



Landslides in Colorado, USA: Impacts and Loss Estimation for the Year 2010

By Lynn M. Highland

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Conversion Factors, Datum, Abbreviations, and Acronyms

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)

Landslides in Colorado, USA—Impacts and Loss Estimation for the Year 2010

By Lynn Highland

Introduction

The focus of this study is to investigate landslides and consequent losses which affected Colorado in the year 2010. By obtaining landslide reports from a variety of sources, this report will demonstrate the feasibility of creating a profile of landslides and their effects on communities. A short overview of the current status of landslide-loss studies for the United States is introduced, followed by a compilation of landslide occurrence and associated losses and impacts which affected Colorado for the year 2010. Direct costs are summarized in descriptive and tabular form, and where possible, indirect costs are also noted or estimated. Total direct costs of landslides in Colorado for the year 2010 were approximately \$9,149,335.00 (2010 U.S. dollars) and are summarized in table 1. (Since not all data for damages and costs were obtained, this figure realistically could be considerably higher.) Indirect costs were noted where available but are not totaled due to the fact that most indirect costs were not obtainable for various reasons outlined later in this report. Casualty data are considered as being within the scope of loss evaluation, and are reported in Appendix 1, but are not assigned dollar losses. More details on the source material for loss data not found in the reference section are reported in Appendix 2, and Appendix 3 summarizes notes on landslide-loss investigations in general and lessons learned during the process of loss-data collection.

Overview of Landslide-Loss Data Acquisition for the United States

Landslide-loss data for Colorado and other States exist in a wide variety of information sources, and the combined data can yield at least an approximation of total landslide losses, both direct and indirect. However, there is no current, ongoing compilation of comprehensive landslide-loss data for any of the 50 States, nor is there a targeted effort to acquire and maintain an accurate landslide inventory or a subset of loss data for the United States as a whole. The landslide-loss information that has been obtained appears in the following: There is little cost information for landslide losses for all of the United States, but what has been documented appears in the following: Schuster and Fleming, 1986; Schuster, 1996; National Research Council, 1999; Wang and others, 2002; Highland, 2003, 2006; and Crovelli and Coe, 2008. Much of the landslide documentation and inventory for landslides in Colorado can be found in Rogers (2003a, 2003b, and 2005).

In this report, we attempt to quantify landslide losses in 2010, for the State of Colorado. Our goal is to demonstrate the feasibility of this quantification using a number of different data sources. One of the main impediments in acquiring accurate landslide-loss information is the lack of landslide inventory collection standards at a National level (although 10 states have landslide-inventory maps and other inventory information tailored to the particular needs of that

State). Some of the individual State Geological Surveys, including Colorado, have compiled landslide inventories for their respective States, although none use a common reporting or archiving method. Additionally, because landslide-inventory information usually does not extend beyond the borders of States that track it, the landslide-loss characteristics of regions across the United States are difficult to determine. As there is no national mandate or incentive to acquire or maintain a landslide inventory, associating historical landslide occurrences with losses is difficult.

Until the 1990s when Global Positioning Systems (GPS) became widespread, landslide locations were described in terms of township/range locations, and (or) latitude/longitude taken from topographic or other types of maps. Some landslides were identified by street addresses, highway mileposts, or distances from landmarks, making exact locations uncertain. Many compilations contain only partial data associated with larger significant events, leaving out small or less significant events. These compilations also contain gaps in time-frame and geographical location, and many reported landslide descriptions and locations are not field-checked for accuracy by State Geological Surveys, consultants or municipal planning and zoning departments. Generally, detailed information is available only when landslides are large and (or) have notable impacts on the built and natural environments. Cost data for landslide effects is sometimes even more difficult to acquire, due to privacy concerns that preclude the public release of cost data. Also, there are difficulties associated with extracting disparate information from data sources; that is, the landslide-loss data that a highway department keeps, for example, are in many instances combined with other types of tabulated costs. Data such as general debris clean-up costs, grading costs, and (or) road detour costs are not itemized sufficiently to separate the general losses from the individual landslide losses.

Modern relational databases, Geographical Information Systems (GIS), GPS, Light Detection and Ranging (LiDAR), and other approaches/methodologies have vastly enhanced the siting, description, and mapping of landslides. These digital advances may contribute to the future cost-effectiveness of tracking landslides in a more systematic, homogenous manner.

A Note on Direct vs. Indirect Losses

The losses from landslides described and tabulated in this report are organized into two categories: Direct and Indirect. Direct losses are the costs for repair, replacement, or maintenance resulting from damage to property or installations within the boundaries of the responsible landslides or from landslide-caused flooding (Schuster, 1996). All other losses from landslides are indirect. Some examples of indirect losses from landslides are:

1. Loss of industrial, agricultural, and forest productivity and tourist revenues as a result of damage to land or facilities or interruption of transportation systems;
2. Reduced real-estate values in areas threatened by landslides;
3. Loss of tax revenues on properties devalued as the result of landslides;
4. Measures that are required to be taken, to prevent or mitigate additional landslide damage;
5. Adverse effects on water quality in streams and irrigation facilities outside the landslide;
6. Loss of human or animal productivity because of injury, death, or psychological trauma; and
7. Secondary physical effects, such as landslide-caused flooding, for which losses are both direct and indirect.

Study Area

Figure 1 shows the State of Colorado along with the locations of Colorado's largest cities and main highways. In order to get a broad understanding about landslide occurrence in Colorado, Figure 2 shows a general landslide, rockfall, alluvial fan and debris-flow map for Colorado released by the Colorado Department of Emergency Management, using data from the Colorado Geological Survey (Colorado Department of Emergency Management, 2011).

Overview of Landslides and Landslide Information for Colorado

Landslides in Colorado are concentrated along the Front Range, central mountains, and western part of the State and are typically associated with areas of significant slope. Landslides are natural and ongoing events. Both human activity disrupting the land and periods of significant precipitation increase the likelihood of landslide occurrence. Many landslides have not damaged structures, caused deaths or injuries, or impacted critical services or facilities. However, some landslides have resulted in deaths or significant damage to public infrastructure (Colorado Division of Emergency Management, 2011). The Colorado Geological Survey has been digitizing all mapped landslides that have been published in geologic and geologic hazard maps of Colorado and placing them in a GIS-based inventory map; however, the information for this current USGS Open-File Report loss study was obtained separately, as the Colorado inventory was released before the year 2010. The map generated by the Colorado Geological Survey is referenced here, for the reader's information. The map is currently online at this link:

http://geosurvey.state.co.us/hazards/Landslides/Pages/CGSLandslide_inventory.aspx
(Jon White, Colorado Geological Survey (written commun., 2011).

Investigation of impacts and losses from Colorado landslides in 2010 was conducted mostly in the year 2011, with a follow-up in early 2012. Many types of sources were consulted and include:

- Newspaper and other media reports, including reports by government entities such as the Colorado Department of Transportation (CDOT);

- Costs incurred by municipal, county, and State governments for landslide hazard-associated expenditures;

- Electrical and power companies both private and public;

- Private consulting companies, for example, those involved in geotechnical engineering and engineering geology; and

- Photographs of landslides were acquired where possible.

It should be noted that some landslide events that occurred in 2010 may not have been documented and (or) studied by anyone, as they could have occurred in remote areas not inhabited or frequented by people. This is also the case for this report. Landslides that occur on private property are sometimes not reported or noted in any type of accessible information.

Aerial photography can indicate past landslide activity in some areas, but does not provide a means of accurate dating without further analysis. Aerial photography was not checked for this report. Some landslides may have been noted but have not yet been mapped or cited in reports, as of this writing.

Significant Colorado Landslides in 2010—Impacts and Costs/Losses

1. Glenwood Canyon, Garfield County Rockfall/Slide, March 8, 2010—Losses and Cost Shifts

This rockfall occurred on March 8, 2010. It is estimated that at least 20 boulders fell onto Interstate-70, ranging in size from 1 to 3 meters (m) in diameter. The largest was estimated to have weighed about 66 tons. Figures 3 and 4 show damage caused by the rockfall. The rocks made holes in the elevated sections of roadway, the largest being in the westbound lanes (closest to the hillside) and measuring 6.2×3.2 m. Another hole in the lower eastbound lanes measured 2×2 m. There were several other holes and craters in the roadway, as well as areas where rocks were embedded. Most of the areas that needed repair appeared to be approximately 3.6×3.6 m. Rocks were scattered over 100 m of roadway. Other rock-fall impacts included damage to three sections of steel guard rail and to sections of median barriers. This damage was similar to that from a 2004 rockfall. (Although the November 25, 2004, (Thanksgiving Day) rockfall was in the same general area, the rocks came from a different height on the slope.)

The 2010 repair work took place between mile markers 124 and 125, just west of Hanging Lake Tunnel. The work involved bridge deck and bridge wall/rail repairs (including 50 m, or 150 feet (ft), of new steel bridge rail); guardrail repairs (about 40 m or 120 ft) to the hillside concrete barrier; median concrete barrier repair (replacement of 133 m, (400 ft)); removal and replacement of 690 square feet (ft²) of concrete retaining walls; straightening of steel bridge girders; some lighting and electrical repairs; and repairs to the bike trail below. Finally, crews used approximately 500 tons of base course material on the roadway, as well as 400 tons of patching asphalt, to repair the driving surface.

Flatiron Construction, with assistance from rockfall contractor Rock Solid Solutions, also installed 1,300 square meters (m²) (14,000 ft²) of wire mesh along a section of the canyon wall, near the bottom of the two chutes down which the rocks from the March 8 rockfall event traveled. "The wire mesh is designed to keep smaller rocks (less than 1 m or 3 feet in diameter) that may release from the talus slope above from reaching the highway," CDOT Geologist Ty Ortiz said (oral commun., 2011). "The goal is to reduce the chances of these smaller rock incidents; the mesh is not intended to mitigate a large event like the one that occurred on March 8." (Tyler Ortiz, written commun., 2011). Figure 5 shows a photo of the rock-blasting by CDOT on Interstate-70 subsequent to the rock slide, which was done in order to bring down any unstable rocks remaining in the area above the impacted road area.

Total direct costs/losses from this rockfall event were: \$2,180,000

Then-Governor Bill Ritter declared a disaster emergency in 2010 to qualify for money from the Federal Highway Administration (FHWA) to help pay for repairs. The Colorado Department of Transportation expenses totaled \$2.2 million, reimbursable by the FHWA. For comparison, the 2004 rock slide in the same area cost \$700,000 to repair.

CDOT is also requesting additional federal assistance to conduct a follow-up study on additional rockfall mitigation in the canyon. No information on costs for this mitigation work is currently available.

Indirect costs/losses:

The rockfall that closed Interstate-70 through Glenwood Canyon forced truckers and other travelers onto a 200-mile (mi) detour that added hours to their trips and increased costs. The closure cost trucking companies millions of dollars in fuel, work hours, and other costs. (Greg Fulton, president of the Colorado Motor Carriers Association, (written commun., 2011). With Interstate-70 closed, Mr. Domenico of Domenico Trucking commented on conditions of

alternate routes: "They are good roads, but it is slow; we don't want to have an accident—it is narrow; and with the increased traffic, you need to keep your speed down. It is adding about six hours a run for our drivers." When Interstate-70 is open, a typical trip from Denver to Glenwood Springs is about three hours, making a round trip six hours. With the interstate closed, it took drivers eight and a half to nine hours for one leg of the journey (Denver Post, 3/12/2011). According to Mr. Domenico, those increases in cost are passed on to consumers, who pay more for the products the trucks deliver to retailers.

Cost shift associated with the Glenwood Canyon rockfall

The term "cost shift" is used here to indicate that losses to one entity resulting from a landslide may increase the income for other entities as a result of a given landslide; for example, an increase in business patronage and subsequent business income along a rerouted detour. The Union Pacific Railroad's tracks through the closed Glenwood Canyon weren't affected by the 2010 rockfall due to their location on the side of the Colorado River through Glenwood Canyon opposite the rockfall. The tracks carry freight trains and Amtrak's California Zephyr. The railway became a form of alternate transportation through the canyon during the rockfall road-closure. Air travel using the many airports in the affected region also saw increased business. These airports included the Aspen Pitkin County Airport, Grand Junction Walker Field, Montrose County Airport, Yampa Valley Regional Airport, and Gunnison County Airport. (Report of Glenwood Springs Chamber of Commerce, March 11, 2010). Charter airline carriers reported brisk sales of \$1,000 tickets for one-way rides between Eagle (east side of the rock slide) and Aspen (west side). Online bookings of short-notice flights from Denver to Grand Junction were priced as high as \$850 round trip. Denver Air Connections, a charter company that flies four days a week between metro Denver (west side of rockfall) and Grand Junction (east side), reported an increase in business, at \$300 round trip as its standard fare. Mountain Aviation in Denver began chartering seven-seat planes from Eagle to Aspen for \$3,280 per plane each way.

Various geotechnical engineering companies also benefited from increased income associated with the 2010 rockfall. Costs incurred by CDOT, which is funded by the U.S. Department of Transportation, are ultimately costs to both State and Federal taxpayers. For purposes of this report, cost shifts were not analyzed in detail as there are incomplete loss data, and no guidance on the proper methods of performing a cost-shift analysis was found.

2. Amtrak train blocked by a rock slide in Gore Canyon, May 15, 2010

On Saturday, May 15, 2010, the westbound Amtrak California Zephyr encountered a rock slide in Gore Canyon between Plain and Crescent, about 30 mi west of Denver, Colorado (Colo.). The slide was near milepost 29.5 and Tunnel 17. Figure 6 shows a photo of the rock slide on the railroad track. Alerted by a monitoring device, the rail crew was warned of the rock slide and safely stopped the train short of the slide; however, the slide diverted the train to travel all the way back to Denver. Buses then moved passengers to their destinations (The Denver and Rio Grande Western Railroad news, May, 2010). Amtrak officials did not respond when queried about costs concerning this event.

Total direct costs/losses: These loss figures were not obtained. Costs would be due to railroad track damage, fuel expended to return to Denver, employee time, and clean-up crew time.

Indirect costs: These consisted of lost time for Amtrak and for the passengers, but no specific data were obtained.

3. Big Thompson Canyon landslides, Larimer County, May 21, 2010

On May 21, 2010, at approximately 5:30 PM, about a dozen large rocks fell onto U.S. Highway 34 at milepost 75. A car traveling westbound on Highway 34 was struck by a large rock (photo), and the driver was uninjured (Trooper Cobler, Colorado State Patrol, written commun., May 21, 2010). This road connects the town of Estes Park with the town of Drake, Colo., through Big Thompson Canyon. See figures 7 and 8 for photos of the event.

CDOT worked quickly to clear the road and repair damage, after closing the road on the evening of May 21. The State Patrol advised alternate routes through the canyon. CDOT crews began further mitigation activities by blasting and scaling loose rocks, bringing down about 500 cubic yards of material.

Total direct costs/losses: Big Thompson Canyon near Drake: \$41,334.51, which includes the cost of a helicopter, a private consultant, and CDOT equipment and personnel (Tyler Ortiz, CDOT, written commun., April 29, 2011). Also included is the cost of damage to a 2006 privately-owned car that had been hit by a rock (total cost of damages unknown).

Indirect losses: These costs are principally the loss of business along Highway 34 during the detour.

4. Debris flows in the Redstone, Carbondale, and Marble area of Colorado in July and August,

Torrential rains which occurred on July 29, 2010, affected an area on the western slope of Colorado near the towns of Aspen, Carbondale, Marble, and Redstone. The storm triggered landslides that were reported by an Aspen Times newspaper as being too numerous to count. A number of effects were reported from this rainfall-induced landslide episode, including the following: a landslide near Carbondale closed westbound Highway 82, and multiple landslides occurred between Penny Hot Springs and Redstone, causing Highway 133 to be closed. The biggest debris flow hit Redstone Boulevard and the entrance to the Redstone Campground (figs. 9 and 10). The debris flow was approximately 1.3 m (4 ft) deep and 100 m (300 ft) wide, and covered the north end of Redstone Boulevard and the entrance road to Redstone Campground; as a consequence, people in the 36 campground sites were trapped. Figure 11 shows the campground area 10 months after the event, where a person disappeared and has been missing since. Nine members of the Carbondale and Rural Fire Protection District rescued two people trapped in their car, which was caught in the debris flow. A major mudslide hit County Road 3 just outside of the town of Marble, Colo. The mud was reported to have reached about 1.6 m (5 ft) in height and was approximately 17 m (50+ ft) wide. The Crystal River, which flows through the valley, was turned from a clear, flowing mountain river into a “muddy muck.” (The Denver Post, 07/31/2010). Finally, a debris flow was also reported on Interstate-70, near Dotsero, and in Pitkin County, Snowmass Creek Road at mile marker 10, most likely due to the same storm system. There are more photos on the USGS Landslide Program website:

http://landslides.usgs.gov/learning/photos/colorado_u.s._/redstone_carbondale_aspen_debris_flows_july_2010

The region was hit again on August 19, 2010, when heavy rain and hail produced three significant road closures at the north end of Redstone. Redstone Campground’s Osgood Loop, Dorais Way, and Highway 133 were all closed due to debris flows (figs 12 and 13). According to Mary Dorais, who owns property in the area, “When it started to hail you could hear and feel the earth shake and rumble. I never saw such a hard rain. Trees began to snap and boulders the size of small cars came down like they were floating on air. (Crystal Valley Echo, page 8).” In addition, state plows had to clear mud off Highway 145, near Norwood, Colo. (fig. 14).

In the Marble, Colorado area, on the upper Crystal River, Slate Creek became the path of a debris flow that covered and closed County Road 3 near the town of Marble, making the road impassable for many hours (The Crystal Valley Echo and Marble Times, September, 2010, vol. 7, no. 9). CDOT provided cleanup, as did the Carbondale and Rural Fire Protection District, and Pitkin County personnel using a front-end loader. CDOT estimated that there was 6,000–6,500 tons of debris to be removed (D'Wayne Gaymon, CDOT Region 3, written commun., May 12, 2010).

Total direct costs/losses: \$34,000.00

Indirect costs/losses: There were none estimated, although losses were probably incurred in the form of lost time and increased travel expenses driving on detour routes and lost revenue to businesses in the towns of Redstone and Marble.

5 .Durango and Silverton Narrow Gauge Railroad debris flows, July 26, 2010

On July 26, 2010, two debris flows on the Durango & Silverton Narrow Gauge Railroad (DSNGR) tracks prevented three trains and about 1,000 passengers from reaching Silverton. Geologist Jeff Coe, U.S. Geological Survey, visited this area after the occurrence and determined that despite the designation of “rock slide” given by some media, the event was actually two debris flows that flowed onto the track (oral commun., April 14, 2010). Heavy rains in the upper Animas Canyon led to the debris flows on Monday, July 26, closing the line to Silverton, and rail crews worked into the late evening clearing the slides and repairing the tracks so the line could reopen on Tuesday. The two debris flows ran across the railroad tracks and also into the Animas River (figs. 15 and 16). Some passengers were stranded on the train for 9 hours (hr) on Monday.

A normal round-trip ride to Silverton involves seven hours on the train with two hours and 15 minutes in Silverton. One family paid \$480 to ride the train initially, and said that passengers were offered a 25-percent refund (Albuquerque Journal, July 29, 2010). More photos of this event can be viewed at this link, on the USGS Landslide Program website:

<https://landslides.cr.usgs.gov/learning/photos/admin/plog-manage.php?level=pictures&id=101>

Total direct losses/costs obtained: Losses included lost revenue for the railroad in having to refund ticket prices and clear the tracks. No cost numbers were available.

6. Clohsey Lake debris flows, San Isabel National Forest, Chaffee County, July 31, 2010

On July 31, 2010, a 6-hr rainstorm was blamed for two debris flows in the backcountry between Buena Vista and Leadville, Colo. Roughly 40 people camping or hiking in the area were trapped above the debris flows, which blocked Clohsey Lake Road. Dozens of vehicles were also trapped. One debris flow was up to 7 ft deep and covered a four-wheel drive trail in the San Isabel National Forest in Chaffee County, according to a camper in the area. See figures 17–21 for photos of the event.

Total direct costs/losses obtained: Cost for equipment (excavator) was \$3,500. This does not include salary (approximately 18 person-days total). (Jon Morrissey, U.S. Department of Agriculture [USDA], Forest Service, written commun., May 10, 2010). There were no data available on the cost of the rescue, although Chaffee County Search and Rescue was queried for information.

Indirect costs/losses: These were the potential lost employment income for stranded people (ABC News online, 08/03/2011).

7. Fourmile Canyon Fire, Boulder County debris-flow potential, September 6, 2010

On September 6, 2010, a fire occurred in Fourmile Canyon, 5 mi northwest of Boulder, Colo. The fire burned 26 km² (6,400 acres) and destroyed 169 homes (fig. 22). The wildfire stripped the area of vegetative ground cover and increased the potential for sudden and destructive flooding and debris flows. More than 60 percent of the burn area drains into Boulder Creek with another 18 percent draining into the Fourmile Canyon Creek. Studies by local, federal, and private-sector scientists suggested an increased risk of flooding along the Boulder and Fourmile Canyon creek floodplains for between 2 and 10 yr, with the increased risk measured at mild to severe (Boulder Daily Camera, 03/01/2011).

Empirical models estimated that several of the burned drainage basins in Fourmile Creek and Gold Run had probabilities of debris-flow occurrence greater than 60 percent, and many more had probabilities greater than 45 percent; these probabilities are based on a 2-yr recurrence from a 1-hr-duration rainstorm (Ruddy and others, 2010). The moderately high probability of large-volume debris flows indicates a potential for substantial debris-flow impact to buildings, roads, bridges, culverts, and reservoirs located both within these drainages and immediately downstream from the burned area (Ruddy and others, 2010).

In response to the post-fire debris-flow concern, Boulder County established the Fourmile Emergency Stabilization Team (FEST) to study ways to mitigate the effects of the fire. The FEST team was composed of county commissioners, plant ecologists, and representatives from the following organizations: Boulder County Open Space, Colorado Department of Transportation, the USDA Forest Service, the USDA National Resources Conservation Service (NRCS), and the USGS. The FEST assessment recommended distributing ground cover on the severely burned areas in order to promote revegetation and to minimize erosion and debris flow during spring and summer rains.

Two episodes of post-fire debris flows were documented in the Fourmile Canyon burn area since the fire in 2010. On July 7, 2011, four reported debris flows occurred at mile marker 8 and beyond, in Fourmile Canyon (<http://www.youtube.com/watch?v=vagneNMWOw>). On July 13, 2011, six roads (including Four Mile Road and Gold Run at Dixon) were closed due to debris flows; these are areas which were highlighted in the 2010 debris-flow potential report (<http://denver.cbslocal.com/2011/07/13/debris-flows-closed-roads-fourmile-canyon/#T481frUn-Q.email>).

Direct Losses: There were no direct losses from post-fire debris flows in 2010.

Indirect Costs/Losses: The 2010 total estimated costs for debris-flow mitigation in the Fourmile Canyon wildfire-burned area was \$1,809,540 (Boulder County Fourmile Emergency Stabilization Team Report, 2011, p. 9).

8. Amtrak Train blocked by rock slide in Gore Canyon, December 22, 2010

On December 22, 2010, rock slides triggered by heavy rain in Glenwood Canyon, Colorado, detoured train traffic between Granby and Glenwood Springs. The resultant delays caused Amtrak travel to be shut down for 2 days, between Salt Lake City, Utah, and Denver, Colo. Passengers were taken to their destination by buses. Amtrak did not respond to a request for cost/loss information (CBS Denver news online, 12/22/2010).

Other Landslide Events in 2010

- February 15, 2010—About 7,000 tons of rock fell on U.S. Highway 50 about 2 mi west of Cotopaxi, Colo. Some of the boulders ranged in size from 5 to 20 tons. Costs involved cleanup by CDOT and a contractor of rock and small repairs to the highway. The highway was closed for a week. School was cancelled due to the rock blockage as students and staff would have had to take a 3-hr detour (KOAA Colorado Springs/Pueblo News, 02/20/2010).
- March 2, 2010—A rock slide on Interstate-70 in De Beque Canyon, Colo. (east of Grand Junction at mile-marker 56), caused two traffic accidents (Channel 11 News website, 03/02/2010).
- August 5, 2010—Twelve cars were trapped by two debris flows between Leadville and Buena Vista, after a 6-hr rainstorm (Durango Herald August 5, 2010).
- October 28, 2010—Road crews from CDOT spent a total of about \$2,000,000 in 2010, fixing ongoing landslide-related damage on Interstate-70 between Eisenhower tunnel and Silverthorne, Colorado. The road had become uneven, and part of the road had begun to sink due to landsliding. Asphalt from the continual repaving of the bumps is now 1.6 m-(5 feet)-deep in some areas. Crews from CDOT reinforced hill slopes with light-weight concrete columns installed under Interstate-70 to block and break up the sliding soil (Summit Daily News, 10/28/2010).
- October 29, 2010—A rock slide occurred behind a Walgreens store in Dillon, Colo. A water-main break sent water down a 20-m (60-ft) retaining wall, causing it to fail. Two homes were evacuated and Little Beaver Trail was closed. Figure 23 shows a photo of road damage that occurred when the retaining wall failed. (Summit Daily News, 01/27/2010).
- The May 14, 2008—East Fork San Juan River Landslide—this landslide resulted in monitoring and repairing of an Xcel Energy Company pipeline that runs through the landslide. The movement of the landslide cost \$716,000 to fix (Chris Hartig, Xcel Energy, Denver, Colo., oral commun., 2011). Ongoing monitoring with extensometers and other devices produce real-time data on the status of the slide, and the slide is a continual cost to Xcel, with the amount of debris varying from year to year.
- Ongoing Rockfall Mitigation throughout Colorado (includes 2010)—This section on rockfall is included under “Notable Colorado Landslide Events of 2010,” because rockfall is a primary geologic hazard in Colorado and losses are incurred by the virtually continuous cleanup and mitigation measures associated with rockfall throughout Colorado. CDOT’s Rockfall Program receives about \$4 million for rock-fall mitigation projects each year (Ortiz, 2004), and this is the cost figure used for the year 2010. As this item is an important aspect of landslide costs, an explanation of the CDOT Rockfall Mitigation Program follows in the next section.

The CDOT Rockfall Mitigation Program

The CDOT Rockfall Mitigation Program, which started in 1996, was created to track rockfall information, implement a rating system, and mitigate potential hazardous areas. When the program first began, CDOT received only \$750,000 for mitigation statewide. Over the last 10 years, funding for the Rockfall Program has quadrupled to \$3 to \$4 million a year to accommodate rising construction costs and to allow for additional rockfall mitigation across the state. To determine which sites are of high priority, several factors are analyzed including slope profile, geological characteristics, and traffic statistics. This information is then incorporated into

the Colorado Rockfall Hazard Rating System (CRHRS), and sites are then prioritized and selected based on their rating. The Colorado Rockfall Simulation Program (CRSP) is a useful computer software application for assessing and modeling rockfall hazard; the CRSP uses the simulation of rocks traveling down a slope to predict the speed, bounce heights, and runout distance of the rocks (Jones and others, 2000). This tool is updated from time to time and version 4.0 is now available; version 5.0 is currently being tested. Since the rockfall-mitigation program began, about 60 sites have been mitigated. Rockfall specialists at CDOT also provide additional assistance at nearly 30–40 locations statewide each year in response to rockfalls and other activity (Mears, 2009). The town of Telluride, Colo., has investigated its rockfall hazard using the CRSP software as one of its tools.

Through its regular funding, CDOT received \$4.3 million for rockfall-mitigation projects for 2010 (Colorado Department of Transportation, 2011b, p. 42). Due to the addition of Funding Advancements for Surface Transportation and Economic Recovery (FASTER) money, CDOT was able to accelerate a few of the projects. An additional \$700,000.00 was allocated by the State Transportation Commission for repairs to rockfall devices and to repair and update fences in Glenwood Canyon. According to CDOT, there are 756 locations statewide having chronic rockfall issues. Just about every canyon in the mountains has some type of rockfall concern (Ortiz, 2004).

- Interstate-70 in Glenwood Canyon: Crews will continue to repair and improve existing rockfall fences in Glenwood Canyon. This \$600,000 project was scheduled to begin in the summer of 2010.

- Interstate-70 at Georgetown Hill: The \$1.4 million project will continue rockfall mitigation at one of the state's most active sites by installing rockfall fencing and draped rockfall netting. Construction was started in late fall 2010 and continued through calendar year 2011.

- U.S. 285 in Turkey Creek Canyon: The project consists of rock scaling, blasting, and installation of rockfall netting. The rockfall-mitigation work will be combined with a safety improvement project on US 285 between Bailey and Richmond. The rockfall mitigation work is expected to cost between \$150,000 and \$300,000.

- State Highway 82 at Shale Bluffs: This project involves the installation of draped rockfall netting along SH 82 between mileposts 35 and 37. The site is being funded with \$350,000 from the rockfall program and the rest, \$1.2 million from FASTER safety funds. This project was originally scheduled to take place in fiscal year 2013, but was accelerated two years due to the availability of FASTER funds. Construction began in late summer to early fall 2010 (Tyler Ortiz, CDOT, written commun., 2012).

- State Highway 145 at Norwood Hill: This \$1.7 million project consists of rock scaling and installation of draped rockfall netting (of the total, \$200,000 was National Highway System funding). The project began in July 2010 (Tyler Ortiz, CDOT, written commun., 2012).

- State Highway 133 at McClure Pass: CDOT has evaluated this site to determine mitigation activities, which could include rock scaling, blasting, and installation of rockfall netting. Construction was set to begin in the spring of 2011 and is expected to cost approximately \$1.2 million.

- Interstate-70 rockfall mitigation project on Interstate-70 in De Beque Canyon: Completion of the work was accomplished in May, 2010. CDOT contracted out a total of \$380,000 for this maintenance project.

- State Highway 145 from mileposts 96 to 98 in San Miguel County: This project consists of rockfall mitigation at three separate sites including cable netting and wire mesh, mesh

anchors, rock anchors, and polyurethane resin on added upon completion. The total cost is \$1.78 million.

Note: These costs most likely exceed the \$4,000,000 cost figure used in this report for 2010 rockfall mitigation costs. However, the projects may extend through years beyond 2010.

Effects of 2010 Colorado Landslides on Roads and Highways

Figure 24 shows a map of major Colorado roadways. Many of Colorado's landslides occur along transportation networks due to the fact that the soil and rock has been disturbed in some manner, and construction occurred with or without proper landslide hazard mitigation procedures. The cost to maintain, cleanup, monitor, and repair roads and highways from landslide activity is difficult to assess, but the best records come from CDOT, which is responsible for maintaining Colorado roads and highways. Other roads in Colorado are either managed by cities and counties, the Federal or State government, or are privately owned. Landslide costs and losses are often combined with general maintenance costs for a city or county, and the specific landslide-related costs are not itemized, making them more difficult to discern.

Effects of 2010 Colorado Landslides on Rail Transportation

Landslide events occurring on, or near, Colorado railways always have the potential to significantly impact rail transportation in Colorado, as there is no cost-effective way of routing railroads around landslides especially rockfall. Some tunnels exist through hazardous areas, but they are extremely expensive to build. Railroads are routinely subject to rockfall, and (or) rock slides, and the railroads have therefore devised various ways of dealing with this hazard. Approaches include the use of small scout vehicles that sweep the tracks for rocks ahead of a moving train, and trip-wires that indicate a rockfall or rock slide in particularly susceptible areas known to cause ongoing problems. Figure 25 shows a map of railroad lines in Colorado. Railways are very vulnerable to landslides. There were two notable rock slide events and one debris flow event that impacted railroad travel in 2010. Although the effects can be documented, it is difficult to acquire costs from landslide damage to railways, as costs are not normally provided to the public.

Effects of 2010 Colorado Landslides on Public Lands

Figure 26 shows a map of public lands in Colorado. Currently, 46 percent of Colorado is public lands. Large tracts of land in Colorado are managed by the Forest Service, Bureau of Land Management, National Park Service, Indian tribal lands, and other Federal agencies, in addition to Colorado state, county, and city governments. Tracking landslides on public lands is not done on a systematic basis; in fact, the only time landslides are usually noted is when they interfere with public access (roads, highways), or with campers, sportsmen, mountain climbers, hikers, campground operation and maintenance, logging roads, or riverine blockage. In 2010, there were several instances of campers being trapped and roads being blocked by debris flows/mudslides. Total costs of these events are not generally tracked. These costs would include man-hours for federal or state workers such as search and rescue personnel, road crews, and equipment for cleanup; and maintenance, fuel, and (or) costs associated with managing detours. All of the deaths from landslide-related hazards that were found to be documented for 2010 were on public lands or highways.

Three documented significant landslide events occurred on public lands in 2010. These landslides include debris flows that occurred July 31 in the Clohsey Lake campground area of San Isabel National Forest, near Leadville, Colo.; the Durango Silverton Narrow Gauge railroad debris flows that occurred in the San Juan National Forest (the debris flows flowed onto private railroad property); and the Redstone Campground debris flows of July 30, in the White River National Forest and along Highway 133 through this National Forest. There are, no doubt, many more landslides that have occurred and will continue to occur on Colorado’s public lands. It is a challenge to document and inventory these landslides because of the vast areas involved and the scarcity of funds and personnel to map, observe, and report every landslide. Loss data are sporadic and difficult to document, and data most likely exist in a wide variety of sources.

Landslide-Related Disaster Declarations in Colorado for 2010

1. A disaster declaration was made by then-Fovernor of Colorado, Bill Ritter, regarding the March 8, 2010, rockfall/rock slide incident on Interstate-70, Colorado:

<http://www.colorado.gov/cs/Satellite%3Fc%3DPAGE&childpagemame%3DGOVRITTER%252FGOVRLayout&cid%3D1251572415216&pagemame%3DGOVRWrapper>

2. On April 4, 2010, Colorado Governor John Hickenlooper issued an emergency disaster declaration due to the imminent threat posed by flooding as a result of the wildfire last fall in Fourmile Canyon. “The wildfire stripped the burn area of vegetative groundcover and, as a result, according to the U.S. Geological Survey, the potential for sudden and destructive flooding and debris flow is dramatically increased,” according to the declaration.

The declaration also stated the Fourmile Emergency Stabilization Team recommends distributing groundcover on the severely burned areas to promote revegetation and to minimize erosion and debris flow during spring and summer rains. “Due to steep terrain in the burn area, aerial distribution of mulch is necessary.” The aerial mulching effort will use no State funds and will be conducted using Federal funding from the U.S. Department of Agriculture. Specifically, the funds will be used by Boulder County to contract for aerial mulching in the Fourmile Fire burn area. These declarations are cited on State and Federal websites. For this report, the full text of the Declaration is linked here:

<http://www.colorado.gov/cs/Satellite?c=Page&childpagemame=GovHickenlooper%2FCBONLayout&cid=1251590836028&pagemame=CBONWrapper>

FEMA (Federal Emergency Management Agency) issued a Fire Management Assistance Declarations for this incident but did not fund mulching or any other debris-flow potential mitigation.

Table 1. Total Loss/Cost Data for all landslides Investigated in Colorado for the Year 2010.

Landslide	Date (2010)	Direct losses/costs (\$)	Description of indirect losses/costs
Glenwood Canyon Rock slide, Garfield County	March 8	\$2,180,000 (CDOT, including private Geotechnical consultants)	Trucking industry re-routing of 200 miles around the slide. Lost time on delivery schedules, loss of tourism dollars (skiing, hot springs, businesses on both sides of the road) closure for several weeks, cost of taking alternate forms of transportation through the canyon such as air and rail.

Table 1. Total Loss/Cost Data for all landslides Investigated in Colorado for the Year 2010.—Continued

Landslide	Date (2010)	Direct losses/costs (\$)	Description of indirect losses/costs
Rockfall at Big Thompson Canyon near Drake, Larimer County, at milepost 75 on U.S. Highway 34	May 21	\$41,335 (CDOT, including private Geotechnical consultant contractors). Rockfall damage to privately owned vehicle (unknown).	Closure of road by CDOT to do further blasting and rock scaling of rock slide area—detour through Lyons, Colo. Loss of business income along detoured route.
Clohsey Lake debris flows, San Isabel National Forest, Chaffee County	July 31	\$3,500 for excavator	Salaries for extra work in clearing roads and campgrounds (18 person days), fuel, cost of rescuing stranded hikers
Redstone & Carbondale area, Pitkin & Garfield Counties	August 19	\$34,000 (CDOT, including private Geotechnical consultant contractors)	Traffic delays due to temporary closures, loss of tourist and roadside business income
Jackson Mountain, U.S. Highway 160. Archuleta County Work began in fall, 2010 to stabilize the landslide with engineered solution	September, 2010 to April 2012	(CDOT) including private Geotechnical consultant contractors: For 2010: \$175,000 (Note: \$5,200,000 was allocated over a period of years)	Same
East Fork of the San Juan River	May 14, 2008–2010 and ongoing	\$716,000 Xcel Energy pipeline relocation, and maintenance for year 2008; costs are ongoing for pipeline adjustment and monitoring equipment placed on landslide, and private consultants (no figures available)	No real indirect costs, as the pipeline did not have to be shut down, which would have meant a cutoff of gas service to homes and businesses.
Landslide mitigation on Interstate-70 between the Eisenhower Tunnel and Silverthorne, Colo.	October, 2010, reported by CDOT	\$2,000,000	Unknown
CDOT Rockfall Mitigation program	Year 2010	\$4,000,000 (CDOT, including private Geotechnical consultants)	Cost of detours to traffic, while blasting and clearing roads; commercial trucking delay time, extra fuel costs for idling traffic (delays of up to ½ hour for all traffic, sometimes both ways)
Total Estimated Direct Costs/Losses (2010 U.S. Dollars)	Year 2010	\$9,149,335	Not totaled due to the difficulty of obtaining indirect costs—total indirect costs are probably considerable.

Conclusion

This summary of losses is extremely conservative. The actual landslide-related loss totals are likely much greater than has been documented in this report. Some loss totals may be available in the future, but unless a targeted, collective approach to tracking landslide losses is undertaken, these loss numbers for the year 2010 will only give a partial picture of what landslide-related hazards actually cost in Colorado. It is not possible to accurately estimate or project a total loss number, except for the category of casualties. Landslide-related casualty reports for Colorado indicate nine people were killed and three were injured in 2010. For more detailed information on Colorado losses for the year 2010 and landslide loss assessments in general, please see the report appendices.

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Figures

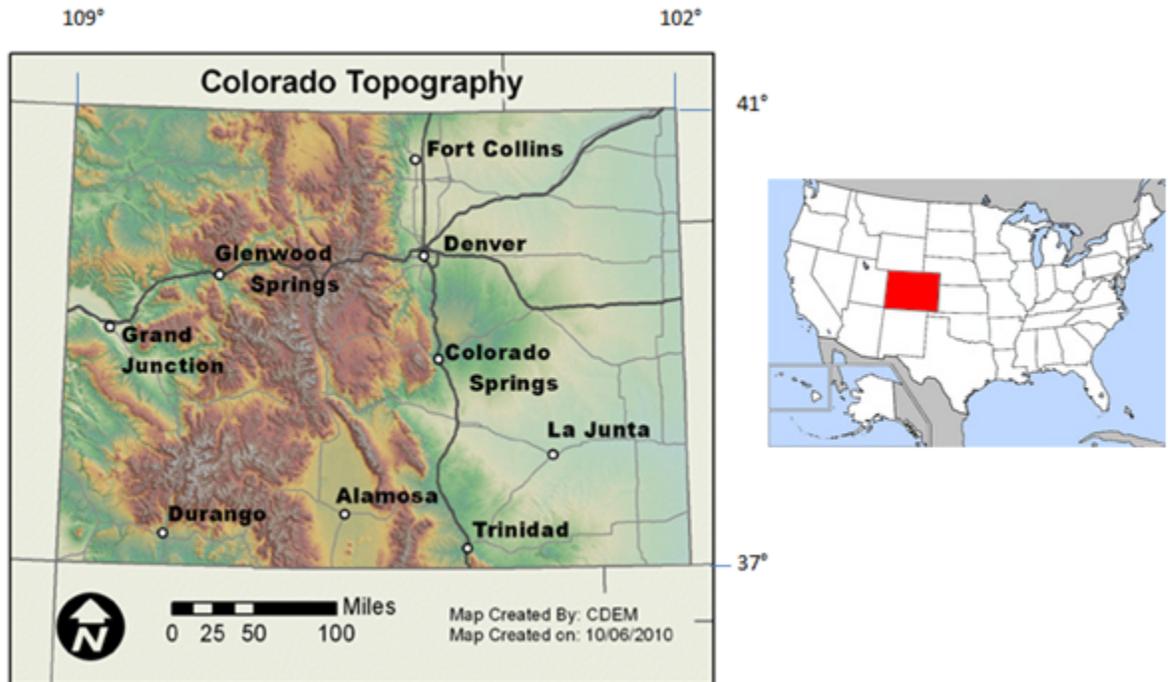


Figure 1. Map of Colorado topography, showing major roads and cities. Elevation is lowest in light-green-colored area and highest in brown- and gray-colored areas. Map is modified from a map found in the Colorado Division of Emergency Management report (2011).

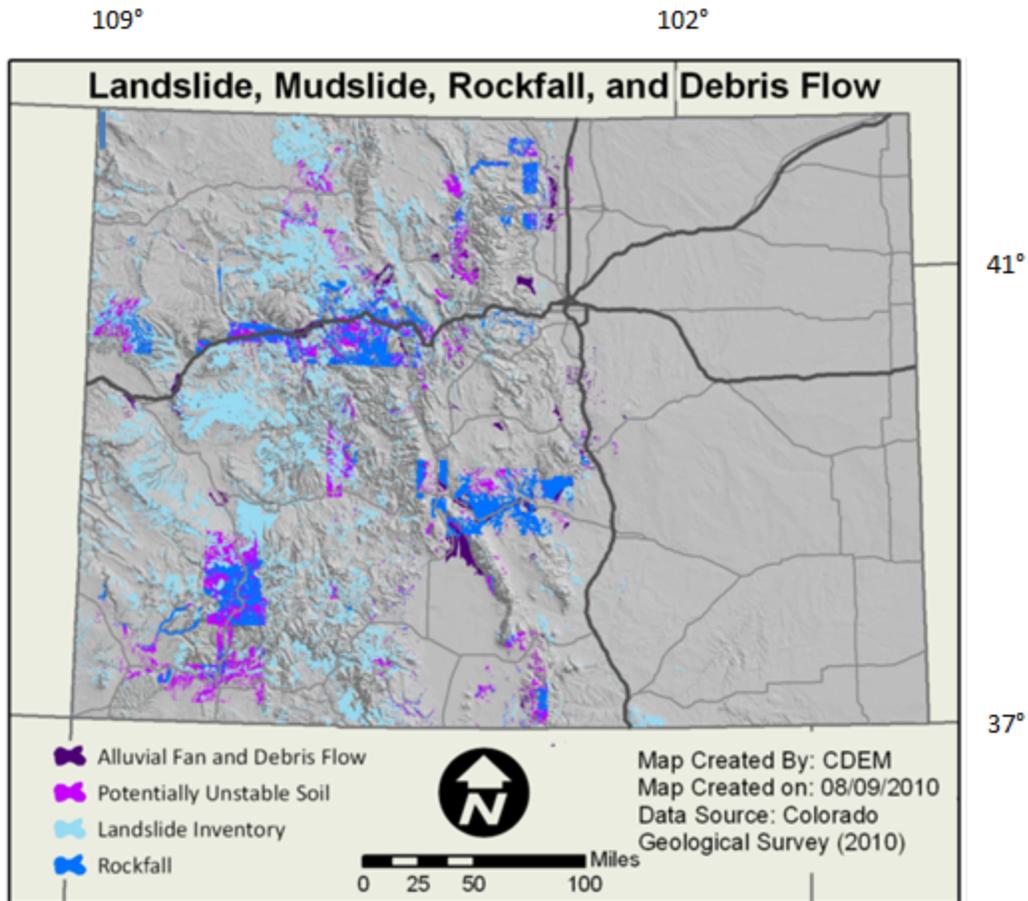


Figure 2. Map of alluvial fan and debris flow, potentially unstable soil, landslide inventory, and rockfall for Colorado. This map is modified from a map created by the Colorado Department of Emergency Management, using data from the Colorado Geological Survey (Colorado Division of Emergency Management, 2011).



Figure 3. Interstate-70 in Glenwood Canyon, Colo. The March 8, 2010, rock slide closed the highway and damaged this elevated portion of Interstate-70. Photograph by Colorado Department of Transportation.



Figure 4. Photo showing an overview of the 2010 Glenwood Canyon, Colo., rockfall showing damage to the road deck on the elevated portion of Interstate-70. Photograph by Colorado Department of Transportation.



Figure 5. Rock-blasting by Colorado Department of Transportation (CDOT) after the March, 2010, Glenwood Canyon rockfall, on Interstate-70. These rocks were removed because they were precariously poised above the rockfall area, could endanger workers repairing the highway, and could possibly be a threat to the highway in the near future. Photograph by CDOT.



Figure 6. A photograph of the rock slide that blocked an Amtrak train on May 15, 2010. The train had to return to Denver, a distance of about 48 kilometers (30 miles). (Photo by "Rovertrain" on <http://www.Trainorders.com>)



Figure 7. Photograph of the source area of the May 21, 2010, rockfall that impacted Highway 34 near Estes Park, Colo. Inset shows a road-level photograph of the area on the highway where rocks fell. Photograph and graphics courtesy of Tyler Ortiz, Colorado Department of Transportation.



Figure 8. Colorado Department of Transportation (CDOT) crews breaking up rocks above the closed Highway 34 after the rockfall event of May 21, 2010, near Estes Park, Colo. The rock was brought down and hauled away to mitigate the rockfall hazard. Photograph courtesy of Tyler Ortiz, CDOT.



Figure 9. Redstone Campground inundated by mud, from the July 31, 2010 event. (Photo by Jeff Bier.)



Figure 10. Deep mud from the debris-flow event of July 31, 2010, near a Redstone, Colo., campground. Photograph by Jeff Bier.



Figure 11. The Redstone Campground debris flows, 10 months after the event. There was one person missing and presumed dead, as a result of the debris flow in July, 2010. Photograph by Lynn Highland, USGS, taken on May 19, 2011.



Figure 12. August 19, 2010. Highway 133 was closed at Redstone, Colo., for several hours, but crews were able to reopen one lane. There were six drainages where mud crossed Highway 133, taking out 100 feet (33.3 meters) of guardrail. The Crystal River (which flows parallel to Highway 133) is shown in the foreground. Photograph by Sue McEvoy.



Figure 13. August 19, 2010. A photo of a debris flow on Katy Creek, on private property, near Redstone, Colo. Photograph is courtesy of Mary Dorais, property owner.



Figure 14. A Colorado Division of Transportation (CDOT) truck monitoring traffic and cleanup near Norwood. Photograph by CDOT, August 20, 2010.



Figure 15. Aerial photograph of two debris flows that flowed over the Durango and Silverton Narrow Gauge Railroad—a scenic railroad company for tourists—that operates out of Durango, Colo. The photo was taken by a zipline participant as he was passing over the area. Photograph courtesy of Tall Timber Resort/Soaring Tree Top Adventures.



Figure 16. A close-up aerial view of the two debris flows that blocked the Durango Silverton Narrow Gauge Railroad track in July, 2010. Cleanup was performed by railroad crews. Photograph courtesy of Tall Timber Resort/Soaring Tree Top Adventures.



Figure 17. This debris flow occurred on July 31, 2010, in the San Isabel National Forest (near Leadville, Colo.). The area experienced 6 hours of heavy rain, which was thought to have triggered two large debris flows in the area. Photograph by Mary Widner.



Figure 18. The area of this photograph was located near Clohsey Lake campground in the San Isabel National Forest. The photo was taken on July 31, 2010. Forty campers were trapped for a number of hours and 15 eventually had to be rescued by Chaffee County Search and Rescue.



Figure 19. Photograph taken at the Clohsey Lake campground area, San Isabel National Forest on July 31, 2010. This man, who is 5' 10" tall, is indicating the height that one of the two large debris flows reached as it moved through the area (red arrow). Photograph by Mary Widner.



Figure 20. One of two debris flows blocking Clohsey Lake Road in the San Isabel National Forest, near Leadville, Colo. Forty campers were initially trapped and 15 had to be rescued. Photograph by Tim Ransom.



Figure 21. Photograph of a debris flow near Clohsey Lake in the San Isabel National Forest, near Leadville, Colo. Photograph courtesy of Jon Morrissey, US Department of Agriculture National Forest Service.



Figure 22. Fourmile Fire burn area, northwest of Boulder, Colo. Photograph by John G. Elliott, US Geological Survey, September 23, 2010.



Figure 23. Slumping roadway above a retaining wall near Dillon Valley Reservoir. Officials are trying to determine what caused the retaining wall to fail after a water main broke nearby. Photograph by Lake Dillon Fire-Rescue.

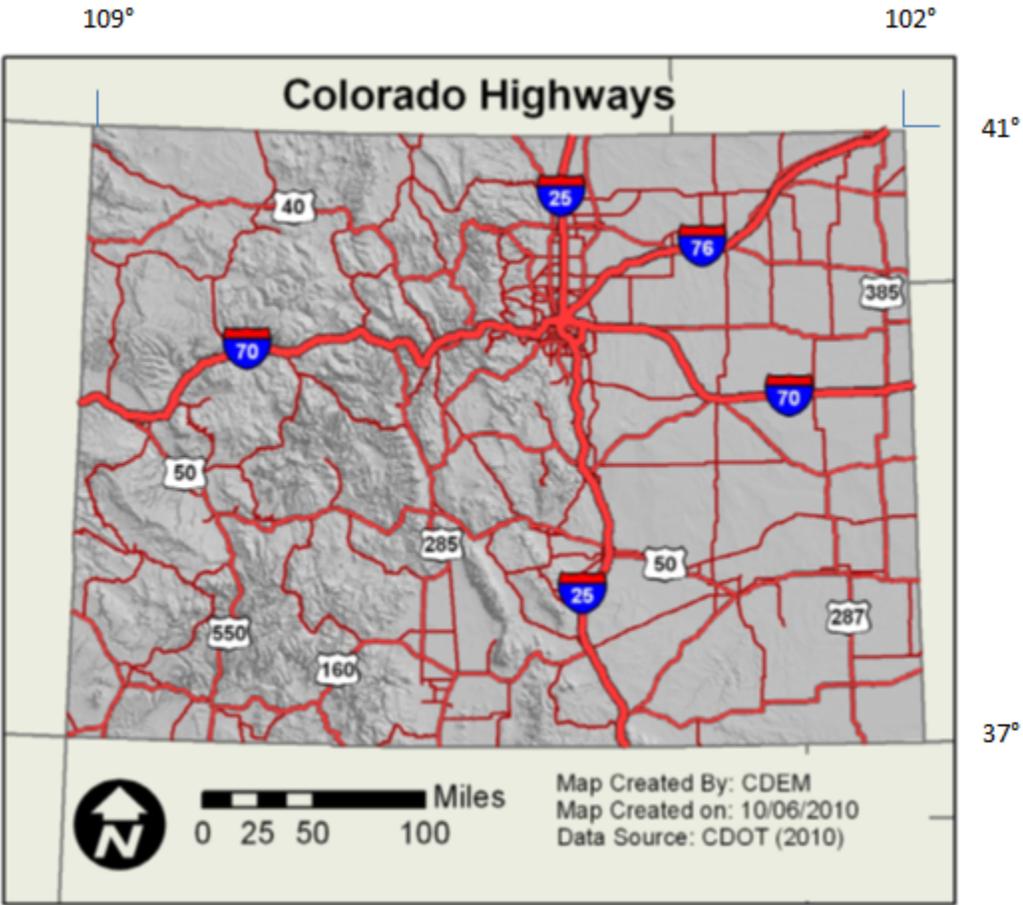


Figure 24. Map of main highways and roads in Colorado. This map is modified from a map created by the Colorado Department of Emergency Management, using data from the Colorado Division of Transportation (Colorado Division of Emergency Management, 2011)

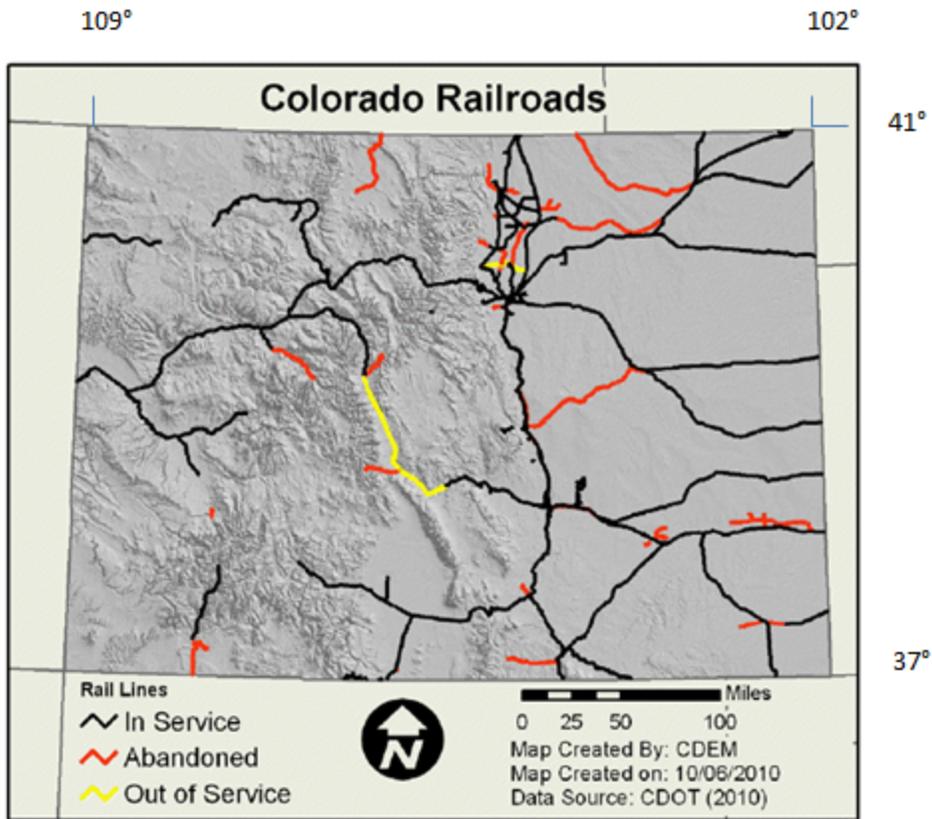


Figure 25. Map of Colorado railroads. This map was modified from a map created by the Colorado Department of Emergency Management, using data from the Colorado Department of Transportation (Colorado Department of Emergency Management, 2011).

109°

102°

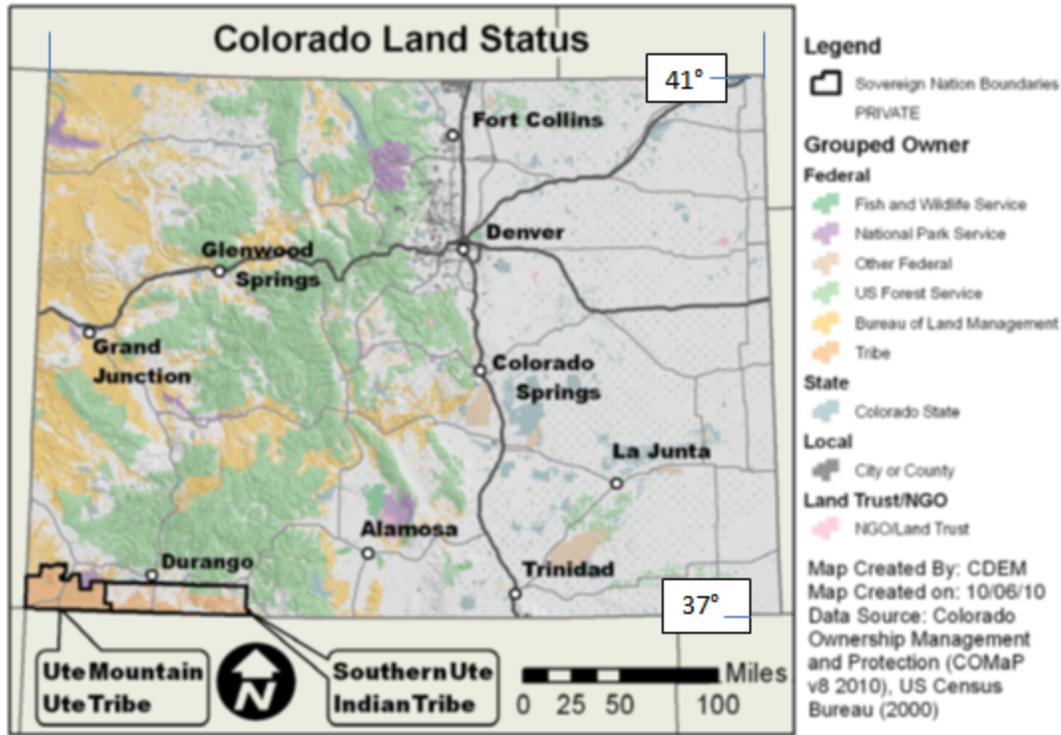


Figure 26. Map showing land ownership and management in the State of Colorado. The map is modified from a map created by Colorado Department of Emergency Management with data from the U.S. Census Bureau and COMaP, a project at Colorado State University. Forty-six percent of Colorado is public lands (Colorado Department of Emergency Management, 2011).

Appendix 1: Landslide Casualties in Colorado for the year 2010

General Overview of Casualties Due to Landslides in Colorado

The State of Colorado Hazard Mitigation Report (Colorado Department of Emergency Management, 2011), and the Hazards & Vulnerability Research Institute (2010), has documented 5 deaths and 10 injuries due to landslides in Colorado dating from the year 1960 to the year 2008. For the year 2010, nine deaths and four injuries caused by various types of landslides were documented. For this report, dollar-loss data have not been documented or assigned to casualties. These deaths and injuries are described in the next section of this Appendix. As mentioned previously, Colorado's population has steadily increased since 1960, and it is probable that more people are vulnerable, due to increased population exposure to landslide hazard. Colorado's population is now over 5 million (U.S. Census Bureau, 2010) as compared to a population of 1.75 million in 1960 (U.S. Census, 1966). Tourists and outdoor enthusiasts have also risen in number; this most likely increases the number of people with exposure to landslide hazards (vulnerability).

In addition, the population of Colorado has increased at a rate of 30 percent between the years 1990 and 2000 and about 10 percent in the years from 2000–2008 (U.S. Census Bureau, 2010). Although there is no present documentation of a commensurate increase in the rate of landside-related casualties with increased population, there may be a relationship that would show a higher rate of casualties from landslides.

A USGS report (Fleming and Taylor, 1980) estimated a landslide-related death rate for the United States at between 25 and 50 people per year, not including injuries from landslide-related events. This estimate has not been updated, as there is no single entity that is charged with keeping an official count of landslide-related deaths and injuries. Information on casualties is gleaned from scientific reports, newspaper reports, blogs, and personal communications, as is the case for assessing 2010 casualty numbers for Colorado.

Also, some economists include the “value of human life” as a means of characterizing loss, but there are many definitions of this value, and this paper does not include a dollar evaluation for the loss of human life.

- March 10, 2010. A woman was killed in March by a falling rock that hit her car on a stretch of Highway 40, east of Hayden, Colorado (Steamboat Today, March 10, 2010).
<http://www.steamboattoday.com/news/2010/mar/10/woman-killed-when-boulder-hits-car-near-mount-harr/>
- July 26, 2010. After leaving El Diente's summit, (a mountain in Dolores County), a group of five climbers worked their way along the ridge towards Mount Wilson. They reached a notch on the ridge and were climbing up a steep gully to the next ridge point when a climber above dislodged some loose rock, which cascaded down, hitting three of the climbers below. The one victim who died was wearing a helmet; however, the rockfall hit him in the head and torso, knocking him unconscious and eventually killing him. It is not known if the victim's group caused the rockfall or if another group ahead of them accidentally dislodged the rocks

and triggered the rock fall. <http://100summits.com/articles/colorado-mountaineering-deaths/2010.html#intro>

- July 30, 2010. Redstone area debris flows: A man is missing and presumed dead as his car was found very near the Redstone Campground area, and he was last reported to be hiking in the area of the debris flows (oral commun., Carrie Click, The Crystal Valley Echo and Marble Times, May, 2011.)
- July 27, 2010. A couple was washed to their deaths during a very violent storm on Crestone Needle, a mountain in Custer County in southern Colorado. They were ascending a near-vertical cliff when they were hit by a torrential downpour of rain. They fell about 152 m (500 ft) and then were carried about 100 m (300 ft) farther by a debris flow that buried their bodies. "It was very violent. It looks like a huge amount of water came down that washed them off the mountain. The mudslide buried them." (Custer County Coroner Art Nordyke). <http://www.thedenverchannel.com/news/24473412/detail.html>
- August 14, 2010. While traversing what is known as one of Colorado's "Four Great Traverses" between North Maroon Peak and Maroon Peak (mountain near Aspen, Colo.), a rock was dislodged from above, which struck the victim, knocking him 200 m (600 ft) down the Bell Cord Couloir. The victim was wearing a climbing helmet at the time of the incident. It was believed that a member of the victim's climbing party knocked the rock loose that knocked him down. The Maroon Bells area, where the victim died, is home some of the most treacherous, loose rock of any mountains in Colorado.
- <http://100summits.com/articles/colorado-mountaineering-deaths/2010.html#intro>
- September 26, 2010. A climber was crushed by a rockfall on El Diente Peak in nearly the same location as the death described on July 26, 2012, and exactly two months later. The victim's dog, Oof, was rescued by a Search and Rescue operation the following day. <http://100summits.com/articles/colorado-mountaineering-deaths/2010.html#intro>
- October 26, 2010. A woman was killed after a rock hit her car on a stretch of Highway 40 east of Hayden, Colo. Another woman was injured as a rock hit her car windshield the previous Sunday, October 24, 2010. This incident occurred very near where a previous car was hit by a falling rock in March (see the first death described). CDOT speculated that it could be a result of the freeze-thaw cycle, and wild mountain goats had been spotted on the slopes in the area; they could have dislodged the rock while traversing the slope (Steamboat Today, October 26, 2010).
- <http://www.steamboattoday.com/news/2010/oct/26/rock-through-womans-windshield-reported-us-highway/>
- June 17, 2010. A boy dislodged a rock on a hiking trail, and it hit a 17-year old girl who was killed when the rock struck her head. The incident occurred near Estes Park, Colo. The incident was ruled an accident, even though the rock was apparently dislodged purposely, although not intended to hit the victim.
- http://www.mlive.com/news/grand-rapids/index.ssf/2011/01/charges_dismissed_in_rock-kick.html

- September 29, 2010. A rock-slide injury occurred where three cars collided with rocks that fell on east-bound Interstate-70 near Palisade. It was unclear whether the cars hit the rocks, or vice versa. Three people were injured and taken to the hospital in Grand Junction (ABC News report, 10/29/2010).

Appendix 2: List of All Sources of Information and Data not found in Reference Section

Note: Some of the internet URL addresses listed in this appendix may change over time and the information then becomes part of a separate archive, or can only be found by means of an internet search engine.

March 8, 2010 Rockfall, Glenwood Canyon, Colorado

Newspaper reports:

Interstate-70 Reopened Through Glenwood Canyon (The Denver Post, March 12, 2010), http://www.denverpost.com/ci_14660036

Interstate-70 rock-slide closure costs truckers valuable time and money (The Denver Post, March 12, 2010)

http://www.denverpost.com/recommended/ci_14644221

(Greg Fulton, president of the Colorado Motor Carriers Association, oral commun., 2011).

He estimated the closure cost trucking companies millions of dollars in fuel, work hours, and other costs.

Press release issued March 8, 2010: Interstate-70 rockfall Disaster Declaration, then-Governor of Colorado, Bill Ritter (Colorado Government web portal, Disaster Declaration for March 8, 2010):

<http://www.colorado.gov/cs/Satellite?c=Page&childpagename=GovRitter%2FGOVRLayout&cid=1251572415216&pagename=GOVRWrapper>

2010 Annual Report, Colorado Department of Transportation (CDOT) News and website:

http://www.coloradodot.info/library/AnnualReports/AnnualReport_2010_downloadable.pdf/view

Rock slide in De Beque Canyon, Colorado, March 2, 2010

Rock slide and Accidents Cleared in De Beque Canyon, 11 News website, 03/02/2010

<http://www.nbc11news.com/home/headlines/85942917.html>

Big Thompson Canyon Rock Slide, May 21, 2010

Rock slide Closes Highway 34 in Larimer County (Colorado State Patrol online Blogspot, 05/21/2010)

<http://coloradostatepatrol.blogspot.com/2010/05/rock-slide-closes-highway-34-in-larimer.html>

June 17, 2010 Rockfall incident, (one casualty), Estes Park, Colorado

Falling rock in Estes Park kills Michigan teen - The Denver Post 06/18/2010 http://www.denverpost.com/breakingnews/ci_15325900?source=rss#ixzzIoBpNmsET

Charges dismissed in rock-kicking incident that killed Kent County girl in Colorado, Grand Rapids News, (01/20/2011)

http://www.mlive.com/news/grand-rapids/index.ssf/2011/01/charges_dismissed_in_rock-kick.html

Durango and Silverton Narrow Gauge Railroad Debris Flows, July 26, 2010

Line Back Open after 3 Trains and About 1,000 Passengers Were Thwarted Monday, Albuquerque Journal, 07/29/2010

<http://www.abqjournal.com/main/2010/07/29/abqnewsseeker/705am-mud-rock-slides-block-durangosilverton-railroad.html>

Carbondale/Redstone/Marble area debris flows, July 31, 2010

The Crystal Valley is . . . Mudslide Central, The Crystal Valley Echo and Marble Times, (September 2010, vol. 7 n. 9 issue).

Large mudslides Hit Redstone, Marble Area, Denver Post, 07/31/2010

http://www.denverpost.com/breakingnews/ci_15649962

Clohsey Lake debris flows, July 31, 2010, Chaffee County, San Isabel National Forest

<http://www.thedenverchannel.com/news/24496924/detail.html>

Jackson Mountain landslide, Highway 160 near Pagosa Springs, CO

Landslide Mitigation and Highway Improvements Begin on U.S. 160 East of Pagosa Springs, High Beam Research news, 09/13/2010

<http://www.highbeam.com/doc/1G1-237078577.html>

Emergency Plan in Place for Jackson Mountain Project, Pagosa Sun, 05/11/2011

<http://www.pagosun.com/archives/2011/05May/051211/pg1jacksonmtn.html>

Landslide mitigation and highway improvements suspended for winter on US 160 east of Pagosa Springs

<http://www.coloradodot.info/news/2012-news-releases/02-2012/landslide-mitigation-and-highway-improvements-suspended-for-winter-on-us-160-east-of-pagosa-springs>

El Paso County - Highway 24 August 9, 2010, Rock Slide Hits Camper Trailer On Hwy. 24, KRDO news station, Pueblo, CO, 08/9/2010

<http://www.krdo.com/news/24569017/detail.html>

Redstone/Carbondale area, August 19, 2010

Mudslides Close Hwy. 133 Near Redstone, Westbound Lanes of Hwy. 82 Near Carbondale (The Aspen times, 08/20/2010).

<http://www.aspentimes.com/article/20100820/NEWS/100829997>

CDOT reported costs of \$34,000 for the August 19 event and there was estimated to be 6000-6500 tons to be removed. (D'Wayne Gaymon, CDOT Region 3 written communications May 12, 2010).

Non-copyrighted photos can be viewed on the USGS Landslide Program website:

http://landslides.usgs.gov/learning/photos/colorado_u.s._/redstone_carbondale_marble_colorado_debris_flows_mudslides--july_31_and_august_19_2010

September 23, 2010 Potential Debris flows due to Fourmile Canyon, Colorado wildfire:

Gov. Hickenlooper Issues Disaster Declaration for Fourmile Fire Burn Area in Boulder County

Colorado Disaster Declaration and Press release issued April 4, 2011, by Colorado Governor Hickenlooper, which includes information on hazard losses from potential debris flows:

<http://www.colorado.gov/cs/Satellite?c=Page&childpagename=GovHickenlooper%2FCBONLayout&cid=1251590836028&pagename=CBONWrapper>

Rock slide injury - On September 29, 2010, near Palisade

Three cars hit each other, possibly trying to avoid the rocks that had fallen on the road – three people were hospitalized (9 News report, September 29, 2010).

<http://www.9news.com/news/story.aspx?storyid=155518&catid=222>

The same story was reported by ABC News. (ABC News, September 29, 2010)

<http://www.thedenverchannel.com/news/25209538/detail.html>

October 29, 2010 – Dillon, Colorado area rock slide

Property Owners Investigating Cause of Dillon Rock Slide, Summit Daily News, 01/27/2010.

<http://www.summitdaily.com/article/20100527/NEWS/100529848>

Fourmile Canyon Fires, September 2010

Boulder County Fourmile Emergency Stabilization Team Report

<http://www.bouldercounty.org/live/environment/land/pages/4milefesteam.aspx>

As a follow up, the area experienced two large debris flows in 2011. On July 7, as a result of a heavy rainstorm, four reported debris flows occurred at mile marker 8 in Fourmile Canyon.

<http://www.youtube.com/watch?v=vagne-NMWOw>

On July 13, 2011, Six roads were closed due to debris flows including Four Mile Road and Gold Run at Dixon—areas which were highlighted in the 2010 Debris-flow Potential report (Ruddy and others, 2010).

<http://denver.cbslocal.com/2011/07/13/debris-flows-closed-roads-fourmile-canyon/#.T481f3rUn-Q.email>

CDOT Website had many of their costs itemized, <http://www.coloradodot.info/>

CDOT Rockfall mitigation program funding and FASTER program funding:

<http://www.realaspen.com/community-content/161/Rockfall-mitigation-project-coming-to-Highway-82>

Federal Highway Administration, <http://www.fhwa.dot.gov/>

December 22, 2010 Amtrak Train Blocked by Rock slide

<http://denver.cbslocal.com/2010/12/22/rock-slides-detour-train-traffic-through-mountains/>

List of sources consulted by phone, email, or personal visit:

Town of Redstone, Colo.

City of Carbondale, Colo.

Planning, Engineering, Emergency Management Departments
Pitkin County, Colo.

Planning, Engineering, Emergency Managements Departments
Garfield County, Colo.

Mesa County, Colo.

Jefferson County, Colo.

City of Glenwood Springs, Colo.

Town of Estes Park, Colo.

CDOT All Regions—7 offices

CDOT Geotechnical Engineering Department, Denver, Colo.

Excel Energy, Denver, Colo.

Flat Top Fuel, Meeker, Colo.

Karolyn Wakefield, Assistant Manager—called April 25, 2011

Domenico Trucking Company, Denver, Colo.

Amtrak (The National Railroad Passenger Corporation)

Durango and Silverton Narrow Gauge Railroad, Durango, Colo.
Manager Environmental Field Operations
Union Pacific Railroad

Indian Tribes:

Ute Mountain Ute Tribe
Southern Ute Indian Tribe

National Forests:

Routt
Roosevelt
Arapaho
White River
Grand Mesa
Pike
Gunnison
Uncompaghre
San Juan
Rio Grande
San Isabel

National Parks and Monuments

Rocky Mountain National Park
Colorado National Monument
All Colorado State Parks

Chaffee County Search and Rescue
Colorado Geological Survey
Colorado Division of Emergency Management, Centennial, Colo.
Yeh and Associates
Colorado School of Mines, Golden, Colo.

Appendix 3: Notes on Landslide Loss Investigations and Lessons Learned

The investigation of losses incurred by all types of landslides in Colorado for the year 2010 was only partially successful due to the fact that many organizations and individuals queried did not know or chose not to disclose this information. CDOT, which is funded publically and is required to disclose the costs of all types of landslides which impact the transportation routes that are within its jurisdiction, was able to provide more information on losses than all other sources combined. CDOT maintains information posted online, employs public relations personnel who can assist with inquiries, and organizes their information in user-friendly databases and reports. The Forest Service provided loss data where information was available. However, much of the potential data from forest lands are not easily retrievable, are kept by another entity, or are blended with other costs and not itemized. As mentioned previously, the vast tracts of public land that exist in Colorado under different jurisdictions generally preclude an accurate accounting of all the landslide occurrences on these lands, except where they effect outdoor activities, access roads, or threaten the built environment. The 2010 Clohsey Lake debris flows described in this report are a good example of the type of landslide event that the Forest Service becomes directly involved in, as they are primary jurisdictional organization.

Much of the city and county data was either not itemized or was not retrievable. Many cities and counties have emergency-management policies that are currently available to view, either online or at the county offices, including contingencies for landslide hazards; however, costs or dollar losses for particular years or any aggregate lengths of time, are usually not available.

Trucking companies and businesses located along landslide-caused detour routes stated that their businesses were affected, either positively or negatively, but did not provide dollar losses or gains. This type of loss is very important in assessing the effects of landslides, although they are classified as indirect losses. Nevertheless, such losses or gains would be difficult for most businesses to estimate.

The State of Colorado has clearly identified and planned for landslide hazards, usually in the context with other geohazards such as swelling soils, mine subsidence, and general erosion. In addition, these geohazards are generally linked with meteorological hazards such as hail, lightning, flood, and tornadoes—not because they are similar in nature, but because they have all been shown to be natural hazards that have effected Colorado in the past. Unfortunately, landslides, debris flows, and other types of landslides associated with flooding are not usually evaluated separately from the damages caused by the floodwaters themselves. Funding for the reduction of landslide hazards is authorized in cities and counties primarily for the maintenance of transportation corridors, evaluation of new-construction site plans for hazards, and personal safety. Landslide-mitigation policy varies from county to county in Colorado, is not standardized, and is mostly in conjunction with development planning and roadway planning and maintenance.

Finally, one of the main reasons that landslide-cost data are difficult to find is that losses due to landslides are not covered by homeowner or commercial insurance. Insurance companies are usually a good source of loss data for most hazard types, except for landslides. The main reason that insurance companies do not cover landslides is that there are no reliable data on landslide history, locations, and costs, although some areas of the United States have published landslide-susceptibility maps. However, landslide-susceptibility maps do not usually include probability or risk-assessment elements. The lack of insurance for landslides is a situation that becomes a circular pursuit of information that deals with too many unknowns, and the unknowns are not easily identifiable by any cost-effective approach that states and municipalities can justify in their budgets. There is little information upon which to base premiums and the situation is currently at a stalemate. There are communities that have implemented Geologic Hazard Abatement Districts (GHADs), which is an attempt at landslide self-insurance for a small area, for example, a housing development or special district. However, GHADs still require landslide-hazard information for the area in question, in order for them to function. As of 2011, there were 40 GHADs in the State of California (Patricia E. Curtin, Morgan Miller Blair, Law Corporation and American Association of GHADs (written commun., 2011, <http://www.ghad.org/>)

The following is a list of general information that will assist those performing future loss studies:

1. Data on highway and public utility repairs are generally (but not always) available:
 - Past data are generally labor intensive to retrieve;
 - Loss data are sometimes absorbed into general maintenance costs, where it becomes cost-of-maintenance data rather than loss data.
2. Data are not generally available for nondisaster event recovery periods:

- Disaster payout for direct cost replacement and repair may be available from Federal and State emergency-management agencies as well as local governments;
 - Loss records kept by emergency management agencies are generally limited to eligibility for disaster assistance;
 - Concerted efforts to conduct studies by devoting personnel, time, and funding can generally be fruitful; however, they take long periods of time to compile because loss data usually become available only after periods of several months and, in some cases, many years. A USGS report on landslide losses from the Nisqually, Washington, Earthquake of 2001 (Highland, 2003) is one exception, as resources were allocated to compile an extensive report within a short period of time. In that case, there was a Federally declared disaster and costs were to be reimbursed on a case-by-case basis, tracked by both Federal and local officials.
3. Recordkeeping of loss data is done most extensively by local governments in urban areas where ordinances require permits for reconstruction:
- Those records that are kept are typically only of direct costs;
 - The records are associated with issuance of rebuilding, repair, or grading permits associated with landslide damage.
4. Where recordkeeping exists, it is not standardized:
- Categories of direct costs (for example, slope stabilization, structural repair, and so forth) are not generally separated from each other during recording;
 - Secondary direct costs, such as geotechnical investigations for remediation, mortgage-company losses on destroyed structures, and so forth, may be kept by different entities than those who keep the direct costs.
 - Indirect-cost data (such as interruption of business and other economic consequences of landslide damage) may only be available by post-event economic surveys and analysis by the business community.
5. Summary conclusions about landslide loss data:
- It is very labor intensive to retrospectively collect loss data from any of the identified sources. The use of information technology in future recordkeeping may provide a practical means of retrieving landslide loss data if the information is coded as it is recorded. A considerable amount of time, money, and personnel would have to be devoted to loss-data collection, at least until methods are streamlined and become routine.
 - Media sources of cost data are sometimes incomplete and not systematic or always reliable. However, many media outlets publish special reports from time to time that review data and knowledge about an incident, which is a boon to researchers trying to put together disparate sources of information
 - Due to copyright issues and privacy concerns, private consulting firms are not a practical source of extensive landslide cost data. However, these sources should not be ruled out, as permission to use private and copyrighted data is sometimes granted, or in some cases can be purchased for a fee. Also, public entities (such as CDOT) who contract with private-sector geotechnical companies for landslide work, for example, are required to disclose the bidding history of each project and how much the private companies were paid. Such disclosure is a good source of information on landslide costs.
 - A standardized approach to landslide-loss inventory would reduce the cost and improve the usability and availability of landslide-loss information. However, previous attempts at implementing a standard landslide-inventory collection or cost-data

acquisition method for all states, for example, have only been partially successful, given that each of the 50 States has the freedom to implement their own ways of dealing with natural hazards.