Slopes Fail, Debris Flows in Extremis

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In the summer of 2006, an unusual set of atmospheric conditions aligned to produce record floods and an unprecedented number of slope failures and debris flows in southeastern Arizona. An upper-level low-pressure system stalled over New Mexico and drew subtropical moisture into southern Arizona, spawning strong convective systems for five consecutive nights. Rainfall from July 27-30 provided sufficient antecedent moisture so that the big storms of July 31-Aug. 1 caused record stream flooding in northeastern Pima and eastern Pinal counties. New floods of record, with recurrence intervals (RIs) of about 100 to 500 years, were established at five gauging stations. In the southern Santa Catalina Mountains north of Tucson, the maximum three-day precipitation measured was 12.04 inches, which has an RI of about 1,000 years. Four-day rainfall totals in three other nearby mountain ranges also exceeded 1,000-year RIs.

Unprecedented Numbers

The watersheds affected in the event had experienced large floods several times in the 20th century, but the 2006 event was unique for the extraordinary number of slope failures and debris flows that occurred. At least 623 slope failures occurred in four mountain ranges, including 435 in the southern Santa Catalinas. Debris flows reached or passed the apexes of alluvial fans in five drainages on the northern edge of Tucson.

Anecdotal records accumulated by the Arizona Geological Survey reveal few previous episodes of slope failures and debris flows in this region, and none with this magnitude. Repeat photography suggests that the 2006 spate of slope failures was historically unprecedented, and geologic mapping and cosmogenic dating of ancient debris-flow deposits indicate that few debris flows have reached alluvial fans in the Tucson basin in the past few thousand years. Although recent watershed changes may have been important locally, the record number of slope failures and debris flows were related predominantly to extreme precipitation and not other factors such as fire history. Large regions of the Santa Catalina Mountains had burned in 2003, but 86 percent of the 2006 slope failures in this range started in unburned or low-intensity burn sites. Of the other affected mountain ranges, one had no record of significant fire and another (Bowie Mountain) had not burned in 80 years.

Relating Precipitation to Slope Failure

The combination of relatively dense point rainfall data and nearby weather radar provided a unique opportunity to compare high-spatial-frequency estimations of storm return periods to slope failures. Radar returns were accumulated in 754 grid cells approximately 0.36 square miles in size over the south half of the Santa Catalinas. Precipitation intensities measured with weather radar on July 31 were not unusual in this region (RI less than one year), but multiday rainfall where slope failures occurred typically had RIs greater than 50 years; isolated grid cells had RIs of 500 to 1,000 years. Sabino Creek watershed in the Santa Catalinas was essentially saturated following four days of rainfall: 92 percent of the precipitation ran off.

Using data from numerous sources, including digital orthophotography, Google Earth images, and airborne Lidar data, the volume of sediment moved from hillslopes by the slope failures in the southern Santa Catalina Mountains was estimated to be 23.7 million cubic feet. LAHARZ, a stochastic debris-flow simulation model typically used to predict the area of deposition of lahars (mudflows associated with volcanic eruptions), was used to simulate the depositional areas observed from the five debris flows that reached or passed the apexes of alluvial fans on the northern edge of Tucson. Using the estimated sediment volumes for slope failures in each watershed, LAHARZ successfully predicted the approximate areas of deposition for four of the five debris flows. The LAHARZ simulations both verified the volume estimates of material released by the 2006 storm as well as demonstrated the feasibility of using this stochastic modeling technique to predict debris-flow-hazard potential in steep mountain watersheds of the arid Southwest.

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Photo: Phil Pearthree

A debris flow filled this section of Sabino Creek and the adjacent roadway in the Santa Catalina Mountains of southern Arizona.