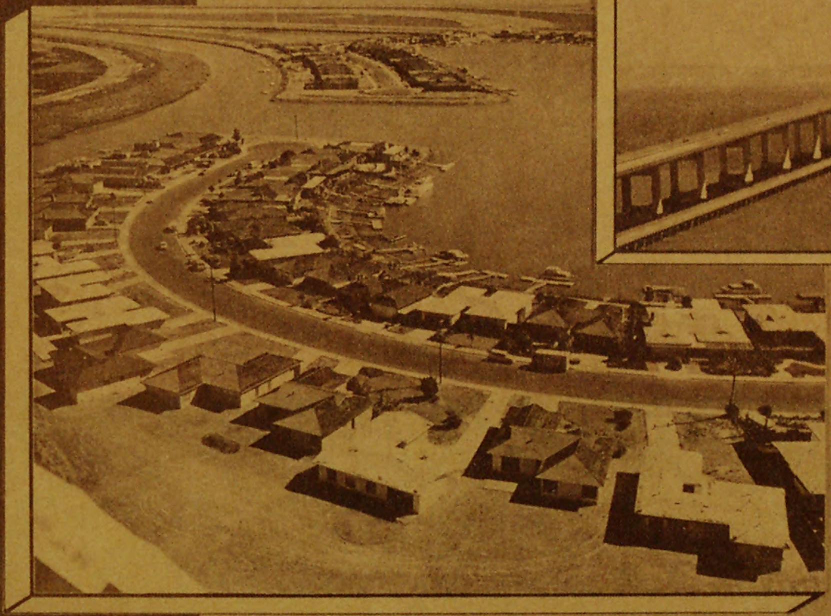
BASIC DATA CONTRIBUTION 25



# PRECIPITATION DEPTH-DURATION-FREQUENCY RELATIONS FOR THE SAN FRANCISCO BAY REGION, CALIFORNIA

by

S. E. Rantz

1971

with ISOHYETAL MAP OF SAN FRANCISCO BAY REGION, CALIFORNIA, SHOWING MEAN ANNUAL PRECIPITATION

U.S. Geological Survey

## SAN FRANCISCO BAY REGION ENVIRONMENT AND RESOURCES PLANNING STUDY

Basic data contribution 25

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
U. S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
RESEARCH AND TECHNOLOGY

# PRECIPITATION DEPTH-DURATION-FREQUENCY RELATIONS FOR THE SAN FRANCISCO BAY REGION, CALIFORNIA

By S. E. RANTZ, Menlo Park, Calif.

*Work done in cooperation with the U.S. Department of Housing and Urban Development*

*Abstract*.—Precipitation depth-duration-frequency relations have been derived for the San Francisco Bay region, California. The regimen of precipitation in the region is such that depth-duration-frequency characteristics for a site are closely related to the mean annual precipitation for that site.

The purpose of this study was to derive precipitation depth-duration-frequency data for the San Francisco Bay region to be used as criteria for both local drainage design and the study of the stability of land slopes. The study region encompasses 7,416 square miles in the nine counties surrounding San Francisco Bay (fig. 1). The frequencies studied were those corresponding to recurrence intervals of 2, 5, 10, 25, 50, and 100 years; the durations studied ranged from 5 minutes to 60 consecutive days. Data for the shorter durations are required for local drainage design and also for the study of surface-erosion potential, with land slope and soil type as additional factors. Data for the longer durations, to be used in conjunction with land slope and soil and geologic factors, are needed for the study of land-slippage potential.

## REGIONAL REGIMEN OF PRECIPITATION

Precipitation in the region is highly seasonal; almost 90 percent of the annual precipitation occurs during the 6-month period November through April. The great bulk of that precipitation occurs in a series of general storms that reach all parts of the region, but the storm centers usually pass to the north of the region, and the result is a general tendency for precipitation to decrease from north to south. Altitude has a strong local influence on the depth of precipitation, and because altitudes range from sea level to 4,400 feet, there is a wide range in mean annual precipitation in the San Francisco Bay region—from 10 inches in low-lying valley areas in the east to 80 inches in some mountain areas in the north. Winter precipitation often occurs as snow at altitudes above 2,000 feet, but snowfalls are generally light, and snow does not remain on the ground for more than a few days. Snow, therefore, has an insignificant role in the hydrology of the region. Intense local convective storms are almost unknown in the region.

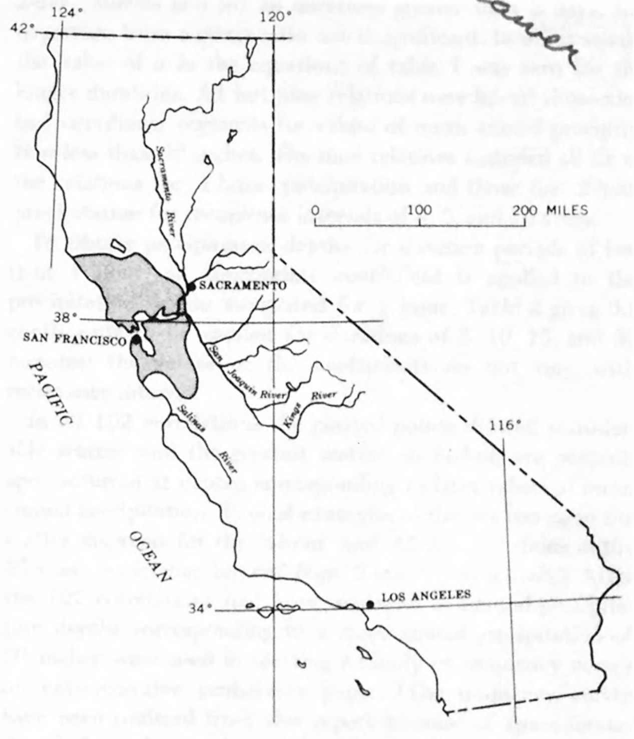



Figure 1.—Location map of California, showing report area (shaded).

## DATA AVAILABLE FOR ANALYSIS

The end product of this study, as mentioned earlier, is a set of precipitation depth-duration-frequency relations for use anywhere within the study region. A preliminary step is the preparation of such data for climatological stations in and near the region. For each year of record at a station a tabulation is made of the maximum precipitation depth experienced for each of the duration periods under consideration. A theoretical statistical distribution is then fitted to the array of annual data for each individual duration period, and precipitation depths for selected recurrence intervals are computed. The California Department of Water Resources has such computations in its files and graciously made them available for this study. Included were data for 35 recording and 45 nonrecording stations. A Pearson type III distribution had been fitted to the arrayed precipitation depths. Duration periods used for the recording stations were 1, 2, 3, 6, 12, and 24 hours; duration periods used for the nonrecording stations were 1, 2, 3, 4, 5, 6, 8, 10, 15, 20, 30, and 60 consecutive days.

For the 35 recording stations, the mean annual precipitation ranged from 9 to 62 inches. For 32 of those stations, the number of years of record ranged from 11 to 28. The other three stations had much longer records—Sacramento, 66 years; San Francisco, 79 years; and San Jose, 60 years.

For the 45 nonrecording stations, the mean annual precipitation ranged from 9 to 73 inches. The number of years of record at the stations ranged from 17 to 94. However, 30 of the stations had more than 30 years of record, and of those, 15 had more than 60 years of record.

## METHOD OF ANALYSIS

The reasoning behind the method used for obtaining depth-duration-frequency relations for ungaged sites was as follows: The bulk of the annual precipitation occurs in several general storms each year, and all areas in the San Francisco Bay region usually experience all these storms. Furthermore, intense local convective storms are almost unknown in the region. Although more rainy days occur at sites that receive greater annual precipitation, there usually is not a great difference among sites in the duration of any particular storm in the region. Therefore, we expect a relation to exist between the mean annual precipitation at a site and the depth of precipitation there for a given duration period and a given recurrence interval. In other words, if the total number of hours or days of precipitation does not vary greatly among sites in the region, there should be a general relation between precipitation intensity and total depth of precipitation. However, because the average annual number of rainy days at a given site is usually greater than the number at another site having less total precipitation, we do not expect the relation to be in the form of a direct ratio. For example, although site A experiences twice as great a mean annual precipitation as site B, we expect the storm precipitation for a short period at site A to be something less than twice that at site B. We also expect the departure from a direct ratio to be more pronounced for the shorter duration periods.

On the basis of the above reasoning, precipitation depths at all appropriate stations for each of the 17 duration periods (1 hour to 60 days) were correlated graphically with their mean annual values. An individual relation was determined for each of the six recurrence intervals chosen for study—2, 5, 10, 25, 50, and 100 years. This resulted in 102 curves of relation—six recurrence intervals for each of the 17 duration periods. Some of the relations were adjusted slightly for internal consistency, as will be explained later, and equations describing the final form of all 102 relations were obtained. These equations, to be used with mean annual precipitation values between 10 and 80 inches, are shown in table 1. Although it had been expected that the relations would not be in the form of a direct ratio, it was found that for the four largest recurrence intervals for 2-day storms and for all durations greater than 2 days, the departure from a direct ratio was insignificant. In other words, the value of $a$ in the equations of table 1 was zero for the longer durations. All but nine relations were linear; those nine had curvilinear segments for values of mean annual precipitation less than 20 inches. The nine relations included all six of the relations for 1-hour precipitation and those for 2-hour precipitation for recurrence intervals of 2, 5, and 10 years.

To obtain precipitation depths for duration periods of less than 1 hour, an appropriate coefficient is applied to the precipitation depths computed for 1 hour. Table 2 gives the coefficients to be applied for durations of 5, 10, 15, and 30 minutes; the values of the coefficients do not vary with recurrence interval.

In all 102 correlations the plotted points showed considerable scatter, and the greatest scatter—in inches, not percentage—occurred at depths corresponding to large values of mean annual precipitation. Typical examples of this are shown in the scatter diagrams for the 3-hour and 15-day durations at the 25-year recurrence interval (figs. 2 and 3, respectively). After the 102 correlations had been made, all computed precipitation depths corresponding to a mean annual precipitation of 80 inches were used in plotting a family of frequency curves on extreme-value probability paper. (The frequency curves have been omitted from this report because of space limitations.) In order to have smooth frequency curves passing through, or very close to, all the plotted points, it was necessary to adjust the values of some of the points. This in turn made it necessary to adjust the coefficient $b$, or slope, of several of the preliminary depth-duration-frequency relations, but none of the coefficients required a change of more than about 3 percent. The purpose behind all these adjustments was to ensure internal consistency among the 102 derived relations, the reasoning being that the form of the derived relations in table 1 is such that if smooth frequency curves are achieved for precipitation depths corresponding to a mean annual precipitation of 80 inches, all frequency curves corresponding to lesser precipitation depths will likewise be smooth.

All equations given in table 1 are in their final adjusted form. To provide a measure of the scatter of the plotted points

Table 1.—*Regression equations for precipitation depths of various durations at selected recurrence intervals*

| Duration (consecutive time units) | Recurrence interval, $T$ (years) | Values of constants in regression equation: $P_T = a + bP_{MA}$[1] $a$ | $b$ |
|---|---|---|---|
| 1 hour . . . . . . . | [2]2 | 0.32 | 0.0080 |
| | [2]5 | .40 | .0105 |
| | [2]10 | .50 | .0115 |
| | [2]25 | .60 | .0130 |
| | [2]50 | .65 | .0140 |
| | [2]100 | .70 | .0150 |
| 2 . . . . . . . . . . | [2]2 | .40 | .015 |
| | [2]5 | .50 | .019 |
| | [2]10 | .55 | .021 |
| | 25 | .68 | .022 |
| | 50 | .75 | .023 |
| | 100 | .80 | .025 |
| 3 . . . . . . . . . . | 2 | .40 | .023 |
| | 5 | .50 | .028 |
| | 10 | .60 | .031 |
| | 25 | .70 | .033 |
| | 50 | .80 | .034 |
| | 100 | .90 | .035 |
| 6 . . . . . . . . . . | 2 | .50 | .041 |
| | 5 | .60 | .054 |
| | 10 | .70 | .060 |
| | 25 | .80 | .066 |
| | 50 | .90 | .070 |
| | 100 | 1.00 | .073 |
| 12 . . . . . . . . . . | 2 | .32 | .072 |
| | 5 | .60 | .084 |
| | 10 | .80 | .090 |
| | 25 | .90 | .100 |
| | 50 | 1.10 | .105 |
| | 100 | 1.25 | .110 |
| 1 day. . . . . . . . | 2 | 0.20 | 0.100 |
| | 5 | .30 | .130 |
| | 10 | .40 | .150 |
| | 25 | .50 | .175 |
| | 50 | .70 | .190 |
| | 100 | .80 | .205 |
| 2 . . . . . . . . . . | 2 | .20 | .132 |
| | 5 | .10 | .190 |
| | 10 | 0 | .230 |
| | 25 | 0 | .275 |
| | 50 | 0 | .305 |
| | 100 | 0 | .340 |
| 3 . . . . . . . . . . | 2 | 0 | .160 |
| | 5 | 0 | .220 |
| | 10 | 0 | .260 |
| | 25 | 0 | .306 |
| | 50 | 0 | .340 |
| | 100 | 0 | .370 |
| 4 . . . . . . . . . . | 2 | 0 | .175 |
| | 5 | 0 | .240 |
| | 10 | 0 | .285 |
| 4 days (con.) . . . | 25 | 0 | 0.340 |
| | 50 | 0 | .380 |
| | 100 | 0 | .420 |
| 5 . . . . . . . . . . | 2 | 0 | .185 |
| | 5 | 0 | .260 |
| | 10 | 0 | .300 |
| | 25 | 0 | .360 |
| | 50 | 0 | .400 |
| | 100 | 0 | .440 |
| 6 . . . . . . . . . . | 2 | 0 | .200 |
| | 5 | 0 | .280 |
| | 10 | 0 | .325 |
| | 25 | 0 | .385 |
| | 50 | 0 | .430 |
| | 100 | 0 | .470 |
| 8 . . . . . . . . . . | 2 | 0 | .225 |
| | 5 | 0 | .305 |
| | 10 | 0 | .350 |
| | 25 | 0 | .410 |
| | 50 | 0 | .450 |
| | 100 | 0 | .490 |
| 10 . . . . . . . . . . | 2 | 0 | .245 |
| | 5 | 0 | .330 |
| | 10 | 0 | .380 |
| | 25 | 0 | .440 |
| | 50 | 0 | .480 |
| | 100 | 0 | .520 |
| 15 . . . . . . . . . . | 2 | 0 | .285 |
| | 5 | 0 | .380 |
| | 10 | 0 | .440 |
| | 25 | 0 | .510 |
| | 50 | 0 | .560 |
| | 100 | 0 | .610 |
| 20 . . . . . . . . . . | 2 | 0 | .310 |
| | 5 | 0 | .425 |
| | 10 | 0 | .490 |
| | 25 | 0 | .570 |
| | 50 | 0 | .630 |
| | 100 | 0 | .680 |
| 30 . . . . . . . . . . | 2 | 0 | .370 |
| | 5 | 0 | .500 |
| | 10 | 0 | .580 |
| | 25 | 0 | .670 |
| | 50 | 0 | .735 |
| | 100 | 0 | .800 |
| 60 . . . . . . . . . . | 2 | 0 | .530 |
| | 5 | 0 | .720 |
| | 10 | 0 | .825 |
| | 25 | 0 | .950 |
| | 50 | 0 | 1.050 |
| | 100 | 0 | 1.130 |

[1] Where $P_T$ = precipitation, in inches, corresponding to recurrence interval of $T$ years; $P_{MA}$ = mean annual precipitation, in inches; $a$ and $b$ are constants.

[2] Equation does not apply for values of mean annual precipitation ($P_{MA}$) less than 20 inches, because relation is curvilinear for short-duration precipitation in subhumid areas.

Table 2.—*Coefficients to convert 1-hour storm precipitation to storm precipitation for shorter duration periods*

| Duration (minutes) | Coefficient[1] |
|---|---|
| 5 | 0.29 |
| 10 | .45 |
| 15 | .57 |
| 30 | .79 |

[1] Adapted from U.S. Weather Bureau (1961, p. 2, 5).

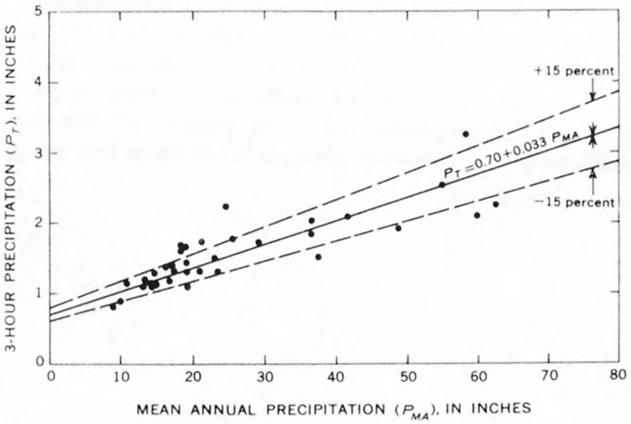



Figure 2.—Scatter diagram relating mean annual precipitation to 3-hour precipitation for the 25-year recurrence interval.

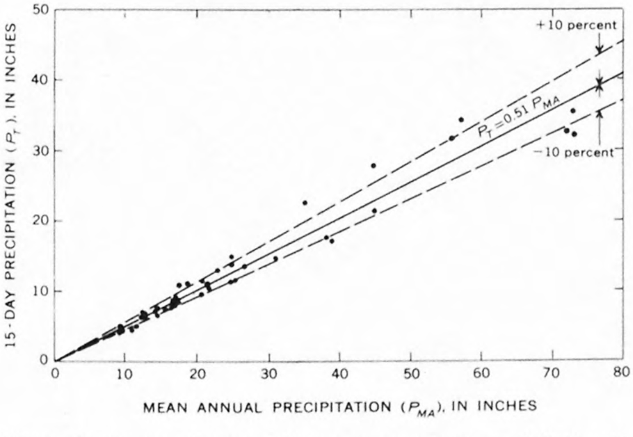



Figure 3.—Scatter diagram relating mean annual precipitation to 15-day precipitation for the 25-year recurrence interval.

in the 102 relations, the tabulation in the next column gives a generalized index of the standard error of the relations. The index shows the percentage deviation from the relations that includes about two-thirds of the plotted points. For example, the relation shown in figure 2 has two-thirds of the plotted points within the ±15 percent band; the relation in figure 3 has two-thirds of the plotted points within the ±10 percent band.

| *Duration (days)* | *Recurrence interval (years)* | *Error index (percent)* |
|---|---|---|
| Less than 1 | 2, 5 | ±10 |
| | 10, 25 | ±15 |
| | 50, 100 | ±20 |
| 1–8 | 2, 5 | ±10 |
| | 10, 25, 50 | ±15 |
| | 100 | ±20 |
| 10–15 | 2, 5, 10, 25 | ±10 |
| | 50, 100 | ±15 |
| 20–60 | All recurrence intervals | ±10 |

## USE OF THE DERIVED PRECIPITATION RELATIONS

To obtain depth-duration-frequency data for any given site in the San Francisco Bay region, first obtain the mean annual precipitation for that site from an isohyetal map. To that value apply the appropriate equations in table 1 for the durations and frequencies that are required. For storm durations of less than 1 hour, first obtain the precipitation for a 1-hour storm of the required frequency, then multiply that value by the appropriate coefficient from table 2. For sites whose mean annual precipitation is less than 20 inches, table 1 indicates that a curvilinear relation exists between mean annual precipitation and storm precipitation of duration shorter than 3 hours; therefore, do not use the first nine equations listed in table 1 for such sites. Space limitations preclude graphical depiction of the nine relations that are curvilinear; they are shown in the as yet unpublished original report from which this paper was abstracted.

## EVALUATION OF RESULTS

As mentioned earlier, the 102 correlations involving storm depth and mean annual precipitation had graphical standard errors of estimate ranging from 10 to 20 percent. Much of this error can properly be ascribed to local departures from the regional relation, although no systematic geographical pattern of departure was evident. However, some of the error may arise from the time-sampling variation introduced by the combining of short-term records with long-term records. It is probable that estimates made from the regional relations are more accurate than estimates derived from short-term records, even at the location of the short-term station. The explanation for that statement is as follows: (1) The station data used in the analysis were derived, as stated earlier, by fitting a Pearson type III distribution to observed data; (2) the Pearson type III distribution uses the coefficient of skew as one of its parameters; (3) use of the coefficient of skew computed from a short array of data may often result in a biased distribution, particularly if unusually large or small values of precipitation are included in the short array of observed data.

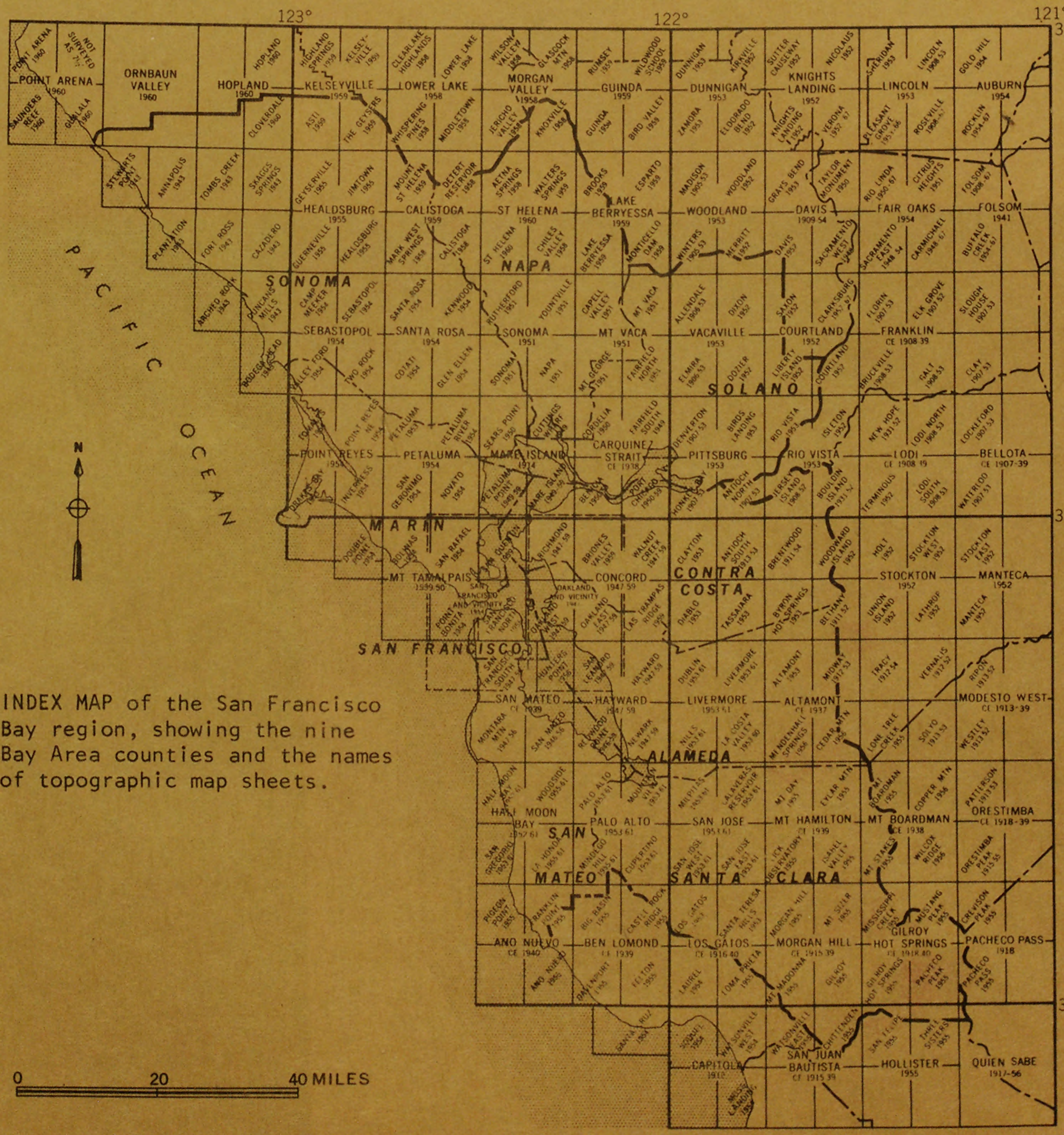
The 102 correlations are independent of the isohyetal map to which they will be applied because the station values of mean annual precipitation used in the correlations were not obtained from any map, but were the mean annual values computed for the various periods of record used in the analysis. The relations may therefore be used with any isohyetal map of mean annual precipitation for the study area; the more reliable the map, the more reliable the final results will be.

It is anticipated that this report may raise two questions in the mind of the reader, and it seems appropriate to conclude with a reply to those anticipated questions. It is easy enough for the reader to see the necessity for precipitation depth-frequency data of short duration for drainage design, but he may well ask: "Why must similar data be obtained for the longer durations for slope-stability studies, in view of the fact that storm precipitation correlates so well with mean annual precipitation; why not just use mean annual precipitation as an index of storm precipitation? Furthermore, why were data computed for so many different duration periods?" In answer to the first question, if we were interested in slope-stability problems solely in the San Francisco Bay region, the use of mean annual precipitation as an index of storm precipitation would probably be adequate. However if the results of slope-stability studies are to have transfer value for use in other regions, and if in those other regions differing relations of storm precipitation to mean annual precipitation exist, as they undoubtedly do, it is necessary that we use actual values of storm precipitation, rather than general index values. In answer to the second question, depth-duration-frequency data were provided for many duration periods because we cannot tell in advance which duration periods will be critical in slope-stability studies.

## REFERENCE

U.S. Weather Bureau, 1961, Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: U.S. Weather Bur. Tech. Paper 40, 115 p.

BASIC DATA CONTRIBUTION 25




INDEX MAP of the San Francisco Bay region, showing the nine Bay Area counties and the names of topographic map sheets.

FURTHER INFORMATION and a listing of publications pertaining to the San Francisco Bay Region Environment and Resources Planning Study may be obtained from the Geological Survey Public Inquiries Office, 504 Custom House, 555 Battery Street, San Francisco, California 94111 or from the U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025.