Influences of Brush Conversion and Weather Patterns on Runoff from a Northern California Watershed

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Highlight: Sixteen years of data were evaluated to determine the influence of annual weather patterns and a brush conversion project on subsequent runoff from an 86.2-ha watershed. Grassy vegetation released 39% more total runoff than did woody vegetation. Total runoff for each hydrologic year was directly proportional to total precipitation, regardless of vegetative cover. However, runoff as a proportion of total precipitation increased 59% following conversion of woody to grassy vegetation, and most closely correlated with March cover.

Unfortunately, brush conversion also drastically increased the number of soil slips and sediment discharged from the watershed. All major landslides occurred in the vicinity of streams when the root systems of woody vegetation along these streams began to decay. Leaving this streambank vegetation intact may have prevented some of the undesirable results of brush conversion on the watershed.

Literature describing watershed management practices typically concludes that reduction of woody vegetation cover, by cutting or other means, results in increased water yields (Burgy and Papazafiriou 1974). Studies as early as 1900 in Switzerland, the Colorado Wagon Wheel Gap Study (Bates and Henry 1928), the Coweeta studies in North Carolina (Hewlett and Hibbert 1961; Hibbert 1969), studies in South Africa (Pereira 1962), forestry and hydrologic research in Oregon (Rothacher 1965), California (Rowe 1948; Biswell and Schultz 1958; Rowe 1963; Bentley 1967; Lewis 1968), Ohio (Harrold et al. 1962), West Virginia (Reinhart et al. 1963), and many others, representing thousands of acres of watersheds and many years of records, all demonstrated the impacts of woody plant reduction in increased water yield.

However, total amounts of increased water yield following conversion from brush to grass are highly variable and unpredictable, and depend not only upon the change in vegetative type, but also upon annual weather patterns (Rowe and Reimann 1961). Where long-term weather records are available, average annual precipitation is usually considered a reliable parameter for predicting water yield (Branson et al. 1962). However, many climatic factors other than average annual precipitation also influence runoff. High levels of either storm intensity or duration may produce runoff, while low intensity storms, not exceeding soil infiltration capacity, may produce no runoff at all. Rainfall distribution over time also affects water yield, as storms separated by periods of clear weather produce maximum interception capacity at the beginning of each shower, with a corresponding decrease in runoff. Temperature regimes during both storms and clear weather exert additional impacts on total water yield. Intercepted moisture becomes more susceptible to evaporation when temperatures are high during periods of clear weather. This evaporation in turn produces a higher moisture holding capacity in the vegetation, thereby increasing interception capacity during the next storm and ultimately reducing runoff.

These variable climatic factors must be separated from the effects of watershed management techniques before evaluating the success of such techniques. Observed changes in runoff following brush conversion projects may result from different weather patterns as well as the reduction in woody vegetation. Therefore, this study evaluates the relative influences of annual weather patterns and a brush conversion project on 16 years of runoff from a northern California watershed.

Location and Methods of Study

The study was conducted at the Hopland Field Station, which is owned and operated by the University of California and is located in Mendocino County in the central portion of the coast mountain ranges. The experimental area, known as Watershed II, is an 86.2-ha drainage basin with a west-facing orientation draining into the Russian River. Elevations range from 183 to 396 m. Soils on the watershed are approximately 1 meter thick overlying sandstone and shale rock of the Franciscan Formation. This formation is extremely shattered and jointed, with intrusions of basic rock and interlaced with faults, very typical of the coastal mountain ranges (Gowans 1958; Burgy and Papazafiriou 1974).

The study began in 1952 when the watershed was fenced and a weir erected for measuring runoff. Other instrumentation to measure precipitation, soil moisture, and groundwater levels, and a settling basin to measure sedimentation were also installed. The vegetative composition of Watershed II prior to brush conversion included 5.2 ha of open grassland; 19.8 ha of mixed grass and deciduous oak trees (*Quercus lobata*); 50.6 ha of black oak (*Quercus kellogii*), live oaks (*Quercus agrifolia, Q. wislizenii*), blue oak (*Quercus douglasii*), and madrone (*Arbutus menzeisii*); and 9.3 ha of brush composed principally of chamise (*Adenostoma fasciculatum*) (Pitt 1975).

The years 1955 through the summer of 1959 marked the first or calibration period of brush conversion. Throughout this calibration period, botanical composition, cover, and standing crop were estimated twice a year; once immediately before the onset of rapid plant growth in February, and again during summer dormancy in June. Precipitation and runoff were sampled monthly. The second, or treatment period of brush conversion on Watershed II, when woody

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vegetation was converted to grassy vegetation, began in December, 1959. The trees were killed by applying 2,4-D amine in surface cuts circling the base of the tree trunks. This procedure required approximately 4 months and concluded in April, 1960. Deciduous trees treated early in the winter generally did not come into leaf the following spring. Deciduous trees treated later in the winter did come into leaf the following spring but typically shed these leaves by September, 1960. The evergreen madrone and live oaks lost their leaves gradually and were bare within a year following treatment. During the second year after treatment, many small limbs fell; and within 3 years following treatment, many of the small tree trunks also rotted and fell. By the end of 1964, over 50% of the trees had fallen and a heavy litter lay on the ground limiting access for both men and livestock.

July 1969 marked the beginning of the third or stabilization period of brush conversion, initiated by burning the watershed to remove the extensive build-up of decaying woody vegetation. Firing procedures utilized two crews beginning at the top of the watershed and firing downhill around the periphery. When the crews reached the bottom of the watershed, a safe, burned boundary strip encircled most of the watershed. Center firing occurred before the perimeter fire completely enclosed the watershed. Within one hour of the firing, the major portion of the burning, with excellent fuel consumption, was complete. Vegetation sampling continued until the stabilization period of brush conversion terminated in June, 1973. Runoff and sedimentation were sampled only through the end of the 1970 hydrologic season.

Results and Discussion

Brush conversion undoubtedly increased runoff from Watershed II, as the formerly intermittent stream draining the center of the watershed became perennial immdiately following herbicidal treatment of the woody vegetation. However, some of this observed increase in runoff (Table 1)[1] may have resulted from different weather patterns following brush conversion as well as the reduction in woody vegetation. Therefore, simple comparison of average runoff before and after brush conversion may lead to conclusions that confound the influences of brush conversion and annual weather patterns.

Table 1. Annual runoff (cm) and precipitation (cm) through June 1 of the hydrologic year, and the corresponding runoff/precipitation ratios (%) on the grazing unit designated as Watershed II, Hopland Field Station.

Hydrologic year	Runoff (cm)	Precipitation (cm)	Runoff / Precipitation (%)
1954–1955	4.44	63.09	7.0
1955–1956	40.64	129.39	31.4
1956–1957	6.32	74.62	8.5
1957–1958	69.22	152.20	45.5
1958–1959	13.69	65.25	21.0
1959–1960	6.63	64.92	10.2
1960–1961	17.25	77.85	22.2
1961–1962	23.16	78.56	29.5
1962–1963	31.88	102.56	31.1
1963–1964	11.33	60.71	18.7
1964–1965	37.67	109.30	34.5
1965–1966	23.62	79.45	29.7
1966_1967	34.64	106.17	32.6
1967–1968	22.61	77.09	29.3
1968–1969	57.15	127.00	45.0
1969–1970	48.77	112.90	43.2

Figure 1 illustrates the relationships among total runoff, total precipitation, and runoff as a percentage of total precipitation. Runoff and precipitation both decreased during the treatment period immediately following brush conversion on the watershed. During the stabilization period of brush conversion, both runoff and precipitation increased, although precipitation was only slightly higher than the average prior to brush conversion.

The trend in runoff as a percentage of total precipitation, however, increased much more than either runoff or precipitation increased throughout the study of Watershed II. Obviously, grassy vegetation subsequent to brush conversion produced greater amounts of runoff as a percentage of total precipitation than did woody vegetation prior to brush conversion (Fig. 1). Indeed, analysis of variance for runoff/precipitation ratios as a function of brush conversion periods on the watershed produced differences significant at the 20% level of significance (F = 2.12). While annual runoff averaged 39% more during the stabilization period than during the calibration period of brush conversion, the ratio of runoff to total precipitation increased 59% between these same two periods. In contrast, total precipitation increased only 3.73% between the calibration and stabilization periods of brush conversion. Therefore, in both absolute and relative terms, grassy vegetation released a higher proportion of precipitation as runoff than did woody vegetation.

This relationship of runoff to total precipitation became particularly important during high rainfall years. Runoff from Watershed II exceeded 40 cm only during the hydrologic years ending in 1956, 1958, 1969, and 1970 (Table 1). Average runoff for the years 1955 through 1970 inclusive equaled 27.94 cm while total rainfall averaged 92.46 cm. During the high runoff years of 1956, 1958, 1969, and 1970, however, total rainfall equaled 129.39, 152.20, 127.00, and 112.90 cm, respectively (Table 1). Furthermore, the amount of runoff as a function of total rainfall increased geometrically. The runoff/precipitation ratios for the hydrologic years ending in 1955 through 1970 averaged 27.5%. Alternatively the runoff/precipitation ratios for the high runoff years of 1956, 1958, 1969, and 1970 equaled 31.4, 45.5, 45.0, and 43.2%, respectively. Runoff through June 1 during these hydrologic years averaged 53.95 cm, 93.1% higher than the average runoff year during the study of Watershed II.

In contrast to runoff, total precipitation during these years of 1956, 1958, 1969, and 1970 averaged 130.35 cm, only 40.8% higher than the average precipitation through June 1 for the hydrologic years ending in 1955 through 1970 inclusive. Therefore, increasingly greater proportional quantities of runoff emanated from increasing quantities of total precipitation. The runoff/precipitation ratios for the years 1956, 1958, 1969, and 1970 averaged 41.3%, 50.2% higher than the average runoff/precipitation ratio throughout the study on Watershed II. Obviously total rainfall, as influenced by the intensity, duration, and separation of individual storms and ambient temperature patterns during and between these storms, significantly influenced total runoff from Watershed II, regardless of the vegetative cover.

Influence of Weather Patterns on Runoff

Results obtained from step-wise multiple regression of runoff on 76 weather variables (Pitt 1975) illustrate that runoff depends primarily on total precipitation (Table 2).[2] Total rainfall through June 1 of the hydrologic year entered the regression equation

[1] The hydrologic year begins October 1 and extends through September 30. Only minor quantities of runoff and precipitation occurred from June 1 to the beginning of the next hydrologic year. Virtually all precipitation was discharged from the watershed during each hydrologic year.

[2] The first five weather variables entering the regression equations in Table 2 are listed from left to right in order of their respective appearance in the step-wise regressions. Direction of influence (positive or negative) and the coefficients are included with each weather variable.

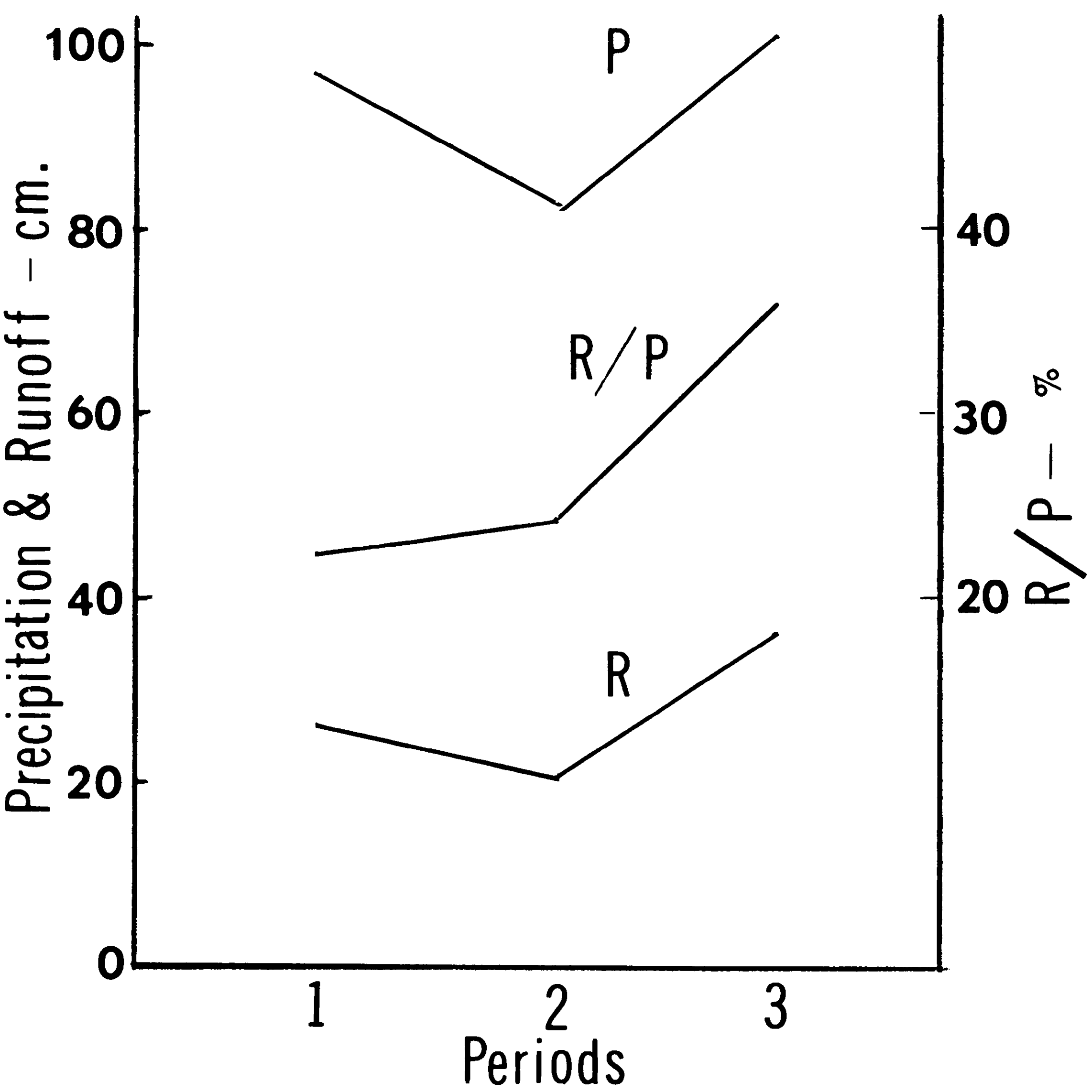

Fig. 1. *Runoff, precipitation, and runoff/precipitation ratio through June 1 of the hydrologic year as a function of the conversion period. (1) Calibration. (2) Treatment. (3) Stabilization.*

first, and by itself correlated with runoff through June 1 with an r^2 of 0.92. The negative correlation of runoff through June with total precipitation in April and May is possibly associated with increased evapotranspiration of annual vegetation during this period of rapid plant growth. High rainfall during these 2 months often produces virtually no runoff from watersheds in that region of California.

Runoff through March 1 of the hydrologic year also highly correlated with total precipitation, particularly during the months of December, January, and February (Table 2). The negative correlations of runoff through March 1 with numbers of days below freezing in October and increasing mean minimum temperatures in October, likely indicate cold weather with no rain, and an extended summer with no rain, respectively. Both these regressions of runoff on weather variables and the following regression equations (Table 3) of runoff on standing crop and cover utilized only those data (Table 4) collected after brush conversion (1960–1969 inclusive) so that results were not

Table 2. Summary of results obtained from step-wise multiple regressions of runoff through both March 1 and June 1 of the hydrologic year on weather variables.

Runoff	Constant	Weather variables					r^2	F
Runoff through June 1	10.0	0.7 Precip. year	−1.0 Precip. A, May	0.3 Precip. 0	−0.2 < .6cm SONMAM	0.2 M. max. ONMA	.99	832.5[1]
Runoff through March 1	9.9	0.6 Precip. DJF	−0.2 < .6cm SON	−3.5 <0°C 0	0.7 Precip. SON	−0.4 M. min. 0	.99	260.7[1]
Runoff through June 1	−12.5	0.6 Precip. year					.92	96.5[1]

[1] Significant at 0.01.

Table 3. **Simple regressions of runoff through both March 1 and June 1 of the hydrologic year on cover and standing crop at the March 1 and June 1 sampling dates on Watershed II, Hopland Field Station, during the years 1960 through 1969 inclusive.**

	r^2	F
March runoff = 1.03 + 0.19(March cover)	.20	2.07
March runoff = 5.20 + 0.36(March standing crop)	.15	1.44
June runoff = 5.96 + 0.15(June cover)	.08	0.70
June runoff = 2.38 + 0.28(June standing crop)	.25	2.67
June runoff = 0.43 + 0.27(March cover)	.33	3.91[1]
June runoff = 6.80 + 0.44(March standing crop)	.18	1.82

[1] Significant at 0.10.

confounded with the different runoff potentials of predominantly brushy versus predominantly grassy vegetation. Following conversion, this annual, grassy vegetation dominated all treated areas of the watershed, and permitted virtually no reinvasion by woody plant species.

Influence of Annual Vegetation on Runoff

The regressions of runoff on standing crop and cover produced relatively low coefficients of determination as simple r^2 values ranged from .08 to .33. The largest coefficient of determination resulted from the regression of runoff through June 1 on cover at the March sampling date. This relationship suggests a delayed influence of annual vegetation on runoff rather than an immediate calendar effect. Indeed, only this particular regression of runoff on vegetational parameters produced results significant at the 10% level of significance.

These regression analyses of runoff on vegetational parameters excluded data collected in 1970, which can therefore be used to "test" the predictive accuracy of the regression equation of June runoff as a function of March cover. From Table 3 June runoff equals 0.43 + 0.27 × March cover. Cover in March of 1970 equaled 54.53%. Therefore, the regression equation predicts 38.48 cm of runoff through June 1 of 1970, a value which compares reasonably well with the observed 48.77 cm through June 1 of 1970. However, since total precipitation is such a dominating factor in terms of runoff, this equation relating March cover to runoff through June 1 should be applied very cautiously.

Managerial Recommendations

Brush conversion not only augmented runoff from Watershed II but also drastically increased the number of soil slips and resulting sediment discharged from the watershed. Relatively stable top soils prevailed on the watershed prior to brush conversion treatments. No massive soil movements occurred during the calibration period of brush conversion, even under heavy precipitation (Burgy and Papazafiriou 1974). However, 61 soil slips occurred during the 10 years immediately following brush conversion. Only five of these slips occurred during the period of 1960–1964, while 18 slips were observed in 1964–1965, 15 in 1965–1968, and 17 in 1968–1969. The remaining six soil slips occurred in 1969–1970 (Burgy and Papazafiriou 1974). Although the rate of soil slips has recently declined, two new slips were observed in the spring of 1974. These slips were relatively small, however, and may represent natural slides very characteristic on clay soils found in the Franciscan Formation.

All of the major landslides occurred in the vicinity of streams (Fig. 2), and in most cases bank cutting preceded the slips. The bulk of these slips did not occur until 5 years following brush conversion, when the root systems of the dense, woody vegetation along stream banks began to decay. Once these roots released their hold upon the top soil, which often reached moisture saturation during the winter months, the total number of land slips in each time period was directly proportional to the total precipitation in that time period (Burgy and Papazafiriou 1974). These land slips produced such enormous quantities of sediment that measurement activities were discontinued. Sedimentation from Watershed II averaged approximately 400 tons per year during the calibration period, but increased to 4,000 tons per year following brush conversion. Intense storms occasionally washed 100 tons of sediment per hour from Watershed II following brush conversion.

The precise economic impacts of brush conversion on Watershed II remain unquantified. However, repeated soil slips

Table 4. **Runoff through March 1 of the hydrologic year, standing crop (oven dry g/ft²) and foliar cover (%) at the March 1 and June 1 sampling dates on Watershed II, Hopland Field Station, during the years 1960 through 1970 inclusive.**

Year	March runoff (cm)	March cover	June cover	March standing crop	June standing crop
1960	4.27	27.90	27.19	1.76	7.30
1961	12.12	44.61	43.65	4.49	27.98
1962	17.32	34.07	33.90	5.56	20.28
1963	17.60	41.58	30.15	6.44	30.91
1964	10.06	29.77	14.69	8.34	26.91
1965	34.29	23.36	18.39	7.41	33.32
1966	21.72	22.01	17.18	3.00	29.74
1967	24.51	46.35	43.58	11.90	28.52
1968	16.64	45.29	40.50	20.08	46.90
1969	50.06	60.89	39.45	13.51	34.92
1970	44.42	54.53	36.31	12.79	16.79

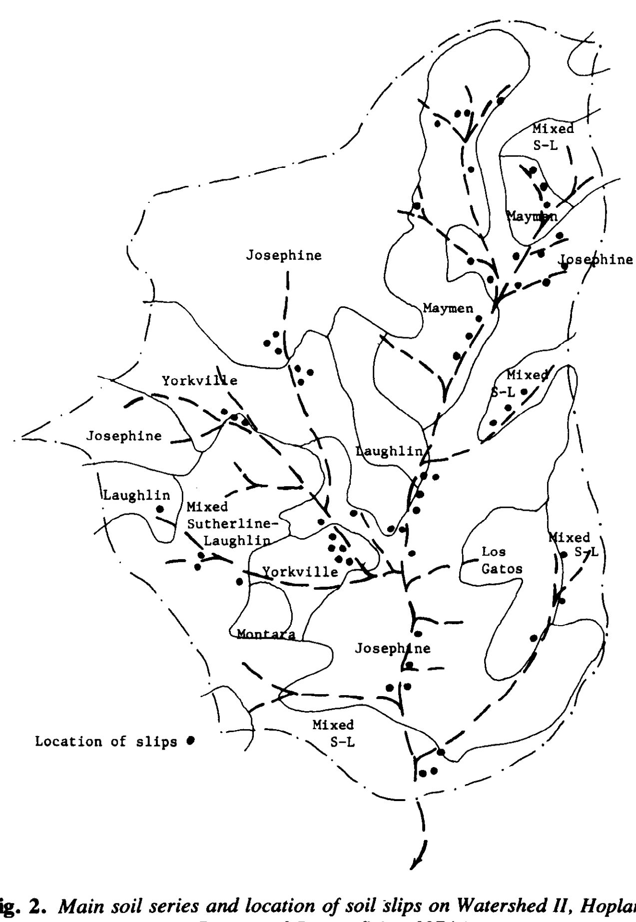

Fig. 2. *Main soil series and location of soil slips on Watershed II, Hopland Field Station. (From Burgy and Papazafiriou 1974.)*

certainly detract from long-term forage production potentials, while subsequent siltation may reduce runoff quality and values for downstream agricultural enterprises. Since most of the soil slips began on the steep slopes adjacent to the stream banks draining the center of the watershed, one implication is that total brush conversion may have been undesirable. Retaining some dense, riparian vegetation intact during brush conversion programs serves to minimize the unwanted side effects of slippage and sedimentation (Lewis and Burgy 1964). However, since these dense, woody sites contributed a very large proportion of the total forage increase following brush conversion (Pitt 1975), leaving them intact would also detract from the benefits of brush conversion prjects. The appropriate balance of these positive and negative results of brush conversion certainly depends upon managerial objectives in any particular regional locale.

Summary and Conclusions

The influences of brush conversion, herbage productivity, and annual weather patterns on runoff emanating from Watershed II, Hopland Field Station, were investigated during the years 1955–1970 inclusive. Grassy vegetation following brush conversion produced approximately 59% more runoff as a percentage of total precipitation than did woody vegetation prior to brush conversion. Once this grassy vegetation became established however, the relative degree of cover and standing crop from one year to the next exerted only negligible influences on total runoff from the watershed. The coefficients associated with cover and standing crop in the simple regression equations for runoff (Table 3) never exceeded 0.44, indicating that a unit increase in either cover or standing crop produces less than a unit increase in runoff. Interestingly, both cover and standing crop positively correlated with runoff, suggesting that increasing cover and standing crop of grassy vegetation produce greater amounts of runoff. However, these relationships among runoff, cover, and standing crop actually represent associations with the overwhelming influence of total precipitation, which positively correlated with all three of these variables (Pitt 1975).

Indeed, total precipitation rather than temperature and rainfall patterns was primarily responsible for annual variability in total runoff emanating from Watershed II subsequent to brush conversion. The first four variables entering the step-wise multiple regression equation of runoff through June 1 on weather patterns all describe amounts of rainfall as opposed to temperature patterns. Although periodicity and intensity of storms as well as temperature patterns certainly influence total water released from any watershed, the single variable, total precipitation through June 1, described 92% of the variability in annual runoff from Watershed II.

In addition to increased runoff, brush conversion at this site drastically increased sedimentation and soil slippage in the vicinity of streams, particularly after the root systems of the dense, woody vegetation on these slopes decayed. Leaving some stream bank vegetation intact may have minimized that undesirable result of brush conversion on Watershed II.

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