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Runoff and Erosion After Brush Suppression on the Natural Drainage Watersheds in Central Arizona

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Brush cover on two small watersheds totaling 26 acres in central Arizona was chemically suppressed in 1954-55. Annual streamflow subsequently increased 22 percent (0.36 area-inch), much less than on other treated chaparral watersheds. Most of the increase in streamflow occurred during the winter season. Annual sediment movement from the treated watersheds was reduced by about 1 ft³/acre. Grasses, forbs and half-shrubs, which were not sprayed, increased after the chemical treatment.

Keywords: Water yield improvement, brush conversion, erosion.

Chaparral covers nearly 4 million acres of intermediate-elevation watershed land in Arizona; about half is on the National Forests. In recent years these lands have been examined as a possible source of increased water. The four Natural Drainage watersheds, located on the Sierra Ancha Experimental Forest about 40 miles north of Globe, are one of several clusters of watersheds where the water resource of the chaparral is being studied by the Rocky Mountain Forest and Range Experiment Station.

General Description and History of Watersheds

The four Natural Drainage watersheds face southeast on slopes of 15 to 25 percent (figs. 1

and 2). Elevations range from 4,525 to 4,970 ft. The drainages are designated watershed A, 13.4 acres; B, 19.5 acres; C, 12.1 acres, and D, 9.1 acres. Lengths vary from 1,300 to 1,650 ft; widths range from 300 to 500 ft. Although the catchments are small, they are contiguous and their surface boundaries are well-defined ridges. Each area is thought to be hydrologically independent of the others.

Two rock types dominate soil development; diabase on upper portions and quartzite below (fig. 1). Diabase soils cover 42 percent of watershed A, 54 percent of B, 44 percent of C, and 28 percent of D. The diabase soils are deeper and sandier than those derived from quartzite. The fine-textured quartzite-derived brown soils appear to favor grass development.

The dominant vegetation type on the watersheds is marginal chaparral interspersed with occasional juniper and pinyon trees. The cover becomes quite sparse and open on south-facing slopes and on the shallow quartzite soils, where

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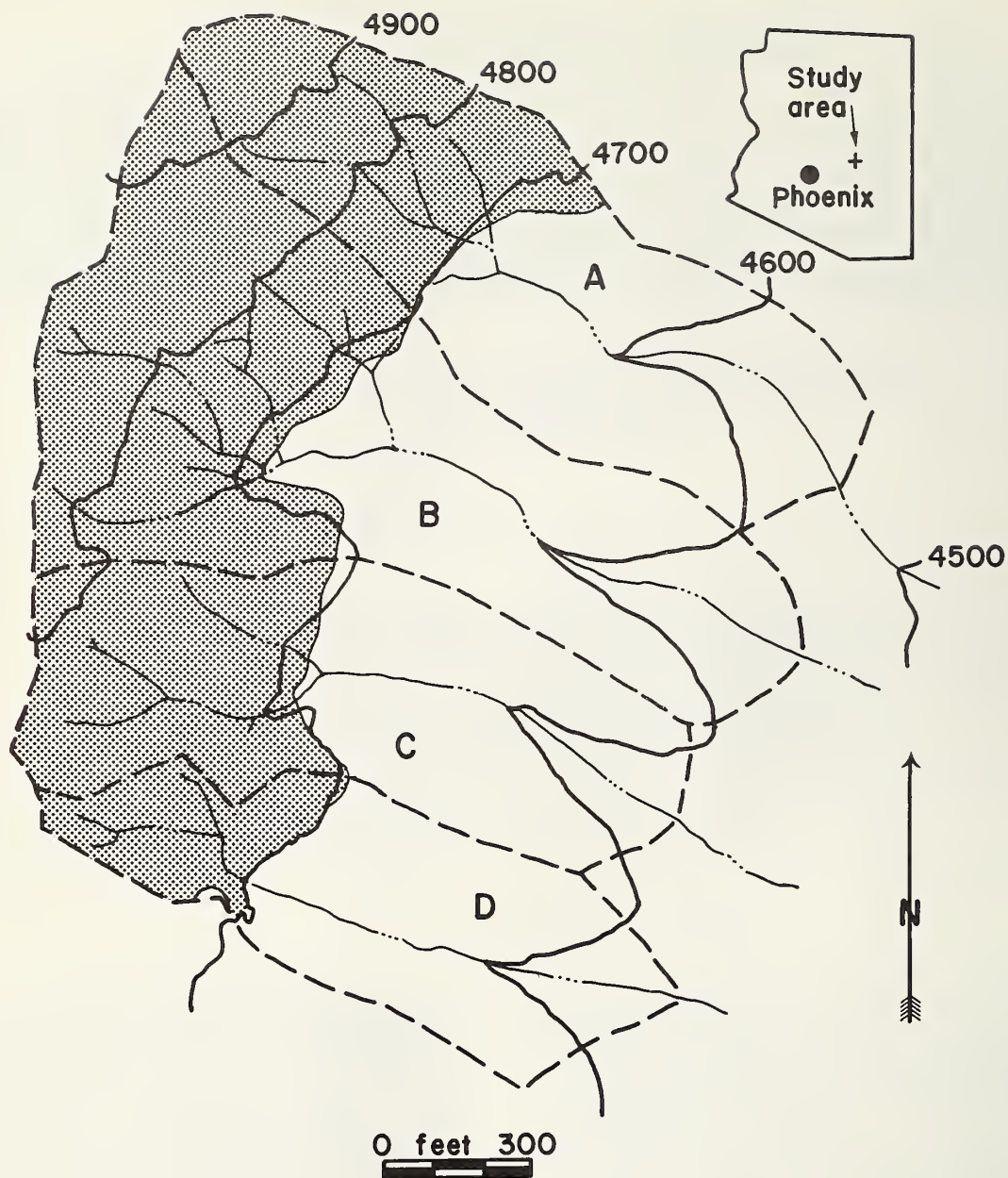


Figure 1.—Natural Drainage watersheds about 40 miles north of Globe, Arizona. Diabase soils (shaded areas) cover upper portions of the watersheds.



Figure 2.—Natural Drainage watersheds in 1960, 5 years after treatment on watersheds A and C.

it merges into the mesquite-grass type. Cover measurements in 1951, 3 years prior to chemical treatment, indicated total plant cover (vertical crown projection) varied from 32 percent on A to 40 percent on C. Of this, shrub cover averaged between 17 and 22 percent on the catchments. The remainder of the cover consisted of half-shrubs, forbs, and grasses (Rich and Reynolds 1963).

The most abundant shrub was shrub live oak (*Quercus turbinella*). Other important shrubs included desert ceanothus (*Ceanothus greggii*), Wright silktassel (*Garrya wrightii*), hollyleaf buckhorn (*Rhamnus crocea*), and pointleaf manzanita (*Arctostaphylos pungens*). Half-shrubs (diminutive shrubs or plants which are slightly woody towards the base) included Wright buckwheat (*Eriogonum wrightii*), false-tarragon (*Artemisia dracunculoides*), Thurber penstemon (*Penstemon thurberi*), and rough Menodora (*Menodora scabra*). Perennial

grasses were common in all subtypes except on diabase-derived soils. Important species included sideoats grama (*Bouteloua curtipendula*), hairy grama (*B. hirsuta*), three-awn (*Aristida* spp.), cane bluestem (*Andropogon barbinoides*), green sprangletop (*Leptochloa dubia*), and bullgrass (*Muhlenbergia emersleyi*).

Livestock first appeared in the general area in about 1880. Grazing on the watersheds was brought under strict control in 1934 when the drainages were fenced and gages installed for the measurement of precipitation and runoff. Since 1934, grazing has been confined to that in controlled studies. Streamflow was originally metered through flumes and tipping buckets, but in 1936 90° V-notch weirs were installed. All cutoff dams in which the weirs were placed were set on solid quartzite rock so that both surface and subsurface flows were trapped. Sediment from the watersheds was collected and measured in the V-notch weir ponds. Most

of the sediment was trapped, but a small proportion passed over the weir blade in suspension.

After a period of calibration ending in 1939 on D and in 1942 on A, the watersheds were used to study the relation of domestic grazing to runoff and erosion. These determinations were completed in 1952 when Rich and Reynolds (1963) found that the intensities of grazing used in the studies had no significant effect on water yields or trapped sediment production. Starting in 1954, chaparral cover was suppressed on two of the watersheds to determine the influence on streamflow. Field work terminated in 1971.

Cover Manipulation with Chemicals

During the summer of 1954, the basal 5 inches of all shrubs and trees on Natural Drainage C was sprayed with a 6.6 percent solution of 2, 4-D and 2, 4, 5-T in diesel oil until the outer bark was saturated. Half-shrubs were not sprayed. Though the first treatment killed most of the sprayed plants, surviving shrubs were resprayed in 1956 and 1958. Shrubs and trees on drainage A were sprayed in similar manner in 1955 and resprayed in 1957. Shrub and tree kill on both watersheds was essentially complete. Drainages B and D were retained as controls.

In 1959 Pond (1964) noted a response in grass, forbs, and half-shrubs to the chemical treatments on watersheds A and C. By 1959 grass cover on the treated quartzite soils was about three times greater than on the untreated areas. Prior to treatment the cover had been similar on all sites. No significant change in grass cover was noted on diabase soils, although crown cover of forbs was greater than on the quartzite soils. Forbs appeared to increase on all treated areas, although these increases were not signi-

ficant. Half-shrubs gained substantially on both soils, with the greatest increase also on the diabase. Yerba-santa (*Eriodictyon angustifolium*), a rhizomatous-rooted shrub almost unnoticed before treatment, increased on the diabase soils until it became the most prominent plant over much of the upper portions of the treated catchments.

Precipitation at the Natural Drainages

Precipitation has been measured in two standard rain gages at Natural Drainages since 1934. Both are near exterior boundaries, but on opposite sides of the cluster of watersheds. Average difference in their annual catch over the years was about 0.3 inch. The largest annual difference between the two was 1.85 inches in 1944 when about 27 inches of precipitation fell. Because of the small difference in catch by the two gages, distribution of precipitation over the four catchments was considered to be uniform. Precipitation has averaged 19.1 inches per year for the 37-year period ending in 1971 (table 1). Annual and winter disposition before and after treatment was similar, although the first period was wetter.

Runoff from the Natural Drainages

Since Rich and Reynolds (1963) found that the early grazing studies had not significantly affected streamflow, the entire period from 1936 through June 1954 is considered nontreatment or calibration. The remaining years through 1971 constitute the treatment years. Watersheds B and D were used as controls to estimate the volume of streamflow that would have occurred on treated watersheds A and C if the cover had

Table 1.--Annual and winter precipitation for a 37-year period on the Natural Drainage watersheds in Arizona

Period	Annual precipitation (July 1 - June 30)		Winter precipitation (November 1 - April 30)		
	Range	Average	Range	Average	Percent of annual
	-- Inches --		-- Inches --		
Before treatment	14.76 - 40.70	20.18	6.80 - 28.48	11.79	58
After treatment	10.75 - 24.57	17.79	3.42 - 17.11	9.76	55
Total	10.75 - 40.70	19.08	3.42 - 28.48	10.86	57

not been altered. Differences between predicted and actual yield are attributed to treatment. Watershed B was used as the control for A, and D for C. Likewise, B and D were combined and used as a control for A combined with C.

Streamflow from all four watersheds always has been intermittent. The streams normally flow for only a day or two after rain. However, when rains are heavy or prolonged, particularly in winter, flows may persist for several weeks. Much more water is yielded during the winter period than in the warm summer months. Although winter accounts for only slightly more than one-half (57 percent) of annual precipitation, it accounts for 83 percent of the water yielded. Treatment did not alter this seasonal distribution of water yield, although flow periods possibly were prolonged somewhat.

Between watersheds, periods of flow are similar and annual variation in volume within the treated and control groups is consistent. Average annual yields before and after the treatment are given in table 2. Correlation of annual streamflows between control watersheds B and D did not change after treatment.

Table 2.--Average annual streamflow and sediment from the Natural Drainage watersheds in Arizona

Watershed and period	Water	Sediment
	Area inches	Ft ³ /acre
Watershed A:		
Before treatment	1.46	3.3
After treatment	1.35	0.5
Watershed B (control):		
Before treatment	0.94	5.5
After treatment	.71	2.5
Watershed C:		
Before treatment	1.86	1.9
After treatment	2.03	.2
Watershed D (control):		
Before treatment	1.75	.9
After treatment	1.42	.4
Watersheds A + C:		
Before treatment	1.65	2.7
After treatment	1.67	.4
Watersheds B + D (control):		
Before treatment	1.20	4.0
After treatment	.94	1.8

However, the relationship between treated watersheds A and C did change after treatment, suggesting that the two watersheds varied in their response to treatment.

Increases in yield and their 90 percent confidence intervals were:

	Mean annual increase	
	Inches	Percentage
Watershed A	0.19±.16	13±11
Watershed C	.50±.20	27±11
Watershed A+C	.36±.23	22±14

Although no explanation is apparent, it is of interest that the 27 percent increase on C is significantly greater than the 13 percent increase on A. Combined, the two treatments yielded 22 percent or 0.36 inch more water than expected. Presumably, the change resulted from a net reduction in water use on the converted areas.

Sediment from the Natural Drainages

Annual sediment trapped in the four weir ponds from 1937 to 1954 varied from 0 to 14 ft³/acre. Watershed averages ranged from 0.9 on D to 5.5 ft³/acre/year on B (table 2). Rich and Reynolds (1963) found no significant difference in annual volumes resulting from the grazing treatments starting in the 1940's and ending in the early 1950's.

Less sediment was measured after treatment on each of the watersheds than before. Sediment declined 55 percent on both control watersheds, possibly because of lower precipitation during this period. The decline was greater on the treated watersheds, however: 85 percent on A, and 89 percent on C. While part of this reduction can be attributed to the same factors affecting erosion on the controls, covariance analysis indicates that a significant portion was due to treatment. By combining the two treated watersheds, the net reduction averaged 72 ± 43 percent (90 percent confidence interval). This reduction, although not particularly large in volume (1.0 ± 0.6 ft³/acre/year), is attributed to a stabilizing influence on the soil by grasses and forbs which increased after shrubs were eradicated.

Discussion

The 22-percent (0.36-inch) average increase in water yield attributed to treatment on the Natural Drainages is much less than obtained

from other chaparral conversions in central Arizona. Onsite increases have averaged 300 to 700 percent (about 3 to 6 inches) on the Three Bar experimental watersheds 20 miles to the west (Hibbert 1971), and about 400 percent (almost 4 inches) following channel-side conversion on 38 acres of brush at Whitespar near Prescott (Ingebo 1972). While a complete explanation for these differences is not assured, we attribute the lower response on the Natural Drainages to the sparse shrub cover, low precipitation, southerly exposure, and shallow soil on the lower portion of each catchment.

The amount of brush cover eradicated by conversion is fundamentally important in reducing evapotranspiration and thereby increasing streamflow. Most of the reduction in evapotranspiration is attributed to a net reduction in transpiration caused by replacing deep-rooted shrubs with shallow-rooted grasses and forbs. Interception loss may also decline after conversion because the grass offers less surface to retain water than brush, but the contribution to water savings from this source is thought to be less than from the reduction in transpiration. Shrub crown cover was less than 25 percent on the Natural Drainages before treatment compared with 50 to 75 percent on Whitespar and Three Bar. With few shrubs to begin with, their removal could not be expected to influence transpiration as much as removal of a dense stand.

Brush density or biomass is largely an expression of the combined influence of precipitation and other climatic and physiographic factors. Water is generally considered the limiting factor in development of brush cover, but the effectiveness of precipitation is modified by site factors such as slope, aspect, elevation, and wind, as well as depth, texture, and permeability of the soil. Integration of these factors into a predictive model could provide a better index of potential increase on a given site than either precipitation or brush density alone, although at present these interrelationships are not quantified.

Slope and aspect, major contributing factors to solar energy input, probably also affect water-yielding characteristics of these watersheds (Lee 1963), although how they respond to treatment is uncertain. Facing southeast, the Natural Drainages receive more energy from the sun than the north-facing Three Bar catchments. The Whitespar watersheds have roughly the same aspect as the Natural Drainages, but their elevation is higher causing them to be cooler. The heavy energy input at the Natural Drainages may contribute to the low response to treatment.

The quartzite-derived soils on the lower portions of the Natural Drainages are finer grained than the granitic soils which cover Three Bar and Whitespar. Though capable of storing more water per inch depth of soil, the lack of depth prevents storage of large amounts of rainfall. Thus, water in this soil is subject to withdrawal (evaporation and transpiration) almost as readily by shallow-rooted grasses and forbs as by deep-rooted shrubs. Removal of the sparse brush cover on these soils likely would have little net effect on evapotranspiration or water yield. Paradoxically, the shallow soils may be the cause of the relatively high ratio of pretreatment runoff to precipitation noted on these catchments (0.08 compared with 0.02 to 0.09 at Three Bar and 0.05 at Whitespar). With limited storage available, heavy rainfall, particularly in winter, cannot be retained and the excess is released to streamflow.

Diabase soils on the upper portions of the Natural Drainage catchments are similar in depth to the granite soils at Three Bar and Whitespar. Removing brush on these soils should result in water savings commensurate with the amount of brush removed, which was sparse. However, these savings may have been reduced by the increase in yerba-santa on the diabase soils after the shrubs were killed. While these shrubs do not root as deeply as the original brush, they probably use more water than grass, thereby reducing water savings attributed to brush removal on these deeper soils.

In light of these distinctive differences between areas, the low response to treatment on the Natural Drainages is not unexpected. Little or no response can be expected from the quartzite soils, and only a limited amount from the diabase soils. Very likely, response to treatment is less than half the amount that otherwise might be obtained under this rainfall regime.

The small but significant decrease in sediment transported to the weir sites on the treated areas is noteworthy because it came during a period when streamflow was being sustained at a slightly higher level than would have occurred without treatment. Minor rilling was observed on the upper slopes of watersheds A, B, and C, which indicates some degree of overland flow. Rilling was not continuous from source to stream channel, however, suggesting that surface runoff was not massive or continuous. Grass and other replacement cover, which increased when the brush was eradicated, retarded the rilling and movement of soil. In watershed C, the filtering effect of grass on streamflow is developing a small meadow from silt brought down in the main channel.

While these results are encouraging, they should not be interpreted to mean that treatment of this type necessarily will reduce erosion. The quartzite soils on which grass increased the most are not typical of chaparral. Therefore, they do not represent the conditions most likely to be encountered when chaparral is converted. On the other hand, there was no evidence of accelerated erosion on the upslope diabase soils, which are more representative of chaparral in Arizona. These results therefore indicate that, if the soil is not disrupted or the protective cover depleted, erosion may not be adversely affected by conversion of brush to grass.

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