Hydrologic Regimes in Chaparral on the Battle Flat Demonstration Area

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The demand for water from Arizona watersheds continues to increase as the public need for other natural resources and amenities continues to grow. The chaparral type has a high potential for water yield augmentation through vegetation manipulation (Hibbert 1979). Arizona supports extensive stands of chaparral. These chaparral communities provide a wide range of benefits, including watershed protection, grazing areas for wildlife and domestic animals, recreational opportunities, and wildlife habitat. With our growing population, issues concerning the wildland-urban interface are gaining importance. Chaparral areas are also subjected to wildfires that can destroy the protective shrub canopy and leave the burned areas susceptible to runoff and erosion for several years (Overby and Baker 1995). Because of these values, uses, and concerns, it is increasingly important to better understand all ecosystem processes in chaparral, particularly its hydrology and how it responds to various types of vegetation manipulations or disturbances.

Chaparral Vegetation Type

The chaparral vegetation type is restricted almost entirely to the Lower Colorado River Basin, where it covers approximately 3.5 million acres, mostly in Arizona (Hibbert 1979). Chaparral is commonly found on areas of rugged terrain ranging from 3,000 to 6,000 feet in elevation. Nearly half of this acreage is located on national forest land; the remainder is divided between the Bureau of Land Management, the state of Arizona, and private and Indian ownership.

Chaparral species tend to be low-growing shrubs with thick, evergreen leaves that are well adapted to heat and drought. Most species sprout prolifically from root crowns after burning or cutting, and others have prolific seed germination capability following a fire. Therefore, chaparral species are often difficult to eradicate. Shrub live oak (*Quercus turbinella*) is the most abundant species, followed by mountain mahogany (*Cercocarpus betulodies*). Other common shrubs are manzanita (*Archtostaphylos pringlei*), Emory oak (*Q. emoryi*), silktassel (*Garrya flavescens*), desert ceanothus (*Ceanothus greggii*), and sugar sumac (*Rhus ovata*).

Chaparral commonly occurs on areas with parent rock materials consisting of deeply weathered and fractured granite, schist, diabase, sandstone, shale, limestone, slate, gneiss, quartzite, or basalt. Granites are found on more than half of the total chaparral areas, with none of the other types making up more than 10 percent (Carmichael et al. 1978). Rock types such as basalt, limestone, quartzite, shale, and slate weather to fine textured and shallow regoliths, but do not support extensive stands of chaparral, even though rainfall and elevation are often similar. Soils developed on these parent materials often support pinyon-juniper woodlands or grass communities.

The intent of this paper is to present a preliminary analysis of the hydrologic regime on the Battle Flat Demonstration Area and to alert managers to the inherent complexity in the chaparral landscape, which must be considered when developing planning and monitoring programs for this ecosystem. The precipitation regime, and how it and the resulting runoff is influenced by the soil and geologic parameters, is specifically addressed. The information is based on 8 years of data (water years 1980–1987). The water year (WY) designation used in this study was defined as the period from July 1 through June 30.

Study Area

The Battle Flat Demonstration Area is a 3,658-acre drainage in the Bradshaw Mountains of central Arizona (Figure 1). The topography is rough and highly dissected. The prevailing aspect of the watershed is southeast; slope gradient ranges from 15 to 60 percent. Elevation is from 5,575 to 5,800 ft above sea level. The Demonstration Area includes two major subdrainages: Tuscumbia Creek (1,356

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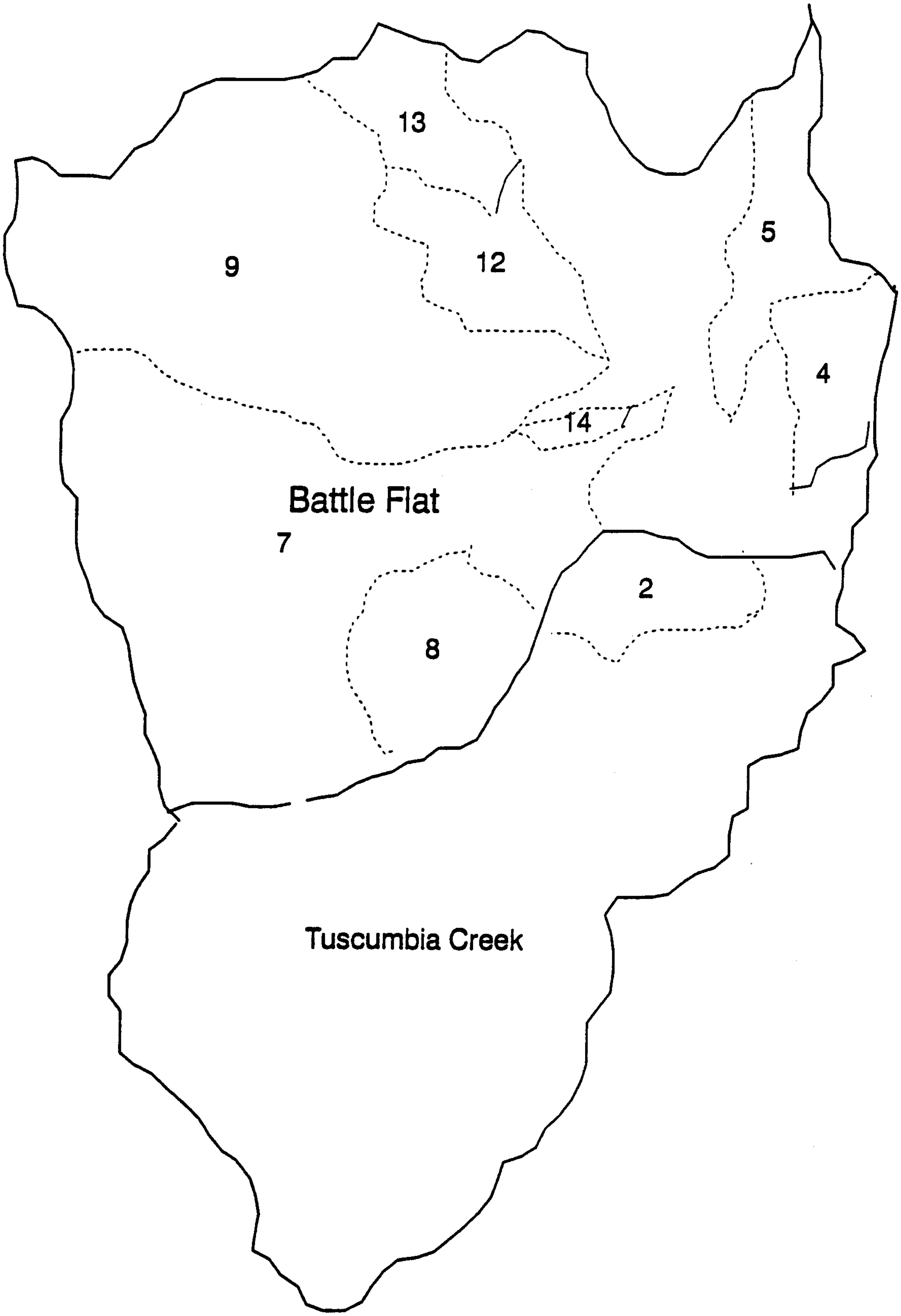

Figure 1. Map of the Battle Flat Demonstration Area including its division into 11 subbasins.

ac) and Battle Flat (2,302 ac). The geology of the two watersheds differs. Rock exposed at the surface of the Tuscumbia Creek watershed consists of the Brady Butte Granodiorite, a hard, dense, intrusive, volcanic rock (Anderson and Blacet 1972). Near the headwaters of this basin, the granodiorite is porphyritic, whereas toward the mouth of the watershed the granodiorite grades into a gneissic phase. Deep alluvial deposits cover the downstream reaches of the Battle Flat watershed (Anderson and Blacet 1972). Upstream and in the northern portion of this basin there are extensive exposures of a massive, bedded, crystal tuff. Locally, the tuff has been intruded by granodiorite dikes. It has been observed that the crystal tuff varies widely in its response to weathering.

Analysis of areal distributions of the various geologic units in the Tuscumbia Creek and Battle Flat watersheds indicates that lithologically the two watersheds are dissimilar. Intrusive igneous rocks (Brady Butte Granodiorite) occupy 99 percent of the Tuscumbia Creek watershed, whereas the extrusive Spud Mountain Volcanics comprise the remaining 1 percent. Within the Battle Flat watershed, the Brady Butte Granodiorite comprises 25 percent, the Spud Mountain Volcanics 43 percent, and alluvium 29 percent. The remaining 3 percent consists of miscellaneous rock units.

Soils on the Battle Flat Demonstration Area are typically deep, coarse textured, and poorly developed. Soil, as used here, includes all porous material (regolith) in which weathering and roots are active. The distinction between soil and solum depth (depth of the A and B soil horizons) is critical because most of the soil supporting chaparral vegetation has little or no A and B horizons. The Moano very rocky loam soils found on the watersheds are classified as loamy-skeletal, mixed, nonacid, mesic Lithic Ustorthents (Humbert et al. 1981).

The chaparral vegetation averages about 75 to 80 percent crown cover. Canopy height varies from 3 to 10 ft on the Battle Flat Demonstration Area; shrub height and cover are greatest on northerly aspects. Dominant shrubs are manzanita, shrub live oak, and birchleaf mountain mahogany. Subdominant shrubs include Emory oak, alligator juniper (*Juniperus deppeana*), desert ceanothus, apache plume (*Fallugia paradoxa*), and yerba santa (*Eriodictyon angustifolium*). The herbaceous understory is sparse.

The mean annual precipitation of 25.0 ± 7.6 inches (water years 1980 through 1987) was about equally distributed between cyclonic winter and convective summer storms. About 15 to 20 percent of the total precipitation is snow. Mean daily temperature is 59° F; the maximum daily temperature range is from –20 to 102° F.

Water yield is generally intermittent with streamflow beginning in early winter during wet years and continuing through May or June. In dry years little or no flow can occur.

Original Study Design

The Battle Flat Demonstration Area (Figure 1) is divided into two major watersheds: Tuscumbia Creek (1,356 acres) and Battle Flat (2,302 acres). The Tuscumbia Creek watershed was designated as the control watershed to predict streamflow on the watershed to be treated (Battle Flat). Additional subwatersheds were gaged with the idea of incorporating rainfall as an independent variable in the regression model to improve on a traditional analysis approach, using a control watershed to predict streamflow on the treated watershed. Watershed 2 in lower Tuscumbia Creek basin (Figure 1) served as a control for the small watersheds 4, 5, and 8 in the Battle Flat watershed. These four watersheds (around 100 acres in size) are located on granodiorite bedrock. Watersheds 7, 9, and 12 are larger watersheds (200 to 800 acres in size) within Battle Flat and have deeper soils and greater water storage capacity than the granodiorite-derived soils on Tuscumbia Creek.

The main reason for gaging watershed 8 was to separate its contribution from that of watershed 7; in 1978, watershed 8 produced most of the early flows observed in watershed 7. By separate gaging of these areas, it was anticipated that treatment response could be appropriately attributed to the contributing areas. Similar reasoning prompted gaging watershed 13 within watershed 12. It was suspected that watershed 13 leaked water and this condition was to be verified by the use of separate gages. Also, by gaging 14 separately, it was hoped that surface runoff and sediment contribution from this small, severely eroded area could be better quantified.

V-shaped flumes were chosen to provide accurate measurement of the expected predominantly low flows. The flumes, designed by the USDA Agriculture Research Service, were made of concrete or prefabricated steel, depending on watershed size and expected discharge. Concrete flumes were installed on the larger watersheds and steel flumes on the smaller basins.

Fourteen recording rain gages were installed on the Battle Flat Demonstration Area. This network provided for one gage to be centrally located in each of the smaller watersheds. The two larger basins received two or more additional rain gages.

Results

The hydrologic regime on the Battle Flat Demonstration Area is dominated by the variability in annual precipitation and to a lesser extent by the influence of the geology and resulting soils on the disposition of this precipitation. Streamflow and precipitation measurements on the Battle Flat Demonstration area were collected from August 1979 through June 1987 (Figure 2). Field observations and measured flow during this period indicated that streamflow was normally ephemeral on all watersheds except for watershed 14, which had perennial flow. Streamflow typically peaked in February or March, quickly receded, and often dried up in the summer (Figures 3 and 4).

Annual runoff from Tuscumbia Creek, Battle Flat, and watershed 14 are used to illustrate runoff relationships on the Battle Flat Demonstration Area (Table 1). Annual streamflow was variable during the years of measurements, and the major factor controlling runoff was the annual precipitation input to the system (Figure 2). Twenty inches or more of annual precipitation was needed before a meaningful amount of runoff was produced, except from the highly eroded watershed 14. Streamflow was only 0.4 inch or less from the two larger basins in water years 1981, 1984, and 1987, with less than 20 inches of precipitation (Table 1). Water years 1980 and 1983 produced the highest annual runoff yields on both watersheds, largely in response to precipitation amounts of more than 30 inches. Although water year 1982 also received more than 30 inches of precipitation, runoff yields from both watersheds were much lower because of the low amount of precipitation received during the preceding year (the driest of the 8 years of record, receiving only 13.5 inches of precipitation).

Measured runoff from watershed 14 (16.4 ac) confirms the initial observations from this highly eroded watershed. Streamflow was perennial from this basin and the mean annual flow was 10.8 inches, or at least two or three times greater than flows from Tuscumbia Creek and Battle Flat (Table 1). Although watershed 14 was only three quarters of a mile above the Battle Flat gage, the continuous flow from watershed 14 disappeared as transmission loss in the alluvial channel before reaching the Battle Flat gage. The lowest annual runoff on watershed 14 (3.0 inches) was in WY 1987 as a result of two consecutive years of low precipitation, 22.3 and 20.0 inches in WY 1986 and 1987.

Runoff efficiencies (ROE; runoff divided by precipitation times 100) on Tuscumbia Creek averaged 12 percent, or two times the 6 percent efficiency on Battle Flat (Table 1). These findings supported the initial observations that because of differences in the geology and soils of these basins—shallow soil on Tuscumbia Creek and the relatively deep alluvial soils on a third the area on Battle Flat (thus higher water storage capacity)—runoff was greater and flashier on Tuscumbia Creek.

ROE on watershed 14 ranged from 15 to 91 percent, with an average of 44 percent. This gives some insight into the possible increases (3 to 8 times) in runoff that can be obtained through watershed treatment or disturbance.

The range in ROE on Tuscumbia Creek of 0.0 to 29 percent and 0.0 to 16 percent on Battle Flat is similar to the reported pretreatment effiencies on another set of chaparral watersheds in Arizona, Whitespar A and B, with 0.6 to 44 percent and 1.0 to 34 percent, respectively (Davis 1993), even though different years were involved between sets of data. These ROEs are also similar to the range of ROE, before treatment, reported for another set of chaparral watersheds, 3 Bar D, 2.4 to 29 percent, and 3 Bar F, 1.2 to 10 percent (Davis 1984).

Streamflow from the Tuscumbia Creek watershed was typically much greater and flashier, and receded much more quickly than flow from Battle Flat (Figures 3 and 4). However, the flow regime on watershed 14, being perennial, was considerably different. Mean annual flow from this watershed (Table 1) was 10.8 inches (varying from 3.0 to 15.8 inches) and monthly flow was seldom less than 0.5 inch (Figures 3 and 4).

The flow regime from watershed 14 typifies flow from an abused watershed. DeBano and Schmidt (1989) suggested that upland watersheds in satisfactory condition are able to absorb storm energies, provide regulation of stormflows through the soil mantle, and bring stability to the entire basin. In contrast, a watershed that has been abused often develops a more extensive channel system throughout its basin, including an ephemeral gully network. The expanded gully network is the hydrologic response to increased surface flows, which result in rapid, concentrated runoff that produces headcutting and gully formation. These expanded gully networks increase peak flows and produce large amounts of sediment.

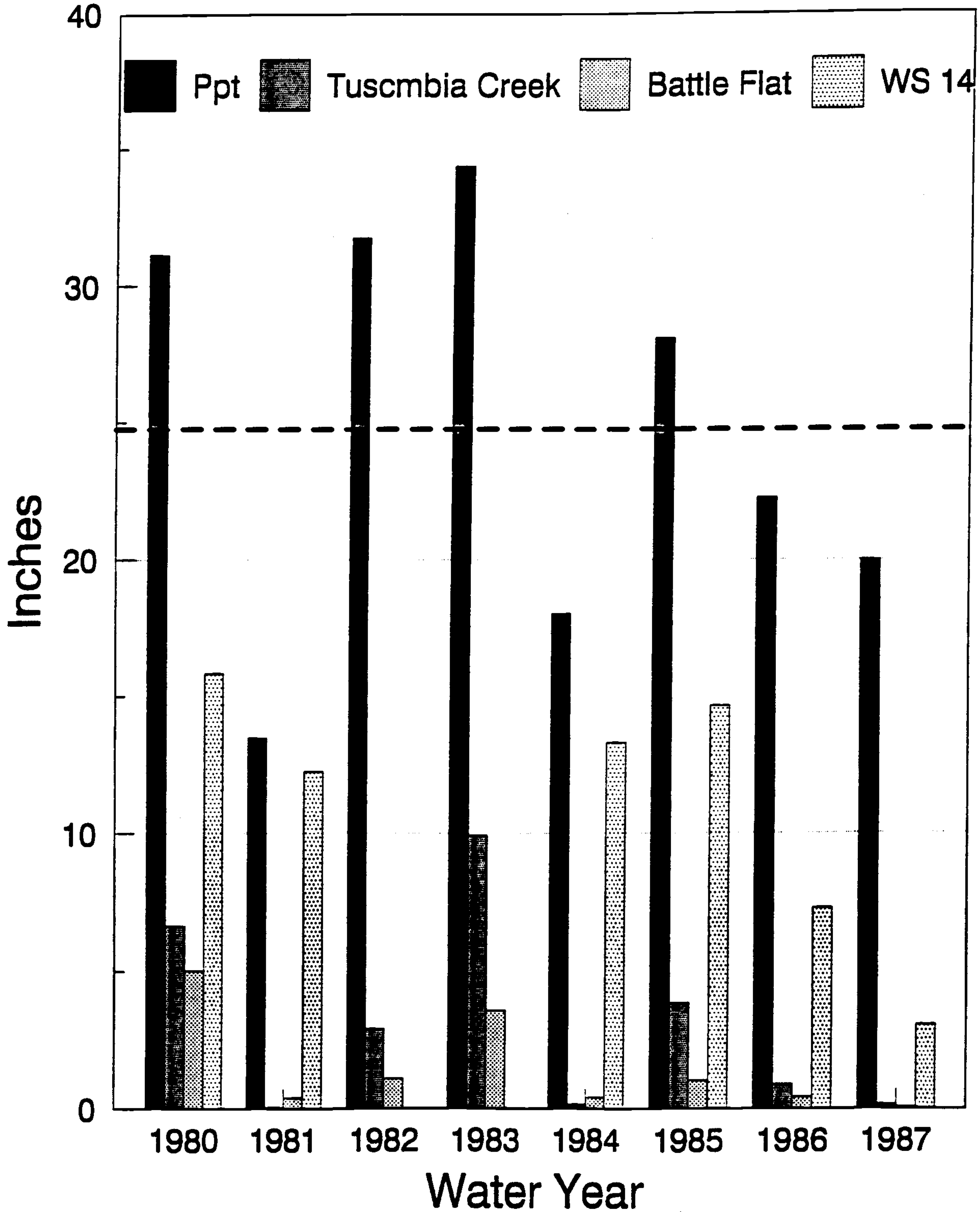

Figure 2. Annual precipitation and runoff from three representative watersheds on the Battle Flat Demonstration Area.

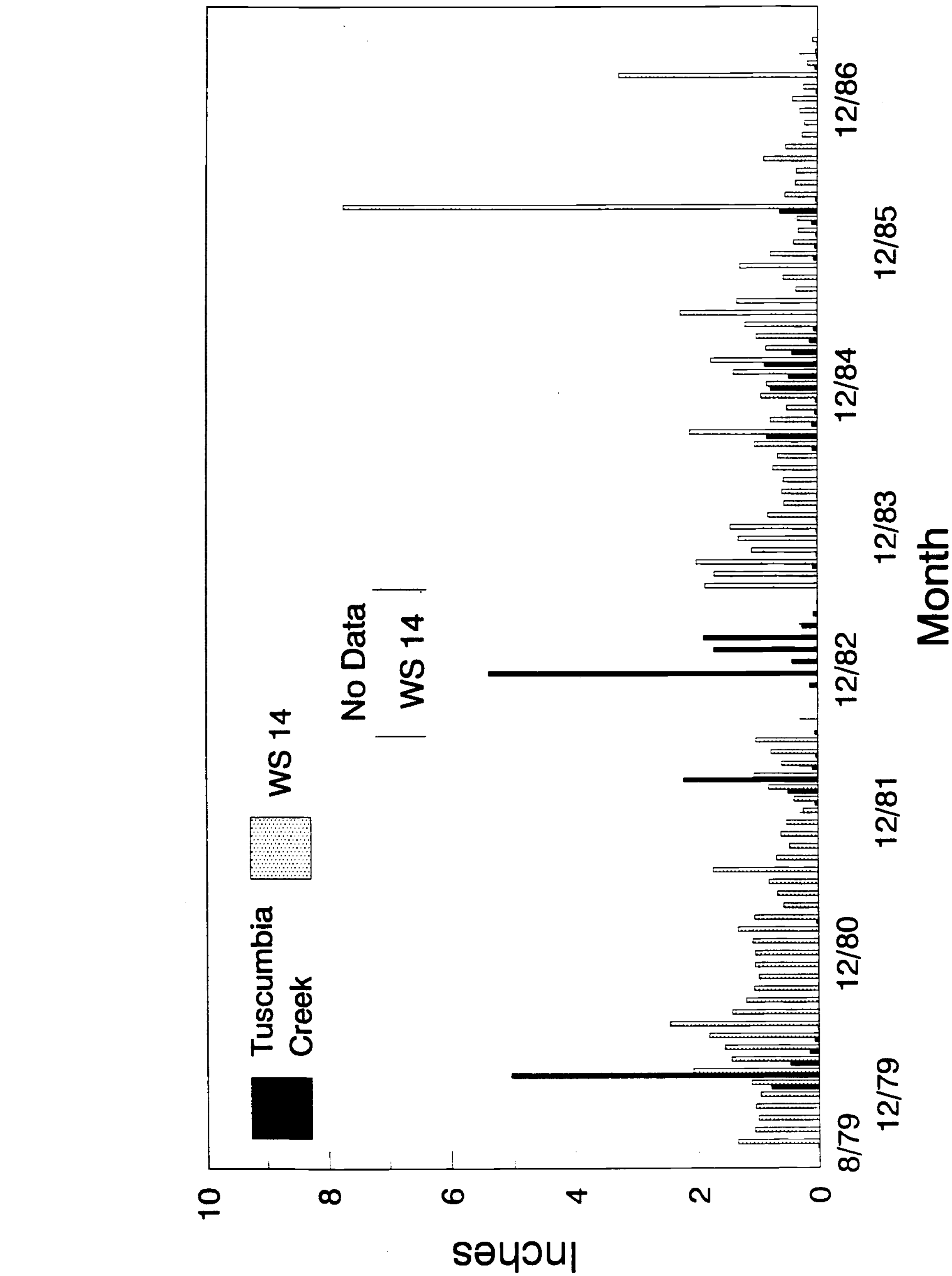

Figure 3. Comparison of monthly streamflow from Tuscumbia Creek and watershed 14.

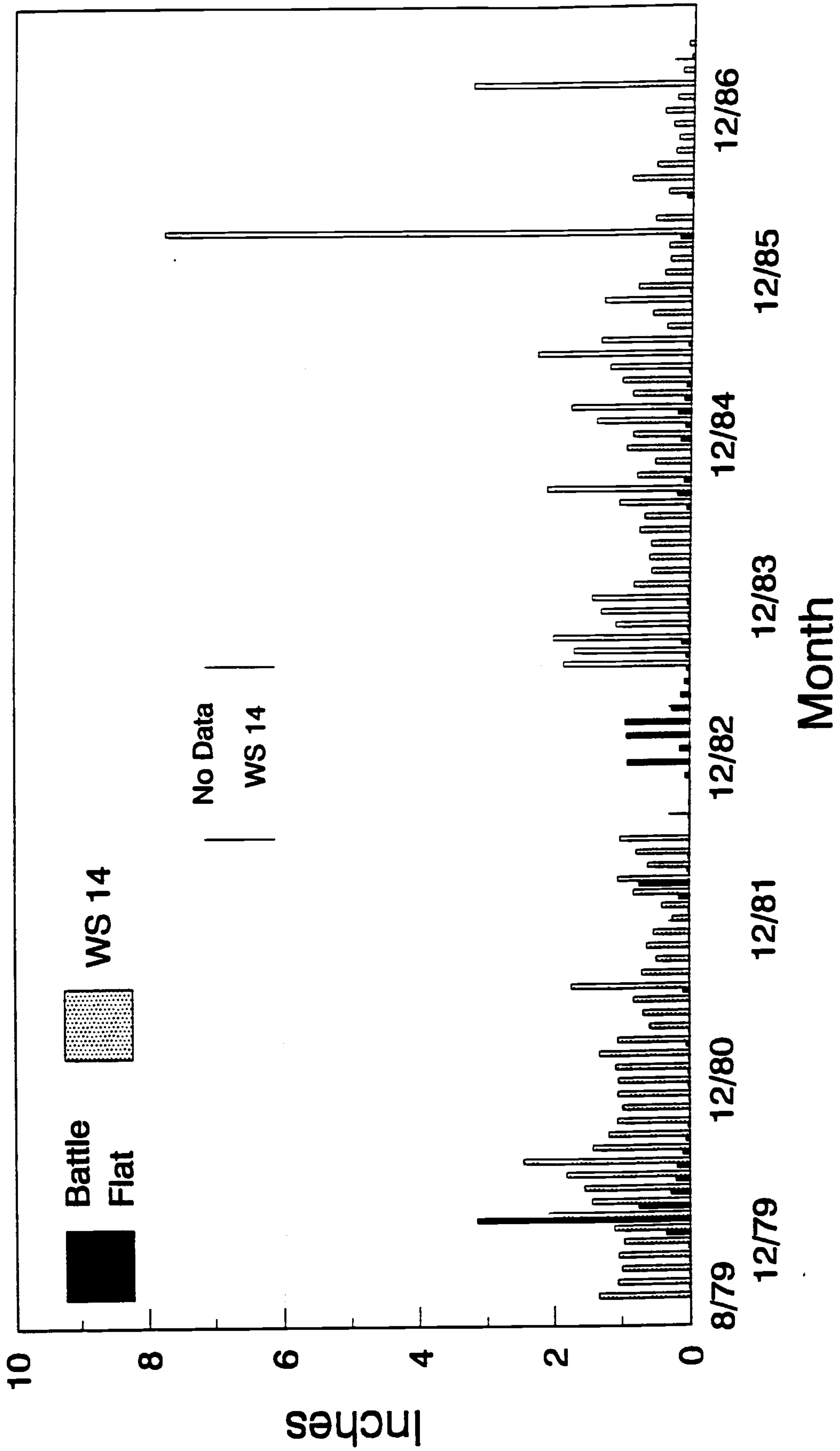

Figure 4. Comparison of monthly streamflow from Battle Flat and watershed 14.

Table 1. Annual hydrologic statistics for three subbasins on the Battle Flat Demonstration Area.

	Tuscumbia Creek			Battle Flat		Watershed 14	
	Ppt (in.)	Flow (in.)	ROE* (%)	Flow (in.)	ROE (%)	Flow (in.)	ROE (%)
1980	31.14	6.62	21	5.01	16	15.82	51
1981	13.46	.05	.004	.39	3	12.25	91
1982	31.77	2.91	9	1.09	3	8.95	28
1983	34.37	9.92	29	3.57	10	—	—
1984	18.03	.16	1	.41	2	13.29	74
1985	28.07	3.84	14	1.03	4	14.63	52
1986	22.28	.89	4	.44	2	7.27	33
1987	19.99	.16	1	.07	.003	3.04	15
Mean	24.89	3.07	12	1.50	6	10.75	44

*Runoff Efficiency = Runoff/Precipitation x 100.

Implications

Differences in streamflow regimes can be expected between adjacent natural or untreated chaparral watersheds.

- Annual precipitation in the U.S. Southwest is quite variable and is a major factor influencing runoff in watersheds (either treated or natural). Twenty inches of precipitation is needed before meaningful amounts of runoff are produced in the chaparral ecosystem.
- Runoff from highly disturbed areas can be 3 to 8 times the amount from natural, undisturbed chaparral areas. However, increased runoff does not necessarily have a major downstream impact. A mean perennial flow of 10 inches from a subbasin was lost in an alluvial channel within a three-quarter mile stretch below the affected watershed.
- Geology and soil depth have a major influence on runoff production. Two adjacent untreated watersheds had ROEs of 12 and 6 percent, and a highly disturbed subbasin had a mean ROE of 44 percent.
- The range of ROE, 0 to 29 percent, from the untreated chaparral watersheds on the Battle Flat Demonstration Area is representative of other chaparral watersheds in Arizona. Treatment or major disturbance of these areas can be expected to increase ROE by a factor of 3 to 8.
- Any future streamflow studies in chaparral should recognize the amount of variability naturally present in the chaparral ecosystem. This variability has a direct effect on the number of years of record needed to get an accurate calibration of the runoff relationship between the watershed to be treated and its control.

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