IMPACTS OF A HIGH-INTENSITY SUMMER RAINSTORM ON TWO SMALL OAK SAVANNA WATERSHEDS IN THE SOUTHWESTERN BORDERLANDS

Gerald J. Gottfried,[1] Daniel G. Neary,[2] Peter F. Ffolliott,[3] and Donald D. Decker[4]

Oak (encinal) woodlands and savannas cover more than 31,000 square miles in the southwestern United States and northern Mexico. About 60 percent of the Coronado National Forest supports oak woodlands and savannas. Emory oak (*Quercus emoryi*) is the most common species in many of the ecosystems. The lands are important for recreation, wildlife habitats, livestock production, and tree products and resources. The ecosystem's trees and herbaceous cover protect important watersheds that provide local water for human and animal populations and support important riparian habitats. They often contain channels that transport water originating from higher-elevation forests to the lowlands where it is utilized. However, little is known about the hydrology of these ecosystems (Lopes and Ffolliott 1992; Baker et al. 1995), although there have been recent studies designed to learn more about the components of the hydrologic cycle within these stands. Ffolliott et al. (2003) and Shipek et al. (2004) studied transpiration of harvested and unharvested Emory oak trees and stands and Haworth and McPherson (1991) studied the effects of Emory oak on the distribution and interception of precipitation. Ffolliott (2004) used this information to develop a water balance for oak woodlands in southeastern Arizona. He assumed that if annual precipitation was 18 inches, only 4–10 percent would become streamflow. Most of the precipitation would contribute to the interception and evapotranspiration components of the hydrologic cycle. Differences in runoff can be related to soil type and condition, plant cover characteristics, and range condition (Baker et al. 1995).

Streamflow and sedimentation data are not available for the oak woodlands and savannas of the southwestern United States. Much of the hydrologic research in the region has been conducted in the semiarid grassland vegetation at Walnut Gulch near Tombstone, Arizona, by the USDA Agricultural Research Service (ARS). However, the ARS has recently conducted rainfall simulation studies on burned and unburned oak and grassland sites (Paige et al. 2005). Surface runoff generally is the result of rainfall, especially runoff generated by high-intensity summer convectional storms although sustained winter storms have produced significant runoff events in the region. Snow does occur in the region's mountains, but the importance of snowmelt runoff is localized to lands surrounding the higher-elevation mountain ranges such as the Santa Catalina Mountains and the Pinaleno Mountains (Ffolliott et al. 1996).

In 2000, the Southwestern Borderlands Ecosystem Management Project of the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station and its cooperators initiated a study in the Peloncillo Mountains to determine the effects of cool season (November–April) or warm season (May–October) prescribed burning on the hydrology, erosion, and sedimentation dynamics of oak savannas in the Southwestern Borderlands. This effort was in response to questions raised during the preparation of the Peloncillo Programmatic Fire Plan by the Coronado National Forest and its partners. Parshall flumes were established on 12 small watersheds and recording precipitation gages were located in a grid throughout the research area.

A secondary objective was to learn more about the basic hydrology of this oak ecosystem. The overall study uses an ecosystem approach and also includes studies of the impacts of seasonal burning on vegetation, fuels, and wildlife (Gottfried et al., in press).

Pre-treatment calibration of the flumes began in 2001. The calibration period continues because the

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[1] USDA Forest Service, Rocky Mtn. Research Station, Phoenix
[2] USDA Forest Service, Rocky Mtn. Research Station, Flagstaff
[3] School of Natural Resources, University of Arizona, Tucson
[4] USDA Natural Resources Conservation Service, Douglas

prolonged regional drought has limited the number of flow events available to compare runoff peaks among watersheds. However, on August 23, 2005, a high-intensity thunderstorm crossing the watersheds produced high peak flows that overtopped several of the flumes and moved large amounts of side-slope and channel sediments. This paper presents preliminary information about the impacts of the storm on two of the watersheds, one draining to the south and the other draining to the north. The information will increase our knowledge about the hydrology and sediment dynamics of the widespread oak savanna ecosystem.

STUDY AREA

The study area, known as the Cascabel Watersheds, is located on the eastern side of the Peloncillo Mountains and west of the Animas Valley of southwestern New Mexico. It is within the Douglas Ranger District of the Coronado National Forest and adjacent to the Diamond A Ranch. The study area covers approximately 451 acres with individual watersheds ranging from about 59 to 19 acres. The watersheds are located along an east-west ridge with six draining to the south into Whitmire Creek and six draining to the north into Walnut Creek. The watersheds have been divided into four groups of three; one watershed in each group will be burned in the cool season, one will be burned in the warm season, and one will remain unburned as a control. Elevations range from 5594 feet on the west side of the study area to 5380 feet on the east side. Long-term average annual precipitation at the Cascabel Ranch headquarters gage is 23.5 inches, with nearly half occurring during the summer.

The geology and soils for the watershed area have been described in detail by Gottfried et al. (2000), Youberg and Ferguson (2001), and Robertson et al. (2002). The bedrock geology is described as Tertiary rhyolite lava overlain by Oligocene-Miocene conglomerates and sandstone. Rhyolite is more apparent on the three western watersheds. Soils on the watersheds have been classified as Lithic Arguststolls, Lithic Haplustolls, or Lithic Ustorthents (Robertson et al. 2002). Soils generally are less than 3.3 feet deep. Streams on the north side of the central ridge have longer, lower gradient channels than those on the south side. This difference might be related to the geomorphology of the two major creeks that border the study area—specifically, their relative sizes, lithologic changes, and relative location with respect to the central ridge (Youberg and Ferguson 2001). Whitmire Creek to the south is closer to the ridge than Walnut Creek which is to the north of the study area.

Emory oak is the dominant tree species on the watersheds, comprising about 60 percent of the tree composition (Gottfried et al., in press). Arizona white oak (*Q. arizonica*), Toumey oak (*Q. toumeyi*), and alligator juniper (*Juniperus deppeana*) are other important species. The density is about 90 trees per acre. Common grasses include several species of grama (*Bouteloua* spp.), *bullgrass (Muhlenbergia emersleyi*), and common wolfstail (*Lycurus phleoides*). Forbs are a relatively minor component of the understory. Shrubs and half-shrubs, such as beargrass (*Nolina microcarpa*), are scattered on the area.

The current evaluation is based on preliminary runoff and precipitation on two of the western watersheds—Watershed A and Watershed I. These two were selected because of the quality of the record and the relative concentration of precipitation gages. Data from the two areas will not be compared statistically. Watershed A, which drains to the south into Whitmire Canyon, covers 31.5 acres and lies at an average elevation of 5550 feet. The channel is 1378 feet long (Neary and Gottfried 2004) and has a slope of 5.6 percent. Side-slopes, based on map measurements, average about 23 percent. The geology is rhyolite with some boulder-cobble conglomerate on the upper ridges (Youberg and Ferguson 2001). The lower slopes are dominated by Lithic Ustorthents, while the ridges have Lithic Arguststolls soils (Robertson et al. 2002). The textures are a very cobbly sandy loam and a very gravelly sandy loam, respectively. Watershed I, which drains to the north into Walnut Creek, covers 52.4 acres and has an average elevation of 5530 feet. Channel length is 5320 feet and channel slope is 3.8 percent. Side-slopes average 17 percent. The geology is boulder-cobble conglomerate (Youberg and Ferguson 2001) and the dominant soils are Lithic Arguststolls (Robertson et al. 2002).

Channel substrate is an important factor in streamflow, base flow, and the availability of sediments for transportation. Channel characteristics for the two watersheds are shown in Table 1.

METHODS

Runoff and Precipitation

Each of the 12 watersheds contains a 9-inch Parshall flume, with a capacity of 4.03 cubic feet per second (cfs) to measure common low flows,

Table 1. Channel characteristics by percent of channel for Watersheds A and I (Neary and Gottfried 2004).

Characteristic	Watershed A	Watershed I
Rock	6.4	15.9
Fine alluvium	24.7	3.0
Coarse alluvium	62.4	74.0
Vegetation	4.6	6.4
Woody debris	0.7	0.7
Other	1.2	0.0

and a larger 3-foot or 4-foot flume with capacities of either 42.7 or 57.5 cfs, respectively. These values assume that the flume is running at 90 percent of full depth. The flume size was determined from pre-installation calculations based on a 10-year return interval and a 2.8-inch rain event within 24 hours (Gottfried et al. 2000). Watersheds A and I contain 4-foot flumes. The small flumes were converted to Replogle long-throated flumes in 2005 to increase their accuracy to measure low flows. Two weather stations were established, one at the western edge of the area and one on a side-ridge in the middle of the area. These are supplemented by six additional recording dipping bucket precipitation gages located throughout the area. For this analysis we used the Watershed H weather station (H Cascabal) on the ridge between Watersheds A and H, the Watersheds A-B dipping bucket gage between Watersheds A and B, and the Watershed I dipping bucket gage near the Watershed I flumes.

Sediment

Sediment is measured at a sediment dam and basin on each watershed. The dam walls are about 2–3 feet in height and are tied into the channel walls. Every dam wall contains an opening to minimize streamflow retention. Each basin contains 10 surveying lines that are tied to a permanent benchmark. These are measured periodically using a surveyor's level and rod. Volumes and volume differences between periods are calculated using the WinXSPRO program (Hardy et al. 2005) and the average end area method (Dendy et al. 1979). In addition, each watershed has a series of permanent channel cross-sections that are also measured with a level and rod. Surface pebble counts were conducted in all basins in 2006. Side-slope erosion is measured at a series of three-pin groups located on five transects that are orientated perpendicular to the main channels within each watershed. Local bulk density measurements were used to convert measurements of average soil loss to erosion rates in terms of tons per acre. Watersheds A and I each have 12 erosion plots that are measured in the spring and fall.

THE STORM OF AUGUST 23, 2005

The Borderlands region and most of the Southwest are currently in the seventh year of a protracted drought. However, there were significant storms on the Cascabel watersheds in January and at the end of February 2005. Some of these winter storms produced measurable runoff. The watersheds received about 2.88 inches of precipitation between January 2 and 6, producing peak flows of 2.0 and 2.2 cfs on Watershed A and 7.5 and 6.5 cfs on Watershed I. Conditions were then relatively dry until mid-July when monsoon rains began to enter the area. Approximately 1.80 inches of rain occurred in July but these storms did not generate any runoff. August was relatively wet; about 5.58 inches of rain fell between August 3 and 22. Two storms produced daily total accumulations of more than 1 inch. Intermittent runoff was measured from Watersheds A and I starting on August 10 when 1.49 inches were recorded at the H Cascabel weather station.

The storm of August 23 began at 12:00 hours and came from the northwest. Some of the storm's characteristics are indicated in Table 2. Periods of high-intensity rain have been converted to equivalent inches per hour values. Other gages on the study area recorded between 2.81 and 1.36 inches of total precipitation. The two gages at the eastern end of the study area recorded the least precipitation. The storm also started between 9 and 21 minutes later on those areas. Gages at Watersheds I and K on the north-facing side of the area recorded the greatest intensities. This storm was the last big monsoon event of 2005 although two smaller spotty storms crossed the area in early September.

RESULTS AND DISCUSSION

Runoff

Four runoff events were measured on Watersheds A and I in August 2005 prior to the storm of August 23. These occurred on August 10, 11, 14, and 20. Flow from the August 23 storm began at the big flume on Watershed A at 12:16 hours and peaked at 13:00. The peak stage was 2.48 feet and the peak flow was 67.20 cfs. This big flume stage was almost at maximum for a 4-foot Parshall flume. However, the debris cover on the walls at Watershed A indicates that this level of flow was likely. We do not know the character of the recession flow because the big flume orifice was

Table 2. Precipitation characteristics for gages surrounding Watersheds A and I at Cascabel for the storm of August 23, 2005.

Station	Total Precip. (inches)	Starting Time (hour)	Ending Time (hour)	Equivalent Highest Intensity (in/hr)
H Cascabel	2.36	12:00	16:00	1.90
Watershed A-B	2.64	12:01	15:44	2.94
Watershed I	2.99	12:06	15:47	3.31

blocked by fine material at approximately 13:09 hours. The downstream small flume began recording at 12:30 but became inoperative because its throat was blocked by a 9-inch cobble and large amounts of vegetative material.

Watershed I began recording runoff at about 12:05 and peaked at 13:02 at a stage of 2.12 feet on the big flume, which indicates a peak flow of 52.57 cfs. Flow was recorded at the big flume until 17:25 that day, lasting 5 hours and 20 minutes. Runoff was measured at the small flume for another 5 days, until 18:09 on August 28. A 0.08-inch storm on August 26 contributed to the sustained flows. Much of the precipitation from the large storm probably became surface or subsurface runoff and little was held by the soil or channel sediments. The flumes at Watershed I started measuring flow about 5 minutes after the storm started at H Cascabel and at about the same time as the I-dipping bucket started recording. The rapid flow response could have been the result of direct channel interception and rapid flows over the bedrock in the channel; peak flow was measured after an hour of rain.

The Soil Conservation Service's curve number procedure was used during the planning phase to simulate a unit hydrograph for each of the 12 watersheds (USDA Soil Conservation Service 1984). The procedure assumes that some of the precipitation does not contribute to runoff. The method classifies watersheds by hydrologic soil groups based on runoff potential, infiltration rates, and water transmission rates, and by hydrologic condition, based on degree of ground cover. A runoff curve number of 84, out of a maximum of 100, was used in the original calculations for all watersheds. Times of concentrations (Tc) were recalculated for the two watersheds based on measurements made after the flumes were installed. The Tc value is defined as the time it takes for runoff to travel from the hydrologic, most distant point of the watershed to its outlet. The Tc values are 8 minutes for Watershed A and 26 minutes for Watershed I. If we assume that the peak flow includes water from all areas of the watershed, which actually is unknown, the estimates for Watershed A and I are too low. However, the value of Tc on unregulated upland streams can be compromised because of pool filling and the formation and breaching of debris dams upstream. The sediment dam walls may have retarded some of the initial flow although they are designed with an opening to minimize their effect. The influence of the dams decreases as the basins are filled with sediment and hold less water. An even distribution of rainfall cannot be assumed because of the cellular nature of summer thunderstorms.

Runoff response is also influenced by subsurface geology. For example, some of the rhyolite coherent facies in Watershed A are relatively impermeable to surface runoff infiltration (Youberg and Ferguson 2001) and would yield water quickly. New calculations of potential peak discharge values for a 10-year recurrence interval based on a curve number of 84 and the new Tc were 60 cfs for Watershed A and 68 cfs for Watershed I. The observed values were 67 and 53 cfs, respectively. It is possible that closer agreement could have occurred if individual curve numbers had been selected for each watershed.

EROSION AND SEDIMENTATION

The storm moved sufficient sediments from side-slopes and redistributed existing sediments in the channels to fill most of the sediment basins located above the flume installations. The small flumes at Watersheds A, B, and H were made inoperative because of the accumulation of large cobbles and vegetative materials including live trees and tree trunks.

Side-Slope Erosion

The erosion pins on Watersheds A and I were measured in the spring and fall of 2005 (Table 3). The first period reflects conditions after the winter

Table 3. Side-slope erosion on Cascabel Watersheds A and I for the 2005 measurement dates.

	Spring 2005		Fall 2005	
Watershed	tons/acre	cubic feet/acre	tons/acre	cubic feet/acre
Watershed A	9.94 ± 1.25	281.83 ± 35.46	10.80 ± 1.25	306.21 ± 35.46
Watershed I	17.70 ± 2.33	502.19 ± 66.09	4.62 ± 0.95	130.99 ± 26.95

storms and the second after the summer events. The spring 2005 values reflect changes since the fall of 2004. The measurements at Watershed A for the two periods are statistically equivalent. The decrease during the summer relative to winter for Watershed I might be linked to the fact that much of the soil had already been moved before the summer storms began. Although we cannot confirm this fact quantitatively, one indication is that peak flows were larger on Watershed I than on Watershed A during the storms of early January 2005.

Similar watershed data from other areas in the southwestern United States are not available for comparison. Paige et al. (2005) reported sediment yields of between 0.94 and 1.97 tons/acre for two small rainfall simulation plots in unburned oak woodland in the San Rafael Valley in southeastern Arizona. However, these values only reflect one event. Nearing et al. (2005) studied 40 years of erosion on two small watersheds at Walnut Gulch, Arizona. One was covered by grass and the other by brush such as creosote (*Larrea tridentata*) and whitethorn (*Acacia constricta*). The brush-covered watershed yielded 1.9 tons/acre/year but eroded areas within the watershed yielded an average of 2.5 tons/acre/year. The values for the grass watershed were 0 and 1.4 tons/acre/year, respectively.

Sediment Dam Measurements

The basins behind the sediment dams collect channel sediments that are redistributed by stream flow and new sediments that are moved from the side-slopes into the channel system. The lower section of the Watershed A sediment basin, containing six transects, was surveyed, cleared of sediments, and resurveyed in late March 2005, providing a comparison of sedimentation that occurred during the 20 months between August 2003 and March 2005 and the 10 months between April 2005 and January 2006 when the dam was surveyed and cleared again. Approximately 52.2 ft^3 of sediment were collected in the first period, which included the storms of January and February 2005, and 190 ft^3 were collected in the second period, which included the storm of August 23. These accumulations are the equivalent of 1 and 7.2 ft^3/acre/year, respectively. Similar information is not available for Watershed I because cleaning of sediments was not necessary in March 2005.

All 10 transects across both sediment dams were surveyed in January 2006. Approximately 295.3 ft^3 of sediments were measured behind the Watershed A dam. The total collected since 2003, including material removed in March 2005, was 347.4 ft^3. The proportion of the 306.2 ft^3 that eroded from the side-slopes during the summer period (Table 3) and was deposited at the dam site is unknown. Much of the eroded material that entered the channel was probably redistributed there. The amounts for Watershed I from December 2003 through January 2006 were 190.3 ft^3. The totals for the full period of record were equivalent to 4.4 ft^3/acre/year for Watershed A and 1.7 ft^3/acre/year for Watershed I.

There are few sedimentation studies in the region with which to compare the Cascabel results. However, Nichols (2006) reported long-term results from eight large semiarid grassland watersheds at Walnut Gulch, an area that receives between 11.9 and 13.4 inches of annual precipitation. This analysis was based on sediment-yield data that covered from 30 to 47 years of record. The Cascabel sediment yields are smaller than those from Walnut Gulch, where yields ranged from 7.1 to 42.9 ft^3/acre/year of sediment and averaged 20.0 ± 14.3 ft^3/acre/year. These watersheds have primarily alluvial channels with little exposed bedrock.

There also appear to be differences in the size of sediments collected at the flume sites and in the sediment dams (Table 4). Most of the sediments coming from both watersheds were in the sand and gravel categories; however, sands were more common at Watershed A. Some of the finer material collected behind the dam and in the upstream channel (Table 1) consisted of volcanic glass that was weathered from the rhyolite formations. Gravels were more common on Watershed I and could

Table 4. Percent distribution of sediments in Watershed A and I determined by pebble counts.

Class Name	Size (in)	Watershed A	Watershed I
Sand	<0.8	46.3	23.3
Gravels	0.08–2.5	33.3	61.8
Small cobbles	2.5–5.0	6.5	7.5
Large cobbles	5–10	9.9	1.5
Small boulders	10–20	4.0	1.5
Medium boulders	20–40	0	0
Large boulders	40–80	0	0
Very large boulders	80–160	0	4.4

be related to its very gravelly sandy loam soils. It is probable that larger material that was moved by the peak flows was buried under the surface or had been moved through the flumes during the peak flow part of the hydrograph. Some of the soil that eroded from the side-slopes probably remained in the channels after flow had ended. Much of the measured finer material settled out of the streamflow during the recession flow. Suspended sediments were not measured.

More sediment was produced on Watershed A than Watershed I since the sediment basins were originally measured in 2003. It is difficult to draw conclusions for the entire study period but there are several potential reasons for the differences in the period surrounding August 23. The differences in geology and geomorphology appear more important than the differences in aspect. The differences in channel length and slope affect the hydrologic characteristics. The peak flows were higher on Watershed A, providing the energy to move more and larger-sized material that had been collecting in the channel over time or was washed into the channel from the side-slopes. Although the 2005 side-slope erosion data appear similar for the two areas, there were larger losses from Watershed A during the summer period. Channel conditions would have had an impact. There is more channel alluvium in Watershed A (87.1%) than in Watershed I (77%), which provides a potential source of material. Watershed I has more exposed bedrock in the channel that would not contribute to sediment yields in the short term.

SUMMARY

There is little information about the hydrology, erosion, and sedimentation characteristics of the oak savanna ecosystems that cover wide areas in the southwestern United States and northern Mexico. This paper attempts to help alleviate this deficiency by describing the impacts of a high-intensity summer rainstorm in 2005 on two small watersheds that are typical of the area's savannas. Although only a small area was studied, the information could be applicable to similar watersheds throughout the region and could be used, with caution, when planning management activities. Streamflow is intermittent; dry channels are more common than flow events, and most events are less than 1 cfs. However, large streamflow events do occur, especially in the summer monsoon period, and they can move large amounts of sediments. Flows of 67 cfs were measured on August 23 at Watershed A and on several adjacent watersheds that were not included in this analysis. Side-slope erosion and sediment movements and characteristics should provide useful information as well. It appears that watershed geology and geomorphology are the main factors influencing the amounts and types of sediments measured from the two watersheds.

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