Slopes Fail, Debris Flows in Extremis

Robert H. Webb, Christopher S. Magirl, *and* ***Peter G. Griffiths*** *– U.S. Geological Survey and* ***Ann Youberg*** *and* ***Philip A. Pearthree*** *– Arizona Geological Survey*

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.

Contact Robert Webb at rhwebb@usgs.gov.

Photo: Phil Pearthree

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

Comparing Groundwater Use Under Contrasting Property Regimes

Christopher Brooks – *Water Strategy Consulting LLC*

Does the type of property right that pertains to a natural resource affect its use? Economic theory predicts that where no property rights exist, users are more likely to undervalue future use, resulting in rapid depletion of the resource from wasteful and inefficient use. In contrast, where property rights *do* exist, users of the resource are predicted to be more likely to properly value future uses, resulting in a rate of consumption consistent with the most efficient use of the resource over its expected life.

Testing the Theory

Groundwater can be used to test this theory, because the legal regimes governing rights to groundwater vary from state to state, even where adjacent states share a common aquifer, as do Texas and New Mexico in the High Plains. In all cases, rights to groundwater are limited to use rights associated with an amount that can be pumped to the surface. But at one extreme, groundwater users in Texas, under the rule of capture, have effectively no property rights in groundwater. In contrast, groundwater users across the border in New Mexico, under prior appropriation, have what has been regarded as the closest approximation to full property rights in groundwater.

Therefore, data on groundwater pumpage and agriculture were compared for three counties in New Mexico and nine counties in Texas that overlie the Ogallala (or High Plains) aquifer, with a similar overall land area in each state. The counties were chosen for their physical similarities and farming practices, as well as their adjacent locations along the state border (see map). The data were compiled from readily available sources, including the U.S. Geological Survey, Department of Agriculture, Census Bureau, and state well-registry databases, and included county-level population data, groundwater pumpage for irrigation by county averaged over 1985 to 2000, the amount of land in agriculture and amount of land in irrigated agriculture by county averaged over 1987 to 2002, and the number of irrigation wells by county.

The entire study area has a semi-arid climate and is dominated by center-pivot irrigation of wheat, corn, sorghum, and cotton. However, previous studies indicate there is significantly more water stored in the Ogallala under Texas than under New Mexico.

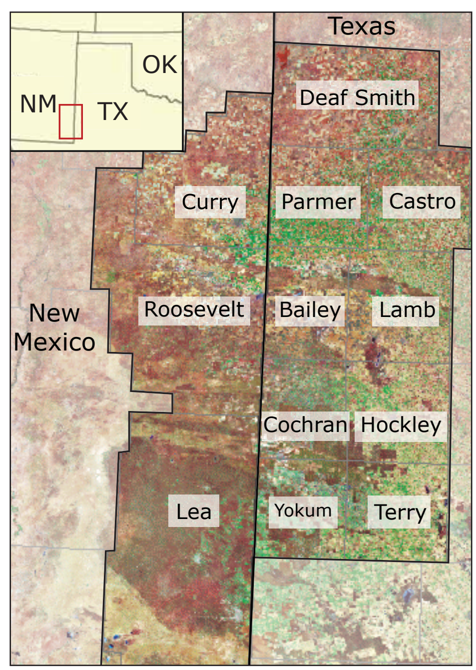
The data showed that nearly six times as much land is irrigated farmland and over three times as much water is used for irrigation in the Texas counties compared to the New Mexico counties. This clearly supports the prediction that more groundwater use and irrigated farming will occur under rule of capture (Texas) than under prior appropriation (New Mexico), all other things being equal. Also, the table (below left) shows that groundwater use per capita, per acre, and per well were all significantly higher in Texas.

County	Irrigation wells per capita	Irrigation wells per acre irrigated	Annual irrigation groundwater use			
			per capita (acre-feet/person)	per acre of land (acre-feet/acre)	per well (acre-feet/well)	per irrigated acre (acre-feet/acre)
New Mexico counties (total area = 5.3 million acres, annual irrigation groundwater use = 536,000 acre-feet)						
Curry	0.03	0.0156	5.37	0.27	173.52	2.70
Lea	0.03	0.0400	2.03	0.04	69.42	2.77
Roosevelt	0.10	0.0224	10.06	0.12	105.54	2.36
Average	**0.05**	**0.0260**	**5.82**	**0.14**	**116.16**	**2.61**
Texas counties (total area = 5.4 million acres, annual irrigation groundwater use = 1.79 million acre-feet)						
Deaf Smith	0.04	0.0047	11.37	0.22	288.00	1.35
Parmer	0.02	0.0013	32.28	0.57	1303.87	1.63
Castro	0.02	0.0009	44.17	0.64	1946.62	1.77
Bailey	0.03	0.0032	25.40	0.32	782.62	2.49
Lamb	0.02	0.0015	20.94	0.47	959.56	1.45
Cochran	0.03	0.0019	16.26	0.12	546.46	1.03
Hockley	0.01	0.0013	4.94	0.19	732.96	0.97
Yoakum	0.01	0.0008	13.60	0.19	1747.02	1.35
Terry	0.01	0.0009	11.19	0.25	1385.83	1.22
Average	**0.02**	**0.00182**	**20.02**	**0.33**	**1076.99**	**1.47**

Analysis of data on wells, irrigated land, and groundwater use in the study area.

Prior Appropriation Drawback

One surprising result was that groundwater use for irrigation appears



Location of counties in study area. Image obtained from www.nationalatlas.gov.

to be more efficient in Texas, where significantly less groundwater is used per irrigated acre. This indicates a potential drawback to quantified groundwater rights under prior appropriation: there is little incentive to increase irrigation efficiency if the user would thereby forfeit a portion of the right and be unable to receive the benefits of higher efficiency. Under the rule of capture, the right is not based on a specified quantity of water, so users who improve efficiency can benefit from their efforts. This observation, that efficiency gains often do not lead to net savings of groundwater, has been noted by others.

The analysis showed that while having well-defined rights to groundwater may reduce overall groundwater use, it may come at the cost of perpetuating inefficient uses of the resource and discouraging future efficiency gains.

Contact Christopher Brooks at cjbrooks@theriver.com.