GEOMORPHOLOGY OF SMALL WATERSHEDS IN AN OAK ENCINAL IN THE PELONCILLO MOUNTAINS

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Oak savannas cover large areas in mountains and high valleys of the southwestern United States and northern Mexico. However, relatively little information is available about these lands to aid in their management (Gottfried et al. 2000a). Twelve small watersheds on the east slope of the Peloncillo Mountains in southwestern New Mexico were selected for study of the hydrology and ecology of oak savannas, and for evaluating the impacts of cool season and warm season fires on a number of ecosystem components.

Fire was the most important natural disturbance in these ecosystems prior to European settlement. During the twentieth century fires became less frequent because of the impacts of past overgrazing on the native herbaceous vegetation and fire suppression activities (McPherson 1992). Some areas currently have high fuel accumulations that could contribute to detrimental stand-replacing wildfires. Prescribed burning is a technique to restore the natural processes within the savannas, to reduce densities of woody species, to increase herbaceous plant cover and production, and to create mosaics of vegetation on the landscape. However, questions remain about the effects of burning season and fire intensities on this ecosystem.

A considerable amount of ecological and related information for the Peloncillo Mountains and the Southwestern Borderlands Region has been collected in recent years through the efforts of the USDA Forest Service, Rocky Mountain Research Station, the Malpai Borderlands Group, the Animas Foundation, Arid Lands Project, and their associates (Gottfried et al. 1999a, 2000b). The channel information presented here was gathered to quantify easily visible differences in the stream channels of the Peloncillo watersheds. This information is crucial to understanding the hydrologic responses of these watersheds before and after fire is reintroduced into the landscape.

THE SOUTHWESTERN ENCINAL

The encinal or oak savannas and woodlands, also referred to as the Madrean evergreen formation, are concentrated in the Sierra Madre Occidental of Mexico and extend northward into southeastern Arizona, southern New Mexico, and Texas. This formation covers approximately 80,290 km^2 (31,000 mi^2; Ffolliott 1999). The differentiation between woodlands and savannas is based on the amount of tree canopy closure; the term savanna is commonly used for areas with an open tree cover and a large, often continuous grass component (Van Devender 1995). The oak savannas and woodlands are a major vegetation type within the Coronado National Forest of southern Arizona and southwestern New Mexico, where they occupy more than 3430 km^2 (1324 mi^2; R. E. Lefevre, personal correspondence, July 1999). Oak and juniper mapping units cover approximately 401 km^2 (155 mi^2) in the Borderlands Project Area (Muldavin et al. 1998).

The woodlands and savannas provide a number of natural resources and amenities (Ffolliott 1992). They supply tree and other vegetative products, such as firewood, fence posts, acorns, and beargrass (*Nolina microcarpa*) for local consumption, and are important for livestock grazing and wildlife habitats, especially for threatened, endangered, or sensitive species. Forty-one species of neotropical birds were tallied in the oak woodlands of southern Arizona, which are important breeding and migration habitats (Block et al. 1992). Water is a critical resource in these arid areas, and watershed management activities are designed to protect soil stability and water quality and to sustain stream flows. Recreational activities, such as hiking, camping, hunting, and bird watching, are increasing as the population of the region grows,

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and they represent a large income producer for local communities.

Annual precipitation in the Borderlands encinal exceeds 406 mm (16 in). More than half falls in the May through August growing season. The late spring and autumn are dry. The proportion of annual precipitation attributed to summer rains decreases from southeastern Arizona to the northwest. Extremes in annual precipitation range from 305 to 1016 mm (12–40 in; Gottfried et al. 1995). Encinal landscapes generally occur between 1189 and 2195 m (3900–7200 ft) in elevation. Precipitation and stand densities are observed to increase with elevation in the Peloncillo Mountains, as has also been reported in the Santa Catalina Mountains, north of Tucson (Whitaker and Niering 1964). Stands commonly are in a variety of sites, including along drainages, on rocky slopes, on alluvial basin fill and fans, and on residual soils of rhyolitic pediments and elevated plains (USDA Forest Service 1997). Soil type and depth influences stand structural development.

A large variety of oaks are found in the encinal woodlands. Emory oak (*Quercus emoryi*) is common in the mountains of the southwestern Borderlands and can be associated with Arizona white oak (*Q. arizonica*), gray oak (*Q. grisae*), and Mexican blue oak (*Q. oblongifolia*). These oaks are small, often multiple-stemmed, irregularly formed trees. Natural oak regeneration from seed is episodic; sprouting from stumps and roots is a more common regenerative mechanism (Borelli et al. 1994). Redberry juniper (*Juniperus erythrocarpa*) or alligator juniper (*J. deppeana*) and border pinyon (*Pinus discolor*) are intermixed with the oaks on many sites. Chihuahua pine (*P. leiophylla* var. *chihuahuana*) is often found along major drainages. Tree densities are variable, from scattered individuals to several hundred stems per hectare. Stand density has been related to soil properties, elevation, and other topographic characteristics, and to fire and human land use histories (Gottfried et al. 1995).

ENCINAL HYDROLOGY

Little information is available about the hydrology of the encinal woodlands and savannas (Lopes and Ffolliott 1992; Baker et al. 1995). Much of the hydrological research in the region has been conducted in the Chihuahuan Desert vegetation at Walnut Gulch, near Tombstone, Arizona (Osterkamp 1999). One of the main gaps concerns streamflow and surface runoff characteristics of the oak woodlands. Surface runoff is the result of both rainfall and snowmelt; however, high-intensity summer rains produce most of the surface runoff and can accelerate erosion and sedimentation. Encinal watersheds also are important because they often contain channels that transmit water from the higher elevation conifer forests. Many of the problems on these watersheds are linked to past overgrazing of livestock. Channels accumulate soil and rocks from the side slopes that are moved by periodic runoff events. Low flows result in a redistribution of sediments in the channels whereas larger flows tend to flush sediments through the system. Good encinal watershed condition, based on erosion rates, gully presence, and soil compaction criteria, is necessary so that accelerated erosion and sedimentation do not impair water quality. This is best accomplished by maintaining healthy, well-stocked stands of trees and herbaceous vegetation (Lopes and Ffolliott 1992; Baker et al. 1995). Watershed management objectives are to minimize any adverse effects of current land use activities to the soil and water resources, to increase water yields, and to rehabilitate degraded watersheds. However, it is unlikely that management practices will increase streamflow from the oak woodlands because of the high evapotranspiration demands relative to the low precipitation.

Research on other aspects of the hydrological cycle include a report by Haworth and McPherson (1991) that up to 70 percent of the late summer–early fall precipitation is intercepted directly under the canopy of Emory oak. Throughfall varied with the amount of storm precipitation; tree size was important for smaller storms. Ffolliott and Gottfried (1999) and Gottfried et al. (1999b) have studied transpiration by Emory oak in the San Rafael Valley of southeastern Arizona.

DeBano et al. (1996) discussed the impacts of fire on water resources in the Madrean Province ecosystems. The most obvious impact occurs from large, high-severity fires that destroy the vegetation and cause a decline in interception by both vegetation and litter, resulting in soil water repellency. The latter can result in increased overland flows and erosion, particularly on steep slopes. A reduction in the plant cover could result in a decrease in evapotranspiration on the watershed and an increase in soil water storage.

THE PELONCILLO WATERSHEDS

Twelve small watersheds were selected on the east side of the Peloncillo Mountains of southwestern New Mexico for evaluating the impacts of cool season and warm season prescribed burning on oak savanna ecosystems common to the region (Gottfried et al. 2000a). Hydrology is a major part of the fire experiments planned for these watersheds. Climatic and hydrological records for the area are scarce, making basic hydrological analyses important in the design of streamflow measurement structures. This region is characterized hydrologically by a very wide range of flows. The main instrumentation problem was to design installations that are not so small that they would be unable to measure uncommon, but significant, naturally high streamflows and any high flows related to the prescribed burning, but not so large that the majority of more common low flows could not be measured accurately.

The 12 watersheds selected for instrumention in 2001 are located north of Whitmire Canyon in the Coronado National Forest, approximately 50 km (31 mi) south of Animas, New Mexico, and north of the Geronimo Trail road. The site is west of the Cascabel portion of the Diamond A Ranch, which holds the permit for the grazing allotment on the watersheds. An east-west ridge between Whitmire and Walnut Canyons is the main topographic divide. Elevations range from about 1640 to 1704 m (5380–5590 ft). Six watersheds were selected for study on the north and south sides of the ridge between Whitmire and Walnut Canyons. The watersheds have been divided into groups of three.

Each set of three watersheds has two burning treatments and an untreated control treatment that will be assigned randomly. The watersheds range in size from 8 to 36 ha (20–83 ac; Gottfried et al. 2000a). Watersheds A through G are on the south side of the ridge and H through N are on the north side. Channel lengths range from 226 to 769 m (743–2522 ft), and slopes are between 2.5 and 7 percent. Areas were determined by Geographic Information System (GIS) procedures, and the other characteristics were determined from U.S. Geological Survey maps and on-the-ground measurements.

GEOLOGY AND SOILS

The basic parent material in the study area is rhyolite, a fine-grained igneous rock that has the composition of granite. Vincent (1998) reported that the surface geology in the Animas Valley was formed by ash flow tuffs and lava flows that erupted from calderas and smaller vents during a period of the Oligocene (36–26 million years before present). Five ancient calderas are in or border the Animas Valley. The tectonic tilt is to the east. Rhyolite results from chemical differentiation (separation or isolation of compounds) as mantle material migrates and melts its way through the earth's crust to vent at the surface. The rocks are rich in potassium and silica, and relatively low in calcium, iron, and magnesium (Vincent and Krider 1998). Biggs et al. (1999) surveyed the geology and geomorphology in adjacent areas of Arizona and indicated that the formations are the result of many separate rhyolite flows that exhibit contorted flow banding. Phenoclasts in the flows are usually less than 1 mm (0.04 in) wide and comprise 1–5 percent of individual flows. Many flows have a vitric base that stands out as a dark band and may have interbeds of lithic tuffs that are several meters thick. Tuffs are rocks consolidated with volcanic ash.

The hillslopes adjacent to the Animas Valley are eroded and generally consist of colluvium-covered bedrock or exposed bedrock (Vincent and Krider 1998). Slopes are commonly between 5 and 30 percent. The resulting colluvial soils are about 0.4 m (1.3 ft) thick and consist of a 5–10 cm (2–4 in) surface horizon of gravelly silt loam to gravelly clay loam and a 10–25 cm (4–10 in) B horizon of 40–70 percent gravel-sized clasts and interstices of clay loam to silty clay and a subsoil of interlocking stones.

The 1991 General Ecosystem Survey conducted by the Southwestern Region of the Forest Service classified the soils in this area of the Peloncillo Mountains as Typic Haplustalfs, mesic, deep, gravelly, loam compacted or deep, very cobbly, sandy loam, gullied. Slopes vary from 0 to 40 percent. Another Forest Service soil survey in the area classified 45 percent of the soils as Typic Haplustolls, coarse-loamy, mixed, mesic, 25 percent as the Typic Haplustalfs, and 15 percent rock outcrops. One site was classified primarily as Lithic Ustorthents, loamy, mixed, nonacid, mesic, typical. Both sites supported Emory oak, Toumey oak (*Q. toumeyi*), alligator juniper, and redberry juniper.

The USDA Soil Conservation Service (Cox 1973) soil survey of Hidalgo County classified all of the soils in the area as rock land with bedrock at 0–30 cm (0–1 ft). The well-drained surface soils, classified in the Lehmans Series, have a permeability of 50–160 mm/hr (2.0–6.3 in/hr). Rock land slopes are between 10 and 25 percent, and in this land type 30–85 percent of the soil surface consists of exposed bedrock, stones, and cobbles.

HYDROLOGY

The baseline data of streamflow and water quality generated by this study will increase the knowledge about the hydrology of small oak watersheds in this region that can be used for land management activities. The initial task was to review existing information (Gottfried et al. 2000a). Cox (1973) indicated that annual precipitation in the rock land units in Hidalgo County ranged from 305 to 457 mm (12–18 in). The highest annual precipitation recorded prior to 1973 was 743 mm (29.27 in) at the old Cloverdale Ranger Station, south of the study area, and the highest monthly total was 257 mm (10.12 in) at the Dunagan Ranch, north of the area. Runoff from these areas is rapid, and the hazard of water erosion is moderate. The water supplying capacity of the soil is between 127 and 203 mm (5–8 in).

Osterkamp (1999) determined runoff and sedimentation for the Upper Animas Creek Basin using records from the Walnut Gulch Experimental Watersheds, the San Simon Wash Valley in Arizona, and the Jornada Experimental Range in south-central New Mexico. The nearest long-term weather records from Animas, New Mexico, which is on the eastern base of the Peloncillo Mountains at an elevation of 1355 m (4445 ft), indicate an average annual precipitation of 288 mm (11.32 in). Ben Brown, Diamond A Ranch, provided precipitation data from recently established weather stations located south and east of the study area at an elevation of 1554 m (5100 ft). These records were only for 2 years (1998 and 1999). They demonstrate the variability of precipitation in the area. Approximately 44 percent of the 417 mm (16.42 in) of the annual precipitation in 1998 fell in the April through September growing season, whereas almost all of the 495 mm (19.50 in) recorded in 1999 fell during this period. Several recording weather stations will be established within the experimental area to measure local conditions.

Osterkamp (1999) presented data from a U.S. Geological Survey gauging station that was active in Upper Animas Creek from 1959 through 1994. The station, which measured flows from the 76.4 km^2 (29.5 mi^2) watershed, was near where Whitmire Creek drains into Animas Creek. Maximum water year discharges ranged from 1.00 m^3/s (35.3 ft^3/s) in 1988 to 95.94 m^3/s (3390 ft^3/s) in 1974. Specific discharges of 0.0130 $m^3/s/km^2$ (1.19 $ft^3/s/mi^2$) had a return period of 1.03 years, and those of 1.272 $m^3/s/km^2$ (115.24 $ft^3/s/mi^2$) had a return period of 36 years. Osterkamp (1999) developed graphs of the relationship between unit runoff and area. However, the flow that was determined from the graph for a 16.2 ha (40 ac) watershed is much lower than has been observed on the smaller oak experimental watersheds. This is probably because small watersheds often are flashier than larger areas where runoff is distributed over a large area. Osterkamp's data are mostly from the Walnut Gulch Watersheds, which are on well-drained sandy loam soils derived from fan deposits and alluvium.

Field estimates of peak discharge were determined for the Peloncillo experimental watersheds using channel slope, cross-sectional area measurements, and high-water marks along the channel (Gottfried et al. 2000a). Discharge was calculated using the Chezy-Manning Equation (Linsley et al. 1958). A roughness value (n) of 0.052 was assumed, indicating a winding channel with pools, shallow stages, and large rocks. Peak flow estimates ranged from 0.06 to 0.79 m^3/s (2–28 ft^3/s). The low-flow channels contain rocks and logs, and occasional pools and adjacent banks are covered with relatively dense herbaceous vegetation and oak trees. Roughness values would vary along the course of the stream and by stage, and some sections would have lower n values of 0.035 or 0.042.

Peak stream discharges were estimated using alternative techniques. The first technique was to utilize discharge equations developed by the U.S. Geological Survey for the southwestern states (Thomas et al. 1994). The 2, 5, and 10 yr recurrence intervals were calculated and compared with the discharges calculated from the field data. The field-estimated values averaged higher than the 2 yr USGS return interval for five of the watersheds, but all were less than the 5 yr and 10 yr estimated discharges (Gottfried et al. 2000a). The Natural Resources Conservation Service (NRCS) developed a similar procedure to simulate a unit hydrograph for streams where rainfall and streamflow data are unavailable (USDA Soil Conservation Service 1984). This model assumes that some of the precipitation remains on the watershed and does not contribute to runoff. Site-specific information, plus tables and charts in the NRCS surface runoff manual, were used to calculate peak discharges for

2, 5, and 10 yr recurrence intervals (Gottfried et al. 2000a, Table 2). Values calculated by the NRCS method for all three return intervals were substantially higher than the field estimates.

CHANNEL CONDITION SURVEY

Because of easily observed differences in channel conditions and the wide range of values in peak discharged produced by the field estimation, USGS, and NRCS methods, a decision was made to determine the character of all the channels in the 12 Peloncillo watersheds. A consensus opinion was reached among the principal investigators that the physical condition of the channel might strongly influence hydrologic response, especially where long reaches of channel were only bedrock outcrops.

Line transect surveys were conducted on all channels, including side channels, up to the point where a distinct channel could not be determined and it blended in with the upper slope topography. A 100 m tape was extended from the main Parshall flume upslope along the channels in sequential stages until each channel was indecipherable. Lengths of channel in the following conditions were measured: bedrock, coarse alluvium, fine alluvium, vegetation, woody debris, and other. Accumulated lengths in these condition classes were summed for each watershed.

Table 1 presents the results of the Peloncillo channel survey. It includes a subdivision of Watershed E into Ea and Eb because of the differences observed in the two forks. Channel distances ranged from 720 to 1020 m (2362–5784 ft) with a mean of 1020 m (3346 ft). There was indeed a great disparity in percentage of individual watershed lengths with rock channels (6.4% in Watershed A to 41.0% in Watershed K). This could make a significant difference in total water yields as well as storm peakflow response. The watersheds with the higher percentages of bedrock channels are apt to be much more flashy in nature than the lower ones. Sub-watershed Eb has almost twice the channel length in bedrock as does its pair, Watershed Ea. These two sub-watersheds also vary considerably in fine and coarse alluvium, with Watershed Eb having more fine alluvium (12.5%) than its pair Ea (1.1%), as well as much less coarse alluvium. There was also a large range between all the Peloncillo watersheds in fine alluvium (0.2–35.7%) and coarse alluvium (18.3–74.0%). The watersheds with the higher percentages of alluvium in their channels might prove to be less flashy and have lower, but sustained flows since their channels would have a larger in-channel water storage capacity. There was far less variation in the remaining three categories (vegetation, woody debris, and other) between the watersheds.

Table 1. Channel characteristics of the Peloncillo Mountains experimental watersheds, Coronado National Forest, New Mexico.

		Percent of Channels					
Watershed	Distance (m)	Rock	Fine Alluvium	Coarse Alluvium	Vegetation	Woody Debris	Other
A	420	6.4	24.7	62.4	4.6	0.7	1.2
B	750	8.6	4.9	73.6	10.7	1.4	0.8
C	685	17.8	0.2	63.3	13.3	1.1	4.3
E	1763	33.5	8.8	38.1	15.9	1.3	2.4
Ea	571	21.6	1.1	56.8	15.1	2.8	2.6
Eb	1192	39.2	12.5	28.6	15.7	1.6	2.4
F	881	21.4	5.4	42.0	27.4	3.0	0.8
G	542	12.0	20.1	34.0	31.7	1.4	0.8
H	1378	11.2	16.2	68.2	3.7	0.7	0.0
I	1622	15.9	3.0	74.0	6.4	0.7	0.0
J2	962	29.2	25.8	31.8	11.7	0.6	0.9
K	875	41.0	27.3	18.3	9.4	0.6	3.4
M	1466	14.0	5.0	67.0	8.0	2.5	3.5
N	1175	26.6	35.7	21.1	10.8	1.5	4.3
Mean	1020	21.3	11.5	47.1	13.2	1.4	2.0
Minimum	420	6.4	0.2	18.3	3.7	0.6	0.0
Maximum	1763	41.0	35.7	74.0	27.4	2.8	4.3

CONCLUSIONS

There is sufficient variation in the geomorphology the Peloncillo experimental watersheds to expect pre-fire and post-fire differences in total water yield and peakflow discharges that are related to channel condition. The percentage of channel lengths that are bedrock range from 6.4 to 41.0 percent. The watershed hydrologic data will need to be analyzed with these differences in mind. The data will supplement research on the hydrology of the larger Upper Animas Valley Basin (Osterkamp 1999) by providing information on the dynamics of small upstream watersheds in encinal woodlands of southeast Arizona and southwest new Mexico.

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