# EFFECTS OF VEGETATION REMOVAL ON SPRING FLOW[1]

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## INTRODUCTION

California ranchers and sportsmen are converting large acreages of brush to grassland to increase forage for livestock and game. In many cases this change in plant cover has resulted in an increase in spring and stream flow. Our objective was to make quantitative measurements of this increase and to observe the situations under which the increase occurred.

This study was made chiefly in the foothills of Madera County at elevations ranging between 1,200 and 3,000 feet; one small segment of the study was made near Clear Lake in Lake County. Climate is typically Mediterranean, with precipitation falling principally in the winter and spring; the summers are long, hot, and dry. In the Madera County foothills precipitation varies with elevation from about 15 to 30 inches annually. Most of the soils are granitic with high infiltration capacity.

The vegetation is woodland-grass (Figure 1). Trees and shrubs are most dense on north exposures and at the higher elevations where moisture is more plentiful. The principal trees are digger pine (*Pinus sabiniana*), blue oak (*Quercus douglasii*), interior live oak (*Q. wislizenii*), and buckeye (*Aesculus californica*). The buckeye leaves dry in July prior to the time when moisture stress is greatest. Blue oak is deciduous but the other species are evergreen. At the higher elevations, California laurel (*Umbellularia californica*) and foothill ash (*Fraxinus dipetala*) are found occasionally.

Principal shrubs are chaparral whitethorn (*Ceanothus leucodermis*), buckbrush (*C. cuneatus*), Mariposa manzanita (*Arctostaphylos mariposa*), bush lupine (*Lupinus albifrons*), redberry (*Rhamnus crocea*), poison oak (*Rhus diversiloba*), and squaw bush (*R. trilobata*). The shrubs are evergreen, except for the two species of *Rhus*. These begin to dry in late July or early August.

The herbaceous plants are mainly annuals and are dry about the first of May at 1,200 feet elevation and two or three weeks later at 3,000 feet. Summer weeds, particularly tarweed (*Hemizonia virgata*), are abundant in some years.

Along stream courses the trees are chiefly white alder (*Alnus rohmbifolia*), willow (*Salix* spp.), sycamore (*Platanus occidentalis*); shrubs

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FIGURE 1. Typical woodland-grass vegetation on north exposure at 1,500 feet elevation in Madera County, California.

are mule fat (*Baccharis viminea*), and button willow (*Cephalanthus occidentalis*). All of these are deciduous except mule fat.

Woody vegetation has increased on the study area in recent years and ranchers have control-burned, or bulldozed and chemically treated from 10,000 to 20,000 acres of brush each year converting to grassland. After the first control-burn in July, 1949, water was observed to have increased in a creek adjacent to the burn. Thereafter, the general procedure in the study was to measure spring flow before and after plant cover manipulation. This was done by clocking the time required to fill a quart bottle, or by measuring the actual amount of water collected in 15 minutes or an hour. In some cases the springs were measured only once or twice per day but in others every hour throughout the day. An attempt was made to use water meters but those used were not sensitive to small flows.

A few studies have been reported showing the effects of brush removal on spring flow. Numerous ones, however, have shown that the removal or reduction in brush or trees have increased the water available for streamflow; others have shown an actual increase in water yield (1, 5, 7, 11, 14, 17). A study in San Benito County showed a spring to increase in flow after the brush and trees were cut around the spring in a radius of about 100 feet (13). Some of the larger oaks were chemically treated with 2,4,5-T. Leonard and Harvey (10) reported that brush was successfully sprayed with chemicals to increase irrigation water.

## SPRING FLOW DATA

This section will present the case histories of the springs measured in Madera and Lake Counties over the past nine years. Three of the springs served as checks to indicate trend in flow throughout the sum-

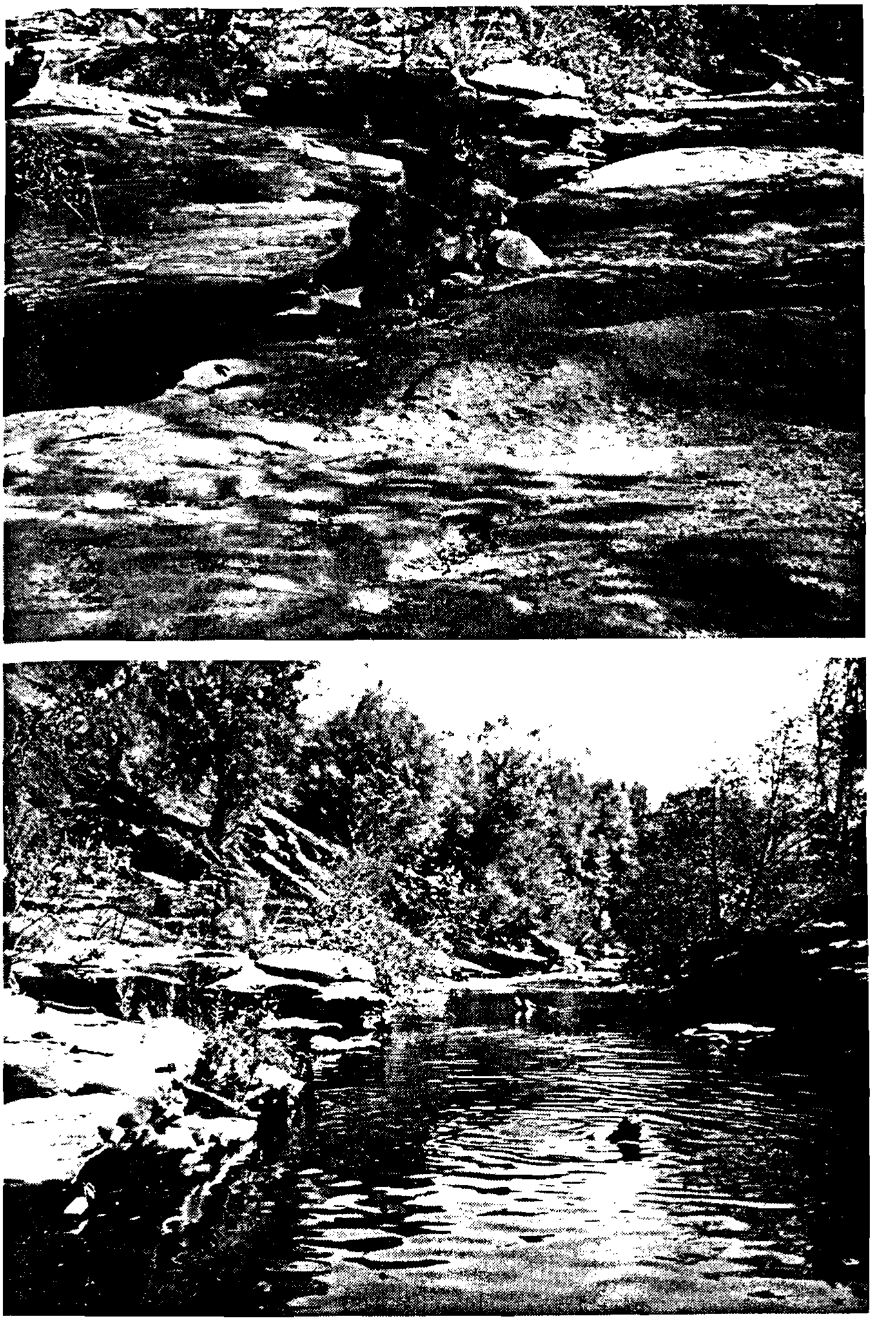

FIGURE 2. (Upper) Taken in Finegold Creek on August 17, 1949, before control-burn on August 20th. (Lower) Rephotographed on September 14, 1949. The hole had filled with water and flow in the rapid was the size of a man's wrist. Weather was clear and hot during the interval.

mer without manipulation of plant cover. The springs were named after some feature in the vicinity.

## Finegold Creek

Finegold Creek lies between two control-burns made in the summer of 1949, the first on July 17th, the second on August 20th. The burn bordered the creek on each side for approximately one mile. The fire burned and killed about 10 percent of the riparian vegetation which consisted chiefly of white alder and mule fat.

On the banks and above, the shrubs and trees consisted chiefly of chaparral whitethorn, buckbrush, Mariposa manzanita, redberry, poison oak, squaw bush, bush lupine, digger pine, interior live oak, blue oak and buckeye. These species were about 65 percent top-killed on the upper slopes but less so near the stream course where the fires were set.

One seep was found in the edge of the stream bed next to the second burn; this was nearly dry before the fire.

Following the first burn, water increased in certain places in the creek but no photographs were taken or definite measurements made before the burn. Three days prior to the second burn, photographic stations were established in the stream bed which was nearly dry except for depressions that had filled with water following the first burn. These stations were re-photographed on September 14th, about three weeks after the burn when water was flowing down the creek (Figure 2). One could not be sure how much of the increase in flow was due to killing of the vegetation in the stream bed and on the slopes, or to the gradual decline in transpiration that occurs in the early autumn before the leaves normally fall (15). Also, the days were getting shorter. Cooler weather was not a factor since this period was uniformly clear, hot, and dry.

## Grapevine Spring

The watershed above this spring was 59 acres. It was control-burned on August 20, 1949. Coverage of brush and trees before the fire was estimated as 50 percent. The reduction in transpiration area of these by burning was approximately 80 percent.

The spring produced 76 drops of water per minute before the fire, equal to 1½ gallons per day; 24 hours after the fire it produced one quart per minute, equal to 360 gallons per day. Measurements were made nine days and 24 days after the fire; the flow continued at about one quart per minute. In addition, a seep developed about 50 yards above the spring.

Measurements of this spring were continued during the summer of 1950. The flow on August 24th was about equal to that on the same date after the fire in 1949. On August 24th a large grapevine near the spring was cut (Figure 3). After this the flow increased by about 15 gallons per day. Before cutting, the difference in morning and afternoon flow amounted to eight seconds per quart. After cutting it amounted to only three seconds, which indicated that most of the increase came from reduced transpiration (Figure 4).

Five days after the grapevine was cut, on August 29th, six interior live oak, two blue oak, one digger pine, and two whitethorn chaparral

FIGURE 3. Grapevine Spring. The large grapevine and trees were removed from area of spring to study effect on water flow. Arrow points to location of spring.

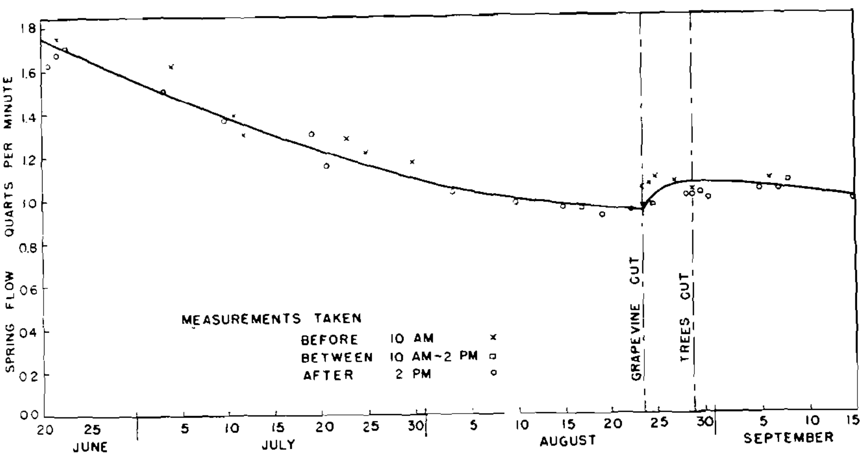


FIGURE 4. Flow of Grapevine Spring before and after removal of grapevine on August 24th, and trees on August 29, 1950.

plants near the spring were cut. This did not give any increase in spring flow.

In the early summer of 1951 the seep above the spring was developed for livestock water, which prevented further measurements.

### Tank Spring

The watershed above this spring was long and narrow and covered about 25 acres. It was control-burned on August 9, 1950. The kill of brush and trees was excellent. The crown cover of shrubs and trees was estimated to be 90 percent. The species composition and top kill were as follows: buckbrush 15 percent, kill 95 percent; whitethorn chaparral 10 percent, kill 95 percent; interior live oak 55 percent, kill 99 percent; California laurel 5 percent, kill 99 percent; buckeye 8 percent, kill 80 percent; foothill ash 5 percent, kill 99 percent; chamise (*Adenostoma fasciculatum*) 2 percent, kill 75 percent. The kill was nearly 100 percent for a considerable distance around the spring.

Tank Spring was shallow and seepage water came from the walls of the drainage above the spring or pipe outlet for a distance of 35 feet. Seepage increased after the fire. Spring flow following burning was more than double that before burning, increasing from about 198 gallons per day to 486 gallons (Figure 5).

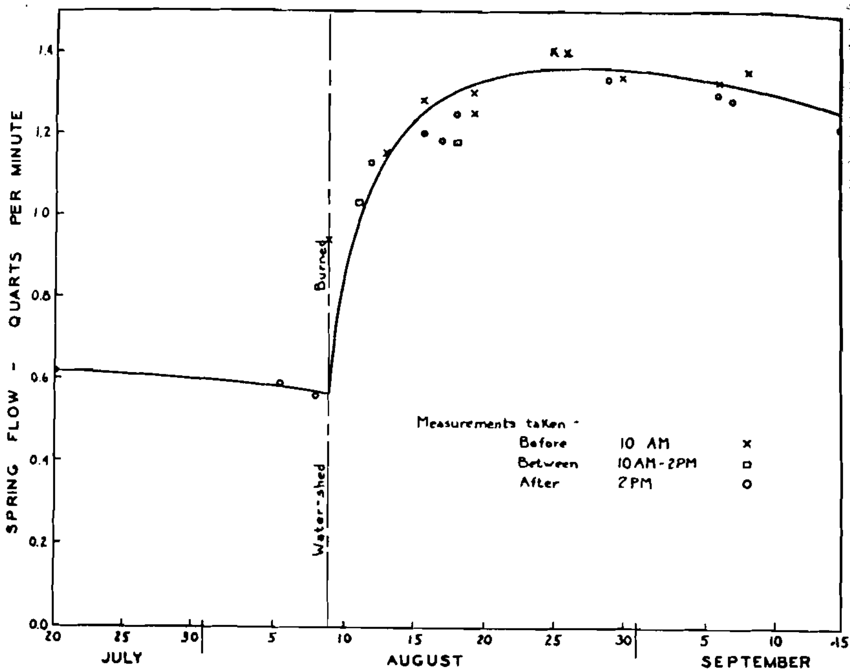


FIGURE 5. Flow of Tank Spring before and after control-burn on August 9, 1950.

### Pipe Spring

The watershed above Pipe Spring was 10 acres in size. The area was control-burned on August 5, 1950. Crown cover of shrubs and trees was 10 percent. The species and percentage top-kill were as follows: blue oak 25 percent, kill 60 percent; interior live oak 15 percent, kill 75 percent; poison oak (dry) 50 percent, kill 90 percent; buckbrush 5 percent, kill 50 percent; digger pine 5 percent, kill 50 percent. In addition, two small grapevines, two small interior live oaks, and two buckbrush plants all near the spring were cut by hand.

Flow of the spring increased after burning and cutting for three or four days but then the trend continued downward at a rate equal to that before treatment (Figure 6). The net result was that the flow was set ahead about 15 days.

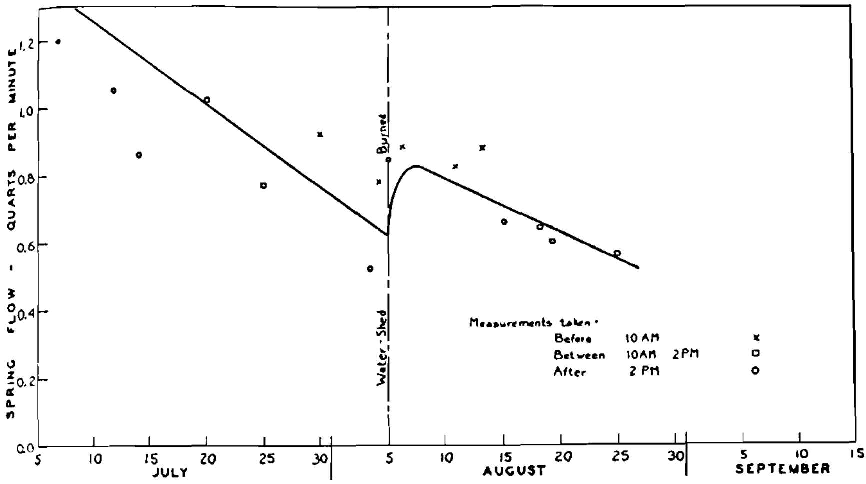


FIGURE 6. Flow of Pipe Spring before and after control-burn on August 5, 1950.

## Rock Spring

This watershed was one of five acres. It was control-burned on July 22, 1950. The crown cover of shrubs and trees was estimated to be 65 percent. The species composition and degree of top-kill were as follows: whitethorn chaparral 50 percent, kill 85 percent; buckbrush 15 percent, kill 85 percent; digger pine 10 percent, kill 85 percent; interior live oak 15 percent, kill 90 percent; manzanita 3 percent, kill 95 percent; blue oak 2 percent, kill 75 percent; buckeye 3 percent, kill 90 percent; redberry 2 percent, kill 90 percent.

The spring water comes from a crack down about 10 feet in solid rock. Several years ago the spring furnished water year-long for a homesteader. However, the ranch owner reported that in recent years it had gone dry each summer.

Before the control burn the spring decreased rapidly in flow and, although the control burn produced an excellent top-kill, no change in trend of flow was found. Apparently the deep-rooted trees and shrubs had already depleted the water at this time (Figure 7).

This spring was measured several times in 1951 between September 12 and October 24, at the time of the first fall rain; also on August 8, 1952, August 30, 1955, and August 13, 1957. The flow data per day are shown in Table 1.

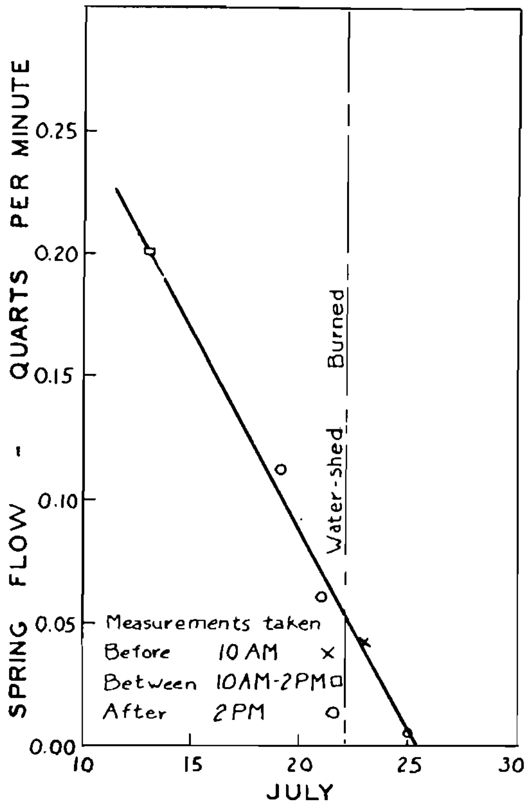


FIGURE 7. Flow of Rock Spring before and after control-burn, July 22, 1950.

TABLE 1
Flow Data for Rock Spring

| *Date* | *Gallons* |
|---|---|
| September 12, 1951 | 474 |
| September 28, 1951 | 511 |
| October 8, 1951 | 406 |
| October 24, 1951 | 408 |
| August 8, 1952 | 840 |
| August 30, 1955 | 628 |
| August 13, 1957 | 732 |

If all measurements had been made on the same date each year the variation, no doubt, would have been smaller. Precipitation for the years of study was recorded as follows for the San Joaquin Experimental Range, about one mile away: 1949-50, 16 inches; 1950-51, 21.4 inches; 1951-52, 24.7 inches; 1952-53, 15.7 inches; 1953-54, 15.6 inches; 1954-55, 16.7 inches; 1955-56, 26.5 inches; 1956-57, 14.5 inches.

The watershed was reburned on July 26, 1952. Its appearance on June 21, 1950, before burning and in August, 1957, is shown in Figure 8.

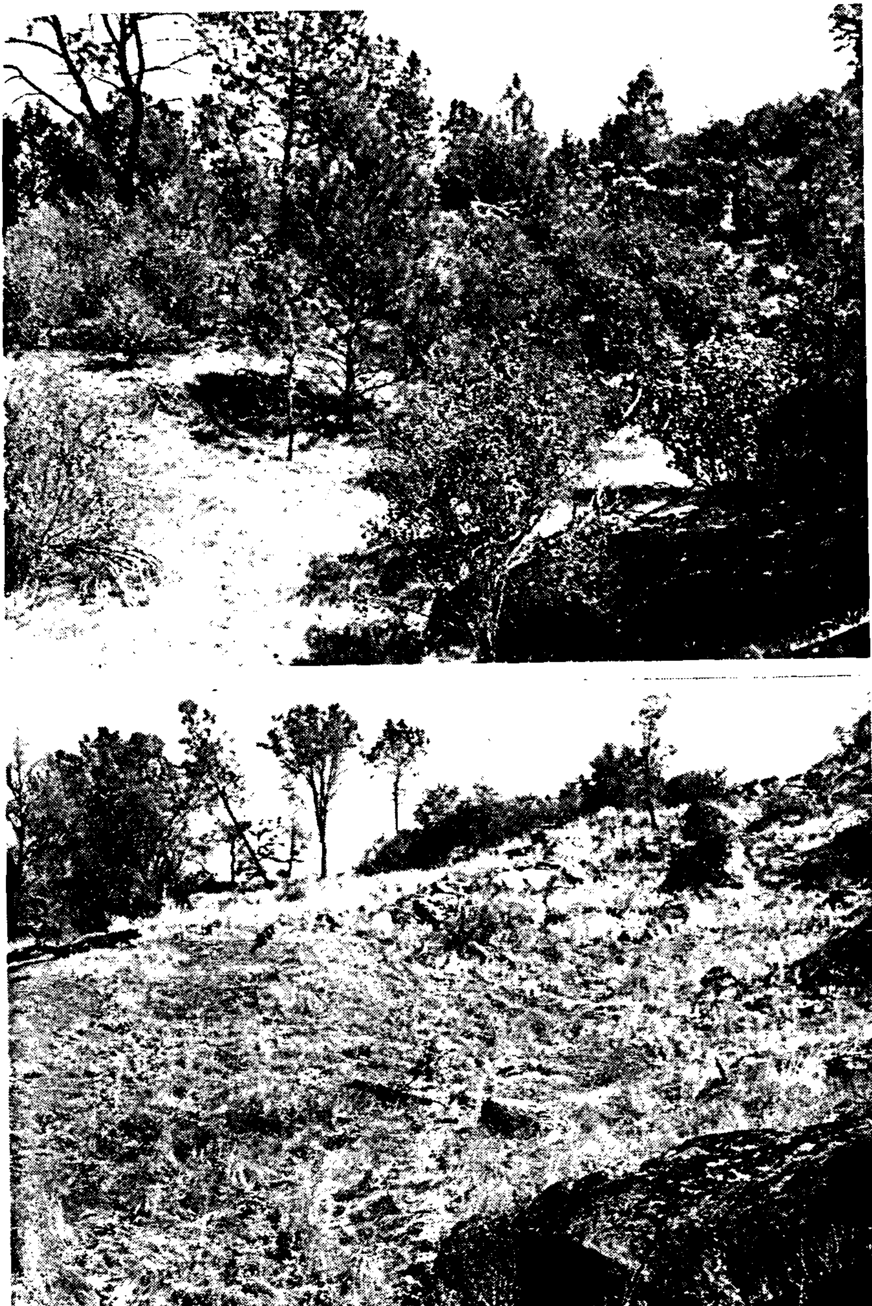

FIGURE 8. A portion of Rock Spring watershed on June 21, 1950, before burning, and (lower) in August, 1957, after two re-burns.

## Mine Spring

Within 30 feet of this spring were eight button willows, three interior live oak clumps, three coffeeberry bushes, three medium-sized digger pines, and one blue oak. All of these were cut by hand on July 11, 1950. The watershed above was not burned.

Before the cutting was done the spring had been decreasing in flow rapidly as shown in Figure 9. Thereafter, the spring increased in flow for about 15 days and then decreased and stopped flowing again about six weeks after it went dry the first time.

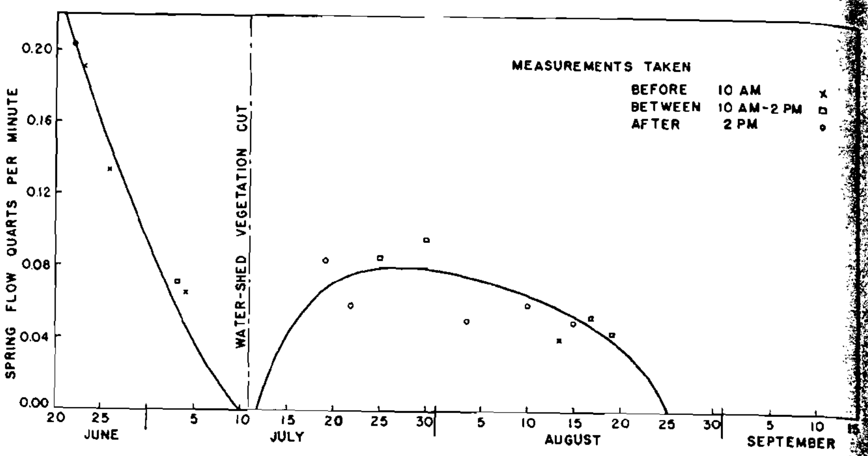


FIGURE 9. Flow of Mine Spring before and after cutting shrubs and trees within a radius of 30 feet, 1950.

## Spring House Spring

This served as a check spring with no manipulation of cover. It was located about one-quarter mile from Mine Spring. It was deep-seated, the flow coming from beneath a large rock. Measurements were taken

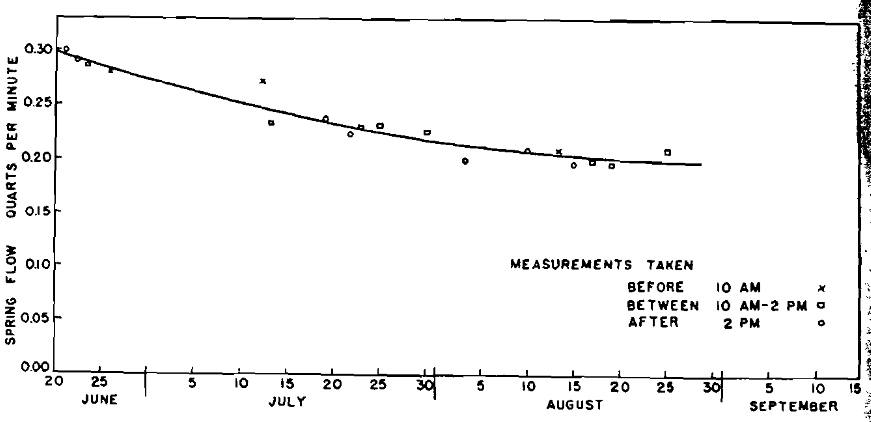


FIGURE 10. Flow of Spring House Spring where there was no manipulation of cover. This served as a check, 1950.

beginning June 20th and ending September 1st (Figure 10). There was a gradual decrease in rate of flow throughout this period. However, it was a little more rapid early in the season than later. This may have been due to drying of poison oak and buckeye on the slope above and less use of water by these plants after about mid-July.

## Cap Hill Spring

This was also a check spring. Its watershed had few shrubs and trees. The rate of flow was gradually downward from July 15th to September 5th (Figure 11). The rancher reported that the spring flowed better than it did the summer before when he had to remove the cattle from the range pasture because of a lack of stock water. Rainfall in the winter and spring season of the year before was about four inches less than the year of measurements. This probably accounts for the difference in flow.

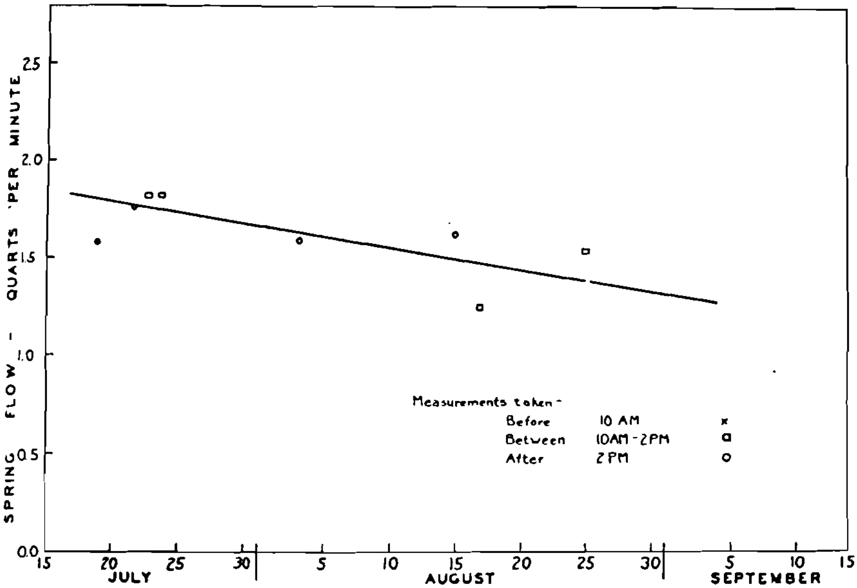


FIGURE 11. Flow of Cap Hill Spring. This served as a check, 1950.

## Willow Spring

This spring was found within a few miles of Clear Lake in Lake County. It was surrounded by a clump of willows as shown in Figure 12. The willows formed a closed canopy about 35 feet in diameter and were 12 feet tall in the center. The spring was boxed, with sidings 38 by 51 inches. No other woody vegetation was near the spring, but up the hill about 150 yards were a few blue oaks and 50 yards higher were blue oaks, manzanita bushes, interior live oaks, and poison oak. The watershed was estimated at 7 to 10 acres.

FIGURE 12. Clump of willows at Willow Spring as it appeared before cutting August 9, 1950. Thirty minutes before cutting the rate of flow was sharply downward; 30 minutes after cutting began the rate of flow was sharply upward.

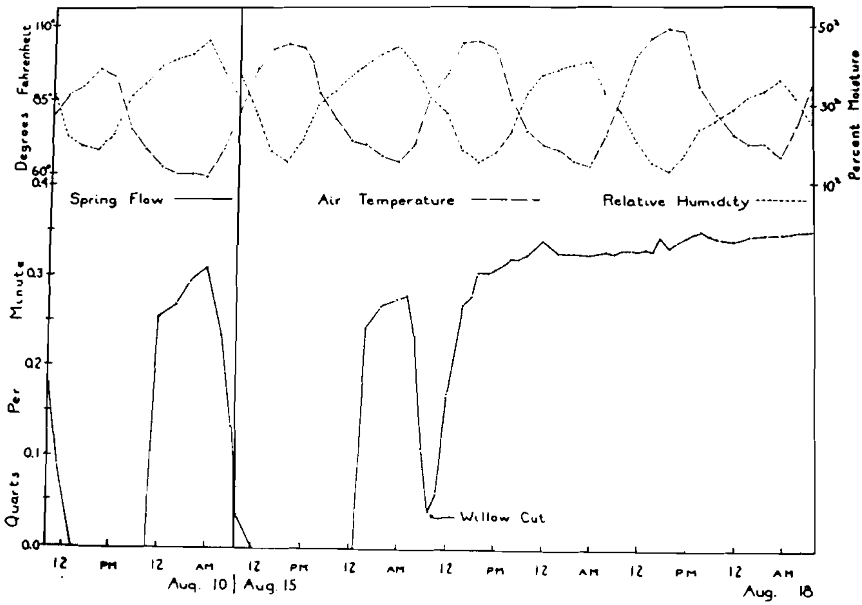


FIGURE 13. Measurements of spring flow, air temperature, and relative humidity at Willow Spring before and after cutting willows in 1950.

Beginning at 10 a.m. on August 9, 1950, records of spring flow were obtained every two hours until 10 a.m. the next day. Temperature and humidity records were obtained also. The spring flow and weather records are shown in Figure 13. Spring flow for the 24 hours amounted to 44.9 gallons. At 1 p.m. water in the spring box fell below the outlet and was down one and one-eighth inch at 6 p.m. It then rose to three-quarters of an inch by 8 p.m. and water came from the outlet at 10.30 p.m.

Spring flow records were again obtained every two hours on August 15th. For this day the flow amounted to 31½ gallons. The day was hotter and drier than August 9th. Flow from the spring stopped at 12 noon and began again 30 minutes past midnight. At 6 p.m. water in the spring box had been one and three-quarters inch below the pipe outlet.

After the flow was measured for 24 hours, cutting of the willows began at 10 a.m. on August 16th. One person removed the willows in two hours. Cutting the willows had about the same effect on the spring flow as opening the faucet on a garden hose. The flow began to increase almost immediately and continued to increase rapidly until the cutting was finished. Thereafter the spring flow continued rather uniformly day and night. The flow was measured every hour during daylight and every two hours during night for 48 hours after cutting. On the second day the spring produced 122.0 gallons of water, in comparison with 31.5 gallons before the willows were removed. Therefore, the clump of willows had been using at least 90.5 gallons of water per day. Other measurements taken on September 5th, 11th, and 12th, showed the spring to increase by about another 20 percent as the area around the spring became recharged. When this increase is figured against the decrease that would normally occur with downward trend in flow, the water use would amount to about 124 gallons per day.

The willows sprouted shortly after cutting and further measurements were made periodically in 1951, 1952, and 1953, as indicated in Figure 14. Generally the trend in spring flow was downward except for fluctuations which corresponded with temperatures and water use by the willows. Sprout growth in 1951, 1952, and 1953 is shown in Figure 15.

Each year, measurements of spring flow were made hourly for two 24-hour periods: August 8-9 and 15-16, 1951; August 11-12 and 18-19, 1952; and August 12-13 and 19-20, 1953. The results for one of the

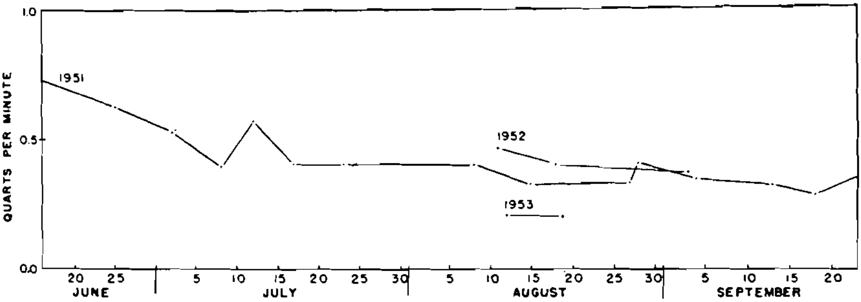


FIGURE 14. Trend in flow of Willow Spring in 1951, 1952, and 1953.

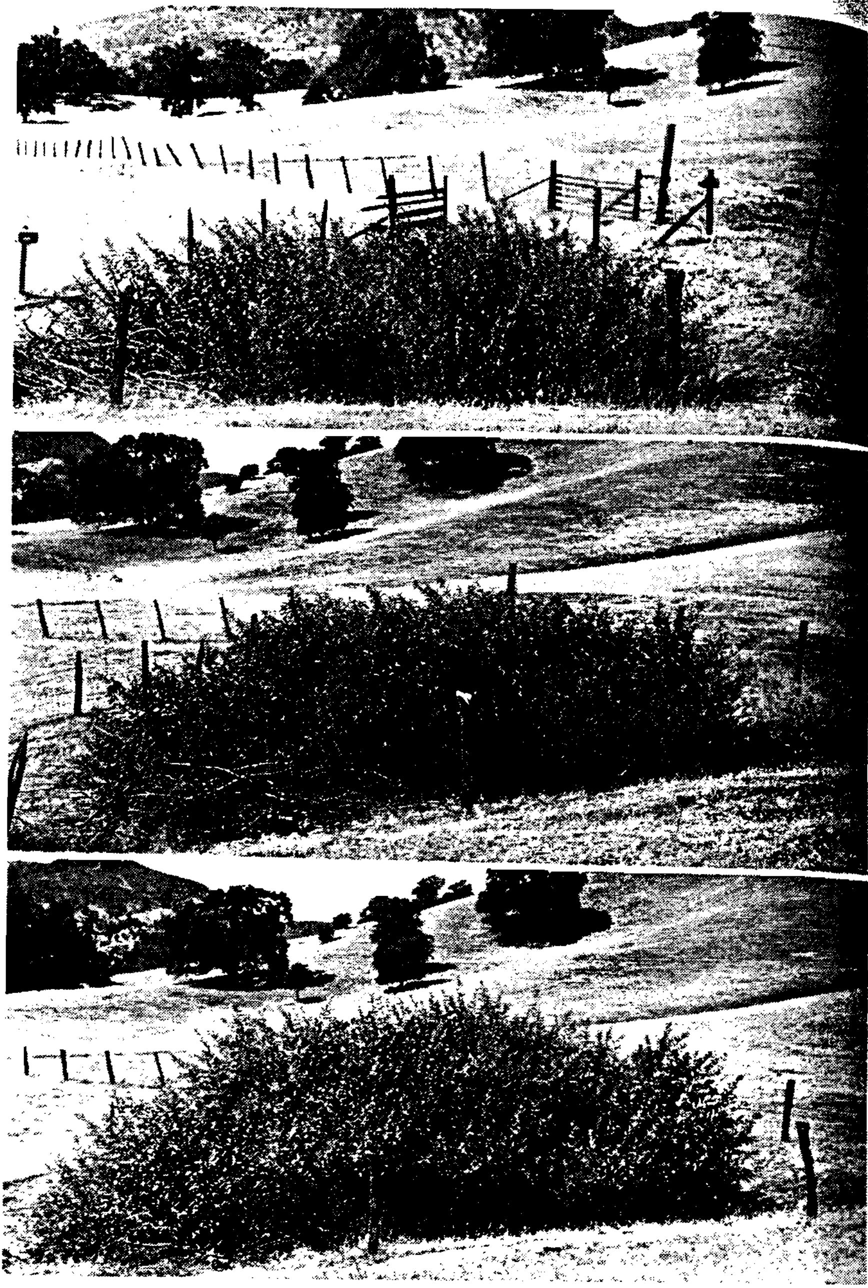

FIGURE 15. Re-growth of willow sprouts after cutting in 1950: in 1951 (upper), 1952 (middle), and 1953 (lower). Sprouts were re-cut in 1953 after lower photograph was taken.

periods in each year are shown in Figure 16. These were within three days of the same date, but the temperatures and humidity varied considerably, the temperature being lowest in 1952. If we use the maximum rate of flow which occurred at approximately 6 a.m. as the potential and then subtract the actual amount of water produced we obtain a partial answer to the amount of water used by the willows. The data for the three years are shown in Table 2.

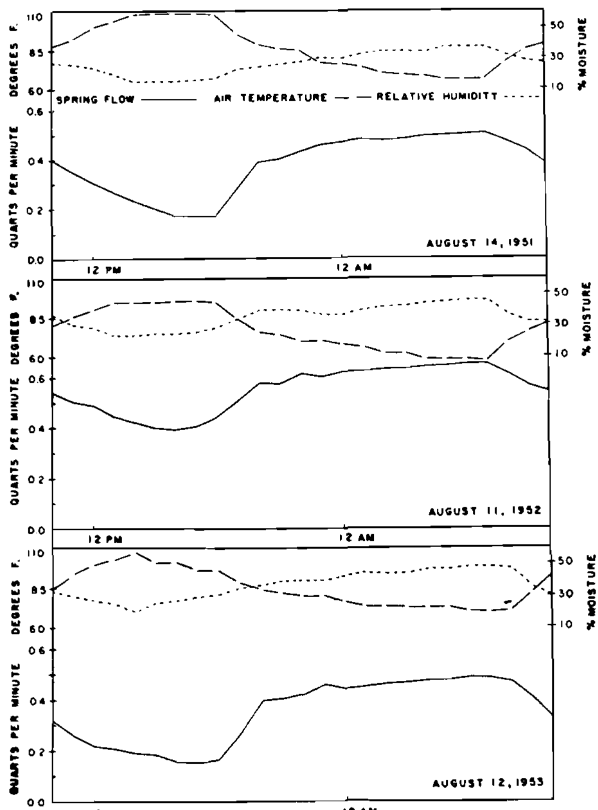


FIGURE 16. Measurements of spring flow, air temperature, and relative humidity at Willow Spring for a 24-hour period for each of three years as the sprouts recovered in growth.

## TABLE 2

### Flow Data for Willow Spring Showing Use of Water by Willows

| Year | Gallons per day | | | Average temperature | Average relative humidity |
|---|---|---|---|---|---|
| | Potential flow | Actual flow | Water used | | |
| 1951 | 188 | 144 | 44 | 84 | 29 |
| 1952 | 232 | 191 | 41 | 77 | 34 |
| 1953 | 176 | 124 | 52 | 80 | 38 |

The willows were cut a second time on August 20, 1953. The trend in flow before and after cutting is shown in Figure 17. The difference in flow for 24 hours before cutting and for 24 hours after cutting amounted to 63 gallons. This is 21 percent greater than the amount shown in Table 2. The flow continued to increase for the remainder of the season as it did in 1950, indicating again that the willows were using considerably more water than the amount calculated by subtracting the flow the day after from the day before cutting.

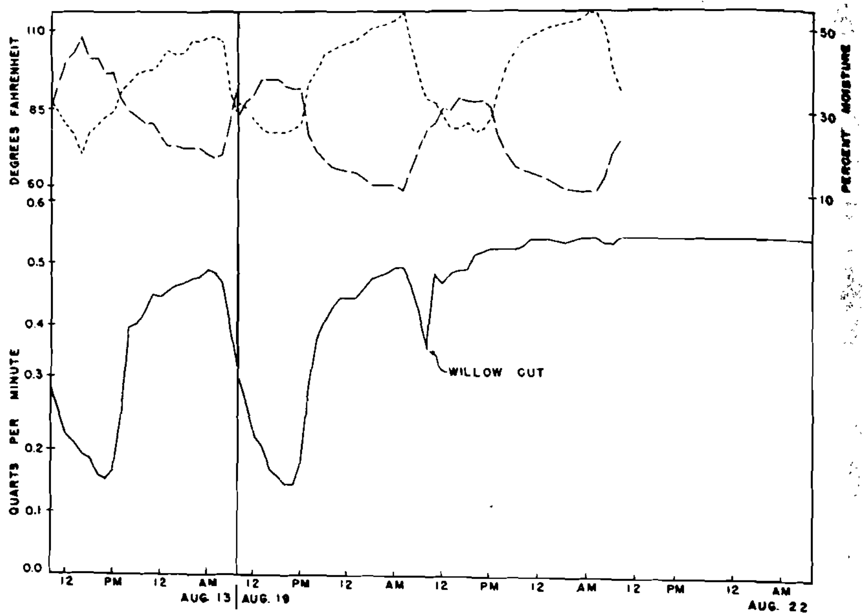


FIGURE 17. Measurements of spring flow, air temperature, and relative humidity at Willow Spring before and after recutting willows in 1953

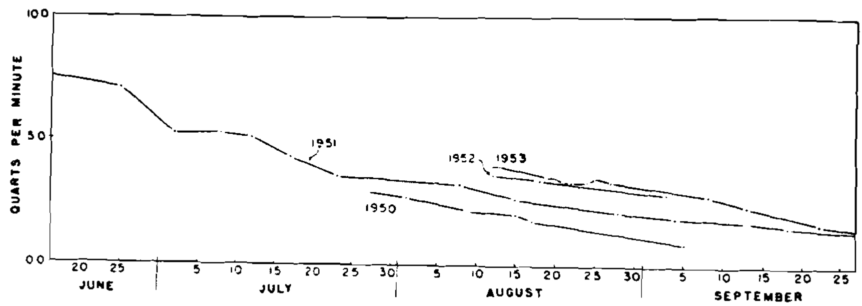


FIGURE 18. Trend in flow of Buckeye Spring for each year of study. This served as a check to Willow Spring. Rainfall at the nearest station (Lakeport) was as follows: Season 1949-50, 21.9 inches; 1950-51, 34.3 inches; 1951-52, 36.7 inches; 1952-53, 31.1 inches.

### Buckeye Spring

This spring was located about one-half mile from Willow Spring and served as a check. The surrounding area was open except for one manzanita bush and a buckeye tree nearby. Leaves of the buckeye began to dry about mid-July.

The trend in flow for this spring was downward for each of the four summer seasons, as indicated in Figure 18.

## DISCUSSION

Springs are an important source of water in California for game and livestock and for domestic use. Just how plant-cover manipulation effects them has been studied but little. The results here indicate that in some cases the flow might be increased markedly by removing or changing plant cover. California is a good place for studies of this sort because of the long summer period when there is no precipitation to complicate matters.

Every spring is different. There are differences in size of watershed, plant species and density of cover on the watershed, type of soil, geological formation, whether or not the spring is shallow or deep seated, and source of water. For some springs the water supply may come from outside of the local watershed.

Where the spring water is dependent on the local watershed, it is not unreasonable to expect some increase in flow as a result of manipulation of the plant cover. Several principles are involved (8, 9, 16). One of these is changing from deep-rooted species, such as shrubs and trees to more shallow-rooted species, such as grasses and shallow-rooted forbs. In this case the moisture left in the soil below the depth of the shallow-rooted species is then available for spring flow. This change in plant cover becomes more significant where the grasses and forbs are annuals and are not using water during the summer. This was probably the case with Rock Spring which flowed water all summer long after the conversion from brush and trees to more shallow-rooted annual grasses and forbs.

Studies by the California Forest and Range Experiment Station showed that the soils under shrubs and pines, lost all the available moisture to evapo-transpiration during each summer dry season, whereas, under grass 10 inches of water remained in the soil (3). This was determined by the use of lysimeters extending down six feet. Field studies also showed important differences in evapo-transpiration loss from deep soils covered with oakbrush and annual grass (4). The field plots were originally covered with dense scrub oak and other native brush, and in the winter of 1951-52 two sets of plots were converted to annual ryegrass. The soil of the undisturbed brush plots was wet to field capacity throughout the 12-foot depth during the first winter, when rain totaled 41 inches. But during the next three winters rainfall was only 12, 25, and 20 inches, and the soil was wet to field capacity to depths of only 4, 10, and 4.5 feet. Each summer evapo-transpiration dried the entire soil of these plots to near or below wilting point, and rain was insufficient after the first year to rewet it fully.

In the plots converted from brush to grass the story was diff Here, the soil was wet to field capacity through its entire depth winter season. During summers the soil dried below field capaci an average depth of only 7 feet and below wilting point to an av depth of 3.2 feet. Consequently, below the 4 foot depth under the there was a greater carry-over of water at the end of each summer there was in the brush where there was none. Thus, it may be seen with low rainfall a grass-covered soil would be more likely to pro spring water than a brush-covered soil where other things are equa somewhat similar studies Veihmeyer and Johnston (14) showed ings in water of two inches after converting from brush to grass. Y and Blaney (18) also point out the differences in water use by brush and grasses in southern California studies.

In our studies roots of grasses, shrubs, and trees were excavat the field to determine rooting depth. Soft chess (*Bromus mollis*) found to penetrate the soil to a depth of 39 inches, and foxtail (*Festuca megalura*) to 23 inches. Both of these annual grasse important components of the resident vegetation. Ryegrass, an a commonly planted in this area on burned-over brushlands, extend roots to 42 inches. In other studies this species penetrated to 54 (12). Tarweed is deeper rooted than the grasses and during those when abundant it depletes the soil moisture to a greater depth tha grasses.

Roots of three five-year-old buckbrush plants were excavated a were found to extend to a depth greater than 10 feet. The roo 11-year-old ponderosa pine (*Pinus ponderosa*) were traced dow feet but they went much farther, as indicated by the size of the ro the 12-foot depth. Hellmers *et al.* (6) in Southern California California scrub oak to extend down 28 feet, canyon live oak 24 and chamise 25 feet. In Texas, mesquite roots were found belo feet (2), and in the Suez Canal area salt cedar was down 90 feet

A second principle concerned with plant-cover manipulation spring flow involves plants that have their roots in free water. W the tops of such plants are removed, more water may immedia become available for spring or creek flow. A common example is str bed vegetation. The roots of these plants may not necessarily be de but neither may the water table. Less well-known is how upland pla tap free water. The excavations of buckbrush give some indication of this. As mentioned above, the roots of three of these plants extended to 10 feet where they reached granite and were beginning to grow horizontally. At this level they were in water flowing over bed rock. This was on April 29, 1952. Thus, in addition to the water removed from the soil it seems that these deeply rooted plants can sometimes tap underground flows of water. This may be important as far as increase spring flow immediately after brush removal is concerned. When the tops—transpiration surface—are removed by burning or cutting th water is then permitted to enter spring flow. This principle, we thin accounts for the quick increase in flow in Finegold Creek, Will Spring, Grapevine Spring, and possibly in the others except Ro Spring. High rates of flow might be maintained permanently where vegetation is nonsprouting; on the other hand, regrowth of sprouts gradually decrease spring flow to its former status.

A third principle that might apply in plant-cover manipulation and spring flow concerns infiltration capacity. If the infiltration should be lowered to the point where most of the precipitation is dissipated through surface runoff and is not permitted to enter the soil, then spring spring flow might decrease or the springs might even go dry. This could result from creation of bare soil that becomes sealed. This situation was not encountered in these studies.

The objective in range and wildlife management should be to maintain high infiltration capacity so water will go into the soil. This will automatically increase forage and will give the greatest yield of water through spring and creek flow.

## SUMMARY

Quantitative measurements were made of the effects of brush removal and manipulation on spring and creek flow. In some cases the brush and trees were top-killed by control burning and the areas converted to grassland, in others the woody plants around springs were cut with an axe. Increases in flow resulted from these operations, in most cases almost immediately.

The amount of increase in spring flow that one could expect would vary considerably, depending on such factors as the size of the watershed, density and kind of plants on the watershed, type and depth of soil, geologic formation, amount of rainfall, and source of water.

Three principles govern spring and stream flow changes resulting from plant-cover manipulations: (1) conversion from deep-rooted species, trees and shrubs, to shallow-rooted species, grass, makes the water in the deeper zones—below the grass roots—available for spring flow. (In our studies the conversions were largely to annuals which are dry during the summer months); (2) removal of transpiring surface of plants whose roots are in free water results in immediate increases in spring and stream flow; (3) practices which decrease the infiltration capacity of the soil resulting in high surface runoff may retard spring flow or stop it altogether.

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