Water Yield Changes Resulting From Treatment of Arizona Chaparral[1]

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Abstract: Annual streamflow from small chaparral watersheds, in a 600-750 mm rainfall zone, was increased 75-150 mm and changed from intermittent to perennial flow by converting brush to grass with herbicides. Increases lasted up to 18 years with maintenance. At drier sites (450 mm rainfall) increases averaged less than 15 mm. Burning increased streamflow for 3-4 years while brush regrew. Both storm and nonstorm flows increased. About 85 percent of the increase occurs in 6 fall-winter months which get 60 percent of the precipitation. Yearly increases tend to be exponentially related to precipitation.

The chaparral vegetation type occupies about 1.2 million hectares (3 million acres)[3] in central Arizona (fig. 1). Average annual precipitation is 400 mm to 750 mm (16-30 inches). Chaparral shrubs transpire large amounts of water, leaving an average of only about 30 mm (1.2 inches) or 5 percent for streamflow. Transpiration can be reduced and streamflow increased by removing part or all of the shrubs and replacing them with shallow-rooted grasses and forbs. This paper updates the water yield potential portion of a detailed "status of knowledge" report (Hibbert and others 1974) on water yield improvement in Arizona chaparral.

Seven to eight years of additional research findings are reported, including several wet years, which are important in the interpretation of hydrologic relations in the chaparral.

The chaparral community in Arizona consists of a variety of deep-rooted, evergreen, sclerophyllous shrubs (fig. 2) usually dominated by shrub live oak (Quercus turbinella), or shrub live oak-mountain mahogany (Cercocarpus betuloides or C. breviflorus); manzanita (Arctostaphylos pringlei or A. pungens) may dominate locally (Carmichael and others 1978). The type occurs mostly at elevations between 1,000 m and 2,000 m and grows best where precipitation exceeds 500 mm (20 inches).

Figure 1--Distribution of chaparral in Arizona and location of experimental watersheds.

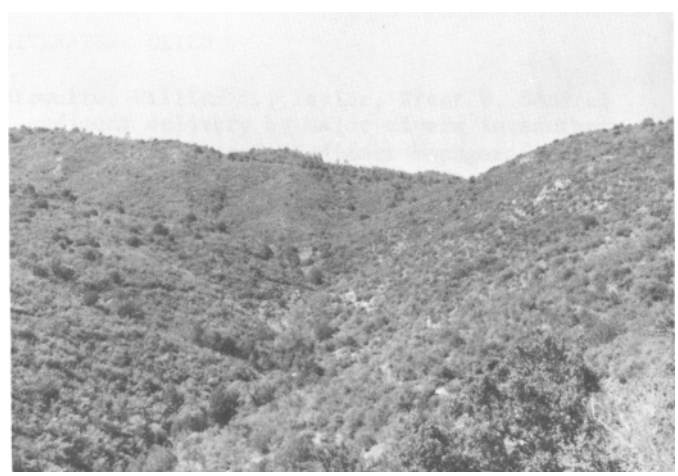

Figure 2--Mixed chaparral dominated by shrub live oak.

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[3]Estimates of chaparral area in Arizona vary widely. The most recent estimate taken from a vegetation type map by Brown and Lowe (1980) indicates nearly 3 million acres of chaparral in Arizona.

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Chaparral shrubs are typically deep-rooted (Davis and Pase 1977) and usually grow on deeply weathered or fractured regoliths. Because the shrubs are evergreen, they transpire whenever atmospheric and soil moisture conditions are favorable. The climate favors high evapotranspiration rates from early spring to late fall; thus summer rains, which account for about one-third of the annual precipitation, seldom contribute to recharge. Consequently, winter rains must usually overcome soil moisture deficits before much water is available for streamflow.

The key to increasing water yield is the replacement of deep-rooted shrubs with shallow-rooted grasses and forbs that consume less water, largely because less water is available to the shallow-rooted plants. Also, interception of precipitation by grass is less than by brush, and seasonal dormancy of grass, particularly during winter, results in less water withdrawal.

WATERSHEDS AND TREATMENTS

The main objective of the chaparral watershed studies was to determine how much water yield could be improved by converting brush to grass. Studies were conducted in areas of low, medium, and high precipitation, corresponding roughly with open, medium, and dense chaparral. Treatments began in 1954 with eradication of the sparse shrub cover on two small so-called Natural Drainage watersheds on the Sierra Ancha Experimental Forest near Lake Roosevelt (fig. 1). Other treatments followed on Three Bar, Whitespar, and Mingus watersheds. Investigations of increasing complexity are now underway to achieve environmentally acceptable designs and treatment prescriptions.

Low Precipitation Areas

The Natural Drainage watersheds, at 1,420 m elevation, receive 485 mm (19.1 inches) mean annual precipitation. Exposure is southeast and slopes are moderate (15-25 percent). Total shrub cover, mostly shrub live oak, was 20 percent to 25 percent before treatment. The basal 150 mm (6 inches) of each shrub on watersheds A (5.4 ha) and C (6.9 ha) was hand sprayed in 1954-55 with a 6.6 percent solution of 2,4-D[4] and 2,4,5-T in diesel oil until the bark was saturated, and shrubs were resprayed as necessary to eradicate all shrubs. Adjacent drainages B and D were left untreated as controls. By 1959, grass production on the lower portions of the treated catchments with quartzite-derived fine-textured soils was over twice as much (420 kg/ha) as without treatment (191 kg/ha). Grass production did not change significantly on the upslope portions with diabase-derived coarse-textured soils. Forbs and half shrubs increased on all treated sites, with the greatest gain on the diabase soils. No seeding was attempted, and the watersheds were not grazed. Precipitation averaged 452 mm (17.8 inches) in the 17-year treatment period.

Mingus watersheds A and B get about the same precipitation (480 mm) as the Natural Drainages, but are at a higher elevation (1,800-2,100 m) and have greater shrub cover (47 percent). Exposure is westerly and slopes are steep (45-55 percent). Gravelly loam soils 38 cm to over 127 cm deep are derived from pre-cambrian volcanic and sedimentary rocks. Shrub live oak and mountain mahogany dominate in association with pinyon pine (*Pinus edulis*) and alligator juniper (*Juniperus deppeana*).

Prescribed burning on Mingus A (38.9 ha) and chemical brush control on Mingus B (26.8 ha) were compared as methods for improving water yield. Mingus C (17.3 ha) served as the untreated control. To minimize any treatment-induced erosion, particularly from burning, the upper halves of the watersheds were burned or chemically treated in 1974; the lower halves were similarly treated in 1975. Chemical treatment consisted of 50 percent active ingredient (ai) karbutilate "brush balls" applied by helicopter at 4.5 kg ai/ha.

Due to the patchy nature of the brush and scarcity of herbaceous understory, not all shrubs burned on Mingus A. Top kill of shrubs was estimated at 65 percent on the upper half and 75 percent on the lower half. The top-killed shrubs sprouted quickly from their root crowns, and within a few years regained much of their prefire crown cover and ability to use water. No follow up control measures were applied on the burned watershed. Treatment effects on Mingus B were delayed because of low rainfall (56 percent of average in 1974 and 63 percent in 1975) and slow release and movement of karbutilate into the shrub root zone. Shrub mortality continues after 6 years. Overall brush reduction on the watershed is estimated at 50 percent.

Medium Precipitation Areas

Whitespar watersheds A and B are located near Prescott, Arizona, between 1,770 m and 2,135 m elevation. Precipitation averages 600 mm (23.6 inches) per year. Exposure is southeast, slopes are steep (25 percent to 65 percent), and the granite derived fine gravelly loam soils are 48 cm to over 100 cm deep. The mature chaparral cover, dominated by shrub live oak and mountain mahogany, is considered medium dense at 51 percent crown cover. Patches of Gambel oak (*Quercus gambelii*) dominate locally on cool northerly slopes, and alligator juniper trees are scattered throughout.

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[4]The herbicides discussed in this report have been used experimentally; their use does not imply that they are recommended or registered for watershed use. The use of any herbicide for project or commercial purposes must conform with regulations of the Environmental Protection Agency and be registered for the intended use.

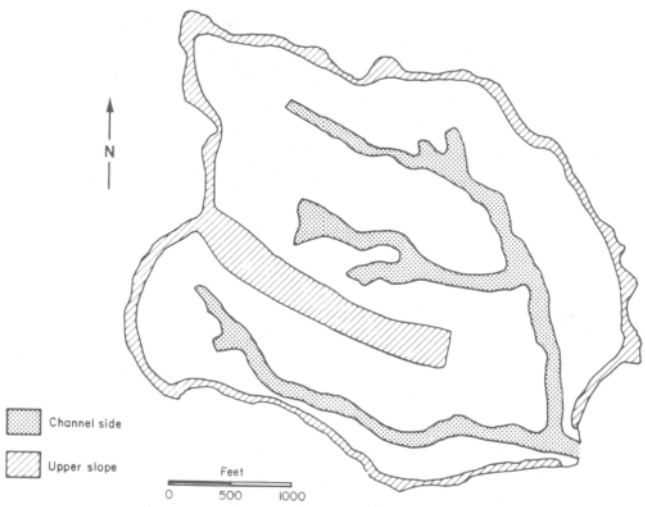

Figure 3--Whitespar watershed B on Prescott National Forest. Channel-side treatment was made in 1967, the upper slope treatment in 1973.

Chemical control of channel-side shrubs was the first of two treatments on Whitespar B (100 ha) (fig. 3). Channel bottoms and lower slopes were considered the most favorable sites to increase water yield because of greater soil moisture there, and therefore, a better opportunity to reduce transpiration. The second treatment, designed to simulate fuel break conditions, was on drier, more exposed ridge lines.

The channel-side treatment consisted of hand placement of pelleted fenuron (25 percent ai) at 26 kg ai/ha beneath the shrubs within 23 m either side of the stream channels in March 1967 on 15.4 ha (15 percent of the watershed). The treatment gave 80-90 percent control of the shrubs and follow up treatment has not been necessary. No grasses were seeded, since a fair population of native grasses and forbs were present; these increased adequately to protect the soil after shrubs were controlled. Cattle graze both watersheds.

The ridge line treatment was a helicopter application in 1973 of fenuron pellets (25 percent ai) at 14.9 kg ai/ha on a strip averaging 37 m wide inside the watershed boundary and a strip 80 m wide along a prominent interior ridge (fig. 3). The treated strips totalled 20 ha, or 20 percent of the watershed. Follow up hand treatment was necessary in 1976 because of uneven distribution of the chemical and poor shrub control from the aerial application. Overall shrub reduction was about 85 percent by 1980 (less than 10 percent shrub cover remaining).

High Precipitation Areas

The Three Bar watersheds (fig. 4) are characteristic of high precipitation, high-density chaparral. Elevation is 1,000 m to 1,600 m, exposure is northerly, and slopes are steep, some exceeding 60 percent. Soils are derived from coarse-grained, deeply weathered (6 m to 12 m) granite, and are capable of storing 500 mm or more of water (Ingebo 1969). Mean annual precipitation increases with elevation from 620 mm on watershed B to 750 mm on watersheds D and F. Shrub crown cover averaged 60-75 percent when gaging began in 1956. Dominants are shrub live oak and birchleaf mountain mahogany with sugar sumac (Rhus ovata), and Emory oak (Quercus emoryi) associated throughout.

Wildfire burned all watersheds in June 1959. Lovegrasses (Eragrostis curvula, E. lehmanniana, E. chloromelas), and yellow sweetclover (Melilotus officinalis) were seeded after the wildfire. Sprouting shrubs regained about one-third of their prefire crown cover in 3 years, and by the mid-1970's, after 11 years, recovery was 90 percent. Little herbaceous cover is present where shrubs were allowed to recover.

Watershed D (32.6 ha) was allowed to recover naturally after the fire to serve as the control; treatments to control regrowth were started in 1960 on watershed C (38.6 ha), in 1965 on watershed B (18.8 ha), and in 1969 on watershed F (27.7 ha).

Four annual spring applications of 2,4,5-T (1.8 kg ai/ha by helicopter) on watershed C beginning the year after the fire suppressed regrowth but killed only about half of the shrubs. Hand treatment of surviving shrubs with fenuron pellets at variable rates in 1964 and again in 1968 killed most of the remaining shrubs and reduced shrub cover to 8 percent. Three control burns (Pase and Knipe 1977) in 1971, 1974, and 1978, using grass

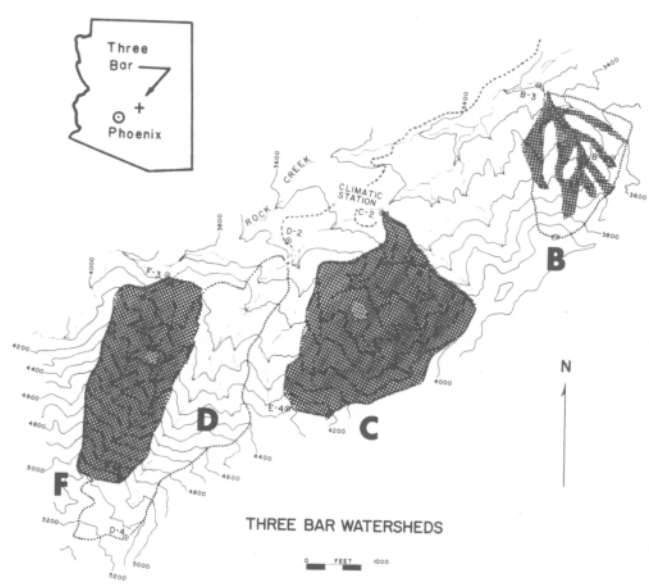

Figure 4--Three Bar experimental watersheds near Roosevelt Lake on Tonto National Forest.

to carry fire, kept shrub cover to less than 10 percent. Seeded lovegrasses and native grasses and forbs increased; their annual combined production averaged 1,345 kg/ha. Livestock have been excluded from the entire Three Bar area since 1947.

Watershed B was treated in two phases. Shrubs on northeast-facing slopes comprising 40 percent of the watershed were hand treated with either pelleted fenuron (20.5 kg ai/ha) or picloram (10.4 kg ai/ha) in 1965, 6 years after the wildfire. Follow up treatments on surviving shrubs in 1968 and 1978 kept shrub cover at about 8 percent. In phase 2, the remaining 60 percent of watershed B was hand treated in 1972 with 50 percent active karbutilate tablets at 7.5 kg ai/ha. The treatment was successful despite no rain for 4 months after treatment; no follow up treatment was required, since less than 10 percent shrub cover remained. Lovegrasses from the original postfire seeding and native grasses and forbs gradually increased on the treated areas, which provided adequate ground cover as the shrubs were controlled.

Watershed F was treated in 1969 with an aerial broadcast application of granular karbutilate at 22.4 kg ai/ha. Shrub crown cover was reduced from 55 percent to 4 percent the first year, and shrub kill increased to more than 95 percent (less than 3 percent shrub cover) after 2 years. Virtually all grasses and herbaceous plants were killed. In the second year after treatment a variety of forbs and grasses invaded the moist banks of the channel. In the third growing season forbs and grasses appeared on interior ridges, and by the fourth season a fair cover was present over all but the steep upper slopes, which were actively eroding. These steep slopes did not reach pretreatment stability for about 10 years.

RESULTS AND DISCUSSION

Changes in water yield are determined by the paired watershed method, in which annual water yields from the treatment watershed are regressed on those from the control watershed for the pretreatment and posttreatment periods. Any signifi-

Table 1--Water yield response to treatment of chaparral.

Watershed	Size	Portion treated	Shrub crown cover: Before[1] treatment	Shrub crown cover: After[2] treatment	Treat. period	No. of years	Precip.[3]	Expected yield[4]	Yield increase
	ha.	---------- pct. -----					- - - - - - mm - -- - - - -		
Natural Drainages									
A	5.4	100	20-25	0	55-71	17	485	34	5 ± 4[5]
	4.9	100	20-25	0	55-71	17	485	43	13 ± 5
Mingus									
A	38.9	100	47	14	76-80	5	480	2	10 ± 5
B	26.7	100	47	24	76-80	5	480	7	5 ± 5
Whitespar									
B Phase 1	99.8	15	51	<10	68-73	6	587	40	16 ± 5
B Phase 2	99.8	35	51	<10	74-80	7	589	47	13 ± 7
Three Bar									
C	38.6	100	73	<10	62-79	18	673	82	148 ± 84
B Phase 1	18.8	40	51	<10	66-72	7	564	9	30 ± 9
B Phase 2	18.8	100	52	<10	73-79	7	671	18	87 ± 54
F	27.7	100	55	<10	70-79	10	777	53	79 ± 34

[1]Prefire cover on Three Bar C and after 6, 13, and 10 years of postfire regrowth, respectively, on Three Bar B-1, B-2, and F.

[2]Shrub cover remaining after two or more years from first chemical application (see treatment descriptions). On Mingus A, unburned shrub cover was 14 pct. the first year, and resprouting shrubs increased the total cover each year thereafter.

[3]Mean precipitation for pretreatment and posttreatment periods combined.

[4]Expected yield is the amount that would be expected to occur without treatment.

[5]95 pct. confidence limits except Natural Drainage A and Mingus B, which are 90 pct.

cant change in the water yield relationship between watersheds after treatment is determined by covariance analysis and is interpreted as treatment effect. Acceptance or rejection of these changes is commonly made at the 95 percent confidence level.

Natural Drainages and Mingus Watersheds (Low Precipitation)

Increases in streamflow were significant at the 90 percent level on Natural Drainage A and Mingus B, and at the 95 percent level on all other treated watersheds (table 1). Average streamflow increases on Natural Drainages A and C for the 17-year posttreatment period were 5 mm (0.2 inch) and 13 mm (0.5 inch) per year, respectively (Ingebo and Hibbert 1974). Response varied from no increase in dry years to 26 mm (1 inch) increase in wet years (in fig. 5 Natural Drainages A and C are combined).

Average annual streamflow from Mingus A increased 10 mm (0.4 inch) for the 5-year period following the prescribed burns. Though small, the increase was nearly five times larger than the expected yield based on the mean yield of the control watershed for pretreatment and posttreatment periods combined (table 1). Precipitation was 22 percent above average for the 5 posttreatment years, due mainly to the fourth and fifth years being much above normal. At least part of the streamflow increase, particularly in the second treatment year, was attributed to an increase in overland flows from intense rains, due to reductions in infiltration and interception of rain caused by burning. We anticipate little if any increases in future years without retreatment.

The average increase on chemically treated Mingus B was 5 mm (0.2 inch) per year, most of which came in 1980, the fifth treatment year (fig. 5). Precipitation in 1980[5] was 768 mm, the most since gaging began in 1959, and 64 percent more than the 22-year mean. The lack of water yield increase from Mingus B during the first 4 posttreatment years is attributed to low rainfall and the slow breakdown of the brush balls. If brush injury and mortality continue to increase, it is anticipated that a water yield increase will be sustained, at least during wet years.

Whitespar Watersheds (Medium Precipitation)

Conversion of channel-side brush on Whitespar B increased annual yield an average 16 mm (0.6 inch) (table 1). If prorated to the area actually treated (15 percent of the watershed) the increase is 108 mm (4.2 inches). The second phase treatment along the ridgeline produced no increase in streamflow. Apparently, any water saved by shrub control on the upper slopes was lost to the intervening downslope vegetation as it moved through the regolith toward the channel.

The channel-side conversion created continuous flow for 5 years in the main channel, which had dried each year before treatment for as long as 8 or 9 months (Ingebo 1971). No follow up treatments were made on the few surviving shrubs after the original channel-side treatment.

Three Bar Watersheds (High Precipitation)

Streamflow increased substantially after brush conversion on all Three Bar watersheds. Increases were largest on watershed C, which averaged 148 mm (5.8 inches) per year more than expected without treatment for the 18-year posttreatment period (table 1). The conversion on watershed F increased streamflow by 79 mm (3.1 inches) per year for 10 years. Partial treatment (40 percent) on watershed B increased streamflow by 30 mm (1.2 inches) (75 mm if prorated to the area actually treated) for 7 years in phase 1, and full treatment increased flows by 87 mm (3.4 inches) in phase 2, also 7 years.

It should not be concluded from the results on Three Bar B that conversion of the entire watershed necessarily made it more water productive per unit area treated than conversion of 40 percent in phase 1. We anticipated that conversion of the entire watershed might increase yield less per unit area than conversion of the moist site areas in phase 1. However, precipitation was greater in the second phase, which created a higher yield potential as reflected by the expected yield in phase 2 being twice that of phase 1 (table 1). Had precipitation been similar in both periods, it is possible that the increase per unit area treated would have been less in phase 2 than in phase 1.

Three Bar C yielded less than control watershed D for each of the 3 prefire years (table 2). However, by the third year after the fire, with shrub sprouts being suppressed on C, there was a shift in the relationship between the two watersheds (Pase and Ingebo 1965). Watershed C produced twice as much as D (163 mm to 79 mm) in the third year when rainfall was near average, and 3.5 times as much in the fourth year with rainfall 67 percent of average. Streamflow on the control also increased relative to prefire conditions for several years after the wildfire, although increases in the third and later years were small (Hibbert 1971). The C/D water yield ratio for the 18-year treatment period, which included several very wet years, was 2.8; for the 12 intermediate years the C/D ratio was 3.5 (table 2).

A larger percent of precipitation was yielded in wet years than in dry years for both treated and control watersheds (streamflow increases exponentially with precipitation). The 3 wettest years, for example, produced 43 percent and 53

[5]Twelve months ending June 30, 1980. A July-June water year is used for all precipitation and streamflow data in this paper.

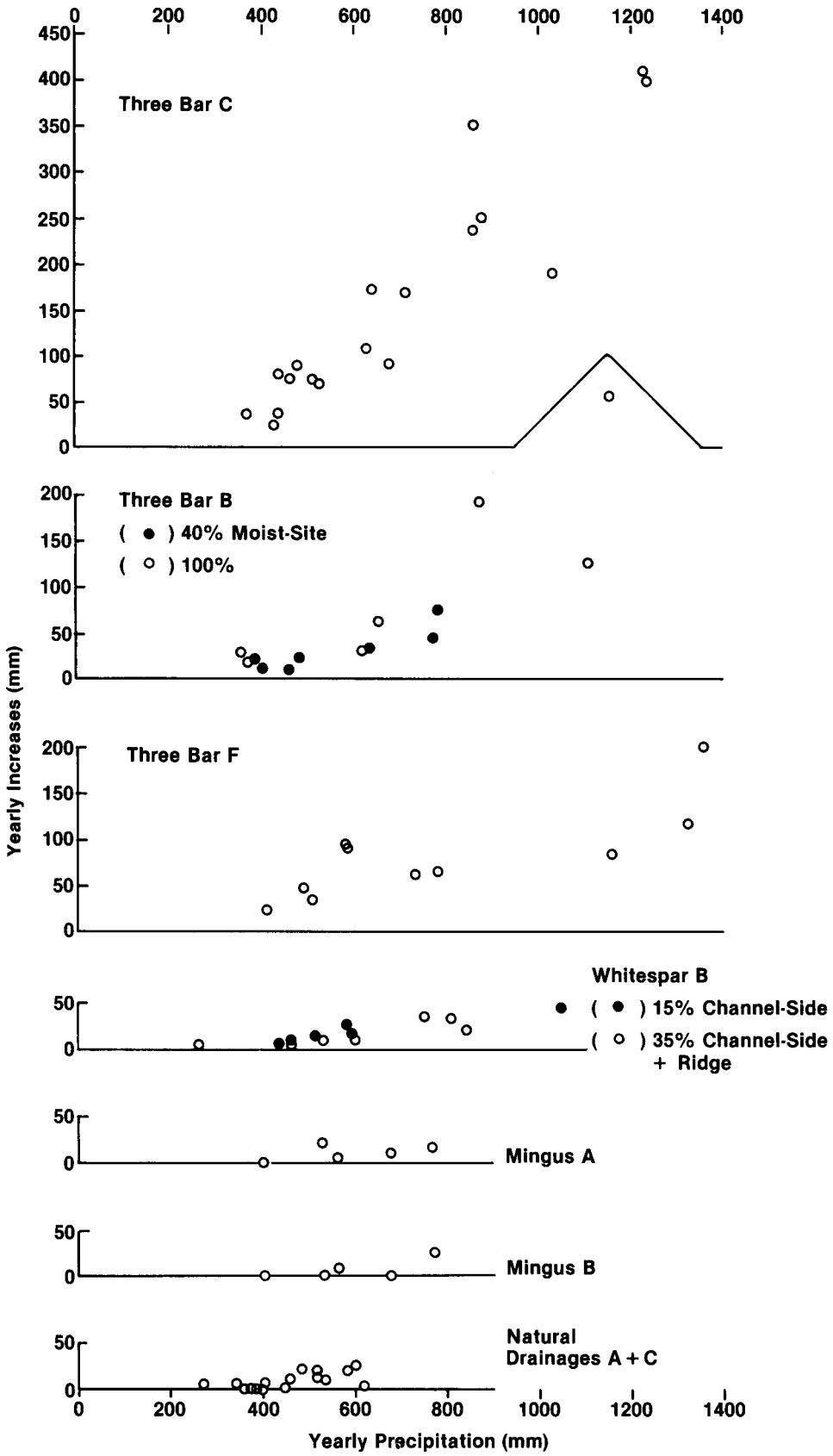

Figure 5--Yearly increases (difference between measured and predicted yield) plotted against yearly precipitation for posttreatment years.

Table 2--Comparison of annual precipitation and water yields on Three Bar watersheds C and D.

	Prefire 3 years	Post treat. 18 years	Wettest single year	Wettest 3 years	Inter-mediate 12 years	Driest 3 years	Driest single year
		Watershed C (treated)					
Mean precip. (mm)	554	693	1,240	1,168	645	414	371
Pct. of 24-yr. mean[1]	81	102	182	172	95	61	54
Mean yield (mm)	19	251	797	643	198	69	40
Pct. of 18-yr. mean [2]	--	100	18	43	53	5	0.3
Yield as pct. of precip.	3.4	36	64	55	31	16	11
		Watershed D (control)					
Mean precip. (mm)	620	765	1,334	1,283	711	465	411
Pct. of 24-yr. mean [1]	82	102	177	171	95	62	55
Mean yield (mm)	24	89	364	284	56	26	10
Pct. of 18-yr. mean[2]	--	100	23	53	42	5	0.6
Yield as pct. of precip.	3.8	12	27	22	7.9	5.7	2.4
C/D yield ratio	0.8	2.8	2.2	2.3	3.5	2.6	4.0

[1]Total period of gaging at Three Bar (1957-1980).

[2]First 2 postfire years were deleted from treatment period because of poor stormflow records and because fire-induced yield increases on the control were still high enough to partially obscure the effect of sprout control on watershed C. Streamflow not available for 1980.

percent of the total 18-year yields from the treated and control watersheds, respectively. This clearly indicates the importance of wet periods in determining and evaluating long term water yield averages.

The tendency for water yield to increase exponentially with precipitation both before and after treatment was apparent on most of the watersheds (fig. 5). However, neither Three Bar B nor F responded to conversion as strongly as did C. Streamflow increased nearly twice as much on C as on F, even though F gets more rain. Yearly increases on F were about the same as those on C in low to intermediate rainfall years, but were less in wet years (fig. 5).

Minor differences in treatment methods and cover reduction do not account for the large differences in response to conversion. There is the possibility of leakage into or out of one or more of the watersheds; watershed F yielded only 55 percent as much as control watershed D before treatment, and a fault extends across watershed F just above the stream gage and continues across the lower part of D and into C where it disappears. We have speculated on the possibility of water moving from F or D or both into C, which would help account for the yield differences between C and F. However, neither watershed C nor D showed any consistent shift in yield, based on precipitation, when F was treated, nor was there any indication before the wildfire that external water was entering watershed C, since it yielded less than D (F was not gaged until 1962).

Sharp increases in overland flow were observed after the wildfire on all the Three Bar catchments. In the summer before the fire, an intense rain (42 mm in 45 minutes) caused no streamflow on any of the watersheds. Six weeks after the wildfire, however, a very similar storm, (44 mm in 60 minutes), literally buried the stream gages under sediment and debris. Accurate measurement of stormflows from this and some of the later storms was not possible. However, it was obvious that rains of even moderate intensities were not soaking into the soil as before, and that overland flow and surface erosion were increased. Despite the spectacular flashiness of the summer stormflows, they contributed less than 20 percent of the early postfire streamflow. After the first summer, which was unusually wet, overland flows subsided gradually, and by 1964, peak flows and stormflows showed little sign of overland flow.

Streamflow on all the treated Three Bar watersheds became perennial at their outlets even though upstream channels were frequently dry. This was true even on watershed B after treatment of only 40 percent of the area. Flow was absent on B during the 3 prefire years, became intermittent shortly after the fire, and remained so until the 40 percent treatment in 1965.

Some of the watersheds responded more quickly to treatment than others. Increases in streamflow usually were detected within the first treatment year, sometimes within a few months of herbicide application. Streamflow responded on watershed F within a few weeks of first observed injury symptoms on the shrubs (Hibbert and others 1974).

Approximately 80 percent of total streamflow from control watershed D at Three Bar is from non storm or delayed flow. Treatment increases both storm and delayed flows, although it is uncertain which increases the most. We do know that about 85 percent of the increases are produced in the dormant season (November-April), which benefits the delivery of the extra water for downstream uses. Since many of the streams draining chaparral areas are dry during summer because of low inflows and heavy evapotranspiration losses along the watercourses, it follows that any small amount of water increases added in the summer might also be evaporated. However, since the increases are generated primarily in winter when streams are flowing already, further losses in transit to downstream storage should be small.

MANAGEMENT IMPLICATIONS

The experiments described in this paper were designed to get basic information on water yield relations in the chaparral, and on ways to increase streamflow. Some of the treatments would be unrealistic for management purposes, and are not recommended for large-scale application. To maximize water yield, shrubs should be eradicated as completely as practicable on the area actually treated, and the treated areas should be adjacent to or as close as possible to drainage ways to avoid loss of water savings to downslope vegetation.

The concept of creating brush-grass mosaics is being researched to integrate management objectives and optimize multi-resource outputs. Steep slopes and unstable soils must be avoided or given special attention to avoid excessive erosion. Likewise, domestic livestock, wildlife, and esthetic interests must be recognized and dealt with in designing treatments. Because of these constraints, water yield increases from future large-scale projects are likely to be less than those obtained from the experimental watersheds. Furthermore, since a disproportionate amount of the increased yield is produced in wet years, the extra water may be lost to the extent that downstream storage capacity is exceeded and water is spilled.

The extent to which these findings can be extrapolated to other areas is uncertain. The small increases obtained on Natural Drainages and Mingus watersheds were not unexpected because of low precipitation and relatively sparse shrub cover, which uses relatively less water, and therefore offers less potential for reducing evapotranspiration by conversion to grass. Based on these results, chaparral areas that receive less than 500 mm (20 inches) mean annual precipitation should be considered marginal for water yield improvement purposes. The potential appears good, however, for areas such as Three Bar, where average precipitation is greater than 500 mm, shrub cover is dense, and soils (regolith) are deep and permeable. But because of the large differences in treatment response at Three Bar, only partly explained by precipitation, extrapolation of these results to other areas involves some risk. Until reasons for the differences are better known, and can be quantified, large errors (± 2/3 of mean) (Hibbert and others 1974) must be expected in predicting response to treatment.

LITERATURE

Brown, David E.; Lowe, Charles H. Biotic communities of the Southwest. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen. Rep. RM-78. Map.

Carmichael, R. S.; Knipe, O. D.; Pase, C. P.; Brady, W. W. Arizona chaparral: Plant associations and ecology. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1978; Res. Pap. RM-202. 16 p.

Davis, Edwin A.; Pase, Charles P. Root system of shrub live oak: Implications for water yield in Arizona chaparral. J. Soil and Water Conserv. 32(4):174-180. 1977.

Hibbert, Alden R. Increases in streamflow after converting chaparral to grass. Water Resour. Res. 7:71-80. 1971.

Hibbert, Alden R.; Davis, Edwin A.; Scholl, David G. Chaparral conversion potential in Arizona. Part I. Water yield response and effects on other resources. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1974; Res. Pap. RM-126. 36 p.

Ingebo, Paul A. Effect of heavy late-fall precipitation on runoff from a chaparral watershed. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1969; Res. Note RM-132. 2 p.

Ingebo, Paul A. Suppression of channel-side chaparral cover increases streamflow. J. Soil Water Conserv. 26:79-81. 1971.

Ingebo, Paul A.; Hibbert, Alden R. Runoff and erosion after brush suppression on the Natural Drainage watersheds in central Arizona. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1974; Res. Note RM-275. 7 p.

Pase, C. P.; Ingebo, P. A. Burned chaparral to grass: Early effects on water and sediment yields from two granitic soil watersheds in Arizona. Arizona Watershed Symposium. [Sept. 1965:Tempe, Ariz.] Proc. 9:8-11. 1965.

Pase, C. P.; Knipe, O. D. Effect of winter burning on herbaceous cover on a converted chaparral watershed. J. Range Manage. 30(5):346-348. 1977.