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## AN ANALYSIS OF PRECIPITATION MEASUREMENTS ON MOUNTAIN WATERSHEDS


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[California Forest and Range Experiment Station, Forest Service, Berkeley, Calif., March 1937]


### INTRODUCTION

The purpose of the study described in this paper was to ascertain, through analysis of precipitation measurements from gage systems upon mountainous watersheds, the reliability of computed rainfall averages, and on the basis of this analysis to decide what modifications of or additions to the original gage distributions are necessary in order to obtain results accurate within preestablished limits.

Since it is known that mountain precipitation varies considerably in amount for any single storm or season, even within quite limited areas, it is not possible to obtain exact data on total precipitation from a single raingage or even from several gages, but an average is required of measurements from sufficient instruments, well distributed over the watersheds in question, to furnish statistically reliable results. In the past, raingages have been distributed in mountain areas with little regard to a planned system; their location has been influenced mainly by proximity to a permanent habitation where continuous measurements could be made. It is not unusual to find only one gage in an area of 25 to 50 square miles. With distributions such as this it is impossible to apply a statistical analysis of the precipitation measurements for a watershed.

The present study was made on the San Dimas Experimental Forest. This research area on the Angeles National Forest has been equipped by the California Forest and Range Experiment Station for investigations into the relation of vegetation to water yield and erosion from mountain watersheds, with the ultimate objective of developing a system of management which will provide a maximum yield of usable water with minimum erosion. This tract of 17,000 acres (26.6 sq. miles) is located on the south slopes of the San Gabriel Mountains about 30 miles east of Los Angeles, California. Topographically the area is typical of a large part of the mountain range, with its sharp, V-shaped ridges and steep-sided canyons. The drainage system has developed to the climax. Elevations range from about 1,700 to 5,400 feet above sea level. (See fig. 1.)

Here the problem of precipitation measurements has been divided into two phases, distinct from one another by reason of their relative requirements of accuracy: first, the obtaining of precise precipitation data on two sets of three small watersheds; and second, the procurement of averages reliable within practical limits for 10 intermediate watersheds of varying size and complexity.

The arrangement of the areas studied in these two phases of the problem is shown in figure 5. The small, intensively studied watersheds, as outlined and labeled on the map, are Bell watersheds at the left, and Fern at the right. Intermediate compartments are the basins included within heavy dashed lines, and located by roman numerals. It should be noted that watershed IV is a large drainage unit including watersheds II and III as well as the unit surrounding numeral "IV" on the map, since these two watersheds drain into the lower section; and that watershed VI similarly includes watersheds I to V, together with the unit labeled "VI" on the map. In the following discussion the small and intermediate watershed groups are treated as independent units.

### RAINGAGE DISTRIBUTION

#### *Small watersheds*

For the distribution of gages within the two groups of small drainages, contour trails were constructed at relatively short altitudinal intervals: 300 feet in Bell Canyon, and 250 feet in Fern Canyon. The selection of contours for this purpose was based upon knowledge of the two principal factors producing rainfall variations in mountains: elevation and surface relief. Beside sampling differences in elevation in a reasonably complete manner, contours traverse all topographic variations. With these trails available, it was necessary to distribute gages upon them at such intervals that variations in surface relief would be sampled as nearly as possible in proportion to the total watershed area occupied by each class of topographic variation.

As the best criterion of variation in surface relief within the triplicate watersheds "facets of slope" were taken—elementary topographic units, each of which, bounded on one side by a ridge and on the other by a canyon or draw, is characterized by a single aspect and degree of slope, with negligible variation. The facets existing within each watershed studied were delineated on an accurate contour map, and from their planimetered areas was determined the total area facing in each of eight compass directions within each watershed (table 1).

In order to obtain the fairest possible sampling of the areas in each aspect, gage locations were established mechanically on the map by several methods, using in each case the intersection of ruled lines with trails: (1) Polar coordinates at angles of 8° to each other, from the point of intersection of the axes of the small watershed units included in each area; (2) rectangular coordinates at 400-foot intervals, with gage locations set on trails at

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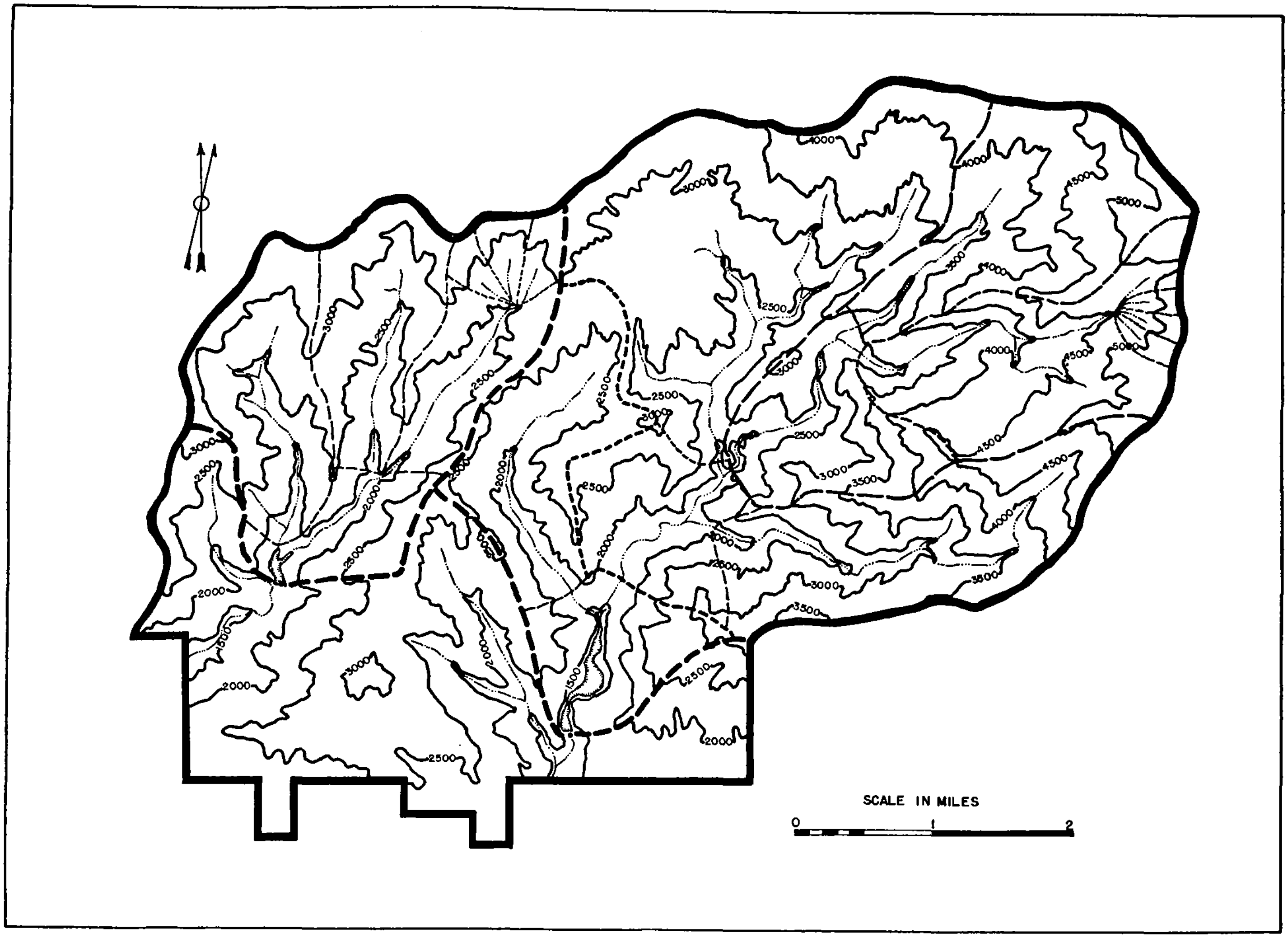


FIGURE 1.—Topographic map of San Dimas Experimental Forest with contour interval of 500 feet. Major drainage boundaries are indicated by heavy dashed lines; intermediate and minor watershed divides are shown by lighter dashes.

points nearest the corners of the rectangles; and (3) parallel lines at 300-foot horizontal intervals, drawn normal to the axis of each watershed (fig. 2).

A site description was obtained for each gage location established by each method, and these descriptions were compared with the actual average environmental characteristics of the watersheds. In comparing the allocation of gages to various aspects, for example, the percentage of gages assigned by each method to each class of topographic variation was determined, and the results compared statistically with the actual relief existing in each watershed (see table 1). The parallel-line method of location was adopted finally, as gage sites obtained by this method most closely fitted the general environmental characteristics of the watersheds and resulted in the smallest deviation of topographic location of instruments from the actual surface relief. Although method 2 gave a slightly better proportion of gages to the individual watersheds than method 3, it was believed that the superiority of method 3 in the matter of exposure outweighed the other considerations.

TABLE 1.—*Comparison of three methods of locating raingages with respect to aspect and watershed*

BELL CANYON TRIPLICATE WATERSHEDS

| Aspect or watershed | Watershed area | Gage distribution, by— | | |
|---|---|---|---|---|
| | | Method 1 | Method 2 | Method 2 |
| | *Percent* | *Percent* | *Percent* | *Percent* |
| North | 0 | 0 | 0 | 0 |
| Northeast | 16.9 | 8.3 | 6.2 | 14.3 |
| East | 17.9 | 16.7 | 20.8 | 23.2 |
| Southeast | 17.6 | 29.2 | 22.9 | 19.6 |
| South | 18.8 | 18.7 | 14.6 | 17.9 |
| Southwest | 13.2 | 14.6 | 12.5 | 10.7 |
| West | 10.3 | 10.4 | 16.7 | 12.5 |
| Northwest | 5.3 | 2.1 | 6.3 | 1.8 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 |
| Deviation [1] | | 5.3 | 5.1 | 2.8 |
| Watershed 1 | 32.3 | 31.3 | 31.3 | 31.6 |
| Watershed 2 | 41.8 | 39.6 | 41.7 | 40.4 |
| Watershed 3 | 25.9 | 29.1 | 27.0 | 28.0 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 |

[1] Square root of mean squared deviation of percentages under each method, from the percentage of area in each aspect.

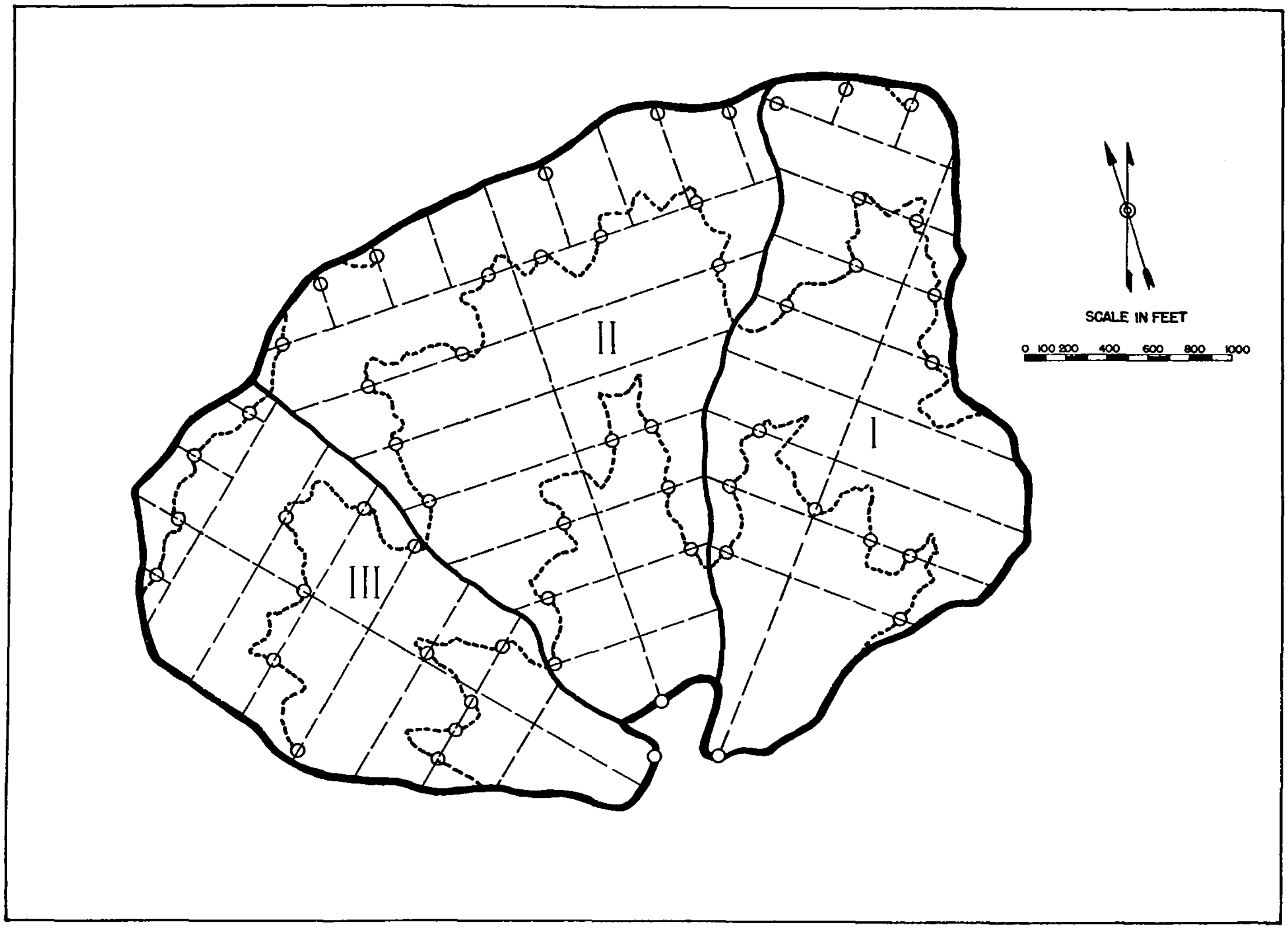


FIGURE 2.—Raingage distribution, Bell Canyon small watersheds. The method adopted for gage distribution is indicated by dashed lines; the gage locations by circles.

*Intermediate compartments*

As illustrated in figure 5, 10 intermediate watersheds in the experimental forest vary in area from a square mile up to approximately 14 square miles. In this large group, the number of gages which may be installed and measured after each storm, and therefore the accuracy of the resulting rainfall averages, are directly controlled by practical limitations of transportation and available man power. The objective in gage distribution was necessarily to obtain the best records possible within these practical limits.

For gage installation it was originally contemplated to construct a complete system of contour trails across the intermediate compartments at 2,100-, 3,100-, 4,100-, and 5,100-foot elevations, since a mechanical distribution of gages along contours at these intervals might be expected to give a good sample of precipitation. An examination of this large area demonstrated, however, that such a trail system fails to give a satisfactory lateral sampling of the forest. In broad, gently sloping basins large blank areas remain between 1,000-foot contours, while in a precipitous zone the same contour may enter a narrow canyon and return within a short horizontal distance. It was decided to utilize, in addition to the contour system, a number of grade trails and roads which satisfactorily fill in the blanks left by contours alone, and therefore give a more complete lateral sampling of the watersheds. Accordingly, during the period encompassed by the initial study of rain-gage distribution, about 175 gages were progressively set out in a mechanical distribution at half-mile intervals along all trails (contour and grade) and roads which were practical for the purpose.

METHOD OF ANALYSIS

Rainfall records obtained in the small watershed areas and each of the intermediate compartments of 10 representative storms occurring between December 1933 and April 1935, were analyzed statistically to determine their reliability, and, where they proved to be inadequate, to find the number of additional gages necessary to furnish a desired degree of accuracy. The dates of the 10 storms occurring in the 16 months of record are as follows:

| Storm No.— | |
|---|---|
| 1 | December 30–31, 1933. |
| 2 | January 24, 1934. |
| 3 | February 22, 1934. |
| 4 | April 14–17, 1934. |
| 5 | June 5, 1934. |
| 6 | October 17, 1934. |
| 7 | November 15, 1934. |
| 8 | December 10, 1934. |
| 9 | January 10, 1935. |
| 10 | April 7, 1935. |

Judgment as to the representative character of these storms was based upon their closeness of fit to an average curve in which, for all storms recorded on the experimental forest, the size of storm was plotted against the coefficient of variability of each storm. A curve illustrating the relationship, taken for Fern Watershed 1, is shown in figure 3. It will be seen that on the average there seems to be a clear relation between the size of any storm and its variability, as expressed by the coefficient of variation; and that this average relationship may be expressed by a curve approaching in form a rectangular hyperbola. The storms chosen for analysis (solid black points in figure 3) fit with reasonable closeness to this curve.

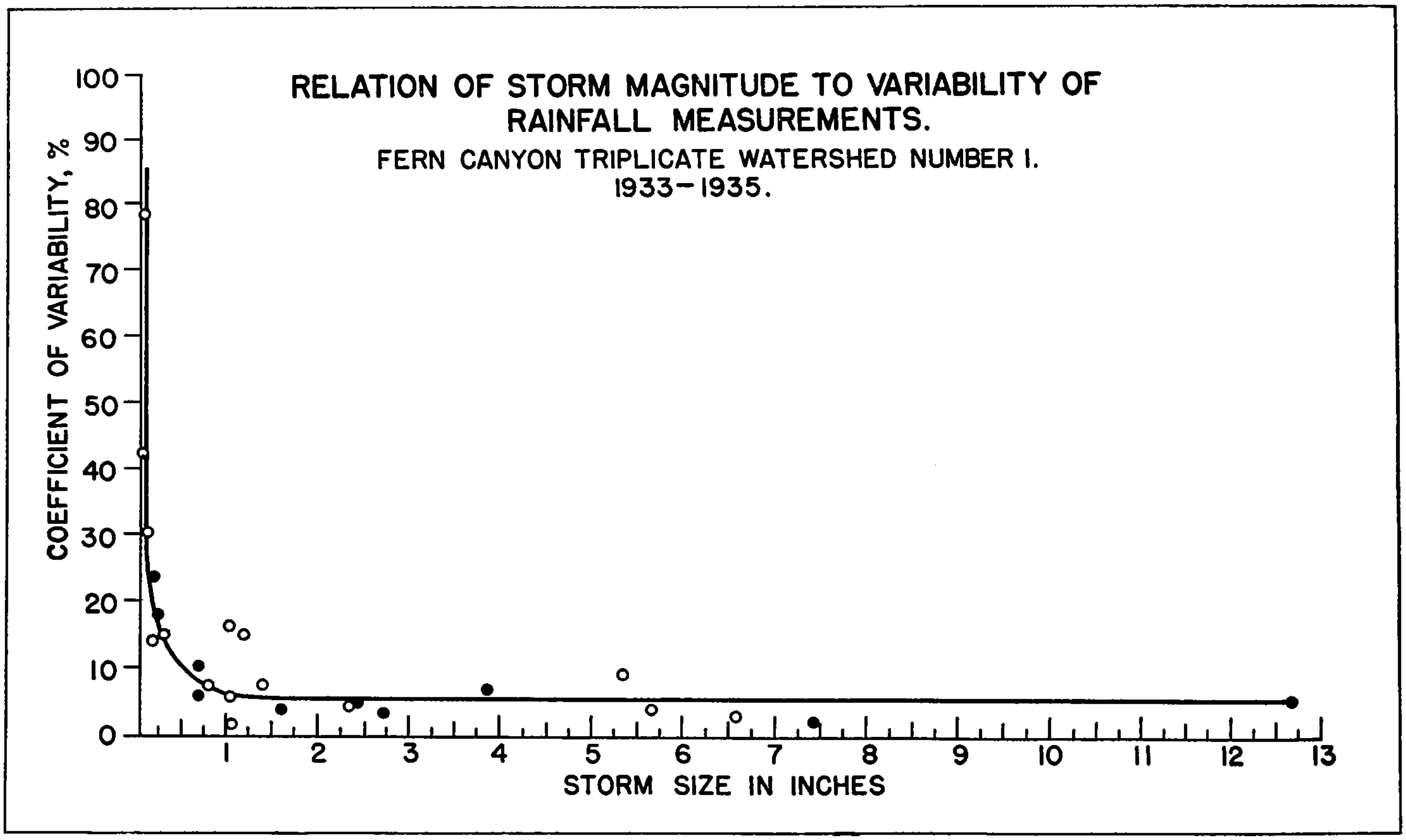


FIGURE 3.—Relation of Storm Magnitude to Variability of Railfall Measurements. Fern Canyon Triplicate Watershed Number 1. 1933-1935.

*Small watersheds*

On these two small watershed groups, gages were installed in sufficient numbers (57 in Bell Canyon, and 47 at Fern) to insure a reasonably certain sample of all rainfall variability which might occur within each area.

Table 2 presents, for each storm in each watershed of the two triplicate areas, the statistical data involved in determining the accuracy of averages obtained with the existing gage distribution. Except for the smallest storms, these averages are reliable in general within 3 to 5 percent (2 times the standard error), although variation of individual readings from the mean may in some cases exceed 25 percent.

In this study of records for the small watersheds, no attempt has been made to isolate the effect of systematic variance, as with elevation, on the means and their statistical constants. Actually, the removal of this effect by computing means weighted by areas within several altitudinal ranges, for instance, and by an analysis of variance, would demonstrate the reliability of data obtained from these gage distributions to be greater than that computed in this study. An analysis of variance made by Dr. George F. McEwen,[2] using five storms in the Bell triplicate area, gave weighted mean values agreeing closely with simple averages, and residual probable errors consistently less than two-thirds of the probable error of each simple average.

As a further check, isohyetal maps of Bell and Fern canyons were constructed for the 10 storms considered above. Maps covering 4 of the storms are shown in figure 4. Volumes of total precipitation catch were computed from the maps by planimetering the areas between adjacent isohyets, multiplying each area by the average of the two isohyets, and obtaining the sum of these products. These quantities were compared with volumes obtained by multiplying a simple average of gage readings by the area of watershed. This is in effect comparing a weighted average with a simple average. Table 3 shows the volumes obtained by both methods and the percent deviation.

The close agreement of results as computed by these three methods indicates that the present gage distributions in the small watersheds are so complete and representative that no alterations or additions to them are necessary.

[2] Scripps Institution of Oceanography, La Jolla, Calif. Paper presented to the American Meteorological Society, 1934.

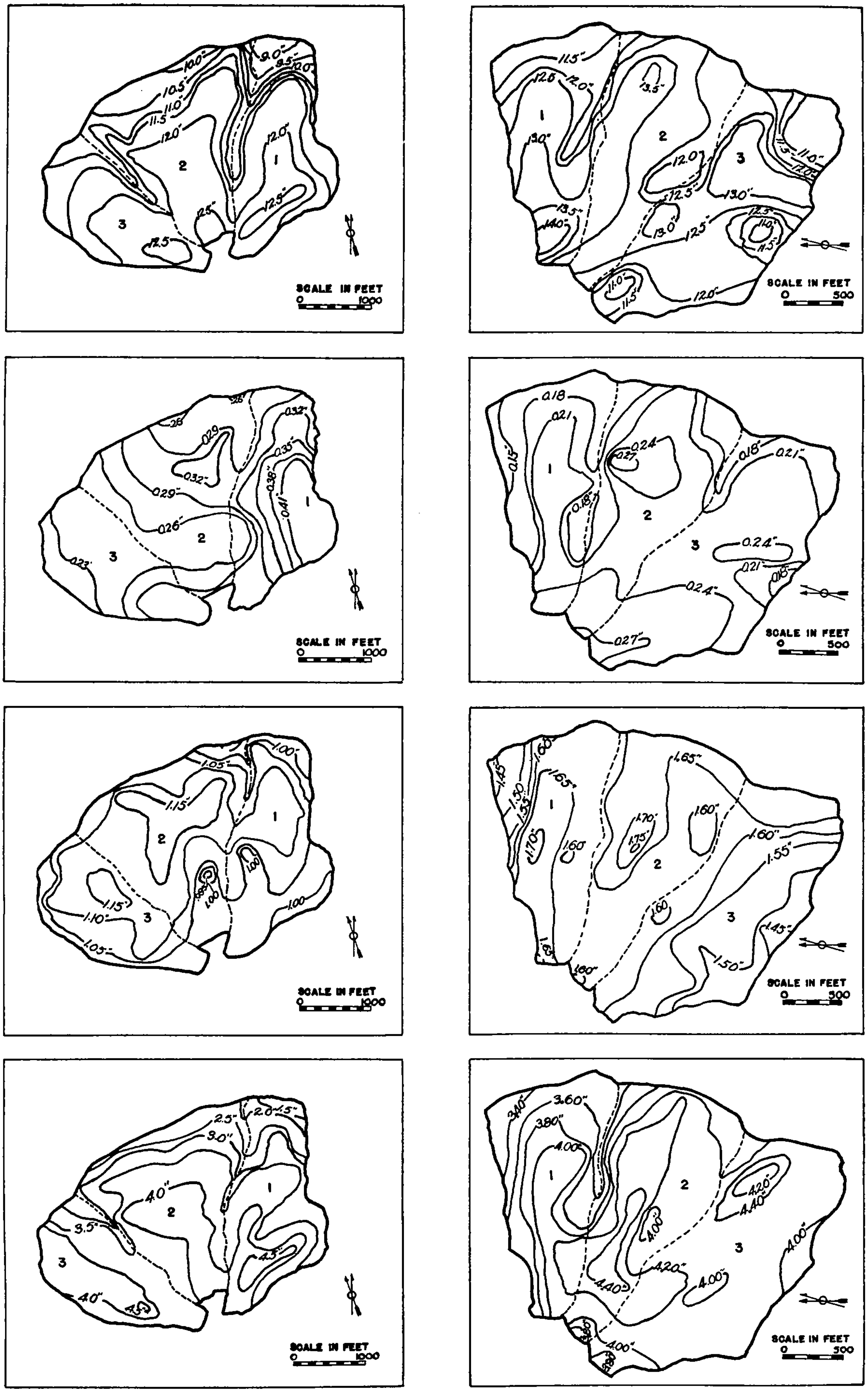


FIGURE 4.—Isohyetal maps for four storms in Bell (left) and Fern Canyons.

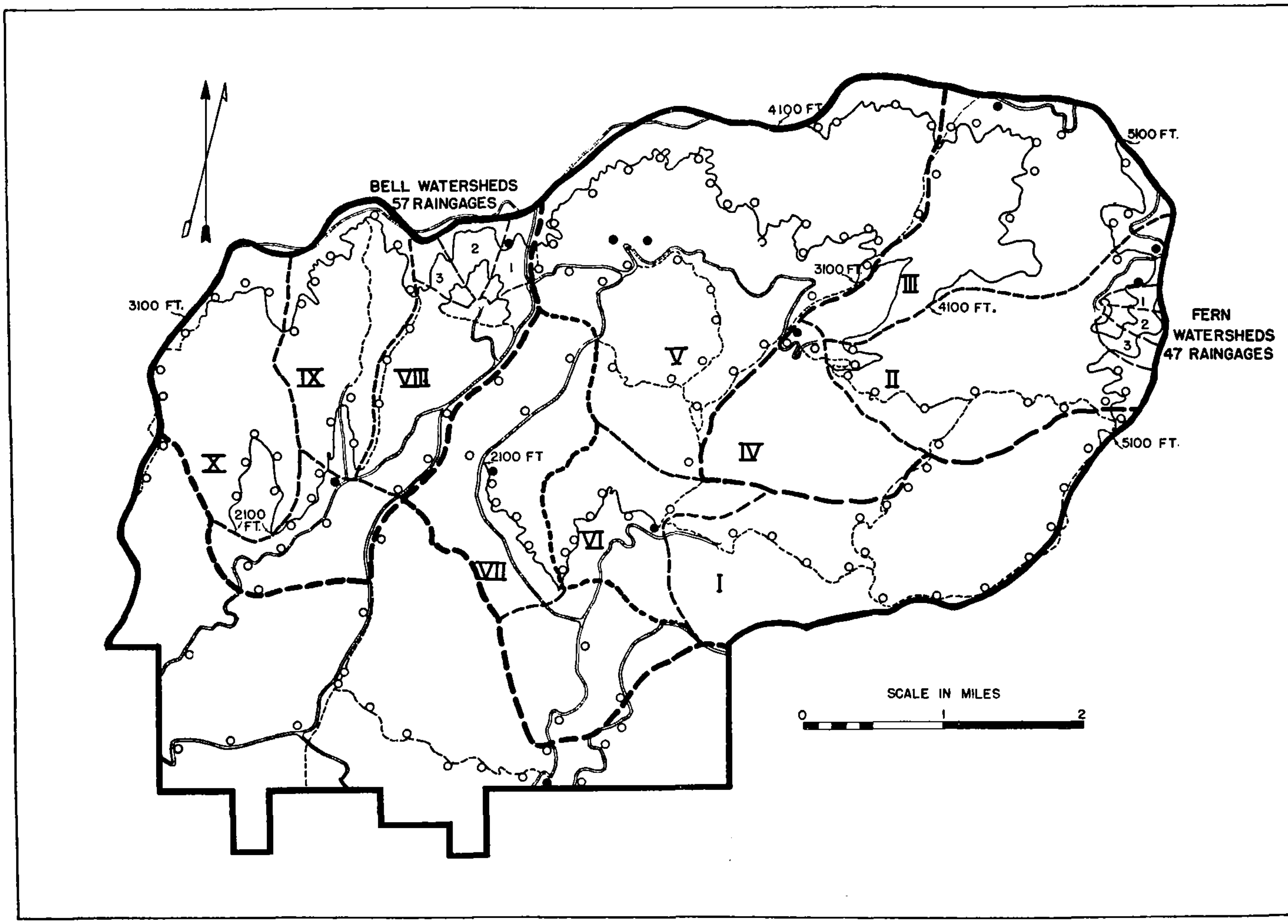


FIGURE 5.—Raingage distribution, San Dimas Experimental Forest. Heavy dashed lines are watershed boundaries; roman numerals, watershed numbers; light double lines are roads; light solid lines, contour trails; and light dashed lines are grade trails. Standard raingage locations are shown by small circles, and intensity gages by solid black dots.

TABLE 2.—*Statistical data for 10 storms, on the basis of existing gage distribution, from small watersheds 1, 2, and 3 of Bell and Fern Canyons* [1]

BELL SMALL WATERSHEDS

| Storm No. | Catch of rainfall | | | Standard deviation | | | Standard error | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | *Percent* | *Percent* | *Percent* |
| 1 | 11.33 | 11.36 | 11.78 | 1.27 | 0.87 | 0.62 | 1.6 | 1.6 | 1.3 |
| 2 | .34 | 27 | .26 | .05 | .02 | .03 | 3.6 | 1.8 | 2.8 |
| 3 | 3.20 | 3.24 | 3.38 | .28 | .26 | .21 | 2.1 | 1.6 | 1.7 |
| 4 | .21 | .23 | .24 | .03 | .02 | .01 | 3.1 | 1.6 | 1.3 |
| 5 | .51 | .52 | .52 | .03 | .03 | .02 | 1.4 | 1.2 | 1.0 |
| 6 | 6.41 | 6.51 | 6.88 | 1.01 | .68 | .48 | 3.8 | 2.2 | 1.8 |
| 7 | 2.56 | 2.52 | 2.43 | .12 | .09 | .08 | 1.1 | .8 | .9 |
| 8 | .62 | .64 | .68 | .33 | .05 | .03 | 1.3 | 1.6 | 1.0 |
| 9 | 1.06 | 1.08 | 1.10 | .05 | .06 | .04 | 1.2 | 1.2 | 1.0 |
| 10 | 3.25 | 3.45 | 3.84 | .93 | .66 | .70 | 6.8 | 4.0 | 4.6 |

FERN SMALL WATERSHEDS

| Storm No. | Catch of rainfall 1 | Catch of rainfall 2 | Catch of rainfall 3 | Standard deviation 1 | Standard deviation 2 | Standard deviation 3 | Standard error 1 | Standard error 2 | Standard error 3 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12.74 | 12.71 | 12.11 | 0.71 | 0.48 | 1.22 | 1.3 | 1.0 | 2.4 |
| 2 | .19 | 23 | .23 | .05 | .03 | .02 | 4.9 | 3.0 | 2.6 |
| 3 | 2.46 | 2.56 | 2.49 | .11 | .13 | .18 | 1.0 | 1.3 | 1.7 |
| 4 | .23 | .21 | .21 | .04 | .05 | .04 | 5.7 | 5.7 | 4.3 |
| 5 | .72 | .78 | .79 | .04 | .03 | .06 | 1.1 | 1.0 | 1.7 |
| 6 | 7.46 | 7.47 | 7.45 | .09 | .09 | .01 | .3 | .3 | 1.2 |
| 7 | 2.67 | 2.67 | 2.67 | .09 | .03 | .02 | .9 | .3 | .2 |
| 8 | .71 | .70 | .69 | .07 | .04 | .04 | 2.9 | 1.3 | 1.4 |
| 9 | 1.64 | 1.64 | 1.57 | .06 | .05 | .07 | 1.1 | .8 | 1.1 |
| 10 | 3.86 | 4.11 | 4.08 | .27 | .17 | .20 | 1.6 | 1.0 | 1.2 |

[1] The number of gages on which these data are based are as follows: In Bell Canyon, 18 gages in No. 1 watershed; 22 in No. 2; and 16 in No. 3. In Fern Canyon, 13 gages in No. 1 watershed; 16 in No. 2; and 18 in No. 3.

### *Intermediate Compartments*

The reliability of any group of measurements used to estimate the average of measurements of a random variable depends not only upon the number of observations available, but just as much upon a truly representative sampling of the variable studied. In the Bell and Fern triplicate areas such sampling was obtained with more than reasonable certainty, because of the large number of carefully distributed gages. Conditions in the 10 intermediate compartments, on the other hand, where gages are widely scattered over a large area, call for a check on the thoroughness of sampling before averages and their statistical constants may safely be used as an estimate of precipitation.

Comparison of simple rainfall averages with totals computed from isohyetal maps affords a means for making such a check. In any of the experimental watersheds, an isohyetal map provides the best weighted mean for the basin, since the rainfall contour lines take into account the effect not only of gages within each watershed, but also of those in adjacent drainages. The effect of a poorly distributed gage system, then, is a wide deviation of simple averages from the isohyetal, or weighted, results. Study of table 4 shows that, after the initial gage distribution was reasonably close to completion, large deviations between simple and isohyetal averages occurred only in rare instances.

TABLE 3.—*Comparison of precipitation catch computed from simple average with that obtained by isohyetal method on three small watersheds of Bell and Fern Canyons*

BELL SMALL WATERSHEDS

| Storm No. | Catch on watershed 1 | | | Catch on watershed 2 | | | Catch on watershed 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Isohyetal method | Simple average | Deviation | Isohyetal method | Simple average | Deviation | Isohyetal method | Simple average | Deviation |
| | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* |
| 1 | 72.05 | 71.47 | −0.8 | 93.84 | 93.08 | −0.8 | 59.38 | 59.24 | −0.2 |
| 2 | 2.15 | 2.13 | −.9 | 2.27 | 2.27 | 0 | 1.27 | 1.27 | 0 |
| 3 | 20.49 | 20.21 | −1.4 | 26.87 | 26.68 | −.7 | 17.00 | 16.93 | −.4 |
| 4 | 1.39 | 1.38 | −.7 | 1.94 | 1.93 | −.5 | 1.23 | 1.21 | −1.6 |
| 5 | 3.30 | 3.30 | 0 | 4.27 | 4.22 | −1.2 | 2.65 | 2.64 | −.4 |
| 6 | 43.92 | 43.11 | −1.8 | 56.98 | 56.69 | −.5 | 36.25 | 35.84 | −1.1 |
| 7 | 12.16 | 12.18 | +.2 | 20.92 | 20.75 | −.8 | 16.13 | 16.02 | −.7 |
| 8 | 3.94 | 3.95 | +.3 | 5.36 | 5.32 | −.7 | 3.37 | 3.43 | +1.8 |
| 9 | 6.58 | 6.58 | 0 | 9.05 | 8.88 | −1.9 | 5.53 | 5.58 | +.9 |
| 10 | 21.47 | 20.54 | −4.3 | 29.26 | 28.45 | −2.8 | 19.46 | 19.33 | −.7 |
| FERN SMALL WATERSHEDS | | | | | | | | | |
| 1 | 34.45 | 35.20 | +2.2 | 41.02 | 40.98 | −0.1 | 51.33 | 51.61 | +0.5 |
| 2 | .52 | .53 | +1.9 | .71 | .73 | +2.8 | .97 | .97 | 0 |
| 3 | 6.73 | 6.70 | −.4 | 8.34 | 8.36 | +.2 | 10.56 | 10.66 | +.9 |
| 4 | .59 | .63 | +6.8 | .67 | .69 | +3.0 | .89 | .92 | +4.5 |
| 5 | 1.98 | 2.02 | +2.0 | 2.48 | 2.53 | +2.0 | 3.28 | 3.37 | +2.7 |
| 6 | 20.50 | 20.52 | +.1 | 24.64 | 24.64 | 0 | 31.21 | 31.21 | 0 |
| 7 | 11.06 | 11.01 | −.5 | 8.56 | 8.50 | −.7 | 7.23 | 7.19 | −.6 |
| 8 | 1.91 | 1.93 | +.1 | 2.23 | 2.23 | 0 | 2.91 | 2.93 | +.7 |
| 9 | 4.41 | 4.48 | +1.6 | 5.25 | 5.22 | −.6 | 6.58 | 6.56 | −.3 |
| 10 | 10.46 | 10.62 | +1.5 | 13.49 | 13.31 | −1.3 | 17.34 | 17.24 | −.6 |

Isohyetal maps were used also to test each gage location for local interference or lack of representative exposure. On these maps an unrepresentative gage reading stands out surrounded by an isohyet in the shape of a small ring. This is caused by the fact that the reading does not fit into the picture drawn from the surrounding gage readings. If one gage gave unrepresentative readings for a series of storms, it would be safe to assume that the gage was poorly located. Some of the gages gave questionable readings for single storms, but in all storms analyzed no gage was consistently out of line with the rest.

The standard error (S. E.) was used as a criterion of the reliability of averages obtained with the existing gage distribution, in the same way that this constant was employed for the small watershed areas. In addition, this concept was employed to compute the number of gages required to furnish a predetermined degree of reliability. Solving the standard error formula for "N," the number of instruments required is:

$$N=\left(\frac{S.\ D.}{\underline{S.\ E.}}\right)^2$$

where $\underline{S.\ E.}$ is any standard error desired, such as 2.5 percent, 5 percent, or 10 percent of the average.

Table 5 presents, for each intermediate compartment, the average rainfall, standard deviation, and percent standard error for each storm; also the number of existing gages and of those required in each case to give a standard error of 2.5, 5, or 10 percent of the average. On watersheds II (Fern) and VIII (Bell), two gages were allowed for the area covered by the small watersheds and included in the total of existing gages for these areas. Computation of the standard error and number of gages required was omitted for all storms in which insufficient gage readings were available to give accurate figures.

Storms 2 and 4, both small in size, show considerable variation throughout each of the 10 intermediate compartments. These two storms, each less than 0.5 inch in amount, comprise only about 2.5 percent of the total precipitation for the season 1933–34. By referring to table 5 it can be seen that to obtain a standard error less than 2.5 percent for such small storms, a great number of gages would be necessary; whereas for the larger storms, almost enough gages exist at the present time on most of the intermediate watersheds. The question that must be answered, therefore, is how much weight small storms should have in influencing the determination of the standard errors to be required, and therefore the number of gages necessary to give these standard errors.

TABLE 4.—*Comparison of precipitation catch computed by using simple average with that obtained by isohyetal method on 10 intermediate watersheds of entire forest*

| Storm No. | Watershed I | | | Watershed II | | | Watershed III | | | Watershed IV | | | Watershed V | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Isohyetal method | Simple average | Deviation | Isohyetal method | Simple average | Deviation | Isohyetal method | Simple average | Deviation | Isohyetal method | Simple average | Deviation | Isohyetal method | Simple average | Deviation |
| | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* |
| 1 | 1,371.07 | 1,417.01 | +3.3 | 1,425.44 | 1,442.15 | +1.2 | 1,209.66 | 1,212.84 | +0.3 | 3,282.50 | 3,373.77 | +2.8 | 2,400.48 | 2,388.77 | −0.5 |
| 2 | 76.60 | 73.24 | −4.4 | 31.08 | 30.79 | −.9 | 22.53 | 21.88 | −2.9 | 74.53 | 73.34 | −1.6 | 79.33 | 82.05 | +3.4 |
| 3 | 281.72 | 292.96 | +4.0 | 280.27 | 286.12 | +2.1 | 288.40 | 298.75 | +3.6 | 710.69 | 730.44 | +2.8 | 707.88 | 720.83 | +1.8 |
| 4 | 54.52 | 59.89 | +9.8 | 37.49 | 37.39 | −.3 | 31.65 | 27.54 | −13.0 | 91.57 | 86.65 | −5.4 | 74.18 | 74.78 | +.8 |
| 5 | 127.90 | 124.69 | −2.5 | 101.62 | 98.56 | −3.0 | 92.89 | 89.75 | −3.4 | 251.88 | 240.33 | −4.6 | 180.41 | 171.72 | −4.8 |
| 6 | 837.23 | 841.36 | +.5 | 800.54 | 790.22 | −1.3 | 757.92 | 789.17 | +4.1 | 1,906.89 | 1,979.24 | +3.8 | 1,485.77 | 1,504.18 | +1.2 |
| 7 | 350.83 | 340.64 | −2.9 | 315.45 | 308.86 | −2.1 | 309.85 | 299.71 | −3.3 | 748.63 | 749.47 | +.1 | 630.27 | 635.28 | +.8 |
| 8 | 75.10 | 76.79 | +2.3 | 90.33 | 87.81 | −2.8 | 96.56 | 95.65 | −.9 | 217.16 | 218.88 | +.8 | 160.77 | 163.34 | +1.6 |
| 9 | 128.99 | 128.07 | −.7 | 163.60 | 165.07 | +.9 | 146.39 | 148.86 | +1.7 | 368.94 | 379.42 | +2.8 | 263.98 | 264.48 | +.2 |
| 10 | 481.33 | 492.73 | +2.4 | 455.46 | 441.93 | −3.0 | 439.75 | 414.30 | −5.8 | 1,106.46 | 1,061.46 | −4.1 | 920.26 | 924.16 | +.4 |

| Storm No. | Watershed VI | | | Watershed VII | | | Watershed VIII | | | Watershed IX | | | Watershed X | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7,679.20 | 7,614.70 | −0.8 | 968.73 | 1,029.73 | +6.3 | 980.32 | 962.67 | −1.8 | 835.18 | 896.52 | +7.3 | ---------- | ---------- | ---------- |
| 2 | 254.86 | 256.52 | +.7 | 31.51 | 28.74 | −8.8 | 25.11 | 25.11 | 0 | 24.53 | 26.47 | +7.9 | ---------- | ---------- | ---------- |
| 3 | 1,831.92 | 1,876.15 | +2.4 | 203.82 | 219.25 | +7.6 | 235.05 | 224.79 | −4.4 | 247.20 | 242.67 | −1.8 | 290.33 | 310.02 | +6.8 |
| 4 | 231.63 | 242.88 | +4.9 | 15.62 | 15.23 | −2.5 | 15.98 | 16.59 | +3.8 | 15.75 | 15.33 | −2.7 | 22.83 | 22.88 | +.2 |
| 5 | 606.05 | 585.71 | −3.4 | 47.84 | 44.72 | −6.5 | 37.87 | 39.17 | +3.4 | 31.63 | 32.08 | +1.4 | 35.22 | 36.28 | +3.0 |
| 6 | 4,506.02 | 4,551.65 | +1.0 | 533.88 | 559.82 | +4.9 | 517.80 | 505.44 | −2.4 | 494.63 | 497.38 | +.7 | 572.19 | 562.59 | −1.7 |
| 7 | 1,847.42 | 1,879.95 | +1.8 | 235.99 | 239.50 | +1.5 | 186.88 | 189.54 | +1.4 | 166.70 | 169.05 | +1.4 | 197.03 | 197.45 | +.2 |
| 8 | 476.49 | 481.57 | +1.1 | 48.76 | 49.20 | +.9 | 45.68 | 45.88 | +.4 | 45.60 | 45.99 | +.9 | 56.59 | 58.20 | +2.8 |
| 9 | 816.64 | 824.01 | +.9 | 80.78 | 80.82 | 0 | 76.10 | 73.16 | −3.9 | 71.02 | 70.39 | −.8 | 83.45 | 81.26 | −2.6 |
| 10 | 2,679.11 | 2,648.89 | −1.1 | 287.92 | 308.90 | +7.3 | 257.52 | 248.97 | −3.3 | 252.74 | 258.74 | +2.4 | 311.91 | 301.80 | −3.2 |

TABLE 5.—*Rainfall averages and statistical constants, and the number of gages required to give various degrees of accuracy, in 10 intermediate watersheds*

| Watershed and storm No. | Observations | Rainfall | Standard deviation | Standard error | Gages required if ratio of S. E. to mean is— 2.5 percent | 5 percent | 10 percent |
|---|---|---|---|---|---|---|---|
| | *Number* | *Inches* | *Inches* | *Percent* | *Number* | *Number* | *Number* |
| Watershed I: | | | | | | | |
| 1 | 9 | 9.56 | 1.377 | | | | |
| 2 | 9 | .48 | .151 | | | | |
| 3 | 16 | 1.97 | .132 | 1.68 | 8 | 2 | 1 |
| 4 | 17 | .40 | .131 | 7.95 | 172 | 43 | 11 |
| 5 | 16 | .85 | .100 | 2.94 | 23 | 6 | 2 |
| 6 | 16 | 5.69 | .483 | 2.12 | 16 | 3 | 1 |
| 7 | 14 | 2.49 | .228 | 2.08 | 14 | 4 | 1 |
| 8 | 16 | .52 | .073 | 3.96 | 32 | 8 | 2 |
| 9 | 14 | .89 | .091 | 2.69 | 17 | 5 | 1 |
| 10 | 16 | 3.33 | .252 | 1.89 | 10 | 3 | 1 |
| Watershed II: | | | | | | | |
| 1 | 9 | 12.01 | .957 | | | | |
| 2 | 10 | .26 | .030 | | | | |
| 3 | 15 | 2.34 | .180 | 1.98 | 10 | 3 | 1 |
| 4 | 15 | .30 | .138 | 11.71 | 331 | 83 | 21 |
| 5 | 16 | .81 | .102 | 3.12 | 25 | 7 | 2 |
| 6 | 16 | 6.75 | .713 | 2.64 | 18 | 5 | 2 |
| 7 | 16 | 2.54 | .245 | 2.41 | 15 | 4 | 1 |
| 8 | 16 | .70 | .077 | 2.72 | 20 | 5 | 2 |
| 9 | 15 | 1.35 | .184 | 3.53 | 30 | 8 | 2 |
| 10 | 14 | 3.61 | .410 | 3.05 | 21 | 6 | 2 |
| Watershed III: | | | | | | | |
| 1 | 5 | 10.06 | 1.745 | | | | |
| 2 | 5 | .21 | .045 | | | | |
| 3 | 5 | 2.65 | .464 | | | | |
| 4 | 6 | .22 | .099 | | | | |
| 5 | 8 | .75 | .035 | 1.65 | 4 | 1 | 1 |
| 6 | 9 | 6.52 | 1.006 | 5.14 | 38 | 10 | 3 |
| 7 | 10 | 2.45 | .154 | 1.99 | 7 | 2 | 1 |
| 8 | 11 | .82 | .100 | 3.67 | 24 | 6 | 2 |
| 9 | 11 | 1.22 | .159 | 3.95 | 13 | 4 | 1 |
| 10 | 10 | 3.42 | .535 | 4.94 | 39 | 10 | 3 |
| Watershed IV: | | | | | | | |
| 1 | 15 | 11.24 | 1.530 | | | | |
| 2 | 16 | .25 | .064 | | | | |
| 3 | 23 | 2.36 | .408 | 3.60 | 48 | 12 | 3 |
| 4 | 24 | .29 | .130 | 9.23 | 327 | 81 | 21 |
| 5 | 27 | .80 | .089 | 2.16 | 21 | 5 | 2 |
| 6 | 28 | 6.53 | .871 | 2.52 | 29 | 8 | 2 |
| 7 | 29 | 2.51 | .214 | 1.59 | 12 | 3 | 1 |
| 8 | 30 | .73 | .118 | 3.03 | 43 | 11 | 3 |
| 9 | 29 | 1.21 | .386 | 5.93 | 164 | 41 | 11 |
| 10 | 26 | 3.50 | .497 | 2.79 | 33 | 8 | 2 |
| Watershed V: | | | | | | | |
| 1 | 22 | 9.91 | .836 | | | | |
| 2 | 22 | .31 | .083 | | | | |
| 3 | 31 | 2.86 | .355 | 2.23 | 25 | 7 | 2 |
| 4 | 31 | .30 | .095 | 2.86 | 164 | 41 | 11 |
| 5 | 28 | .68 | .122 | 3.37 | 51 | 13 | 4 |
| 6 | 29 | 5.91 | .433 | 1.36 | 9 | 3 | 1 |
| 7 | 34 | 2.55 | .110 | .74 | 202 | 75 | 19 |
| 8 | 34 | .66 | .108 | 2.89 | 43 | 11 | 3 |
| 9 | 33 | 1.05 | .101 | 1.67 | 15 | 4 | 1 |
| 10 | 34 | 3.62 | .298 | 1.41 | 11 | 3 | 1 |
| Watershed VI: | | | | | | | |
| 1 | 50 | 10.43 | 1.450 | | | | |
| 2 | 49 | .32 | .132 | | | | |
| 3 | 71 | 2.50 | .452 | 2.15 | 53 | 14 | 4 |
| 4 | 73 | .32 | .125 | 4.63 | 251 | 63 | 16 |
| 5 | 78 | .74 | .139 | 2.12 | 56 | 14 | 4 |
| 6 | 80 | 6.04 | .739 | 1.37 | 24 | 6 | 2 |
| 7 | 84 | 2.55 | .247 | 1.01 | 15 | 4 | 1 |
| 8 | 87 | .65 | .129 | 2.19 | 64 | 16 | 4 |
| 9 | 84 | 1.08 | .280 | 2.85 | 109 | 28 | 7 |
| 10 | 82 | 3.46 | .426 | 1.36 | 25 | 6 | 2 |
| Watershed VII: | | | | | | | |
| 1 | 8 | 12.19 | .737 | | | | |
| 2 | 7 | .28 | .022 | | | | |
| 3 | 6 | 2.58 | .263 | | | | |
| 4 | 5 | .18 | .023 | | | | |
| 5 | 9 | .51 | .134 | 8.67 | 110 | 27 | 7 |
| 6 | 10 | 6.46 | .399 | 1.96 | 7 | 2 | 1 |
| 7 | 10 | 2.67 | .121 | 1.42 | 4 | 1 | 1 |
| 8 | 10 | .57 | .035 | 1.95 | 7 | 2 | 1 |
| 9 | 10 | .92 | .036 | 1.24 | 3 | 1 | 1 |
| 10 | 10 | 3.46 | .749 | 6.86 | 77 | 19 | 5 |
| Watershed VIII: | | | | | | | |
| 1 | 4 | 11.10 | 1.202 | | | | |
| 2 | 7 | .32 | .064 | 7.40 | 62 | 16 | 4 |
| 3 | 8 | 3.06 | .396 | 4.58 | 27 | 7 | 2 |
| 4 | 5 | .23 | .016 | 3.03 | | | |
| 5 | 6 | .53 | .048 | 3.72 | | | |
| 6 | 7 | 6.79 | .456 | 2.54 | 8 | 2 | 1 |
| 7 | 8 | 2.56 | .159 | 2.19 | 7 | 2 | 1 |
| 8 | 8 | .61 | .047 | 2.72 | 10 | 3 | 1 |
| 9 | 8 | 1.00 | .066 | 2.33 | 7 | 2 | 1 |
| 10 | 8 | 3.44 | .351 | 3.61 | 17 | 5 | 1 |
| Watershed IX: | | | | | | | |
| 1 | 4 | 12.94 | .130 | | | | |
| 2 | 4 | .39 | .036 | | | | |
| 3 | 11 | 3.55 | .283 | 2.40 | 11 | 3 | 1 |
| 4 | 11 | .23 | .043 | 5.63 | 56 | 14 | 4 |
| 5 | 11 | .46 | .046 | 3.02 | 16 | 4 | 1 |
| 6 | 11 | 7.41 | .484 | 1.97 | 8 | 2 | 1 |
| 7 | 11 | 2.48 | .215 | 2.62 | 12 | 3 | 1 |
| 8 | 11 | .67 | .054 | 2.45 | 11 | 3 | 1 |
| 9 | 11 | 1.03 | .112 | 2.28 | 19 | 5 | 2 |
| 10 | 11 | 3.68 | .513 | 4.20 | 32 | 8 | 2 |

TABLE 5.—*Rainfall averages and statistical constants, and the number of gages required to give various degrees of accuracy, in 10 intermediate watersheds*—Continued

| Watershed and storm No. | Observations | Rainfall | Standard deviation | Standard error | Gages required if ratio of S. E. to mean is— 2.5 percent | 5 percent | 10 percent |
|---|---|---|---|---|---|---|---|
| | *Number* | *Inches* | *Inches* | *Percent* | *Number* | *Number* | *Number* |
| Watershed X: | | | | | | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | 3 | 3.56 | .308 | | | | |
| 4 | 6 | .30 | .050 | | | | |
| 5 | 6 | .43 | .020 | | | | |
| 6 | 12 | 6.66 | .693 | 3.01 | 18 | 5 | 2 |
| 7 | 12 | 2.43 | .122 | 1.44 | 4 | 1 | 1 |
| 8 | 11 | .70 | .051 | 2.19 | 9 | 2 | 1 |
| 9 | 12 | 1.01 | .121 | 3.96 | 23 | 6 | 2 |
| 10 | 11 | 3.60 | .672 | 5.63 | 56 | 14 | 4 |

Records of rainfall for the city of Glendora covering 54 years give an average annual rainfall of 22.85 inches, of which only 9.3 percent (S. D., 5.4) fell in storms of less than half an inch and 22.3 percent (S. D., 13.3) in storms of less than 1 inch. From these data it may be estimated that rains of half an inch or less may seldom be expected to exceed 20 percent of the annual precipitation (mean+2 S. D.); and that storms of an inch or less will not be expected to exceed 50 percent of the total annual precipitation. From this knowledge, and to compromise with practical expediency in gage distribution, it was decided to set up the following arbitrary requirements of accuracy for storms of various magnitudes: For storms below 0.5 inch, a standard error of 10 percent; storms between 0.5 and 1 inch in size, 5 percent; and all larger storms, 2.5 percent.

Table 6 presents the number of gages at present installed in each intermediate watershed, and the approximate number which will be necessary in order to give the required accuracy of results. The latter figure is the simple average of the numbers apparently required for each of the 10 storms. Figure 5 is a map of the entire forest showing location of trails, rain gages and watershed boundaries.

By the beginning of the 1935–36 rainy season, the gage distribution was completed according to the requirements set up in the above analysis for watersheds I–VIII. To check the adequacy of sampling by these gages, a study was made of all storms of any appreciable size during this season, occurring on the following dates:

Storm No.—

| | |
|---|---|
| 11 | October 14, 1935. |
| 12 | November 17–18, 1935. |
| 13 | December 3–4, 1935. |
| 14 | December 29, 1935. |
| 15 | February 1–2, 1936. |
| 16 | February 10–20, 1936. |
| 17 | February 22–23, 1936. |
| 18 | March 21, 1936. |
| 19 | March 24, 1936. |
| 20 | March 30, 1936. |
| 21 | April 3–4, 1936. |

Table 7 shows that the standard errors of these rainfall averages were well within desirable limits for most storms. It will be noted in this respect that number of gages required as set up in table 6 are based on an average figure, and therefore, storms with an unusually high variability will fall outside the required limits of accuracy. (See standard errors *underlined*, in table 7.)

**Table 6.**—*Number of gages required statistically in 10 intermediate watersheds*

| Watershed No. | Present number gages | Total number gages required [1] | Watershed No. | Present number gages | Total number gages required [1] |
|---|---|---|---|---|---|
| I | 17 | 10 | VI | 87 | 34 |
| II | 16 | 16 | VII | 87 | 34 |
| III | 11 | 18 | VIII | 8 | 10 |
| IV | 30 | 40 | IX | 11 | 12 |
| V | 34 | 37 | X | 12 | 20 |

[1] Average number necessary to give standard errors ($S.E._M$) of 2½, 5 and 10 percent, respectively, for storms over 1 inch, between ½ and 1 inch, and under ½ inch. In computing these averages, storms were omitted in which variation was not completely sampled.

Present number of gages in watershed VI greater than number required, because it includes those in watersheds I, IV, and V.

**Table 7.**—*Rainfall averages and statistical constants, 10 intermediate watersheds, season 1935–36*

| Storm No. | Watershed I: Gages | Rainfall | Standard deviation | Standard error | Watershed II: Gages | Rainfall | Standard deviation | Standard error |
|---|---|---|---|---|---|---|---|---|
| | *Number* | *Inches* | *Inches* | *Percent* | *Number* | *Inches* | *Inches* | *Percent* |
| 11 | 9 | 0.28 | 0.081 | 9.7 | 8 | 0.30 | 0.087 | 10.2 |
| 12 | 13 | .40 | .043 | 3.0 | 13 | .45 | .065 | 4.0 |
| 13 | 11 | .33 | .098 | 9.0 | 17 | .31 | .111 | 8.7 |
| 14 | 20 | .84 | .144 | 3.8 | 20 | .83 | .071 | 2.0 |
| 15 | 24 | 3.91 | .574 | *3.0* | 20 | 4.62 | .518 | 2.6 |
| 16 | 24 | 10.71 | .620 | 1.2 | 17 | 11.04 | .598 | 1.3 |
| 17 | 23 | 1.86 | .159 | 1.8 | 20 | 1.97 | .189 | 2.1 |
| 18 | 23 | .37 | .101 | 5.7 | 22 | .28 | .102 | 7.8 |
| 19 | 23 | .61 | .080 | 2.7 | 22 | .64 | .087 | 2.9 |
| 20 | 23 | 1.54 | .150 | 2.0 | 23 | 1.99 | .195 | 2.0 |
| 21 | 24 | 1.92 | .166 | 1.8 | 23 | 2.24 | .253 | 2.4 |
| | **Watershed III** | | | | **Watershed IV (including II and III)** | | | |
| 11 | 2 | 0.23 | 0.010 | 3.1 | | | | |
| 12 | 14 | .35 | .035 | 2.6 | 28 | 0.40 | 0.070 | 3.3 |
| 13 | 15 | .28 | .070 | 6.5 | 35 | .30 | .090 | 5.2 |
| 14 | 14 | .74 | .073 | 2.6 | 43 | .80 | .082 | 1.6 |
| 15 | 15 | 4.09 | .627 | *3.9* | 43 | 4.30 | .604 | 2.1 |
| 16 | 15 | 10.58 | .975 | 2.4 | 40 | 10.76 | .768 | 1.1 |
| 17 | 15 | 1.79 | .123 | 1.8 | 44 | 1.89 | .177 | 1.4 |
| 18 | 18 | .24 | .085 | 8.5 | 50 | .28 | .099 | 5.0 |
| 19 | 18 | .61 | .071 | 2.7 | 50 | .62 | .079 | 1.8 |
| 20 | 19 | 1.96 | .262 | *3.1* | 52 | 1.94 | .224 | 1.6 |
| 21 | 18 | 2.26 | .153 | 1.6 | 51 | 2.20 | .232 | 1.5 |
| | **Watershed V** | | | | **Watershed VI (I, IV, V, inclusive)** | | | |
| 11 | 10 | 0.30 | 0.053 | 5.7 | 30 | 0.29 | 0.070 | 4.5 |
| 12 | 31 | .36 | .043 | 2.2 | 72 | .38 | .058 | 1.8 |
| 13 | 35 | .28 | .036 | 2.1 | 88 | .30 | .073 | 2.6 |
| 14 | 35 | .84 | .173 | 3.5 | 105 | .82 | .130 | 1.5 |
| 15 | 37 | 3.62 | .700 | *3.2* | 111 | 3.94 | .642 | 1.5 |
| 16 | 36 | 10.57 | 1.119 | 1.8 | 107 | 10.51 | 1.136 | 1.0 |
| 17 | 36 | 1.78 | .244 | 2.3 | 110 | 1.84 | .202 | 1.0 |
| 18 | 37 | .28 | .056 | 3.3 | 117 | .29 | .079 | 2.5 |
| 19 | 32 | .60 | .045 | 1.3 | 112 | .61 | .069 | 1.1 |
| 20 | 35 | 1.82 | .141 | 1.3 | 117 | 1.81 | .238 | 1.2 |
| 21 | 37 | 2.26 | .155 | 1.1 | 119 | 2.14 | .247 | 1.1 |

**Table 7.**—*Rainfall averages and statistical constants, 10 intermediate watersheds, season 1935–36*—Continued

| Storm No. | Watershed VII: Gages | Rainfall | Standard deviation | Standard error | Watershed VIII: Gages | Rainfall | Standard deviation | Standard error |
|---|---|---|---|---|---|---|---|---|
| | *Number* | *Inches* | *Inches* | *Percent* | *Number* | *Inches* | *Inches* | *Percent* |
| 11 | 4 | .27 | .006 | 1.1 | 6 | .30 | .012 | 1.6 |
| 12 | | | | | 9 | .36 | .025 | 2.3 |
| 13 | 9 | .33 | .023 | 2.3 | 9 | .32 | .018 | 1.9 |
| 14 | 9 | .77 | .040 | 1.7 | 9 | .75 | .074 | 3.3 |
| 15 | 9 | 3.93 | .251 | 2.1 | 8 | 3.60 | .208 | 2.0 |
| 16 | 9 | 11.67 | .406 | 1.2 | 9 | 11.54 | 1.045 | *3.0* |
| 17 | 9 | 1.86 | .151 | 2.7 | 9 | 1.63 | .152 | *3.1* |
| 18 | 9 | .24 | .042 | 5.8 | 9 | .25 | .039 | 5.1 |
| 19 | 9 | .61 | .053 | 2.9 | 9 | .63 | .036 | 1.9 |
| 20 | 9 | 1.82 | .135 | 2.5 | 9 | 1.87 | .178 | *3.1* |
| 21 | 9 | 2.10 | .219 | *3.5* | 9 | 2.24 | .238 | *3.5* |
| | **Watershed IX** | | | | **Watershed X** | | | |
| 11 | | | | | | | | |
| 12 | 10 | .43 | .089 | 6.6 | 9 | .44 | .054 | 4.1 |
| 13 | 10 | .33 | .022 | 2.1 | 11 | .37 | .030 | 2.4 |
| 14 | 3 | .85 | .040 | 2.7 | 5 | .81 | .203 | *11.3* |
| 15 | 10 | 4.02 | .826 | *6.5* | 10 | 3.94 | .643 | *5.2* |
| 16 | 10 | 12.58 | .818 | 2.1 | 10 | 12.90 | 1.047 | 2.6 |
| 17 | 10 | 1.36 | .184 | *4.3* | 11 | 1.38 | .260 | *5.7* |
| 18 | 10 | .20 | .073 | *11.5* | 11 | .28 | .080 | 8.6 |
| 19 | 10 | .65 | .052 | 2.5 | 11 | .64 | .061 | 2.9 |
| 20 | 10 | 2.07 | .116 | 1.8 | 11 | 2.03 | .169 | 2.5 |
| 21 | 10 | 2.31 | .232 | *3.2* | 11 | 2.20 | .245 | *3.4* |

| Storm No. | Entire forest above flood-control dams: Gages | Rainfall | Standard deviation | Standard error | Storm No. | Entire forest above flood-control dams: Gages | Rainfall | Standard deviation | Standard error |
|---|---|---|---|---|---|---|---|---|---|
| | *Number* | *Inches* | *Inches* | *Percent* | | *Number* | *Inches* | *Inches* | *Percent* |
| 11 | 50 | 0.31 | 0.107 | 4.8 | 17 | 180 | 1.70 | 0.285 | 1.2 |
| 12 | 125 | .39 | .062 | 1.4 | 18 | 187 | .29 | .102 | 2.5 |
| 13 | 153 | .31 | .060 | 1.5 | 19 | 179 | .61 | .067 | .8 |
| 14 | 157 | .81 | .126 | 1.2 | 20 | 188 | 1.84 | .313 | 1.2 |
| 15 | 178 | 3.80 | .698 | 1.4 | 21 | 191 | 2.10 | .349 | 1.2 |
| 16 | 176 | 10.90 | 1.301 | .9 | | | | | |

In table 8, the deviation of rainfall catch computed by simple averages from those obtained by isohyetal maps are excessive only in small storms, for which only a part of the rain gages had been read and these not well enough distributed to sample adequately individual watersheds.

**Table 8.**—*Comparison of precipitation catch computed by using simple average with that obtained by isohyetal method on 10 intermediate watersheds, extensive system, season 1935–36*

| Storm No. | Watershed I: Isohyetal method | Simple average | Deviation | Watershed II: Isohyetal method | Simple average | Deviation | Watershed III: Isohyetal method | Simple average | Deviation | Watershed IV: Isohyetal method | Simple average | Deviation | Watershed V: Isohyetal method | Simple average | Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* | *Acre-feet* | *Acre-feet* | *Percent* |
| 11 | 42.08 | 40.91 | −2.8 | 32.25 | 36.51 | +13.0 | 28.33 | 27.63 | −2.5 | | | | 75.80 | 75.57 | −.3 |
| 12 | 60.44 | 59.18 | −2.1 | 52.73 | 54.64 | +3.6 | 43.54 | 42.51 | −2.4 | 119.59 | 121.54 | +1.6 | 86.03 | 90.56 | +5.3 |
| 13 | 43.41 | 47.45 | +9.3 | 36.88 | 37.82 | +2.5 | 33.11 | 33.78 | +2.0 | 90.16 | 90.64 | +.5 | 72.45 | 71.98 | −.6 |
| 14 | 116.36 | 121.95 | +4.8 | 101.41 | 102.51 | +1.1 | 92.83 | 91.80 | −1.1 | 253.09 | 252.63 | −.2 | 208.96 | 212.58 | +1.7 |
| 15 | 580.44 | 548.49 | −5.5 | 552.66 | 555.76 | +.6 | 505.86 | 499.21 | −1.3 | 1,286.55 | 1,301.48 | +1.2 | 925.12 | 913.18 | −1.3 |
| 16 | 1,569.94 | 1,571.97 | +.1 | 1,354.01 | 1,358.79 | +.4 | 1,305.19 | 1,317.21 | +.9 | 2,969.83 | 3,019.55 | +1.7 | 2,751.15 | 2,705.53 | −1.7 |
| 17 | 279.79 | 273.56 | −2.2 | 242.10 | 242.87 | +.3 | 222.02 | 220.62 | −.6 | 582.20 | 581.79 | −.1 | 453.31 | 452.13 | −.3 |
| 18 | 48.61 | 54.21 | +11.5 | 30.74 | 33.83 | +10.3 | 29.55 | 28.67 | −3.0 | 81.83 | 86.00 | +5.1 | 70.24 | 72.13 | +2.7 |
| 19 | 84.75 | 90.14 | +6.4 | 77.83 | 78.98 | +1.5 | 73.06 | 74.71 | +2.3 | 186.87 | 190.61 | +2.0 | 153.37 | 151.93 | −.9 |
| 20 | 220.86 | 226.96 | +2.8 | 243.50 | 241.72 | −.7 | 243.59 | 238.39 | −2.1 | 599.05 | 593.49 | −.2 | 456.94 | 462.32 | +1.2 |
| 21 | 275.39 | 280.70 | +1.9 | 279.70 | 274.52 | −1.9 | 272.92 | 276.34 | +1.3 | 670.71 | 673.52 | +.4 | 582.13 | 575.44 | −1.1 |
| | **Watershed VI** | | | **Watershed VII** | | | **Watershed VIII** | | | **Watershed IX** | | | **Watershed X** | | |
| 11 | 210.74 | 219.03 | +3.9 | 24.67 | 22.00 | −10.8 | 23.82 | 22.83 | −4.1 | 21.35 | 35.21 | +64.9 | | | |
| 12 | 286.25 | 290.28 | +1.4 | | | | 26.57 | 27.21 | +2.4 | 29.29 | 29.40 | +.4 | 36.27 | 36.76 | +1.3 |
| 13 | 224.23 | 226.41 | +1.0 | 29.21 | 28.45 | −2.6 | 23.73 | 24.53 | +3.4 | 23.42 | 22.49 | −4.0 | 32.65 | 30.59 | −6.3 |
| 14 | 615.16 | 624.92 | +1.6 | 64.43 | 63.47 | −1.5 | 56.67 | 60.42 | +6.6 | 50.63 | 59.25 | +17.0 | 60.29 | 66.91 | +10.5 |
| 15 | 3,031.85 | 3,028.04 | −.1 | 335.43 | 327.89 | −2.2 | 298.41 | 287.21 | −3.8 | 280.71 | 277.37 | −1.2 | 349.13 | 328.06 | −6.0 |
| 16 | 8,148.88 | 8,059.26 | −1.1 | 925.58 | 954.98 | +3.2 | 927.15 | 945.05 | +1.9 | 871.48 | 868.63 | −.3 | 1,038.68 | 1,069.14 | +2.9 |
| 17 | 1,416.21 | 1,409.33 | −.5 | 147.58 | 153.79 | +4.0 | 120.93 | 132.28 | +9.4 | 95.13 | 92.92 | −2.3 | 117.19 | 114.96 | −1.9 |
| 18 | 212.50 | 225.35 | +6.0 | 20.50 | 20.43 | +.3 | 18.27 | 20.50 | +12.2 | 15.65 | 14.16 | −9.5 | 24.63 | 23.60 | −4.2 |
| 19 | 457.13 | 465.95 | +1.9 | 53.10 | 52.89 | −.4 | 44.01 | 48.12 | +9.3 | 45.75 | 44.85 | −2.0 | 53.93 | 52.80 | −2.1 |
| 20 | 1,349.65 | 1,379.32 | +2.0 | 152.10 | 156.70 | +3.0 | 144.74 | 143.83 | +.6 | 144.70 | 143.22 | −1.0 | 170.25 | 167.82 | −1.4 |
| 21 | 1,629.03 | 1,629.99 | 0 | 168.94 | 177.48 | +5.1 | 172.32 | 170.34 | −1.1 | 161.52 | 159.23 | −1.4 | 188.80 | 182.58 | −3.3 |

### CONCLUSIONS

1. A mechanical distribution of gages such as described in this study appears to give reasonably thorough sampling of rainfall variation in mountain watersheds. Additions to or modifications of such distributions in order to improve sampling may be made by a study of isohyetal maps and statistical constants based upon a preliminary rain gage installation.

2. The gage system employed iu this experiment gives results accurate for most storms measured, within practical limits.

3. In order to avoid employing an impracticably large number of rain gages, the requirements for accuracy of averages should be modified in inverse relation to the size and importance of storms.

4. With a system of gages distributed so as to sample rainfall variation as thoroughly as possible, a simple average of their readings will agree within close limits with rainfall catch computed from isohyetal maps. Application of the former method requires much less time and skill than the isohyetal method.

# PRELIMINARY RESULTS OF PILOT-BALLOON ASCENTS AT LITTLE AMERICA

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The meteorological observations at Little America during the two Byrd Expeditions include 969 pilot-balloon ascents. These have been worked up fairly completely and the results of the two years of observation combined, although it has not yet been possible to give the results the study they deserve, it will be of interest to point out some of the more obvious facts which they disclose.

From the combined data for both the expeditions, there have been computed the mean direction and mean velocity as well as the resultant direction, resultant velocity, and stability. The above quantities have also been worked out for each of the 4 seasons.

The mean direction should be distinguished from the resultant direction; the former is computed by using the frequency with which the different directions occur, while the latter is computed by using the velocities as well as the directions and gives the direction of the vector representing the resultant air transport.

The stability, mentioned above, refers to directional stability, and is computed by forming the ratio $\frac{\text{resultant velocity}}{\text{mean velocity}} \times 100$; this gives a measure of the steadiness of the wind direction, for, if the wind always blows from the same direction, the resultant velocity and the mean velocity are the same and the stability is 100 percent. If, on the other hand, the directions are equally distributed and also have the same velocity, the resultant velocity and therefore the stability will be zero.

TABLE 1.—*Mean values of direction, velocity, and stability of the wind at Little America* [1]

[Based on 2 years of observation, 1929 and 1934]

| Altitude (meters) | Number of observations | Mean direction from— | Resultant direction from— | Mean velocity | Resultant velocity | Stability | Mean direction—resultant direction |
|---|---|---|---|---|---|---|---|
| | | | | *m. p. s.* | *m. p. s.* | *Percent* | |
| 12,000 | 4 | N 19° W | N 7° W | 17.5 | 6.8 | 39 | −12° |
| 11,000 | 9 | N 8° W | N 18° W | 11.6 | 5.7 | 49 | 10° |
| 10,000 | 30 | N 8° E | N 5° W | 8.9 | 3.2 | 36 | 13° |
| 9,000 | 65 | N 12° E | N 14° W | 11.0 | 2.2 | 20 | 26° |
| 8,000 | 115 | N 10° W | N 59° W | 13.0 | 3.7 | 28 | 49° |
| 7,000 | 172 | N 23° W | N 66° W | 12.5 | 3.2 | 26 | 43° |
| 6,000 | 236 | N 37° W | N 70° W | 11.2 | 2.4 | 21 | 33° |
| 5,000 | 318 | N 55° W | S 85° W | 9.7 | 1.2 | 12 | 40° |
| 4,000 | 415 | S 1° E | S 28° W | 8.4 | 1.0 | 12 | −29° |
| 3,000 | 549 | S | S 29° W | 7.7 | 1.4 | 18 | −29° |
| 2,500 | 625 | S 9° E | S | 7.4 | 1.5 | 20 | −9° |
| 2,000 | 704 | S 17° E | S 9° E | 7.4 | 2.0 | 27 | −8° |
| 1,500 | 772 | S 18° E | S 9° E | 7.3 | 2.2 | 30 | −9° |
| 1,000 | 854 | S 20° E | S 10° E | 7.4 | 2.0 | 27 | −10° |
| 750 | 883 | S 25° E | S 16° E | 7.5 | 2.0 | 27 | −9° |
| 500 | 924 | S 34° E | S 30° E | 7.7 | 2.3 | 30 | −4° |
| 250 | 957 | S 35° E | S 40° E | 7.1 | 2.9 | 41 | 5° |
| Surface | 969 | S 22° E | S 40° E | 4.0 | 1.8 | 45 | 18° |

[1] Latitude 78°34′06″ south, longitude 163°55′58″ west.

In table 1 are given the mean values of the direction, velocity, and stability of the wind at standard levels for the 2 years of observation, 1929 and 1934. The vertical

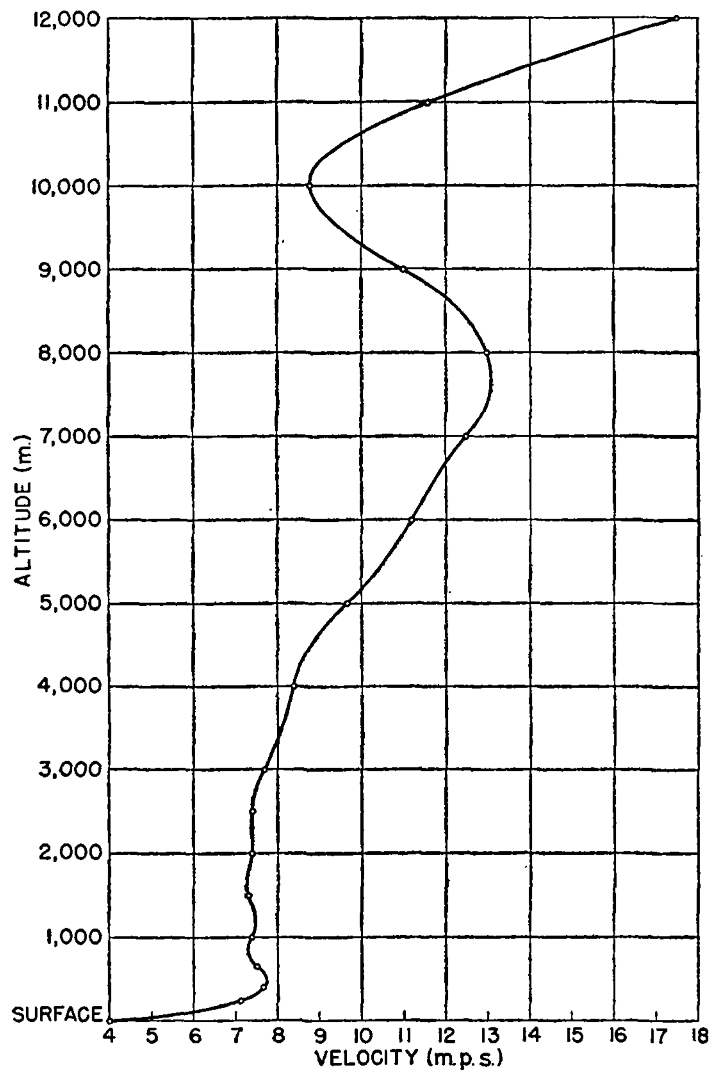


FIGURE 1.—Vertical distribution of the mean wind velocity at Little America.

distribution of the mean velocity is shown in figure 1, from which it is seen that a maximum value is reached at about 7,700 m. From the studies of Peppler (1) and Dobson (1A), this wind maximum can be related to the