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P. W. Bauer
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 New Mexico Geological Society Guidebook, 55th Field Conference, Geology of the Taos Region, 2004, p. 282 -288.

EROSIONAL RETREAT OF A RIVER-DAMMING DEBRIS FLOW ON THE RIO GRANDE, TAOS COUNTY, NEW MEXICO

PAUL W. BAUER
New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM 87801

Abstract.—The 22 km (14 mi) stretch of NM-68 along the Rio Grande, between Velarde and Pilar, skirts the base of notoriously unstable slopes of Quaternary landslides and fractured Proterozoic bedrock and talus. Rockfalls, rockslides, and debris flows are common hazards to motorists, especially along the Pilar cliffs. On July 25, 1991, an intense rainfall event spawned a series of mass wasting events that closed the highway for 19 hours. A 3600 m^3 (4700 yd^3) debris flow at Sleeping Beauty rapid temporarily dammed the Rio Grande and changed the fluvial geomorphology. A 12-year photographic record of the erosional retreat of the debris flow documents a relatively rapid two-year modification of the debris flow, followed by 10 years of minor adjustments to the surface and slope of the flow. Apparently, the peak flows of the highly constricted river had the carrying capacity to move cobble-sized bed load out of the channel until approximately half the channel was clear of the debris flow. At that point, even a peak flow of 7000 cubic feet per second (cfs) could do little to modify the remainder of the debris flow.

INTRODUCTION

Recurrent rockfalls, rockslides, and debris flows create an acute hazard to motorists driving on NM-68 between Velarde and Pilar, south of Taos. The most tragic incident occurred in September 1988 when five people were killed and 14 injured in a Greyhound passenger bus that impacted a falling 5.2 ton (11,600 lb) basalt boulder near the village of Embudo.

There are two geologic settings for mass wasting on this stretch of NM-68. Between Velarde and Rinconada (Fig. 1), the highway is flanked by unconsolidated Quaternary landslide deposits that contain large boulders of Pliocene Servilleta Formation basalt. Similar landslides exist upstream in the Pleistocene Rio Grande gorge where interlayered basalt and sandy basin fill were oversteepened by Rio Grande incision (Kelson and Bauer, 1998). In many places, highway construction has further destabilized the naturally oversteepened slopes of the landslide deposits and talus aprons. The most common hazards along NM-68 are cobbles and boulders that roll onto the highway, although there exists the potential of large, catastrophic slope failures as well. In the early 1990s, the New Mexico Highway & Transportation Department installed a rock retention system along several stretches of the highway between Velarde and Rinconada. The system includes 3.6-m-high (12 ft) energy-absorbing rockfall protection fences on the slopes and galvanized steel chain link covers on the lower embankments.

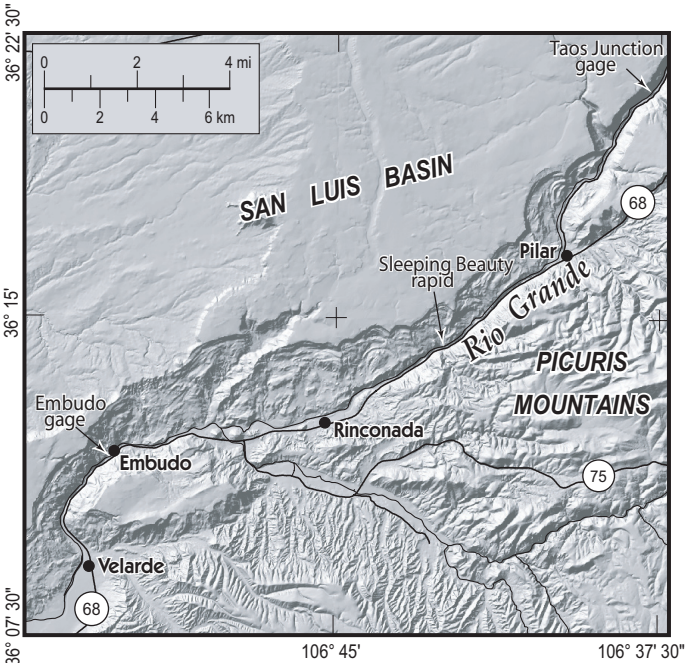


FIGURE 1. Shaded relief location map of the Sleeping Beauty rapid region.

The second geologic setting for mass-wasting hazards is along the Pilar cliffs between Rinconada and Pilar where highly fractured Proterozoic quartzite and schist form a 300-m-high (1000 ft) precipice of bedrock and talus (Fig. 1). The cliffs are due to the north-down throw along the Embudo fault zone, which has juxtaposed Paleoproterozoic metamorphic rocks of the Picuris Mountains against the Plio-Pleistocene deposits of the San Luis Basin (Bauer and Helper, 1994). The Pilar cliffs are also dissected by several debris-clogged canyons that drain northward into the Rio Grande. NM-68 is constructed at the base of the cliffs, and in places is cut into angle-of-repose talus slopes (Fig. 2).

On the evening of July 25, 1991, after several days of hard rain, and triggered by a massive precipitation event, 11 debris flows and numerous rockslides and falls caused a five-mile stretch of NM-68 between Pilar and the Taos County line to be closed for 19 hours. Many of the concrete Jersey barriers that line the south side of the highway were demolished by rolling rocks. The largest debris flow on the highway was approximately 30 m (100 ft) wide and 2.4 m (8 ft) deep. The most spectacular rockfall was a 300+ ton Rinconada Formation schist boulder that rolled 300 vertical meters (1000 feet) down the cliffs, creating a 14x4.5x4.5 m (45x15x15 ft) impact crater where it struck the highway (Haneberg and Bauer, 1993). The boulder came to rest on the north side of the Rio Grande at Big Rock Rapid after careening across the river (Fig. 3). The boulder was traveling at about 75 km/hr (47 mi/hr) when it struck the roadway with total kinetic energy of approximately 81 million ft-lbs (Bauer and Haneberg, 1992), approximately 135-773 times the energy-absorbing capacity of rock fall protection nets installed along downstream portions of NM-68 (Haneberg and Bauer, 1993). A highway maintenance



FIGURE 2. View southward of NM-68 at the base of the Pilar cliffs. The light-colored track down the slope was caused by rockfalls during the July 25, 1991 event.

engineer stated that during his 27 years on the job this was the largest rock that has struck any New Mexico highway.

Although 20 cars were trapped along the highway, there were no reported injuries. Among the vehicles trapped was a State Police cruiser that was responding to the emergency. Highway crews worked throughout the night and next day to clear and repair the roads. In places, where landslides reached the highway, heavy equipment was used to push debris into the Rio Grande channel (Fig. 4). Approximately 2300 cu m (3000 cu yds) of fill were required to repair the holes in the highway, and cleanup costs were estimated at $75,000.

Arguably, the most intriguing mass wasting event of July 25 was a debris flow that left the highway untouched. It did however have a profound affect on the Rio Grande and the recreationists who navigate whitewater along the popular Racecourse (a.k.a. Pilar to County Line) section of the river. The debris flow was channeled under NM-68 through a culvert, whereupon it temporarily dammed the Rio Grande and modified Sleeping Beauty rapid. This paper is primarily a description of the event and the debris flow, and a 12-year photo documentary of its erosional retreat across the Rio Grande.



FIGURE 3. View up the Rio Grande of 300+ ton schist boulder that rolled down the Pilar cliffs in the July 25, 1991 event. Kayaker for scale.

THE SLEEPING BEAUTY DEBRIS FLOW OF JULY 25, 1991

An unnamed canyon (herein called Sleeping Beauty Canyon) drains approximately 5 sq km (2 sq mi) of Proterozoic quartzite/schist/phyllite of the Hondo Group and Tertiary sandstone/conglomerate of the Santa Fe Group in the northwestern Picuris Mountains (Bauer and Helper, 1994). The canyon empties into the Rio Grande after passing through a triple culvert under NM-68 approximately 6 km (3.7 mi) southwest of the village of Pilar (Fig. 5). The canyon is narrow, steep sided, and choked with unsorted rock debris that ranges up to boulder-size.

Although no eyewitness reports were filed, field observations indicate that the debris flow moved down the canyon, through the culvert, and across the river in a single flow event that briefly dammed the river. The toe of the flow lobe is preserved on the



FIGURE 4. View upstream of Souse Hole rapid on the Rio Grande as highway maintenance crews push rock debris into the canyon in July 1991.

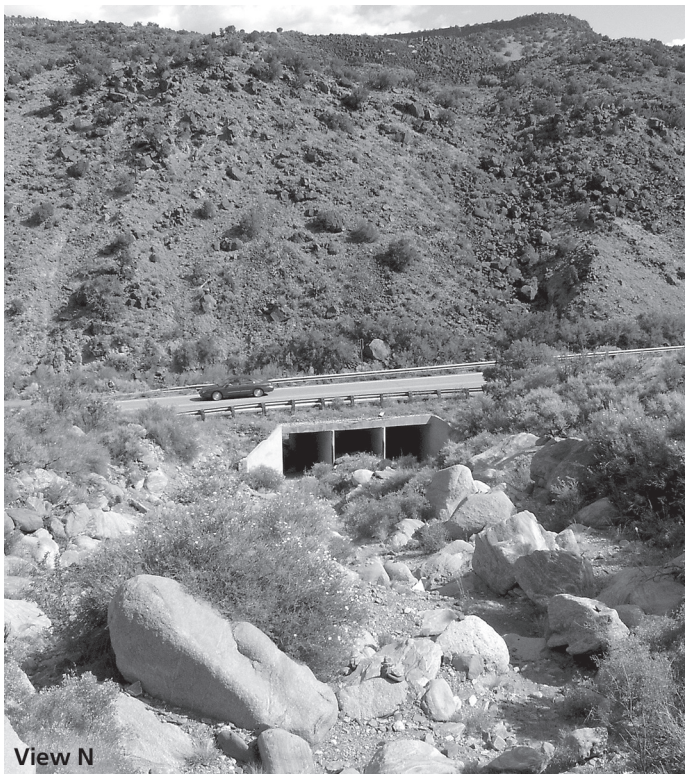


FIGURE 5. View downstream in 2004 of Sleeping Beauty Canyon and the culvert under NM-68. Note the coarse rock debris in the canyon.

far shore as cobbles of Proterozoic schist (Fig. 6). The river is approximately 46 m (150 ft) wide at that point. An unconfirmed second-hand report from a downstream riverside restaurant patron stated that during the evening of July 25 the noise of the river diminished for a short period before it recommenced flowing with a sudden roar. According to the USGS gage at the Taos Junction Bridge, 16 km (10 mi) upstream of Sleeping Beauty rapid, the river was moderately rising during the preceding rainstorm, and flowing at about 700 cfs on the evening of July 25.

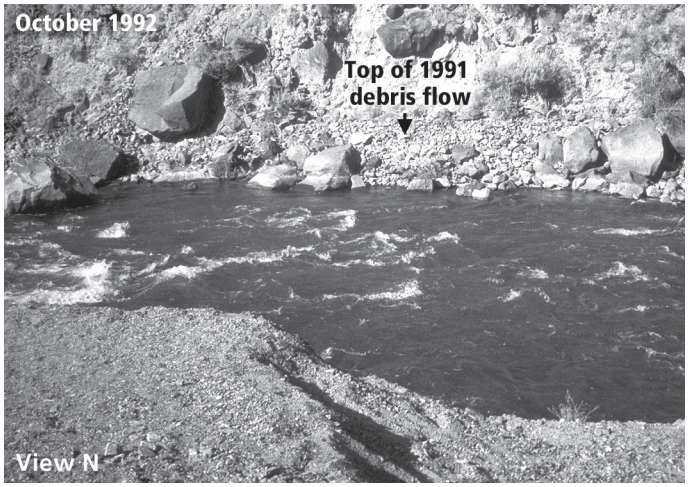


FIGURE 6. View across the Rio Grande of the remnant toe of the Sleeping Beauty debris flow in October 1992.

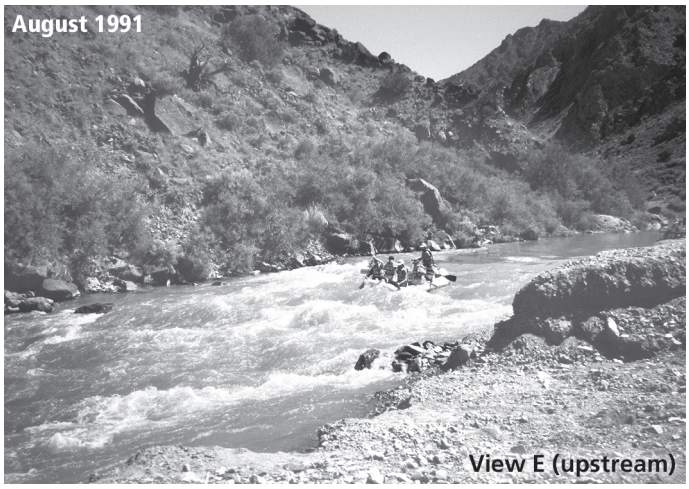


FIGURE 7. July 1991 photograph of the new whitewater at Sleeping Beauty rapid.

When the author arrived at Sleeping Beauty rapid several days after the event, the river had already cut a 10-m-wide (33 ft) channel through the toe of the debris flow, and newborn Class III rapids were thrilling whitewater rafters (Fig. 7). The rapids had developed on debris flow boulders and cobbles that were beyond the carrying capacity of the river. Sand and pebbles had clearly been winnowed out of the main channel (Fig. 8), and a 200-m-long (650 ft) gravely sandbar had formed in the slack water downstream from the debris flow (Fig. 9).

The debris flow was composed of pebble- to boulder-sized clasts of mostly Proterozoic schist and quartzite in a sandy/silty matrix (Fig. 10). The largest clasts in the debris flow were approximately 2 m (6.5 ft) in diameter, although much larger boulders exist in Sleeping Beauty Canyon just above the culvert. The deposit is unsorted and no sedimentary bedding or grading is visible. The top of the flow was planar, and sloped gently towards the river. The flow was highly fluidized when it reached the concrete culvert, as the culvert was clear of boulders and debris on

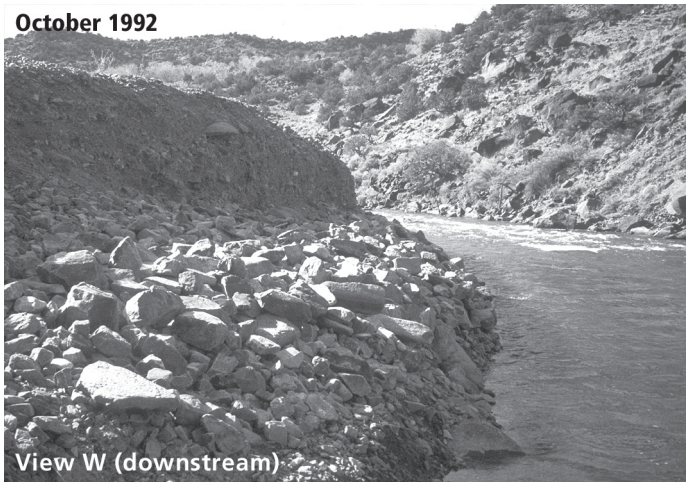


FIGURE 8. October 1992 view of the river-winnowed lower part of the debris flow. The river-cut bench probably represents the 2700 cfs high water mark of April 1992.

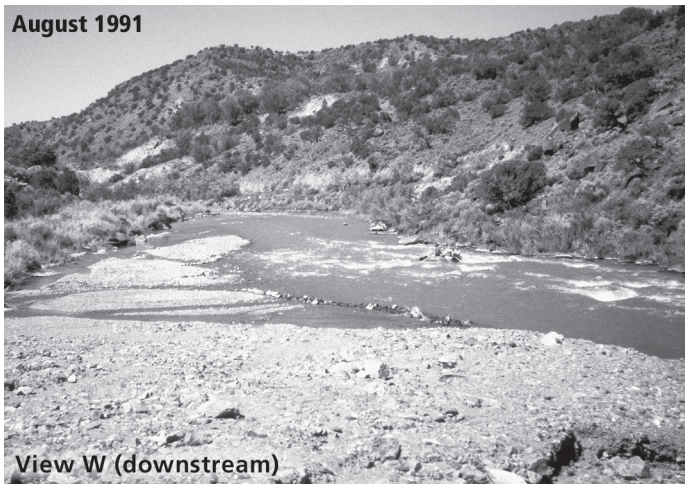


FIGURE 9. August 1991 view of the pebbly sandbar that rapidly formed downstream of the debris flow.

its upstream side. Assuming a surface area of 1800 m^2 (19,375 ft^2) and an average thickness of 2 m (6.5 ft), a rough volume of the Sleeping Beauty debris flow is 3600 m^3 (4700 yd^3).

12-YEAR EROSIONAL RETREAT OF THE DEBRIS FLOW

Photographs of the debris flow were taken from an upstream overlook over a period of twelve years, from 1991 to 2003. Fortuitously, the author had taken a photograph of the same site in 1998, thus documenting the pre-debris flow landform (Fig. 11).



FIGURE 10. View of poorly sorted Proterozoic material in the debris flow. Camera bag for scale.

Because the Rio Grande streamflow is so variable, it was not feasible to capture identical water levels throughout the photo history. However, the period of record, 1991-2003, appears to reasonably represent the range of annual streamflow highs and annual mean streamflows for the period of record of the Taos Junction gage from 1926 to 2001. Between 1926 and 2001, the annual mean streamflow ranged between 1887 cfs (1941) and 281 cfs (1964). During the same period, the peak streamflow varied between >9000 cfs during several seasons, and <1000 cfs during several seasons. Between 1991 and 2003, the annual mean streamflow ranged between 1181 cfs (1995) and 357 cfs (2000). During the same period, the peak streamflow varied between 7200 cfs (1995) and 550 cfs (2000).

The following eight photographs document the erosional retreat of the Sleeping Beauty debris flow every other year (Figs. 11-18). The figure captions provide a running commentary of the major changes and an estimate of streamflow in cubic feet per second (cfs). All reported streamflow peaks are based on hydrographs from the USGS Taos Junction gage.

DISCUSSION

The 1991 Sleeping Beauty debris flow provides some insights into the erosional retreat of a river-damming debris flow during 12 seasons of ordinary (based on last 75 years of records) Rio Grande hydrographs. The toe of the debris flow was rapidly overtopped and eroded by the river. Within a few days, the river had established a 10-m-wide (33 ft), boulder-choked, high-gradient, high-velocity channel. A pebbly sandbar quickly formed behind the debris flow. The constricted river apparently had the carrying capacity to move cobble-sized bed load downstream, leaving only boulders in the channel.

For the next two years, slack water extended several hundred meters upstream and effectively covered other rapids, including a popular kayak playhole (Fig. 12). For several years after the debris flow, a local kayaker attempted to restore the drowned playhole by moving large rocks from the debris flow into the river in order to widen the channel. The consequences of his bioturbation are not quantified, but he probably did hasten the erosional retreat of the debris flow.

Peak flows of 2700 cfs in 1992 and 5200 cfs in 1993 resulted in major changes to the size and shape of the debris flow. The instream edge of the debris flow escarpment swiftly retreated during those first two seasons, until the channel was approximately half the width of the river. At that point, the footprint of the flow changed very little over the next 10 years, in spite of the 7000 cfs peak streamflow in 1995. It is proposed that retreat slowed when the river widened to a point where the gradient and velocity had dropped to below the threshold required to move a cobble-sized bed load.

From 1993 to 2003, the most noticeable changes were erosion of fine-grained material, recession of the steep riverward slope, and development of channels in debris flow sediments by flash floods down Sleeping Beauty Canyon. After 12 years, the 1991 debris flow differs from the pre-1991 landform predominantly by the residual undissected sand- and pebble-rich material. As

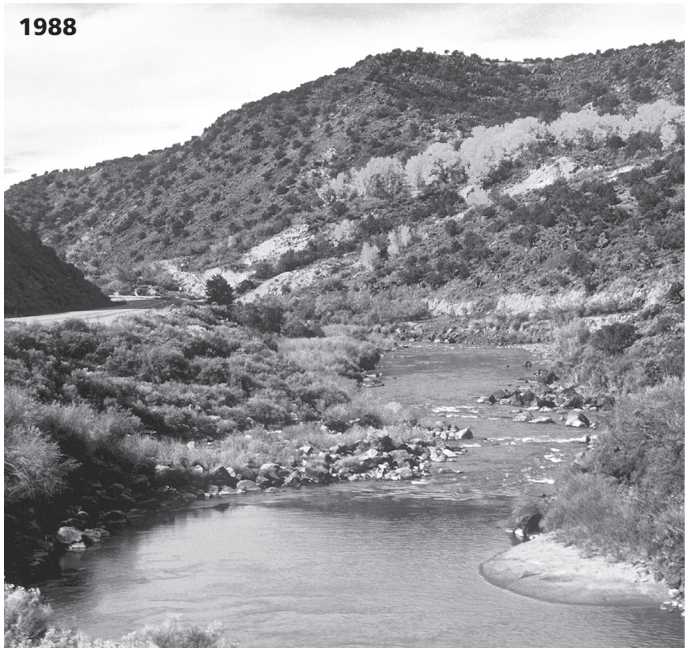


FIGURE 11. October 1988 view of Sleeping Beauty rapid at ca. 300 cfs. Note the well-vegetated, highly dissected old debris flow of cobbles and boulders on the left side of the river. The footprint of the flow extends about half way across the river channel. The age of the older flow is unknown, but had remained essentially unchanged since at least 1979 according to reports from a local rafter. In 1988, Sleeping Beauty rapid was a slow, modest drop with only minor whitewater.

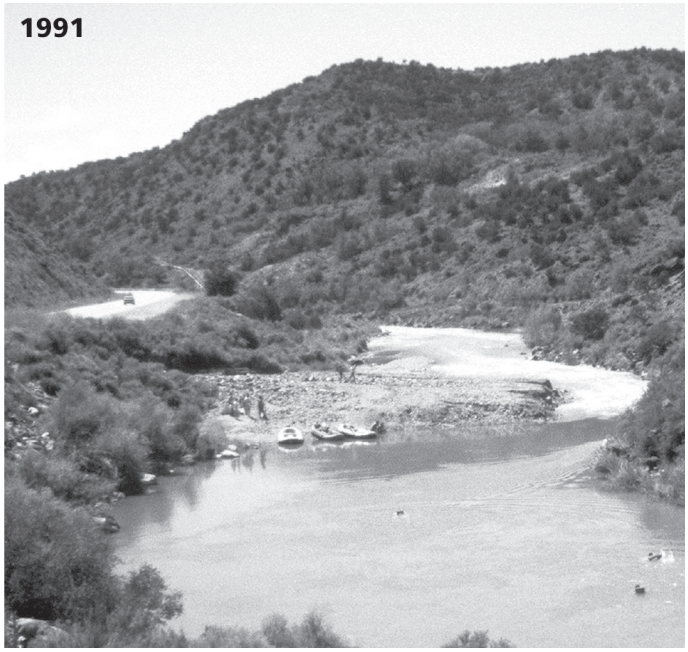


FIGURE 12. August 1991 view of Sleeping Beauty rapid at ca. 500 cfs. This photo was taken a week after the July 25 debris flow. The debris flow has constricted the river to a 10-m-wide (33 ft) channel and modified the local river gradient. Sleeping Beauty rapid is now a fast drop of several feet with continuous whitewater. Note the swimmers enjoying the slack water upstream from the constriction.

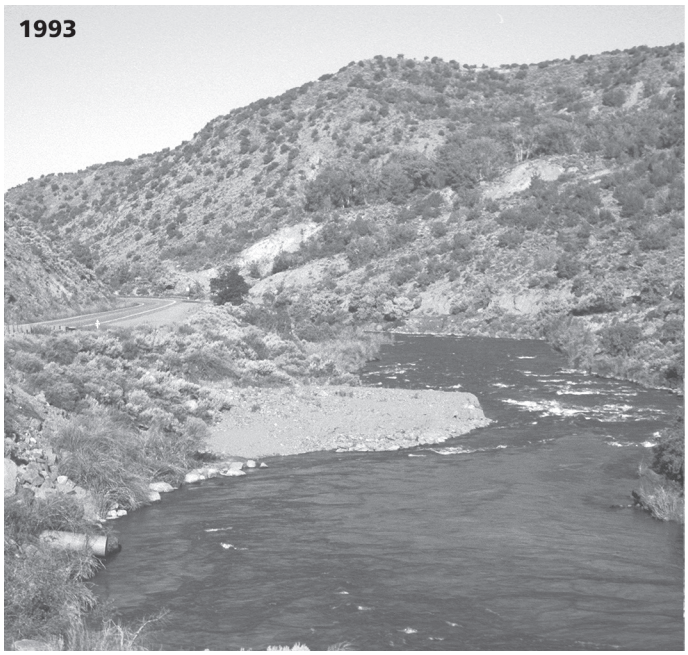


FIGURE 13. June 1993 view of Sleeping Beauty rapid at ca. 1600-2500 cfs. The debris flow has been reduced to about half the river channel, retreating about 13 m (43 ft) since 1991. This photo was taken after the 1993 streamflow peak of 5200 cfs in early June. The instream bank of the debris flow is steep and much of the fine-grained material remains on the debris flow. Minor vegetation has occupied the top of the flow. At this water level, Sleeping Beauty rapid is fast with powerful hydraulics and whitewater across the lower half of the drop.

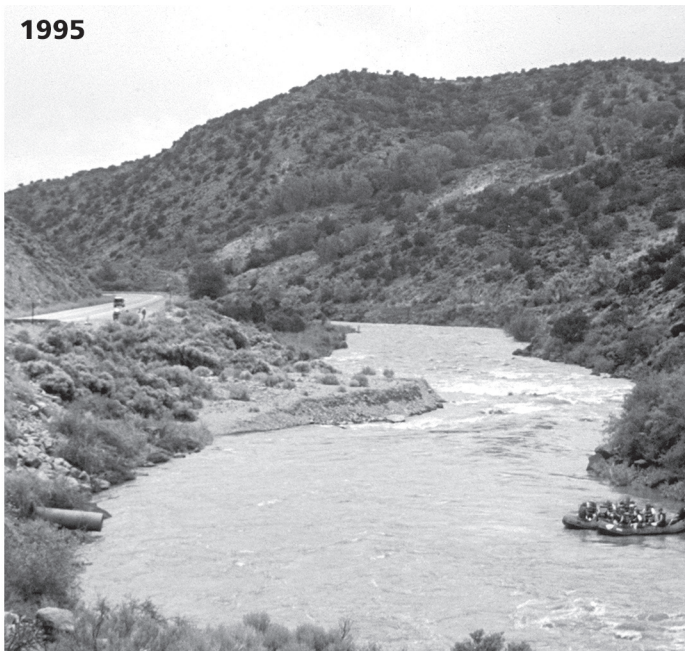


FIGURE 14. July 1995 view of Sleeping Beauty rapid at ca. 2000-3000 cfs. The debris flow has retreated only a meter or two since 1993. The photo was taken after a late June streamflow spike of 5300 cfs, but prior to the 1995 streamflow high of 7000 cfs. The instream bank of the debris flow has shallowed and boulders are visible along the edge of the deposit. Vegetation is established on the top and sides of the flow. At this water level, Sleeping Beauty rapid is fast with powerful hydraulics and whitewater across its bottom half.

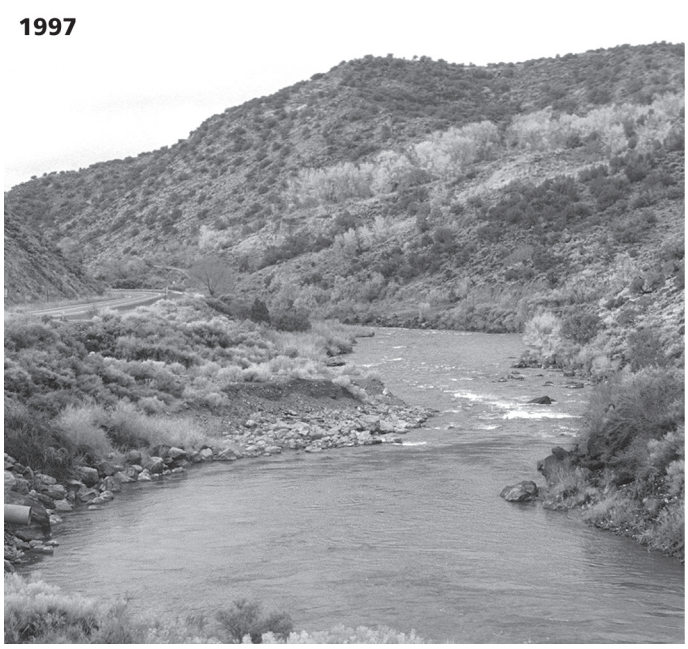


FIGURE 15. November 1997 view of Sleeping Beauty rapid at ca. 1200 cfs. The photo postdates the 1995 streamflow high of 7000 cfs and the 1997 streamflow high of 4100 cfs. The 1996 streamflow high was only 750 cfs. The debris flow has retreated a small amount, but the instream bank of the debris flow has significantly shallowed and many boulders and cobbles are visible along the lower edge of the deposit. Vegetation covers the top of the flow. Sleeping Beauty rapid is fast with rocks and whitewater along the bottom half.

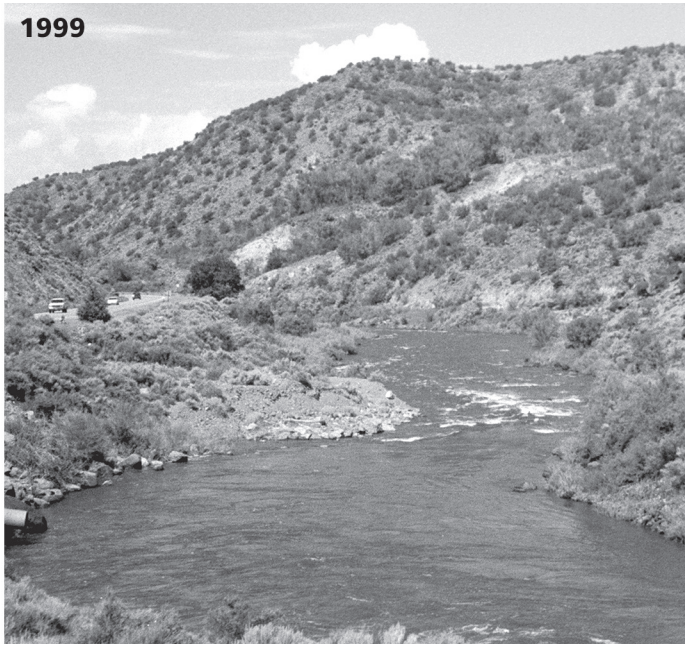


FIGURE 16. July 1999 view of Sleeping Beauty rapid at ca. 1400 cfs. The photo postdates the moderate streamflow highs of 2000 cfs in 1998 and 2700 cfs in 1999. The debris flow is relatively unchanged since the 1997 photograph, although the top of the debris flow appears to have been dissected by water that flowed down Sleeping Beauty Canyon.

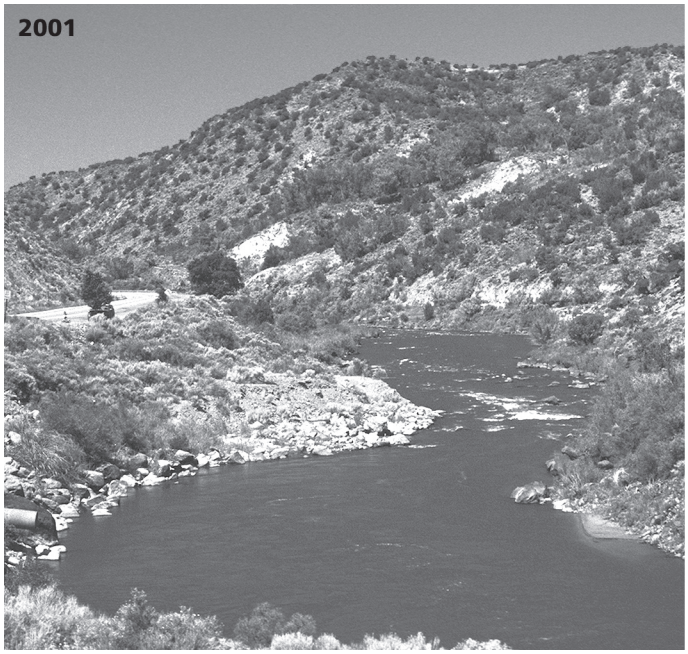


FIGURE 17. June 2001 view of Sleeping Beauty rapid at ca. 1000 cfs. The photo postdates the streamflow highs of 550 cfs in 2000 and 2700 cfs in 2001. The debris flow is relatively unchanged since the 1999 photograph. Dissection of the top of the debris flow has continued and much of the vegetation has been removed. Much of the fine-grained material has been removed by erosion, and the deposit is now dominated by cobbles and boulders.

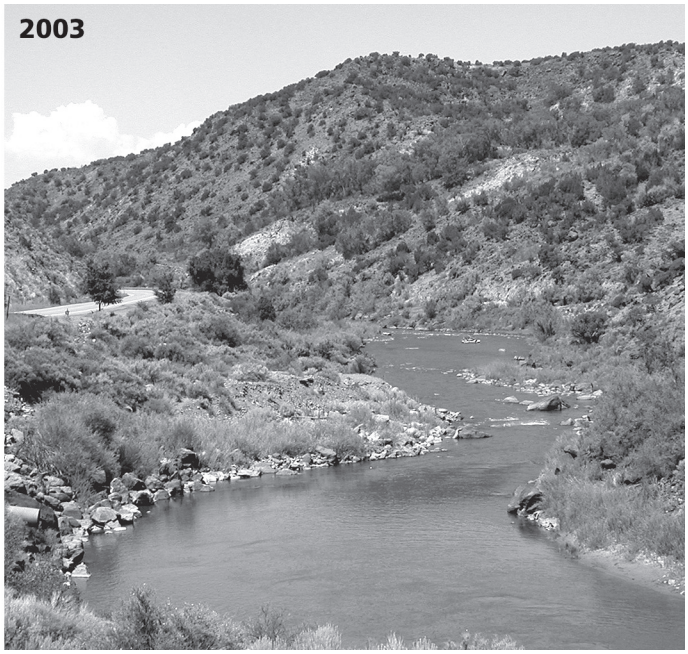


FIGURE 18. July 2003 view of Sleeping Beauty rapid at ca. 220 cfs. The photo postdates the streamflow highs of 580 cfs in 2002 and 1600 cfs in 2003. The debris flow is relatively unchanged since the 2001 photograph. The deposit is dominated by cobbles and boulders. Vegetation has reestablished on the flow. Twelve years after the debris flow of 1991, the general configuration of the landform is now quite similar to that of the older flow in the 1998 photo (Fig. 11). It is likely that pre-1991 boulders form the substrate for the modern landform.

these materials are removed by a combination of high Rio Grande streamflows and flashy Sleeping Beauty Canyon discharges, the 1991 debris flow sediments are expected to continue to slowly devolve into a form that resembles the pre-1991 landform. Prolonged drought may be allowing Sleeping Beauty Canyon to accumulate another surplus of sediment that may repeat this cycle when stormwater runoff next mobilizes sediments into a debris flow.

ACKNOWLEDGMENTS

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