Field Reconnaissance of Debris Flows Triggered by a July 21, 2007, Thunderstorm in Alpine, Colorado, and Vicinity

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Frontispiece. Oblique aerial view of debris flows in Weldon Gulch upslope from the community of Alpine. View to the northwest. Photograph by J.W. Godt on July 25, 2007. Total relief visible in the photograph is about 730 m.

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Abstract

On the evening of July 21, 2007, a slow-moving thunderstorm triggered about 45 debris flows on steep mountainsides near the community of Alpine, Colorado. Most of the debris flows were initiated by surface-water runoff that eroded and entrained loose sediment in previously existing channels. About 12 of the debris-flow channels were located in the lower half of Weldon Gulch upslope from Alpine, which is on a debris fan at the mouth of the Gulch. Most of these channels were deeply incised by the flows, and many of the resulting oversteepened channel banks are now failing and beginning to refill the channels with sediment. Debris flows that emerged from the mouth of Weldon Gulch primarily flowed onto the eastern half of the debris fan and closed roads and damaged vehicles and structures. Debris-flow deposits on the fan generally become finer grained and thinner with distance from the head of the fan. Given the existing conditions in Weldon Gulch, it is estimated that the debris-flow hazard on the fan has neither decreased nor increased as a result of the July 21 debris flows. Preventive measures that need to be considered by Alpine residents and government officials concerned with safety on the fan include: (1) establishing a channel and(or) catchment/diversion structure on the fan that routes future water and debris flows in a manner that protects existing roads and structures, and (2) maintaining vigilance during rainstorms by watching and listening for unusual flows of water or debris that may indicate debris-flow activity upstream, particularly during the summer months when thunderstorms are common in the area.

Introduction

On the evening of July 21, 2007, a slow-moving thunderstorm triggered debris flows that impacted the community of Alpine (frontispiece and fig. 1) in the valley of Chalk Creek about 19 km west of Nathrop, Colorado. The debris flows damaged structures in Alpine and closed roads in the immediate vicinity of Alpine. On July 24 and 25, 2007, landslide scientists from the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS) visited the Alpine area to define the areal extent of the event and inspect debris-flow source areas, transport paths, and deposits. This report summarizes the observations made during this visit and provides a preliminary interpretation of the ongoing hazard from debris flows on the fan in Alpine. Throughout this report, we use the term "debris flow", rather than “mudslide”, which is a term commonly used by print and television news media. A debris flow is defined as a poorly sorted mixture of soil, rock, vegetation, and water that rapidly flows downslope in response to gravity (Varnes, 1978; Iverson, 1997).

Geologic Setting of Alpine

The Chalk Creek Valley where Alpine is located is a formerly glaciated valley that contains glacial deposits and extensive younger rock-fall, colluvial, and debris-fan deposits. In the last 25 years, debris flows have been documented on debris fans along the north side of the Chalk Creek Valley to the east of Alpine (Dillon and Grogger, 1982; Mortimer, 1997; Coe and others, 2002; Coe and others, in press).

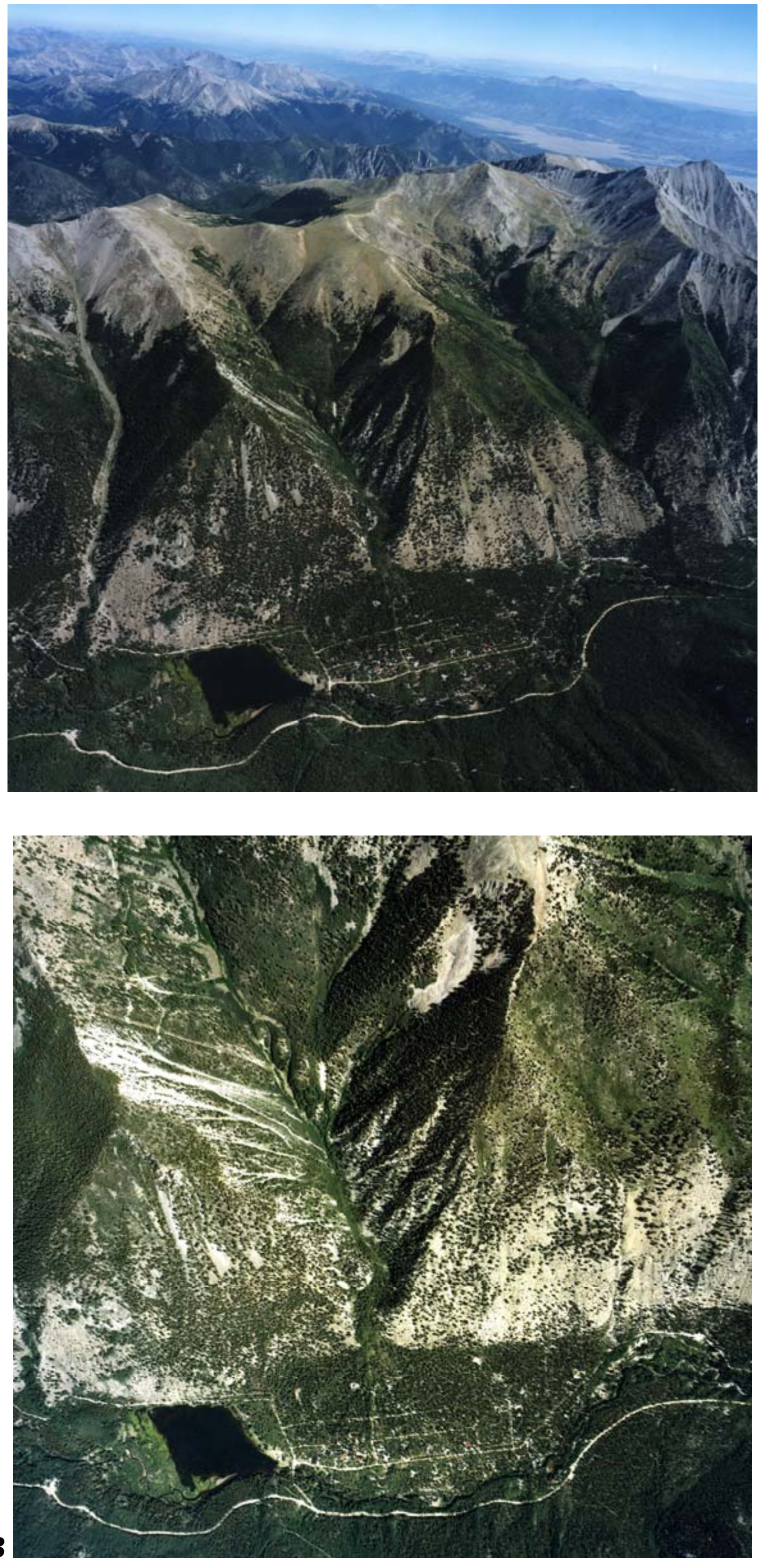
The Alpine town site is located on a large, vegetated debris fan at the mouth of Weldon Gulch on the north side of the Chalk Creek Valley (fig. 1). The debris fan is cone shaped and has maximum dimensions of about 1.3 km by 0.6 km. The average slope down the fall line from the head of the fan to the toe is about 9º. Debris flows of the magnitude of July 21 probably have not occurred on the fan in the last several decades based on statements of local residents. The existence of a previously undisturbed(?) cemetery on the surface of the eastern one-half of the fan that dates from the late 1800s indicates that major debris flows probably have not inundated the eastern one-half of the fan in the last 130 years.

The bedrock underlying Weldon Gulch and the northern flank of the Chalk Creek Valley is Tertiary quartz monzonite (Tweto and others, 1976). Several prospect pits, probably excavated into hydrothermally altered quartz monzonite, are visible in the field and on topographic maps of the area. Aerial photographs and field observations indicate that the surficial geology within the Gulch consists of deposits formed by glaciers, deep-seated landslides, and rock falls. Previously existing debris-flow tracks and deposits along the western flank of the Gulch are visible on aerial photographs taken in August 2002 (fig. 1*B*). On the basis of immature vegetation (predominantly small aspen trees) in the area of these tracks, and a steep, east-facing bedrock outcrop at the ridgeline near the head of the tracks, the area also appears to be a path for snow avalanches.

Rainfall Trigger for the July 21 Debris Flows

Residents of Alpine indicated that the debris flows occurred during a thunderstorm between about 6:30 and 7:30 p.m. on July 21 after about a week of periodic afternoon rainfall. A local resident whose house is located closest to the head of the debris fan, had a plastic, fence-post-style rain gage mounted on the side of his deck during the thunderstorm. He reported that this gage recorded about 76 mm (3 in.) of rainfall in about 1 hour, starting at about 6:30 and ending at about 7:30. This is the only known ground-based rainfall data in Alpine during the storm.

July 21, 2007 thunderstorm). *A*, Oblique photo with view to the north, and *B*, vertical photo.



A

B

Figure 1. Aerial photos of Weldon Gulch and Alpine taken on August 10, 2002 (prior to the July 21, 2007 thunderstorm). *A*, Oblique photo with view to the north, and *B*, vertical photo.

The meteorologist-in-charge at the National Weather Service (NWS) Weather Forecast Office in Pueblo, Colorado, described the storm that affected Alpine as a “slow-moving thunderstorm with heavy rain” (Bill Fortune, personal commun., August 1, 2007). Doppler-radar data available from the NWS office in Pueblo (fig. 2) indicated that rainfall from the thunderstorm was concentrated in the immediate vicinity of Alpine between 6:14 and 7:14 p.m. One-hour precipitation totals derived from radar data during this time (fig. 2) show rainfall amounts near Alpine that ranged from 13 mm (0.5 in.) to 44 mm (1.75 in.).

Three additional ground-based rain gages located east and northeast of Alpine recorded very small amounts of rain on the evening of July 21 and, thus, were in agreement with the radar data in indicating that the thunderstorm at Alpine was highly localized. Between 4 and 9 p.m. on July 21, a USGS rain gage located in the Chalk Cliffs area, about 9 km east of Alpine, recorded 0.3 mm of rain, and a Remote Automated Weather Station (RAWS) at the mouth of Cottonwood Canyon (the Red Deer station), about 14 km northeast of Alpine, recorded no rain. A gage at the Central Colorado Regional Airport in Buena Vista, about 18 km northeast of Alpine, recorded a daily total of 3 mm of rain on July 21.

Field Observations from July 24 and 25

Areal Extent of the Debris-Flow Event

Field reconnaissance consisted of hiking to debris flows on the ground and an overflight of the area in a light airplane. The overflight was used to assess the areal extent of debris flows. Consistent with the rainfall data, the areal extent of debris flows was highly localized. About 45 debris-flow tracks were visible from the air (fig. 3). About 80 percent of these tracks were either in the lower part of Weldon Gulch or along the steep north flank of the valley of Chalk Creek within 5 km of Alpine (fig. 3). The remaining tracks were located in the upper reaches of Sheep Canyon, Coal Camp Canyon, and Robey Gulch. The debris flows in these drainages initiated above tree line from landslides in talus. Debris flows in Weldon Gulch and along the north flank of the Chalk Creek Valley are described in the following sections.

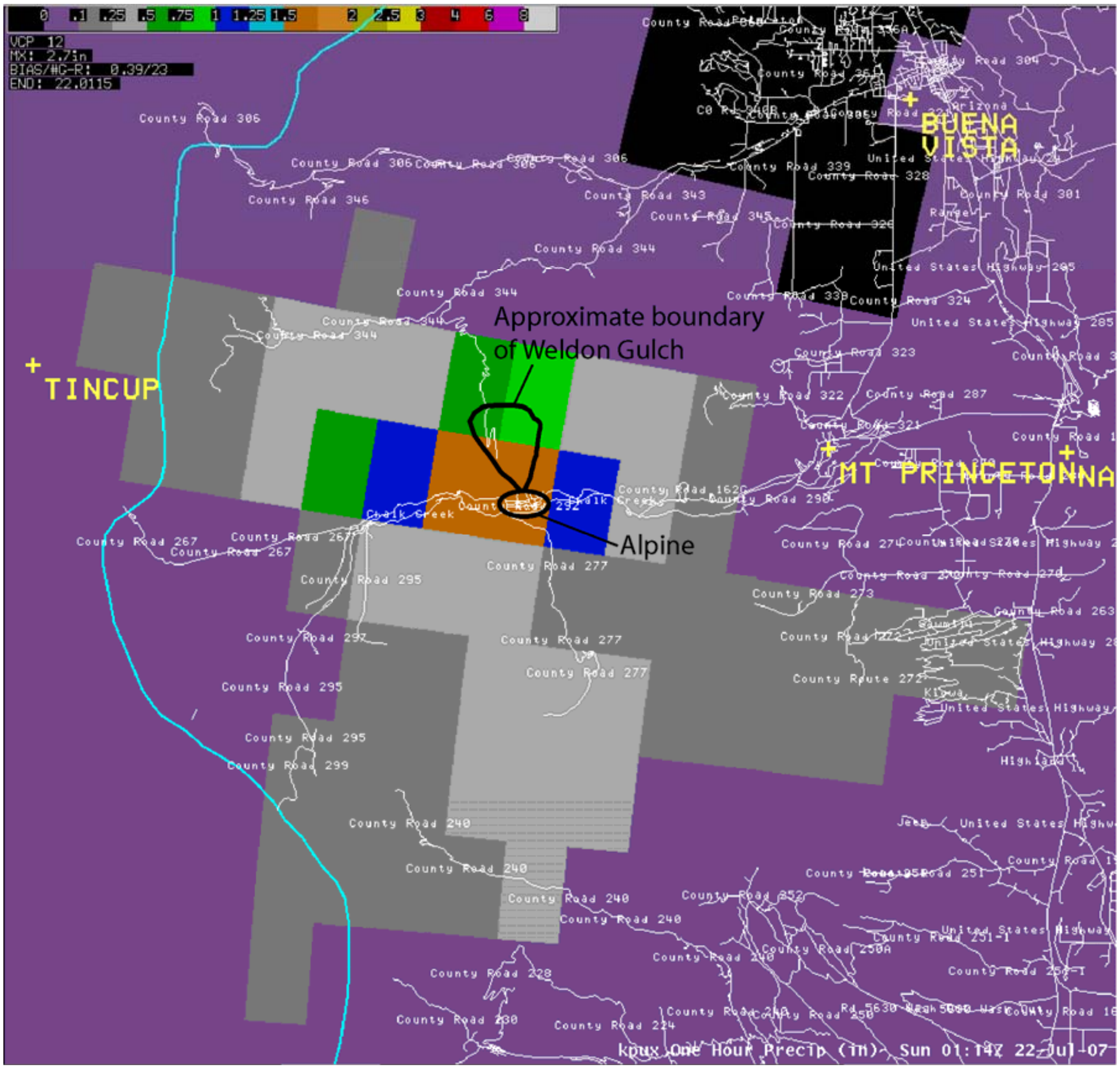


Figure 2. Image showing 1-hour precipitation in the southern Sawatch Mountain Range between 6:14 and 7:14 p.m. on July 21. Index in upper left corner shows rainfall amounts in inches. Horizontal distance across the image is about 35 kilometers. Image from National Weather Service Doppler Radar station KPUX at Pueblo, Colorado. Provided by Paul Wolyn, National Weather Service, Pueblo.

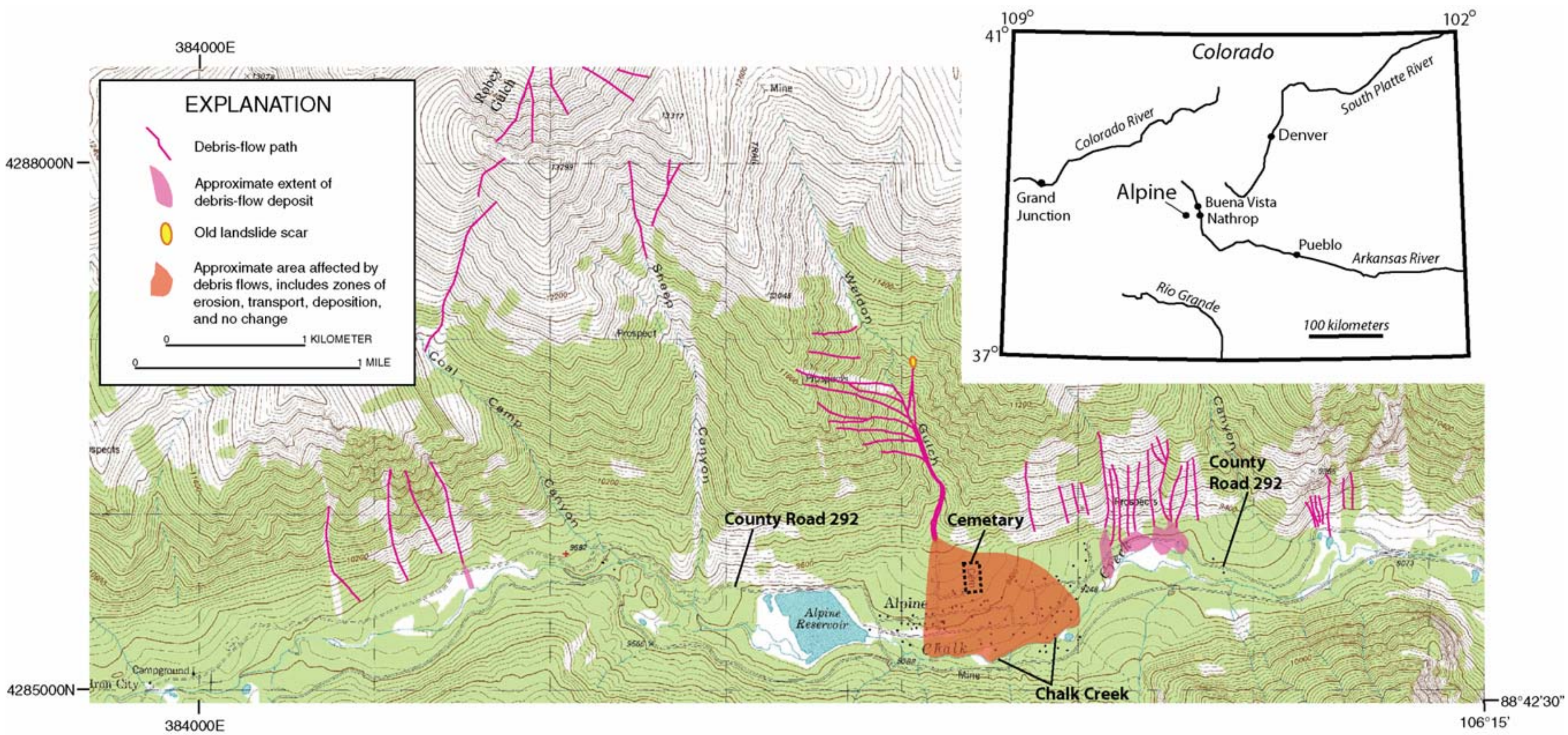


Figure 3. Reconnaissance map showing debris flows triggered by the July 21, 2007 thunderstorm. Base map from USGS St. Elmo quadrangle, scale 1:24,000. Universal Transverse Mercator, zone 13 values (meters) are shown on left side of map, latitude/longitude values are shown in lower right corner of map.

Weldon Gulch

The debris flows in Weldon Gulch were investigated by entering the Gulch from both the ridgeline at the head of the Gulch and from the mouth of the Gulch at the fan. The upper one-half of the Gulch (the part above tree line) did not contain any debris flows (fig. 3). There were no scars on slopes at the head or flanks of the upper Gulch, and the channel coming from the upper half of the Gulch was not eroded and did not appear to have transported debris. All of the debris flows initiated from the east and west flanks of the lower one-half of Weldon Gulch. On the east flank, debris flows initiated from several small, shallow landslides (fig. 4), and from entrainment of sediment through rilling and channel erosion by the runoff of water (fig. 4), within a large, pre-existing landslide scar (fig. 4). The rills and shallow slides were easily visible because they contrasted with undisturbed parts of the scar, which had grass and bushes growing on the surface. There were no large, unstable blocks of old landslide material visible in the scar, but the flanks of the scar were steep and appeared to be gradually failing by raveling and periodic, small earth falls. The slope on the undisturbed northern edge of the old landslide scar was 33º. The channel downslope from the old landslide scar was eroded by water runoff and debris flows flowing from the scar. The channel split into two channels approximately 100 m downslope from the old scar (fig. 3). Both of these channels existed prior to July 21. On the basis of exposed roots and soil horizons, incision in these two channels ranged from about 0.5 to 2 m (fig. 5). In some locations, bedrock was exposed in the channel bottoms. The best estimate is that sediment eroded from these two channels on the east flank of Weldon Gulch contributed approximately 10 to 20 percent to the total amount of debris deposited on the debris fan.

On the west flank of Weldon Gulch, debris flows initiated in about 10 previously existing channels (compare fig.1*B* with the frontispiece and fig. 6), 9 of which were directly downslope from steep bedrock outcrops (fig. 7). One channel was downslope from a mine dump (the northern most channel on the west flank of Weldon Gulch, see frontispiece and figure 3). The debris in this channel had been eroded from the dump by rilling, but was deposited on the western flank of Weldon Gulch and, thus, did not contribute any debris to the fan at Alpine. Field observations indicate that no other prospect pits or mine dumps were related to debris flows. The position of the nine debris-flow channels with respect to the bedrock outcrops (figs. 6 and 7), as well as a lack of slides at the heads of the channels, indicates that the initiation mechanism for the debris flows was entrainment of channel material from water running off the bedrock, commonly known as “firehose” initiation (Johnson and Rodine, 1984). Firehose initiation is caused by the mobilization of material by a concentrated flow of water, just as if the material had been washed away by a firehose. Deepening and widening of the channels by erosion was extensive. Most of the newly expanded channels had widths of 2 to 4 m and depths of 1 to 3 m (fig. 8*A*, *B*), but maximum widths and depths were 9 and 4 m, respectively (fig. 8*C*). The slope of undisturbed ground adjacent to the channels ranged from 30° to 35º. On the basis of exposed roots and soil horizons, it is estimated that incision of the channels from the July 21 storm ranged from about 0.5 to 3 m. Channel banks were nearly vertical (fig. 9) and were actively failing and contributing sediment to the channel bottoms (fig. 9). Bedrock was exposed in channel bottoms at some locations, but, in general, colluvium was exposed along the bottoms of most channels. Fresh debris-flow levees and lobes were common along the flanks of channels, particularly in the middle and lower parts of the slope (fig. 10). The best estimate is that sediment eroded from the channels on the western flank of the Gulch contributed 80 to 90 percent to the total sediment deposited on the debris fan.

Erosion and deposition occurred in about equal proportions along multiple, anastomosing channels on the floor of Weldon Gulch (fig. 11). Maximum channel incision was 1 to 2 m, and maximum thickness of deposition appeared to be about 1 m. Incision was limited mostly to channels, whereas deposition occurred as levees along the flanks of channels, and in lobate deposits where debris flows left channels and flowed along the floor of the Gulch. Numerous trees (mostly aspen as much as 20 cm in diameter) were sheared off by, and incorporated into, the debris flows along the floor of the Gulch (fig. 11). The slope of the floor of the Gulch above the head of the fan ranged from about 14° to 17º.

Debris Fan at Alpine

Debris flowed onto the head of the debris fan in about three separate channels and then spread across the center and eastern parts of the fan in numerous smaller channels, as well as across the surface of the fan outside of previously existing channels. Several of the larger channels near the head of the fan were incised 1 to 2 m by the debris flows. Most of the debris flowed down the eastern one-half of the fan (fig. 3). Also, on July 25, most of the clear surface water coming from the Gulch also was flowing down the eastern side of the fan.

Most of the trees that had been sheared off in Weldon Gulch, as well as old dead trees that had been lying in or near previously existing channels in the Gulch, were deposited near the head of the fan (fig. 12). The trees typically were deposited when they became trapped against larger, intact trees. Many of these deposits of trees created natural dams that then trapped mud and rocks. Numerous scars from impacts by flowing debris were observed on trees. Some scars reached heights of about 2 m above the surface of fresh deposits (fig. 12).

Fresh debris-flow deposits on the fan generally became finer grained and thinner with distance from the head of the fan (fig. 13). Deposits near the fan head had maximum thicknesses of about 1 m and contained boulders up to about 1 m in diameter. Larger boulders were observed in and near channels on the fan, but it was unclear how far these boulders had been transported by the debris flows (fig. 13*A*). The debris flows reached Chalk Creek in at least two locations. Deposits at these locations were thin (less than about 10 cm thick), fine grained, and did not dam the creek (fig. 13*D*).

At several locations on the fan, debris flowed along roads and driveways (fig. 14) and impacted adjacent structures (houses, garages, and trailers), but no one was injured. A few vehicles were buried and(or) transported by the debris flows (fig. 14). Numerous structures had deposits around them (fig. 14), and some were damaged by the flows (fig. 14).

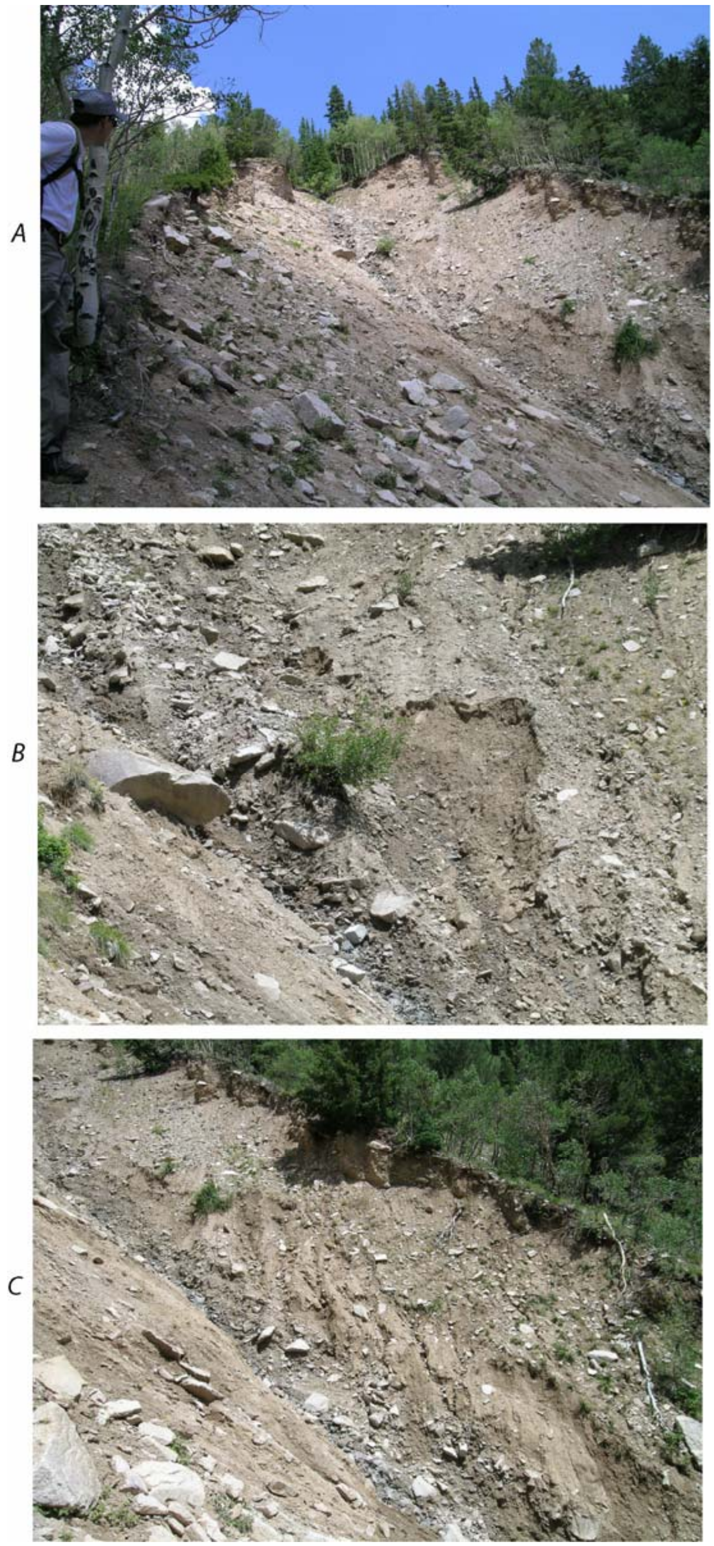


Figure 4. Landslides and erosion on eastern flank of Weldon Gulch. *A*, Pre-existing landslide scar. *B*, 3-meter-wide shallow slide in pre-existing landslide scar. *C*, Rill erosion in pre-existing landslide scar. Rills are approximately 5 to10 centimeters wide.

A

B

Figure 5. Channels downslope from old landslide scar on the eastern flank of Weldon Gulch (see fig. 3 for location). *A*, Eastern channel, and *B*, western channel.

Figure 6. Composite of ground-based photographs showing debris-flow channels on the western flank of Weldon Gulch. Total relief visible is about 420 meters.

Figure 7. Bedrock at the head of debris-flow channels on the western flank of Weldon Gulch. Total relief visible is about 120 meters.

Figure 8. Debris-flow channels on the western flank of Weldon Gulch. *A*,*B*, Channels 2 to 4 meters wide and 1 to 3 meters deep. *C*, Channel with maximum observed width (9 meters) and depth (4 meters).

A

B

Figure 9. Channel banks on the western flank of Weldon Gulch. *A*, Nearly vertical, 3-meter bank of loose colluvium, and *B*, 3-meter bank that has failed into the channel.

Figure 10. Debris-flow deposits along the flank of a channel on the western flank of Weldon Gulch. Channel is about 4 meters wide.

A

B

C

Figure 11. Photographs from the floor of Weldon Gulch. *A*, Area of channel erosion, *B*, trees sheared off by debris flows, and *C*, steep, bouldery front of a debris-flow deposit.

Figure 12. Photographs of trees on the debris fan. *A*, Natural dam formed by trees, and *B*, scar on tree from passing of debris flow.

Figure 13. Photographs showing progressive fining of debris-flow deposits from head to toe of the debris fan. *A*, Deposits near head of the fan. Large boulder is about 2 meters high. *B*, Deposits in the cemetery (see fig. 3 for location). *C*, Deposits just south of County Road 292, the main east/west trending road in Alpine. *D*, Deposits at Chalk Creek.

Figure 14. Photographs showing damage from debris flows in Alpine. *A*, Deposit in driveway of a residence. *B*, Damaged garage and propane tank. *C*, Damaged garage. *D*, Damaged car.

Debris Flows to the East and West of Alpine

In addition to Weldon Gulch and the community of Alpine, debris flows also occurred in areas along the north flank of Chalk Creek east and west of Alpine (fig. 3). Based on viewings from the valley floor and the air (fig. 15), nearly all of the debris-flow channels began at steep bedrock outcrops and progressed downslope over an apron of colluvium before reaching the floor of the Chalk Creek Valley. All observations indicate that the debris flows were caused by streams of water flowing from bedrock that entrained material from the channel and the colluvial apron (a "firehose" initiation process, Johnson and Rodine, 1984). Some material from these debris flows was deposited adjacent to channels in the form of levees, but most made it to the valley floor where it was deposited at multiple locations on County Road 292 (CR 292) (fig. 16). The sedimentology of the deposits on CR 292 varied from boulder-rich (fig. 16*A*, *B*, *D*) to boulder-poor and mud-rich (fig. 16*C*).

Interpretation of Existing Debris-Flow Hazard on the Fan

The hazard posed by debris flows on the debris fan at Alpine is currently (August 2007) difficult to quantify. No data are available on either the magnitude (volume) or frequency of debris-flow events on the fan. Data from a rain gage and Doppler radar indicate that the amount of rain that triggered the debris flows was probably from 25 mm (1 in.) to 76 mm (3 in.) in 1 hour, but the expected frequency of such a storm is not currently known. However, some aspects of the current and future debris-flow hazard in Alpine can be broadly characterized. The Chalk Creek Valley has contained glaciers multiple times during the Pleistocene, and the last glacier receded about 11,000 years ago (Colman and others, 1985). Therefore, the debris fan at Alpine, a conical-shaped fan that covers glacial deposits, has been deposited in about the last 11,000 years. Observations at a recent foundation excavation for a new home under construction along the western part of the fan revealed debris-flow deposits in the subsurface to a depth of least 3 m. Based on the character of deposits, debris flows seem to be the primary process that deposits material on the fan. Relatively fresh debris-flow tracks were visible on aerial photographs of the west flank of Weldon Gulch in August 2002 (see fig. 1*B*), but the debris flows responsible for the tracks do not appear to have made it to the fan. Therefore, on the scale of recent geologic time, debris flows are not unusual events in Weldon Gulch or on the fan. On a human scale, however, debris flows on the fan might be considered relatively rare events, based on evidence that debris flows comparable to those on July 21 probably have not inundated part of the eastern one-half of the fan in at least 130 years.

Figure 15. Photographs of debris-flow channels and source areas along the north flank of the valley of Chalk Creek. *A*, Debris-flow track and source area just west of the mouth of Coal Camp Canyon (see fig. 3 for location). Relief visible on the mountain side where the track is located is about 700 meters. *B*, *C*, and *D*, Debris-flow tracks and source areas upslope from County Road 292, east of Alpine.

Figure 16. Debris-flow deposits on and near County Road (CR) 292 to the west and east of Alpine. *A*, Deposit just to the west of the mouth of Coal Camp Canyon (see fig. 2 for location). *B* and *C*, Deposits on CR 292 to the east of Alpine. *D*, Deposits just upslope from CR 292 to the east of Alpine.

Within Weldon Gulch, channels that contributed sediment on July 21 have been deeply scoured, removing much of the loose material available for incorporation into debris flows. However, the now oversteepened banks of these channels are actively failing and refilling the channels with loose debris. There is not a good estimate of the rate of channel filling, and so an accurate estimate of the amount of debris that will be available for incorporation into debris flows in the future cannot be made. Prevention or mitigation of the buildup of debris in the channels appears to be impractical because of their steep slopes and large sizes. Also, although the upper one-half of Weldon Gulch did not produce debris flows in the July 21 thunderstorm, a storm having a different extent and intensity could produce debris flows from the upper one-half of the basin that could travel to the fan. Given these constraints, the best estimate is that the debris-flow hazard on the fan is about the same as it was before the debris flows on July 21.

Given this estimate of relative hazard, residents and government officials might consider the following suggestions.

1. Mitigation techniques for the debris-flow hazard in Alpine could include establishing a channel on the fan that routes potential water and debris flows in a manner that protects existing roads and structures. The Colorado Geological Survey has made a similar suggestion to the Colorado Department of Emergency Management (Berry, 2007), and this technique is already being used near the Chalk Cliffs east of Alpine. Currently, there are multiple channels on the fan; some have been scoured (deepened), some have been filled, and some are carrying the current flow of water from Weldon Gulch to locations that could cause problems for existing roads and structures. The natural geomorphic processes on fans like the one in Alpine are that these channels migrate laterally through time, effectively distributing material across the fan surface. Establishing a channel, possibly in combination with a deflection wall(s), debris catchment basin(s), debris rack(s), or check dam(s) to catch or divert debris-flow material away from roads and structures and prevent the channel from becoming plugged could help reduce the impacts of some future debris-flow events.

Any mitigation methods that are proposed for Alpine need to be designed by a qualified engineering geologist, hydrologist, or hydraulic or geotechnical engineer familiar with debris-flow hazards. Downstream effects on Chalk Creek need to be considered and a maintenance plan for routine upkeep of the channel and(or) mitigation structures needs to be established. It also is important to recognize that not all debris-flow events can be mitigated, but a good design could reduce the hazard, particularly for small or moderate events.

Some communities have formed Geologic Hazard Abatement Districts (GHADs) as a mechanism to prevent, mitigate, or control geologic hazards that cross property boundaries and affect a community. A GHAD gives local residents the ability to collectively address their specific geologic hazard issues. It gives the affected area (district) the legal and taxation authority to implement mitigation measures and continue maintenance of mitigation structures.

2. Residents of Alpine should be vigilant during rainstorms, particularly during the summer months when thunderstorms are common. The following advice has been extracted from Highland and others (1997). "During storms, listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing mud or debris may precede larger flows. Be alert for sudden increases or decreases in water flow or for a change from clear to muddy water. Such changes may indicate debris-flow activity upstream, so be prepared to move quickly." Additional information on the geologic hazards associated with debris flows and debris fans in Colorado is available through the Colorado Geological Survey's web site at http://geosurvey.state.co.us/.

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