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FREQUENCY ANALYSIS OF RAINFALL MAXIMUMS FOR CENTRAL AND SOUTH FLORIDA

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This project could never have been completed without the extensive cooperation and assistance of several individuals and groups within the Resource Planning Department of the South Florida Water Management District. Mr. Ronald Mierau was extremely helpful in providing computer-based data validation routines and also made an important contribution during the statistical analysis phase of the study. The Data Management staff, under the direction of Bill Jenkins, handled the enormous task of amassing five thousand years of daily rainfall data and organizing it for computer processing. Don Paich provided very able Fortran programming assistance. Finally, the Land Resources staff deserves much of the credit for the outstanding graphical quality of the maps which were produced on the Computer Vision system.

I. INTRODUCTION

Estimated rainfall amounts for various durations and statistical return frequencies are a basic ingredient in many engineering and planning analyses related to Water Resources. The South Florida Water Management District, with responsibility for all matters affecting water supply and flood control, is committed to using and making available to the public the most accurate and up to date rainfall frequency data.

The current standard for rainfall frequency estimates for storm durations from one to twenty four hours is the U.S. Weather Bureau's Technical Paper No. 40 (1) published in 1961. This document presents the results of a comprehensive nation-wide rainfall analysis and mapping program incorporating data through 1958 from recording rain gages and through 1957 from the non recording gage network. This publication (1) was followed in 1964 by Technical Publication No. 49 (2) for rainfall durations from 2 to 10 days. The same analysis and mapping technique was used in TP49 and included data through 1961.

The Corps of Engineers produced a design memorandum (3) on rainfall frequency estimates for the District area as part of the Central and Southern Florida Project. Published in 1953, the study encompassed durations from one day to one year and return periods from two to one hundred years. Rainfall data through 1952 were used as the basis of this report.

Two major factors affecting the accuracy of rainfall frequency maps are the number and distribution of gaging points and the length of record at each station. The location of the stations influences the shape of the contour lines and determines the extent to which localized phenomena can be reflected in the maps. The addition of new stations has a much greater impact on the reliability of the maps than the extension of the record at current long record stations. The length of record at a station controls the confidence limits on the rainfall estimates at that point for any particular return period. The credibility of the estimated value for the more extreme events is directly related to the length of record upon which the analysis was based.

II. PURPOSE

Additional data has become available that should enable the production of rainfall frequency maps for South Florida that are not as limited by the sparse station network and short term records that hampered earlier studies. Also, the confidence level of the rainfall estimates, particularly at the higher return frequencies, can be improved significantly by the relatively large amount of data now accumulated. In view of these factors and the importance of accurate historical rainfall information to many District actions, the Water Management District decided to undertake an in-depth analysis of recorded rainfall data for the entire District area. The goal of the project was to produce a comprehensive series of rainfall-frequency maps summarizing the predicted maximum precipitation for durations ranging from one day to one year and predicted minimum rainfall (drought) for monthly, seasonal and annual durations. This report represents the first phase of the study in which the maximum rainfall behavior is presented.

III. BASIC DATA

The data for this study were compiled from all rainfall gages within or near the District for which at least twenty years of daily record were available. The majority of the data were obtained from published Weather Bureau records although other agencies such as the South Florida Water Management District, Lake Worth Drainage District, and the Corps of Engineers also supplied a significant portion of the data. Table A-1 (see Appendix) summarizes pertinent station information for the rainfall gages used in this analysis. Figure 1 shows the areal distribution of these stations.

Types of Data

The majority of the rainfall values represent gage readings taken once a day. In some cases the daily values are derived from the sum of hourly measurements from 0100 to midnight and, in a very few instances, the daily value may be the maximum amount recorded for a 24 hour interval ending that day. Because of the difficulty involved in trying to adjust all the daily data to the same 24 hour period, and the very limited effect such an adjustment would have on the final results, no attempt was made to modify the recorded amounts according to the period covered by the measurement. The Weather Bureau (1) used an empirically derived factor to increase the observational-day amounts to make them equivalent to the maximum 24 hour values. There was insufficient hourly data available to determine the validity of this factor for South Florida; consequently, the analysis for the daily duration storms was based completely on observational-day values.

The exposure of the gage and the type of gage used can have a systematic effect on the recorded rainfall amounts. The complexity of the problem of quantifying this type of bias, and the lack of detailed

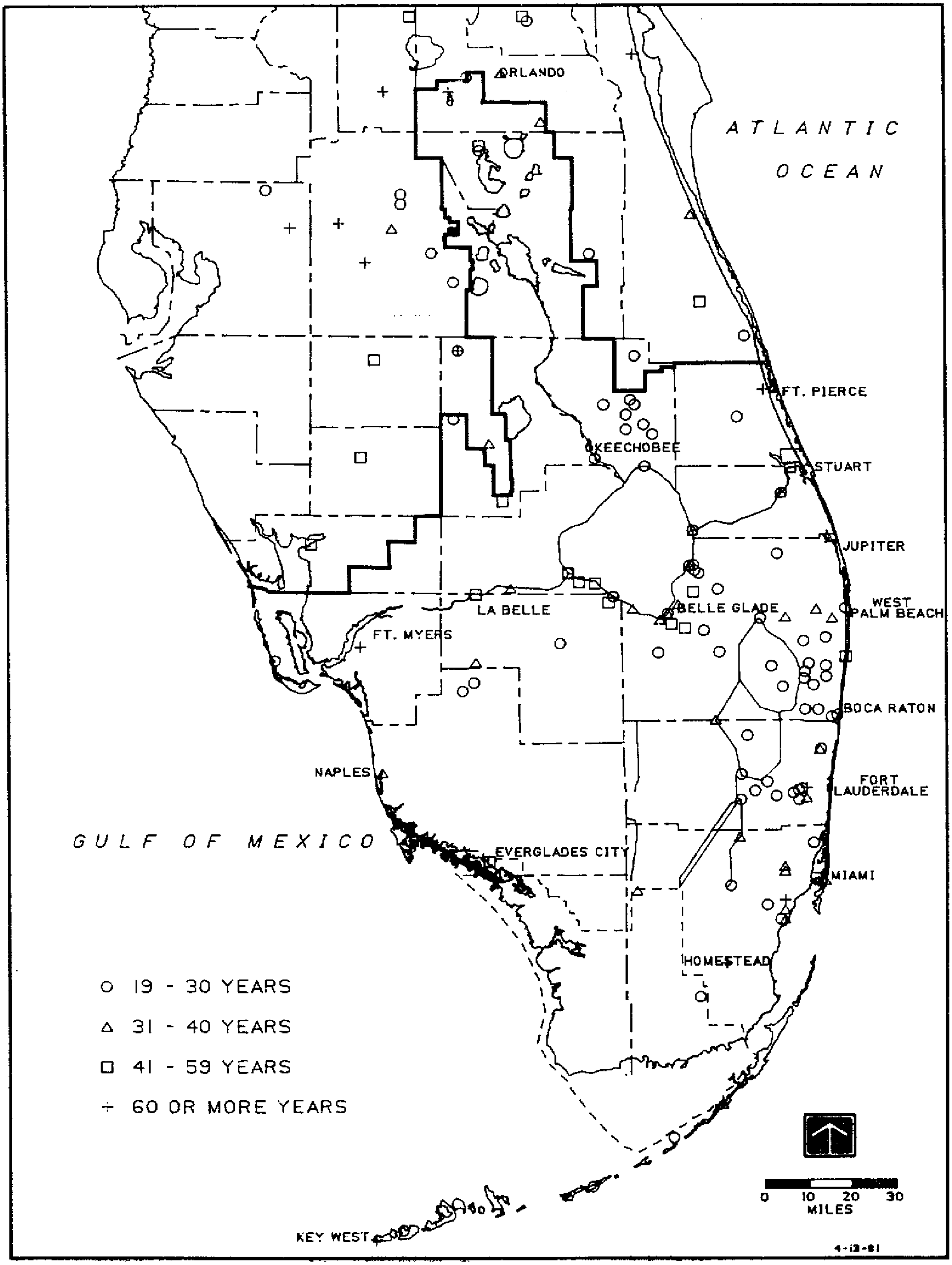

FIGURE 1: RAIN GAGE LOCATIONS

site information upon which to base an investigation of these issues, precluded any attempt to make adjustments to the data for gage type or exposure.

Data Preparation

A basic assumption of this analysis was that each year of data represented an independent observation at that location. Since many of the records contained gaps a filling technique had to be used to estimate the missing values and to give some idea of the influence of filled data on the final results. Station years with more than 150 days of missing record were excluded from the analysis. The remaining missing data were estimated with the normal ratio method (4). This is a linear interpolation scheme which uses the ratio of the average annual precipitation at the respective nearby stations as a weighting factor, or

$$P_x = \left(\sum_{i=1}^{N} \frac{M_x}{M_i} P_i\right)/N \qquad \text{(I)}$$

where P is daily precipitation, M is the average annual precipitation and N is the number of nearby stations used to estimate the missing value. The x subscript refers to the point for which the rainfall is being estimated while i refers to nearby stations with recorded data for the date that is needed. Three stations were used to estimate missing days if valid data were available on that date.

Several stations, especially in the Lower East Coast area, have a large amount of accumulated data. A two step procedure was used to distribute the rainfall measurement among the days over which the recorded amount was accumulated. First, Equation (I) was used to calculate an estimated value as if the data was missing. Next the estimated value was multiplied by a correction factor defined as the ratio of the actual accumulation to the sum of the estimated amounts for the period of the accumulation, or,

$$P_A = P_X \left(A / \sum_{i=1}^{M} P_{Xi}\right) \qquad \text{(II)}$$

where P_A is the final rainfall estimate, P_X is the estimate from Equation (I) for that day, A is the recorded accumulation and M is the number of days over which the measured amount was accumulated. This method preserves a mass balance between the sum of the estimated amounts and the actual measured value. The rainfall data from nearby stations are used only to determine the distribution of the rainfall over the respective days.

All the rainfall information was kept on a computer with a data base management system that included a tag on each day to differentiate between the estimated values (missing or accumulated) and the recorded data. The annual series at each station for each duration were then compiled and reviewed to determine the significance of the estimated data points on the values to be used in the statistical analysis. Stations with a large number of estimated points in their annual series or with extreme events derived from estimated rainfall were deleted from the analysis. The daily, wet season, and annual duration maps were derived using 140 rainfall stations with an average period of record of 32.9 years. The dry season maps were based on 138 stations averaging 31.12 years of record.

IV. FREQUENCY ANALYSIS

Type of Data Series

Two common data sets for frequency analyses on short duration storms (1, 2, 3 and 5 days in this report) are the partial duration series and the annual series. The annual series consists of the largest rainfall amount recorded for the respective durations in each calender year. The size of the data set is equal to the number of years for which reliable data is available. The partial duration series is the same size, but is made up of the largest independent events on record regardless of when they occurred. The partial duration series is characterized by a higher mean and a lower variance than the annual series. For predictive purposes the major differences are noted at the lower return periods where the partial duration series results in higher rainfall estimates. The empirical analysis performed by the Weather Bureau (1) concluded that the rainfall estimates for return periods greater than 10 years were essentially the same regardless of which series was used. The annual series values were used for all durations in this study and no adjustments were made to any of the return period estimates to make them equivalent to those derived from a partial duration series.

Frequency Distribution

The prediction of return period values requires a method, either empirical or theoretical, to relate the observed series of maximum events to some probability versus rainfall depth relationship. Statistical parameters such as the mean, variance, and skew of the observed data along with a theoretical probability distribution can be used to calculate the needed rainfall estimates.

Unlike flood frequency analysis, there is no standard probability function accepted for use in rainfall frequency investigations. Most studies (1,3) have relied on a combination of empirical and theoretical methods to arrive at their predicted values. The problem is complicated by the fact that the rainfall measurements and return period estimates are tied to a specific location while the objective of the analysis is to provide area-wide information. Gumbel's method, which utilizes the Fisher Tippett Type I distribution, was used to estimate the rainfall amounts for all return periods and durations covered in this analysis. (See Appendix B for computational details).

The method of moments was used to estimate the mean, variance, and skew of the data series at each station. Calculations of the standard error associated with each of these parameters showed that even for the long term stations, the length of record available was not sufficient to provide reliable estimates of the third moment (skew). Therefore, a two parameter probability function was needed to estimate the return period values. Gumbel's method of fitting annual series to the Fisher-Tippet Type I distribution for extreme values has been used extensively in statistical analyses of climatological phenomena. It was used by the Weather Bureau to estimate return periods beyond 20 years in TP40 and TP49 and has been used in studies of wind and temperature extremes (6). The theoretical development by Gumbel requires that the extreme values represent single, independent events from a homogeneous population. For rainfall analyses the homogeneity requirement implies that the gage type, location, and exposure did not change for the period of record being used. The mean and standard deviation of the data series and the number of years of record at the site are all that is necessary to determine the rainfall estimates using Gumbel's procedure.

Another distribution that is used quite often in flood flow frequency studies is the three parameter Log Pearson Type III distribution. Several techniques have been proposed to compensate for the uncertainty associated with the third moment, including the use of regionalized skew coefficients. The United States Water Resources Council (7) has recommended this approach along with an adjustment based on the expected probability which varies with the number of years of record available. Other researchers (3,8) have proposed their own methods for modifying the calculated estimate of the skew coefficient based on empirical or theoretical analyses. Virtually all of these studies have dealt with stream flow records only. The Corps of Engineers (3), however, as part of their general design studies connected with the Central and Southern Florida project, used the Log Pearson distribution for their rainfall frequency estimates. They used a fixed skew coefficient derived empirically for each rainfall duration by analyzing the data from several of the stations with the longest periods of record.

Some statistical tests were performed to compare the results of these two distributions applied to the one-day storm data. Table 1 summarizes the predicted rainfall and the associated confidence limits for 117 rainfall stations in the central and south Florida area. The average return period estimates are quite similar, but the range of values is significantly larger with Log Pearson at the higher return periods. The 80 percent confidence band is also much narrower for the Gumbel estimates. Table 2 gives a summary of the Gumbel estimates and their confidence limits for the other rainfall durations presented in this report. A Chi square goodness of fit test was applied to the data series from each

TABLE 1

GUMBEL RESULTS (1-Day)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	9.1	4.0	5.7	19.9	7.4	12.2
10	11.7	4.6	7.0	21.4	8.6	13.9
25	15.2	5.5	8.5	22.9	9.7	15.5
50	17.7	6.1	9.7	23.7	10.4	16.5
100	20.3	6.7	10.8	24.3	10.9	17.3

LOG PEARSON RESULTS (1-Day)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	7.7	3.8	5.2	21.2	6.9	12.0
10	10.2	4.3	6.3	27.8	8.2	15.3
25	14.2	4.7	7.9	41.3	10.9	22.2
50	18.2	5.1	9.2	56.8	13.3	28.7
100	23.1	5.4	10.7	77.6	16.0	36.0

The confidence limits are expressed as a percentage of the return period estimates. The high and low columns represent individual station values.

TABLE 2

GUMBEL RESULTS (2-Days)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	10.4	4.9	7.0	18.1	6.4	11.8
10	13.2	5.7	8.5	19.7	7.6	13.6
25	16.7	6.6	10.3	21.4	8.7	15.3
50	19.4	7.3	11.6	22.3	9.5	16.3
100	22.1	8.0	12.9	23.1	10.0	17.1

GUMBEL RESULTS (3-Days)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	11.0	5.4	7.7	16.9	6.0	11.5
10	13.5	6.2	9.2	18.7	7.1	13.2
25	16.9	7.2	11.1	20.6	8.3	15.0
50	19.5	7.9	12.5	21.6	9.0	16.0
100	22.1	8.6	13.9	22.4	9.6	16.8

GUMBEL RESULTS (5-Days)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	11.7	6.5	8.6	16.5	6.1	10.0
10	14.5	7.6	10.3	18.2	7.2	12.7
25	17.9	8.9	12.3	20.0	8.4	14.5
50	20.3	9.9	13.8	21.1	9.1	15.5
100	22.8	10.9	15.3	22.0	9.7	16.3

TABLE 2 (continued)

GUMBEL RESULTS (Dry Season)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	25.8	12.4	18.6	18.7	7.5	12.6
10	31.7	15.2	22.7	20.7	8.7	14.3
25	39.3	18.1	27.8	22.5	9.8	15.9
50	44.9	20.2	31.6	23.5	10.5	16.8
100	50.5	22.4	35.5	24.3	11.0	17.5

GUMBEL RESULTS (Wet Season)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	60.3	34.2	47.7	13.1	4.0	7.7
10	69.8	39.2	53.8	15.3	4.9	9.4
25	81.7	45.1	61.6	17.5	6.0	11.1
50	90.6	47.7	67.4	18.7	6.7	12.2
100	99.4	50.3	73.1	19.7	7.3	13.2

GUMBEL RESULTS (Annual)

Return Period	Rainfall Depth (in.) High	Low	Average	80% Confidence Limits (%) High	Low	Average
5	77.8	46.8	63.1	12.6	3.4	7.2
10	90.4	52.6	70.7	14.8	4.3	8.8
25	107.5	57.4	80.4	17.0	5.3	10.6
50	120.2	61.0	87.5	18.2	6.0	11.7
100	132.7	64.5	94.6	19.2	6.5	12.6

station in order to test the hypothesis that the series came from a population with either a Gumbel or Log Pearson Type III distribution. The hypothesis was rejected much more often when the assumed distribution was the Log Pearson Type III.

Although statistical tests can give a valuable insight into the consequences or the validity of certain assumptions, they are often inconclusive when applied to data sets as large and varied as those required by this project. As a regulatory agency charged with enforcement of design rainfall values throughout a sixteen county area, factors other than the purely technical questions must be considered. Among these are general acceptance by practicing professionals, results of other similar research efforts, and an established precedent for using the chosen method as a design standard. Although published literature on the subject of rainfall frequency distributions is somewhat limited, there have been studies (9,4) which concluded that Gumbel's method was most appropriate for estimating rainfall extremes for return periods beyond the range of the data. Discussions with specialists in statistics and hydrology reinforced our position that Gumbel's method was more appropriate than Log Pearson for rainfall frequency analyses.

Prior to this study rainfall estimates for most drainage design projects were obtained from the Weather Bureau's rainfall frequency atlas published in 1961 (1). A major impetus behind the District's undertaking of an isohyetal program was the belief that sufficient additional data had become available since 1960 to significantly improve the areal definition of the Weather Bureau maps. Both map series utilized Gumbel's method for estimation of the rainfall amounts for return periods beyond twenty years. Although the mapping techniques were different, the primary reasons for the differences in the shape and values of the contours were the additional data and the greater number of stations used in the District's analysis.

V. ISOHYETAL MAPPING PROCEDURE

The isohyetal maps were produced using a two step procedure that combined a mathematical and a manual system for placing the contour lines. The first step consisted of using a computer plotting routine and the Calcomp plotter to produce a rough draft of the contour maps. The computer program superimposed a 3154 point grid over the District area with a grid spacing of 3.8 miles between points. The location of each rain gage and its return period value were read into the program and used to calculate a return period estimate at each grid point. The grid point values were determined from the eight closest rain gages using a reciprocal distance squared (RDS) interpolation scheme. Once the grid points were calculated, the plotting routine was called to draw a smooth curve at the specified contour values.

The computer process for producing the first draft of the maps had no option for adjusting the computed values according to the reliability of the data, length of record, or exposure of the gage at each site. Also, in areas where the station distribution was very sparse, small isolated contours would be drawn that were a reflection of the numerical behavior of the RDS interpolation procedure and not of any natural phenomena at the site. To compensate for deficiencies in the Calcomp plots, the rough plots were entered into an interactive graphics computer system that allowed manual adjustment of the contours. Using the

Calcomp plots as a guide, smooth curves were drawn that ignored the numerical distortions of the computer program and reflected knowledge about individual stations or areas that could not be directly incorporated into a strict mathematical formulation. Where individual station values were noticeably different from surrounding stations the specific data in the area were checked to isolate the cause of the discrepancy and reflect it in the final form of the contours. In this process stations with longer records were given more weight. Professional meteorologists were consulted on the general shape of the isolines, especially in areas where data were scarce or the computed values were ambiguous. The discussions centered mostly on the seasonal maps. The experience of these individuals and their knowledge of the dominant meteorological phenomena in the area were helpful in confirming and clarifying the behavior shown on the maps.

VI. NOTES ON THE ISOHYETAL MAPS

1. An attempt was made to maintain a constant contour interval on each map. To enhance the clarity of presentation on some maps, however, a uniform contour interval was not used over the entire area. On these maps isolines which do not conform to the dominant contour interval are dashed.

2. The isopluvial lines on these maps should not be used to estimate rainfall falling on Lake Okeechobee. There is some rainfall data collected over the lake itself which indicates that significantly less precipitation falls on the lake than on the nearby land area (10). This data is not of sufficient quality or duration for

frequency analysis; therefore no attempt was made to estimate return period amounts for the lake surface area.

3. The predominance of convective type rainfall in South Florida during the wet season results in much higher rainfall totals on the mainland than along the shore or on the coastal islands. Because of the scale to which the maps are drawn, it was not feasible to place a series of closely spaced contours paralleling the coast. There are also very few gages close enough to the coast to precisely quantify the seasonal rainfall values in those areas. There is enough information, however, to state that the wet season and annual rainfall values within about one mile of the coast are 15 to 25 percent below the closest contour value.

4. The coastal barrier islands extending from Miami Beach to Key West also exhibit a much different precipitation regime than the mainland during the wet months. In this case there are sufficient data available to give reliable rainfall estimates for these areas. Again, to maintain the clarity of the maps, it was deemed inappropriate to draw a series of closely spaced contours between the mainland and the coastal islands. The isolines in the Keys should be considered separate from those on the mainland on the wet season and annual duration maps. The northernmost contour value in the Keys applies to rainfall estimates from there to, and including, Miami Beach.

5. The primary objective of this project was to provide accurate rainfall estimates for the area governed by the South Florida Water

Management District. The contours near the District boundary were drawn only for the purpose of providing information within the District area. The shape of these contours may have been different had the project encompassed the entire state. The actual values near the District boundary would not be different than shown on these maps, however.

6. For this analysis the dry season was defined as the six month period from November 1 through April 30. The period from May 1 to October 31 was considered the wet season.

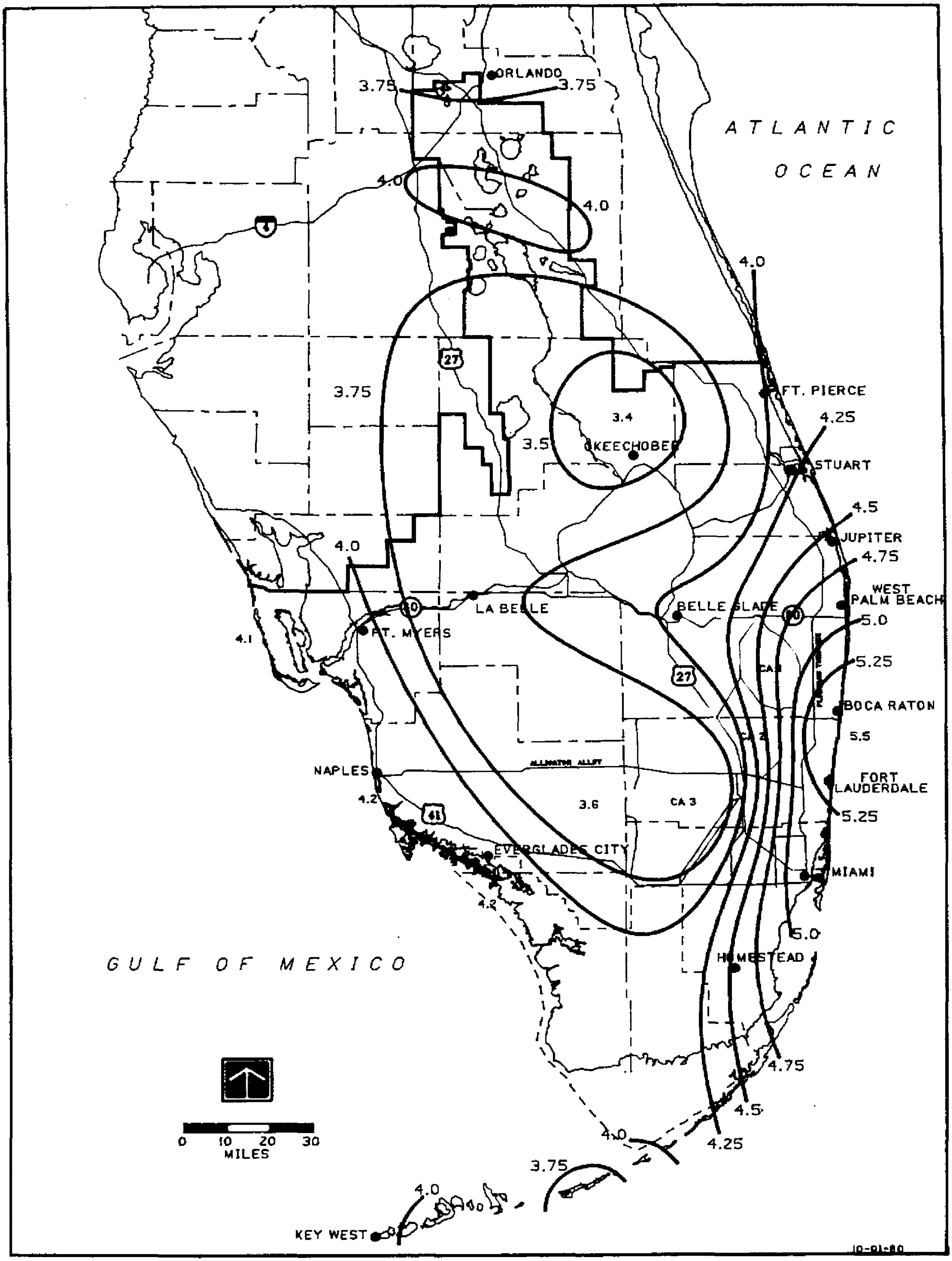

FIGURE 2. 1-DAY RAINFALL: AVERAGE ANNUAL MAXIMUM

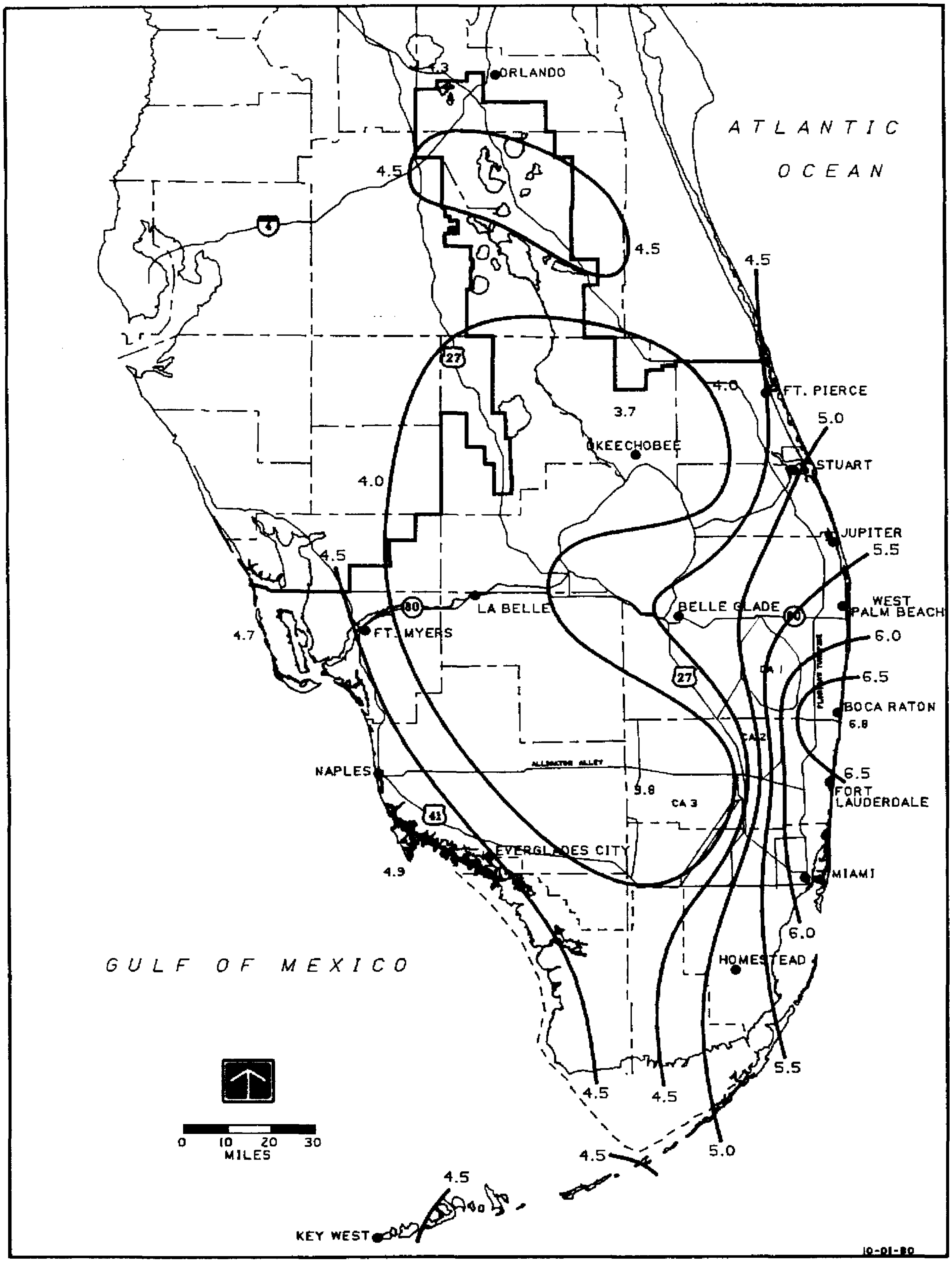

FIGURE 3. 1-DAY RAINFALL: 3 YEAR RETURN PERIOD

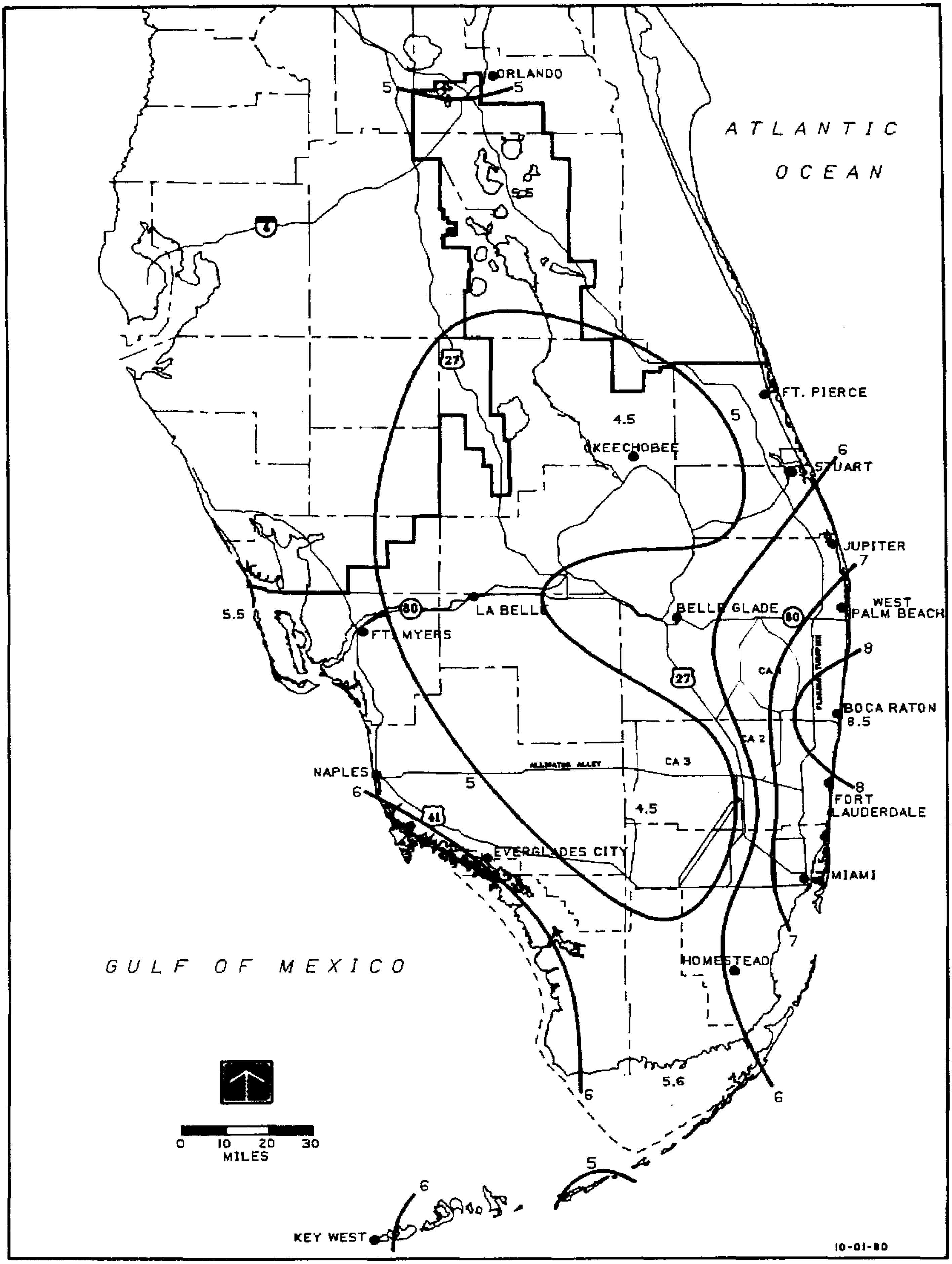

FIGURE 4. 1-DAY RAINFALL: 5 YEAR RETURN PERIOD

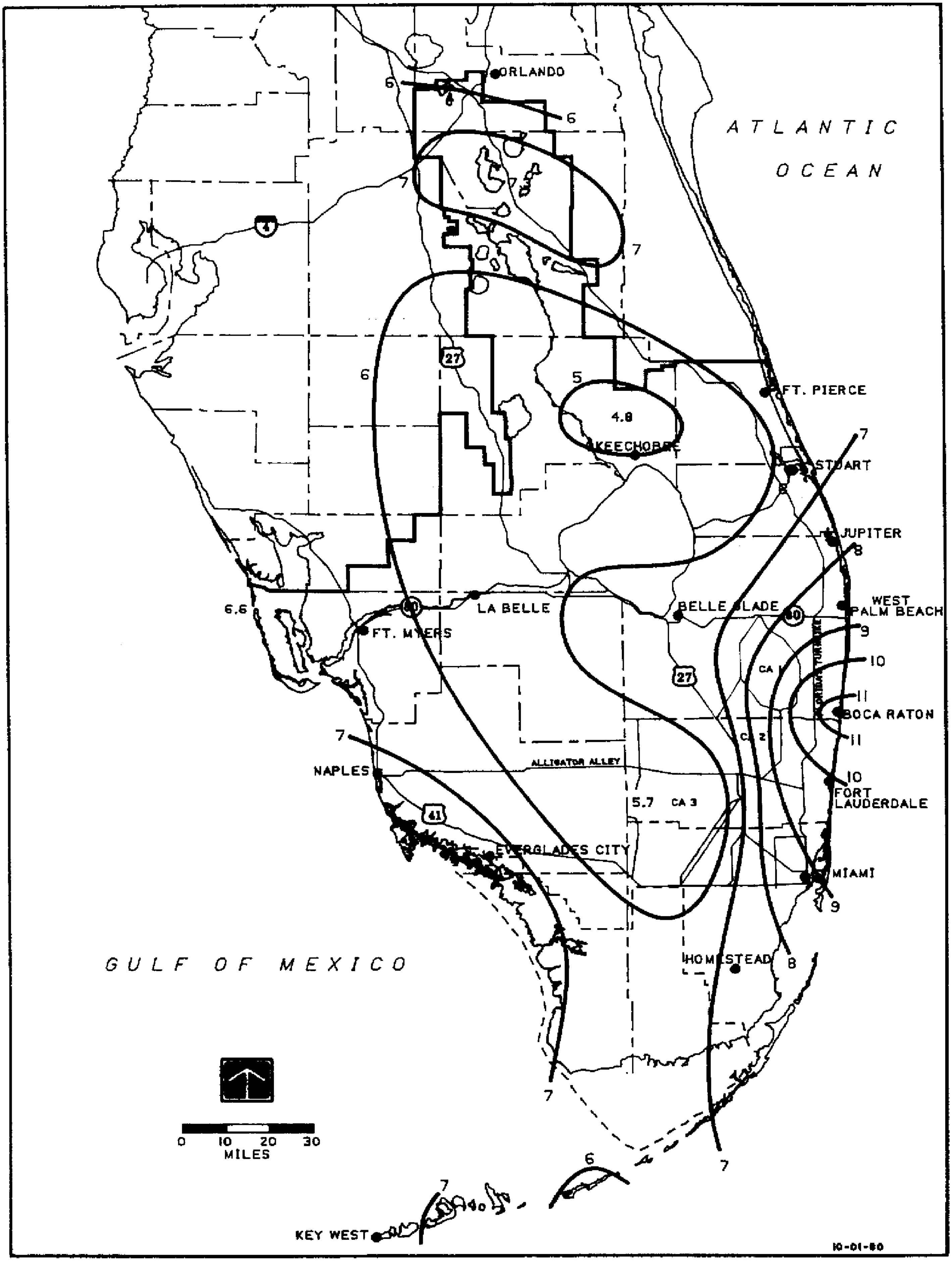

FIGURE 5. 1-DAY RAINFALL: 10 YEAR RETURN PERIOD

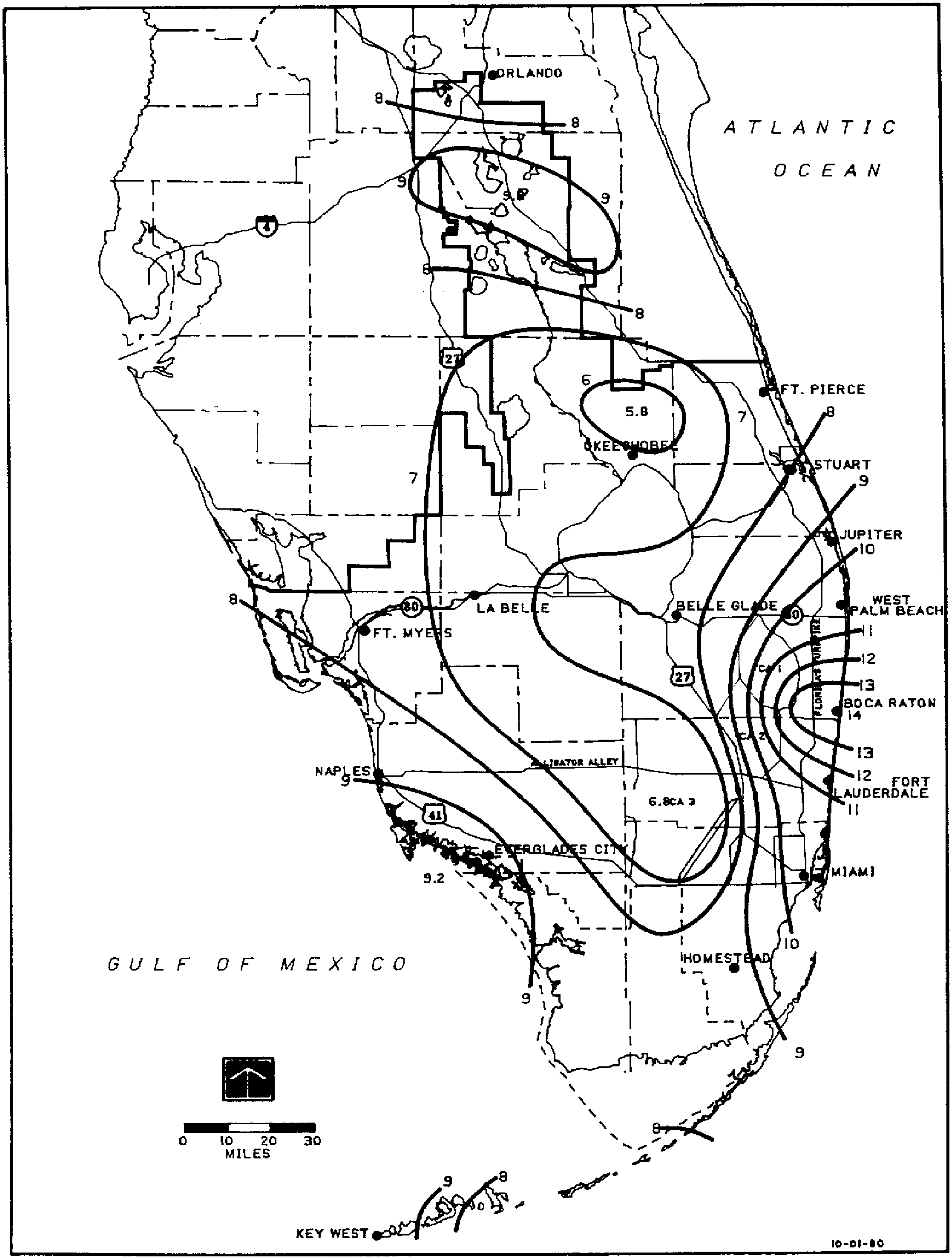

FIGURE 6. 1-DAY RAINFALL: 25 YEAR RETURN PERIOD

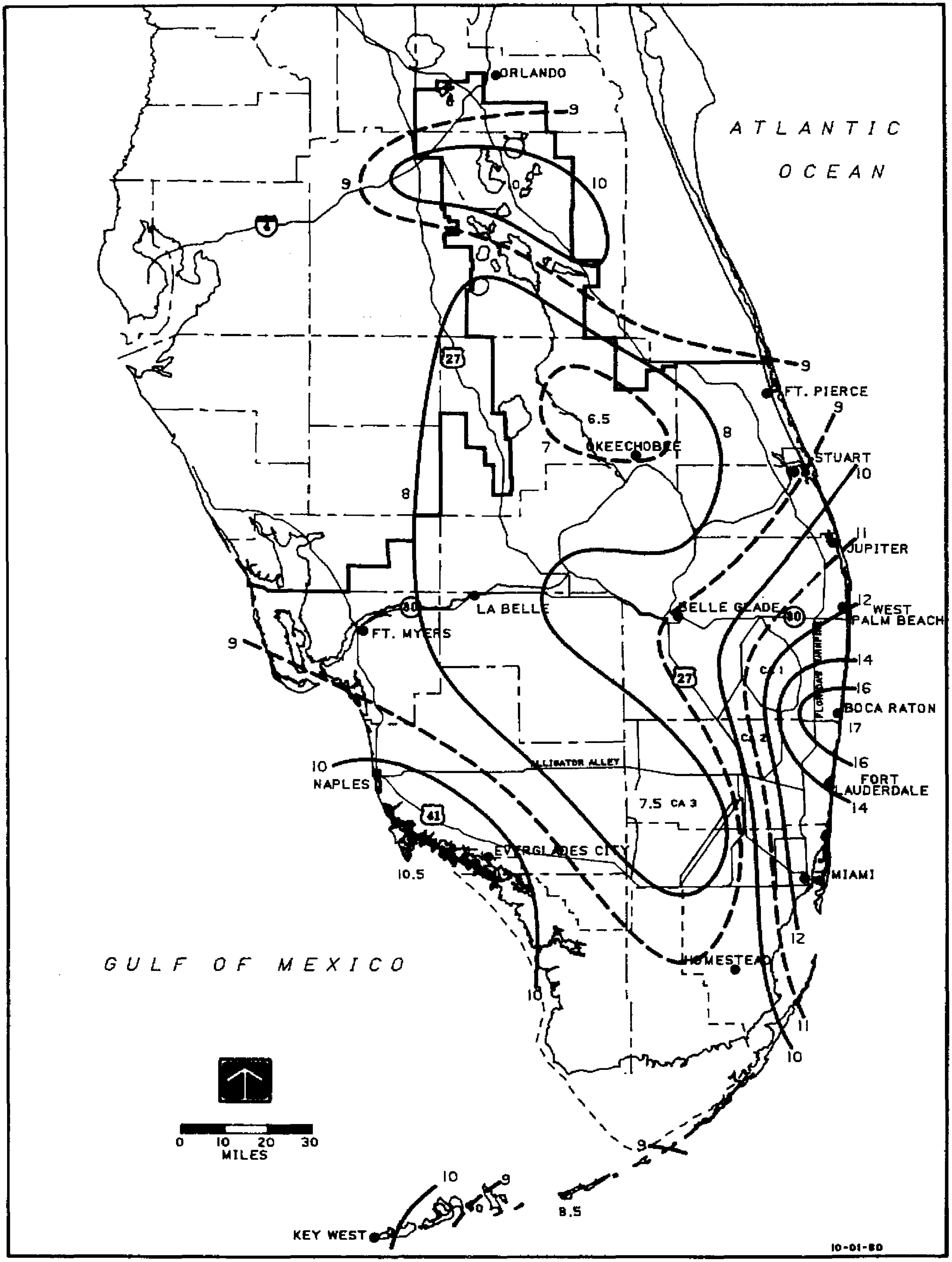

FIGURE 7. 1-DAY RAINFALL: 50 YEAR RETURN PERIOD

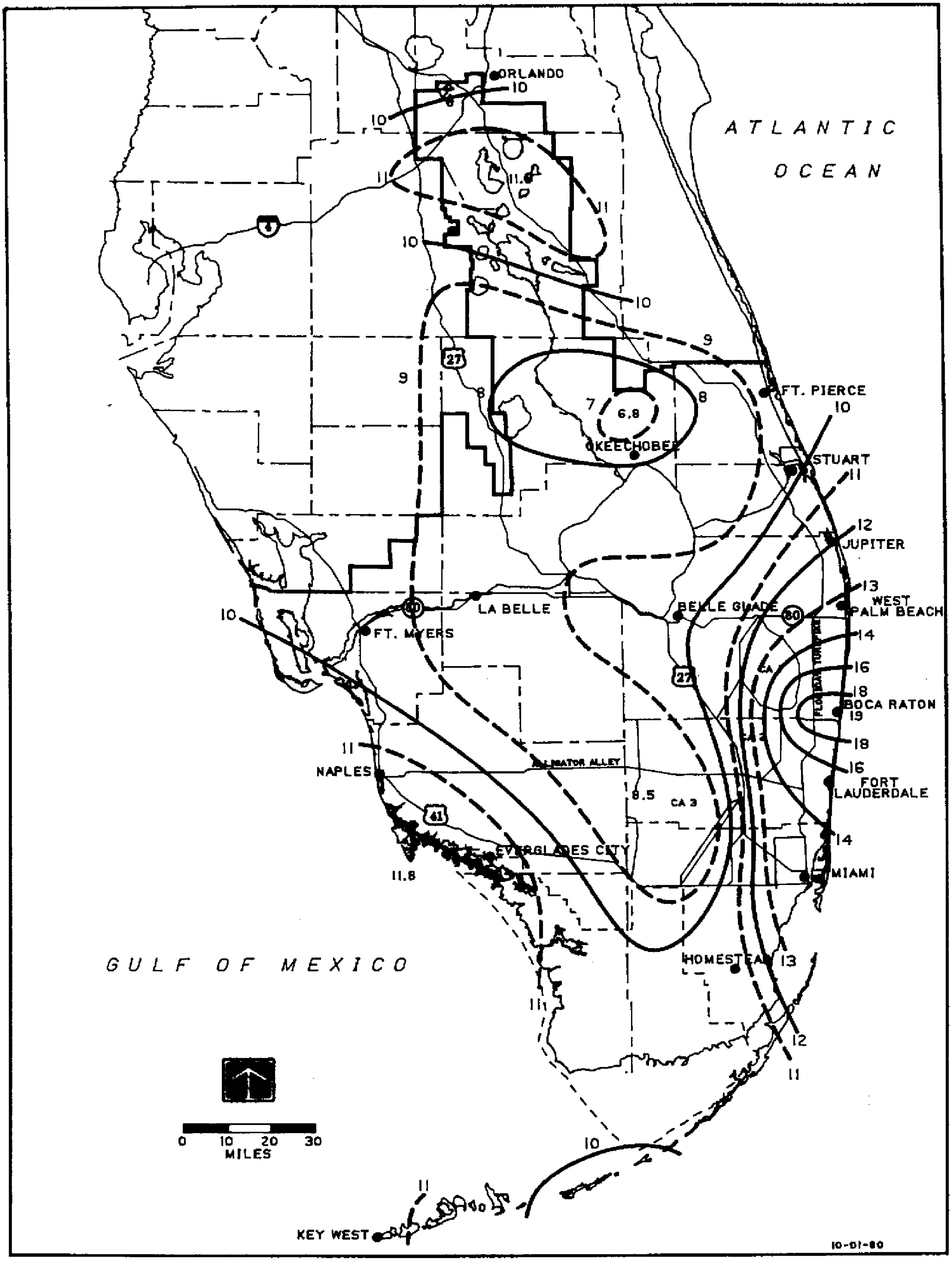

FIGURE 8. 1-DAY RAINFALL: 100 YEAR RETURN PERIOD

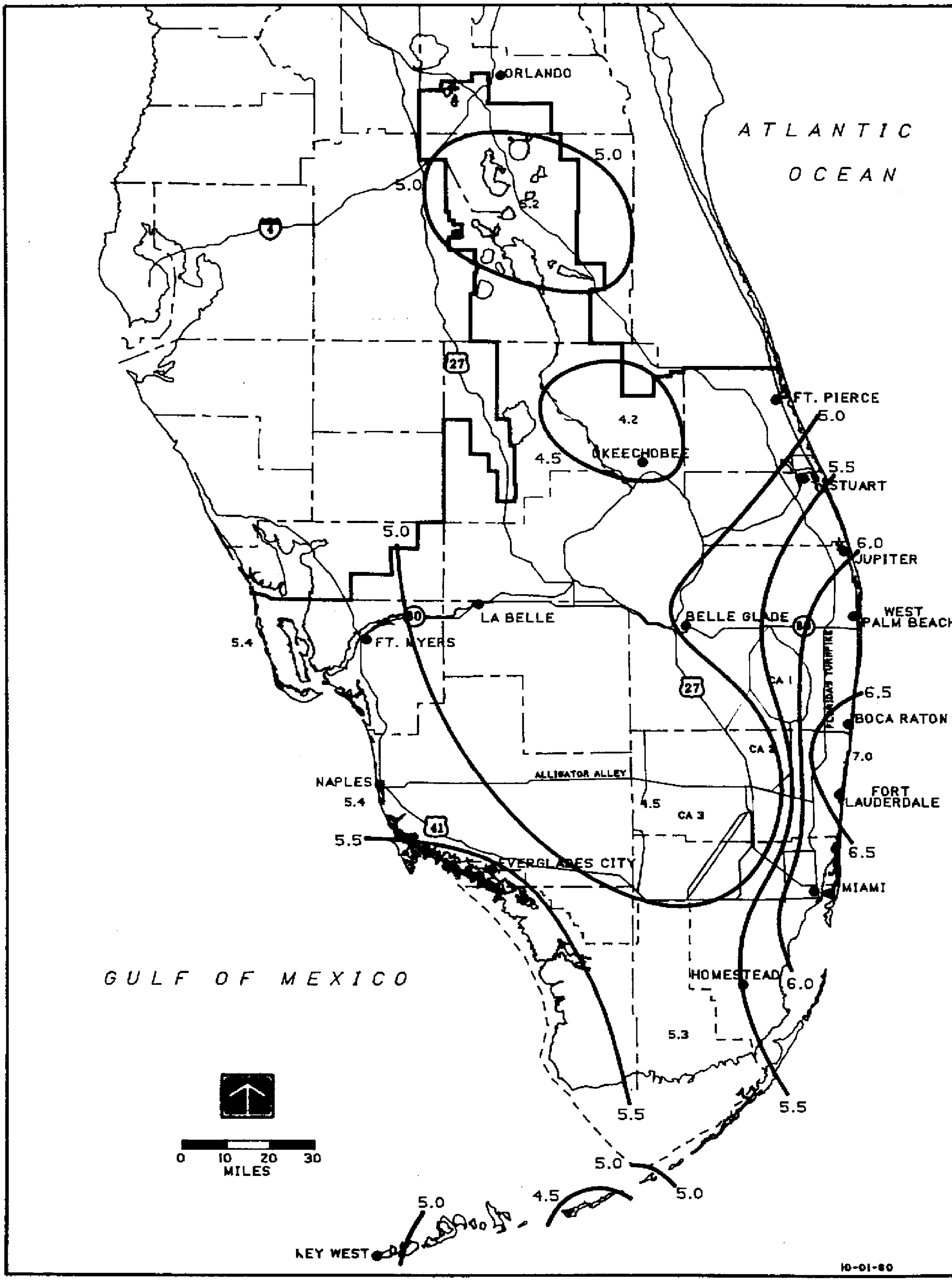

FIGURE 9. 2-DAY RAINFALL: AVERAGE ANNUAL MAXIMUM

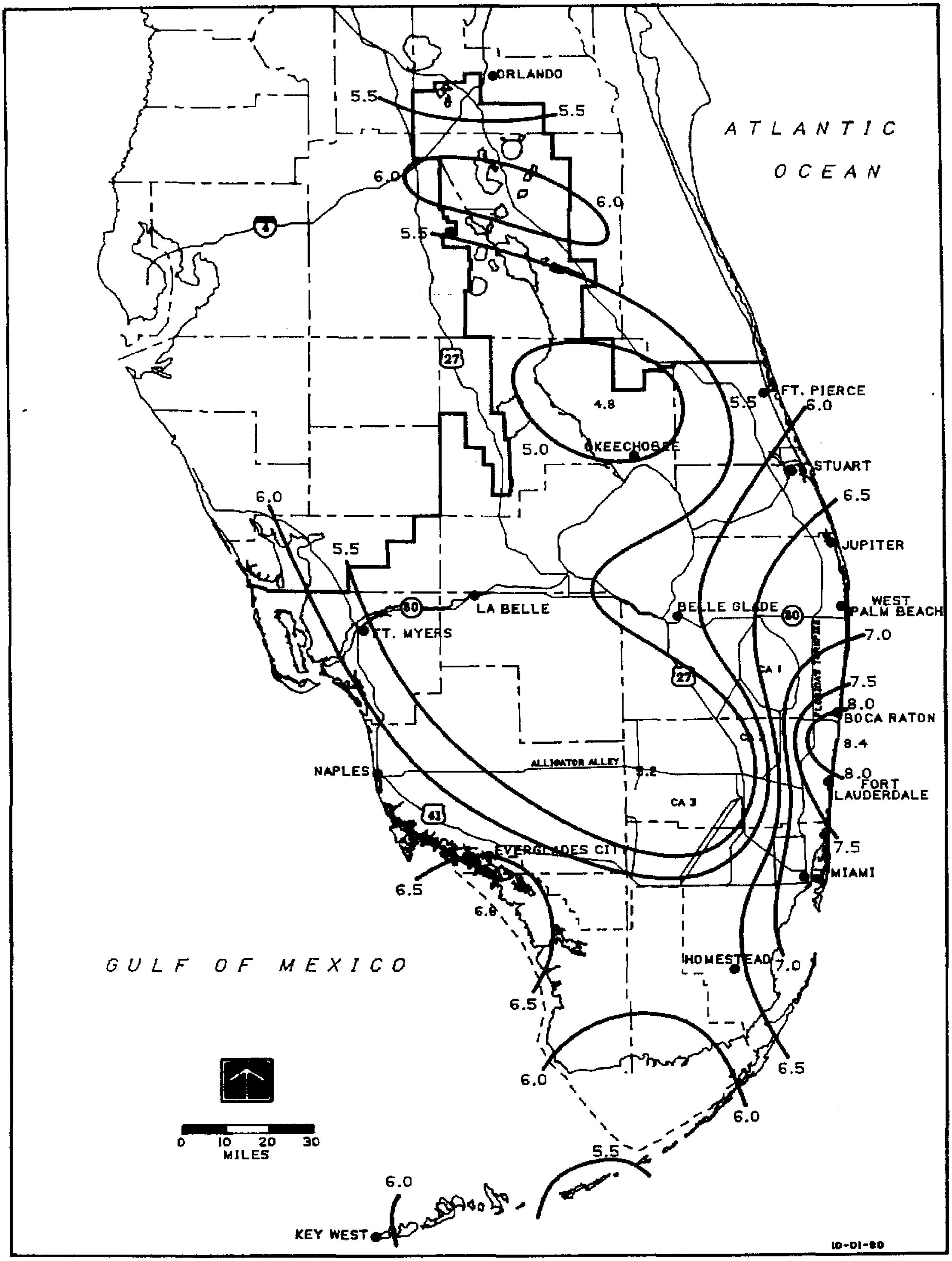

FIGURE 10. 2-DAY RAINFALL: 3 YEAR RETURN PERIOD

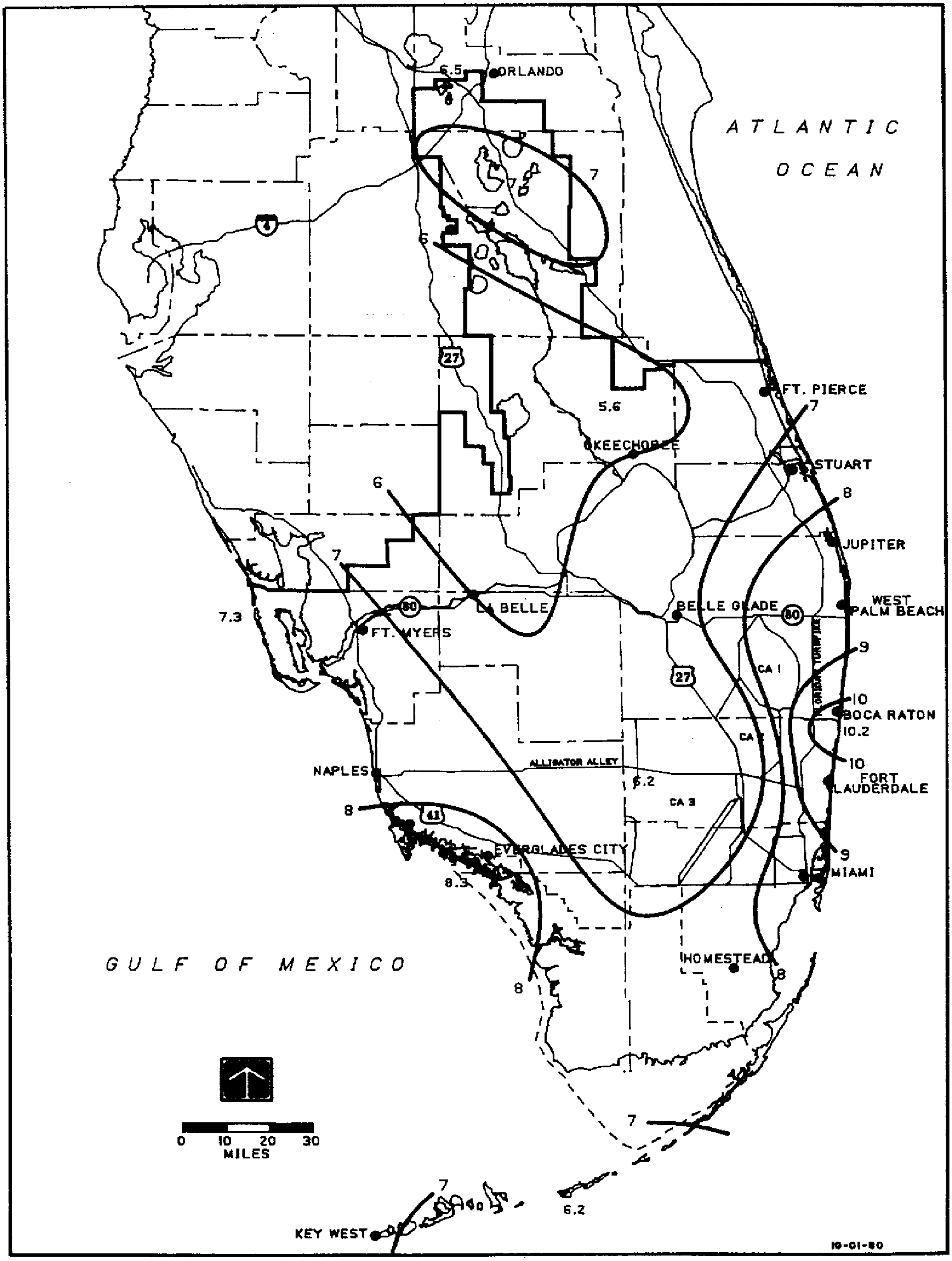

FIGURE 11. 2-DAY RAINFALL: 5 YEAR RETURN PERIOD

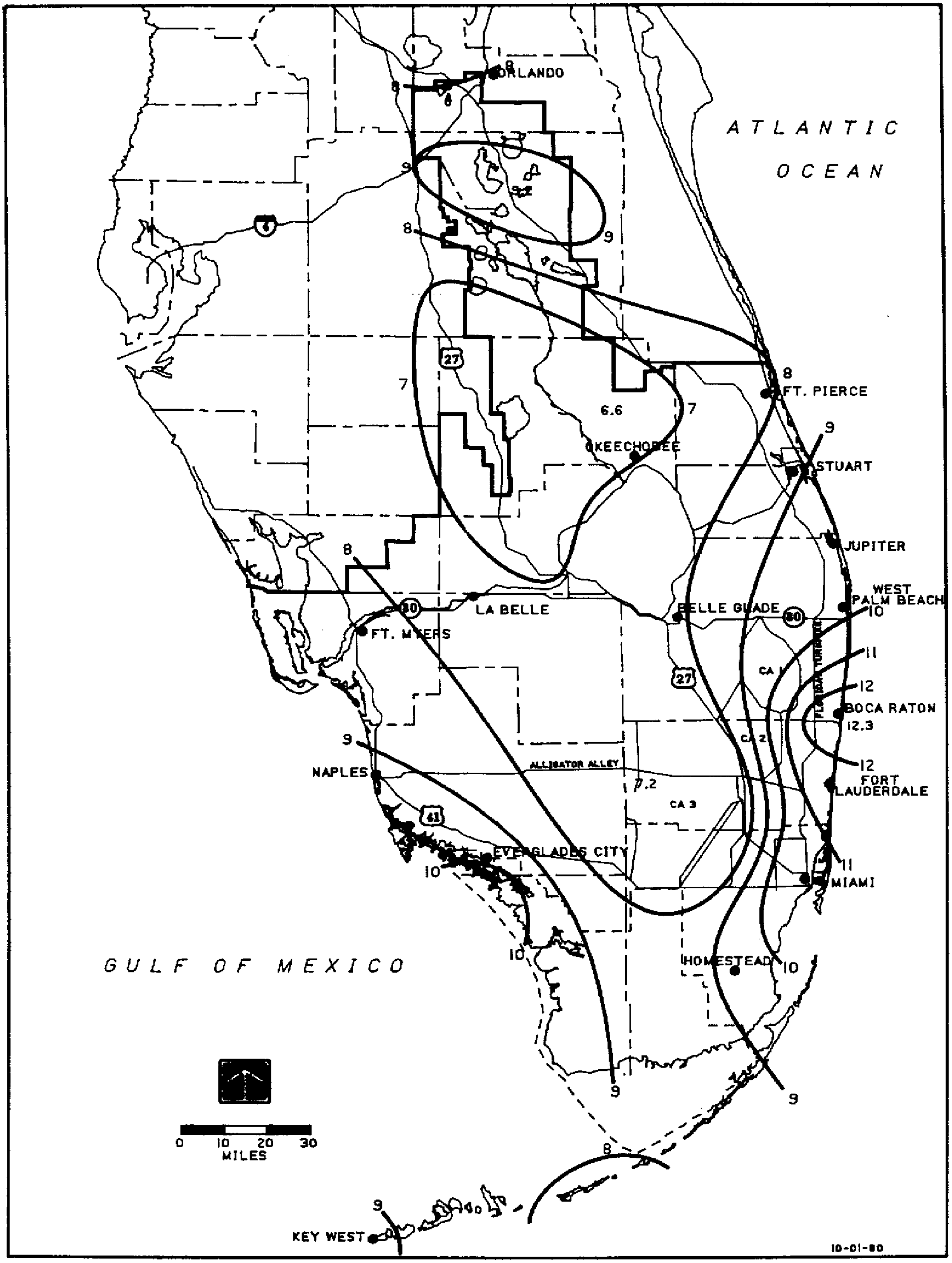

FIGURE 12. 2-DAY RAINFALL: 10 YEAR RETURN PERIOD

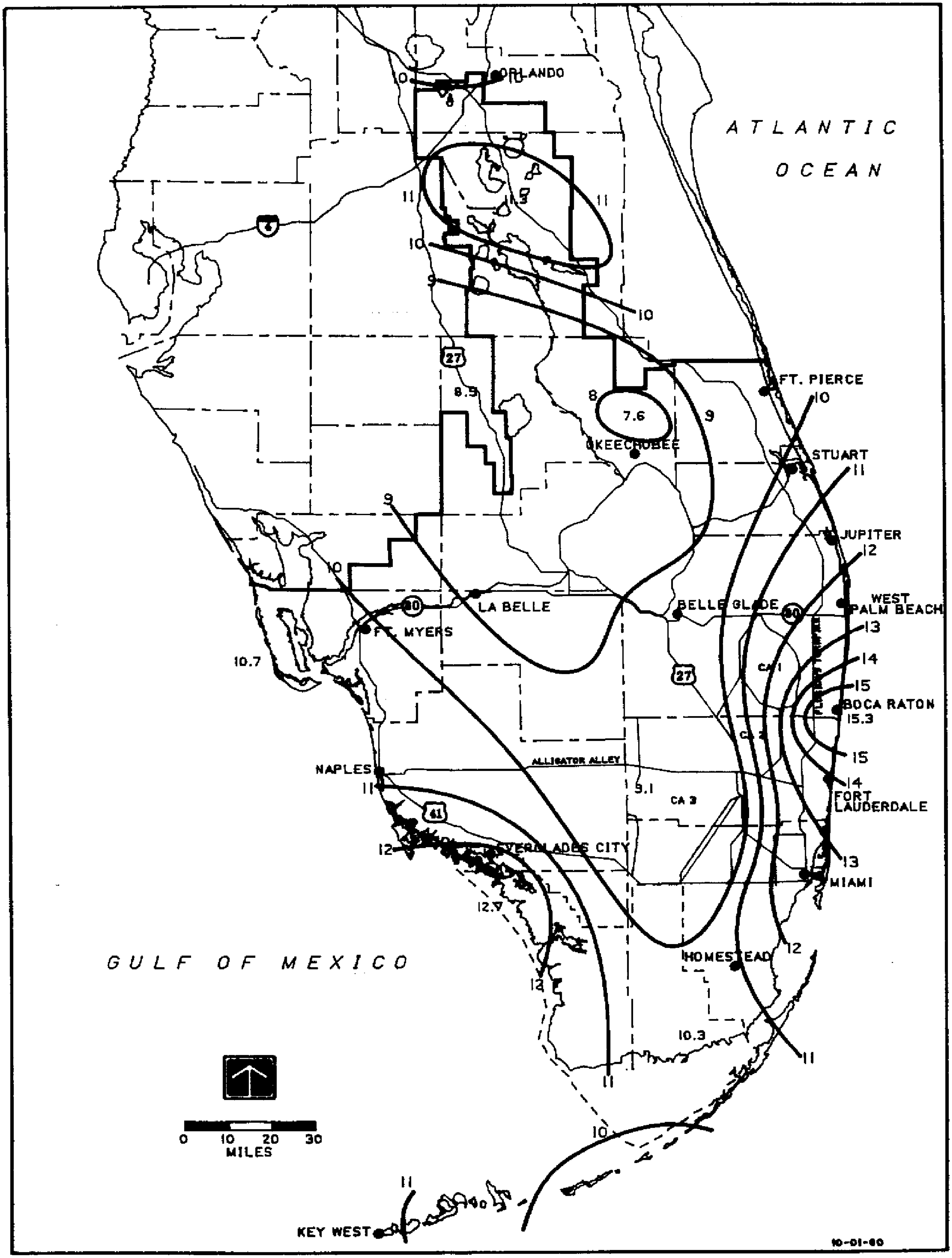

FIGURE 13. 2-DAY RAINFALL: 25 YEAR RETURN PERIOD

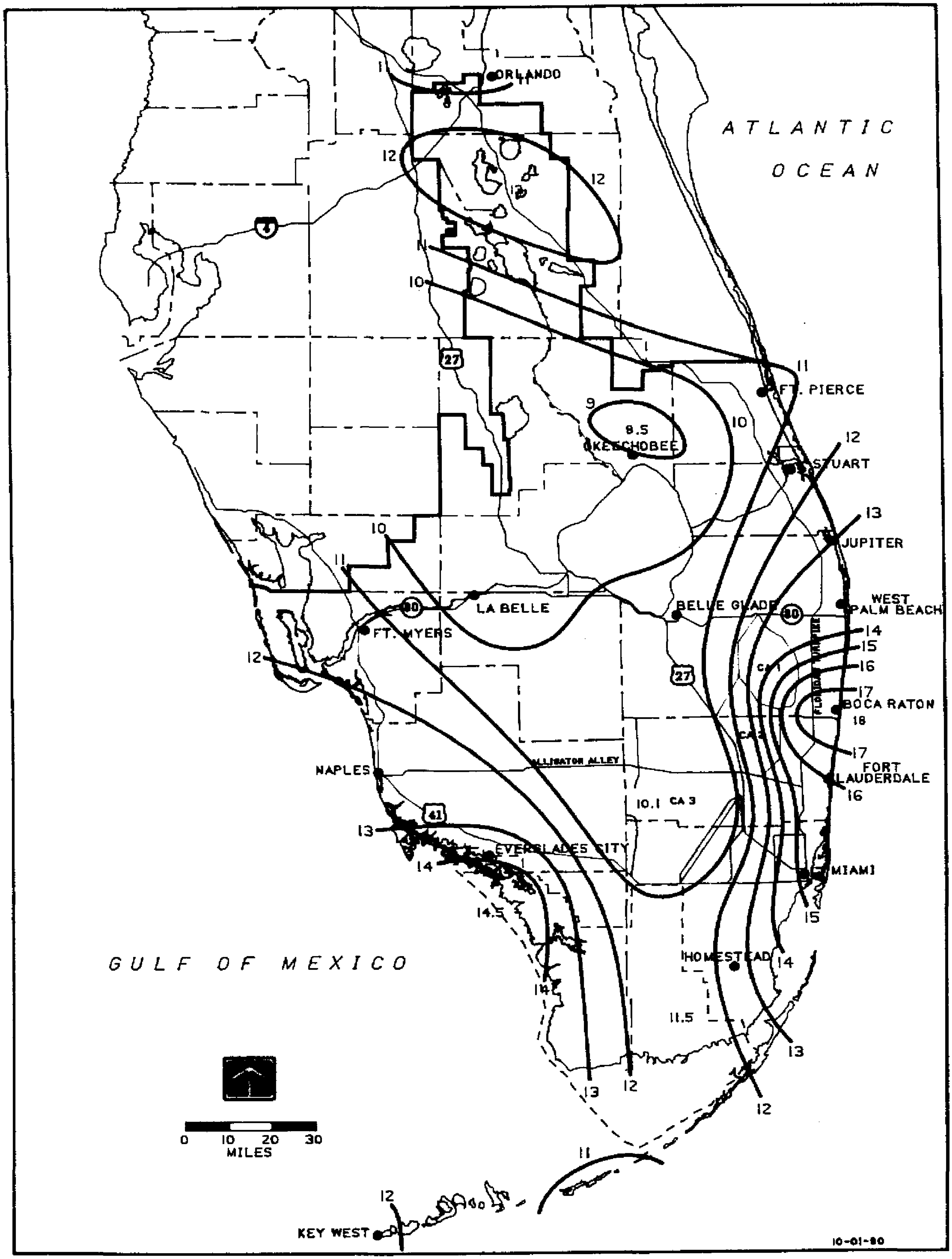

FIGURE 14. 2-DAY RAINFALL: 50 YEAR RETURN PERIOD

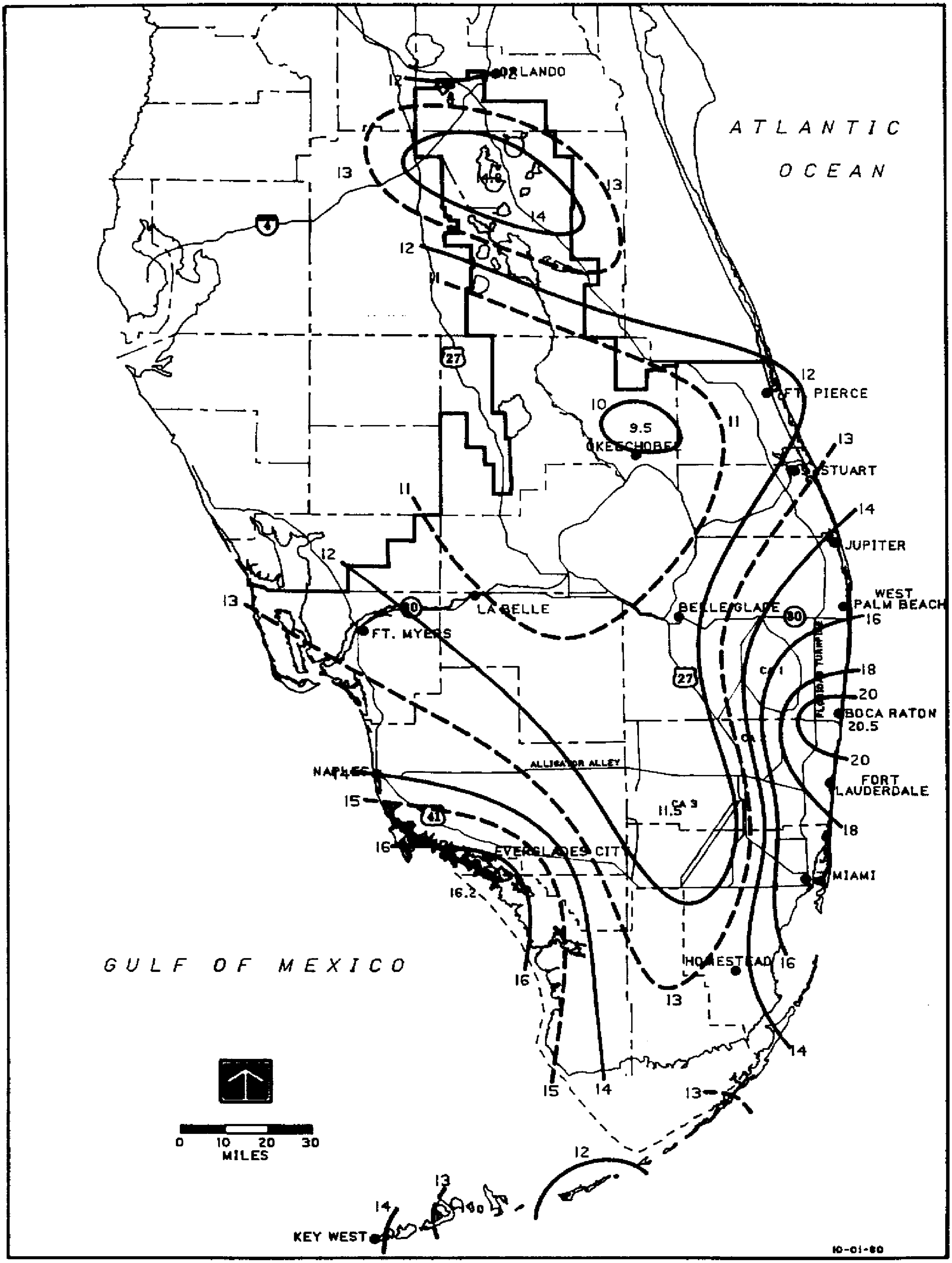

FIGURE 15. 2-DAY RAINFALL: 100 YEAR RETURN PERIOD

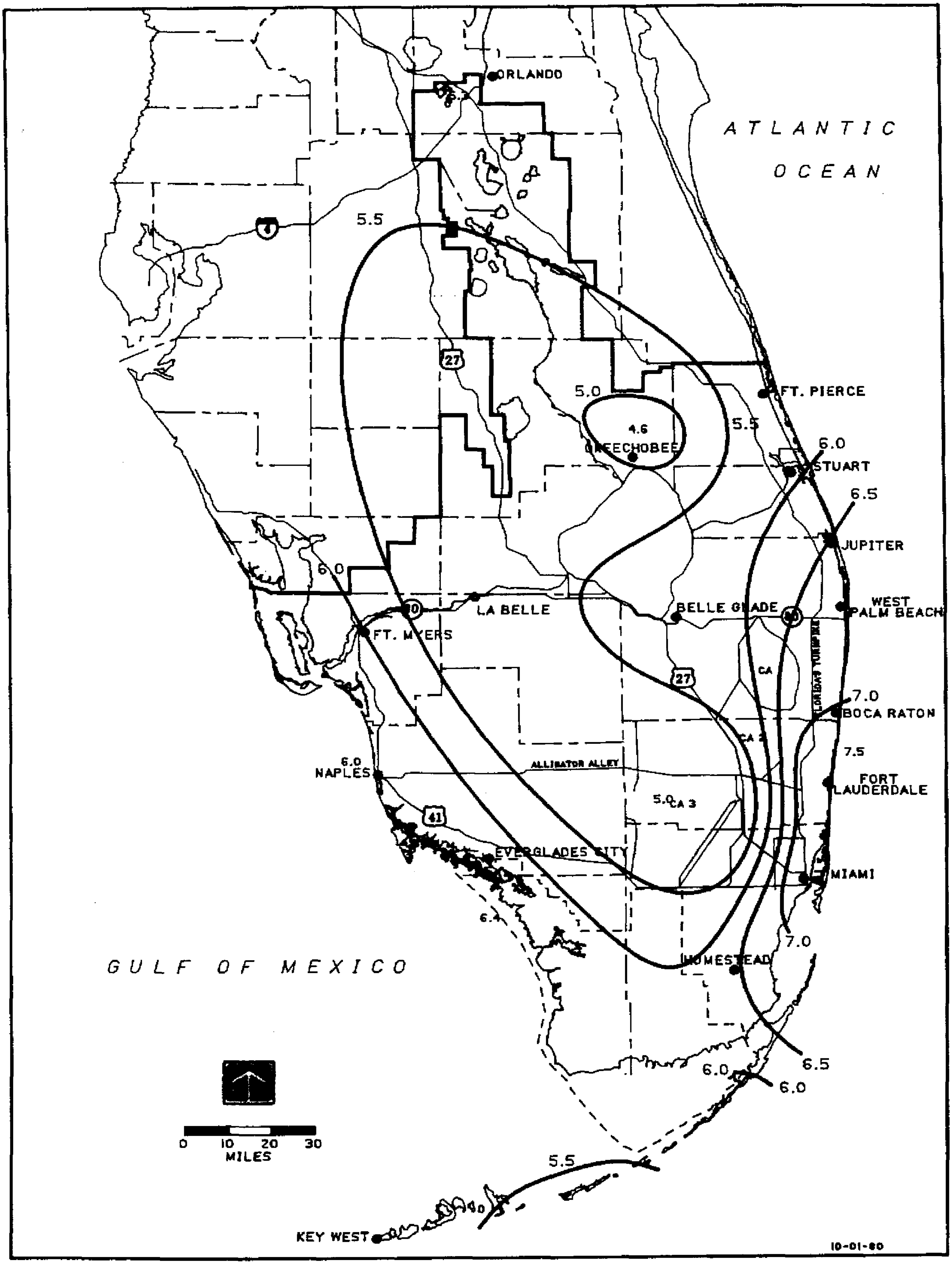

FIGURE 16. 3-DAY RAINFALL: AVERAGE ANNUAL MAXIMUM

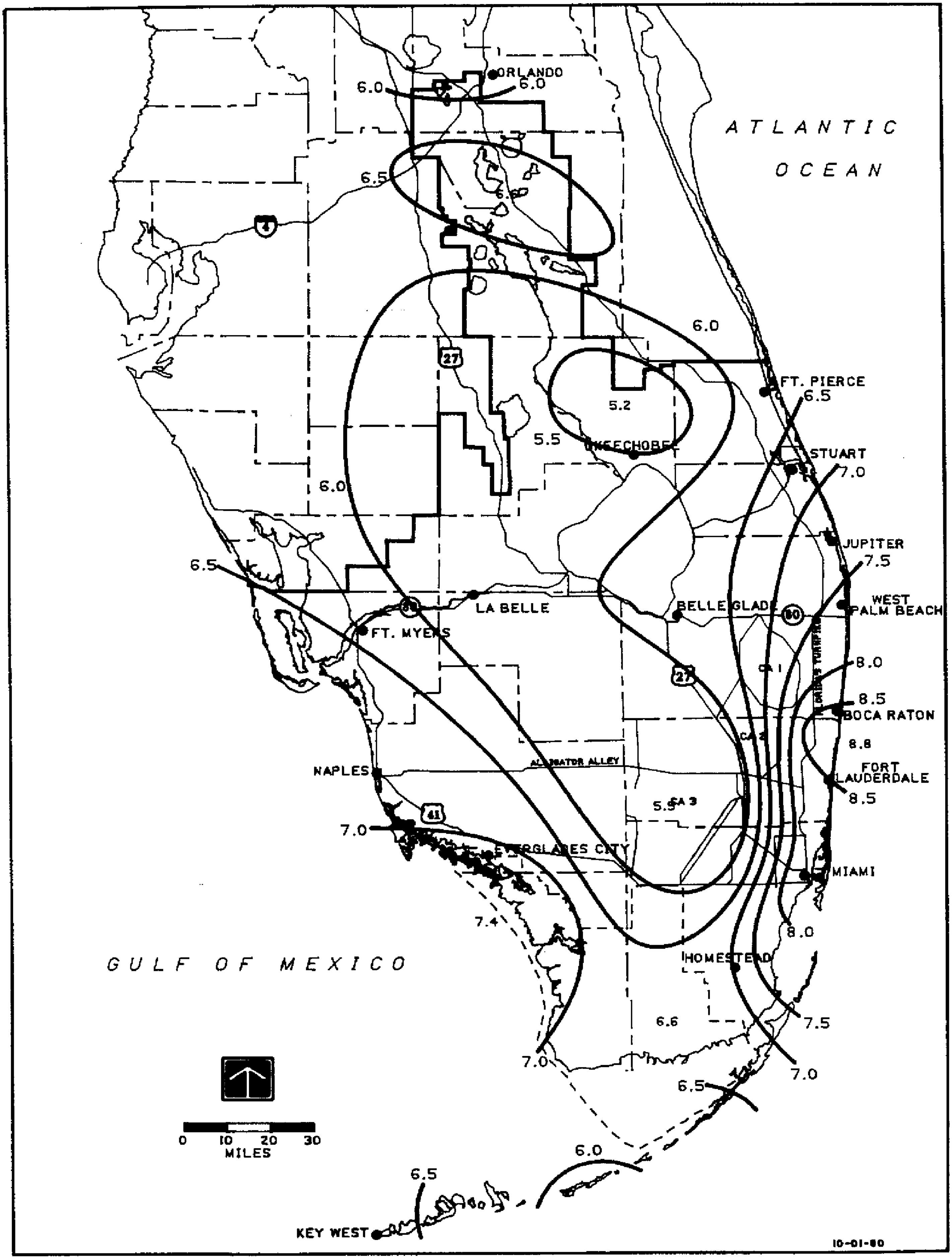

FIGURE 17. 3-DAY RAINFALL: 3 YEAR RETURN PERIOD

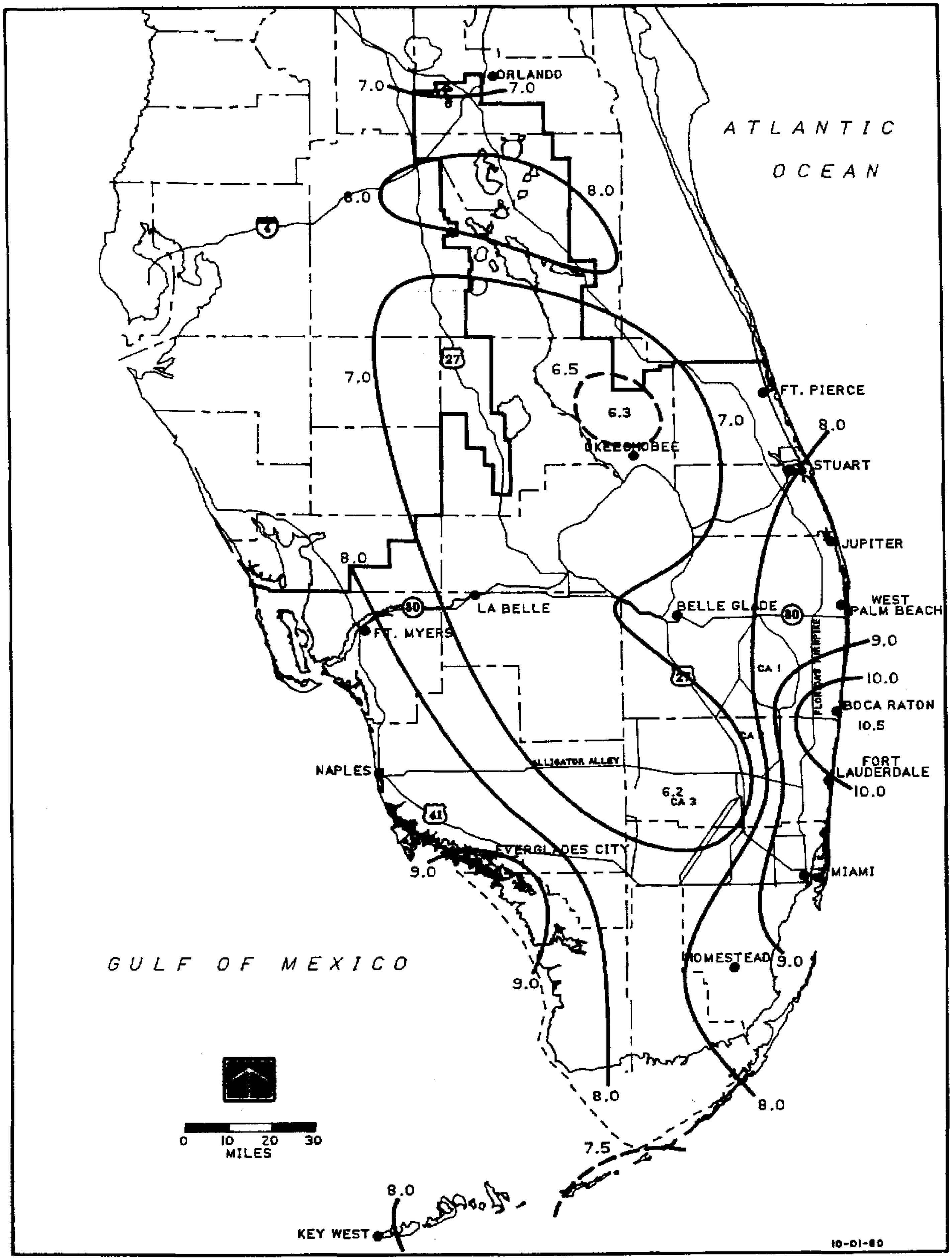

FIGURE 18. 3-DAY RAINFALL: 5 YEAR RETURN PERIOD

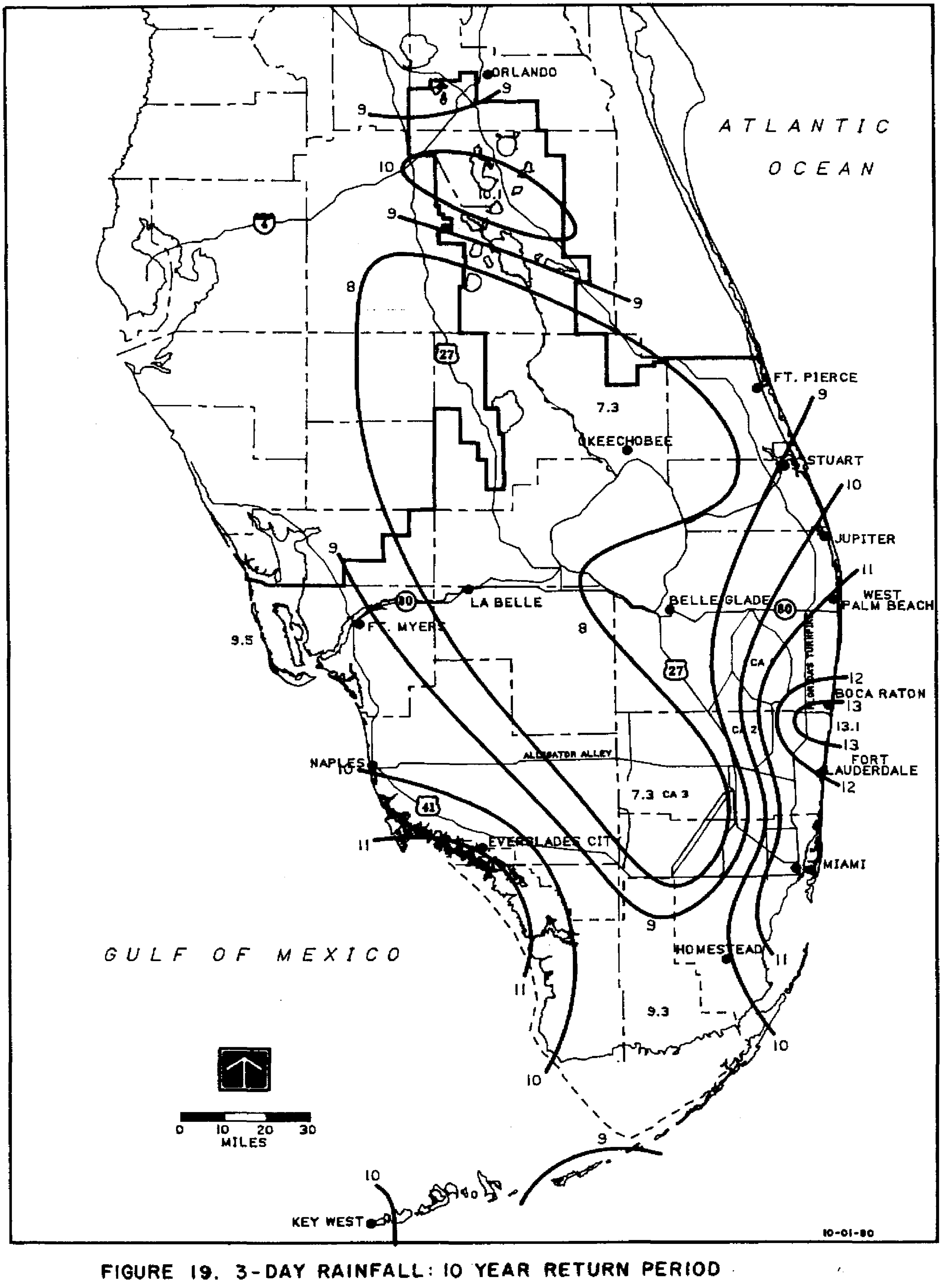

FIGURE 19. 3-DAY RAINFALL: 10 YEAR RETURN PERIOD

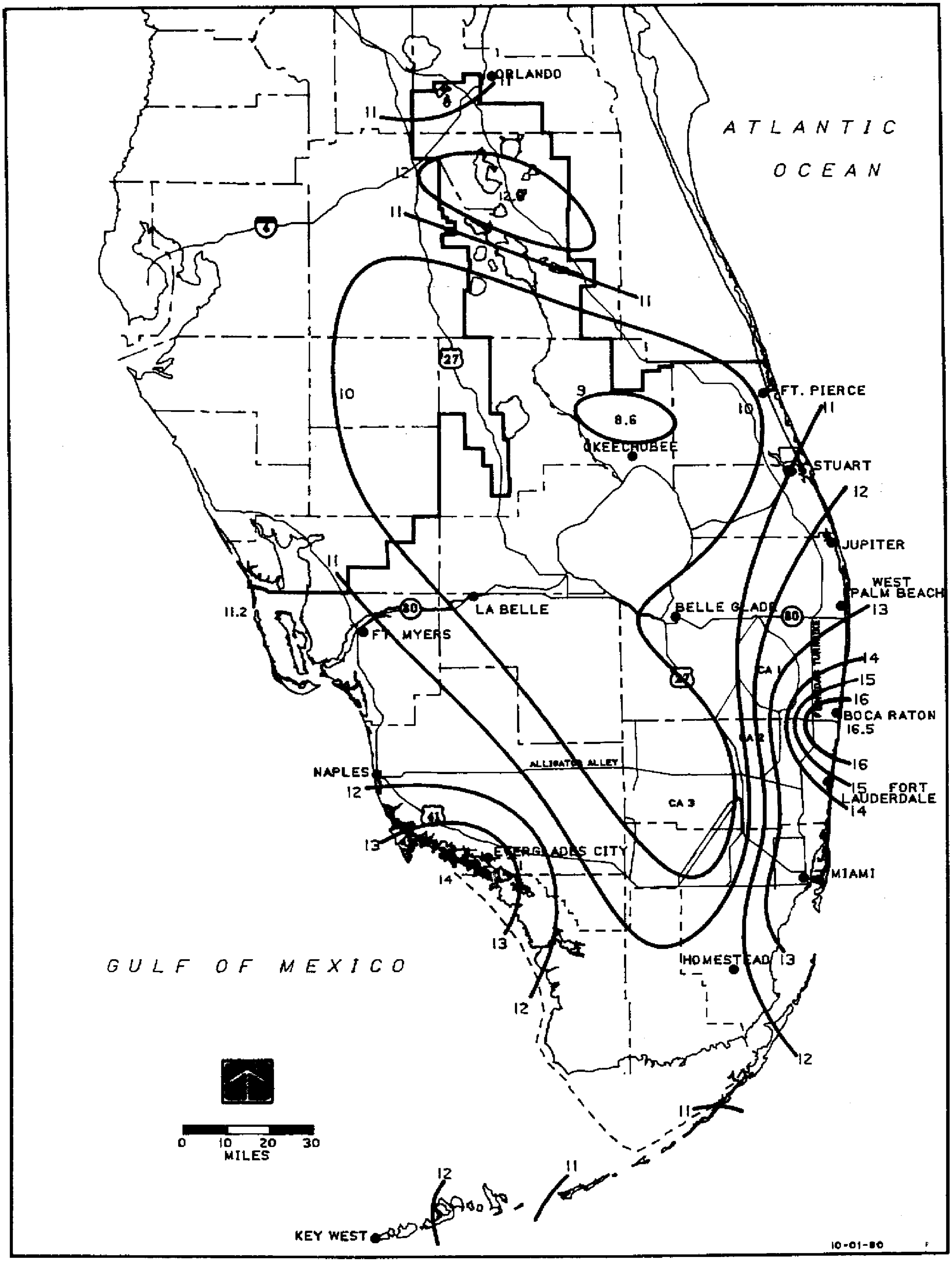

FIGURE 20. 3-DAY RAINFALL : 25 YEAR RETURN PERIOD

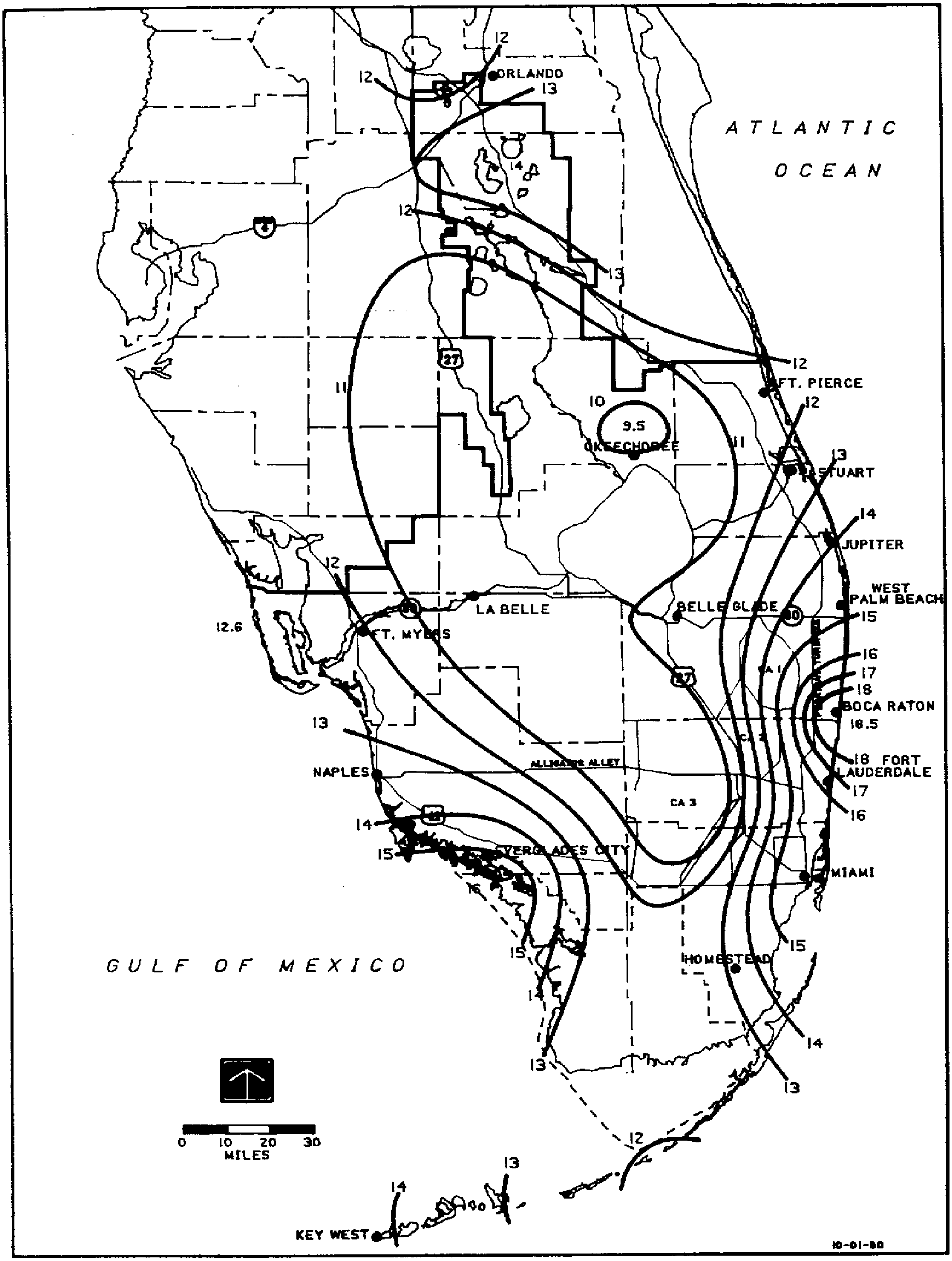

FIGURE 21. 3-DAY RAINFALL: 50 YEAR RETURN PERIOD

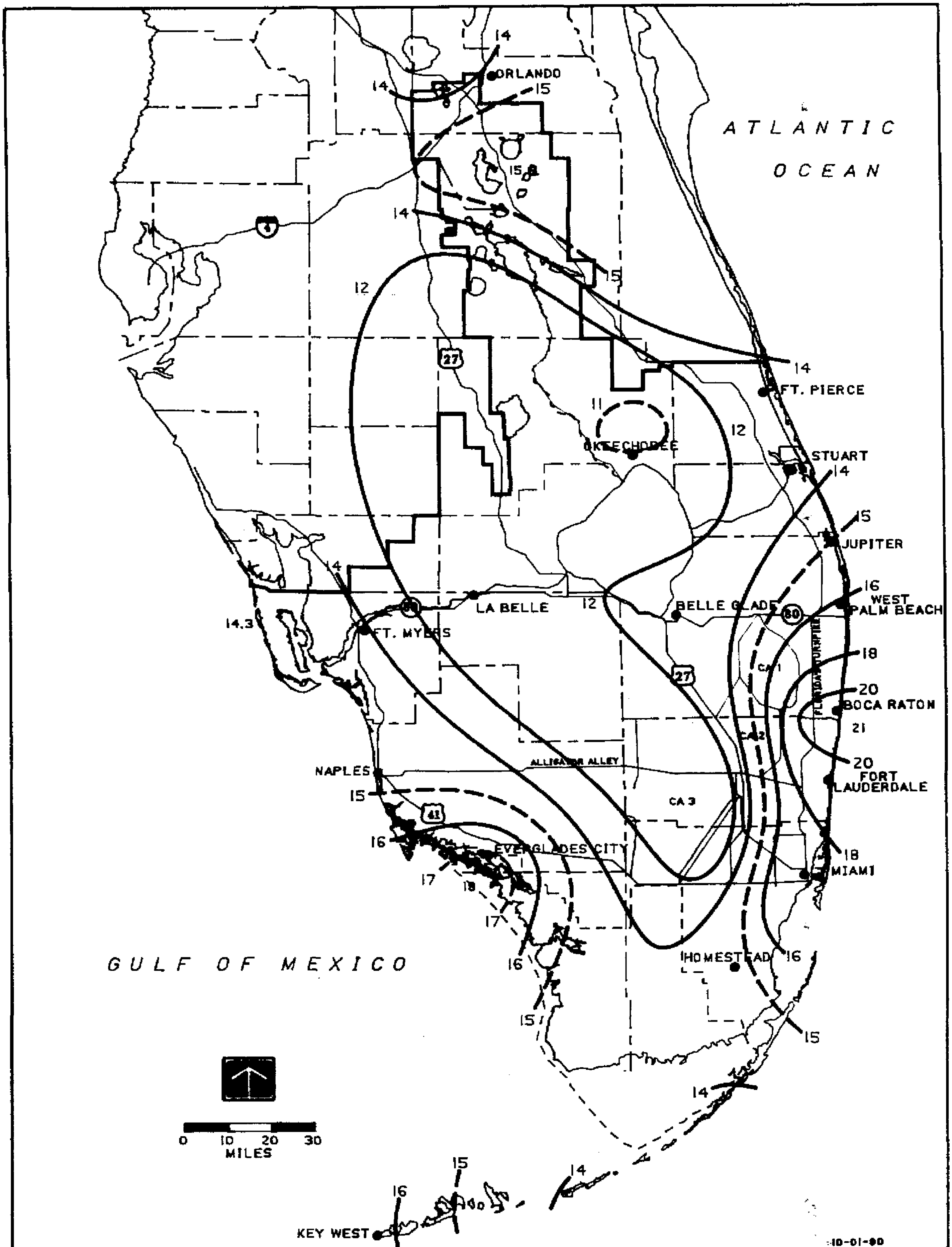

FIGURE 22. 3-DAY RAINFALL: 100 YEAR RETURN PERIOD

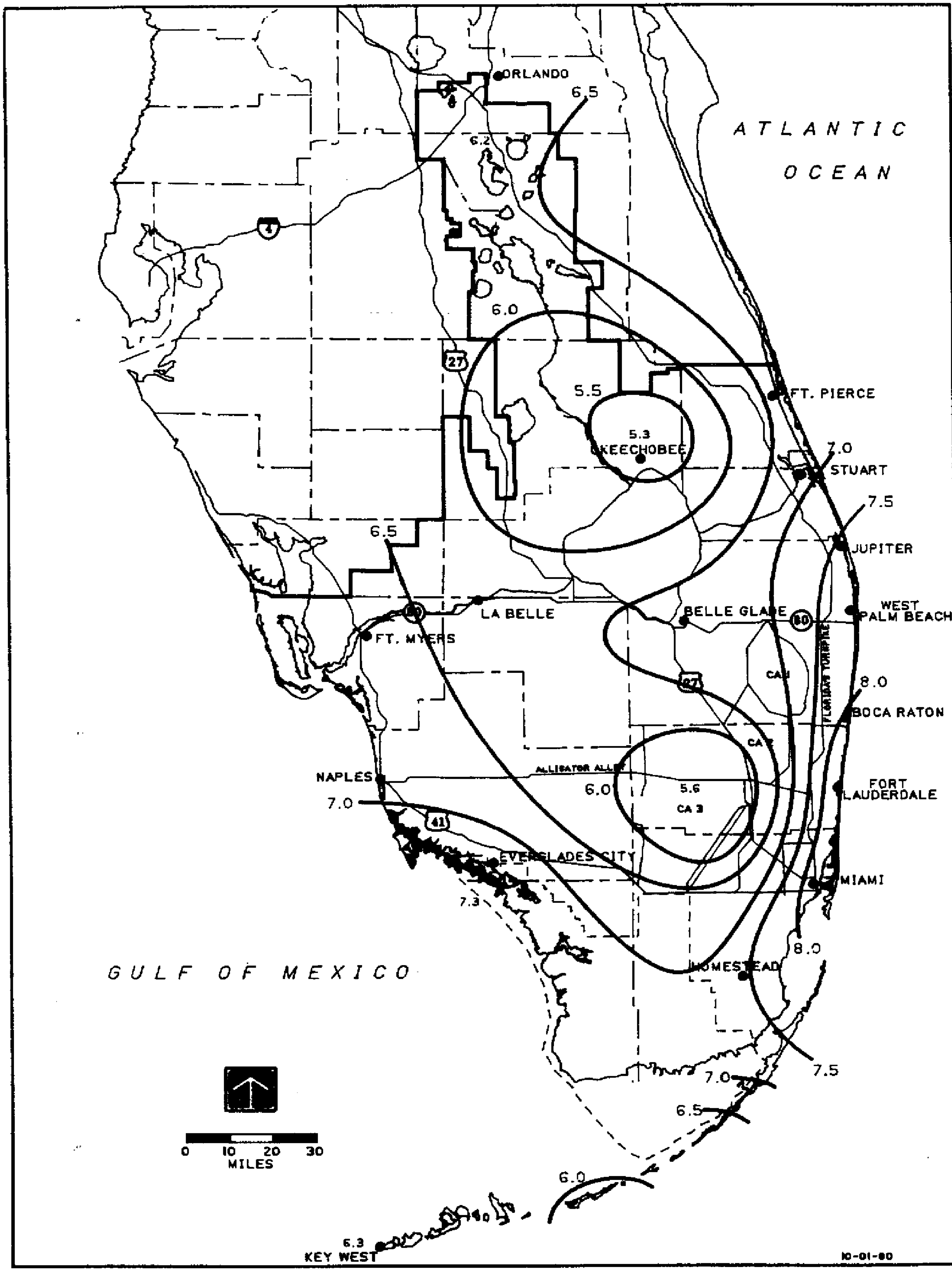

FIGURE 23. 5-DAY RAINFALL: AVERAGE ANNUAL MAXMIUM

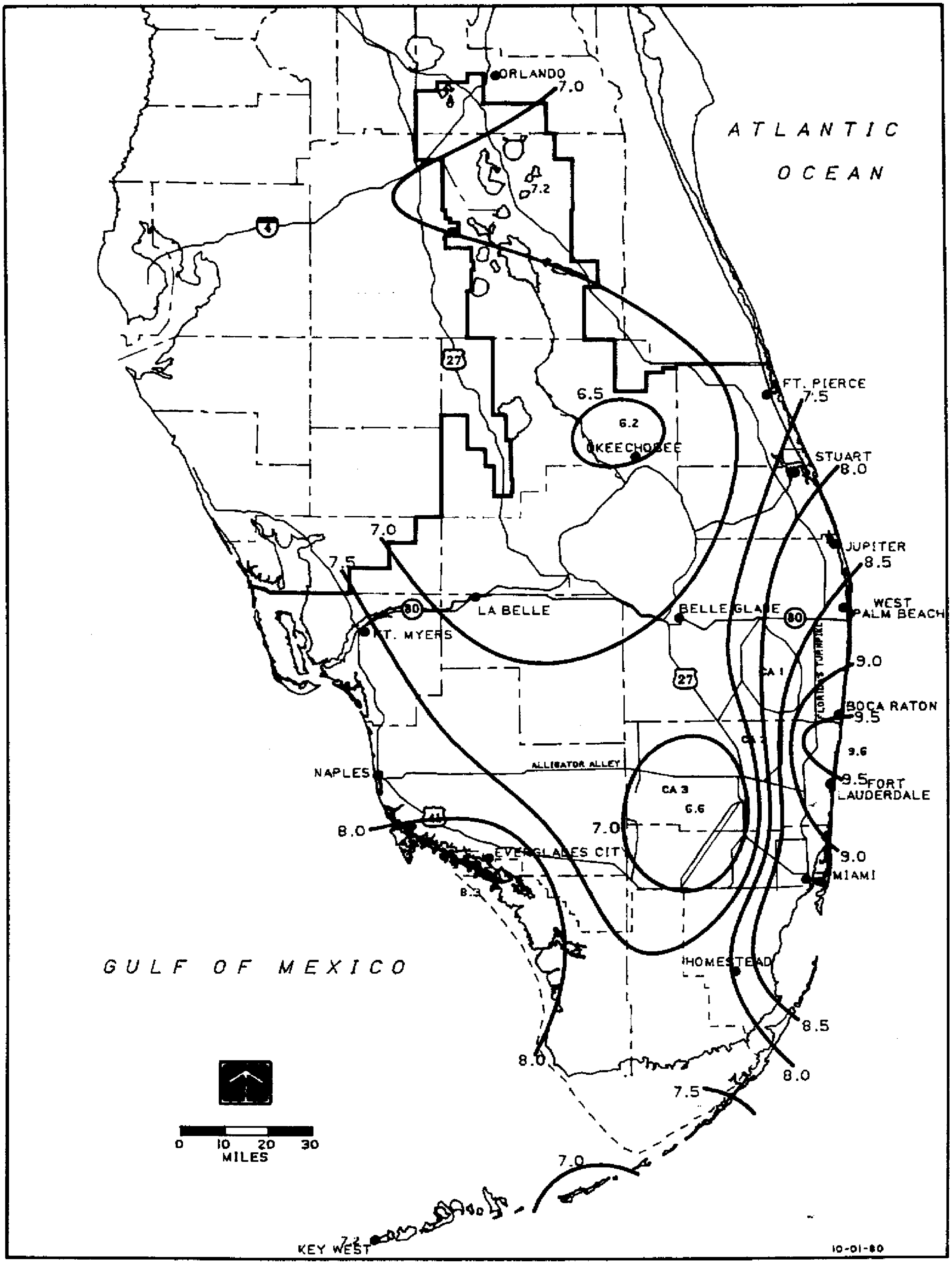

FIGURE 24. 5-DAY RAINFALL: 3 YEAR RETURN PERIOD

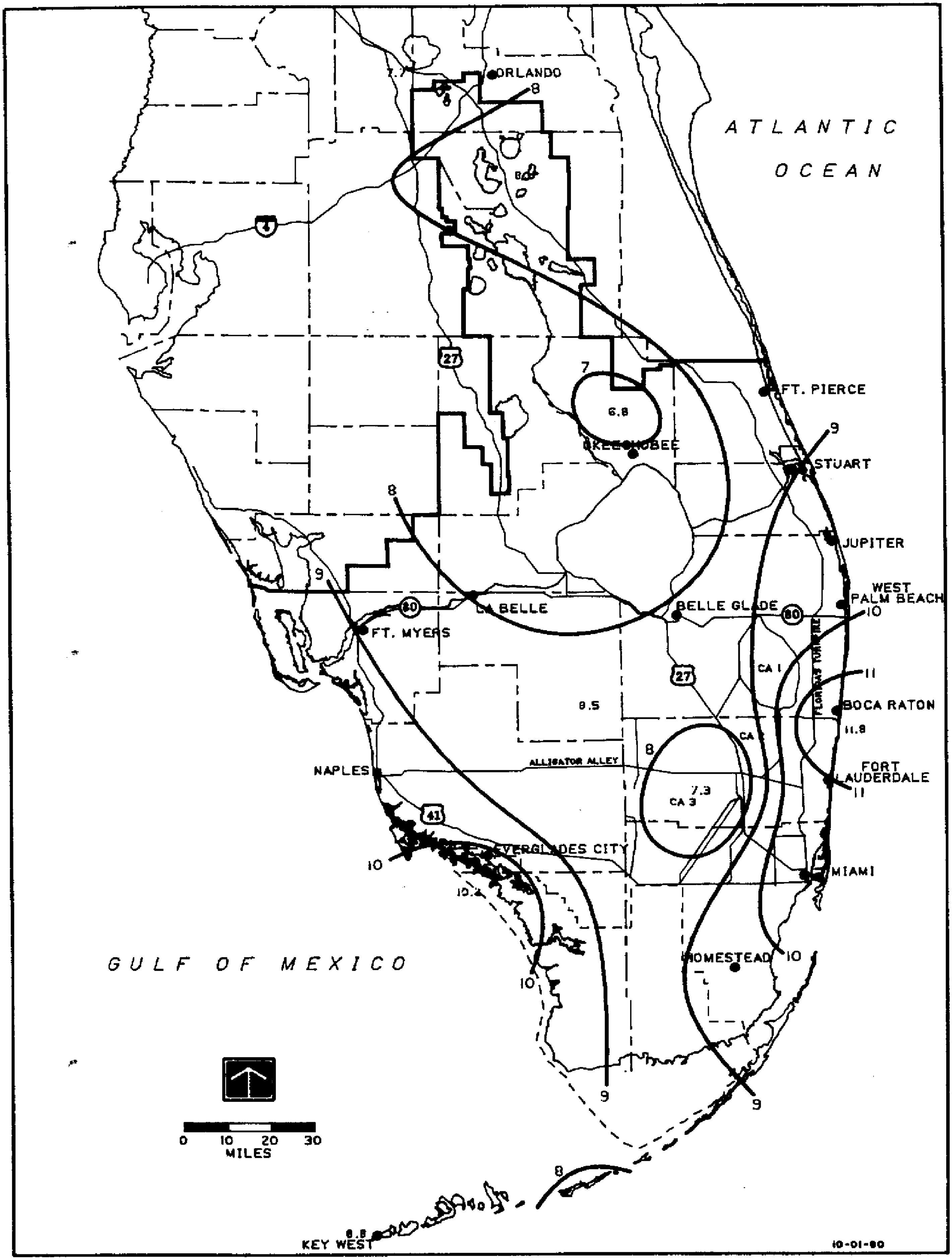

FIGURE 25. 5-DAY RAINFALL: 5 YEAR RETURN PERIOD

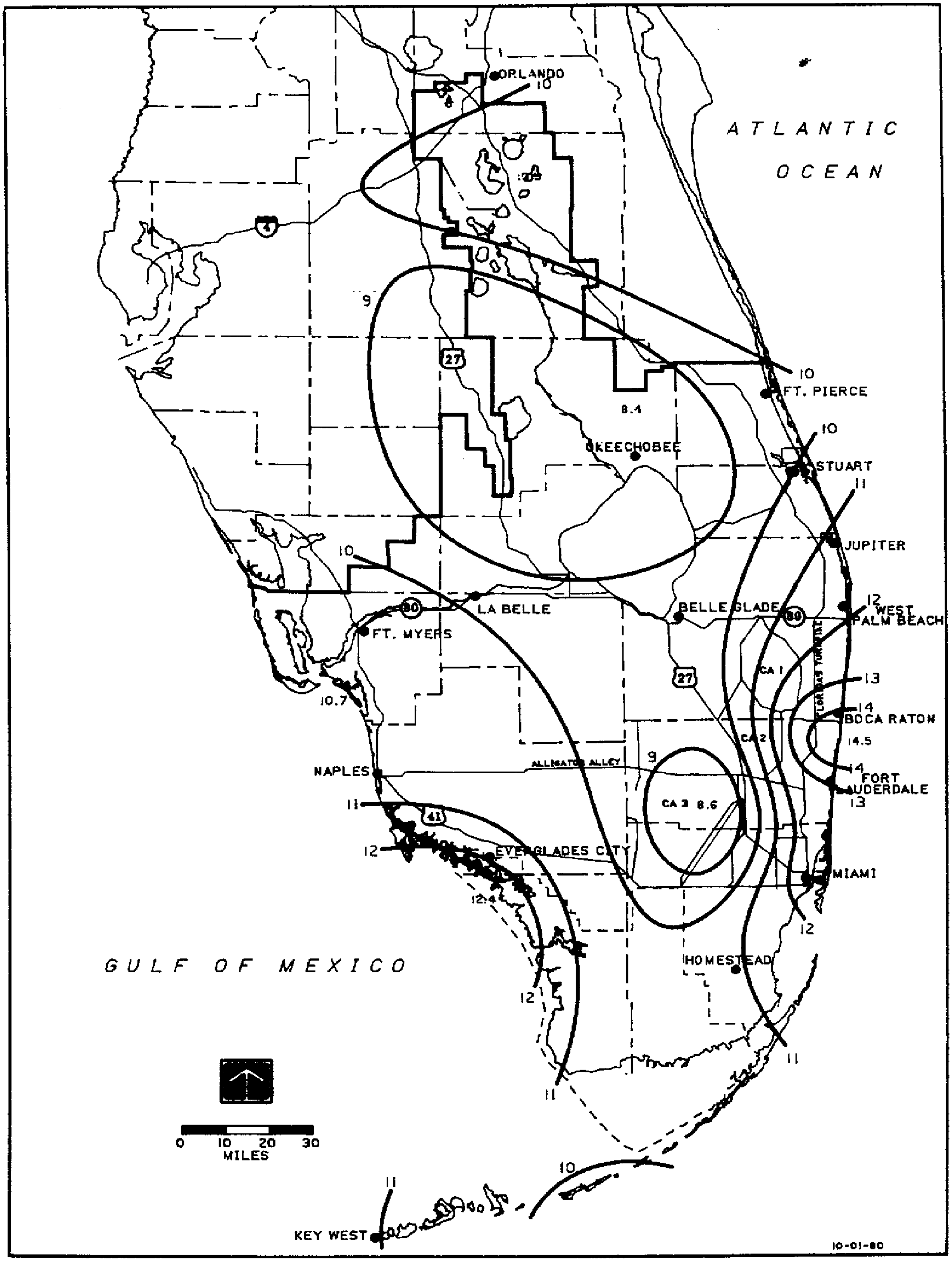

FIGURE 26. 5-DAY RAINFALL: 10 YEAR RETURN PERIOD

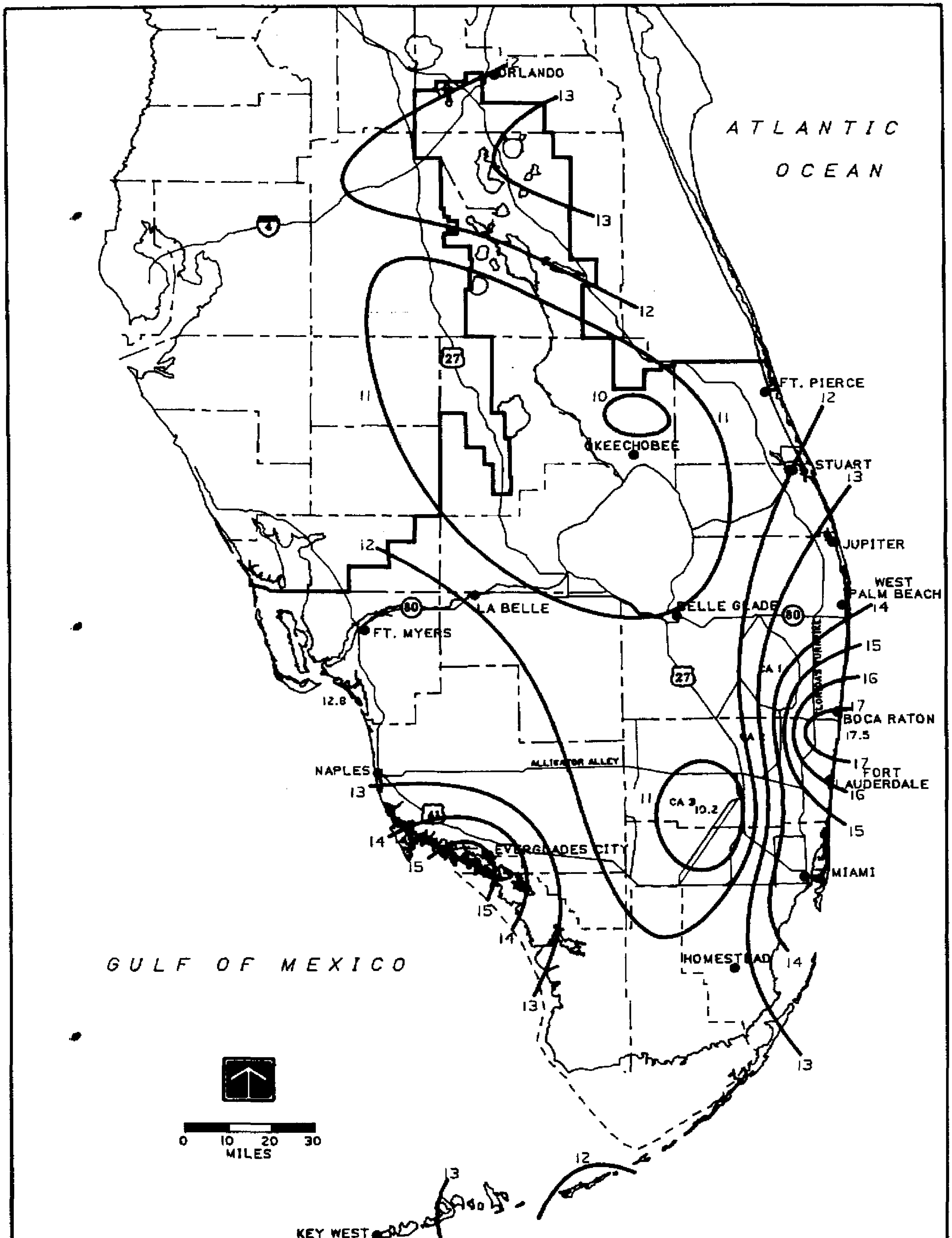

FIGURE 27. 5-DAY RAINFALL: 25 YEAR RETURN PERIOD

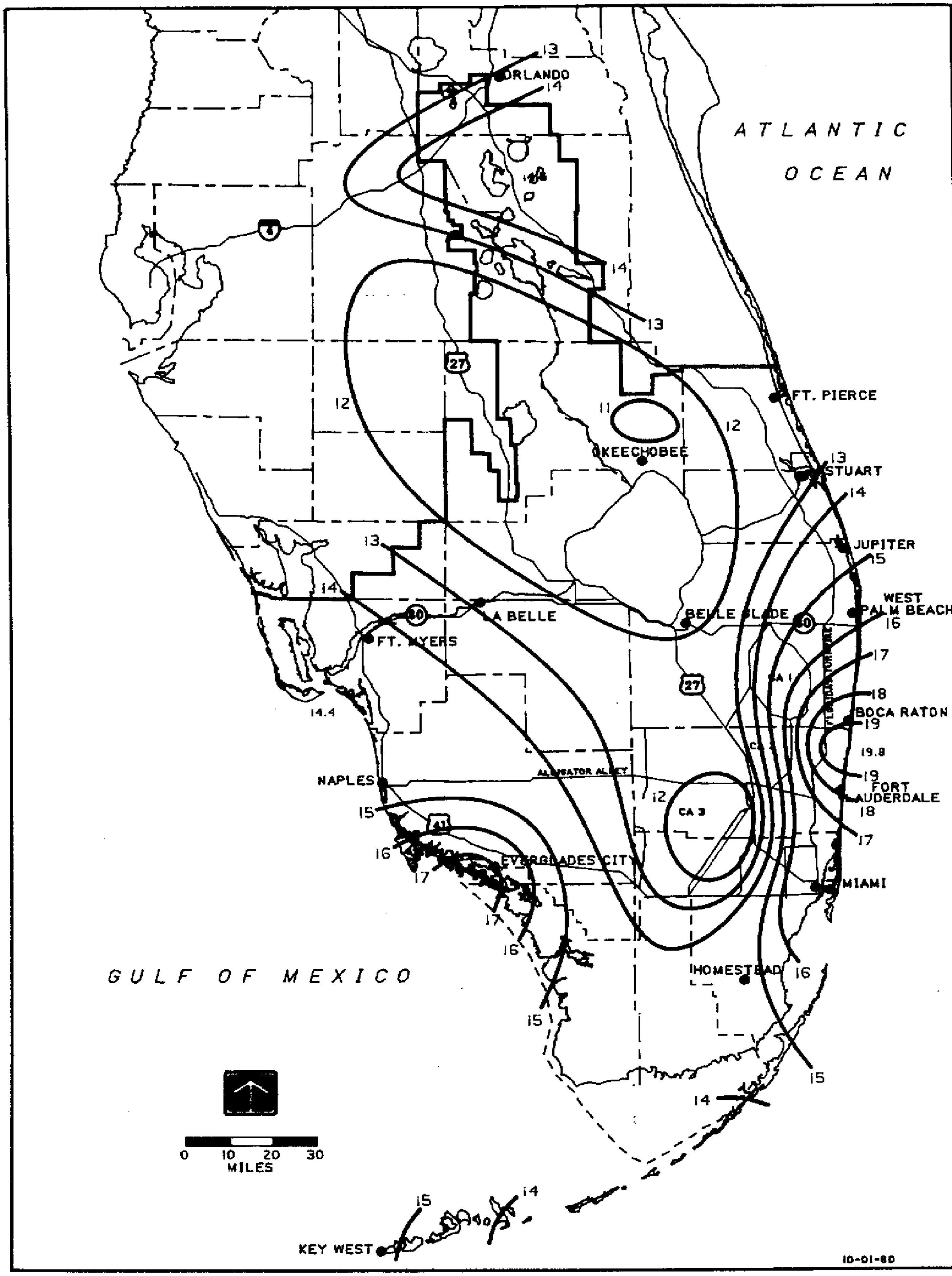

FIGURE 28. 5-DAY RAINFALL: 50 YEAR RETURN PERIOD

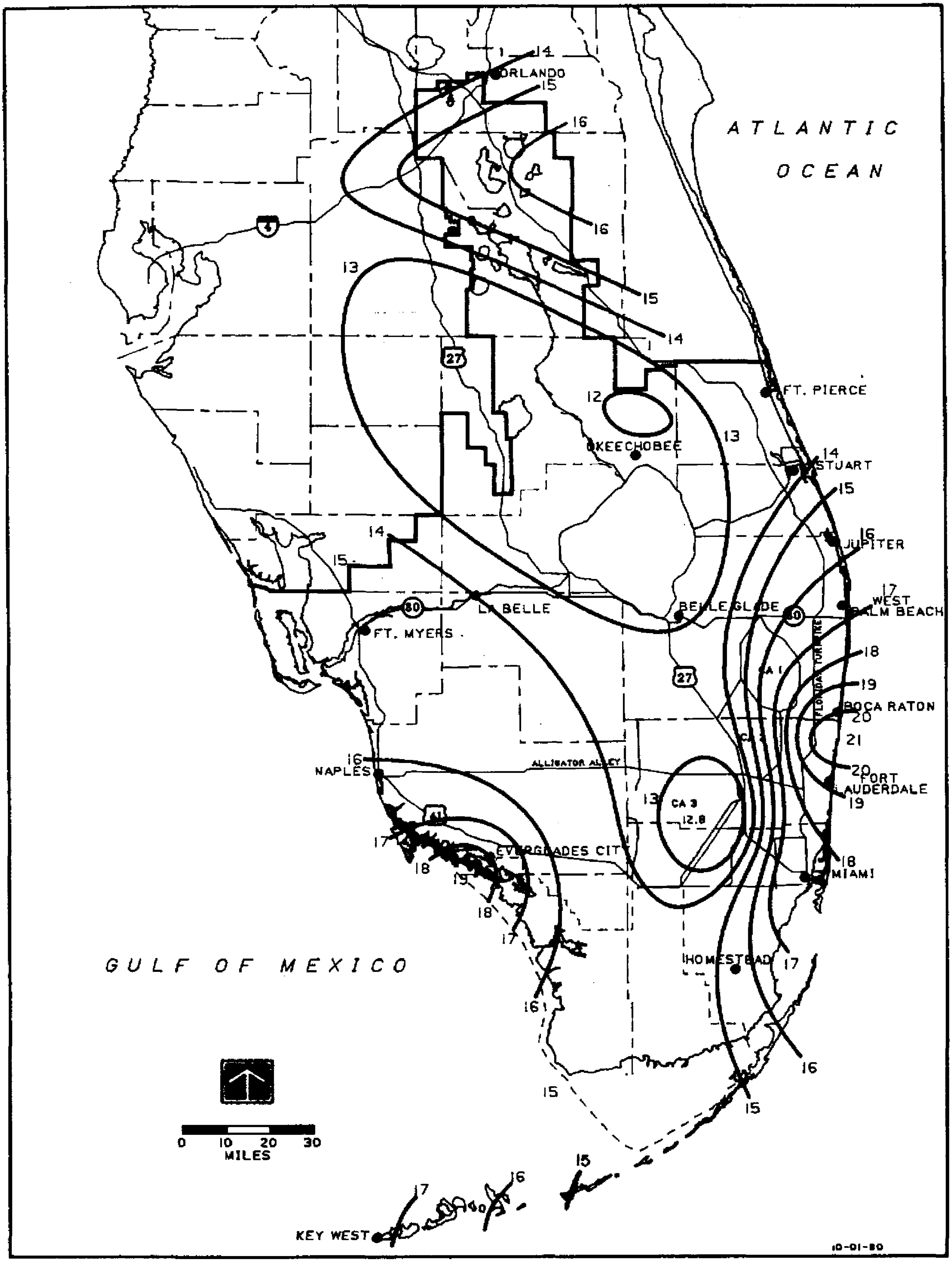

FIGURE 29. 5-DAY RAINFALL : 100 YEAR RETURN PERIOD

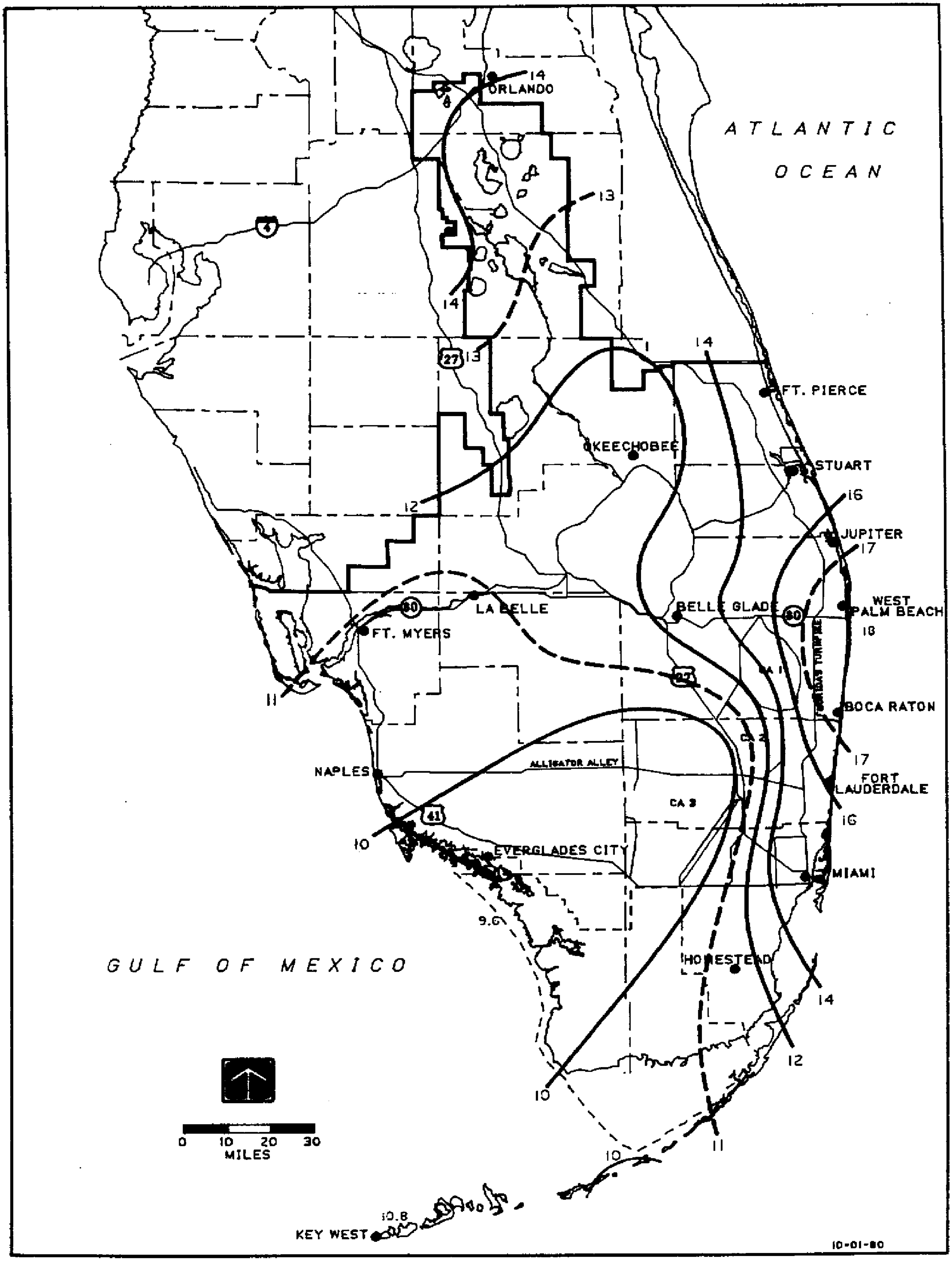

FIGURE 30. MEAN TOTAL DRY SEASON RAINFALL

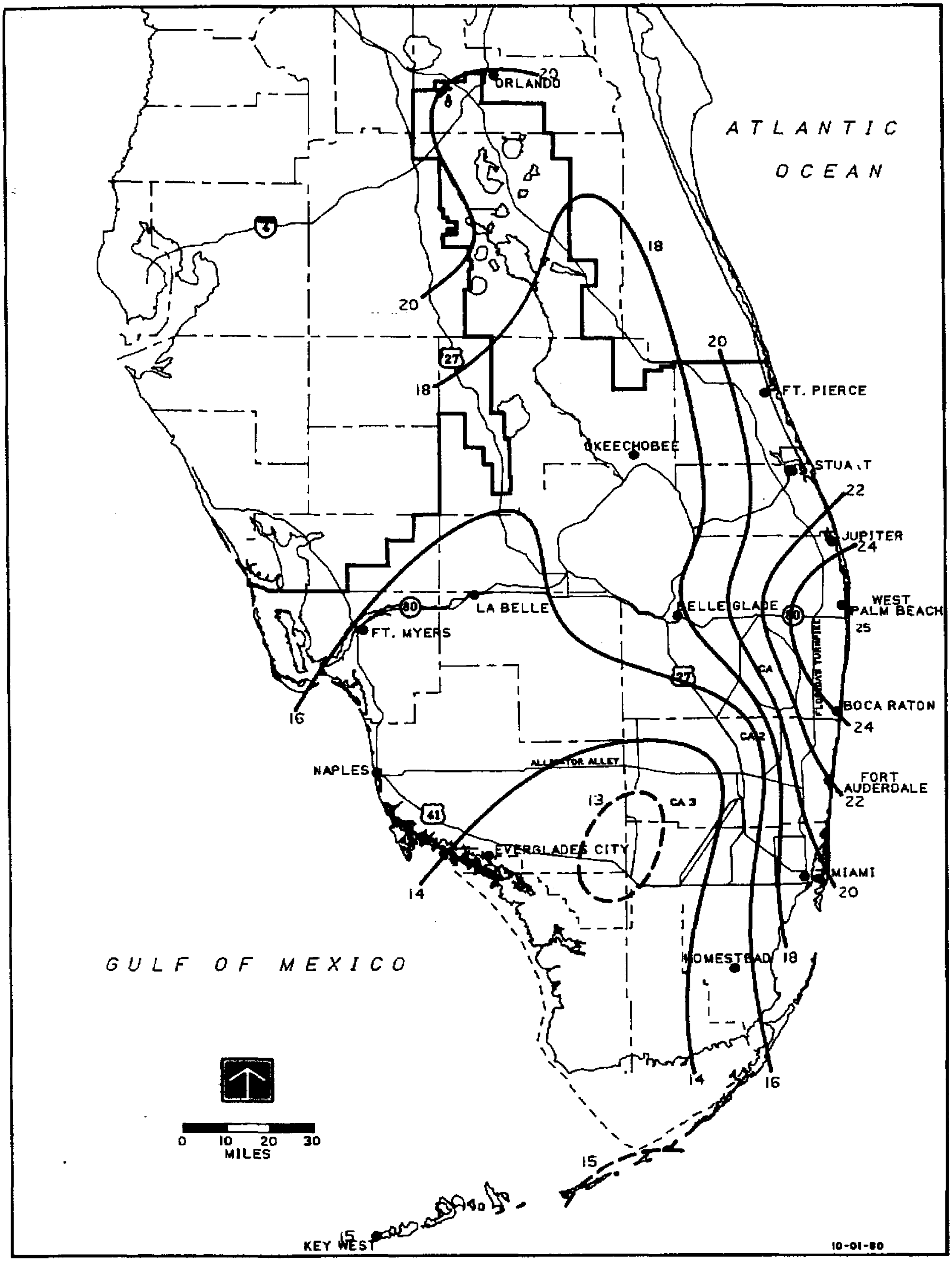

FIGURE 31. DRY SEASON RAINFALL: 5 YEAR RETURN PERIOD

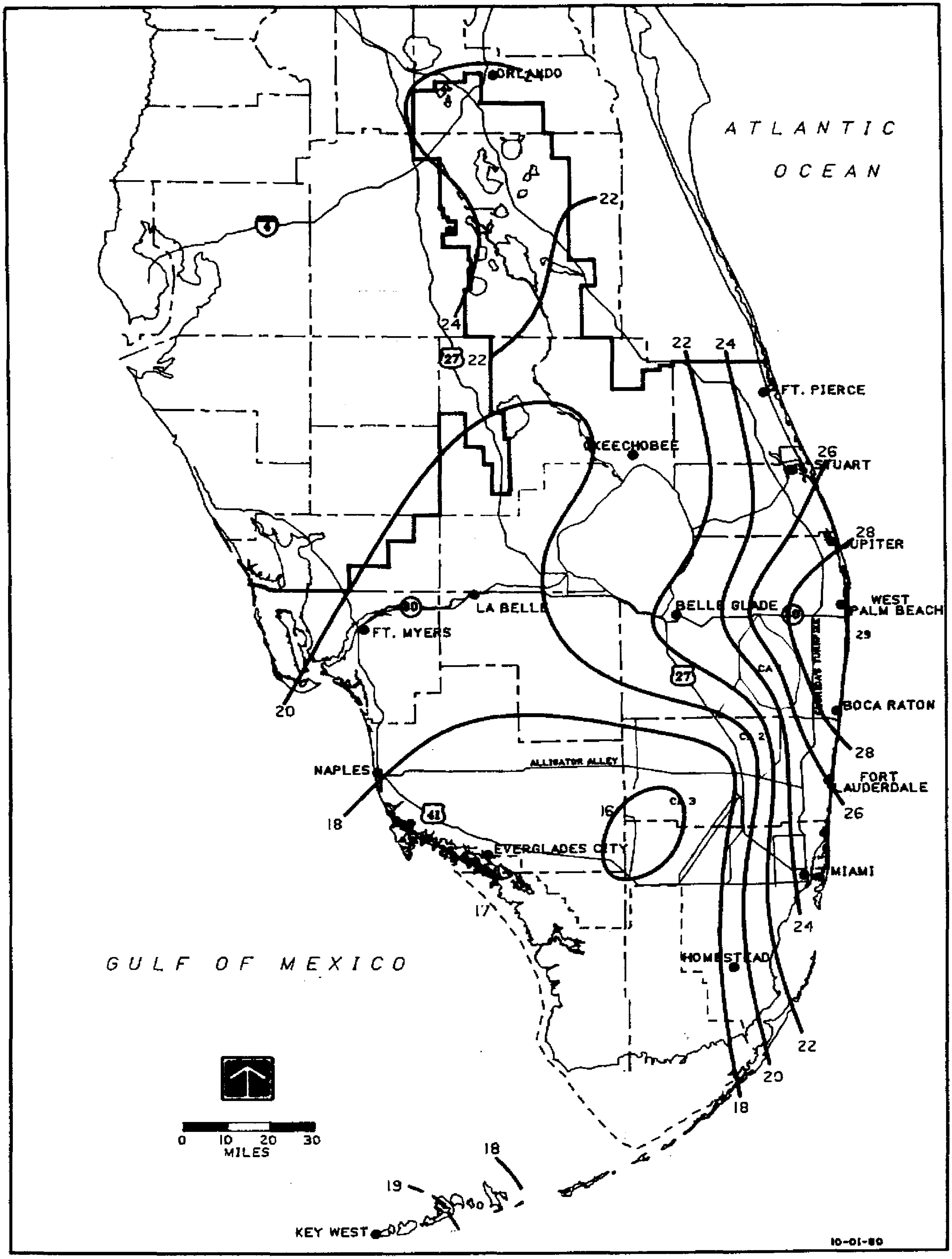

FIGURE 32. DRY SEASON RAINFALL: 10 YEAR RETURN PERIOD

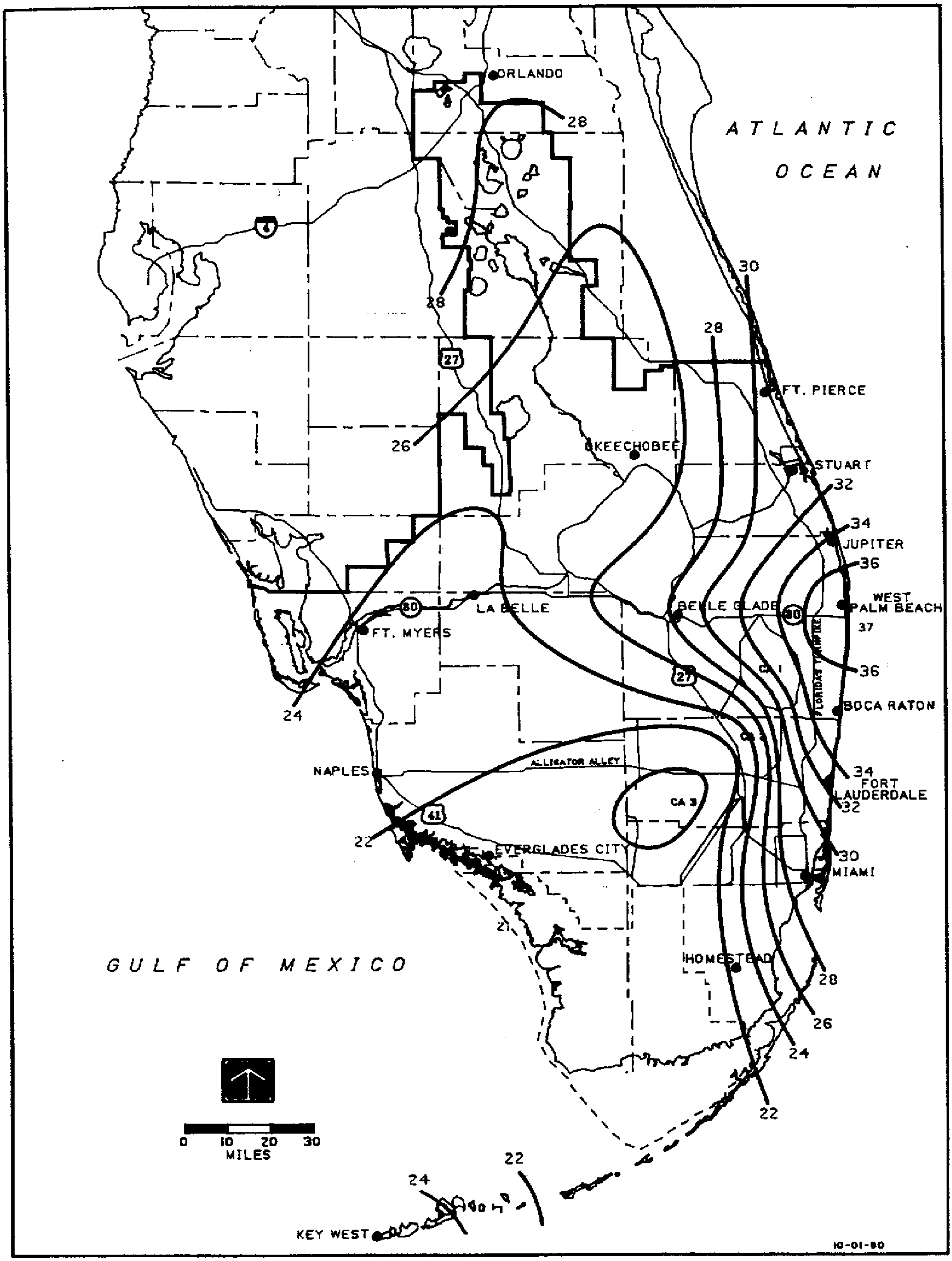

FIGURE 33. DRY SEASON RAINFALL: 25 YEAR RETURN PERIOD

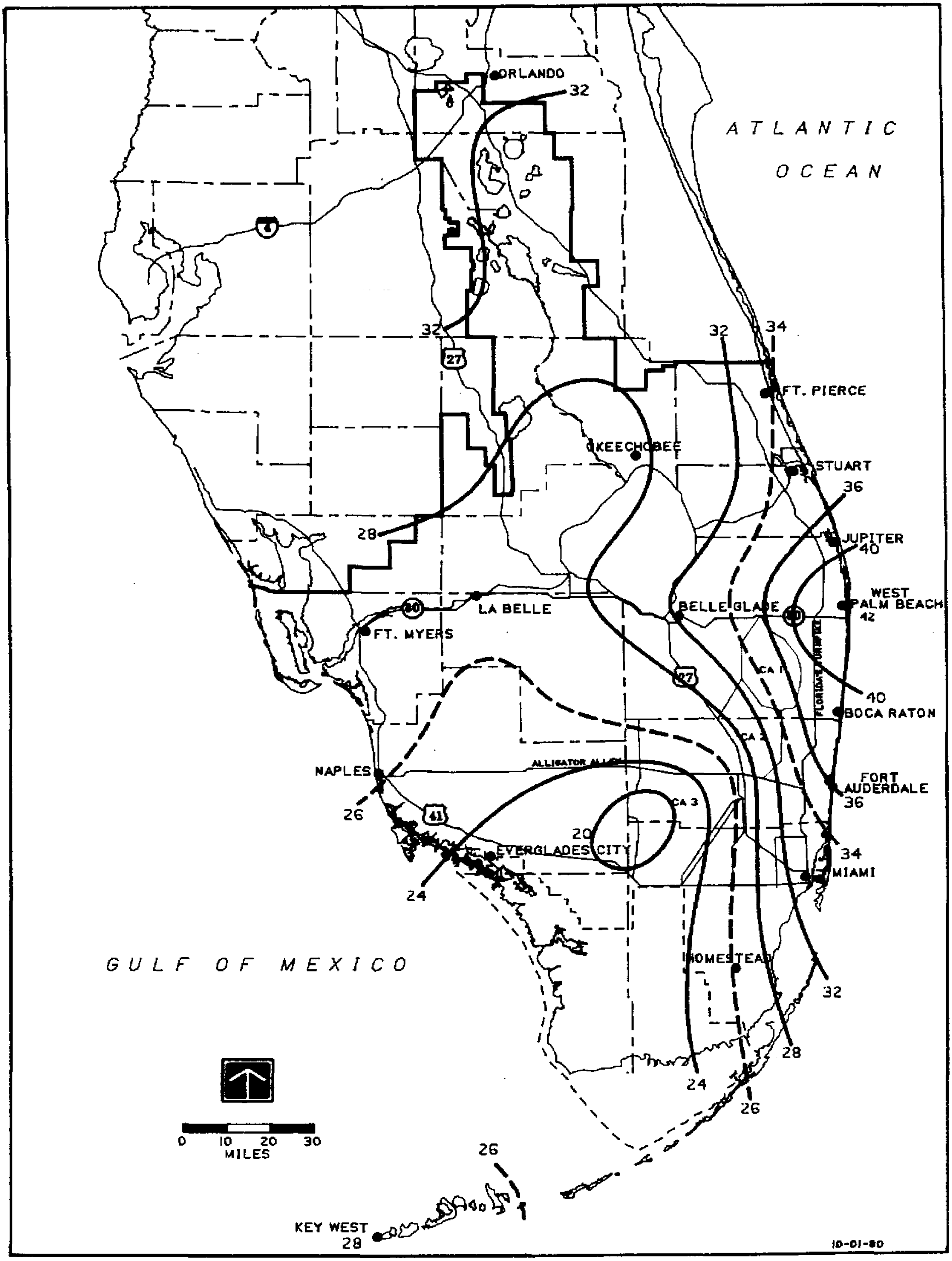

FIGURE 34. DRY SEASON RAINFALL: 50 YEAR RETURN PERIOD

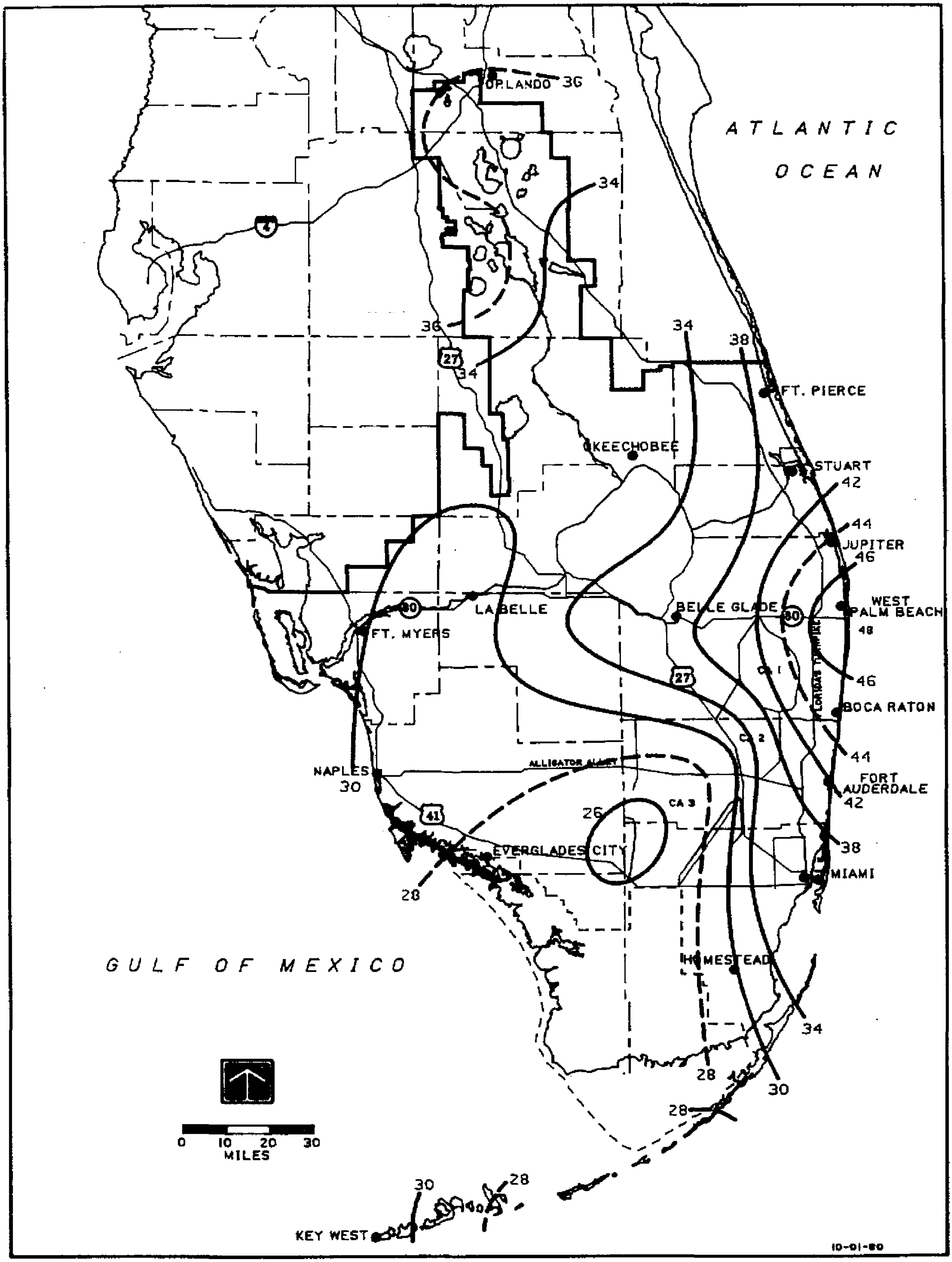

FIGURE 35. DRY SEASON RAINFALL: 100 YEAR RETURN PERIOD

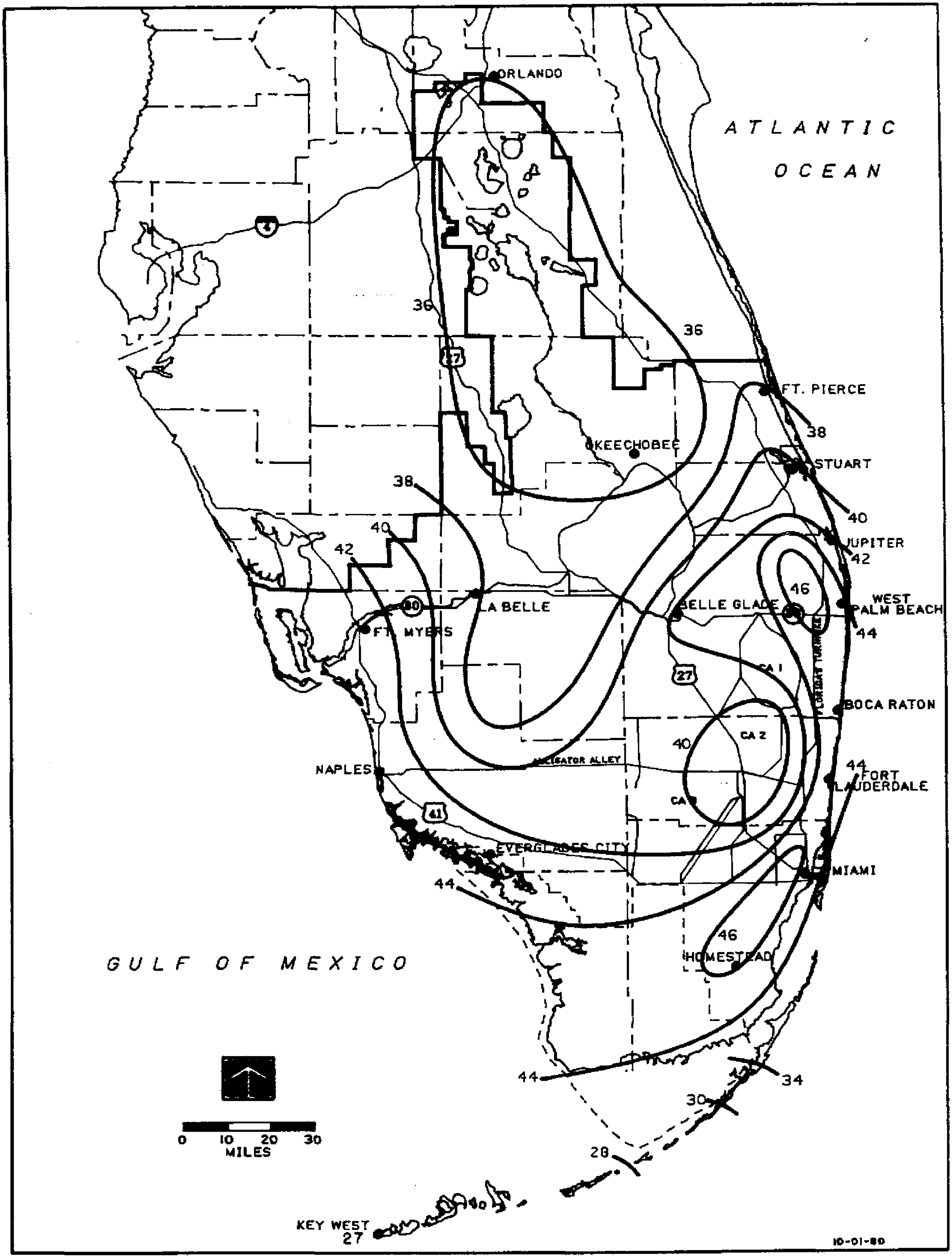

FIGURE 36. MEAN TOTAL WET SEASON RAINFALL

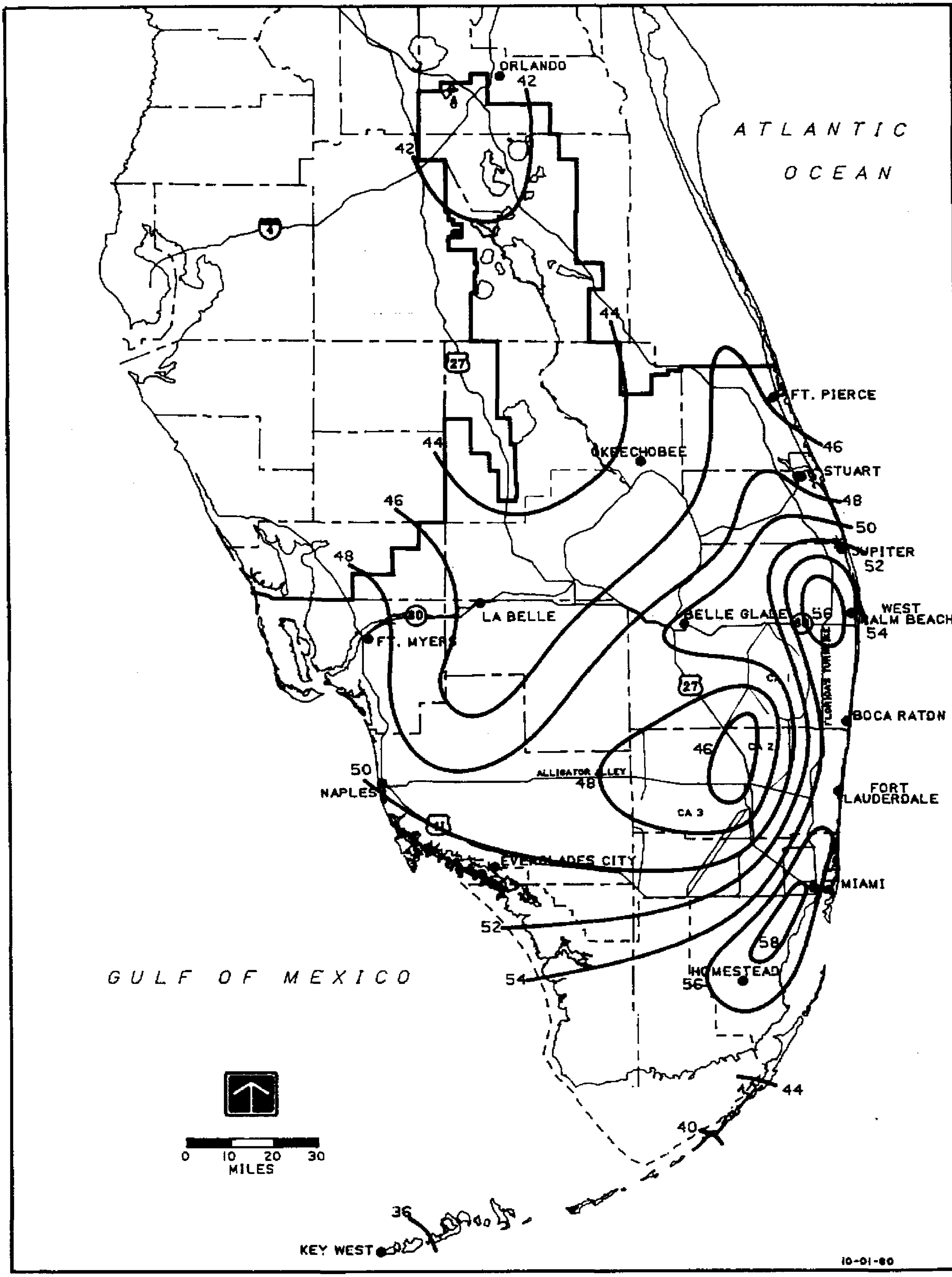

FIGURE 37. WET SEASON RAINFALL: 5 YEAR RETURN PERIOD

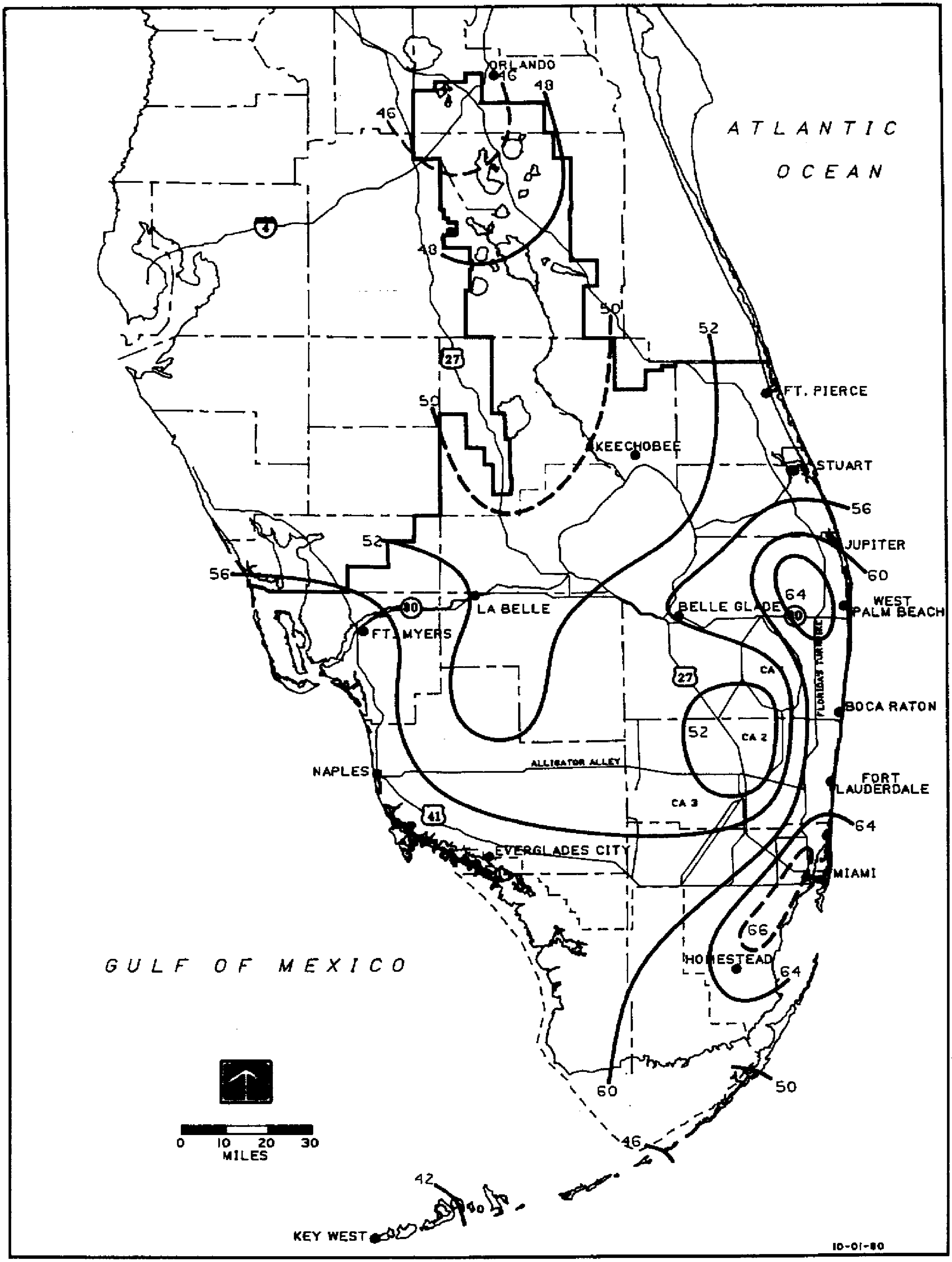

FIGURE 38. WET SEASON RAINFALL: 10 YEAR RETURN PERIOD

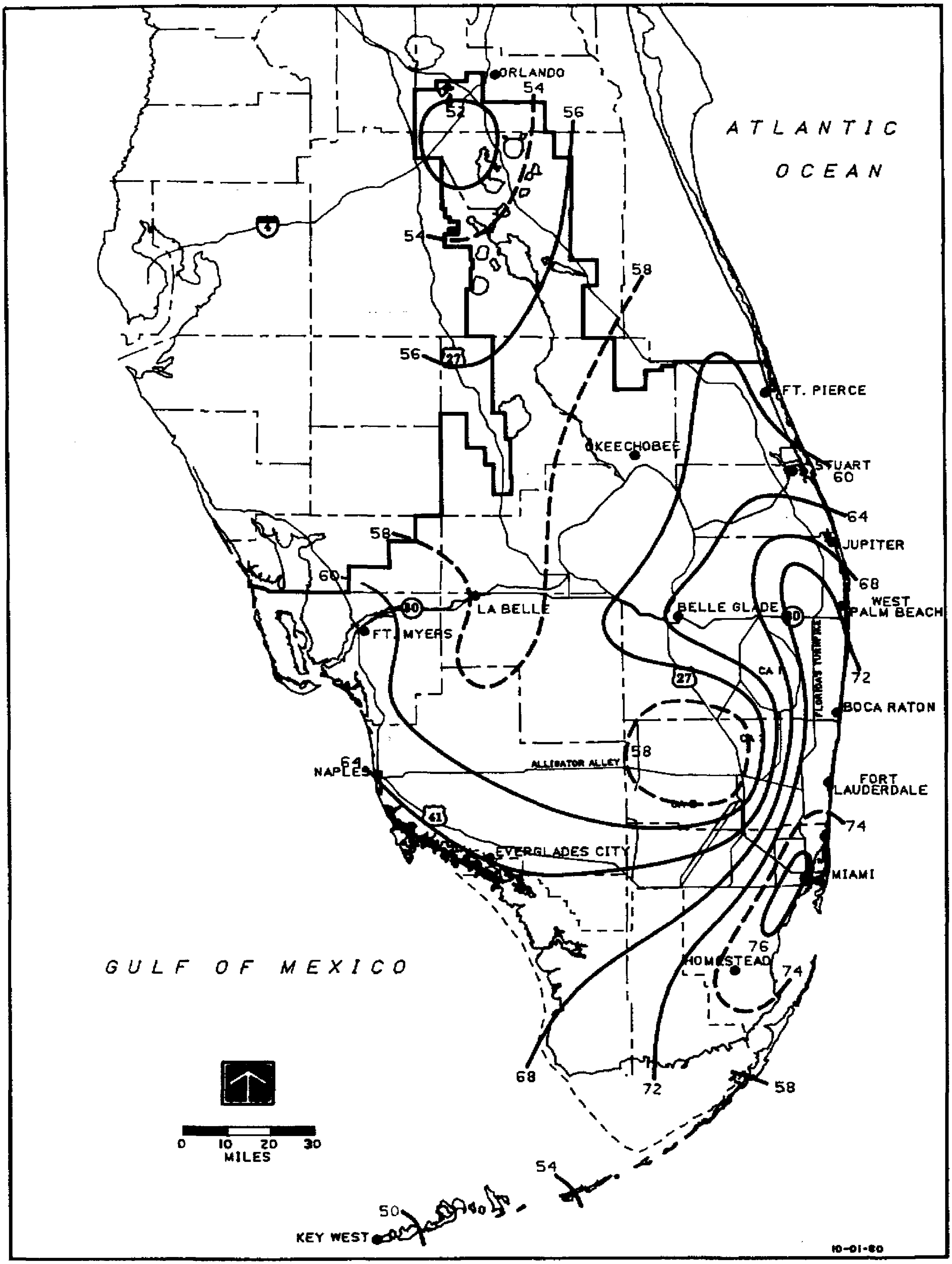

FIGURE 39. WET SEASON RAINFALL: 25 YEAR RETURN PERIOD

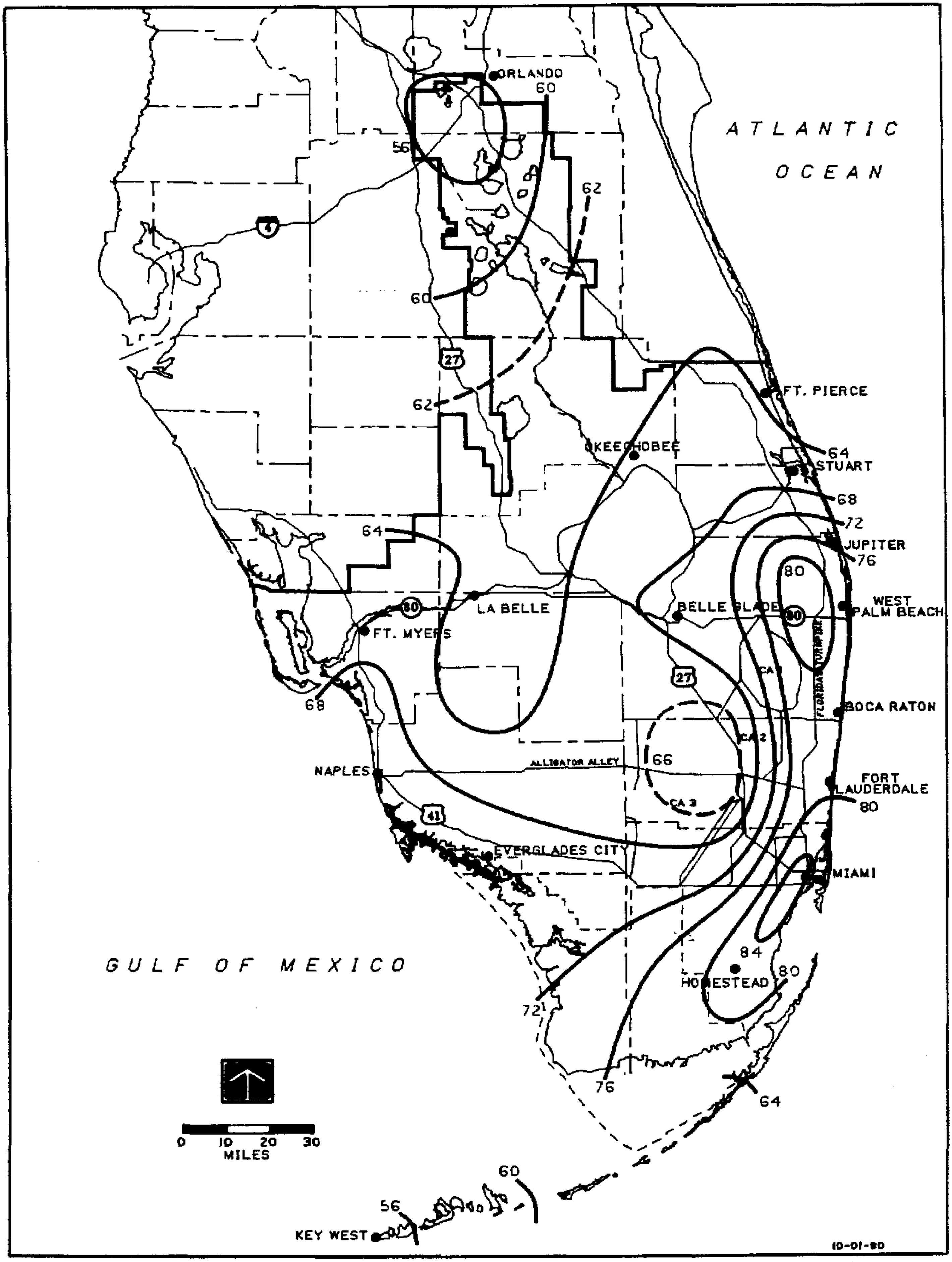

FIGURE 40. WET SEASON RAINFALL: 50 YEAR RETURN PERIOD

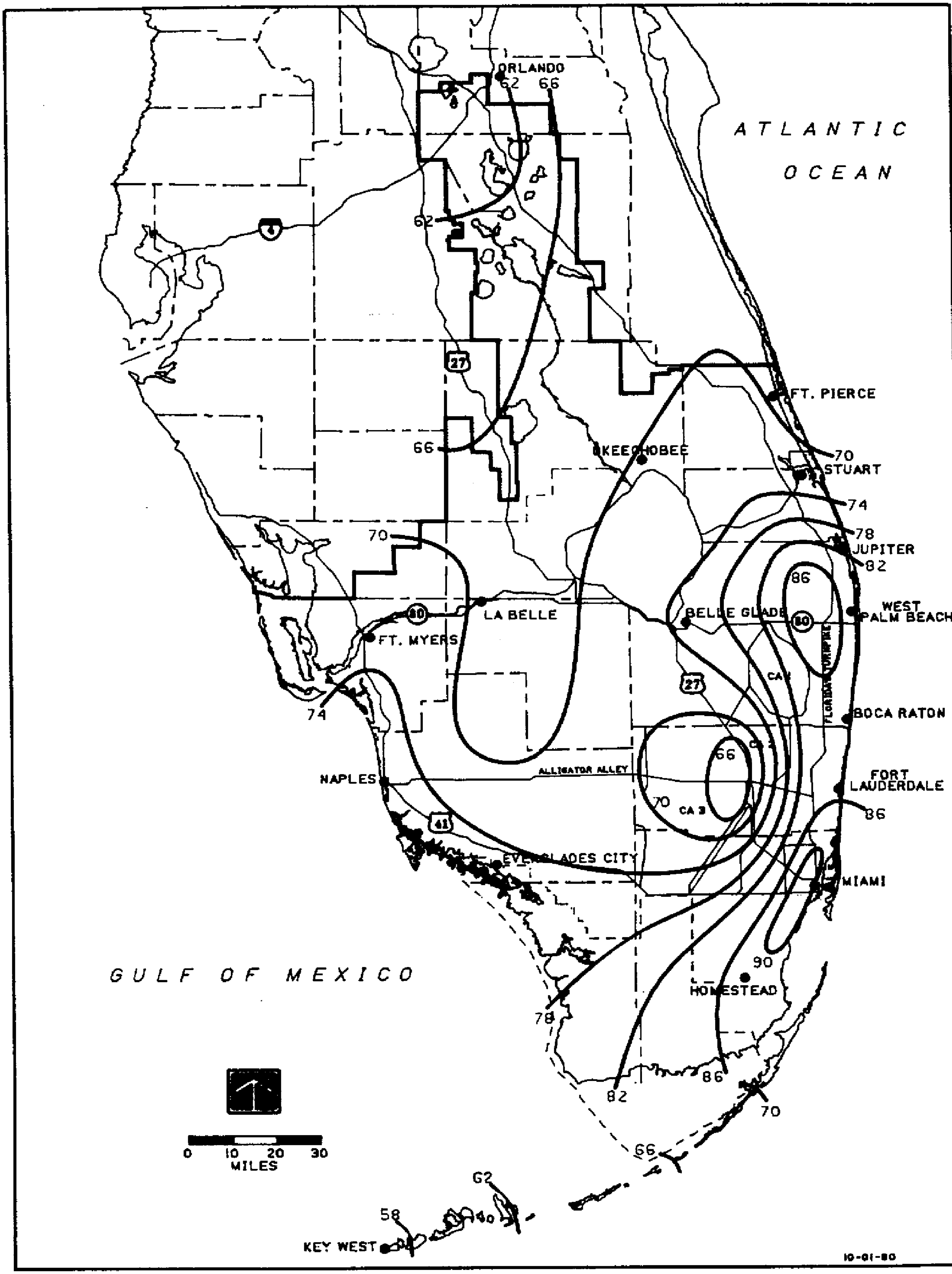

FIGURE 41. WET SEASON RAINFALL: 100 YEAR RETURN PERIOD

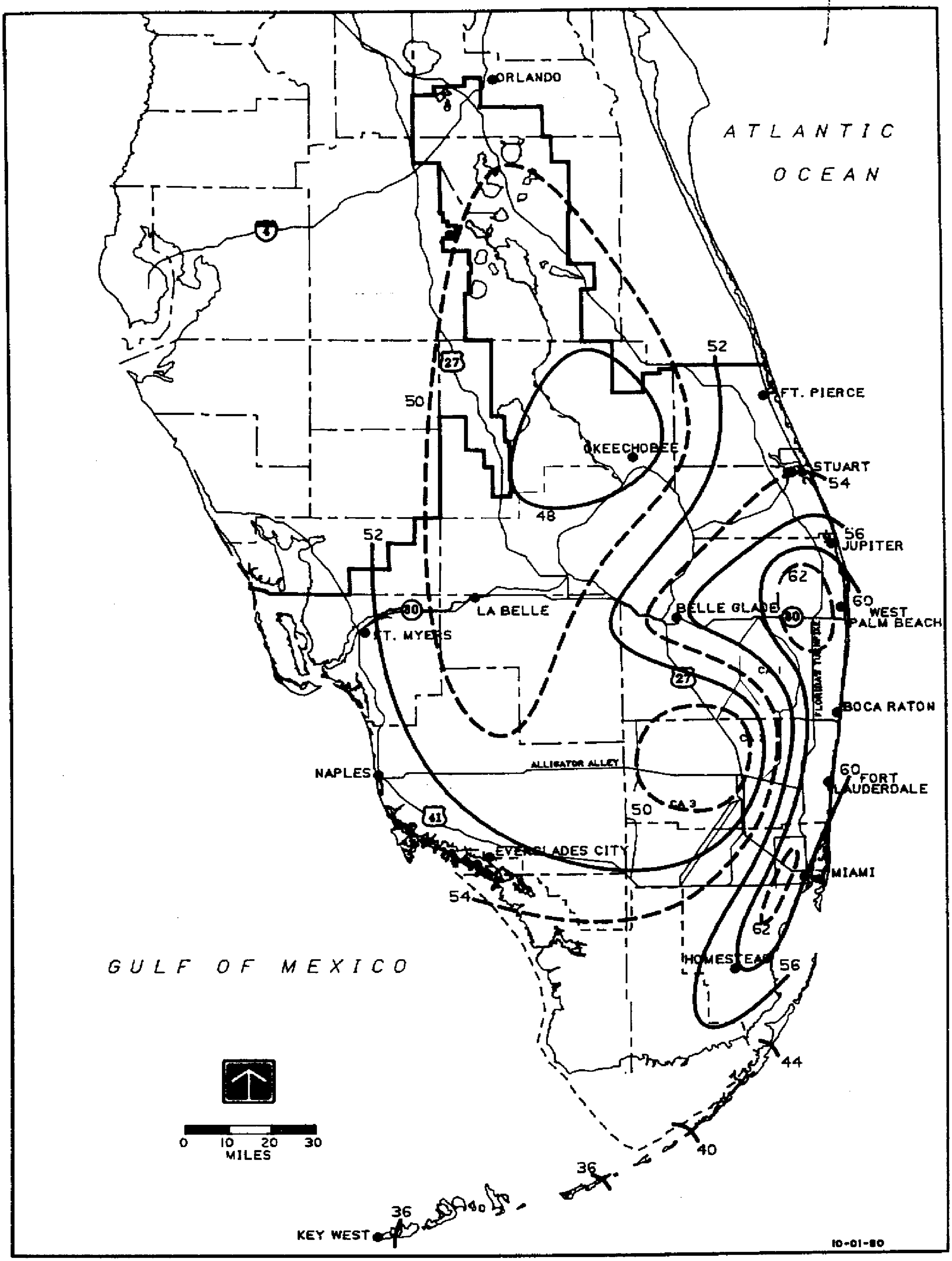

FIGURE 42. AVERAGE ANNUAL RAINFALL

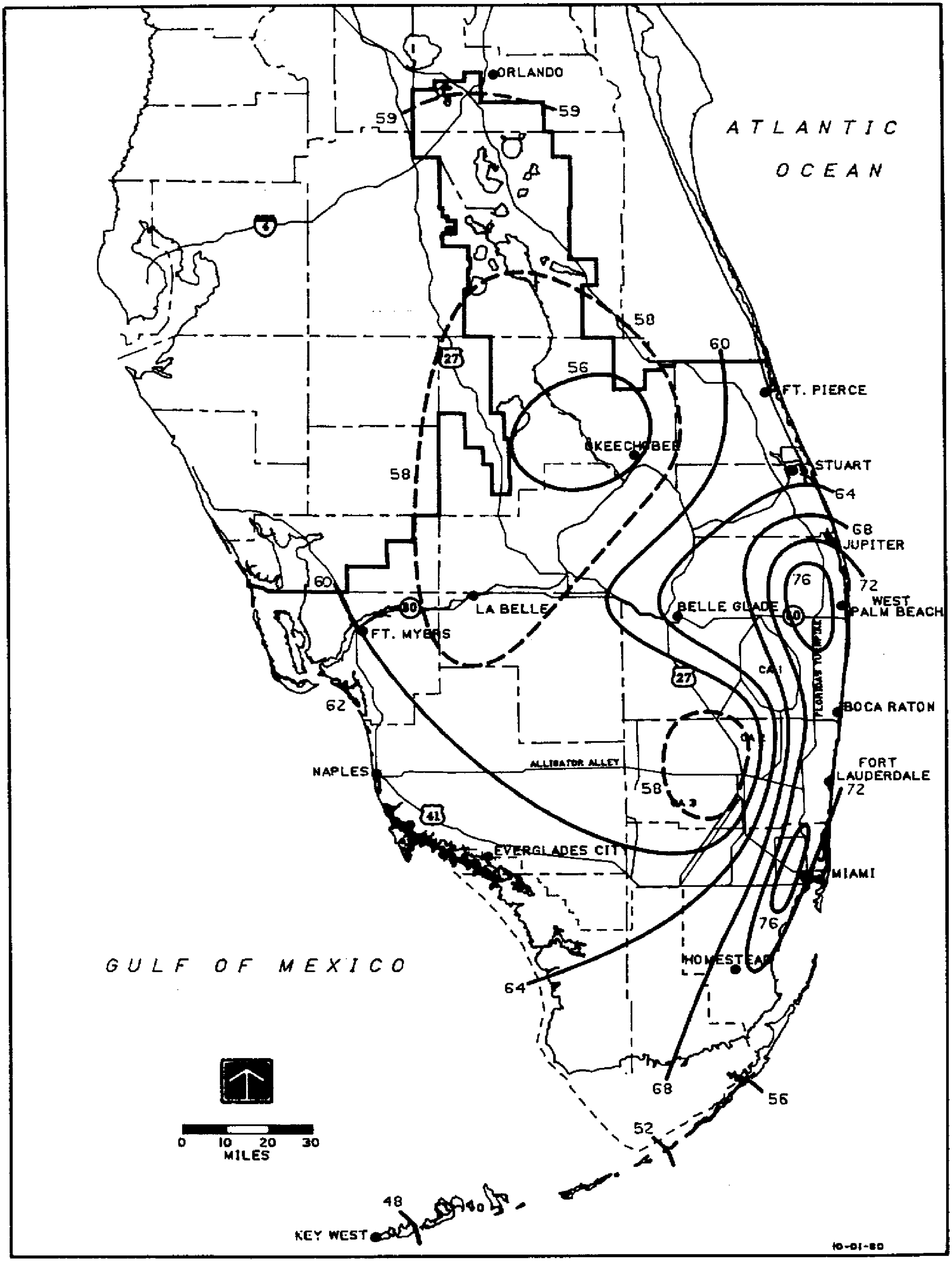

FIGURE 43. ANNUAL RAINFALL: 5 YEAR RETURN PERIOD

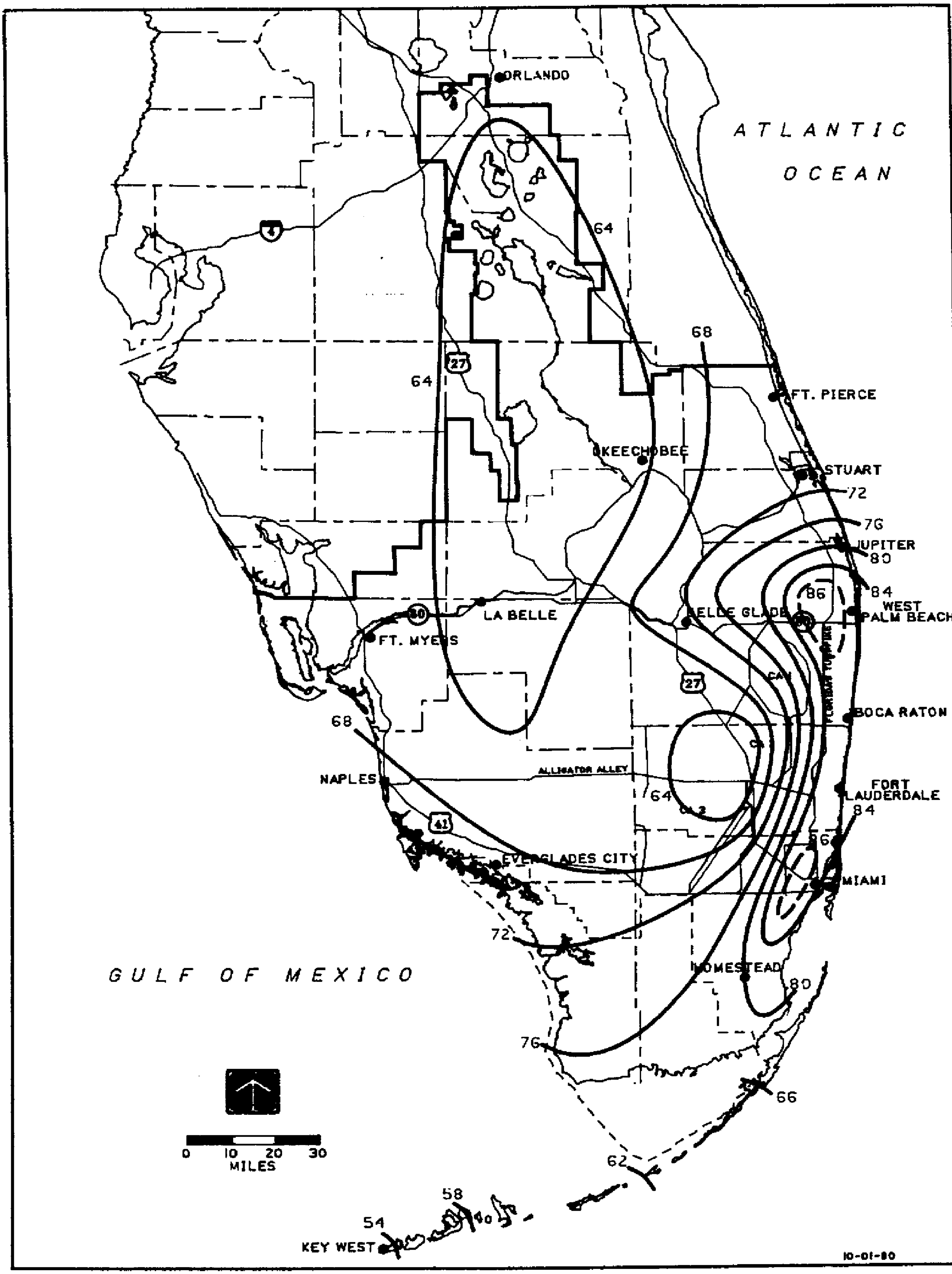

FIGURE 44. ANNUAL RAINFALL: 10 YEAR RETURN PERIOD

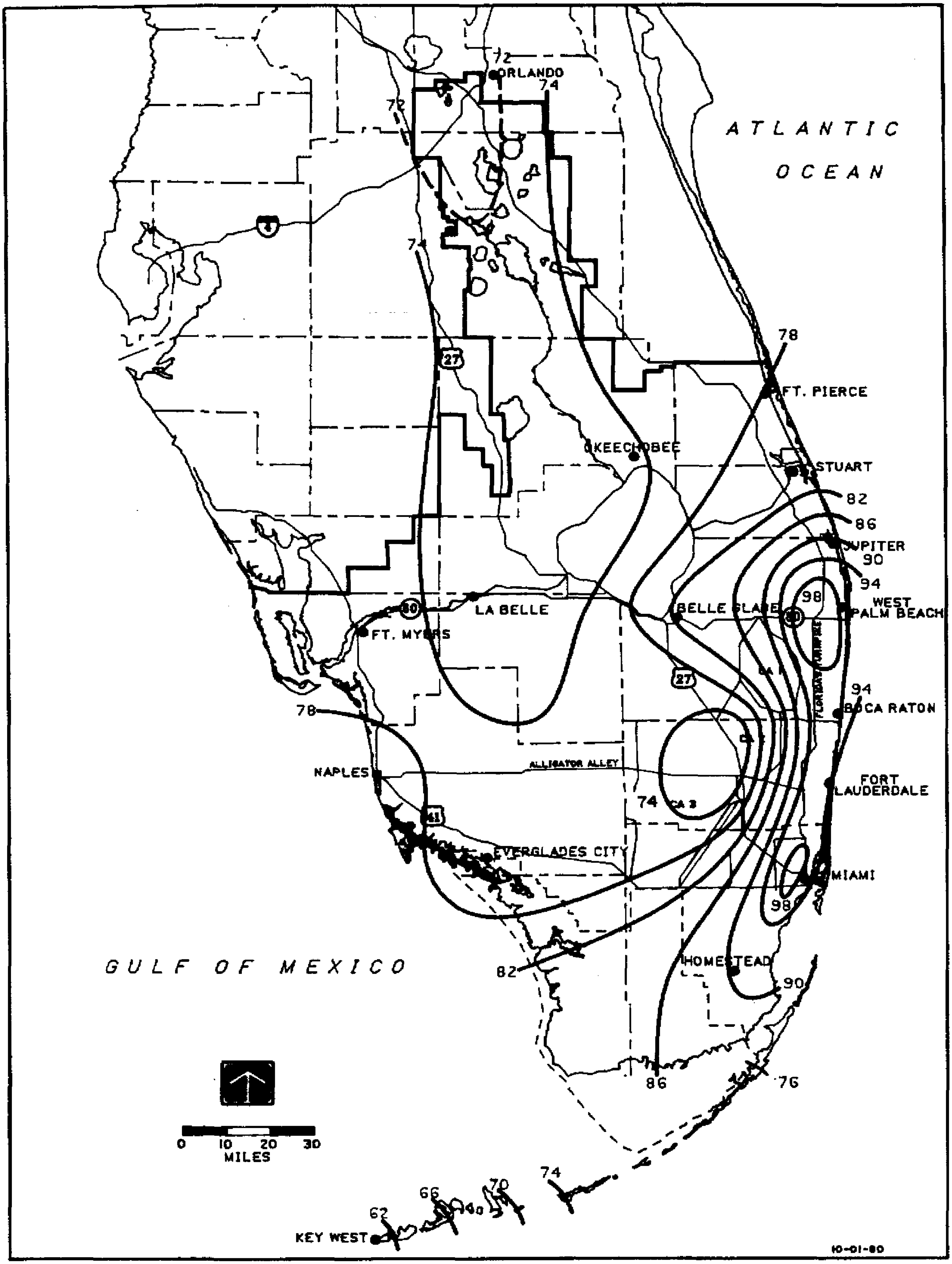

FIGURE 45. ANNUAL RAINFALL: 25 YEAR RETURN PERIOD

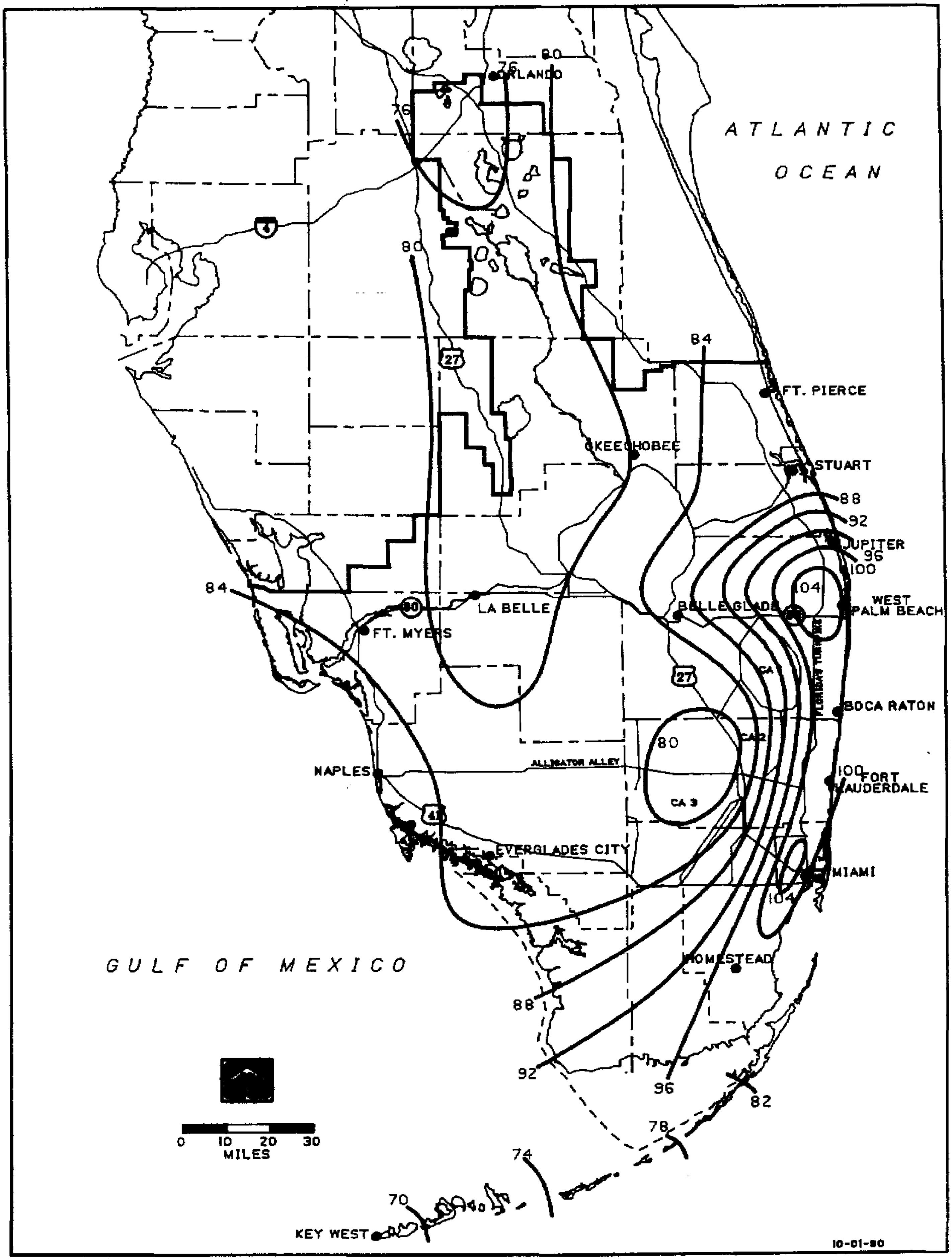

FIGURE 46. ANNUAL RAINFALL: 50 YEAR RETURN PERIOD

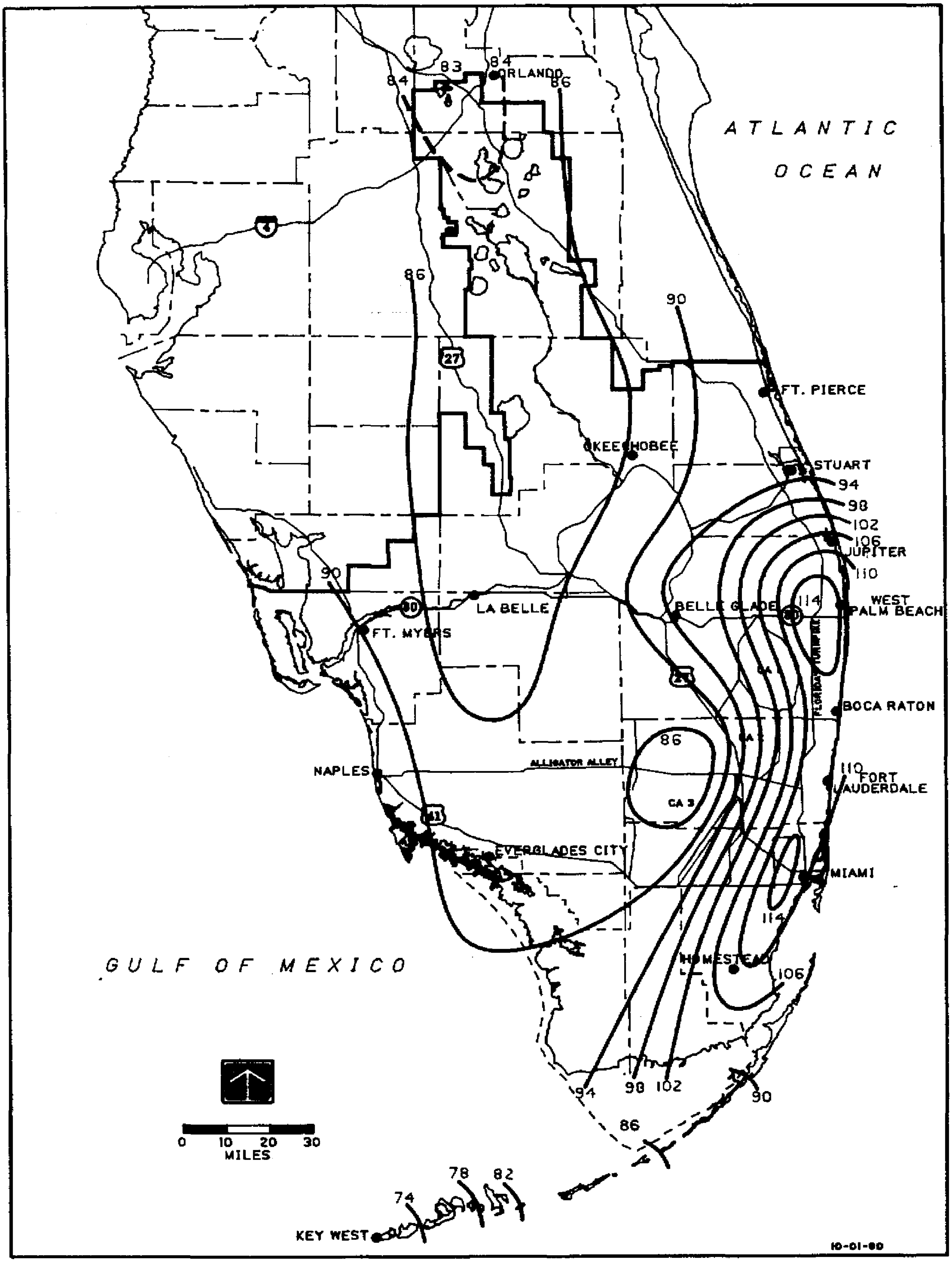

FIGURE 47. ANNUAL RAINFALL: 100 YEAR RETURN PERIOD

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9. Hershfield, D. M., and M. A. Kohler, "An Empirical Appraisal of the Gumbel Extreme Value Procedure", Journal of Geophysical Research, Vol. 65, No. 6, pp 1737-1746, June 1960.

10. Riebsame, W. E., Woodley, W. L., and Davis, F. E., "Radar Inference of Lake Okeechobee Rainfall for Use in Environmental Studies", Weatherwise, 27(5):pp 206-211, 1974.

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APPENDIX A: Rainfall Station Information

TABLE A-1

STATION	PERIOD		STATION NAME	SE	TP	RG
AR T1 H	1955	1976	TAYLOR CREEK - WILLIAMS	08	35	35
AR T2 H	1955	1976	TAYLOR CREEK - BASSETT 2	22	35	34
AR T3 H	1955	1976	TAYLOR CREEK - RAULERSON	31	35	35
AR T4 H	1955	1976	TAYLOR CREEK - JUDSON 4	21	35	35
AR T5 H	1955	1976	TAYLOR CREEK - DIXIE 5	18	36	35
AR T6 H	1955	1976	TAYLOR CREEK - MOBLEY 6	10	36	35
AR T7 H	1955	1976	TAYLOR CREEK - OPAL 7	19	36	36
CW0001	1944	1977	PLANT INTAKE - WPB WATER PLANT	21	43	42
DC0018	1953	1977	STONEBRAKER	17	52	42
WB0228	1907	1975	ARCADIA	25	37	24
WB0369	1902	1975	AVON PARK	22	33	28
WB0369H	1942	1972	AVON PARK	22	33	28
WB0390	1955	1975	BABSON PARK	28	30	28
WB0478	1901	1975	BARTOW	08	30	25
WB0611	1924	1980	BELLE GLADE EXPERIMENT STATION	05	44	37
WB0616H	1942	1972	BELLE GLADE HURICANE GATE 4	26	43	36
WB0845H	1949	1977	BOCA RATON	19	47	43
WB1271H	1940	1972	CANAL POINT AT HURRICANE GATE 5	33	41	37
WB1276	1953	1979	CANAL POINT USDA	34	41	37
WB1310	1939	1967	CAPTIVA	29	45	22
WB1641	1901	1975	CLERMONT	14	23	25
WB1654	1951	1980	CLEWISTON (CORPS #2)	11	43	34
WB1654H	1940	1972	CLEWISTON (CORPS)	11	43	34
WB1716	1923	1958	COCONUT GROVE 7S	24	55	40
WB2114	1942	1973	DANIA 4 WNW	30	50	42
WB2288	1925	1975	DESOTO CITY 8SW	03	36	28
WB2827	1901	1958	EUSTIS 2S	14	19	26
WB2850	1924	1975	EVERGLADES	14	53	29
WB2923H	1941	1972	FELDA -RECORDING GUAGE	28	45	29
WB2936	1914	1975	FELLSMERE 4W	23	31	37
WB3137	1956	1975	FORT DRUM 5NW	29	33	35
WB3163	1914	1977	FORT LAUDERDALE	17	50	42
WB3171	1953	1977	LAUDERDALE EXP STA	22	50	41
WB3186	1909	1975	FT MEYERS	01	45	24
WB3207	1901	1975	FORT PIERCE	08	35	40
WB3840	1942	1975	HART LAKE	21	24	31
WB3909	1941	1977	HIALEAH	18	53	41
WB3986	1943	1975	HILLSBOROUGH RIVER STATE PARK	08	27	21
WB4091	1914	1977	HOMESTEAD EXPERIMENT STATION	35	56	38
WB4198	1900	1959	HYPOLUXO	10	45	43
WB4332	1916	1975	ISLEWORTH	17	23	28
WB4518	1942	1974	KENDALL 2E	06	55	41
WB4570H	1941	1975	KEY WEST WSO AIRPORT	26	67	25
WB4575	1901	1973	KEY WEST (RECORDER & STD CAN)	29	67	25
WB4620	1901	1958	KISSIMMEE	22	25	29
WB4625H	1942	1972	KISSIMMEE 2	22	25	29
WB4662	1929	1975	LA BELLE	04	43	29
WB4707	1949	1975	LAKE ALFRED - LAKE ALFRED	28	27	26
WB4712	1923	1948	LAKE ALFRED	16	27	26
WB4771	1941	1964	LAKE HIAWASSEE	02	23	28

TABLE A-1 (continued)

STATION	PERIOD		STATION NAME	SE	TP	RG
WB4797	1915	1975	LAKELAND WB CITY	36	28	23
WB4845	1933	1968	LAKE PLACID 2SW	02	37	29
WB4866	1943	1968	LAKE TRAFFORD	35	46	28
WB5035H	1942	1972	LIGNUMVITAE KEY	06	64	37
WB5182	1941	1977	LOXAHATCHEE	32	43	41
WB5351	1950	1975	MARATHON SHORES	01	66	32
WB5612	1937	1975	MELBOURNE	11	28	37
WB5658	1927	1977	MIAMI BEACH	33	53	42
WB5663H	1939	1977	MIAMI WB AIRPORT	30	53	41
WB5668H	1901	1975	MIAMI WB CITY	19	54	41
WB5678	1958	1977	MIAMI 12S S.W.	14	55	40
WB5895	1918	1975	MOORE HAVEN LOCK 1	12	42	32
WB5973	1935	1975	MOUNTIAN LAKE	27	29	27
WB6078	1942	1975	NAPLES	19	50	25
WB6251	1942	1972	NITTAW 1S	26	29	33
WB6318H	1941	1966	NORTH NEW RIVER CANAL 1	16	45	36
WB6323H	1941	1972	NORTH NEW RIVER CANAL 2	27	47	38
WB6480	1948	1974	OKEECHOBEE 9W	24	37	33
WB6485H	1942	1971	OKEECHOBEE HURICANE GATE 6	35	37	35
WB6638H	1942	1972	ORLANDO WB AIRPORT	30	22	30
WB6657H	1940	1972	ORTONA LOCK 2	26	42	30
WB6988H	1941	1975	PENNSUCO 5NW	10	52	39
WB7205	1901	1975	PLANT CITY	29	28	22
WB7254	1941	1977	POMPANO BEACH	34	48	42
WB7293H	1940	1972	PORT MAYACA ST.LUCIE CANAL	22	40	37
WB7395	1914	1965	PUNTA GORDA	06	41	22
WB7760	1949	1977	ROYAL PALM RANGER	14	58	37
WB7859H	1940	1972	ST. LUCIE NEW LOCK 1	13	39	40
WB7977	1914	1956	SANFORD	30	19	31
WB7982	1956	1975	SANFORD EXPERIMENT STATION	30	19	31
WB8396	1954	1974	SOUTH MIAMI 5W	32	54	40
WB8620	1936	1979	STUART 1N	32	37	41
WB8775H	1941	1966	TAMIAMI CANAL AT DADE-BROW. LEV.	04	54	39
WB8780	1941	1979	TAMIAMI CANAL @ 40 MILE BEND	16	54	35
WB8841	1936	1975	TAVERNIER	26	62	38
WB8942	1901	1975	TITUSVILLE 2W	33	21	35
WB9184H	1928	1978	VENUS 4SSW	17	39	30
WB9214	1943	1965	VERO BEACH FAA AIRPORT	34	32	39
WB9401	1933	1975	WAUCHULA 2N	33	33	25
WB9520	1929	1960	WEST PALM BEACH	22	43	43
WB9525	1939	1977	WEST PALM BEACH AIRPORT	31	43	43
WB9707	1941	1975	WINTERHAVEN	06	29	26
WM 39	1960	1980	SCOTTI GROVES	04	36	39
WM 47H	1951	1980	S-193 (HGS-6) - (CORPS)	35	37	35
WM 49H	1957	1979	ST LUCIE LOCK (CORPS)	13	39	40
WM 51H	1951	1980	PORT MAYACA LOCK (CORPS)	22	40	37
WM 54	1957	1980	PRATT AND WHITNEY	24	41	40
WM 55H	1951	1980	HGS-5 (CORPS)	33	41	37
WM 56H	1951	1980	HGS-1 (CORPS)	12	42	32
WM 57	1957	1980	PELICAN LAKE DRAINAGE DI#2	12	42	37

TABLE A-1 (continued)

STATION		PERIOD		STATION NAME	SE	TP	RG
WM	60	1929	1973	BENBOW - US SUGAR	20	42	33
WM	61	1929	1973	LIBERTY POINT - US SUGAR	24	42	33
WM	62	1951	1980	HGS-2 STANDARD CAN	11	43	34
WM	65	1929	1973	PELICAN 34 - US SUGAR	34	42	37
WM	67	1941	1973	RUNYON - US SUGAR	18	43	37
WM	68	1938	1980	RITTA - US SUGAR	28	43	35
WM	70H	1951	1980	HGS-4	26	43	36
WM	72	1940	1972	SOUTH SHORE - US SUGAR	09	44	36
WM	73	1929	1973	SOUTH BAY - US SUGAR	13	44	36
WM	76H	1956	1980	S-5A RECORDER	32	43	40
WM	78	1955	1980	GREENACRES	23	44	42
WM	79	1957	1980	MANTEE PLANTATION @ 6 MI BEND	18	44	38
WM	81	1955	1980	LAKE WORTH ROAD AND E1	31	44	42
WM	84	1955	1980	BOYNTON ROAD AND MILITARY	23	45	42
WM	85	1955	1980	SR804 NEAR TURNPIKE	20	45	42
WM	86	1957	1980	SHAWANO PUMP 6	11	45	38
WM	88	1955	1980	SR804 AND SR7	31	45	42
WM	90	1955	1980	LAKE WORTH DRAINAGE DIST. OFFICE	11	46	42
WM	92	1955	1980	SR806 7.5 MILES WEST OF DELRAY	17	46	42
WM	93	1955	1980	SR806 AND SR7	19	46	42
WM	101RD	1955	1980	BOCA RATON @ SR441 - LWD	18	47	42
WM	102RD	1955	1980	BOCA RD @ POWERLINE	16	47	42
WM	104RD	1957	1980	POMPANO FARMERS MARKET	34	48	42
WM	106H	1960	1980	CONSERVATION AREA 3 - 26	28	49	39
WM	107RD	1957	1980	KEY GROVES	03	50	40
WM	108RD	1957	1980	DIXIE WATER PLANT	18	50	42
WM	109RD	1957	1980	SEWELL'S LOCK	14	50	41
WM	110RD	1957	1980	CARROLL RANCH	16	50	40
WM	111RD	1947	1972	FLAMINGO GROVES	24	50	40
WM	114	1957	1980	GILL REALTY	35	50	41
WM	115H	1960	1980	S-9	27	50	39
WM	125RD	1929	1972	TOWNSITE - US SUGAR	17	43	34
WM	135	1957	1980	PELICAN LAKE DRAINAGE DI#1	02	42	37
WM	138	1957	1980	PAHOKEE 2	27	42	38
WM	141	1957	1980	DEERFIELD LOCK	35	47	42
WM	242H	1959	1980	SOUTH FLORIDA FIELD LAB IMMOKALEE	20	46	29
WM	252H	1951	1980	CONSERVATION AREA 1 - 7	34	45	40
WM	253H	1952	1980	CONSERVATION AREA 1 - 9	18	46	41
WM	254H	1951	1980	CONSERVATION AREA 2 - 17	14	48	39
FS5002		1956	1980	DEVILS GARDEN TOWER	34	44	32

ID PREFIXES

AR Agricultural Research Service
CW City of West Palm Beach
DC Dade County
WB U.S. Weather Bureau
FS Forest Service
WM SFWMD, Corps, Lake Worth Drainage District

SE Section
TP Township
RG Range

APPENDIX B: Estimating Return Period Values (Gumbel, 1954, (5))

1. Calculate moment estimates of the mean, M, and standard deviation, S.

$$M = \left(\sum_{i=1}^{N} X_i\right)/N$$

$$S^2 = \sum_{i=1}^{N} (X_i - M)^2/(N-1)$$

N is the number of years of data at the station and X is the set of annual maximums or seasonal totals depending on the rainfall duration under study.

2. Using Table B-1 determine the expected mean, $\bar{y}$, and the expected standard deviation, σ, for a fixed sample size, N.

3. Compute value of Y

$$Y = -\ln(-\ln(p))$$

where p is the non exceedance probability for a specific return period.

4. Determine return period estimate of rainfall, X_f.

$$X_f = M + \frac{S}{\sigma}(Y - \bar{y})$$

TABLE B-1*

N	$\bar{y}$	σ
15	.513	1.021
20	.524	1.063
25	.531	1.091
30	.536	1.112
35	.540	1.128
40	.544	1.141
45	.546	1.152
50	.549	1.161
60	.552	1.175
70	.555	1.185
80	.557	1.194

*Reference 5, p. 29.

APPENDIX C: GLOSSARY OF TERMS

ANNUAL SERIES - A data set composed of the maximum rainfall amount, for the desired storm duration, recorded in each calendar year of the period of interest.

ISOHYETALS - Lines of equal rainfall depth (in inches for this report) produced by some type of interpolation among the nearest rainfall measurement stations.

OBSERVATIONAL-DAY RAINFALL - Daily rainfall data taken from gages that are read once a day. Some of the rain may have occurred on the calendar day before or after the date the amount was recorded.

PARTIAL DURATION SERIES - The data set composed of the maximum rainfall amounts, for the desired storm duration, recorded in the period of interest. The number of data points is equal to the number of years in the period, although there may be more than one storm from from some years and no storms that qualify from other years.

RETURN PERIOD - A statistically derived time interval during which a specific rainfall amount is likely to be equaled or exceeded one time.

TWENTY-FOUR HOUR RAINFALL - Cumulative rainfall for any continuous twenty-four hour period ending on the date the amount was recorded. Collection of this type of data requires a recording rain gage.

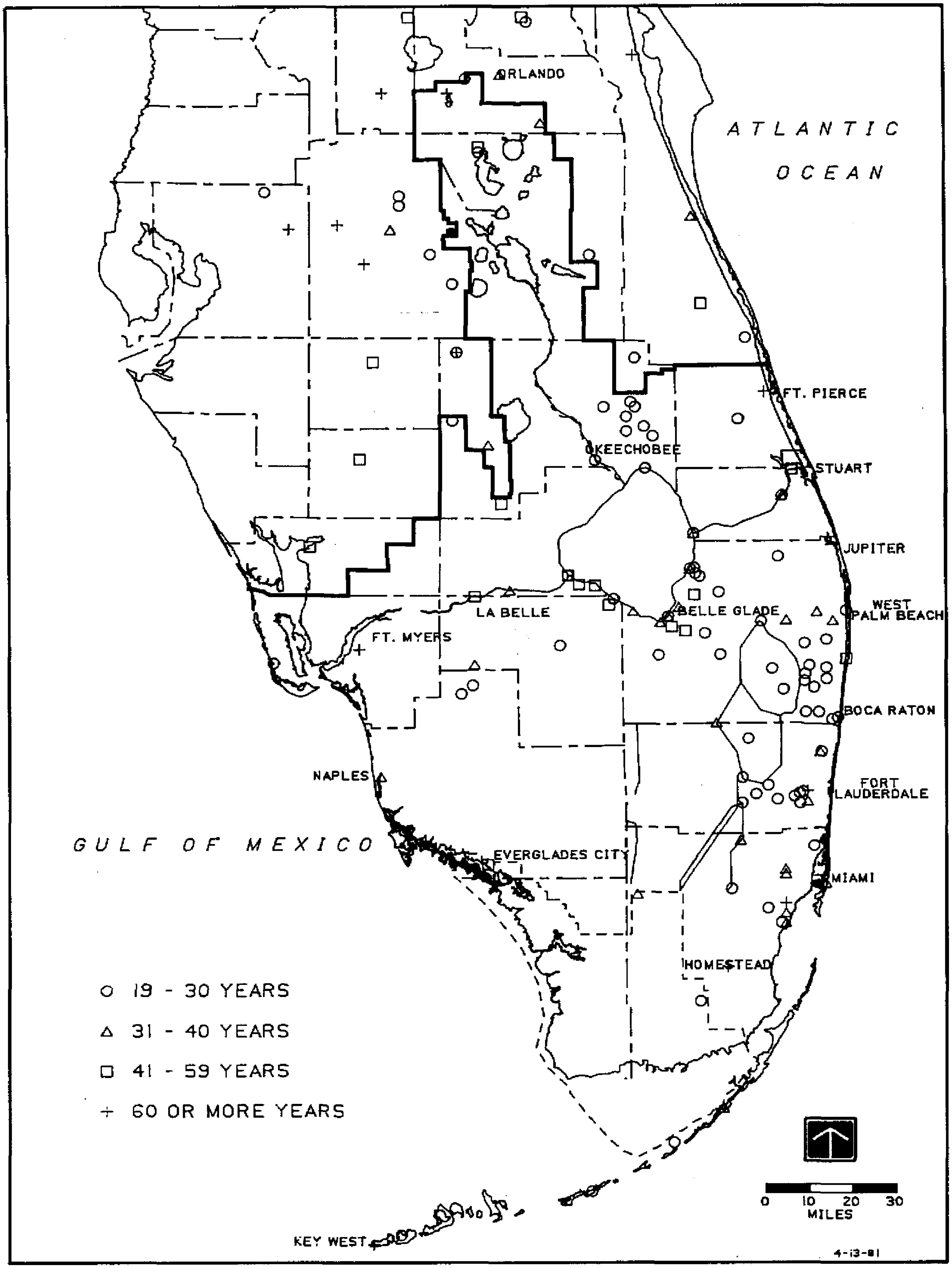

FIGURE 1: RAIN GAGE LOCATIONS