RAINFALL DROUGHT FREQUENCY AND AVAILABILITY OF SURFACE WATER IN MARTIN COUNTY

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ABSTRACT

This report provides statistical information on rainfall drought frequency and on the availability of surface water in Martin County. This analysis is part of a comprehensive study by the South Florida Water Management District to assist Martin County in their water resources planning. The discussion consists of four sections. The first section describes the background and objectives of this study, the connotation of surface water availability, and the definition of C-44 inflow. Section II describes procedures used to prepare data for statistical analysis. The C-44 inflow record was extended by regression with rainfall and the acceptability of the extension was examined. Section III describes procedures used to conduct frequency analyses on the rainfall and C-44 inflow data. The results are presented in a series of frequency curves in the Appendix and the same information is summarized in four isofrequency diagrams (pages 14 to 17). Interpretation and use of the frequency information is illustrated. The final section discusses the implications of the frequency information, reiterates the limitations and assumptions made, and recommends alternatives to increase water availability in Martin County. The results of this analysis indicate that while the C-44 inflow is plentiful during the wet months, it is inadequate to meet the current demand during part of the dry season, and that supplemental releases from Lake Okeechobee are needed for a duration of about one month in a normal year to three months once in 10 years.

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I. INTRODUCTION

As a result of the February 15, 1984 meeting between the South Florida Water Management District (SFWMD) and Martin County, the SFWMD outlined a scope of study to assist Martin County in their water resources planning. The study goal is stated in the documentation of "Martin County: SFWMD Water Resources Planning Assistance Program" as:

> *The study will provide the Martin County Board of County Commissioners with an analysis of water availability and will provide water resource planning recommendations to be used for the county's future growth management strategies.*

As part of a comprehensive study, the Water Resources Division of the SFWMD is committed to provide analyses on rainfall drought frequency and on the availability of surface water in Martin County. A major objective is to quantify the availability of C-44 canal water that can be developed for use in Stuart and other rapidly growing urban areas in Martin County. This report documents the results of the above analyses.

The major source of surface water in Martin County is from C-44 (St Lucie Canal). A minor source of water can also be obtained from C-23, which lies on the boundary of St Lucie and Martin Counties. A decision has been made, however, to exclude C-23 in this study because the major portion of the drainage area of C-23 lies within St Lucie County, and the availability of canal water in C-23 has been known to be limited.

Surface water can be obtained from C-44 by direct withdrawal or by diversion and interception of secondary canal inflows to the canal. An analysis of surface water availability in Martin County is equivalent to analyzing the availability of C-44 inflow. In this report C-44 inflow refers to the portion generated within the canal basin. The portion contributed by Lake Okeechobee is excluded in the analysis because it involves a policy decision of how Lake

Okeechobee storage should be shared among all counties. A SFWMD water supply (computer) model can be used as a tool to address the second question.

Rainfall and flow are highly variable entities. The variability must be quantified in such a way that water resources planning can be made. The goal of this report is to make available a comprehensive series of diagrams depicting the drought frequency distribution of rainfall and surface water availability.

Section II describes procedures used to prepare the rainfall and C-44 inflow data for this analysis. The inflow record is limited and an extension of the historical record by regression is necessary. A number of regression models were compared to select the most appropriate one. The suitability of the extension was also examined. Section III describes procedures used to conduct frequency distribution analyses on the rainfall and inflow data for both calendar months and for durations of one to twelve months. The results are presented in a series of frequency distribution curves in the appendix and the same information is summarized in four isofrequency diagrams (pages 14 through 17). The usefulness of these diagrams depends on their proper interpretation and application. The intention of Section III is to provide such explanations. The final section discusses the implications of the frequency diagrams, reiterates the limitations and assumptions made, and recommends alternatives to increase water availability in Martin County.

II. DATA PREPARATION

Relatively long and good quality rainfall data are available for this analysis. The C-44 inflow data, on the other hand, are not entirely adequate. The quality of the S-308 discharge data is affected by the difficulty in quantifying the lock flow, and the record is too short for rigorous frequency analysis. This section describes procedures used to calibrate the flow data, to extend the flow record, and to examine the suitability of the extension.

Two long term rainfall stations are available within the C-44 basin, one located at S-80 (St Lucie Lock, MRF-7035) and the other at S-308 (Port Mayaca, MRF-51). The quality of data is generally good with relatively few missing records. Since these two stations are located at the two ends of the C-44 basin, the mean basin rainfall was calculated as the arithmetic average of the data from these stations. A total of 31 years of data, covering the period 1952 to 1983, was used for the present rainfall frequency analysis.

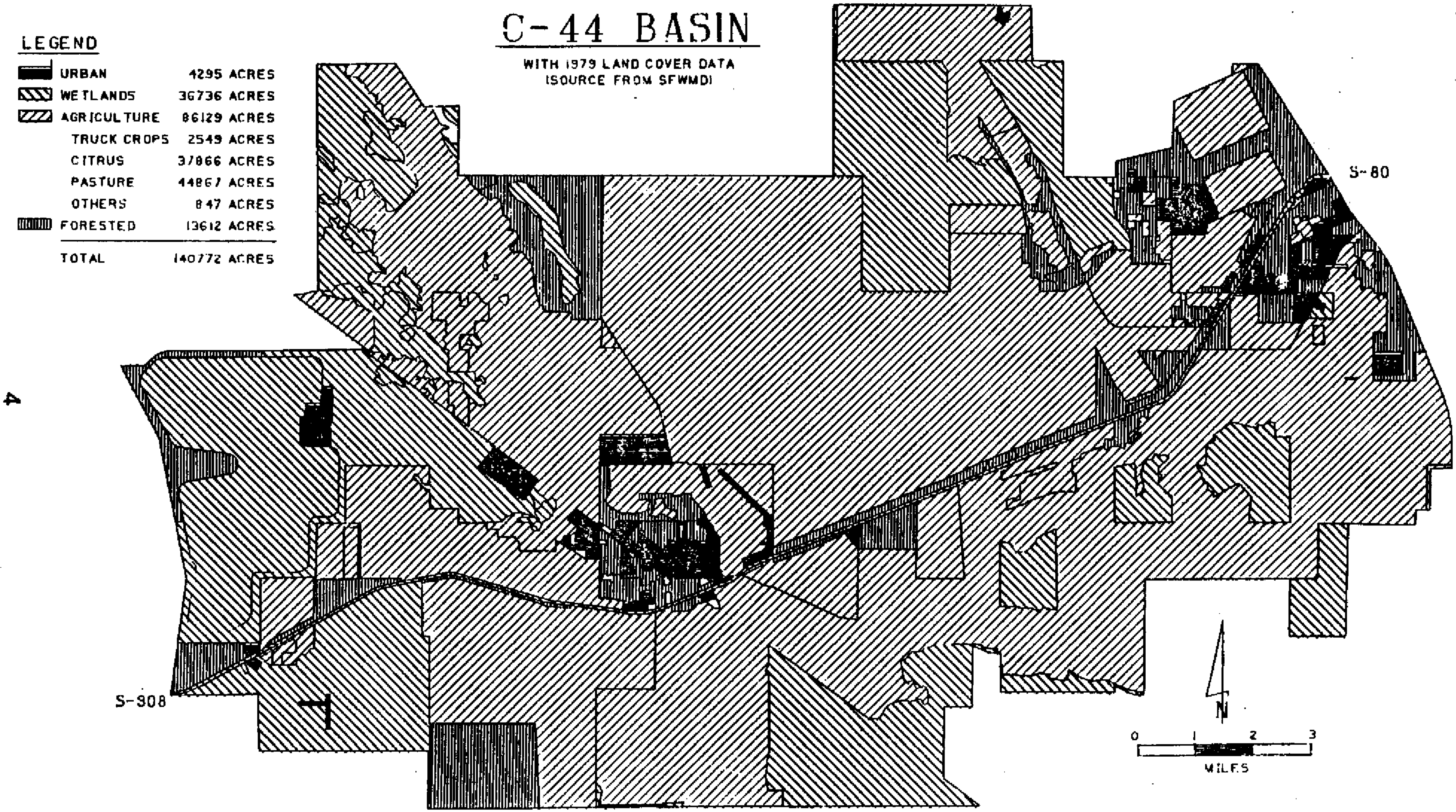
The C-44 inflow was calculated as the difference in discharges of S-80 and S-308, and adjusted for storage change in the channel. Because of the way it was calculated, the C-44 inflow included the effect of the existing (1978-1983) canal water usage in the basin. The calculated inflow represented the net amount available for additional usage as of the conditions in 1978-1983. If calculated inflow was negative, it represented the amount supplemented by Lake Okeechobee. Figure 1 shows the 1979 land use pattern in the C-44 basin, which is considered representative of the 1978-1983 study period. Any major change in land use within the C-44 basin from 1979 may increase or decrease the canal water availability. The canal water availability presented here must then be adjusted accordingly if the change is significant.

Discharge data for both S-80 and S-308 were obtained from the USGS. The USGS data for S-308, however, included only the spillway flow, the lock flow was excluded. Moreover, at the date of this report, only six years of data for S-308 were available because the structure did not exist prior to 1978. Two adjustments of the S-308 data, therefore, were necessary.

FIGURE 1

C-44 BASIN

WITH 1979 LAND COVER DATA
(SOURCE FROM SFWMD)

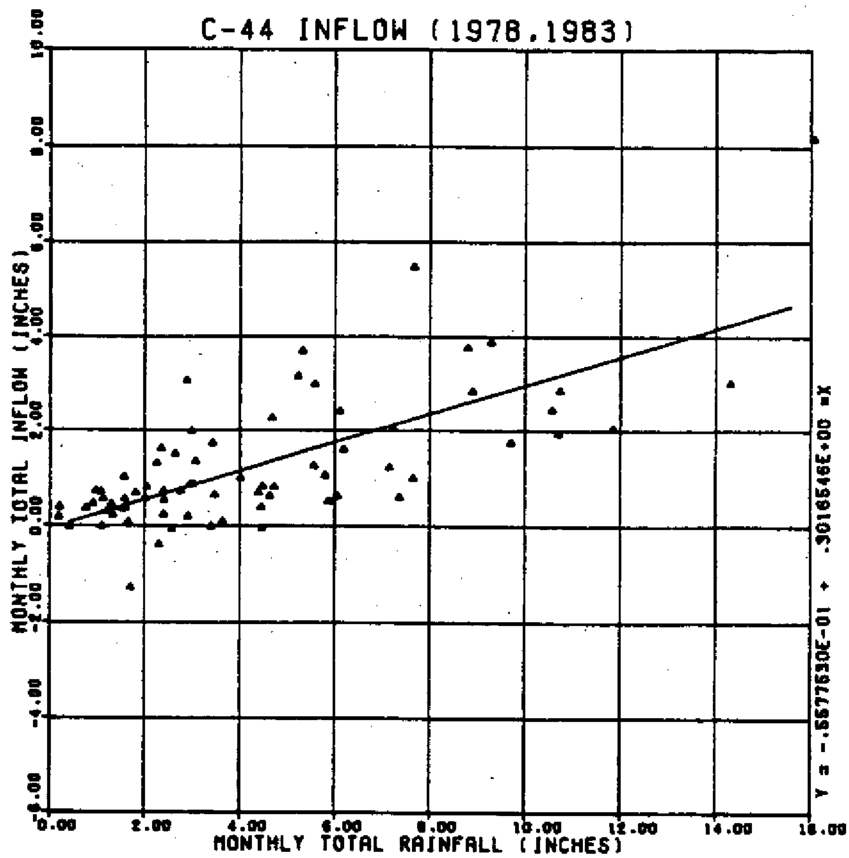


First, the lock flow must be included. Second, the limited record must be extended if possible.

The adjustments of S-308 data were based on work done by Alvin Castro (SFWMD), who applied the South Florida Water Management Model to the Upper East Coast of Florida. Essentially, the adjustments were based on a mass balance method, taking into account the stage difference between Lake Okeechobee and C-44 when the lock was open. Description and application of the computer model can be found in SFWMD Technical Publication 84-3.

The C-44 inflow record was extended by regression with rainfall. The usefulness of the extension is related to the degree of correlation . The first step was to search for a regression model that would optimize the correlation. A number of regression models were examined. These included simple linear regression of inflow versus rainfall, regression of inflow versus rainfall on each calendar month to account for the seasonality effect, and multiple regression of inflow versus concurrent and antecedent rainfall of different durations to account for the antecedent wetness effect. Stepwise multiple regression and graphical plots were used to assist in the selection. Although more complex regression models always improved the correlation coefficient, the improvements were found to be too small (less than 0.04) to warrant their usage. At the end, a simple linear regression model of monthly inflow versus monthly rainfall was selected. This regression equation has a correlation coefficient of 0.72 and is plotted in Figure 2.

Two questions arose after the selection of an appropriate regression model. First, how long the record should be extended, and second, whether the extended record will improve the statistical information. Linear regression with correlation coefficient less than one has a tendency to reduce the variance of the predictions, except when the independent variables used in the extension have greater variability to compensate the reduction. To assure that the extension is worthwhile, a statistical F-test was used to compare the variance before and after the extension. A criterion was set such that if the variance was significantly reduced, the extension would be rejected.



Note: One inch inflow equals 11731 acre-ft, based on basin area of 140772 acres.

Figure 2. C-44 Inflow and Rainfall Relationship

The original record was extended backward from 1978 to 1969, 1960, and 1952. The F-test indicated that, within one percent significance, the extended record back to 1969 was acceptable; beyond 1969, the variance would be significantly reduced. Based on the F-test results, the C-44 inflow record was extended backward to 1969. The rainfall and C-44 inflow data (original and extended) are shown in Table 1.

Some implications can be derived from the regression equation. The negative intercept (-0.056) indicates that there is a net withdrawal from the canal when the monthly rainfall is zero or very small. The positive slope (0.302) indicates that the monthly runoff coefficient is approximately 0.3, which is considered typical in this region.

Table 1. Rainfall And C-44 Inflow Data

Note: All data in inches over basin area of 140772 acres

<u>C-44 Basin Rainfall</u> (Mean rainfall at St Lucie and Port Mayaca locks)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1952	1.28	5.17	2.54	1.67	2.11	2.71	6.76	6.19	3.49	12.53	.08	.25
1953	1.91	2.01	2.07	4.33	.90	13.38	10.96	8.89	10.65	8.82	1.39	1.79
1954	.23	2.70	2.82	5.30	5.54	11.15	7.00	5.20	9.82	4.32	2.33	1.48
1955	1.67	2.35	1.47	3.22	2.11	11.20	6.95	5.83	4.67	2.74	.09	4.60
1956	.82	.95	.53	3.65	2.68	4.75	3.47	5.36	5.27	8.09	.22	1.33
1957	2.78	2.99	3.61	5.97	5.09	3.87	7.65	7.59	6.83	6.07	.97	5.19
1958	8.61	.62	5.81	3.44	7.41	3.73	4.36	3.83	6.83	5.10	.78	4.99
1959	2.84	.34	6.09	3.20	10.03	11.33	6.68	5.55	8.50	7.94	3.63	2.74
1960	.13	6.00	1.24	5.92	4.10	7.89	6.06	4.50	16.15	3.71	1.19	.53
1961	2.99	.50	1.74	1.76	7.31	2.96	2.77	6.87	1.44	5.08	1.50	.03
1962	.62	.84	3.83	5.06	1.32	6.46	8.50	9.24	9.10	2.21	1.45	.14
1963	.88	4.39	1.06	.91	4.55	7.16	4.82	4.80	6.21	3.57	2.68	6.85
1964	1.93	2.65	.41	3.76	3.83	6.79	10.46	12.04	4.68	8.38	.66	1.38
1965	.54	5.01	1.92	.75	.90	10.58	6.10	7.15	5.32	9.73	.36	.91
1966	5.83	4.38	1.71	4.77	4.35	14.25	5.00	5.17	7.08	9.77	1.40	1.00
1967	1.12	3.46	1.43	.05	2.63	10.79	6.16	9.49	7.01	10.92	.63	1.50
1968	.31	2.36	.77	.24	8.99	16.03	6.94	6.03	7.10	9.37	2.42	.00
1969	1.68	1.89	6.60	1.54	9.71	6.59	5.17	5.81	7.12	11.32	2.10	3.13
1970	4.37	4.15	14.97	.02	7.60	8.75	6.12	6.64	5.42	4.44	.05	.16
1971	.34	2.95	1.19	.19	8.14	3.99	9.05	5.76	5.71	7.17	3.59	2.26
1972	1.16	1.86	2.75	4.81	8.93	12.48	8.28	3.57	2.90	2.53	2.58	2.36
1973	2.14	1.92	2.33	1.16	3.70	7.52	13.03	7.61	5.57	5.06	1.15	1.30
1974	1.67	.16	1.23	1.57	2.63	11.29	7.95	6.99	6.89	3.83	2.45	1.09
1975	.66	2.33	1.47	.56	6.56	3.61	13.29	3.04	7.53	3.49	1.10	.46
1976	.24	2.35	.06	1.66	10.13	6.85	3.68	9.59	4.85	1.59	3.28	1.99
1977	3.61	.45	.73	1.01	1.95	3.94	7.03	7.04	9.73	5.78	4.74	4.50
1978	2.40	1.58	2.41	1.66	3.63	7.66	7.15	4.68	5.56	4.47	3.46	7.35
1979	5.32	.19	1.59	2.58	7.65	3.39	2.91	3.07	16.07	2.89	2.64	1.54
1980	2.40	2.95	1.30	2.01	5.87	1.20	4.72	4.63	9.70	2.26	1.81	1.12
1981	.91	1.57	.97	.20	2.31	1.08	4.38	14.31	5.23	2.05	1.10	.41
1982	.76	3.01	10.56	3.42	11.85	8.80	8.90	5.58	6.05	2.99	7.22	1.33
1983	4.45	10.73	4.47	2.76	1.71	6.19	5.80	10.70	6.11	9.29	2.35	4.01

<u>C-44 Inflow</u> (Difference between S80 and S308 flows. 1969-1977 data estimated)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1969	.45	.51	1.94	.41	2.87	1.93	1.50	1.70	2.09	3.36	.58	.89
1970	1.26	1.20	4.46	-.06	2.24	2.58	1.79	1.95	1.58	1.28	-.04	-.01
1971	.05	.83	.30	.00	2.40	1.15	2.67	1.68	1.67	2.11	1.03	.63
1972	.29	.51	.77	1.40	2.64	3.71	2.44	1.02	.82	.71	.72	.66
1973	.59	.52	.65	.29	1.06	2.21	3.87	2.24	1.62	1.47	.29	.34
1974	.45	-.01	.32	.42	.74	3.35	2.34	2.05	2.02	1.10	.68	.27
1975	.14	.65	.39	.11	1.92	1.03	3.95	.86	2.22	1.00	.28	.08
1976	.02	.65	-.04	.44	3.00	2.01	1.05	2.84	1.41	.42	.93	.54
1977	1.03	.08	.16	.25	.53	1.13	2.06	2.07	2.88	1.69	1.37	1.30
1978	.73	.55	.54	.07	.09	5.47	1.22	2.26	1.25	.82	.64	.59
1979	3.69	.18	.37	-.07	.99	-.02	.19	1.35	8.18	3.06	1.50	.36
1980	.23	.86	.45	.57	.51	.30	.81	.62	1.74	1.31	.68	.56
1981	.46	1.01	.72	.38	-.39	.70	.69	3.01	3.15	.80	-.01	-.03
1982	.36	.87	2.44	1.73	2.05	3.76	2.83	2.98	.62	1.98	2.04	.22
1983	.39	2.85	-.05	.72	-1.28	1.59	1.05	1.93	2.41	3.88	1.61	1.00

III. FREQUENCY ANALYSIS

In water supply planning it is important to know the probabilistic distribution of the availability of water in space as well as in duration and seasonal trends. This section describes procedures used to prepare frequency distribution curves for calendar months and for durations of one to twelve months. In addition, a flow duration curve and a frequency table depicting the time occurrences of annual minima are included. The information is summarized in four isofrequency curves (pages 14 through 17). The meanings of the frequency curves are defined to provide guidelines in their proper interpretation and application.

1. Flow Duration Curve

A flow duration curve is not a true frequency distribution curve, because probabilistic levels cannot be assigned to the data. A basic requirement for frequency analysis is that the data must be independent. Monthly or daily data are not independent but are serially correlated. For example, the flow in May is influenced by the flow in April, less by the flow in March, and so on. A flow duration curve is a straightforward presentation of the historical flow record in such a way that the percent of time the flow is exceeded or not exceeded is shown.

Although flow duration curves are not frequency curves, they have been used similarly to frequency curves. When the flow record is too short (less than two years) for frequency analysis, flow duration curves are often used as the sole source of information for hydraulic design and water supply planning purposes. In view of the relatively short historical record available for C-44 inflow (six years), a monthly flow duration curve is shown in Figure 3 for reference.

2. Frequency Distribution Curves, Calendar Month

Frequency distributions by calendar months are useful in water supply planning where seasonal variation is important. Such uses include developing a regulation schedule for a reservoir or projecting irrigation water requirements which vary with season.

The statistical sample is a set of monthly data of an individual calendar month such as, all flows in January, all flows in February, and so on. Since the individual data points are at least 12 months apart, the data can be assumed to be independent. The frequency distributions of the data were plotted on Normal and Gumbel (extremal) probability papers to see which distribution fits the data best. Log distributions (Log Pearson, Log Gumbel, Log Normal, etc.) were not considered because they could not accommodate negative values that were common with C-44 inflow. The differences in fit between the two distributions are small. In a majority of the cases the data fit slightly better in a Gumbel distribution, and based on this a Gumbel distribution was selected for this application.

Irrespective of the distribution used, the trends of the plots are similar. A statistical sample of hydrologic data in a calendar month is a heterogeneous combination of flood events, drought events, and normal events. A frequency distribution plot of such data reveals generally two distinct slopes; the flatter slope belongs to the drought events and the steeper slope to the flood events. Normal events appear to be in the transitional region. For water supply planning purposes, only the normal and drought events are of concern. Accordingly, least squares straight lines were fitted to the lower zone. By examining a number of the scatter plots, it was decided that the fitting should cover the lower two-thirds of the data points, which delineates the slope of the drought events. The calendar month frequency distribution curves for rainfall and C-44 inflow are included in the Appendix (page A2 through A13).

3. Frequency Distribution Curves, Monthly Duration

In water supply planning, it is important to know the critical conditions for various durations of time. Duration frequency curves provide information to define drought itself, to plan the storage capacity of a reservoir, or to determine the amount of supplemental water required from outside sources to satisfy the local demand.

The statistical sample is a set of annual minima of a specific duration, and here one through twelve month durations were included. For example, a sample of two months duration will be a set of two month minima (which may be any two consecutive months) taken from a number of annual cycles. The annual cycle used here is a water year which extends from November through October of the following year. Water year, rather than calendar year, is used to ensure that the entire dry season is included without splitting it into two consecutive annual cycles. This has been shown to produce a better fit on long duration frequencies. The duration frequency distributions for rainfall and C-44 inflow are included in the Appendix (pages A14 through A25).

4. Isofrequency Curves

The frequency distribution curves described above provide basic information to estimate rainfall or C-44 inflow at any probability level. For water supply planning purposes, however, it is seldom necessary to know more than a few probability levels. Isofrequency curves of both calendar months and durations are constructed (Figures 4 through 7) for 50%, 20%, 10%, and 5% probability levels, which correspond to return intervals of once in 2 years (normal year), once in 5 years, once in 10 years and once in 20 years, respectively.

Although estimates at any probability level can be made from the frequency distribution curves, the reliability of the estimates decreases with decreasing probability levels. As a rule, the maximum return interval that can be projected is limited to twice the length of the data record. Considering the lengths of records available, it is permissible to project rainfall up to once in 60 years, and C-44 inflow up to once in 12 years. If the flow extension is considered, it is probably reliable to project C-44 inflow up to once in 20 years. The longest return interval selected for the isofrequency curves is once in 20 years which is considered to be within reasonable confidence limits as well as adequate enough for most water supply planning purposes.

Although the construction procedures of the isofrequency curves for calendar months and durations are essentially identical, the meanings of the two isofrequencies are different. Calendar month isofrequency curves are not frequency hydrographs. The dashed lines (Figures 4 and 5) joining the discrete data points are for visual guidance only and do not indicate that the occurrences are sequential. Therefore, it is incorrect to read a calendar month isofrequency curve as the probable flow or rainfall distribution in a calendar year at the probability level indicated. The probability of such joint occurrences will be very small. The isofrequency curve is simply a concise summary of the same information provided by the basic frequency curves (page A2 through A13).

The duration isofrequency curves, on the other hand, are frequency mass hydrographs (from here on they are also referred to as frequency mass curves). The data points are continuous and it is legitimate to interpolate between them. Frequency mass curves, in addition to concisely summarizing the basic frequency information, can be used directly for many water supply planning purposes. If a mass demand curve is superimposed onto a frequency mass curve, the duration of the critical drought period can be determined as the duration to the interception point. The maximum deviation of the two curves is an estimate of the storage requirement for a reservoir, and in the case of Martin County, it is an estimate of the amount of supplemental water needed from Lake Okeechobee. An example of such an application is illustrated in Figure 7.

The applications illustrated are suitable if the demand can be expressed in constant draft rate, as is the case for most urban water demand. For demands that are variable and probabilistic in nature, such as irrigation water demand, more complex analytical techniques are needed. This may require the construction of frequency demand curves similar to the frequency curves presented here, or the use of water budget modeling to analyze the situation.

5. Frequency Time Table, Annual Minimum

The frequency duration curves provide statistical information on the magnitudes only without reference to the time of occurrence. For example, an annual minimum rainfall of two months duration may occur in any two consecutive months in a calendar year, although it will most likely occur during the dry season. In some planning applications, it is of interest to know when the critical conditions are most likely to occur. A frequency table depicting the times of occurrence of the annual minima is included in Table 2.

Table 2
Frequency Time Table on the Occurrence of Annual Minimum

RAINFALL

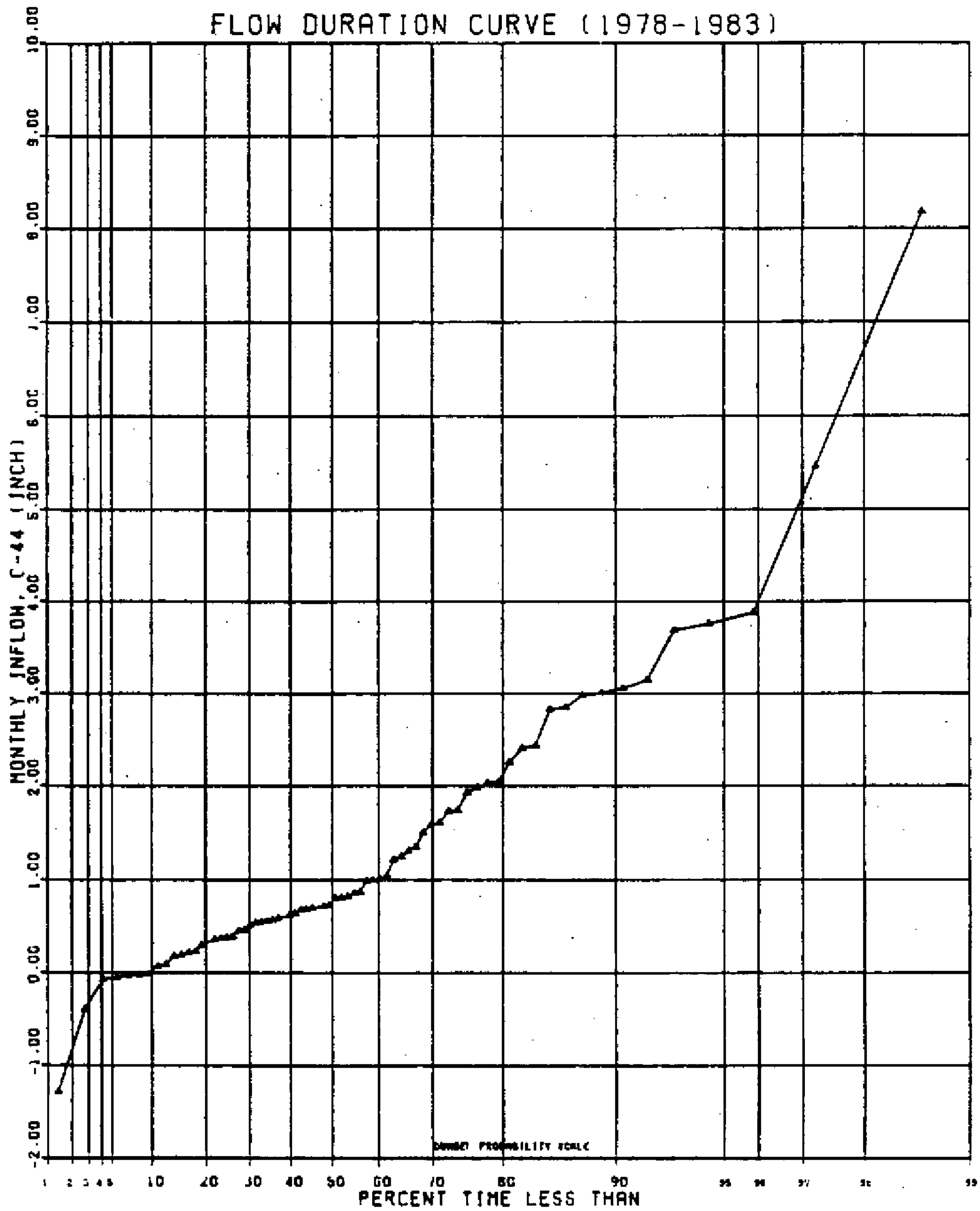
Duration (months)	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	16%	16%	13%	***23%***	10%	19%	0%	3%	0%	0%	0%	0%
2	23%	***32%***	7%	19%	16%	3%*	0%	0%	0%	0%	0%	0%
3	***48%***	16%	7%	29%	0%	0%	0%	0%	0%	0%	0%	0%
4	***48%***	19%	29%	3%	0%	0%	0%	0%	0%	0%	0%	0%
5	***48%***	36%	13%	3%	0%	0%	0%	0%	0%	0%	0%	0%
6	***87%***	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

C-44 INFLOW

Duration (months)	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	7%	13%	20%	13%	7%	***27%***	13%	0%	0%	0%	0%	0%
2	20%	***33%***	7%	7%	7%	20%	0%	7%	0%	0%	0%	0%
3	***27%***	20%	7%	20%	13%	13%	0%	0%	0%	0%	0%	0%
4	***33%***	13%	13%	13%	13%	13%	0%	0%	0%	0%	0%	0%
5	***33%***	***33%***	13%	7%	13%	0%	0%	0%	0%	0%	0%	0%
6	***60%***	27%	7%	7%	0%	0%	0%	0%	0%	0%	0%	0%

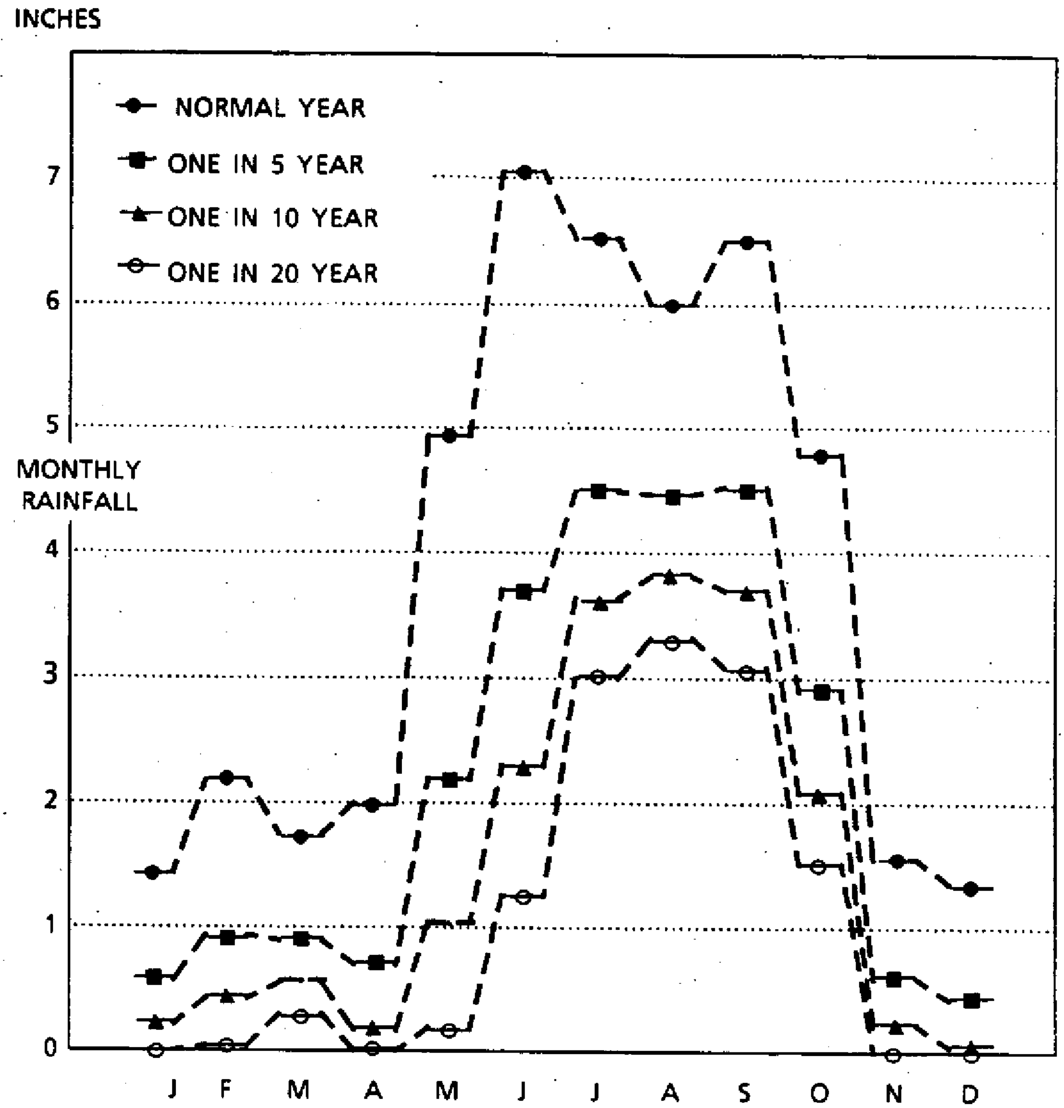
*Example: 3 percent of the time annual minimum rainfall of 2-month duration occurs in April and May (April is the beginning month).

Note: ***Bold*** figures refer to the most frequent time of occurrence.



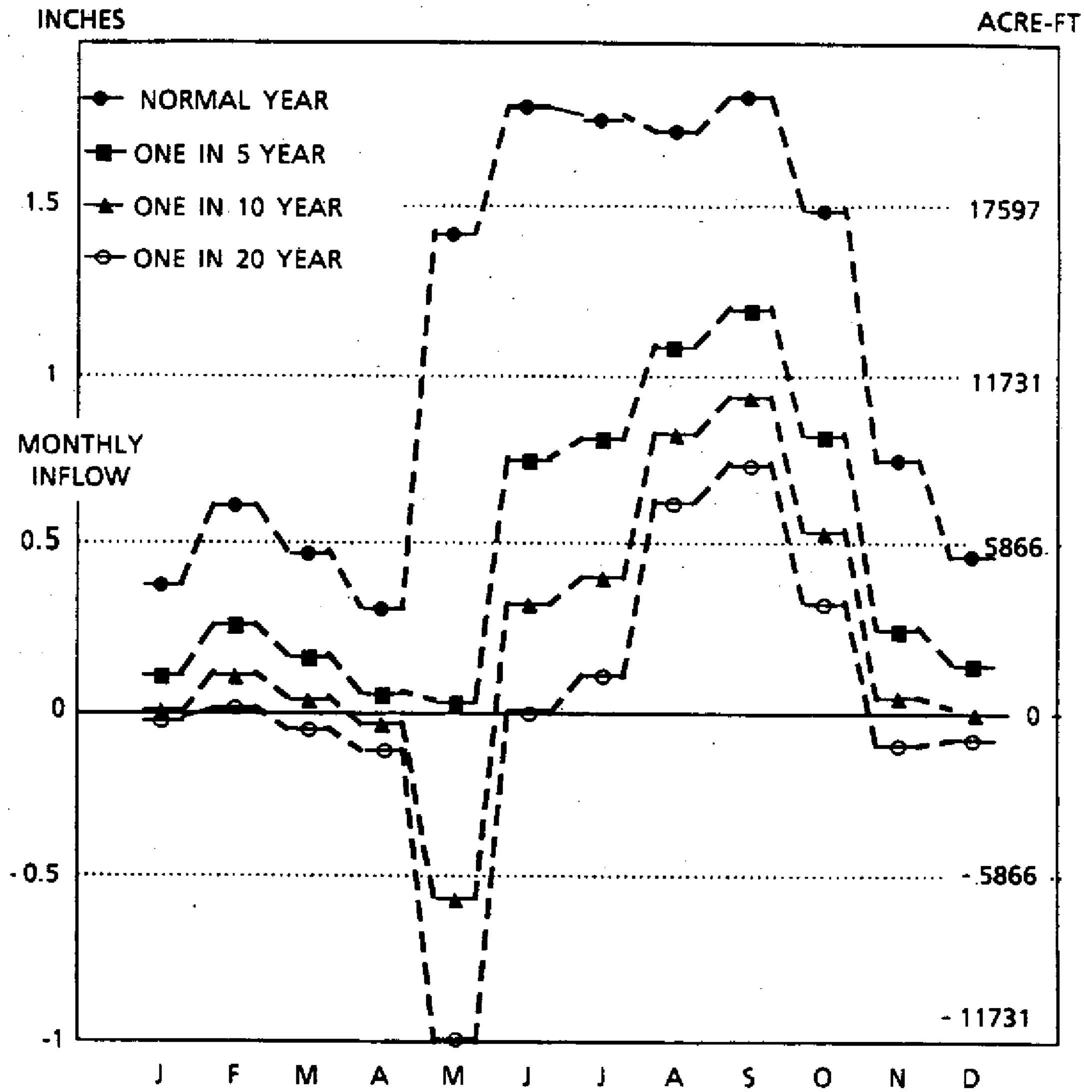
Note: One inch inflow equals 11731 acre-ft, based on basin area of 140772 acres

Figure 3. Flow Duration Curve, C-44 Inflow (1978-1983)



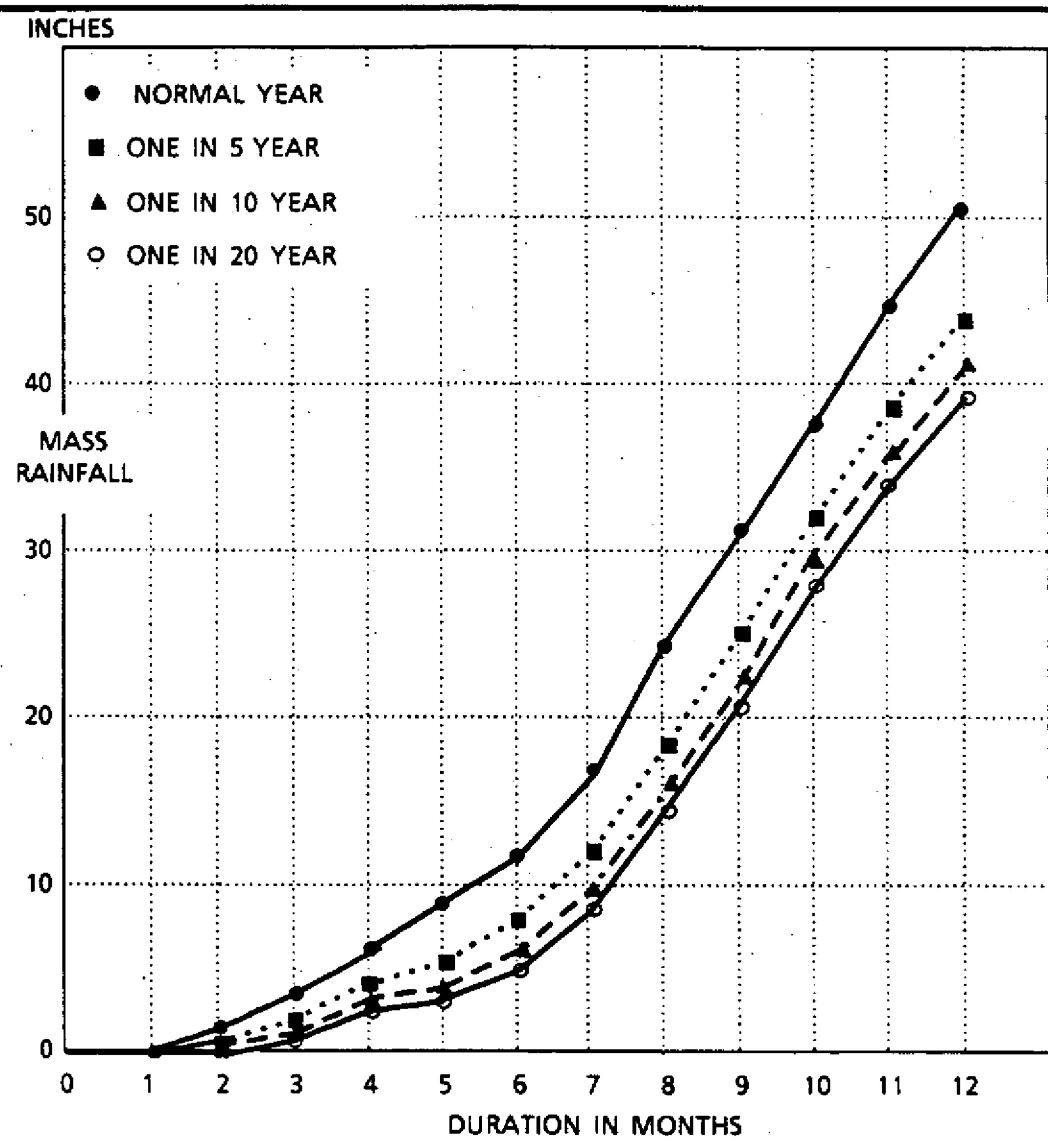
Return Interval (years)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	(data in inches)											
1 in 20	0	.05	.30	0	.20	1.26	3.02	3.33	3.09	1.52	0	0
1 in 10	.22	.44	.57	.19	1.06	2.31	3.66	3.82	3.71	2.11	.22	.06
1 in 5	.59	.96	.93	.74	2.23	3.72	4.53	4.48	4.55	2.92	.62	.46
Normal	1.48	2.20	1.79	2.05	4.99	7.09	6.59	6.05	6.54	4.83	1.58	1.41

Figure 4. Rainfall Isofrequency Curves, Calendar Months



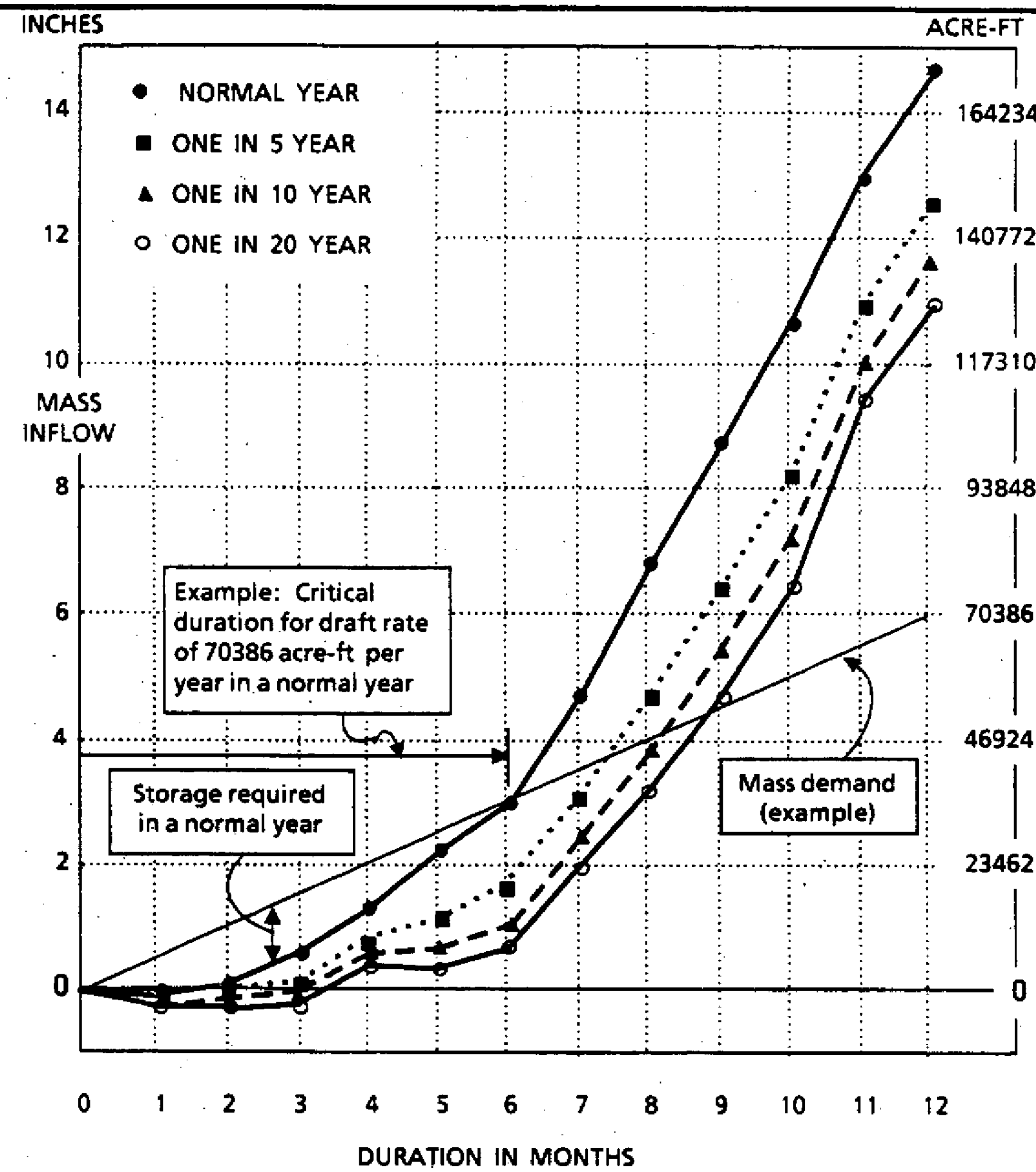
Return Interval (years)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	(data in inches over basin area of 140772 acres)											
1 in 20	-.03	.01	-.06	-.12	-1.08	-.01	.11	.63	.74	.33	-.11	-.09
1 in 10	.05	.12	.04	-.04	-.64	.32	.41	.83	.94	.55	.04	.01
1 in 5	.17	.27	.17	.06	-.04	.76	.83	1.10	1.21	.84	.25	.15
Normal	.44	.63	.48	.32	1.37	1.82	1.81	1.75	1.85	1.53	.75	.47

Figure 5. C-44 Inflow Isofrequency Curves, Calendar Months



Return Interval (years)	Duration in months 1	2	3	4	5	6	7	8	9	10	11	12
	(data in inches)											
1 in 20	0	.12	.91	2.66	3.32	5.20	8.73	14.47	20.84	28.03	34.23	39.23
1 in 10	0	.44	1.44	3.35	4.42	6.48	10.27	16.33	22.78	29.86	36.19	41.32
1 in 5	.05	.86	2.15	4.29	5.91	8.21	12.34	18.83	25.40	32.33	38.84	44.14
Normal	.35	1.86	3.86	6.52	9.45	12.33	17.27	24.80	31.62	38.19	45.13	50.85

Figure 6. Rainfall Isofrequency Curves, Monthly Durations



Return Interval (years)	Duration in months 1	2	3	4	5	6	7	8	9	10	11	12
	(data in inches over basin area of 140772 acres)											
1 in 20	-.25	-.34	-.24	.43	.38	.71	1.97	3.20	4.73	6.48	9.40	10.93
1 in 10	-.21	-.23	-.07	.60	.73	1.12	2.46	3.86	5.46	7.22	10.04	11.61
1 in 5	-.15	-.08	.17	.83	1.20	1.68	3.12	4.75	6.45	8.23	10.90	12.53
Normal	-.01	.27	.72	1.38	2.31	3.00	4.69	6.86	8.80	10.63	12.95	14.71

Figure 7. C-44 Inflow Isofrequency Curves, Monthly Durations

IV. DISCUSSION AND RECOMMENDATIONS

The purpose of this report is to provide statistical information on rainfall drought frequency and on the availability of surface water in Martin County. A major objective is to quantify the availability of C-44 canal water that can be developed to meet the growing needs in Stuart and other urban areas in Martin County. This analysis is part of a comprehensive study by the SFWMD to assist Martin County in their water resources planning. The limitations and assumptions of this analysis are reiterated below:

(a) The C-44 inflow was calculated as the difference between the discharges at S-80 and S-308. Because of the way it was calculated, the C-44 inflow included the effect of the existing (1978-1983) canal water usage. The calculated inflow represented the amount available for additional usage as of the conditions in 1979-1983. If calculated inflow was negative, it represented the amount supplemented by Lake Okeechobee. The 1979 land use pattern of the C-44 basin is shown in Figure 1 (page 4). Any major change in land use within the basin from that of 1979 may increase or decrease the canal water availability. The canal water availability presented in this report must then be adjusted accordingly if the change is significant.

(b) The rainfall data were based on the averages from two long term rainfall stations within the C-44 basin, one located at S-80 and the other at S-308. A total of 31 years of data, covering the period of 1952 through 1983, was used in the present analysis. Table 3 compares the rainfall drought frequencies in this report with those currently used by the SFWMD for the upper east coast. The existing SFWMD drought frequencies were based on the average of several long term rainfall stations in Martin and St Lucie Counties with data records through 1977. In comparison, the existing SFWMD estimates are about the same for the longer durations but somewhat higher for the shorter durations. This is because the previous study: (i) covered all of upper east coast and thus used more stations to average rainfall. This has a tendency to smooth out the extremities, (ii) used data through 1977 and thus excluded the 1980-82 drought, and (iii) used Log Pearson Type III distribution for fitting, which may produce slightly different estimates from those produced by the Gumbel distribution used in this analysis.

(c) Relatively long records are available for the rainfall data but only six years of data are available for the C-44 inflow. The C-44 inflow record was extended by regression with rainfall. A statistical F-test was used to check that the variance was not significantly reduced by the extension thereby assuring that the extension is worthwhile. The reliability of the frequency estimates is related to the length of the data record available. In the present case it is permissible, within reasonable confidence limits, to project rainfall up to once in 60 years and for C-44 inflow up to once in 20 years.

Table 3
Comparison of Rainfall Drought Frequencies

Return Interval (years)		Duration In Months							
		1	2	3	4	5	6	7	12
		(data in inches)							
1 in 10	This report[1]	0	.44	1.44	3.35	4.42	6.48	10.27	41.32
	SFWMD[2]	.15	.98	2.00	3.57	5.11	7.24	10.65	41.96
1 in 5	This report	.05	.86	2.15	4.29	5.91	8.21	12.34	44.14
	SFWMD	.22	1.23	2.63	4.45	6.40	8.87	12.85	44.81
Normal	This report	.35	1.86	3.86	6.52	9.45	12.33	17.27	50.85
	SFWMD	.43	1.94	4.18	6.62	9.54	12.65	17.66	50.99

Notes: [1]Based on average basin rainfall in C-44. Data covered up to 1983.
[2]Based on average basin rainfall in upper east coast (St Lucie and Martin Counties). Data covered up to 1977.

The results of this analysis are presented in a series of frequency distribution curves in the Appendix (pages A2 through A25). The same information is summarized in four isofrequency curves and a frequency table, and from these the following implications are observed:

Figure 4. Rainfall Isofrequency Curves, Calendar Months (page 14)

There is a sharp decrease in rainfall after October. The rainfall remains at about the same low level between November and April but rebounds sometime in May or June. The amount of rainfall in May is most variable. A question is often asked as to whether the dry season in Florida begins in October or November. The results here indicate clearly that the dry season in the C-44 basin begins in November and usually ends in April.

Figure 5. C-44 Inflow Isofrequency Curves, Calendar Months (page 15)

The seasonal trend of the C-44 inflow generally follows that of the rainfall with one exception. In a normal year the flow reaches a minimum in April, and in a drier year it reaches minimum in May. For rainfall, there is no sharp month to month differences during the dry season. The inflow, however, follows a slow recession curve which responds to the cumulative effect of dry season rainfall with a lag of one to two months. The flow in May, similar to rainfall, is most variable and unpredictable, as it is dependent on the arrival of the wet season rainfall. Similar responses have been observed in C-43 (Caloosahatchee River Basin) which, hydrologically, is analogous to C-44.

Figure 6. Rainfall Isofrequency Curves, Monthly Durations (page 16)

The annual rainfall in the C-44 basin is about 50 inches in a normal year and 40 inches once in 20 years. In years drier than normal, there is zero to negligible rainfall for at least one month, and less rainfall than evapotranspiration for at least two months out of a year. In other words, rainfall deficit conditions occur for a duration of at least two months for years drier than normal. Much of the difference in rainfall between dry and normal years can be accounted for in the initial six month duration as indicated by a gradual equalization of the slopes among the isofrequency curves.

Figure 7. C-44 Inflow Isofrequency Curves, Monthly Durations (page 17)

A deficit condition is said to occur when there is more withdrawal from the canal than inflow into it. The part of the isofrequency curve that is below zero delineates the magnitude and duration of the deficit condition. Negative inflow represents the amount currently supplemented by Lake Okeechobee. In a normal year, deficit conditions occur for a duration of about one month and reaches three months once in 10 years. Thus, any additional withdrawal from C-44 will prolong the deficit condition and increase the demand from Lake Okeechobee, unless an alternative source of water is developed or the surplus flow in the wet months can be stored in some way for use later. The situation in the C-44 basin is similar to that of the C-43 basin — though the canal flow is plentiful during the wet months, it is inadequate to meet the current demand during some of the dry months and supplemental water from Lake Okeechobee is needed.

Table 2. Frequency Time Table on the Occurrence of Annual Minimum (page 12)

The frequency table indicates that minima of short durations are equally likely to occur in any of the dry months, but for longer durations the time of occurrence is better defined. For example, about 87 % of the time a minimum 6-month rainfall begins in November, but with nearly the same likelihood a minimum 2-month rainfall may occur in November, December, or February (23%, 32%, and 19% respectively).

Under current conditions, supplemental releases from Lake Okeechobee are needed for a duration of about one month in a normal year and three months once in 10 years. Additional withdrawals from C-44 will inevitably impose greater stress on Lake Okeechobee unless an alternate source of water is developed, or a plan to store wet season runoff for use at the time of shortage is implemented.

Storing surplus runoff in surface impoundments is generally inefficient in south Florida as the reservoir would have to be very large but shallow, and the evapotranspiration loss per unit depth of storage would be large. Storing the water in the shallow aquifer is equally difficult because of the lack of storage capacity during the wet months. The following alternatives appear to be reasonable and it is recommended that they should be investigated in detail:

(a) Divert surplus canal flow to recharge depleted wellfield storage as is currently practiced in Lee County, Florida.

(b) Develop wellfields in more inland locations to create cones of depression so as to increase rainfall recharge, and to create storage capacities to store surplus canal water.

(c) Store surplus canal water in the saline artesian aquifer by injection wells and recover the storage for use during the dry season, as is currently under experimentation in Manatee County, Florida.

(d) Increase storage in Lake Okeechobee by backpumping treated runoff during the wet season. The availability of storage capacity in Lake Okeechobee and the cost in treating the runoff may be limiting factors.

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LIST OF APPENDIXES

EXPLANATION ON THE USE OF FREQUENCY DISTRIBUTION CURVES

The frequency distribution curves included in the following pages can be used to project rainfall or C-44 inflow to any drought probability level. The use of these curves is explained below:

1. All data are expressed in inches over the C-44 basin area. This permits comparison of rainfall and C-44 inflow in the same scale. To convert inches to acre-ft, multiply inches by 11731, which is based on a basin area of 140772 acres.

2. The frequency distribution data are plotted on Gumbel probability paper. The x-scale is in percent probability. The reciprocal of the percent probability equals the return interval; for example, a 5 % probability is equivalent to once in 100 / 5 or once in 20 years.

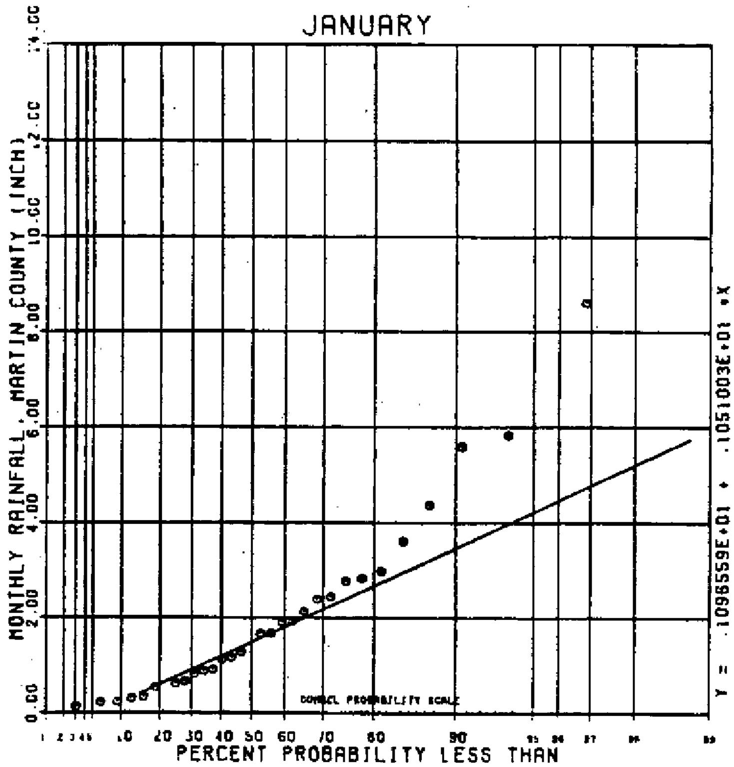
3. The magnitude of rainfall and C-44 inflow at any probability level can be read directly from the curve. In some situations, it is more accurate to calculate from the least squares fitted equation listed along the right side of the graphs. The equation is expressed as $y = A + Bx$, where A and B are the regression coefficients, y is the magnitude of rainfall or inflow, and x is a Gumbel probability transformed variable. The relation between x and probability level P is as follows:

$$x = -log_e(-log_e P)$$

4. For the calendar month frequency curves, only the lower two-thirds of the data points are used in the frequency fitting because only the dry conditions are of concern. Thus, it is permissible only to project droughts but not floods.

5. The reliability of the probability projection is dependent on the length of data record available for the analysis. In this case, projection should be limited to once in 60 years for rainfall and once in 20 years for C-44.

JANUARY



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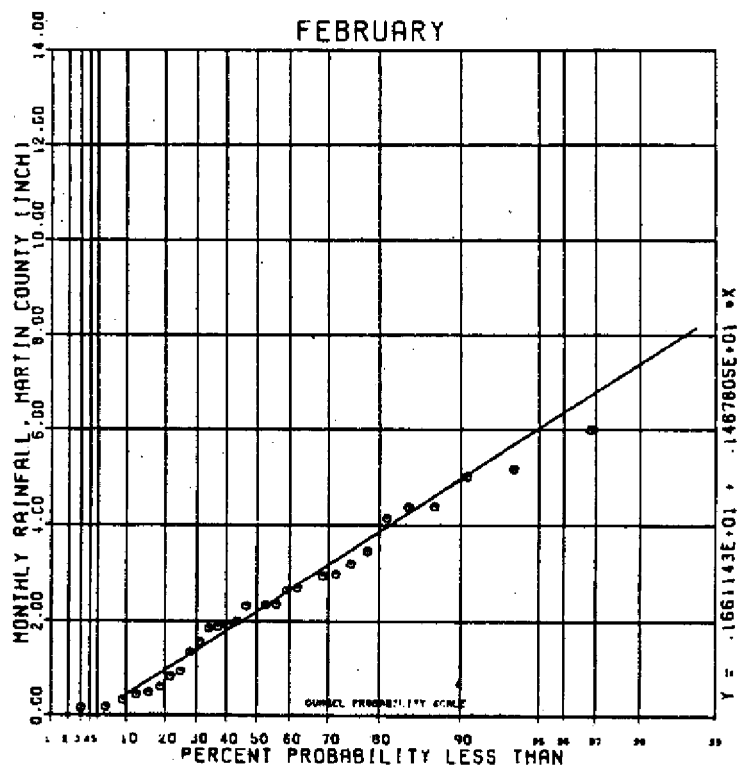

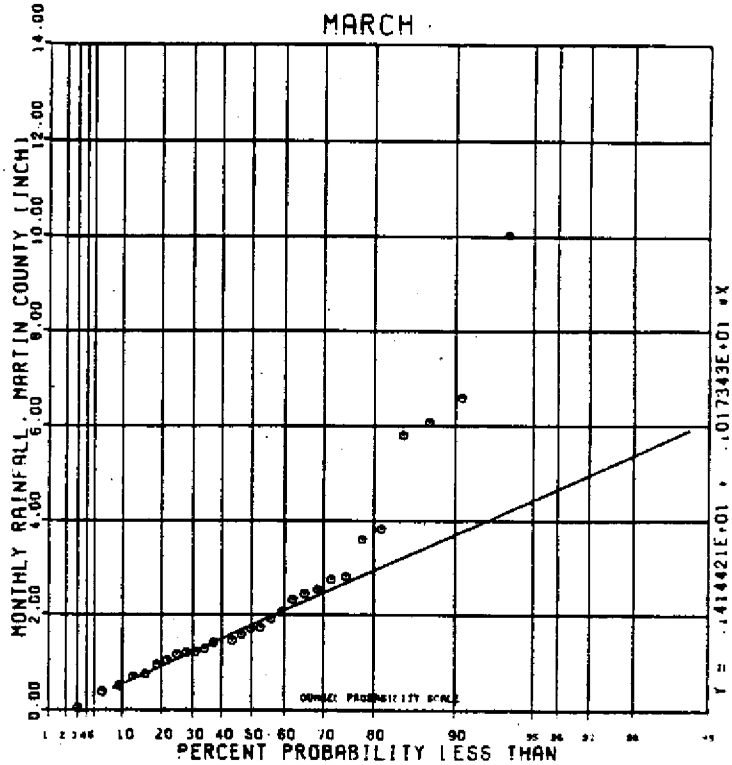
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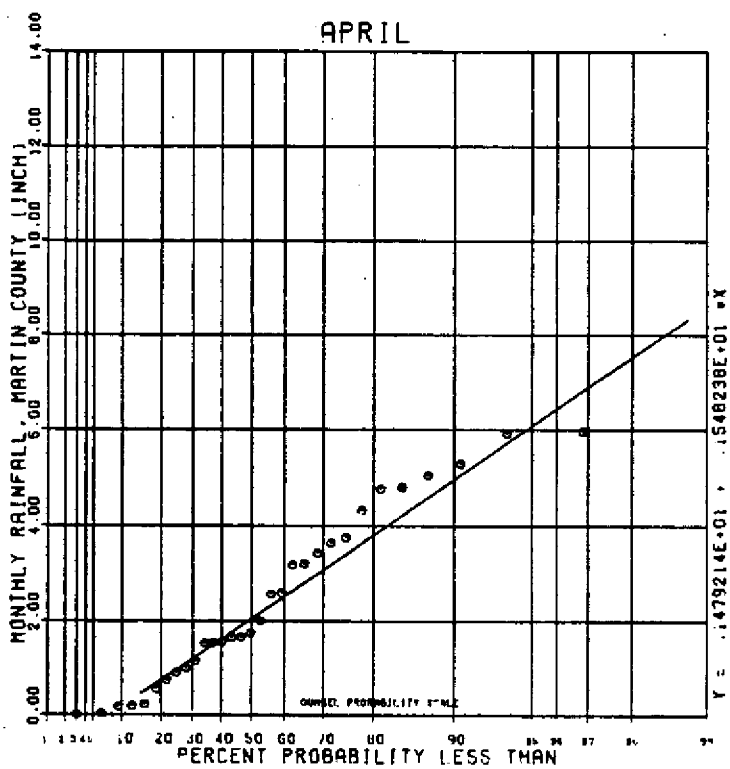
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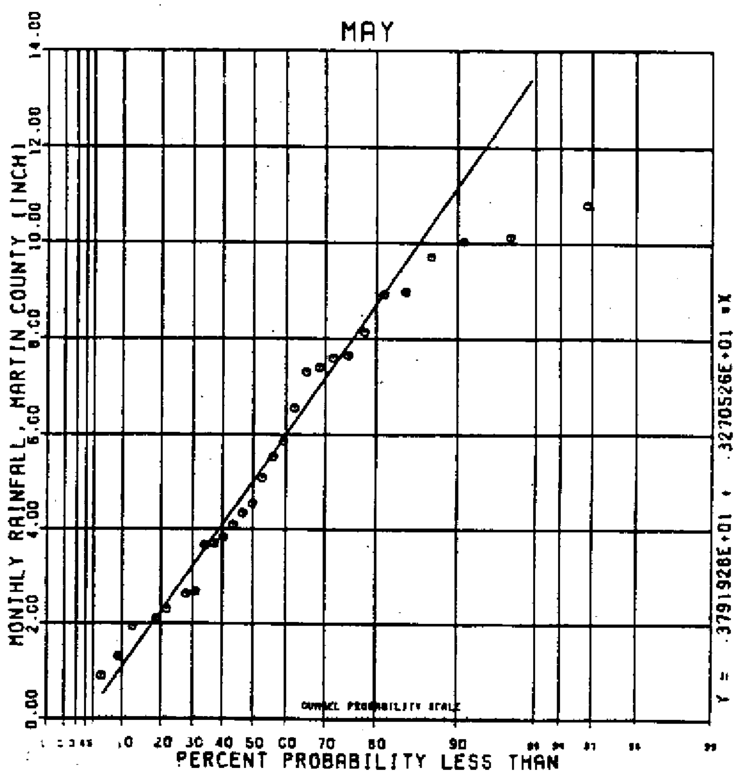
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2.00
4.00
6.00
8.00
10.00
12.00
14.00
10
20
30
40
50
60
70
80
90
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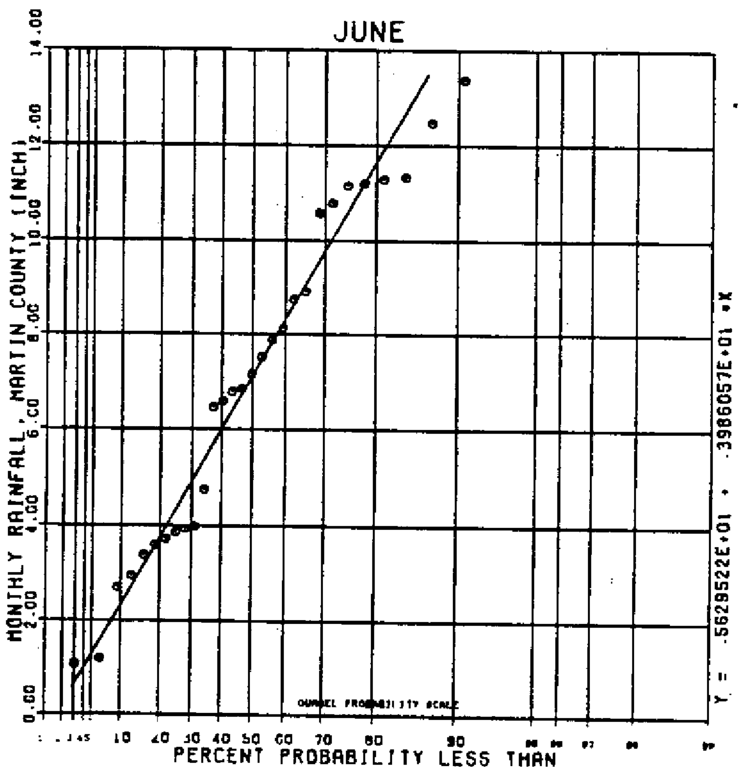
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2.00
4.00
6.00
8.00
10.00
12.00
14.00
10
20
30
40
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80
90
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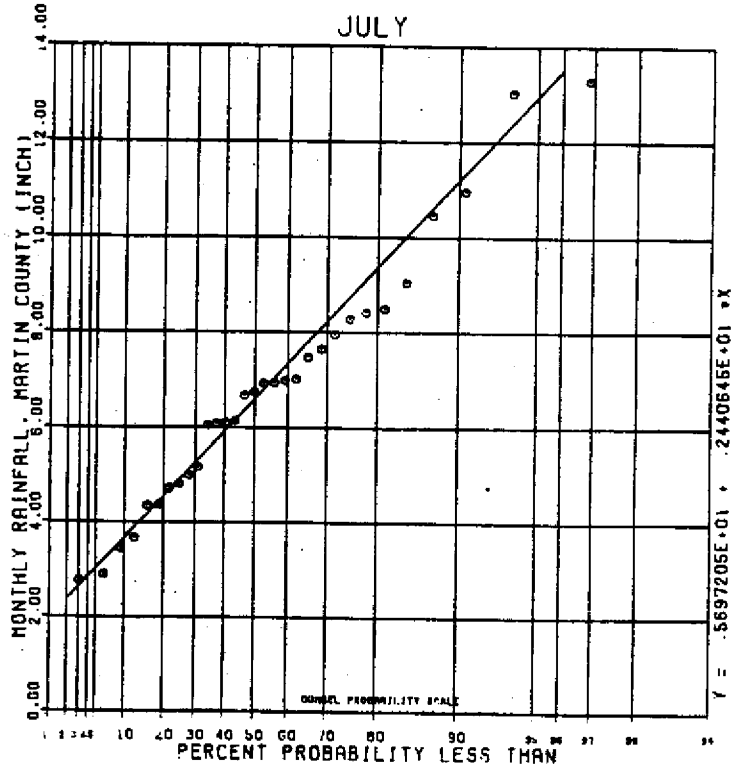
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2.00
4.00
6.00
8.00
10.00
12.00
14.00
10 20 30 40 50 60 70 80 90
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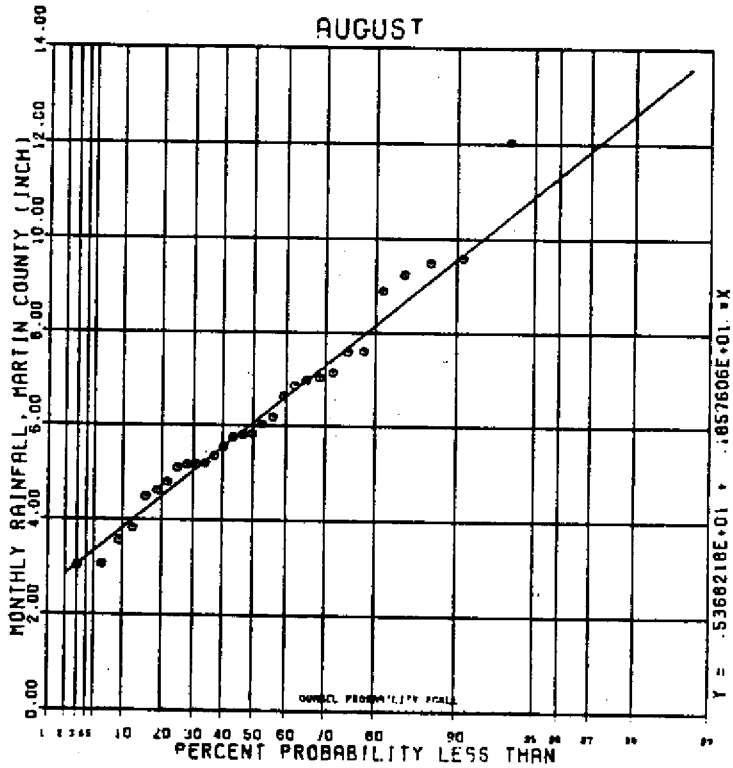
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2.00
4.00
6.00
8.00
10.00
12.00
14.00
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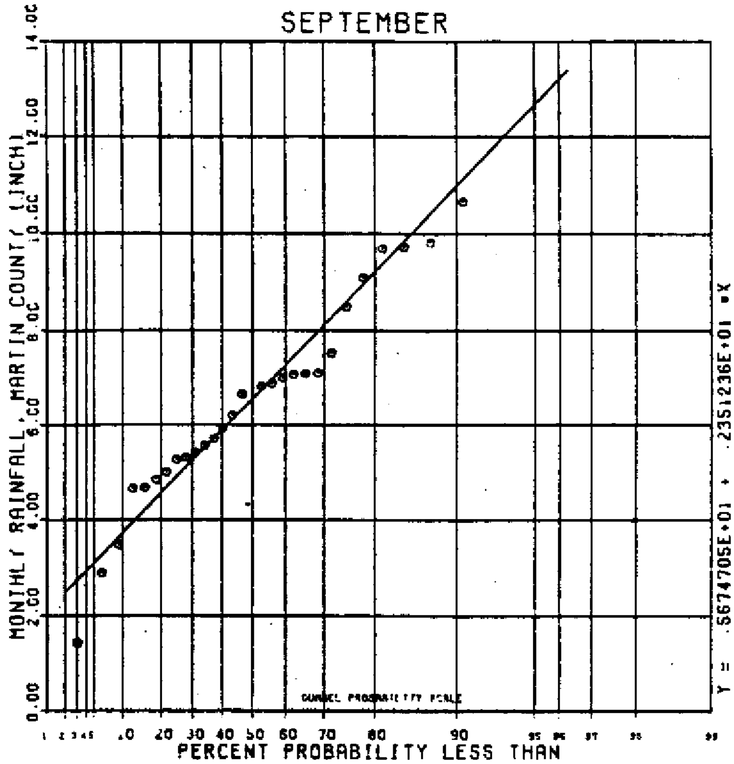
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2.00
4.00
6.00
8.00
10.00
12.00
14.00
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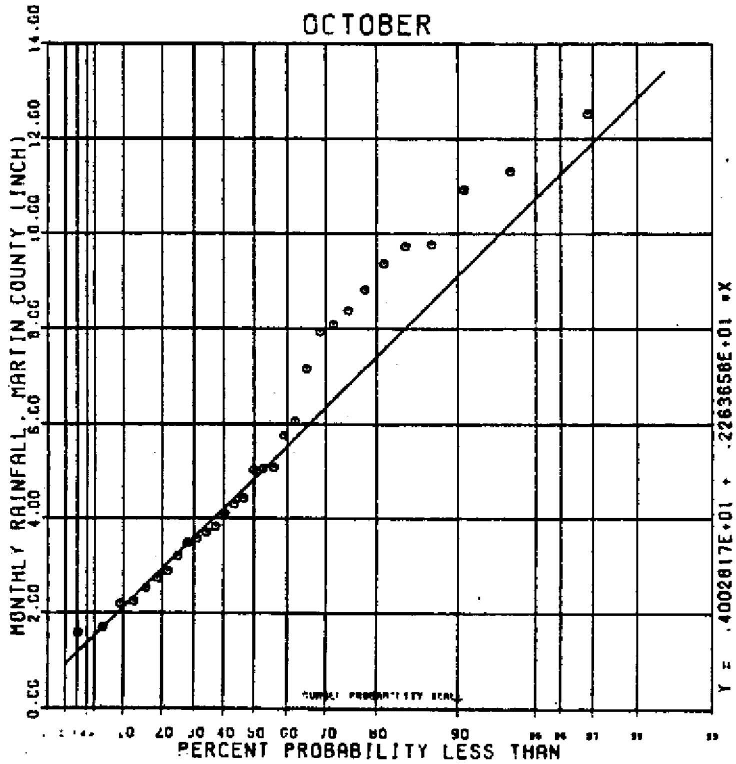
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6.00
8.00
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14.00
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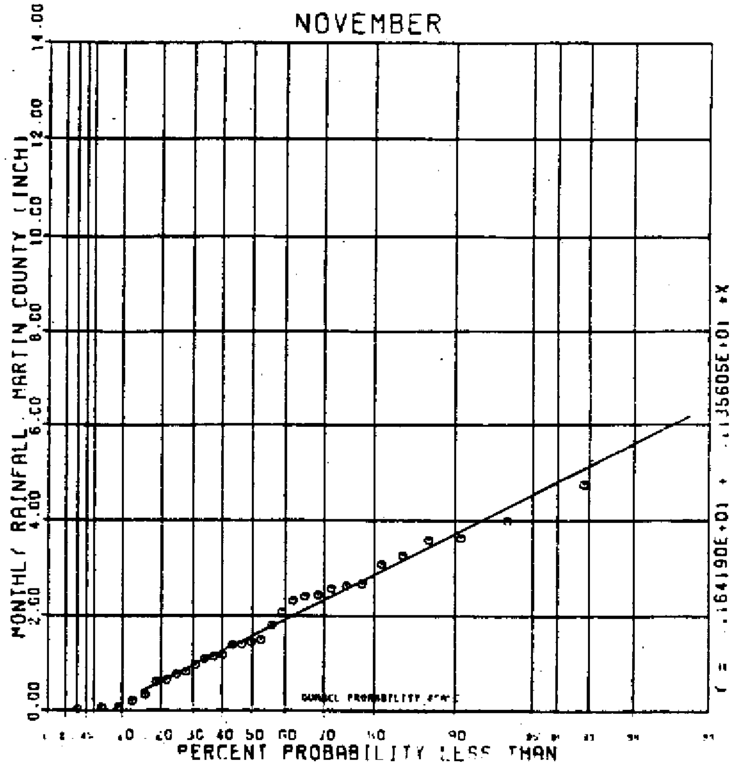
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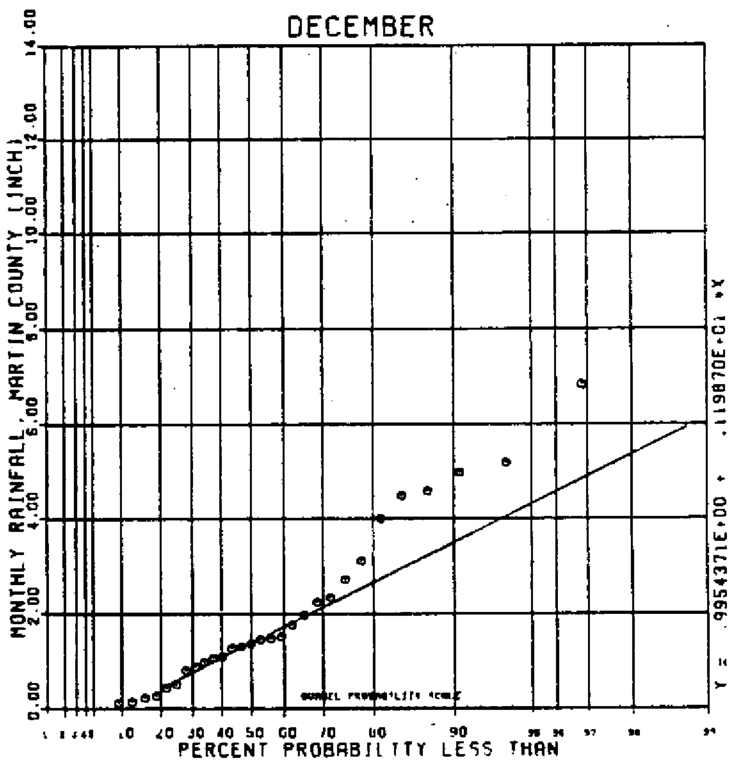
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14.00
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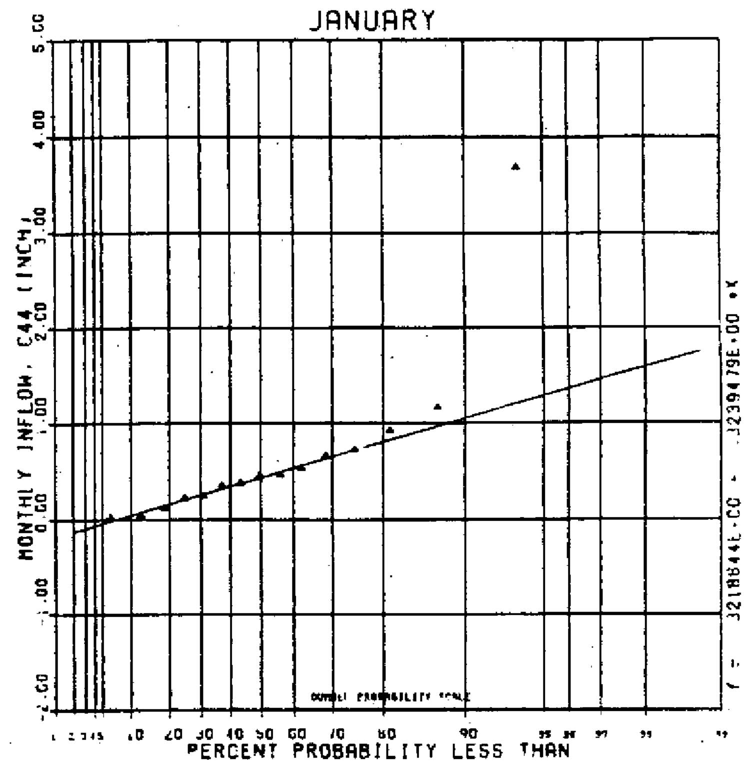
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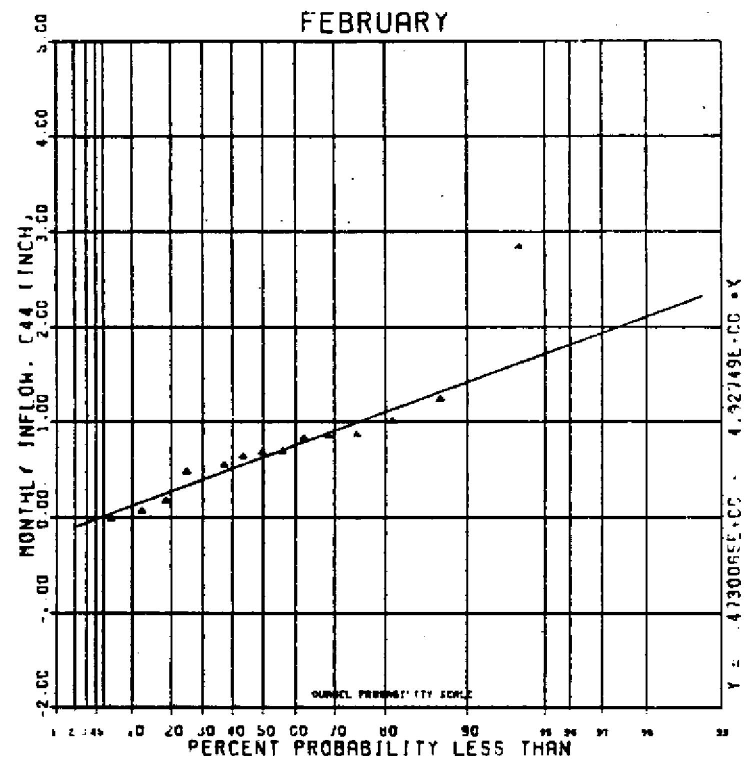
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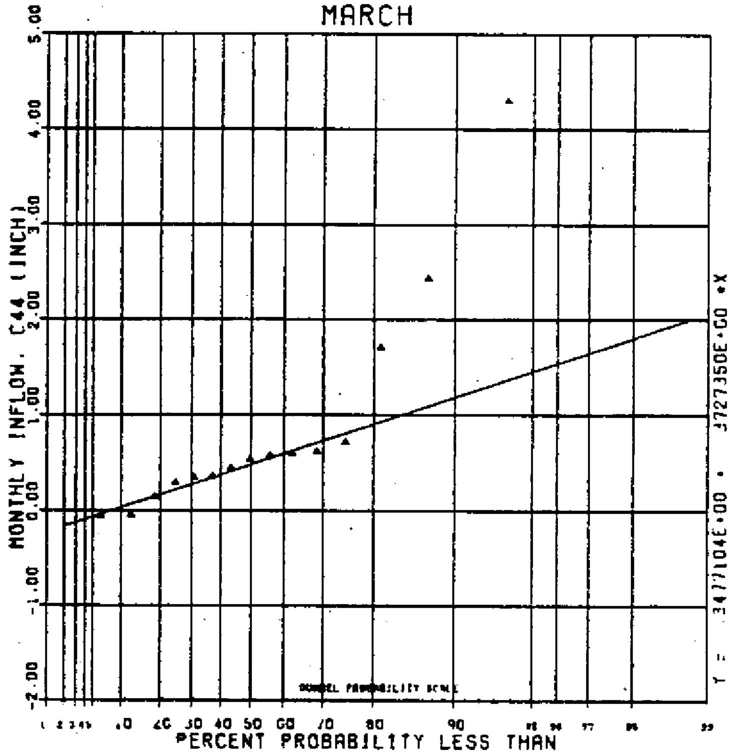
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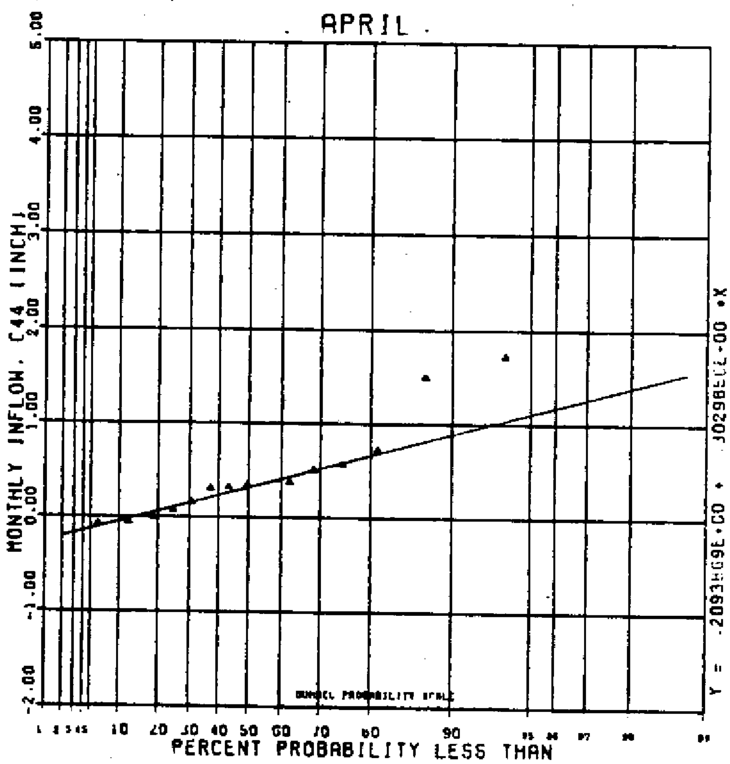
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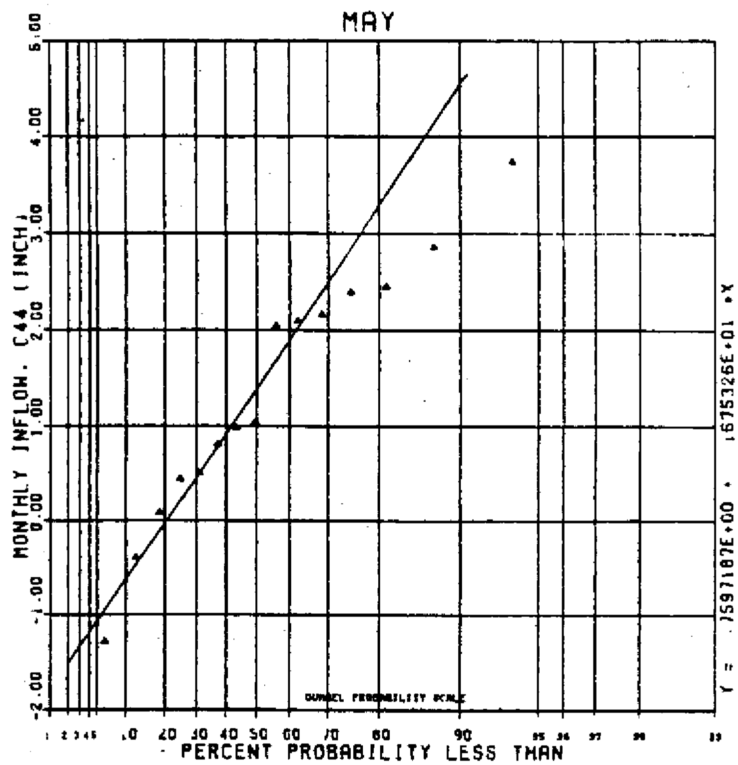
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GUMBEL PROBABILITY SCALE
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30
40
50
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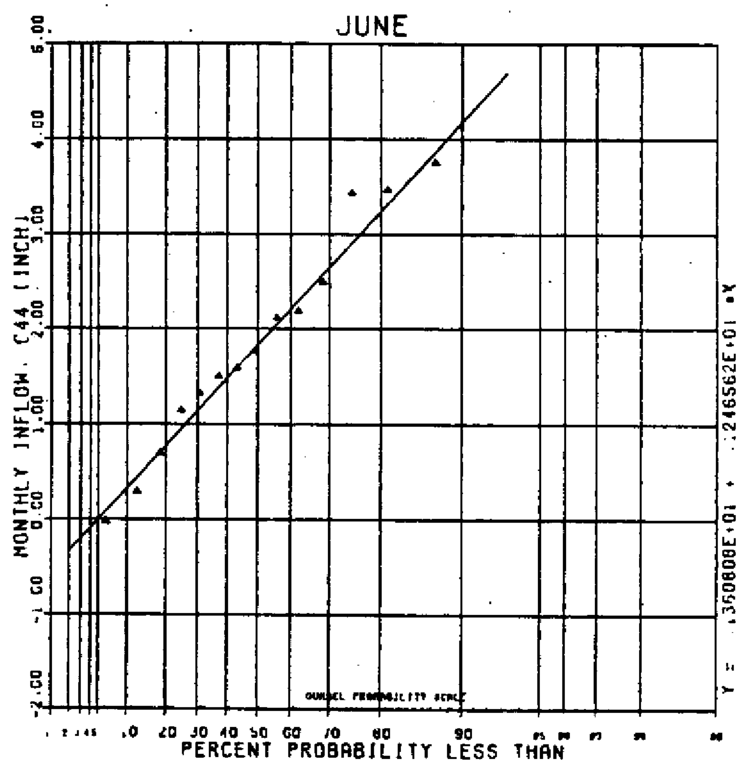
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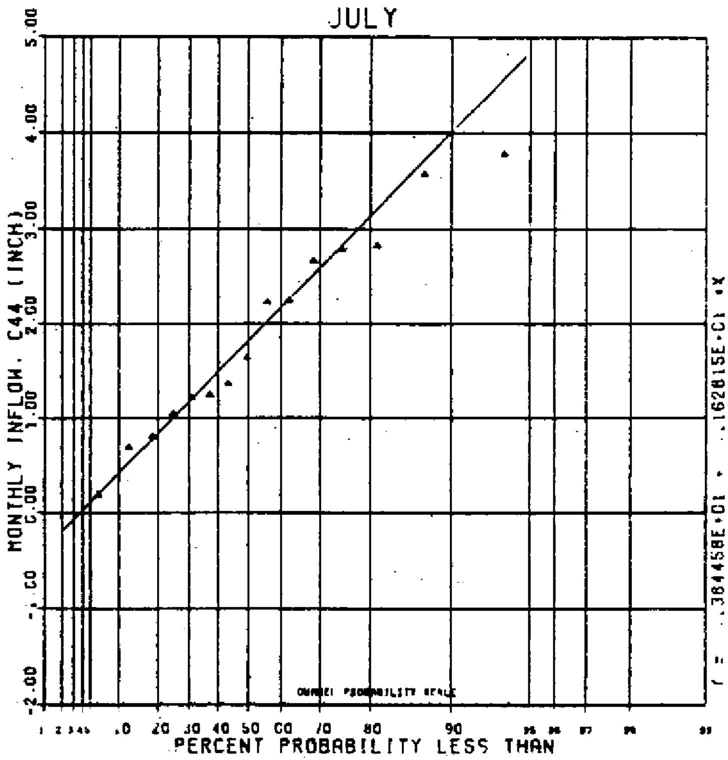
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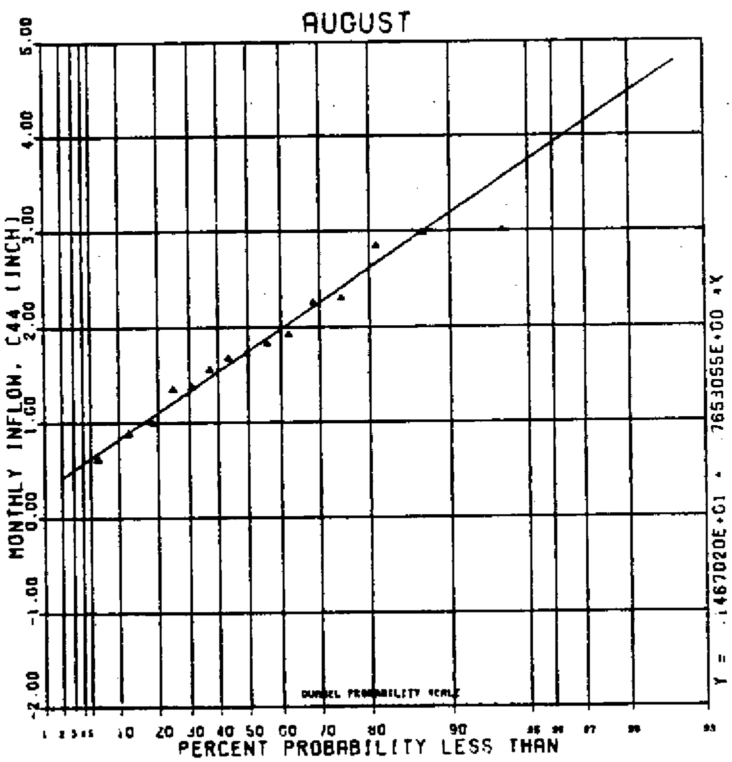
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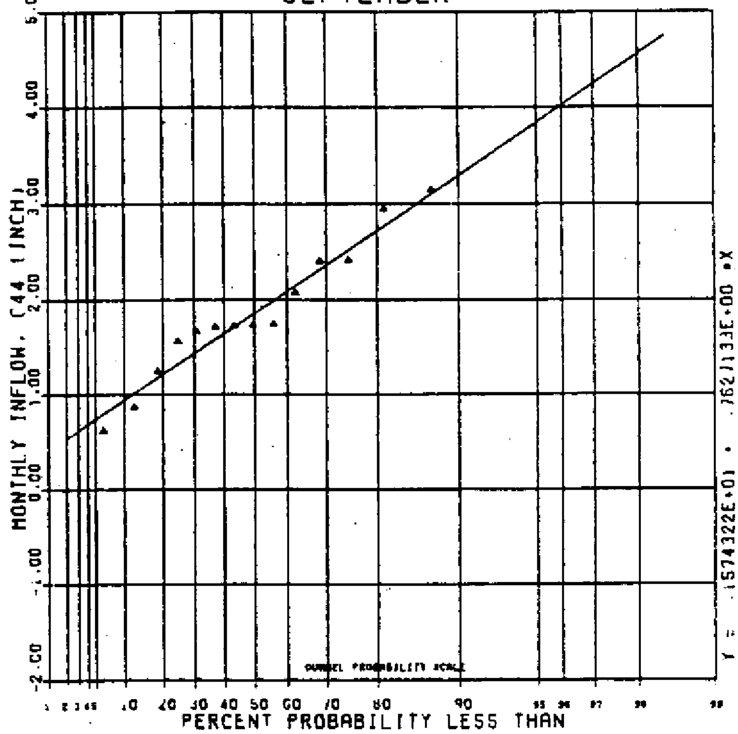

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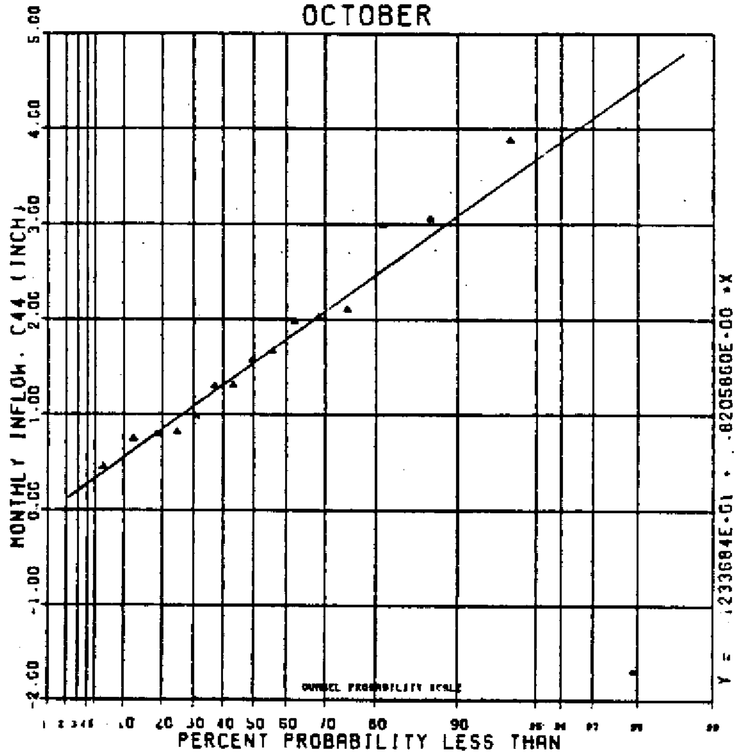

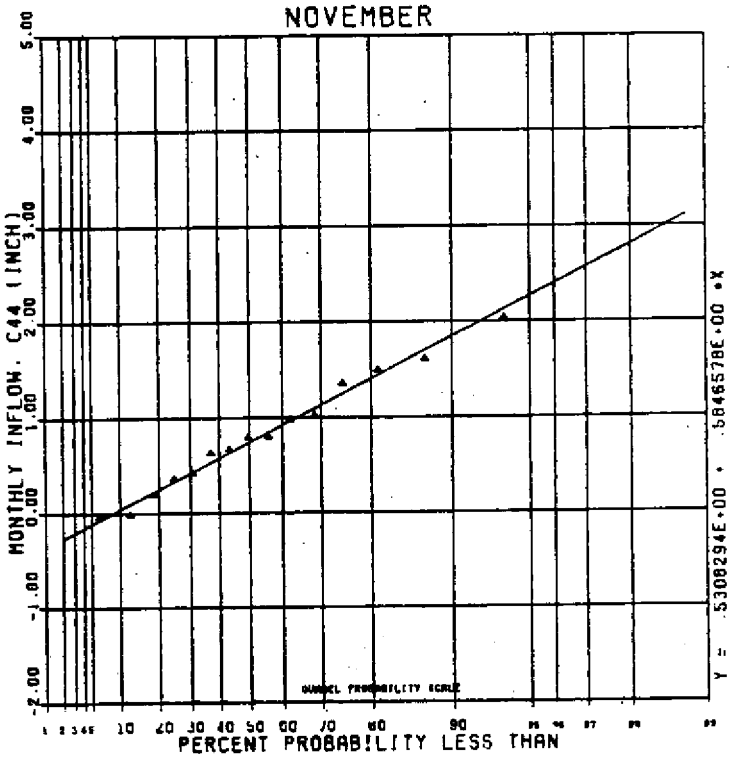
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4.00
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-2.00
PERCENT PROBABILITY LESS THAN
10
20
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80
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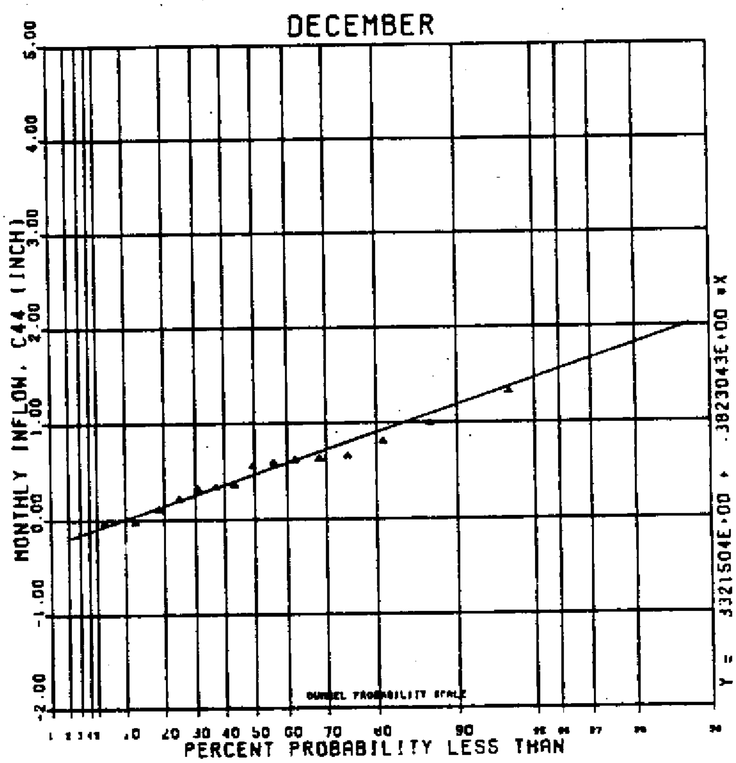
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MONTHLY INFLOW. C44 (INCH)
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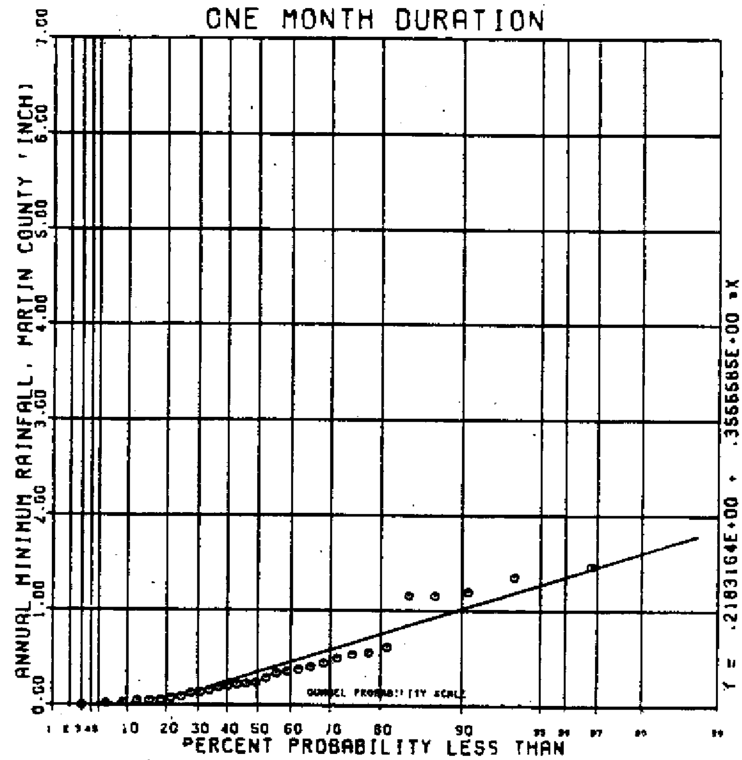
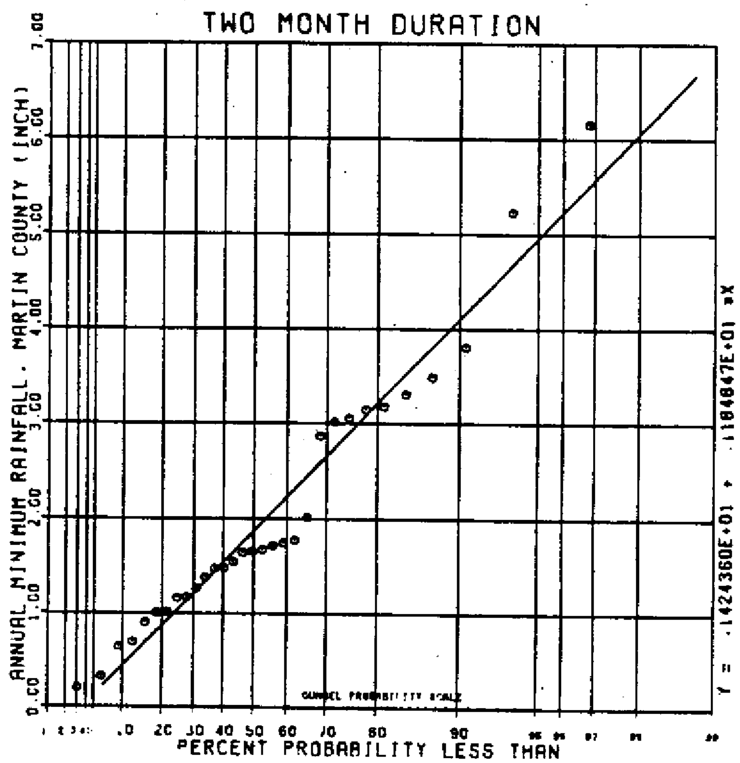
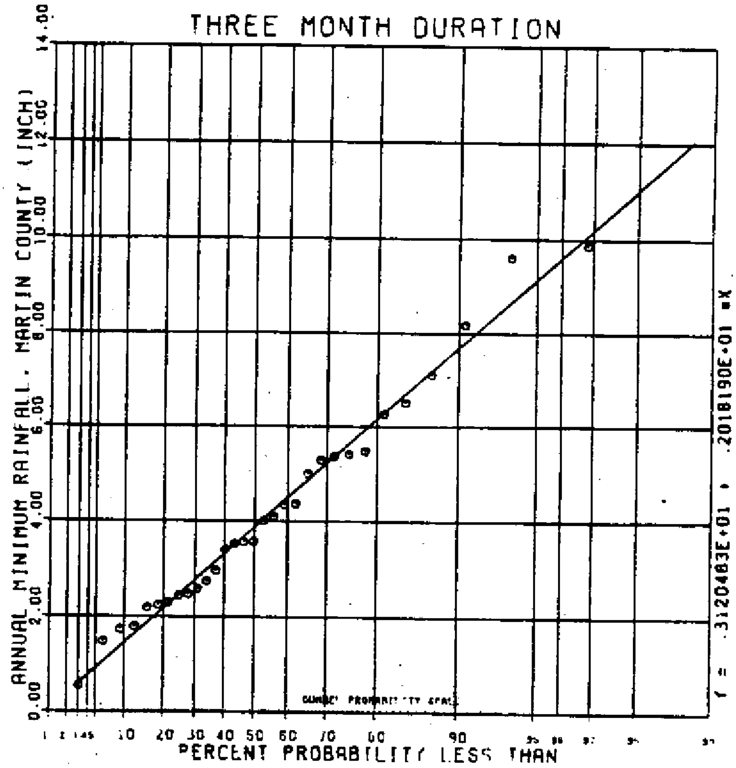
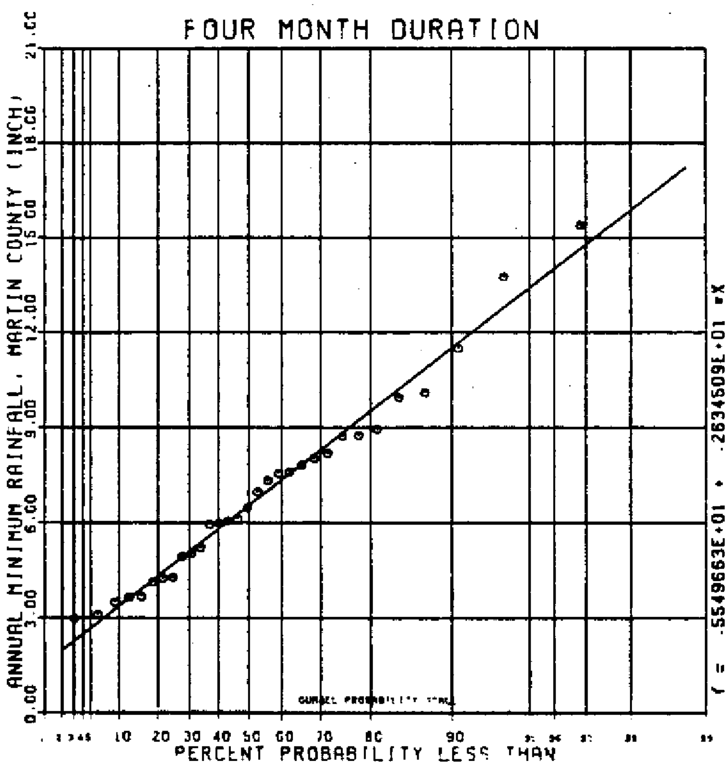
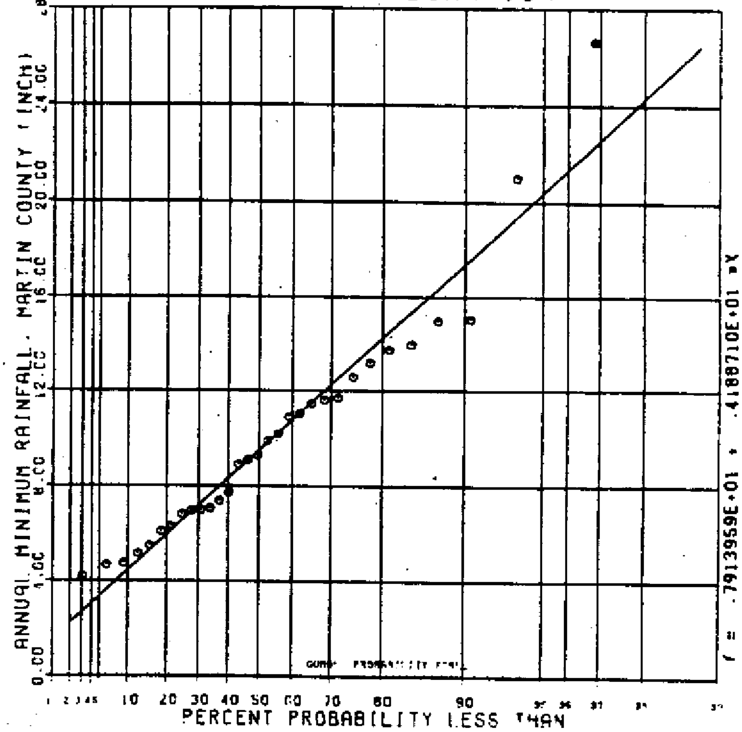

ONE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = .2183164E+00 + .3565585E+00 *X
GUMBEL PROBABILITY SCALE


TWO MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = .1424360E+01 + .1184847E+01 *X
GUMBEL PROBABILITY SCALE

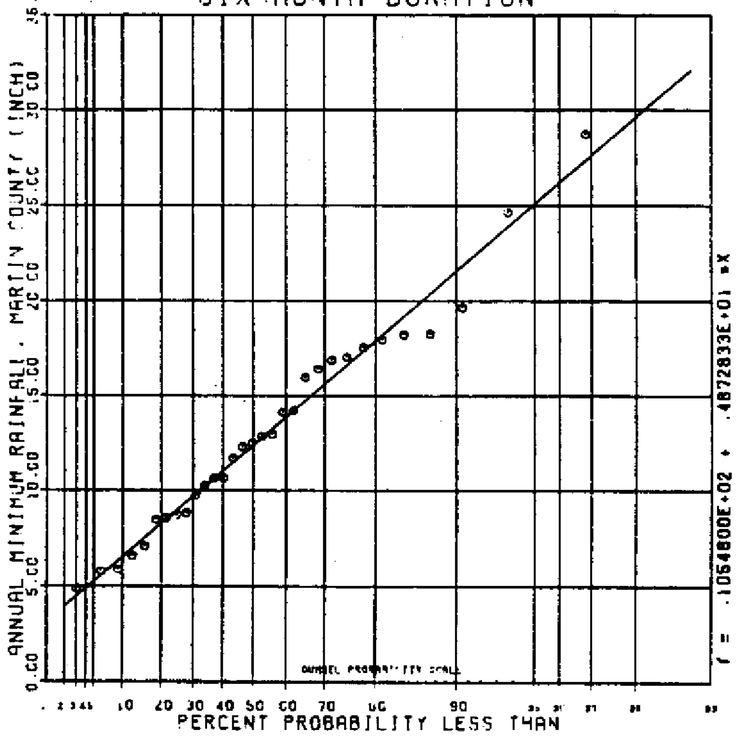

THREE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = 3.120483E+01 + .2018190E+01 *X

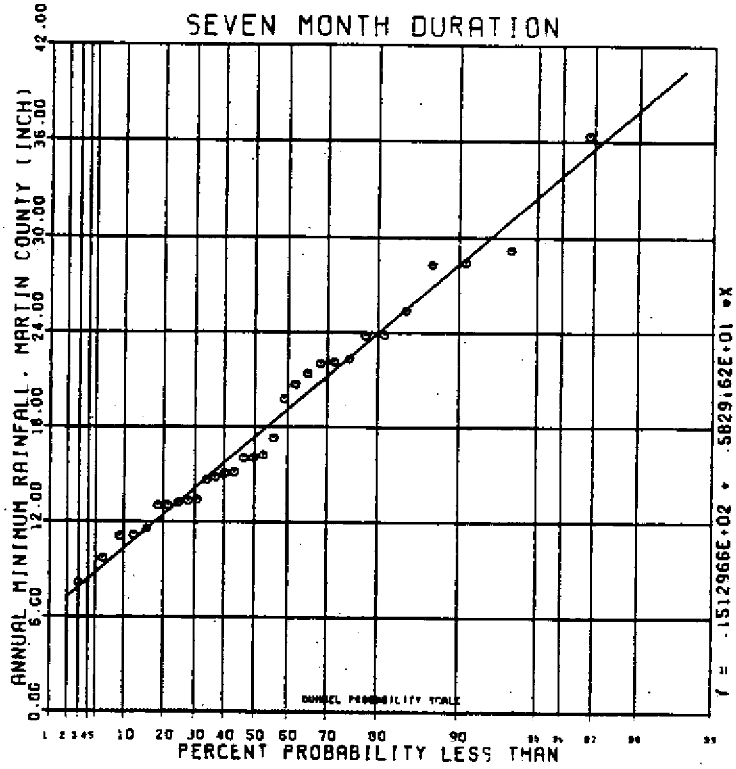

FOUR MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = .5549663E+01 + .2634509E+01 *X

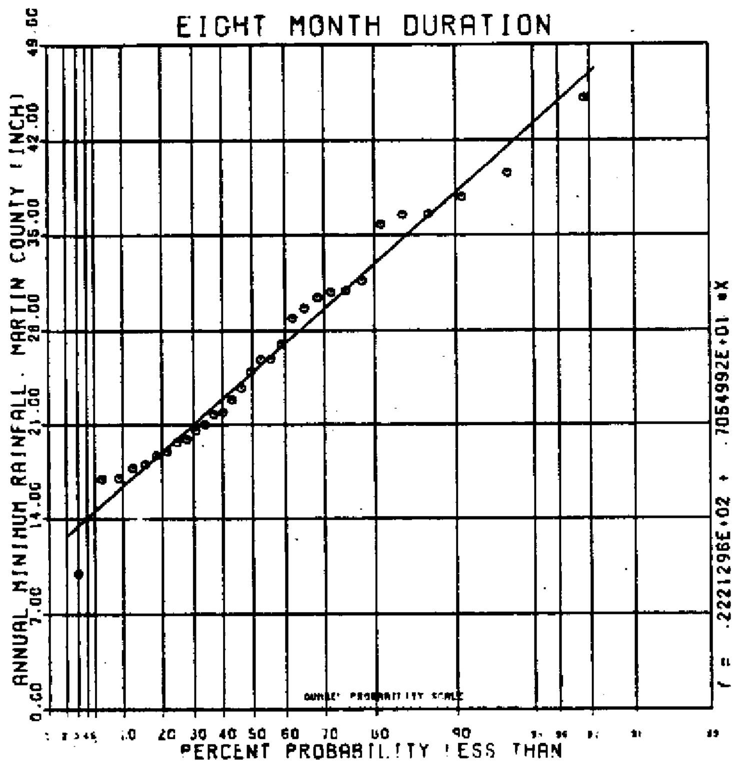
FIVE MONTH DURATION

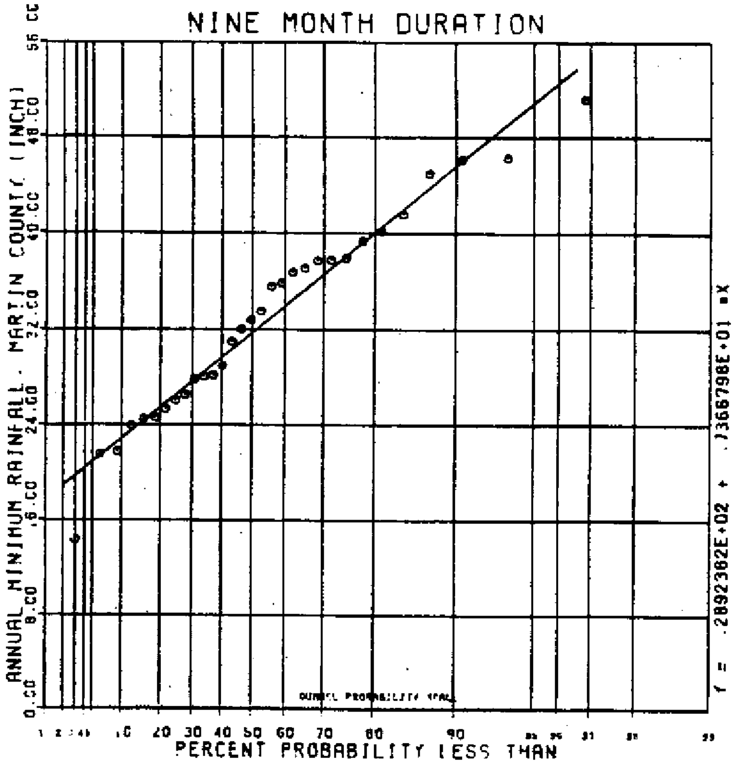


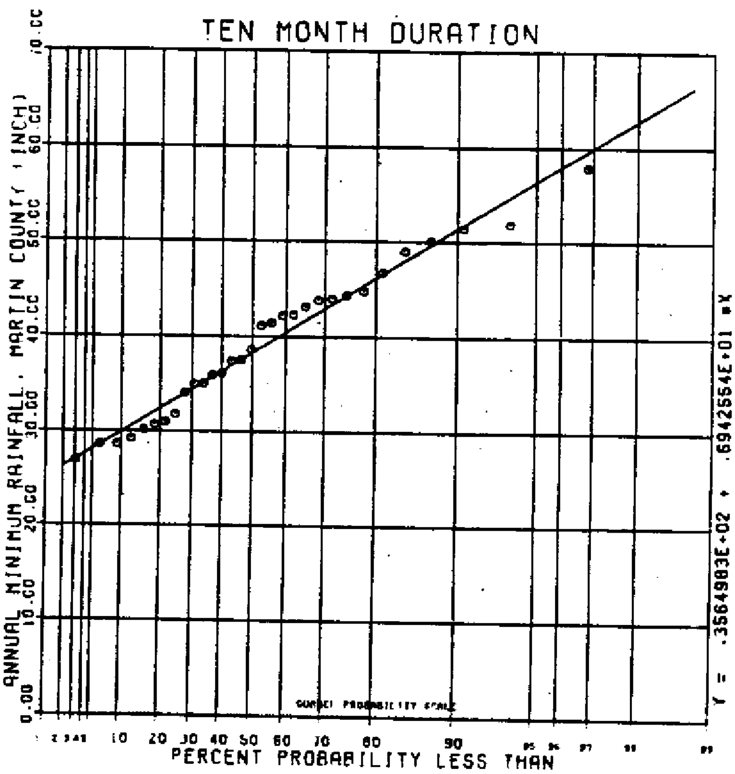
SIX MONTH DURATION

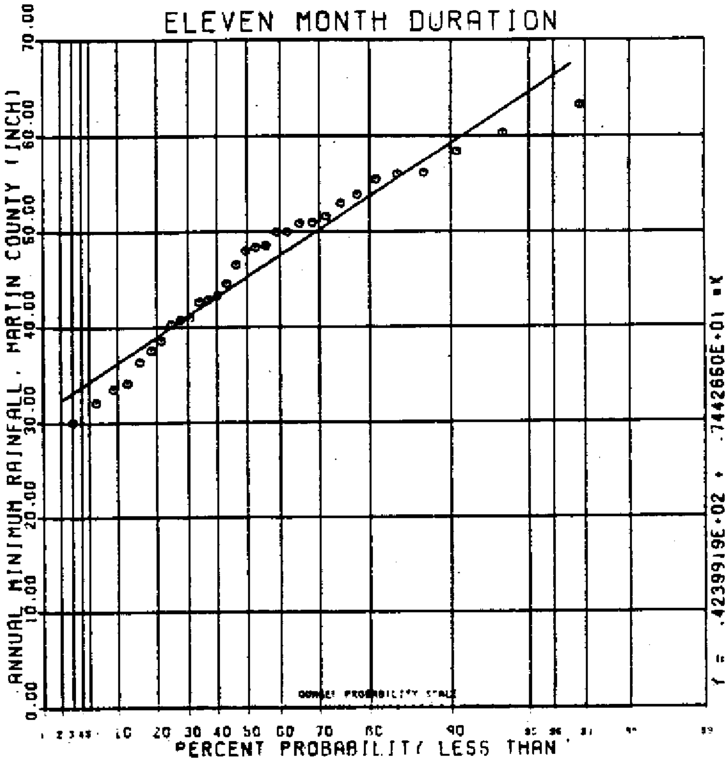


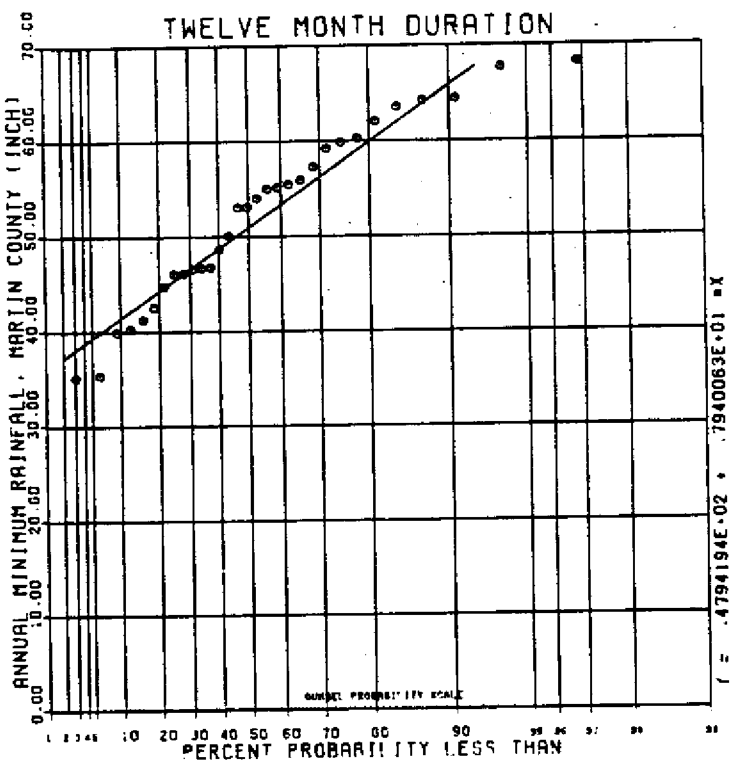

SEVEN MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = -.1512966E+02 + .5829162E+01 *X


EIGHT MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = .2221296E+02 + .7054992E+01 *X

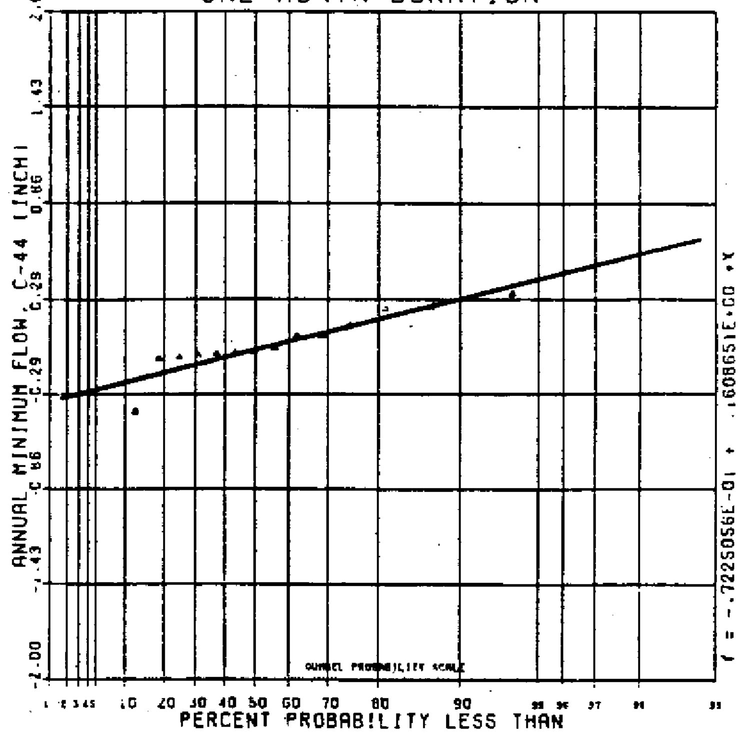

NINE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .2892382E+02 + .7366798E+01 *X


TEN MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .3564983E+02 + .6942554E+01 *X

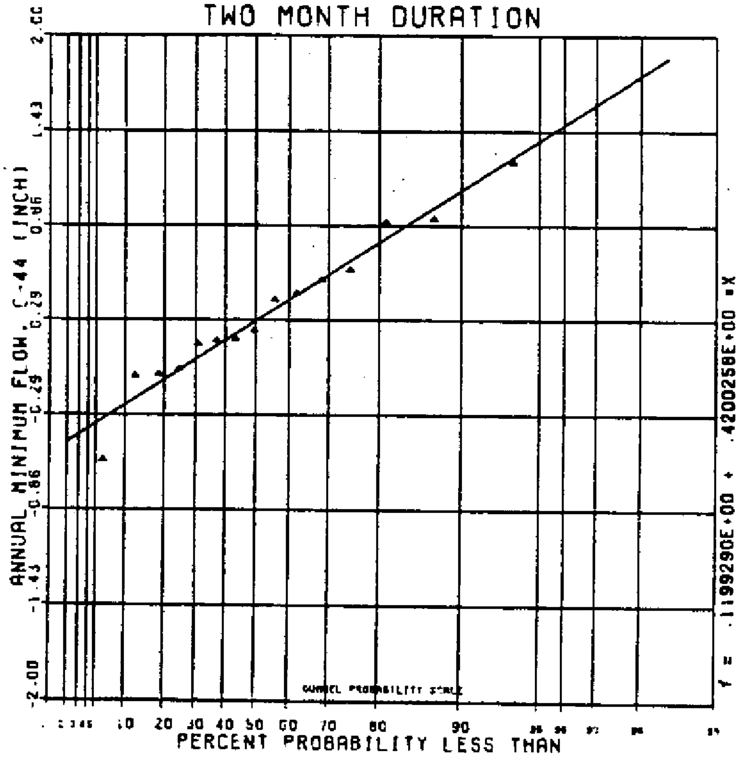

ELEVEN MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = .4239919E+02 + .7442660E+01 *X


TWELVE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
Y = .4794194E+02 + .7940063E+01 *X

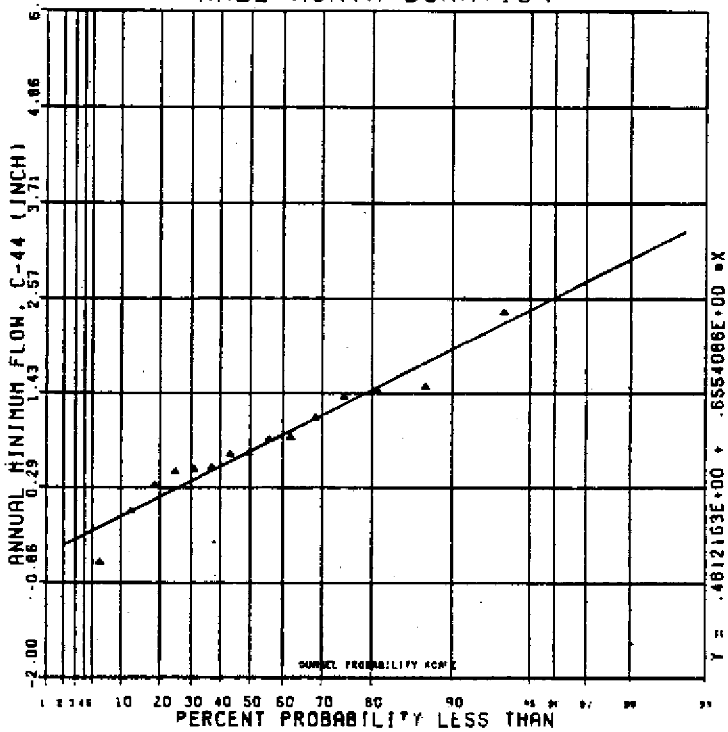
ONE MONTH DURATION



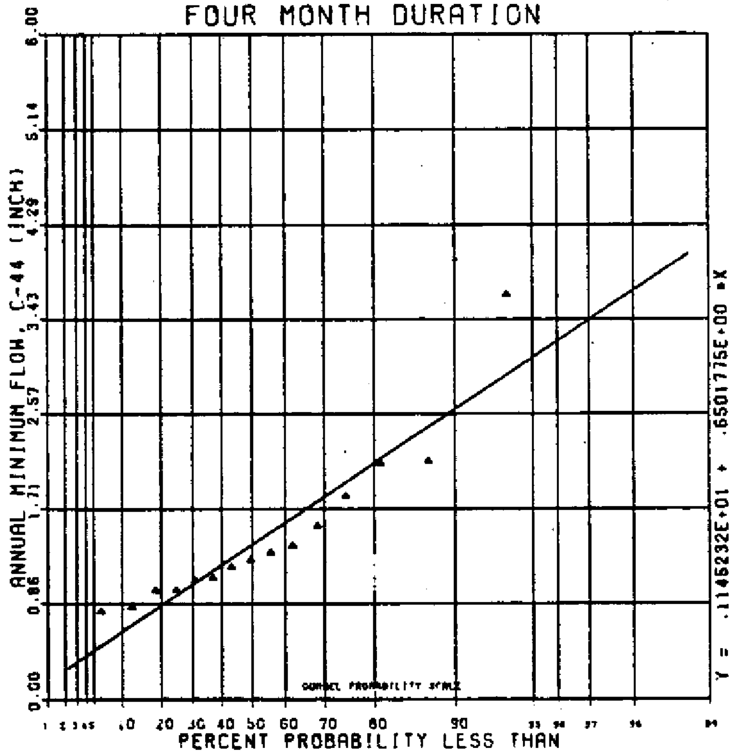
TWO MONTH DURATION

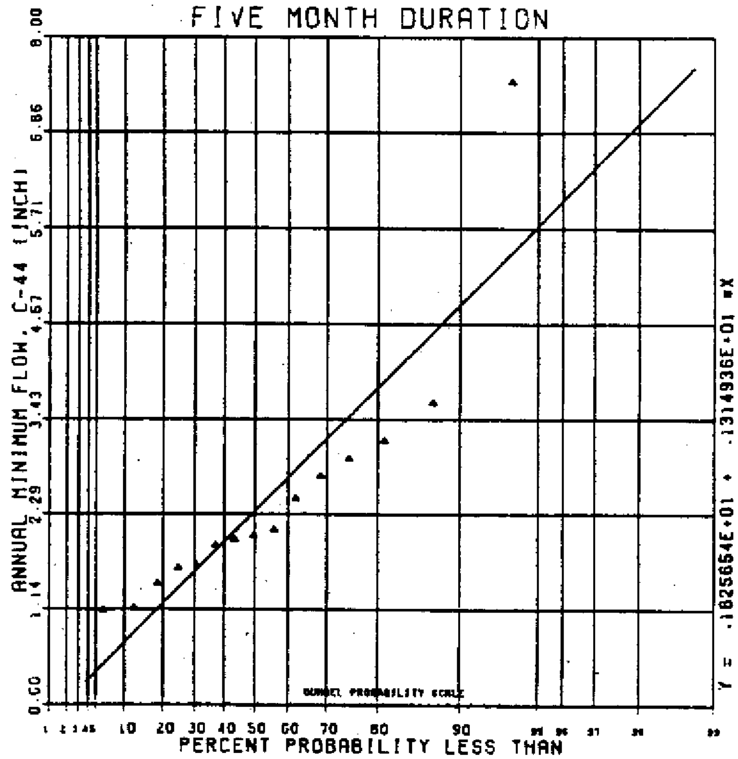


THREE MONTH DURATION

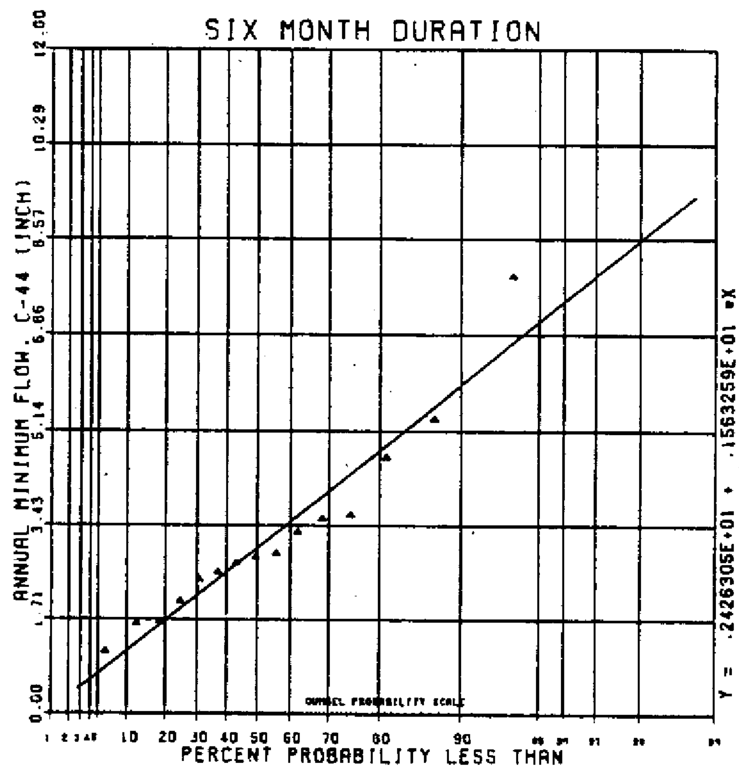


FOUR MONTH DURATION

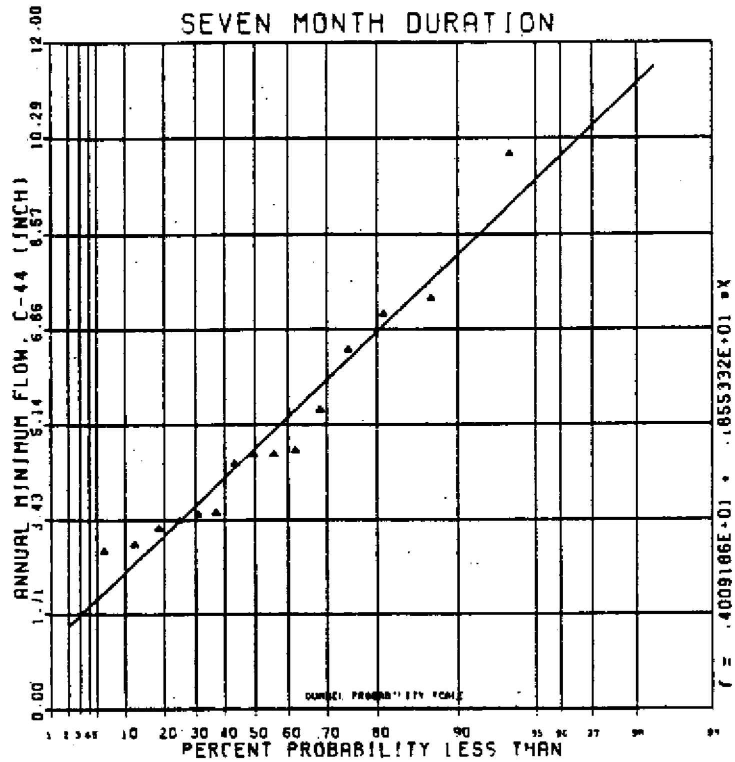


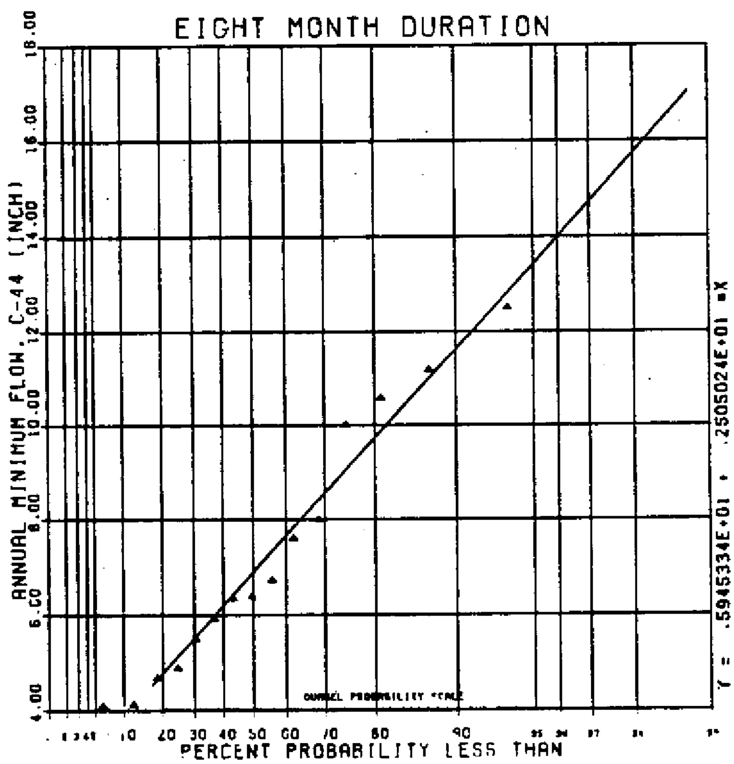


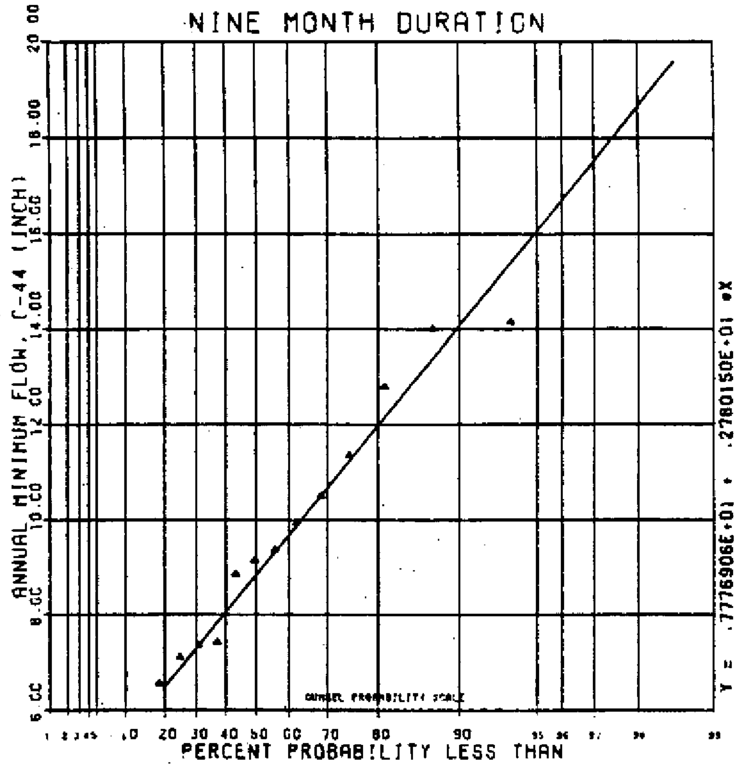
FIVE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
0.00
1.14
2.29
3.43
4.57
5.71
6.86
8.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
Y = .1825654E+01 + .1314936E+01 *X

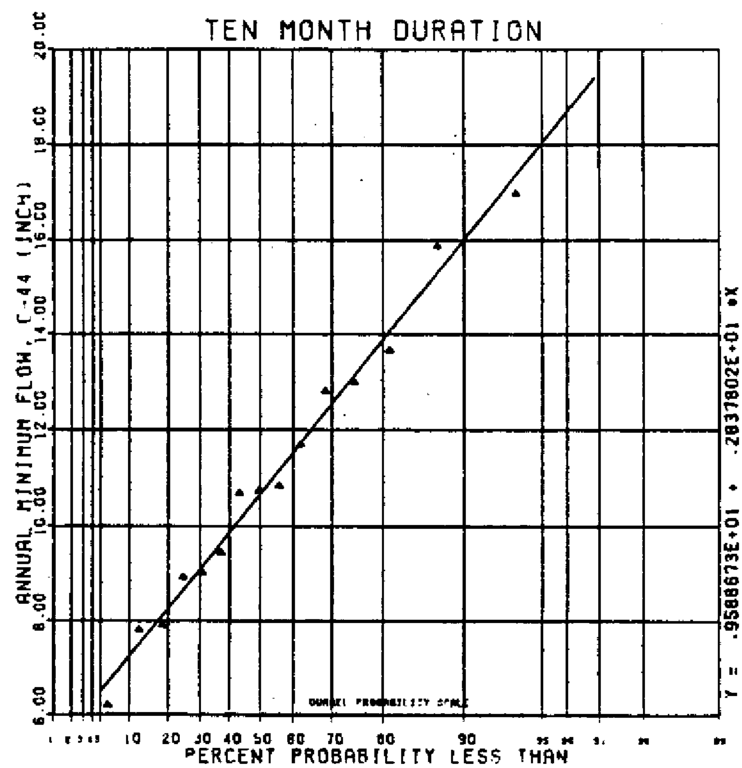


SIX MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
0.00
1.71
3.43
5.14
6.86
8.57
10.29
12.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
Y = .2426305E+01 + .1563259E+01 *X

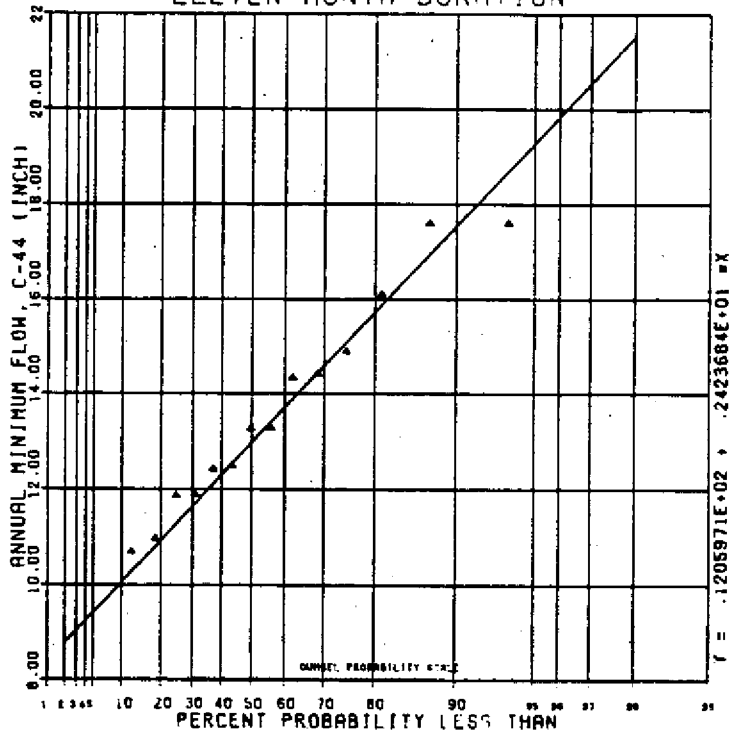

SEVEN MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
0.00
1.71
3.43
5.14
6.86
8.57
10.29
12.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
Y = .4009106E+01 + .1855332E+01 *X


EIGHT MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
Y = .5945334E+01 + .2505024E+01 *X


NINE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
PERCENT PROBABILITY LESS THAN
Y = .7776906E+01 + .2780150E+01 *X


TEN MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
PERCENT PROBABILITY LESS THAN
Y = .9588673E+01 + .2837802E+01 *X

ELEVEN MONTH DURATION



TWELVE MONTH DURATION