LONG TERM TROPICAL STORM INCIDENCE

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April 11, 1982

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M E M O R A N D U M

April 9, 1982

TO: Director, Resource Planning Department

FROM: R. L. Hamrick, Resource Planning Department

SUBJECT: Long term tropical storm incidence

Over the last few months, a couple of memos (February 5 and March 4) have been generated in response to questions flowing from the Marshall-Jones "Rain Machine" theory. One of the components discussed in these is the incidence of tropical storms and their variation over the past. The discussions in those memos were based on a plot made a couple of years ago as an index of tropical activity in Florida. That plot basically came from data contained in a Corps of Engineers report entitled "Appraisal Report - Hurricanes Affecting the Florida Coast." Since that time, I have gotten a copy of the Weather Bureau's report "Tropical Cyclones of the North Atlantic 1871-1977" along with their updated maps through 1980. A comparison of a plot derived from the Weather Bureau data to the earlier one indicates that there is an apparent difference in the criteria used to define applicable events.

The attached Figures 1, 2, and 3 are derived from the Weater Bureau data. Figure 1 is a running 10 year summary of all events in the North Atlantic from 1871 to 1980. This in essence shows a peak in activity of about 9 per year before 1895 with a fairly rapid decline to a minimum level of about 5 per year in the early 1920s. By 1940 the rate had recovered to over 10 per year. Since that time, the incidence has had a rather rhythmic fluctuation with a period of about 16 years from lows of about 8.5 or 9 to highs running at about 10 to 10.5 per year. The range of this fluctuation seems to be narrowing, but there is no clear indication of an eminent decline similar to that following the turn of the century. A trend line through the entire record would indicate a definite uptrend in the number of events.

Figure 2 is a similar running 10 year plot of all events actually hitting some point in the state of Florida. This is not an identical plot to the earlier one based on Corps of Engineers data. That one was based on events classed as hurricanes. This plot as compared to the earlier one shows a deeper decline in the decade before the 20s and a lesser decline in the last decades of the record. Beyond this, in general shape, it shows similar characteristics to Figure 1 with a major shift of occurrence to the earlier portion of the record rather than the later periods. A trend line through this record would indicate a definite downtrend on the number of events affecting Florida. The average number of events in Florida for the decade ending in 1980 is 0.81 per year which is as low as any in this century.

When we shift to Figure 3, which focuses on events in the SFWMD, the same cyclic patterns are apparent. The lower line in this plot represents the events of hurricane force that passed over some point in the District. If we treat this as an index of the strength of tropical influence in the District area, it indicates a very definite weakening since the early 1950s.

In summary, while tropical cyclone activity appears to be increasing in the North Atlantic in general, the activity in the state seems to be decreasing. Activity in the SFWMD, while still showing cyclical characteristics, seems to be decreasing to some extent since the early 1950s. If hurricane activity is taken as an indication of the strength of tropical influence, there has been a very definite decline since the early 1950s.

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RLH:et

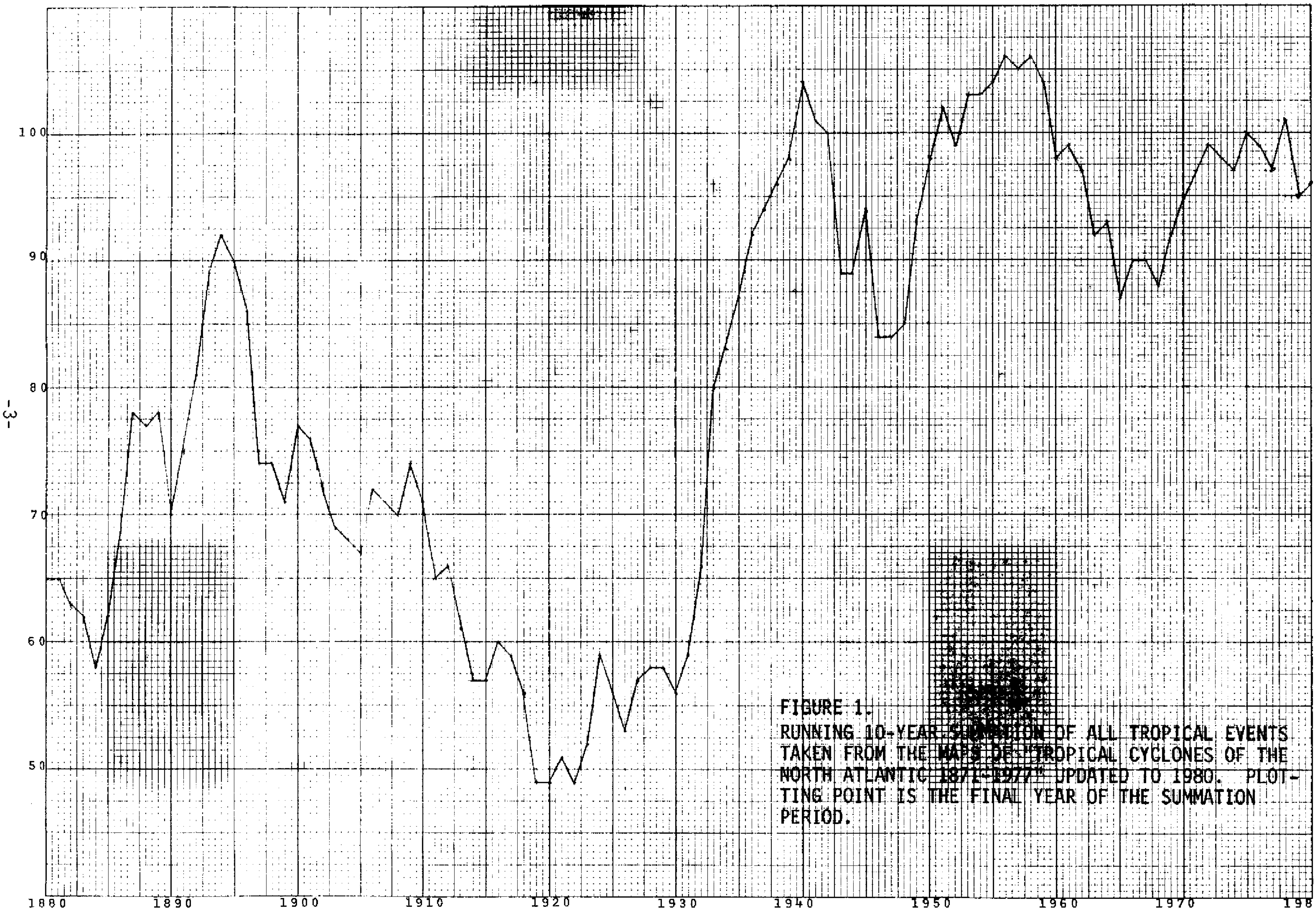

FIGURE 1.
RUNNING 10-YEAR SUMMATION OF ALL TROPICAL EVENTS TAKEN FROM THE MAPS OF "TROPICAL CYCLONES OF THE NORTH ATLANTIC 1871-1977" UPDATED TO 1980. PLOTTING POINT IS THE FINAL YEAR OF THE SUMMATION PERIOD.

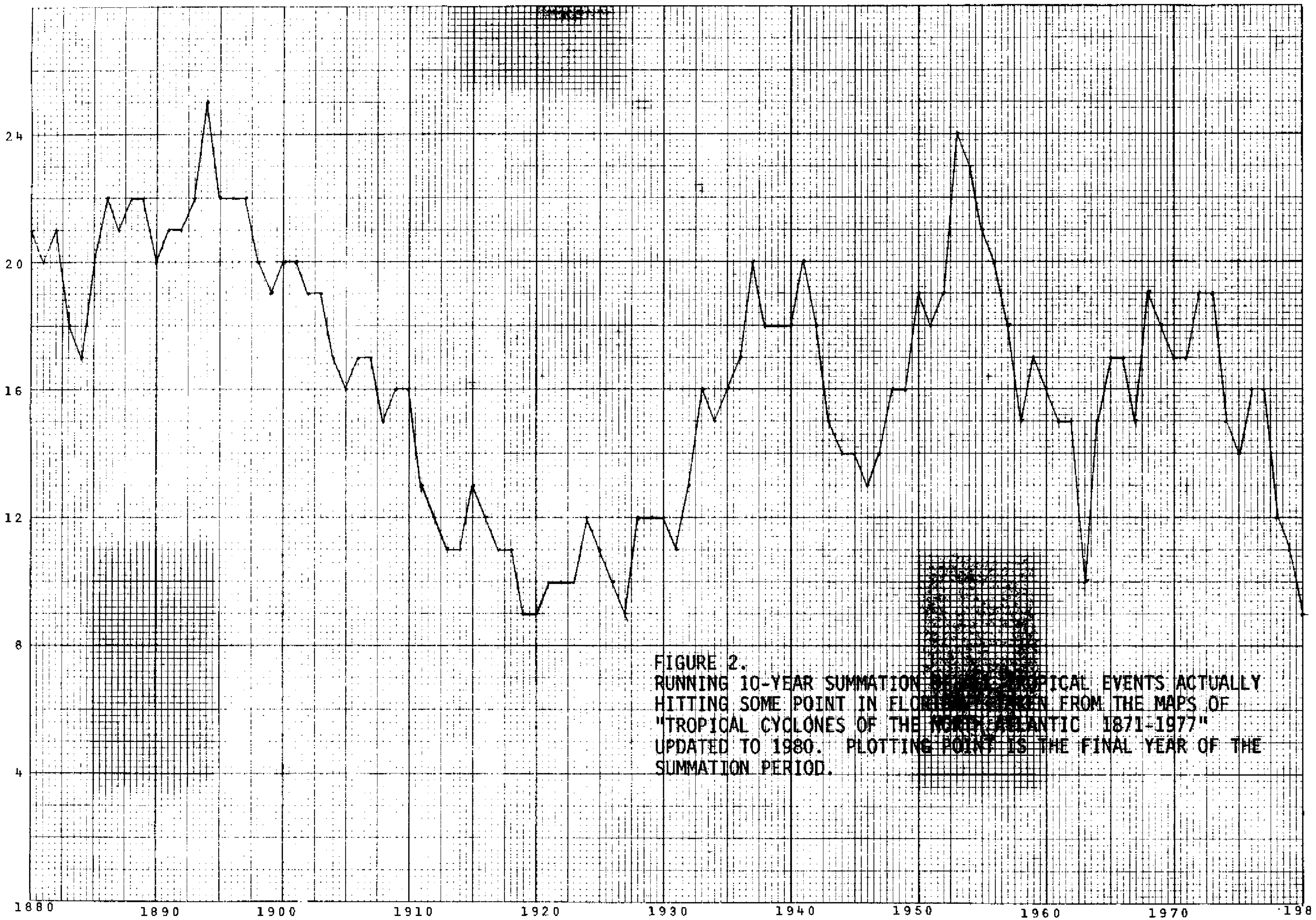

FIGURE 2.
RUNNING 10-YEAR SUMMATION OF ALL TROPICAL EVENTS ACTUALLY HITTING SOME POINT IN FLORIDA TAKEN FROM THE MAPS OF "TROPICAL CYCLONES OF THE NORTH ATLANTIC 1871-1977" UPDATED TO 1980. PLOTTING POINT IS THE FINAL YEAR OF THE SUMMATION PERIOD.

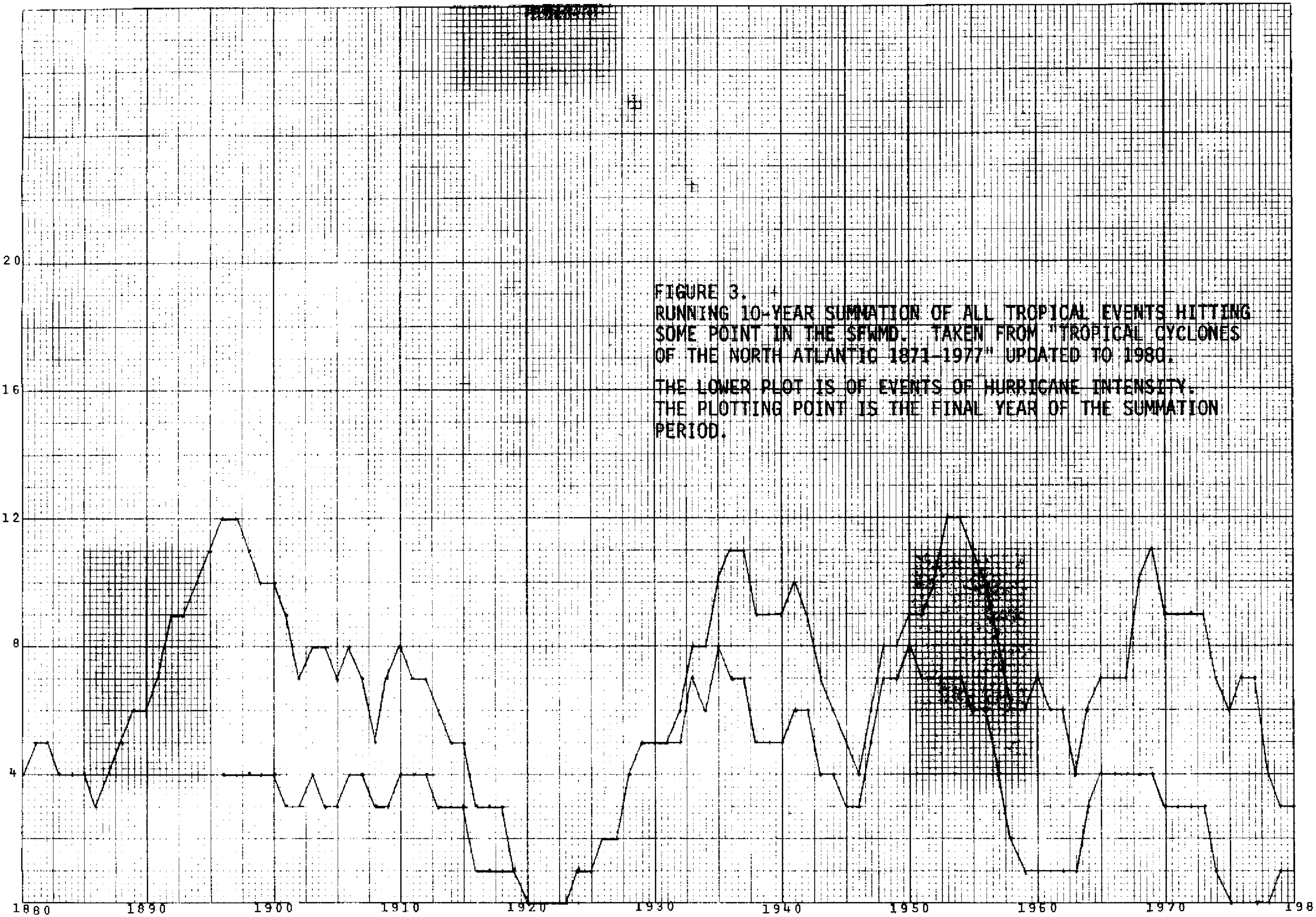

FIGURE 3.
RUNNING 10-YEAR SUMMATION OF ALL TROPICAL EVENTS HITTING SOME POINT IN THE SFWMD. TAKEN FROM "TROPICAL CYCLONES OF THE NORTH ATLANTIC 1871-1977" UPDATED TO 1980.

THE LOWER PLOT IS OF EVENTS OF HURRICANE INTENSITY.
THE PLOTTING POINT IS THE FINAL YEAR OF THE SUMMATION PERIOD.

KISSIMMEE RIVER BASIN

RAINFALL ANALYSIS

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April 11, 1982

FINDINGS

1. Annual rainfall deficit for the years of 1980 and 1981 was felt not only in south Florida, but in the whole state. During the 1980's, the South Florida and the St. Johns River Water Management Districts experienced the greatest deficits. During 1981 all five water management districts had severe rainfall deficits.
2. Analysis of the long term annual rainfall from several stations inside and outside of the SFWMD area shows both positive and negative declines. Negative declines, however, outweigh the positive ones.
3. Pre-project (1930-1964) and post-project (1965-1981) annual rainfall analysis of the Kissimmee River Basin show decreasing trends in both cases. The post-project statistical characteristics (mean and standard deviations) are slightly lower. It could be due to smaller post-project sample size (17) in comparison to larger pre-project sample size (35).
4. Tests of hypotheses for both the difference in means and standard deviations (pre-and post-project) show that at .975 and .990 significant probability levels, the hypotheses cannot be rejected that the subsample means and standard deviations are the same and that the differences in them are due to chance. In other words, there is a 1% or lower probability that there is a significant difference in means and standard deviations.
5. Analysis of the tropical depressions and hurricanes in the Kissimmee River Basin shows that during the pre-project period (1930-64) the hurricane occurrences were more frequent. The basin was receiving in excess of 1.74 inches of extra rainfall on an average annual basis from tropical events. Since 1964 there were only two storm events in the study basin and the average annual rainfall contribution from these storm events decreased to .54 inch per year. This could be the main reason for the decrease in mean and the increase in negative trends of the post-project annual rainfall.

INTRODUCTION

Qualitative statements, such as the recent drought (less rainfall than normal year) of 1980 and 1981 was not a meteorological aberation but rather a predictable consequence of the land development and the drainage of wetlands in the Everglades and the Kissimmee River Valley, have been reported in national and local publications. These publications also state that land development has disrupted the normal rain cycle of the area.

The intent of this short report is to analyze and examine scientifically whether, in fact, the normal rain cycle has been disrupted by land development or whether it is just a natural event. Two scientific approaches of analysis can be used: (1) the deterministic approach - an approach to describe and represent the system by theoretical and/or empirical physical relations, and (2) the stochastic approach - time series analysis which aims to represent the most relevant statistical characteristics of the historic rainfall events.

The second approach of analysis has been to analyze the long term historic rainfall events.

The specific objectives of this study are as follows:

(1) Comparison of the 1980-81 Kissimmee River Basin rainfall with other area rainfall in Florida;

(2) Analysis of data to detect the historic long term trend; and

(3) Comparison of the historic long term trend with the trend established after some degree of man-made control of flows and water levels in the Kissimmee River Basin started.

THEORY

Annual rainfall is subject to inconsistency and non-homogeneity (changes in nature by human or by natural disruptive, evolutive, or sudden processes). This inconsistency and non-homogeneity may affect the long term characteristics of rainfall such as the mean, standard deviation, and serial correlation by producing a trend and/or systematic positive and negative departures from normal. Such changes can be identified by use of stochastic or time series analysis.

The identification and description of the characteristics of changes in rainfall time series are based on (a) fitting a trend function and testing that its parameters are significantly different from zero, and (b) testing that the basic statistical characteristics of subseries of the sample series are statistically different among themselves. The trend analysis assumes a monotonic function (either increasing or decreasing continuously) expanded in power series form as:

$$X_t = A_0 + A_1 t + A_2 t, + \ . \ . \ . \ +, A_m t^m$$

where: A_0, A_1,.....A_m are the parameters to be estimated. Only when any of the parameters are found to be significantly different than zero, then a linear or a non-linear trend becomes a characteristic of the series.

The second technique divides the historic rainfall series into two or more subseries and the main historical characteristics are estimated for each series. The breaking points of the subseries should be the time of hypothethical change of characteristics (say man-made control of the Kissimmee River hydrology) of the rainfall series in the mean, and the standard deviation. Then the statistical characteristics of the subseries needs to be tested to check whether they are or are not statistically different among themselves. The classical t-statistics can be used for testing whether the differences of two means, $\bar{X}1$

and $\bar{X}2$, are significant. The χ^2 test can be used for testing whether the variances $S1^2$ and $S2^2$ of subsamples are significantly different.

ANALYSIS

<u>Comparison of the 1980-81 Kissimmee River Rainfall with Other Area Rainfall in Florida</u>

In an effort to check whether the Kissimmee River Valley was the only area with deficit rainfall during the years 1980 and 1981, the four other water management districts were contacted. Presented in Figure 1 is the annual rainfall departure from normal for the years 1980 and 1981 for all the five water management districts. This figure documents that the whole State of Florida received less rainfall than average for both the years. During 1980 the South Florida Water Management District and the St. Johns River Water Management District had the highest rainfall departure from normal, in comparison to other districts. However, during 1981, the Northwest Florida Water Management District had the highest deficit. Figure 1 can be used to emphasize the point that the rainfall deficit of 1980 and 1981 was not an isolated local area (Kissimmee River Basin) event.

HISTORIC LONG TERM TREND DETECTION

As was stated earlier, changes in the rainfall regime can be identified by use of trend analysis. A linear trend analysis was performed on annual rainfall values observed at several selected stations inside and outside the district area (Figure 2). Presented in Table 1 is the mean, standard deviation, the intercept, and the slope (trend) of the annual rainfall values. The minimum length of record used was 52 years (1930-1981).

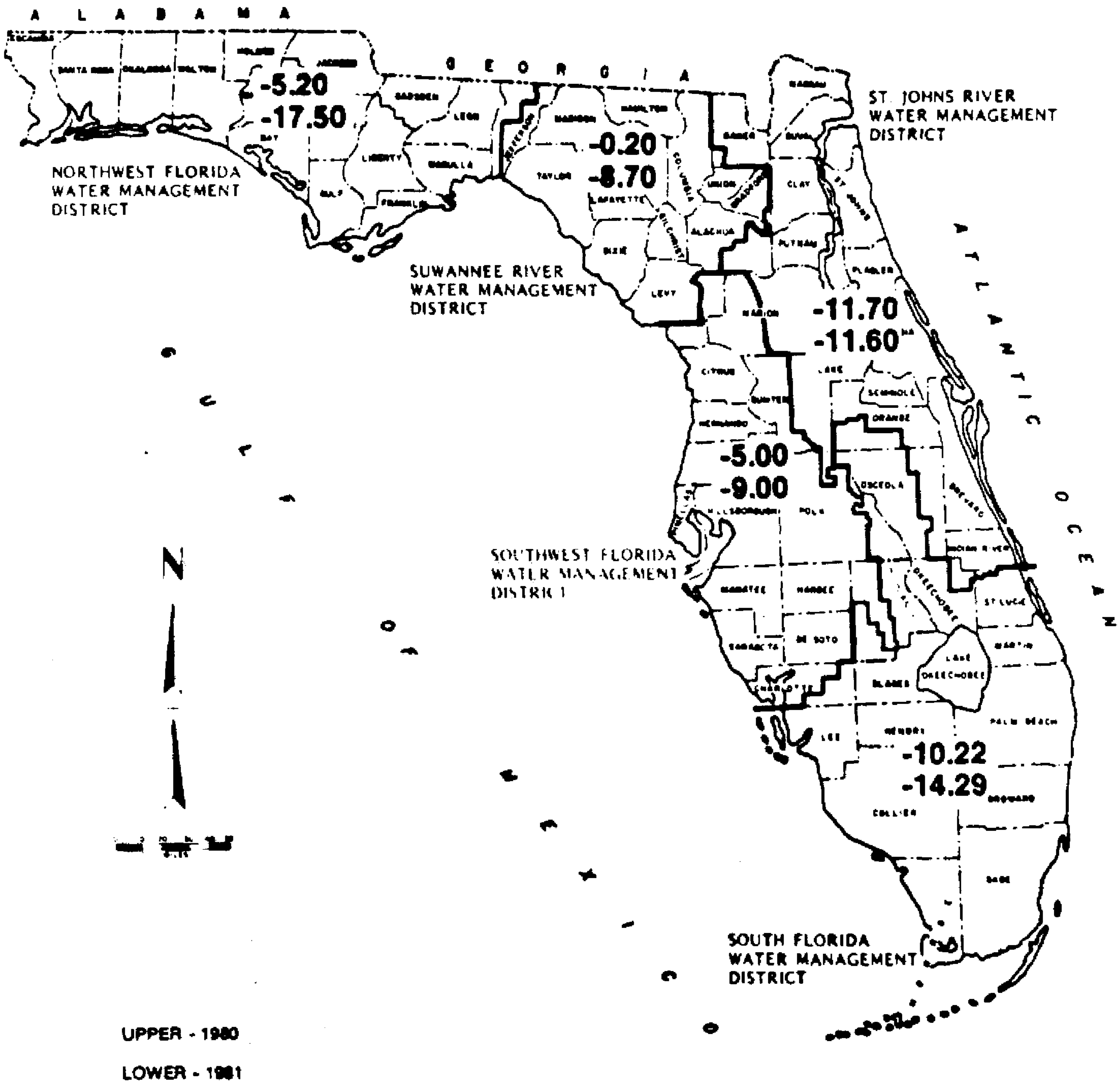
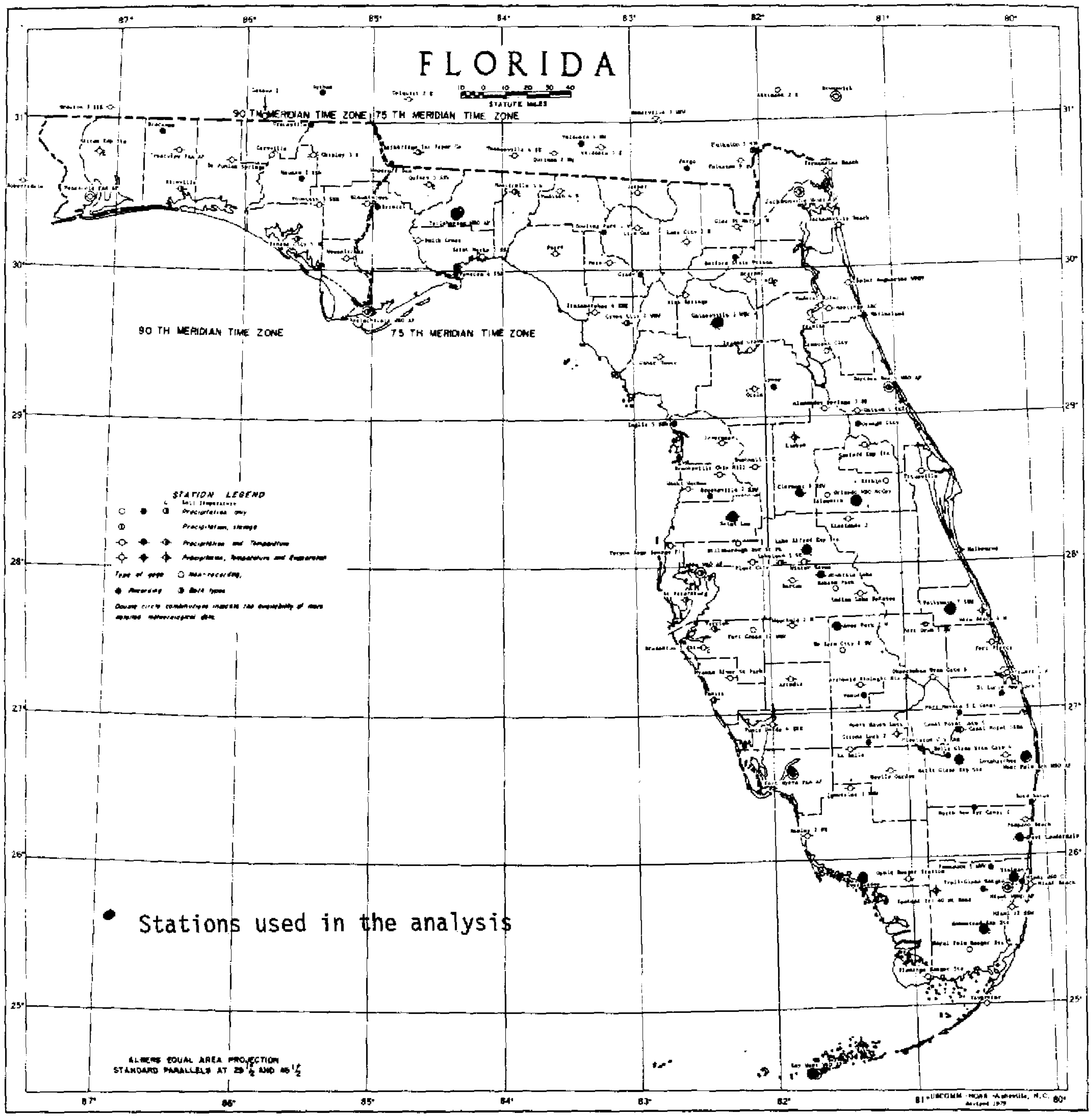


Figure 1.

RAINFALL DEPARTURE FROM AVERAGE ANNUAL DURING 1980 AND 1981



Data for non-recording stations shown on this map may be found in the publication Climatological Data.

Figure 2.

TABLE 1. MEAN, STANDARD DEVIATION, INTERCEPT, AND THE SLOPE (TREND) OF LONG TERM ANNUAL RAINFALL VALUES OBSERVED AT SEVERAL STATIONS. (Inches)

Station Name	Mean	Standard Deviation	Intercept	Slope(Trend)
Inside SFWMD				
Fellsmere	43.85	13.91	47.02	-.288
Lake Alfred	50.00	10.55	53.25	-.138
Isleworth	51.72	9.50	54.57	-.118
Mountain Lake	51.30	10.02	53.56	-.100
Avon Park	53.05	10.22	53.33	-.00587
Miami Airport	58.38	13.73	59.36	-.04789
Key West	38.31	12.18	37.07	+.06030
Everglades	51.67	11.00	53.63	-.09582
West Palm Bch	60.70	14.06	62.43	-.08482
Belle Glade	56.54	11.38	61.82	-.25732
Homestead	61.06	13.59	65.56	-.21952
Clermont	50.84	8.18	50.03	+.0169
Ft. Laud.	57.87	17.09	51.48	+.31175
Ft. Myers	52.99	10.07	51.33	+.0340
Outside SFWMD				
Tallahassee	60.69	14.87	53.98	+.2490
Gainesville	52.28	8.85	52.28	+.00002
St. Leo	55.09	10.19	57.30	-.083

Analysis of the long term annual rainfall reveals that a majority of the raingauge stations show an overall declining trend since the 1930's. However, there are stations within and outside of the District which show a positive increasing trend also.

Comparison of the Pre- and Post-Project Rainfall Trend in the Kissimmee River Basin

The previous trend analysis of rainfall which included several stations in the Kissimmee River Basin was based on the total historic record (52 years). The analysis was also based on single station rainfall (univariate) data.

Attention is now focused on a multi-variate time series of rainfall observed in the Kissimmee River Basin at several stations. The area average rainfall was obtained by use of the Theissen Polygon Method. Additionally, the 52 years of record is divided into two subsets: (1) 1930-1964, and (2) 1965-1981. The trend analysis was performed to the above two subsets of data to detect whether there is any change in the statistical characteristics of annual rainfall before and after the Kissimmee River channelization. Presented in Table 2 is the average rainfall over the Kissimmee River Basin for the period 1930-1981.

TABLE 2. AVERAGE RAINFALL OVER KISSIMMEE RIVER BASIN

Period	Year	Average Annual Rainfall (Inches)
PRE PROJECT ANNUAL RAINFALL	1930	67.13
	1931	48.25
	1932	46.28
	1933	57.18
	1934	52.48
	1935	51.73
	1936	57.19
	1937	50.59
	1938	37.32
	1939	55.79
	1940	51.25
	1941	59.41
	1942	45.59
	1943	48.36
	1944	49.29
	1945	52.06
	1946	41.87
	1947	67.79
	1948	56.97
	1949	53.10
	1950	42.02
	1951	50.99
	1952	49.28
	1953	72.16
	1954	47.61
	1955	38.34
	1956	47.28
	1957	58.29
	1958	50.48
	1959	68.03
	1960	64.18
	1961	36.17
	1962	45.00
	1963	50.04
	1964	47.30
POST PROJECT ANNUAL RAINFALL	1965	46.03
	1966	52.63
	1967	42.46
	1968	51.45
	1969	59.67
	1970	45.04
	1971	46.01
	1972	44.39
	1973	51.62
	1974	47.38
	1975	45.46
	1976	47.64
	1977	41.93
	1978	51.83
	1979	52.96
	1980	41.51
	1981	35.00

The statistical characteristics of the pre- and post-project rainfall is presented in Table 3.

Table 3. STATISTICAL PROPERTIES OF PRE- AND POST-PROJECT RAINFALL IN THE KISSIMMEE RIVER BASIN (INCHES)

Period	Number of Observations	Mean	Standard Deviation	Intercept	Slope (Trend)
Pre-Project	35	51.90	8.69	53.14	-.068
Post-Project	17	47.23	5.74	50.81	-.398

A visual examination of the statistical characteristics of the pre- and post-project annual rainfall shows that the mean and the standard deviation of pre-project period is higher than the post-project. The same holds true for the intercept and the trend line. However, visual examination of the above characteristics alone is not enough to arrive at the conclusion that pre-project annual rainfall mean is higher than post-project. The statistical characteristics could be higher due to larger pre-project sample points (35 versus 17). Therefore, to determine whether a change exists in the mean and the standard deviation, some hypothesis testing is necessary.

The classical t- statistics were used for testing whether the difference of two means, $\bar{x}1$ and $\bar{x}2$ (Pre- and Post-Project) is significant, that is: if $\bar{x}1$ and $\bar{x}2$ denote sample means, we have to decide between the hypothesis

H0:x1 = x2 and the difference in sample mean is due to chance

H1:x1 > x2 and the difference in sample mean is probably real

under the hypothesis H0, $t = \dfrac{\bar{x}1 - \bar{x}2}{\sigma\sqrt{\frac{1}{N1} + \frac{1}{N2}}}$ and $\sigma = \sqrt{\dfrac{N1S1^2 + N2S2^2}{N1 + N2 - 2}}$

$$\sigma = \sqrt{\frac{35(75\cdot51) + 17(32\cdot94)}{35 + 17 - 2}} = 8.053$$

$$t = \frac{51.90 - 47.23}{8.053\sqrt{\frac{1}{35} + \frac{1}{17}}} = 1.963$$

The critical value t_c for 97.5% and 99% significant probability level for (N1 + N2-2) degrees of freedom are 2.37 and 2.01.

As both the table values exceed the calculated value, it cannot be said that the means are different at .975 and .990 significant probability levels. Therefore, we cannot reject HO at the .01 and .025 levels of significance. At less than the .01 level, the HO hypothesis does not hold. Therefore, additional information needs to be analyzed.

The classical χ^2 hypothesis can be applied to test whether the decrease in variability is significant.

The decision has to be made between the hypothesis

HO:α = 8.69 inches, and the post-project variability is due to chance

H1:α < 8.69, and the variability has decreased.

The value of χ^2 for the post-project subset is $\chi^2 = NS^2/\alpha^2 = \frac{17 \times (5.74)^2}{(8.69)^2} =$

$$\frac{560.10}{75.51} = 7.41$$

Using a one-tailed test, we would reject the hypothesis HO at .01 and .025 levels of significance if the sample value of χ^2 were greater than $\chi^2_{.99}$ and $\chi^2_{.975}$ which equals for ν =17-1 = 16 degrees of freedom 32.0 and 28.8. Thus we cannot reject the hypothesis HO that the post-project variability is due to chance.

HURRICANES AND TROPICAL DEPRESSIONS

The study area (Kissimmee River Basin) is subject to hurricanes and tropical depressions. Presented in Table 4 are the years in which hurricanes and tropical depressions passed through the basin, the monthly amount of rainfall associated with each storm event, the monthly average, and the departure from the monthly average. It is interesting to note that before 1964 there were 14 storm events, but only 2 events after this period. The post-project total departure from normal during storm event months has been only 9.32 inches, whereas the comparative pre-project figure was 61.15 inches of rainfall. On an average yearly basis, these tropical events were contributing 1.74 inches (61.15/35) of excess rainfall before 1964. However, this contribution has decreased to only .54 (9.32/17) inches. This could be one of the major reasons why the rainfall has decreased in the mean and increased in the negative trend after the year 1964. It is beyond the scope of this study to determine the cause of the less frequent occurrence of tropical storms and hurricanes in the Kissimmee River Basin.

Table 4. Hurricanes and Tropical Depressions Which Passed Through the Kissimmee River Basin and Resulting Rainfall (Inches)

YEAR	DATE	MONTHLY TOTAL (INCHES)	MONTHLY AVERAGE (INCHES)	Δ CHANGE (INCHES)
1925	Nov. 30	3.47	1.62	+ 1.85
1928	Aug. 8	9.27	7.07	+ 2.20
1928	Sept. 17	9.43	6.80	+ 2.63
1933	July 31	11.25	7.83	+ 3.42
1933	Sept. 31	12.27	6.80	+ 5.47
1934	May 27	7.94	4.19	+ 3.75
1939	Aug. 11	13.90	7.07	+ 6.83
1944	Oct. 19	5.48	3.61	+ 1.87
1945	Sept. 16	9.76	6.80	+ 2.96
1946	Nov. 2	1.62	1.62	-
1947	(3 hurricane events; however, they did not pass through the Kissimmee River Basin)			
1949	Aug. 27	13.64	7.07	+ 6.57
1950	Sept. 6	8.93	6.80	+ 2.13
1950	Oct. 18	8.83	3.61	+ 5.22
1951	Oct. 2	6.32	3.61	+ 2.71
1953	Oct. 9	6.30	3.61	+ 2.69
1959	June 17	9.65	7.57	+ 3.08
1959	Oct. 18	9.20	3.61	+ 5.59
1960	Sept. 10, 24	14.13	6.80	+ 7.33
1964	Aug. 27	8.60	7.07	+ 1.53
1968	June 4, 18	14.66	7.57	+ 7.09
1968	Aug. 5	4.90	7.07	- 2.17
1969	Sept. 7	7.39	6.80	+ .59
1969	Oct. 3	7.42	3.61	+ 3.81