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Two- to Ten-Day Rainfall for Return Periods of 2 to 100 Years in the Hawaiian Islands

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U.S. DEPARTMENT OF COMMERCE
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TECHNICAL PAPER NO. 51

Two- to Ten-Day Rainfall for Return Periods of 2 to 100 Years in the Hawaiian 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 200 square miles and durations from 2 to 10 days are presented. The data consist of generalized estimates of rainfall-frequency data for return periods from 2 to 100 years.

Accuracy of results. The degree of 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 200 stations used since the approach involved the projection of the 24-hr. rainfall-frequency maps of *Technical Paper* No. 43 [1], which are based on data from about 300 stations. The approach also made use of median annual precipitation values from maps based on about 1400 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. Coordination with the Soil Conservation Service was maintained through H. O. Ogrosky, Chief, Hydrology Branch, Engineering Division.

CONTENTS

	Page
PREFACE	iii
1. INTRODUCTION	1
2. BASIC DATA	1
Summarization of data—Period and length of record—Station exposure.	
3. DURATION ANALYSIS	1
n-hour vs. observational-day precipitation—Duration-interpolation diagram.	
4. FREQUENCY ANALYSIS	3
Two types of series—Frequency considerations—Construction of return-period diagram—Use of return-period diagram—General applicability of return-period diagram—Secular trend.	
5. ISOPLUVIAL MAPS	4
Relation between 2-year 24- and 240-hour amounts—Smoothing of isopluvial maps—2-year 10-day map—Ratio of 100-year to 2-year values—100-year 10-day map—22 additional maps—Reliability of results—Smoothing values read from maps.	
6. DEPTH-AREA RELATIONSHIPS	8
7. SEASONAL VARIATION	9
REFERENCES	9

LIST OF ILLUSTRATIONS

Figure No.		Page
1.	Precipitation stations	2
2.	Duration-interpolation diagram	3
3.	Return-period—interpolation diagram	4
4.	Relation for estimating 2-year 10-day rainfall	4
5.	Test of relation of figure 4	4
6.	Points for which rainfall-frequency data were computed	5
7.	100-year to 2-year 10-day ratio map	6
8.	Comparison of estimated vs. computed 10-year 4-day rainfall	8
9.	Smoothing values read from isopluvial maps	9
10.	Depth-area curves	9
11.	2-year 2-day rainfall (in.)	11
12.	5-year 2-day rainfall (in.)	12
13.	10-year 2-day rainfall (in.)	13
14.	25-year 2-day rainfall (in.)	14
15.	50-year 2-day rainfall (in.)	15
16.	100-year 2-day rainfall (in.)	16
17.	2-year 4-day rainfall (in.)	17
18.	5-year 4-day rainfall (in.)	18

LIST OF ILLUSTRATIONS—Continued

Figure No.		Page
19.	10-year 4-day rainfall (in.)	19
20.	25-year 4-day rainfall (in.)	20
21.	50-year 4-day rainfall (in.)	21
22.	100-year 4-day rainfall (in.)	22
23.	2-year 7-day rainfall (in.)	23
24.	5-year 7-day rainfall (in.)	24
25.	10-year 7-day rainfall (in.)	25
26.	25-year 7-day rainfall (in.)	26
27.	50-year 7-day rainfall (in.)	27
28.	100-year 7-day rainfall (in.)	28
29.	2-year 10-day rainfall (in.)	29
30.	5-year 10-day rainfall (in.)	30
31.	10-year 10-day rainfall (in.)	31
32.	25-year 10-day rainfall (in.)	32
33.	50-year 10-day rainfall (in.)	33
34.	100-year 10-day rainfall (in.)	34

TWO- TO TEN-DAY RAINFALL FOR RETURN PERIODS OF 2 TO 100 YEARS IN THE HAWAIIAN ISLANDS

1. INTRODUCTION

"Rainfall Frequency Atlas of the Hawaiian Islands," [1] presents generalized estimates for durations from 30 minutes to 24 hours and return periods from 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 the Hawaiian Islands for durations from 2 to 10 days and for return periods from 2 to 100 years.

A relation for obtaining 2-year 10-day rainfall from 24-hour and annual data was developed. The 24-hour values of [1] and the median annual values of "Rainfall of the Hawaiian Islands" [2] were used in this relation to obtain the 2-year 10-day rainfall map (fig. 29). This map was used in combination with the 100-year to 2-year 10-day ratio map (fig. 7) to obtain the 100-year 10-day map (fig. 34). The 2-year and 100-year 10-day maps, together with the 2-year and 100-year 24-hour maps from [1], were then used with generalized duration and return-period diagrams to provide estimates for a 1610-point grid for 22 intermediate maps.

2. BASIC DATA

Summarization of data. First, daily data from 52 stations were summarized into sequences from 1 to 10 days. The stations (encircled dots in fig. 1) were so distributed geographically as to represent various rainfall regimes. Their data were the basis for testing conversion factors for adjusting observational-day amounts to n-hour amounts and for the duration- and return-period—interpolation diagrams. One- and 10-day data were then summarized for 139 additional stations (plain dots in fig. 1). These data were used to supplement the data from the first group of 52 stations to develop the relation between 1- and 10-day amounts.

Period and length of record. Data for the 52 stations in the first category were tabulated for the 50-year period, 1913–1962. However, there were relatively few stations in operation during the entire period. The average length of record available from these stations was 43 years. Data for the 139 stations in the second group were tabulated for the 20-year period, 1943–62. Breaks in record at some stations necessitated tabulation of data prior to 1943 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, 1943–62 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*

Island	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		
	Length of record (years)							
	10–19	20–29	30–39	≥40	Totals	10–14	≥15	Totals
Hawaii	1	3	0	14	18	7	39	46
Kauai	3	2	0	6	11	1	21	22
Lanai	0	0	0	1	1	0	0	0
Maui	1	1	1	7	10	7	23	30
Molokai	0	0	2	2	4	0	0	0
Oahu	0	2	0	6	8	0	41	41
Total	5	8	3	36	52	15	124	139

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 are not appropriate for extreme values. Except for selection of stations that had consistent exposures during the period of record used, no attempt has been made to adjust precipitation values to a standard exposure.

3. DURATION ANALYSIS

n-hour vs. observational-day precipitation. Since the basic data consisted mostly of observational-day amounts, relations developed in an

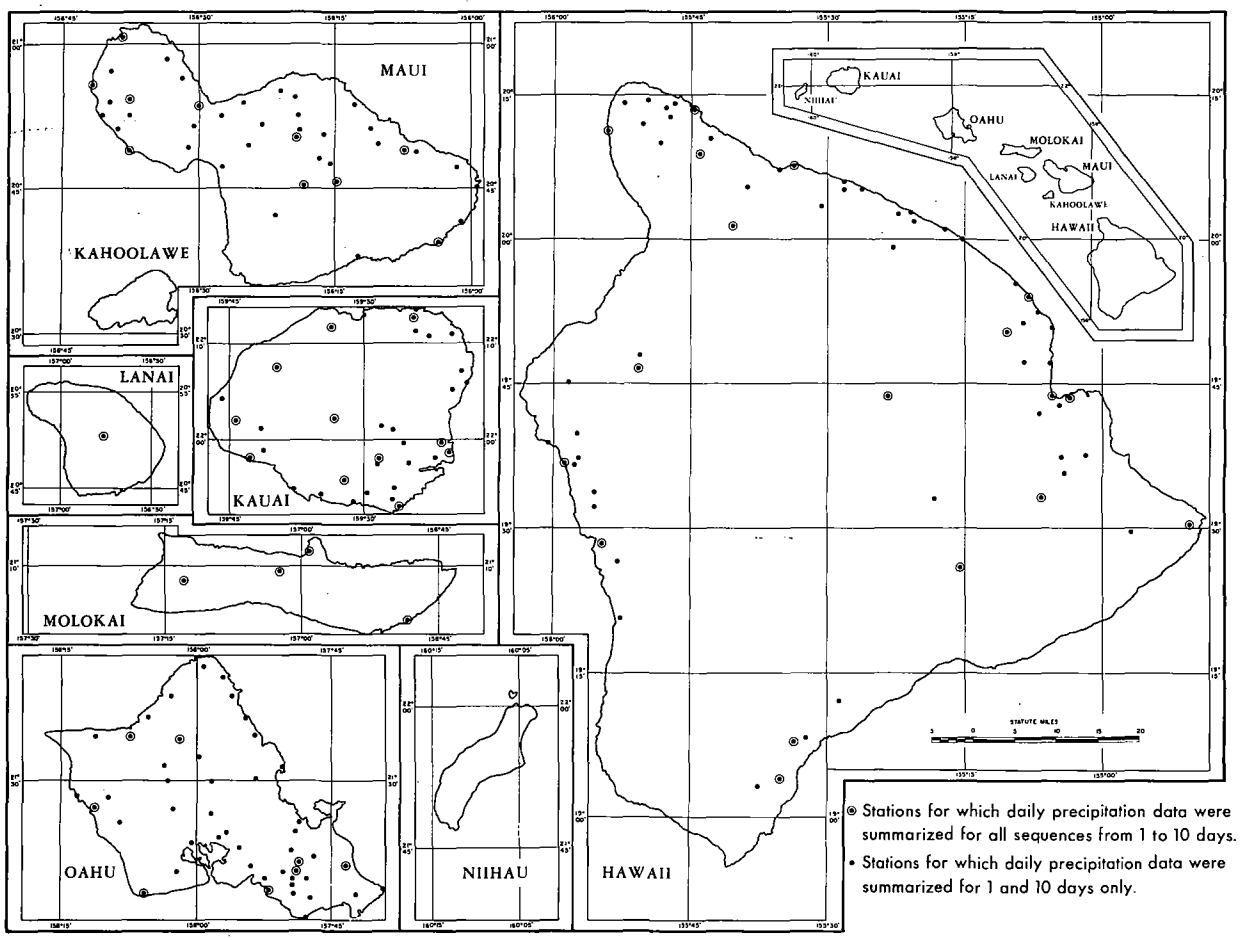


Figure 1.—Precipitation stations.

earlier rainfall-frequency study [4] 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 tested and found appropriate. These relations are ratios of the mean of the annual series (Sec. 4) of the n-hour precipitation 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 precipitation 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 the 52 stations (Sec. 2). The duration-interpolation diagram was developed using data for the 2-year return period. Though developed for the 2-year return period, tests have shown the relationship to be appropriate for use within the range of return periods covered in this report. To use the 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.

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

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

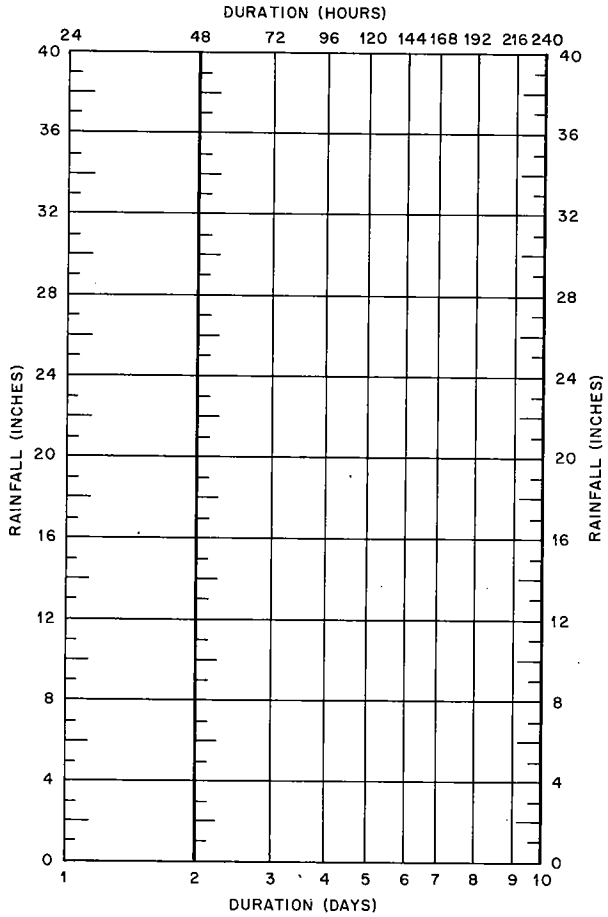


FIGURE 2.—Duration-interpolation diagram.

4. FREQUENCY ANALYSIS

Two types of series. Frequency analyses of precipitation 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 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 34 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 in [4]. 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 in practice (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.

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

Return period	Conversion factor
2-yr.	0.88
5-yr.	0.95
10-yr.	0.99

Construction of return-period diagram. The return-period diagram of figure 3 was obtained by the method described by Weiss [5]. If values 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.

Use of the return-period diagram. The two intercepts needed for the frequency relation of figure 3 are the 2-year and 100-year values obtained from the maps of this report. 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.

General applicability of return-period diagram. Tests have shown that within the range of the data and the purpose of this paper, the return-period relationship is independent of duration. Com-

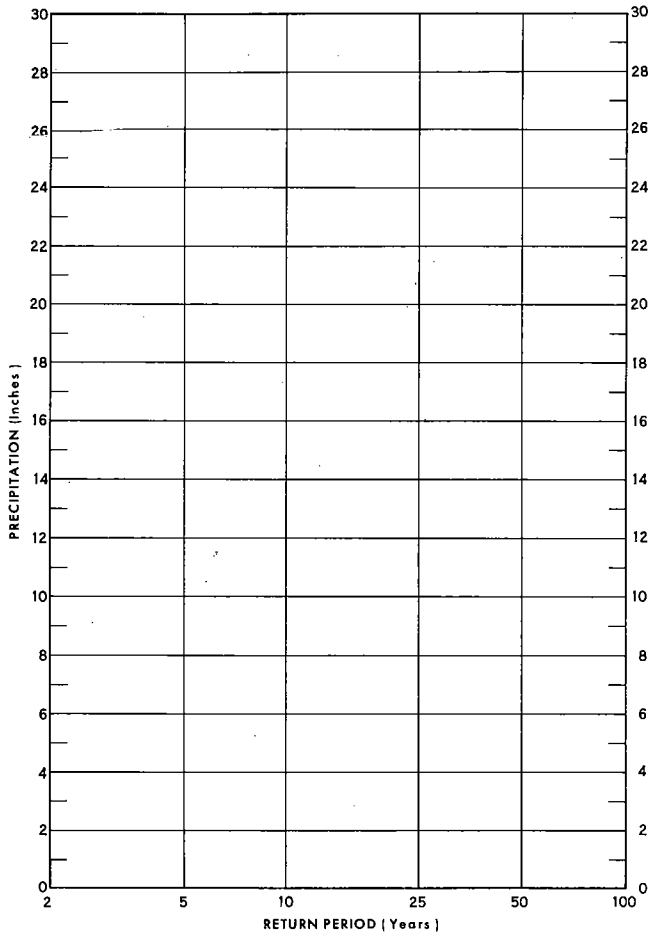


FIGURE 3.—Return-period—interpolation diagram.

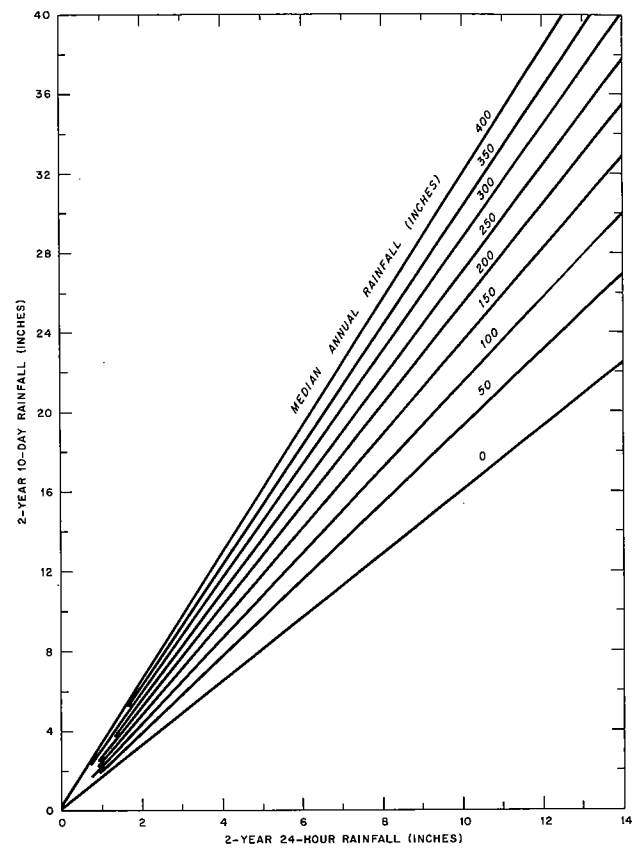


FIGURE 4.—Relation for estimating 2-year 10-day rainfall.

parison of this relationship with that developed for durations less than 24 hours [1] has shown only negligible differences.

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.

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 not available. Since generalized charts of 2-year 24-hour [1] and median annual [2] precipitation were already available, these factors were selected to develop the

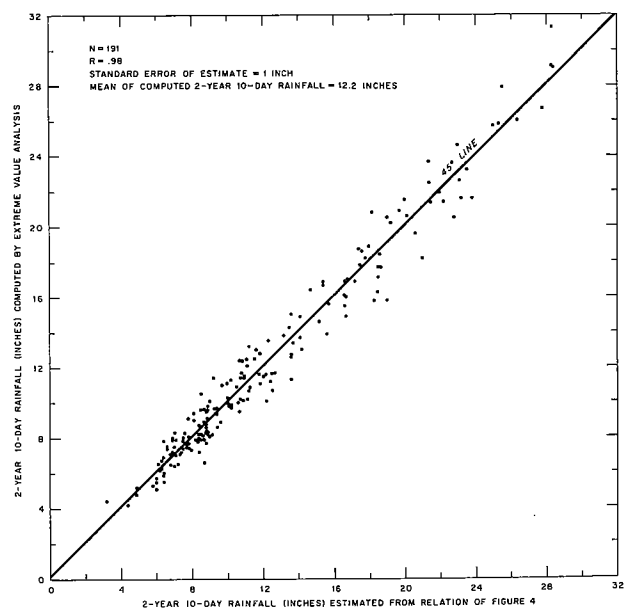


FIGURE 5.—Test of relation of figure 4.

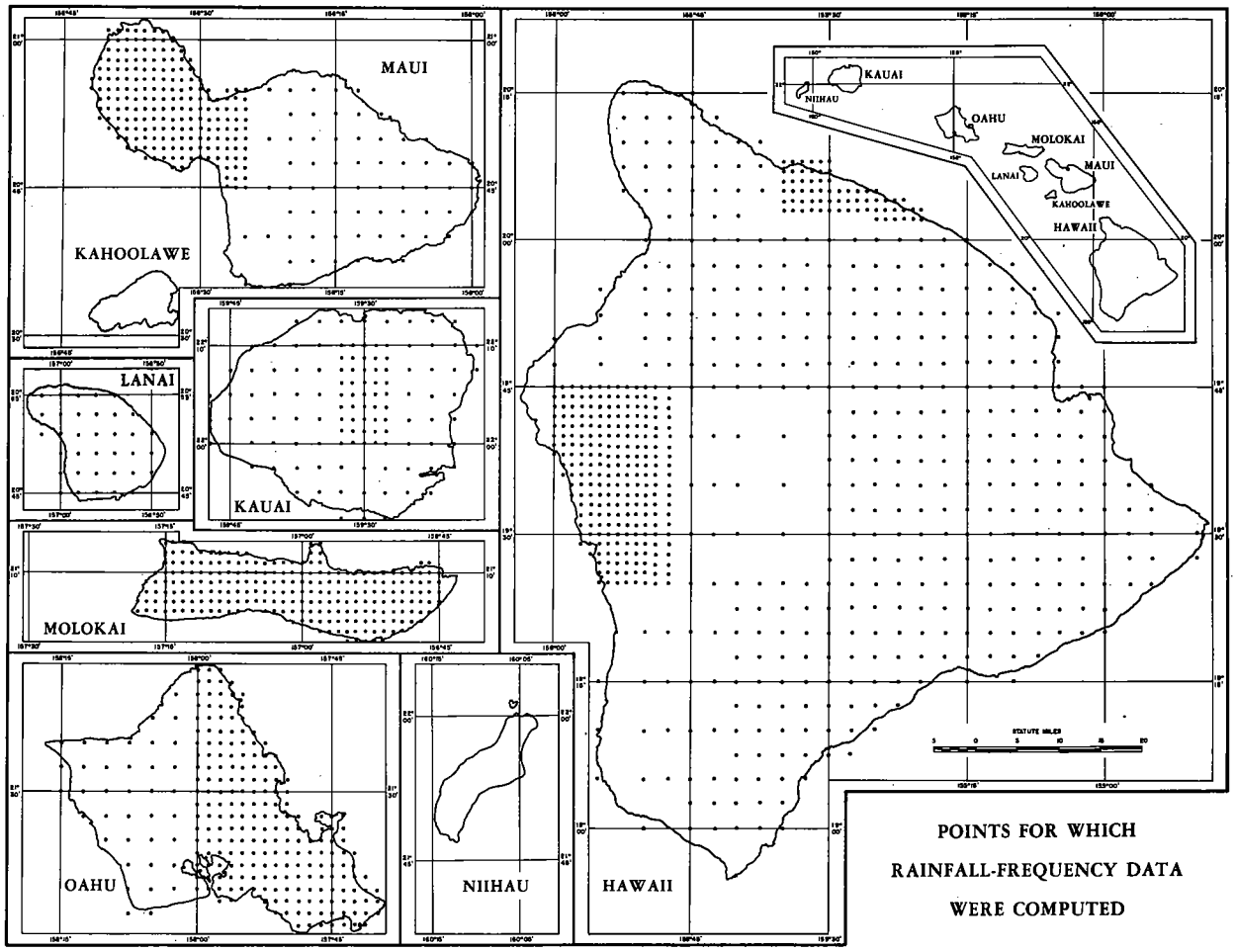


FIGURE 6.—Points for which rainfall-frequency data were computed.

relation. A total of 191 stations (Sec. 2) provided the basic data. In the development of the relationship (fig. 4) all 24-hour data were adjusted to the corresponding n-minute amounts. The 10-day values were adjusted to the corresponding 240-hour amounts. The correlation coefficient between the computed and estimated amounts was 0.98, with a standard error of estimate of 1.0 inch. The mean of the computed values was 12.2 inches. The scatter of estimated vs. computed values is shown in figure 5.

Smoothing of isopluvial maps. The analysis of a series 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, in some important respects, to drawing regression lines 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. Any 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 map (fig. 29). The relationship (fig. 4) described in the preceding paragraphs, the 2-year 24-hour map of [1], and the median an-

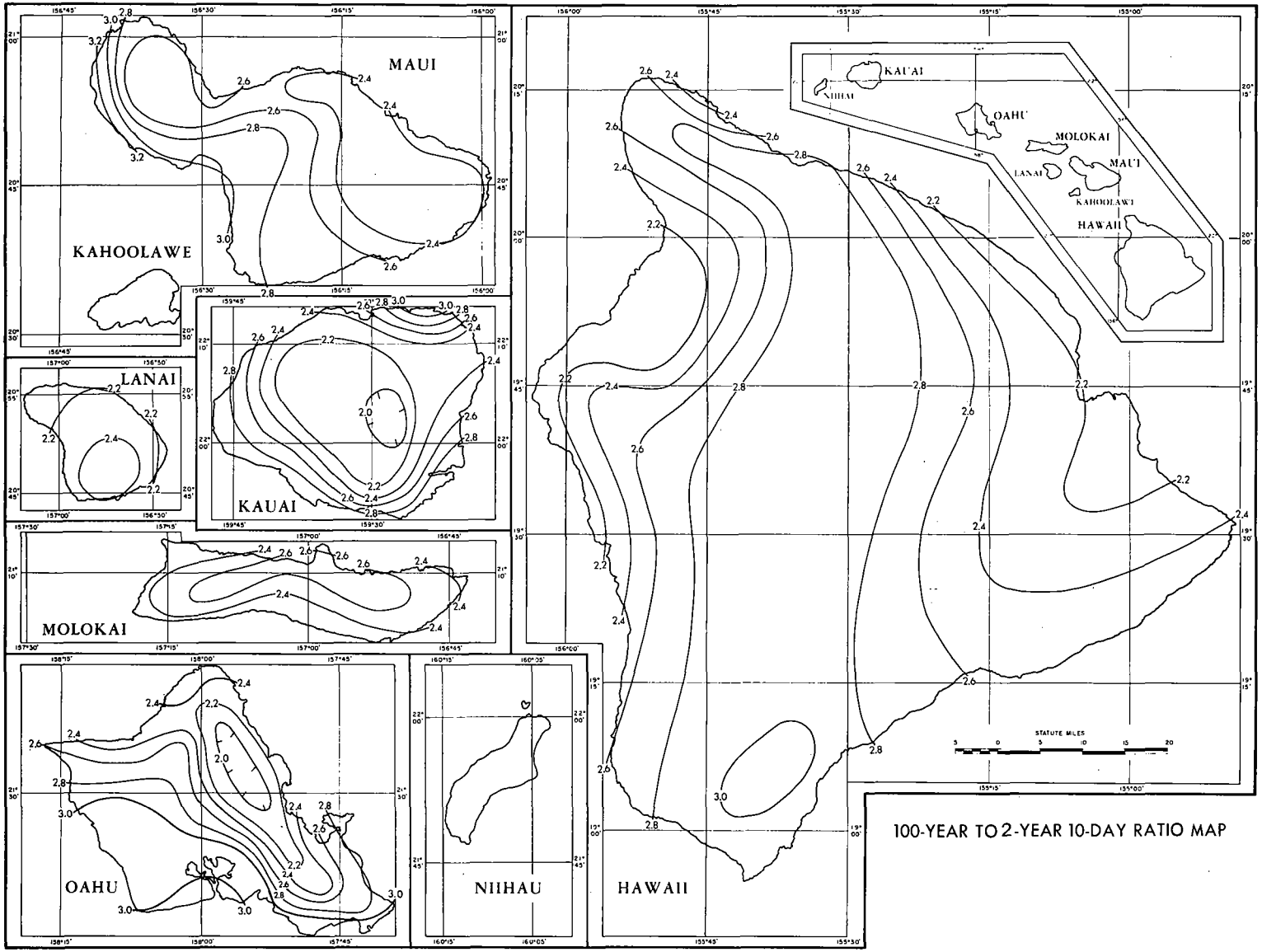


Figure 7.—100-year to 2-year 10-day ratio map.

nual rainfall map of [2] were used to estimate the 2-year 10-day values for a grid of 1610 points (fig. 6). Also plotted on the map were the data for the 191 stations (fig. 1) for which 10-day data had been tabulated. On this 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 (fig. 7) was prepared showing the 100-year to 2-year ratio for the 10-day amounts. The ratio varied from about 1.9 to 3.1 with an average ratio about 2.3. The highest ratios were found in southwestern portions of Oahu and Hawaii, with the lowest ratios in eastern Oahu along the Koolau Range and in central Kauai.

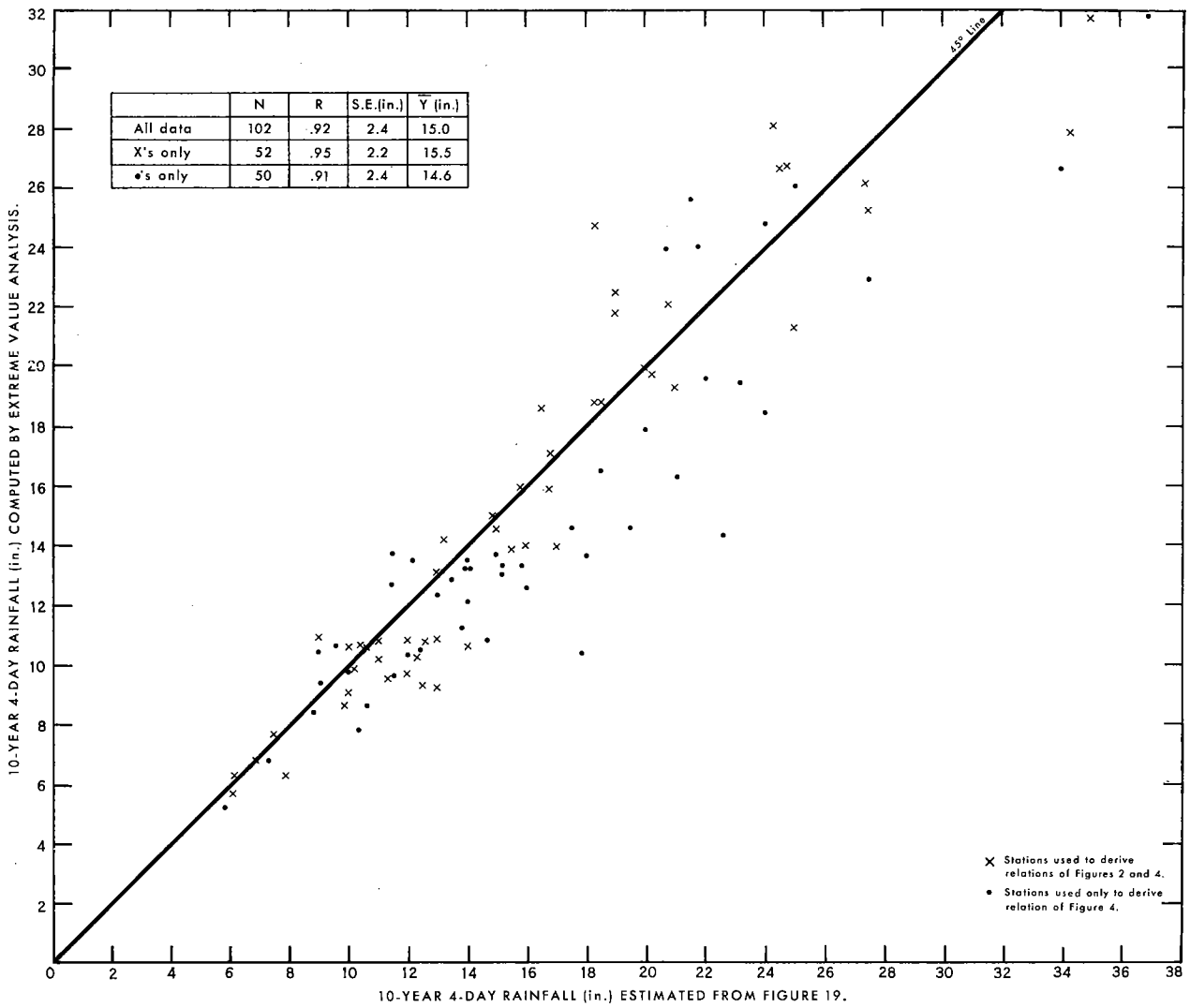
100-year 10-day map (fig. 34). The 100-year 10-day values were computed for the grid points of figure 6 by multiplying the values read from the 2-year 10-day map (fig. 29) by those from the 100- to 2-year ratio map (fig. 7). As a further aid in the analysis of the isopluvial pattern, the 100-year 10-day values computed for the 191 stations for which data had been processed were also plotted, in addition to the grid points.

22 additional maps. For the 22 intermediate maps required for this report, values were computed for the 1610 grid points (fig. 6). First, values were read from the 2-year 24-hour and 10-day maps and the 100-year 24-hour and 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 24 precipitation-frequency maps are shown at the end of the text (figs. 11–34).

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 reliability of the relationships developed for the present study was assessed by reference to scatter diagrams of observed vs. estimated values like that of figure 5. 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.

Tests of the 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 rainfall 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. The data of figure 8 show some tendency for the maps to indicate higher values than those computed from station records. This bias suggests that the analysts tended to give greater weight to the higher of adjacent values. This practice may be considered conservative since rainfall-frequency values tend to increase with increasing length of record. However, as can be seen from figure 8, the standard errors of estimate do not exceed the 20-percent limitation considered acceptable for this type of data. Of course, such tests do 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 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) 21°06′ N., 156°57′ W. on Molokai, and the other (b) at 21°30′ N., 158°00′ W. on Oahu. 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).



	N	R	S.E.(in.)	$\bar{Y}$ (in.)
All data	102	.92	2.4	15.0
X's only	52	.95	2.2	15.5
•'s only	50	.91	2.4	14.6

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

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 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 for a point is an average depth for the location, for a given return period and duration. The depth-area curve attempts to relate this average point value, for a given duration and frequency and within a given area, to the average depth over that area for the same duration and frequency. The curves of figure 10 depict the relationship for durations of 1 to 10 days and for areas up to 200 square miles, and are to be used in reducing the point values of precipitation shown on the maps of figures 11–to 34 to areal values. The curves

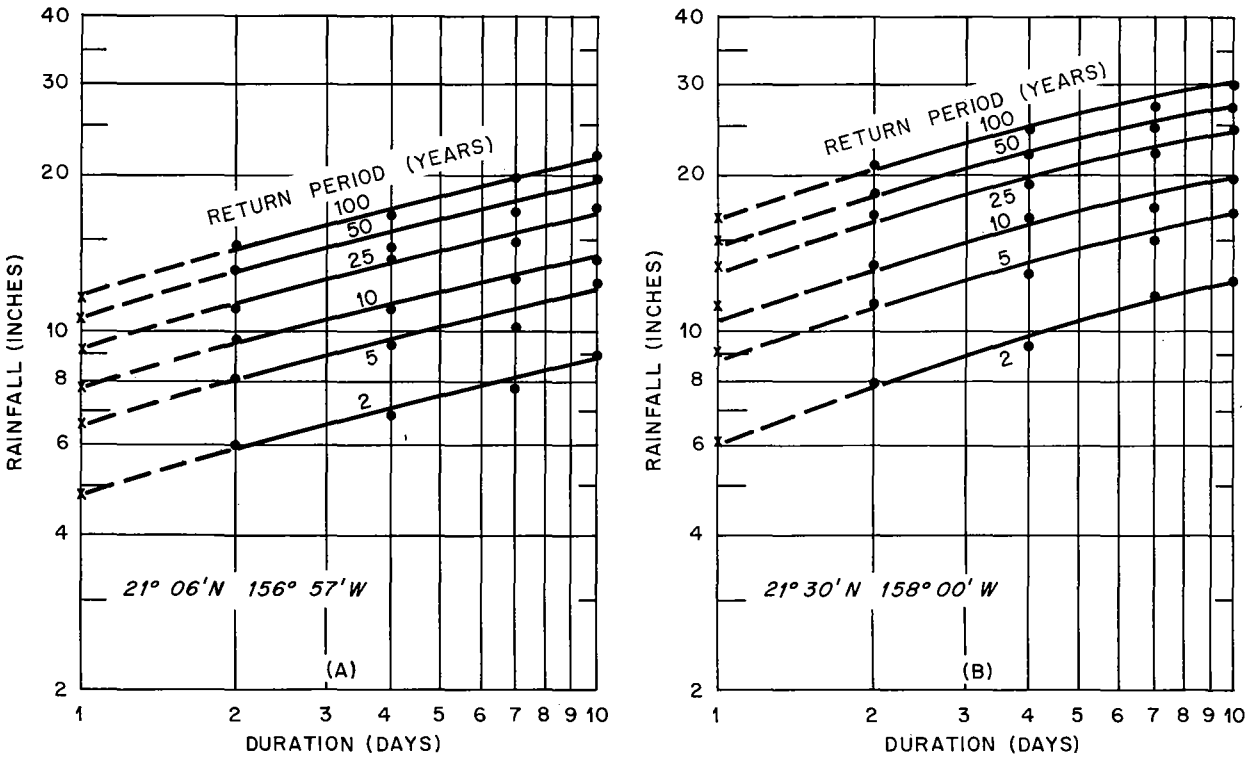


FIGURE 9.—Smoothing values read from isopluvial maps.

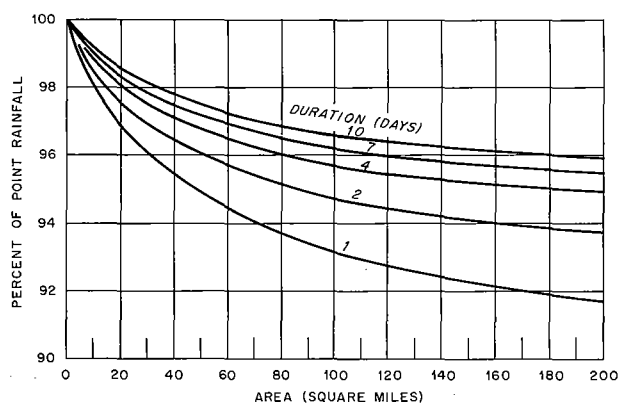


FIGURE 10.—Depth-area curves.

are based on data from 27 dense rain-gage networks in the contiguous United States, and are identical with those of [4]. Search of available data failed to reveal any dense network data for the Hawaiian Islands that could be used to test the relationship. Consideration of storm isohyetal patterns presented in *Hydrometeorological Report* No. 39 [6] and other meteorological parameters suggests that the adopted areal reduction curves are reasonable.

7. SEASONAL VARIATION

The basic data for the precipitation-frequency maps of figures 11 to 34 show seasonal trends. Some months may contribute most of the annual series or partial series data used in the frequency analyses, while other months may contribute little or nothing. Also, the 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 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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5. L. L. Weiss, "A General Relation between Frequency and Duration of Precipitation," *Monthly Weather Review*, vol. 90, No. 3, Mar. 1962, pp. 87–88.
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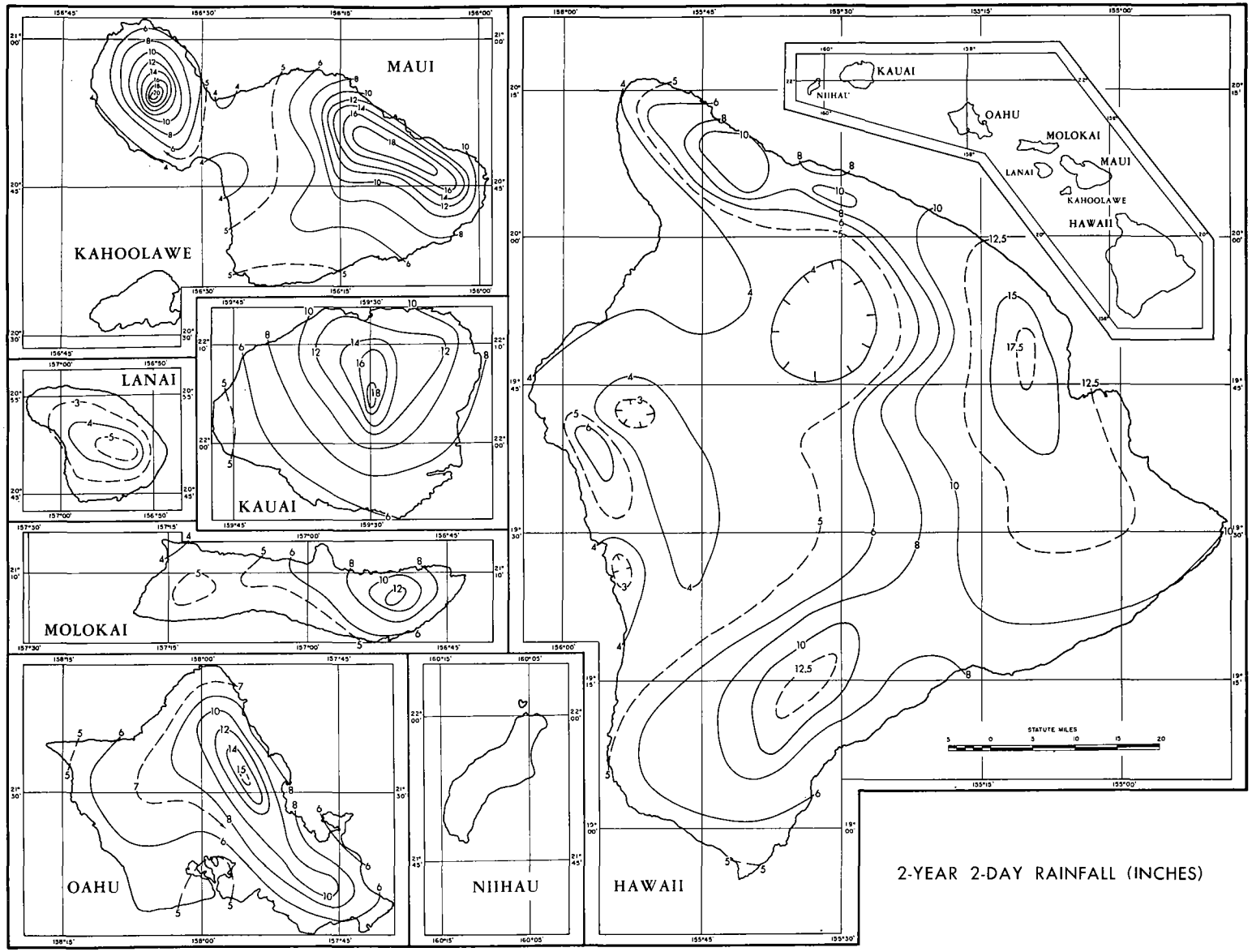

FIGURE 11.—2-year 2-day rainfall (in.).

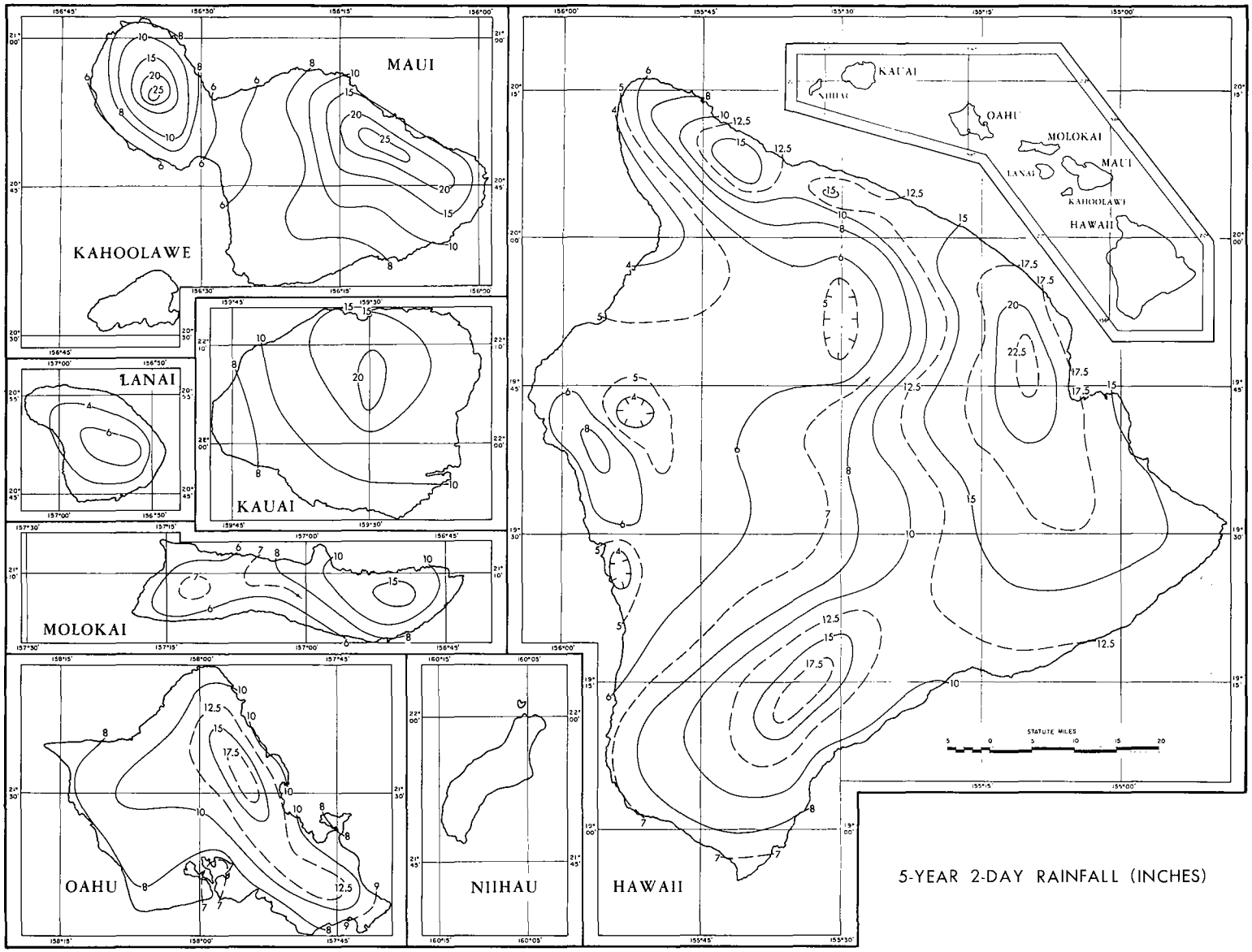

FIGURE 12.—5-year 2-day rainfall (in.).

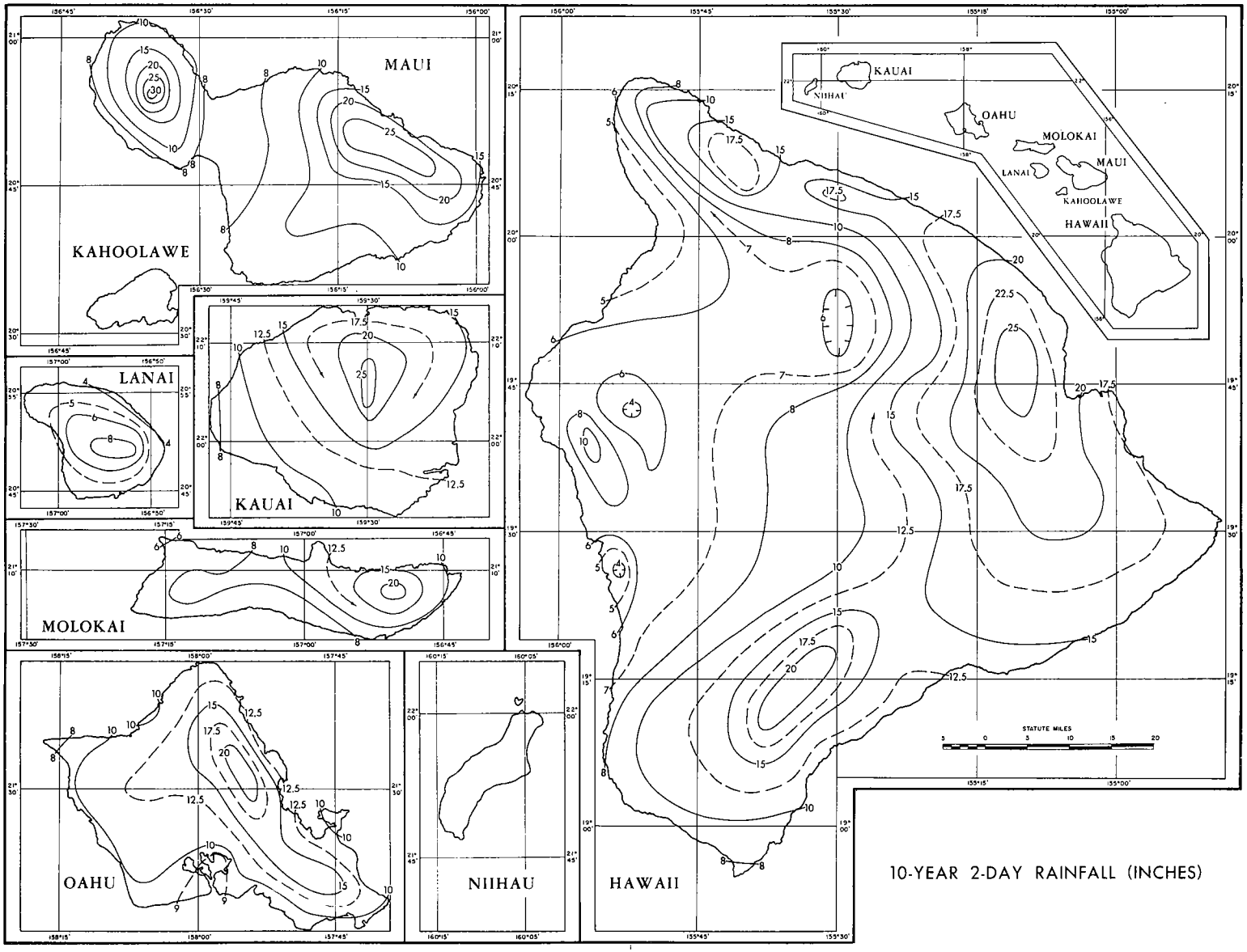

FIGURE 13.—10-year 2-day rainfall (in.).

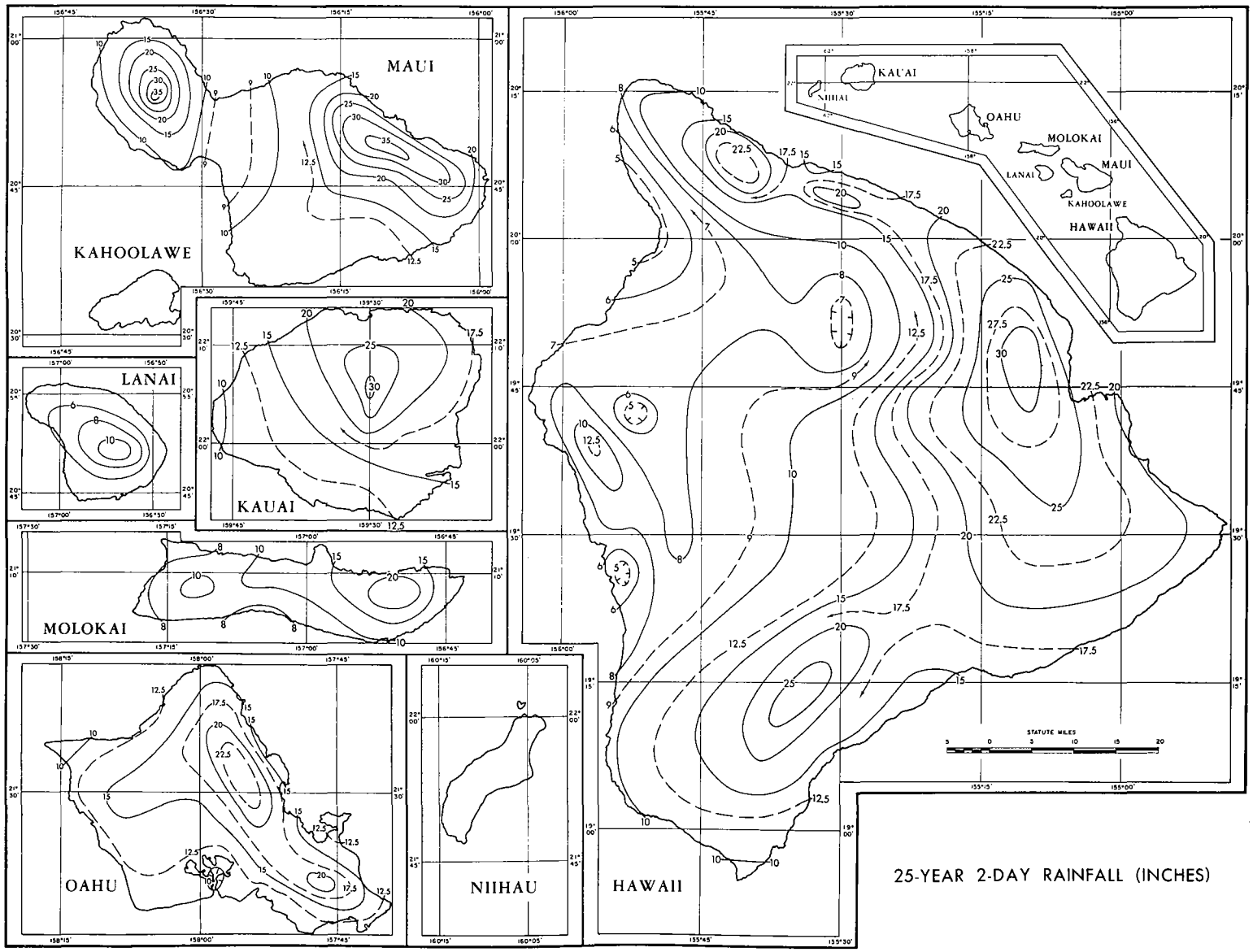

FIGURE 14.—25-year 2-day rainfall (in.).

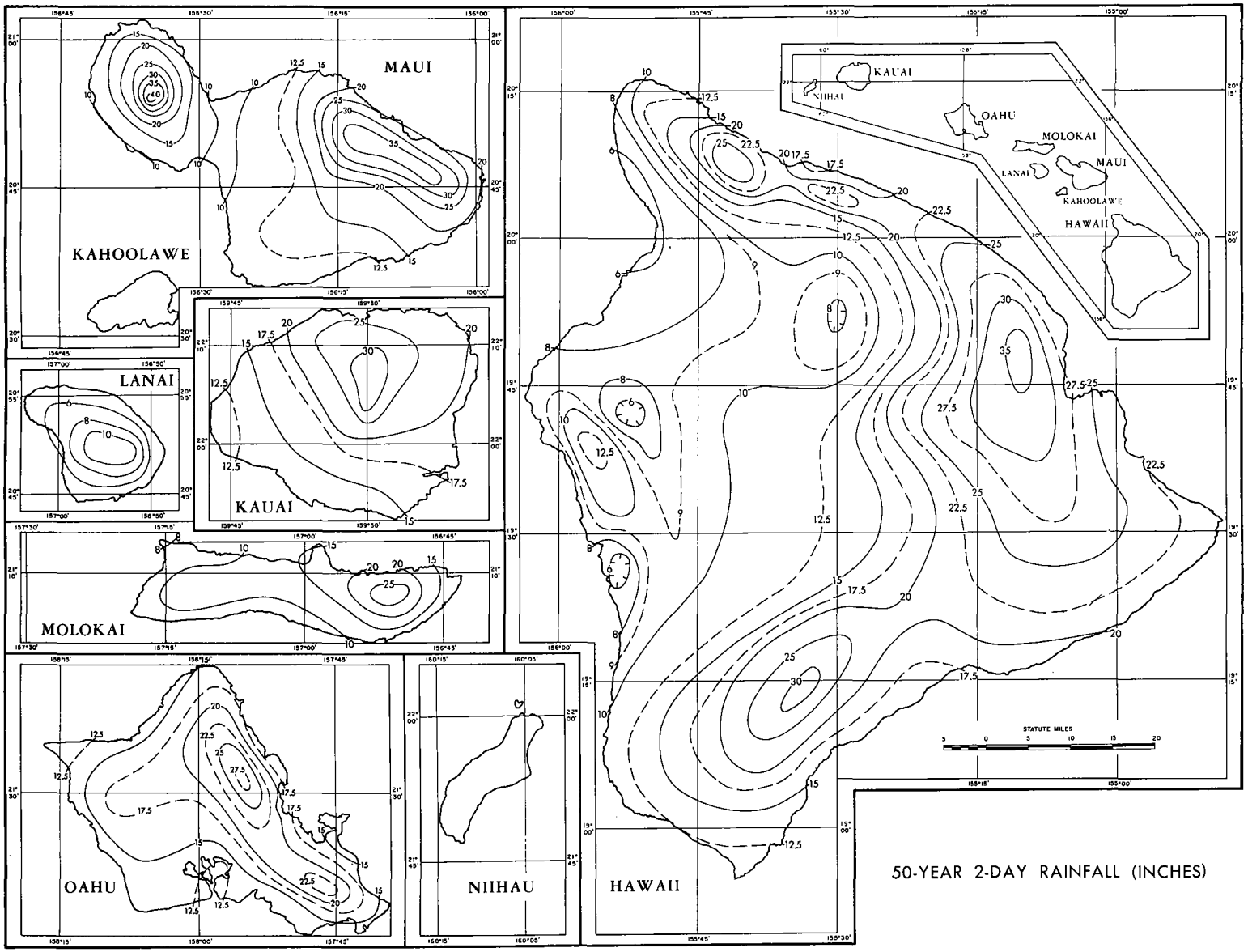

FIGURE 15.—50-year 2-day rainfall (in.).

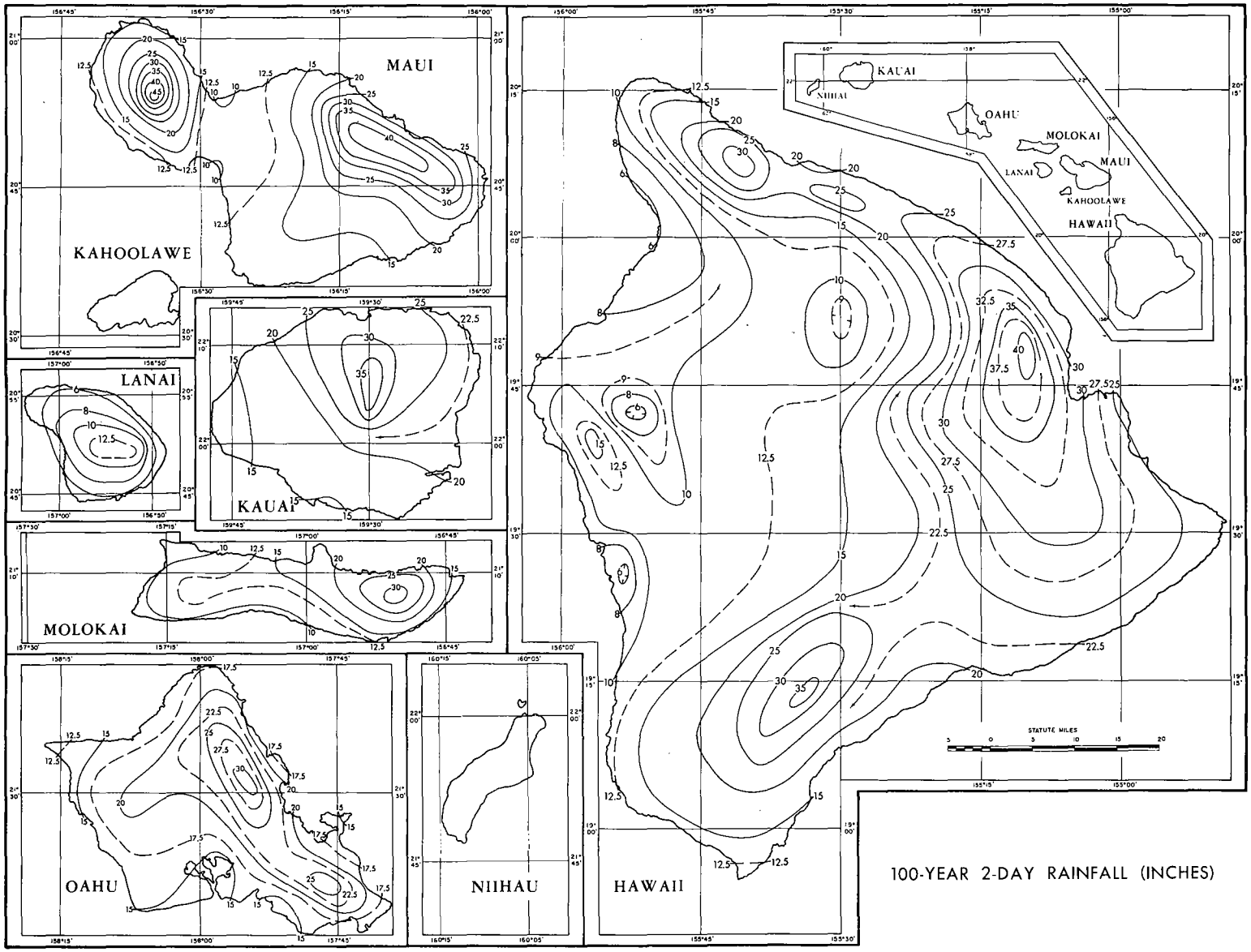

FIGURE 16.—100-year 2-day rainfall (in.).

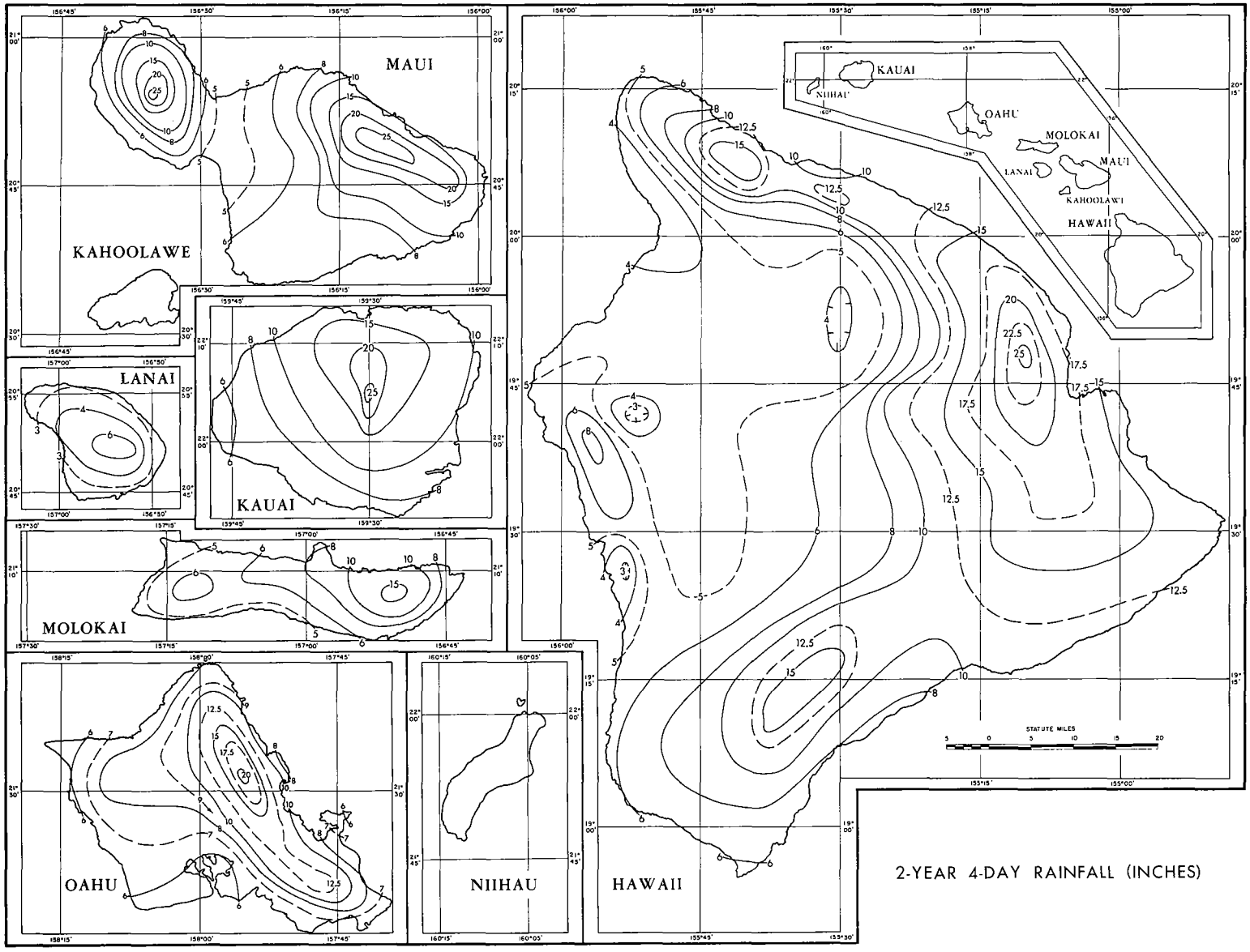

FIGURE 17.—2-year 4-day rainfall (in.).

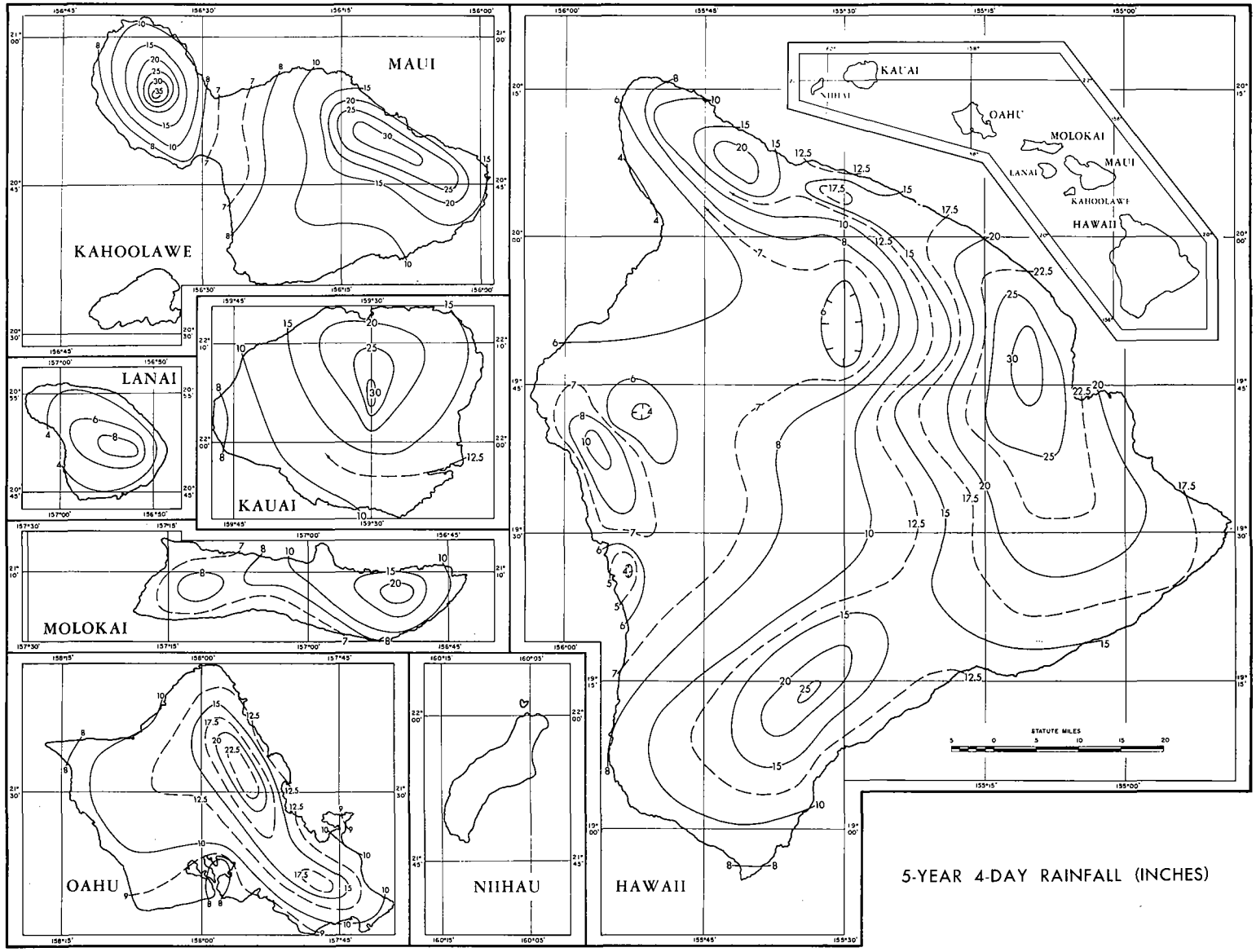

FIGURE 18.—5-year 4-day rainfall (in.).

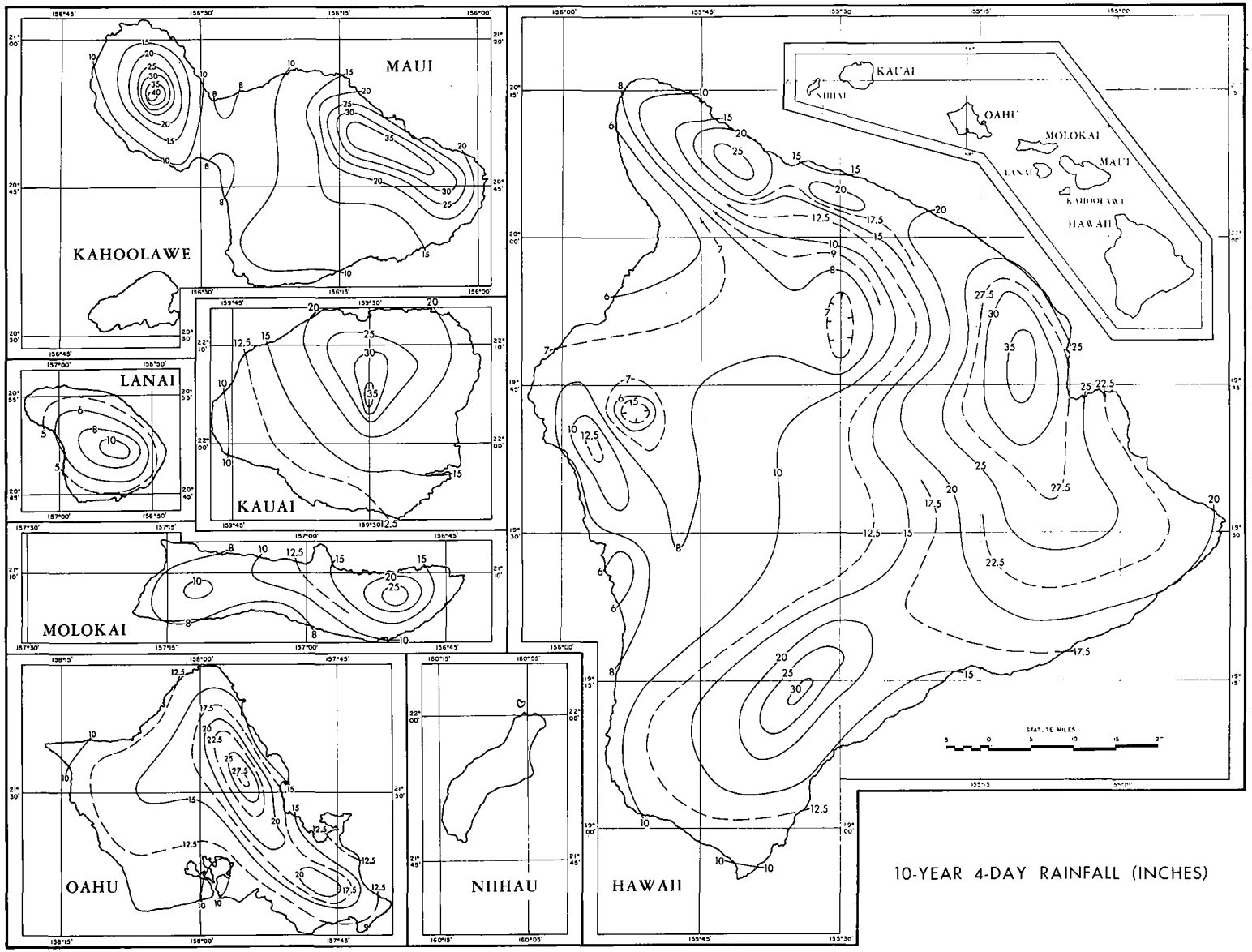

FIGURE 19.—10-year 4-day rainfall (in.).

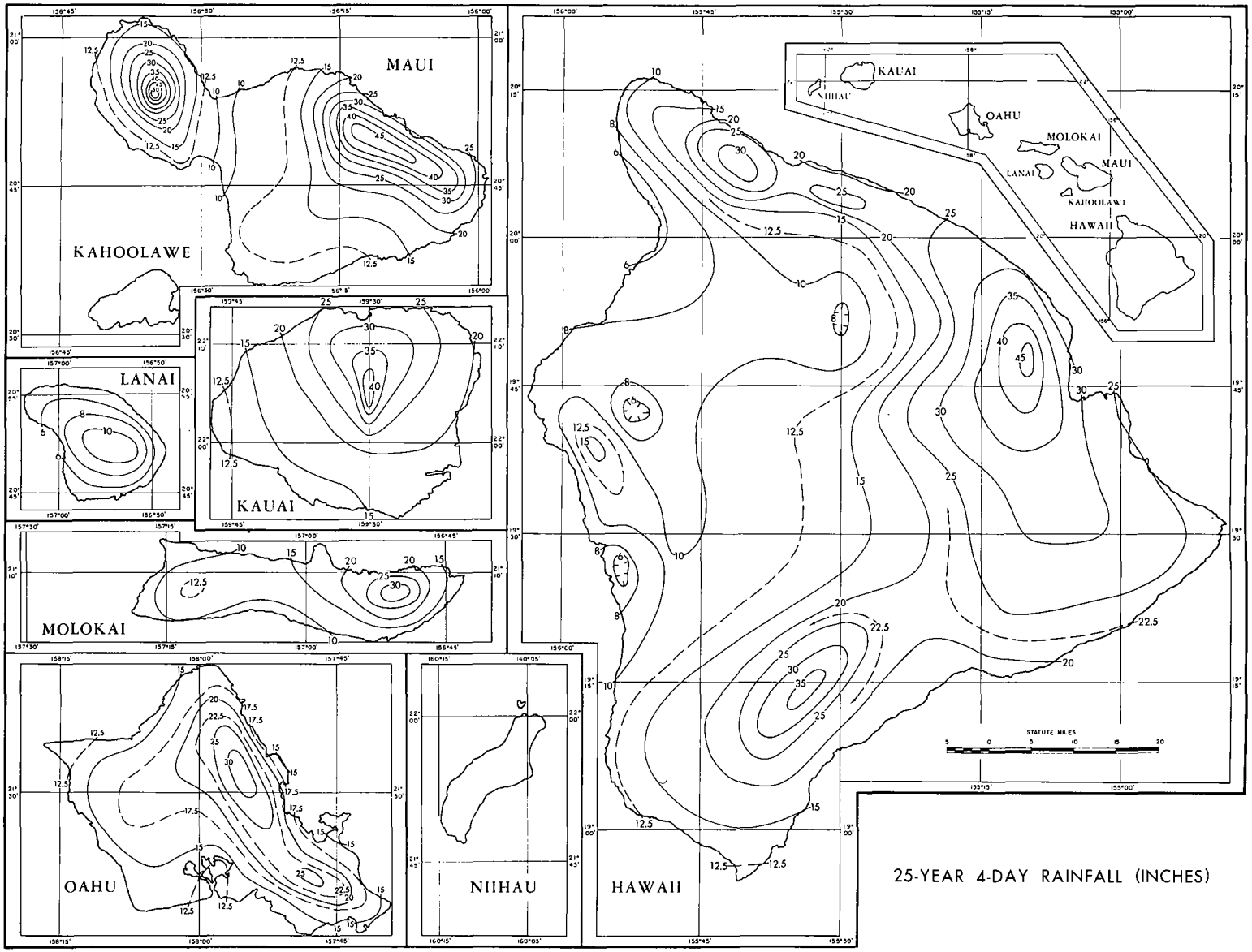

FIGURE 20.—25-year 4-day rainfall (in.).

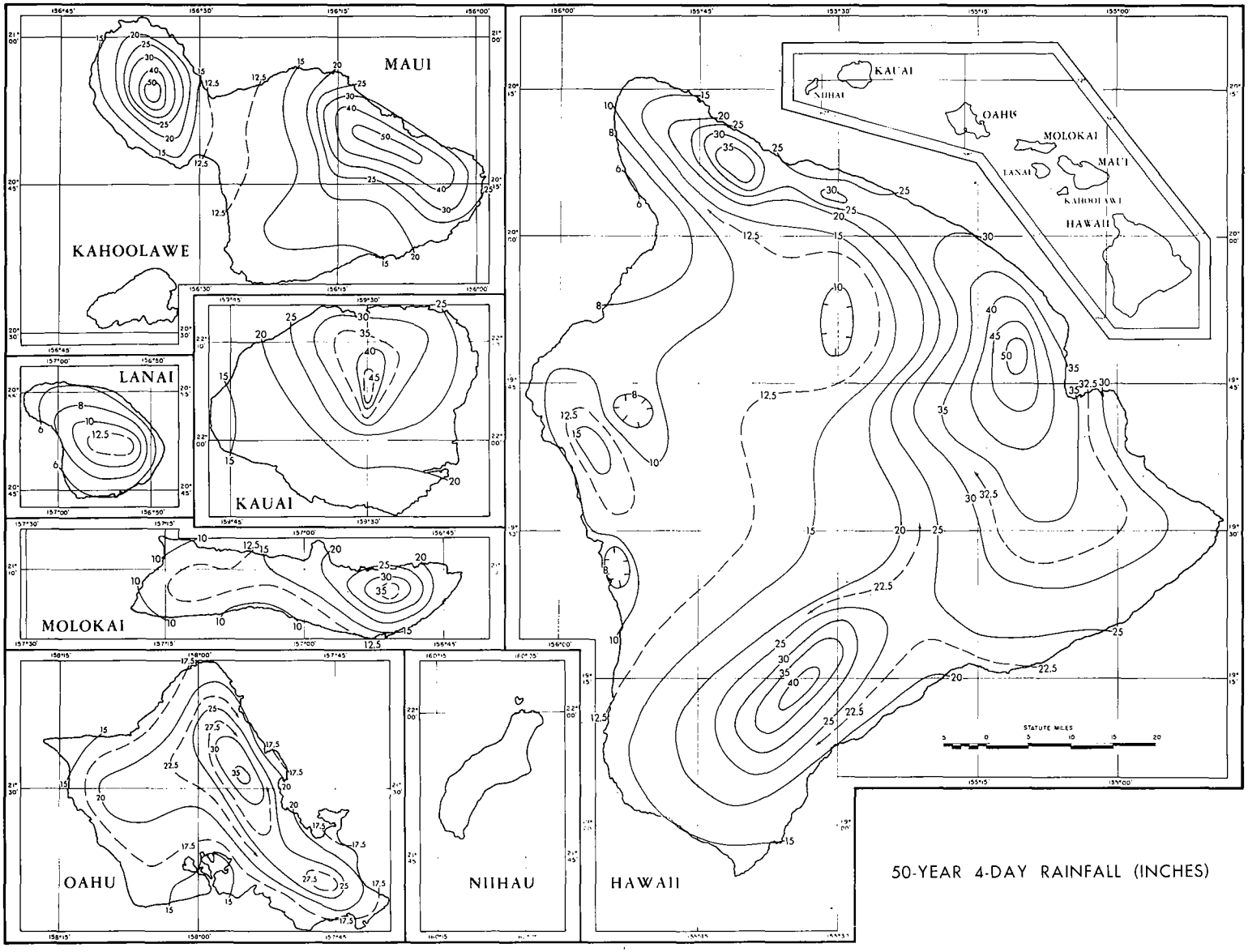

Figure 21.—50-year 4-day rainfall (in.).

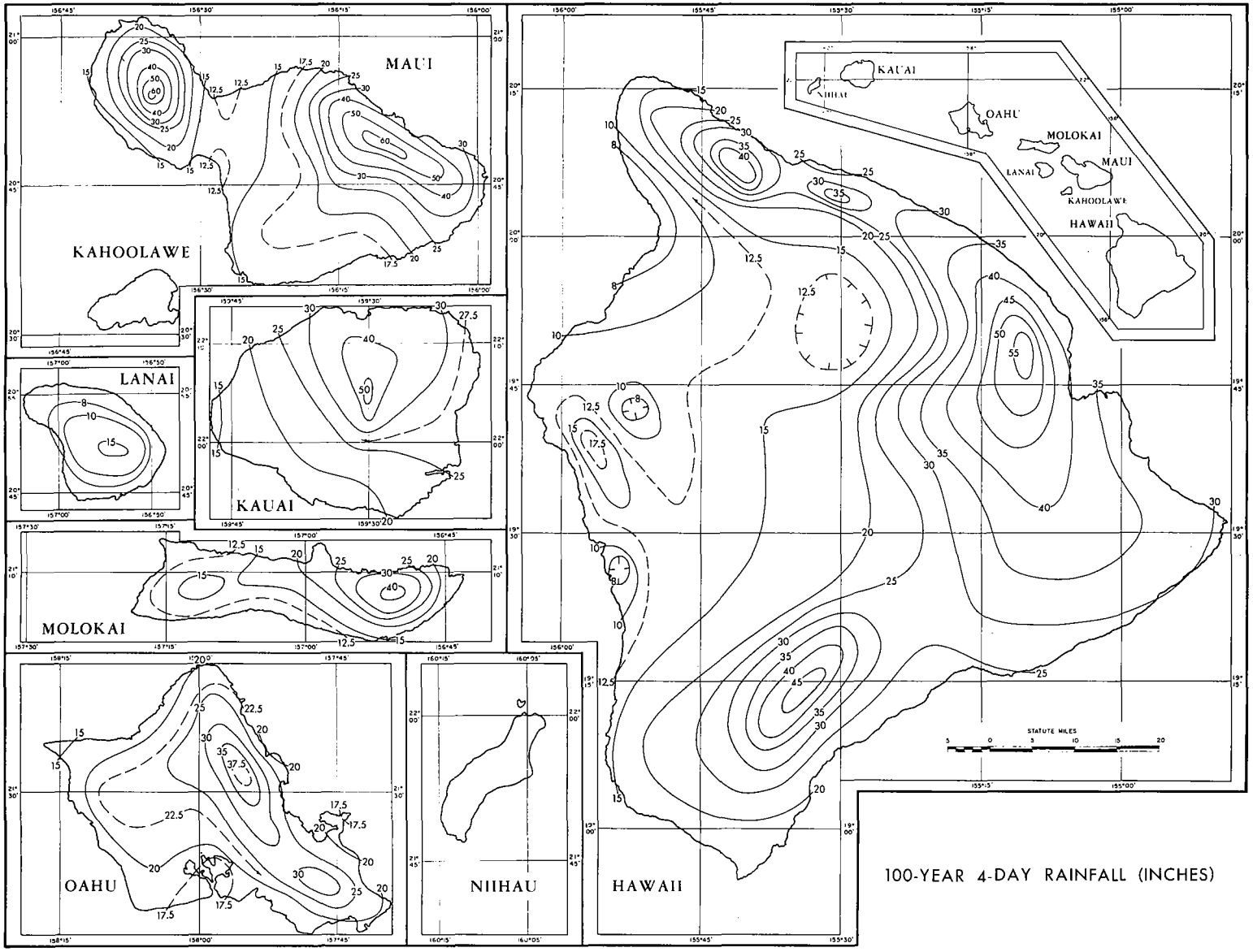

FIGURE 22.—100-year 4-day rainfall (in.).

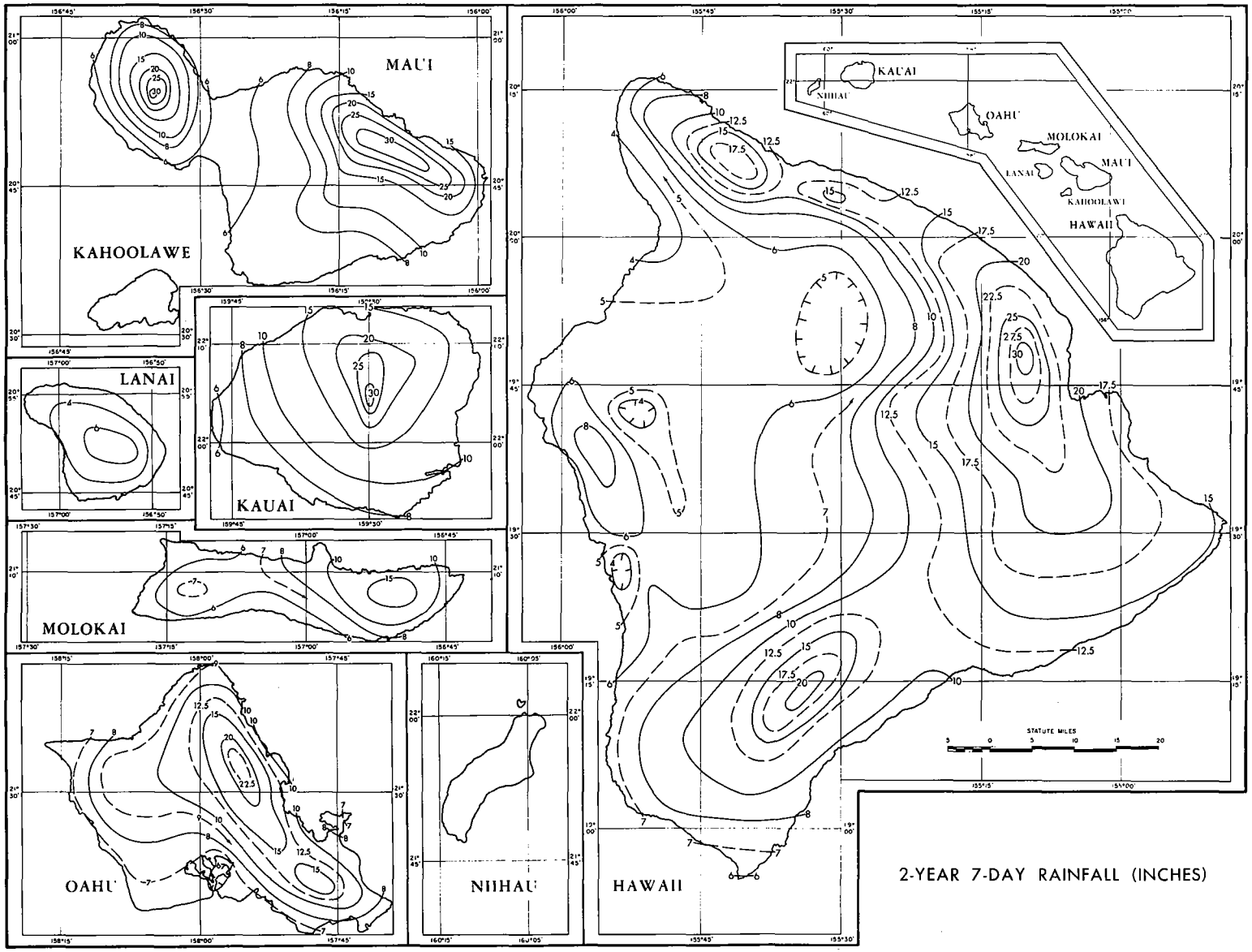

FIGURE 23.—2-year 7-day rainfall (in.).

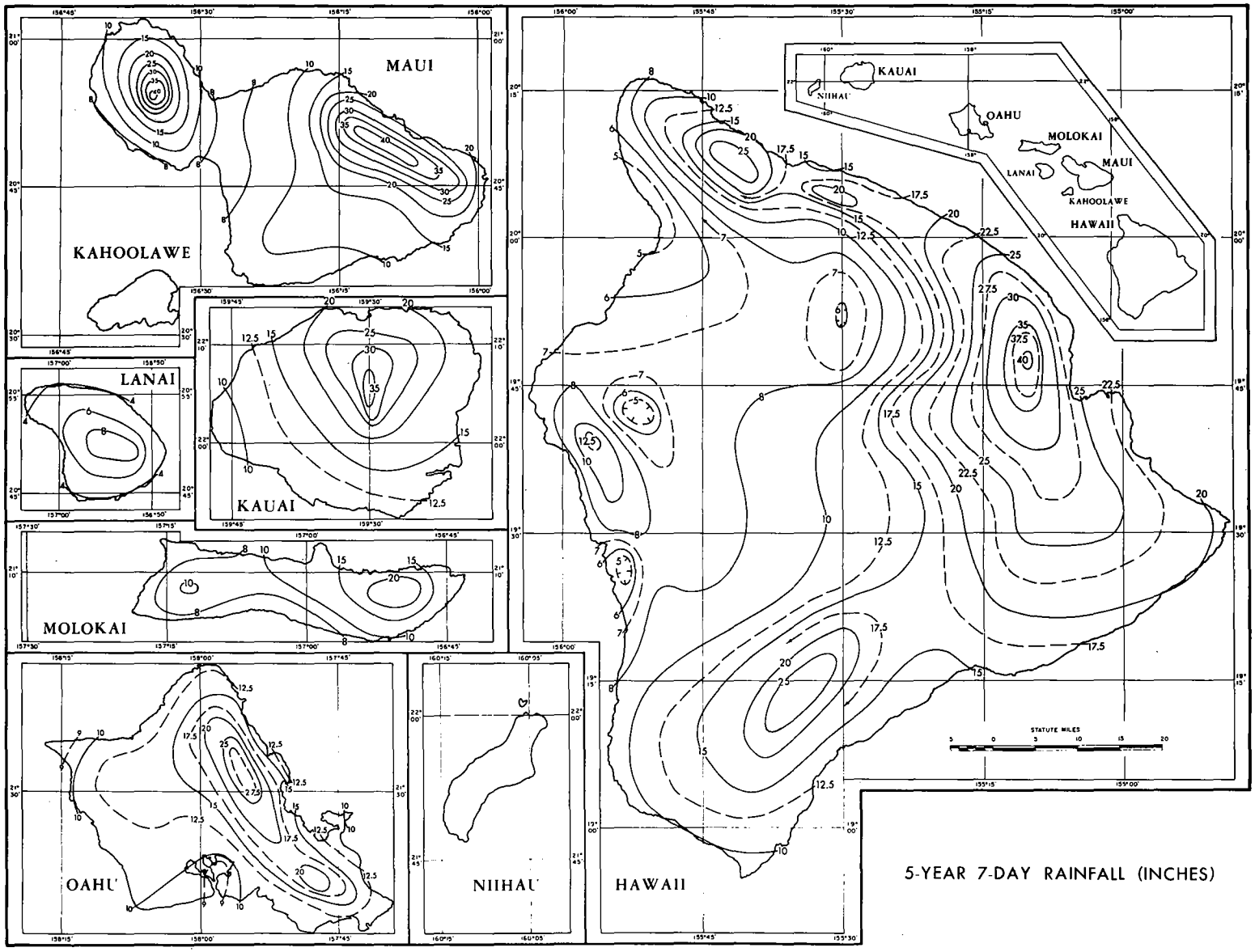

FIGURE 24.—5-year 7-day rainfall (in.).

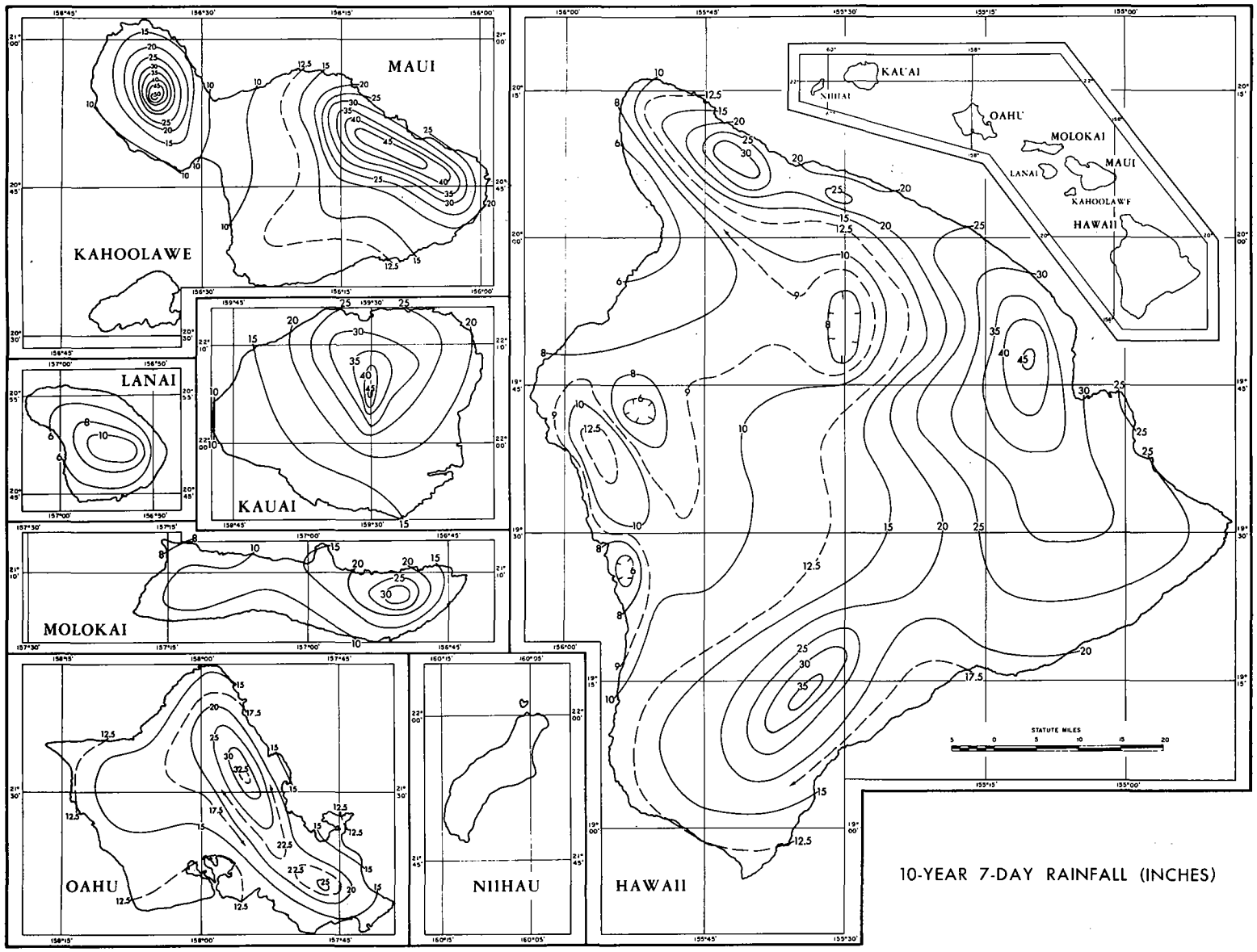

FIGURE 25.—10-year 7-day rainfall (in.).

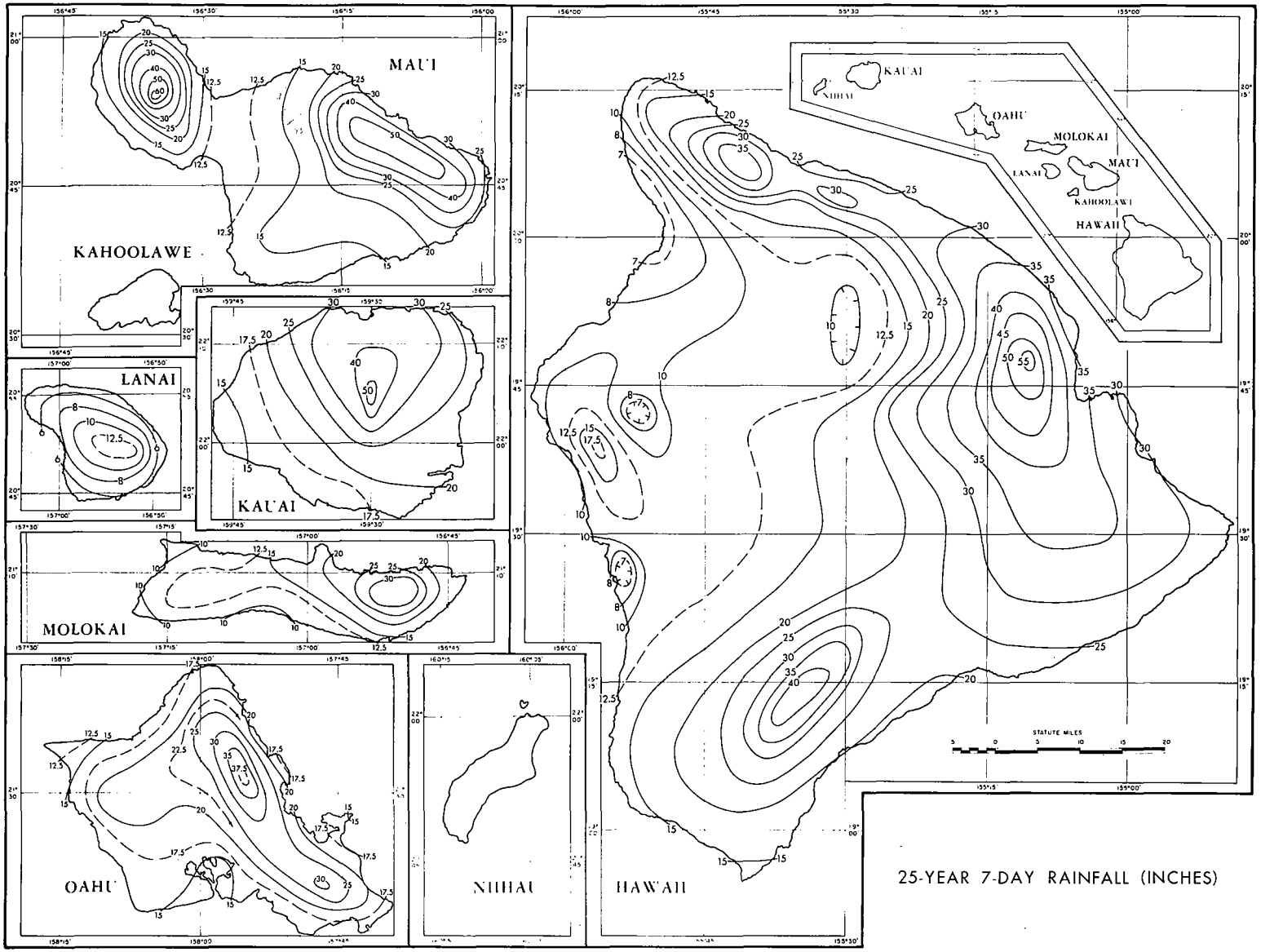

FIGURE 26.—25-year 7-day rainfall (in.).

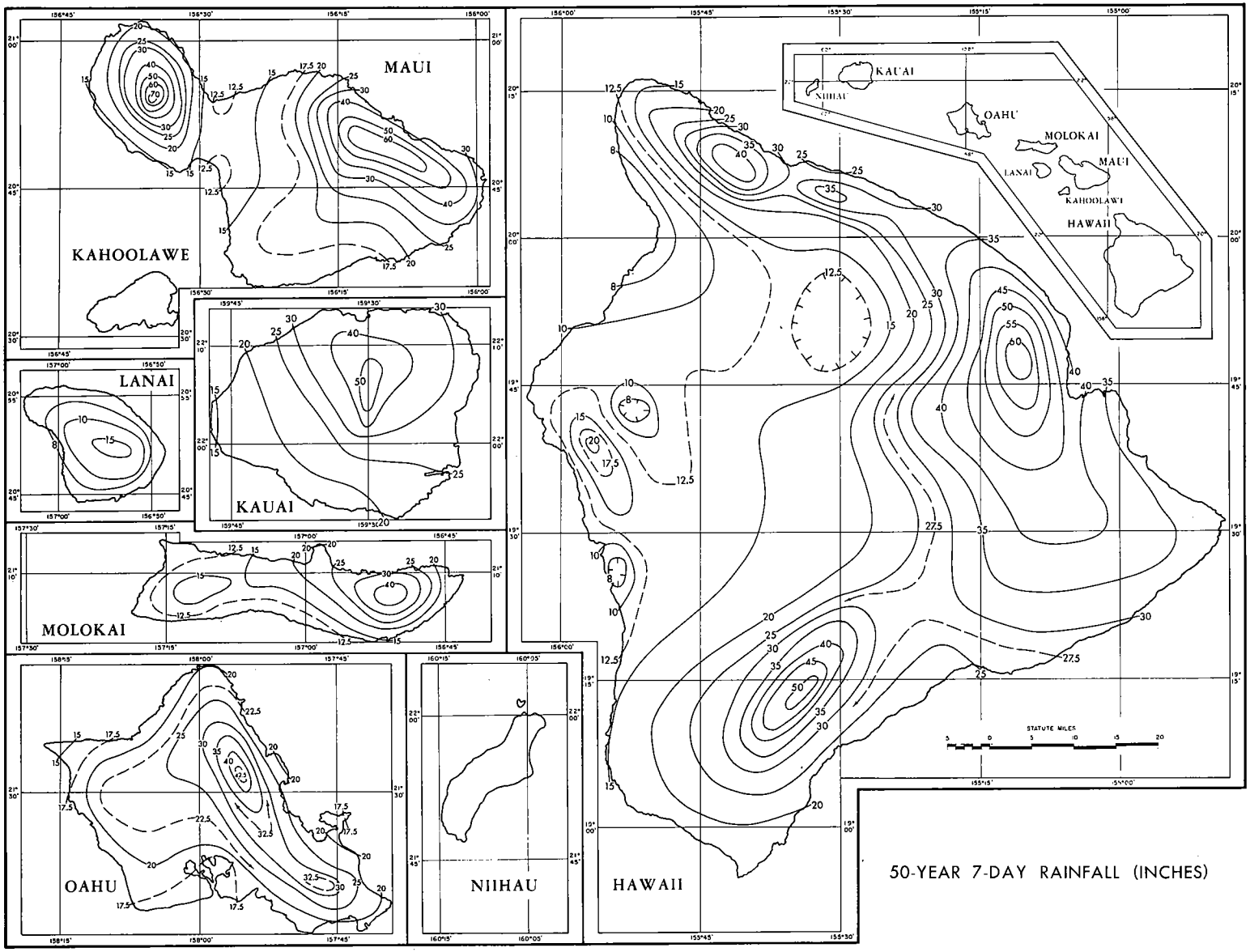

FIGURE 27.—50-year 7-day rainfall (in.).

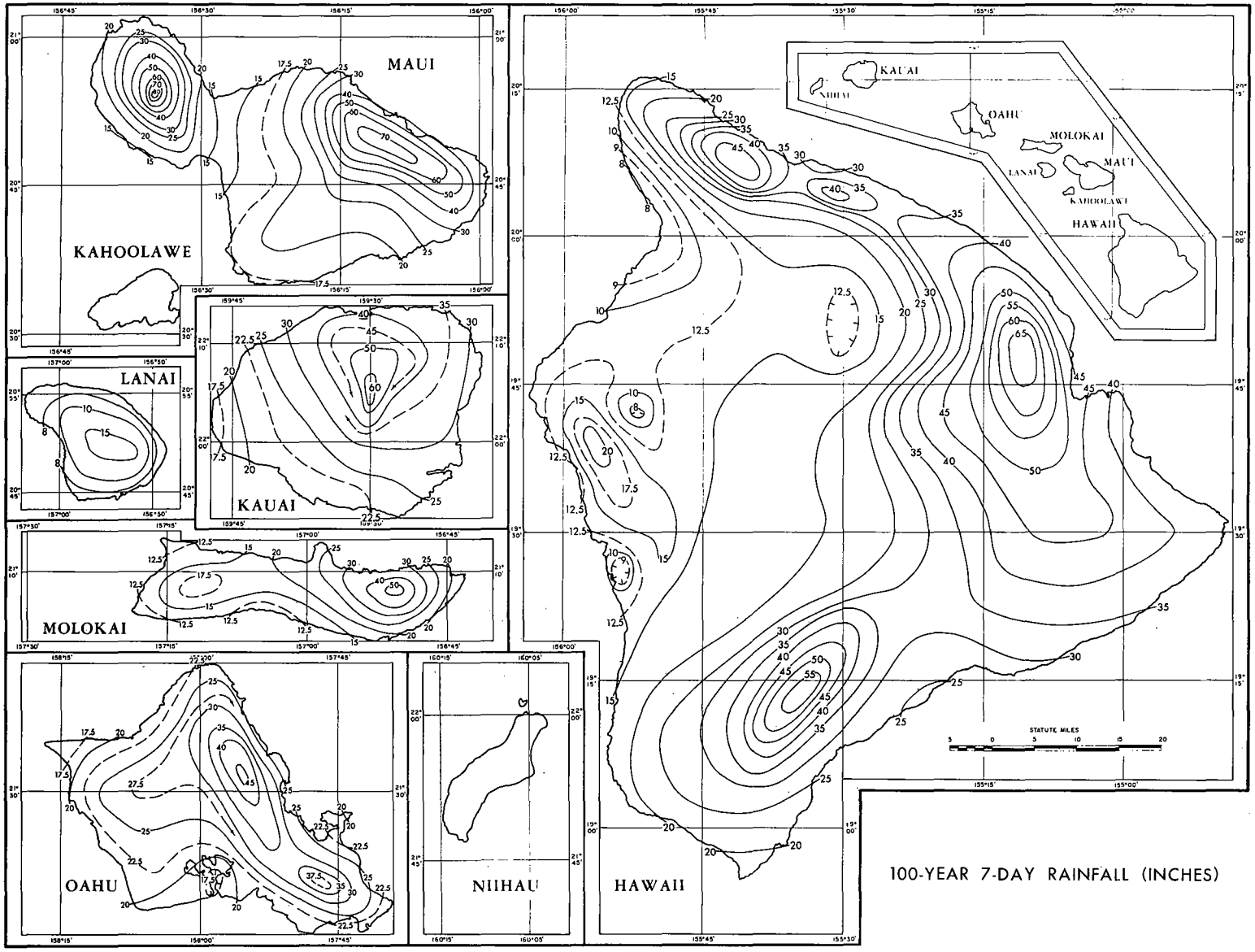

FIGURE 28.—100-year 7-day rainfall (in.).

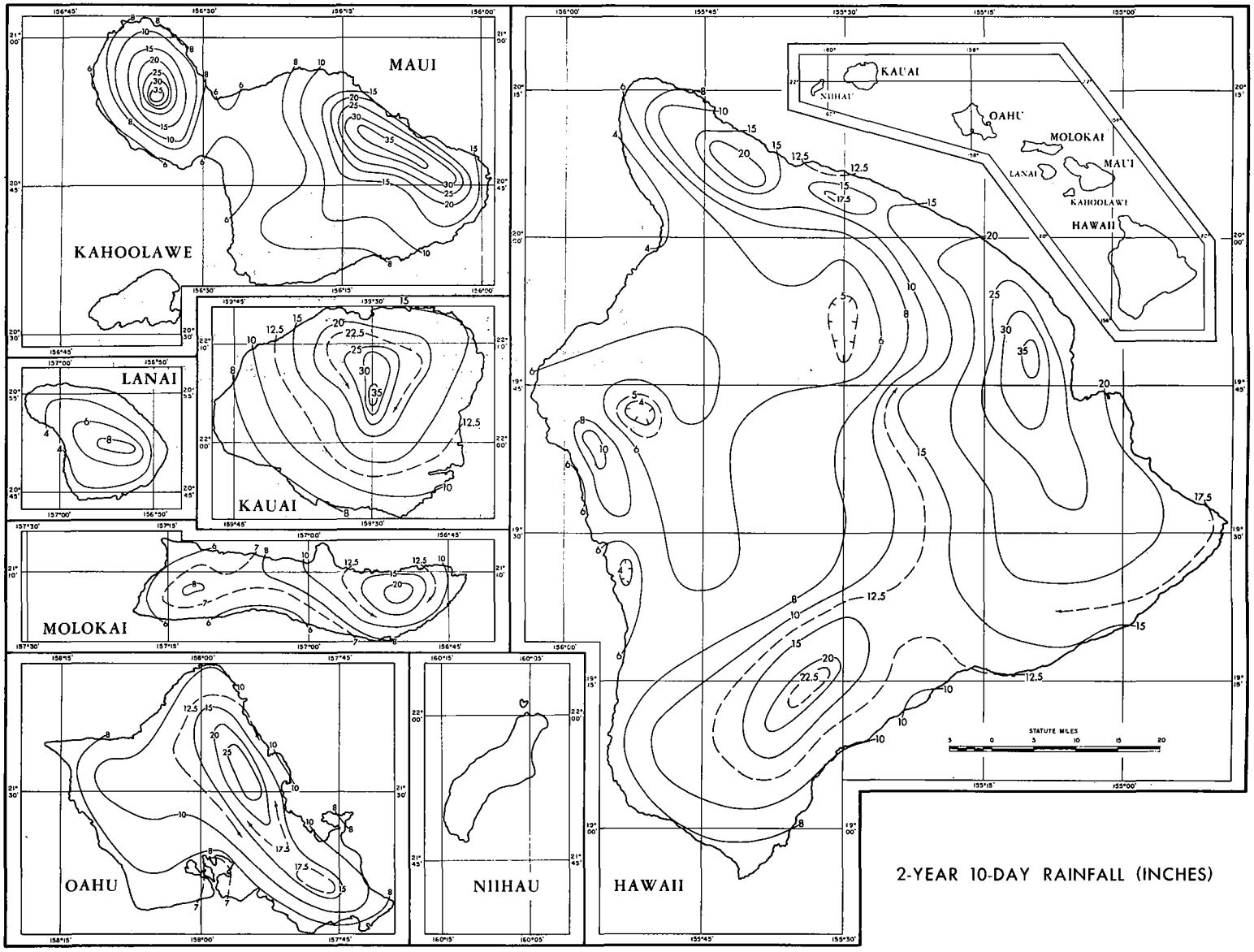

FIGURE 29.—2-year 10-day rainfall (in.).

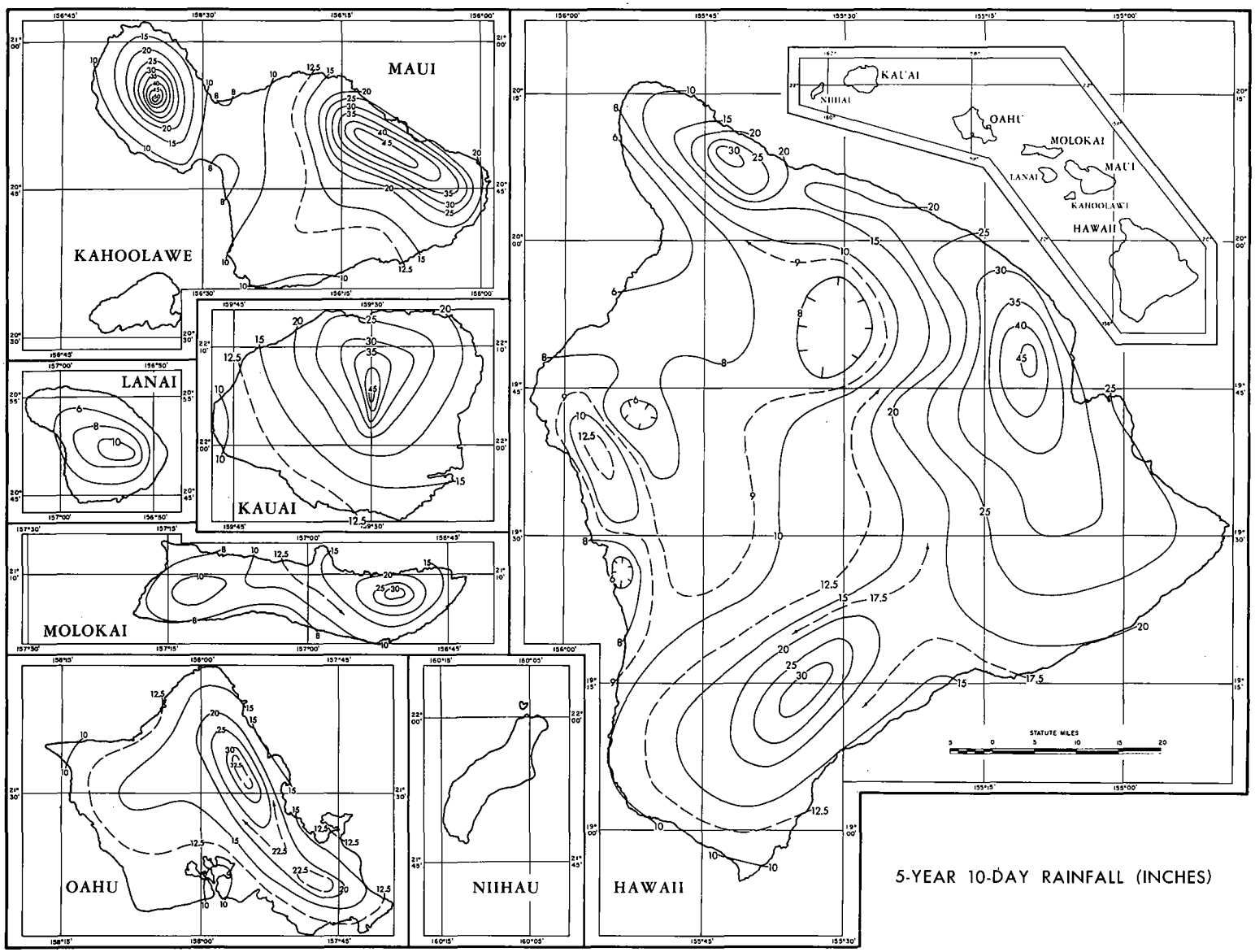

FIGURE 30.—5-year 10-day rainfall (in.)

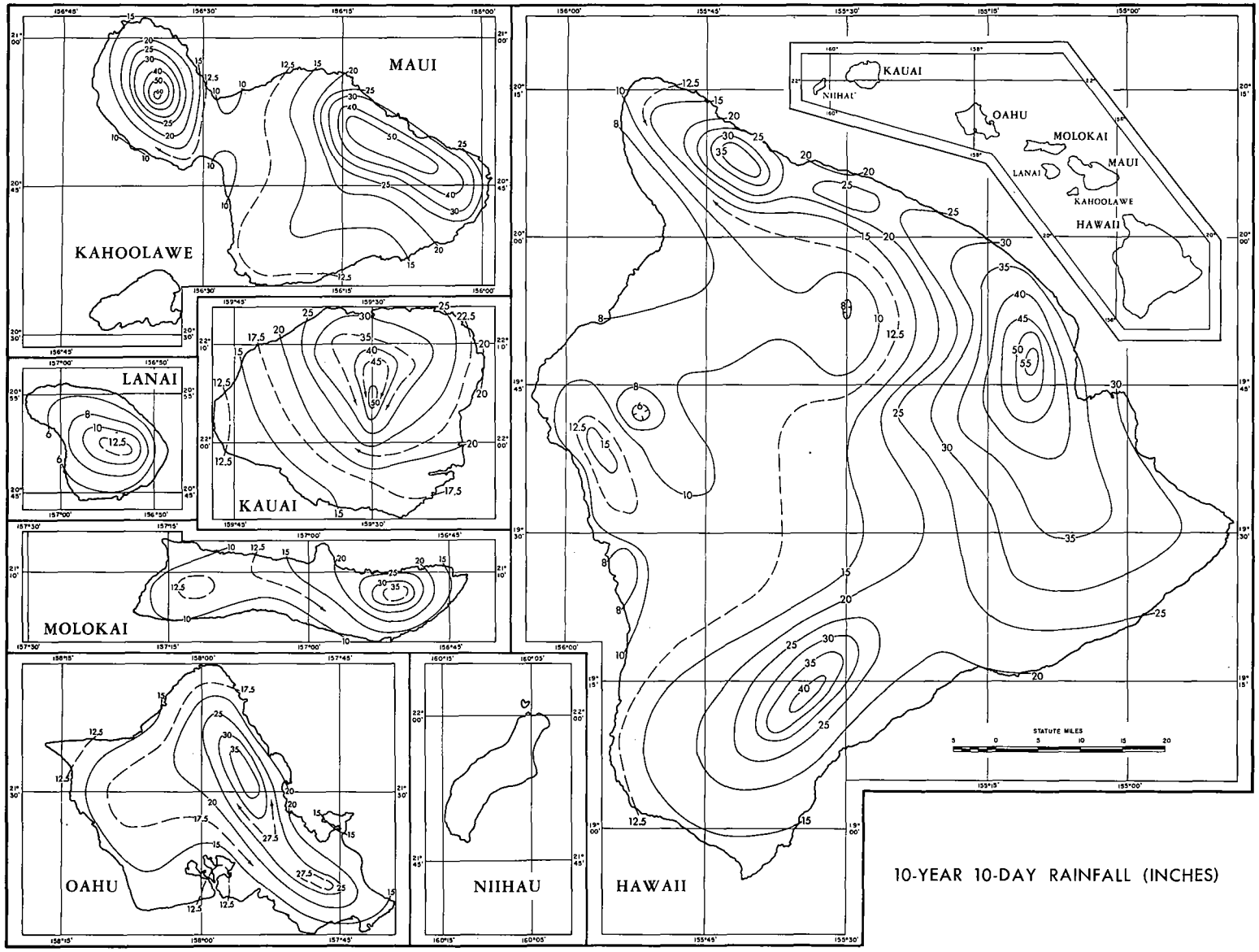

FIGURE 31.—10-year 10-day rainfall (in.).

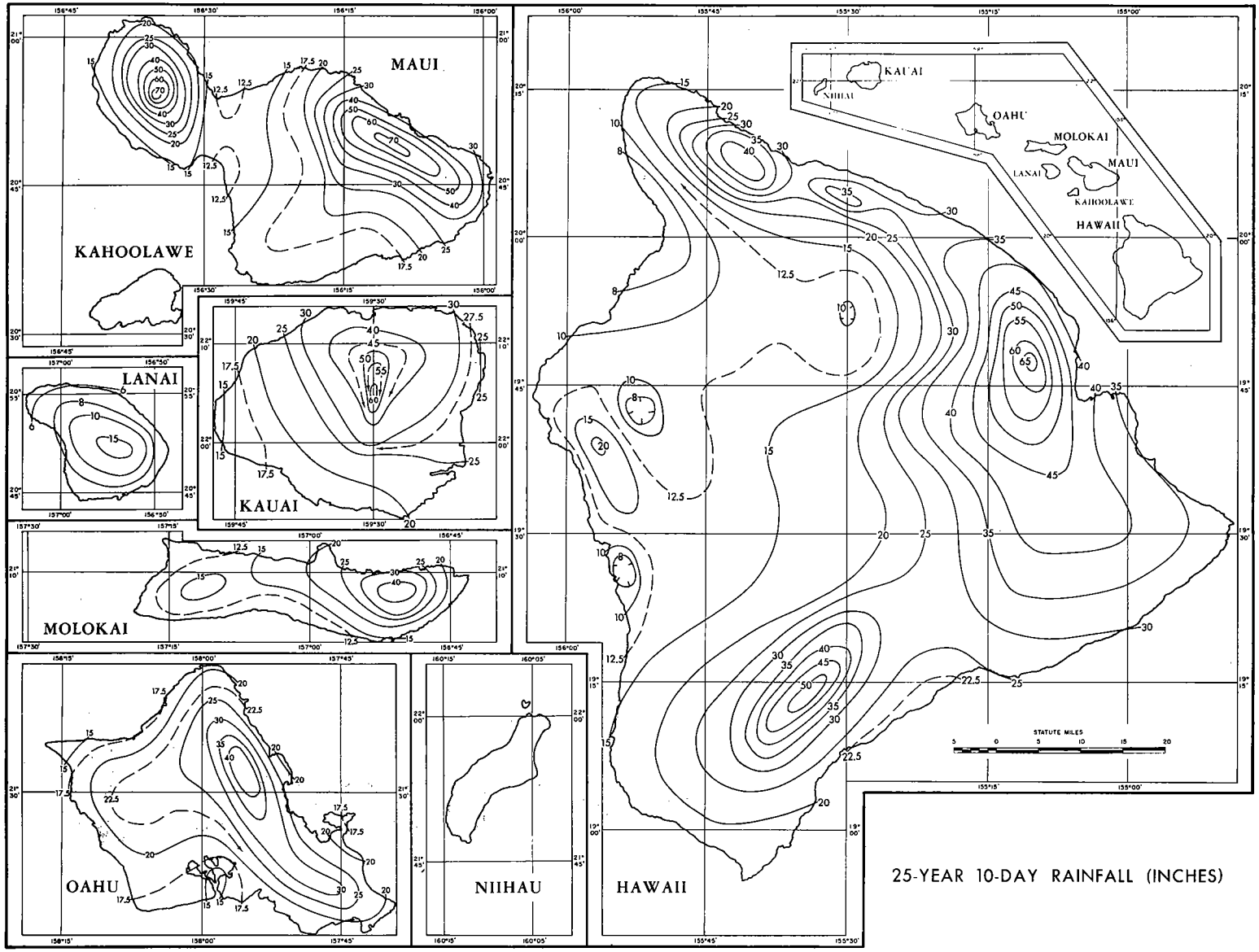

FIGURE 32.—25-year 10-day rainfall (in.)

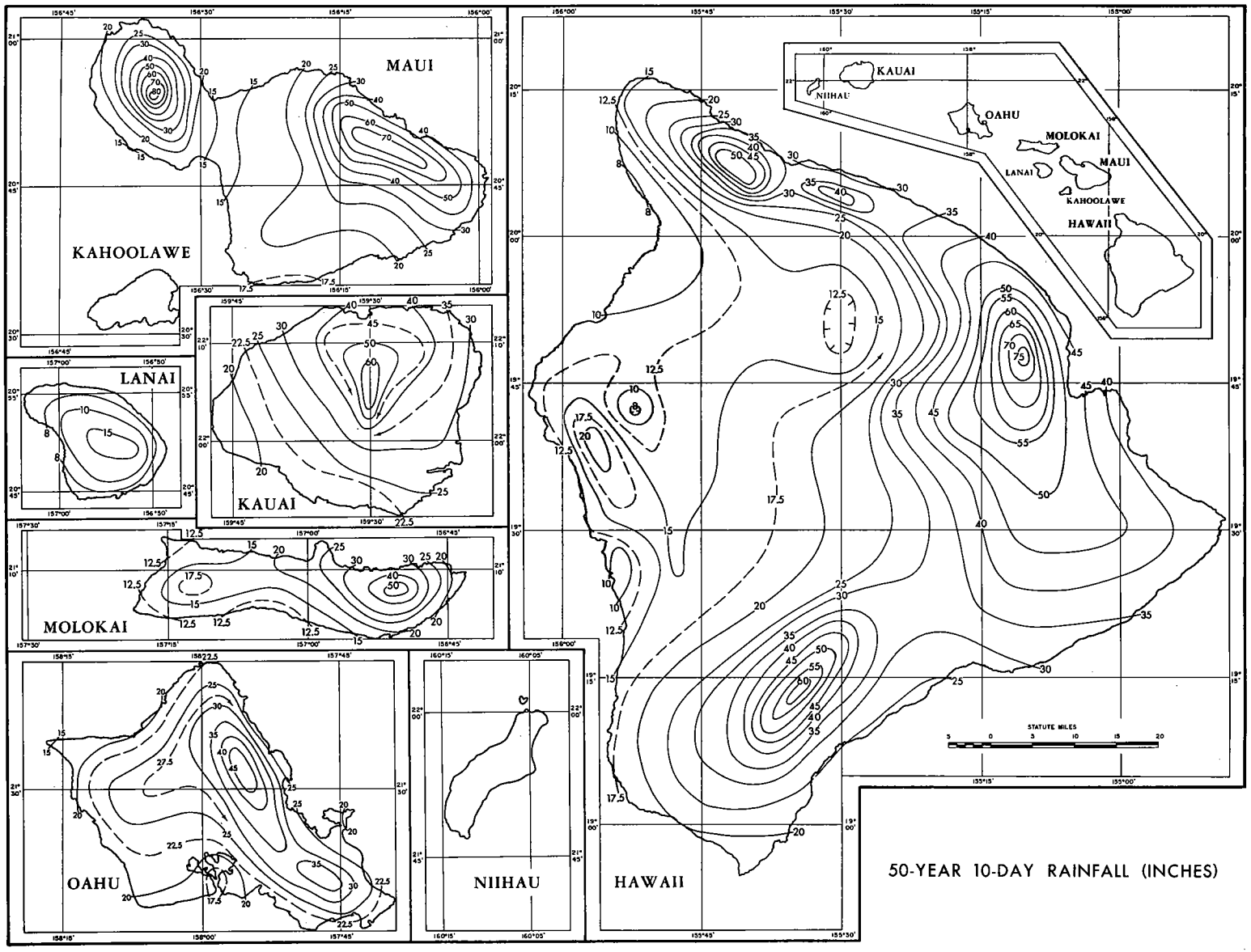

FIGURE 33.—50-year 10-day rainfall (in.).

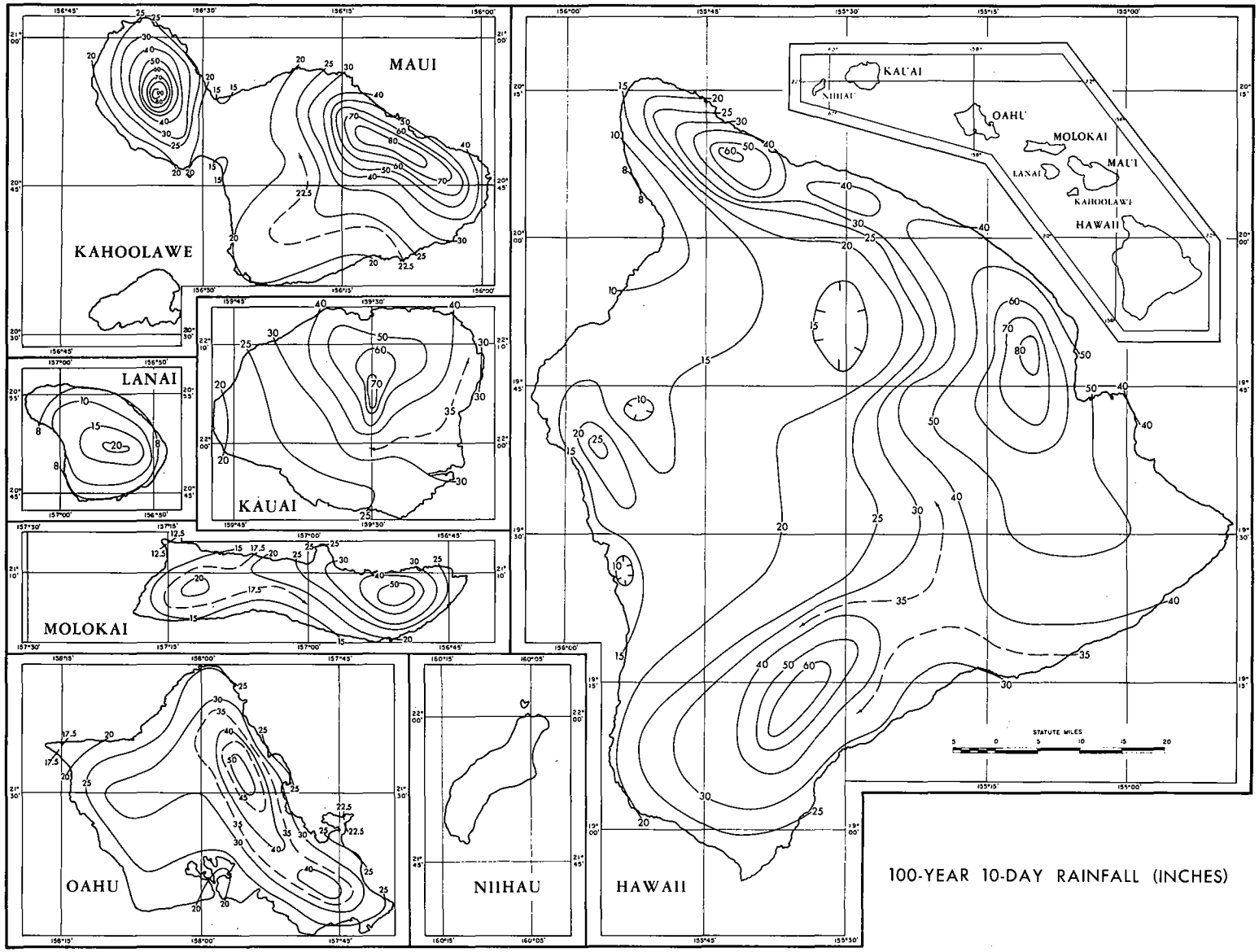

FIGURE 34.—100-year 10-day rainfall (in.).

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