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TECHNICAL PAPER NO. 53

Two- to Ten-Day Rainfall for Return Periods of 2 to 100 Years in Puerto Rico and Virgin Islands

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PREFACE

Authority. This report was prepared for the Soil Conservation Service to provide generalized rainfall information for planning and design purposes in connection with its Watershed Protection and Flood Prevention Program (authorization: P.L. 566, 83d Congress, and as amended).

Scope. Precipitation data for various hydrologic design problems involving areas up to 400 square miles and durations of 2 to 10 days are presented. The data consist of generalized estimates of rainfall-frequency values for return periods of 2 to 100 years.

Accuracy of results. The accuracy of the generalized estimates depicted on the rainfall-frequency maps presented in this report is believed to be adequate for most engineering purposes. The accuracy of the results obtained is greater than might be expected from the approximately 65 stations used since the approach involved the use of the 24-hour rainfall-frequency maps of *Technical Paper No. 42* [1] as a base. These maps were constructed from data for about 120 stations.

Acknowledgments. The project was under the general supervision of J. L. H. Paulhus, Manager, Water Management Information Division of the Office of Hydrology, W. E. Hiatt, Director. W. E. Miller and N. S. Foat supervised the collection and processing of the basic data. The comments and suggestions by personnel of the Water Management Information Division in the preparation and review of this report are gratefully acknowledged. Coordination with the Soil Conservation Service was maintained through H. O. Ogrosky, Chief, Hydrology Branch, Engineering Division.

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1. INTRODUCTION

"Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands," [1] presents estimates of rainfall-frequency values for durations of 30 minutes to 24 hours and return periods of 1 to 100 years. The present report is an extension of that work. In a series of maps and diagrams this report provides generalized estimates of the rainfall-frequency regime of Puerto Rico and Virgin Islands for durations of 2 to 10 days and for return periods of 2 to 100 years.

A relation for obtaining 2-year 10-day rainfall values from 24-hour data and orientation was developed (fig. 4). The 2-year 10-day maps were then constructed (figs. 29 and 53). These maps were used in combination with a 100-year to 2-year ratio map for Puerto Rico (fig. 7) and a uniform 100-year to 2-year ratio for the Virgin Islands to prepare the 100-year 10-day maps (figs. 34 and 58). These 4 maps, the 2-year and 100-year 10-day maps for Puerto Rico and the Virgin Islands, together with the 24-hour maps from [1] were then used with generalized duration and return-period interpolation diagrams to provide estimates for a 560-point grid for 44 additional maps (22 for Puerto Rico and 22 for the Virgin Islands).

2. BASIC DATA

Summarization of data. First, daily rainfall data from 32 stations, 24 in Puerto Rico and 8 in the Virgin Islands, were summarized into sequences of 1 to 10 days. The stations (solid square symbols in fig. 1) were so distributed geographically as to represent the various rainfall regimes. These data were the basis for developing the duration-interpolation diagram. The return-period—interpolation diagram used in a previous study [2] was tested using these data (Sec. 4). One- and 10-day data were then summarized for 28 additional Puerto Rican and 6 Virgin Island stations. The locations of the stations are shown as open squares in figure 1. These data were used to supplement the data from the first group of 32 stations to develop the relation between 1- and 10-day amounts.

Period and length of record. Data for the 32 stations in the first category were tabulated for the 50-year period, 1914–63. However, there were relatively few stations in operation during the entire period. The average length of record available from these stations was 38 years. In a few cases data prior to 1914 were tabulated to obtain sufficient length of record. Data for the 34 stations in the second group were tabulated for the 20-year period, 1944–63. Breaks in record at some stations necessitated tabulation of data prior to 1944 to obtain a 20-year record. In order to obtain a better sampling of the various rainfall regimes, data for other periods of record at favorably located stations not in operation during the period 1944–63, were also used. In some cases, a 20-year record was not available. In no case, however, was less than 10 years of data used. The average length of record for all stations in the second group was 19 years. Table 1 groups the number of precipitation stations used by length of record.

TABLE 1.—*Precipitation stations grouped by length of record*

Length of record (years)	Stations for which data were summarized for sequences from 1 to 10 days	Stations for which data were summarized for only 1 and 10 days
10-14	2	4
15-19	2	1
20-24	1	29
25-29	3	
30-34	3	
35-39	3	
40-44	4	
45-49	5	
50	9	
Total	32	34

Station exposure. In refined analysis of mean annual and mean seasonal rainfall data it is necessary to evaluate station exposures by methods such as double-mass-curve analysis [3]. Such methods do not disclose changes in exposure when applied

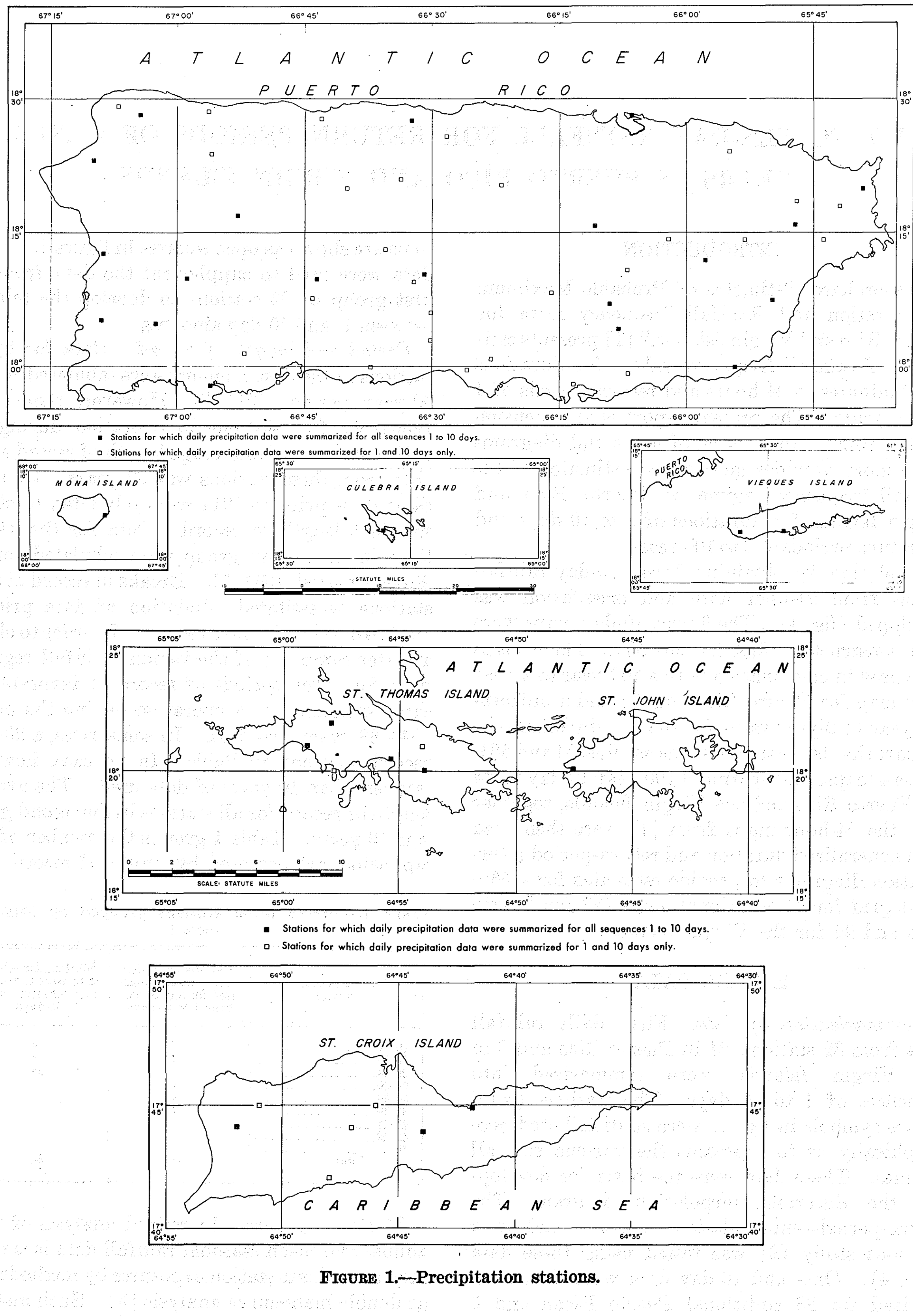

FIGURE 1.—Precipitation stations.

to a series of extreme values. Selection of stations was limited to those which had not moved more than 5 miles and station elevation had not changed more than 100 feet during the period of record used. Stations that satisfied these criteria were considered to have had a consistent exposure and no attempt was made to adjust their rainfall values to a standard exposure.

3. DURATION ANALYSIS

n-hour vs. observational-day rainfall. Since the basic data consisted mostly of observational-day amounts, relations developed in an earlier rainfall-frequency study [2] between observational-day data and corresponding *n*-hour amounts, i.e., the 2-observational-day to 48-hour, the 3-observational-day to 72-hour, etc., were used. These relations were developed using hundreds of years of data from widely scattered stations in the contiguous United States. Some of these stations in the southeastern States have rainfall regimes similar to those of Puerto Rico and the Virgin Islands. Comparison of ratios based on data for San Juan, Puerto Rico with those for stations in the contiguous United States indicated the use of ratios developed for [2] was reasonable. These relations are ratios of the mean of the annual series (Sec. 4) of the *n*-hour rainfall to the mean of the annual series of the corresponding observational-day data. The adjustment factors are shown in table 2. The conversion factor between the observational-day and *n*-hour amounts is an average relationship.

Duration-interpolation diagram. A generalized relationship was developed for estimating rainfall for any duration between 2 and 10 days for a selected return period when the 2- and 10-day amounts for that return period are given (fig. 2). This generalization was obtained empirically from data for 32 stations (Sec. 2). Puerto Rican and Virgin Island stations were identified separately but no consistent differences could be determined.

TABLE 2.—***Empirical factors for converting observational-day amounts to the corresponding n-hour amounts***

Observational-day	Conversion factor to *n*-hour	Observational-day	Conversion factor to *n*-hour
2	1.04	7	1.02
3	1.03	8	1.02
4	1.03	9	1.01
5	1.02	10	1.01
6	1.02		

Attempts to separate the stations into northern and southern exposures or other regionalizations failed to yield a consistent relationship.

The duration-interpolation diagram was developed using data for the 2-year return period. Similar diagrams were developed for other return periods and no significant differences were found. Thus the relation of figure 2 is considered applicable within the range of return periods covered by this report. To use this diagram, a straightedge is laid across the values given for 2 and 10 days, and the amounts for other durations are read at the proper intersections.

4. FREQUENCY ANALYSIS

Two types of series. Frequency analyses of rainfall data are based on one of two types of data series. The annual series consists only of the highest value for each year. The partial-duration

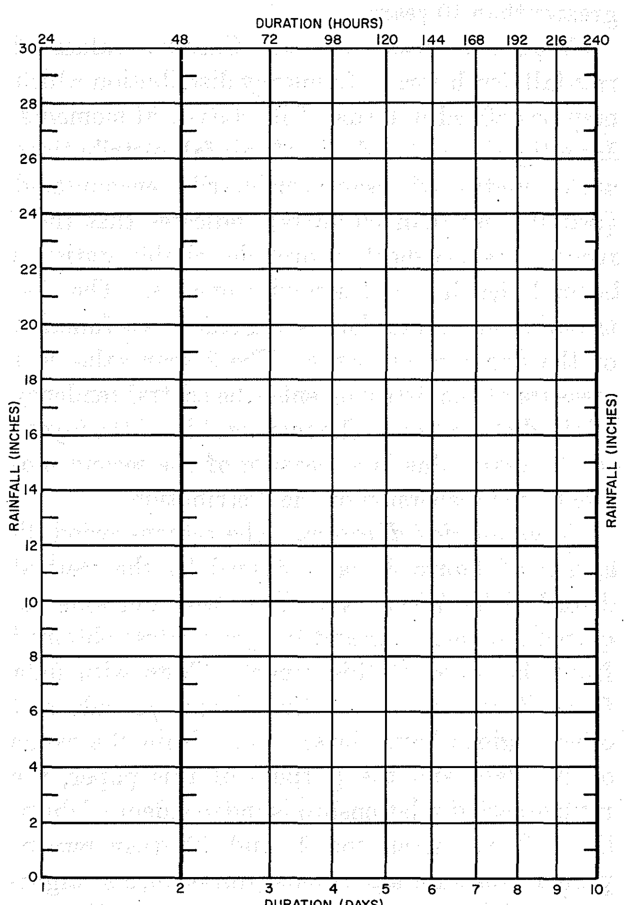

FIGURE 2.—Duration-interpolation diagram.

series recognizes that the second highest of some year occasionally exceeds the highest of some other year, and utilizes all items above a base value which is selected to yield n-items for n-years. The highest value of record, of course, is the top value of either series, but the lower values in the partial-duration series tend to be higher than those of the annual series.

The purposes served by this publication require that the results be expressed in terms of partial-duration frequencies. In order to avoid laborious processing of partial-duration data, the annual series were collected, analyzed, and the resulting statistics transformed to partial-duration statistics. Consequently, the maps of figures 11 to 58, are, in effect, based on partial-duration series data. These data may be converted to annual series data by multiplying by the factors given in table 3. These factors are the same as those developed for a previous study [2]. The two types of data series show no appreciable differences for return periods greater than 10 years.

Frequency considerations. Extreme values of rainfall depth form a frequency distribution which may be defined in terms of its statistical moments. Investigation of hundreds of rainfall distributions with lengths of record ordinarily encountered (usually less than 50 years) indicates that these records are too short to provide reliable statistics beyond the first and second moments. The distribution must therefore be regarded as a function of the first two moments. The 2-year value is a measure of the first moment—the central tendency of the distribution. The relationship of the 2-year to 100-year value is a measure of the second moment—the dispersion of the distribution.

Return-period diagram. The return-period diagram of figure 3 was obtained by the method described by Weiss [4]. The two intercepts required are the 2-year and 100-year values obtained from the maps of this report. Tests with data from Puerto Rico and the Virgin Islands and other regions have shown that within the range of the data and the purpose of this paper, the return-period relationship is independent of duration. Thus, given the 2- and 100-year return-period values for a particular duration, a straightedge is laid across these values on the diagram and the intermediate values determined. If values

TABLE 3.—*Empirical factors for converting partial-duration series to annual series*

Return period	Conversion factor
2-yr.	0.88
5-yr.	0.96
10-yr.	0.99

for return periods between 2 and 100 years are read from the return-period diagram, then converted to annual series values by applying the factors of table 3 and plotted on either extreme or log-normal probability paper, the points will very nearly define a straight line.

Secular trend. The use of short-record data introduces the question of possible secular trend and biased sample. Routine tests with subsamples of equal size from different periods of record for each of several stations showed no appreciable trend, indicating that the direct use of the short-record data is legitimate.

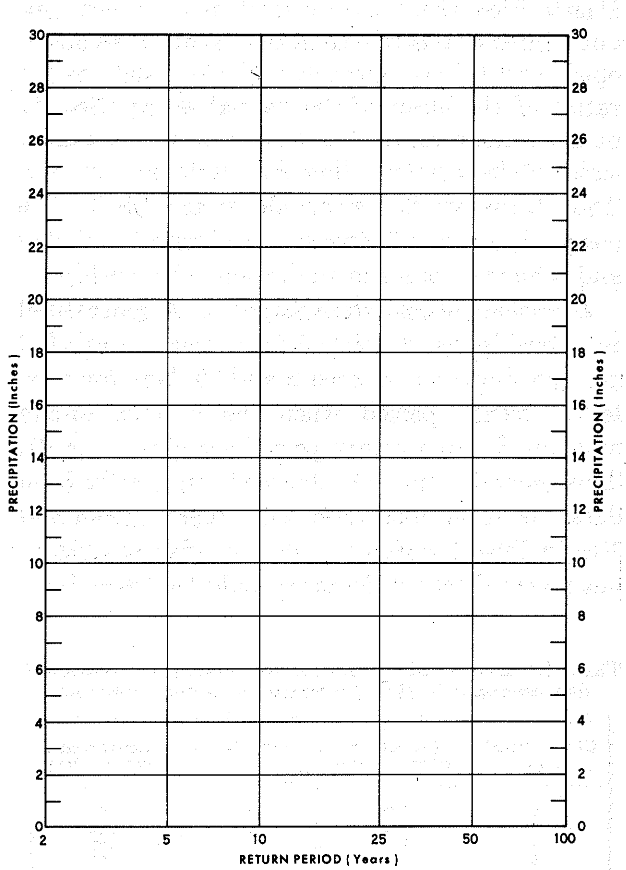

FIGURE 3.—Return-period—interpolation diagram.

5. ISOPLUVIAL MAPS

Relation between 2-year 24- and 240-hour amounts. It was necessary to develop a relationship for estimating 10-day values for points in regions for which data were either unavailable or inadequate. Since a generalized chart of 2-year 24-hour rainfall was already available, the values for this duration were selected to develop such a relation. Observations from 66 stations (sec. 2) provided the basic data. Comparison of the meteorological situations resulting in heavy rains and examination of the rainfall-frequency characteristics of Puerto Rican and Virgin Island stations indicated some regional differences.

Puerto Rico and the Virgin Islands are located on the northern edge of the Carribbean Sea in the path of the northeasterly trades. The primary orographic feature of Puerto Rico is a range of mountains oriented east-west. In the Virgin Islands generalized elevation contours show a primarily east-west ridge orientation. The stations on the northern slopes of these ridges are favorably exposed for almost daily showers which are orographically augmented. These stations, therefore, indicated a higher 10- to 1-day ratio than those on the leeward or southern slopes. The stations were separated into windward and leeward groups and separate curves were drawn (fig. 4).

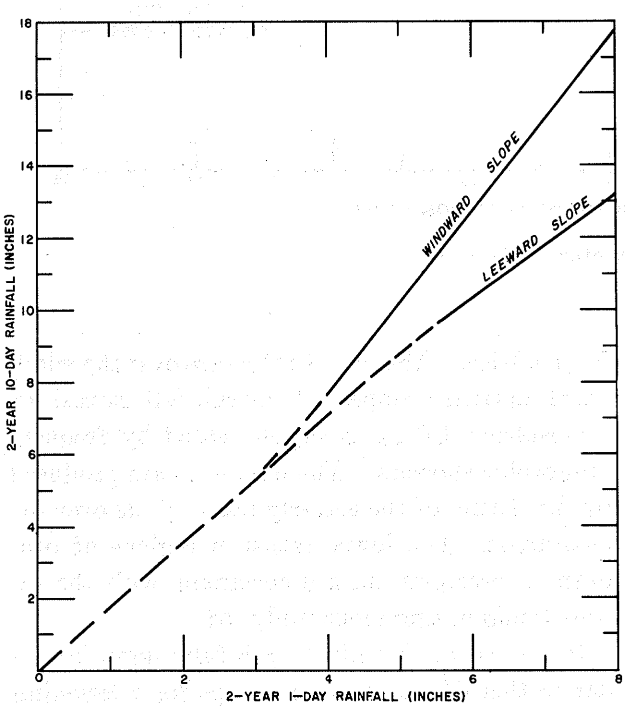

FIGURE 4.—Relation for estimating 2-year 10-day rainfall.

In the development of the relationship of figure 4 all 24-hour data were adjusted to the corresponding 1440-minute amounts. The 10-day values were adjusted to the corresponding 240-hour amounts. The correlation coefficient between the computed and estimated amounts was 0.85, with a standard error of estimate of 0.8 in. The mean of the computed values was 9.3 in. The scatter of estimated vs. computed values is shown in figure 5.

Smoothing of isopluvial maps. The analysis of maps involves the question of how much to smooth the data. An understanding of the degree of smoothing in the analysis is necessary to the most effective use of the maps. The problem of drawing isopluvial lines through a field of data is analogous to drawing a regression line on a scatter diagram. Just as an irregular regression line can be drawn to every point on a scatter diagram, the isolines may be drawn to fit every point. Such a complicated pattern of many small highs and lows would be unrealistic in most cases. There is a degree of inconsistency between smoothness and closeness of fit. Analysis must strive for a balance between the two, sacrificing some closeness of fit for smoothness and vice versa. The maps of this report were drawn so that the standard error of estimate was commensurate with the sampling and other errors in the data and methods used.

2-year 10-day maps (figs. 29 and 53). The relationship (fig. 4) described in the preceding paragraphs, and the 2-year 24-hour maps of [1] were used to estimate the 2-year 10-day values for a grid of 560 points, about 490 points on Puerto Rico and 70 points on St. Croix (fig. 6). Also plotted on the map were the data for the 66 stations (fig. 1) for which 10-day data had been tabulated. On these and similar maps all precipitation data have been adjusted by the factors of table 2 to n-hour amounts, i.e., the 2-day map presents 48-hour amounts, the 4-day presents 96-hour amounts, etc.

Ratio of 100-year to 2-year values. A map of Puerto Rico (fig. 7) was prepared showing the 100-year to 2-year ratio for 10-day amounts. This map was based on data for 52 stations (sec. 2). The ratios indicated a smooth geographical pat-

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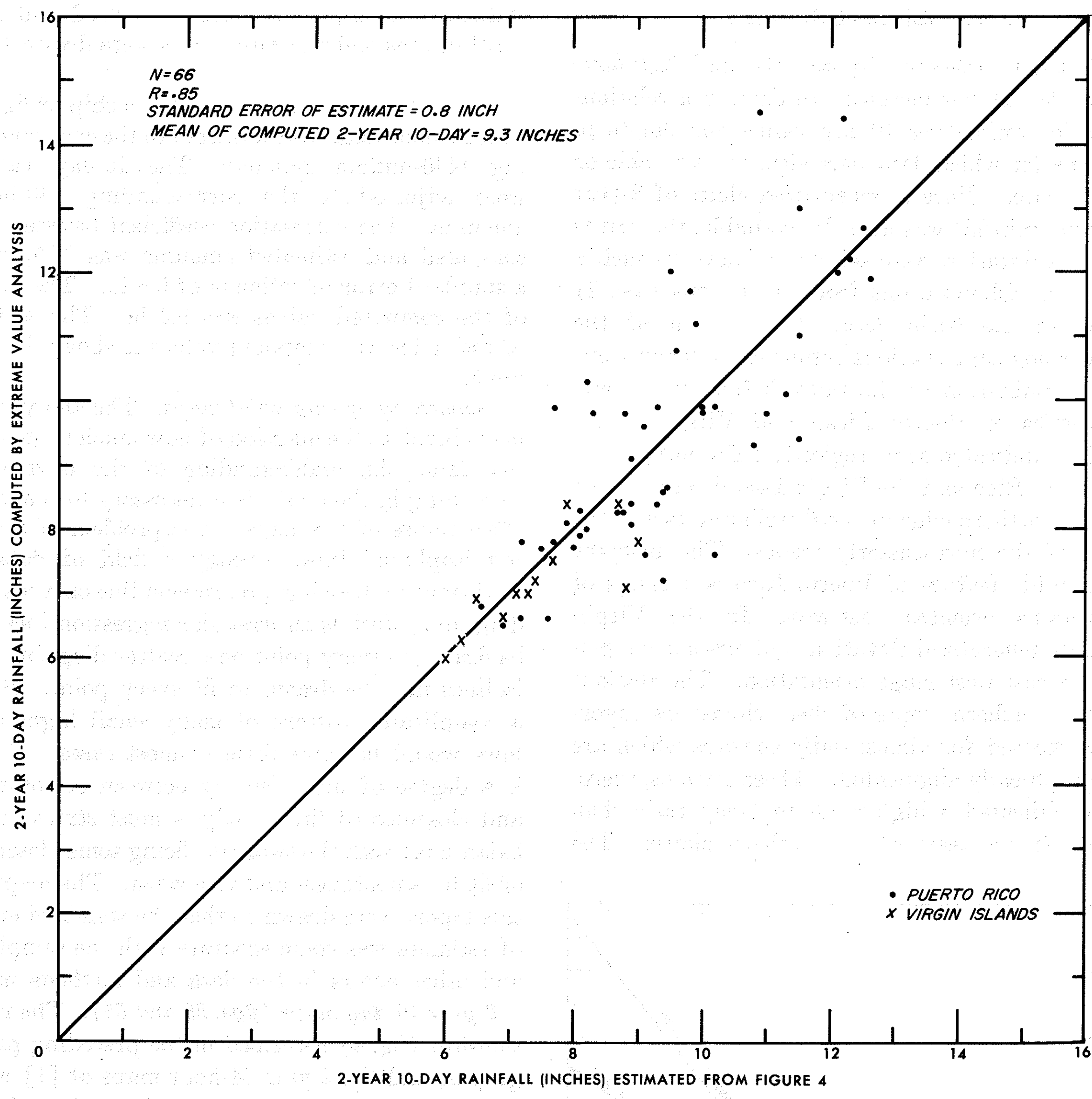

FIGURE 5.—Test of relation of figure 4.

tern. The ratio varied from 1.6 to 2.5 with an average about 2.1. The highest ratios were along the southern and northern coasts. The lowest ratios were along the northern slopes of the mountains. These variations are meteorologically reasonable. The highest ratios are in regions where orographic influence is not the most important factor. Rainfall in these regions results primarily from atmospheric processes of lifting, the principal causes being easterly waves or cold fronts penetrating far enough south to produce rainfall over Puerto Rico. The lowest ratios are over the windward northern slopes where rainfall caused by atmospheric lifting is supplemented by frequent orographic showers. These showers are produced by the lifting of the easterly trade winds over the mountains. The lower ratios in regions of orographic precipitation are consistent with the results found in a previous study [5].

In the Virgin Islands the rainfall regime is similar to that of Puerto Rico except for a lessening of the orographic effect. Plotting the data for the

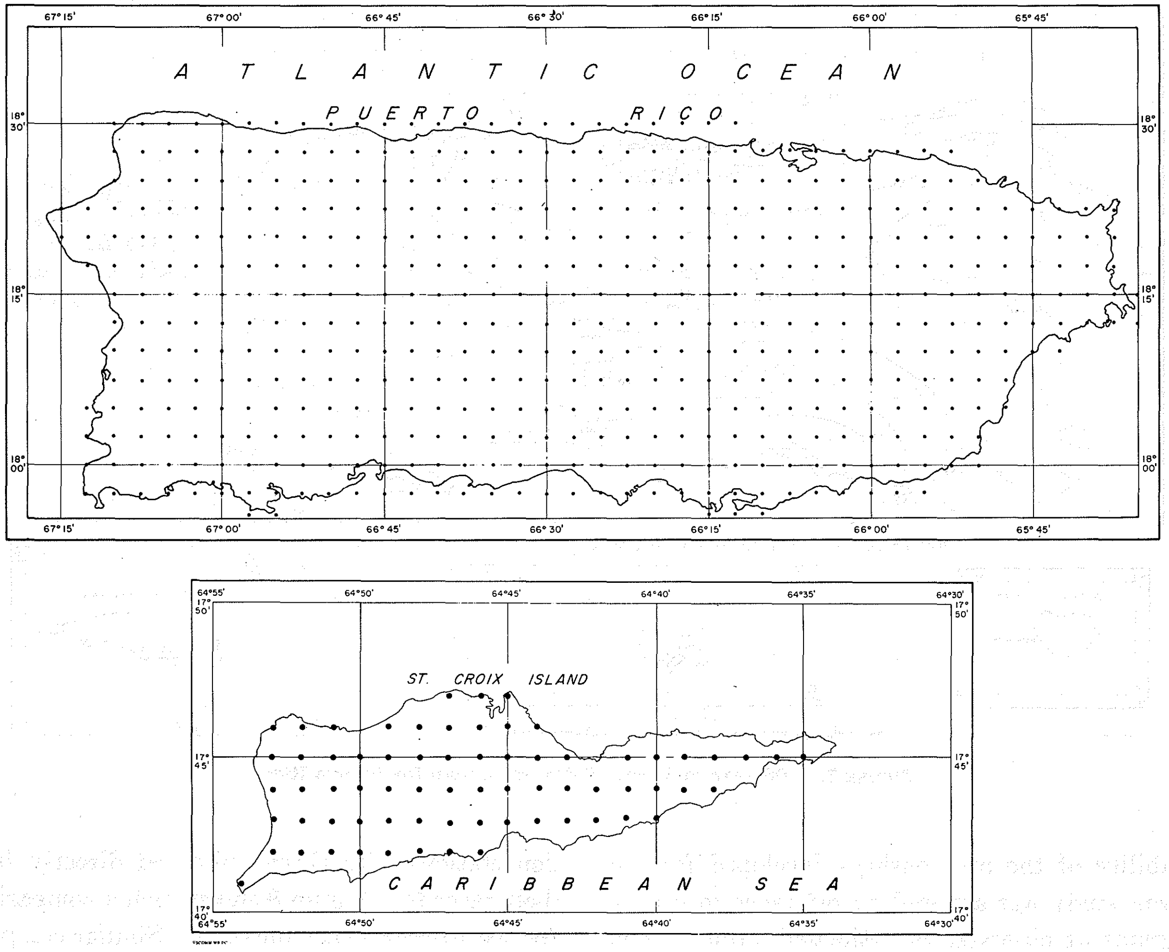

FIGURE 6.—Points for which rainfall-frequency data were computed.

14 stations (sec. 2) in the Virgin Islands revealed no consistent geographical variation. Differences between stations were small so a uniform ratio of 2.5 was adopted.

100-year 10-day maps (figs. 34 and 58). The 100-year 10-day values were computed for the grid points of figure 6 by multiplying the values read from the 2-year 10-day map by those from the 100- to 2-year ratio map for Puerto Rico or by 2.5 for the Virgin Islands. As a further aid in the analysis of the isopluvial pattern, the 100-year 10-day values computed for the 66 stations for which data had been processed were also plotted.

44 additional maps. For the 44 intermediate maps required for this report, values were computed for the 560 grid points (fig. 6). First, values were read from the 2-, 5-, 10-, 25-, 50-, and 100-year 24-hour maps of [1] and the 2- and 100-year 10-day maps. Then, the duration-interpolation diagram (fig. 2) and the return-period diagram (fig. 3) were used to compute amounts for the grid points. The frequency values computed for stations for which data were processed were also plotted on each of the maps. Isolines were then drawn. Pronounced "highs" and "lows" are positioned in consistent locations on all the maps. The 48 rainfall-frequency maps (24 for Puerto Rico and 24 for the Virgin Islands) are shown at the end of the text (figs. 11–58).

Reliability of results. The term is used here in the statistical sense to refer to the degree of confidence that can be placed in the accuracy of the results. The reliability is influenced by the accuracy of [1] and the accuracy of the relationships developed for this report. The accuracy of the results presented in [1] was discussed in that report. The

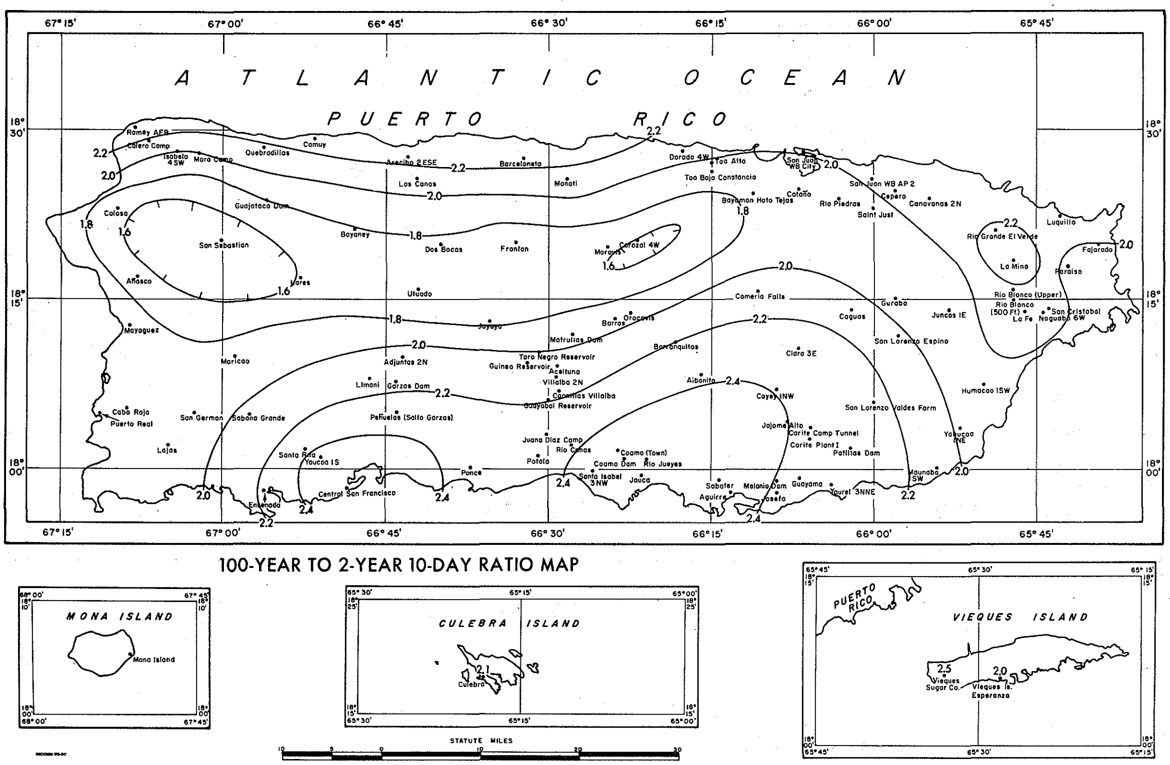

Figure 7.—100-year to 2-year 10-day ratio map for Puerto Rico.

reliability of the relationships developed for the present study was assessed by reference to scatter diagrams of observed vs. estimated values. The scatter of points in these diagrams may be largely the result of sampling error in time and space. Sampling error in space is a result of: (1) the chance occurrence of an anomalous storm which has a disproportionate effect on the record at a station as compared with that of a nearby station, and (2) the use of station data that are not representative of the rainfall regime of the surrounding area. Similarly, sampling error in time results from the use of data for a given period that is not representative for a longer period. Elimination of all sampling error, however, would still leave some scatter, indicative of the geographic variation unexplained by the graphical relation.

Tests of individual relationships used to estimate point rainfall amounts for various durations and return periods do not indicate the accuracy of the final generalized maps. The reliability of these maps can be partially assessed by comparison of the values indicated for various precipitation stations with those computed directly from their records. Figure 8 shows such a comparison for the 10-year 4-day amounts. Similar comparisons were made for other durations and return periods and the results were very nearly the same.

The data of figure 8 show essentially no bias. The scatter of points results from the generalization procedures used in the development of the maps. It would be impossible to produce on maps of reasonable scale sufficient detail to accurately represent every point. The standard errors of estimate, however, are less than the 20 percent of the mean generally considered acceptable for this type of data. Of course, this test does not eliminate possible errors of larger magnitude in those areas where lack of observed data preclude comparisons with estimated values.

Smoothing values read from the maps. The complex patterns and steep gradients of the isopluvials combined with the difficulties of interpolation and accurate location of a specific point on a series of maps might result in inconsistencies in data read from the maps. Such inconsistencies

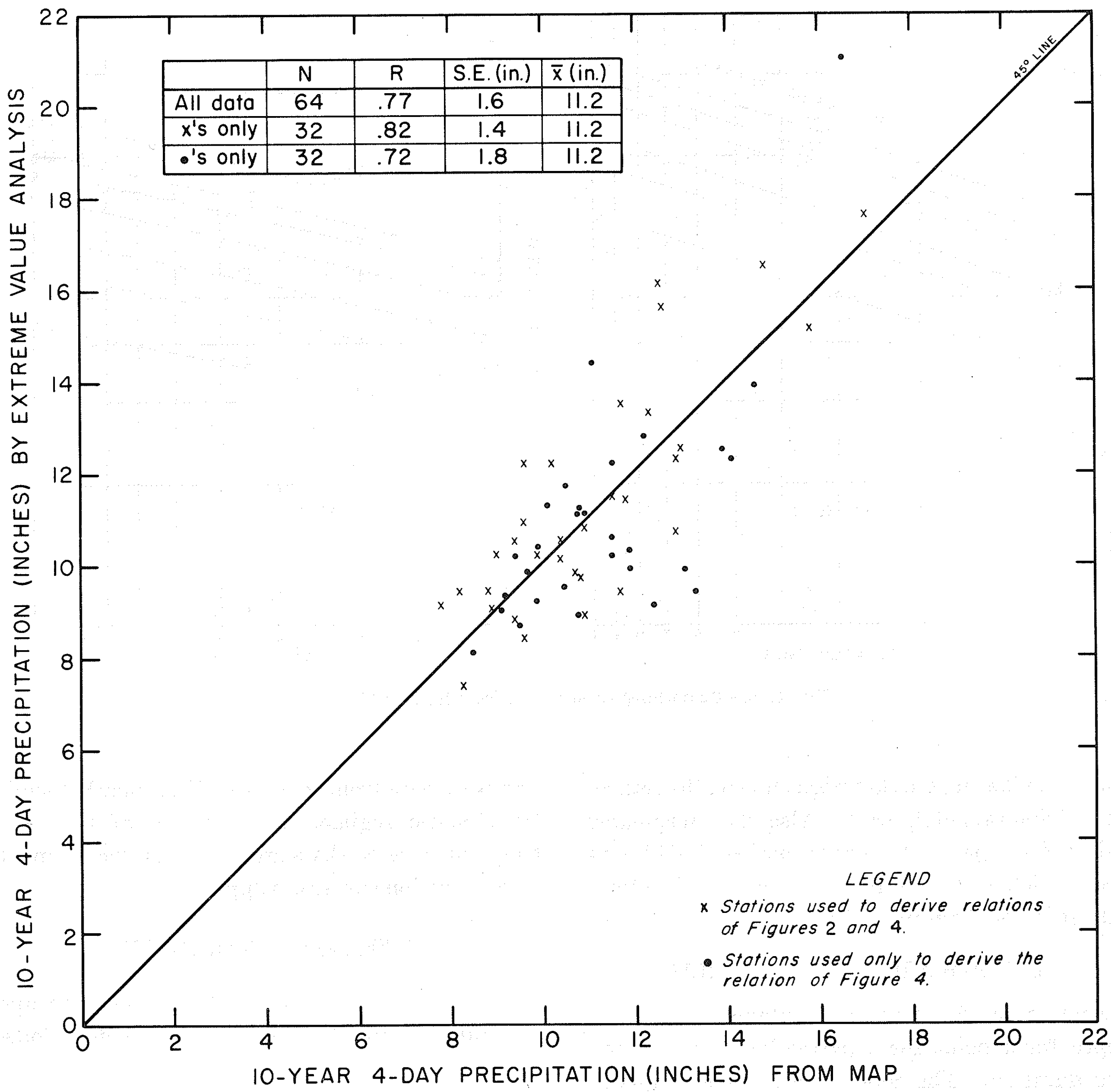

FIGURE 8.—Comparison of estimated vs. computed 10-year 4-day rainfall.

can be minimized by fitting smooth curves to a plot of the data obtained from the maps. Figure 9 illustrates two sets of curves on logarithmic paper, one for a point (a) 18°17′30″ N., 67°47′30″ W. and the other (b) at 17°57′30″ N., 66°55′ W. Data for the 24-hour values for these curves have been taken from [1]. An alternative procedure would be to read these values from the duration-interpolation diagram (fig. 2).

In regions where the isopluvial pattern is relatively simple and exhibits flat gradients, minor differences in locating points have less effect on the interpolated values, and the plotted points will more clearly define a smooth set of curves. In mountainous regions complex patterns and steep gradients complicate interpolation, and the curves will be more poorly defined.

Interpolated values for a particular duration

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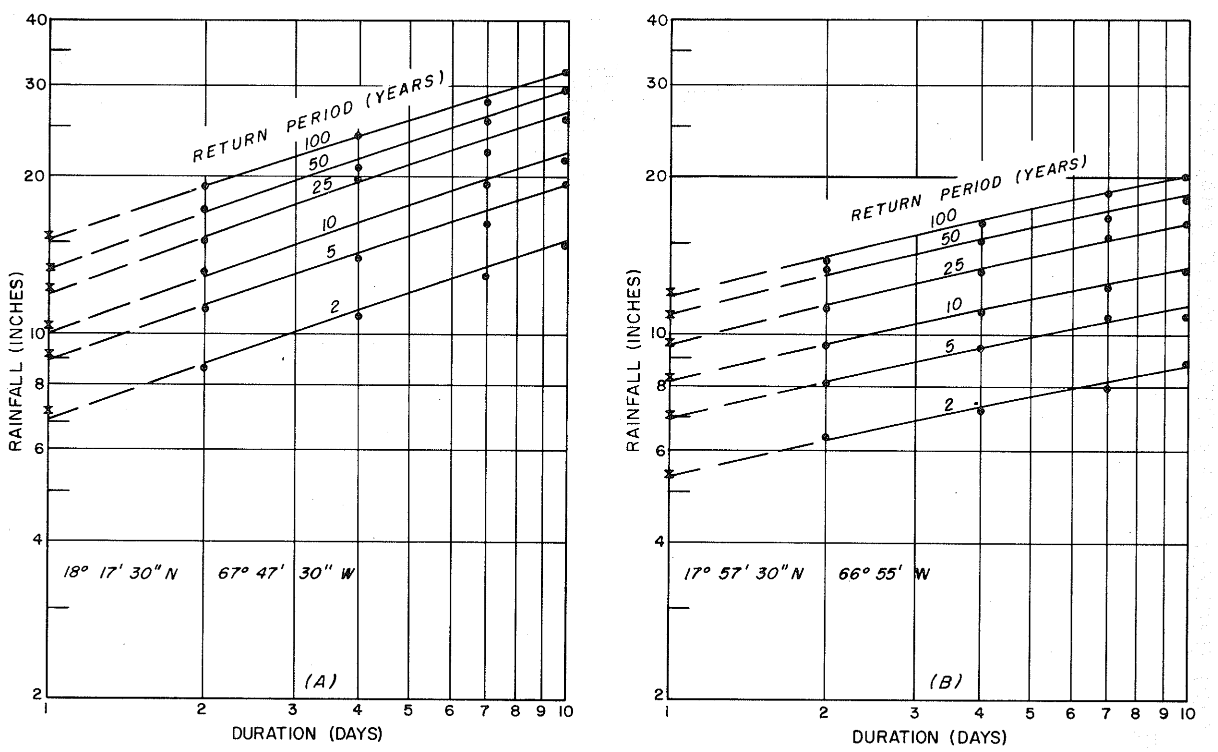

FIGURE 9.—Smoothing values read from isopluvial maps.

should define an almost straight line on the return-period diagram of figure 3. Also, the interpolated values for a particular return period should very nearly define a straight line on the duration-interpolation diagram of figure 2.

6. DEPTH-AREA RELATIONSHIPS

Any value read from an isopluvial map is the depth for a point for a particular return period and duration. The depth-area curve attempts to relate the average of the point values over an area to the average depth over that entire area for a particular return period and duration. The curves of figure 10 depict the relationship for durations of 1 to 10 days and for areas up to 400 square miles, and are to be used in reducing the point values of rainfall shown on the maps of figures 11 to 58 to areal values. These curves are the same as those of [2] and are based on 27 dense raingage networks in the contiguous United States. A survey failed to reveal any dense networks in Puerto Rico and the Virgin Islands that could be used to test the relationship. Some of the networks used, however, were from regions with a somewhat similar climatic regime. Examination of the data from these networks suggested that the adopted area-reduction curves are applicable.

7. SEASONAL VARIATION

The basic data for the rainfall-frequency maps of figures 11 to 58 show seasonal trends. Some

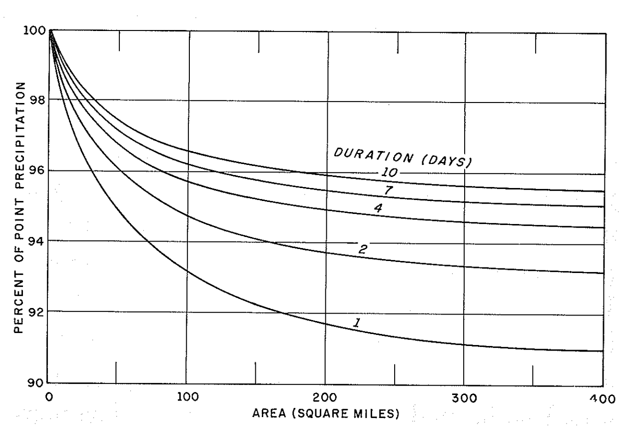

FIGURE 10.—Depth-area curves.

months may contribute most of the annual series or partial-duration series data used in the frequency analyses, while other months may contribute little or nothing. Also, months contributing most of the series data for the shorter durations, say, one or two days, may not be the same as those contributing most of the data for the longer durations, say, nine or ten days. A seasonal probability chart for 24-hour rainfall for Puerto Rico and the Virgin Islands was presented in [1]. Seasonal probability curves were not derived for this report because it appeared that their usefulness was not commensurate with the costs of collecting and processing the additional data required for their construction.

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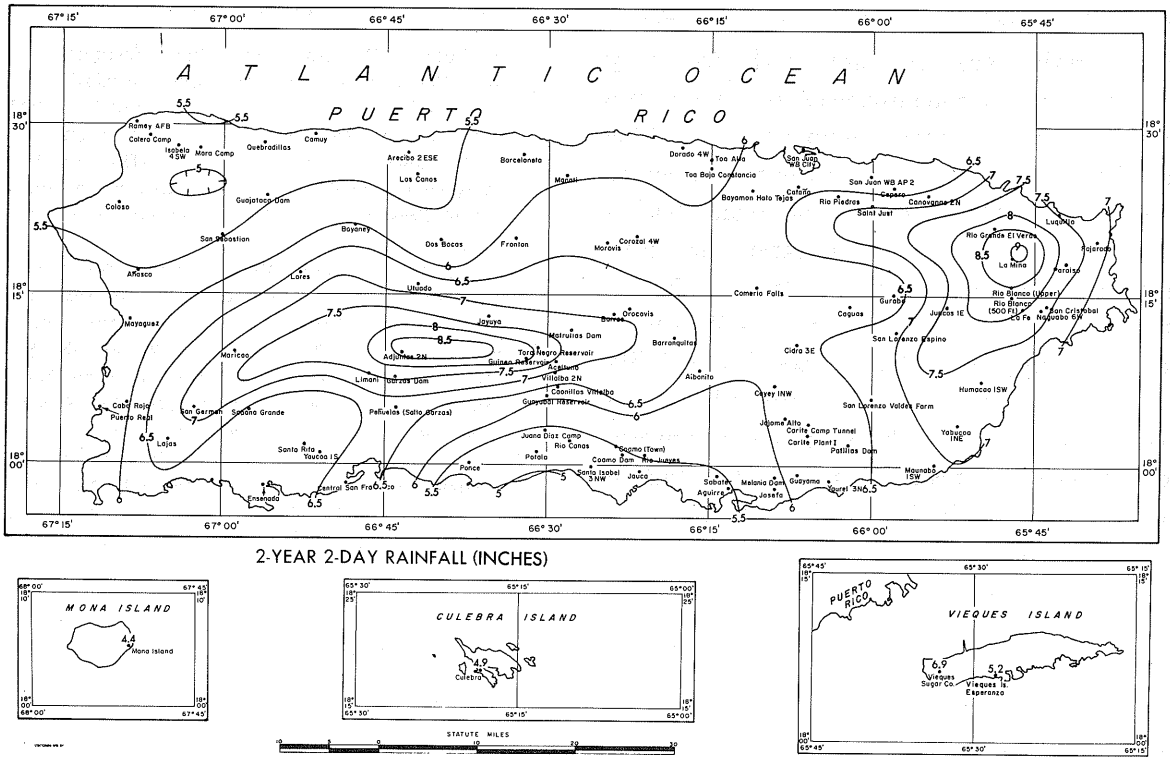

FIGURE 11.—2-year 2-day rainfall (in.) for Puerto Rico.

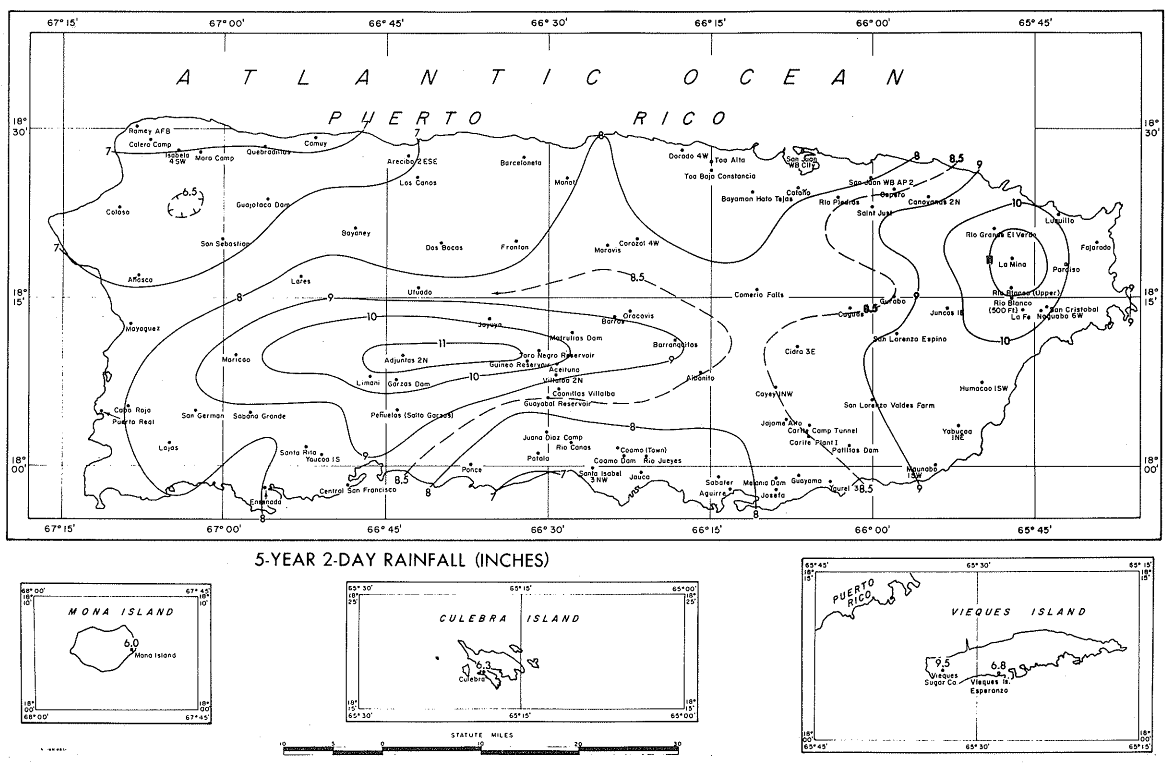

FIGURE 12.—5-year 2-day rainfall (in.) for Puerto Rico.

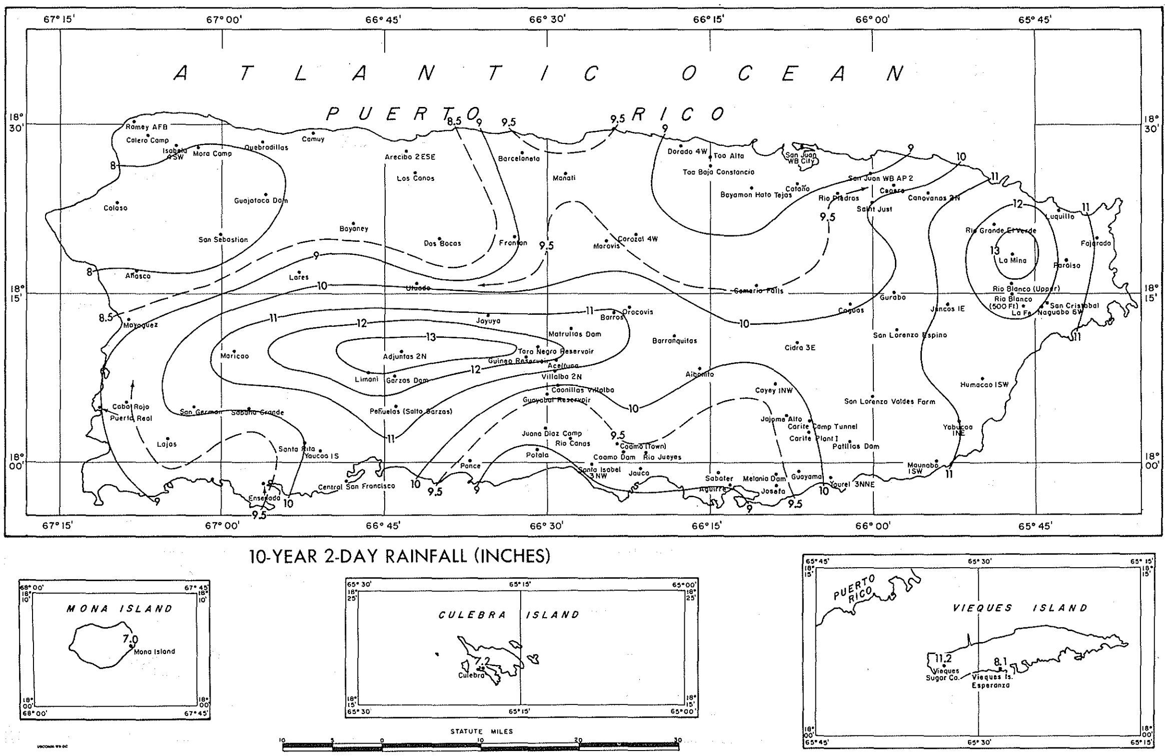

FIGURE 13.—10-year 2-day rainfall (in.) for Puerto Rico.

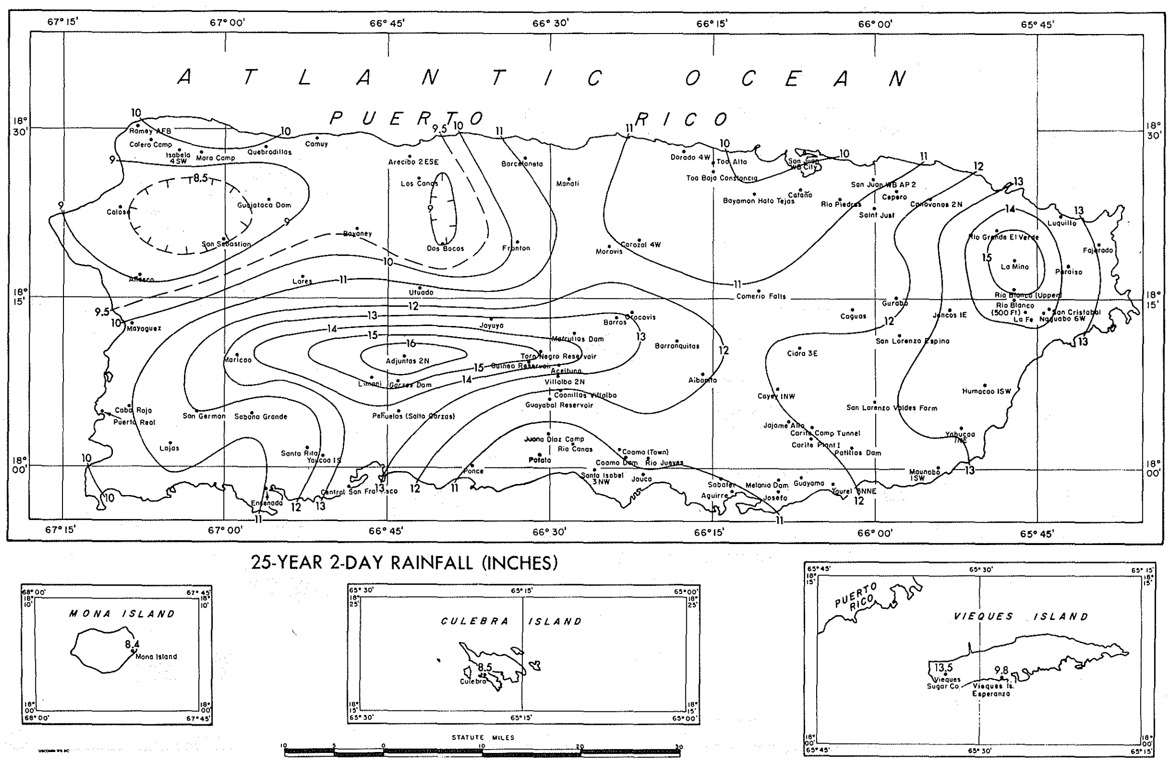

FIGURE 14.—25-year 2-day rainfall (in.) for Puerto Rico.

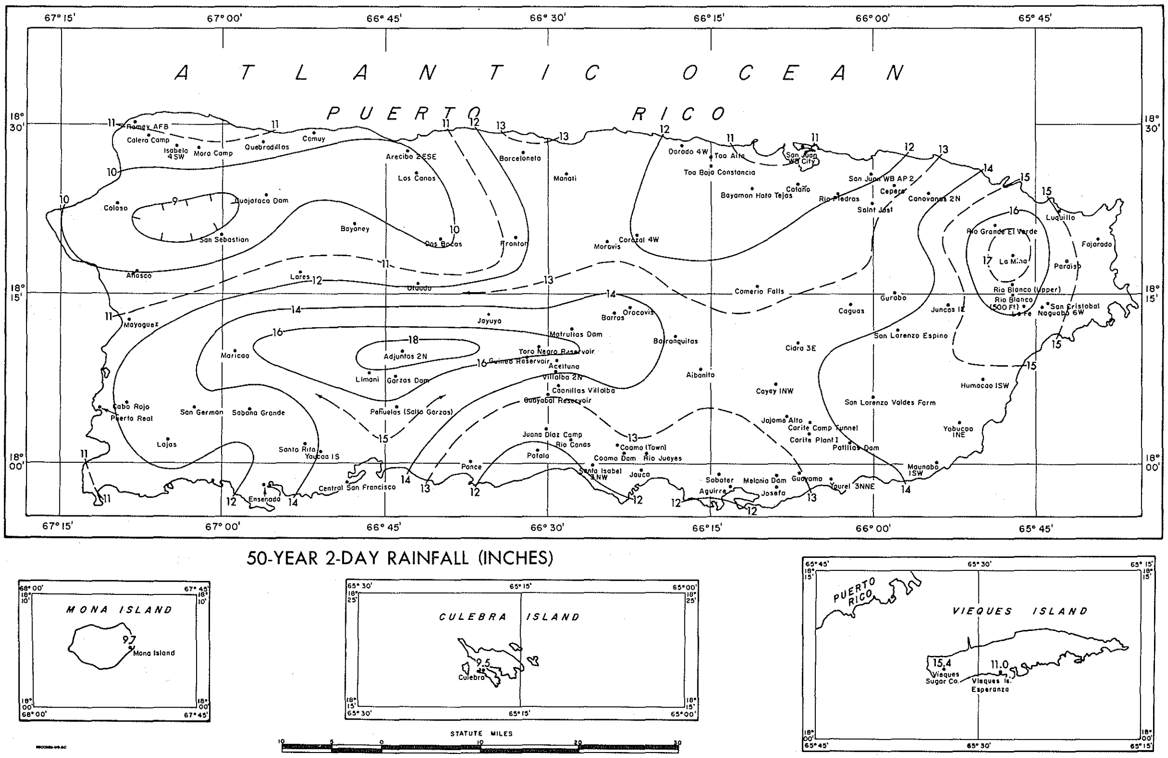

FIGURE 15.—50-year 2-day rainfall (in.) for Puerto Rico.

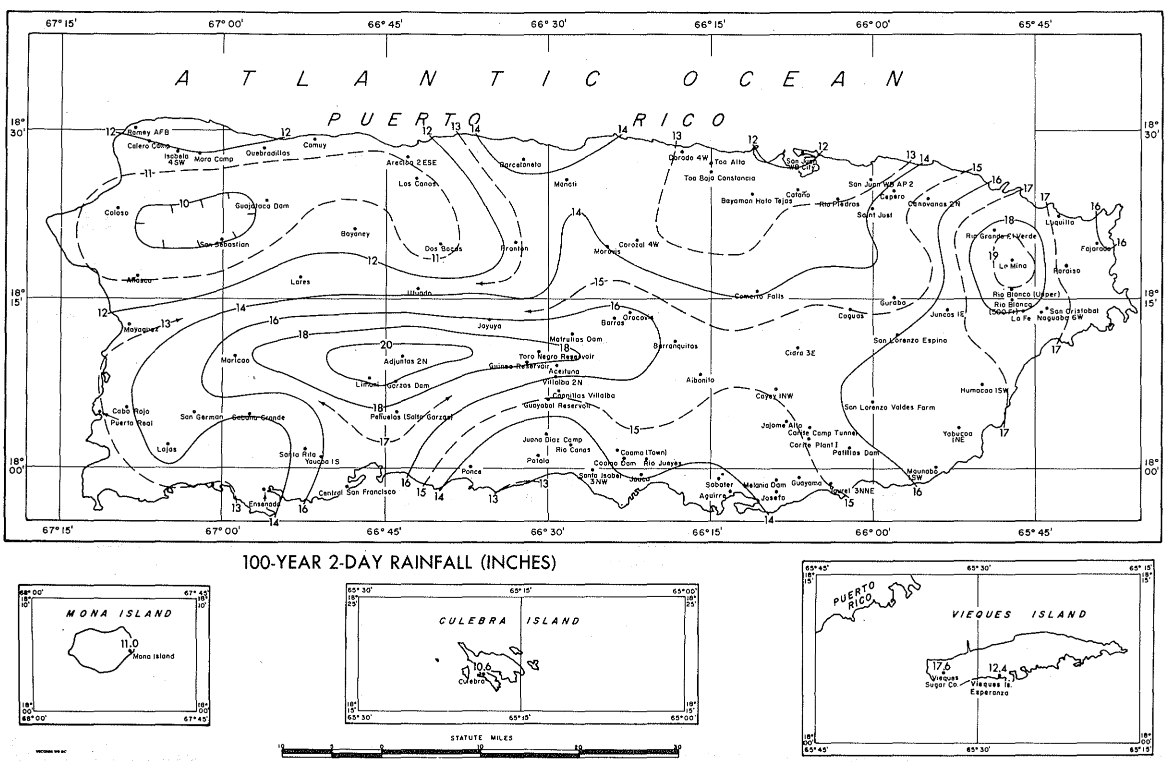

FIGURE 16.—100-year 2-day rainfall (in.) for Puerto Rico.

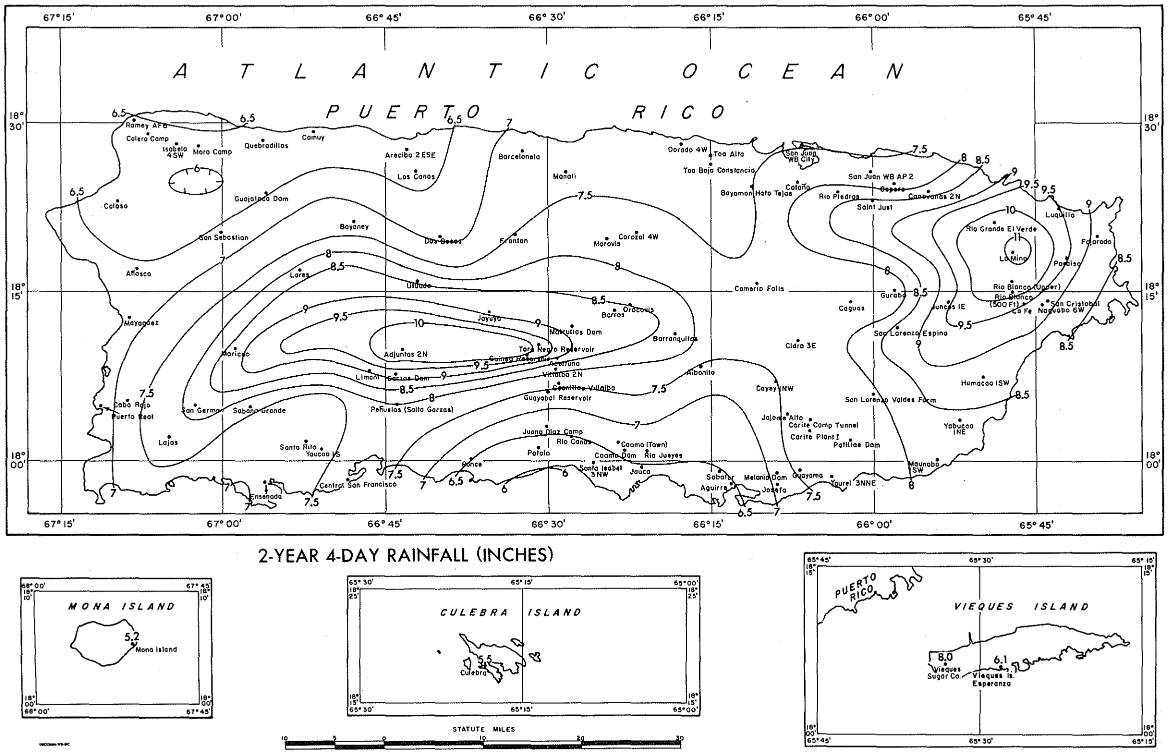

FIGURE 17.—2-year 4-day rainfall (in.) for Puerto Rico.

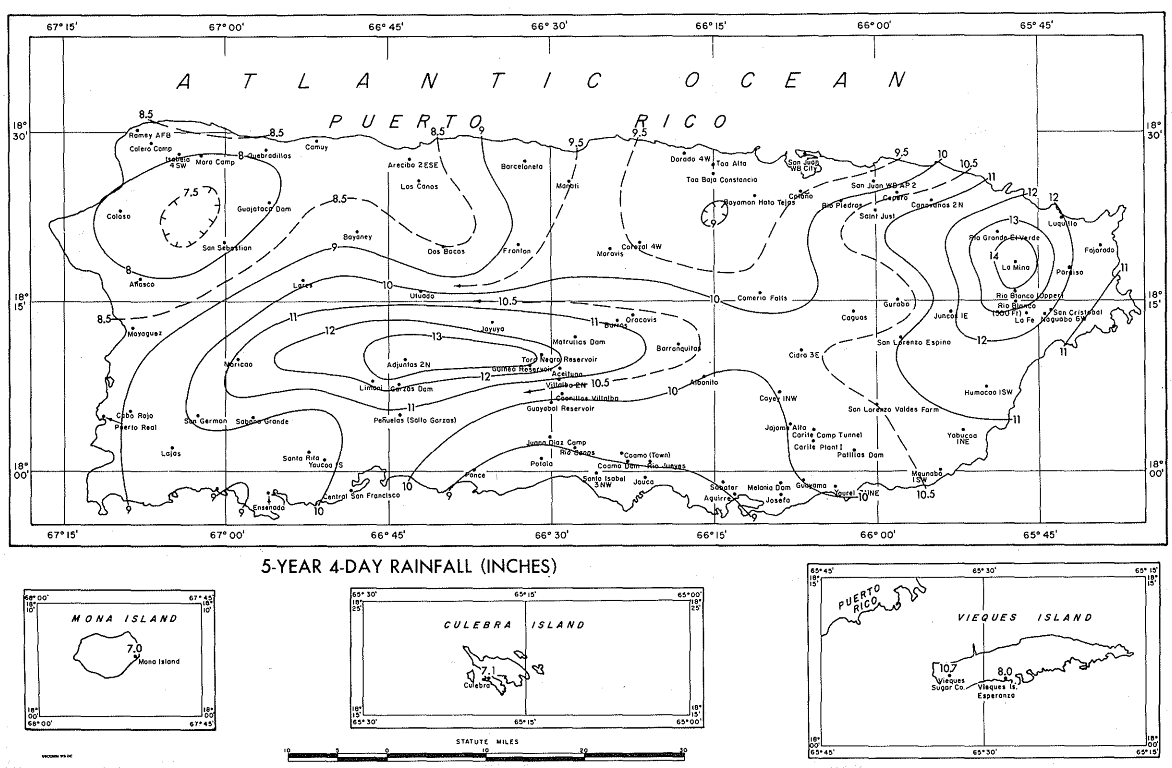

FIGURE 18.—5-year 4-day rainfall (in.) for Puerto Rico.

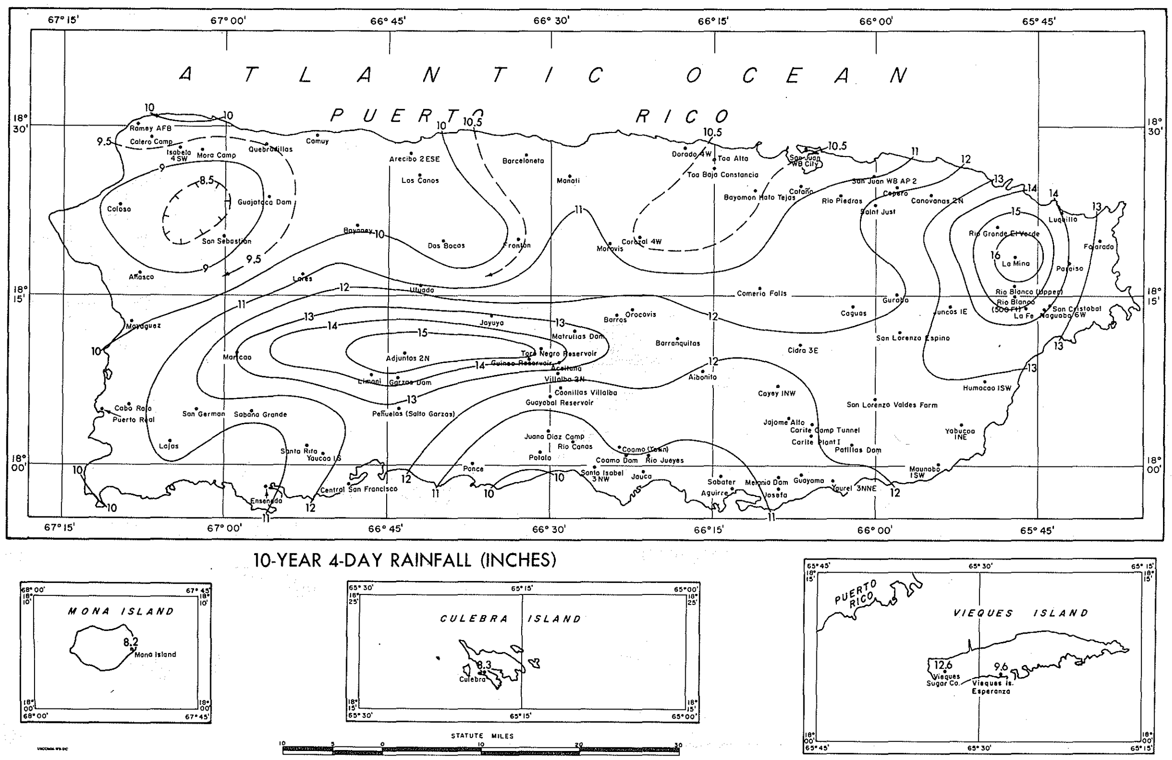

FIGURE 19.—10-year 4-day rainfall (in.) for Puerto Rico.

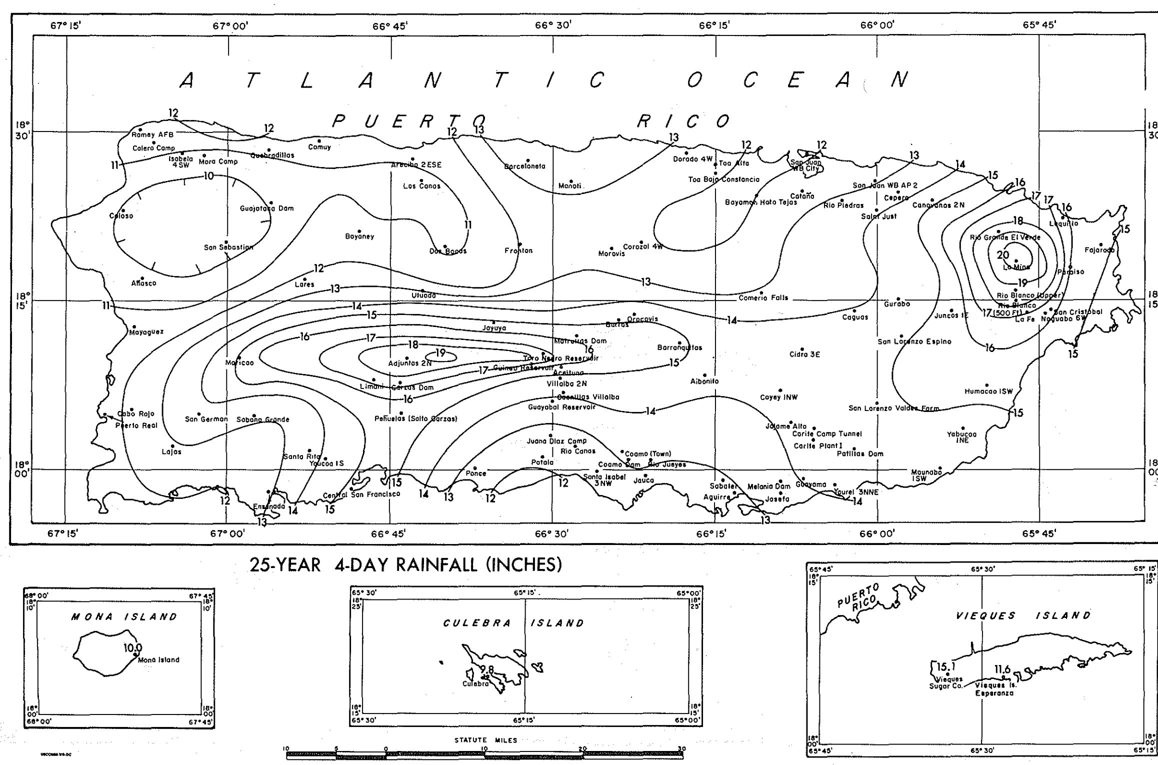

FIGURE 20.—25-year 4-day rainfall (in.) for Puerto Rico.

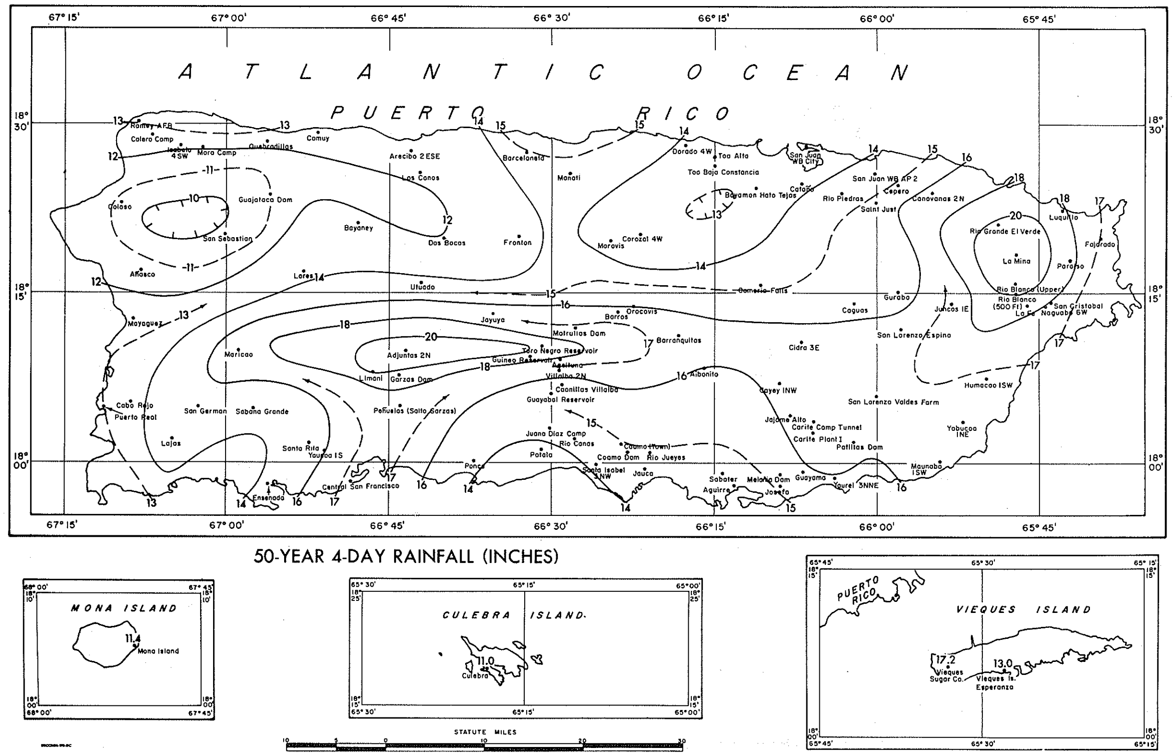

FIGURE 21.—50-year 4-day rainfall (in.) for Puerto Rico.

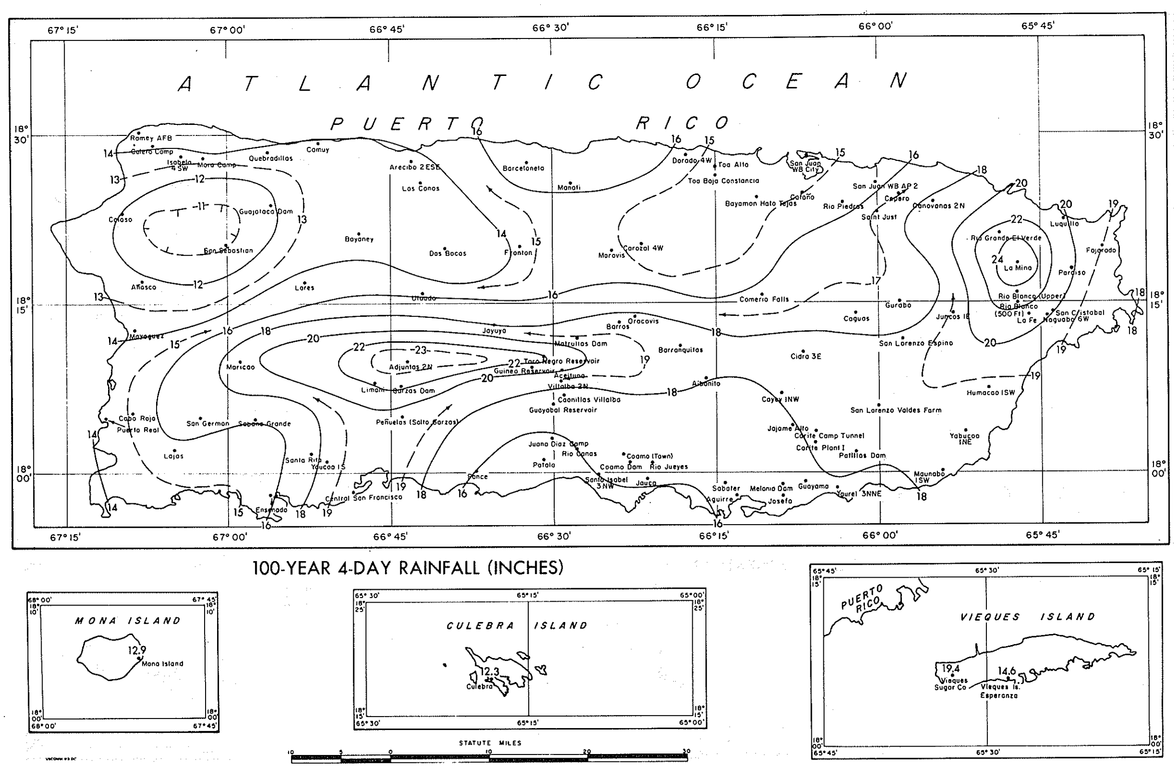

FIGURE 22.—100-year 4-day rainfall (in.) for Puerto Rico.

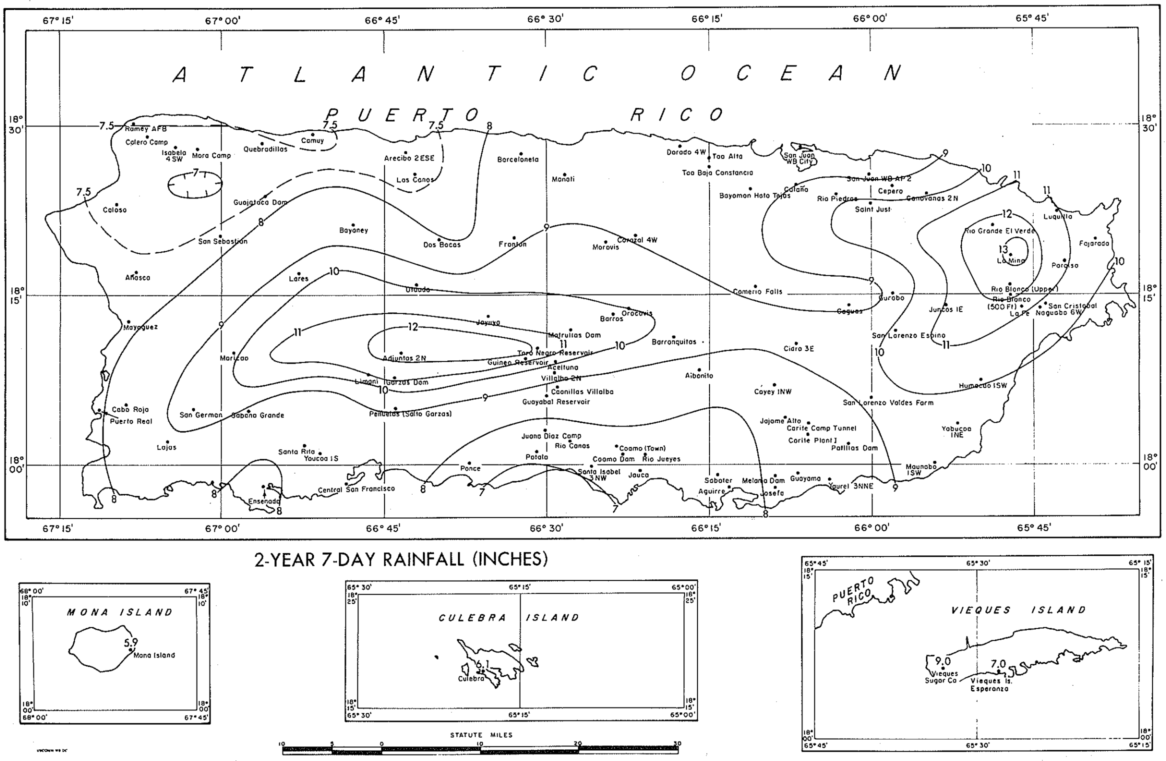

FIGURE 23.—2-year 7-day rainfall (in.) for Puerto Rico.

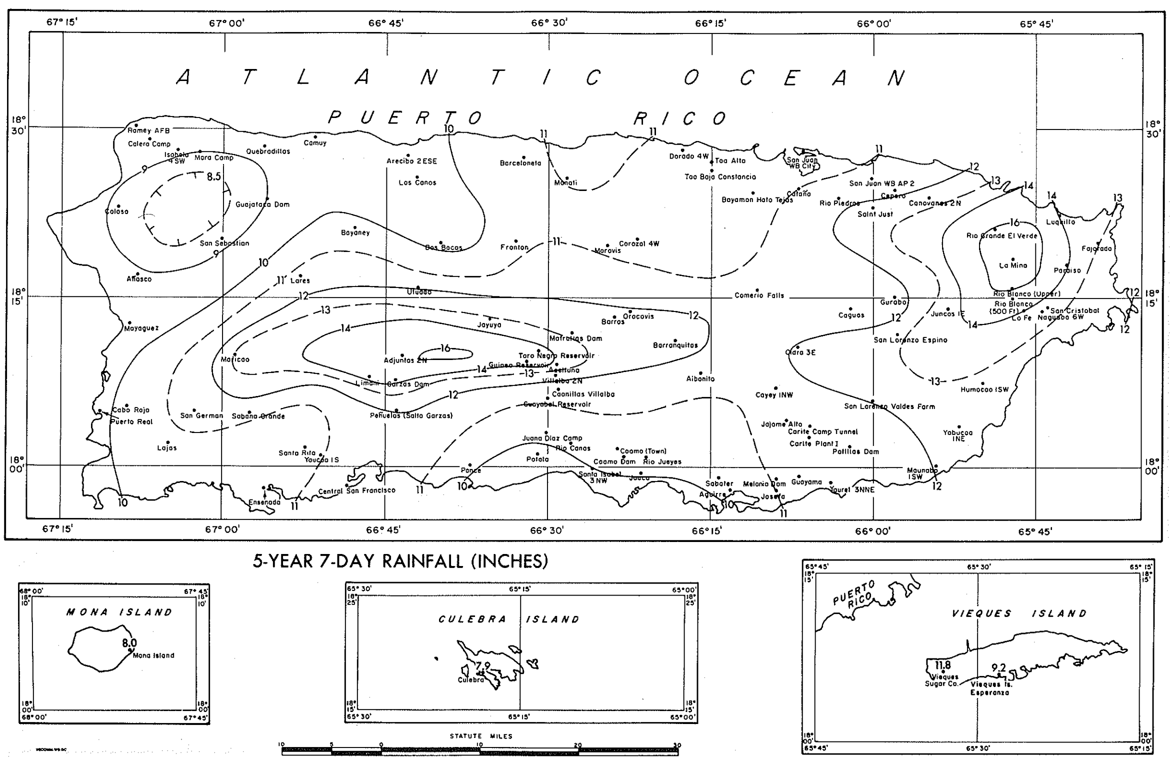

FIGURE 24.—5-year 7-day rainfall (in.) for Puerto Rico.

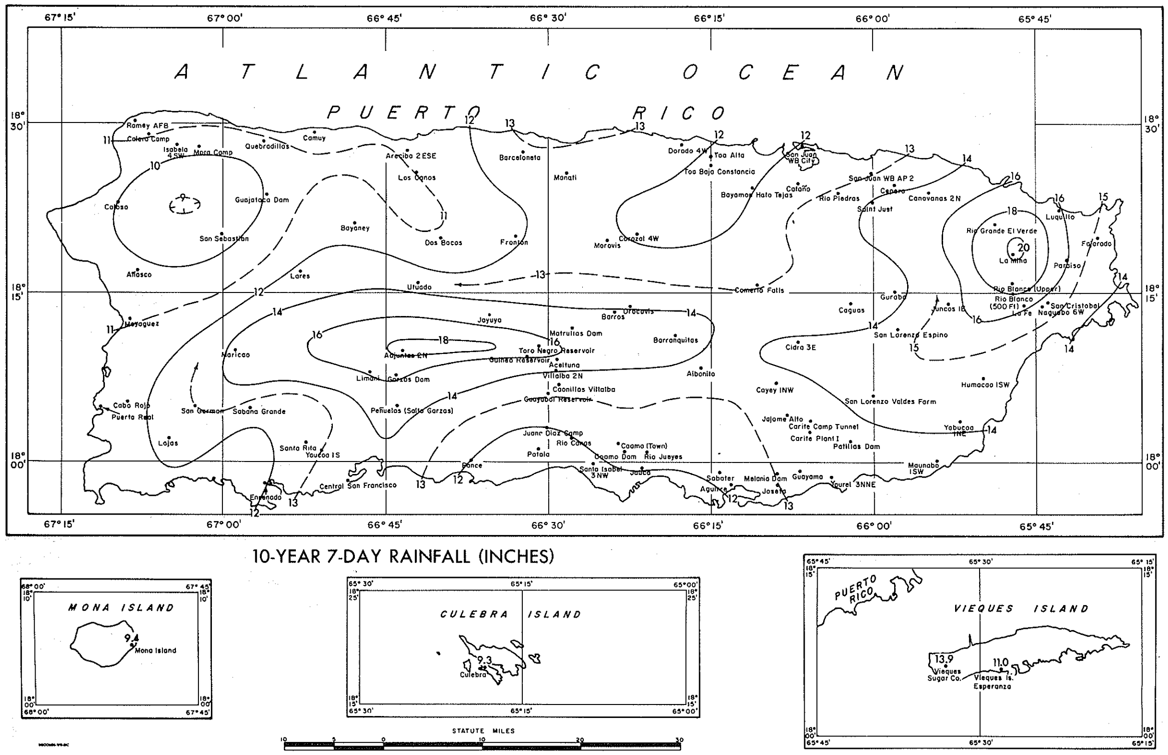

FIGURE 25.—10-year 7-day rainfall (in.) for Puerto Rico.

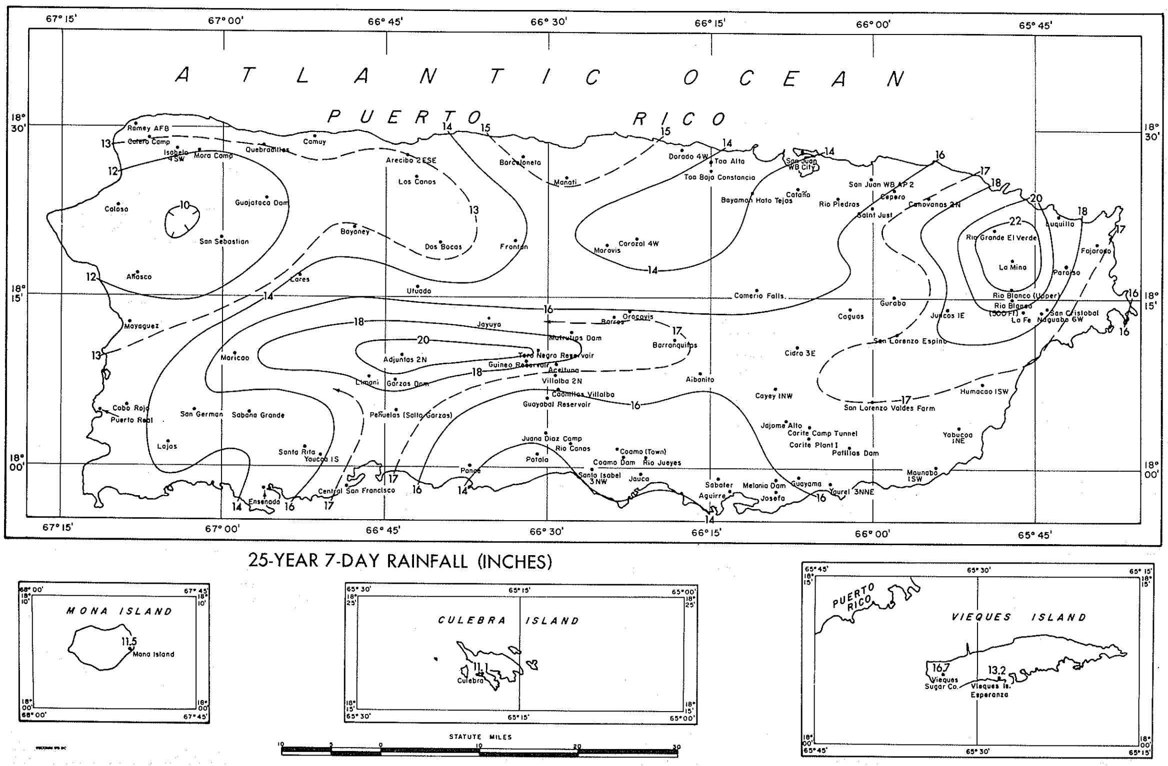

FIGURE 26.—25-year 7-day rainfall (in.) for Puerto Rico.

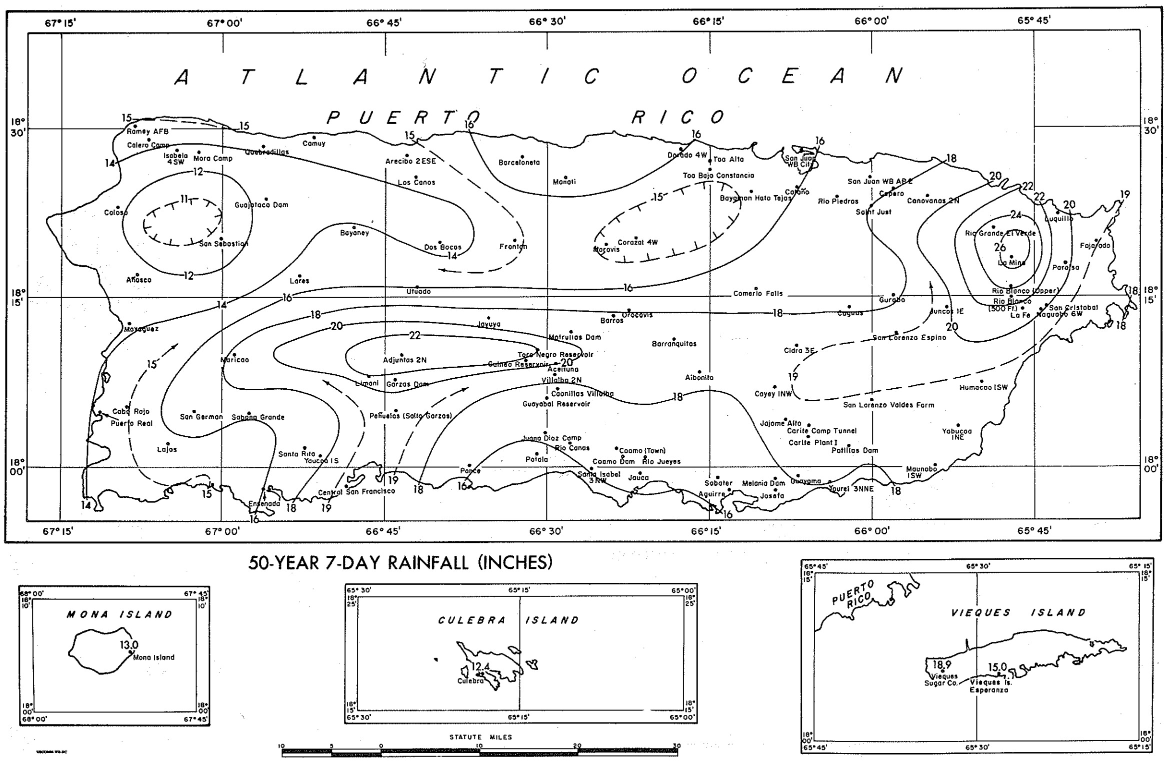

FIGURE 27.—50-year 7-day rainfall (in.) for Puerto Rico.

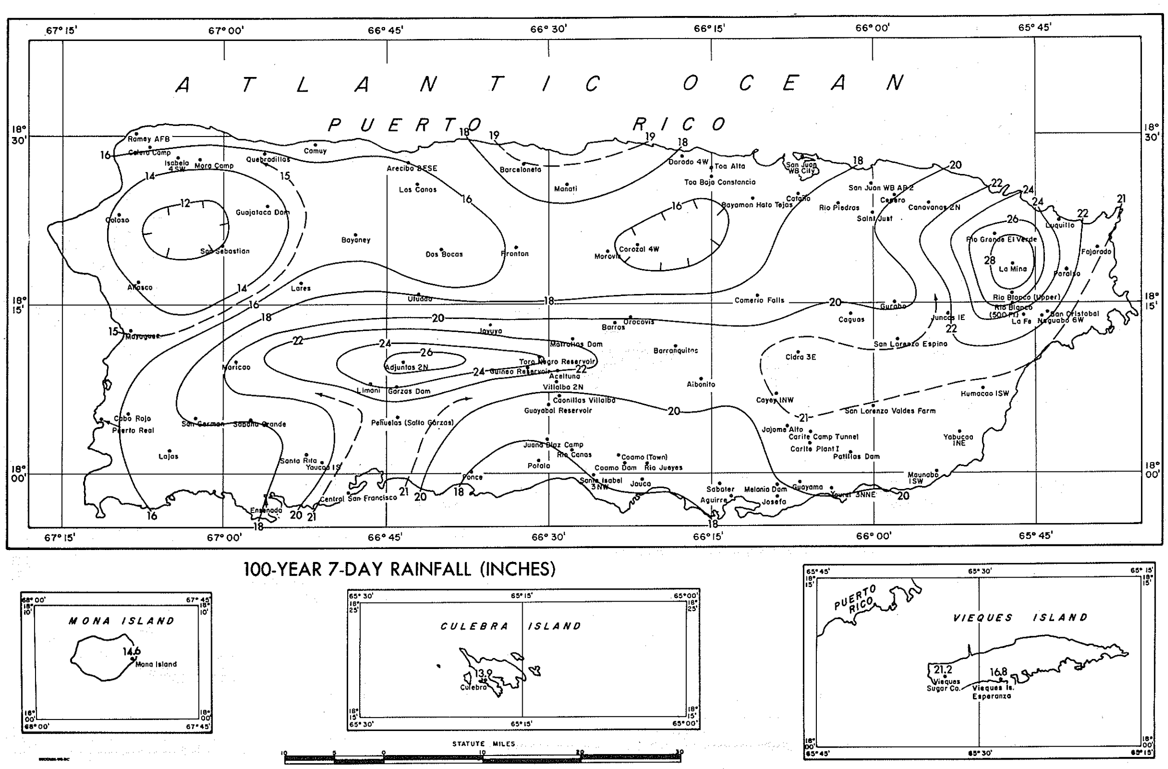

FIGURE 28.—100-year 7-day rainfall (in.) for Puerto Rico.

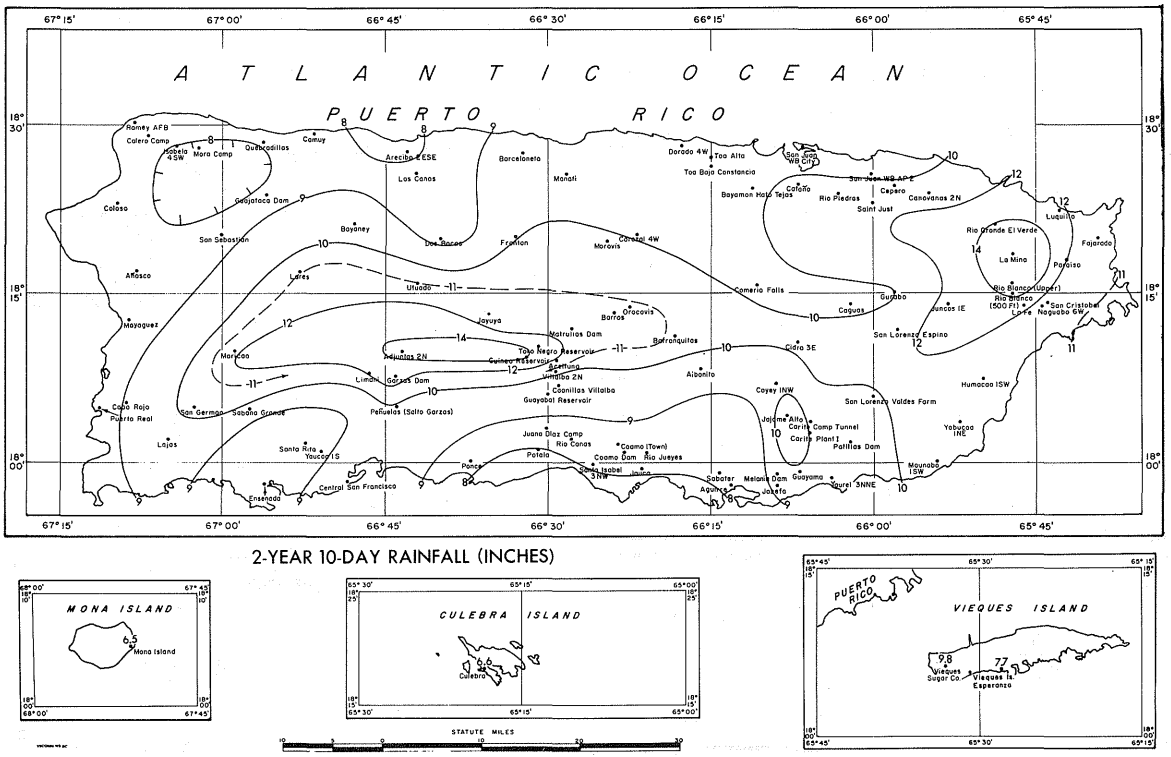

Figure 29.—2-year 10-day rainfall (in.) for Puerto Rico.

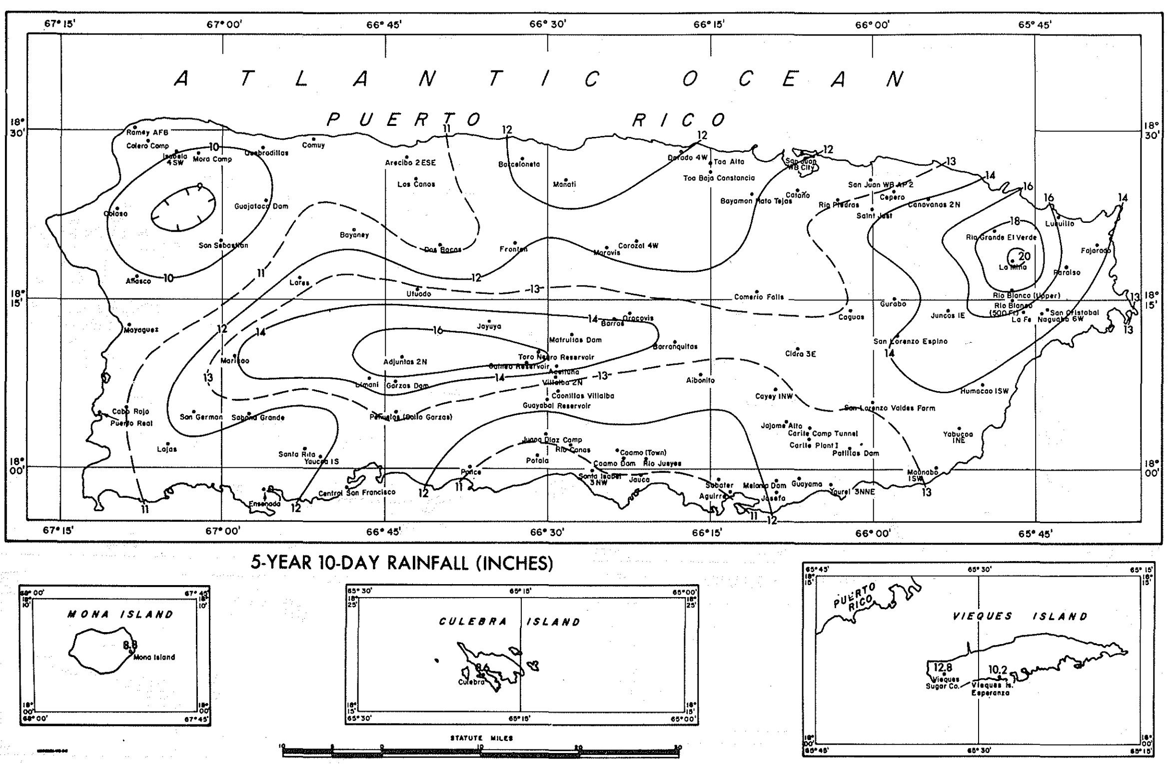

Figure 30.—5-year 10-day rainfall (in.) for Puerto Rico.

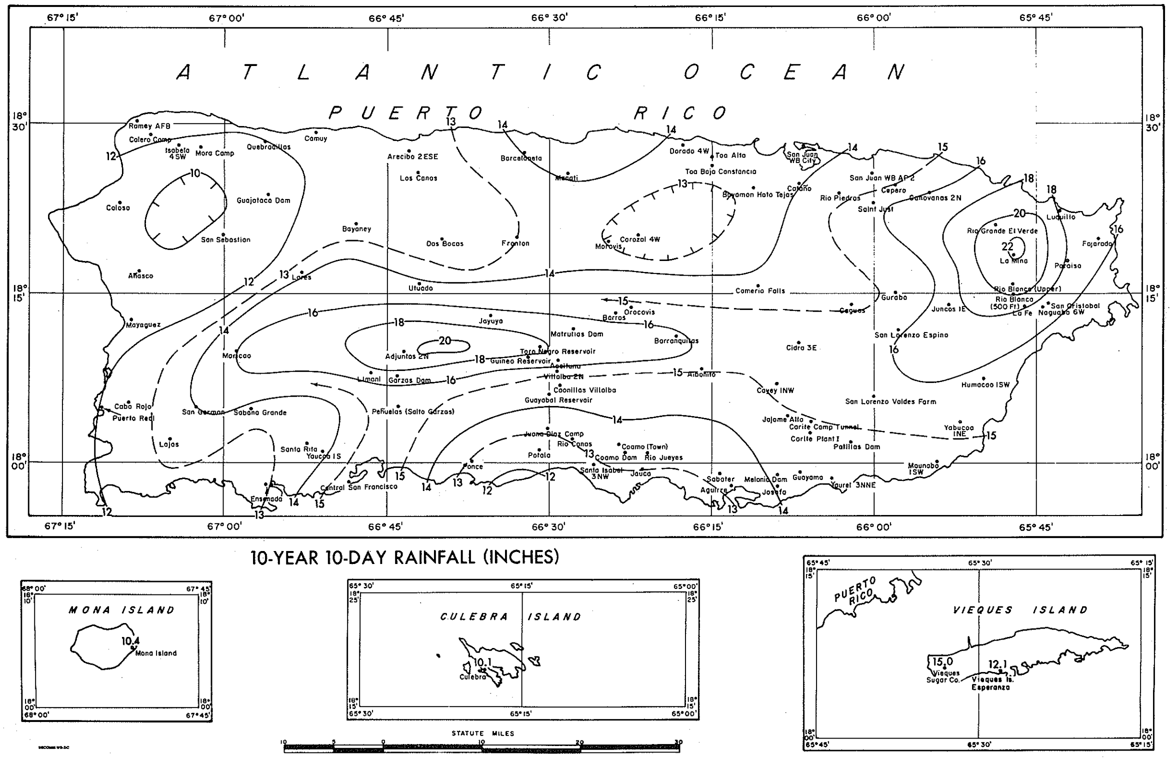

FIGURE 31.—10-year 10-day rainfall (in.) for Puerto Rico.

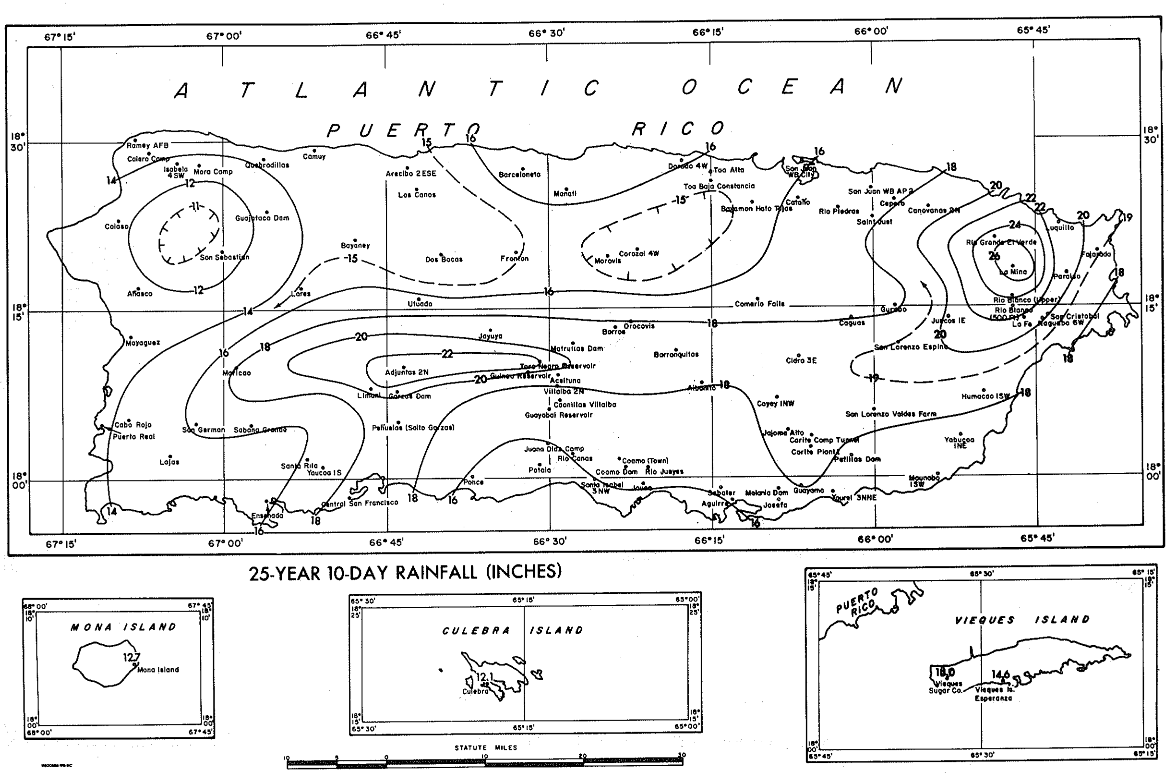

FIGURE 32.—25-year 10-day rainfall (in.) for Puerto Rico.

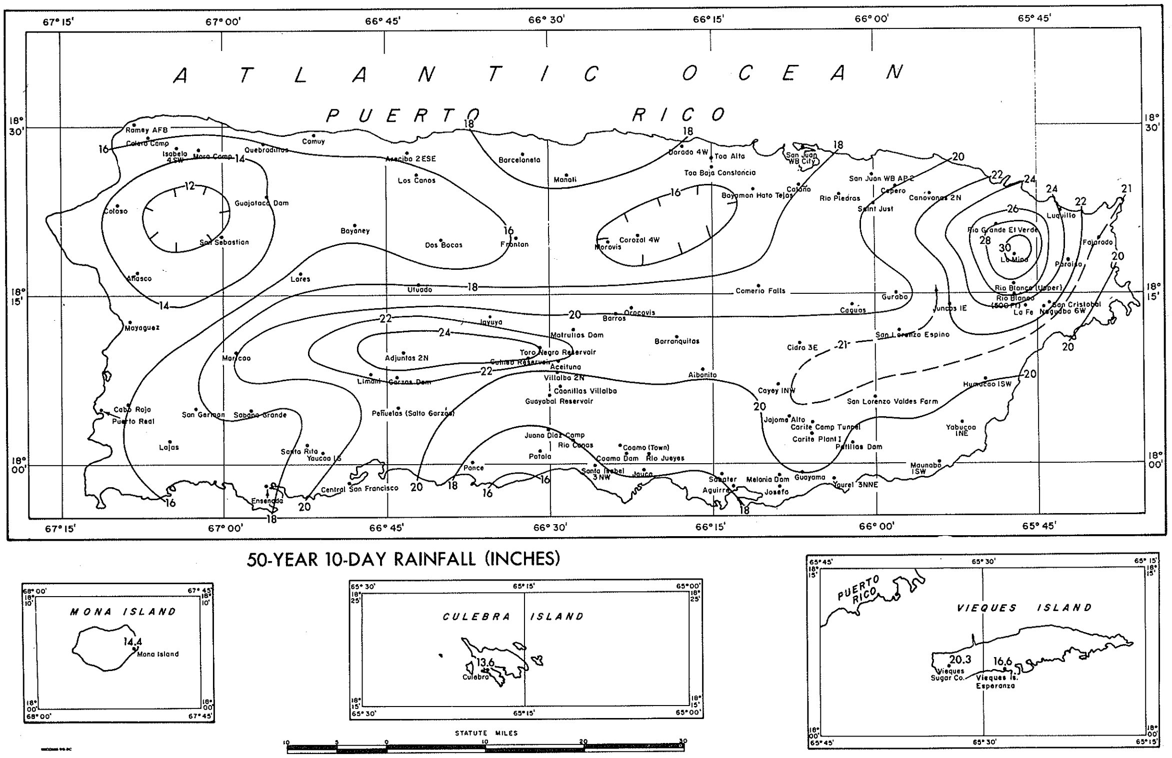

FIGURE 33.—50-year 10-day rainfall (in.) for Puerto Rico.

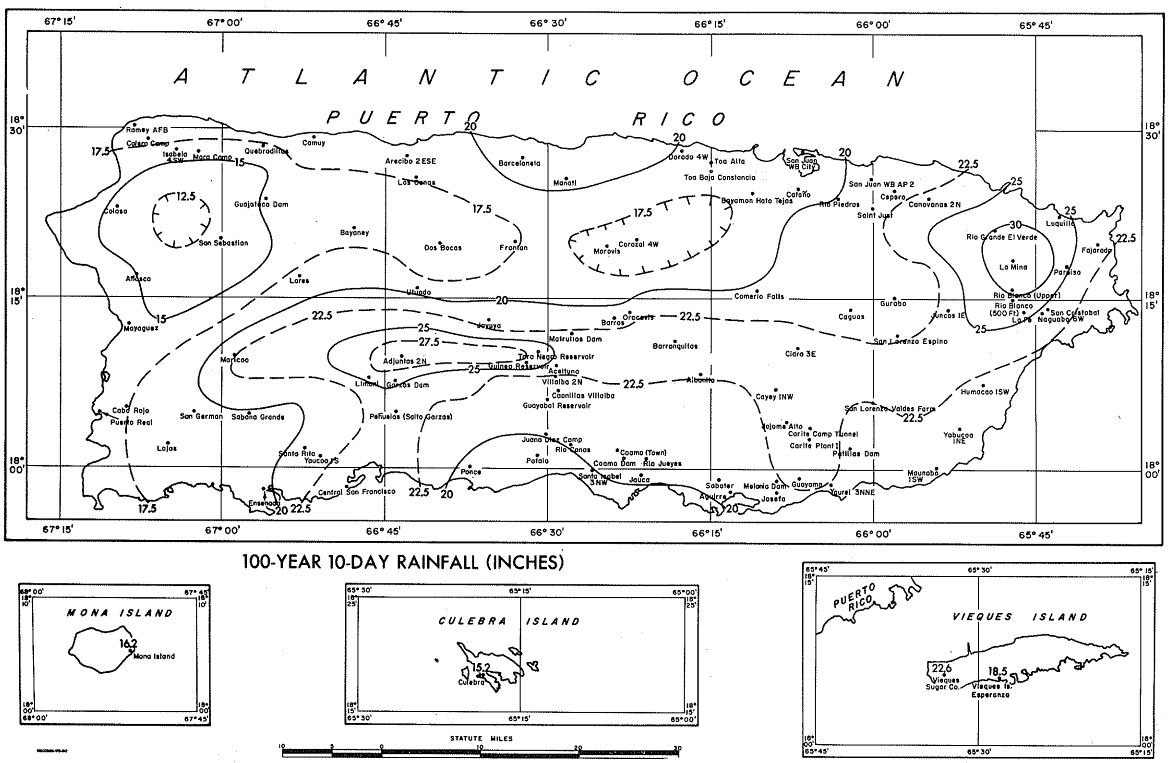

FIGURE 34.—100-year 10-day rainfall (in.) for Puerto Rico.

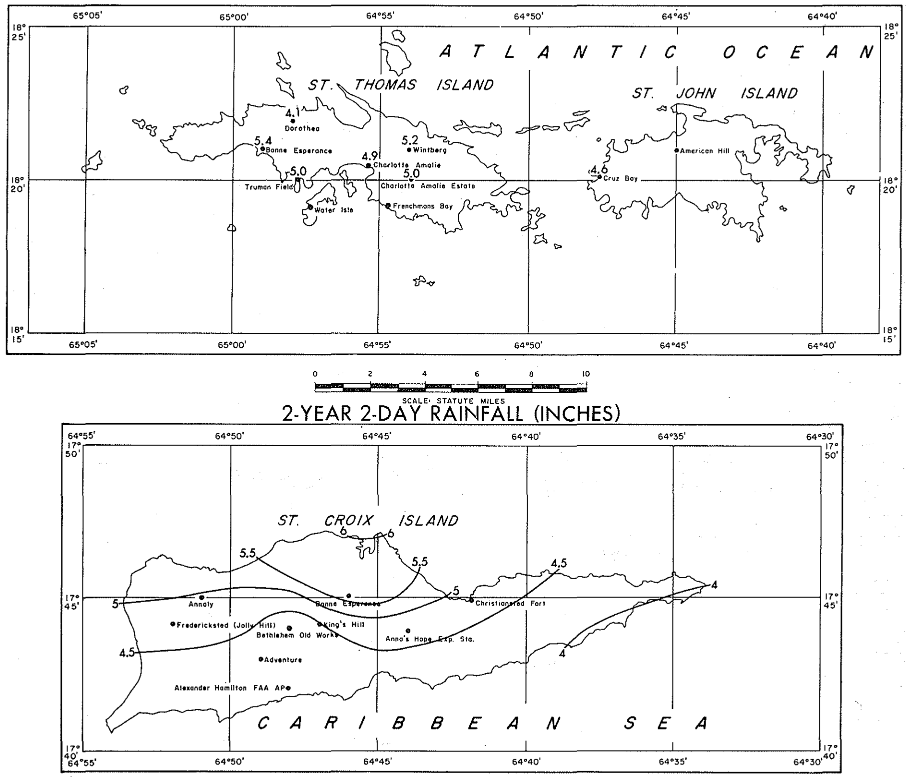

FIGURE 35.—2-year 2-day rainfall (in.) for Virgin Islands.

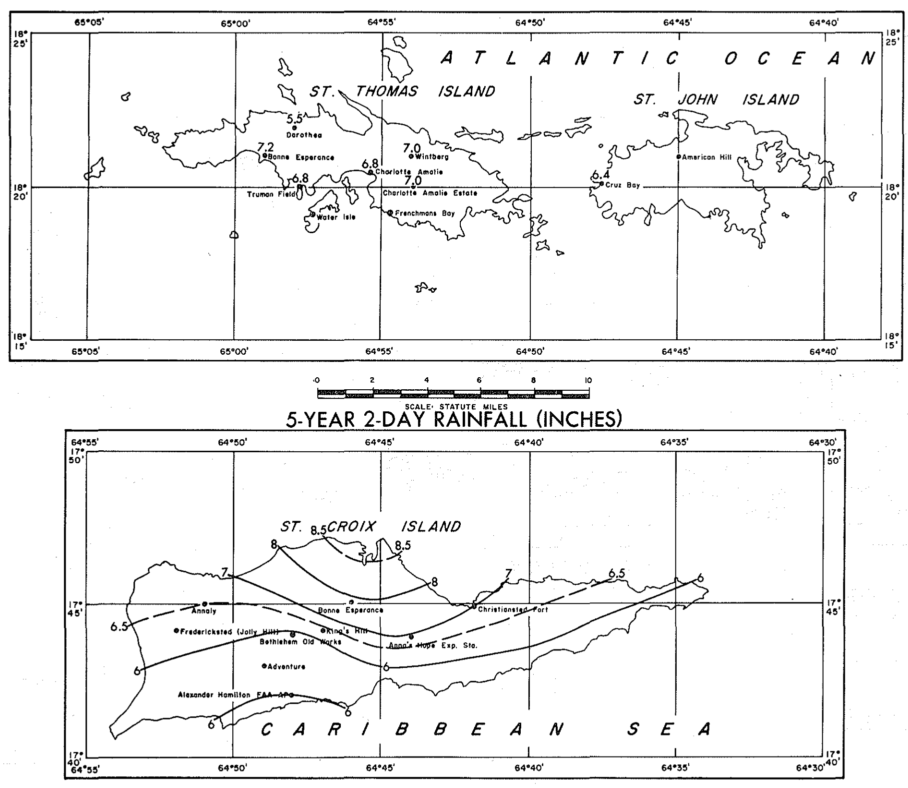

FIGURE 36.—5-year 2-day rainfall (in.) for Virgin Islands.

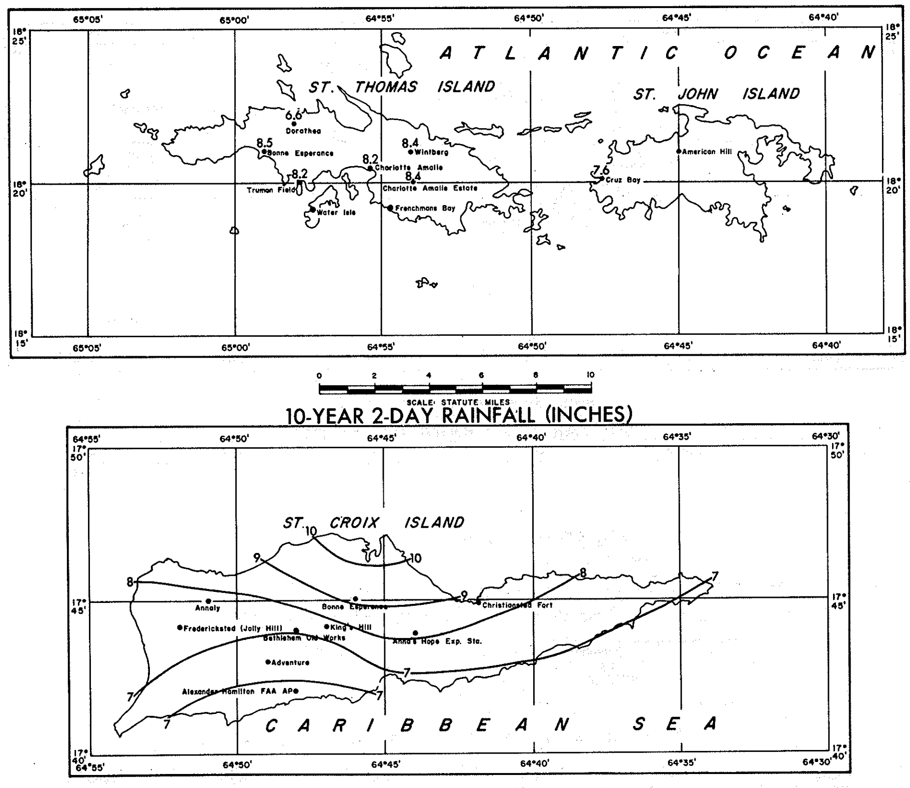

FIGURE 37.—10-year 2-day rainfall (in.) for Virgin Islands.

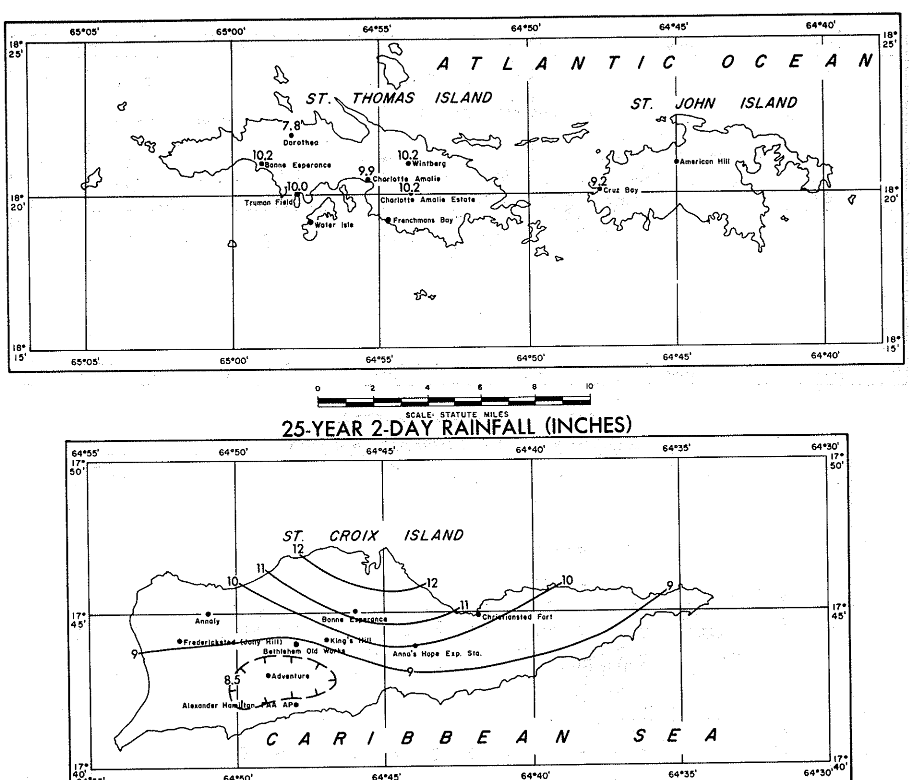

FIGURE 38.—25-year 2-day rainfall (in.) for Virgin Islands.

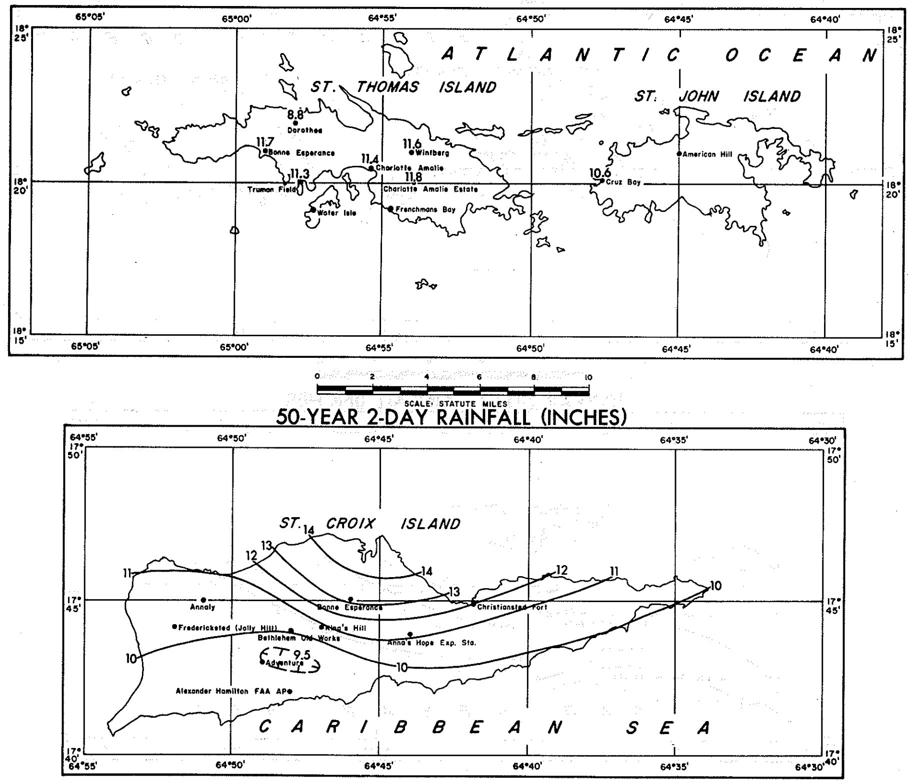

Figure 39.—50-year 2-day rainfall (in.) for Virgin Islands.

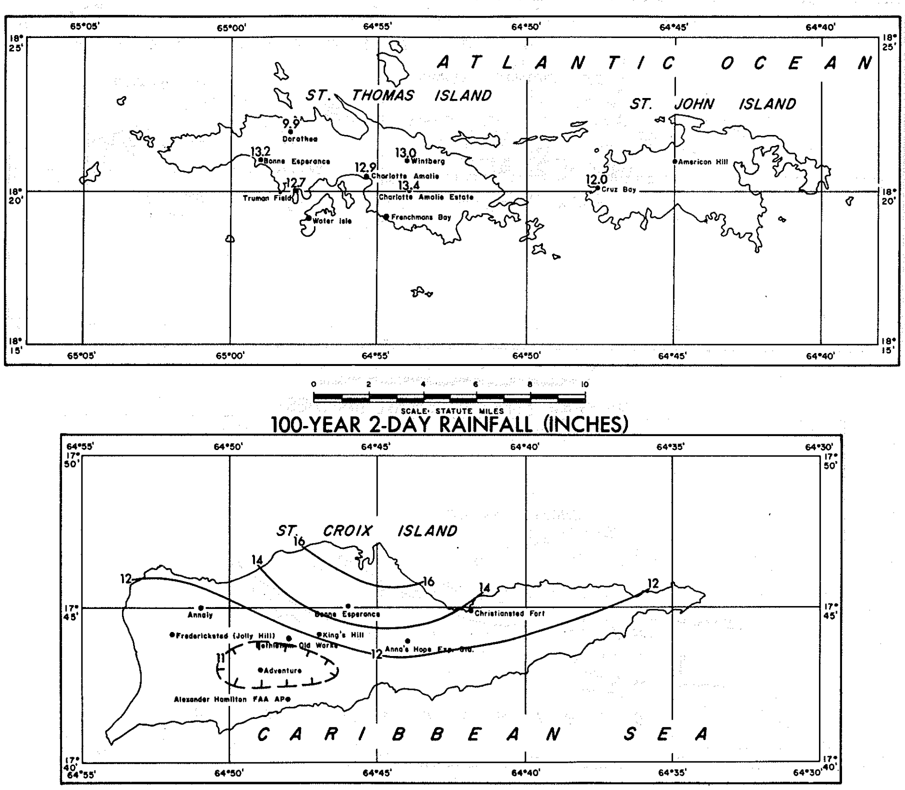

Figure 40.—100-year 2-day rainfall (in.) for Virgin Islands.

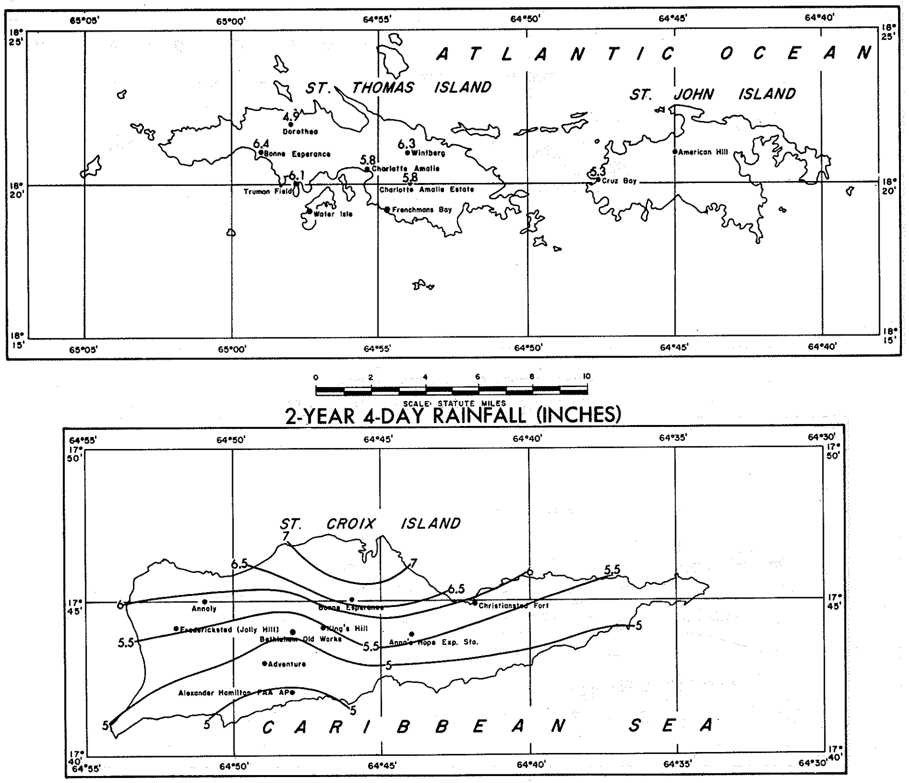

Figure 41.—2-year 4-day rainfall (in.) for Virgin Islands.

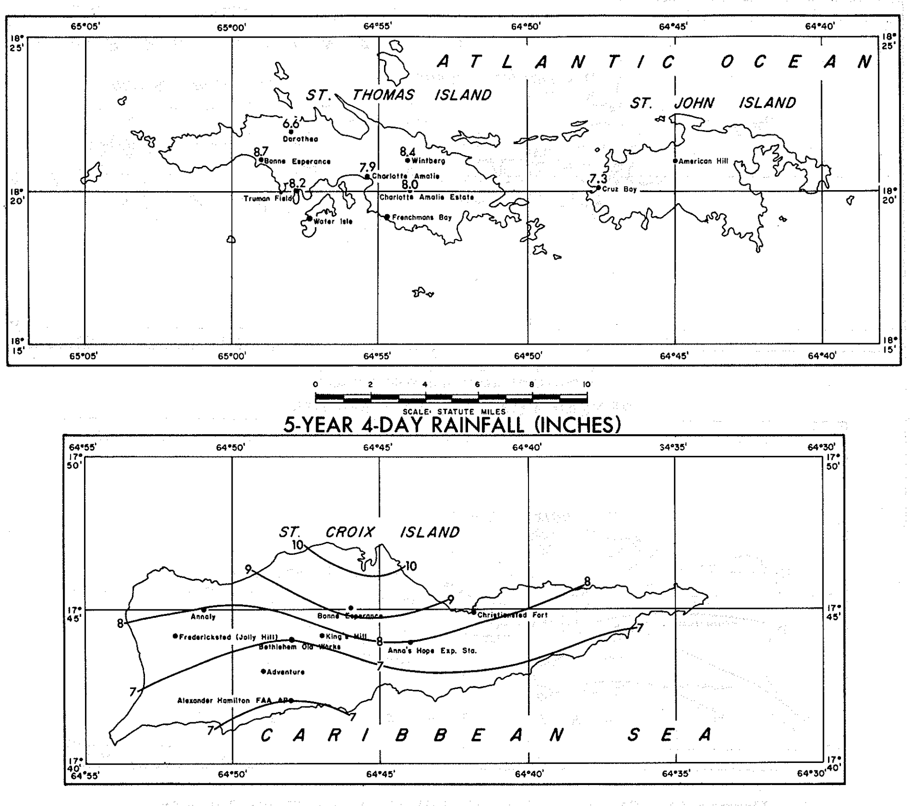

Figure 42.—5-year 4-day rainfall (in.) for Virgin Islands.

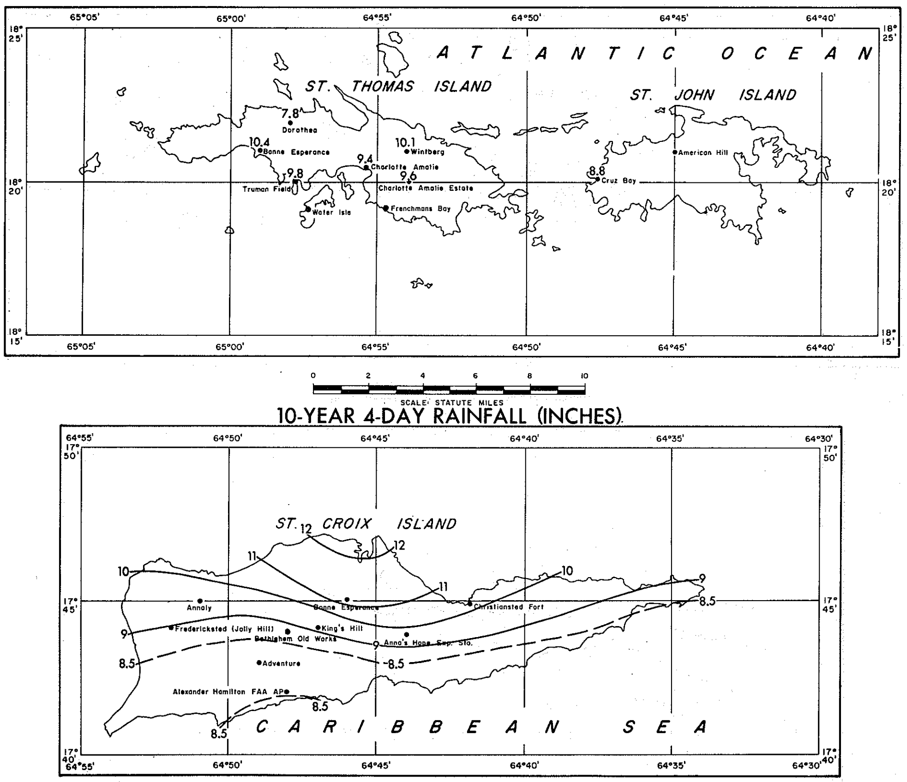

FIGURE 43.—10-year 4-day rainfall (in.) for Virgin Islands.

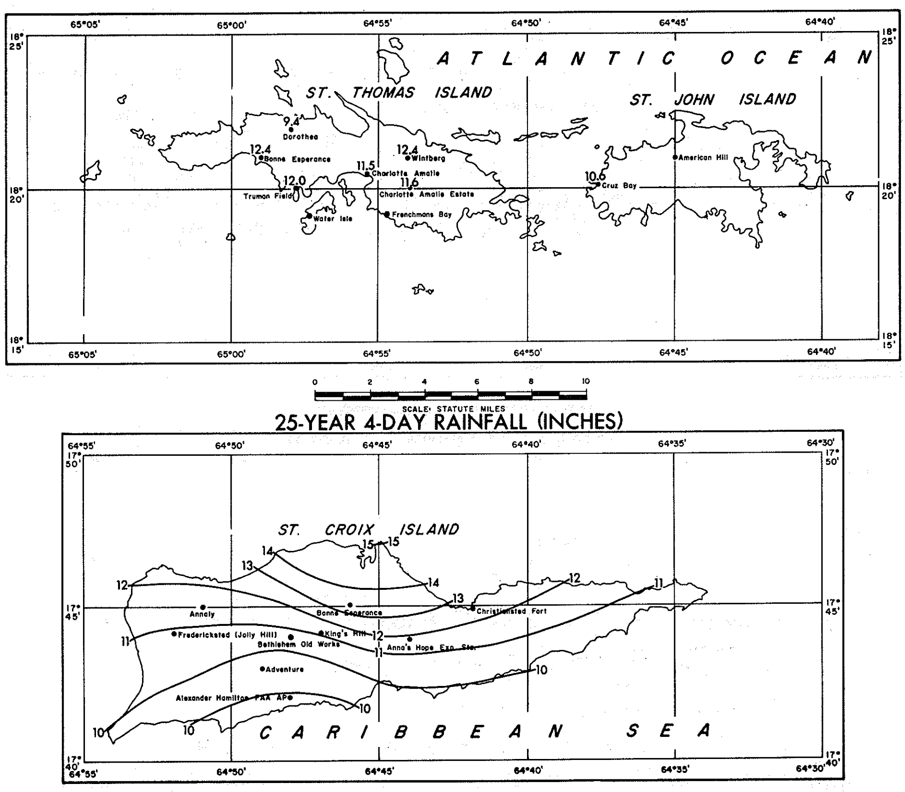

FIGURE 44.—25-year 4-day rainfall (in.) for Virgin Islands.

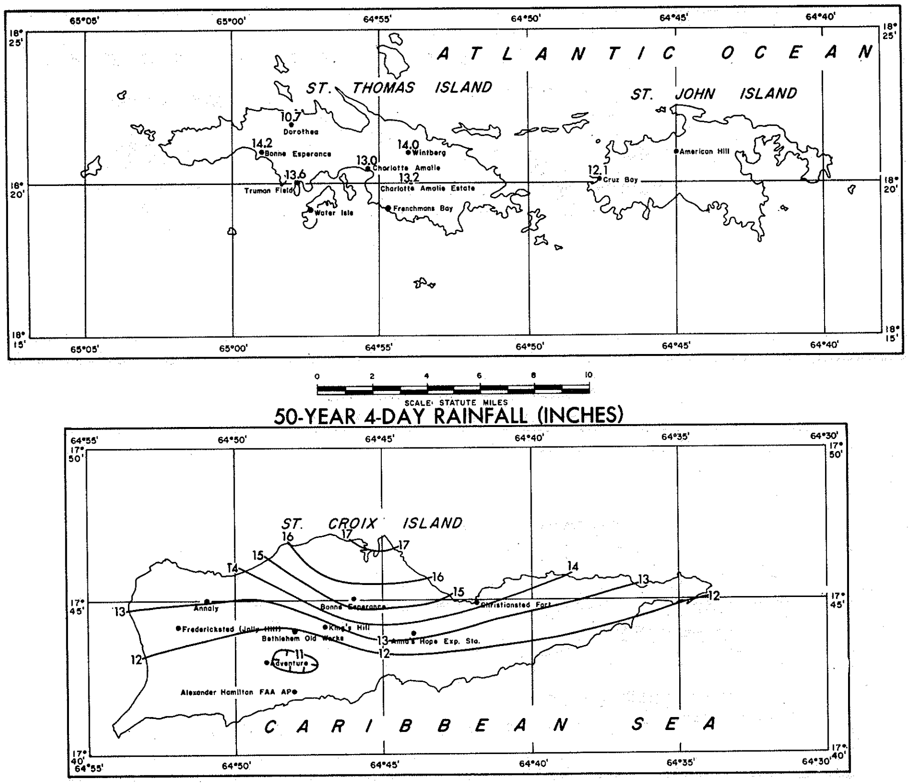

FIGURE 45.—50-year 4-day rainfall (in.) for Virgin Islands.

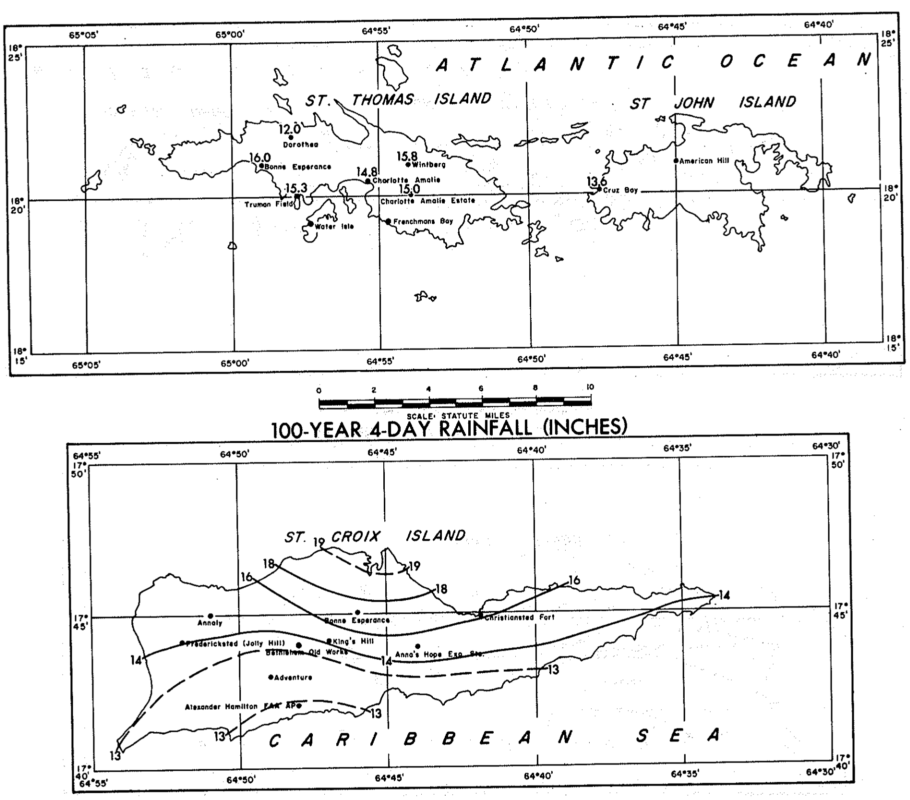

FIGURE 46.—100-year 4-day rainfall (in.) for Virgin Islands.

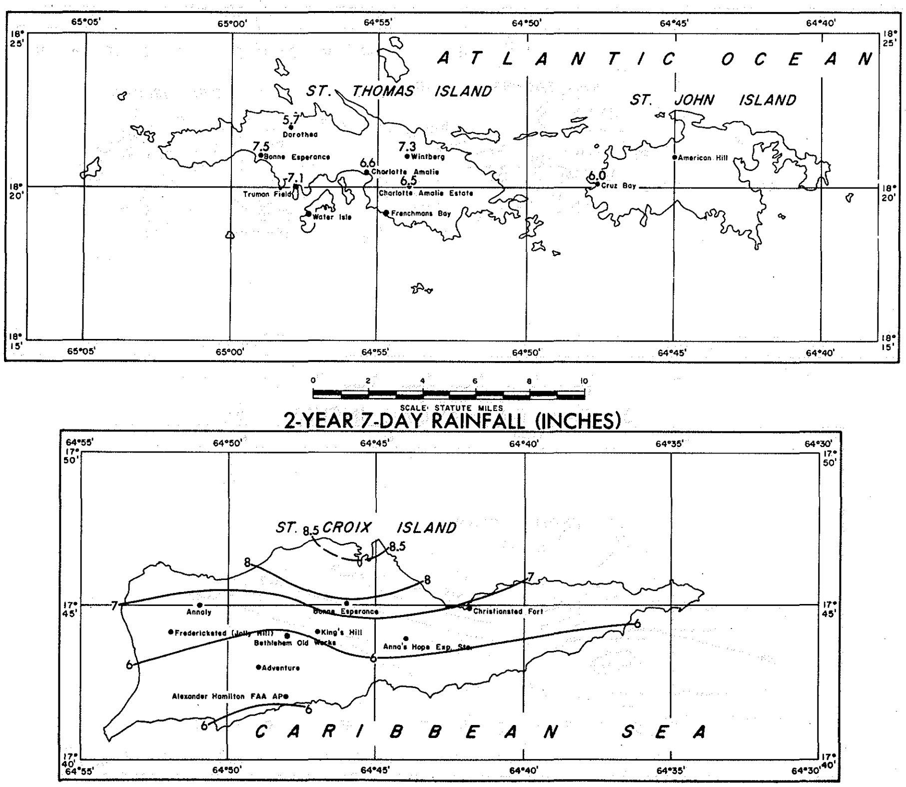

FIGURE 47.—2-year 7-day rainfall (in.) for Virgin Islands.

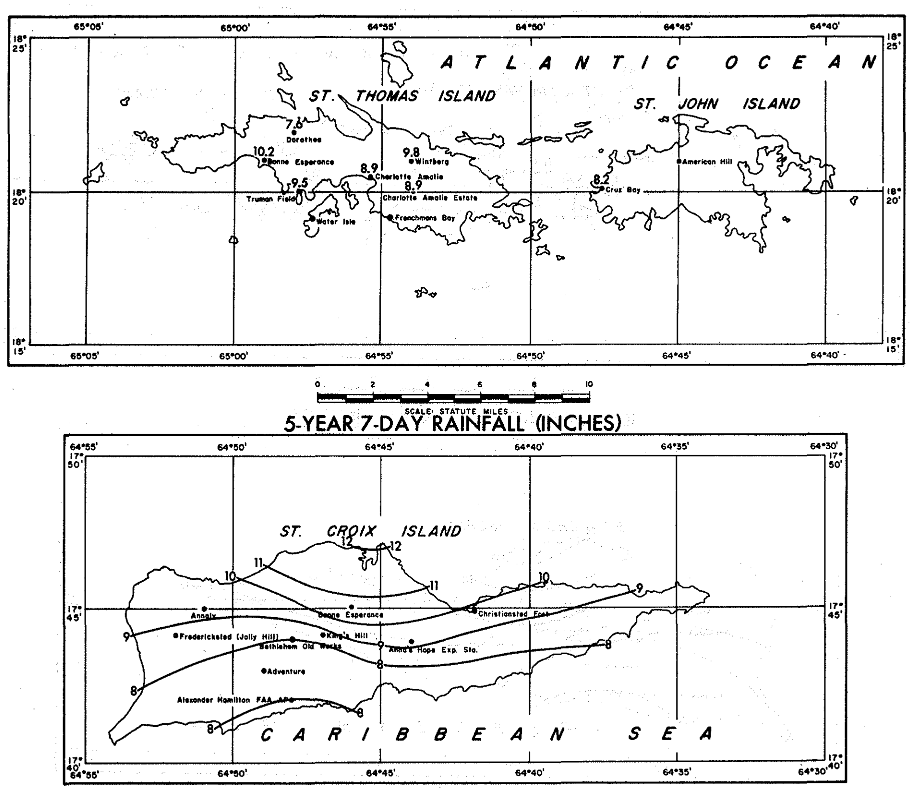

FIGURE 48.—5-year 7-day rainfall (in.) for Virgin Islands.

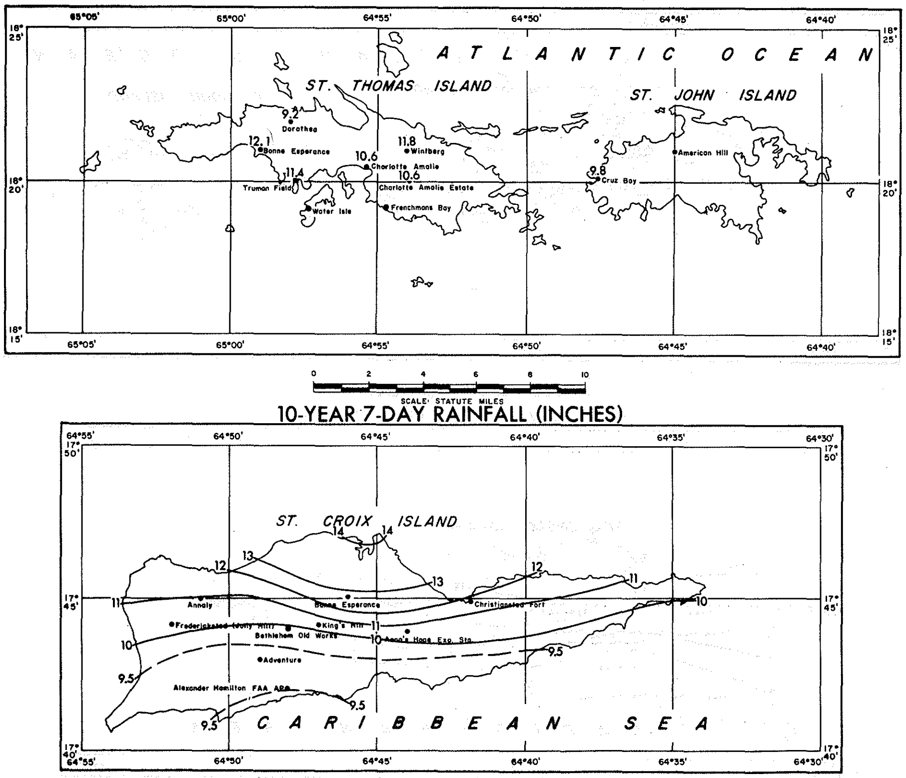

FIGURE 49.—10-year 7-day rainfall (in.) for Virgin Islands.

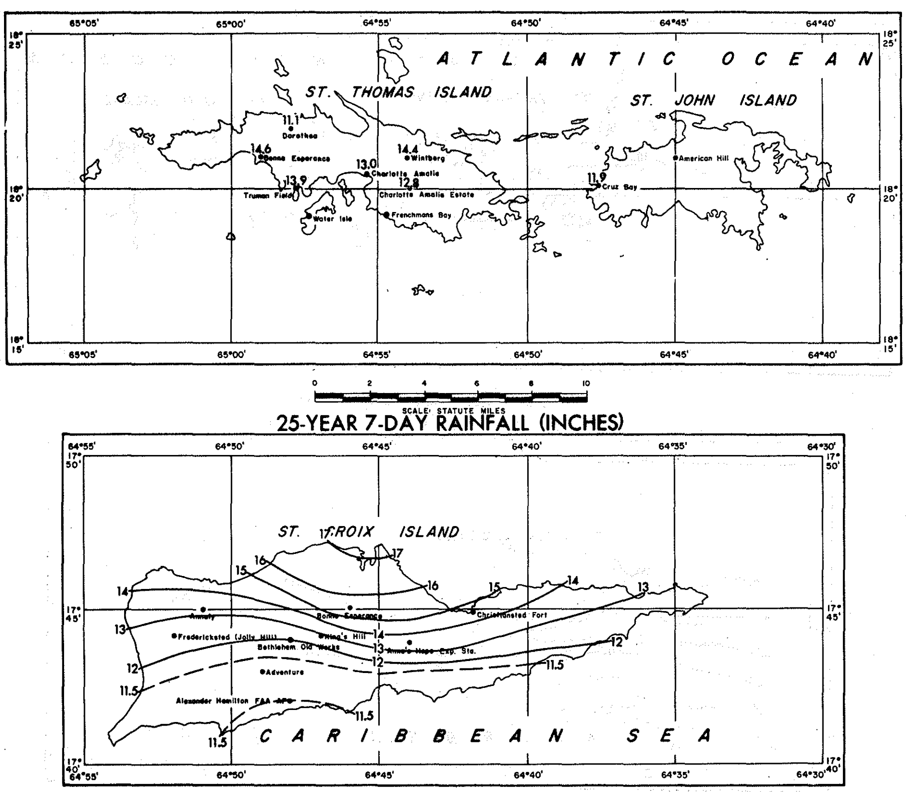

FIGURE 50.—25-year 7-day rainfall (in.) for Virgin Islands.

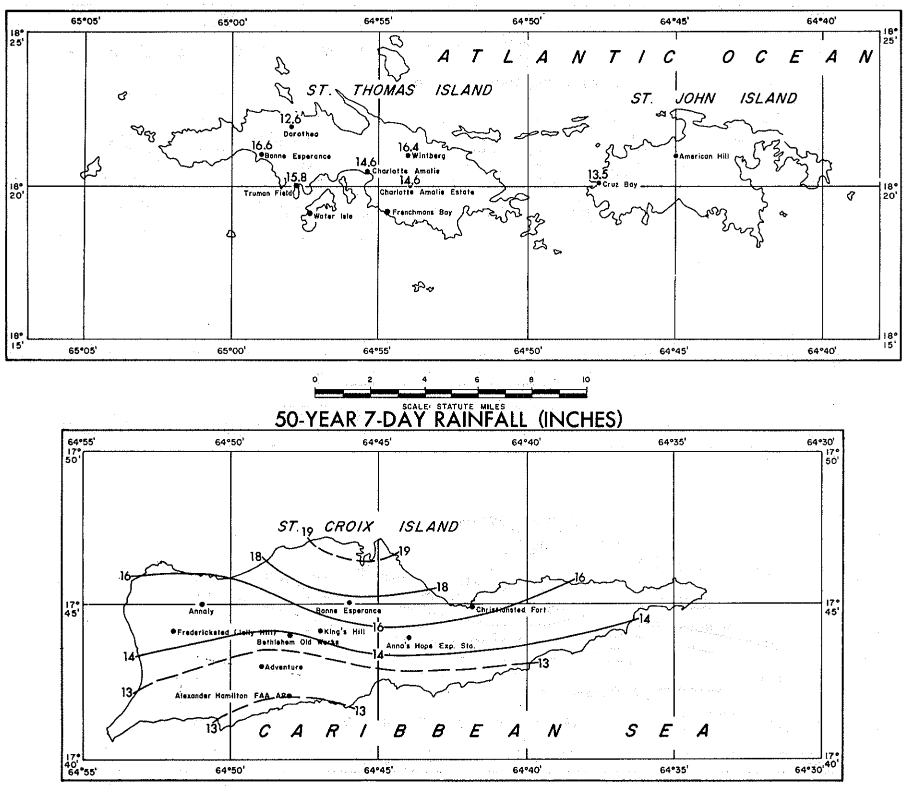

FIGURE 51.—50-year 7-day rainfall (in.) for Virgin Islands.

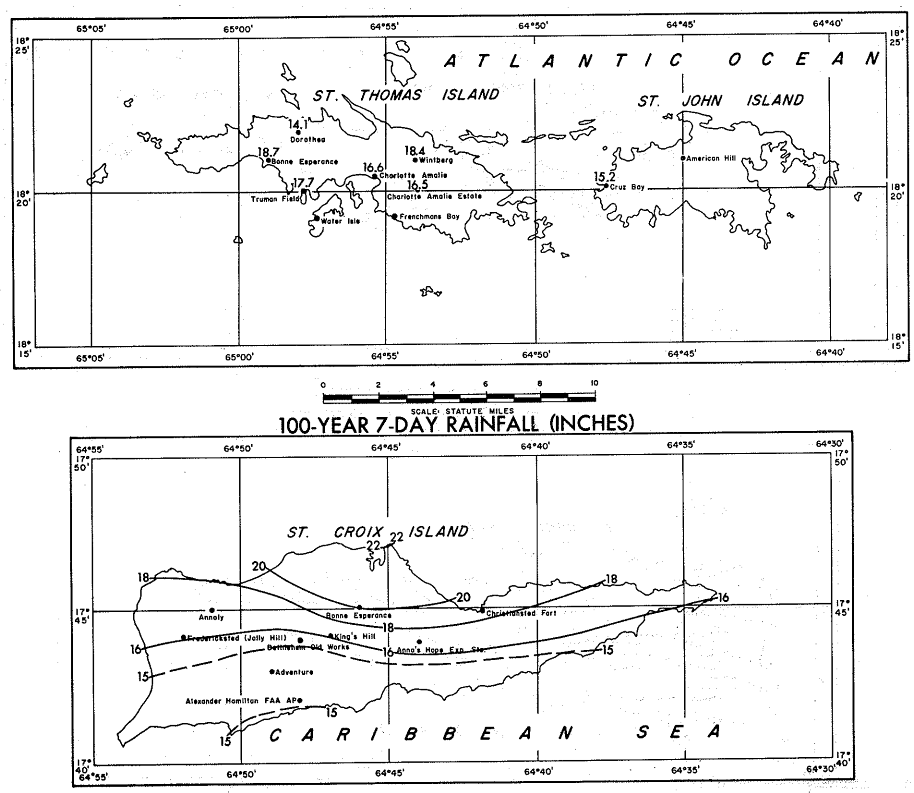

FIGURE 52.—100-year 7-day rainfall (in.) for Virgin Islands.

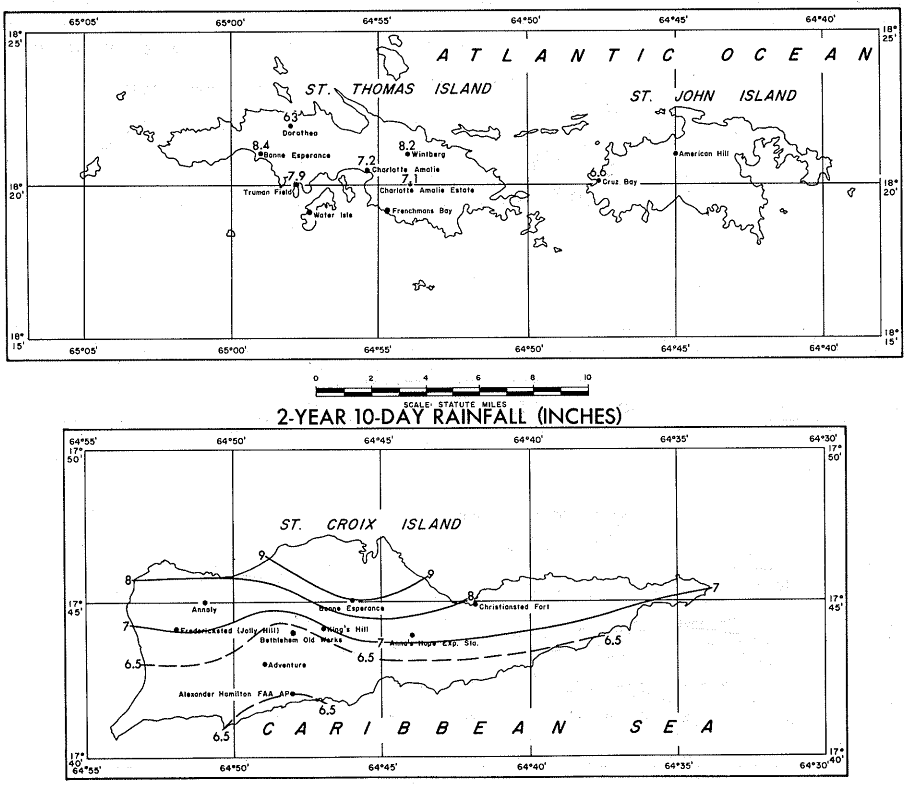

FIGURE 53.—2-year 10-day rainfall (in.) for Virgin Islands.

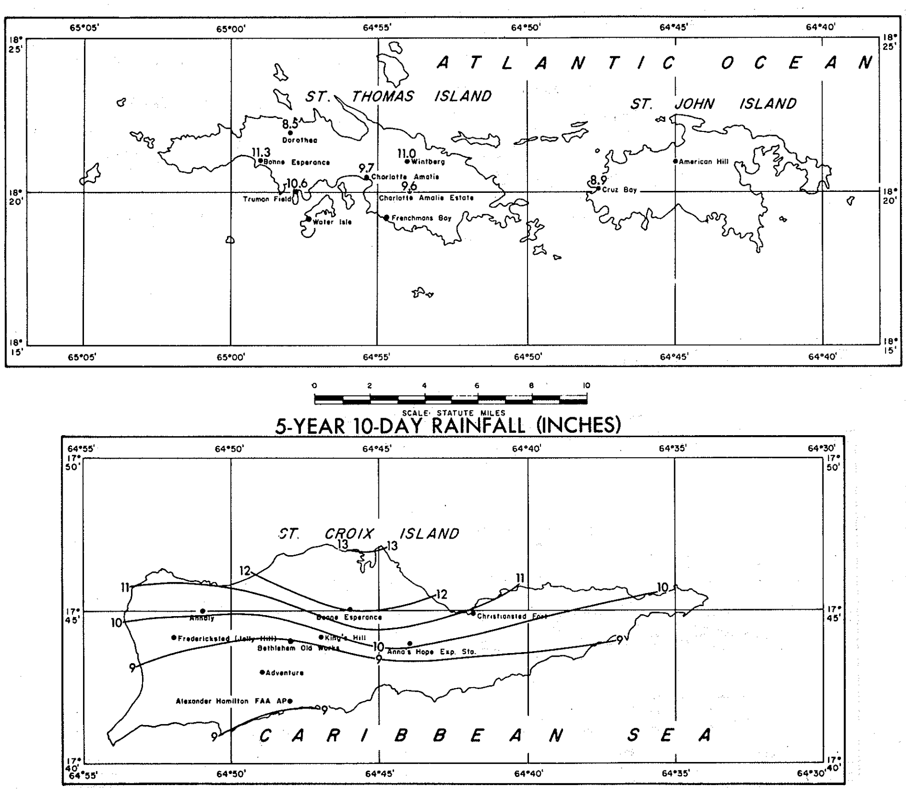

FIGURE 54.—5-year 10-day rainfall (in.) for Virgin Islands.

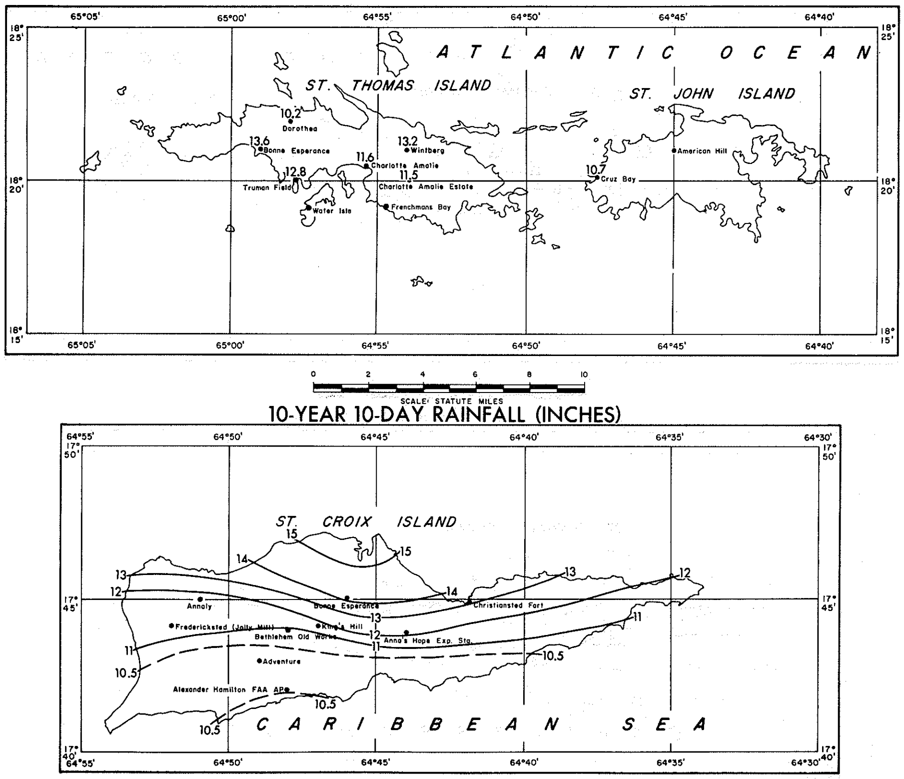

Figure 55.—10-year 10-day rainfall (in.) for Virgin Islands.

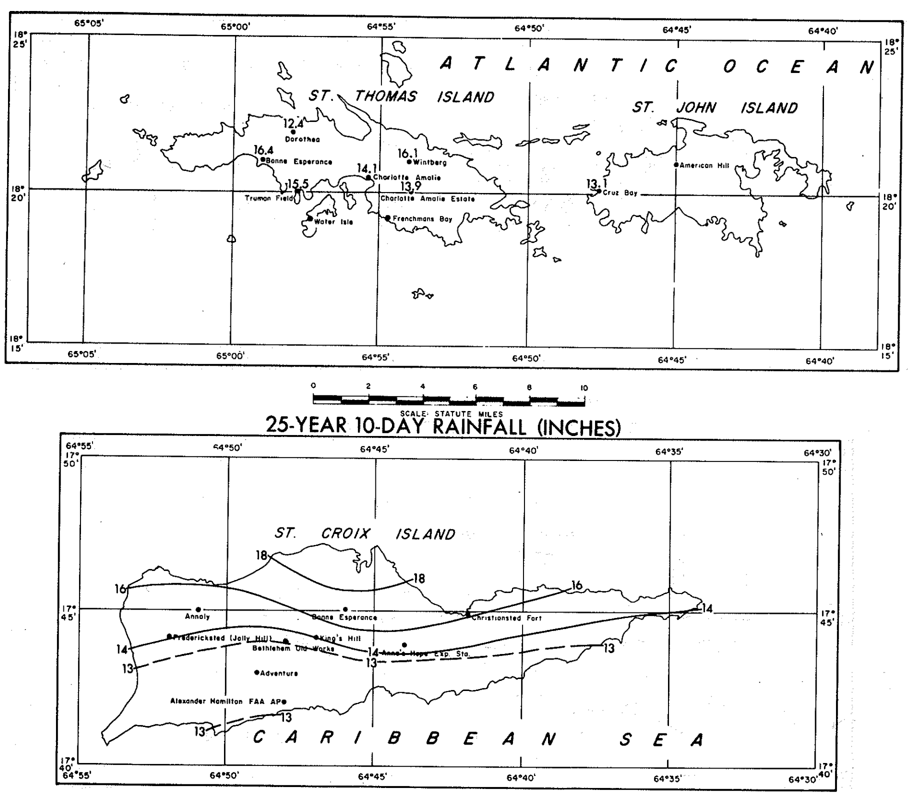

Figure 56.—25-year 10-day rainfall (in.) for Virgin Islands.

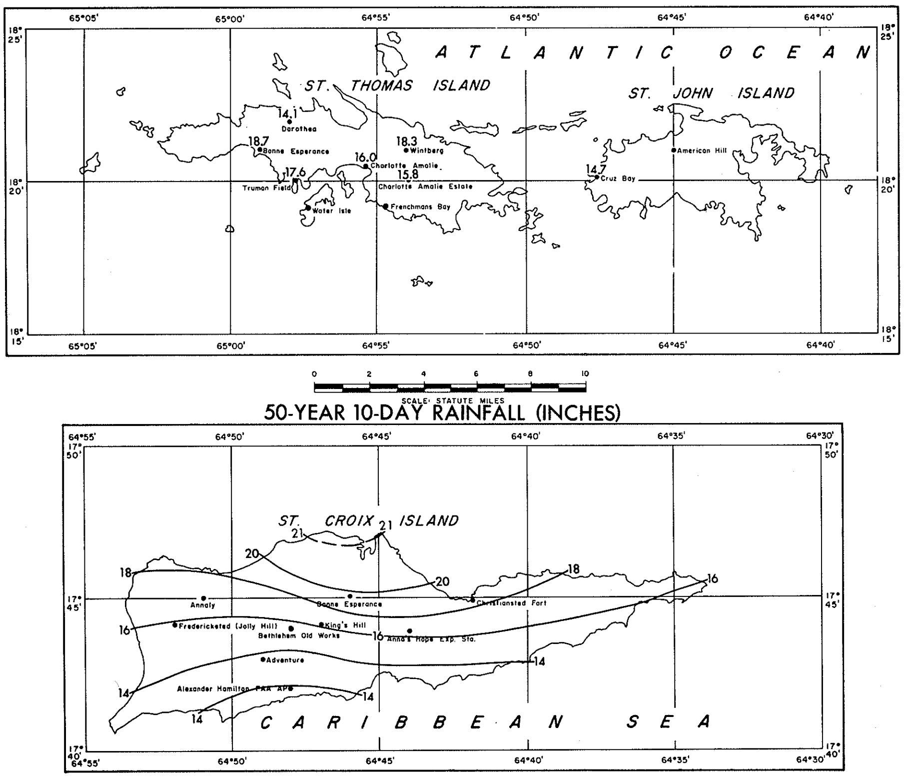

FIGURE 57.—50-year 10-day rainfall (in.) for Virgin Islands.

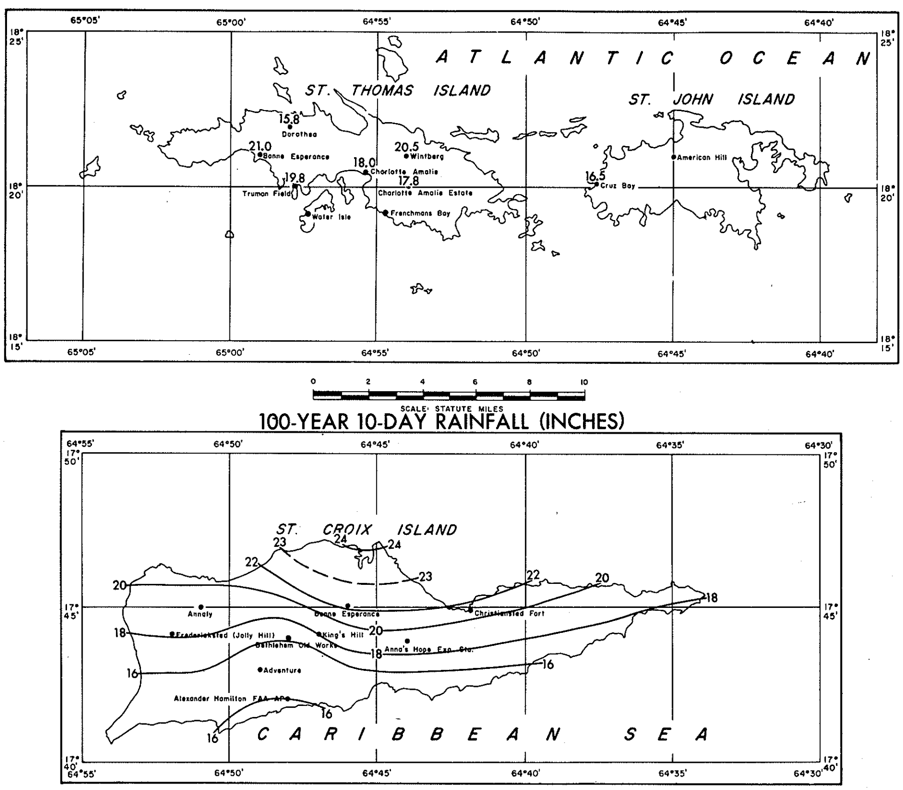

FIGURE 58.—100-year 10-day rainfall (in.) for Virgin Islands.

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