Rapid Reactivation of a Large Composite Earth Slide - Earth Flow

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Abstract

A dormant earth flow crossed by Forest Highway 78 in Montrose County, Colorado, reactivated as an earth slide - earth flow in June 1997. The earth slide - earth flow moved at rates of up to a few meters per day and accumulated more than 150 meters of displacement during the summer of 1997, causing considerable damage to the highway and temporary road closures. An irrigation ditch crossing the earth slide - earth flow was also damaged and required reconstruction several times during the summer. Movement slowed rapidly and has essentially stopped. This paper presents the investigation into the cause of the reactivation, the rapid cessation of movement, and the probability of a similar period of activity occurring in the future. The investigation includes study of subsurface conditions, sliding history in the area, climate, and manmade impacts to the slide, such as the road and irrigation ditch.

Introduction

The Cimarron Valley is south of U.S. 50 and east of U.S. 550, near the town of Montrose, in southwest Colorado. There are numerous historic and prehistoric landslides in the valley. A pre-existing earth flow, part of a landslide complex referred to herein as the Prehistoric Wells Basin Landslide (Figure 1) had been exhibiting slow creep for years. The earth flow has had an unlined irrigation ditch crossing its upper half since the early 1900's and, prior to 1996, maintenance efforts required of the irrigation ditch company, the electric utility that has a

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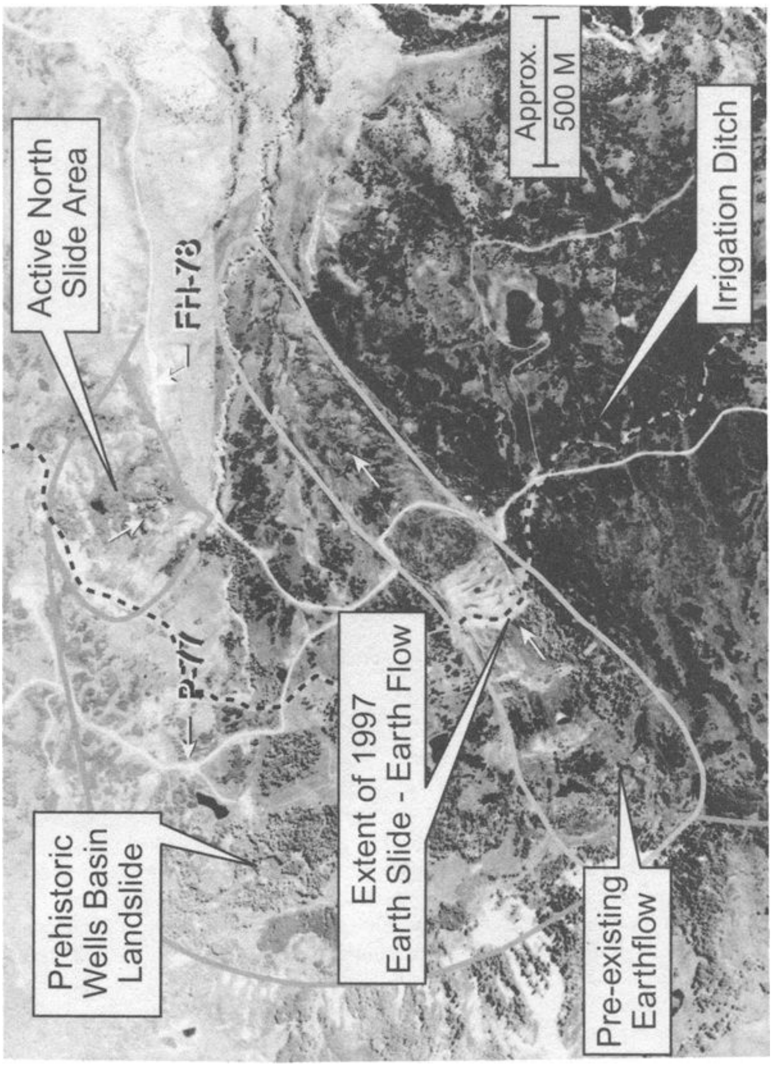

Figure 1. Wells Basin Landslide in 1998. Arrows show direction of movement.

power line crossing the slide, and road maintenance crews were minor. By 1996, however, the ditch width has reached about 50m, probably through gradual movement and erosion. In 1996 the ditch company reconstructed the ditch to its narrower section (Autrey, 1998) and the Forest Service filled a depression that had developed in Forest Highway 78 where it crosses the earth flow below the ditch (Burke, 1998). No other actions were taken in 1996 and no unusual movement was observed.

The spring of 1997 was wetter than average and in June 1997 part of the earth flow started to move rapidly, reaching rates of up to a few meters per day. More than 150 m of horizontal movement accumulated during the summer and the rapid movement stopped by November. This paper discusses the conditions leading to the 1997 reactivation of the earth flow and the rather spectacular amount of movement that occurred. Using observations of movement, site reconnaissance, and results of investigation on the slide mass, hypotheses are presented to explain the rapid remobilization.

Research for this work led to uncovery of descriptive reports of similar landsliding in the valley more than 100 years ago (Cross, 1886). Because Cross's descriptions are very vivid, they are very valuable in the understanding of this type of landsliding. For this reason and because Cross's publication is somewhat obscure, we have included several quotes here.

Site Description

The Cimarron River flows northward from the Uncompahgre Plateau to the Gunnison River, about 30 km east of the town of Montrose, in southwest Colorado. Colorado Forest Highway 78 provides access from U.S. 50, through the Cimarron River valley to the Uncompahgre National Forest. The landslide site is located in the Cimarron River valley, about 9.5 km south of U.S. 50, in an area known as Wells Basin. The site is crossed by Forest Highway 78, as shown on Figure 1.

The Cimarron River valley elevation is between about 2,100 m and 2,800 m above sea level. The lower valley slopes are vegetated with grass and sagebrush, and limited other woody vegetation. The upper slopes contain aspen and conifer trees. The lower valley slopes are gently sloped and undulating, and the upper slopes are notably steeper, in many places consisting of bedrock outcrop.

The geology of the area has been mapped by Yeend (1961). The primary surficial deposit on the valley slopes is Wisconsin till. In many places the till has been moved by landsliding, and Yeend has mapped distinct areas of recent slides, recent mudflows, and Pleistocene landslides and slumps. So pervasive is the landsliding that Colton et al. (1975) mapped essentially the entire valley as landslide deposits. The lower valley slopes are underlain by Mancos shale, which does outcrop in a number of locations. The upper slopes are capped by sedimentary and volcanic rocks that form the mesas and ridges east and west of the valley. These rocks include the Alboroto rhyolite, San Juan tuff, Telluride conglomerate, and Mesa Verde sandstone (which structurally overlies the Mancos shale).

Historic Landsliding

Cimarron Earth Flow

The historic record of landsliding in the Cimarron River valley dates back more than 100 years to an earth flow that occurred in 1886. The disturbance was first thought to have been caused by an earthquake and an earthquake was described in newspaper articles in Montrose and in Denver (Cross, 1886). The earth flow occurred between July 18 and July 25, the period between subsequent visits to the site by ranchers. Cross, who was from the U.S. Geological Survey in Denver, visited the site in August 1886 and described the discovery of the site as follows:

> "On the 25th of July Mr. Samuel Scheldt was engaged in looking after his cattle that ranged over these slopes, and found that a considerable area of hill-side had been terribly convulsed and very much changed in appearance. The trees, here growing quite luxuriantly, had been overturned, the earth fissured, and large masses of soil with the trees growing upon them had been broken off from the steeper slopes. In one jungle of fallen timber a bunch of cattle were imprisoned, unable to make their way out. He at once procured assistance, and the terrified cattle when liberated ran for miles before stopping. On examining the region, Mr. Scheldt and his companions found the detailed features over an area of several hundred acres very much changed. A small lake they had previously known could not be found, and apparently on its site was a ridge. Near by another sharp ridge had been thrown up some 25 feet, and one side had again sunk down, leaving a vertical wall. Everywhere the trees had been disturbed, and in some small areas none were left standing. The ground was traversed by innumerable fissures which were all shallow, owing to the soft, crumbling nature of the soil. The news of the phenomenon spread rapidly and the spot was visited by many. The explanation uniformly adopted was that the convulsions were caused by an earthquake."

Following his site reconnaissance, Cross described the nature of the movement as follows:

> "The movement was a downward sliding of the whole surface, unequal in different places, apparently greatest in the upper part, and dying out gradually as distance from the upper line increased. The upper limit of movement runs along the steep mesa slope at a present elevation of 50-125 feet above the basin floor. A steep surface of freshly exposed earth and shaley rock marks the line. Above are undisturbed trees, turf or debris. At

> the foot of this surface is a tangle of overturned trees and bushes, half buried in loose soil and rocks. Upon the slide surface lies a few uprooted trees, or a small patch of earth which has caught, half way down. Along the upper edge are partly detached sections, with their trees inclined at various angles.
>
> The shoulder mentioned as projecting from the mesa out into the upper part of the basin has suffered on all its steep sides, as did the above slope; and the entire mass is divided into sections by fissures, so that it seems strange that all did not slip, piece by piece, to the basin below.
>
> Along the northern side, near the base of the bounding ridge, runs a more or less continuous line, which is nothing less than an anticlinal fold or plication of the surface soil or turf, caused by the lateral pressure of the downward moving mass. On the outer or northern side of this fold the bushes and trees, where such exist, are simply tipped from the vertical position, corresponding to the sharpness of the plication. They are not uprooted, and in many places this side of the little ridge is unbroken, while on the basin side the downward movement has torn away nearly all of that half. A mile below the head of the slide this lateral movement is manifested very plainly by the cracking of a grassy surface, the turf from the basin side being simply shoved sideways a foot or more over the undisturbed part on the ridge side."

Cross drew several conclusions as to the cause of sliding and its significance in the formation of the valley. These conclusions include the following:

1. There was no earthquake. The movement is attributed to landsliding as a result of heavy rain. Local ranchers said that although little rain fell where they were it appeared to be raining all week up in the valley.
2. This type of landsliding has occurred elsewhere in the valley and apparently at this very site in the past. Observations from vantage points within the valley suggest such landsliding is an important valley forming process.
3. Sag ponds provide some of the water necessary for such fluid movement of the earth, but other contributing sources would be required.
4. The level to which sections of the slide are disturbed varies considerably.
5. A small slip may have started the movement and been followed by progressive failure up the slope, described by Cross as follows:

   > "A small slip may have started the movement and, by removing the resistance which held another mass in place, have paved the way to a successive slipping of section after section until the higher bounding grounds were reached.

> Such a theory would allow a slight movement in the lower portions to lead to much greater displacements on the upper limit, and such seems to be in fact the case. That the slipping did occur in sections is shown by the appearance or ridges here and there in the midst of the area, which were plainly formed as was the one on the northern limit, described above."

Aside from the general reference to landslide features such as hummocky ground, closed drainage basins, sag ponds, and dead trees covering a large part of the valley, Cross made no reference of movement at the site of the pre-existing Wells Basin earth flow. Based on observations of Yeend (1961), the initial earth flow episode at Wells Basin apparently predates the 1886 Cimarron earth flow visited by Cross. Given the thoroughness of Cross's observations the fact that he would have practically had to traverse the Wells Basin site to get to the Cimarron earth flow, and the lack of reference to the Wells Basin site, it seems probable that the pre-existing earth flow at Wells Basin was not active during 1886. The close proximity of the Wells Basin earth flow and the Cimarron earth flow (same site as the 1997 earth slide-earth flow) is shown on Figure 2.

Wells Basin Landslide

Wells Basin developed its basin-like morphology as the result of prehistoric landsliding, which is shown on Figures 1 and 2. As identified on Figure 1, the most recent landslide activity is along the lateral margins of the prehistoric landslide. The North Slide Area has experienced some movement in recent years, requiring maintenance to the irrigation ditch that crosses near the headscarp. There has been no recent impact to the Forest Highway (FH-78) that passes along the toe of the slide area.

The Pre-existing Earth Flow identified on Figure 1 along the southern margin of the prehistoric landslide is apparently not active over its full length. However, the distinct earth flow morphology of this feature suggests it is more recent than other inactive parts of the prehistoric landslide. The central 1200 m portion of the older earth flow is the area that reactivated in 1997; the reactivation included the entire width but not the entire length of the older earth flow.

1997 Reactivated Earth Slide - Earth Flow

The characteristics of the movement and the landslide morphology lead to the classification of the landslide as an earth slide - earth flow (Cruden and Varnes, 1996). Herein, the generic term, landslide, is used. The reactivated landslide is approximately 300 - 400 m wide and 1200 m long and the overall slope angle is about 6 - 7 degrees.

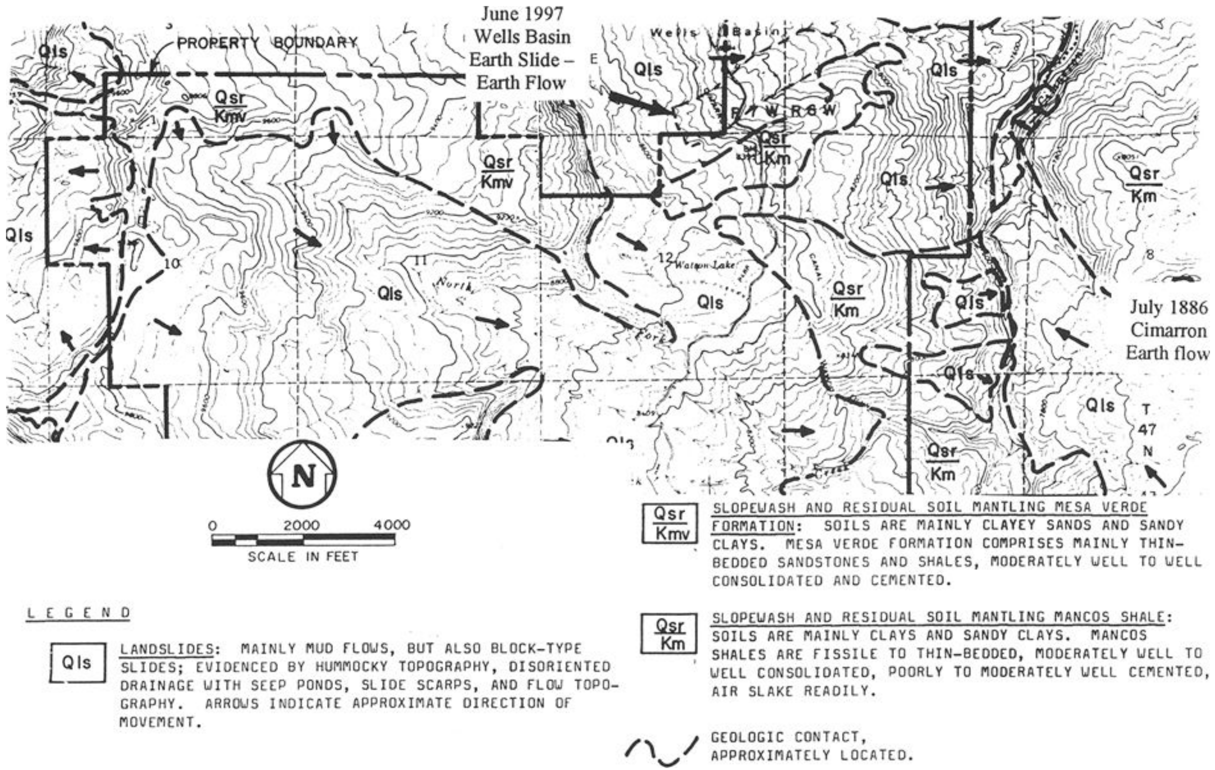

Figure 2. Geologic Map of part of the Cimarron River Valley showing the Cimarron earth flow and Wells Basin earth slide - earth flow (URSGWC, 1973).

Conditions Leading to Reactivation

The landslide had been experiencing slow movement for at least 18 to 30 years based on the records of the Delta Montrose Electric Association - the owner of a power line across the site (Blowers, 1998), and Montrose County Maintenance (Jeffries, 1998). The landslide is crossed by an unlined irrigation ditch and according to the ditch owner, the ditch has been there since the early 1900's and has not required significant maintenance in this area; the North Slide area has been more problematic (Autrey, 1998). Nevertheless, by 1996, the ditch width had increased from probably about 5 m to approximately 50 meters where it crossed the pre-existing earth flow.

A "sink hole" in the road was repaired with fill in the summer of 1996 (Burke, 1998) and the ditch was moved about 50 meters in the upslope direction at approximately the same time (Autrey, 1998). The specific amount or nature of earthwork conducted in 1996 is not known but, given the large size of the reactivated landslide, it seems unlikely that the earthwork itself would have significantly impacted its global stability.

The rapid movement started on June 16, 1997 and it was apparently preceded by somewhat wetter than average weather. The 1997 precipitation totals were exceeded only one to four times in the previous 45 years. Because some precipitation probably fell as snow at the site, mean temperature was evaluated as a potential indicator of unusual snowmelt; the temperature for April was about normal, May was warmer than any previous year, and June was above average. The warm temperatures during the snowmelt season suggest snowmelt may have been more rapid than average.

Flood frequency analysis performed on the stream gage data from a gage farther up the valley indicate the peak flow, which occurred on June 5, has a return interval of 25 years. This peak apparently occurred 5 days after one period of heavy rain and before a second period of heavy rain (June 8-10), as indicated by newspaper reports on precipitation in Montrose.

In summary, none of the precipitation or stream gage data is for the site itself. The data and reports from Montrose indicate regional precipitation was greater than average. The lack of precise agreement of the peak flows to the heavy rain indicates there is some uncertainty with respect to how much the precipitation and infiltration amounts were above normal at the site itself.

Reactivation

The reactivated landslide at Wells Basin has an appearance very similar to the Cimarron earth flow described by Cross (1886), with open cracks, grabens, and horsts, in some areas, pressure ridges in some areas, and considerably less evidence of movement elsewhere. Sag ponds near the head of the pre-existing earth flow (see Figure 1) appear well established in 1973 aerial photos, and were not impacted by the 1997 reactivation. The landslide moved at a peak rate of a few meters per day and accumulated more than 150 m of displacement during the summer.

The active movement of the reactivated landslide caused considerable maintenance difficulties for Montrose County and the ditch company. The County provided maintenance for Forest Highway 78 and, during the period of the peak rate of movement, this required stationing equipment and an operator continuously at the site. Since the traffic volume is low, the road would undergo considerable distress between vehicles, and grading was required for nearly every vehicle. The ditch company had to reconstruct the irrigation ditch five times during the summer because of downslope movement of the landslide. Figure 3 shows the road crossing the landslide and the abandoned ditch segments. Observations from these maintenance efforts provide the only record of movement rates during the summer. The greatest displacement occurred near the irrigation ditch and Forest Highway.

Cessation of Rapid Movement

By November 1997 landslide movement had essentially stopped and it was judged safe to drill through the slide. An inclinometer installed in November showed movement was continuing. There was 25 mm of movement at 22.5 m depth between November and February, and the inclinometer casing was sheared by May 1998. The inclinometer showed sliding (after November 1997) was occurring within a discrete shear zone at the top of the Mancos shale. The investigation and analysis continued over the winter because it was uncertain what would happen the following spring. As it turned out, the spring of 1998 was relatively dry and movement, as observed at the surface, was not notable.

In contrast to 1998, the spring of 1999 was wet, and in many aspects similar to the conditions of 1997, when the reactivation occurred. Records from the Cimarron weather station are compared in Table 1. Despite the apparently similar precipitation histories near the site, no movement was noted in 1999.

Table 1
Precipitation Records from the Cimarron Weather Station

Month	1997	% Normal	1999	% Normal
March	22 mm	90	2 mm	7
April	58 mm	251	59 mm	257
May	63 mm	263	51 mm	213
June	46 mm	244	49 mm	256
July	17 mm	46	34 mm	95
Total for Period	206 mm	163	195 mm	154

Figure 3. Portion of reactivated earth slide - earth flow showing multiple abandoned canal sections, cracking, and sag ponds. Note 18-wheel truck on road for scale. Movement is from top right to bottom left of photograph.

Investigation and Analysis

As a result of the 1997 reactivation, Montrose County had a road that was passable, but not to design specifications, and surrounded by unstable ground with fresh open cracks and, at times, ponded water. The road needed to be restored because it provided important access to the National Forest, permanent residences, and Silver Jack dam, a 42 m high U.S. Bureau of Reclamation dam. Montrose County looked for assistance in evaluating the preferred alternative of either rebuilding across the landslide on the original alignment, or reconstructing the road on a new alignment to avoid the landslide and, because the road provided National Forest access, the county was eligible to receive federal funding assistance through the Federal Highway Administration - Central Federal Lands Highway Division (FHWA). The FHWA contracted URS Greiner Woodward