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# Rainfall Interception by Chaparral in California

*by*

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# RAINFALL INTERCEPTION BY CHAPARRAL IN CALIFORNIA

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## INTRODUCTION

Not all rain drops reach the ground in a free fall from their parent cloud mass. Many are diverted from their course by trees, shrubs, buildings, and other obstructions. This interruption of the free fall of rain is generally termed rainfall interception. It has long intrigued farmers, foresters, engineers, and others who are concerned with the use or control of water because it represents a loss of rainfall to the soil. In any project of water supply, power development, agriculture, or flood control, the measurement of rainfall is a primary consideration. Rainfall is commonly measured by gages placed in the open, with generally accepted standards defining the allowable proximity of vegetation and other obstructions. Such gages, however, do not provide a measure of intercepted rain that may return to the air by evaporation from wetted obstructions. Because the land surface nearly everywhere is covered with some form of vegetation, precision in applying rainfall measurements to land-use problems requires information concerning the amount of water caught by the vegetation. This information should answer such questions as: How much rain actually reaches the ground? How much is lost by evaporation from the vegetation? Is the rain that runs down the stems an important quantity? If the rainfall lost through interception appears considerable in amount, how can it be measured?

Widespread interest in such questions is indicated by numerous articles dealing with interception. Studies seeking definite answers to these questions date back to the late Nineteenth Century and have been conducted in many countries (see bibliography, pages 32 to 35). Most of this work has been summarized in three publications. In 1919 Horton *(30)*[2] summarized much of the existing data on interception while presenting the results of his own research. In 1941 Wicht *(67)* brought the subject further up-to-date with his historical review of the work of many investigators. In 1948 Kittredge *(35)* gave an excellent resume of interception research in his book "Forest Influences" and summarized a number of the latest studies.

Relatively little has been published on research dealing with interception by shrub types of vegetation. Horton *(30)*, using sketchy observations and much extrapolation, reported on rainfall interception by willow shrubs and hedges. Grah and Wilson *(21)* gave the results of controlled laboratory experiments with Baccharis *(Baccharis pilularis)*. Rowe *(57)* has reported some results of plot studies with shrub species.

It is our purpose to present the results of three rainfall [3] interception studies conducted in shrubby vegetation native to California. These

[1] Maintained by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of California, Berkeley, California.
[2] Italicized numbers in parentheses refer to literature cited from the Bibliography.
[3] "Rainfall" is used hereafter to include all forms of precipitation; thus, rainfall and precipitation are used synonomously in this discussion of experimental results.

studies have shown that much of the rainfall caught by this vegetation, and generally assumed to be lost by evaporation, actually reaches the ground by flowing down the stems. Equally important for practical application of the results, the studies have demonstrated that the amount of interception loss in this vegetation bears a definite relation to the amount of storm rainfall. Once this relation has been established for a given type of vegetation, the interception loss can be readily determined from rainfall measurements alone. Finally, the studies have provided a picture of the interception process by showing how interception loss develops during typical storms and how the storm rainfall is redistributed by vegetation.

Results of these studies have direct application in the solution of California's watershed problems. Brush-covered or chaparral lands comprise about 10 percent of the State's total area [4]—in Southern California alone, about 56 percent of the area.[5] These lands are important local sources of the water essential for agricultural, industrial, and urban development. The studies show the magnitude of interception loss in the chaparral—the first of a series of losses that must be determined for the solution of water-supply and flood-control problems.

The results should also be of interest in other areas, for the California chaparral formation is one of a group of shrub formations occurring in many parts of the world. It is known as the temperate brush or sclerophyll brushland. In the Mediterranean region this type is called "maquis," "macchia," or "garigue"; in South Africa, "Fijnbos" or sometimes "heath"; in south Australia, "malle-scrub," "mulga-scrub," or "Brigalow scrub." In Spain it is called "Tomillares" and in the Balkans "Phyrgana." Brushland somewhat similar to the chaparral is also found extensively in Arizona, New Mexico, Texas, and in Mexico, Chile, and other South American Countries. The scrub oak areas of Pennsylvania, New York, New Jersey, and elsewhere in the United States are also roughly comparable to chaparral.

## DEFINITION OF TERMS

In the literature on interception, the terminology of the subject has not yet become standardized or consistent. Many investigators have sampled the rainfall in the open and under a vegetative canopy and termed the difference "interception." Others stated that the amount of interception reported was "corrected for water running down the stems." Very often it has been difficult to make comparisons between different studies because of this uncertainty of terminology. In order to clarify this discussion the following definitions are used:

*Interception* is the process in which rainfall is caught by the vegetative canopy and redistributed as throughfall, stemflow, and evaporation from the vegetation.

*Throughfall* is that portion of the rainfall which reaches the ground directly through the vegetative canopy, through intershrub spaces in the canopy, and as drip from the leaves, twigs, and stems.

*Stemflow* is that portion of the rainfall which, having been intercepted by the canopy, reaches the ground by running down the stems.

[4] Wieslander, A. E. and Herbert A. Jensen. Forest areas, timber volumes, and vegetation types in California. Calif. Forest and Range Expt. Sta. Forest Survey Release No. 4, 66 pp. 1946. Berkeley.

[5] Wyckoff, Stephen N. California's watersheds. Jour. Forestry 46(2): 99-103, 1948.

*Interception loss* is that portion of the rainfall which is retained by the aerial portion of the vegetation and is either absorbed by it or is returned to the atmosphere through evaporation.

*Gross rainfall* is the total amount of rainfall as measured in the open or above the vegetative canopy and directly applicable to a particular unit area.

*Net rainfall* is the quantity which actually reaches the ground. It is the sum of throughfall and stemflow.

*Storage area* is the surface area of leaves, twigs, branches, and stems that can retain water against gravity either as a film or in the form of drops.

## THE STUDY AREAS

Rainfall interception by chaparral was studied at two research centers: The North Fork Experimental Area and the San Dimas Experimental Forest, which are some 200 miles apart in the south half of California (Fig. 1). The two centers have similar seasonal distribution of rainfall and storm characteristics. The annual rainfall at North Fork averages about 33 inches and occurs in about 24 storms; at San Dimas an average of about 30 inches occurs in about 20 storms. The greater part of the rainfall comes during the fall, winter, and early spring months, mostly in a few heavy storms each year. For example, on the San Dimas Experimental Forest 41 percent of the annual rainfall is yielded by only 5 percent of the storms;[6] this ratio applies at North Fork, too. Maximum hourly rates of 1.56 inches and 1.29 inches have been recorded at North Fork and San Dimas respectively. Some mid-winter storms in the study areas include periods with snow, but this snow usually melts very soon after it falls.

The North Fork Experimental Area is in the upper portion of the woodland-grass type where the vegetation varies with exposure from open woodland to dense chaparral; two studies were conducted here: North Fork A in partially deciduous ceanothus-buckeye-oak vegetation, and North Fork B in evergreen ceanothus-manzanita vegetation. The San Dimas Experimental Forest is in the chaparral formation typical of southern California mountains; a third study was conducted here, in evergreen scrub oak-ceanothus vegetation.

The North Fork A study area was a 1/20-acre plot in vegetation which had been previously burned and was 19 years old when the study was started in 1937. The vegetation was mostly brush and small trees (Fig. 2) and included five deciduous species and four evergreen species:

Deciduous species:
- California buckeye *(Aesculus californica)*
- Deerbrush ceanothus *(Ceanothus integerrimus)*
- Pacific poison oak *(Rhus diversiloba)*
- California black oak *(Quercus kelloggii)*
- California fremontia *(Fremontia californica)*

Evergreen species:
- Interior live oak *(Quercus wislizenii)*
- Buckbrush ceanothus *(Ceanothus cuneatus)*
- Mountain mahogany *(Cercocarpus betuloides)*
- Mariposa manzanita *(Arctostaphylos mariposa)*

[6] Hamilton, E. L. Rainfall-measurement as influenced by storm-characteristics in southern California mountains. Amer. Geophys. Union Trans. Pt. III, pp. 502-518. 1944.

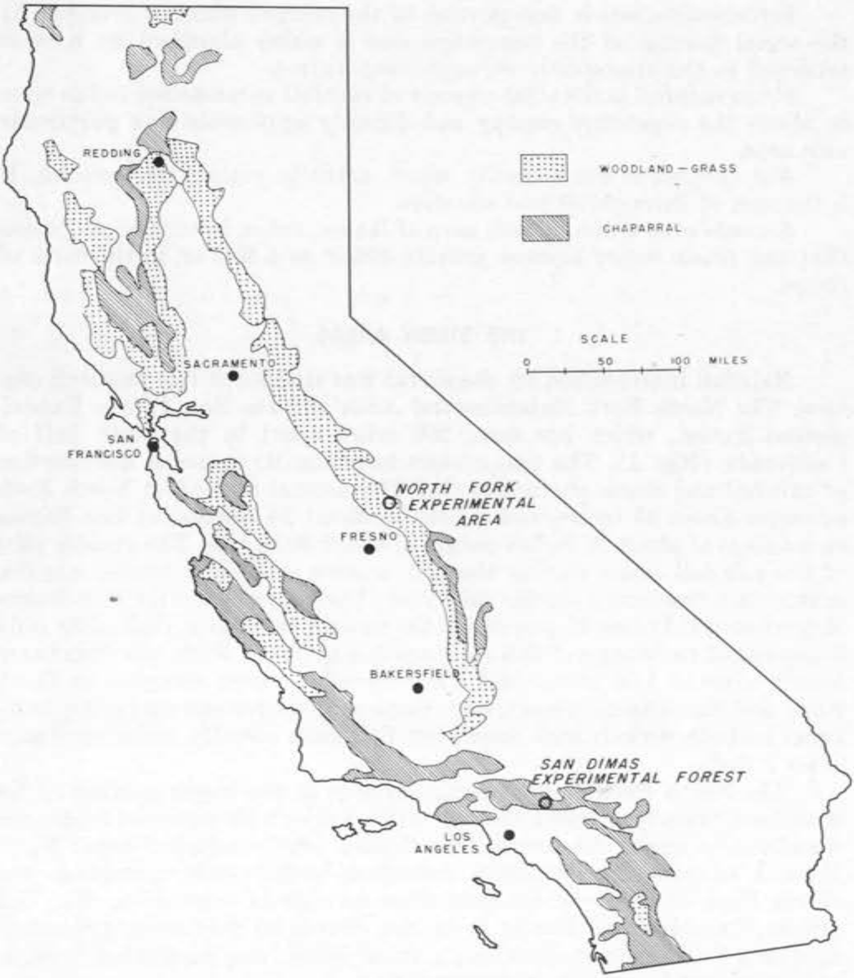


FIGURE 1. Experimental areas and general extent of shrub vegetation types in California. (Vegetation types from: "Forest areas, timber volumes, and vegetation types in California," by A. E. Wieslander and Herbert A. Jensen. Forest Survey Release No. 4. Calif. Forest and Range Experiment Station. March 1, 1946. Berkeley, California.)

The crown density of the brush ranged from a minimum of about 20 percent in winter to about 50 percent in late spring and summer. There was a total of 731 stems on the plot, 409 of which were California buckeye. In general the stems were from one-quarter inch to 5 inches in diameter just above the root crown with 70 percent being one inch or less. The shrubs were from 4 to 20 feet high.

The North Fork B study area was a 1/200-acre plot in vegetation 22 years old when the study was started in 1940. The vegetation on the plot (Fig. 3), consisting of buckbrush ceanothus and mariposa manzanita, averaged about 10 feet in height, and had a crown density of about 50

FIGURE 2. Vegetative canopy of the North Fork A interception plot in late May, 1938

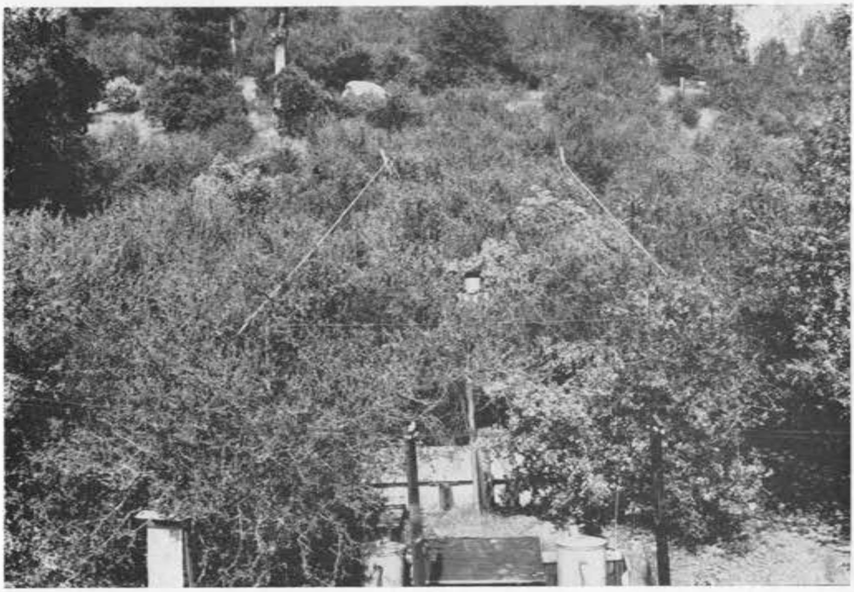

FIGURE 3. Vegetative canopy of the North Fork B interception experiment. Study plot is in lower right quarter of the area outlined by white cords. Vegetation is ceanothus and manzanita. Late May 1938

percent. The shrubs occurred as basally branching clumps of which 27 were ceanothus and 5 were manzanita. There were from 2 to 50 stems per clump.

The San Dimas study area was a 1/45-acre plot in vegetation 23 years old when the study was started in 1942. The vegetation (Fig. 4) consisted of California scrub oak *(Quercus dumosa)*, hairy ceanothus *(Ceanothus oliganthus)*, hoaryleaf ceanothus *(Ceanothus crassifolius)*, and mountain mahogany *(Cercocarpus betuloides)*. Crown density was estimated at about 75 percent. The shrubs were 10-12 feet high, and the plot contained 140 stems, more than two-thirds of which were scrub oak. The oak, mountain mahogany, and hoaryleaf ceanothus occurred mainly as clumps with stems ranging from ½ to 3½ inches in diameter just above the root crown. Hairy ceanothus shrubs were individuals with stems 4-6 inches in diameter.

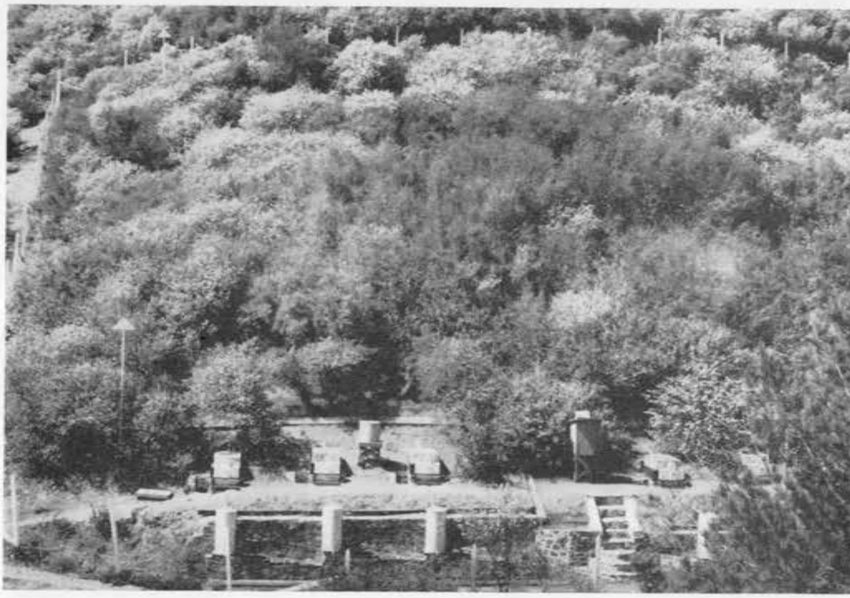

FIGURE 4. San Dimas interception study plot was a strip 12 feet wide and 76 feet long extending uphill from a point a few feet above the stone steps at lower right. Vegetation is chiefly scrub oak and ceanothus. March, 1939

## METHOD OF STUDY

In all three studies the general procedure was to measure directly gross rainfall, throughfall, and stemflow. Interception loss was computed by subtracting the sum of throughfall and stemflow from gross rainfall. The experimental installation differed in some details for each study.

### North Fork A Experimental Installation

In the North Fork A study gross rainfall was measured by two trough-type rain gages placed in the open, one on each side of the plot. Rate records of gross rainfall were obtained from a standard tipping-bucket rain gage with a 12-inch funnel. Throughfall was measured by 14 trough-type gages (Fig. 5) placed in a regular grid pattern under the canopy to sample fairly the rain falling through the vegetation. All of the trough gages were 5 feet long and were set parallel with the ground surface (32 percent slope) and 12 to 6 inches above ground to clear surface obstructions. Stemflow was caught by metal collars applied over a modeling clay filler fitted around the stems near the bases of the shrubs, and was piped to tanks in which volume was measured in cubic inches. The stemflow units were placed on 29 stems or stem-clumps representing the range of species and diameter classes found on the plot, and stemflow for the entire plot was calculated from this sample (*57*, pp. 67, 68).

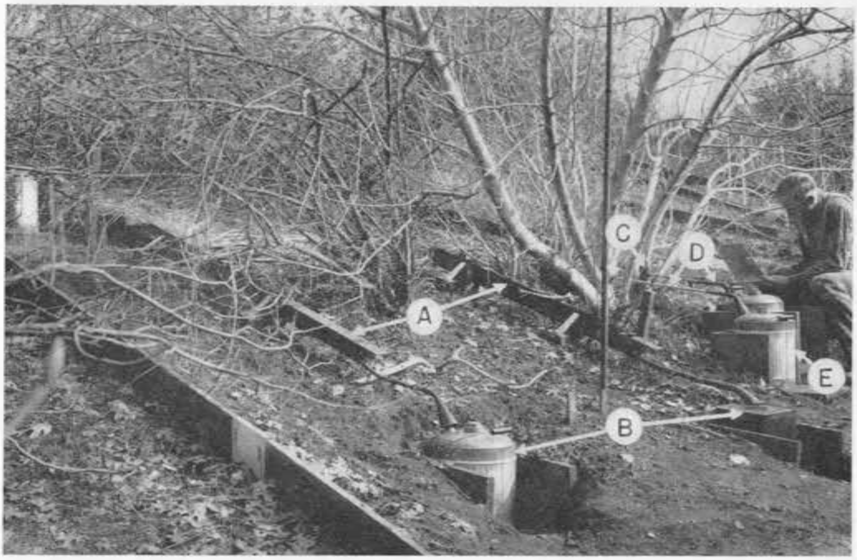


FIGURE 5. Installations in North Fork A interception study plot: (A) trough gages and (B) tanks for measuring throughfall; (C) stemcollars (D) tubes, and (E) tanks for measuring stemflow. March, 1938

## North Fork B Experimental Installation

For North Fork B, gross rainfall was measured in trough gages, each 4 x 60 inches in horizontal area, placed along the sides of the plot level with the top of the vegetative canopy. Check measurements of precipitation were obtained from two standard 8-inch gages placed in openings near the plots. One gage of each type was equipped with a tipping bucket for recording rainfall rates.

Throughfall was measured by flooring the ground surface of the entire plot with galvanized iron sheets (Fig. 6). The sheets were applied closely about the shrub stems and were turned up around the stems and at the outside edges of the plot to prevent any leakage. Thus the whole plot was converted into a kind of pan which collected all the rainfall passing through or dripping from the canopy of the vegetation on the plot. The water so collected was conducted by a drain at the lower end of the plot through a tipping bucket of 0.5 cubic foot capacity, for measurement of flow rate, and thence to a series of tanks for measurement of total throughfall.

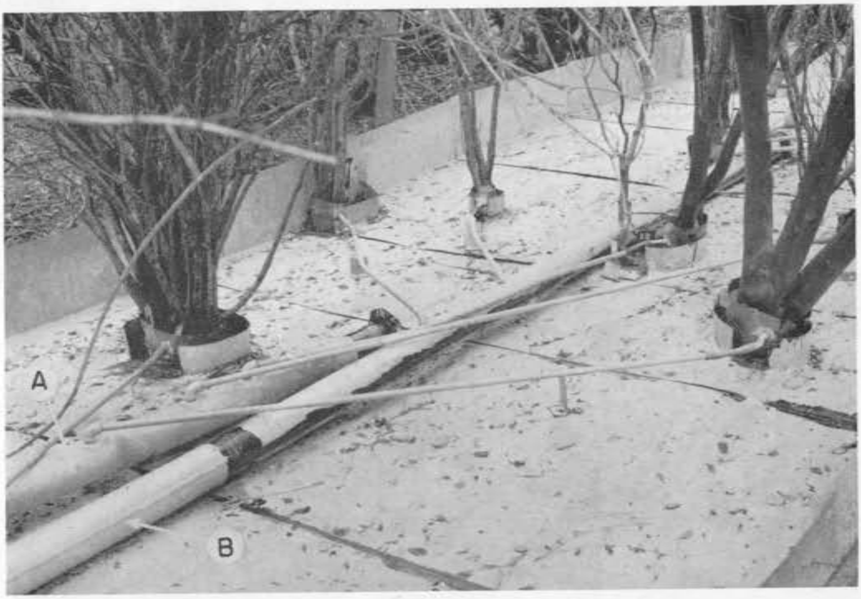


FIGURE 6. North Fork B interception study showing ground surface covered with sheet iron for total collection of throughfall; stemflow from collar at base of manzanita clumps conducted to pipe *A*, from ceanothus clumps to pipe *B* (see text)

Total stemflow from all the shrub clumps (32 in number) on the plot was also measured. Each stem clump on the plot was fitted with a collar of the type developed for the North Fork A experiment. The flow from all the ceanothus stems was piped to a single large conduit, and the flow from all the manzanita stems to another similar conduit (Fig. 6). This was done to make possible an analysis of stemflow by species, but for this discussion only combined stemflow from both species was used.

At the lower end of the plot each conduit discharged into a tipping-bucket unit of 0.1 cubic foot capacity (Fig. 7). Final measurement of total stemflow was made in large tanks below the tipping buckets. A synchronous record of rainfall, throughfall, and stemflow was obtained by electrically connecting each tipping bucket to a multiple-pen strip-chart recorder.


FIGURE 7. Measuring devices and collection tanks at North Fork B; one-half cubic foot tipping bucket *(A)* for throughfall measurement; one-tenth cubic foot tipping buckets for measurement of stemflow from manzanita *(B)* and ceanothus *(C)*. Collection tanks in foreground

In computing interception loss the values of throughfall for each storm were corrected by the addition of a "wetting constant," representing the water film which clings to the iron pan and is evaporated at the storm's end. This wetting constant was determined by thoroughly wetting the pan with a measured amount of water and computing the amount retained after drainage.

## San Dimas Experimental Installation

At San Dimas gross rainfall was measured by a standard 8-inch rain gage installed in an opening in the brush at the upper end of the plot. This gage was equipped with a tipping-bucket mechanism for measurement of rainfall rates. Two other standard 8-inch rain gages located above and below the adjacent runoff and erosion plots, and a 12-inch Weather Bureau type tipping-bucket gage, served to check the gross rain measurement.

Throughfall was sampled by a long trough (Fig. 8) made of commercial semicircular galvanized iron flume 9½ inches in diameter. It was installed on the ground surface so as to extend up the middle of the plot through its full length. Water collected in the trough passed through a trash collecting tank, which was kept filled with water, into a tipping-bucket unit and thence to a large collector tank for measurement of the total catch. The trough had a catchment area of 80 square feet, or about one-twelfth of the plot area. The tipping bucket was calibrated to measure one-tenth cubic foot per tip, or 0.015 surface inches of rainfall.

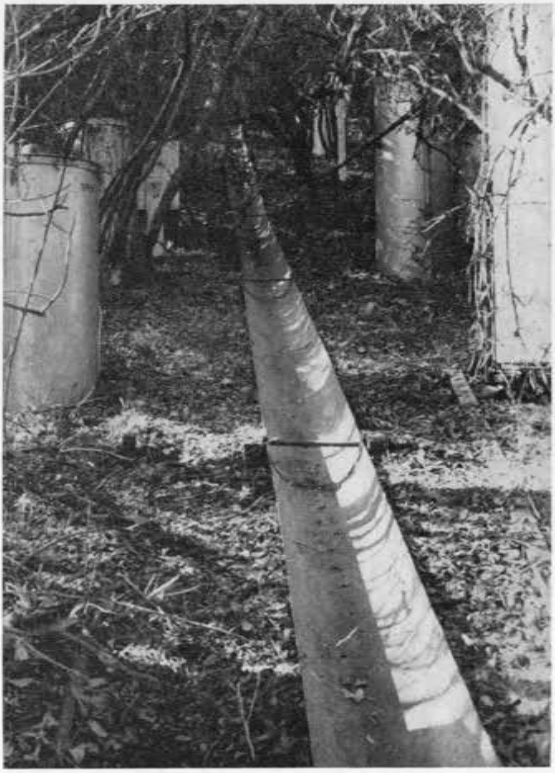

FIGURE 8. Trough rain gage 80 feet long used to sample throughfall on the San Dimas study. Stemflow measuring tanks shown on both sides of trough

All of the stemflow on the plot was measured by means of stem collars similar to those used on the North Fork plots. The collars (Fig. 9) were of sheet lead applied over a thick layer of "Mastic," or expansion-joint filler, spread on the stem. To facilitate measurement, the flow from several stem collars was conducted to a manifold and thence to a tipping-bucket unit of 6 cubic inches capacity. Total stemflow from each group of stems was measured in a tank that also served as a housing for the tipping bucket. The sum of all collector tank readings was the total amount of stemflow on the plot in cubic inches and could be easily converted to inches depth for the plot area.

FIGURE 9. System of stem collars, drain pipes, and manifolds used for measurement of stemflow from a group of scrub oaks at San Dimas interception study

## RESULTS OF THE STUDY

From the summary of data from the 298 storms[7] analyzed in these studies (Table 1) two facts of major interest have emerged:

> First, the simple measurement of rainfall under the shrub canopy does not provide a correct measure of the rain reaching the ground, and hence does not give a correct measure of the interception loss when subtracted from the gross rainfall.
>
> Second, a considerable part of the rainfall reaches the ground by stemflow, and must be taken into account in determining both the amount of rain reaching the ground and the amount of interception loss.

For example, in the partially deciduous vegetation of the North Fork A plot the annual stemflow was 1½ to 3 times as much as the interception loss; the amount of water conducted to the soil by stemflow averaged nearly 6 inches annually. Rain gages placed beneath the vegetative canopy would not catch this stemflow, and hence would indicate too great a loss of water due to interception. Stemflow was a significant part of the precipitation reaching the ground in all three study areas, but the percent of precipitation lost to interception was different for each area.

[7] A storm was defined as an atmospheric disturbance accompanied by precipitation lasting from an hour to several days. During a stormy period extending over several days parts of the period were considered individual storms if separated by intervals of at least 24 hours without precipitation.

TABLE 1

**Annual Distribution of Precipitation According to Throughfall, Stemflow, and Interception Loss, in Inches Depth and Percent of Precipitation for Three Experimental Installations**

| Year (October 1-September 30) | Number of storms | Annual precipitation, inches | Inches depth of precipitation going to— | | | Percent of precipitation going to— | | |
|---|---|---|---|---|---|---|---|---|
| | | | Throughfall | Stemflow | Interception loss | Throughfall | Stemflow | Interception loss |
| **North fork A** (Partially deciduous woodland chaparral) | | | | | | | | |
| 1937-38 | 35 | 61.3 | 49.2 | 9.0 | 3.1 | 80 | 15 | 5 |
| 1938-39 | 33 | 24.2 | 19.9 | 2.6 | 1.7 | 82 | 11 | 7 |
| 1939-40 | 28 | 41.8 | 33.5 | 6.2 | 2.1 | 80 | 15 | 5 |
| Average | ---------- | 42.4 | 34.2 | 5.9 | 2.3 | 81 | 14 | 5 |
| **North fork B** (Evergreen chaparral) | | | | | | | | |
| 1940-41 | 28 | [1] 42.4 | 25.9 | 13.6 | 2.9 | 61 | 32 | 7 |
| 1941-42 | 31 | 39.4 | 23.8 | 12.3 | 3.3 | 61 | 31 | 8 |
| 1942-43 | 28 | 37.8 | 23.0 | 11.6 | 3.2 | 61 | 31 | 8 |
| 1943-44 | 35 | 27.8 | 17.6 | 7.2 | 3.0 | 63 | 26 | 11 |
| 1944-45 | 30 | 42.4 | 26.5 | 12.4 | 3.5 | 63 | 29 | 8 |
| Average | ---------- | 38.0 | 23.4 | 11.4 | 3.2 | 62 | 30 | 8 |
| **San Dimas** (Evergreen chaparral) | | | | | | | | |
| 1942-43 | 22 | [2] 33.3 | 26.8 | 2.6 | 3.9 | 80 | 8 | 12 |
| 1943-44 | 12 | [3] 20.4 | 16.6 | 2.0 | 1.8 | 81 | 10 | 9 |
| 1944-45 | 16 | [4] 29.5 | 23.6 | 2.4 | 3.5 | 80 | 8 | 12 |
| Average | ---------- | 27.7 | 22.3 | 2.3 | 3.1 | 81 | 8 | 11 |

[1] Total annual precipitation 47.4 inches. Throughfall and stemflow measurements not started until after the first 5 inches of precipitation had fallen.
[2] Total annual precipitation 45.2 inches }
[3] Total annual precipitation 33.5 inches } Amounts shown in table exclude storms in which measuring facilities for throughfall and stemflow failed.
[4] Total annual precipitation 29.6 inches.

## Annual Throughfall, Stemflow, and Interception Loss

In the North Fork A study the annual rainfall ranged from 24 to 61 inches, averaging about 42 inches or 9 inches more than the long-time average for the vicinity. For the two years of high precipitation, throughfall was 80 percent, stemflow 15 percent, and interception loss 5 percent of the annual rainfall. During the 1938-39 season of low rainfall the proportion of throughfall was 2 percent greater, but stemflow was about 4 percent less; thus 7 percent of the annual precipitation went to interception loss in that year. The lower proportion of stemflow and higher proportion of interception loss in 1938-39 appeared to be largely due to the low total rainfall and the high proportion of small storms during this year. (For the individual storm records, see appendix tables pp. 39 to 43). Evidently in years of small storms a greater proportion of the precipitation was required to wet the vegetation so that less was left to run down the stems. For the three years, throughfall was 81 percent, stemflow 14 percent, and interception loss 5 percent of the average annual gross rainfall.

In the North Fork B study annual rainfall ranged from about 28 to 42 inches, and averaged about 5 inches above normal. Throughfall was about 62 percent, stemflow 30 percent, and interception loss about 8 percent of the gross rainfall. Here, too, in the year with low precipitation and many small storms, stemflow was a lesser and interception loss a larger proportion of the gross rainfall than during the other years. It is noteworthy that interception loss averaged appreciably greater for the denser evergreen vegetation of this plot than for the less dense, partially deciduous type of the North Fork A plot. The way in which rainfall reached the ground was quite different, too; a much smaller portion fell through the foliage and much more ran down the stems than in the North Fork A plot. The greater stemflow in the North Fork B study may be explained by the branching habit of the vegetation. The buckbrush ceanothus dominating the plot has stiff, upright stems and branches that readily conduct water downward from the leaves by surface flow; since the abundant evergreen leaves catch large amounts of rain, the whole plant-form leads to heavy stemflow. By contrast, the vegetation on the North Fork A and San Dimas plots contains several species with stems and branches of a relatively spreading habit, with horizontal or drooping twigs more conductive to raindrip than to stemflow.

In the San Dimas area the rainfall during the 3-year study period averaged 6 inches above normal, ranging from 30 to 45 inches. However, two major storms had to be excluded from the analysis. In 1943 a storm of 22 inches, and in 1944 one of 12 inches overtaxed the throughfall and stemflow measuring facilities at the study plot and satisfactory records were not obtained. Throughfall amounted to about 81 percent of the average annual rainfall, stemflow about 8 percent, and interception loss about 11 percent. In the low rainfall year, 1943-44, interception loss was a smaller proportion of the gross rainfall than in the other two years, the opposite of what happened with low rainfall in the North Fork studies. Also, stemflow at San Dimas was greater during the year of low rainfall than in other years. These reversals probably were reflections of the character of storms at San Dimas during this year: The precipitation per storm (not shown in Table 1) was much greater than in the low rainfall years of the North Fork studies. A relatively large storage capacity in the surface area of the vegetation seems to be the chief reason for greater interception loss in this southern California scrub oak-ceanothus vegetation. At San Dimas, the percent of throughfall was about the same as for the North Fork A study, but the denser vegetation exposed greater surface areas to evaporation. As a result, stemflow was low and interception loss correspondingly high.

In the partially deciduous vegetation of the North Fork A plot, there was a notable difference in disposition of rainfall between the fall-winter season, when many of the shrubs were leafless, and the spring-summer season, when the shrubs were in full foliage (Table 2). The fall-winter interception loss averaged only a little over 4 percent, whereas the spring-summer loss averaged about 14 percent of the gross rainfall. Stemflow and throughfall were both less in the spring. However, only 4.3 inches or 11 percent of the average annual rainfall occurred in the spring-summer season so that, even though the percent loss is greater, the quantity lost during the spring-summer season is small.

Seasonal differences, however, were not due wholly to differences in the densities of the vegetative cover. The amounts and intensities of precipitation were also important. When the average storm rainfall was relatively great, as in the fall-winter season of 1937-38 and the spring-summer season of 1939-40 (Table 2), the percent of interception loss was relatively low. Conversely, the percent lost was high when precipitation per storm was small, as in the fall-winter and spring-summer seasons of 1938-39. Averaged for all three years, precipitation per storm was about 1.6 inches in the fall-winter season and only about 0.5 inch in the spring-summer season; hence, part of the seasonal differences in interception loss was undoubtedly due to differences in the amount of storm rainfall. Average rainfall intensities of the fall-winter storms were also greater than those of the spring-summer storms.

In all three studies snowfall appeared to decrease stemflow and to increase interception loss. However, since snows in the study areas are usually preceded and followed by intervals of rain in the same storm, it is difficult to distinguish the snow effect from the over-all effect of the storm, and no significant relation could be developed.

If the results from the three experiments are taken together, the average interception loss is 8 percent of the average annual rainfall. This is markedly lower than the 25 percent losses for broadleaved trees reported by Horton *(30)* and others, *(35)*, *(47)*, *(63)*, *(67)*, *(74)*. It is also much lower than the 25 to 50 percent losses for herbaceous vegetation reported by Haynes *(23)* and Clark *(10)*. Still, roughly 2 to 4 inches of annual rainfall were lost through interception by chaparral in these California experiments. These quantities are great enough to require consideration in the study of watershed problems. For many purposes, estimates based on the percent of interception loss determined for representative types of vegetation will be adequate. For application in hydrologic problems, it was necessary to determine interception loss storm by storm. To do this, the storm interception was studied in relation to certain characteristics of the storm. The objective was to develop an equation from which interception loss could be predicted.

TABLE 2

**Annual Disposition of Precipitation in the North Fork A Study by Seasons**

| Year | Number of storms | Seasonal precipitation, inches | Inches depth of precipitation going to— | | | Percent of precipitation going to— | | |
|---|---|---|---|---|---|---|---|---|
| | | | Throughfall | Stemflow | Interception loss | Throughfall | Stemflow | Interception loss |
| **Fall and winter storms** (October 1-March 31) | | | | | | | | |
| 1937-38 | 25 | 55.4 | 44.8 | 8.3 | 2.3 | 81 | 15 | 4 |
| 1938-39 | 23 | 21.2 | 17.8 | 2.4 | 1.0 | 84 | 11 | 5 |
| 1939-40 | 24 | 37.7 | 30.2 | 5.7 | 1.7 | 80 | 15 | 5 |
| Average | 24 | 38.1 | 30.9 | 5.5 | 1.7 | 81 | 14 | 4 |
| **Spring and summer storms** (April 1-September 30) | | | | | | | | |
| 1937-38 | 10 | 5.9 | 4.3 | .7 | .9 | 73 | 12 | 15 |
| 1938-39 | 10 | 2.9 | 2.1 | .2 | .6 | 72 | 7 | 21 |
| 1939-40 | 4 | 4.2 | 3.3 | .5 | .4 | 78 | 12 | 10 |
| Average | 8 | 4.3 | 3.2 | .5 | .6 | 74 | 12 | 14 |

The variables tested were: Storm size, wind velocity, season of the year, storm duration, rainfall intensity, actual raining time, and character of precipitation (whether rain, snow, or hail). Only storm size provided a satisfactory equation, but for the North Fork deciduous vegetation the estimate was improved by separate equations for fall-winter and spring-summer seasons.

### Relation of Interception Loss to Storm Size

In every trial of the storm-size variable, its relation to throughfall, stemflow, and interception loss proved highly significant. Graphs were made by plotting the throughfall and stemflow data of each study against precipitation for each storm (Figs. 10-13). The computed interception losses were similarly plotted. For storms with more than 0.3 inch of rainfall the trend was in a straight line. Excluding storms of less than 0.3 inch, linear regression equations were derived by the method of least squares. The close grouping of plotted points about their respective regression lines shows that throughfall, stemflow, and interception loss are directly related to storm size.

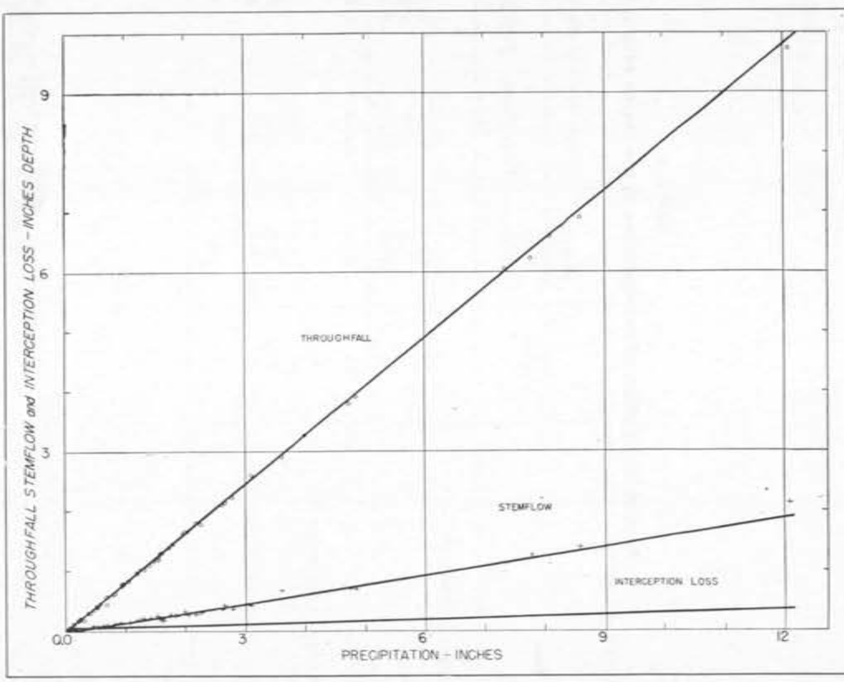


FIGURE 10. Relation of throughfall, stemflow, and interception loss to storm size for fall-winter storms at North Fork A

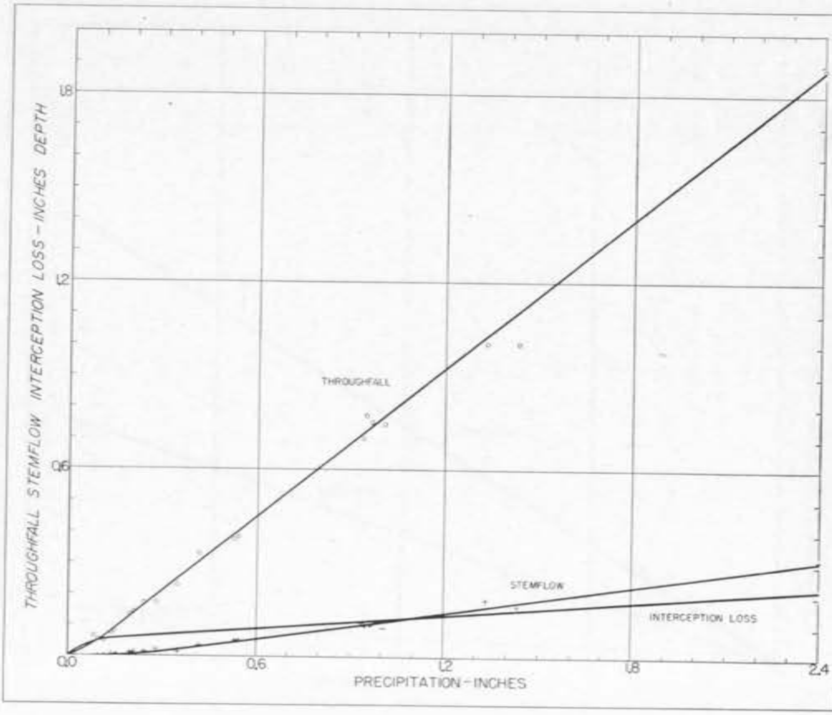


FIGURE 11. Relation of throughfall, stemflow, and interception loss to storm size for spring-summer storms at North Fork A

In storms of less than 0.3 inch the quantity of water necessary to wet the vegetation amounts to a relatively large percent of the rainfall, and the interception loss is proportionately high (50 to 80 percent of the gross rainfall). Because of this initial wetting, the relations of throughfall, stemflow, and interception loss to precipitation in these small storms are curvilinear. The portion of the graphs showing these relations was obtained by extending the regression lines back through the points representing the small storms.

For the North Fork A experiment the deciduous character of the vegetation seemed to warrant separate graphs for fall-winter and spring-winter seasons. The graph for the spring-summer storms (Fig. 11) is drawn to a more expanded scale than the one for fall-winter storms (Fig. 10). It serves chiefly to illustrate the seasonal differences in water loss previously indicated in Table 2. Throughfall and stemflow are both reduced after the vegetation is in full foliage, with a resultant increase of interception loss. The spring-summer graph also brings out the fact that most of the storms in this season occur as showers less than 0.6 inch in size, showing again that while the percent of interception loss is high the actual quantity of loss is low.

The storms having less than 0.3 inch of rainfall comprise less than 3 percent of the annual precipitation. Since these storms contribute little

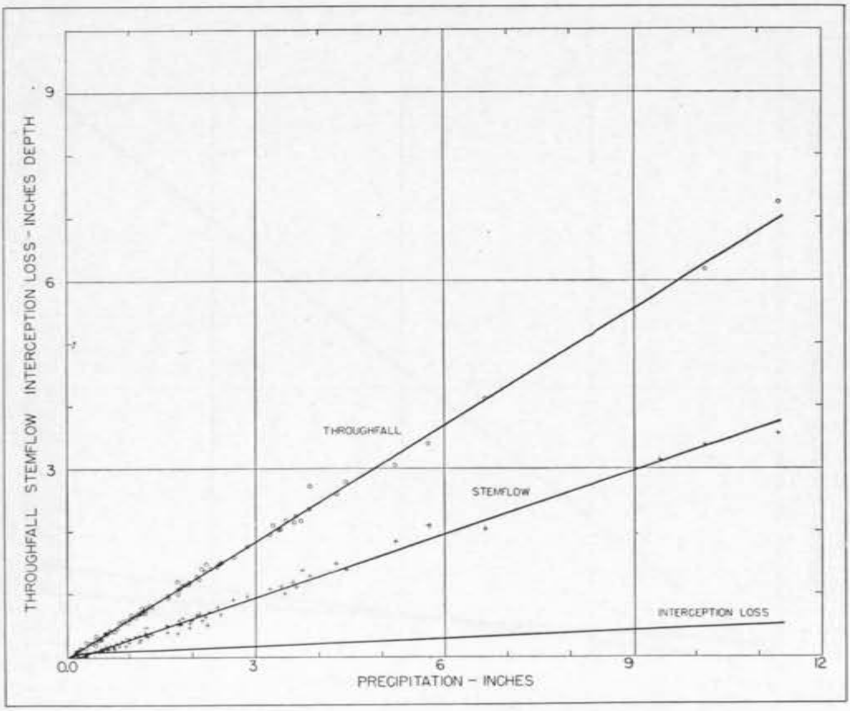


FIGURE 12. Relation of throughfall, stemflow, and interception loss to storm size at North Fork B

to water yield they are of minor importance in most hydrological problems. It was therefore deemed unnecessary to derive special equations for the estimation of interception loss of these small storms.

The equations that provide the best estimates of interception loss for storms of more than 0.3 inch of rainfall for the 3 study areas are:

North Fork A (fall-winter conditions) ............... IL = .027P + .031
North Fork A (spring-summer conditions) ............ IL = .070P + .050
North Fork B ........................................ IL = .041P + .061
San Dimas ........................................... IL = .062P + .083
(IL = interception loss; P = storm precipitation)

The first constant of each equation is the coefficient of evaporation from the vegetation and indicates the average proportion of rainfall evaporated from the shrub surface during the course of the storm. The second constant is the wetting coefficient and indicates the average amount of rainfall required to wet the vegetation at the beginning of a storm.

In determining the coefficients, a series of measurements, leaf counts, and estimates was made on the North Fork A plot in 1939, indicating a total stem and leaf surface area during the spring-summer season of about 2,600,000 square inches. Grah and Wilson *(21)* have determined experimentally that the over-all depth of water retained on a coastal chaparral species, *Baccharis pilularis*, is approximately 0.007 inch. A film

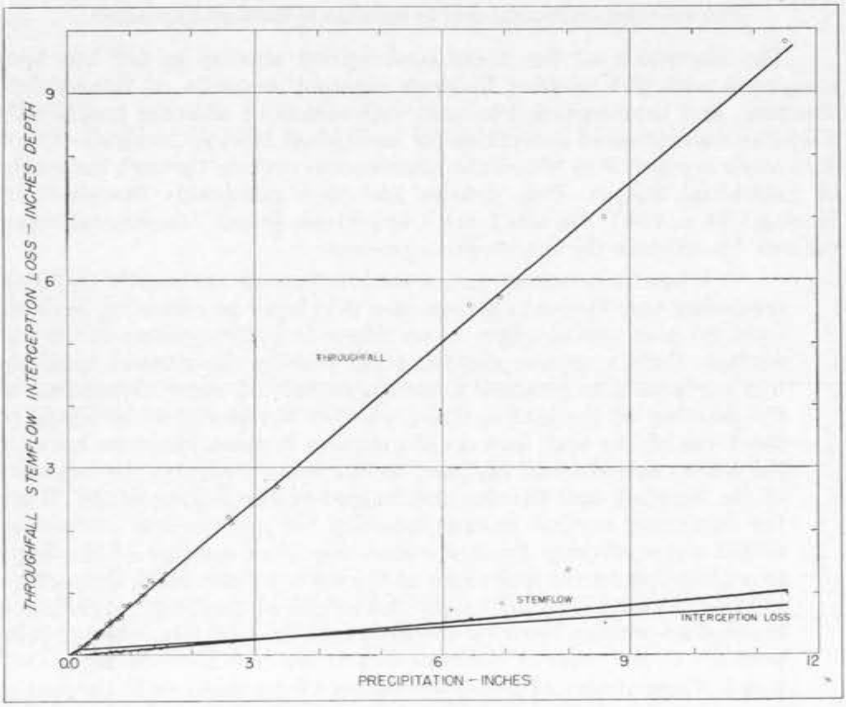


FIGURE 13. Relation of throughfall, stemflow, and interception loss to storm size at San Dimas

of water 0.007 inch deep on the storage area of the North Fork A plot would have a volume of about 18,200 cubic inches—the equivalent of 0.058 of an inch depth over the plot. This value is reasonably close to the quantity of water represented by the wetting coefficient of 0.050 in the regression equation for interception loss from the North Fork A plot under spring-summer conditions of vegetation. This volume of water is subject to evaporation throughout and at the end of the storm. Because it occurs in the form of thin films or small droplets it is particularly susceptible to evaporation.

The smaller coefficients of the fall-winter North Fork A equation as compared with the spring-summer, indicate the effects of lack of foliage and probably also of the lower temperatures prevailing in the fall-winter season. The fall-winter vegetation had less foliage to wet and thus a lesser evaporating surface. Furthermore, as indicated by evaporation pan records obtained near the plot, evaporation from the vegetation during the winter was retarded by the lower temperature. The other studies, however, showed no appreciable seasonal variation in throughfall, stemflow, or interception loss other than that caused by differences in size of storms. The San Dimas wetting coefficient, .083, is higher than at North Fork and reflects the difference in densities, surface area, and growth forms of the vegetation.

## The Interception Process and Its Relation to Rainfall Disposition

The discussion of the three interception studies so far has been concerned with the broader findings—annual amounts of throughfall, stemflow, and interception loss, and with means of showing graphically a similar separation of quantities for individual storms. Analysis of rate data made it possible to follow the interception process through the course of individual storms. This process has been admirably described by Horton (30, p. 604): He sets forth a hypothesis based "on general observations" to explain the interception process:

> "When rain begins, drops striking leaves are mostly retained, spreading over the leaf surfaces in a thin layer or collecting in drops or blotches at points, edges, or on ridges or in depressions of the leaf surface. Only a meager spattered fall reaches the ground, until the leaf surfaces have retained a certain volume of water, dependent on the position of the leaf surface, whether horizontal or inclined, on the form of the leaf, and on the surface tension relations between the water and the leaf surface, on the wind velocity, the intensity of the rainfall, and the size and impact of the falling drops. When the maximum surface storage capacity for a given leaf is reached, added water striking the leaf causes one after another of the drops to accumulate on the leaf edges at the lower points. Each drop grows in size (the air being still) until the weight of the drop overbalances the surface tension between the drop and the leaf film, when it falls, perhaps to the ground, perhaps to a lower leaf hitherto more sheltered. These drops may also be shaken off by wind or by impact of rain on the leaf. The leaf system temporarily stores the precipitation, transforming the original rain drops usually into larger drops. In the meantime the films and drops on the leaves are freely exposed to evaporation.
>
> "It is evident that the amount of interception in a given shower comprises two elements. The first may be called interception storage. If the shower continues, and its volume is sufficient, the leaves and branches will reach a state where no more water can be stored on their surfaces. Thereafter, if there is no wind, the rain would drop off as fast as it fell, were it not for the fact that even during rain there is a considerable evaporation loss from the enormous wet surface exposed by the tree and its foliage. As long as this evaporation loss continues and after the interception storage is filled, the amount of rain reaching the ground is measured by the difference between the rate of rainfall and the evaporation loss. When the rain ceases, the interception storage still remains on the tree and is subsequently lost by evaporation. If there is wind accompanying the rain, then, owing to motion of the leaves and branches, it is probable that the maximum interception storage capacity for the given tree is materially reduced, as compared with still air conditions. Furthermore, in such a case, after the rain has ceased, a part of the interception storage remaining on the tree may be shaken off by the wind, and the storage loss in such a case is measured only by the portion of the interception storage which is lost by evaporation and is not shaken off the tree after the rain has ceased. One effect of wind is, therefore,

to reduce materially the interception storage. As regards evaporation loss during rain, the effect of wind is, of course, to increase it materially."

It would be futile to attempt a better description than Horton's. Examining actual storm data, however, will serve to corroborate and amplify Horton's concepts.

For this purpose, three typical storms have been selected. The first, a 3-day storm of 3.35 inches at San Dimas, interrupted by many short rainless intervals, exemplifies the prolonged but intermittent type of storm defined by the old saying, "Three days' rain will empty any sky." The second, also at San Dimas, exemplifies a shorter, harder, nearly continuous type of storm; it delivered 2.61 inches in 27 hours with only a single rainless break of 4 hours. The third, at North Fork B, also was a short intense storm, delivering 3.14 inches in 23 hours, with one rainless interval of 1½ hours.

The 3-day intermittent storm at San Dimas (fig. 14) had 12 rainless intervals of from a half hour to 12 hours. Of the total rainfall of 3.35 inches, 2.69 inches was throughfall, 0.28 inch stemflow, and 0.38 inch interception loss. Following the "interception storage" curve of figure 14 in relation to rainfall, throughfall, and stemflow curves will show how the interception loss took place.

This interception storage curve was computed by determining the differences between the cumulative gross rainfall, and the sum of the cumulative throughfall and stemflow during the course of the storm. A point on the curve therefore represents the sum of the two elements mentioned by Horton: The amount of rainfall retained on the vegetation at a given time and the amount lost by evaporation up to that time. Hence, the final value of this curve, 0.38 inches, represents the total amount of rainfall which did not reach the ground.

The storm began with a hard shower, evidenced by the steep rise of the rainfall curve between 1.00 and 4.00 a.m., December 18. The corresponding sharp peak in the storage curve indicates a momentary interception storage of about 0.10 inch. The sharp dip in this curve immediately after the rain stopped indicates rapid and heavy drip from the vegetation, probably caused in part by the wind.

During the ensuing 15 hours, the interception storage increased to an indicated value of about 0.10 inch at 8.00 p.m., December 18, which is close to the amount of the wetting coefficient, 0.083, given in the formula for interception loss (p. 22). This initial wetting of the vegetation and coincident evaporation loss had been accomplished during the fall of about 0.40 inch of rain. During the next 24 hours interception storage increased an additional 0.15 inch, out of 1.20 inches of precipitation. In this period the rain was of relatively low intensity, with several rainless intervals during which evaporation could take place. This explains the relatively high value of 0.25 inch of interception storage at this point (8.00 p.m., December 19).

At about 7.00 p.m. on December 19, the intensity of the storm increased somewhat; after an additional 0.55 inch of rainfall, the interception storage and accumulated evaporation loss had increased by 0.15 inch (1.15 a.m., December 20), making a total of 0.40 inch since the

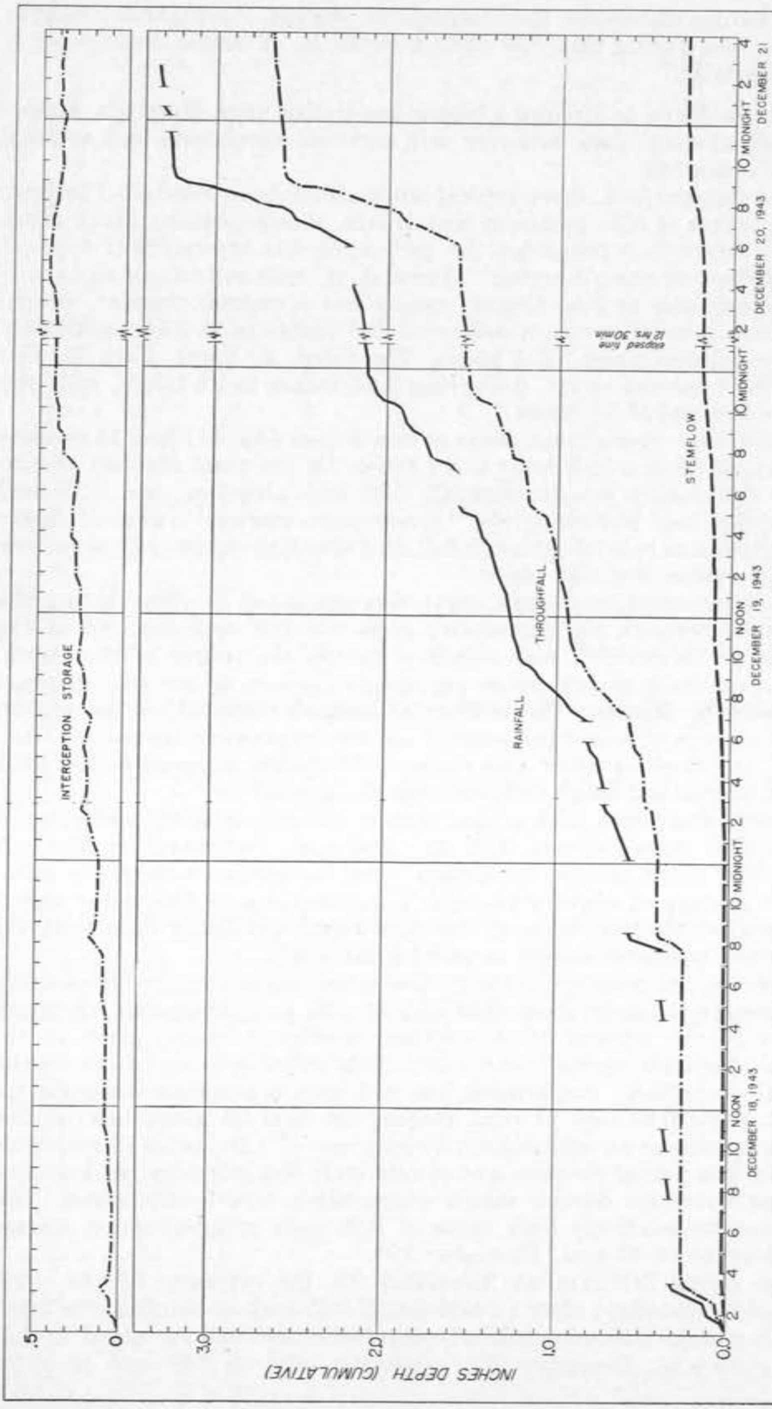


FIGURE 14. Cumulative gross rainfall, throughfall, stemflow, and interception storage for the storm of December 18 to 21, 1943, San Dimas Plot. (Interception storage includes water loss by direct evaporation from the vegetation)

beginning of the storm. Following this rain period there was a break in the storm lasting 12½ hours. Undoubtedly a considerable amount of water evaporated from the wet vegetation during this break. This made storage space again available and after rainfall resumed at 2.00 a.m. on December 20, a light shower of 0.05 inch appeared to be completely withheld as indicated by the 0.05-inch increase in the interception storage curve.

Following another break of 2 hours the storm went into its most intense phase, producing an inch of rain in 3 hours. During this period and also during the final showers the interception storage curve trended steadily downward. The corresponding rise in both the cumulative throughfall and stemflow graphs tells us that the final hard rain battered and agitated the canopy to such an extent that much stored rainfall was actually shaken or flushed off the vegetation to augment the recorded amounts of throughfall and stemflow. Rainfall ended at 2:30 a.m. on December 21 but throughfall, in the form of drip from the foliage, and stemflow persisted for almost 2 hours after cessation of the rain. By

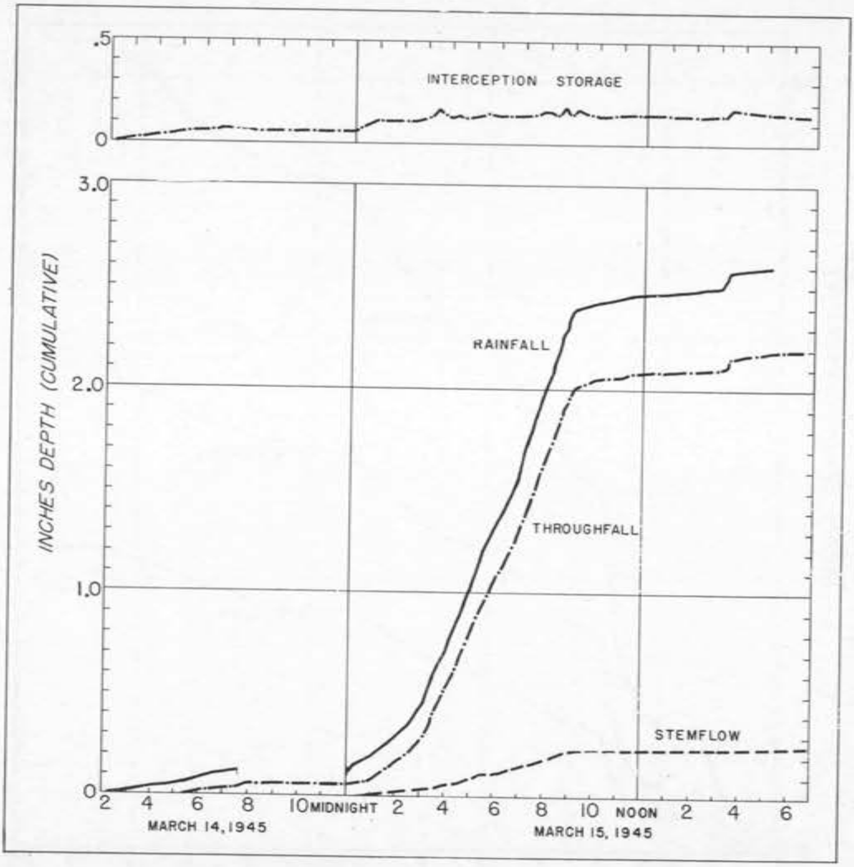


FIGURE 15. Cumulative gross rainfall, throughfall, stemflow, and interception storage for the storm of March 14 to 15, 1945, San Dimas plot

then, the interception loss amounted to 11 percent of gross rainfall for the storm.

In contrast, the hard, short, nearly continuous storm of March 14-15, 1945, at San Dimas (Fig. 15) lost only 6 percent of gross rainfall to interception. The total rainfall was 2.61 inches, of which 2.20 inches were throughfall, 0.25 inch was stemflow, and 0.16 inch was interception loss. The storm started with light, misty rain—0.12 inch in 5 hours, 0.06 inch of which was intercepted by the vegetation. The interception storage curve rose to 0.08 inch but fell to 0.06 inch during a 4-hour rainless period. Undoubtedly evaporation accounts for some of this fall. Nevertheless, the rise and fall illustrates the accumulation of raindrops on the

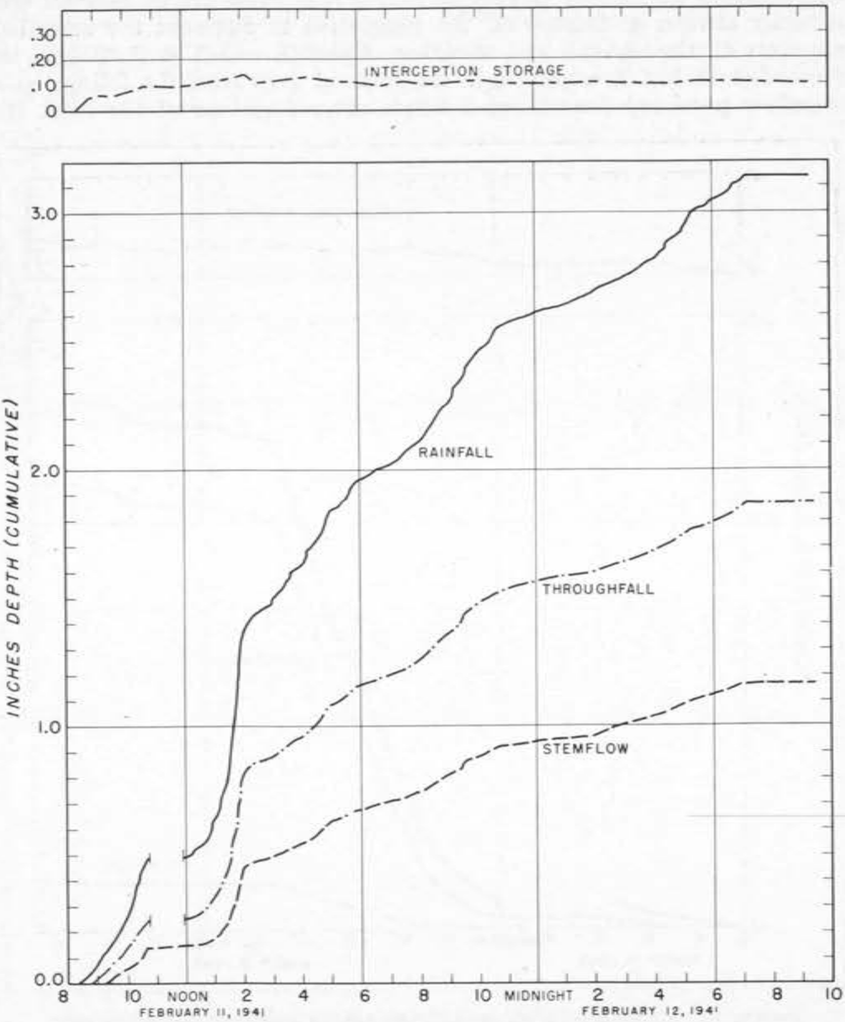


FIGURE 16. Cumulative gross rainfall, throughfall, stemflow, and interception storage for the storm of February 11 and 12, 1941, North Fork evergreen chaparral plot

vegetation and their fall to the ground as a result of overbalancing surface tension. We can assume this is so because throughfall in the form of drip persisted through the rainless interval even though the vegetation had not been thoroughly wetted; stemflow did not start until after rainfall was resumed.

During the next 10 hours, 2.28 inches of rain fell at rates reaching 0.42 inch per hour. This rainfall quickly filled most of the remaining storage space, as shown by the rapid rise of the interception storage curve to a value of 0.16 inch. During this period and a final 8-hour drizzle with occasional showers, the curve remained at about the same level, except for temporary fluctuations caused by heavy bursts of rainfall. The end value of the interception storage curve is also 0.16 inch; this indicates that there was little evaporation loss during the final periods of continuous rainfall. Thus the chief difference between these two San Dimas storms was in amount of evaporation: In the long-drawn-out storm, evaporation of rain stored on the vegetation occurred during 12 breaks in rainfall; the shorter, more intense storm had only one break during which the vegetation might have dried appreciably.

A similar short, intense storm from the North Fork B study (Fig. 16) showed similar relations between precipitation and throughfall, stemflow, and interception loss, but produced different quantitative results because of differences in vegetation. Comparative rates and amounts of throughfall were less, and rates and amounts of stemflow much greater for the shorter-stemmed, smoother-barked evergreen chaparral vegetation at North Fork. The total rainfall was 3.14 inches, of which 1.87 inches was throughfall, 1.17 inches stemflow, and 0.10 inch interception loss. Throughfall was approximately 24 percent less, and stemflow 27 percent more of the precipitation in this North Fork storm than in the San Dimas storm of March 14, 1945.

Horton places the major emphasis on interception storage by leaf surface; stem surface should be considered as well. Measurements at both North Fork A and San Dimas indicate an average surface area of about 600 square inches per stem. This surface absorbs and retains water, particularly if bark is rough or laminated. Furrows, crevices, and other irregularities in the stems also hold appreciable amounts of water. Thus, the stems are both conductors of stemflow and reservoirs for interception storage.

## SUMMARY AND CONCLUSIONS

Studies were conducted at research centers in central and southern California to determine the loss of rainfall as a result of its interception by shrub vegetation. At North Fork in the foothill woodland-chaparral sub-type of central California two studies were conducted: One in partially deciduous ceanothus-buckeye-oak vegetation and another in evergreen ceanothus-manzanita vegetation. At San Dimas Experimental Forest in the southern California chaparral formation a third study was conducted in the evergreen scrub oak-ceanothus type. Gross rainfall, throughfall (the quantity of rain actually falling to the ground), and stemflow (the rain which reached the ground as flow down the shrub stems) were measured. Interception loss was computed from these measurements.

Five percent of the gross rainfall was lost annually in the buckeye-ceanothus-oak vegetation at North Fork. This vegetation was partly deciduous; the interception loss under fall-winter conditions when the deciduous shrubs were bare was slightly more than 4 percent, but under spring-summer conditions when the deciduous shrubs were in leaf, the loss was about 14 percent. The higher spring-summer loss, although due largely to the increased density of the vegetative cover when in full foliage, was also due in part to the smaller average size of the spring-summer storms. Eight percent was lost annually in the ceanothus-manzanita vegetation at North Fork, and 11 percent was lost in the oak-ceanothus vegetation at San Dimas. In general the annual loss of rainfall through interception ranged from 1.7 to 3.9 inches, depending on the total annual rainfall and the character of storms producing it.

Stemflow was influenced to a considerable extent by the branching habit and character of the bark of the various shrub species. Shrubs of the woodland-chaparral at North Fork (a large part having smooth bark and upright stems) yielded an average of over 11 inches of stemflow out of an average annual precipitation of 38 inches. On the other hand oak-ceanothus species at San Dimas (having comparatively rough bark and spreading branch habit) yielded an average of only slightly over 2 inches of stemflow out of an average annual rainfall of 27 inches.

Throughfall, stemflow, and interception loss were generally directly proportional to storm size. For small storms the amount of interception loss can be as much as 50 to 75 percent, and for large storms as little as 3 to 6 percent of the gross rainfall. The relation between precipitation and interception loss is curvilinear for small storms of less than 0.30 inch in size, and linear for storms of more than 0.30 inch. Equations are given for estimating interception loss in storms of more than 0.30 inch.

Analysis of the interception process, using rate data, showed graphically how interception loss accumulated during typical storms. For a long storm interrupted by several rainless intervals, alternate wetting and drying of the vegetation caused relatively great interception loss. For two short storms having almost continuous rainfall, evaporation caused only small additions to the loss after initial wetting of the vegetation; consequently, total interception loss was relatively low.

Results of the three studies show that stemflow is an important factor of the interception process and cannot be ignored in considering the disposition of rainfall in brush types. The quantities of stemflow from chaparral species are not negligible amounts such as have been reported by investigators who worked with coniferous tree species. The average annual stemflow for the three studies was $7\frac{1}{2}$ inches or about 20 percent of the total rainfall.

Had these three studies measured interception loss simply by catching the precipitation falling through the vegetation, the loss would appear to be 19 to 38 percent of the annual precipitation. Actually, only 5 to 11 percent was lost.

Stemflow is all the more important as an addition to the groundwater regimen because it is delivered as a slow, steady flow at the base of the shrubs. Here the soil is loose and friable; well covered with litter, it has a high infiltration capacity. The stemflow is readily absorbed, making a significant contribution to soil moisture.

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# APPENDIX

TABLE 3

**Basic Data of Precipitation and Interception—North Fork A (Fall and Winter)** [1]

| Date | Inches, depth | | | | Date | Inches, depth | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Precipitation | Throughfall | Stemflow | Interception loss | | Precipitation | Throughfall | Stemflow | Interception loss |
| 11/14/37 | .11 | .08 | .01 | .02 | 12/10-11/39 | 1.54 | 1.21 | .25 | .08 |
| 3/7/39 | .14 | .12 | .01 | .02 | 1/28-29/38 | 1.56 | 1.25 | .21 | .10 |
| 11/30/38 | .19 | .15 | .02 | .02 | 12/18-21/38 | 1.59 | 1.31 | .22 | .06 |
| 1/20-21/39 | .20 | .16 | .02 | .01 | 10/1-2/39 | 1.62 | 1.32 | .20 | .11 |
| 11/29/38 | .28 | .23 | .03 | .02 | 2/18-19/38 | 1.75 | 1.42 | .27 | .06 |
| 12/14-15/38 | .36 | .29 | .04 | .03 | 2/2-4/39 | 1.79 | 1.64 | .04 | .12 |
| 2/6/40 | .41 | .31 | .05 | .05 | 10/30/38 | 1.82 | 1.49 | .26 | .07 |
| 2/17/40 | .41 | .32 | .05 | .04 | 1/4-5/39 | 1.96 | 1.62 | .28 | .06 |
| 11/16-17/37 | .47 | .36 | .06 | .05 | 2/22-23/40 | 2.00 | 1.61 | .33 | .06 |
| 11/10-11/38 | .49 | .40 | .04 | .05 | 3/9-10/39 | 2.00 | 1.65 | .28 | .07 |
| 10/24/39 | .52 | .41 | .07 | .04 | 2/2-4/40 | 2.07 | 1.68 | .28 | .12 |
| 12/22-23/37 | .54 | .42 | .07 | .05 | 1/29-31/39 | 2.17 | 1.80 | .28 | .09 |
| 11/11/37 | .57 | .46 | .06 | .05 | 3/26-27/40 | 2.26 | 1.80 | .33 | .13 |
| 1/19/38 | .58 | .47 | .07 | .04 | 2/6-10/39 | 2.60 | 2.28 | .13 | .18 |
| 1/27/39 | .68 | .57 | .09 | .02 | 9/25-26/39 | 2.62 | 2.13 | .38 | .10 |
| 11/1/38 | .71 | .58 | .10 | .03 | 1/1-2/40 | 2.67 | 2.15 | .44 | .08 |
| 1/16-17/38 | .79 | .64 | .12 | .03 | 1/14-15/38 | 2.78 | 2.24 | .37 | .18 |
| 3/20/38 | .85 | .68 | .12 | .05 | 3/25-28/39 | 3.10 | 2.60 | .42 | .08 |
| 3/7-8/38 | .93 | .75 | .14 | .04 | 1/24-26/40 | 3.60 | 2.92 | .57 | .11 |
| 3/14-16/38 | .95 | .78 | .15 | .02 | 2/25-29/40 | 4.72 | 3.81 | .72 | .18 |
| 10/14-15/38 | .96 | .76 | .12 | .08 | 1/31-2/4/38 | 4.83 | 3.91 | .70 | .22 |
| 1/2/38 | .98 | .80 | .13 | .05 | 2/8-12/38 | 7.32 | 6.06 | .95 | .30 |
| 3/23-24/38 | 1.04 | .84 | .15 | .05 | 3/11-13/38 | 7.77 | 6.25 | 1.28 | .24 |
| 2/13-15/38 | 1.20 | .97 | .17 | .06 | 2/28-3/4/38 | 8.09 | 6.61 | 1.12 | .36 |
| 1/3-4/40 | 1.32 | 1.03 | .20 | .08 | 1/5-12/40 | 8.59 | 6.91 | 1.40 | .27 |
| 10/6/39 | 1.40 | 1.11 | .21 | .09 | 12/9-12/37 | 12.10 | 9.74 | 2.14 | .21 |
| 2/13-14/40 | 1.47 | 1.18 | .21 | .08 | | | | | |

[1] Nineteen small storms have been omitted. Each brought less than 0.10 inch of precipitation. In total they accounted for 0.80 inch of gross rainfall, 0.53 inch throughfall, trace stemflow, and 0.27 inch interception loss.

TABLE 4

**Basic Data of Precipitation and Interception—North Fork A (Spring and Summer)** [1]

| Date | Inches, depth | | | | Date | Inches, depth | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Precipitation | Throughfall | Stemflow | Interception loss | | Precipitation | Throughfall | Stemflow | Interception loss |
| 9/12-13/39 | .10 | .06 | T | .04 | 9/27/38 | .53 | .38 | .06 | .10 |
| 5/16/38 | .11 | .05 | T | .05 | 6/14-15/39 | .54 | .39 | .06 | .10 |
| 9/18-20/39 | .14 | .08 | T | .06 | 4/4/40 | .60 | .51 | .06 | .04 |
| 5/10-11/39 | .15 | .08 | T | .06 | 4/12-13/38 | .94 | .70 | .12 | .12 |
| 10/2/38 | .20 | .14 | .01 | .05 | 4/1-2/39 | .95 | .78 | .11 | .07 |
| 4/23/39 | .21 | .15 | .01 | .05 | 4/25-26/40 | .96 | .75 | .11 | .10 |
| 4/15/40 | .24 | .18 | .02 | .05 | 4/29-5/2/38 | 1.05 | .74 | .10 | .21 |
| 7/26/38 | .29 | .17 | .03 | .09 | 4/4-5/38 | 1.33 | 1.05 | .18 | .10 |
| 5/21-22/39 | .35 | .23 | .02 | .10 | 4/24-25/38 | 1.43 | 1.06 | .17 | .21 |
| 4/13/39 | .42 | .33 | .04 | .05 | 3/27-30/40 | 2.40 | 1.88 | .32 | .20 |

[1] Four small storms have been omitted. Each brought less than 0.10 inch of precipitation. In total they accounted for 0.16 inch of gross rainfall, 0.07 inch throughfall, trace stemflow, and 0.08 inch interception loss.

TABLE 5

**Basic Data of Precipitation and Interception—North Fork B[1]**

| Date | Inches, depth | | | | Date | Inches, depth | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Precipitation | Throughfall | Stemflow | Interception loss | | Precipitation | Throughfall | Stemflow | Interception loss |
| 5/14-15/44 | .10 | .05 | T | .05 | 2/17-18/45 | .34 | .22 | .03 | .10 |
| 1/15/45 | .10 | .06 | .01 | .04 | 4/8/44 | .34 | .22 | .06 | .06 |
| 4/7/41 | .11 | .04 | T | .06 | 4/9-11/42 | .37 | .22 | .08 | .07 |
| 10/20/44 | .11 | .06 | T | .04 | 5/12-14/45 | .39 | .20 | .08 | .11 |
| 6/21/44 | .11 | .06 | .01 | .04 | 10/19-21/41 | .40 | .25 | .05 | .09 |
| 12/25/43 | .12 | .07 | T | .04 | 2/1-3/42 | .40 | .23 | .09 | .09 |
| 12/2/42 | .13 | .06 | .01 | .06 | 12/9-10/41 | .41 | .26 | .11 | .04 |
| 11/27/42 | .14 | .07 | T | .06 | 12/6/42 | .42 | .26 | .08 | .08 |
| 10/11-12/42 | .14 | .08 | T | .05 | 11/16/41 | .45 | .31 | .10 | .04 |
| 9/30/44 | .14 | .10 | .01 | .04 | 1/29-31/44 | .46 | .27 | .10 | .10 |
| 4/24/41 | .14 | .09 | .02 | .03 | 4/25/41 | .47 | .36 | .08 | .03 |
| 3/13/44 | .15 | .09 | .01 | .05 | 5/29-30/45 | .47 | .25 | .20 | .10 |
| 8/16/41 | .15 | .09 | .01 | .05 | 5/4/45 | .50 | .33 | .12 | .05 |
| 2/24/42 | .18 | .11 | .02 | .05 | 10/26-27/41 | .51 | .32 | .10 | .09 |
| 6/1/43 | .19 | .10 | .02 | .07 | 6/3-5/45 | .52 | .32 | .11 | .10 |
| 5/17-19/44 | .19 | .09 | .01 | .09 | 5/11-12/42 | .54 | .29 | .14 | .12 |
| 12/5/43 | .20 | .14 | .02 | .04 | 5/25-26/42 | .55 | .33 | .15 | .07 |
| 5/1-3/41 | .20 | .10 | .02 | .07 | 4/26-5/6/44 | .62 | .37 | .16 | .09 |
| 11/3/42 | .20 | .12 | .02 | .06 | 3/28-29/41 | .64 | .38 | .18 | .08 |
| 4/17/41 | .22 | .14 | .01 | .07 | 3/3-6/41 | .66 | .38 | .15 | .14 |
| 5/14-16/42 | .22 | .10 | .04 | .08 | 3/21-22/43 | .67 | .40 | .15 | .12 |
| 2/27/45 | .23 | .13 | .04 | .06 | 3/14/43 | .69 | .40 | .19 | .09 |
| 10/7/44 | .26 | .17 | .02 | .06 | 3/29/43 | .70 | .43 | .21 | .06 |
| 5/13-14/41 | .26 | .15 | .04 | .08 | 12/20-23/41 | .71 | .42 | .16 | .12 |
| 9/21/45 | .28 | .17 | .05 | .06 | 11/15/42 | .74 | .47 | .17 | .10 |
| 6/26/41 | .29 | .20 | .04 | .04 | 4/5-9/43 | .76 | .40 | .15 | .21 |
| 1/17-19/45 | .30 | .16 | .02 | .12 | 4/16-17/42 | .79 | .47 | .25 | .07 |
| 4/29-30/41 | .30 | .18 | .06 | .06 | 10/24/41 | .83 | .56 | .20 | .08 |
| 5/19/45 | .30 | .21 | .05 | .04 | 12/30/40 | .89 | .58 | .28 | .03 |
| 11/1-2/41 | .31 | .18 | .05 | .08 | 12/28-30/43 | .94 | .61 | .20 | .13 |
| 11/6-7/44 | .40 | .19 | .07 | .05 | 11/29/41 | .94 | .61 | .28 | .04 |

TABLE 5—Continued

**Basic Data of Precipitation and Interception—North Fork B—Continued**

| Date | Inches, depth | | | | Date | Inches, depth | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Precipitation | Throughfall | Stemflow | Interception loss | | Precipitation | Throughfall | Stemflow | Interception loss |
| 4/30-5/1/42 | .96 | .55 | .33 | .09 | 1/29-30/43 | 1.99 | 1.21 | .58 | .20 |
| 12/27-28/44 | 1.00 | .64 | .24 | .13 | 3/3-4/44 | 2.07 | 1.30 | .68 | .09 |
| 1/13-16/41 | 1.03 | .64 | .33 | .06 | 12/12-16/41 | 2.10 | 1.26 | .71 | .14 |
| 10/18-20/43 | 1.04 | .68 | .16 | .20 | 3/25-26/45 | 2.15 | 1.42 | .61 | .12 |
| 4/27-28/42 | 1.10 | .64 | .35 | .11 | 10/30-31/44 | 2.20 | 1.38 | .66 | .16 |
| 2/3/44 | 1.11 | .68 | .34 | .08 | 2/8-14/44 | 2.23 | 1.50 | .53 | .20 |
| 2/21/42 | 1.16 | .70 | .36 | .10 | 2/28-3/1/44 | 2.28 | 1.42 | .74 | .11 |
| 1/5-6/44 | 1.17 | .71 | .37 | .08 | 1/4-8/41 | 2.40 | 1.46 | .82 | .13 |
| 11/19-21/43 | 1.17 | .73 | .26 | .19 | 3/3-6/43 | 2.44 | 1.52 | .71 | .21 |
| 2/13-15/45 | 1.19 | .78 | .31 | .09 | 2/21-24/43 | 2.47 | 1.53 | .69 | .25 |
| 4/19-20/44 | 1.22 | .73 | .35 | .15 | 2/6-7/42 | 2.66 | 1.60 | .95 | .12 |
| 2/14-17/41 | 1.25 | .72 | .40 | .13 | 12/2-3/41 | 2.86 | 1.77 | .98 | .10 |
| 4/27-28/43 | 1.26 | .73 | .48 | .05 | 2/28-3/2/41 | 3.23 | 1.96 | 1.10 | .17 |
| 4/10-12/44 | 1.26 | .74 | .38 | .15 | 12/15-19/40 | 3.27 | 2.11 | 1.05 | .12 |
| 11/29-12/1/44 | 1.26 | .80 | .36 | .09 | 12/18-22/43 | 3.38 | 2.06 | 1.09 | .24 |
| 2/7-9/43 | 1.33 | .85 | .35 | .13 | 12/20-25/42 | 3.39 | 2.04 | 1.16 | .19 |
| 4/8-9/45 | 1.36 | .81 | .39 | .17 | 3/8-11/43 | 3.48 | 2.19 | 1.03 | .25 |
| 3/31-4/1/41 | 1.36 | .81 | .38 | .17 | 1/21-28/42 | 3.62 | 2.16 | 1.22 | .23 |
| 2/5-6/41 | 1.59 | .99 | .54 | .06 | 3/10-15/42 | 3.64 | 2.26 | 1.13 | .25 |
| 1/1-3/44 | 1.61 | 1.00 | .48 | .13 | 3/14-17/45 | 3.73 | 2.18 | 1.41 | .13 |
| 3/3-6/45 | 1.62 | 1.02 | .42 | .19 | 2/19-26/44 | 3.86 | 2.74 | .82 | .29 |
| 4/13-14/42 | 1.62 | .96 | .53 | .13 | 1/19-27/41 | 3.86 | 2.36 | 1.33 | .16 |
| 1/23-24/44 | 1.76 | 1.24 | .40 | .12 | 12/25-27/40 | 4.29 | 2.60 | 1.52 | .17 |
| 4/3-6/42 | 1.77 | 1.00 | .55 | .21 | 12/21-23/40 | 4.44 | 2.80 | 1.41 | .22 |
| 4/4/41 | 1.78 | 1.10 | .60 | .08 | 11/16-19/42 | 5.22 | 3.07 | 1.86 | .29 |
| 12/18-23/44 | 1.78 | 1.09 | .54 | .15 | 2/8-12/41 | 5.75 | 3.40 | 2.13 | .22 |
| 4/9-13/41 | 1.82 | 1.14 | .55 | .13 | 11/9-13/44 | 6.65 | 4.13 | 2.06 | .45 |
| 3/21-23/45 | 1.84 | 1.15 | .55 | .14 | 1/20-27/43 | 9.41 | 5.87 | 3.15 | .39 |
| 3/17-19/43 | 1.86 | 1.16 | .64 | .06 | 12/25/41-1/7/42 | 10.15 | 6.18 | 3.37 | .61 |
| 2/20-25/41 | 1.94 | 1.16 | .58 | .21 | 1/30-2/3/45 | 11.32 | 7.27 | 3.57 | .49 |
| 11/3-4/44 | 1.95 | 1.21 | .56 | .18 | | | | | |

[1] Twenty-nine small storms have been omitted. Each brought less than 0.10 inch of precipitation. In total they accounted for 0.97 inch of gross rainfall, 0.31 inch throughfall, trace stemflow, and 0.65 inch interception loss.

TABLE 6

**Basic Data of Precipitation and Interception—San Dimas**

| Date | Inches, depth | | | | Date | Inches, depth | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Precipitation | Throughfall | Stemflow | Interception loss | | Precipitation | Throughfall | Stemflow | Interception loss |
| 1/31-2/1/44 | .10 | .04 | | .06 | 1/23-24/44 | .81 | .59 | .06 | .16 |
| 1/29-31/44 | .13 | .04 | | .09 | 3/25-26/45 | .86 | .60 | .07 | .19 |
| 1/26-27/44 | .13 | .04 | | .09 | 3/21/45 | .88 | .64 | .06 | .18 |
| 6/1-3/43 | .14 | .04 | | .10 | 2/8/44 | .91 | .80 | .07 | .04 |
| 2/17/44 | .18 | .05 | .01 | .12 | 3/11-13/44 | .98 | .78 | .08 | .12 |
| 3/21-22/43 | .18 | .09 | .01 | .08 | 1/29/31/43 | 1.01 | .82 | .07 | .12 |
| 4/13-15/43 | .19 | .09 | .01 | .09 | 12/28-30/43 | 1.15 | .86 | .06 | .23 |
| 4/11-12/43 | .19 | .12 | .01 | .06 | 11/13-14/44 | 1.20 | .95 | .07 | .18 |
| 3/4/44 | .21 | .14 | .01 | .06 | 2/3-4/44 | 1.26 | .97 | .07 | .22 |
| 4/8/44 | .25 | .14 | .01 | .10 | 10/18/43 | 1.26 | 1.10 | .08 | .08 |
| 11/17/43 | .30 | .18 | .02 | .10 | 11/4-5/44 | 1.34 | 1.21 | .07 | .06 |
| 12/5-6/43 | .32 | .20 | .01 | .11 | 12/27-29/44 | 1.42 | 1.15 | .16 | .11 |
| 12/2/44 | .32 | .19 | .02 | .11 | 4/26-28/44 | 1.50 | 1.20 | .12 | .18 |
| 1/5-6/44 | .45 | .27 | .02 | .16 | 1/25-27/43 | 1.52 | 1.20 | .10 | .22 |
| 2/14-15/44 | .46 | .30 | .03 | .13 | 4/5-6/43 | 1.60 | 1.30 | .17 | .13 |
| 4/8-9/45 | .48 | .33 | .04 | .11 | 2/29-3/4/44 | 2.34 | 1.87 | .21 | .26 |
| 3/16-17/45 | .52 | .32 | .05 | .15 | 3/14-15/45 | 2.61 | 2.20 | .23 | .18 |
| 8/17-18/45 | .52 | .37 | .03 | .12 | 2/27-3/4/45 | 2.65 | 2.12 | .22 | .31 |
| 2/15-19/45 | .57 | .38 | .01 | .18 | 12/17-21/43 | 3.35 | 2.69 | .28 | .38 |
| 2/23-26/44 | .63 | .50 | .03 | .10 | 12/10-12/43 | 5.10 | 4.21 | .40 | .49 |
| 2/8/43 | .66 | .47 | .04 | .15 | 1/31-2/3/45 | 6.14 | 5.10 | .74 | .30 |
| 3/22-23/45 | .69 | .55 | .08 | .06 | 2/20-24/43 | 6.45 | 5.60 | .58 | .27 |
| 1/19/45 | .72 | .53 | .04 | .15 | 3/3-5/43 | 6.94 | 5.72 | .84 | .38 |
| 3/17-18/43 | .74 | .56 | .06 | .12 | 11/10-12/44 | 8.60 | 7.01 | .54 | 1.05 |
| 4/7-8/43 | .79 | .60 | .08 | .11 | 2/19-22/44 | 11.50 | 9.80 | .99 | .71 |

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