Technical Publication SJ 88-6

DEVELOPMENT OF SITE-SPECIFIC HYPOTHETICAL STORM DISTRIBUTIONS

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DEVELOPMENT OF SITE-SPECIFIC HYPOTHETICAL STORM DISTRIBUTIONS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

efinitions of some of the terms used in this report are a ollows:

ypothetical Storm - A storm sequence based on generalize aximum rainfall data.

esign Storm - Same as hypothetical storm

ite specific rainfall distribution - a hypothetical stor istribution based on rainfall data for a specific watershed.

tandard rainfall distribution - a hypothetical stor istribution for a given return period (T= 10 yr, 25 yr, 100 y tc.) This distribution is derived for a given surface wate asin.

eneralized rainfall distribution - an average rainfal istribution for a given surface water basin. It is applicabl o a rainfall event of any return period.

INTRODUCTION

Accurate prediction of peak discharges is essential fo planning and design of storm water management systems. watershed's response to storm events is best evaluated b streamflow monitoring. Long term data collected in this fashio constitutes the basic information for estimating maximum flow for various return periods. Very few watersheds, however possess adequate monitoring networks. In some instances, th historic data may become obsolete due to changing basi conditions, especially in urbanizing watersheds. For thes reasons, peak discharges for a watershed are often calculated b rainfall runoff models using hypothetical or synthetic stor data. This procedure is also useful in evaluating the effects o different alternative management practices and future watershe conditions.

A hypothetical or design storm combines the most critica features of several past storms into a single event. Two basi components of a hypothetical storm are the total rainfall amoun during the storm duration and the time distribution of rainfall These components are determined based on a detailed analysis o long-term rainfall data. A hypothetical storm is specific for given watershed size, location and return period. Thus, i modeling peak flows for a large river basin, it is necessary t develop several hypothetical storms, i.e., one each for each sub watershed size and for each return period.

For some studies use of a generalized rainfall distribution may be satisfactory. The Soil Conservation Service (SCS) of the United States Department of Agriculture developed generalized distributions applicable to specific regions of the United States (U.S.) (SCS, 1986). These distributions have been extensively used by several agencies throughout the U.S. Generalized distributions, however, lack accuracy. For example, the SCS Type II distribution developed in the 1960's and applicable to Florida was modified in 1980 (for use in Florida) because the peak discharges based on this distribution were found to be unrealistically high for Florida watersheds. In 1986, the SCS introduced a new distribution, Type III, for use in Florida and other regions. A brief study conducted at the St. Johns River Water Management District (SJRWMD) has indicated that none of the SCS rainfall distributions are uniformly applicable to the entire District (Rao, 1987). Therefore, development and use of site-specific distributions or a generalized distribution developed for a specific watershed is desirable for accurate prediction of peak discharges.

This technical publication describes various components of a hypothetical storm. In addition, it presents detailed procedures for deriving a site-specific hypothetical storm and summarizes the approximations made in developing a generalized rainfall distribution. The Little Wekiva River and the Howell Creek basins located in Orange and Seminole counties, Florida (Figure 1) are used as example basins for illustrating various results. In a future study, generalized rainfall distributions for all other surface water basins of the District (Figure 2) will be developed.

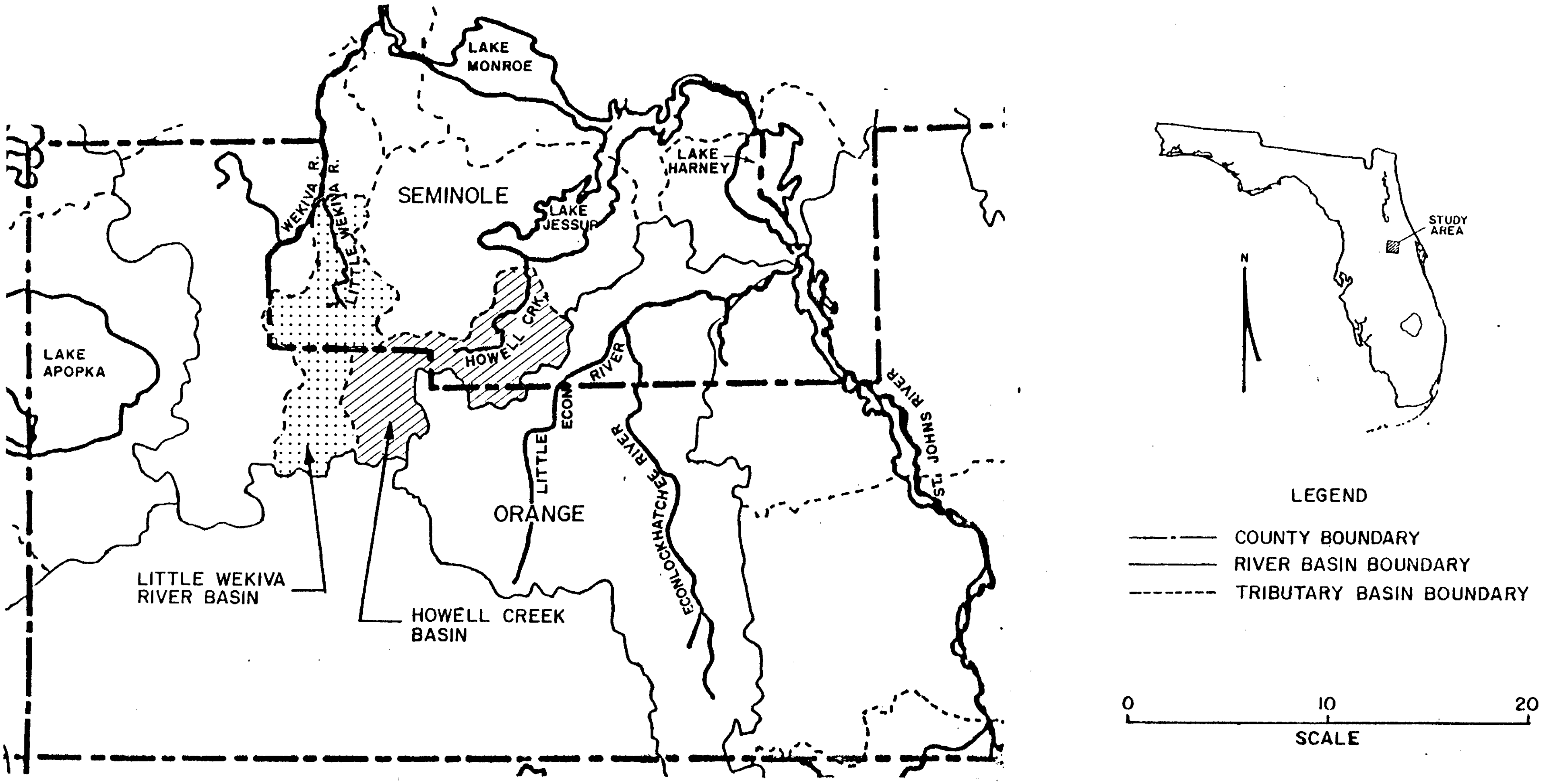

Figure 1. The Little Wekiva River and Howell Creek Basins

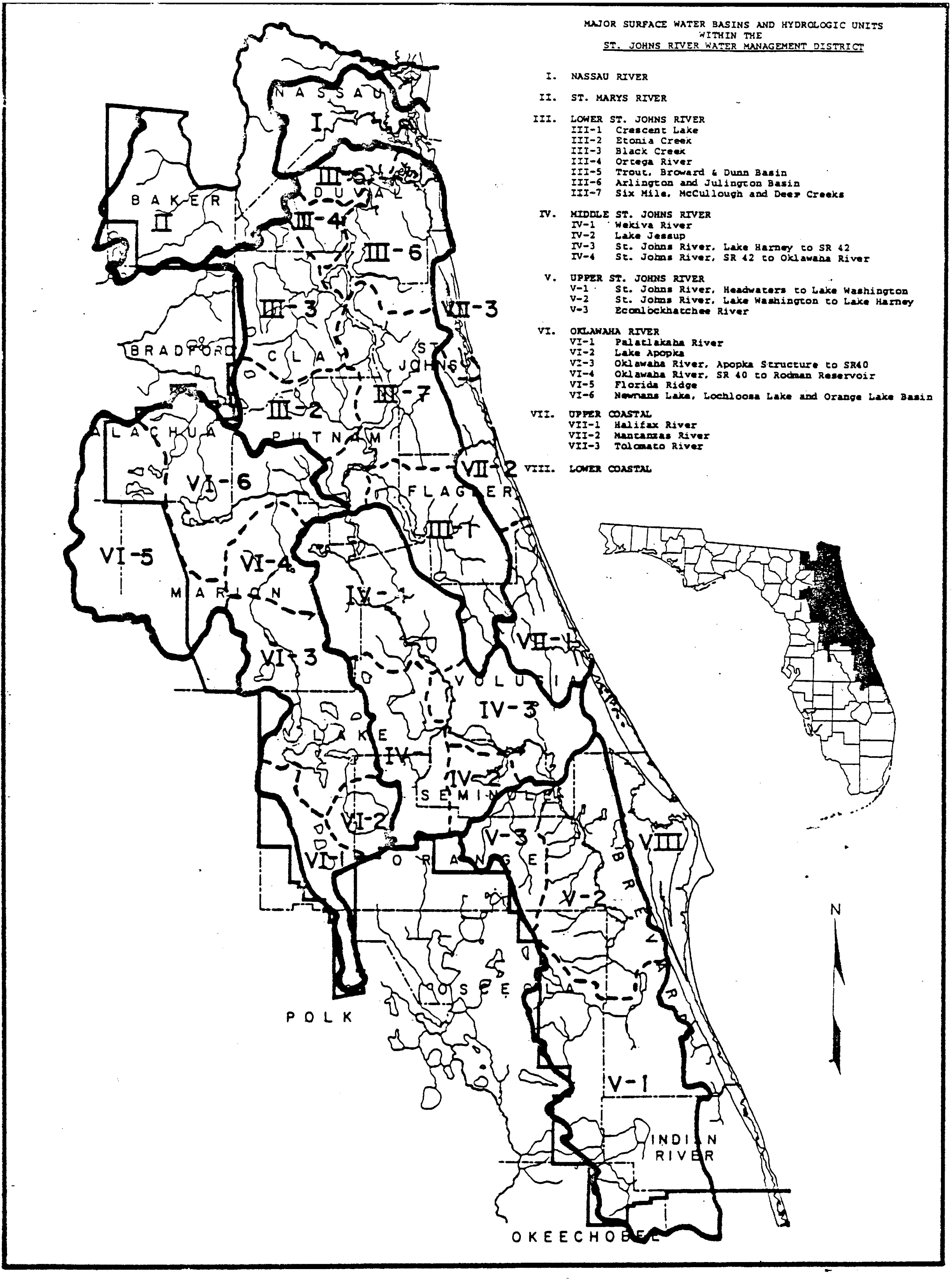

Figure 2. Surface Water Basins in the St. Johns River Water Management District

CONSTRUCTION OF HYPOTHETICAL STORMS

The highest peak discharges from small watersheds usually result from intense, brief rainfalls that may occur as discrete events or as a part of a longer duration storm (SCS, 1986). In developing a t-hr hypothetical storm for a given probability level (or return period) maximum rainfall depths for several progressively increasing durations within the t-hr period (at the same probability level) are first compiled. Then these depths are so arranged that the t-hr storm includes the intensities of all shorter duration storms. A hypothetical storm developed in this fashion is called a 'balanced storm,' because for each duration within the storm period the rainfall depth has the same recurrence interval. Such consistent frequency-depth-duration relationships are very unlikely to occur in nature because of the randomness of rainfall events. The balanced storm concept, however, does allow for logical construction and arrangement of a storm event for a particular return period (HEC, 1982).

The follwing steps are involved in developing a site-specific rainfall distribution: 1) compile maximum rainfall depths for various durations f~~or a~~ given return period, 2) make adjustments to rainfall values in step 1 to compensate for the size of the drainage area and also adjust for partial to annual series, if necessary, 3) draw the maximum rainfall depth-duration curve from data in Step 2 and obtain incremental rainfall depths at a chosen time step from the depth-duration curve, and 4) arrange the incremental rainfall depths obtained in Step 3 in the desired storm pattern. Each of these steps is described below with examples.

Step 1: Determine or compile maximum rainfall depths for various durations for a given return period.

If extensive rainfall records are available, these values can be determined by statistical frequency analysis. In the absence of such data for a basin, generalized rainfall charts given in the following publications provide the necessary data.

Publication	Applicable Durations
National Weather Service Publication, NWS HYDRO-35 (1977)	15-, 30-, and 60- minutes
National Weather Service Technical Publication-40 (TP-40) (1961)	2-, 3-, 6-, and 12- hours
SJRWMD Technical Publication SJ 88-3	24-, 48-, and 96-hours
National Weather Service Technical Publication-49 (TP-49) (1964)	7-, and 10-days

The foregoing publications give rainfall depths for return periods 2 yr to 100 yr. Rainfall charts given in SJ 88-3 have been developed specifically for the District from rainfall data available through 1983. These charts should be used for 24 hr, 48 hr and 96 hr durations because they are an update over the other publications. Likewise, the 30-minute and 1-hr values available in TP-40 should be ignored and those given in the NWS HYDRO-35 should be used.

In this study, the hypothetical rainfall distributions will be developed at 15 minute time steps. Derivation of a 24-hr distribution will be described in detail and the 96-hr distribution will be briefly explained.

The 2-hr and 12-hr values, although available in TP-40, are not used because they are transitional values between two different sources of data and, thus, may be inconsistent with the rest of the data. For easy reference, all the relevant charts from the three sources are reproduced in Appendix A.

The NWS HYDRO-35 presents charts for t=15 min and 30 min, and T= 2 yr and 100 yr. The 30 minute value, and the 10 yr and 25 yr return period values are computed by the following equations:

$$\text{30-min value} = 0.49\ (\text{60-min value}) + 0.51\ (\text{15-min value}) \quad (1)$$

$$\text{10-yr} = 0.449\ (\text{100-yr}) + 0.496\ (\text{2-yr}) \quad (2)$$

$$\text{25-yr} = 0.669\ (\text{100-yr}) + 0.293\ (\text{2-yr}) \quad (3)$$

Note that to compute the 10-yr 30-min value, the 2-yr and 100-yr 30-min values should be computed first by Eq. 1 and then the 10-yr value by Eq.2. Table 1 summarizes the maximum rainfall data for the Little Wekiva River and Howell Creek basins. The two basins have similar maximum rainfall characteristics..

Step 2: Rainfall adjustments for the basin size.

Rainfall values given in TP-40, TP-49, HYDRO-35 and SJ 88-3 are "point rainfall depths," i.e., as measured at a rain gage or a single point. When spread over a large area a storm cannot be as intense as it can be at a single point. TP-40 and TP-49 give area-depth relations for adjusting the point rainfalls for basin size. These relationships are partially reproduced in Figure 3.

TABLE 1: Maximum Rainfall Depths (Inches) for the Little Wekiva and Howell Creek Basins

Duration (1)	Little Wekiva River 10 yr (2)	25 yr (3)	100 yr (4)	Howell Creek 10 yr (5)	25 yr (6)	100 yr
15 min.	1.59	1.79	2.11	1.59	1.79	2.11
30 min.	2.38	2.73	3.28	2.38	2.73	3.28
60 min.	3.21	3.71	4.50	3.21	3.71	4.50
3 hr	4.15	4.75	5.80	4.20	4.80	5.81
6 hr	5.10	5.85	7.20	5.11	5.85	7.25
24 hr	6.75	8.40	11.40	6.90	8.50	11.50
48 hr	7.80	9.80	13.10	7.95	9.95	13.35
96 hr	9.10	11.25	14.80	9.25	11.40	14.9

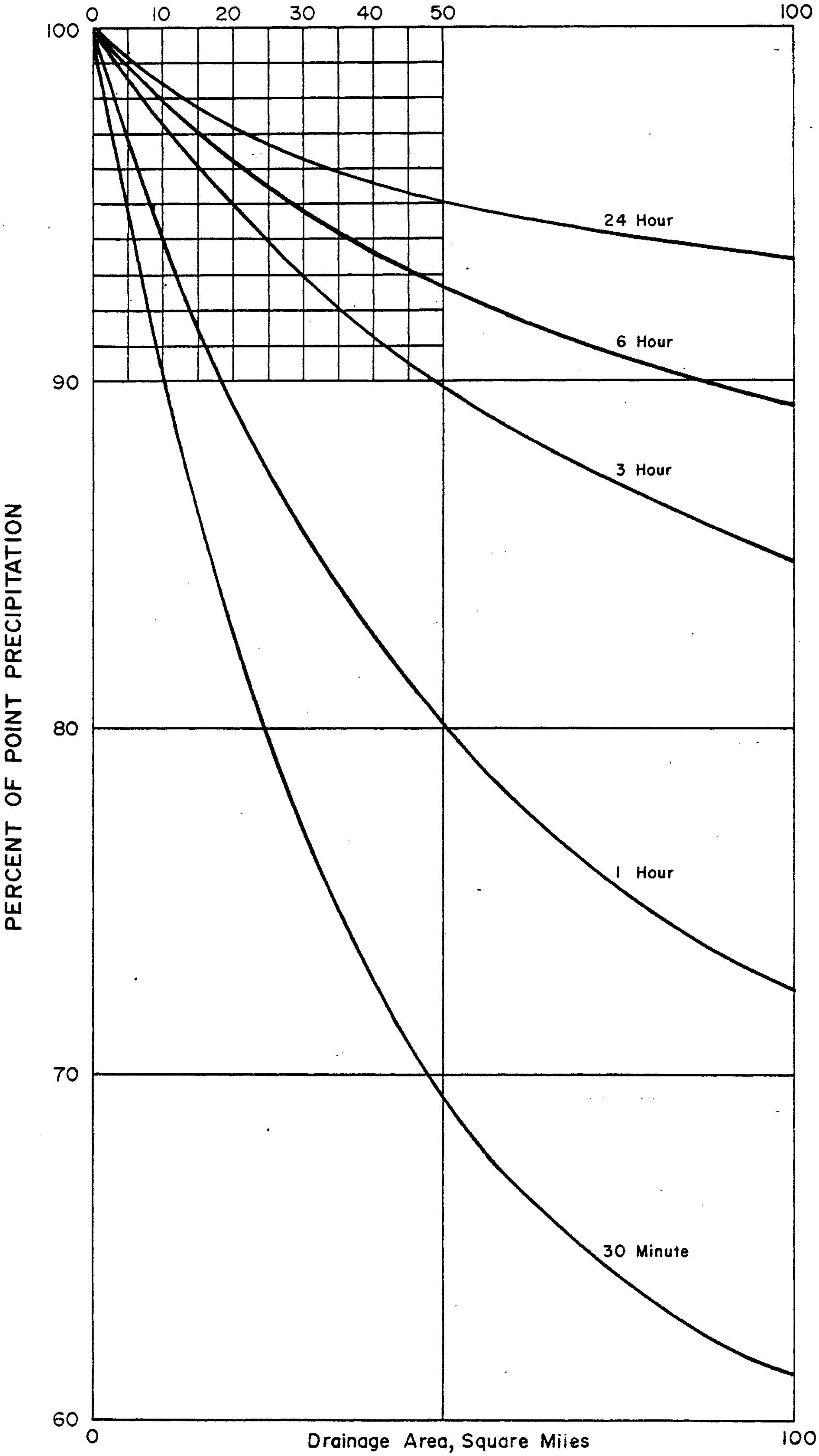

Figure 3a. Area-Depth Relationships (30 Min to 24 Hr Rainfalls)

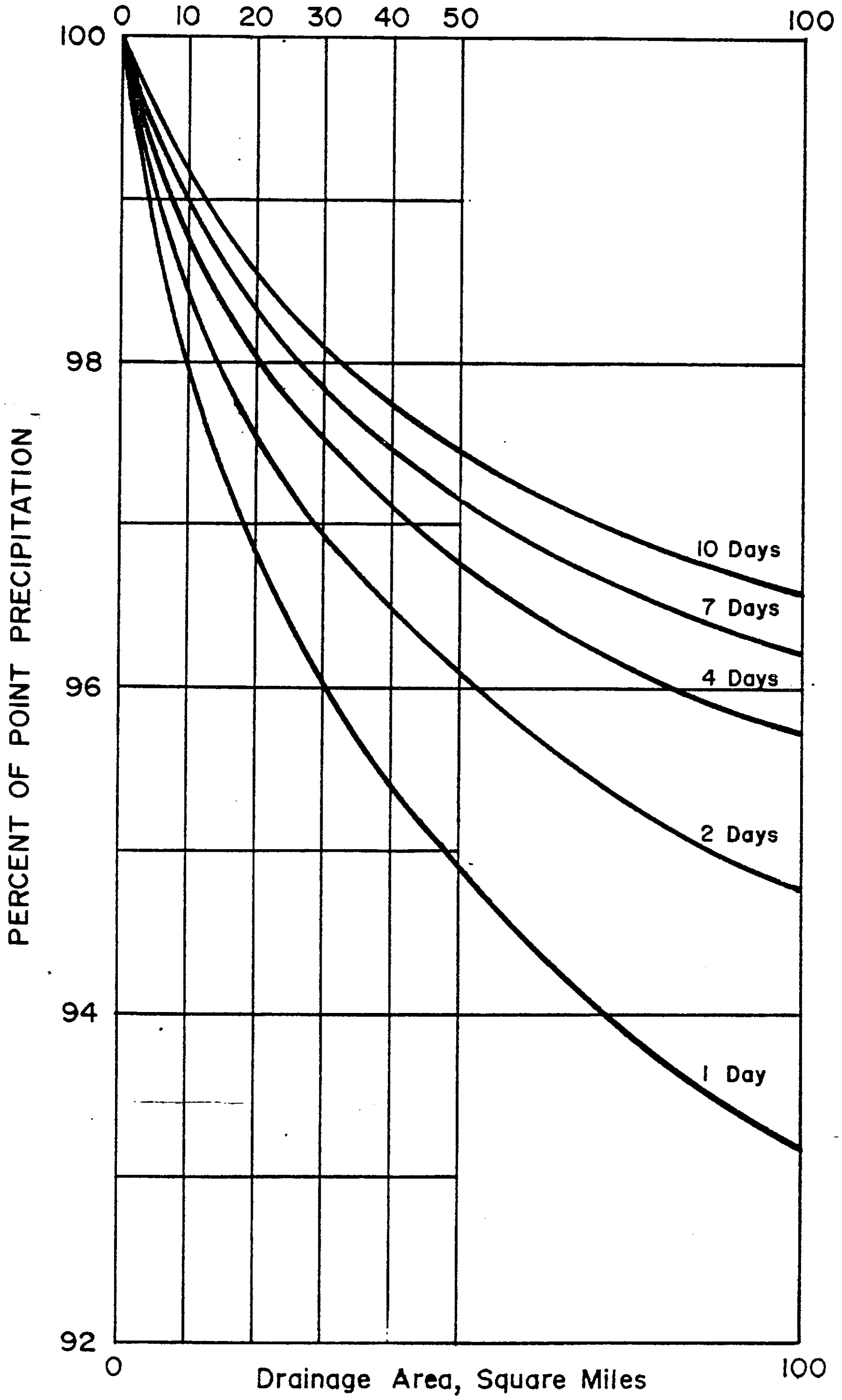

Figure 3b. Area-Depth Relationships (1 Day to 10 Day Rainfalls)

To obtain runoff consistent with a particular event and basin size, rainfall depths for each duration should be appropriately adjusted. When modeling a large basin with several tributaries and sub-areas, it is necessary to develop a different hypothetical storm for each sub-area. As an example, assume that peak discharges are required at three locations in the Little Wekiva River Basin, and the drainage areas (D.A.) at these locations are 10 sq. mi., 20 sq. mi., and 40 sq. mi., respectively. Table 2 presents adjustments made to the 100-yr point rainfall values. For small drainage areas below 5 sq. mi. the adjusted rainfall may not differ greatly from the point rainfall. For larger areas the adjustment becomes significant, particularly for smaller durations, as shown in Table 2.

If T-yr rainfall values are calculated based on the annual series data, as in SJ 88-3, the values should be adjusted for T=10 yr or less (see TP-40). For T=10 yr, the adjustment factor is 1.01 which is not significant, and can be ignored when using SJ 88-3 values. Rainfall charts given in TP-40, TP-49 and NWS HYDRO-35 are already adjusted for annual series.

Step 3: Draw maximum rainfall depth-duration curves. Obtain incremental rainfall depths from these curves at a chosen time step.

Depth-duration curves give maximum rainfall depths for a given duration and can be constructed from the data compiled in Table 2. Figure 4 presents the 100 yr rainfall depth-duration curves for different drainage areas within the Little Wekiva River Basin for durations up to 24-hr. In drawing these curves,

TABLE 2. Adjusted 100-Year Rainfall Values for Di asin Sizes in the Little Wekiva River Basin

Duration	Point Rainfall, Inches	D.A. = 10 sq mi.		D.A. =	D.A.= 40 sq. mi.	
		Adjustment Factor	Adjusted Rainfall Inches	Adjustm Factors	Adjustment Factor	Adjusted Rainfall Inches
(1)	(2)	(3)	(4)	(5)	(7)	(8)
30 min.	3.28	.905	2.97	.825	.725	2.38
60 min.	4.50	.942	4.24	.890	.824	3.71
3 hr	5.80	.973	5.64	.950	.911	5.28
6 hr	7.20	.979	7.05	.961	.936	6.74
24 hr	11.40	.983	11.21	.971	.956	10.91
48 hr	13.10	.984	12.89	.976	.965	12.64
96 hr	14.80	.986	14.59	.980	.971	14.37

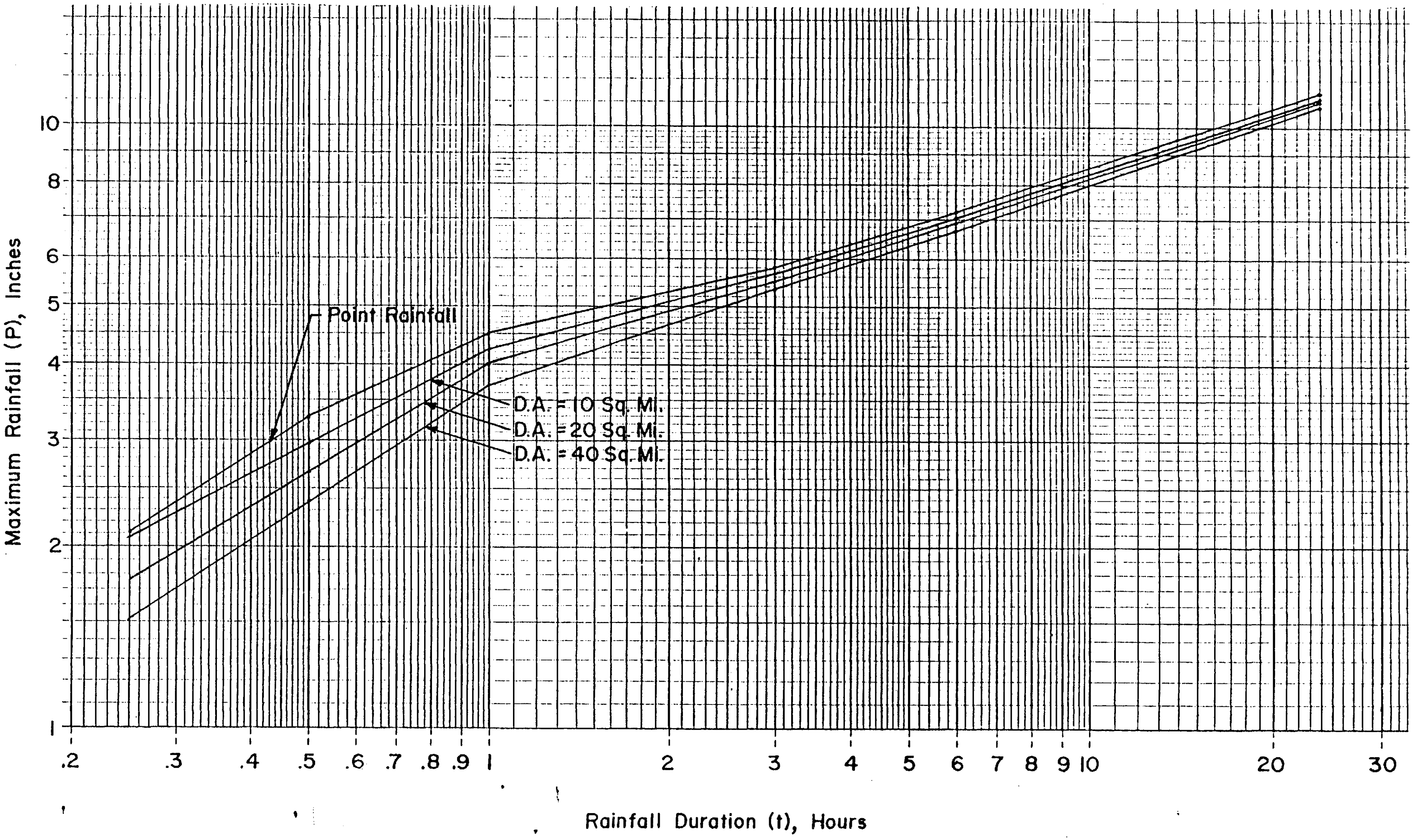

Figure 4. Maximum Rainfall Depth-Duration Curves for Different Drainage Areas in the Little Wekiva River Basin (T=100 yr)

a linear approximation is made for the segments between known data points, i.e., the data plotted from Table 2 (on a log-log paper) are linearly joined.

Incremental rainfall depths are the rainfall amounts a storm may precipitate during each time interval selected for the storm. For a real storm these depths can be determined from the rainfall records obtained from a continuous rain gage. The maximum depth-duration curves developed in Figure 4 furnish this data for hypothetical storms, without giving the storm sequence. Columns (2) and (3) in Tables 3 and 4 illustrate the derivation of these depths. Column (1) gives the cumulative depths obtained from the depth-druation curve at the end of each time step. [Reading these values directly from Figure 4 would be rather tedius and less accurate. Instead, an equation relating P (cumulative rainfall) to t is developed for each linear segment of the depth-duration curve, and the P values at the desired t are calculated from these equations.] The incremental depths given in Column (3) are the differences between successive cumulative depths and represent the largest 15-min rainfall, the next largest, and so on.

Step 4: Arrange the incremental rainfall depths obtained in Step 3 in the desired storm pattern

Rainfall sequences are random in nature. The 96 rainfall values derived for 15-min time intervals in the preceding step can occur in any sequence (i.e., permutation) during a 24-hr period. Thus these 96 values can be arranged in 96P96= 96! ways. The 'balanced storm' concept presented earlier, however, gives rise to a cognizable pattern for hypothetical storms. By this

TABLE 3. Derivation of 100-Year 24-Hour Storm Distribution for the Little Wekiva River Basin (Point Rainfall Values in Inches)

15 Min Time Steps (1)	Cumulative Depth (2)	Incremental Depth (3)	Hypothetical Storm Incremental Depth (4)	Hypothetical Storm Cumulative Depth (5)
1	2.109	2.109	0.040	0.040
2	3.283	1.174	0.040	0.080
3	3.950	0.666	0.041	0.121
4	4.503	0.553	0.042	0.162
5	4.741	0.238	0.042	0.205
6	4.945	0.204	0.043	0.247
7	5.124	0.179	0.044	0.291
8	5.284	0.160	0.044	0.335
9	5.430	0.146	0.045	0.380
10	5.563	0.134	0.046	0.426
11	5.687	0.124	0.047	0.472
12	5.803	0.115	0.047	0.520
13	5.949	0.147	0.048	0.568
14	6.089	0.139	0.049	0.617
15	6.221	0.133	0.050	0.668
16	6.348	0.127	0.051	0.719
17	6.469	0.121	0.052	0.771
18	6.586	0.117	0.054	0.825
19	6.698	0.112	0.055	0.880
20	6.806	0.108	0.056	0.936
21	6.911	0.104	0.057	0.993
22	7.012	0.101	0.059	1.052
23	7.110	0.098	0.060	1.112
24	7.205	0.095	0.062	1.174
25	7.303	0.098	0.064	1.238
26	7.398	0.095	0.066	1.304
27	7.491	0.093	0.068	1.372
28	7.582	0.091	0.070	1.442
29	7.671	0.089	0.072	1.514
30	7.757	0.087	0.075	1.589
31	7.842	0.085	0.078	1.667
32	7.925	0.083	0.081	1.748
33	8.006	0.081	0.085	1.833
34	8.085	0.079	0.089	1.922
35	8.163	0.078	0.093	2.015
36	8.240	0.076	0.098	2.113
37	8.315	0.075	0.098	2.211
38	8.388	0.074	0.104	2.315
39	8.461	0.072	0.112	2.427
40	8.532	0.071	0.121	2.549
41	8.602	0.070	0.133	2.681
42	8.671	0.069	0.147	2.828
43	8.739	0.068	0.124	2.952
44	8.805	0.067	0.146	3.097
45	8.871	0.066	0.179	3.276
46	8.936	0.065	0.238	3.514
47	9.000	0.064	1.174	4.689
48	9.063	0.063	2.109	6.798

TABLE 3 -Continued

15 Min Time Steps (1)	Cumulative Depth (2)	Incremental Depth (3)	Hypothetical Storm Incremental Depth (4)	Hypothetical Storm Cumulative Depth (5)
49	9.125	0.062	0.666	7.464
50	9.186	0.061	0.553	8.017
51	9.246	0.060	0.204	8.221
52	9.306	0.060	0.160	8.382
53	9.365	0.059	0.134	8.515
54	9.423	0.058	0.115	8.631
55	9.481	0.057	0.139	8.770
56	9.537	0.057	0.127	8.897
57	9.593	0.056	0.117	9.013
58	9.649	0.055	0.108	9.121
59	9.703	0.055	0.101	9.222
60	9.758	0.054	0.095	9.317
61	9.811	0.054	0.095	9.413
62	9.864	0.053	0.091	9.504
63	9.916	0.052	0.087	9.590
64	9.968	0.052	0.083	9.673
65	10.019	0.051	0.079	9.752
66	10.070	0.051	0.076	9.829
67	10.121	0.050	0.074	9.903
68	10.170	0.050	0.071	9.974
69	10.220	0.049	0.069	10.043
70	10.268	0.049	0.067	10.109
71	10.317	0.048	0.065	10.174
72	10.365	0.048	0.063	10.237
73	10.412	0.047	0.061	10.298
74	10.459	0.047	0.060	10.358
75	10.506	0.047	0.058	10.416
76	10.552	0.046	0.057	10.473
77	10.597	0.046	0.055	10.528
78	10.643	0.045	0.054	10.582
79	10.688	0.045	0.053	10.635
80	10.732	0.045	0.052	10.687
81	10.777	0.044	0.051	10.738
82	10.820	0.044	0.050	10.788
83	10.864	0.044	0.049	10.836
84	10.907	0.043	0.048	10.884
85	10.950	0.043	0.047	10.931
86	10.992	0.042	0.046	10.977
87	11.035	0.042	0.045	11.023
88	11.076	0.042	0.045	11.067
89	11.118	0.042	0.044	11.111
90	11.159	0.041	0.043	11.154
91	11.200	0.041	0.042	11.197
92	11.241	0.041	0.042	11.239
93	11.281	0.040	0.041	11.280
94	11.321	0.040	0.041	11.320
95	11.361	0.040	0.040	11.360
96	11.400	0.039	0.039	11.400

TABLE 4. Derivation of 100-Year 24-Hour Storm Distribution for the Little Wekiva River Basin (Drainage area = 40 sq. mi.; Rainfall in Inches)

15 Min Time Steps (1)	Cumulative Depth (2)	Incremental Depth (3)	Hypothetical Storm Incremental Depth (4)	Hypothetical Storm Cumulative Depth (5)
1	1.529	1.529	0.040	0.040
2	2.383	0.854	0.040	0.080
3	3.089	0.707	0.041	0.121
4	3.714	0.625	0.042	0.162
5	3.991	0.277	0.042	0.205
6	4.233	0.241	0.043	0.247
7	4.448	0.216	0.043	0.291
8	4.644	0.196	0.044	0.335
9	4.823	0.180	0.045	0.380
10	4.990	0.167	0.046	0.426
11	5.145	0.156	0.046	0.472
12	5.292	0.146	0.047	0.519
13	5.443	0.151	0.048	0.567
14	5.586	0.144	0.049	0.616
15	5.723	0.137	0.050	0.666
16	5.855	0.131	0.051	0.718
17	5.981	0.126	0.052	0.770
18	6.102	0.121	0.053	0.823
19	6.219	0.117	0.054	0.877
20	6.332	0.113	0.056	0.933
21	6.441	0.109	0.057	0.990
22	6.548	0.106	0.058	1.048
23	6.651	0.103	0.060	1.108
24	6.751	0.100	0.061	1.170
25	6.847	0.096	0.063	1.233
26	6.941	0.094	0.065	1.298
27	7.032	0.091	0.067	1.365
28	7.121	0.089	0.069	1.434
29	7.208	0.087	0.072	1.506
30	7.293	0.085	0.074	1.580
31	7.376	0.083	0.077	1.657
32	7.458	0.082	0.080	1.736
33	7.538	0.080	0.083	1.820
34	7.616	0.078	0.087	1.907
35	7.693	0.077	0.091	1.998
36	7.768	0.075	0.096	2.094
37	7.842	0.074	0.103	2.197
38	7.915	0.073	0.109	2.307
39	7.987	0.072	0.117	2.424
40	8.057	0.070	0.126	2.550
41	8.126	0.069	0.137	2.687
42	8.194	0.068	0.151	2.838
43	8.261	0.067	0.156	2.993
44	8.327	0.066	0.180	3.173
45	8.392	0.065	0.216	3.388
46	8.457	0.064	0.277	3.665
47	8.520	0.063	0.854	4.519
48	8.582	0.062	1.529	6.048

TABLE 4 -Continued

15 Min Time Steps (1)	Cumulative Depth (2)	Incremental Depth (3)	Hypothetical Storm Incremental Depth (4)	Hypothetical Storm Cumulative Depth (5)
49	8.644	0.061	0.707	6.755
50	8.704	0.061	0.625	7.380
51	8.764	0.060	0.241	7.621
52	8.823	0.059	0.196	7.817
53	8.882	0.058	0.167	7.983
54	8.939	0.058	0.146	8.129
55	8.996	0.057	0.144	8.273
56	9.053	0.056	0.131	8.404
57	9.108	0.056	0.121	8.526
58	9.163	0.055	0.113	8.639
59	9.218	0.054	0.106	8.745
60	9.271	0.054	0.100	8.845
61	9.325	0.053	0.094	8.939
62	9.377	0.053	0.089	9.028
63	9.429	0.052	0.085	9.113
64	9.481	0.052	0.082	9.194
65	9.532	0.051	0.078	9.273
66	9.583	0.051	0.075	9.348
67	9.633	0.050	0.073	9.421
68	9.682	0.050	0.070	9.491
69	9.731	0.049	0.068	9.559
70	9.780	0.049	0.066	9.625
71	9.828	0.048	0.064	9.689
72	9.876	0.048	0.062	9.752
73	9.923	0.047	0.061	9.812
74	9.970	0.047	0.059	9.871
75	10.016	0.046	0.058	9.929
76	10.062	0.046	0.056	9.985
77	10.108	0.046	0.055	10.040
78	10.153	0.045	0.054	10.094
79	10.198	0.045	0.053	10.147
80	10.243	0.045	0.052	10.198
81	10.287	0.044	0.051	10.249
82	10.330	0.044	0.050	10.298
83	10.374	0.043	0.049	10.347
84	10.417	0.043	0.048	10.395
85	10.460	0.043	0.047	10.442
86	10.502	0.042	0.046	10.488
87	10.544	0.042	0.045	10.533
88	10.586	0.042	0.045	10.577
89	10.628	0.042	0.044	10.621
90	10.669	0.041	0.043	10.664
91	10.710	0.041	0.042	10.707
92	10.750	0.041	0.042	10.749
93	10.791	0.040	0.041	10.790
94	10.831	0.040	0.041	10.830
95	10.870	0.040	0.040	10.870
96	10.910	0.039	0.039	10.910

concept, the t-hr maximum rainfall should also include the maximum intensities of less than t-hr, e.g., the maximum 30-min rainfall should include the maximum 15-min rainfall. Thus, in arranging a hypothetical storm pattern the largest and the next largest 15-min values should be placed in succession, but in any order (note that these two values together constitute the maximum 30-min rainfall). Extending this procedure to other higher durations requires placing the first, second and third largest values in a sequence; the first, second, third and the fourth largest values in a sequence (but not necessarily in the same order), and so on. Some possible patterns with this requirement are shown in Figure 5. The pattern shown by Figure 5C is normally preferred for hypothetical storms. In the SCS Type II distribution, the largest four 15-min rainfall amounts are arranged as shown in Figure 5D. For this study, this pattern is adopted with the other values arranged as in Figure 5D. The hypothetical storm incremental and cumulative depths (for T=100 yr) are given in columns (4) and (5), respectively, in Tables 3 and 4 for the Little Wekiva River Basin. As illustrated by Tables 3 and 4, the average intensity of rainfall will decrease with the increase in the basin size.

GENERALIZED DISTRIBUTIONS (24-HOUR)

It may not be convenient or practical to always develop site-specific rainfall distributions by the procedures described in the foregoing section. For this reason, the District will develop 'generalized' 24-hr rainfall distributions for various

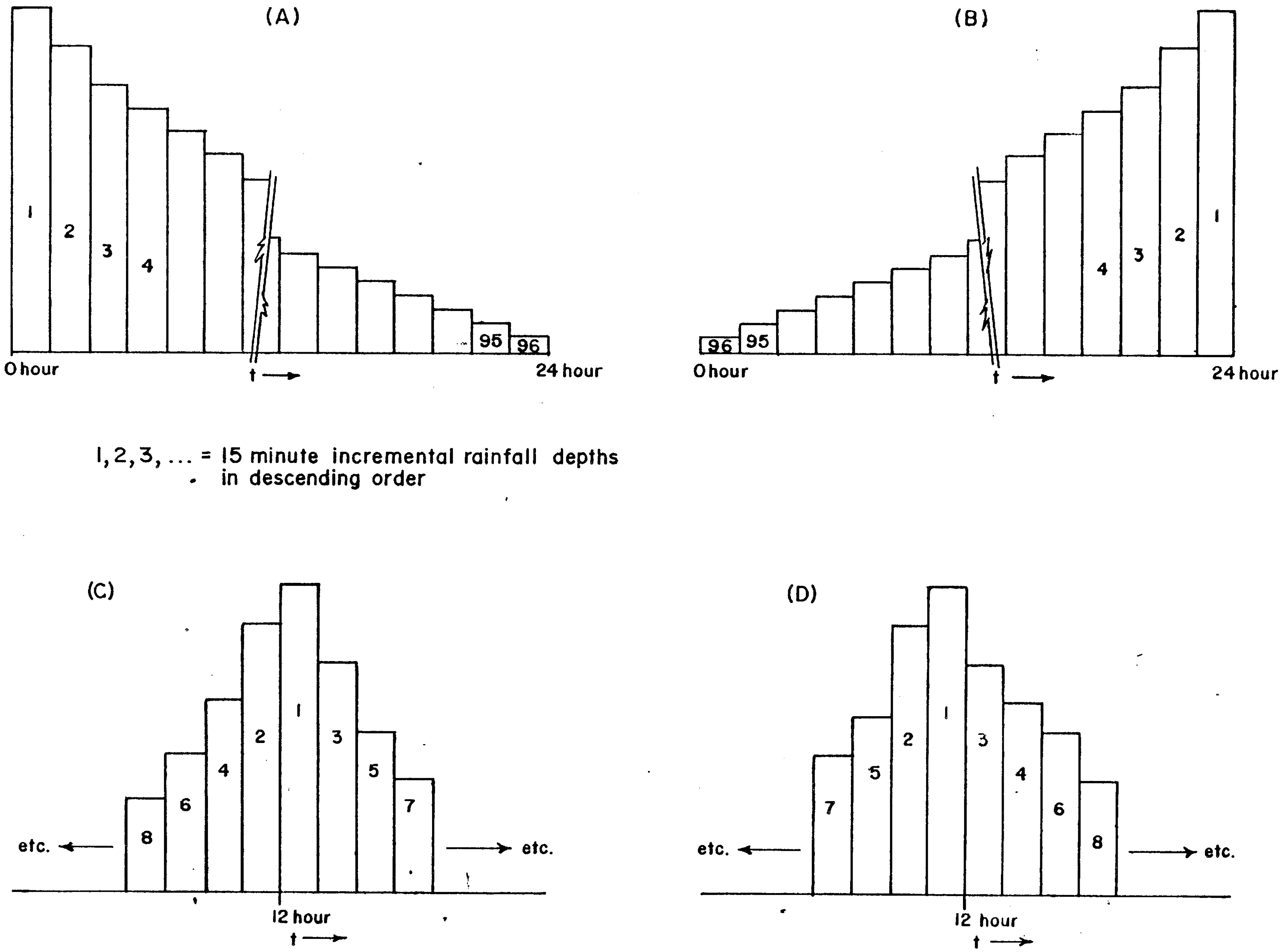

Figure 5. Hypothetical Storm Patterns

surface water basins within the District (Figure 2). These will be published in a future report. Generalized distributions are dimensionless and can be used with a rainfall event of any return period (T) and any basin size. The 24-hr rainfall value corrected for the basin size (using the 24 hr curve in Figure 3a) is all that is required for applying these distributions. Derivation of generalized distributions is as follows:

Step 1: compile maximum rainfall depths for various durations and various return periods

[See Table 1 (duration 15 min through 24 hr) for this data.]

Step 2: for each return period, express the rainfall values in the preceding step as ratios to 24-hr rainfall. For each duration compute the average ratio, and

[Table 5 summarizes the data generated by this step. Note that for a given duration, the rainfall ratios decrease with the increase in return period for the Little Wekiva River Basin. While about 24 percent of the 24-hr rainfall is expected to occur within 15 minutes during a 10 yr event, such proportion is only about 19 percent for the 100-yr event.]

Step 3: draw depth-duration curves based on t-hr to 24-hr rainfall ratios and develop the rainfall distributions for the basin using the procedures described in the previous section.

Figure 6 presents various depth-duration curves for the Little Wekiva River Basin. The 25-yr curve practically coincides

TABLE 5. Maximum Rainfall Data Expressed as Ratios to 24 Hour Rainfall (Point Rainfalls)

Duration	Little Wekiva River Basin				Howell Creek Basin			
	10 yr (2)	25 yr (3)	100 yr (4)	Average (5)	10 yr (6)	25 yr (7)	100 yr (8)	Average (9)
(1)								
15 min.	0.236	0.213	0.185	0.211	0.230	0.211	0.183	0.208
30 min.	0.353	0.325	0.288	0.322	0.345	0.321	0.285	0.317
60 min.	0.476	0.442	0.395	0.438	0.467	0.436	0.391	0.431
3 hr	0.615	0.565	0.509	0.563	0.609	0.565	0.505	0.560
6 hr	0.756	0.696	0.632	0.695	0.741	0.688	0.630	0.686
24 hr	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

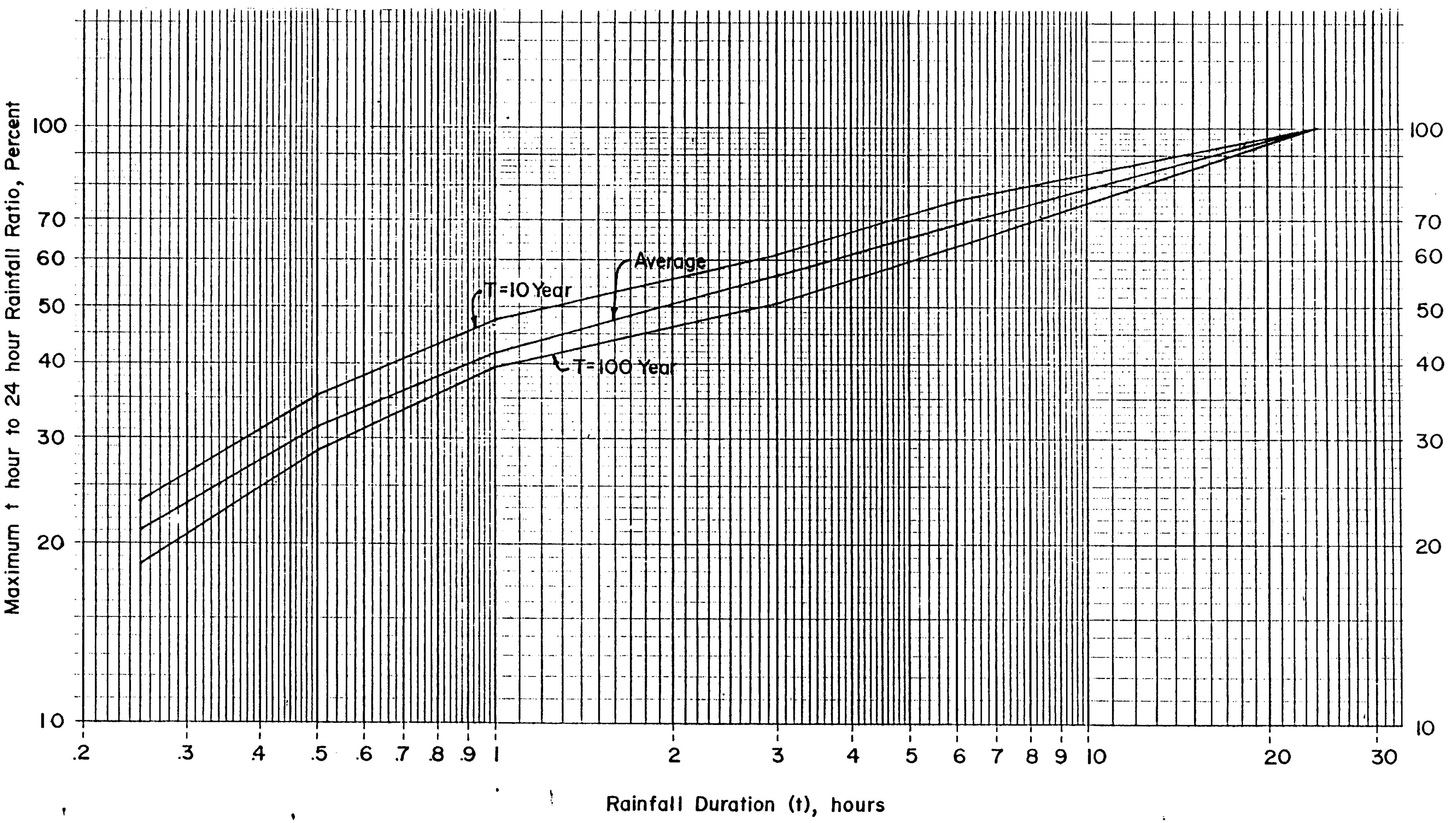

Figure 6. Maximum Rainfall Depth-Duration Curves for the Little Wekiva River Basin (Point Rainfall Ratios)

with the average-ratio curve and thus is not shown. Generalization of results calls for some sacrifice of accuracy. In this study, a storm distribution based on the average ratio curve is regarded as the 'generalized' rainfall distribution for the basin. By this approximation, small duration rainfalls (within the 24 hr period) in the case of Little Wekiva River and Howell Creek basins are reduced for T=10 yr and increased for T=100 yr. For watersheds with a relatively low basin lag (i.e., time of concentration) this will result in an underestimation of peak discharges for T=10 yr and overestimation for T=100 yr. This will be illustrated shortly.

Table 6 illustrates the derivation of the generalized rainfall distribution for the Little Wekive River Basin from the rainfall ratios given in Table 5, Column (5). The values given in Column (5) Table 6 can be rearranged as input data for the HEC-1 (U.S. Army Corps of Engineers, 1981) or the TR-20 (U.S. Department of Agriculture, Soil Conservation Service, 1983) computer programs. The PC cards in the HEC-1 input data appear as given in Table 7. In addition to the 'generalized' distribution, rainfall distributions also are developed separately for T=10 yr, 25 yr, and 100 yr storm events and included as PC cards in Table 7. These T-yr distributions are called "standard" distributions for the basin. Table 8 presents these distributions for the Howell Creek Basin. A computer program, HYPSTORM, is developed to generate PC cards for a given 24-hr storm event from the 15 min through 6 hr rainfall ratios, e.g., see Columns (2)-(9), Table 5. A listing of this program is given in Appendix B.

TABLE 6. Derivation of Generalized Rainfall Distribution for the Little Wekiva River Basin (Values Shown are Ratios to 24 Hour Rainfall)

15 Min Time Steps (1)	Cumulative Depth (2)	Incremental Depth (3)	Hypothetical Storm Incremental Depth (4)	Hypothetical Storm Cumulative Depth (5)
1	0.211	0.211	0.003	0.003
2	0.322	0.111	0.003	0.006
3	0.385	0.063	0.003	0.008
4	0.438	0.053	0.003	0.011
5	0.461	0.023	0.003	0.014
6	0.481	0.020	0.003	0.017
7	0.498	0.017	0.003	0.020
8	0.513	0.015	0.003	0.023
9	0.527	0.014	0.003	0.027
10	0.540	0.013	0.003	0.030
11	0.552	0.012	0.003	0.033
12	0.563	0.011	0.003	0.037
13	0.577	0.014	0.003	0.040
14	0.590	0.013	0.004	0.043
15	0.602	0.013	0.004	0.047
16	0.614	0.012	0.004	0.051
17	0.626	0.011	0.004	0.054
18	0.637	0.011	0.004	0.058
19	0.647	0.011	0.004	0.062
20	0.658	0.010	0.004	0.066
21	0.667	0.010	0.004	0.070
22	0.677	0.010	0.004	0.075
23	0.686	0.009	0.004	0.079
24	0.695	0.009	0.005	0.084
25	0.702	0.007	0.005	0.088
26	0.710	0.007	0.005	0.093
27	0.717	0.007	0.005	0.098
28	0.724	0.007	0.005	0.103
29	0.730	0.007	0.005	0.109
30	0.737	0.007	0.006	0.114
31	0.743	0.006	0.006	0.120
32	0.750	0.006	0.006	0.126
33	0.756	0.006	0.006	0.132
34	0.762	0.006	0.007	0.139
35	0.767	0.006	0.007	0.146
36	0.773	0.006	0.007	0.154
37	0.779	0.006	0.009	0.163
38	0.784	0.005	0.010	0.173
39	0.789	0.005	0.011	0.183
40	0.795	0.005	0.011	0.195
41	0.800	0.005	0.013	0.207
42	0.805	0.005	0.014	0.221
43	0.810	0.005	0.012	0.233
44	0.815	0.005	0.014	0.247
45	0.820	0.005	0.017	0.264
46	0.824	0.005	0.023	0.287
47	0.829	0.005	0.111	0.398
48	0.834	0.005	0.211	0.609

TABLE 6 -Continued

15 Min Time Steps (1)	Cumulative Depth (2)	Incremental Depth (3)	Hypothetical Storm Incremental Depth (4)	Hypothetical Storm Cumulative Depth (5)
49	0.838	0.005	0.063	0.673
50	0.843	0.004	0.053	0.725
51	0.847	0.004	0.020	0.745
52	0.851	0.004	0.015	0.760
53	0.856	0.004	0.013	0.773
54	0.860	0.004	0.011	0.784
55	0.864	0.004	0.013	0.797
56	0.868	0.004	0.012	0.809
57	0.872	0.004	0.011	0.820
58	0.876	0.004	0.010	0.830
59	0.880	0.004	0.010	0.840
60	0.884	0.004	0.009	0.849
61	0.888	0.004	0.007	0.856
62	0.892	0.004	0.007	0.863
63	0.895	0.004	0.007	0.869
64	0.899	0.004	0.006	0.876
65	0.903	0.004	0.006	0.882
66	0.906	0.004	0.006	0.887
67	0.910	0.004	0.005	0.893
68	0.913	0.004	0.005	0.898
69	0.917	0.004	0.005	0.903
70	0.920	0.003	0.005	0.908
71	0.924	0.003	0.005	0.913
72	0.927	0.003	0.005	0.917
73	0.931	0.003	0.004	0.922
74	0.934	0.003	0.004	0.926
75	0.937	0.003	0.004	0.930
76	0.941	0.003	0.004	0.934
77	0.944	0.003	0.004	0.938
78	0.947	0.003	0.004	0.942
79	0.950	0.003	0.004	0.946
80	0.953	0.003	0.004	0.950
81	0.956	0.003	0.004	0.953
82	0.959	0.003	0.004	0.957
83	0.963	0.003	0.003	0.960
84	0.966	0.003	0.003	0.964
85	0.969	0.003	0.003	0.967
86	0.972	0.003	0.003	0.970
87	0.974	0.003	0.003	0.974
88	0.977	0.003	0.003	0.977
89	0.980	0.003	0.003	0.980
90	0.983	0.003	0.003	0.983
91	0.986	0.003	0.003	0.986
92	0.989	0.003	0.003	0.989
93	0.992	0.003	0.003	0.992
94	0.994	0.003	0.003	0.994
95	0.997	0.003	0.003	0.997
96	1.000	0.003	0.003	1.000

TABLE 7. 24-Hour Rainfall Distributions as PC Cards for the HEC-1 Input Data (The Little Wekiva River Basin)

GENERALIZED DISTRIBUTION

PC	0.000	0.003	0.006	0.008	0.011	0.014	0.017	0.020	0.023	0.027
PC	0.030	0.033	0.037	0.040	0.043	0.047	0.051	0.054	0.058	0.062
PC	0.066	0.070	0.075	0.079	0.084	0.088	0.093	0.098	0.103	0.109
PC	0.114	0.120	0.126	0.132	0.139	0.146	0.154	0.163	0.173	0.183
PC	0.195	0.207	0.221	0.233	0.247	0.264	0.287	0.398	0.609	0.673
PC	0.725	0.745	0.760	0.773	0.784	0.797	0.809	0.820	0.830	0.840
PC	0.849	0.856	0.863	0.869	0.876	0.882	0.887	0.893	0.898	0.903
PC	0.908	0.913	0.917	0.922	0.926	0.930	0.934	0.938	0.942	0.946
PC	0.950	0.953	0.957	0.960	0.964	0.967	0.970	0.974	0.977	0.980
PC	0.983	0.986	0.989	0.992	0.994	0.997	1.000			

10 YEAR DISTRIBUTION

PC	0.000	0.002	0.004	0.006	0.009	0.011	0.013	0.016	0.018	0.021
PC	0.023	0.026	0.028	0.031	0.034	0.037	0.039	0.042	0.045	0.049
PC	0.052	0.055	0.059	0.062	0.066	0.069	0.073	0.077	0.081	0.086
PC	0.090	0.095	0.100	0.105	0.111	0.117	0.123	0.133	0.143	0.155
PC	0.167	0.180	0.195	0.208	0.224	0.243	0.268	0.385	0.621	0.689
PC	0.744	0.766	0.783	0.798	0.810	0.824	0.837	0.849	0.859	0.870
PC	0.879	0.885	0.891	0.896	0.901	0.906	0.911	0.915	0.920	0.924
PC	0.928	0.931	0.935	0.939	0.942	0.946	0.949	0.952	0.955	0.958
PC	0.961	0.964	0.967	0.969	0.972	0.975	0.977	0.980	0.982	0.984
PC	0.987	0.989	0.991	0.994	0.996	0.998	1.000			

25 YEAR DISTRIBUTION

PC	0.000	0.003	0.006	0.008	0.011	0.014	0.017	0.020	0.023	0.027
PC	0.030	0.033	0.036	0.040	0.043	0.047	0.051	0.054	0.058	0.062
PC	0.066	0.070	0.074	0.079	0.083	0.088	0.093	0.098	0.103	0.108
PC	0.114	0.120	0.126	0.132	0.139	0.146	0.153	0.162	0.172	0.183
PC	0.194	0.206	0.220	0.232	0.246	0.262	0.285	0.397	0.610	0.674
PC	0.727	0.746	0.762	0.774	0.785	0.798	0.810	0.821	0.831	0.840
PC	0.849	0.856	0.863	0.870	0.876	0.882	0.888	0.893	0.898	0.903
PC	0.908	0.913	0.918	0.922	0.926	0.931	0.935	0.939	0.942	0.946
PC	0.950	0.954	0.957	0.961	0.964	0.967	0.971	0.974	0.977	0.980
PC	0.983	0.986	0.989	0.992	0.994	0.997	1.000			

100 YEAR DISTRIBUTION

PC	0.000	0.003	0.007	0.011	0.014	0.018	0.022	0.026	0.029	0.033
PC	0.037	0.041	0.046	0.050	0.054	0.059	0.063	0.068	0.072	0.077
PC	0.082	0.087	0.092	0.098	0.103	0.109	0.114	0.120	0.126	0.133
PC	0.139	0.146	0.153	0.161	0.169	0.177	0.185	0.194	0.203	0.213
PC	0.224	0.235	0.248	0.259	0.272	0.287	0.308	0.411	0.596	0.655
PC	0.703	0.721	0.735	0.747	0.757	0.769	0.780	0.791	0.800	0.809
PC	0.817	0.826	0.834	0.841	0.849	0.855	0.862	0.869	0.875	0.881
PC	0.887	0.892	0.898	0.903	0.909	0.914	0.919	0.924	0.928	0.933
PC	0.937	0.942	0.946	0.951	0.955	0.959	0.963	0.967	0.971	0.975
PC	0.978	0.982	0.986	0.989	0.993	0.997	1.000			

TABLE 8. 24-Hour Rainfall Distributions as PC Cards for the HEC-1 Input Data (The Howell Creek Basin)

GENERALIZED DISTRIBUTION

```
PC 0.000   0.003   0.006   0.009   0.012   0.015   0.018   0.021   0.024   0.028
PC 0.031   0.034   0.038   0.041   0.045   0.049   0.052   0.056   0.060   0.064
PC 0.068   0.073   0.077   0.082   0.086   0.091   0.096   0.101   0.107   0.112
PC 0.118   0.124   0.130   0.136   0.143   0.151   0.158   0.167   0.176   0.186
PC 0.197   0.209   0.223   0.235   0.249   0.267   0.291   0.400   0.608   0.670
PC 0.722   0.742   0.758   0.771   0.783   0.795   0.807   0.817   0.827   0.836
PC 0.844   0.852   0.859   0.865   0.872   0.878   0.884   0.889   0.895   0.900
PC 0.905   0.910   0.915   0.919   0.924   0.928   0.932   0.936   0.940   0.944
PC 0.948   0.952   0.955   0.959   0.963   0.966   0.969   0.973   0.976   0.979
PC 0.982   0.985   0.988   0.991   0.994   0.997   1.000
```

10 YEAR DISTRIBUTION

```
PC 0.000   0.002   0.005   0.007   0.009   0.012   0.014   0.017   0.019   0.022
PC 0.025   0.027   0.030   0.033   0.036   0.039   0.042   0.045   0.049   0.052
PC 0.055   0.059   0.062   0.066   0.070   0.074   0.078   0.082   0.087   0.091
PC 0.096   0.101   0.106   0.112   0.118   0.124   0.131   0.140   0.150   0.160
PC 0.172   0.184   0.198   0.212   0.228   0.247   0.273   0.388   0.618   0.685
PC 0.740   0.762   0.780   0.794   0.807   0.820   0.832   0.843   0.853   0.863
PC 0.872   0.878   0.884   0.890   0.895   0.900   0.905   0.910   0.914   0.919
PC 0.923   0.927   0.931   0.935   0.938   0.942   0.945   0.949   0.952   0.955
PC 0.958   0.961   0.964   0.967   0.970   0.973   0.975   0.978   0.981   0.983
PC 0.986   0.988   0.991   0.993   0.995   0.998   1.000
```

25 YEAR DISTRIBUTION

```
PC 0.000   0.003   0.006   0.009   0.012   0.015   0.018   0.021   0.024   0.027
PC 0.031   0.034   0.038   0.041   0.045   0.048   0.052   0.056   0.060   0.064
PC 0.068   0.072   0.077   0.081   0.086   0.091   0.095   0.101   0.106   0.111
PC 0.117   0.123   0.129   0.136   0.142   0.150   0.157   0.166   0.175   0.185
PC 0.195   0.207   0.220   0.232   0.247   0.265   0.288   0.398   0.609   0.672
PC 0.724   0.744   0.760   0.774   0.785   0.797   0.808   0.819   0.828   0.837
PC 0.845   0.853   0.860   0.866   0.873   0.879   0.884   0.890   0.895   0.901
PC 0.906   0.910   0.915   0.920   0.924   0.928   0.933   0.937   0.941   0.945
PC 0.948   0.952   0.956   0.959   0.963   0.966   0.970   0.973   0.976   0.979
PC 0.982   0.985   0.988   0.991   0.994   0.997   1.000
```

100 YEAR DISTRIBUTION

```
PC 0.000   0.004   0.007   0.011   0.014   0.018   0.022   0.026   0.030   0.034
PC 0.038   0.042   0.046   0.050   0.055   0.059   0.063   0.068   0.073   0.078
PC 0.083   0.088   0.093   0.098   0.104   0.109   0.115   0.121   0.127   0.134
PC 0.140   0.147   0.154   0.162   0.169   0.178   0.186   0.195   0.204   0.214
PC 0.225   0.237   0.250   0.261   0.274   0.289   0.310   0.412   0.595   0.653
PC 0.701   0.719   0.733   0.745   0.755   0.767   0.779   0.789   0.799   0.808
PC 0.816   0.825   0.833   0.840   0.848   0.855   0.861   0.868   0.874   0.880
PC 0.886   0.892   0.897   0.903   0.908   0.913   0.918   0.923   0.928   0.932
PC 0.937   0.942   0.946   0.950   0.954   0.959   0.963   0.967   0.971   0.975
PC 0.978   0.982   0.986   0.989   0.993   0.997   1.000
```

Table 9 summarizes peak discharges calculated for a hypothetical watershed of 1 sq. mi. located within the Little Wekiva River Basin using different basin lag times. These results are obtained by the HEC-1 program. For each storm event, results based on the 'Basin-T yr' distribution are shown on the first line for each event (Table 9). Other results which are based on generalized distributions are approximate. The three generalized distributions considered in Table 9 underestimate peak discharges for T=10 yr and overestimate for T=100 yr. The discrepancies decrease with increasing lag time. The reason for the occurrence of these results is explained earlier. Where accuracy in discharge estimates is desired, e.g., in sizing culverts and other hydraulic elements, use of 'Basin T-Year', i.e, standard distributions may be considered.

Another approximation made in developing generalized rainfall distributions is with respect to adjustment of rainfall values to compensate for the basin size (Figure 3). This adjustment involves correcting rainfall values for each sub-duration within the storm based on the given watershed size (see Table 2). Since the study area sizes can vary vastly it is not possible to develop a generalized distribution which accounts for variation in basin sizes. However, since most study areas are small watersheds or larger basins are divided into sub-basins in modeling, the average distribution developed based on the point rainfall ratios (Table 6) may still be regarded as the 'Basin Generalized' distribution. For larger watersheds an adjusted 24 hr rainfall value (based on basin size) should be used in calculating peak discharges. Table 10 summarizes the effect of

TABLE 9. Summary of Peak Discharges (cfs) for a Hypothetical Watershed in the Little Wekiva River Basin (Drainage Area = 1 sq. mi.; Runoff Curve No.= 70)

Rainfall Distribution (1)	Basin Lag		
	1 hr (2)	2 hr (3)	4 hr (4)
T=10 yr; 24 hr Rainfall= 6.75 in.			
Basin-10 yr	795	490	295
Basin-Generalized	738	457	276
SCS Type II	781	479	285
SCS Type III	711	457	281
T= 25 yr; 24 hr Rainfall = 8.4 in.			
Basin-25 yr	1,060	655	395
Basin-Generalized	1,050	652	394
SCS Type II	1,110	684	406
SCS Type III	1,010	650	400
T= 100 yr; 24 hr Rainfall = 11.4 in.			
Basin-100 yr	1,490	935	572
Basin-Generalized	1,640	1,020	618
SCS Type II	1,730	1,070	638
SCS Type III	1,590	1,020	625

TABLE 10. Summary of Peak Discharges (cfs) for Sub-Watersheds of Different Sizes Within the Little Wekiva River Basin (Return Period, T=100 yr; Runoff Curve No.=70)

Basin Lag	Rainfall Distribution		
	Site-Specific	Basin-100 yr	Basin-Generalized
Drainage Area= 5 sq. mi.(24 hr adjusted rainfall = 11.31 in.)			
2 hr	4,590	4,620	5,060
3 hr	3,450	3,470	3,770
4 hr	2,820	2,830	3,060
Drainage Area= 10 sq. mi. (24 hr adjusted rainfall = 11.21 in.)			
3 hr	6,790	6,850	7,440
4 hr	5,550	5,590	6,040
6 hr	4,160	4,170	4,450
Drainage Area= 20 sq. mi. (24 hr adjusted rainfall = 11.07 in.)			
4 hr	10,800	11,000	11,900
6 hr	7,380	8,200	8,740
8 hr	6,610	6,650	6,990

this approximation on 100 yr peak discharges for various watershed sizes within the Little Wekiva River Basin. The 'site-specific' distribution is similar to the distribution derived in Table 4 and considers all the required adjustments. The 'Basin-100 yr' and 'Basin-Generalized' distributions are those presented in Table 7. In general, the discrepancies between results given by the 'site-specific' and 'Basin-100 yr' distributions are minor. However, noticeable discrepancies exist between 'Basin-Generalized' and 'Basin-100yr' distribution results. These discrepancies are primarily due to differences in the two distributions.

THE 4-DAY RAINFALL DISTRIBUTION

The 4-day storm rainfall distribution may be developed by obtaining the incremental rainfall depths at 24-hr time steps from the depth-duration curve and rearranging the values in a suitable pattern. For T=100 yr, the following rainfall depths are obtained from Figure 7.

Little Wekiva River Basin 100 Yr Rainfall Depths

Time, hrs	Accumulative Rainfall, in.	Incremental Rainfall, in.
24	11.4	11.4
48	13.1	1.7
72	14.0	0.9
96	14.8	0.8

Based on the distribution for the Standard Project Storm used by the U.S. Corps of Engineers (see HEC-1 Users Manual, 1981) the Applicant's Handbook, Management and Storage of Surface

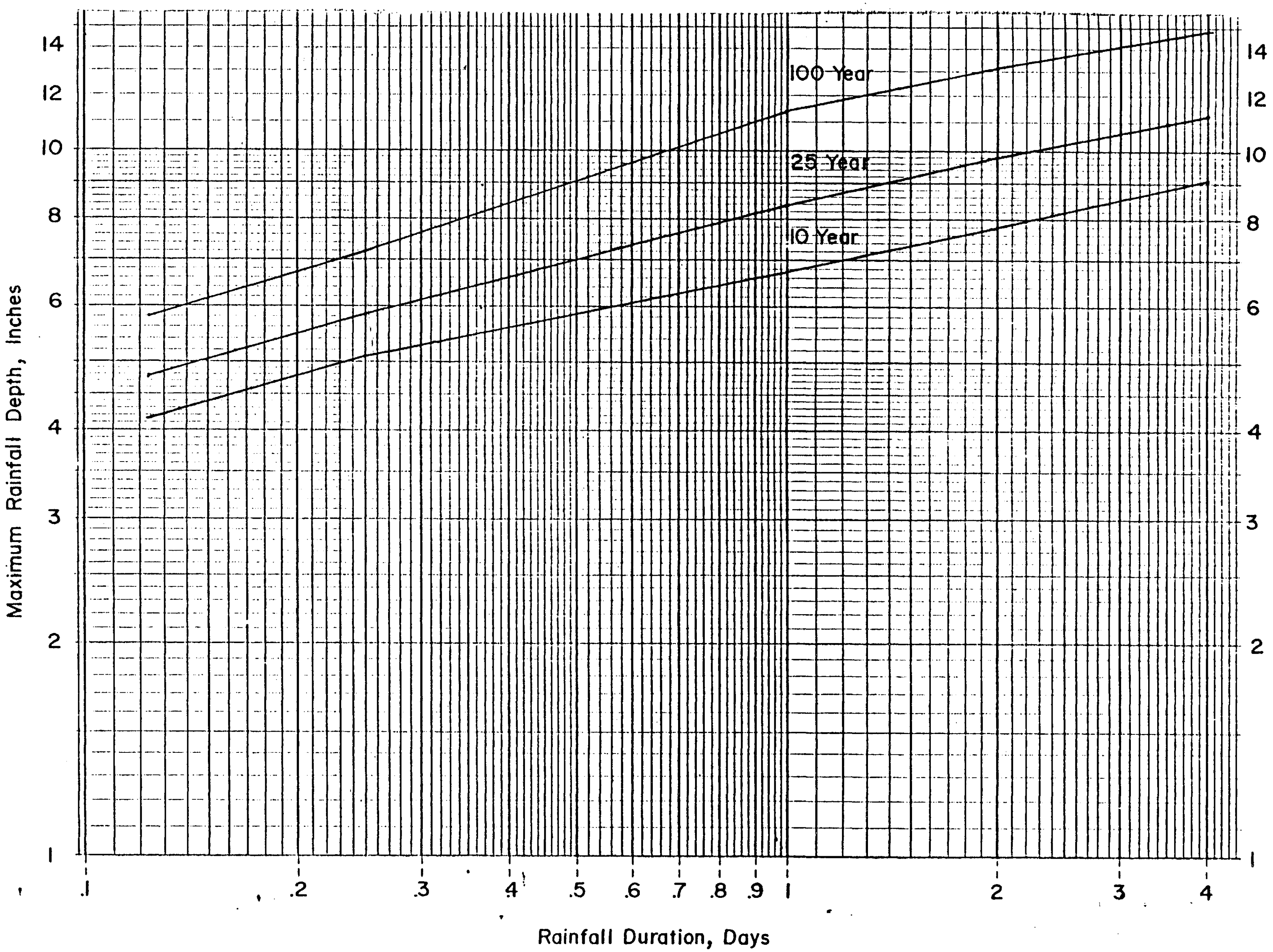

Figure 7. Maximum Rainfall Depth-Duration Curves for the Little Wekiva River Basin (Point Rainfalls)

Waters (SJRWMD, 1984) suggests the following pattern for the 4-day storm.

a) The maximum 24-hr rainfall occurs on day three of the 4-day duration storm; b) the second maximum 24-hr rainfall occurs on day two; c) the third maximum 24-hr rainfall on day four; and 3) the fourth maximum rainfall on day one.

In general, the largest 24 hr depth will be several times the depth of any other 24-hr period in the 4-day storm. For this reason, the peak discharge for the storm is generated primarily by the largest 24-hr rainfall and the contribution of adjacent days' rainfall to the peak will be insignificant. For day three rainfall, the 24-hr rainfall distribution derived previously is applied. For the other three days a uniform distribution may be assumed.

APPLICATIONS IN SURFACE WATER BASIN MODELING

To compute peak discharges in large river basins, the drainage area is normally divided into several sub-basins based on drainage divides and other controlling features (Figure 8). One of the difficult problems in hydrologic simulation is deriving peak discharges or flood hydrographs (say for T=100 yr event) at a series of locations throughout a complex basin. Recall that the average depth of storm rainfall decreases with the size of the basin (i.e., contributing area) in the same vicinity (Figure 3). Each location of interest on a stream may have a different contributing area (see locations 1, 2, 3, etc. on Figure 8). In modeling, rainfall must be distributed throughout the basin in such a manner that at each computation point the hydrograph generated will be based on rainfall depth that is consistent with the actual drainage area. Let the 100-yr point rainfall for the basin in Figure 8 be 11.4 in. The average depths of rainfall over the contributing areas for various locations of the basin are as follows:

Location	Contributing Area sq. mi.	*Average 100 yr rainfall, in.
1	5	11.31
2	15	11.15
3	3	11.33
4	15	11.15
5	20	11.07
6	35	10.94
7	3	11.33
8	20	11.07
9	55	10.82

* Point rainfall value adjusted based on Figure 3.

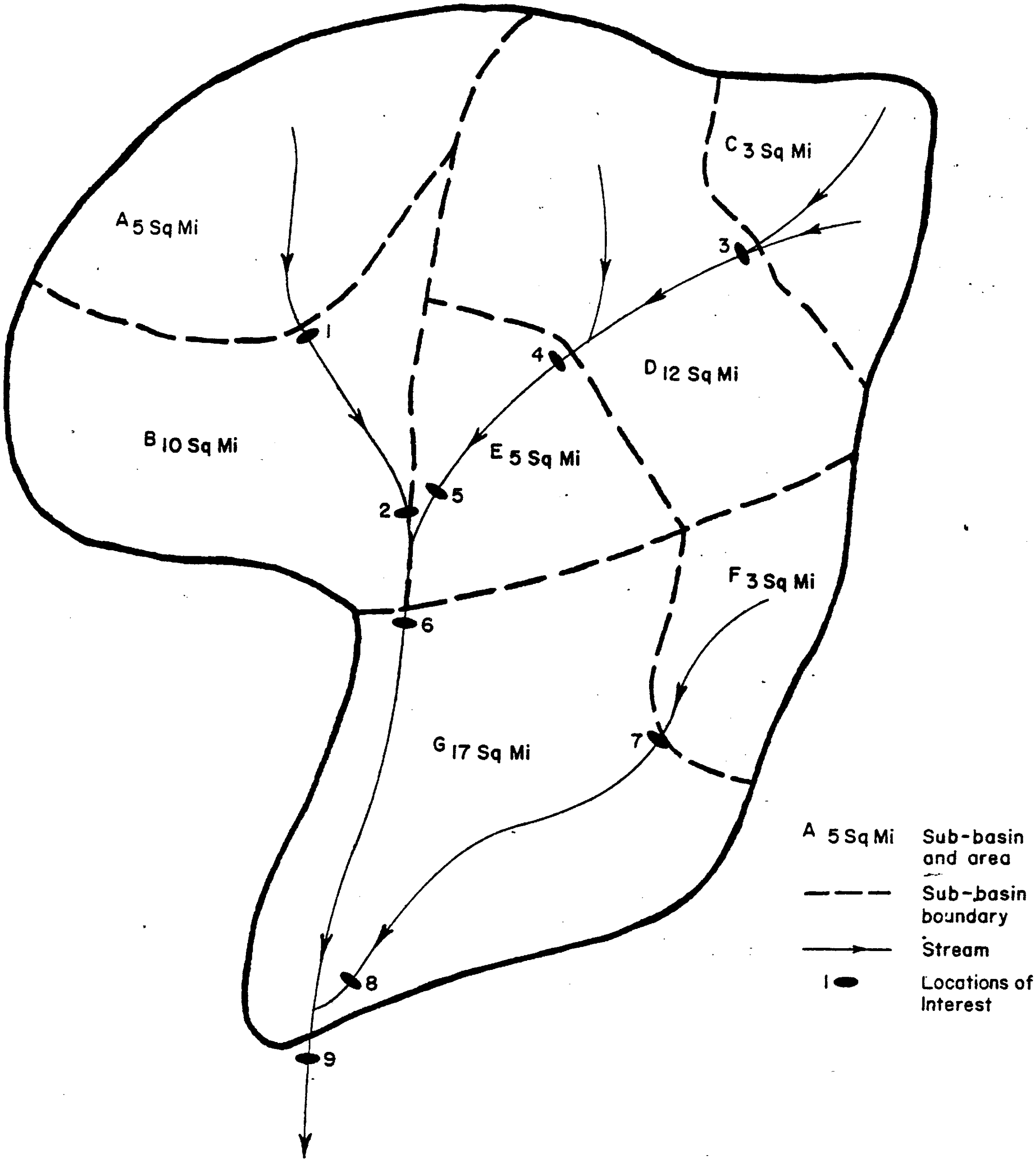

Figure 8. Sub-basin Delineation for a Large Drainage Basin.

Consider locations 3, 4, and 5 which are situated in tandem on the same tributary. Discharge at Location 1 is contributed by sub-basin 3 for which the average 100-yr rainfall is 11.33 in. Discharge at Location 4 is contributed by sub-basins C and D, which together have 100-yr rainfall = 11.15 in. Likewise, for the contributing area of Location 5 (sub-basins C, D, and E) the 100 yr average rainfall = 11.07 in. In modeling the basin above each location of interest, the respective area rainfall should be used to generate hydrographs consistent with the upstream runoff contribution. This involves setting up a separate computer file (HEC-1 or TR-20) for each location. The HEC-1 program, however, has a provision to compute a set of index hydrographs (maximum 10) based on specified rainfall depths for each location and obtaining the location hydrograph by interpolation. Using this method it is necessary to set up only one computer file for the entire basin. Consistent hydrographs at each location in the basin are generated based on cumulative area at each location. See HEC-1 Users Manual for further details.

SUMMARY AND RECOMMENDATIONS

Peak discharges for surface water basins are often calculated by rainfall-runoff models by simulating single storm events. A hypothetical distribution is assumed for the storm rainfall sequence. Use of a site-specific hypothetical storm, which incorporates the local rainfall characteristics, is necessary for accurate prediction of peak discharges using these models. The steps for developing such storms include:

- determine total storm duration and return period,
- extract maximum rainfall data for various sub-durations from the appropriate publications,
- adjust each sub-duration rainfall for area of the basin,
- adjust for annual series, if necessary,
- develop relation(s) for accummulated depth versus time,
- determine time interval for subdividing the storm and obtain incremental depths, and
- arrange storm.

A computer program, HYPSTORM (Appendix B), has been developed to generate site-specific storm distribution data in the form of PC cards for HEC-1 model input data.

Hypothetical distributions are specific for a given location, basin size and return period. In this study, for a given surface water basin, a distribution developed from the averages of 10 yr, 25 yr, and 100 yr point rainfall depths is regarded as the 'Generalized Rainfall Distribution.' The 10-year and 100 yr peak discharges based on Generalized Distributions, however, will be less accurate; e.g., in the case of the Little

Wekiva River Basin, use of the Generalized Distribution results in an underestimation of the 10 yr peak discharges and overestimation for T=100 yr. Generalized Rainfall Distributions fulfill the needs of all general studies, e.g., comparing pre- and post-development peak discharges. Use of specific T-year distribution is recommended in designing water control structures or other hydraulic elements of a storm water management system.

In modeling surface water basins, since peak discharges are needed at numerous locations throughout the basin, development and use of site-specific distributions for each location becomes rather unwieldy. The following recommendations are made:

- use T-year distribution for the entire basin, and
- adjust total storm depth (e.g., 24 hr rainfall) for the contributing area of each loaction. [To avoid multiple calculations, i.e., multiple computer runs involved in this procedure, HEC-1 users may use the 'consistent depth/area relationship (JD card)' option].

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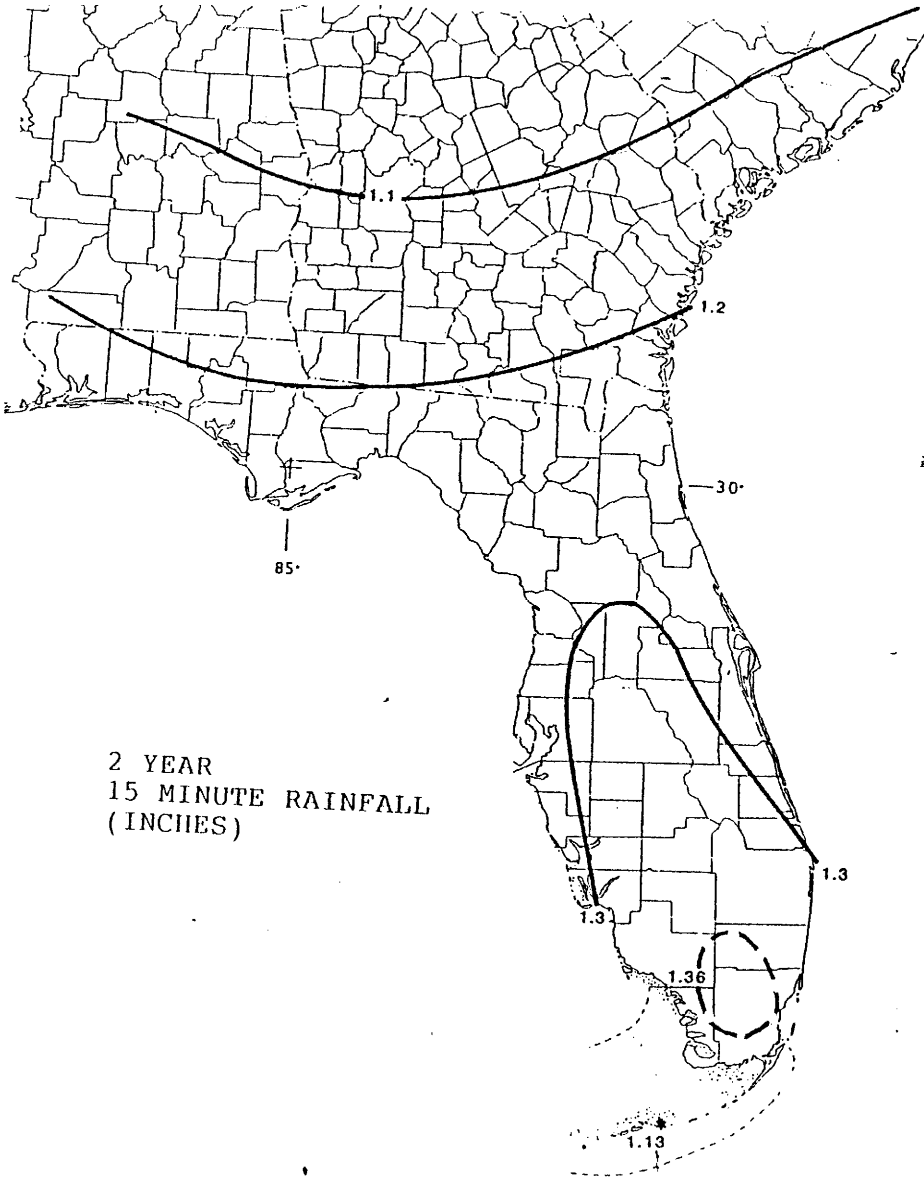
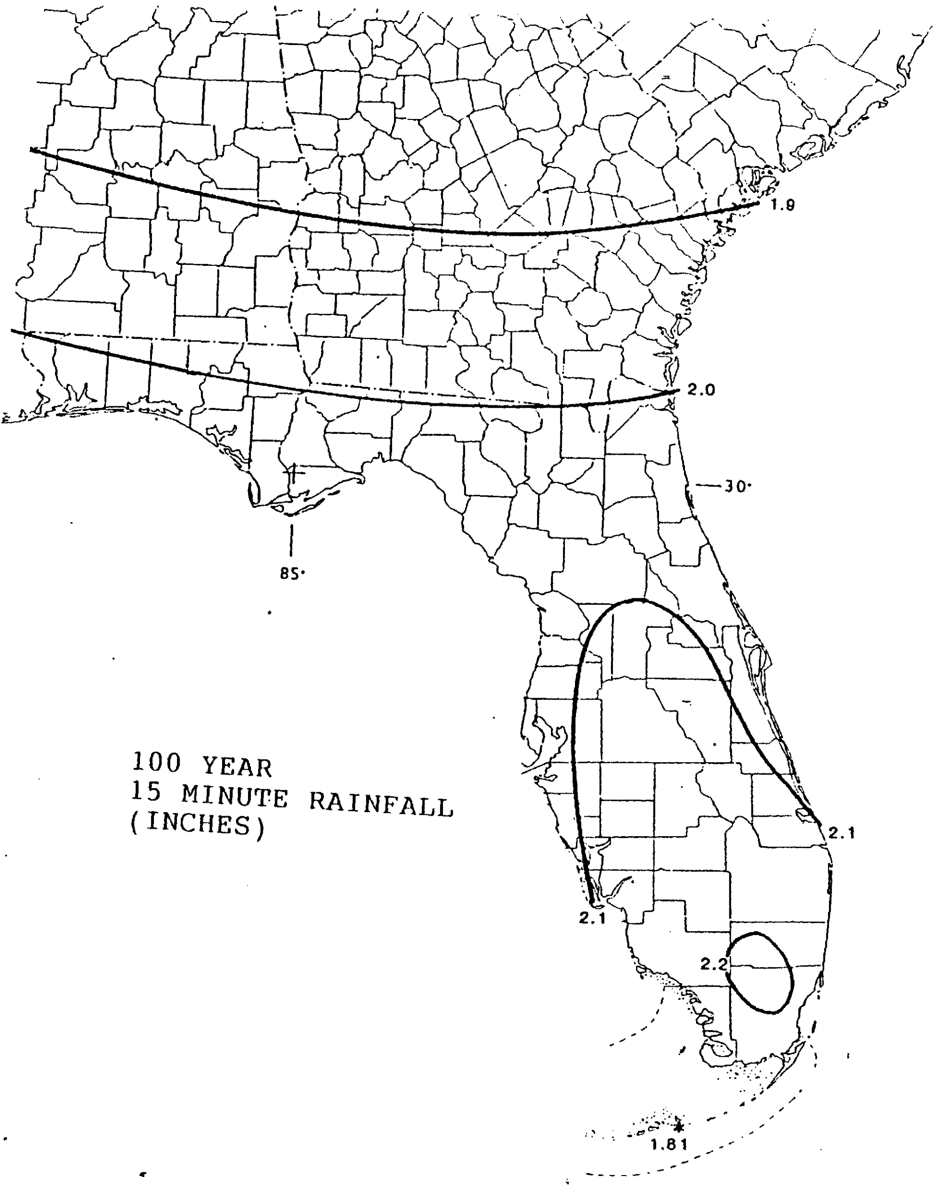
11. ______________________________, 1986. "Urban Hydrology for Small Watersheds," Technical Release 55, Washington, D.C.

APPENDIX A

GENERALIZED RAINFALL CHARTS

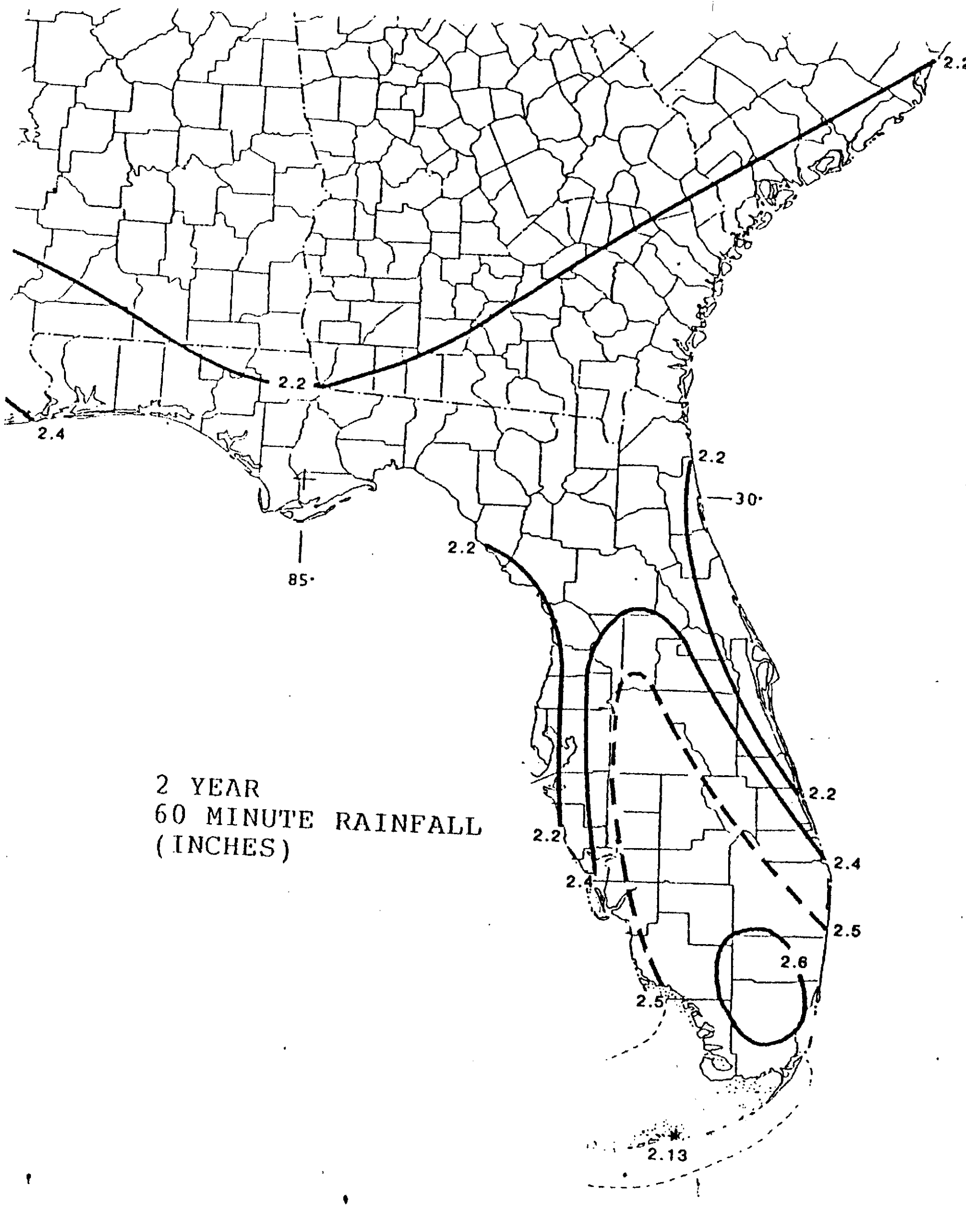


2 YEAR
15 MINUTE RAINFALL
(INCHES)

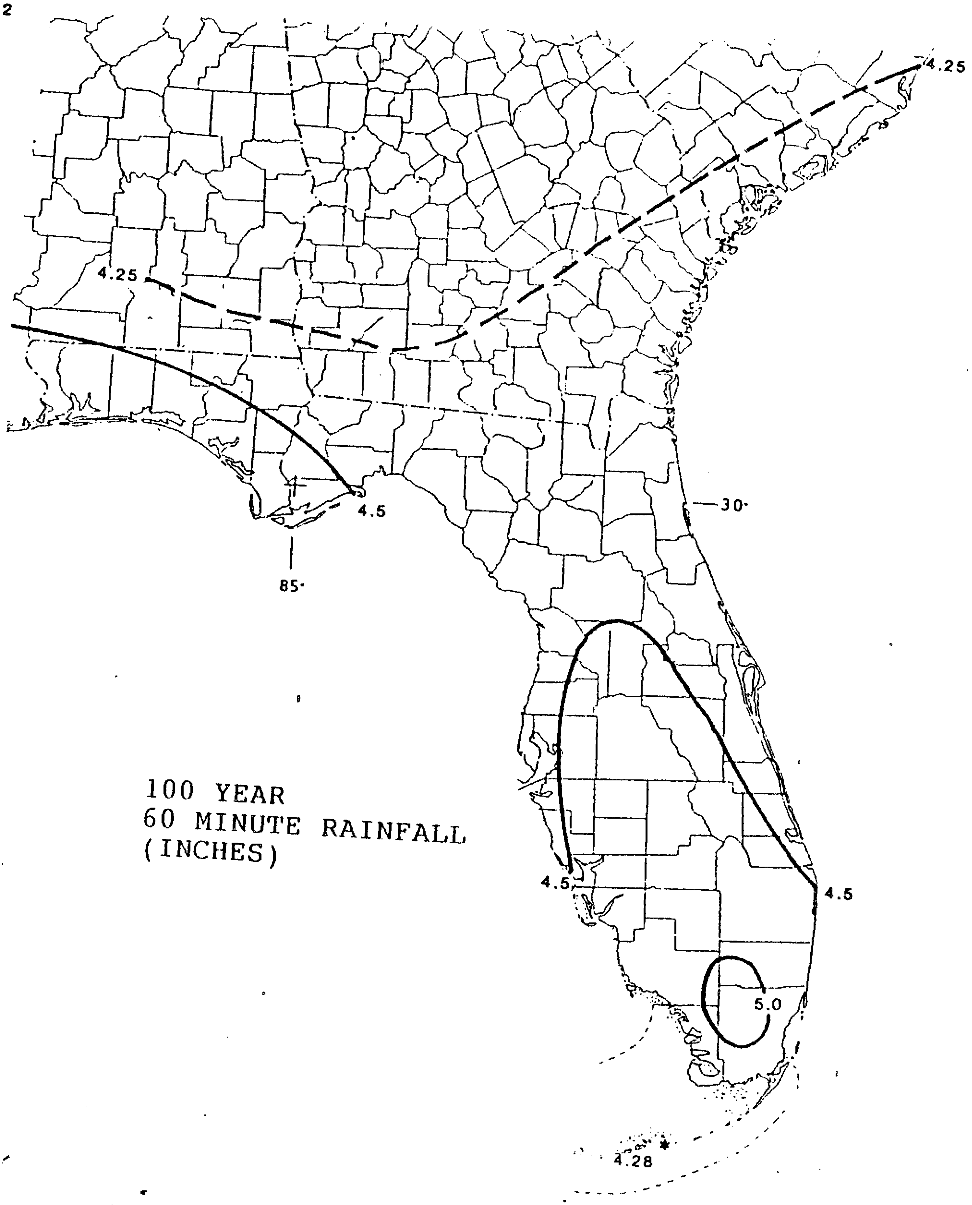


100 YEAR
15 MINUTE RAINFALL
(INCHES)

(Based on NWS HYDRO-35)

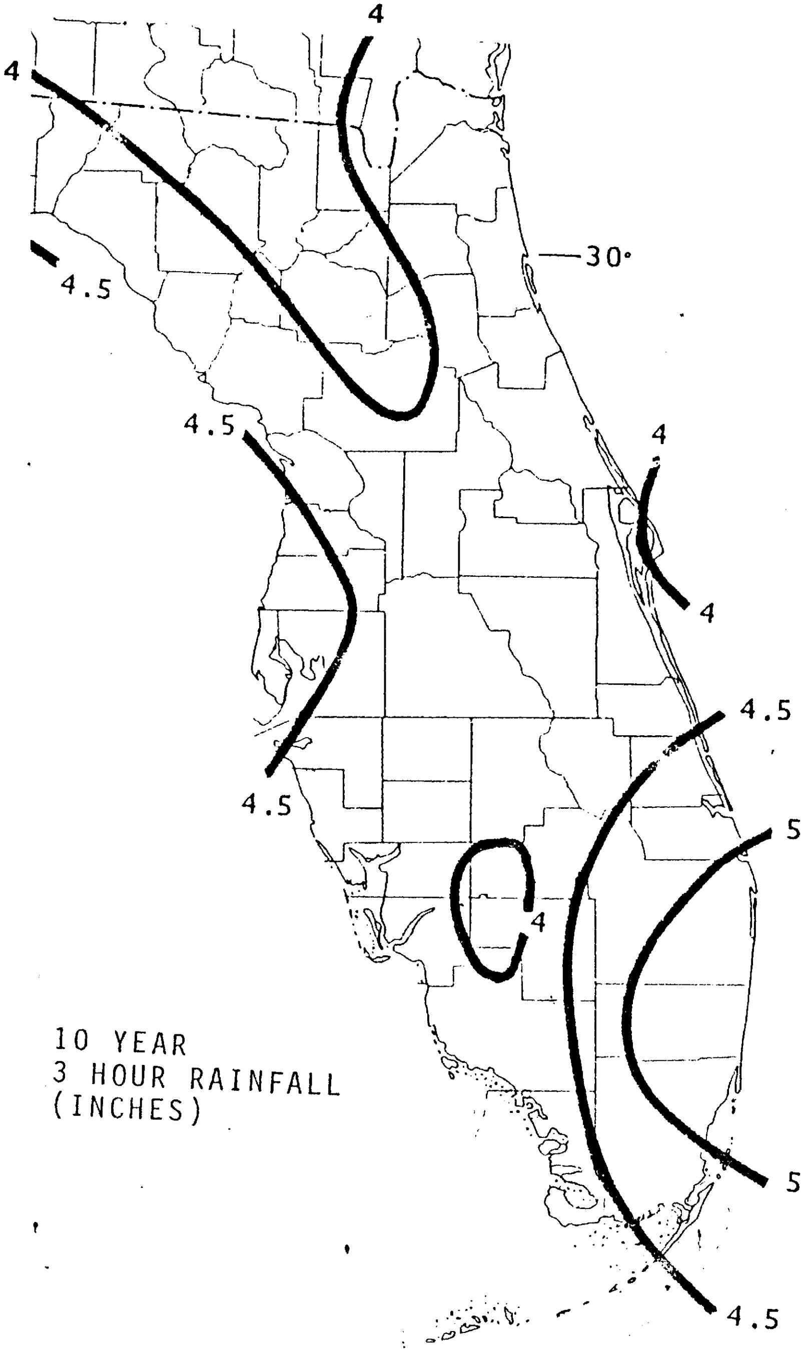


2 YEAR
60 MINUTE RAINFALL
(INCHES)

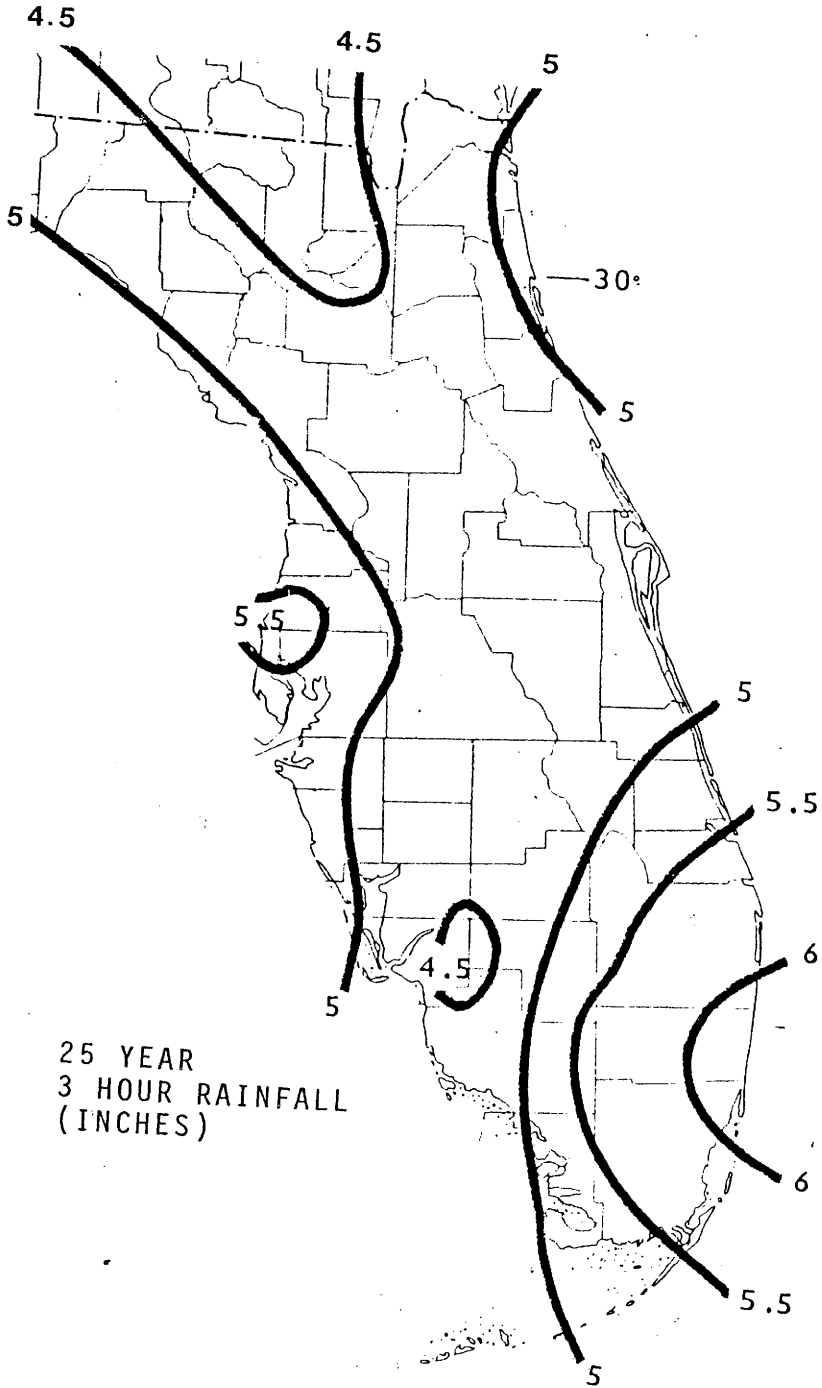


100 YEAR
60 MINUTE RAINFALL
(INCHES)

(Based on NWS HYDRO-35)

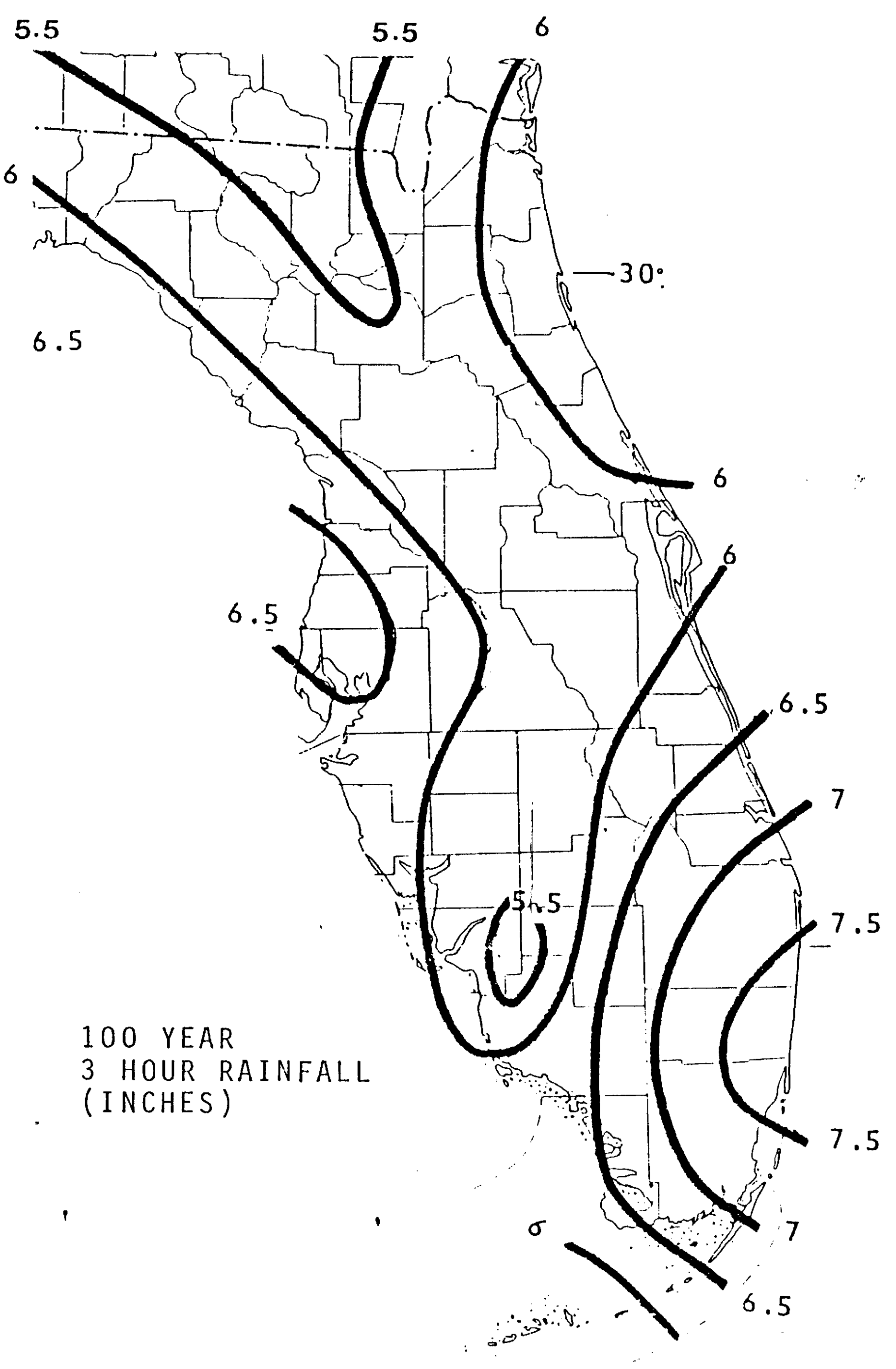


10 YEAR
3 HOUR RAINFALL
(INCHES)

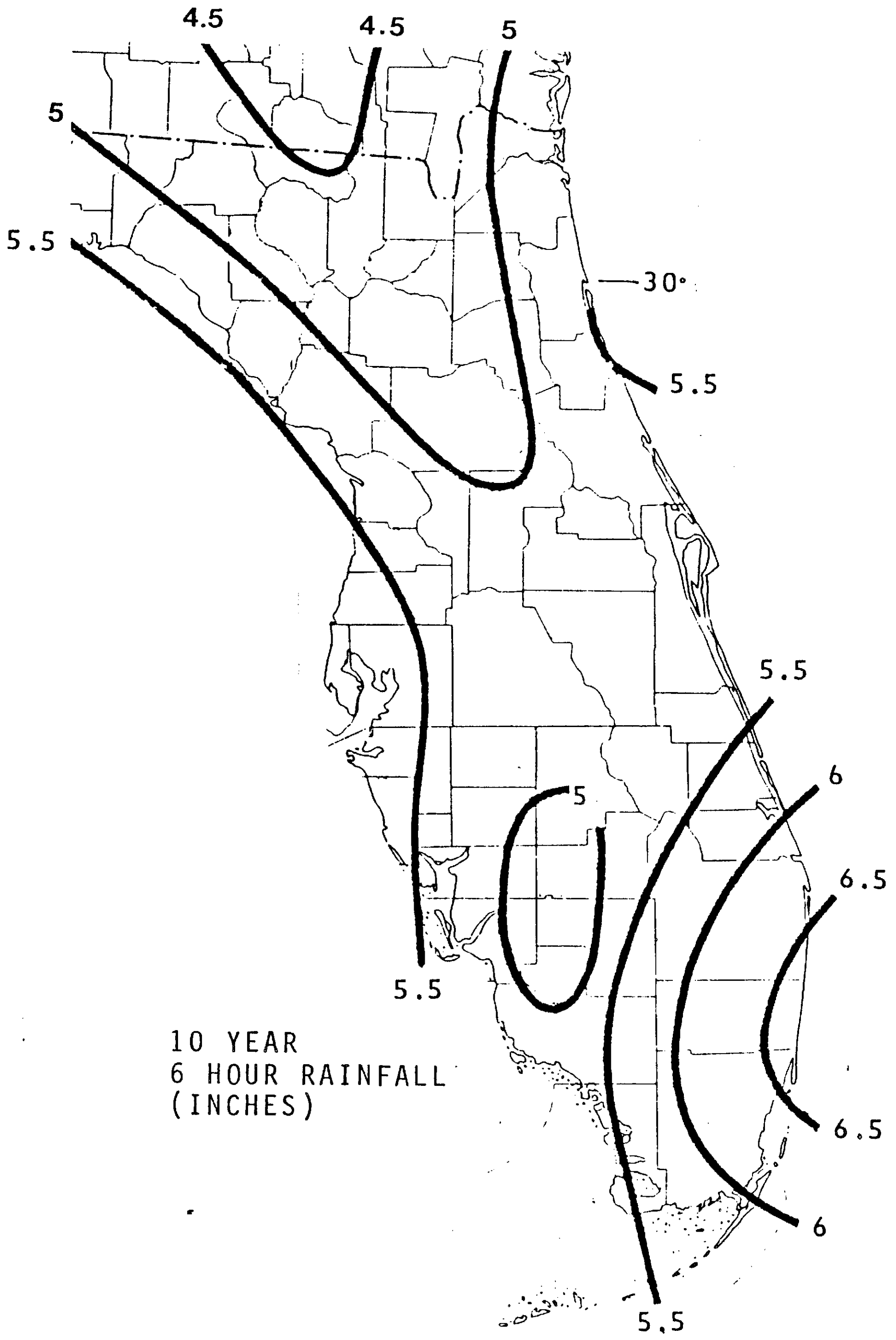


25 YEAR
3 HOUR RAINFALL
(INCHES)

(Source: Weather Bureau TP-40)

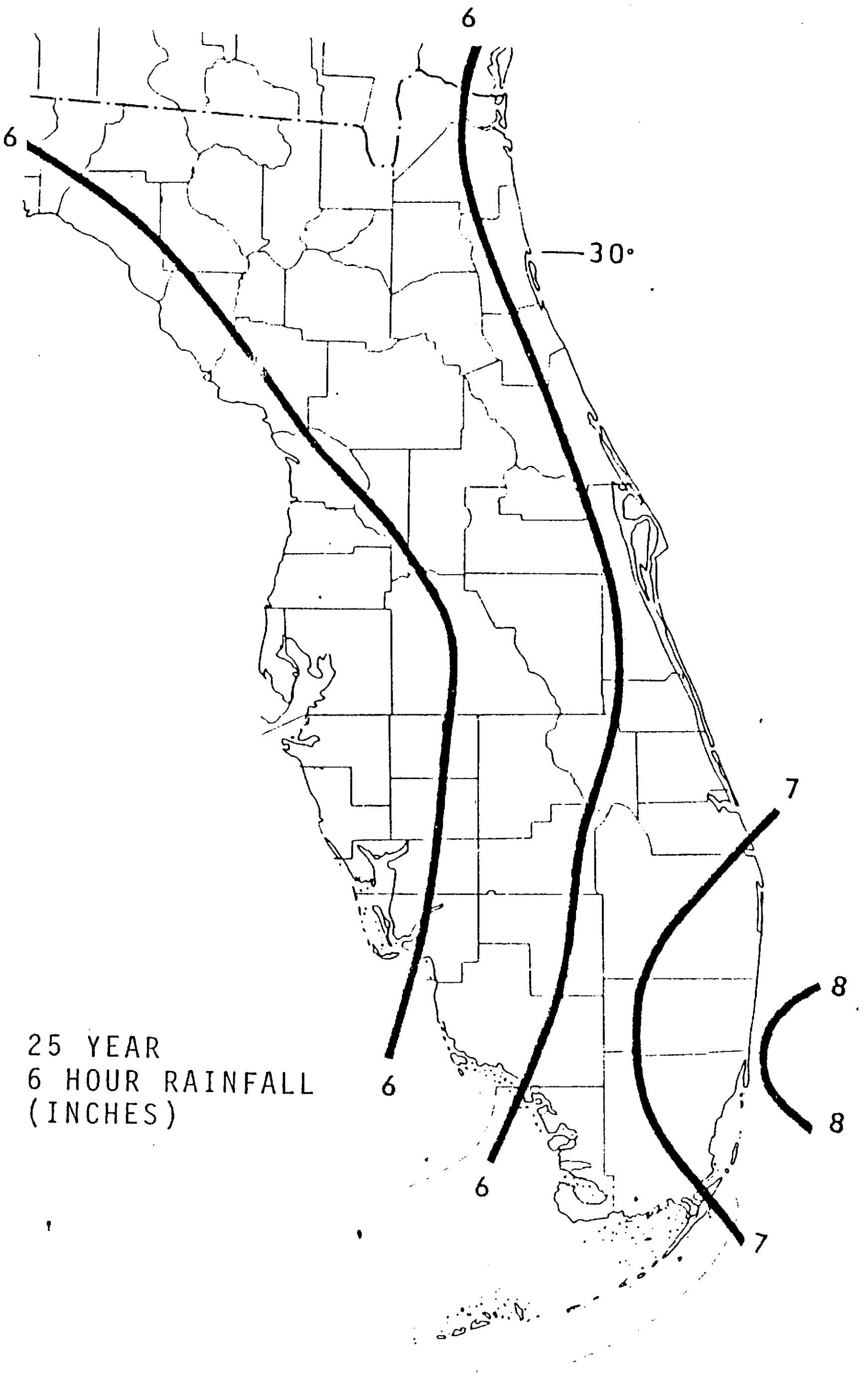


100 YEAR
3 HOUR RAINFALL
(INCHES)

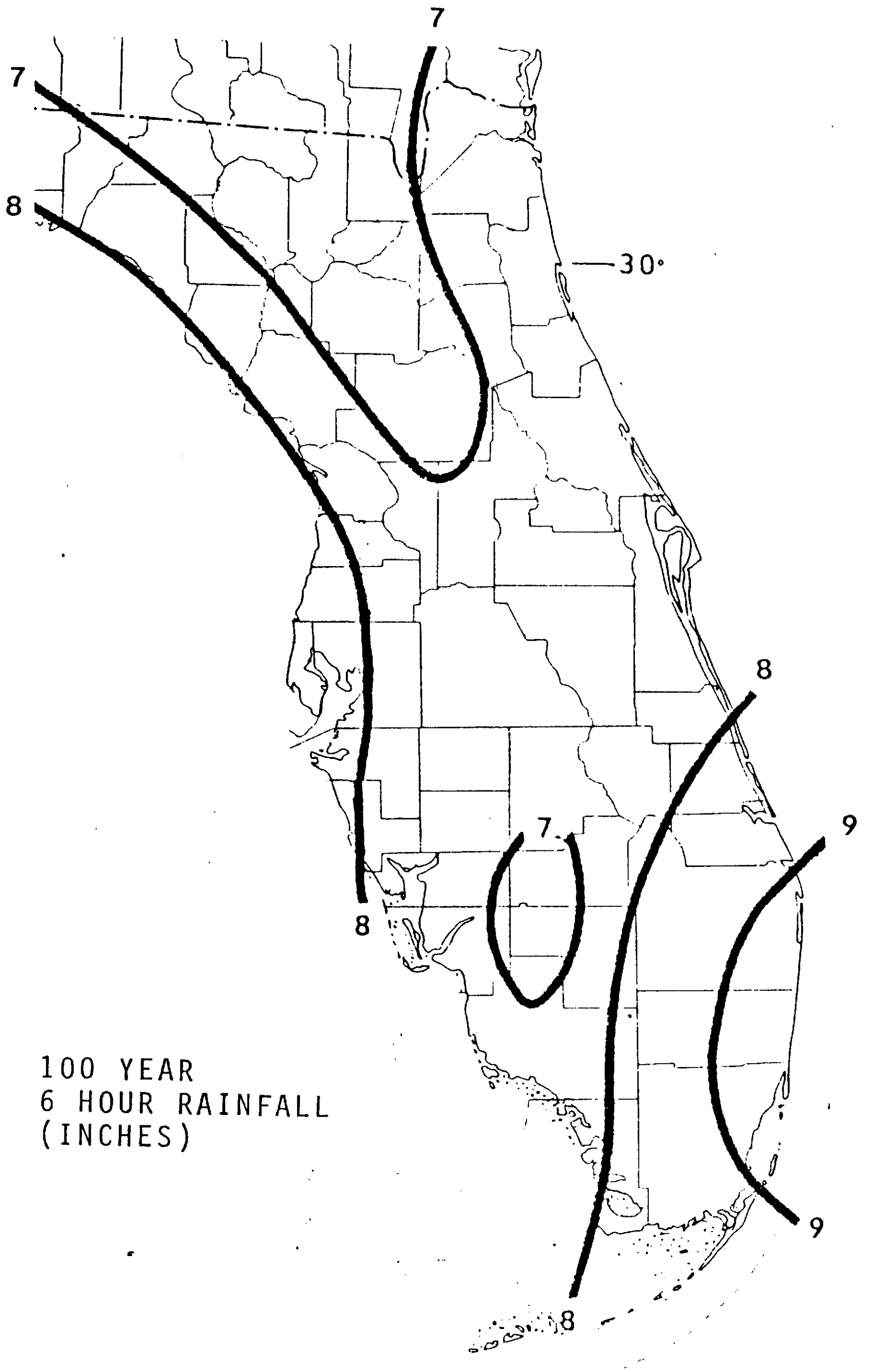


10 YEAR
6 HOUR RAINFALL
(INCHES)

(Source: Weather Bureau TP-40)

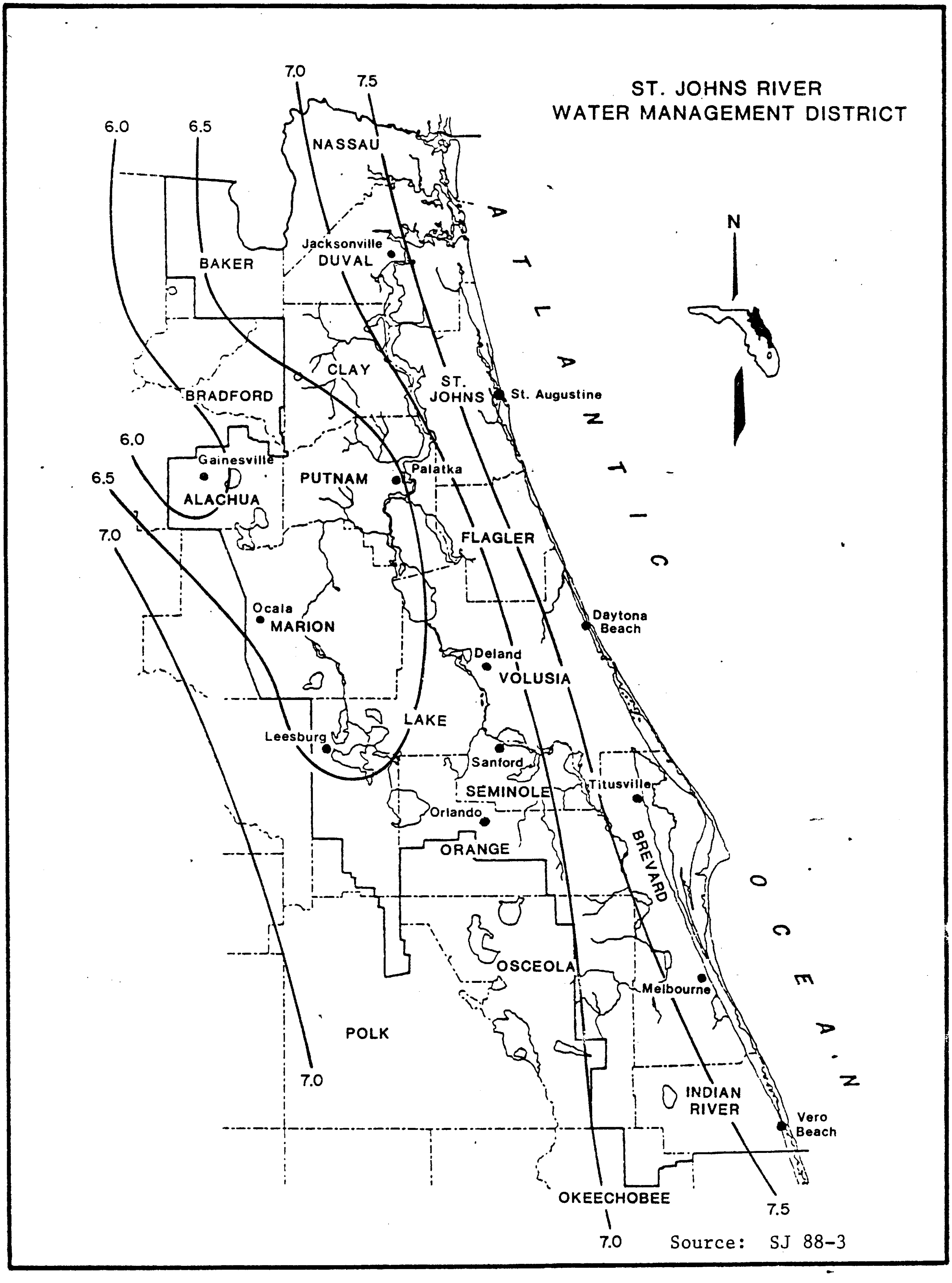


25 YEAR
6 HOUR RAINFALL
(INCHES)



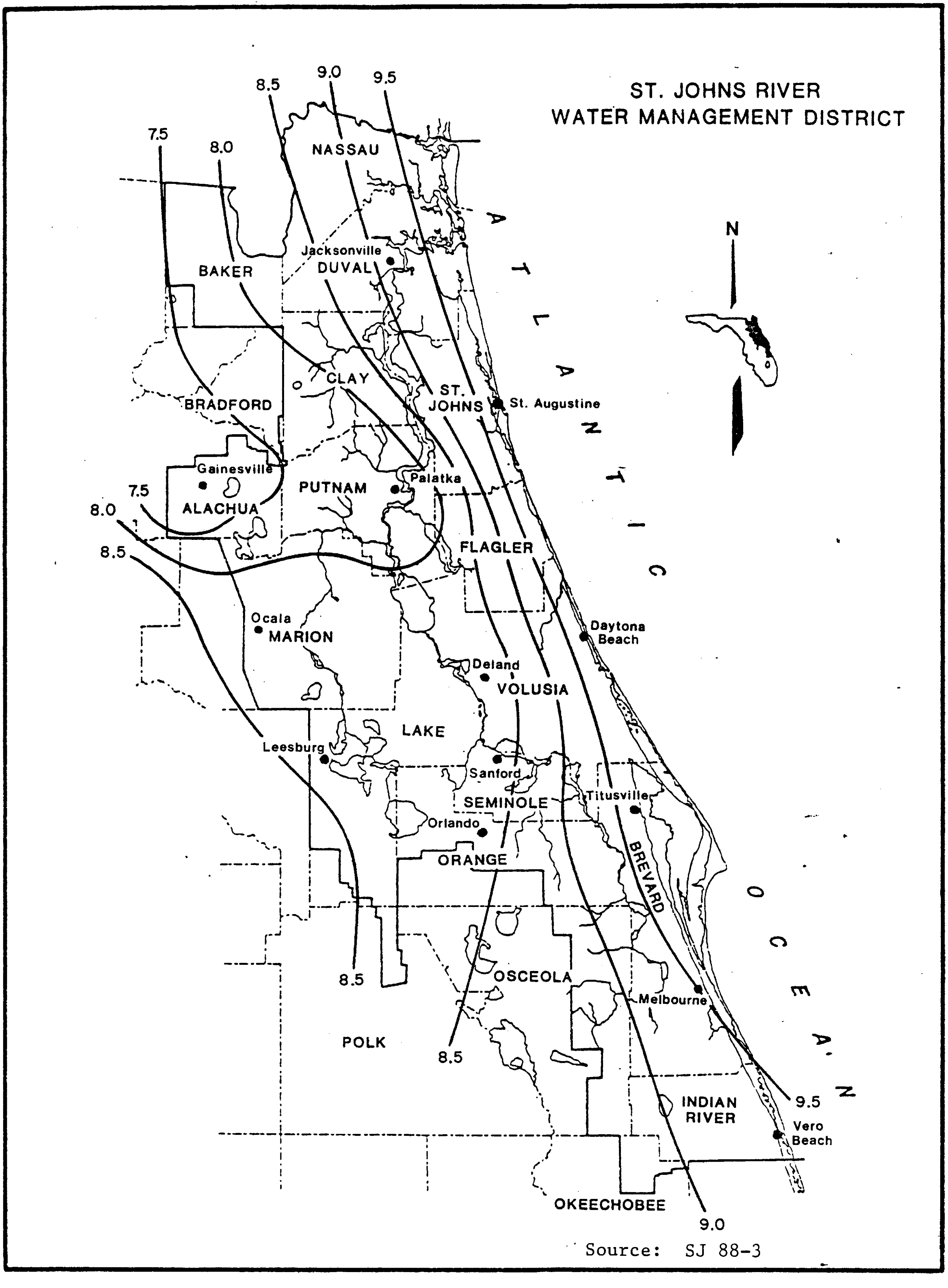
100 YEAR
6 HOUR RAINFALL
(INCHES)

(Source: Weather Bureau TP-40)



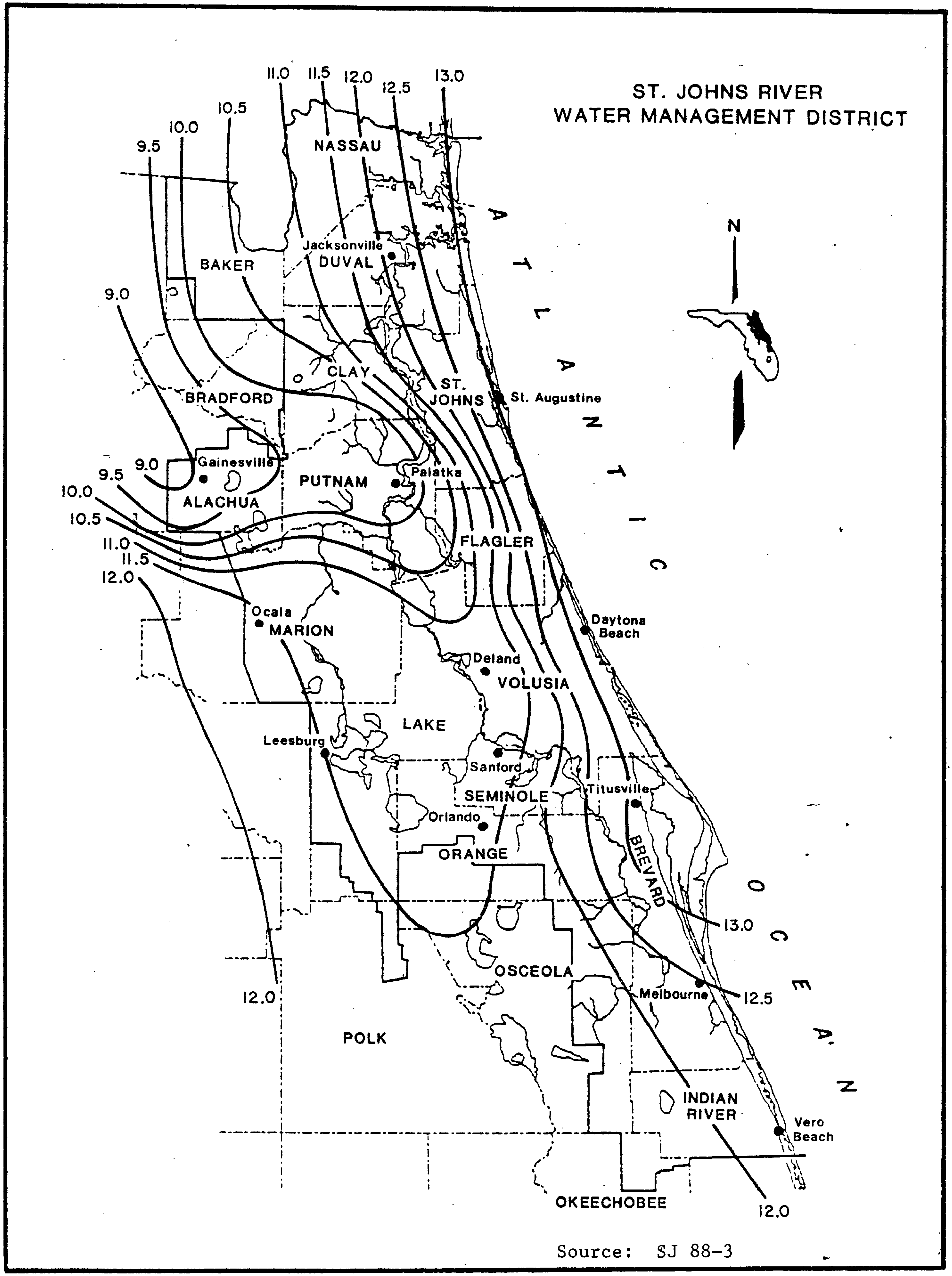
Source: SJ 88-3

10-Year 24-Hour Maximum Rainfall for Northeast Florida, Inches.



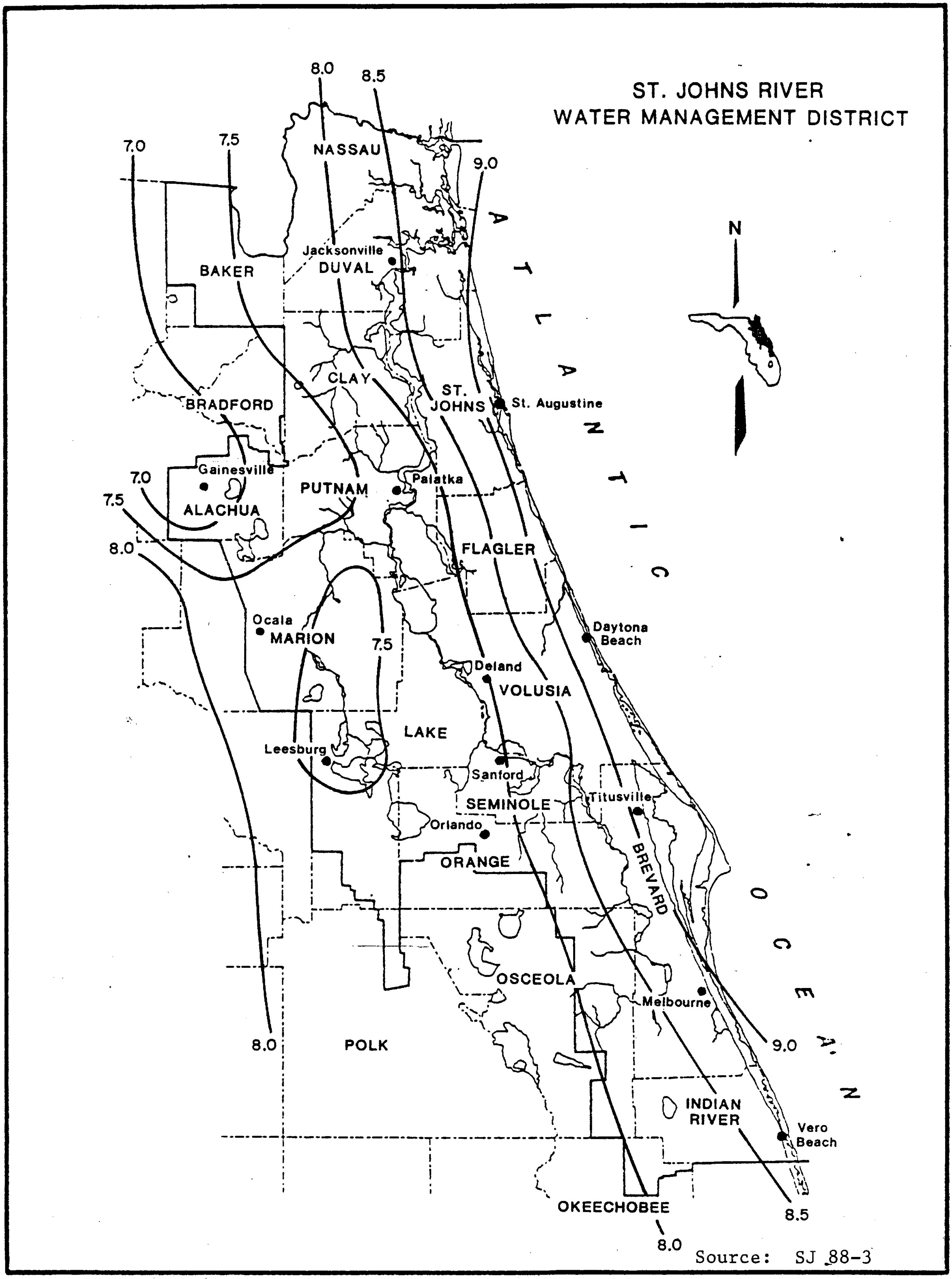
Source: SJ 88-3

25-Year 24-Hour Maximum Rainfall for Northeast Florida, Inches.



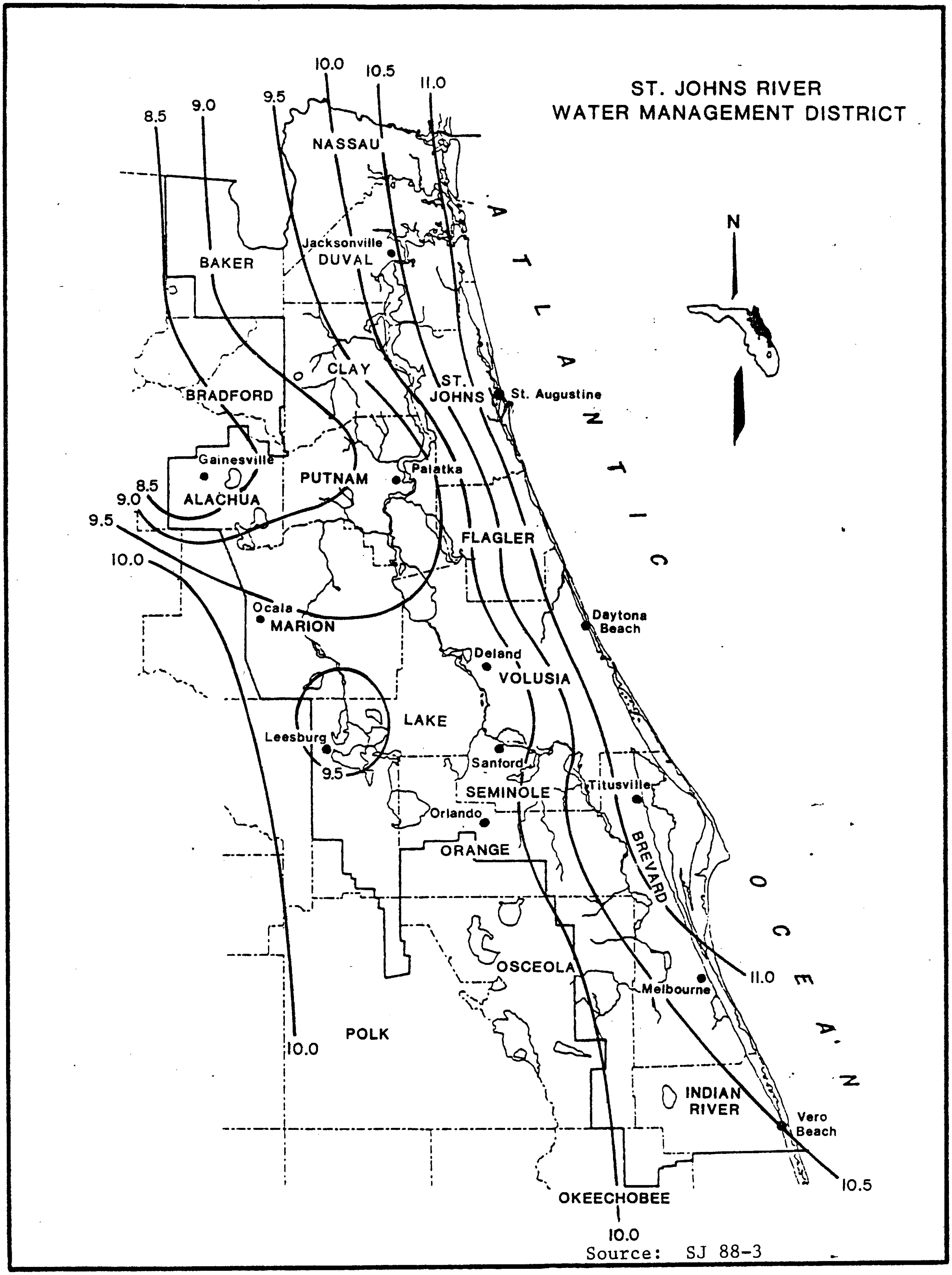
Source: SJ 88-3

100-Year 24-Hour Maximum Rainfall for Northeast Florida, Inches.



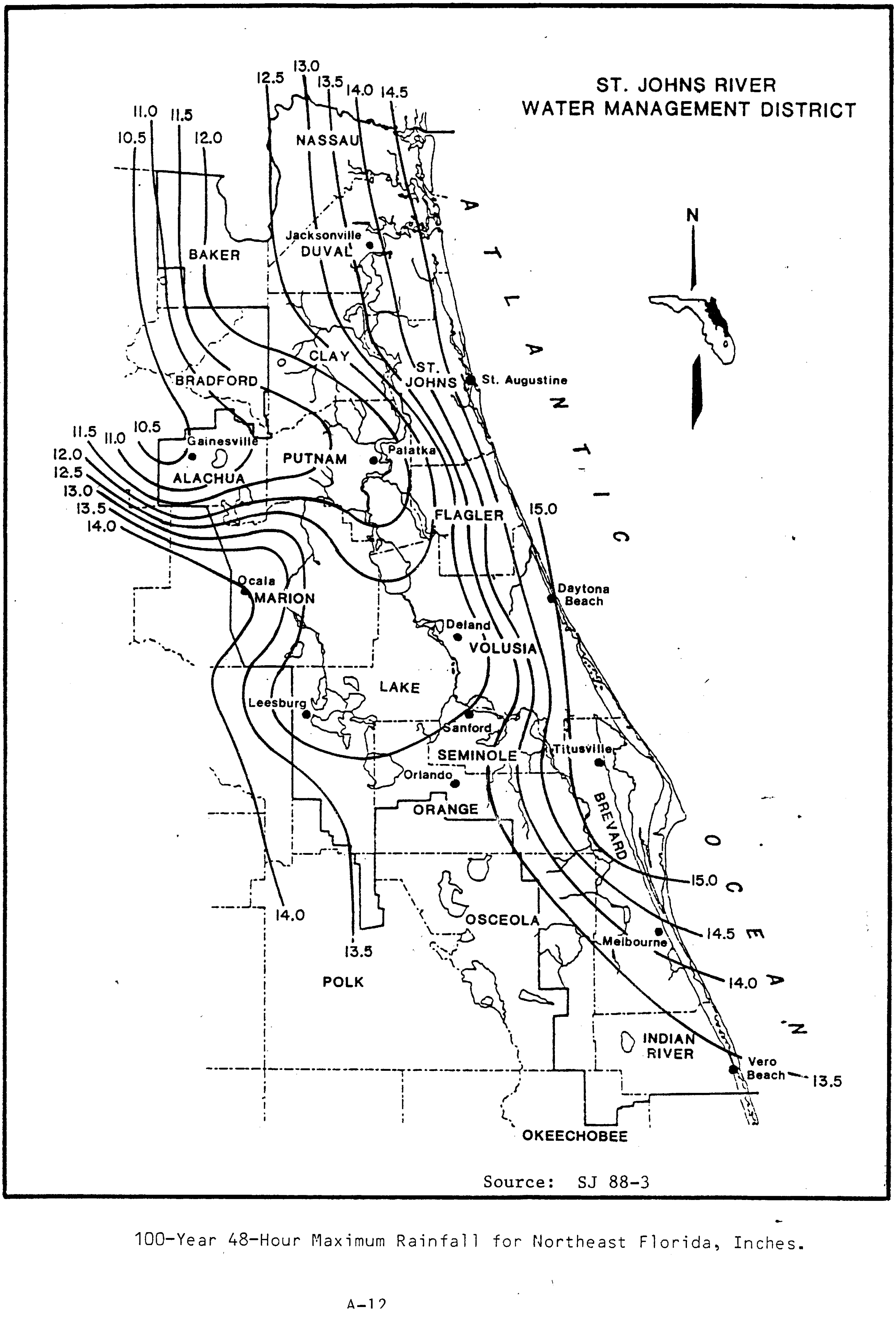
Source: SJ 88-3

10-Year 48-Hour Maximum Rainfall for Northeast Florida, Inches.



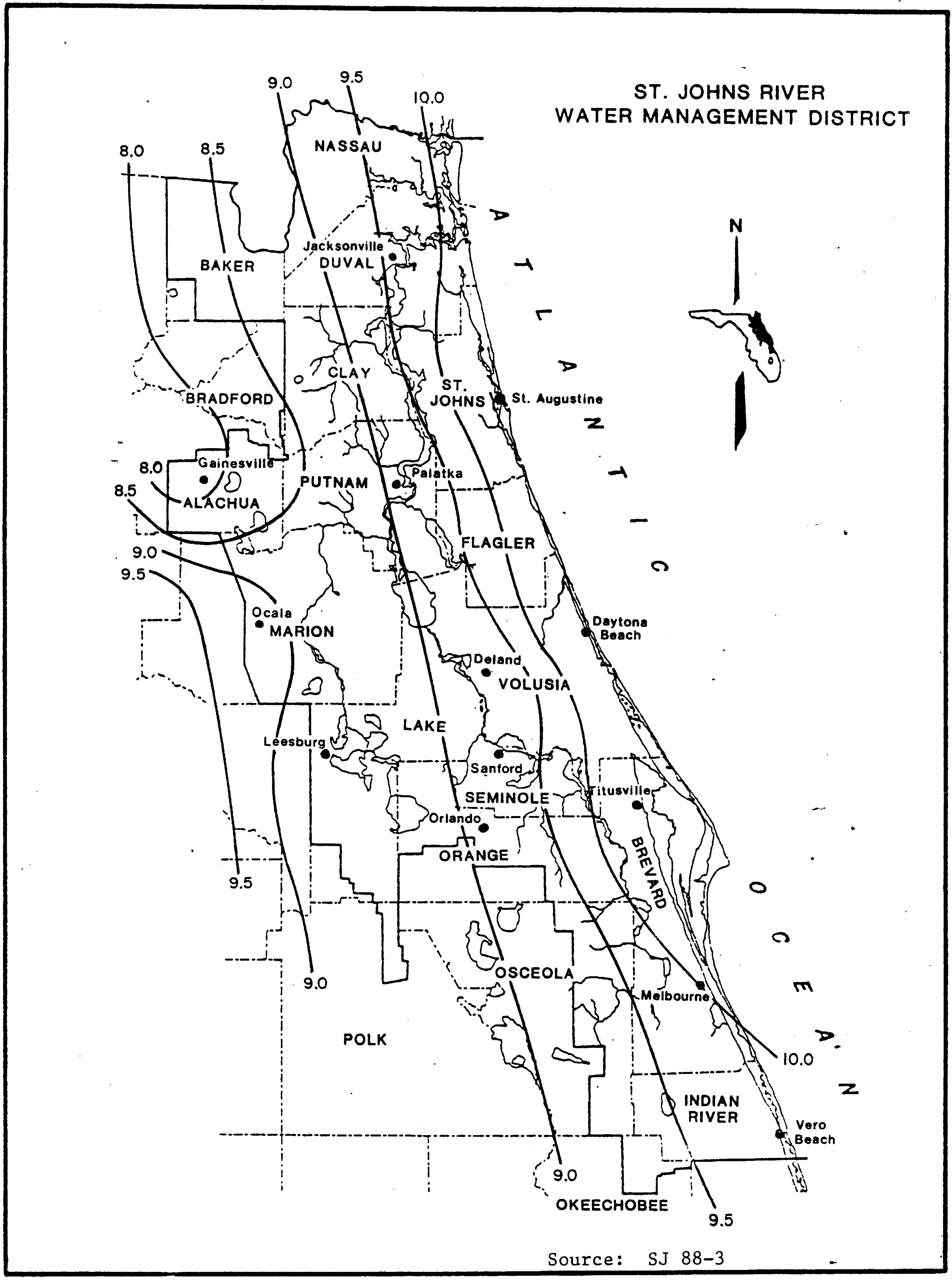
Source: SJ 88-3

25-Year 48-Hour Maximum Rainfall for Northeast Florida, Inches.



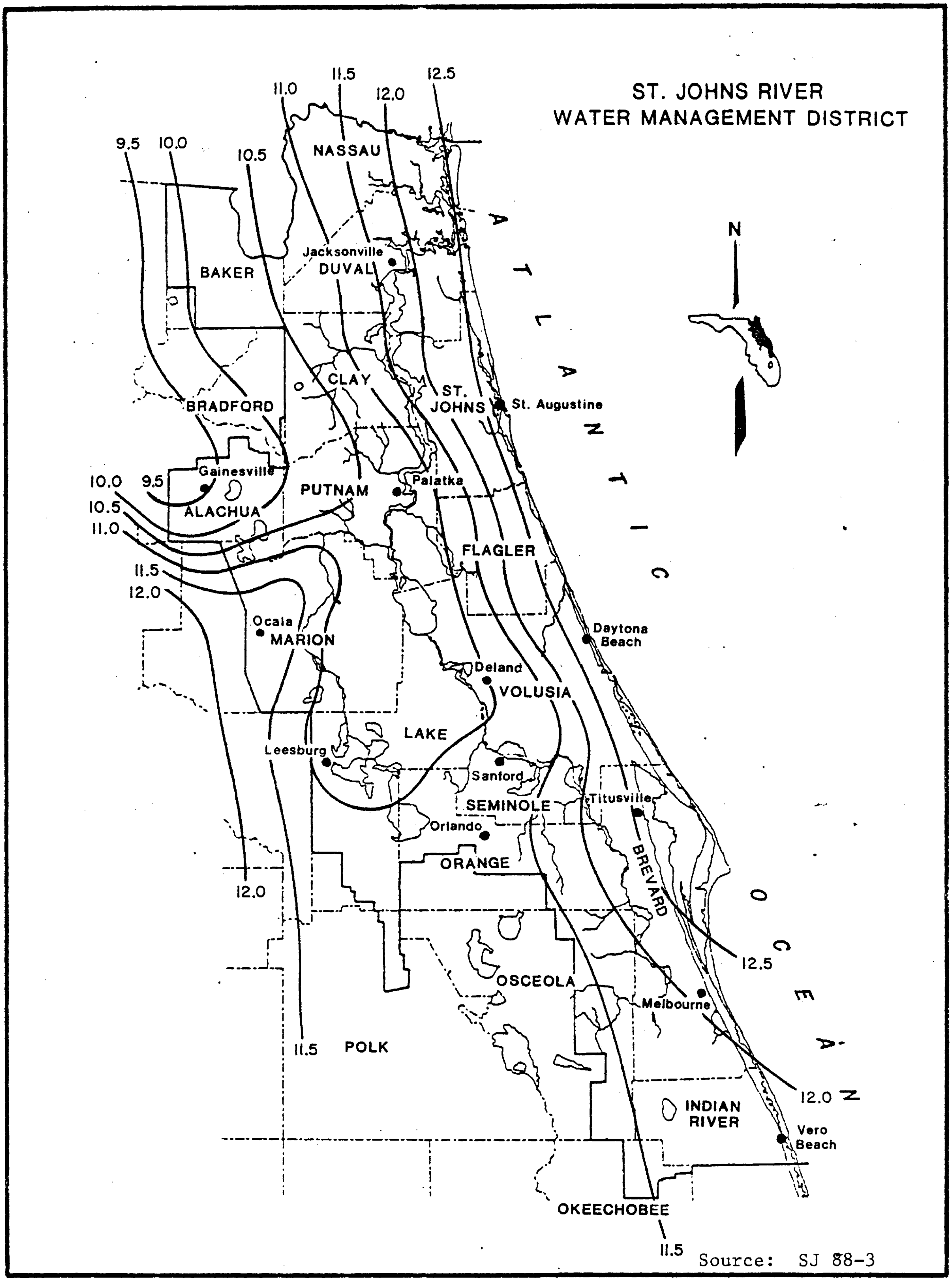
Source: SJ 88-3

100-Year 48-Hour Maximum Rainfall for Northeast Florida, Inches.



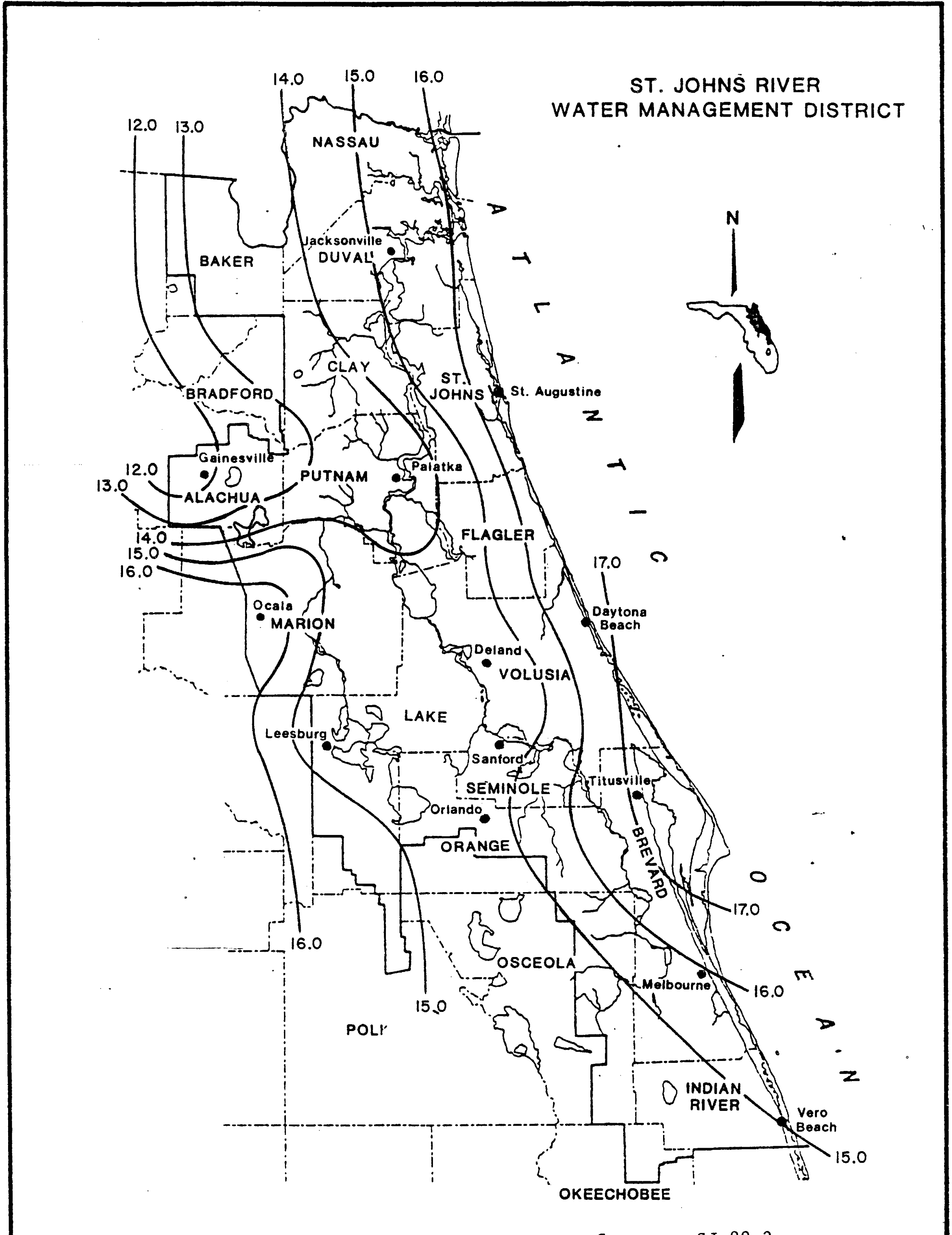
Source: SJ 88-3

10-Year 96-Hour Maximum Rainfall for Northeast Florida, Inches.



Source: SJ 88-3

25-Year 96-Hour Maximum Rainfall for Northeast Florida, Inches.



Source: SJ 88-3

100-Year 96-Hour Maximum Rainfall for Northeast Florida, Inches.

APPENDIX B

COMPUTER PROGRAM 'HYPSTORM'

LISTING OF THE COMPUTER PROGRAM 'HYPSTORM'

```
C-----------------------------------------------------------------------------
C  HYPSTORM - DEVELOPS A SITE SPECIFIC 24-HR HYPOTHETICAL STORM DISTRIBUTION.
C             OUTPUT IS GIVEN AS PC CARDS OF HEC-1 PROGRAM INPUT DATA.
C-----------------------------------------------------------------------------
C   PROGRAMMER:
C          DR. DONTHAMSETTI V. RAO, P.E.
C          ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
C          PALATKA, FL 32078-1429
C
C  THE PROGRAM IS DEVELOPED ON PRIME 6350 COMPUTER. THE I/O STATEMENTS SHOULD
C  BE SUITABLY REVISED FOR ADAPTING TO OTHER SYSTEMS. THE PROGRAM PROMPTS FOR
C  INPUT DATA AND THE DATA IS ENTERED FROM A CRT.
C-----------------------------------------------------------------------------
C  INPUT CONSISTS OF 15 MIN, 30 MIN, 1 HR, 3 HR, 6 HR RAINFALL RATIOS. THE
C  DISTRIBUTION CAN BE ADJUSTED FOR DEPTH-AREA RELATION. IN THIS CASE THE 15 MIN
C     RATIO IS OBTAINED BY EXTRAPOLATION. STORM PATTERN SIMILAR TO SCS TYPE II.
C  Y = CUMULATIVE DEPTH FROM DEPTH-DURATION CURVE
C  Z = INCREMENTAL DEPTH,  T2 = INCREMENTAL DEPTH FOR HYPOTHETICAL STORM
C  T2C = CUMULATIVE DEPTH FOR HYPOTHETICAL STORM
C-----------------------------------------------------------------------------
      DIMENSION Y(96),Z(96),T2(96),T2C(96),P(5),XX(4),DD(4)
      CALL WRITEB(IO)
      WRITE(1,11)
      READ(1,21) DD1,DD
      WRITE(1,12)
      READ(1,14) ADJ
      Y(1)=DD1
      Y(2)=DD(1)
      Y(4)=DD(2)
      Y(12)=DD(3)
      Y(24)=DD(4)
      XM=(ALOG10(100.*Y(4))-ALOG10(100.*Y(2)))/(-ALOG10(.5))
      IF(ADJ.EQ.'NO') GO TO 13
      WRITE(1,10)
   10 FORMAT('ENTER 30 MIN, 60MIN, 3HR, 6HR, 24HR AREA FACTORS')
   11 FORMAT('ENTER 15MIN, 30MIN, 60MIN, 3HR, AND 6HR RATIOS')
   12 FORMAT('DO YOU WISH AREA ADJUSTMENT, ENTER YES OR NO')
   14 FORMAT(A2)
   21 FORMAT(10F8.3)
   22 FORMAT('PC',F6.3,9F8.3)
      READ(1,21) P
      DO 9 I=1,4
    9 XX(I)=DD(I)*P(I)/P(5)
      Y(2)=XX(1)
      Y(4)=XX(2)
      Y(12)=XX(3)
      Y(24)=XX(4)
      XM=(ALOG10(100.*Y(4))-ALOG10(100.*Y(2)))/(-ALOG10(.5))
      Y1=ALOG10(100.*Y(2))-XM*(ALOG10(2.))
      Y(1)=10.**Y1/100.
```

LISTING -CONTINUED

```
 13 Y1=ALOG10(100.*Y(2))+XM*(ALOG10(1.5))
    Y(3)=10.**Y1/100.
    XM=(ALOG10(100.*Y(12))-ALOG10(100.*Y(4)))/ALOG10(3.)
    DX=.25
    X=1.
    DO 16 I=5,11
    X=X+DX
    Y1=ALOG10(100.*Y(4))+XM*ALOG10(X)
 16 Y(I)=10.**Y1/100.
    XM=(ALOG10(100.*Y(24))-ALOG10(100.*Y(12)))/ALOG10(2.)
    X=3.
    DO 17 I=13,23
    X=X+DX
    Y1=ALOG10(100.*Y(12))+XM*(ALOG10(X)-ALOG10(3.))
 17 Y(I)=10.**Y1/100.
    XM=(2.-ALOG10(100.*Y(24)))/(ALOG10(24.)-ALOG10(6.))
    X=6.
    DO 20 I=1,72
    X=X+DX
    Y1=ALOG10(100.*Y(24))+XM*(ALOG10(X)-ALOG10(6.))
    J=I+24
 20 Y(J)=10.**Y1/100.
    Z(1)=Y(1)
    DO 25 I=2,96
 25 Z(I)=Y(I)-Y(I-1)
C
C    STORM ARRANGEMENT
C
    T2(48)=Z(1)
    T2(47)=Z(2)
    T2(49)=Z(3)
    T2(50)=Z(4)
    J=6
    DO 30 I=51,96
    T2(I)=Z(J)
 30 J=J+2
    J=95
    DO 35 I=1,46
    T2(I)=Z(J)
 35 J=J-2
 39 T2C(1)=T2(1)
    DO 40 I=2,96
 40 T2C(I)=T2C(I-1)+T2(I)
    TT=0.
    WRITE(IO,22) TT,T2C
    CALL CLOSE
    CALL EXIT
    END
```

EXAMPLES

Site-specific 24-hr hypothetical storm distributions can be generated by HYPSTORM in the form of PC cards of HEC-1 input data. On the PB card, the user is required to provide 24-hr rainfall depth adjusted for the drainage area governed by the location of interest. HYPSTORM requires the following input data:

A. The 15 min, 30 min, 60 min, 3 hr and 6 hr rainfall data expressed as ratios to 24-hr value. For your basin, extract maximum rainfall data for T=10 yr, 25 yr, and 100 yr from the appropriate rainfall charts (Appendix A). Express the values as ratios to 24 hr rainfall. For each duration also calculate the average ratio. For developing T-year distribution the corresponding ratios should be used. The average ratios should be used for obtaining Generalized Distribution.

B. If the distribution needs adjustment for basin size, read the rainfall adjustment factors for the following durations from Figure 3: 30 min, 60 min, 3 hr, 6 hr, and 24 hr.

HYPSTORM prompts for entering the necessary input data from the terminal.

EXAMPLE 1.

Develop 10 yr hypothetical storm distribution for the Little Wekiva River Basin (disregard basin size).

Col. 2, Table 1 of the report shows various 10-yr rainfall values extracted from Appendix A. Col. 2, Table 5 gives the rainfall ratios. The prompts given by HYPSTORM, the input for each prompt, and the program output are presented on the next page.

EXAMPLE 2.

Develop 100 yr hypothetical storm distribution for a sub-basin of 20 sq. mi. within the Little Wekiva River Basin.

For T= 100 yr, the rainfall values and the rainfall ratios are given by Col. 4 of Tables 1 and 5, respectively. For D.A.= 20 sq. mi., the rainfall adjustment factors for durations 30 min, 60 min, 3 hr, 6 hr, and 24 hr are read as 0.825, 0.89, 0.95, 0.961, and 0.971, respectively. See next page for various prompts, input data and output from the program.

APPLICATIONS OF HYPSTORM

EXAMPLE 1

```
ENTER 15MIN, 30MIN, 60MIN, 3HR, AND 6HR RATIOS      (PROMPT)
.236,.353,.476,.615,.756                            (INPUT)
DO YOU WISH AREA ADJUSTMENT, ENTER YES OR NO        (PROMPT)
NO                                                  (INPUT)
PC 0.000   0.002   0.004   0.006   0.009   0.011   0.013   0.016   0.018   0.021
PC 0.023   0.026   0.028   0.031   0.034   0.037   0.039   0.042   0.045   0.049
PC 0.052   0.055   0.059   0.062   0.066   0.069   0.073   0.077   0.081   0.086
PC 0.090   0.095   0.100   0.105   0.111   0.117   0.123   0.133   0.143   0.155
PC 0.167   0.180   0.195   0.208   0.224   0.243   0.268   0.385   0.621   0.689     OUTPUT
PC 0.744   0.766   0.783   0.798   0.810   0.824   0.837   0.849   0.859   0.870
PC 0.879   0.885   0.891   0.896   0.901   0.906   0.911   0.915   0.920   0.924
PC 0.928   0.931   0.935   0.939   0.942   0.946   0.949   0.952   0.955   0.958
PC 0.961   0.964   0.967   0.969   0.972   0.975   0.977   0.980   0.982   0.984
PC 0.987   0.989   0.991   0.994   0.996   0.998   1.000
```

EXMAPLE 2

```
ENTER 15MIN, 30MIN, 60MIN, 3HR, AND 6HR RATIOS      (PROMPT)
.185,.288,.395,.509,.632                            (INPUT)
DO YOU WISH AREA ADJUSTMENT, ENTER YES OR NO        (PROMPT)
YES                                                 (INPUT)
ENTER 30 MIN, 60MIN, 3HR, 6HR, 24HR AREA FACTORS    (PROMPT)
.825,.89,.95,.961,.971                              (INPUT)
PC 0.000   0.004   0.007   0.011   0.015   0.018   0.022   0.026   0.030   0.034
PC 0.038   0.042   0.047   0.051   0.055   0.060   0.064   0.069   0.074   0.079
PC 0.084   0.089   0.094   0.100   0.105   0.111   0.117   0.123   0.129   0.135
PC 0.142   0.149   0.156   0.164   0.172   0.180   0.189   0.198   0.207   0.217
PC 0.228   0.240   0.254   0.267   0.282   0.301   0.325   0.404   0.570   0.633     OUTPUT
PC 0.687   0.708   0.725   0.739   0.752   0.764   0.776   0.786   0.796   0.805
PC 0.814   0.823   0.831   0.838   0.846   0.853   0.860   0.866   0.872   0.879
PC 0.885   0.890   0.896   0.901   0.907   0.912   0.917   0.922   0.927   0.932
PC 0.936   0.941   0.945   0.950   0.954   0.958   0.962   0.966   0.970   0.974
PC 0.978   0.982   0.986   0.989   0.993   0.996   1.000
```