	7	11,886	Paonia	9	51,261
Boone	2	26,147	Gilpin Co.*	3	1,462	Park County	1	343
Boulder Co.*	54	122,136	Glenwood Spgs	9	26,591	Pierce	1	312
Boulder, City of	82	147,603	Golden	13	5,694	Pitkin Co.*	13	36,019
Breckenridge	2	28,060	Grand Junction	6	6,125	Prowers Co.*	7	2,783
Brighton	3	3,292	Greeley	6	63,895	Pueblo Co.*	23	67,945
Broomfield	8	416	Green Mtn Falls	4	0	Pueblo, City of	47	34,634
Brush	18	3,261	Greenwood Vill.	12	21,142	Rangely	5	2,693
Buena Vista	2	1,007	Gunnison Co.*	27	126,836	Rifle	6	44,686
Calhan	1	0	Gunnison, City of	3	6,331	Rio Blanco Co.*	3	21,259
Canon City	42	54,369	Gypsum	1	0	Rio Grande Co.*	3	1,305
Central City	1	0	Hayden	2	1,236	Rocky Ford	8	25,803
Chaffee Co.*	2	0	Hinsdale Co.*	1	0	Routt Co.*	3	49,996
Clear Creek Co.*	8	14,595	Holyoke	1	2,244	Salida	1	1,310
Collbran	3	0	Hotchkiss	1	1,566	San Miguel Co.*	2	23,037
Colorado Springs	172	276,645	Huerfano Co.*	1	769	Silver Plume	2	1,460
Cortez	1	2,487	Idaho Springs	3	369	Silverton	1	1,144
Crested Butte	2	197	Jamestown	4	696	Steamboat Sprgs	14	4,749
Del Norte	2	1,346	Jefferson Co.*	74	176,959	Sterling	34	67,815
Delta Co.*	7	34,247	La Junta	28	457,113	Summit Co.*	11	8,623
Delta, City of	2	5,223	La Plata Co.*	22	425,103	Teller Co.*	4	680
Denver, City/Co.	120	404,400	Lakewood	110	369,724	Telluride	4	0
Dolores Co.*	1	270	Lamar	12	6,746	Thornton	6	7,453
Dolores, Town of	1	0	Larimer Co.*	95	552,394	Trinidad	3	10,992
Douglas Co.*	7	52,530	Limon	5	4,362	Vail	10	98,980
Durango	5	31,827	Littleton	19	16,465	Walsenburg	4	1,116
Eagle Co.*	11	18,860	Logan Co.*	18	131,814	Weld Co.*	26	61,684
Eaton	1	0	Longmont	9	2,260	Wellington	7	4,209
Edgewater	23	51,637	Loveland	7	12,909	Westminster	31	253,793
El Paso Co.*	86	236,645	Lyons	10	6,793	Wheat Ridge	34	82,659
Englewood	5	78	Manitou Springs	23	85,096	Wiley	1	6,705
Erie	2	986	Mesa Co.*	30	246,486	Winter Park	1	5,960
						Woodland Park	2	1,749
*Unincorporated areas.						Total	1,959	7,930,782

Source: FEMA, Community Information System 2007

Building elevated in Morgan County
Photo by CDEM

The following table was developed from information in the Community Information System, which is part of the Federal Emergency Management Agency database for the National Flood Insurance Program. Communities and unincorporated areas of counties participating in the program are asked to report on population and structures at risk and other items of interest. Some communities have not determined the population or structures at risk in their area. These are represented by zeroes and no data. The numbers only reflect areas in the program. Statistics for individual areas are available.

According to FEMA National Flood Insurance Program information, the State of Colorado has 40 repetitive loss structures in 2007. Structures are located in 18 counties.

REPETITIVE LOSS COMMUNITIES/NUMBER

- Arapahoe County 1
- Boulder County 1
- Canon City 1
- Colorado Springs 5
- Delta County 1
- Denver 1
- Durango 1
- El Paso County 4
- Gunnison County 1
- Jefferson County 1
- La Junta 3
- Lakewood 8
- Larimer County 1
- Littleton 1
- Logan County 1
- Manitou Springs 2
- Mesa County 1
- Pueblo (City of) 1
- Rio Blanco County 1
- Steamboat Springs 1
- Sterling 1
- Weld County 1
- Westminster 1

Source: CIS database 2007

Population and Structures in Flood Hazard Areas

County	Population	1-4 Family Structures	Other Structures
Adams	7,432	1,449	192
Alamosa	9,380	1,071	463
Arapahoe	6,089	726	245
Archuleta	802	300	212
Baca	0	0	0
Bent	0	0	0
Boulder	12,270	1,735	905
Broomfield	75	-	-
Chaffee	856	145	0
Cheyenne	55	0	0
Clear Creek	2,545	501	82
Conejos	901	30	0
Costilla	98	55	0
Crowley	53	42	0
Custer	0	0	0
Delta	335	183	42
Denver	2,079	738	571
Dolores	94	43	2
Douglas	315	100	32
Eagle	858	122	9
El Paso	9,869	3,244	551
Elbert	65	0	3
Fremont	9,586	329	367
Garfield	1,746	538	17
Gilpin	147	42	0
Grand	192	56	3
Gunnison	1,071	879	26
Hinsdale	19	36	16
Huerfano	767	293	164
Jackson	0	0	0
Jefferson	12,705	2,454	1,499
Kiowa	0	0	0
Kit Carson	0	0	0
La Plata	2,062	437	138
Lake	0	0	0
Larimer	5,413	1,864	298
Las Animas	380	170	112
Lincoln	279	135	37
Logan	4,273	3,143	1,445
Mesa	2,717	248	22
Mineral	180	40	35
Moffat	360	111	64
Montezuma	947	767	67
Montrose	1,249	42	7
Morgan	2,384	225	7
Otero	1,150	355	399
Ouray	285	0	0
Park	72	0	0
Phillips	332	120	15
Pitkin	446	97	11
Prowers	2,213	1,008	261
Pueblo	877	350	0
Rio Blanco	1,255	526	90
Rio Grande	1,201	3,418	23
Routt	1,294	380	282
Saguache	0	0	0
San Juan	14	12	11
San Miguel	628	230	64
Sedgwick	7	4	11
Summit	500	220	102
Teller	173	25	28
Washington	38	14	2
Weld	3,485	144	28
Yuma	715	389	15

Source: FEMA, Community Information System 2007

As of August 2007, a total of 40 repetitive loss properties (15 of which carry flood insurance) are present in Colorado. Although mitigation offers have been made to property owners over the previous decade, the State will continue to actively work with local governments to mitigate these properties. The focus will be on full mitigation to the 100-year flood event, commonly through acquisition, elevation, relocation, or in some cases, minor drainage/flood projects that improve the flood conveyance of the vicinity. Additional focus will be placed on encouraging flood insurance for owners of these properties. All available FEMA grant programs will be considered for mitigation activities, including the Flood Mitigation Assistance (FMA) Program, the Pre-Disaster Mitigation (PDM) program, the Hazard Mitigation Grant Program (HMGP), Repetitive Flood Claims Program (RFC), and the Severe Repetitive Loss (SRL) program. Each of these programs has different eligibility requirements, but under the right circumstances, each is available to provide funding for mitigation of repetitive loss structures. Local match will come from state or local resources or from property owners as is determined appropriate for each individual case.

Although the grant applicant is actually the local government working through the appropriate state agency, it is important for the owners of repetitive loss structures to be aware that: the structure they own is classified as a repetitive loss structure; grant funding is available for mitigation of the flood threat; flood insurance is available for the structure; the State of Colorado is actively working with local governments (including their own) to provide mitigation activities in order to remove repetitive loss structures from the list.

To reach these goals, each year the Water Conservation Board will send a letter to the local governments that have repetitive loss structures within their jurisdiction. This letter will state the above awareness points and offer assistance in mitigating the structure. Information regarding repetitive loss statistics will be obtained from FEMA. The letter will offer followup assistance to any community that wishes to pursue any activities. It will be up to the local government to coordinate with the property owner to determine what, if any, actions the property owner is willing to consider. The State will communicate directly with property owners if they express a desire. In the event a property owner accepts an offer of mitigation, documentation of sufficient mitigation from the 100-year flood will be provided to FEMA upon completion. The State will encourage the property owner to maintain flood insurance following mitigation, but this will be up to the owner as to whether it is actually done.

The Colorado Water Conservation Board prepared an implementation plan for Map Modernization of Colorado communities (table below).

COUNTY	STATUS	RANK	COUNTY	STATUS	RANK
Denver	effective	2	Rio Grande		102
Jefferson	effective	3	Elbert		103
El Paso		4	Lake		110
Arapahoe	Preliminary	5	Park		112
Adams	effective	6	Clear Creek	effective	119
Boulder	preliminary	9	Archuleta	In Production	121
Larimer	Preliminary	10	Huerfano		122
Pueblo	In Production	13	Saguache		131
Weld	Preliminary	15	Yuma		144
Douglas	effective	18	Kit Carson		148
Mesa	In Production	20	Lincoln		149
Fremont	In Production	31	Grand	Preliminary	158
Garfield	In Production	36	Bent		160
Broomfield	effective	37	San Miguel		162
La Plata	In Production	38	Gilpin		174
Logan		42	Ouray		175
Morgan		43	Rio Blanco		176
Routt	effective	46	Conejos		179
Otero		57	Phillips		192
Delta		59	Custer		194
Montrose		60	Costilla	No study	197
Montezuma	In Production	68	Crowley		214
Summit		69	Dolores		216
Alamosa		70	Hinsdale		248
Eagle	Preliminary	73	Mineral	No study	250
Moffat		75	Sedgwick	No study	251
Gunnison		76	Washington	No study	254
Prowers		81	Jackson	No study	267
Las Animas		83	Baca	No study	274
Chaffee		84	San Juan	No study	278
Pitkin	effective	86	Kiowa	No study	283
Teller	In Production	88	Cheyenne	No study	288

Source: Colorado Water Conservation Board 2007

The Division of Water Resources runs the Dam Safety Program. A description of this program is in the State Assessment section. The program is responsible for approximately 2,900 jurisdictional and nonjurisdictional dams. DWR concentrates on the 1,833 that are "jurisdictional" dams and reservoirs as defined in Section 37-87-105, C.R.S. (1999 Supp.). These are greater than 10 feet high at the spillway or 20 acres in surface area or 100 acre-feet in capacity at the high water line. Of these dams, 126 are federally owned, 1,802 are nonfederal, including private ownership. Of the non-federal dams, approximately 677 are classified as dams that, in the event of a failure, would be expected to cause loss of life and/or significant property damage within the flood plain areas below the dams. Colorado has Emergency Action Plans for 100% of the high hazard dams.

For more information on dam safety, refer to the Colorado Department of Natural Resources Division of Water Resources website at http://water.state.co.us/dams.asp and the Standard State Hazard Mitigation Plan Dam and Levee Failure Mitigation plan Annex.

Cherry Creek Dam Photo provided by U.S. Army Corps of Engineers

The table and the map on the following pages depict Class I and II dams in the state.

CLASSIFICATION OF DAMS

CLASSIFICATION	DESCRIPTION
Class I-High	Loss of human life is expected.
Class II-Significant	Significant damage is expected, but not loss of human life. Significant damage refers to structural damage where humans live, work, or recreate or public or private facilities exclusive of unpaved roads and picnic areas. Damage refers to making the structures uninhabitable or inoperable.
Class III-Low	Loss of human life and damage to structures and public facilities not expected.
Class IV-No Public Hazard	No loss of human life is expected and damage will only occur to the dam owner's property in the event of dam failure.

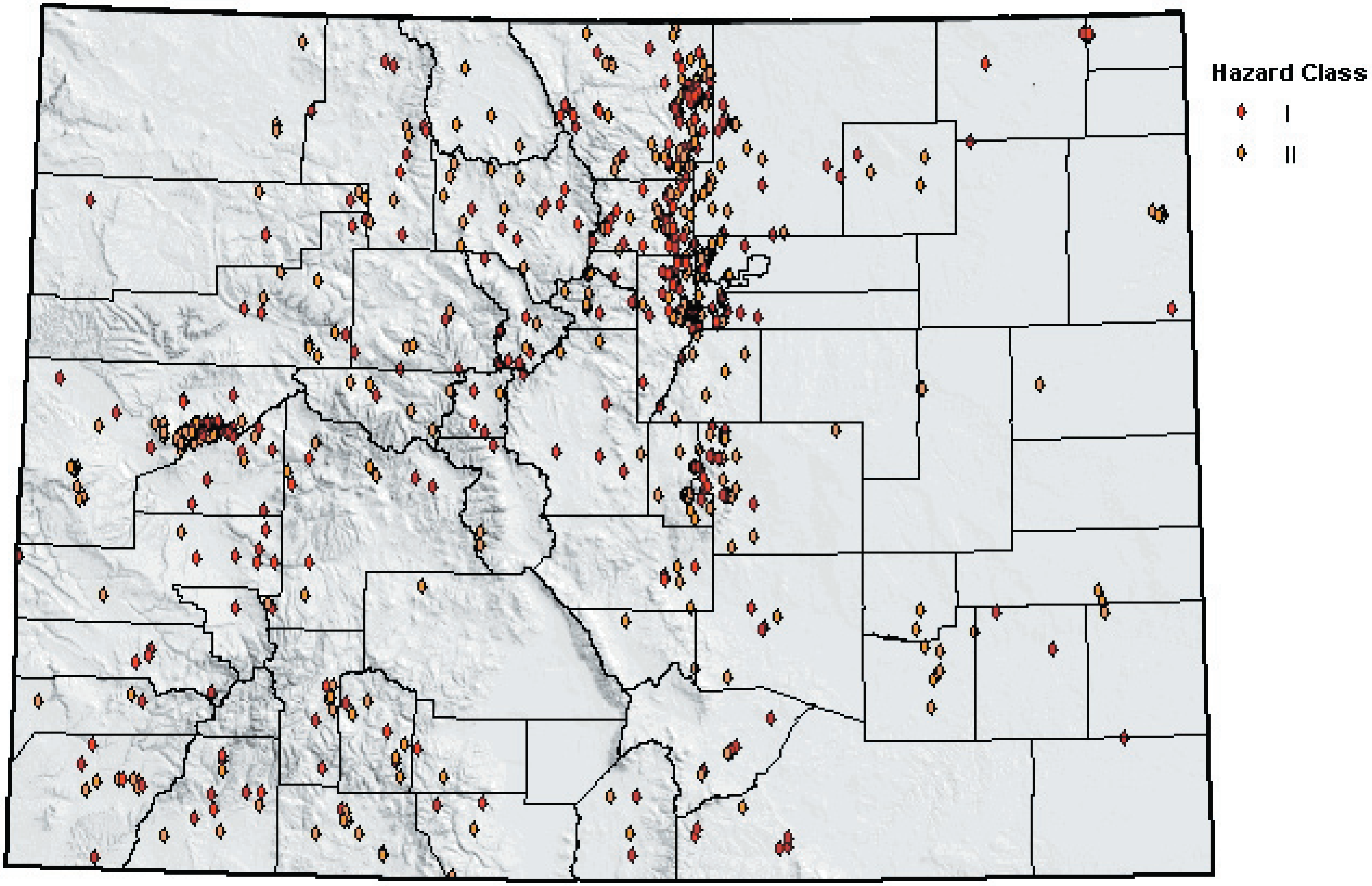
Source: Division of Water Resources 1988

CLASS I AND II DAMS IN COLORADO BY COUNTY

COUNTY	CLASS I	CLASS II
Adams	8	12
Alamosa	0	0
Arapahoe	8	4
Archuleta	2	8
Baca	1	0
Bent	2	0
Boulder	28	21
Broomfield	3	1
Chaffee	2	2
Cheyenne	0	0
Clear Creek	8	5
Conejos	2	3
Costilla	3	1
Crowley	0	2
Custer	0	1
Delta	17	13
Denver	7	3
Dolores	1	2
Douglas	2	6
Eagle	8	5
El Paso	18	15
Elbert	0	0
Fremont	3	3
Garfield	6	11
Gilpin	1	0
Grand	7	12
Gunnison	6	6
Hinsdale	3	4
Huerfano	5	3
Jackson	0	4
Jefferson	22	17
Kiowa	0	2
Kit Carson	1	0
La Plata	8	6
Lake	3	2
Larimer	51	40
Las Animas	6	1
Lincoln	1	2
Logan	3	0
Mesa	22	29
Mineral	5	6
Moffat	1	3
Montezuma	8	7
Montrose	9	1
Morgan	0	6
Otero	0	7
Ouray	1	0
Park	5	3
Phillips	0	0
Pitkin	2	7
Prowers	0	1
Pueblo	3	4
Rio Blanco	3	3
Rio Grande	1	1
Routt	8	5
Saguache	0	1
San Juan	0	0
San Miguel	5	0
Sedgwick	3	0
Summit	5	2
Teller	4	10
Washington	1	0
Weld	12	17
Yuma	1	7

Division of Water Resources 2001

Hazard Class I and II Dams



Dam Safety Incidents, as identified in the *State Engineer's 22nd Annual Report on Dam Safety to the Colorado General Assembly Fiscal Year 2005-06* include the following (copied directly from the report):

"Gillett Reservoir Dam Failure
The Division 2 office reported the failure of a dam near Gillett, Colorado. The failure caused road damage along State Highway 67 and there were no reports of injury or loss of life. Field observations by the Division Dam Safety Engineer revealed that poor quality and construction of an earthen embankment within a previous breach of the embankment was the probable cause of the failure.

McElroy Dam
McElroy Dam, a Low Hazard dam in Grand County unexpectedly experienced large discharge of turbid water from the outlet. The flow and turbidity varied for a few days then a large sinkhole formed at the left end of the dam and just left of the outlet pipe. The owner had the dam breached in order to replace the deteriorated 18" CMP outlet pipe.

Other Dam Incidents
Intense rainfall events resulted in several dam incidents that were reported to the Dam Safety Branch throughout the year. The reports were followed through on, and provided good exercises of, the emergency communication system without having serious consequences. Dam incidences reported are as follows:

1.Non-Roster Jurisdictional sized dam in Teller County, Division 1, experienced overtopping during an intense rainfall event. The dam was severely damaged but did not fail.

2. Keeton Dam in El Paso County, Division 1 is a restricted dam due to inadequate spillway experienced discharge flows out both the service and emergency spillways during an intense rainfall event.

3. J.O. Hill Dam in Douglas County, Division 1, experienced a storm that generated 100 year rainfall on 15 percent of the basin which generated the 100 year runoff of a 56-square-mile basin.

4. Stillwater Dam in Douglas County, Division 1 experienced a crack in the outlet/spillway conduit resulting in loss of embankment material.

5. Goose Pasture Tarn in Summit County, Division 1, experienced water seeping out of the service spillway into the RCC emergency spillway with the movement of fines."

As reported in the *State Engineer's 22nd Annual Report on Dam Safety to the Colorado General Assembly Fiscal Year 2005-06,* many accomplishments took place during the three year update period of this plan:

"The Dam Safety Data Management System database was updated and upgraded in FY05-06."

"The Dam Safety Branch was able to develop a Risk-Based Profiling System (RBPS) software tool to quickly rank the relative condition of High Hazard (Class 1) and Significant Hazard (Class 2) dams."

"Funded by the Dam Safety Branch NDSP grant and the CWCB, a beta version of the Extreme Precipitation Analysis Tool (EPAT) for the West of the Continental Divide was released for use within the Dam Safety Branch in the Spring of 2006. The tool was initially developed for the western slope with drainage basins of less than 500 square miles. EPAT is an objective GIS-based analysis tool that utilizes existing National Weather Service storm databases as well as the Colorado extreme weather database developed by Colorado State University and modern meteorological techniques to analyze extreme precipitation events. EPAT provides dam owners an alternative to costly site-specific studies. The Branch will provide training sessions to the public on how to effectively use EPAT. The initial use of EPAT has shown that the tool emulates site-specific Probable Maximum Precipitation (PMP) and Hydrometeoro-logical Report (HMR) PMP events. The Branch is optimistic that this state-of-the-practice tool in hydrology and hydrometeorology in Colorado will be available for the east of the Continental Divide in 2007."

"Through the efforts of a nationally recognized consulting hydrologist and a select group of dam safety engineers with an expertise in hydrology, a draft of the Guidelines and Procedures for Estimating Basin Response Factors in Colorado was presented to the Branch in the fall. Comments were provided and the final publication will be available for use in early 2007."

This section depicts the counties in Colorado most at risk from flooding. Calculations were based on the following:

The population in the flood risk area as listed in the Community Information System database provided by FEMA. Values were assigned as follows:

Population in Flood Risk Area	Value
1,001 +	3
501 – 1000	2
1 – 500	1
0	0

The numbers of 1-4 family structures identified as being in the flood risk area for each county were assigned a value as follows:

Number of Structures	Value
75+	3
37-74	2
1-36	1
0	0

The number of repetitive loss structures in each county as provided by FEMA:

Repetitive Loss Structures	Value
7+	3
4-6	2
1-3	1
0	0

The number of Class I and II dams in each county as provided by the Department of Natural Resources Division of Water Resources State Engineer's Office:

Number of Class I & II Dams	Value
10+	3
6-9	2
1-5	1
0	0

The values of the four factors were totaled. Values were ranked as follows:

Value	Risk Assessment
10+	Highest
6-9	Moderate
1-5	Lower
0	Lowest

The resulting values range from 0 to 12. Values from 10 through 12 represent areas determined to be at highest risk. Values from 6 through 9 represent areas with moderate risk and values less than 5 represent areas with comparatively lower risk.

Mitigation activities in high and moderate risk areas should have priority, however projects dealing with localized flooding will be addressed in lower/lowest risk counties on a small scale. Highest risk areas include sections of Adams, Boulder, Denver, El Paso, Fremont, Jefferson, Logan and Mesa Counties. Moderate risk include areas of Alamosa, Arapahoe, Archuleta, Clear Creek, Delta, Douglas, Eagle, Garfield, Gilpin, Grand, Gunnison, Huerfano, La Plata, Larimer, Moffat, Montezuma, Montrose, Morgan, Otero, Phillips, Prowers, Pueblo, Rio Blanco, Rio Grande, Routt, San Miguel, Summit, and Weld.

Mitigation activities should focus on improving communication, life safety activities, and floodproofing properties. Improving communications includes improving methods to alert persons to floods in the vicinity. Life safety plans should be encouraged in homes, schools, institutions, etc., and plans should be practiced regularly. Activities that involve making public and private property more flood resistant should be encouraged. Public education and information should be developed, improved, and disseminated on a continual basis. Communities at risk are encouraged to develop flood plans.

Mapping priorities have been updated recently. A list of the communities has been provided on a previous page. Contact the Colorado Water Conservation Board for more information on scheduling.

A flood acquisition project was funded after the 1999 presidential disaster declaration. In Otero County, 58 properties were acquired using Community Development Block Grants, Unmet Needs program, and Hazard Mitigation Grant Program, and other funds and three homes were acquired in Manitou Springs. Other flood mitigation projects have been accomplished with Hazard Mitigation, Flood Mitigation Assistance, Project Impact, and Unmet Needs funds: La Junta built a lift station, Canon City built retention ponds, Crowley floodproofed a historic public building, Fort Collins floodproofed residences and one historic building, Fort Collins and Pueblo improved their early warning systems, Morgan County did improvements to a pre-school property to protect it from flood, Larimer County improved drainage in the West Vine area, Otero County improved drainage along a county road by an Aurora reservoir, Georgetown improved drainage in the creek through the Town, Delta built a flood protection structure around the treatment plan, and Jamestown buried pipelines under the creek. Under the Pre-Disaster Mitigation grant program, Fort Collins has done five drainage improvement projects including detention projects; Colorado Springs is implementing an erosion control project near a critical communications facility, Erie is rebuilding a culvert under an access road at the airport, Grand Junction is implementing drainage improvements through the city, and Denver is putting in a detention pond and improvements near a police substation.

Top: Morgan County pre-school and Georgetown Clear Creek and South Clear Creek confluence
Center: Otero County drainage and Pueblo RAWs station
Bottom: Canon City detention pond system and Fort Collins floodproofing
Photos by Bill Archambault and Marilyn Gally

Hailstorms

hail - showery precipitation in the form of irregular pellets or balls of ice …, falling from a cumulonimbus cloud.

cumulonimbus (thundercloud, thunderhead) - a cloud of a class indicative of thunderstorm conditions, characterized by large, dense, and very tall towers.

precipitation - falling products of condensation in the atmosphere, as rain, snow, or hail.

HAIL FACTS

Colorado's damaging hail season is considered to be from mid-April to mid-August. Colorado's Front Range is located in the heart of "Hail Alley," which receives the highest frequency of large hail in North America and most of the world, so residents usually can count on three or four catastrophic (defined as at least $25 million in insured damage) hailstorms every year. In the last 10 years, hailstorms have caused nearly $2 billion in insured damage in Colorado. - Rocky Mountain Insurance Information Association

Hail forms when water droplets freeze and thaw as they are carried up and down in updrafts and downdrafts in thunderstorms.

An area in northern Colorado and southeastern Wyoming endures hailstorms 8+ days each year. Most inland regions experience hailstorms at least 2 or more days each year.

The Colorado plains are ranked #1 by the insurance industry for being hammered by hail.

Hail is responsible for nearly $1 billion in damage to crops and property each year in the U.S.

In July 1979, a baby hit by grapefruit-size hailstones in Fort Collins was killed and 25 others were injured, according to the Mountain States Weather Service.

The largest hailstone ever recorded fell in Coffeyville, Kansas in 1970. It measured over 5.6 inches in diameter and weighed almost 2 pounds!

Hailstones can fall at speeds of 120 mph.

The National Weather Service considers a thunderstorm severe if it produces hail ¾+ inch in diameter or wind gusts 58+ mph or tornados.

Sources: National Weather Service, 2000; FEMA, 1997; www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms; Rocky Mountain News, 6/12/99

HAILSTORM HAZARD IN COLORADO

The following is a summary of reported hailstorm events by county from 1/1/1950 through 12/31/2006.

Summary of Hailstorm Events, Deaths, Injuries, and Damage in Colorado by County: 1/1/50 - 12/31/06

County	Number of Events	Deaths	Injuries	Damage ($millions)
Adams	235	0	5	204.1
Alamosa	10	0	0	1.0
Arapahoe	268	0	0	88.4
Archuleta	2	0	0	0.0
Baca	190	0	0	0.2
Bent	83	0	0	9.3
Boulder	158	0	7	1.0
Broomfield	10	0	0	0.0
Chaffee	3	0	0	0.0
Cheyenne	268	0	0	0.0
Clear Creek	10	0	0	0.0
Conejos	3	0	0	0.0
Costilla	5	0	0	0.7
Crowley	37	0	1	0.0
Custer	49	0	0	0.0
Delta	7	0	0	0.1
Denver	154	0	21	156.5
Douglas	149	0	3	3.0
El Paso	703	0	2	35.1
Elbert	211	0	0	0.0
Fremont	41	0	0	0.0
Garfield	7	0	0	0.0
Gilpin	12	0	0	0.0
Huerfano	42	0	0	0.0
Jefferson	251	0	60	0.0
Kiowa	162	0	0	0.5
Kit Carson	382	0	0	0.5
La Plata	17	0	0	0.0
Larimer	278	0	0	3.4
Las Animas	152	0	0	0.0
Lincoln	269	0	0	0.1
Logan	193	0	0	0.1
Mesa	38	0	0	0.9
Moffat	7	0	0	0.0
Montezuma	18	0	0	1.3
Montrose	9	0	0	0.0
Morgan	231	0	2	4.7
Otero	114	0	0	0.1
Park	21	0	0	0.0
Phillips	106	0	0	0.5
Pitkin	5	0	0	0.0
Prowers	177	0	0	5.5
Pueblo	209	0	10	77.6
Rio Blanco	5	0	0	1.0
Rio Grande	16	0	0	0.0
Routt	10	0	0	0.2
Saguache	24	0	1	0.3
Sedgwick	72	0	0	0.0
Teller	49	0	0	0.0
Washington	323	0	0	1.2
Weld	512	0	0	38.0
Yuma	456	0	0	1.2
Total	6,796	0	112	636.4

Source: www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storm

Of the 2000+ events reported, there were five or less reported incidents for 13 counties: Dolores, Eagle, Grand, Gunnison, Hinsdale, Jackson, Lake, Mineral, Montrose, Ouray, San Juan, San Miguel and Summit Counties. El Paso County has the greatest number of events reported with 703, followed by Weld, Yuma, and Kit Carson Counties. Upon review of the NCDC database, it was found that only four hailstorms with damages of $50 million or greater were listed. The following $50+ million storms were accounted for: Pueblo 8/4/93 - $50 million in damages, Metro area 5/22/96 - $120 million; Arapahoe County/Buckley Field - 10/16/98 - $88 million; and Denver 6/9/04 - $146.5 million. Storms missing from NCDC and therefore not in the county breakout table on the previous page are highlighted on the table below in gray.

Hailstorms with high damage costs are listed in the following table. Damages from these storms were over $2 billion.

NOTABLE HAILSTORM EVENTS IN COLORADO WITH DAMAGES GREATER THAN $50 MILLION: 1984 - 1998

DATE	LOCATION	DAMAGE ($MILLIONS)
6/13-14/84	Denver/Arvada	277
8/21/84	Pueblo	58
8/2/86	Denver/Fort Collins/ Longmont	145
6/23/87	Pueblo/Fort Lupton/La Junta	79
7/11/90	Denver/Front Range	626
5/30-6/2/91	Metro Area	100
8/4/93	Pueblo	50
10/1/94	Denver	225
5/22/96	Adams & Jefferson Counties	122
6/21-22/96	Denver/Larimer County	100
8/11/97	Denver area	128
10/16/98	Arapahoe County/ Buckley Field	88
6/8-9/04	Golden/SW Denver	146
8/9-11/04		62
Total		2,206

Source: http://www.rockymountainnews.com/drmn/local/article/0,1299,DRMN_15_688081,00.html, Rocky Mountain News 6/11/04

Many times the size of hailstones will be reported using everyday objects. Observers may use the table below when estimating the size of hailstones.

MEASURING HAILSTONES

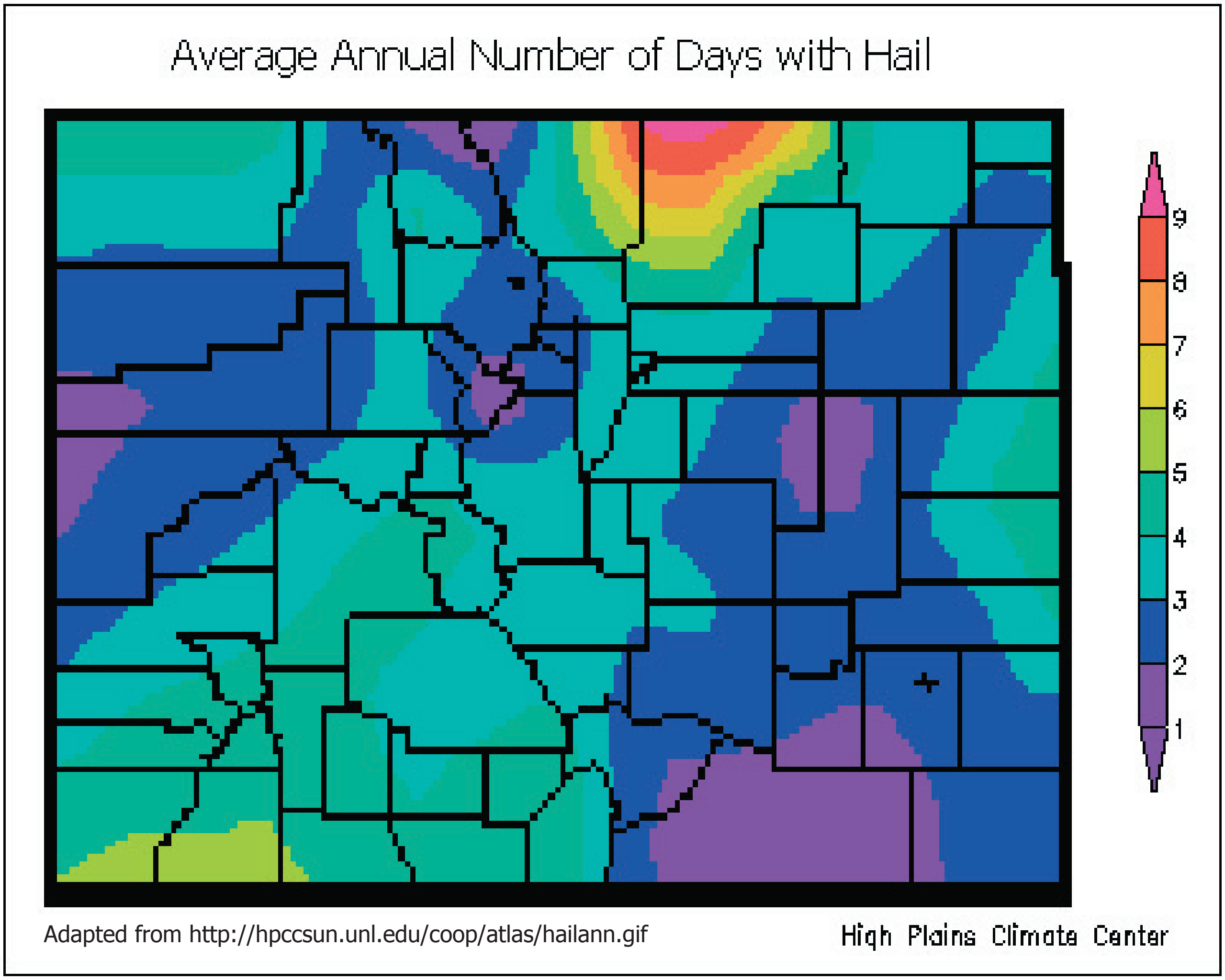
ESTIMATED SIZE	AVERAGE DIAMETER
Pea	$^1/_4$ inch
Marble/mothball	½ inch
Dime/penny	¾ inch
Nickel	$^7/_8$ inch
Quarter	1 inch
Ping-pong ball	1 ½ inch
Golf ball	1 ¾ inch
Tennis ball	2 ½ inch
Baseball	2 ¾ inch
Tea cup	3 inch
Grapefruit	4 inch
Softball	4 ½ inch

Source: www.nws.noaa.gov/er/cae/svrwx/hail/hail.html

Hail in Denver area Photos by Marilyn Gally

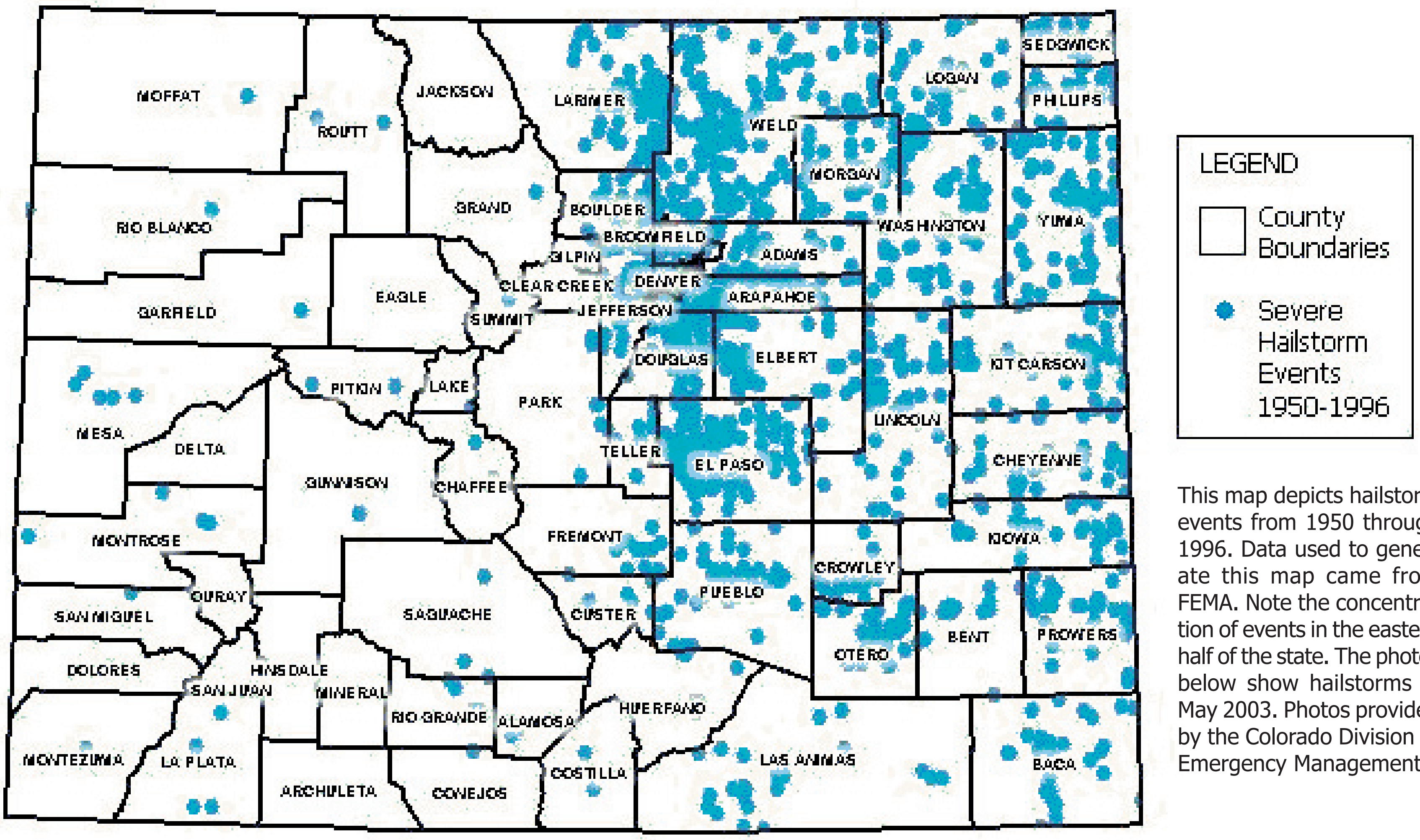
> "Long-stemmed vegetation is particularly vulnerable to damage by hail impact and accompanying winds. Severe hailstorms also cause ... damage to buildings and automobiles but rarely result in loss of life."
>
> -from Multihazard Identification and Risk Assessment, 1997

The following map, originally created by the High Plains Climate Center and adapted to just show Colorado, depicts the average number of days per year with hail. The north-central area, specifically northeast Larimer and north Weld Counties, show the highest number of days in the state with 6 or greater.



Adapted from http://hpccsun.unl.edu/coop/atlas/hailann.gif

Severe Hailstorm Events In Colorado: 1950-1996



This map depicts hailstorm events from 1950 through 1996. Data used to generate this map came from FEMA. Note the concentration of events in the eastern half of the state. The photos below show hailstorms in May 2003. Photos provided by the Colorado Division of Emergency Management.

Landslides and Rockfalls

landslide - downward and outward movement of slopes composed of natural rock, soils artificial fills, or combinations thereof. Common names for landslide types include slump, rockslide, debris slide, lateral spreading, debris avalanche, earth flow, and soil creep (Colorado Geological Survey (CGS)).

mud flow - a mass of water and fine-grained earth materials that flows down a stream, ravine, canyon, arroyo or gulch (CGS).

debris flow - 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 (CGS).

rockfall - the falling of a newly detached mass of rock from a cliff or down a very steep slope (CGS).

FACTS

Precipitation, topography, and geology affect landslides. Landsliding in areas of Colorado intensified during the 1980s due to higher than normal annual precipitation levels.

It is estimated that there are thousands of landslides in Colorado.

It is estimated that at least 18 damaging debris flow events have occurred in Glenwood Springs since 1900.

Garfield County, in 1985, recorded the largest debris flow in Colorado history, a 175-foot thick mass of debris a mile long and 1,000 feet wide.

Millions of dollars in federal emergency highway funds were used to restore highways damaged by landslides at Douglas Pass, Muddy Creek and other sites.

In the past 30 years, landslides have resulted in approximately 40 disaster declarations. According to FEMA, best estimates of losses attributed to landslides in the United States are 25 to 50 lives per year and $1-2 billion in property damage. Colorado received a Presidential declaration for floods, mudslides and landslides in 1999.

Human activities trigger slope failures. Activities include mining and construction.

Landslides, mudslides, debris flows, and rockfalls damage and destroy homes, roads, railroads, pipelines, electrical and telephone lines, mines, oil wells, commercial buildings, canals, sewers, dams, bridges, seaports, airports, forests, parks, and farms.
Sources: Colorado Geological Survey 1988; FEMA 1997

LANDSLIDE AND MUD FLOW/DEBRIS FLOW HAZARDS IN THE UNITED STATES

According to FEMA (1997), no state is free from the effects of landslides. The California coastal ranges, the Colorado Plateau, the Rocky Mountains, and the Appalachian Mountains have been identified as the areas where landslides most commonly occur. "The best estimates of annual losses resulting from landslides in the United States are 25 to 50 lives and $1 to $2 billion in property damage." Approximately forty presidential disaster declarations in the past twenty-five years have been landslide-related. http://landslides.usgs.gov/.

California, Washington, and Colorado were the first three states to use federal disaster funds for property acquisitions for landslide hazard areas.

Home Destroyed by Landslide in Colorado Springs
Photo provided by Colorado Springs OEM

LANDSLIDE AND MUD FLOW/DEBRIS FLOW HAZARDS IN COLORADO

The following photograph demonstrates the serious nature of these hazards in Colorado. The structural integrity of this home was destroyed. The home was condemned and has been demolished.

Landslide Damage to Home in Colorado Springs
Photo provided by Colorado Springs OEM

Notable Events in Colorado

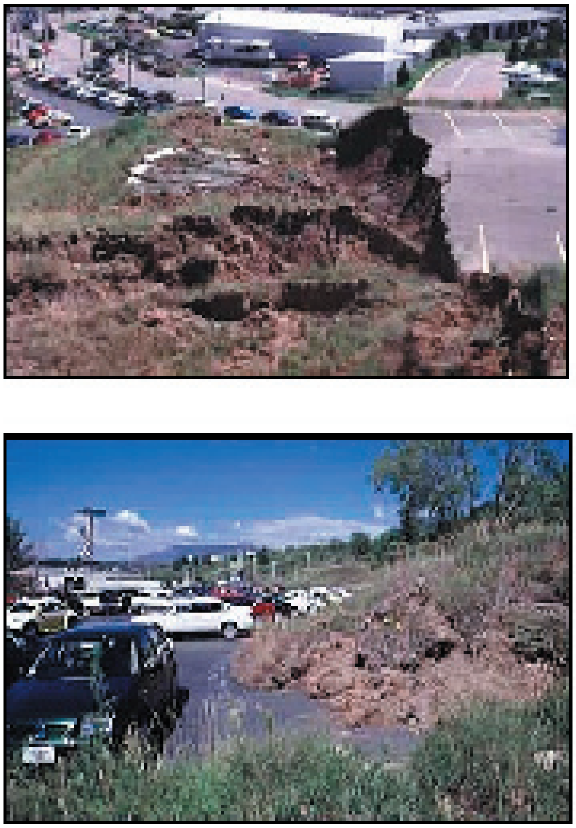
Year	Location	Description
?	Near Lake City, Hinsdale Co.	Slumgullion earthflow dammed Lake Fork of Gunnison River, forming Lake San Cristobal.
1903	South of Glenwood Springs, Garfield Co.	Debris flow. Rainstorm caused mud and rock to cover a railroad line. Train wreck, one member of train crew killed.
1912	Brownville, Clear Creek Co.	Debris flows. Community engulfed and destroyed.
1914	Telluride, San Miguel Co.	Debris flows in Coronet Creek, flooding in San Miguel River.
1924	DeBeque Canyon	Landslide. Blocked Colorado River, resulted in forced relocation of a small community, highway and railroad.
1930s 1940s	Marble, Gunnison Co.	Debris flows. Town nearly destroyed.
1937	Glenwood Springs, Garfield	Debris flow. Much of town covered. Mud 2 feet deep.
1969	Telluride, San Miguel Co.	Debris flows in Coronet Creek, flooding in San Miguel River.
1976	Big Thompson Canyon, Larimer Co.	Interrelated landslide/ flood event. Mountain torrent flood.
1977	Glenwood Springs, Garfield Co.	Debris flow. Losses between $500,000-$1 million. 200 acres of residential district covered up to 14' deep.
1981-1982	Ouray, Ouray Co.	Debris flows in Canyon, Cascade, Portland Creeks, etc. Flooding in Uncompahgre River.
1983, 1984	Dowds Junction, Eagle Co.	Landslides blocked I-70. Highway closed.
1984	15 Western Slope Counties	Floods and landslides. Declared disaster areas by President. Related to spring runoff. Over $6.6 million spent in federal, state, and local disaster assistance.
1984	Grand Junction, Mesa Co.	Most homes in a subdivision affected. Some condemned.
1985	Two Western Counties	Floods and landslides. State emergency declaration. $1.4 million in damages.
1999	El Paso County (and other counties for flood)	Floods, mudslides, landslides. Presidential disaster declaration. Estimated over $30 million in infrastructure and property damage, including road repairs and twisted utility lines. Several residences condemned.

Source: Colorado Landslide Hazard Mitigation Plan 1988, 2002

LANDSLIDES

The following landslide sections are reprinted from the Colorado Geological Survey website at http://geosurvey.state.co.us/pubs/geohazards/docs/landslides.asp.

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



Photos by Colorado Geological Survey

Characteristics

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

Scarp of the Green Mountain Landslide
Photo by Colorado Geological Survey

Aggravating Circumstances

Landslides are one of the primary natural processes shaping the land. Human 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 pushed the slide material downslope,
3. Addition of moisture to the landslide mass, increasing the weight and decreasing the strength

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

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.

For a more complete list, refer to the Landslide Hazard Mitigation Plan 2002 in the appendices.

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, landslide-prone areas are unavoidable and mitigation measures must be utilized to fit the circumstances.

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 know 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 on 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.

Landslides: Definitions From CGS Special Publication 6

Many types of mass movement of natural material are included in the general geologic term "landslide." However, for purposes of these guidelines the term will be restricted to mean those mass movements where there is a distinct surface of rupture or zone of weakness that separates the slide material from more stable underlying material. Such slides involve en masse downward and outward movement of a relatively dry body of rock and/or surficial material in response to gravitational stresses. Other varieties of landslides that are treated separately in these guidelines include: 1) rockfall which involves either direct fall or forward rotation of a rock mass followed by free-fall and/or rolling, bounding, or rapid sliding motions with only intermittent contact with the ground surface; and 2) mud flows and closely related phenomena which involve movement by viscous flow of material with high water content and which may lack a distinct surface of separation between the moving mass and underlying more stable material.

Landslides as defined above include two major types: 1) Rotational slides which refer to all landslides having a concave upward, curved failure surface and involving a backward rotation of the original slide mass; and 2) translational slides in which the surface of rupture along which displacement occurs is essentially planar. Either type of landslides can involve various combinations of bedrock, broken bedrock, and unconsolidated surficial material, and the displaced material in either type of slide may be either greatly deformed or nearly intact.

Rate of movement of landslides varies from very slow to very rapid. They may be extremely small in extent or measurable in miles. Volumes of material involved may range from a few cubic feet to millions of cubic yards. Landslides result from some change in the physical condition of an unstable slope area (see section of guidelines on potentially unstable slopes).

Such changes may be natural or man-induced. Some of the major mechanisms that initiate slides are: removal of the toe or lower end of a potentially unstable slope (commonly known as "day-lighting"); removal of lateral support material adjacent to an unstable area; placement of additional material on the upper portion of an unstable area (commonly referred to as "loading"); weakening of clay or other fine-grained materials by wetting; weakening of natural cohesive forces by ground water circulating along potential failure surfaces; or decrease of stability by excessive pore water pressures within the slope-forming materials or along a potential failure surface. Other mechanisms include; redistribution of mass by erosion and deposition; chemical and physical weathering which may weaken slope materials; earthquake vibrations and release by erosion of stresses related to active faulting or past stresses "locked in" rock materials.

Many of the above-described disturbances that are capable of inducing land sliding of unstable slopes can result from activities of man. The most common activities of man that can produce land-sliding include: Excavations such as road cuts, quarries, pits, utility trenches, site grading, landfill operations, stockpiling of earth, rock or mine waste; alteration of natural drainage which may lead to increased runoff and erosion or to local ponding and saturation of potentially unstable slopes; and vibrations from blasting or heavy vehicular traffic.

Actual landslide movement can occur in several ways. It may be rapid, and of short duration, after which natural equilibrium (stability) of landslide material is achieved. It may consist of intermittent periods of active movement, separated by relatively inactive periods. A third possibility involves slow, continuous move-slide material may involve movement that can be measured in a few feet, or it may involve displacement measurable in hundreds or thousands of yards, and in some cases even miles. Differential movement may also occur within an active slide mass. Isolated smaller slides may take place within the body of a large slide during its movement (multiple sliding), or they may occur after much of the larger slide has stabilized. Also, the reverse is true, where large parent slides include, or incorporate, smaller slides.

Permanent features that commonly aid identifying the presence of old slides are the appearance of a main scarp and a corresponding bulge of landslide deposits on hillside. These features or relict anomalous slope changes often remain for many years as evidence of past instability. It should be noted that all such breaks in the natural profile of a hillside are not necessarily remnants of landslide scarps or deposits, and that determination of slope stability requires study by an experienced engineering geologist.

Rotational slides can occur anywhere that the following conditions are present, and in the necessary combination to promote sliding: 1) slopes sufficiently steep to allow lateral downslope movement of materials in response to gravity; 2) gravitational stress sufficient to move such material; 3) presence of unstable material susceptible to sliding; 4) underlying zone of weakness as a potential surface of rupture; 5) introduction of a disturbing factor – natural or man-made – sufficient to initiate instability and movement.

A translational landslide is characterized by a planar surface of rupture, and frequently by little deformation of slide material. Physical relationships prevalent in this type of slide are the presence of relatively competent materials above and beneath a planar zone of weakness along which sliding occurs. This condition is quite common in nature and may be the result of various combinations of materials and/or physical conditions. Translational slide material may range from fairly loose unconsolidated soil to extensive slabs of hard, resistant rock. Movement of translational slide material may be initiated by a variety of conditions, which are listed under general description of factors tending to produce land sliding.

The same criteria outlined above as prerequisites for rotational sliding to occur, apply to translational gliding, with the exception of item 3. In contrast to rotational slides, the entire slide mass in a translational slide need not necessarily be weak, unstable material itself – there may be very thin zone of weakness such as thin layer; bedding, joint or foliation plane; or the surface separating weak surficial material from underlying competent material.

Severity of problem

Landslides are widespread, naturally occurring geologic events through much of Colorado. Only when such phenomena conflict with the works of man do they constitute a serious problem or hazard. The severity of such a problem is directly related to the extent of man's activity in areas affected, and adverse effects can be mitigated by early recognition and avoidance or by corrective engineering. Actual losses can range from mere inconvenience or high maintenance costs where very slow or small-scale destructive slides are involved.

Rapidly moving large slides have the capacity to completely destroy buildings, roads, bridges, and other costly manmade structures. Such slides also have the potential for inflicting loss of life when they occur in developed areas. Occurrence of landsliding is widespread throughout the mountainous and hillier regions of the state, and countless slides take place annually. Costs in terms of road maintenance in slide areas, building damage, lost time on construction projects, inconvenience, and in some cases threat to life are large. Where man's activities invade areas of high landslide potential, this becomes one of Colorado's most severe geologic hazards.

Criteria of Recognition

Some indications of past sliding in an area are: erratic drainage patterns, trees growing in disarray at divergent angles; irregular, hummocky, poorly drained ground surface; anomalous slope changes described earlier; and disturbed or displaced cultural features such as roads, walkways, and buildings. Recognition of potentially unstable slopes is treated in a separate section of the guidelines.

Consequence of Improper Utilization

The consequence of improper utilization of areas subject to landslide for building and development may range from minor damage in extremely fortunate cases, to total destruction of structures and accompanying loss of life. Maintenance of structures in active slide areas is very costly, and in many cases will equal or exceed the price of the structure prior to expiration of its useful life.

Non-conflicting use
Where the proposed use is simply not compatible with an existing slide hazard, the hazard is best avoided by selective use of available development land and complete avoidance of high-risk areas.

Rotational Slide Terminology
Main scarp: steep undisturbed ground surface above the highest part of the slide, resulting from downward movement of slide material.

Minor scarp: steep surfaces in slide material resulting from differential movement within the body of the slide.

> **"Colorado's vulnerability to the landslide hazard is largely a consequence of the increasing expansion of commercial and residential development onto steep or unstable terrain that is prone to landsliding."**
> **-From the Colorado Landslide Hazard Mitigation Plan 1988**

Crown: in-place material just above the main scarp.
Head: uppermost part of slide material along the contract between the main scarp and the slide material.
Transverse cracks: tension cracks more or less perpendicular to the direction of slide movement, generally resulting from downward and outward movement of slide material over a hump in the rupture surface.
Radial cracks: tension cracks resulting from lateral spreading of unconfined slide material.
Tip: furthest forward extension of slide material.
Toe: furthest forward margin of slide material.
Foot: contact between original ground surface, and lowermost extension of surface of rupture.
Surface of rupture: projection of main scarp surface beneath the slide mass.
Right flank: right extent of slide as viewed from the crown, looking down onto the slide.
Left flank: left extent of slide as viewed from the crown, looking down onto the slide.
Prevailing slope: direction of predominant ground surface slope in undisturbed area.
Original ground surface: undisturbed ground surface surrounding disturbed slide area.
Longitudinal fault zone: faulting resulting from differential forward progress of downward moving slide material.

Engineered design and construction for correction of adverse conditions

Where economic pressures and limited available land militate for use of unstable or potentially unstable areas another alternative is to develop moderately unstable areas under specified and closely controlled conditions. This approach calls for careful evaluation of the physical extent, seriousness, and causes of geologic problems, and strict adherence to recommended design and construction procedures, as set forth by competent professional geologists and professional engineers evaluating the landslide area.

There are several common preventive methods employed to avoid sliding. One is to refrain from removing natural support material in the area immediately beneath or adjacent to the slide area. Another is the addition of artificial support material to this area. Such support can be in the form of rock- or earth- fill buttressing, retaining walls or cribbing, concrete slurry, rock bolting and reinforced pilings.

Another approach is to permanently improve and control surface and subsurface drainage in the vicinity of a potential slide area. This greatly decreases the lubricating and pore water pressure effects of water, and accompanying decrease in stability. This approach is often very effective, however, it may involve complex de-watering systems and costly long-term maintenance and monitoring problems.

Other alternatives include stabilizing the slide area by chemical treatment, bridging weak zones, removal of unstable material, and avoidance of loading on unstable areas.

In summary, it should be stated that landslides, and landslide-prone areas can be very complex in nature, and pose serious risks to any development placed in their vicinity.

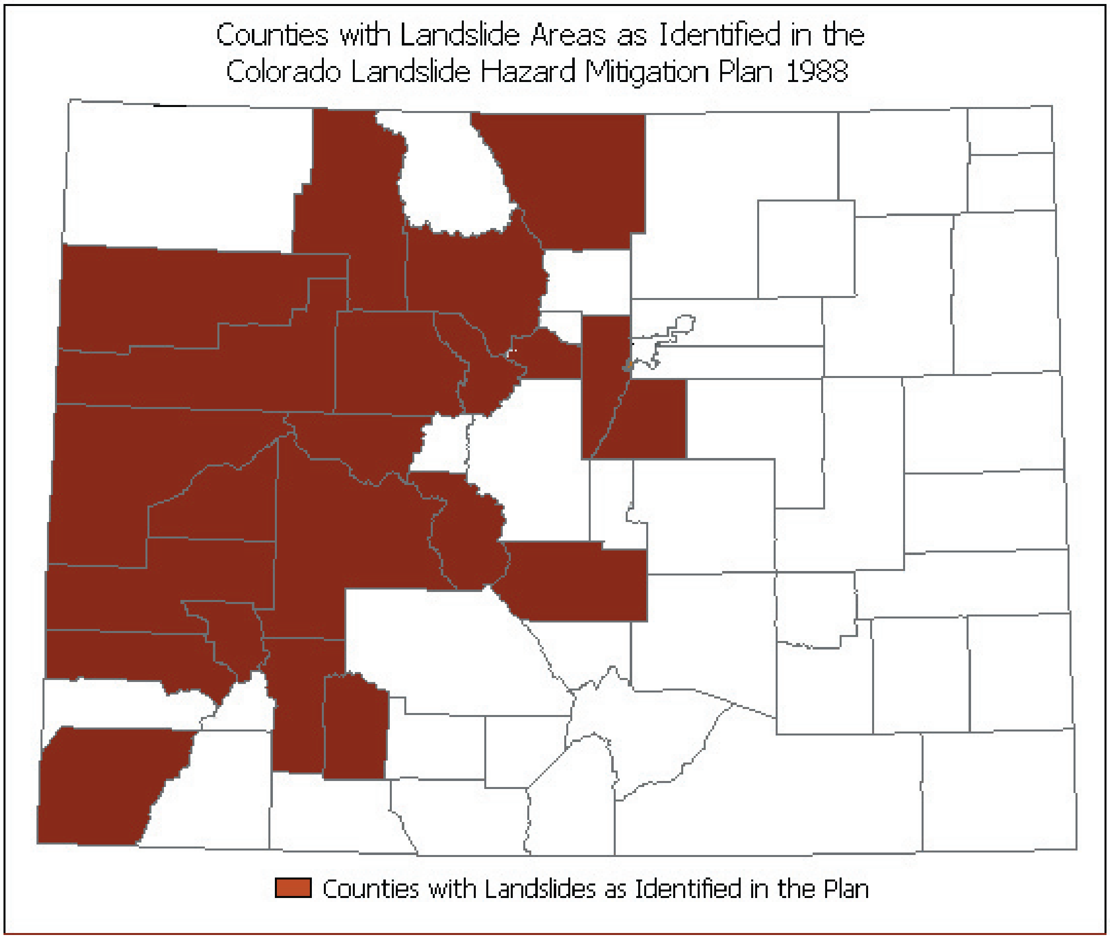
Only competent professional engineering geologists and soil engineers should evaluate landslides and potential slide areas. The information contained in the guidelines is only an introduction to the subject.

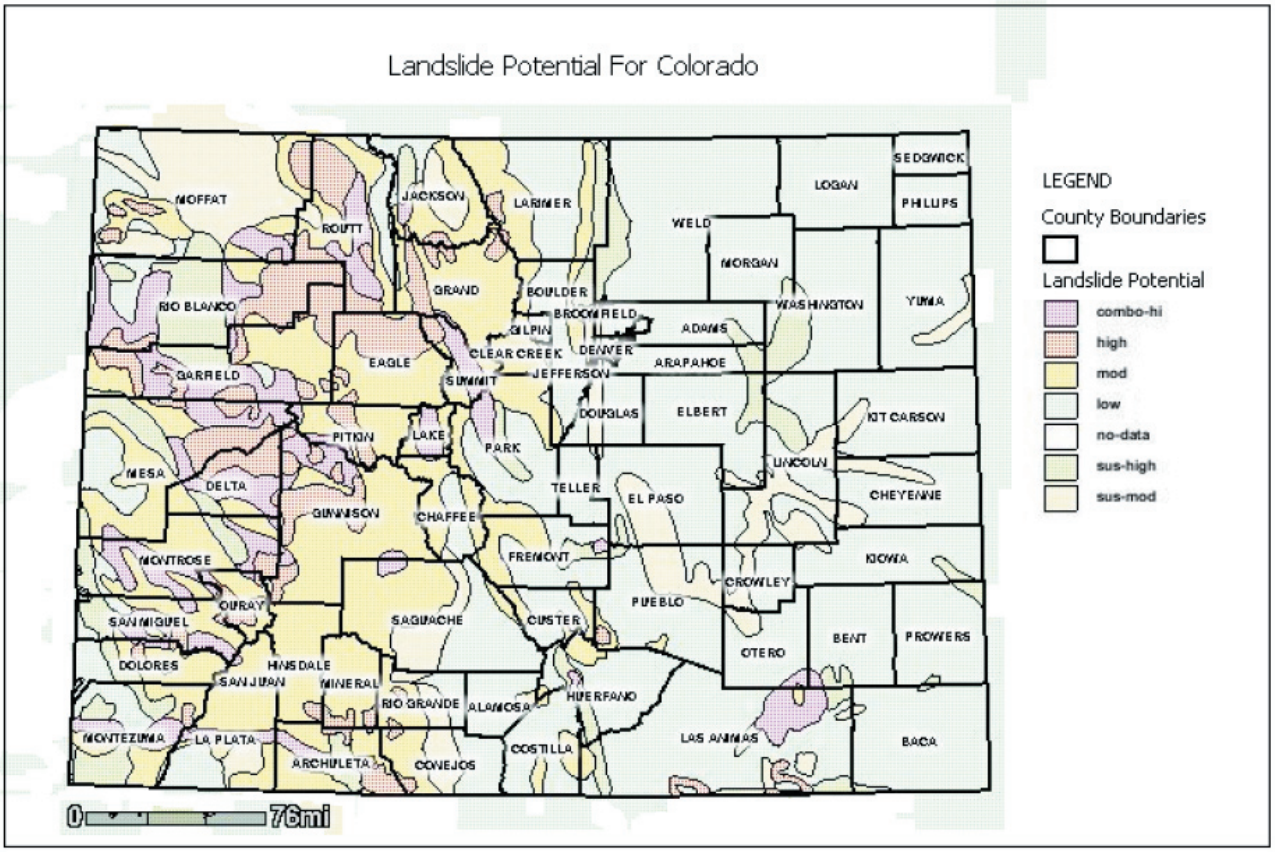
As noted in the Colorado Landslide Hazard Mitigation Plan (1988), 49 areas have been identified as having the "most serious or immediate potential impacts on communities, transportation corridors, life lines, or the economy."

The following counties have landslides identified in the plan: Chaffee, Clear Creek, Delta, Douglas, Eagle, Fremont, Garfield, Grand, Gunnison, Hinsdale, Jefferson, Larimer, Mesa, Mineral, Montezuma, Montrose, Ouray, Pitkin, Rio Blanco, Routt, San Miguel, and Summit. Refer to the Landslide Plan for locations and details on the landslides. Included in the plan are the community/ areas affected, the type of landslide, facilities at risk, and mitigation activities. The Colorado Geological Survey has determined that twelve large landslides have "high potential for very large future losses". The following map illustrates the counties.

Two landslide acquisition projects were completed as a result of presidential disaster declaration DR-1276-CO. Three homes were acquired in Manitou Springs and 25 homes in Colorado Springs. Federal funds from the Hazard Mitigation Grant Program and Unmet Needs were applied toward this project. Loans from the Small Business Administration were also received. Pre-Disaster Mitigation grant program funds were used to acquire and demolish one more house in Colorado Springs in 2007.

Above: Acquisition/demolition/ slope stabilization in Manitou Springs
Below: Same in Colorado Springs
Photos by Marilyn Gally





This digital representation of the map above was created by the USGS after the original publication in 1982.

MUD FLOW/DEBRIS FLOW: From CGS Special Publication 12

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 mud flow 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 that increase the amount of water or soils 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 that 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. Recognizing natural mud flow areas and avoiding them can prevent property damage. 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.

Debris Fan in Garfield County
Photo by Colorado Geological Survey

Manitou Springs Debris Flow
Photo by Patricia Gavelda

Legal definition From CGS Special Publication 6

H.B. 1041, Part 1, 106-7-103 (12) defines a mud flow as follows: "Mud flow" means the downward movement of mud in a mountain watershed because of peculiar characteristics of extremely high sediment yield and occasional high runoff. H.B. 1041, Part 1, 106-7-103 (4) defines a debris-fan floodplain as follows: "Debris-fan floodplain" means a floodplain that is located at the mouth of a mountain valley tributary stream as such stream enters the valley floor.

Descriptive definition

A mud flow is a geologic phenomenon whereby a wet, viscous fluid mass of fine-to coarse-grained material flows rapidly and turbulently downslope, usually in a drainageway. This results typically from torrential rainfall or very rapid snowmelt runoff that initiates rapid erosion and transport of poorly consolidated surficial materials that have accumulated in the upper reaches of the drainage area. Included in this complex process are such strict terms as earthflow, mud flow, and debris flow (A.G.I., Varnes, 1958). Very high viscosity usually results in slow earthflow movement or a combination of slow movement and internal fracturing of landslides.

Fluvial (water) transport of materials is characterized by flow of very low viscosity water and fine-grained sediments in suspension.

Mud is composed predominantly of silt and clay, whereas the term "debris" is commonly applied to material that consist mostly of boulders and cobbles mixed with displaced soil and vegetation.

Mud flows are typically recurrent event in certain drainage basins. The combination of climatic and geologic conditions that produces mud flows is a characteristic of mud flow-prone drainages. The moving mixture of water, soil, rock and vegetation most commonly has the consistency of freshly mixed concrete. As it moves down a drainageway, a mud flow may incorporate nearly anything in its paths – trees, rocks, and debris left by previous flows, that in turn increase the erosive power and destruction energy of the moving mass. In the lower reaches of the drainageway, the stream channel may be deeply eroded, overrun and flooded by the flow, or filled, and the location and configuration altered.

A debris fan is a triangular-shaped landform that forms by deposition of material at the intersection of a tributary valley with a larger valley. The material consists of stream-flood sediments and/or mud flow material and is deposited where the stream changes gradient as it enters the larger valley.

Like the mud flows to which they are related and sometimes associated, flooding and deposition of material on debris fans are recurrent events. The cause of flooding is a cloudburst, extended rain or rapid snowmelt followed by rapid runoff into the drainage-way. As the water and associated debris move downstream, they pick up and carry large amounts of material—rocks, vegetation, soil, and at times man-made works. Farther downstream, where the drainage course is less confined by valley walls and where the stream gradient is lower, the water spreads out into multiple channels. It is this area, typically near or at the mountain front, that is called a debris-fan floodplain. At this point stream and debris velocities are lower, and there is insufficient energy to move the debris. The debris load is deposited as a mixed mass forming the debris fan, and the water progressively changes from multiple-channel flow to sheet flow.

Most mud flows in Colorado originate in drainage basins that head in high barren mountainous areas. Such areas are more susceptible to erosion by rapid runoff than are gentler, vegetated slopes. Associated debris fans and their flood plains occur mostly along mountain fronts and steep valley sides.

Severity of problem

Mud flows become a serious threat to man-made works and human life when man inadvertently chooses to live in active mud flow areas. Mud flows can occur with no more advance warning than a rising storm cloud or rapid increase in springtime temperature. Most Colorado mud flows occur in the spring and summer, the months of great snowmelt runoff and rainfall.

Many scenic mountain valley areas in Colorado are under intense development pressure. The uncertain periodicity of mud and debris flows and floods, combined with the short memories of people can result in very dangerous circumstances if these mud flow prone areas are developed.

Because debris fans and mud flows are genetically related, problems associated with them are similar. The location of debris fans at mountain fronts makes them more accessible to people and development pressure.

Criteria for Recognition

Nearly all mud flow areas in Colorado are located in the lower parts of tributary streams of major streams as they enter the major valley. They are most easily recognized by occurrence of recent mud flow deposits and by the distinctive undulating topography of the fan areas. The maximum extent of these deposits and the associated fan represents the probable maximum extent of mud flows and danger. This is true even though some parts of the fan may be covered by vegetation, indicating temporary inactivity. Mud flow material is a heterogeneous mixture of mud, angular pebble- to boulder-sized or larger rocks, soil, vegetation, and coarse debris of trees. The top of a mud flow or debris fan is usually rough to undulatory when larger sized material predominates and relatively smooth if most of the material in the flow is fine grained. The color and composition of the flow material is commonly similar to the predominant bedrock near the upper reaches of the drainage basin from which it was derived. At the edge of the flow area, there is a pronounced transition from disturbed vegetation and undulatory ground surface to normal vegetation and slope conditions. The most recent mud flows are nearly devoid of vegetation. The gross appearance of the mud flow area is most commonly a mud and debris-laden streambed terminating down valley as a fan in the depositional area. In the case of certain drainages that carry a large volume of water as well as occasional mud flows, the stream may cut its channel deeply into the fan rather than shifting channels constantly. In such cases the typical debris-fan topography is absent or not easily recognized and the mud and debris may be deposited in or near the stream occupying the major valley.

Preliminary recognition of debris fans is aided by their location near mountain fronts, their irregular surface, the multiplicity of small stream channels on their surface, their triangular (fan) shape, poorly sorted deposits typical of debris flows. Other criteria for recognition include bruised and/or partially buried standing trees. Careful inquiries may provide documentation of historic occurrences.

Consequences of Improper Utilization

The consequences of improper utilization of mud flow and debris-fan areas range from occasional inconvenience to human inhabitants to loss of life and total destruction of all works of man in the area affected. Few mud flow-prone areas are suitable sites for construction of permanent structures. The unpredictable nature and often rapid movement of mud flows makes even the location of semi-permanent structures, such as mobile homes, extremely hazardous. Even in cases where either frequency or magnitude of mud or debris flows is such that some development is acceptable, the nature of old mud flow deposits is uncertain, and normal humanactivities such as excavations and lawn irrigation could upset and possibly reactivate movement of the deposits. In addition many fan areas have very high seasonal water tables that can adversely affect on-site sewage disposal and other planning considerations. In general, the more hazardous mud flow and debris flow areas should be avoided. In less severe cases, careful mitigation measures and compatible kinds of development are recommended.

Mitigation Procedures

Mud and debris flows can be channelized, diverted, or in some cases dammed, although the cost may be very high relative to the amount of real protection afforded. The principal difficulties associated with engineering structures to control mud flows are related to the great volume and mass of material contained in the flow. Because most of the flow consists predominantly of heavy solid matter, structures must be physically very strong and consequently expensive. Debris basins will fill and become ineffective unless cleaned out after each flow. Channelization may be effective in some cases, but this usually diverts the mud flow into the nearest stream or adjacent property to become a problem at a different location. In many cases, the unpredictability of which channels will act as distributaries for future flows makes siting of protective structures conjectural. In less severe cases, combinations of channelization, diversion dikes, and special foundations may be acceptable. In such cases careful geologic evaluations and engineering designs will be essential.

Notable Recent Mudslide Events in Colorado

Year	Location	Description
2007	Alpine, Chaffee County	Ninety-eight people evacuated. $33,000 in infrastructure damage. Homes filled with mud, propane tanks pushed off foundations.
1999	El Paso County	Floods, mudslides, landslides. Presidential disaster declaration. Estimated over $30 million in infrastructure and property damage, including road repairs and twisted utility lines. Several residences condemned.
1997	I-70 near Palisade	Four-mile stretch of westbound I-70 closed due to mudslide.
1996	Approx. 1 mi. SW of Aspen	"The first debris flow came down the mountain [Keno Gulch] on Monday, May 13th at about 4:30 pm. A second came down the next day [Tuesday, May 14] at about 4:00 pm. The parking lot was covered with mud and debris about 5-ft thick, six cars were virtually buried (4 were totaled). The mud and debris flowed into and structurally damaged the Music Hall and partially filled the large pond beside the Music Hall. Neither flow was moving so fast that you couldn't walk away from it." (David Pearcy, Director, Aspen Day School, personal commun., 1996)
1984	Approximately 7 miles SW of Telluride	"Woman dies in mud slide; melting snow wrecks county roads--A 24-year old woman student at Western State College in Gunnison died a gruesome death after the car she and a friend were driving back to school washed off Highway 145 near Trout Lake Sunday [May 13th] afternoon and tumbled about 150 feet before coming to rest upside down in the mud."

Source: http://cbs4denver.com/topstories/local_story_203105149.html; http://www.denverpost.com/news/ci_6440314; http://www.fema.gov/news/event.fema?id=367; Telluride Times, 5/17/84, p. 1; http://pubs.usgs.gov/of/1997/027/pdf/Tab1g.doc

ROCKFALL: From CGS Special Publication 12

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.

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

Consequences

Rockfalls can demolish structures and kill people. Rocks falling on highways may strike vehicles, block traffic, cause accidents, and sometimes damage the road. Minor but costly consequences 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.

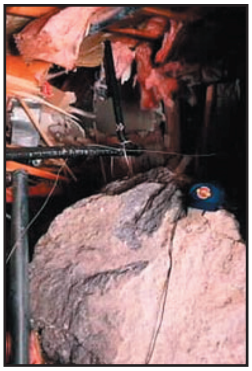
The area and damage of the Booth Creek Rockfall of March 1997. The town of Vail is below the cliffs above Booth Creek. The cliff is the origin of the boulder that damaged houses in the town below. Photo by Jon White, Colorado Geological Survey

Aggravating Circumstances

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

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 rock fall. This measure could save lives, but will not protect property.



The image shows the damage created by the falling boulder in the Booth Creek Rockfall. Photo by Jon White, Colorado Geological Survey.

Falling Rock Sign on Highway 6 Photo by David C. Marlin

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.

Legal definition: From CGS Special Publication 6

H.B. 1041, Part 1, 106-7-103(8) Rockfall is defined only as a kind of geologic hazard.

Descriptive definition

In a rockfall, relatively large fragments of rock become detached and by means of free-fall, rolling, bounding or rapid sliding, or a combination of these methods, moves rapidly down a very steep slope under the force of gravity. Rockfall can be a continuous process over a considerable period of time or a single or series of single, intermittent events. Simultaneous activation of a large mass of rock can result in a rockfall avalanche or very rapid down slope and spreading movement of a large quantity of rock material. Rockfall can be initiated by several means. Most commonly this includes exposure to multiple freeze-thaw cycles, precipitation wetting and weakening of material under blocks, seismic activity, or undercutting of cliffs by erosion or flow of weak rock material.

Rockfall is common where there are cliffs of massive broken, faulted, or jointed bedrock; or where steep bedrock ledges are undercut by natural processes or activities of man. A major cause of rockfall is the repeated freeze-thaw action of water. Because freezing water expands, it develops pressures capable of wedging apart contiguous blocks of massive rock. Water from rain or melting snow also plays an important role in producing rockfalls by erosion, air slaking, and weakening of soft rocks, and by percolation of rainwater through joints. These actions remove the support for the overlying blocks of rock and can eventually initiate down slope movement. Some rock types (shales) that contain a high percentage of clay become weak and slippery when wet. The result is a reduction of static friction at the base of overlying metastable blocks. This can cause slippage, which leads to forward rotation and results in subsequent rolling, bounding, or falling of rock fragments. Equilibrium of unstable blocks in rock exposures can be upset by shock from natural earthquakes, blasting, or movement of heavy vehicles.

Undercutting of rock slopes by stream erosion or construction excavations such as road-cuts, that remove support for overlying or overhanging rock, can result in conditions conducive to rockfalls. Talus and talus slopes are the usual natural result of numerous small rockfalls, and their constituent rocks have come to rest in metastable equilibrium, especially those rocks on the surface of the talus slope. Thus, cuts into, and construction on, these slopes can interfere with the active natural rockfall process from the cliffs above, or cause increased movement or falling of the talus material below. Certain over-steepened road-cuts or other excavations are common and dangerous areas for rockfalls.

Severity of problem

The combination of conditions that produce rockfalls is common in the hilly, mountainous, and tableland areas of Colorado. Rockfalls can result in almost unpredictable, nearly instantaneous losses of life and property, when man chooses to live or build structures in their paths without due consideration for the danger. Fortunately, many rockfall areas can be identified (see Criteria), and with proper recognition and engineering, much of the potential danger can be alleviated, if economic costs and benefits are justified and proper actions taken.

Criteria for Recognition

Many areas where rockfall may occur are relatively easy to recognize. Other areas where rockfall is a potential hazard are difficult to identify and evaluation of the degree of hazard present may be virtually impossible. Potential rockfall areas are those where relatively steep or barren cliffs rise above less steep talus or colluvial slopes. The talus slope and areas adjacent to it, occupied by larger angular randomly oriented rocks, constitute the long-term potential rockfall danger zone even though the talus may be partially overgrown with vegetation. Active rockfall areas are those showing evidence of recent falling and rock movement. Rock displaced or damaged vegetation, fresh "tracks" of rocks rolling down-slope, fresh scars on cliffs, anomalous or disoriented lichen growth on rock blocks, eyewitness accounts, and damage to fences or man-made works are some common criteria for identifying active rockfall areas. The most common difficulty with 'inactive" rockfall areas is unexpected reactivation due to activities of man or exceptional natural conditions. Questionable rockfall areas should be monitored if there is the possibility that reactivation of a rockfall may take place and present a hazard to man.

Consequence of Improper Utilization

Improper utilization of rockfall areas is any use for which occasional, unpredictable, rolling, bounding, or falling of rocks could constitute a threat to life or property. Unless completely protected (see mitigation), buildings, some roads, pipelines, railroads, and most other works of man are in potential jeopardy in rockfall areas. A 3-ton of sandstone, for example, rolling downhill into a typical unprotected house, probably would destroy it, whereas this same block crossing a concrete roadway probably would do relatively little damage. A major rock avalanche could, however, destroy a roadway or a whole subdivision. In the case of costly engineered structures, expenses for mitigation of rockfall danger would likely be warranted, especially if alternative locations are prohibitively expensive.

Housing, on the other hand, might easily be planned elsewhere with less expense if other potential sites are available.

Areas of potential rockfall are subject to constraints similar to those of active rockfall areas. However, if activation can be prevented, such areas could be used safely, but the cost of protection from the potential hazard can in many cases exceed the economic gain from the change in land use.

Mitigation Procedures

The simplest and most effective way to mitigate rockfall hazard is to avoid rockfall-prone areas entirely. There is no way to completely eliminate possible damage by rockfall, and practically any human use of active rockfall areas is incompatible with the risk. However, if a rockfall area is to be used, there are several ways that the hazard can be decreased. They fall into the following general classes: 1) stabilization of rocks; 2) slowing or diverting the moving rocks; 3) and physical barriers against rock impact around vulnerable structures. Rocks can be stabilized by bolting, gunite application (cementing), outright removal of unstable rocks (scaling), cribbing, or installation of retaining walls. Movement of rocks can be slowed or diverted by rock fences, screening, channeling and dams, or by concrete barriers or covered galleries. All these measures are expensive, and seldom completely eliminate the hazard. All require periodic maintenance. Stabilization is usually only a short-term solution. Complete removal of all potentially unstable rocks is usually not possible. Dams and fences fill with rock and deteriorate structurally, and concrete barriers and galleries are relatively short-lived considering their cost.

An important factor to keep in mind is that although the place of potential rockfalls is to some degree predictable, the time of failure is not. Hence, complete avoidance of areas of potential rock-fall is the most sensible mitigation measure where human lives or high property values are at stake.

Rockfall Area Along I-70 Corridor Near Lawson, CO
Photo by David C. Marlin

A description of the CDOT rockfall mitigation program is in the State Assessment section.

NOTABLE ROCKFALL EVENTS IN COLORADO

YEAR	LOCATION	DESCRIPTION
2007	El Dorado Springs	Huge boulder crashes into home into living room.
2007	U.S. 6	Rock crashed through roof of SUV, driver had minor injuries. Rock the size of a beachball.
2006	Ouray Cty Rd 361	One fatality. Driver hit in head.
2006	West Creek and Deckers	Boulders and mudslides during rainstorms over previous burn areas.
2006	Trail Ridge	Rockslide shut down Trail Ridge Road, two lanes wide and 100 feet long.
2006	I-70 Debeque Canyon	Woman killed from rockslide while driving tractor trailer. A slide occurred there about 3 weeks earlier.
2006	U.S. 6 Clear Creek Canyon	Car (unoccupied at the time) flattened under a slab of rock.
2005	I-70	Rockslides near Downie-ville. Highway closed about five days.
2005	U.S. 6 Clear Creek Canyon	1,400 tons of rock. Two truck drivers and a motorist escaped injury. One boulder the size of a minivan.
2004	I-70 Georgetown	Boulders 2-9 feet landed across both lanes. I-70 Closed about 8 hours. One semitrailer truck hit median while avoiding debris. Two fuel tanks ruptured, spilling 250 gallons. A second truck hit the first.
2002	CO 133	One death, a 7-year old child. Rock hit truck.
2002	U.S. 550 Red Mountain Pass	Rock slide south of Ouray.
2000	Capitol Peak Pitkin County	Death of a climber in rock slide.
2000	I-70 Glenwood Canyon	Westbound lanes closed for an hour. No injuries.
2000	U.S. 6 Clear Creek Canyon	A vehicle crashed into a 2-ton rock on the highway. No serious injuries.
2000	U.S. 6 Clear Creek Canyon	One motorist injured. Basketball-sized rock crashed through windshield and hit him in leg.
1997	U.S. 285	Turkey Creek Canyon. Two slides. Blocked one lane. The cliff between the slides is moving.
1996	Brainard Lake	Two hikers trapped around 12,000 feet.
1995	Mesa Verde NP	One girl injured when van was hit by boulders.
1993	El Diente Peak	One fatality, one injury. Climbers.
1992	I-70 Silver Plume	Rockslide near Silver Plume. One injury. Boulders weighing 300 to 400 pounds.
1990	Rollins Pass	A section of Needle's Eye Tunnel collapsed. One injury.
1990	US 24	Highway closed 12 hours. 1,000 tons of rock slid down hill and onto the road. Occurred around 2 a.m. No injuries.

Source: Rocky Mountain News articles located in appendix.