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CRITICAL LANDSLIDES IN COLORADO
A YEAR 2002 REVIEW AND PRIORITY LIST

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Foreword

Colorado, with its abundant foothills and mountainous terrain, contains many thousands of active and inactive landslides. Most of these features are in remote or undeveloped areas and have caused little damage. However, as development and transportation routes continue to encroach into hilly and mountainous terrain, the risk of damage, and actual damage, from landslides increases significantly. Although the cumulative costs and damages have not been calculated, landslides, debris flows, and rockfall occur with some regularity across the state and are a serious threat to life and property.

One of the main objectives of the Colorado Geological Survey (CGS) is to determine areas of natural geologic hazards that could affect the safety of, or economic loss to, the citizens of Colorado. In this publication, former CGS Chief Engineering Geologist William Pat Rogers identifies and describes the state's most critical landslide areas, drawing upon his thirty-plus years of experience working with state- and local-government agencies on landslide issues.

The purpose of this publication is to list and rank Colorado's most severe landslide hazards in terms of past and potential future landslide activity and impacts. This Priority List, which contains 47 areas of concern, is intended as a tool to direct statewide mitigation efforts. In particular, it highlights the historical role of the CGS, USGS, and other partners in their response and mitigation efforts to date, and offers recommendations for future efforts.

The CD-ROM contains a report file with a bibliography of published studies for these critical areas, and a 1:500,000 map file showing the location of each of the 47 Priority List areas. These materials have been delivered to the Colorado Office of Emergency Management for inclusion in their updated State Hazard Mitigation Plan.

This report deals with known landslides. However, because hilly areas do not currently have landslides does not mean that they are not susceptible to landslides. There are many documented instances where human activities have activated new landslides. A detailed, statewide susceptibility study remains to be conducted.

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INTRODUCTION

The Colorado Landslide Hazard Mitigation Plan was published in 1988 as Colorado Geological Survey Bulletin 48 (Jochim and others, 1988). It was written by authors from the CGS, the Colorado Division of Disaster Emergency Services (now Office of Emergency Management), and the University of Colorado Center for Community Development and Design. The plan was adopted by the state of Colorado and was cited for implementation, along with Flood Hazard and Wildfire Hazard plans, in the Governor's 1989 Executive Order that created the Colorado Natural Hazards Mitigation Council (CNHMC). Until 1998, the CNHMC had a standing committee on Geologic Hazards and a subcommittee on Landslides.

One of the tasks done by CGS for Bulletin 48 was preparation of a list of Colorado's communities, areas and facilities most at risk from landslides. That list consisted of 49 locations believed at that time to pose the most serious landslide threats (Jochim and others, pages 37-44). The list was prepared using "landslide" in its broadest sense, which included debris flow and rockfall areas. Hazard areas for which debris flows were the predominant hazard were listed separately in recognition of the fact that they nearly always occur in association with stream courses and their depositional fan areas. Both of these conventions are retained in the new Priority List herein.

The rationale for including this Priority List as an essential element of the Colorado Landslide Hazard Mitigation Plan was to provide an action list of manageable size which scarce staff and funding resources from a variety of sources would yield the greatest benefits. This concept has proven effective over the past fourteen years with significant progress in evaluation and/or mitigation being made in more than one-half of the areas. Funding and other substantial contributions have been provided by more than twenty state, federal, local, academic and private organizations.

The Year 2002 Review and Priority List was done as part of an update of the 1988 Colorado Landslide Mitigation Plan in cooperation with the Office of Emergency Management. Our charge is to review and revise, as needed, the action list. In this report, we will summarize new information or investigations, monitoring results and mitigation activity. We will also make an evaluation and recommendations on each case as deemed advisable.

Changes in the Year 2002 Priority List include additions, deletions and reorganization. This results in some very similar adjacent areas of the older list being grouped together and some local hazard areas being incorporated into larger hazard corridors. The previous list was not arranged by hazard severity, but alphabetically by the county in which the hazard was located. This led to confusion for some users and to breaking of logical hazard corridors at county lines into two areas. The revised list presented herein groups the hazards by relative severity into three tiers as described below. Within each tier, the hazards are arranged alphabetically by county. Also for each tier, hazard areas predominated by debris flows are listed separately from all other landslides. Each hazard area or corridor is given a number to readily relate the text to the index map (Plate 1).

Description of tiers

1. **Tier One** listings are serious cases needing immediate or ongoing action or attention because of the severity of potential impacts.

2. **Tier Two** listings are very significant but less severe; or where adequate information and/or some mitigation is in place; or where current development pressures are less extreme.

3. **Tier Three** listings are similar to tier two but with less severe consequences or primarily local impact.

Several listings from the 1988 Priority List have been deleted, while others have been incorporated into a larger hazard area or corridor. In either case, an explanation of the action is provided in the text after the year 2002 listings. Deleted areas do not appear on the index map (Plate 1). Those that were regrouped are shown only as part of the newly expanded hazard area in which they occur.

Use and limitations of this report

The areas or corridors described in this report comprise a “working list,” intended to assist in guiding and assisting mitigation efforts in areas considered by the author to be the most critical based on current information and development pressures. There are many other areas in the state where landslides and debris flows occur, some of which may become critical at a future time on account of new landslide, debris flow, rockfall, or development activity.

This report should not be interpreted to include all existing areas of critical landslides or exclude areas unknown to the author or where circumstances have changed. In all cases of hillside development, the CGS recommends that site-specific geotechnical studies should be conducted to identify, assess, and mitigate or avoid landslide and other related geologic hazards that could impact the development project.

DESCRIPTION OF PRIORITY LANDSLIDES

TIER ONE LANDSLIDE/ROCKFALL AREAS

(1) San Juan River (Jackson Mountain) Landslide, one-half-mile below confluence of East Fork and West Fork of San Juan River, Archuleta County

This active landslide is caused by erosion of the west bank of the San Juan River as it impinges on the weak shaley bank materials to the northwest. The slide is horseshoe shaped and is about 2,000 ft. in width at the highway and extends about one-half mile upslope. The slide is known to have been active since about 1970. Several times since then it has severed the highway, requiring closures. It has also disrupted water and gas supply lines for the town of Pagosa Springs. Each time the slide has advanced, the highway and utility lines have eventually been restored, only to repeat the cycle the next time that river erosion and high soil moisture prevail.

Year 2002 evaluation and recommendations

The utility lines for the town of Pagosa Springs have been re-designed to above-ground lines to minimize damage and repair costs. Structural mitigation by armoring and buttressing the river bank/roadway fill would probably not be effective for very long considering the size and instability of the upslope slide mass. Because of its reactivation, with disruption of US Hwy 160 at approximately ten-year intervals, this is a continuing serious hazard that must eventually be mitigated. Avoiding the slide area would involve two river crossings for the highway and re-routing and two river crossings for the utilities. Our recommendation is that this alternative be given serious consideration in medium to long range planning for US Hwy 160 corridor and the utility lines.

(2) North Fork of Gunnison River, landslide areas, from Hotchkiss to the Paonia Reservoir, Delta and Gunnison counties

This landslide area is a new listing that includes No. 6 of the 1988 Priority List but is now being extended to include the entire North Fork of the Gunnison River corridor as indicated above. This corridor has a history of serious and frequent landslide problems along its entire length. The area includes the towns of Hotchkiss, Paonia and Somerset, and several coal mines and their facilities. CO Hwy 133 and the D & RGW Railroad (now Union Pacific) serve the area and are at risk. Irrigation water for orchards and other crops is conveyed along the valley. The irrigation ditches are frequent victims of the landslides but also contribute to instability of slopes by leakage.

Year 2002 evaluation and recommendations

Numerous landslide incidents occur every year in the North Fork valley and serious damage to all types of facilities of the valley is common. Facilities at risk include CO Hwy 133, the D & RGW Railroad (now Union Pacific), irrigation water conveyances, several coal mines and their appurtenant structures. The most common factor in causing these landslides is the very steep foot slopes that are often composed of old landslide deposits and colluvial debris, which forms a wedge on the lower valley sides. An additional factor is the percolation of water into the slopes from irrigation conveyance ditches and natural spring seeps on the sides of gravel-capped mesas. Consequently, these slopes are so potentially unstable that any natural or human-induced changes in soil moisture or slope configuration by construction can trigger serious landsliding. The aggregate annual cost of direct landslide losses and excess maintenance in this hazard corridor is estimated to be at least $1 million.

The geologic hazards of this entire corridor, from Hotchkiss to the Paonia Reservoir, have been mapped and published by the CGS as open File Report 78-12 (Junge, 1978a). These maps can serve well for initial project planning including mitigation and/or hazard avoidance. However, final plans and designs will require detailed site-specific engineering geologic and geotechnical studies and designs. The hazard maps were published in 1978 but are now unknown to or underutilized by many potential users. It is recommended that CGS and OEM make a concerted effort to inform and educate the many partners with facilities and structures at risk in the area. It is of interest that, although many landslides have encroached on the North Fork River channel in the past 30 years, none have caused serious blockage of the stream. The landslides do not appear to have the "runout potential" to form a large debris dam with potential for related downstream collateral damage. There is, however, serious potential of displacing the channel and causing severe and perhaps damaging erosion of the opposite bank.

(3) Clear Creek Forks (Junction) Rockslide, Clear Creek County

This high-priority landslide area has a history of intermittent, slow movement dating back to the mid-1940s. Actual monitoring of surface movements was initiated by CDOT (then Colorado State Highway Department) in 1951. The U.S. Geological Survey continued and expanded monitoring with readings made sporadically until 1975. No additional measurements were made until the Colorado Geological Survey, as part of their Landslides Program, in 1987 established five new control points and made periodic EDM readings until 1996. At that time, the U.S. Geological Survey became interested in resuming study of this landslide. They did an admirable job of assembling and reconciling data of the older stations and surveys from all of the sources mentioned above. They also resumed monitoring using both EDM and GPS (Global Positioning System) techniques. The U.S. Geological Survey Open File Report 98-150 (Savage and others, 1998) provides an excellent summary of the merged and reconciled data. This landslide was named the "Junction Slide" in CGS Bulletin 48 and is termed the

"Clear Creek Forks Landslide" by the U.S. Geological Survey. Because of USGS' long involvement and their valuable summary publication on this slide, we suggest that the latter term be used.

Year 2002 evaluation and recommendations

With a well-documented history of recurrent recent movement, this area is considered a major and potentially very dangerous rockslide situation. The combination of extremely steep slope angles that parallel the foliation planes, low-friction (micaceous) rock material, and a history of periodic damage to highway bridge and roadway structures support this conclusion. A large and very rapid failure appears possible. This highway junction of U.S. Hwy 6 and Co. Hwy 119 has very high traffic flows related to the small-stakes gambling destinations at Black Hawk and Central City. The highway intersection has recently been relocated by the CDOT, bypassing tunnel No. 4 and the damage-prone bridge on Clear Creek. Part of the roadway at the active toe of the slide has been replaced with a mechanically stabilized earth (MSE) buttressing fill to limit damage to the roadway. These are useful measures from a maintenance perspective but do not mitigate the threat of a future large or rapid rock slope failure.

We recommend that the USGS be encouraged to maintain readings of the monitoring arrays at least twice annually. CDOT and CGS should consider adding downhole monitoring to establish the depth to the failure plane(s). In the longer term, both surface and inclinometer (or equivalent) monitoring should be continued and augmented with observational field data. State and local governments should seriously consider developing an emergency response and/or mitigation plan for dealing with a possible major event at this location.

(4) I-70 east of US Hwy 6 junction, near bottom of Floyd Hill grade, rock and debris slide, Clear Creek County

This large rock and debris slide area has been active at least since the I-70 construction about 35 years ago. It has required periodic ongoing roadway cleanup and repair. The rockslides occur in foliated metamorphic schist and movement is to the northeast, the dip direction of the foliation planes. The rockslide area intercepts at least 1,000 ft of I-70 and it extends about 2,000 ft. upslope. CDOT staff have observed intermittent movement at the roadway level throughout the past 10 years (R. Andrew, oral comm.).

Year 2002 evaluation and recommendations

CDOT maintenance has been able to deal with the slowly advancing rock rubble at the highway level and repair the roadway as needed since I-70 was constructed. However, because moving rockslides are subject to sudden and unpredictable increases in rate of movement, this rockslide could easily sever the entire I-70 roadway and seriously block Clear Creek. If this were to happen, it would cause a long term closure of this critical transportation corridor.

It is recommended that the currently in-place, surface-movement monitoring and inclinometers be maintained at secure locations to monitor both surface movement and movement at depth. Data from such monitoring could provide emergency response alerts and the geotechnical data needed to evaluate long-term mitigation. Any reconstruction in the area must avoid destabilizing the large upslope slide mass.

(5) Georgetown Incline Rockfall Area on I-70, Clear Creek County

This extreme hazard area affects the westbound lanes of I-70 on the steep grade (incline) between Georgetown and Silver Plume. There are many rockfall events and occasional debris flows onto the roadway each year at several different locations on this segment of I-70 that have caused damage, injuries and a few fatalities over the past several years. The sources include crumbling rock from the steep rock cuts made during the original construction, but also rockfall and debris flows from farther upslope beyond construction disturbance. The steepness of the natural slope and the narrow roadway makes most conventional mitigation difficult or ineffective. The source areas have been identified and characterized in the CDOT statewide rockfall inventory (Andrew, 1994). They include some of the highest hazard ratings in the entire Colorado Highway System. Jersey barriers, scaling and other routine mitigation have mitigated many smaller events, but the larger and more dangerous events continue to reach the roadway. As this report is in final review, the CDOT has begun some more comprehensive mitigation work in this important area.

Year 2002 evaluation and recommendations

This is probably the most serious rockfall hazard area in the state. It will be difficult and extremely costly to mitigate effectively. In the short term, all effort should be made to implement interim mitigation to protect the traveling public. A parallel and longer-term effort should be made to design, budget and build more effective structural mitigation works. This longer-term effort will be especially important in the planning for an expanded I-70 system.

(6) Booth Creek Rockfall Hazard Area, Town of Vail, Eagle County

This serious rockfall hazard area elicited urgent attention in May of 1983 when a severe rockfall event occurred in the residential area (Stover, 1983). Since that time, concerted efforts to mitigate the hazard have been made by the CGS cooperatively with the Town of Vail, homeowners groups and engineering design firms. Mitigation efforts have been complicated by the affected homes being in two different Homeowners Associations: one representing the single family units (Vail Village Filing 12) and another representing the multifamily units (Booth Creek Falls Condominiums). In addition, the unstable cliffs that constitute the rockfall source area are located on U.S. Forest Service lands that are in a designated wilderness area.

Due to the CGS 1983 report and follow-up mitigation design studies commissioned by the town of Vail, a ditch and berm mitigation barrier was constructed. The actual structural mitigation was funded through a Geologic Hazard Abatement District formed by the homeowners of Vail Village Filing 12. Since its completion in 1990, this barrier has provided excellent protection to the eastern 2/3 of this high hazard rockfall zone. At that time, the condominium owners in the western part of the area did not elect to participate in the tax district and barrier construction. However, the need for rockfall protection in the multifamily units was again brought into sharp focus in March 1997 when another major rockfall event occurred near the western end of the barrier. About 1/3 of the swath of high velocity rocks were effectively retained by the barrier, but the western part that was outside the barrier wreaked havoc upon the upper row of the condominiums. Engineering geologist Jon White of the CGS investigated the 1997 event and prepared a report for the Town of Vail and homeowners (White, 1997).

Following this incident and the new CGS report, the Town of Vail commissioned design studies for a rockfall barrier to protect the Booth Creek Falls Condominiums. After the damaging and potentially lethal rockfall event of March 1997, the Homeowners Association for the condominiums became active in seeking a shared-cost solution to construction of a barrier. The town of Vail paid for design studies that are now complete. Actual contracting for the construction of the protective barrier awaits completion of administrative details by Vail and funding arrangements by the homeowners.

Year 2002 evaluation and recommendations

This serious and potentially lethal rockfall area has been receiving study and mitigation efforts for the past 16 years. A ditch and berm protective barrier has been in place for the eastern 2/3 of the area for about nine years and it appears to be quite effective. More recently, because of the very serious incident of March 1997 in the unprotected western 1/3 of the hazard area, renewed efforts have been made by CGS, the Town of Vail and the Homeowners Association to provide protection to the condominium area. Geotechnical evaluation and engineering design studies have been carried out and actual construction awaits funding arrangements by the Homeowners Association and the Town of Vail.

We recommend that the highest priority be given to construction of the protective barrier that has been designed for this area. Until this is completed, the area will continue to expose residents to extreme danger to life and property, especially during the months of March through June of each year. [Editor’s Note: In 2003, two Mechanically Stabilized Earth (MSE) inertial impact barriers were constructed just uphill from the condominiums.]

(7) Dowds Junction, landslides, junction I-70 and US Hwy 24, Eagle County

This critical landslide area has received a great deal of attention, especially during the past 15 years (Minturn Earthflows Task Force, 1986; Soule, 1986a). It was a case study in the 1988 Landslide Plan and the summary description and location map of that report should be consulted regarding investigations and mitigation through 1987 (Jochim and others, 1988); and progress since 1987 is outlined below.

Meadow Mountain Landslide

1) The CGS has continued EDM surface movement monitoring through 1998.

2) The US Forest Service has continued to make surface drainage improvements in the lower part of the major landslide area.

3) A Master of Science thesis study was completed in 1993 of the entire Meadow Mountain landslide area by Darin Duran of the Mackey School of Mines, University of Nevada (Duran, 1993). His project received support from the CGS and CDOT.

Dowds No. 1 Landslide

1) The CGS has continued the EDM surface monitoring.

2) In 1990, CDOT installed 13 small-diameter (approximately 1.5 in.) horizontal drains in the toe of this landslide, just above the upslope ditch line of the eastbound lanes of I-70 at the approach to the bridge. This was a seep area throughout the year in most years. The drains obtained very high flows, estimated at about 10 gpm each, for a few weeks each year during and just after the peak spring snowmelt runoff. During much of the remainder of the year the yield was small to no flow.

3) As part of a required hazard analysis for an Eagle County land use decision in the vicinity of the River Run Apartments, a developer commissioned a hydrologic study and analysis of a possible landslide blockage and consequent dam breach for the Dowds No.1 landslide. This study was done in 1995 by FLO Engineering, Inc. of Breckenridge, Colorado. The CGS and Colorado Water Conservation Board staffs assisted in establishing technical parameters for the analysis and reviewed the results.

4) Starting in 1997, the US Forest Service observed an insect infestation was killing the spruce tree cover at the Dowds No. 1 location. They expressed concern that, if not stemmed by removal of infested trees, the landslide area would become deforested. This could lead to increased saturation of soil and contribute to the instability of the landslide. At last report, they had not been able to obtain special funding needed to remove the infested trees by helicopter and the loss of trees is progressing rapidly.

Dowds No. 2 Landslide

We are aware of no new work or serious problems at this location since a major event in 1983. The keyed rock buttress that was installed by CDOT, on the upslope bank of the eastbound lanes of I-70, in response to several slide incidents through the early 1980s, is still intact. This buttress covers only about one-third of the width of the Dowds No. 2 toe at the oversteepened highway cut that has been most troublesome.

Whisky Creek Landslide

The geological investigation done in the Dowds Junction area in the active 1985-87 period did not resolve several questions related to this landslide. This was because most of the available budget was expended on more pressing needs at the Meadow Mountain and Dowds No. 1 landslide areas. The most urgent unresolved problem had to do with possible hazard to existing and proposed land use development that was close to the northeast lobe of the Whisky Creek earthflow. Land in this area was owned by the State of Colorado and administered by the State Land Board, and high density residential and commercial development had already taken place by the middle 1980s on land under long-term lease from the State Land Board.

When this situation came to the attention of Governor Romer during a "Home on the Range" tour in 1989, he urged the various stakeholders to fund and carry out the needed hazard evaluations. A summary of the resulting investigations and land use recommendations is contained in a CGS letter to Eagle County dated November 21, 1996 (Rogers, 1996, written comm.). In that letter, CGS removed its “hold” recommendation on the final stage of developments at the River Run Apartments, which are located northeast of the Whisky Creek Slide. Subsequent investigations, carried out by CGS and the developer’s consultants, showed that past major events on the Whisky Creek Landslide had never reached the subject site and were very unlikely to do so in the future, even in the event of a major reactivation.

Year 2002 evaluation and recommendations

Surface monitoring by the CGS using electronic distance measurements (EDM) for the past ten years shows no indication of extensive reactivation of the ancient mega-landslides of Meadow Mountain and Whisky Creek. However, serious highway blockage and damage from smaller landslides related to highway cuts on the toes of these landslides has been a serious ongoing problem in the past and will almost certainly continue. Future monitoring on the Whisky Creek and Meadow Mountain landslides should include semi-annual EDM and inclinometer readings upslope from the active toes. These would serve to provide advanced warning of a developing larger or deeper slide mass activation that might presage more extensive and serious landslide events. Both of these slide areas have adequate EDM coverage and this monitoring should continue. The minimum instrumental surveillance recommended is continued EDM observations on a semi-annual schedule and establishment of annual readings on all in-service inclinometers on both of these landslides.

Some inclinometers in the Dowds Junction landslide complex have been lost to maintenance or reconstruction and the two on Meadow Mountain Landslide have not been read since 1987 because available staff and instrumentation were diverted to resolving the land use issues near the Whisky Creek landslide.

The Dowds No. 1 Landslide is believed to be active and continues to pose a serious threat to all facilities of the I-70 corridor. Slow but continuing movement is demonstrated by the damage to the west abutment of the eastbound bridge and the recurring damage to several hundred feet of roadway on the western approach to the bridge. This roadway and guardrail has been rebuilt twice since 1987. In the eleven years of EDM monitoring, all but one station on this landslide has shown a slow but consistent downslope displacement. Taken together, these facts strongly suggest that there is active movement, not only at the roadway cut, but also extending at least 1000-ft. upslope. Annual displacement rates are still small but appear to be increasing since late 1993. The horizontal drains in the upper highway cut have almost certainly enhanced slope stability and may well have forestalled more serious problems, and additional drains should be considered. A further recommendation is that two or three inclinometers at secure locations should be established to determine the depth(s) of movement within the active landslide mass. This will provide essential information that is needed for emergency planning and possible hydrologic and structural mitigation.

Although the Dowds No. 2 Landslide caused serious damage that resulted in highway closures in the past, this slide has received no special attention other than reconnaissance geological mapping in 1985 (Soule, 1986a). This landslide is considered active and it is recommended that it receive an engineering geological study including drilling, and that surface and downhole instrumentation be installed and monitored semiannually. Depending on the results of such an evaluation, additional structural or other mitigation should be considered.

(8) City of Colorado Springs, reactivated old landslide areas in western developing suburbs, El Paso County

In the western suburbs of Colorado Springs during the past 25 years, development has occurred in many hillslope areas that are underlain by landslide deposits and other potentially unstable materials. The edges of hilltops have been loaded with fill, hillsides and foot slopes have been excavated, and pervasive lawn irrigation has raised subsurface water levels. In short, these marginally stable hillslope areas have become less stable because of human development. This has made the marginally stable areas more sensitive to climatic events such as heavy snowfall seasons, prolonged and heavy “monsoon” precipitation events, or large “cloudburst”-type thunderstorms.

Numerous landslides occurred in Colorado Springs during spring of 1995 following a winter of very heavy snowfall that saturated the ground during spring runoff. In April of 1999, a three-day precipitation event in Colorado Springs and vicinity resulted in up to

14.5 inches of rainfall of both monsoonal and downpour events. These events resulted in both new landslides and reactivation of older, “dormant” slides (CGS, 1999).

These events of the mid to late 1990s resulted in increasing numbers of homes being destroyed or damaged by landslides following major precipitation episodes. In response to this situation, the city of Colorado Springs passed a Geologic Hazards Ordinance in 1996. A further development resulted from the extended 1999-rainfall event when damage from floods and landslides in southeast Colorado led to a Federal Disaster Declaration that included El Paso County. An inventory of landslide damage in Colorado Springs revealed about twenty homes destroyed and another thirty that were damaged or at very high risk.

Year 2002 evaluation and recommendations

Although local officials and developers were sobered by the recent landslide events, development continues on steep slopes and old landslide areas, but with more caution and hazard mitigation than before. There also remains the large number of residences and facilities that were built before the geologic hazards were taken seriously, some of which could be subject to future landslides.

It is recommended that the CGS, OEM and all other relevant state agencies assist and support the City of Colorado Springs in administering their Geologic Hazards Ordinance. It is also necessary to track the performances and safety of the many potentially at-risk residences that were developed in old landslide areas over the past twenty-five years.

In the wake of the serious landslide problems of the 1990s, the City of Colorado Springs perceived the need for a “landslide susceptibility” map to help guide both future land use, response planning and mitigation of already developed areas. In support of these objectives, the CGS began basic geologic mapping of the Colorado Springs metropolitan area (Carroll and Crawford, 2000). This was followed by CGS preparation of a Landslide Susceptibility Map of Colorado Springs (White and Wait, 2003), which was supported by CGS funding from the Mineral Severance Tax Fund and FEMA funding administered by the Colorado Water Conservation Board.

(9) Manitou Springs Town Site, rockfall, debris flow and flash flood areas, El Paso County

These hazards have been a fact of life as long as this community has existed, but they are becoming more severe with construction of new homes and facilities. The town is located in the canyon of Fountain Creek and the lower reaches of its tributary streams. New building is in part in-fill, but the only other sites are in the steep tributary valleys and other sideslope areas. Both older areas of town and new areas are subject to rockfall and debris flow/flash flooding. Weak, shaley zones of the Fountain Formation erode during high runoff events and undercut the more durable sandstone ledges, creating rockfall and rock debris slide situations. The town has responded reactively to hazard events, and some areas have been mitigated effectively with assistance from CGS and others. Heavy runoff in the main channel of Fountain Creek and its tributaries causes flash flooding quite frequently.

Year 2002 evaluation and recommendations

Town officials and residents are reasonably aware of the multiple hazards of their area. However, there has been little planning for dealing with those hazards in advance of emergencies. This would be an excellent opportunity for the OEM, CGS and Colorado Water Conservation Board staffs to take the lead in cooperatively developing a multi-hazard community response plan.

(10) Douglas Pass-Baxter Pass Region, landslide and debris flow areas, Garfield County

Historically, this is one of the most active landslide areas of Colorado. It is located along the drainage divide between the White River and the Colorado River. The most unstable area extends for a few miles on each side of the divide. Slope failures include earthflows, debris flows, rockfall, and a variety of rotational and translational landslides. During some years, landslides are so active that the entire terrain can change within the period of year, and highways have been closed for months at a time. Affected facilities include CO Hwy 139, a Garfield County road, and numerous energy-related pipelines. All of these have been adversely affected on numerous occasions.

In 1985 and 1986, CGS did a two-phase study for the CDOT (Stover, 1986a). The first was a detailed study along the existing alignment of Colorado Highway 139 to identify all landslide areas and evaluate possible mitigation or relocation near the present right-of-way. The second phase was a broad regional study centered on Douglas Pass, to be used in long-term facilities planning for a major highway relocation that would avoid the troublesome landslide areas (Stover, 1992). Although these studies revealed no easy or inexpensive solutions, the information continues to provide needed regional data for facilities planners and engineers for both project and long-range regional planning.

The perceived priority for substantial improvements in this strategic transportation and utility corridor has fallen because of lower soil moisture since the late 1980s, resulting in fewer and less-extensive damaging landslides and highway closures. In addition, the envisioned plans for a large oil shale industry in the Piceance Basin area collapsed in the 1980s, resulting in much lower priority and attendant funding from federal agencies.

Year 2002 evaluation and recommendations

The anticipated robust oil shale development scenario of the 1980s did not materialize, but ongoing conventional natural resource development, mostly gas and oil and nahcolite, has continued at a moderate pace in the Piceance Basin. Because of these factors, the need for a vastly improved CO Hwy 139 corridor is no longer high on state or federal priority lists. However, the Engineering Geologic studies by the CGS led to several conclusions:

1) A significantly better alignment for CO Hwy 139 is not a realistic expectation at any location reasonably close to the current one in the vicinity of either the Douglas Pass or Baxter Pass alignments.

2) The most promising alternative would probably be a tunnel driven under the steepest and most unstable part of Douglas Pass. This would entail a tunnel several miles in length, and the cost could probably not be justified under present usage.

3) At the current location, high maintenance costs and long periodic closures must be expected, especially during wetter years. Continuing slow movement of many sections of roadway will make it difficult or impractical to maintain a paved surface.

4) The regional maps published by the CGS for a ten-quadrangle portion of the Douglas Pass-Baxter Pass region (Stover, 1992) should be acquired and used by all government agencies, companies, and consultants engaged in construction of roads, pipelines, transmission lines, well locations, etc. These maps will assist in making a "first cut" at route or location selection and should be followed up by site-specific, detailed geologic and engineering studies, designs, and mitigation.

The areas described above, No. 18 and No. 22 of the 1988 Priority List, are merged into one broader area for purposes of the Year 2002 Priority List of the Colorado Landslide Mitigation Plan. This is because they are geographically adjacent and share identical geologic hazard problems. In the long term, efforts to attain a more permanent and dependable solution for an infrastructure facilities corridor in western Garfield County will involve and affect current and future facilities of the entire Douglas Pass-Baxter Pass region. This corridor is retained as a Tier One priority because of the extreme severity of the landslide/debris flow problems. It also seems likely, due to the recurrent nature of "energy crises", that conditions will eventually mandate the needed priority and funding to solve the problems of this strategic area.

(10.5) Glenwood Canyon along I-70 corridor, rockfall areas, Garfield County

The Glenwood Canyon rockfall hazard corridor extends along the I-70 roadway as it follows the narrow Colorado River valley floor that it shares with the river and the Union Pacific Railroad right-of-way. Towering cliffs and potentially unstable rock slopes extend far above the highway along most of this canyon area. When the new I-70 highway was constructed in the 1980s and early 1990s, the severe and numerous rockfall hazards were recognized and extensively studied. Mitigation of these hazards was given a high priority in roadway location and design. Specific hazard areas that could not be avoided received special attention including structural mitigation.

These extreme measures served well for several years and when initial work on the new Priority Landside List was begun in 1999, the area was considered to be adequately protected and was not included on the list. However, in the past several years as this report was in preparation, several severe rockfall events occurred in the canyon area that have caused highway closures and endangered the traveling public. Accordingly, the area is being added as an addendum to the Year 2002 Priority Landslide List.

Year 2002 evaluation and recommendations

Renewed and serious rockfall activity in this corridor warrants a comprehensive restudy. This study should follow the format of CDOT's Colorado Rockfall System as detailed in Andrews (1994). Identification of current rockfall hazard localities and their mitigation should be a very high priority, as they appear to pose serious hazards to life and property of the traveling public as well as dependability of the I-70 roadway.

(11) Black Mesa, landslide, earthflow, and rockfall corridor, Colorado Highway 92, Gunnison and Montrose counties

This area includes both No. 28 and No. 40 of the Priority List in the Colorado Landslide Mitigation Plan of 1988. This 21-mile section of CO Hwy 92 was severely damaged during the very high precipitation and heavy runoff during the spring of 1984 and 1985. More than twenty locally severe landslides and earthflows occurred in this area at that time. Much of the area is also subject to rockfall, as shown in the statewide highway rockfall inventory prepared by CGS and CDOT (Andrew, 1994). The slope failures originate in part from cut slopes and steep natural slopes in unstable materials above the roadway, and in part by failure of the overly steep fill embankments that had been placed on the outer slope to support the roadway. Many of the slope failures were caused or exacerbated by poorly controlled surface drainage.

John Post, a Geological Engineer, and Tim Pfeiffer, an Engineering Geologist, with the Colorado Dept of Highways, performed a field reconnaissance and wrote an informal letter report giving recommendations for repairing each of the areas (Post and Pfeiffer, 1985). Over the next year, CDOT maintenance crews restored the roadway but did little to improve long range stability. CDOT has continued to repair the roadway when needed but to date there have been no episodes as severe or widespread as those of mid 1980s.

This hazard area continues to have the potential for road closures, excess maintenance and even fatalities just as it did in 1988 when the Priority List was prepared. However, the potential for greatly increased traffic and the need for a safe and dependable road with passing lanes, guardrails, and other refinements seems inevitable, giving the area a much higher priority in the year 2002. This anticipated need is related to the expansion and redesignation of the Black Canyon from a National Monument to a

National Park in late 1999. Expansion of the Park included acquisition of additional land on the North Rim of the Black Canyon. Colorado Hwy 92 provides the only logical and practical access to the North Rim for visitors from the two existing, major scenic and recreational attractions: The Curecanti National Recreational Area that borders the Blue Mesa Reservoir and the South Rim Scenic Overlook of Black Canyon.

The existing CO Hwy 92 roadway in this area will not have the capacity, safety, or dependability to accommodate traffic and related facilities that will be needed as the entire Black Canyon-Curecanti recreational complex develops as a single major attraction for national and international tourists, as well as local (instate) users. If well handled, this expectable growth will have a significant positive impact on the economies of the communities of Montrose, Gunnison and Crawford. However, serious long range planning must include the North Rim access routes of CO Hwy 92 and the county road along Grizzly Gulch, from Crawford to the prime North Rim sites. If the usual incremental and current need-based "improvement" approach is used to develop the North Rim access routes and facilities, the results will be disappointing at least and perhaps disastrous. The nearby Mesa Verde National Park access problems provide a case study of the inadequacy of an incremental-improvements approach to meet burgeoning needs in a high-use geologic hazards area.

Year 2002 evaluation and recommendations

The CO Hwy 92 corridor on the North Rim of Black Canyon is already unsafe and inadequate much of the time because of minimal design and numerous landslide, debris flow, and rockfall areas. Very recent developments related to the creation of the Black Canyon of the Gunnison National Park can be expected to create greatly increased traffic volume on a road that is less than adequate for current, local traffic flow. It is not realistic to expect "business as usual" at the Black Canyon with the expanded and more prestigious status of a National Park.

It is recommended that early and "outside the box" planning for safe, functional and attractive transportation facilities begin immediately in order to develop a long-range plan to cope with increased Park visitations and to minimize environmental impacts. This should involve the National Park Service, other federal land management agencies, CGS, CDOT, other Colorado agencies, and county and municipal representatives.

(12) East Muddy Creek, landslides and earthflows, above Paonia Reservoir, Gunnison County

This old landslide complex, located on the east side of East Muddy Creek just upstream from the Paonia Reservoir, is continuing to show major activity during historic times. It consists of three very large landslides: North, Central (Middle) and South Landslides. They have been known to the CGS and under surveillance since about 1974. Alarming evidence of increasing movement was noted in 1985, prompting the CGS to put it at the top of their in-house priority list of areas for further study. Cooperative funding from the USGS Landslide Program allowed us to have detailed topographic maps compiled in 1985, and slide features were mapped at that time (Stover, 1986b).

In April of 1986, large-scale active movement began on the Central and North Landslides with significant but lesser movement on the South Landslide. The encroaching and upthrusting front of the Central Landslide soon began disrupting the stream channel and the embankment of CO Hwy 133, which was on the opposite (west) side of the stream channel. The landsliding continued and eventually the active landslide mass extended two miles upslope and involved an estimated 200 million cubic yards. The front of the Central Landslide advanced more than 200 ft. About one mile of CO Hwy 133 was engulfed and disrupted, and the East Muddy Creek channel was blocked during spring runoff. Timely and massive intervention by CDOT maintenance crews, with guidance from CGS and CDOT geotechnical staff, managed to raise and armor the roadbed as much as 50 ft while removing fresh slide material to maintain streamflow near (but above) the old channel. This operation was continued for about five weeks, until the slide reached an equilibrium configuration and the entire landslide mass slowed to a “creep” rate of movement (Stover and Cannon, 1987a; 1987b; 1999).

During the emergency and most of the ensuing year, CGS installed surface monitoring stations and piezometers and drilled numerous coreholes to define the shear surfaces and landslide materials. Several reports were prepared with maps showing both pre-slide and post-slide surface features of the landslide area. In addition to the loss of CO Hwy 133, these slides are immediately up-valley from the Paonia Reservoir and there was serious concern regarding effects of possible flood water release and/or excess sedimentation on the integrity of the reservoir (Appel and Butler, 1991). The U.S. Bureau of Reclamation is operator of the Paonia Reservoir, and they participated along with the CGS, CDOT, USGS, and FHWA in supporting geologic studies and monitoring of the landslide complex. The permanent file for this landslide at the CGS contains copies of numerous reports, maps, and other data.

Year 2002 evaluation and recommendations

There has been very little additional study on these landslides since 1987 except for surface-movement monitoring by the CGS and U.S. Bureau of Reclamation that continued after 1986. The piezometer clusters in the Central Landslide did not function as anticipated and have now been destroyed by corrosion and slide movements. The continuing surface-movement monitoring was possible because of the survivable nature of the electronic distance measuring (EDM) target posts and well-chosen base stations. Informal field reconnaissance of the landslide surface has been carried out at least annually by CGS.

All three of the East Muddy Creek landslides are still active. The North Landslide received no instrumentation in 1986, although it had strong potential for additional movement. This was because it is believed to have the lowest potential for causing damage. Surface visual observations indicate continuing slow downslope movements for the 14 years since 1986.

The Central (Middle) Landslide continues to advance at the toe (front) into East Muddy Creek as shown by monitoring and the disappearance of marker stakes and trees near the landslide front. The combination of slow advance by the landslide and erosion by the stream maintains a very steep front on the east bank of the creek, in the region most active in 1986. Downcutting by the creek since its channel was raised in 1986 has begun to undercut the lower part of the embankment built for the roadbed during the 1986 slide event. This is removing the armor and fill at the base of the embankment material, and in some places sloughing and stream erosion are threatening the roadway. Although the Central Landslide continues to move slowly, it is still reasonably well buttressed by the 1986 landslide material and the higher roadway embankment, and does not appear to be an immediate threat. There is now a severe rockfall hazard from the steep rock cut slope on the west side of CO Hwy 133 as it traverses the Central Landslide area.

Surface monitoring showed that the South Landslide moved downslope throughout most of its mass in 1986, but did not advance at its toe into Muddy Creek or the CO Hwy 133 roadway at that time. The EDM monitoring of the South Landslide from 1986 to 1998 shows that the same pattern has continued, and that the rate of movement on the middle and upper stations has increased to several feet per year since about 1990. This suggests that landsliding from above is continuing to load and steepen the lower area, which has advanced little as yet. There are also other reasons to believe that the South Landslide poses a greater potential threat than the Central Landslide did in 1986. It appears almost inevitable that this large landslide will, in the near future, break out at the toe and rapidly disrupt Muddy Creek and CO Hwy 133. Any flood releases from a landslide dam could affect the operation and safety of Paonia Reservoir, because the potential height of a landslide dam here could be much greater than it was for the Central Landslide in 1986. In addition, the South Landslide is below the confluence with West Muddy Creek and would impound the combined floodwaters from East Muddy Creek and West Muddy Creek.

Year 2002 evaluation and recommendations

All three of these landslides are active. The Central and North Landslides are less hazardous in the near term but both should, as a minimum, be observed by an expanded and modernized surface-monitoring array. The erosive action of East Muddy Creek is undercutting the raised embankment for CO Hwy 133 in the Central Landslide area and should be repaired and armored.

The South Landslide is considered one of the most threatening and potentially dangerous landslides in Colorado. A thorough geotechnical investigation is needed in order to devise needed data for emergency planning and longer-term mitigation plans. Expanded EDM coverage and real-time monitoring of this landslide should be seriously considered. The US Bureau of Reclamation and the Federal Highway Administration should be approached to assist in mitigation planning efforts and funding.

(13) Red Creek Landslide, US Hwy 50, north shore of Blue Mesa Reservoir, Gunnison County

Several reactivated, older landslides are present in the Morrison Formation-derived soil/rock on the north side of the Blue Mesa Reservoir. The Red Creek Slide that extends below reservoir level has been the most persistent and troublesome of these, causing serious periodic closures and repairs of US Hwy 50 dating back to 1974. A drilling investigation consisting of six core holes was completed by the CDOT in 1995. At that time, graduate student Scott Walker from the University of Missouri, Rolla, inquired about a challenging M.S. thesis problem and this landslide was suggested. Mr. Walker, with financial and in-kind assistance from CGS and CDOT, completed a very comprehensive investigation, evaluation, and report on the Red Creek landslide (Walker, 1999).

Year 2002 evaluation and recommendations

The mitigation solution chosen by CDOT was a geo-grid, reinforced-fill platform across the entire area of deformation. Although this is not a permanent “fix,” it is expected to have a life expectancy of about ten years. Further ideas on modifications of annual reservoir drawdown rates were suggested from the results of Walker’s modeling. These should be explored as they could considerably extend the period between necessary roadway reconstruction, and perhaps minimize the possibility of a sudden catastrophic failure. Surface and downhole monitoring should be established and read at least twice each year.

(14) Clear Creek Canyon/US Hwy 6, rockfall areas, Jefferson and Clear Creek counties

This rockfall hazard area extends along US Hwy 6 from the mouth of Clear Creek Canyon near Golden to the junction with I-70 east of Idaho Springs. It consists of numerous, intermittent to nearly continuous rockfall segments along Clear Creek Canyon. The roadway is closely confined by the walls of the narrow canyon and vulnerability of travelling public has increased greatly with burgeoning bus, passenger van, and auto traffic to the low-stakes gambling destinations of Blackhawk and Central City. Detailed information on the hazard areas can be found on the Rockfall Hazard publication prepared by the CDOT and CGS (Andrew, 1994). This publication shows the location and numerical hazard rating of the individual segments.

Year 2002 evaluation and recommendations

Because of the very high hazard exposure to the traveling public, these hazard areas should be given a high priority in CDOT highway improvement. Partial funding from the State Lottery Commission should be explored to expedite mitigation of these hazards.

(15) De Beque Canyon (Tunnel) Landslide, Mesa County

This complex landslide had its modern origin during a catastrophic event early in the 20th century. At the time, it partially blocked and changed the course of the Colorado River. It also forced the relocation of a small community, the railroad, and the highway. Since that time, it has sporadically reactivated on a smaller scale, causing additional damage to the highway. Because of its apparent threat to the new I-70 highway corridor, it was placed on an earlier priority list by CGS, and in 1985, special aerial photography was flown and a reconnaissance hazard review was made by CGS geologist Bruce Stover (unpublished). Because of the landslide's history of recurrent movement and other serious concerns uncovered by the 1985 reconnaissance study, the De Beque Canyon Landslide was placed on the Priority List in the Colorado Landslide Hazard Plan of 1988.

In April 1997, the De Beque Canyon slide again became active, requiring closures and extensive reconstruction of Interstate Highway 70. Immediately following the onset of this latest Interstate 70 disruption by this landslide, geologists and engineers from CDOT and CGS formed a working group to focus attention on a long-range solution for this critical hazard area. This group was expanded to include Federal Highway Administration staff and the Geologic Hazards Committee and Landslide Hazards Subcommittee of the Colorado Natural Hazards Mitigation Council. A report was produced with specific recommendations for a program to investigate and find solutions to the De Beque Canyon Landslide problems. As a result of this timely attention, the CDOT received an Emergency Response Grant from FHWA to completely fund the investigation and analysis as requested. CDOT formed a partnership of State, academic and private consulting groups to carry out the comprehensive investigation. The study and report were completed in April 2000 (Golder Assoc., 2000). Real-time monitoring of the slide is in place and results of the investigation are being evaluated preparatory to action recommendations to the CDOT.

Year 2002 evaluation and recommendations

This critical landslide hazard area, which has potentially very severe public safety, transportation, and economic consequences, is now receiving the attention it needs. A comprehensive geotechnical investigation with an analysis and evaluation of the hazard(s) and mitigation options has been completed. Recognition of the problem and funding of a comprehensive, solution-oriented investigation has been the result of ongoing effort by many agencies and individuals. It also demonstrates the value of having the Colorado Landslide Hazard Mitigation Plan and a Priority List to spotlight and maintain attention to known critical hazard areas. The Colorado Natural Hazards Mitigation Council, through its Geologic Hazards Committee and Landslide Hazards Subcommittee, provided a broader peer input into designing and supporting the needed hazard evaluation study.

The major study that is now completed on the De Beque Canyon landslide established complete monitoring on all major elements of the slide. This information will be available in real time to CDOT staff and emergency services staff as well as the project technical staff. This information should be utilized to meet interim needs of Emergency Services managers and CDOT maintenance staff for protection of Public safety and transportation needs. In the long term, State agencies and the CNHMC should encourage and assist the CDOT and FHWA in funding and implementing the needed mitigation as a high-priority project. Preliminary findings and updated monitoring data from the investigation can be seen on a project-specific page at the CGS web site (http://geosurvey.state.co.us/Default.aspx?tabid=144). During 2002, after considering the options, CDOT decided to: 1) continue monitoring and 2) build an interception drainage system above the top landslide scarp. [Editor's Note: The interceptor system was built in 2003.]

(16) Lamplite Park Landslide, Grand Junction, Mesa County

This is a small landslide area, but it has been responsible for the destruction of ten homes that were placed on the backfilled headscarp area of an active landslide in the early 1980s. It is a classic case of an ill-advised land use in a recognized active landslide area. By 1984, structural distress had necessitated removal of two homes and by 1988, ten homes had been lost to the slide. The CGS began a study in late 1985 with partial funding from the Governor's Emergency Fund and the City of Grand Junction. This was completed in 1986 (CGS, 1986) and it became evident that rehabilitation of the structures and sites would far exceed the value of the properties. As a result, additional homes were declared unsafe and removed. A phase 2 study was done in 1988 to establish a durable subsurface movement array to monitor any additional landsliding that might affect city utilities or remaining nearby homes (CGS, 1988). This area was used as a case study for the 1988 Colorado Landslide Mitigation Plan (Jochim and others, 1988; pages 48-49 and 146-149), where more detailed information can be found.

Year 2002 evaluation and recommendations

The danger that existed in 1985 to residents of the most seriously affected homes, from possible structural collapse or fire and explosion from ruptured gas lines, was mitigated by removal of those homes by the City of Grand Junction. To provide early warning of longer-term and more problematic future damage to other residences and city utilities, the CGS established ten monitoring drill holes and an easily used system for measuring water levels and landslide movement at depth. Because of turnover of city staff and officials, the monitoring installations have not been used as intended. However, CGS staff has continued to make visual surface observations of the area as opportunity afforded on other project work. For the past eleven years, there has been no visible evidence of renewed encroachment of the landslide toward the utilities or remaining occupied residential structures. However, two structures, comprising three dwelling units, remain in use within the extremely high hazard zone defined by proximity to the head scarp of the active landslide. This area should be retained as a Tier One priority as long as these three homes remain occupied.

This landslide area was well chosen as a “type” case study in the 1988 plan. In 2001, two additional areas within Grand Junction have reported damage or destruction of homes from bluff retreat adjacent to the south (left) bank of the Colorado River. The potential hazard area should be expanded to include all homes of the Grand Junction area that are similarly situated or known to be affected by bluff retreat.

(17) Mesa Verde National Park, access road landslide, Point Lookout Area, Montezuma County

This continues to be a very high-priority landslide area for Colorado. It consists of a mile-long segment of the only access road to the Park. The slide-prone area traverses the upper slope on the east side of Point Lookout, a narrow northward extension of the mesa. Historically, the Park has had serious access problems since it opened in 1906. The first automobile road was constructed along the current alignment, and within months of opening in 1929 had serious landsliding problems. This has continued to the present, and the Point Lookout section has been under heavy maintenance and reconstruction on an annual basis. Closures and detours are a serious and frequent detriment to this popular National Park.

Since the Priority Landslide list was prepared in 1988, a comprehensive history and analysis of the Point Lookout landslides has been completed by Daniel J. Plazak as an MS thesis in Applied Mechanics at the Colorado School of Mines (Plazak, 1989). This study was undertaken at the suggestion of the Colorado Geological Survey and received support from the National Park Service and Federal Highway Administration. A second very incisive report, *Rehabilitation Needs Study, Mesa Verde National Park, Point Lookout Area*, was completed by the FHWA (1987). That report describes a necessary program expenditure of $1.4 million per year for the foreseeable future to maintain the current roadway. This estimate does not include debris cleanup and maintenance of drainage.

Year 2002 evaluation and recommendations

A great deal of time and money has been spent in landslide studies, reconstruction, and maintenance—mostly toward relatively short-term fixes on or near the current alignment. These could probably be given longer “lives” using advanced MSE and soil anchoring technology. Problems recur at the same locations but also at new ones. It is apparent that some “thinking outside the box” will be needed to improve the reliability and long-term costs of maintaining dependable access road(s). Some such ideas have been suggested or mentioned by FHWA technical staff in their reports but none have been acted on. These include building bridge sections over the worst landslide areas, or an alternate route, generally along the aqueduct line and jeep road that are east of the Mancos Valley Overlook. An even more open-ended approach would be an engineering geological study of the entire Park and environs, serving as the basis for locating and designing a road system.

It is recommended that the Mesa Verde Access Road landslide be retained high on the Priority List, and that the CGS and CNHMC continue to monitor and encourage progress toward a long-term solution by the Federal land managers and their technical-support agencies. In addition, the wildfires that occurred in 1999 and even more seriously in 2000 drive home the point that a second and dependable access/egress for the Park is a necessity. The wildfire burn areas themselves need to be evaluated for post-burn debris flow potential on flank areas of the mesa. The fact that staff and families were trapped on the mesa during July 2000 wildfires accentuates the public-safety need for alternative and dependable roadways.

TIER ONE DEBRIS FLOW AREAS

(18) Clear Creek/I-70 Corridor, from junction of US Hwy No 6 and I-70 to east portal of the Eisenhower Memorial Tunnel, intermittent debris flow and rockfall areas, Clear Creek County

This expanded hazard area includes Nos. 2, 3, and 4 of the Colorado Landslide Plan Priority List of 1988. These areas consisted of the town sites of Idaho Springs, Georgetown, and Silver Plume. They were all identified in the older list as having serious potential debris flow and rockfall hazards (e.g., Soule, 1975). Additional information has revealed that similar hazard areas exist at many localities along the entire corridor from east of Idaho Springs to the Eisenhower Memorial Tunnel (CGS, 1999; pages 3-4). Circumstances have now evolved that can make a much wider approach feasible and conducive to collaborative mitigation efforts. The expanded hazard area is interspersed along most of the corridor. Natural events and technical and historical research since 1988 have revealed many other dangerous rockfall, debris flow, and snow avalanche hazards distributed along the corridor that threaten public and private property. Two especially large and severe hazard areas within this segment of the I-70 corridor are each being listed as separate new priority areas on the year 2002 Priority List. They are the Georgetown Incline Rockfall Area (No. 5) and the I-70/US6 Junction (Floyd Hill) rock and debris slide area (No. 4).

The changed situation referred to that presents an opportunity for a much broader and more aggressive approach to ongoing hazard mitigation of the entire corridor includes:

1) The Governor of Colorado and the CDOT are currently placing a very high priority on developing an improved I-70 transportation corridor from the Denver Metropolitan area through the Eisenhower Memorial Tunnel that will be designed to meet the much larger expected peak traffic volumes in the near future.

2) Clear Creek County has received a Project Impact grant from FEMA to address multi-hazard flooding and geologic hazards of the Clear Creek corridor. Clear Creek County has developed a GIS system and is integrating available hazard maps into their planning and emergency services databases.

3) Additional rockfall and debris flow incidents, affecting both private and public property, have been identified and described by both CGS and U.S. Geological Survey, and the USGS has an ongoing debris flow research project in this area (Coe and others, 2002, 2003). The Colorado Geological Survey is active in basic geological mapping and geologic-hazard mapping within the Clear Creek Corridor (Mears, 1979; Widmann and Rogers, 2003).

4) The CDOT has a Programatic Environmental Impact Study under contract to Yeh and Associates Inc., Geotechnical Consultants. This study is compiling and

evaluating all available information relating to the Clear Creek I-70 corridor, from valley side to valley side.

Year 2002 evaluation and recommendations

A combination of technical studies by the CDOT, Colorado Geological Survey, U.S. Geological Survey, and Clear Creek County has generated a wealth of new information throughout this area since 1988 (Andrew, 1994; Soule, 1999; CGS, 1999; Widmann and Rogers, 2003). The impetus for this has been, in part, related to local hazard mitigation and potential for new residential development sites. However, more recently, much additional interest and effort has been driven by the prospect of an expanded I-70 transportation corridor. This high level of effort and expertise now available presents a rare opportunity to develop collaborative projects to address and mitigate local geologic hazards. If these opportunities can be exploited, the result will be safer home sites on private lands and an improved I-70 transportation corridor that is safer and less prone to closures and excessive maintenance costs.

(19) Steep sideslopes of mesas, debris flows, debris avalanche, and rockfall, Douglas County

Certain steep-sided mesas of Douglas County, starting south of Castle Rock and extending to the El Paso County line, are subject to extremely hazardous debris avalanches and debris flows. Events generally start as debris avalanches on the steep upper slopes and extend as debris flows and flash floods for long distances on the footslope areas. Occurrences are sporadic and unpredictable, but are potentially very dangerous (Soule, 1978).

Year 2002 evaluation and recommendations

The hazards of this area are depicted on the geologic-hazard maps of CGS Open File Report 78-05 (Soule, 1978). Most of the areas are under county administration. Douglas County is currently avoiding development of known serious hazard areas but many sites were approved in hazard areas before their land use policies were firmly established. Consequently, there are numerous subdivided sites, mostly in 5A to 10A, low-density configurations. Some of the lots are built on but many are not. At this stage, it is recommended that geotechnical evaluation and mitigation designs be required before building is allowed in the hazard zones on the mesa flanks of Douglas County.

(20) Vail and adjacent development corridor along Gore Creek and the Eagle River, debris flows, Eagle County

Debris flow hazards are common throughout this corridor, from East Vail to Wolcott, where tributaries meet the mainstream valley floors. The last widespread and severe debris flow events were in 1985 and 1986, and development has since at least doubled the exposure of lives and property. Following the damaging events of the mid 1980s, the Town of Vail commissioned a consultant report that found 20 existing homes to be in high-hazard areas and an additional 120 homes or other buildings that were located in moderate-hazard areas where structural damage was possible. Land-use controls by both the Town of Vail and Eagle County tend to avoid the highest-hazard areas, which in some cases may also have snow avalanche hazards. However, considerable development has occurred in the moderate- and lower-hazard areas, generally without structural mitigation.

Year 2002 evaluation and recommendations

It is recognized that development options of the Eagle River and Gore Creek Valleys are limited because of major landslide hazards of the adjacent valley sides. The debris flow areas occupy the most attractive parts of the valley floors, and in many reaches of the valley are the only sites available that are not within a mainstream flood plain. If intensive recreational/residential development is to continue, the only prudent solution is to avoid the high-hazard upper fan areas and channels, and design structural mitigation works for the moderate- and lower-hazard zones of the debris fan areas. This requires a coordinated mitigation approach for each debris flow area that cannot be achieved with a lot-by-lot approach.

(21) Glenwood Springs and vicinity, multiple debris flows and associated hydrocompactive soils, Garfield County

The Glenwood Springs town site and surrounding growth areas are extensively affected by debris flows where more than twenty steep mountain stream courses enter the sides of the narrow valley floors. The town has been impacted by debris flows throughout its history, and there have been twenty or more major damaging debris flow events since 1900. Many of the events affected several fans. The CGS, Town of Glenwood Springs, and Garfield County have cooperated in sponsoring both regional and detailed hazard analyses and maps of the area (e.g., Mears, 1977; Lincoln DeVore, 1978; ESA Geotechnical Consultants and Arix, 1982). These are used by local officials in land-use decisions for current development. Particular emphasis is being given to high-hazard debris flow areas and the rockfall hazard that also occurs on some of the debris fans.

Soils of the entire complex of debris fans are generally also subject to hydrocompaction (moderate to severe subsidence when wetted). The debris flow deposits often contain excessive void space and can experience extreme settlement under hydrological changes with development. This soil condition is now generally known to soils engineers of the area, and various types of mitigation are in use. Glenwood Springs is a case study in the 1988 Colorado Landslide Hazard Mitigation Plan, where additional information can be found (Jochim and others, 1988, pages 46-48 and 143-146).

Year 2002 evaluation and recommendations

This remains a very high-priority debris flow hazard area, with most of the entire town site, old and new, subject to some level of potential damage. Mitigation efforts by local government on new development are commendable, but some development continues to occur in moderate- and lower-hazard areas. To some extent, this is unavoidable because of the widespread multiple hazards present throughout the town and potential growth areas. The recommendation is to continue to work toward prudent control on land use, using mitigation as needed, in all hazard areas. Coping with the residual hazards of older development must rely on emergency planning, public education and/or major debris flow management projects.

(22) Marble Town Site and vicinity, debris flows and rockslide, Gunnison County

This community is affected by two large debris-flow-producing creeks that form a coalescing fan on which the town site is located. Slate Creek produces debris flows of serious consequence at three to five year intervals and smaller ones about every year. Since 1985, Slate Creek has shifted its channel eastward and now threatens the few remaining houses on the active fan. Carbonate Creek has not experienced extreme debris flow activity since the disastrous events of the 1930s and 1940s, but much of the remaining town is extremely vulnerable to any new debris flows or flash floods from Carbonate Creek (Rogers and Rold, 1972; Morris, 1986, pages 147-153).

The Mount Daly rockslide, which was listed as No. 27 on the 1988 Priority List, is combined with the Marble town site, for the new list. No new activity of this rockslide has been reported in the last 20 years, and its potential impacts are mostly to the Marble town water supply intake and possible contribution to flash floods or debris flows on the Carbonate Creek fan.

Year 2002 evaluation and recommendations

Several homes are at serious risk on both the Slate Creek and Carbonate Creek areas of the fan. Gunnison County has high maintenance costs each year on cleanup of the roadway in the lower Slate Creek fan area, and in constraining the spring runoff flows to an unstable channel across the Carbonate Creek fan. If Carbonate Creek breaks out of its present, very tenuous channel during heavy runoff or debris flow events, much of the remaining old town site would be seriously threatened.

It is recommended that both the Town of Marble and Gunnison County discourage any further development of the high hazard areas of the Slate and Carbonate Creek fans. For peripheral development the CGS hazard maps of 1972 and 1978 are available (Rogers and Rold, 1972; Junge, 1978b). More recent, detailed hazard and environmental maps produced by Wright Water Engineers (Rold and Wright, 1996) are also available in both hard copy and GIS formats.

(23) Ouray Town Site and vicinity, debris flows, Ouray County

The main town site of Ouray is located on the coalescing debris fans of Portland and Cascade Creeks. A small portion of the town lying on the west side of the Uncompahgre River is on the debris fan of Oak Creek. Recently, the fan of Sky Rocket Creek at the north edge of town was subdivided into several residential sites. One or more of these fans has had debris flow and flash flood events on 22 occasions between 1874 and 1982. Efforts were made to control the debris by construction of a timber-lined channel ("flume") with a concrete bottom that was completed in 1909. These provided some protection, but damage continued when the flumes became clogged or overflowed. Major events occurred in 1981 and 1983 and the decrepit flumes were overwhelmed, resulting in damage to many homes, businesses, and town facilities.

Following these destructive events, the city received grants for design and replacement of the flumes with reinforced concrete structures. These new structures have yet to be tested by a major debris flood. They are more durable structures that will probably handle moderate-sized events, but it remains to be seen if they can tolerate the massive debris flow plugs of major events without malfunctioning. Debris plug fronts 25 to 30 ft. high have been reported, and deposits at the highway of 40 ft. depth have occurred (Jochim, 1986).

Some engineering studies and mitigation designs were made by private consultants to the developer before the Sky Rocket fan was subdivided in 1996. A key part of the mitigation is the redesign and replacement of an old diversion structure above the fan. A wooden diversion structure at this location was built in the spring of 1929, and it failed during massive debris flows in July that same year. When the diversion failed, a drift of debris 40 ft. high was deposited on the highway below the fan. The new diversion is intended to intercept most of the debris flow volume and divert it to the north side of the Sky Rocket fan. If this functions, it could minimize debris flow and flash flooding on the main fan that now contains several new homes. If it doesn't perform as intended, these homes and older city and residential areas west of US Hwy 550 will continue to be in very high-hazard areas.

Year 2002 evaluation and recommendations

Our recommendations in the year 2002 is that further building of homes on the Sky Rocket fan be held in abeyance until adequacy of the diversion structures has been tested by a major debris event or until an independent review of the mitigation scheme confirms it to be adequate. For other parts of Ouray and vicinity, the report and maps of Jochim (1986), should be consulted for guidance in land-use decisions.

(24) Telluride and San Miguel River corridor west to Placerville, debris flows, debris slides, and rockfall, San Miguel County

This part of the San Miguel River corridor continues to undergo intense resort development related to the ski area and year around recreational attractions. There are serious debris flow hazards on all of the debris fans of the corridor, and the rockfall hazard is severe to moderate locally from the steep cliffs of the north valley side. Very large debris flows from Cornet Creek devastated large parts of Telluride in 1914 and 1969 (Mears and others, 1974). Under current conditions, very similar debris flows and attendant flooding could occur in the Telluride community, and there are now additional buildings and population exposed to the hazard.

In 1987, a series of landslides, originating in a fill area constructed for the Telluride Airport on Deep Creek Mesa, mixed with runoff water and formed a series of destructive debris flows that ran all the way to the San Miguel Valley floor. Damage to the airport, CO Hwy 145, and a gravel quarry exceeded $2.4 million (Stover and Cannon, 1987c). The north edge of the Telluride town site and expansion areas to the east and west have exposure to frequent rockfall events from the cliffs of the north valley wall. In July 1999, a small but potentially lethal rockfall and debris flow occurred at a school site just west of the Telluride town site. Heavy rainfalls in the summer of 1999 caused numerous debris flows, rockfall, and flash flooding incidents in the still sparsely populated western end of this growth corridor (CGS, 1999, page 2).

Year 2002 evaluation and recommendations

Development in the upper San Miguel Valley of Telluride and vicinity has continued to occur rapidly since the Colorado Landslide Plan and List were developed in 1988. Although many projects have avoided the worst debris flow and rockfall hazards, some have not. Many of the older residences, especially in Telluride, are in hazard zones. The sparsely developed corridor between Society Turn and Placerville is subject to both debris flow and rockfall, and it is especially important that future development in these areas recognizes and avoids or mitigates these hazards. Existing hazards, especially rockfall, can often be mitigated after development has occurred. The threat to the “Old Town” Telluride from major debris flows from Coronet Creek continues to need attention, focused on mitigation and emergency planning.

(25) New and recent wildfire burn areas in forest or brush lands, debris flows, statewide

Since 1989, a close relationship between wildfire burn areas and excessive runoff and sediment/debris production during heavy runoff events has been documented in Colorado. The loss of vegetative cover and the water-repellant properties often found in post-fire soils can combine to cause extreme flash flooding, accompanied by hyper-concentrated sediment flows, debris flows, and intensive erosion.

Examples of wildfire burn areas that provided the learning experience for Colorado include:

1) The Black Tiger Gulch wildfire burn area, Boulder County, 1989 – flash floods, debris flows, and hyperconcentrated flows over a five day period (Berry, 1989).

2) Storm King Mountain wildfire area, Garfield County, 1994 – multiple debris flows and hyperconcentrated flows that engulfed three miles of Interstate 70 with mud and rock debris and flood water, covering many cars and sweeping two into the Colorado River (Cannon and others, 1995; Kirkham and others, 2000).

3) Buffalo Creek wildfire area, Jefferson County, 1996 – flash flooding and hyperconcentrated flows that exceeded ten times the flood volume predicted by standard flood plain formulas (CWCB, 1996; Henz Meteorological Services, 1998).

Year 2002 evaluation and recommendations

It is recommended that all new and recent wildfire burn areas of Colorado receive special attention from pertinent technical and emergency response officials of State, Federal and local government agencies. This would make an excellent project for the CNHMC utilizing the expertise of the Wildfire, Flooding and Geologic Hazards committees. New areas of particular concern in year 2002 are the major wildfire burn areas of High Meadows, Jefferson County; Bobcat Gulch, Larimer County, and Mesa Verde National Park, Montezuma County. The CGS and USGS cooperatively studied the High Meadows and Bobcat Gulch burn areas to estimate the post-fire susceptibility to flash flooding, debris flows and excessive sediment production (Cannon and others, 2000a, 2000b). Several additional major wildfires occurred in 2002, including the Hayman in Teller and Douglas counties; Missionary Ridge in La Plata County, near Durango; and Coal Seam in Garfield County, near Glenwood Springs, and others.

TIER TWO LANDSLIDE/ROCKFALL AREAS

(26) Town of Castle Rock, rockfall areas, Douglas County

A moderately severe hazard for rockfall remains in the northeast part of the town of Castle Rock. This is mostly in areas developed since about 1980 and where residences are near the base of the low cliffs. One serious incident was mitigated in 1981 by partial removal and cable lashing of loose slabs (CGS, 1999, page 6). There are numerous other similar areas where future rockfall events could affect residences. One serious rockfall area problem was solved recently when the town of Castle Rock acquired the "Castle" and adjacent foot slopes for park land, thus avoiding hazards that would have accompanied residential development.

Year 2002 evaluation and recommendations

Local government officials are well aware of these hazards, which are depicted on hazard maps of CGS Open File Report 78-05 (Soule, 1978). Officials and residents should be especially alert during late winter and early spring each year. Avoidance is the best option on rockfall sites that are not yet developed.

(27) I-70 corridor near Wolcott and adjacent private lands of Bellyache Ridge, old landslide complex, Eagle County

Since 1988, the I-70 roadway in this area has required annual maintenance, debris removal, and repair at various localities. Damage caused in July 2000 by an active landslide has been repaired at the west end the intersection of I-70 and US Hwy 6.

In the early 1990s, pressure began to build for recreational/residential development of the private lands of the old landslide complex on Bellyache Ridge south of I-70 (Robinson and Associates, 1975). Eagle County asked for guidance from the CGS and the Landslide Committee of the CNHMC. Following on-site meetings with Eagle County staff, the committee recommended comprehensive area-wide geotechnical studies, with limited and selective development to be based on the technical findings. They also noted potential problems with access roads, sewage treatment facilities, and the need for fully engineered plans for individual sites.

Year 2002 evaluation and recommendations

On the I-70 corridor part of this slide area, the CDOT approach of reactive maintenance and repair as needed has been adequate to maintain a viable interstate roadway in the area. In the longer range, especially during extended high moisture periods, it is likely that more aggressive structural mitigation will be needed. Development of private lands of the old landslide complex has been slowed by the cautious approach taken by Eagle County. However, some large tract (35+acre) subdivisions have been approved and a golf course and cluster housing proposal is being considered. In the latter case, the heavy irrigation for a golf course could easily lead to reactivation of old landslides and must be very carefully evaluated. Also even for a sparsely developed community, adequate and alternative access and egress must be considered.

(28) Fraser Canyon (AMTRAK) landslide area, landslides, debris flows, rockfall, Grand County

Hazards of the Fraser Canyon corridor were emphasized by a landslide on April 16, 1985 that undercut the embankment and tracks. Because of this damage, a 14-car Amtrak passenger train was derailed and two locomotives and five passenger cars were catapulted into the breach. There were no fatalities, but 26 people were injured and damage was estimated at $3.4 million. The incident was investigated by R.L. Schuster of the U.S. Geological Survey, who published a short paper in the Spring issue of Ground Failure (Schuster, 1986). The landslide was extensively investigated and repairs made by the railroad immediately following the incident. An alarm fence was installed along all potential landslide areas of the railroad in Fraser Canyon.

Year 2002 evaluation and recommendations

This incident provides a prime example of the very serious potential consequences of even a small, strategically located slope failure (its volume was estimated to be only about 4,000 cubic yards). Because of the large property losses and the potential for many fatalities, this landslide area was rigorously investigated and mitigated at the time. This Fraser Canyon site was selected for the 1988 Priority List to exemplify vulnerability of major rail transportation corridors that are constrained to the narrow floors of Colorado's many hazardous canyons (CGS, 1987). In these areas, the consequences of landslides, rockfall, or snow avalanches are so severe that extreme measures of mitigation and surveillance are a necessity. This is especially sobering in the year 2002, as Colorado faces the prospect of high level radioactive waste being transported across the state by both rail and highway.

(29) The Slumgullion Landslide/Earthflow, Hinsdale County

This landslide is located on the Lake Fork of the Gunnison River, about two miles upstream from the town of Lake City in Hinsdale County. It is in an area of highly altered Tertiary volcanic rocks of the San Juan Mountains in southwestern Colorado. This world-famous geological feature has been described in the geological literature dating back to 1876, and photographs have been widely used as illustrations in numerous text books.

The Slumgullion Landslide is famous because of its large size and the fact that it blocked the Lake Fork and formed Lake San Cristobal. Although this occurred 700 years ago, the landslide dam has not been breached by erosion. The river continues to flow along the toe of the landslide where it meets colluvium and bedrock of the opposite (west) valley wall, and a major natural lake survives as Lake San Cristobal. The landslide is also somewhat unusual in that its main mass is only 700 years old, whereas most of Colorado's very large landslides were originally emplaced at least several thousand years ago.

It is currently recognized as a very complicated landslide complex rather than an exemplary "earthflow" as earlier believed. The major landslide mass that formed Lake San Cristobal is about four miles long and has a width that varies but is generally less than a half mile. However, at its terminus where it dammed the Lake Fork it spread out to occupy about 1-1/2 miles of the old valley floor. This major landslide mass is estimated to have a volume of 170 million cubic meters. A very significant feature of the Slumgullion Landslide is that the dormant main landslide is being overridden by a similar but smaller active landslide, which extends from the base of the main headscarp to within 800 ft of where Colorado Highway 149 crosses the main landslide. The active landslide is about 2.4 miles long and 500 ft to 1000 ft wide. Its volume is estimated to be about 20 million cubic meters (Fleming and others, 1996).

This Slumgullion landslide area was placed on the 1988 Colorado Landslide Hazard Mitigation Plan Priority List for several reasons. Colorado Highway 149 is only about 800 ft. from the advancing toe of the active landslide and could be seriously affected by accelerated advance (surging) of the landslide. There was also concern for possible reactivation of all or part of the older (and larger) landslide mass. This could cause failure of the landslide dam, with serious local and downstream consequences. In addition, there was residential/resort development on the toe of the old landslide adjacent to Lake San Cristobal that increased public exposure to potential hazards. At that time, the only substantial technical study of the area had been done by the U.S. Geological Survey. Crandall and Varnes (1961) reported on 20 years of surface-displacement studies of the active landslide. These showed a rather constant role of downslope movement of 2.5 ft. to 16 ft./yr., which appeared to not be affected by seasonal or longer-term temperature or precipitation conditions.

The USGS continued sporadic field observation until 1985, when the Colorado Geological Survey included the Slumgullion Landslide on a list of critical landslides for special large-scale aerial color photography. The USGS staff flagged many of their old survey stations in advance of the new photography and started an initiative for a long term and multi-faceted research study of the Slumgullion landslide area. This resulted in an ongoing cooperative investigation with Italian scientists from the Italian National Research Council, starting in about 1990 and continuing to the present. An immense body of data and interpretation has been produced (e.g., Parise and Moscariello, 1997).

Year 2002 evaluation and recommendations

Since 1987, when the Priority Landslide List was created, a great number of geotechnical investigations, evaluations and reports have been published on many facets of the history, behavior, and hazards posed by the Slumgullion Landslide. Most of this has been done by the US Geological Survey and their cooperators from the Italian Research Council. Their findings are summarized in 15 short papers in USGS Bulletin 2130 (Varnes and Savage, 1996). Although this research has not resolved all of the questions about the landslide and its future hazard potentials, it has vastly increased our knowledge base and is providing ongoing observation and monitoring throughout the landslide area. The research has also provided transferable knowledge that can be applied to similar earthflow/landslides in many parts of the world.

One tangible threat from the Slumgullion Landslide complex is the advancing toe of the active landslide. It has a steep, bulging front that is 130 feet high and is moving forward over the older main landslide surface at a rate of a few feet per year. The only works of man that are nearby is Colorado Highway 149 as it crosses the older landslide about 800 ft. downslope. At its current rate, it would be a few hundred years before the active toe engulfed the roadway. However, the active landslide has, in the past, moved much more rapidly to attain a length of 2.4 miles since its origin about 300 years ago. More rapid future movement could be caused by surging of the front from buildup of the steep toe or an influx of new landslide material in the depleting upper half of the landslide, which could come from a major collapse of the main head scarp. These possibilities can be evaluated and monitored in the field and through ongoing photogrammetric and GPS survey methods.

A second and much more speculative potential hazard from an advancing active landslide would involve destabilization of the older landslide material of the valley area, which might affect the landslide dam and residential/resort development near Lake San Cristobal. Currently, this sort of scenario does not seem to have a very high probability. This can be re-evaluated periodically as study and observation of the active landslide continues.

Serious questions regarding the integrity of the 700-year old landslide dam that forms Lake San Cristobal were a real concern in 1988. This was because, in general, valley-blocking landslides do not make good or long-lived natural lakes, as they usually fail by piping or overtopping and erosion. This aspect of the Slumgullion landslide dam was investigated by R.L. Schuster of the US Geological Survey. Dr. Schuster, who has done worldwide studies of landslide dams and their histories, concluded that the landslide dam and its natural outlet channel are stable and there is no reason to expect failure (Schuster, 1996, page 37).

(30) Vega Reservoir and Buzzard Creek areas, landslides and multiple earthflows, Mesa County

These historically landslide-prone areas were very active in 1970s and 1980s, but much less so in the past 12 years. It is a prime recreational area, including Vega Reservoir and numerous related residential areas. It is also the site of active oil and gas development and related facilities, including regional gas and electrical transmission lines and U.S. Forest Service access roads. All of these vulnerable structures have been affected in the past. Mitigation has been assisted by completion of area-wide geologic-hazard reports and maps by CGS (Soule, 1986b, 1988). Mesa County, energy facilities owners, and consultants can use these maps to avoid or mitigate hazard conditions. One conclusion of the reports is that the probability of massive, catastrophic landslides is not very high. Although landslides and earthflows can be quite extensive they are generally thin and would not form dangerous stream blockages with attendant backwater and flood release hazards downstream.

Year 2002 evaluation and recommendations

The recommendation is to concentrate effort on education of new county staff, consultants, and facilities owners on hazard conditions of the area and how they can be mitigated. Two areas, No. 36 and No. 37 of the 1988 Priority List, were merged to form this hazard area because these are in the same general area and share almost identical geologic-hazard problems.

(31) Wolf Creek Pass area, US Hwy 160 corridor, landslides, debris flows, rockfall, Mineral County

This corridor extends both ways, along the US Hwy 160, from the Continental Divide at Wolf Creek Pass. It has a long history of high maintenance and road closures from landslides, debris flows, rockfall, and snow avalanches. Many cut-slope and road-fill failures have been due to unstable, clay-rich volcanic rocks and glacial debris that failed during heavy snowmelt runoff.

Year 2002 evaluation and recommendations

The CDOT has been very active in this serious hazard area and, in the past 15 years, has mitigated many of the most serious hazards. This includes a structural, cantilevered roadway support on a unstable shelf-road sector, several MSE rockfall barriers and roadway redesign and reconstruction of landslide-prone areas. The proposed ski area on the west side of Wolf Creek Pass has been abandoned and reclaimed, and no longer poses land-use related geologic hazard problems. A debris basin was built on the ski area property for a debris flow path that frequently reached US Hwy 160. The basin is not large enough to retain a large debris flow event, but will partially mitigate the hazard which primarily caused occasional road closures and massive roadway cleanup (Morris 1986, pages 176-178). It is recommended that CDOT continue their excellent mitigation program in this area based on emerging priorities.

(32) Wells Basin landslide, Cimarron River corridor, Montrose County

This very active landslide is located about five miles southwest of where the Cimarron River Road intersects US Hwy 50. It is a recently reactivated part of a much larger and complex old landslide feature known as Wells Basin. The currently active landslide is about one quarter mile wide and a mile in length. This primarily translational landslide has repeatedly displaced both the Cimarron Irrigation Canal and the Montrose County P77 Road for a total of about 1,000 ft. This road is an important U. S. Forest Service access road that provides access to recreational and other facilities. The Cimarron Canal provides irrigation water to eastern Montrose County. Attempts to alleviate continuing landslide damage to the road and irrigation canal have thus far had limited success.

Year 2002 evaluation and recommendations

The CNHMC should assist and encourage the Federal Land Managers and their technical support agencies in solving this difficult landslide problem.

(33) Green Mountain Reservoir area, landslide complex on south side of reservoir, Town of Heeney, Summit County

Geologic-hazards mapping by the CGS (Price, 1980) showed a large old landslide to exist on the south shore of the reservoir. The old landslide includes all of the town of Heeney and adjacent developed shore area for about 1.5 miles. The toe of the old landslide is believed to extend below the water level of the reservoir. Although there were no signs of large scale active sliding on the old landslide, it was considered to have the potential of becoming a large and serious landslide that could threaten both the town and Green Mountain Reservoir.

Year 2002 evaluation and recommendations

To our knowledge, no indications of large-scale landsliding were observed nor had any technical studies been undertaken since the Priority List of 1988 was created. However, large reservoir drawdowns in 2002, due to the Colorado drought, have prompted the U.S. Bureau of Reclamation to begin a study and evaluation of the area. We recommend that such a study be pursued vigorously while there is access to the exposed reservoir side slopes for direct observation and drilling to facilitate a hazard evaluation. There should be particular emphasis on safety of the town site and the reservoir, including the possible effects of various drawdown scenarios on stability of the old landslide.

TIER TWO DEBRIS FLOW AREAS

(34) Chalk Creek area, vicinity of Mt. Princeton Hot Springs, debris flows and rockfall, Chaffee County

This is an area of existing and expanding recreational development. Much of the area's development, including existing residential and summer youth camp facilities, is located on a large debris fan complex with shifting, multiple distributary channels. Moderately severe rockfall hazards are also present adjacent to the steep and unstable Chalk Cliffs, which also are the source for debris flow material to the distributary channels of the fan. There has been no evident improvement toward mitigation of existing hazards in developed areas since 1988 when the Priority List was developed. Recreational-home development has continued in the interim, placing more people and property in potential hazard areas. A reconnaissance study was done in the area as part of a Master's Thesis at Colorado State University (Morris, 1986, pages 161-167). In the summer of 2002, debris flows occurred on Cottonwood Creek about six miles northwest of Chalk Creek, causing road closures and property damage.

Year 2002 evaluation and recommendations

County officials and staff need to become more involved in promoting safer and better land use in hazard areas. In addition to needed CGS and OEM outreach to Chaffee County staff, the Chalk Creek and adjacent area need a comprehensive geologic hazards study with a map and report to guide county officials and developers. This would be an excellent subject for a graduate thesis in Engineering Geology or Geological Engineering.

(35) Red Cliff Town Site, debris avalanche and rockfall, Eagle County

Following debris avalanche and debris flow actively in both 1984 and 1985, a cooperative effort was made by state agencies and Eagle County to mitigate this serious threat to residents of the Town of Red Cliff. Hazard mapping was provided by the CGS, and consultant Art Mears was retained to design mitigation structures (Stover, 1986c; Mears, 1986). Cooperative funding from state agencies and Eagle County was used to contract out the construction of the barriers and guide walls. The structures have now been in place for 13 years but have not been "tested" by actual, large debris flow events.

Year 2002 evaluation and recommendations

Because engineered structural mitigation works are in place, the area is lowered from a Tier One to a Tier Two rating. There also remain rockfall and snow avalanche hazards that have not been carefully analyzed or mitigated.

Currently the CGS does a visual inspection of the mitigation structures each year before winter, and in March or April Town officials are contacted by phone as a reminder and to get a report on snow accumulation in the high basins that are the debris sources. This level of yearly on-the-ground monitoring should be maintained by CGS, OEM, and Eagle County.

(36) Lower reaches and alluvial fans of Arkansas River tributaries between Salida and Parkdale, debris flows and flash flooding, Fremont County

U.S. Hwy 50, CO Hwy 69, and county roads of this corridor have been flooded periodically with rock, mud, woody debris and floodwater from tributary streams, requiring frequent cleanup and roadway repairs after the larger events.

Year 2002 evaluation and recommendations

Detailed study and hazard mapping are badly needed, as these events are both a serious safety problem and a source of excessive maintenance costs. With hazard maps and process studies in hand, more effective plans for mitigation could be devised by the CDOT and affected counties.

(37) Tributary streams to Big Thompson River from Estes Park to Loveland, debris flows, flash flooding, Larimer County

This basin was the site of the catastrophic Big Thompson flood and debris flows of 1976. The area was studied and mapped by CGS immediately following the catastrophic flood (Soule and others, 1976). This event was of particular interest because it graphically showed the deadly interplay of mainstream mountain torrent flooding with simultaneous debris flow activity from the smaller tributary streams (McCain and others, 1979). Under similar conditions, many Colorado mountain canyons are capable of incurring such destruction.

Year 2002 evaluation and recommendations

The geologic-hazard maps produced by CGS in 1976 are adequate for planning and reconnaissance hazard evaluation in advance of site-specific studies for recreational and residential projects. Many of the most vulnerable residential and commercial developments were destroyed in the catastrophic flooding and debris-flow events of 1976. For the most part these were not rebuilt, and in combination with the more prudent land-use controls now in place, this area is lowered to a Tier Two priority.

(38) Poudre River corridor between Fort Collins and Rustic, debris flows, landslides, Larimer County

This area consists of the CO Hwy 14 corridor that follows the canyon of the Cache La Poudre River west of Fort Collins to Rustic. The area is similar in many ways to the Big Thompson Canyon (2002 Priority List No. 37). The corridor contains numerous residential and commercial clusters and campgrounds, as well as the highway, that would be similarly vulnerable to mountain torrent flooding or isolated debris flows, debris slides, or rockslides. A large rockslide in 1999 caused a 6-week closure of CO Hwy 14 (R. Andrew, pers. comm.).

Year 2002 evaluation and recommendations

This corridor needs a geologic hazards study and maps. Future land use should be carefully controlled using avoidance or mitigation as needed. Residents, tourists, and public lands managers should be made aware of the hazards and how to survive during a natural-hazard emergency in the canyon.

(39) Aspen Mountain Ski Area and vicinity, debris slides and debris flows in natural slope materials and mine waste, Pitkin County

Potential slope failure problems occurred on the north side of Aspen Mountain in the spring of 1985. New landslide scarps were observed on the steep face of Aspen Mountain directly above a resort facility complex that was being developed at the foot of the ski slopes. It was feared that the landslide scarps could lead to extensive debris slides and debris flows that could affect the development at the foot of the mountain slope. The hazard was evaluated by consultants for the ski area, the developer, and local officials, and the project was eventually completed. Mitigation included improved drainage, regrading and removal of loose mine and construction waste, and redesign of parts of the development plan. There have been no subsequent reports of recurrent slide movement or related problems at this locality.

In May of 1996, two destructive debris flows occurred on the fan of Keno Gulch on the west side of Aspen Mountain. These flows originated in an old landslide mass near the head of the gulch. The landslide material mixed with snowmelt water in the main gulch, forming a debris flow that moved rapidly down the channel to the fan. The fan is occupied by a parking lot and several buildings of the Music Associates of Aspen and Aspen Country Day School. The flows severely damaged facilities and vehicles of the private school campus. Mitigation, already in place, prevented much more extensive damage. The incident was reviewed by CGS, USGS, and private consultants, and additional protective structural mitigation was recommended as there was still much potentially unstable landslide debris at the head of the gulch. The old landslide material source area was subject of a study by the U.S. Geological Survey (Chleborad and others, 1997). In the spring of 1997, the USGS instrumented the site during the peak snowmelt season. Creep of the old landslide source area was noted, and small shortlived debris flows formed in the steep upper channel from bank slides and loose channel debris. These small debris flows became diluted with runoff water and were seen only as muddy water flows on the fan. It was concluded that the threshold conditions for failure of the old slide mass were not reached during the spring of 1997.

Year 2002 evaluation and recommendations

This area obviously remains capable of additional debris flows, and facilities and residents of the fan are at risk each spring. The added mitigation and awareness should lessen damage in the future. The entire Aspen Mountain area is replete with potential geologic-hazard conditions. All residents, local officials, and resort facility owners and developers should bear this in mind in their development and operating plans and decisions.

(40) Devils Hole Gulch/Wilson Creek area, debris flows, landslides, extreme erosion, Rio Blanco and Moffat counties

The extreme debris flow, landslide and erosion activity that occurred in this area during the mid 1980s has not recurred. Oil field facilities and company access roads were repaired by the operators. The electrical transmission lines and county roads that were severely damaged have been repaired or vacated.

Year 2002 evaluation and recommendations

The area is still subject to severe geologic hazards that will eventually affect this sparsely populated area of Rio Blanco and Moffat counties again. The recommendation is to keep the county and other involved parties aware of the problems especially in any new public or private development projects involving construction.

TIER THREE LANDSLIDE/ROCKFALL AREAS

(41) West side of McClure Pass along Lee Creek, landslides and earthflows, Gunnison County

These landslides occur on the western side of McClure Pass as it descends along Lee Creek, about five miles past the summit. They originate in weak and unstable soil and rock from the slopes composed of the Wasatch Formation, upslope from CO Hwy 133. The landslides include slumps and translational landslides that displace the roadway and become shallow earthflows on the lower slopes below the road alignment. These extensive and serious slides periodically displaced or engulfed large sections of roadway during the period 1970 to 1986 (Rogers and others, 1974, Fig. 11, page 28). Since that time, road maintenance has not been excessive and major landslides have not occurred.

Year 2002 evaluation and recommendations

Landslide activity in this area has been amenable to CDOT maintenance efforts for the past 15 years. The area is retained as a Tier Three with a “watch and wait” recommendation.

(42) Golden to Boulder along CO Hwy 93, landslides and earthflows, Jefferson and Boulder counties

Hill slopes of this area are mostly composed of weak claystone bedrock and derived soils. The slopes show numerous landslide features of many ages including historic. Earlier routes that were made by conventional cut and fill were subject to severe landsliding.

Year 2002 evaluation and recommendations

During the past 15 years, many parts of the roadway have been widened, realigned, or relocated with generally excellent results. There is no reason to expect a recurrence of roadway damage or lengthy detours as long as the ongoing improvements continue to follow good engineering practices consistent with geological conditions.

(43) Morrison Town water plant, landslide, Jefferson County

This landslide became active in the spring of 1985. It was directly upslope from the town’s water treatment plant. The landslide plane was within a weak shaley bed of the Fountain Formation, creating a translational rock and debris slide that incorporated overlying loose colluvial soils. The landslide was mitigated by removal of most landslide material upslope from the water plant. There have been no problems reported in the past 15 years and the facility remains functional. It is probable that removal of the upper slide mass enhanced stability of the lower slope where the facility is located. No trouble is anticipated unless the lower slope area is modified.

Year 2002 evaluation and recommendations

It is recommended that good drainage be maintained and no reconstruction or expansion of the facility be done without thorough geological evaluation and engineering design.

(44) Snowmass Village and vicinity, landslides, slumps, and earthflows, affecting ski slopes and potential residential areas, Pitkin County

In the 1970s and 1980s, there were numerous landslide problems both in developing residential areas and with lift structures on the ski slopes. Local governments, ski area managers, and developers and their consultants are aware of the problems and appear to have been successful in dealing with them in the last twelve years.

Year 2002 evaluation and recommendations

There have been no reports of serious new problems in this area since 1988. Ski area managers and their consultants are aware of the problems and appear to be successful in dealing with them. Development in residential areas is administered by Pitkin County. The CGS continues to review all subdivision applications for geologic hazard problems.

TIER THREE DEBRIS FLOW AREAS

(45) Sweetwater Creek area, debris flows, Garfield and Eagle counties

This is a remote area in northeastern Garfield County and adjacent Eagle County that is still sparsely developed with recreational and residential facilities, especially near Sweetwater Lake, and some existing structures are at risk. There have been no new reports of disruptive debris flow activity since the mid 1980s.

Year 2002 evaluation and recommendations

This is an attractive area and will almost certainly continue to grow. Care should be taken in siting new structures on or near the debris fans and intermittent stream channels. Site-specific geologic-hazard studies are recommended for all new development proposals in the area.

(46) Dutch Creek, Coal Creek, and Redstone area, debris flows, debris avalanche, flooding, Pitkin County

Since the original Colorado Landslide Plan and Priority List was prepared in 1988, the coal mines of the Coal Creek Basin have been abandoned. These mines were located in the steep, upper part of the Dutch Creek sub-basin of Coal Creek, and the mine facilities were frequently disrupted by debris flow activity. The mine site has been under reclamation for several years and the geologic hazard concerns for the mine facilities and staff are no longer a concern.

Year 2002 evaluation and recommendations

Through the 1990s, the upper basin has continued to experience frequent debris flows. With the mine facilities and personnel removed and no longer at risk, the remaining serious problem is the abundant supply of coarse rock and woody debris produced annually by the smaller streams of the upper basin and fed into the main channel of Coal Creek. During spring runoff, this creates downstream problems almost every year at Redstone, which is located at the confluence of Coal Creek and the Crystal River. At this location the rock and wood debris piles up, causing backwater and erosion by both streams. This condition worsens the spring flood threat to the town of Redstone and CO Hwy 133. Town, county, and CDOT maintenance staff are aware of this problem and have managed to cope with it each year.

DELETED OR MERGED ITEMS FROM 1988 LIST

Areas regrouped and retained in year 2002 Priority List

(A) Areas No. 2, No. 3 and No. 4 consisted of the town sites of Idaho Springs, Georgetown, and Silver Plume respectively. They were all identified in the older list as having debris flow and rockfall hazards. More complete information now available has shown that these conditions are prevalent all along the I-70/Clear Creek corridor. For reasons more fully explained under No. 18 on the Year 2002 Priority List, the entire corridor is combined and identified as a high-priority hazard area with all of the towns and residential clusters of the corridor as special interest locations.

(B) Area No. 6 on the 1988 Priority List, the Fire Mountain Irrigation Ditch Landslide, would have been more correctly identified as the Stewart Ditch or Lennox Mesa landslide. It occurred in 1986 in Delta County, destroying 1200 ft of the Stewart Ditch and cutting off irrigation water to several thousand acres of orchard lands. The situation was assessed by the Colorado Geological Survey, and the U.S. Soil Conservation Service (now NRCS) provided assistance to the ditch company in design and reconstruction of the ditch. There have been no reports of additional problems at this site. However, this incident is symptomatic of numerous other incidents that occur every year in the North Fork Valley. This area is included as part of the new North Fork Valley corridor hazard area, No. 2 on the Year 2002 Priority List.

(C) Areas No. 18 and No. 22 on the 1988 Priority List are merged into one larger, high-priority area that covers the entire Douglas Pass and Baxter Pass region. These previous areas were geographically adjacent and shared identical geologic hazard problems. By combining the two into a single area, No. 10 on the Year 2002 Priority List, recognition is given to the long-term need of solving infrastructure problems for this entire strategic area of western Colorado.

(D) Areas No. 25 and No. 27 on the 1988 Priority List involved the town site of Marble and vicinity. The Mt. Daly rockslide that was No. 27 is now combined with No. 25, which consisted of the frequent and destructive debris flows at Marble. No new activity has been reported on the rockslide in the last 20 years, and its potential impacts are mostly to worsen the effects of debris flow and flash flooding hazards on the Carbonate Creek fan area of the town site. Accordingly, it was decided to combine the two as No. 22 on the Year 2002 Priority List.

(E) Areas No. 28 and No. 40 on the 1988 Priority List are combined to form one continuous hazard area, No. 11 on the Year 2002 Priority List. The areas are interconnected on CO Hwy 92 in the Black Mesa region. They were previously separated at the county line between Gunnison and Montrose counties. The areas share the same geological conditions and problems, and with creation of the new Black Canyon of the Gunnison National Park, the entire CO Hwy 92 corridor will have a key role in the development of the North Rim of the new National Park. It is now more conducive to the problem-solving needed to address this as a single priority area.

(F) Areas No. 36 and No. 37, the Vega Reservoir and Buzzard Creek areas, on the 1988 Priority List, have been combined as No. 30 on the Year 2002 Priority List. This is a result of hazard mapping by the Colorado Geological Survey, which showed that the two areas share very similar landslide problems as well as being adjacent and affecting the same clientele involving public land access, energy development, and recreational and residential use.

Deletions from the 1988 Priority List

(G) Area No. 9 on the 1988 Priority List is deleted from the Year 2002 Priority List. The hazard involves widespread but localized areas near stream banks in Douglas County that were subject to extreme erosion and shallow earthflows when disturbed. These areas are mostly in unincorporated parts of Douglas County. Officials and staff of the county are now well aware of the problem. They currently have two fulltime staff members reviewing and monitoring potential erosion, excess siltation, and earthflows as related to development proposals. No further action is needed at this time.

(H) Area No. 15 on the 1988 Priority List is being deleted from the Year 2002 Priority List. This area involved a single debris avalanche in a residential area of Beaver Creek, Eagle County. There has been no other debris flow events reported since 1985 at Beaver Creek. This isolated event is believed to have been caused by an improperly vacated irrigation ditch that saturated and destabilized hillslope regolith, which failed suddenly and initiated a debris avalanche and flow. The condition has now been corrected and should not cause a recurrence. This specific area is deleted, but the general area is included in the more extensive limits of No. 20 on the Year 2002 Priority List.

(I) Area No. 17 on the 1988 Priority List is being deleted. This area involved debris flow and landslide activity near Fourmile Creek north of Canon City in Fremont County. This was a very local incident where a Fremont County road was seriously affected by a debris slide in 1986. It was evaluated by CGS and found to be initiated by a leaking irrigation pipeline. Necessary repairs were made by Fremont County and the irrigation company. There have since been no recurrences and this area is dropped from the Year 2002 Priority List.

(J) Area No. 20 on the 1988 Priority List, the Roan Creek Landslide/Earthflow, is being deleted from the Year 2002 Priority List. A comprehensive evaluation described below enabled us to move this area from a very high priority in 1988 to being removed from the Year 2002 Priority List.

This large, new earthflow formed and advanced ominously overnight in April 1985. The Colorado Geological Survey assisted the State Office of Emergency Management staff in installing a warning system to alert a nearby rural resident if the flow advanced to where it was an immediate threat. In addition, CGS staff made a field reconnaissance of the landslide and its environs, and did photogeologic studies of adjacent reaches of Roan Creek to determine if similar older landslides had previously blocked the stream or shown other serious consequences. This preliminary report and evaluation was sent to Garfield County and the Division of Disaster Emergency Services (now Office of Emergency Management).

Immediately following the sudden occurrence and advance of this large landslide in April 1985, there were several areas of interest and concern. These included: a) urgent concerns for the home site and improvements of the ranch that were directly across the channel of Roan Creek from the snout of the advancing earthflow; damage could potentially have resulted from either direct action of the massive earthflow, or from rapid erosion of the highly erodible terrace materials upon which the buildings were located, if the channel became partially blocked, b) serious concern that a "landslide dam", with a subsequent flood release, could occur if the earthflow continued to enlarge and advance, c) concern increased when another landslide occurred on the opposite (north) side of Road Creek Valley, and d) the Roan Creek Earthflow was considered an excellent opportunity to study and map a newly emplaced large earthflow.

For all of the above reasons, the Roan Creek Landslide area was selected along with a dozen other active landslide hazard areas in Colorado for new stereoscopic aerial photography in 1985. The aerial photography was made possible by Emergency Funds disbursed to the CGS from the Governor's Office.

To meet the first concern, CGS worked with the Division of Disaster Emergency Services and the landowner to arrange an emergency monitoring and alarm system. Observations showed that advance had slowed to negligible in a few weeks, and there has been no evidence of significant mass movement since. The CGS also assigned staff geologist Julia Turney to do a reconnaissance report on the active landslide, and to do a photogeologic scan of adjacent areas of Roan Creek to see if there had been earlier valley–blocking landslides. This report (Turney, 1985) concluded that there was no evidence of such landslide events, and that landslides from the north valley landside did not appear to have the "runout potential" of the 1985 and earlier earthflows originating from the south (north-facing) valley side. In general, even the largest older earthflows had only reached a mid-valley terminus.

For a more complete and technical analysis of the earthflow and its valley-blocking potential, a Master's thesis by David Umstot of Colorado School of Mines was commissioned. This study had the advantage of new large-scale aerial photography and detailed post-slide topography compiled from the aerial photography. Mr. Umstot's conclusions were very similar to the earlier CGS report (Umstot, 1989). There was no evidence of serious landslide damming in the past, and if the channel was affected, it would quickly re-establish its channel in the erodible valley-fill deposits. The landslides from the north valley wall were smaller and "dryer" and in general did not run out into the valley floor as far (this conclusion included the "Phantom Landslide" which had occurred opposite the larger Roan Creek earthflow in 1985).

Year 2002 evaluation and recommendations

A detailed study and continued follow-up observations show no indication of serious further advance of the Roan Creek earthflow since 1985. Photogeologic studies also show that several much earlier earthflows from the south valley side of that reach of Roan Creek did not block the valley to the extent that the creek could not maintain its channel in the valley fill. Small debris flows and less mobile landslides can occur from the north valley side slopes. These will probably not reach the valley floor, but will continue to affect the county road on that side.

Because the level of information now available allows us to exclude the probability of a catastrophic (valley blocking) event in the area, it is recommended that this landslide be deleted from the Year 2002 Priority List. However, it should be maintained as an active file with occasional CGS field inspections and contact with Garfield County road and emergency service officials as needed.

(K) When the 1988 Priority List was prepared, there were reports of partial failure in the dam embankment of the water supply reservoir for the town of Oak Creek in Routt County (area No. 46). This was a matter of great concern to the Office of Emergency Management at that time. The matter was referred to the Dam Safety Section of the Colorado Water Resources Division and was resolved. Area No. 46 is now deleted.

(L) Area No. 47 on the 1988 Priority List is being deleted from the Year 2002 Priority List. This area involved landslides that affected Dunkley Pass road in Routt and Rio Blanco counties. There have been no new reports of serious problems in this area. It is primarily a U.S. Forest Service access road that connects with a Routt County road on the east and a Rio Blanco County Road on the west. Because of its remoteness and lack of reported landslide activity, it is being deleted from the Colorado Landslide Priority List for year 2002.

SUMMARY AND CONCLUSIONS

The Colorado Landslide Mitigation Plan has been in place more than fourteen years. The Priority List of Critical Landslides of that document has been reviewed, updated and revised. This report presents the review and revision process and the resulting Year 2002 Priority List. Of the 49 areas listed in 1988, thirty have remained intact on the new list. Six areas were deleted, either because of effective mitigation or additional information that downgraded the perceived hazard. Eight listings from the 1988 Priority List were “doubled up” with an adjacent hazard area to form four larger hazard areas. Four very small hazard areas on the 1988 priority list are now included in two extensive hazard-corridor areas. Finally, nine entirely new areas have been added, based on new landslide activity and information.

The alphabetical order used for the 1988 priority list has been replaced by a system of three tiers, which are based on estimates of the severity of the hazard and extent or magnitude of potential impacts. Although the priority landslide areas of the Year 2002 Priority List are numbered sequentially from 1 through 46 [Editor’s Note: plus area 10.5], there is no intent to indicate relative severity except for the tier designation.

Creation and maintenance of a Priority Landslide List is of necessity an ongoing process. New landslide events occur and new hazard studies are completed, and our knowledge of natural and human derived influences evolves. The extent and intensity of our use of the land continues to increase to accommodate Colorado’s rapid population growth, with accompanying needs for residential, infrastructure and commercial development. All of these factors place more people and facilities in potentially hazardous areas, creating new hazard situations. On the other hand, some listed hazard areas may be effectively mitigated, and additional knowledge of other previously listed areas may allow them to be removed or downgraded. For these reasons, we conclude that the landslide priority list should be thoroughly reviewed and revised as needed, but at no greater than ten-year intervals.

The Year 2002 Priority List, as well as all previous lists (e.g., Rogers, 1986; Jochim and others, 1988; Colorado Water Conservation Board, 1985), were derived from the collective knowledge and experience of the Colorado Geological Survey staff during the past 35 years. During that time, we had extensive contact with other geologists and engineers, and participated in numerous cooperative landslide projects with CDOT, U.S. Geological Survey, U.S. Bureau of Reclamation, local governments, and professional consulting organizations. We have also worked with staff and graduate students at many academic institutions to encourage and support geologic hazard studies. This combination of institutional knowledge and valuable input from our peers has provided us with the background to identify and spotlight 47 critical landslide areas for special attention. It is our hope that this list will continue to be useful in focusing scarce staff and funding resources from many sources: state, federal and local government as well as academic and private sources to evaluate and mitigate Colorado’s most severe landslide hazards.

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In a broader context, stalwart support and encouragement for the challenging task of maintaining a landslide program throughout my tenure at the CGS came from colleagues and managers at the Colorado Geological Survey, the Colorado Department of Transportation, the U.S. Geological Survey, and the Colorado Office of Emergency Management. Many other federal, state, local government, academic, and private industry groups and individuals contributed assistance and support in a variety of ways. The importance of this networking with the many other dedicated workers in the field of landslide studies cannot be over emphasized. With the ebb and flow of official/public interest and funding for landslide studies and mitigation, the peer-group contacts helped to maintain a subsistence-level program during the inevitable lean years. For such contributions by a very large number of unnamed individuals, we also express our sincere thanks.

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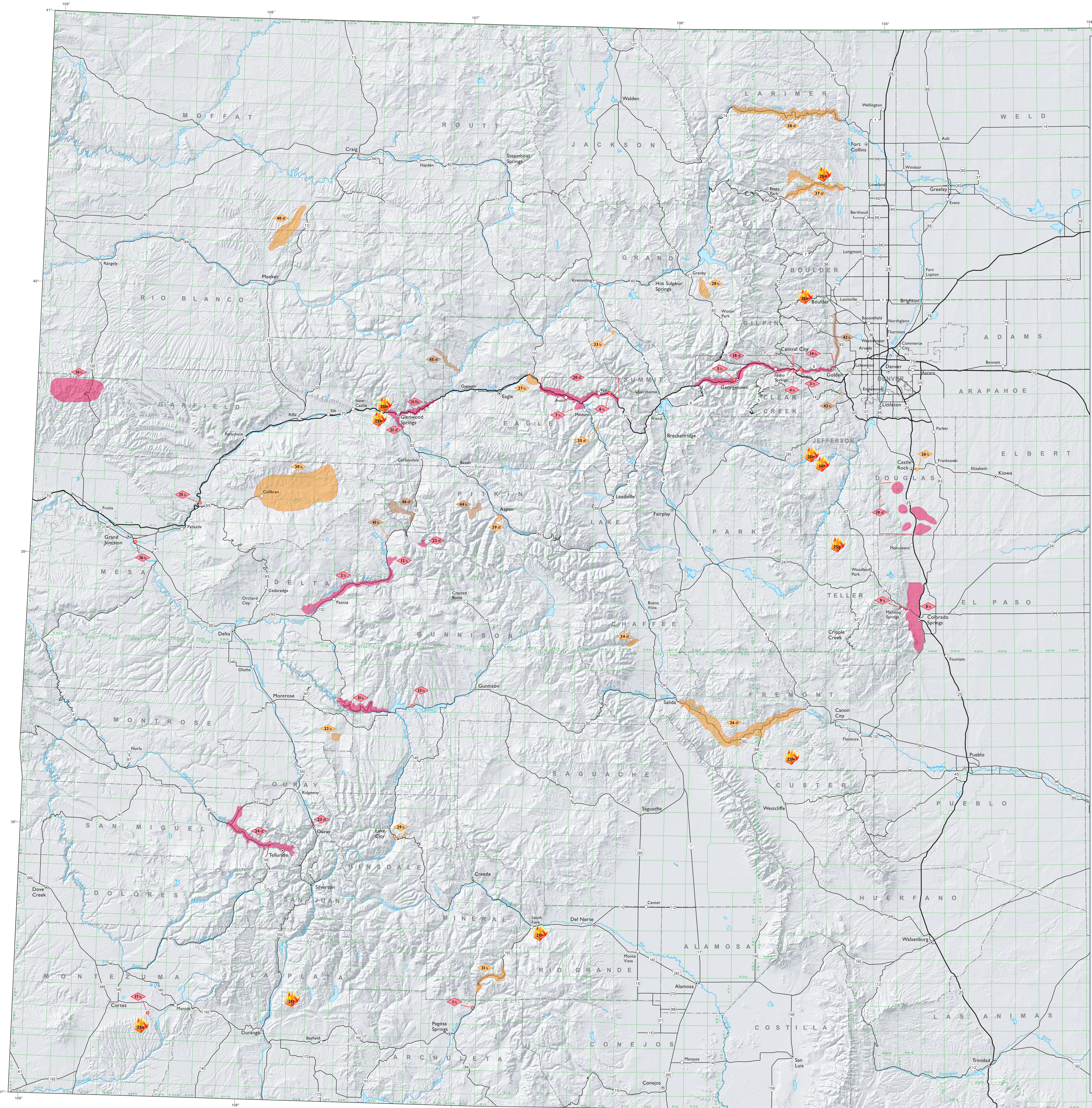
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN FILE REPORT 03-16
CRITICAL LANDSLIDES OF COLORADO
MAP PLATE 1 OF 1
2005

CRITICAL LANDSLIDES OF COLORADO

By William P. Rogers



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LANDSLIDE LOCATIONS AND CAPSULE DESCRIPTIONS

Tier One Landslide/Rockfall Areas

No.	Name of Feature	Location and Center Township	Description and Impacts, References (as numbered in text)
1 ls	San Juan River (Jackson Mountain), landslide	Archuleta County, 0.5 mile below confluence of East Fork and West Fork. T. 36 N., R. 1 W.	Active landslide affecting U.S. Hwy. 160 and utility lines. It is known to have been active since about 1970 and has severed the highway several times since then, requiring closures.
2 ls	North Fork of Gunnison River, landslide areas	Delta and Gunnison Counties, North Fork corridor from Hotchkiss to the Paonia Reservoir. T. 13 S., R. 90 W.	Extremely active landslides along entire corridor, severe rockfall hazard on west side of Paonia Reservoir. Landslides affect Colo. Hwy.133, D&RGW Railroad (now Union Pacific), mine and irrigation facilities of the valley. **27**
3 ls	Clear Creek Forks (Junction), rockslide	Clear Creek County, south side of Clear Creek Canyon on U.S. Hwy. 6 near junction with Colo. Hwy. 119. T. 3 S., R. 72 W.	Active rockslide showing intermittent slow movement since 1940s. Highway damage is ongoing and blockage of Clear Creek is possible. **47**
4 ls	Floyd Hill grade, rock and debris slide area	Clear Creek County, on I-70 east of U.S. Hwy. 6 junction near bottom of Floyd Hill grade. T. 4 S., R. 72 W.	Large intermittently active rock and debris slide affecting I-70. Blockage of Clear Creek is possible.
5 ls	Georgetown Incline, rockfall area	Clear Creek County, on west side of I-70 and extending from Georgetown to Silver Plume. T. 4 S., R. 74 W.	Very severe rockfall hazard from steep cut slopes and natural slopes. Causes damage, high maintenance and closures of westbound I-70 lanes. Hazard to travelling public including vehicle damage, injuries and occasional fatalities. Major mitigation was begun in 2002. **1**
6 ls	Booth Creek, rockfall area	Town of Vail, Eagle County, on debris fan of Booth Creek. T. 5 S., R. 80 W.	Very severe rockfall hazard to affected residents. Partially mitigated by ditch and berm barrier in 1990. Western part of area in the condominium area urgently needs barrier construction. **57, 70**
7 ls	Dowds Junction, landslides	Eagle County, at junction of I-70 and U.S. Hwy. 24 on southwest side of both highways. T. 5 S., R. 81 W.	Complex of four large old landslides, activated in lower regions (toes) by highway construction. Continuing, sporadic damage to both I-70 and U.S. Hwy. 24. The Dowds No. 1 slide shows slow, large-scale ongoing movement west of the eastbound I-70 Eagle River bridge. This entire area is a case study in the 1988 Colorado Landslide Mitigation Plan. **18, 22, 26, 36, 52**
8 ls	City of Colorado Springs, reactivated old landslides	City of Colorado Springs, El Paso County, various locations between I-25 corridor and the mountain front. T. 14 S., R. 67 W.	Extensive areas of marginally stable hill slopes and old landslides. Modification under urbanization triggers sporadic landslides, damaging or destroying residences and infrastructure. **7, 14, 71**
9 ls	Manitou Springs town site, rockfall, debris flow and flash flood area	Manitou Springs town site and vicinity, El Paso County. T. 14 S., R. 67 W.	Much of the existing town site and adjacent growth areas are subject to intermittent rockfall, landslide, debris flow, and flash flooding activity.
10 ls	Douglas Pass/Baxter Pass region, landslide and debris flow areas	Garfield County, a very broad area including the passes and approaches on both sides of the Colorado River/White River divide. T. 5 S., R. 102 W.	This is an extremely active landslide and debris flow area that affects Colo. Hwy. 139, a county road, and critical energy-related infrastructure facilities. **58, 61**
10.5 ls	Glenwood Canyon along I-70 corridor, rockfall areas	Garfield county, along I-70, corridor at numerous locations in Glenwood Canyon. T. 5 S., R. 88 W.	Renewed rockfall activity has occurred in the past few years on the I-70 corridor through Glenwood Canyon. High cliffs and unstable rock slopes extend above the roadway at numerous locations. During construction of I-70 about fifteen years ago, the severe rockfall potential was recognized. The rockfall hazard mitigation implemented at that time served well until recently, when serious rockfall events occurred that have impacted the traveling public and required highway closures. Restudy and improved mitigation is needed. **1**
11 ls	Black Mesa, landslide, earthflow and rockfall corridor	Gunnison and Montrose counties, along Colo. Hwy. 92, from vicinity of Blue Mesa Reservoir dam westerly along the north rim of the Black Canyon of the Gunnison River. T. 49 N., R. 5 W.	This highway corridor is periodically subject to landslides, earthflows, and rockfall. The new status of the Black Canyon as a National Park will greatly increase the need for safe and adequate access to the North Rim sites along the Colo. Hwy. 92 alignment. **1, 40**
12 ls	East Muddy Creek, landslides and earthflows	Gunnison County, on east side of Muddy Creek and Colo. Hwy. 133, starting just upstream of Paonia Reservoir and extending about 2.5 miles north. T. 12 S., R. 89 W.	This is currently a very active landslide area that is a reactivated older landslide complex. Monitoring and surface observations show continuing movement with the south slide being the most threatening. Disruption of Colo. Hwy. 133 and blockage of the flow of Muddy Creek appear to be impending. **2, 59, 62, 63, 65**
13 ls	Red Creek, landslide	Gunnison County, on U.S. Hwy. 50 and north shore of the Blue Mesa Reservoir near Red Creek. T. 49 N., R. 3 W.	This is a reactivated, old landslide that extends below the reservoir level and periodically causes extensive damage to the highway. **69**
14 ls	Clear Creek Canyon/US Hwy 6, rockfall corridor	Jefferson and Clear Creek Counties, along U.S. Hwy. 6 corridor in Clear Creek Canyon from near Golden to the junction of U.S. Hwy. 6 and I-70 east of Idaho Springs. T. 3 S., R. 71 W.	This hazard corridor consists of intermittent to nearly continuous rockfall segments that seriously affect safety and maintenance of U.S. Hwy. 6. There is greatly increased traffic and exposure to the public since low stake gambling was initiated in Black Hawk and Central City. **1**
15 ls	DeBeque Canyon (Tunnel), landslide	Mesa County, on south side of I-70 and the Colorado River, within DeBeque Canyon and about 1 mile upstream from the I-70 Beaver Tail Tunnel. T. 10 S., R. 97 W.	This is a complex landslide that had its modern origin in a catastrophic rockslide/landslide early in the 20th century. Currently, it periodically disrupts the I-70 highway. A comprehensive geotechnical study was completed in April, 2000 by CDOT, CGS, Golder Associates, and CSM. **23**
16 ls	Lamplite Park, landslide	Grand Junction, Mesa County, in the Orchard Mesa area adjacent to the Colorado River. T. 1 S., R. 1 W. (Ute Meridian)	This landslide is periodically activated by bluff retreat caused by the Colorado River eroding the bluff base. Ten homes were damaged and removed in the 1980s and three residences remain in the high hazard zone. This site was a case study in the Colorado Landslide Mitigation Plan of 1988. **11, 13, 26**
17 ls	Mesa Verde National Park, access road landslide	Montezuma County, Point Lookout area of Mesa Verde National Park access road. T. 35 N., R. 14 W.	This is a mile-long segment of the main (and only) access road that has been subject to repeated landslides since the Park opened in 1929. The landslides have caused closures and detours that are a frequent and serious detriment to this popular National Park. **20, 39**

Tier One Debris Flow Areas

No.	Name of Feature	Location	Description and Impacts, References
18 df	Clear Creek/I-70 corridor, debris flow and rockfall areas	Clear Creek County, along I-70 from its junction with U.S. Hwy. 6 east of Idaho Springs to the East Portal of Eisenhower Memorial Tunnel. T. 3 S., R. 74 W.	Intermittent debris flow and rockfall areas, including parts of most towns and development clusters. Threatens public and private property, the traveling public and the I-70 roadway. Will become even more important if this route becomes a rapid transit corridor. **1, 9, 10, 14, 33, 50, 55, 72**
19 df	Steep sideslopes of mesas, Douglas County, debris avalanches	Douglas County, near I-25 corridor between Castle Rock and the El Paso County line. T. 10 S., R. 67 W.	Certain steep mesa sideslopes and adjacent footslope areas are subject to debris avalanching and debris flow runout. These events are sporadic but potentially very dangerous. **51**
20 df	Vail and adjacent development corridor, debris flow areas	Eagle County, intermittent to nearly continuous areas from East Vail to Wolcott in the valleys of Gore Creek and the Eagle River. T. 5 S., R. 81 W.	These debris flow hazard areas consist of the debris/alluvial fans of tributary streams as they reach the major valley floors. They are subject to frequent but unpredictable debris flow events. Some areas also subject to snow avalanches. **33**
21 df	Glenwood Springs and vicinity, debris flow areas	Glenwood Springs town site and vicinity, Garfield County. T. 6 S., R. 89 W.	More than 20 steep mountain stream courses enter the narrow valley floors of the Colorado and Roaring Fork rivers in and around Glenwood Springs. The area has been severely impacted throughout its history by damaging debris flows. Underlying older deposits of these debris fan areas are composed of hydrocompactive soils that cause additional potential building hazards. The Glenwood Springs area was a case study in the 1988 Colorado Landslide Mitigation Plan. **19, 26, 30, 32**
22 df	Marble town site and vicinity, debris flows	Marble town site, Gunnison County, on the extensive debris/alluvial fans of Carbonate and Slate Creeks and other smaller creeks of the area. T. 11 S., R. 88 W.	The debris/alluvial fans of this area are subject to frequent and destructive debris flows that have plagued the area throughout its history. Active channels of the fans shift often and most of the remaining structures are quite vulnerable to future flow events. **28, 37, 45, 46**
23 df	Ouray town site and vicinity, debris flows	Ouray town site and adjacent areas, Ouray County. T. 44 N., R. 7 W.	Because of its location in the narrow canyon of the Uncompahgre River, Ouray is located almost entirely on the debris/alluvial fans of Portland, Cascade and Oak Creeks, all of which have been subject to numerous large and destructive debris flows events in historic times. Recent development has occurred on the fan of Sky Rocket Creek, and other debris fan areas may be considered for future development. Some structural mitigation is in place but may not be adequate to protect lives and property from future large debris flow events. **25**
24 df	Telluride and San Miguel River corridor, debris flow and rockfall areas	Telluride town site and vicinity, San Miguel County, including the San Miguel River Valley corridor west to Placerville. T. 43 N., R. 10 W.	This entire area is subject to frequent debris flows from the numerous, steep tributary streams that form the debris fans of the valley fringe. Rockfall is also a serious hazard, especially from the cliffs of the north valley wall. Present and future residential areas and infrastructure are vulnerable at many locations. In August 2001, more than 20 debris flows caused havoc along the entire Colo. Hwy. 145 corridor of this area. Roads were engulfed and damaged and vehicles were swept into the San Miguel River. **14, 35, 64**
25	New and recent wildfire burn areas, potential for debris flows, rockfalls, and extreme erosion	Various locations throughout forest and brush land of Colorado. These include the following recent wildfire areas: **25a** Mesa Verde National Park, Montezuma County. T. 35 N., R. 14 W., 2000 **25b** Storm King Mountain, Garfield County. T. 5 S., R. 89 W., 1994 **25c** Hi Meadows, Jefferson County. T. 7 S., R. 71 W., 2000 **25d** Bobcat, Larimer County. T. 6 N., R. 71 W., 2000 **25e** Black Tiger, Boulder County. T. 1 N., R. 71 W., 1989 **25f** Buffalo Creek, Jefferson County. T. 8 S., R. 71 W., 1996 **25g** Hayman, Teller and Douglas Counties. T. 11 S., R. 70 W., 2002 **25h** Iron Mountain, Fremont County. T. 20 S., R. 72 W., 2002 **25i** Million, Rio Grande County. T. 39 N., R. 3 E., 2002 **25j** Missionary Ridge, La Plata County. T. 36 N., R. 8 W., 2002 **25k** Coal Seam, Garfield County. T. 6 S., R. 90 W., 2002	Loss of vegetative cover and water repellent soils resulting from wildfire burns can vastly increase the sediment and debris flow potential of watersheds. Recent examples include Black Tiger Gulch, Boulder County; Storm King Mountain, Garfield County; and Buffalo Creek in Jefferson County. In all of these areas, there were extremely severe and dangerous debris flow and flash flood events following wildfires. The hazards tend to diminish through time as the burn areas become revegetated. As this report was in final preparation, several major wildfire burn areas of 2002 were added. **3, 4, 5, 6, 16, 24, 29**

Tier Two Landslide/Rockfall Areas

No.	Name of Feature	Location	Description and Impacts, References
26 ls	Town of Castle Rock, rockfall areas	Castle Rock town site, Douglas County, residential areas at base of the low cliffs in the northeast part of town. T. 8 S., R. 67 W.	Large slabs of caprock can become detached and move both as rockslide and rockfall during seasons of high slope moisture. One serious event that occurred in 1981 was detected and mitigated without property damage or injury. **14, 51**
27 ls	I-70 corridor and adjacent private lands near Wolcott, landslide	Eagle County, I-70 roadway and private lands from Bellyache Ridge northeast to I-70 near Wolcott. T. 4 S., R. 83 W.	Very large, old landslide complex that has been re-activated in part by construction of I-70. Adjacent private lands to the southwest are marginally stable and suitable only for selective and prudent development. **42**
28 ls	Fraser Canyon (Amtrak), landslide areas	Grand County, in the Fraser River Canyon between Tabernash and Granby. T. 1 N., R. 76 W.	This area is subject to landslides, debris flows and rockfall. A very small landslide in 1985 severed the embankment and tracks, resulting in a major derailment of the Amtrak passenger train. Mitigation has been done and warning devices have been installed. This area typifies many of the hazardous canyons of Colorado with vulnerable railroad routes. **12, 48**
29 ls	Slumgullion landslide/earthflow	Hinsdale County, near Lake City on the Lake Fork of the Gunnison River. T. 43 N., R. 4 W.	This very large and famous landslide/earthflow formed the natural dam that created Lake San Cristobal. The upper part is very active and is a long-range threat to Colo. Hwy. 149. Extensively studied by the U.S. Geological Survey and is not believed to pose short-term hazards. **17, 21, 38, 49, 68**
30 ls	Vega Reservoir and Buzzard Creek area, landslides and earthflows	Mesa County, in the area surrounding Vega Reservoir and Buzzard Creek to the vicinity of Collbran. T. 9 S., R. 93 W.	These areas have historically been very prone to landslides. The most recent widespread events were in the middle 1980s. At risk are public roads that provide access to residential, recreational and energy production activities. **53, 54**
31 ls	Wolf Creek Pass area, landslides, debris flows and rockfall	Mineral County, Colo. Hwy. 160 corridor on both sides of Wolf Creek Pass. T. 37 N., R. 1 E.	This has historically been an area of unstable slopes, rockfall and landslides. CDOT has corrected many of these problems in the past 15 years, improving the reliability and safety of the highway for the traveling public. **37**
32 ls	Wells Basin, landslide	Montrose County, on west side of the Cimarron River Valley five miles south of the Cimarron community. T. 47 N., R. 7 W.	The Wells Basin topographic feature is created by a very large old landslide. A very active landslide that is a small part of the older landslide has moved about a thousand feet, displacing Montrose County Rd. P77 and the irrigation ditch that is adjacent. Efforts to mitigate have had very limited success to date.
33 ls	Green Mountain Reservoir area, old landslide complex	Summit County, on the south shore of Green Mountain Reservoir, including all or most of the community of Heeney. T. 2 S., R. 80 W.	This is a large, ancient landslide that has been mapped as extending 1.5 miles along the south shore of Green Mountain Reservoir. It probably extends below reservoir levels. New movement during 2002 drought as a result of reservoir draw down is under evaluation by USBR. **41**

Tier Two Debris Flow Areas

No.	Name of Feature	Location	Description and Impacts, References
34 df	Chalk Creek area, debris flows and rockfall	Chaffee County, along Chalk Creek in the vicinity of Mt. Princeton Hot Springs and extending to the base of the Chalk Cliffs to the northwest. T. 15 S., R. 79 W.	This area consists of multiple debris flow fans with numerous shifting distributary channels. Rockfall hazards are present below the Chalk Cliffs. At risk are numerous residential structures and youth summer camp facilities. Little or no mitigation has been done and both existing and future development needs attention. **37**
35 df	Red Cliff town site, debris avalanche and rockfall	Red Cliff town site, Eagle County, north side of town from "high road" to Turkey Creek. T. 6 S., R. 80 W.	This area experienced very severe debris avalanche/debris flow activity in 1984 and 1985. Cooperative efforts by state agencies and Eagle County assisted in structural mitigation that should be monitored for condition and performance. Rockfall hazard has not been evaluated, but may be serious. **34, 60**
36 df	Lower reaches and alluvial fans of Arkansas River tributaries	Fremont County, along U.S. Hwy. 50 and Arkansas River corridor between Salida and Parkdale. T. 48 N., R. 12 E.	U.S. Hwy. 50, Colo. Hwy. 69 and county roads have been flooded periodically with rock, mud, woody debris and flood water, requiring frequent cleanup and roadway repairs after the large events.
37 df	Tributary streams to Big Thompson River, debris flows and flash flooding	Larimer County, Big Thompson Canyon/U.S. Hwy. 34 corridor between Loveland and Estes Park. T. 5 N., R. 71 W.	This is the area of the catastrophic flood in Big Thompson Canyon of 1976. Much of the damage and loss of life at that time was from debris flows and debris slides that accompanied the mountain-torrent flooding. Most destroyed homes were not rebuilt, and more conservative land use regulations have decreased but not eliminated hazards of this area. **31, 56**
38 df	Poudre River corridor, debris flows, landslides	Larimer County, Colo. Hwy. 14 corridor in Poudre Valley between Fort Collins and Rustic. T. 8 N., R. 72 W.	This corridor contains numerous residential and commercial clusters and campgrounds as well as Colo. Hwy. 14. All are vulnerable to mountain-torrent flooding, isolated debris flows, debris or rockslides. A large rockslide in 1999 caused a six-week road closure.
39 df	Aspen Mountain Ski Area and vicinity, debris slides and debris flows	Pitkin County, in and adjacent to the ski area and in resedential areas on debris fans or foot slopes. T. 10 S., R. 85 W.	Several slope failures and/or debris flows have occurred in the 1980s and 1990s. Considerable mitigation has been done by the ski area and other property owners. The area still has potential for further problems and should be closely monitored by owners and city/county officials. **8**
40 df	Devils Hole Gulch / Wilson Creek area, debris flows, landslides and extreme erosion	Rio Blanco and Moffatt Counties, starting approximately 10 miles NNW from Meeker and extending along Devils Gulch, through the Wilson Creek Oil Field and northeast along the axis of Wilson Creek to its confluence with Taylor Creek. T. 3 N., R. 94 W.	This area experienced extreme debris flow, landslide, and erosion activity in the middle 1980s. County roads, oil field roads, and electrical transmission lines were severely damaged. The facilities have been repaired or relocated, but future damage of a similar nature is probable.

Tier Three Landslide/Rockfall Areas

No.	Name of Feature	Location	Description and Impacts, References
41 ls	West side of McClure Pass along Lee Creek, landslides and earthflows	Gunnison County, on the west side of Lee Creek on Colo. Hwy. 133 about 5 miles past the summit of McClure Pass. T. 11 S., R. 89 W.	These landslides originate in weak and unstable soil and rock that are upslope from Colo. Hwy. 133. They displace the roadway and become shallow earthflows on lower slopes below the highway. These were very serious during the period 1970-1986. Since that time, additional maintenance and repair have not been excessive. **45**
42 ls	Golden to Boulder along CO Hwy 93, landslides and earthflows	Jefferson and Boulder Counties, along Colo. Hwy. 93 from Golden to Marshall. T. 2 S., R. 70 W.	Slopes adjacent to the Colo. Hwy. 93 corridor are mostly composed of weak claystone bedrock and derived soils. Earlier routes were plagued by severe landsliding. During the last 15 years, much of the highway has been widened, realigned or relocated with generally excellent results.
43 ls	Morrison town water plant, landslide	Morrison town site, Jefferson County, in the southwest part of town near Bear Creek. T. 5 S., R. 70 W.	This landslide became active in 1985. Landslide material upslope from the water plant began to move downslope, threatening the facility. Most of the landslide mass was removed at the time, and no subsequent problems have been reported.
44 ls	Snowmass Village and vicinity, landslides, slumps, and earthflows	Snowmass Village and vicinity, Pitkin County, residential areas and ski lift tower locations. T. 10 S., R. 86 W.	In the 1970s and 1980s there were numerous landslide problems both in developing residential areas and with structures on the ski slopes. Local governments, ski area managers, and developers and their consultants are aware of the problems, and appear to have been successful in dealing with them during the past 12 years.

Tier Three Debris Flow Areas

No.	Name of Feature	Location	Description and Impacts, References
45 df	Sweetwater Creek area, debris flows	Garfield and Eagle Counties, along Sweetwater Creek north of Dotsero. T. 3 S., R. 87 W.	This is a remote area that is still sparsely developed with recreational and residential facilities, especially near Sweetwater Lake. Numerous debris flows that required roadway maintenance were reported and investigated by CGS in 1985. There have been no subsequent reports of serious problems.
46 df	Dutch Creek, Coal Creek, and Redstone area, debris flows, backwater flooding, and erosion	Redstone town site, Pitkin County, channels of Coal Creek and tributaries from the Crystal River at Redstone to the Coal Creek basin coal mining area. T. 10 S., R. 88 W.	Tributaries of the upper basin continue to experience frequent, large debris flows, but the coal mines are abandoned and under reclamation. The remaining hazard is at Redstone where the debris from the upper basin obstructs the confluence of Coal Creek and the Crystal River, causing backwater flooding and erosion that affects the town site and Colo. Hwy. 133. Town, county, and CDOT maintenance staff deal with these problems each year during spring runoff.

EXPLANATION

Landslide or Rockfall Area or Corridor *

12 ls — **Tier One landslide**—denoted by magenta/red color, listings are serious cases needing immediate or ongoing action or attention because of the severity of potential impacts. Identification number of landslide or rockfall area or corridor inside diamond. Approximate location of smaller landslide or rockfall area indicated by circle, approximate extent of larger landslide or rockfall area indicated by polygon.

30 ls — **Tier Two landslide**—denoted by orange color, cases are very significant but less severe; or where adequate information and or some mitigation is in place; or where current development pressures are less extreme. Identification number of landslide or rockfall area or corridor inside diamond. Approximate location of smaller landslide or rockfall area indicated by circle, approximate extent of larger landslide or rockfall area indicated by polygon.

44 ls — **Tier Three landslide**—denoted by brown color, cases are similar to Tier Two, but with less severe consequences or primarily local impact. Identification number of landslide or rockfall or corridor inside diamond. Approximate location of smaller landslide or rockfall area indicated by circle, approximate extent of larger landslide or rockfall area indicated by polygon.

Debris Flow Area or Corridor *

22 df — **Tier One debris flow**—denoted by magenta/red color, listings are serious cases needing immediate or ongoing action or attention because of the severity of potential impacts. Identification number of debris flow area or corridor inside diamond. Approximate location of smaller debris flow area indicated by circle, approximate extent of larger debris flow area indicated by polygon.

25c — **Tier One wildfire burn**—approximate location denoted by flame symbol, listings are serious cases needing immediate or ongoing action or attention because of the severity of potential impacts. Identification number of wildfire burn area inside flame.

35 df — **Tier Two debris flow**—denoted by orange color, cases are very significant but less severe; or where adequate information and or some mitigation is in place; or where current development pressures are less extreme. Identification number of debris flow or corridor inside diamond. Approximate location of smaller debris flow area indicated by circle, approximate extent of larger debris flow area indicated by polygon.

46 df — **Tier Three debris flow**—denoted by brown color, cases are similar to Tier Two, but with less severe consequences or primarily local impact. Identification number of debris flow or corridor inside diamond. Approximate location of smaller debris flow area indicated by circle, approximate extent of larger debris flow area indicated by polygon.

Data Sources

State Boundary modified from Colorado Department of Transportaion

Counties and Highways from Colorado Department of Transportaion

Township and Range from Tobin International, Ltd.

100 meter Digital Elevation Model from U.S. Geological Survey

Digital Cartography by Jason C. Wilson

* Landslide (ls) or Debris Flow (df) designates only the predominant hazard process. More complete information and description of areas are contained in the accompanying text of the report.

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