Converting from Brush to Grass Increases Water Yield in Southern California[1]

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Southern California has no monopoly on water supply problems. But its problems are acute because of an unprecedented population increase accompanied by an overdraft of groundwater supplies. Most of California's water comes from its wildland areas. In southern California, brush-covered wildlands comprise about five and one half million acres. How these wildlands are managed is one key to supplying some of the large and increasing demands for inexpensive and high quality water.

To help meet this challenge, the San Dimas Experimental Forest was established in 1933.[2] A major objective was to develop watershed management methods that would produce more usable water. This paper reports some answers we have found.

The Experimental Area

The 17,000-acre San Dimas Experimental Forest stands on the southern slope of the San Gabriel Mountains, about 35 miles east of Los Angeles. It is representative of the brush-covered mountains of southern California. The land is highly dissected into numerous drainages which range from less than one square mile to more than 15 square miles. These are generally fan-shaped and have short, steep stream channels and precipitous side slopes.

Rocks have been subjected to most of the recognized types of alteration, including folding and faulting, extensive weathering and erosion, extreme heat, and pressure. This geologic activity has resulted in the present complex body of metamorphic and igneous rocks. Because of faulting, the rock mass is extensively and deeply fractured (Storey, 1947).

The soils on the Experimental Forest are generally residual and immature, moderate- to coarse-textured, normally intermixed with large amounts of fractured rock, and very unstable. They usually have no profile development, low water-retention capacity, and shallow depth. Only seven percent of the area has soils greater than three feet deep (Crawford, 1962).

A Mediterranean-type climate prevails—dry, hot summers, and rainy mild winters. Summer temperatures often exceed 100°F., and winter temperatures seldom drop below 25°F.[4] The average annual temperature is 57.9°, and average annual evaporation (from free water surface) is 64 inches. Annual precipitation has ranged from 48.2 to 11.5 inches, averaging 26.7 inches. Nearly three-quarters of this falls from December through March. Almost no rain occurs during the summer.

Rainfall Disposition and Water Use By Plants

A rainfall disposition study on an 875-acre watershed showed that a considerable amount of water was lost that might be saved by alternative management practice (Anonymous, 1955). Over a 15-year period the average loss from the watershed was more than 50 percent of the rainfall. The largest single loss was from evaporation (Table 1).

If we could alter the kind, structure, and density of the watershed vegetation, we might reduce evapotranspiration and increase streamflow. However, many questions needed answering before we finally selected vegetation management as a means for increasing water yield: What happens to precipitation once it reaches the soil? Do native plants differ in their water requirements? What changes in vegetation do we make, where, and how? If we do get more water, what happens to it? How much goes into underground storage and how much is realized as streamflow? Lysimeter and plot studies helped to answer some of these questions.

Lysimeter Study

Twenty-six lysimeters were built in 1937 in order to compare water losses and yields under several kinds of plants native to the mountains of southern California. Each lysimeter, a concrete tank 10.5 feet wide, 21 feet long, six feet deep, was filled with uniformly-mixed soil. After a suitable calibration period perennial grasses and native shrubs were planted in 20 tanks. Rainfall, runoff, seepage, and soil moisture data were collected and analyzed for rainfall disposition differences between the several cover types (Patric, 1961; Sinclair and Patric, 1959)

Compared to bare soil, vegetation markedly decreased runoff (Table 2). Infiltration under grass and shrubs was more than twice that of the bare lysimeter during the low-rainfall period and more than three times greater during the high-rainfall period. Only under grass did ap-

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[1] *Presented at sixteenth annual meeting, American Society of Range Management, Rapid City, South Dakota, February 14, 1963.*

[2] *The San Dimas Experimental Forest is maintained by the Forest Service in cooperation with the California Division of Forestry.*

[3] *Climatic data are based on 27 years of record, 1933-1960.*

Table 1. Disposition of annual rainfall in Monroe Canyon, 1938-1939 to 1952-1953.

Disposition	Driest year 1950-1951	Wettest year 1940-1941	15-year average 1938-1953
	(Inches)		
Rainfall	12	52	27
Interception	2	5	3
Evapotranspiration	10	14	12
Total Loss	12	19	15
Streamflow yield	(1)	11	3
Groundwater yield	(1)	22	9
Total Yield	(1)	33	12

[1] Trace

preciable amounts of water percolate through the soil and become available as net yield. Since the grasses became dormant early in summer, they did not reduce soil moisture to the same extent and depth as did the deeper-rooted brush, which used water all summer. Consequently, less winter rainfall was needed to recharge the grass-covered soil. The excess rainfall percolated below the root zone as water yield.

We can conclude from this study that (a) plant cover increased infiltration, (b) percolation yields were always greater under the grass cover, (c) evaporative losses under the grass did not differ markedly between low and high rainfall periods, and (d) the study did not reveal how much water native plants might use in their natural environment.

Plot Study

Before testing the lysimeter results on a watershed, a plot study was begun to find out if percolation yields could be increased by replacing deep-rooted brush with a shallow-rooted annual grass cover. This study was carried out under natural conditions (Figure 1).

For several years we measured rainfall, runoff, erosion, and soil moisture on nine hillside plots heavily covered with native brush, mostly scrub oak (*Quercus dumosa*). These plots had an average gradient of 35 percent. The soil was a permeable, stony, sandy loam averaging 12 feet deep.

In 1951, we converted two sets (six plots) of plots to annual ryegrass (*Lolium multiflorum*), and left the third set undisturbed. During the next two years we maintained a grass cover on the converted plots by killing all brush sprouts and seedlings, and forbs with 2, 4, 5-T. The third year (1954-1955) we permitted a heavy stand of summer-growing forbs to develop.[4]

Once the grass cover was completely established, no appreciable amount of runoff or erosion from the plots occurred. But the change in vegetation greatly altered water losses and soil moisture relations (Rowe and Reimann, 1961).

The soil of the undisturbed brush plots was wet to field capacity through the 12-foot depth the first winter. Rainfall that season totaled 41 inches. During the next three winters, however, rainfall was only 15, 25, and 20 inches, and the soil was wet to field capacity to depths of only four, nine and one half, and four feet. Each summer, evapotranspiration dried the entire soil of these plots to near or below wilting point. Rainfall was not enough after the first year to fully re-wet the soil (Figure 2).

In contrast, the soil of plots converted from brush to grass was wet to field capacity the entire depth each rainy season. During the first three summers the grass-covered soils dried below field capacity to about seven feet and below wilting point to about three feet. Consequently, there was a greater carry-over of water in the three to 12-foot depth of soil under grass than under brush at the end of summer.

A substantial soil moisture

Table 2. Annual rainfall disposition on the San Dimas lysimeters, average of five consecutive dry years and in one wet year.

Vegetation	Rainfall	Surface runoff	Infiltration [1]	Percolation	Evaporative loss[2]
LOW RAINFALL PERIOD, 1952-1957					
	(Inches)				
Bare	20.6[3]	27.7	7.9	0	7.4
Brush[4]	20.6	3.0	17.6	0	17.6
Grass	20.6	3.4	17.2	1.8	15.7
HIGH RAINFALL PERIOD, 1957-1958					
Bare	48.4	39.1	9.3	(5)	8.7
Brush[4]	48.4	19.4	29.0	3.8	24.6
Grass	48.4	20.3	28.1	11.5	16.5

[1] Not adjusted for interception. But, other studies have shown that brush intercepts about 11 percent of annual rainfall whereas grass intercepts about 6.5 percent.

[2] Evaporative loss = rainfall - (runoff + percolation - increase or + decrease in soil moisture).

[3] Annual rainfall ranged from 16.01 to 27.39 inches.

[4] Disposition data are averaged for all brush species.

[5] Trace

FIGURE 1. Cover converted from brush to grass; before conversion, *above;* after conversion but before forbs were permitted to develop, *below.*

saving and potential groundwater yield, 6.4 inches, was obtained under grass (Table 3). But when we permitted deep-rooted, summer-growing forbs to invade the grass, soil moisture and percolation gains were lost (Table 4). The soil throughout the 12-foot depth was nearly as dry by summer's end as under the brush.

The study pointed out three important considerations. Vegetation conversion to increase water yield (a) must be done on soils more than three feet deep, (b) the grass must be maintained free of weeds, and (c) more than enough rainfall to replace the soil water used by grass during the previous year must be received.

Managing For Increased Water Yield

Drawing on the results of the two earlier studies, we placed an entire watershed under intensive management to increase the yield of usable water (Rowe, 1957).

Plants in the canyon bottom have the most opportunity to waste water. Consequently, for our first water yield improvement trial, we removed 38 acres of thirsty canyon-bottom trees and brush from 875-acre Monroe Canyon (Figure 3) during the spring of 1958 and 1959. Volfe Canyon, an adjacent 740-acre watershed, was chosen as an untreated control to evaluate treatment effects in Monroe. These drainages, similar in their hydrologic and vegetal characteristics, are comparable to many mountain watersheds in southern California.

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[4] *Forbs included: common yellow mustard* (Brassica campestris), *prickly lettuce* (Lactuca serriola), *Douglas nightshade* (Solanum douglasi), *soap plant* (Chlorogalum pomeridianum), *and Sierra thistle* (Cirsium californicum).

[5] *Wildfire denuded the study watersheds in July 1960.*

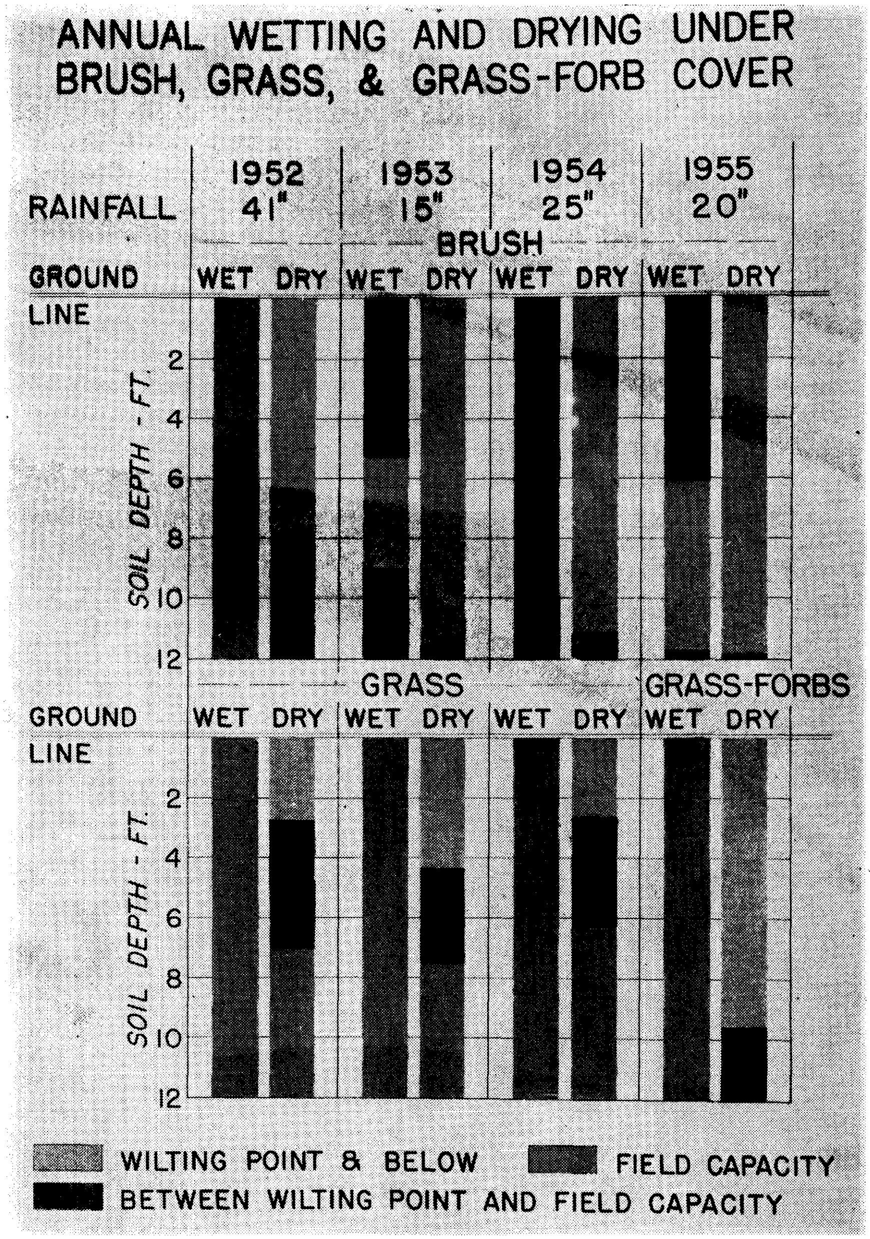

FIGURE 2. Water-use differences under brush, grass, and grass-forb cover.

Chamise-chaparral and scrub oak-chaparral formations, unburned since 1919, clothed the slopes.[5] Riparian woodland occupied the canyon bottom and covered about ten percent of the watershed (87 acres). The true riparian vegetation occupied about ten percent of the area treated (3.8 acres). It consisted of white alder *(Alnus rhombifolia)*, bigleaf maple *(Acer macrophyllum)*, California laurel *(Umbrellaria californica)*, willow (Salix spp.), mulefat *(Baccharis viminea)*, California sycamore *(Platanus racemosa)*, and several associated herbaceous plants—about 25 acres of the treated area were occupied by oak-woodland. The main species included California live oak *(Quercus agrifolia)*, California laurel, interior live oak *(Quercus wislizenii)*, bigleaf maple, canyon live oak *(Quercus chrysolepis)*, and bigcone Douglas-fir *(Pseudotanga macrocarpa)*. Scattered trees, native shrubs, grasses, forbs, and rock outcrop occupied the remaining part of the cleared area.

Fifteen acres were cleared the first spring and 23 acres the next spring. The 1.3-mile long clearing varied from 100 feet to over 400 feet wide. It extended up the side slopes an average of 50 feet above the stream.

After clearing, the area was hand sprayed to kill sprouting vegetation, brush seedings and weeds. Native grasses, mostly ripgut *(Bromus rigidus)*, quickly invaded the area and provided good soil protection.

Treatment Effect on Water Quantity

Water yield gains first appeared during the summer and fall of 1958. With only 15 acres cleared, streamflow was 17.4 acre feet more than predicted without treatment (Table 5). This increase resulted from lower day-to-day evapotranspiration losses. Rainfall was light (1.8 inches) and contributed to streamflow only the small amount intercepted by the stream.

Twenty-three more acres were cleared during the 1958-1959 rainy season, bringing the total to 38 acres cleared. Streamflow during this period was increased 12.8 acre feet. Most of it came immediately after storm rainfall which was insufficient to satisfy soil moisture deficits on the 23 acres cleared this season. It was enough, however, to wet soils be-

Table 3. Water regimen under brush and grass during a year of moderate rainfall, 1953-1954.

Vegetation	Water storage Beg. of yr. (10/19/53)	Water storage End of yr. (11/8/54)	Rainfall	Percolation	Evapotranspiration
	(Inches)				
Brush	9.9	11.4	24.9	0.0	23.4
Grass	21.6	24.9	24.9	6.4	15.5

Table 4. Water regimen under brush and grass-forb cover during a year of moderate rainfall, 1955-1956.

Vegetation	Water storage Beg. of yr. (11/9/55)	Water storage End of yr. (11/30/56)	Rainfall	Percolation	Evapo-trans-piration
	(Inches)				
Brush	10.7	13.0	20.5	0.0	18.2
Grass-forb	13.2	16.7	20.5	0.0	17.0

low the root zone of the previously-cleared 15 acres. Here soil moisture deficits were low so that 8.4 acre feet of the season's increased streamflow came from this area. The rest, 4.4 acre feet, resulted from lower day-to-day evapotranspiration from all 38 acres cleared. This gain came during inter-storm periods.

Streamflow gain the second dry season, summer and fall, 1959, was 14 acre feet. Rainfall during the period was only 1.3 inches and contributed little to streamflow. As before, this season's gain in streamflow was principally due to lower day-to-day evapotranspiration.

During the second rainy season (winter and spring, 1959-1960) streamflow gain was eight acre-feet. Rainfall, 22.9 inches, was enough to satisfy soil moisture deficits. As in the 1958-1959 rainy season, the largest proportion of the gain came during and immediately after storms.

The largest gains in streamflow came during the dry season when water is most needed. Before treatment, streamflow in Monroe Canyon usually dried up in early July. Since the treatmen began, however, streamflow has been continuous.

Effects On Water Quality

Streamflow yields during the rainy seasons were among the highest on record (1934-1960) yet no increase in storm discharge or erosion rates was detected. In fact stream channel banks, and side slopes — some of which eroded before treatment—appeared to be completely stabilized. There were no flood-producing storms during the study period. Therefore, we cannot predict what effect clearing and subsequent grass cover establishment might have had on erosion and flood peaks.

Chemical analyses showed no trace of herbicides in the streamflow. But small traces of oil (two to 30 p.p.m.) used in the spray mixture were found in some samples.

Water temperature in Monroe Canyon appeared to be higher than untreated Volfe Canyon. During the summer, temperatures were generally above 65°F. A relatively high concentration of green algae (*Cladophora* spp.) was associated with these temperatures.

The study was short-lived because of a July 1960 fire. Nevertheless, several conclusions can be drawn:

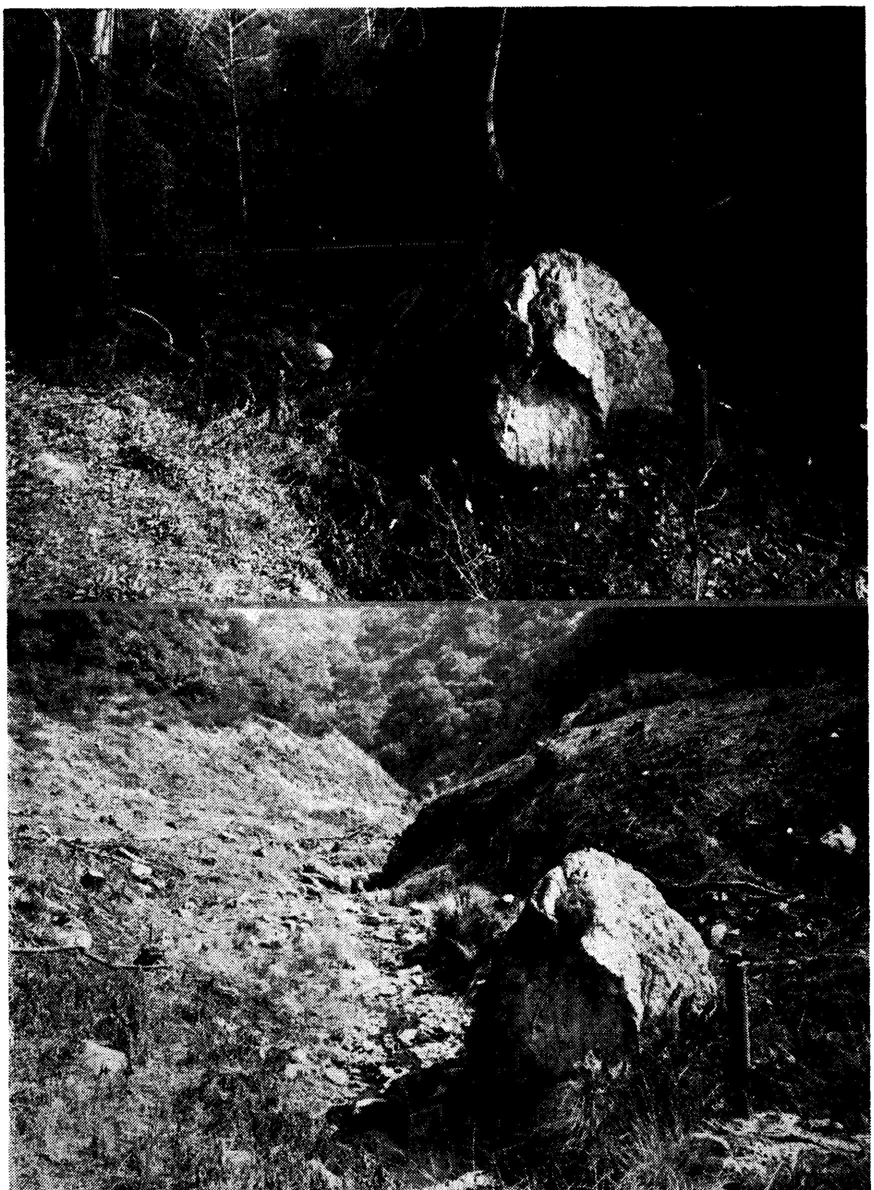

FIGURE 3. Part of the treated canyon bottom in Monroe Canyon; before clearing, *above*; the same area after clearing, *below*.

Table 5. Gains in streamflow from removing 38 acres of woodland-riparian vegetation in Monroe Canyon.

Season	Rainfall Preceding season	Rainfall During season	Total gain in streamflow	Gain in streamflow per acre cleared
	(Inches)		(Acre feet)	
First Year Dry Season[1]	47.0	1.8	17.4	1.1
First Year Rainy Season[2]	1.8	13.2	12.8	0.3
Second Year Dry Season	13.2	1.3	14.0	0.4
Second Year Rainy Season	1.3	22.9	8.0	0.2
First year total	....	15.0	30.2	0.8
Second year total	....	24.2	22.0	0.6

[1] 15 acres cleared
[2] 38 acres cleared

1. The study was conducted during two years of below-average rainfall which were preceded by an above-average rainfall year. Gains in streamflow during the post-treatment period are probably associated with this high rainfall as well as with the treatment.
2. Seasonal gains in streamflow were less the second year than in the first year. This decline probably reflects the below average rainfall conditions during the second year's rainy season. We would expect larger gains with average rainfall.
3. Gains in streamflow were highest during the dry season when water is most needed and lowest during the rainy season. Streamflow has been continuous since treatment began.
4. Dry season streamflow was highest because the grass died early in summer and, consequently, used little soil water. On the other hand, tree and shrub growth in the control watershed was in full foliage and at the peak of annual growth. It withdrew soil water all season, and from a much greater depth.
5. If soils are not saturated during the rainy season, treatment may have little effect on this season's streamflow.
6. Streamflow gains were probably least from the area where free water and wet soil surfaces were exposed to wind and sun. Gains were probably greatest from the area where grass roots did not penetrate continuously saturated soil.

Multiple Benefits From Brush Conversion

We have demonstrated at San Dimas that water yields can be improved by converting canyon-bottom vegetation from woodland-brush to a grass cover. At present we are converting 140 acres of brush-covered side slopes with deep soil in Monroe Canyon to grass cover. We expect additional yields in streamflow to result from this treatment. But water yield improvements are not the only benefits of a brush conversion program. Extensive brush fields are broken into smaller, more manageable units for more effective fire control. Grassed areas provide for wildlife a new habitat that is not found in dense brush. In areas suitable for grazing, new range for livestock is developed. Research is underway at San Dimas to determine the integrated effect of some of these multiple benefits.

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