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ESTIMATION OF RAINFALL FOR THE KISSIMMEE RIVER BASIN

By

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SUMMARY:

Real-time estimation of rainfall at two-tenths of an hour intervals from sparse raingaging stations over upper Kissimmee River Basin is presented from the viewpoint of developing a long term (week, month, year) operational policy and executing it on a short term (day to day) basis.

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INTRODUCTION

A common experience, perhaps almost everybody has experienced, is that rainfall occurs over small areas. For example, it may be raining at one place and just about one-half mile or less away from that place it may be quite dry with bright sunshine. This is probably what caused Muller, et. al. (19) to state that rainfall occurs in a complex and, as yet not completely understood manner; while Holtan (8) states that precipitation is still beyond reliable estimation or management by man. It is this complicated primary input, rainfall, to which the management and operation of a water resource system of channels, reservoirs and spillways has to be keyed.

Considerable efforts, however, are being made to estimate rainfall by using stochastic as well as deterministic approaches. The stochastic approach, in general, attempts to derive a probability distribution function and then uses it with a random number generator to synthesize sequences of rainfall events. Research reports (1, 5, 6, 7, 13, 14, 15, 16, 18, 26, 27 and 28) in this category are available. The deterministic approach is based essentially upon empiricism where a line of best fit for the historical data is obtained for estimation purposes. Several research reports (2, 9, 10, 11, 17, 24 and 25) in this category are also available. Reasonably good fits of observed rainfall amounts have been obtained under both approaches over time periods such as months or years. A few publications (3, 12 and 20) are available for estimating rainfall at shorter time intervals, such as one day, one hour, or less. A major difficulty in finding acceptable theoretical distributions of rainfall amounts over shorter time intervals (one hour or less, for example) is that of variability. Precipitation amounts sampled at time intervals of one hour or less experience the phenomenon of the deviation being greater than the mean. Also, a large value of skewness exhibited by precipitation amounts at intervals of one hour or less limits the range of statistical distribution which is applicable (23). Unfortunately, the problem becomes more complex if the rainfall amounts have to be estimated from sparse raingaging stations over a large area (say 100 square miles or more) on real-time scale with short intervals. In this paper an estimation of rainfall from twelve raingaging stations at two-tenths of an hour intervals on real-time scale over the upper Kissimmee River Basin (nearly 1600 square miles in area) is described. A picture of the upper Kissimmee River Basin, divided into fourteen sub-basins with the location of raingages and the control structures, is presented in Figure 1 in accordance with the East Zone of Florida coordinate system.

RAINFALL ESTIMATION

Real-time estimation of rainfall at two-tenths of an hour intervals from sparse raingaging stations over a large space is being done here from two viewpoints. One is the development of a long term (week, month, year) real-time operational policy in advance by utilizing the daily rainfall values synthesized at sparse locations within or near the basin boundaries. Another is the execution of a short term (day to day) real-time operation.

With this as a background and that the estimated rainfall is to be used as an input to a model capable of producing streamflow as an output, a solution is being formulated in a sequence of two steps. Step one in the sequence is the development of a technique to distribute daily rainfall values at a point into twenty-four hourly values and then divide each hourly rainfall value into five equal parts to obtain rainfall values at two-tenths of an hour intervals. Step two in the sequence is the development of a technique to estimate the two-tenths of an hour interval rainfall values from widely separated raingaging stations over a large area. Step one is necessary not only for the development of a long term real-time operational policy in advance but also for the reproduction of history where only the daily rainfall records are available in the majority of cases. Step one could not be used in a short term real-time operation because it would, at best, be twenty-four hours later than the real world. For a short term real-time operation, the data must be transmitted from the field on a frequent time interval. Therefore, a remote sensing and telemetry system is being established which will transmit rainfall information at shorter time intervals from several raingaging stations in the basin to a central processing unit. In conjunction with the communication system radar raingages may be used. Senn and Andrews (22) have conducted a feasibility study for the Central and Southern Florida Flood Control District (FCD) for real-time cumulative rainfall measurements using radar raingages. An optimum time interval for summation and transmission of the quantitative data is presently thought to be 12-15 minutes by the FCD. It is intended that at least parts of the existing conventional raingage network of the District will be maintained to permit studies of the effectiveness of two ways of measuring rainfall for various purposes in the future. Thus, it is hoped that for real-time operation a nearly reliable estimate of rainfall values could be provided in this way for use as an input to the model capable of producing streamflow as an output.

Distribution of Daily Rainfall into Twenty-four Hourly Values. The development of relationships is based here essentially upon the work of Pattison (21). He takes into consideration a well acknowledged characteristic of persistency in daily rainfall values, although an exception to this acknowledgement has been found by DeCoursey (4). A definition of four classes of daily rainfall persistence, G_d, is presented in Table 1. The values that G_d can thus assume for the day are 1, 2, 3 and 4.

If X_d represents the hour of start of rainfall on day, d, the possible values of X_d are 1, 2, ..., 24. Since the class of daily rain and its persistence pattern is always available for the purpose of distributing a known amount of daily rainfall, the value of X_d is assumed to depend on the form of a conditional probability, as given below.

$$\Pr [X_d = k | C_{d+1} = c_{d+1}, \dots , C_1 = c_1] = (\Pr[G_d = g_d | C_{d+1} = c_{d+1}, \dots , C_{d-1} = c_{d-1}]) \cdot (\Pr[X_d = k | G_d = g_d]) \quad (1)$$

for k = 1, 2, ..., 24 with Pr being the probability and C_d being the class of daily rainfall. The ten classes of rainfall, as defined by the magnitude of daily rainfall values, are presented in Table 2.

Assuming a linear relationship between the rainfall values observed during consecutive hours and that the model parameter values are different for each class of daily rainfall, a regression model of the form used is

$$H_{t+1} = A_{C_d} + B_{C_d} (H_t) + e_{C_d,t} \tag{2}$$

for $C_d = 1, 2, \ldots, 10$

and $t = (X_d - 1), X_d, \ldots, 23$

where A_{C_d} and B_{C_d} are regression coefficients corresponding to class C_d daily rainfall and $e_{C_d,t}$ is a random variable with mean = 0. The random variable $e_{C_d,t}$ is assumed to take the form

$$e_{C_d,t} = (T_t) (\sigma_{C_d}) \tag{3}$$

where T_t is a normally distributed random variable with zero mean and unit standard deviation and σ_{C_d} is the standard deviation of $e_{C_d,t}$. σ_{C_d} can be estimated from

$$S_{C_d} = \left(\frac{\sum_{i=1}^{N_{C_d}} (H_{t+1} - \hat{H}_{t+1})^2}{N_{C_d} - 1} \right)^{1/2} \tag{4}$$

where N_{C_d} is the number of hours included in analysis for C_d class of daily rainfall, H_{t+1} is an observed hourly rainfall and $\hat{H}_{t+1}$ is the equivalent expected value derived from

$$\hat{H}_{t+1} = A_{C_d} + B_{C_d} (H_t) \tag{5}$$

The conditional probabilities required to estimate the hour of start of daily rain were estimated by using the following relationships:

$$\hat{P}_{ij} = \frac{f_{ij}}{F_j} \tag{6}$$

for $i = 1, 2, \ldots, 24$

$j = 1, 2, 3, 4$

where $F_j = \sum_{i=1}^{24} f_{ij}$

f_{ij} = the number of times the hour i was observed to be the first hour of rain when the persistence was class $G_t=j$, and

$\hat{P}_{ij}$ = estimated probabilities for each class of daily rainfall C_d.

There were 18 years (1952 through 1969) of historic hourly rainfall data available at Kissimmee 2, identified as raingage station number 13 in Figure 1. These data were used to estimate the probabilities, P_{ij}, and coefficients A and B and standard deviations of e in Equation 2 for each daily rainfall class and daily rainfall persistence class. These values were estimated for each month of the year and the values for the months of June, July, August and September with the exception of $\hat{P}_{ij}$ values, are presented in Table 3.

The mathematical relationships and the values of coefficients determined for Station 13, Kissimmee 2, were used to distribute daily rainfall values at the remaining twelve raingaging stations in the Upper Kissimmee River Basin. The daily rainfall values were distributed for the period of June 20 through September 26, 1969. The ratios of distributed to historic total wet hours for each of the four months are presented in Table 4 for each of the twelve raingage sites. The average ratios of twelve raingaging sites for each of the four months are plotted in Figure 2. With the exception of June, the distributed wet hour counts are less than historic wet hour counts. However, considering all the sites and all the months together, the distributed wet hour counts approximate 95 percent of the historic wet hour counts.

The average number of wet hours for each of the four months presented in Table 5 for each of the twelve raingaging sites indicate August and September to be the wettest months. Also, it can be seen from Table 6 that, in general, the rain occurs between noon and midnight. Average of each hour during the day being wet for all twelve raingaging stations during the period June 20 through September 26, 1969 is presented in Figure 3. The distributed values appear to be less than the historic values; however, the distributed values, in general, seem to approximate the historic values reasonably well.

Estimation of Rainfall over a Large Space from Widely Separated Raingaging Stations. This is based essentially upon a square grid system where the rainfall at any grid point or node is computed by applying an appropriate weighting factor. Solomon, et. al. (25) have illustrated the use of a square grid system for estimating rainfall amounts over an area while Brooks and McWhorter (2) have used distance weighting factors in estimating rainfall depth over an area. Now, consider a space, Figure 4, defined by X and Y coordinates. Let this space be divided uniformly by equal grid intervals ΔX and ΔY in X and Y directions, respectively.

The radius of influence, EC, of any raingage station, E, at any grid point, C, can be computed by

$$EC_{i,j} = DCK_{i,j} = [(CD)^2 + (DE)^2]^{0.5}, \; EC_{i,j} \leq DCK_{max} \qquad (7)$$

where CD = number of grid intervals in X direction, DE = number of grid intervals in Y direction,

DCK = radius of influence of any raingage station in number of grid intervals,

max = maximum permissible value of DCK,

i = raingage station number = 1, 2, ..., M, and

j = node number = 1, 2, ..., N.

If $EC_{i,j} > DCK_{max}$, the i^{th} raingage station is assumed to have no influence on the rainfall value at j^{th} node number.

A weighting factor of the raingage stations associated with each node number is obtained as

$$W_{i,j} = \frac{1/(DCK_{i,j})^{XN}}{\sum_{i=1}^{M} 1/(DCK_{i,j})^{XN}} \tag{8}$$

such that $\sum_{i=1}^{M} W_{i,j} = 1$, and

W = weighting factor, and

XN = an exponent.

The rainfall at any time for any sub-basin is then computed as

$$RF_{n,t} = \frac{\sum_{j=1}^{N_n} \sum_{i=1}^{M} (RF_{i,j,t})\,(W_{i,j})}{N_n} \tag{9}$$

where RF = rainfall value,

n = sub-basin identification,

t = time, and

N = total number of nodes.

Equation 9 has been used to compute rainfall at two-tenths of an hour intervals in the Upper Kissimmee River Basin from twelve raingaging stations. The basin, divided into 14 sub-basins, is laid out on the State of Florida coordinate system (Figure 1). The grid intervals, X and Y, are taken as 5,000 feet. The value of DCK_{max} is assumed to be 50 grid intervals while the value of XN determined by trial is 1.5. The daily average rainfall value, KRBAV, for the Upper Kissimmee River Basin was computed as

$$KRBAV = \frac{\sum_{n=1}^{14} \sum_{t=1}^{120} RF_{n,t}}{14} \tag{10}$$

where 120 = total number of two-tenths of an hour intervals in one day, and

14 = total number of sub-basins in the Upper Kissimmee River Basin.

The average daily rainfall value, GAV, of the twelve raingaging stations was determined as

$$GAV = \frac{\sum_{i=1}^{12} \sum_{t=1}^{120} RF_{i,t}}{12} \tag{11}$$

where 12 is the total number of raingaging stations.

The KRBAV values compare very well with the GAV values (Figure 5).

SUMMARY AND CONCLUSIONS

Management and operation of a water resource system has to be keyed to the primary input, rainfall, to the system. A sequence of two steps has been described here to estimate rainfall for the Upper Kissimmee River Basin on a real-time scale. Step one is to distribute the daily rainfall values into twenty-four hourly values and then divide linearly each hour of rainfall value into five values at two-tenths of an hour intervals. Step two is to estimate rainfall spatially, using the two-tenths of an hour rainfall values at sparse locations.

When the results from all the raingaging sites and all the four months were combined, the technique used to distribute daily rainfall values approximated 95 percent of the historic wet hours. The investigation further indicated that in the Upper Kissimmee River Basin August and September are the wettest months of the year and the rain occurs mostly between noon and midnight. It is felt that further improvement can be achieved in distributing daily rainfall into twenty-four hourly values by incorporating the following changes:

(i) replace equation 2 by some nonlinear relationship,

(ii) estimate the coefficients of new equation 2 for each raingaging site, and

(iii) use coefficients estimated under (ii) to distribute a major portion of rainfall between noon and midnight (PM) and the remaining portion of the rainfall between midnight and noon (AM) periods of the day.

The spatially distributed rainfall values at two-tenths of an hour intervals approximated the recorded rainfall values very well on the basis of daily averages.

Step one can be used for the development of a long term (week, month, year) real-time operational policy in advance by utilizing the daily rainfall values synthesized at several points within the basin. However, availability of a sophisticated communications system with a compatible central processing unit is an essential and integral element of the real-time operation on a short term (day to day) basis. It is thus hoped that for real-time operation, a nearly reliable estimate of rainfall values can be provided in this way for use as an input to the model capable of producing streamflow as an output.

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Table 1. Definition of Daily Rainfall Persistence

Day(t-1)	Day(t)	Day(t+1)	Pers. Class for Day(t)
No Rain	Rain	No Rain	1
Rain	Rain	No Rain	2
No Rain	Rain	Rain	3
Rain	Rain	Rain	4

Table 2. Daily Rainfall Class

Class C_d	Daily Rainfall Interval
1	.01 - .10
2	.11 - .20
3	.21 - .30
4	.31 - .40
5	.41 - .50
6	.51 - .75
7	.76 -1.00
8	1.01 -1.50
9	1.51 -2.00
10	>2.00

Table 3. Regression Coefficients for Four Months and for each of the Daily Rainfall Class

DAILY RAIN-FALL CLASS	JUNE			JULY			AUGUST			SEPTEMBER		
	A	B	Std. Devia-tion	A	B	Std. Devia-tion	A	B	Std. Devia-tion	A	B	Std. Devia-tion
1	.0282	-.3402	.0228	.0221	.2280	.0328	.0253	-.3404	.0233	.0201	-.1745	.0232
2	.0432	-.2151	.0447	.0451	.2558	.0461	.0376	-.0899	.0407	.0394	-.1997	.0470
3	.0628	-.1862	.0748	.0557	-.1331	.0705	.0691	-.2267	.0684	.0700	-.2439	.0866
4	.0740	-.1819	.0982	.2380	-.8718	.1732	.0960	-.2492	.1194	.0582	.0174	.0978
5	.0763	-.0014	.1159	.1000	-.1825	.1216	.1368	-.2703	.1373	.1461	-.3000	.1249
6	.1350	-.1204	.1880	.1727	-.2222	.2084	.1058	-.0600	.1629	.0987	-.1086	.1480
7	.2221	-.2254	.2645	.1705	-.0725	.2484	.2206	-.2063	.2799	.1492	-.1083	.2312
8	.1512	-.0635	.2620	.2584	-.1456	.3806	.3000	-.0995	.4937	.1086	.1043	.1964
9	.1519	.1404	.3404	.3528	-.1052	.5078	.2721	-.1178	.3357	.2273	-.1457	.4607
10	.2015	.1283	.3885	.5642	-.0701	.6214	.2730	-.0128	.6329	.3740	.3043	.7763

Table 4. Ratio of Distributed to Historic Total Wet Hour Counts for Four Months at Twelve Rainfall Stations.

Station Name	Serial No.	June	July	August	September
Reedy Creek	1	.60	.84	.63	.88
Lake Marion	2	2.10	.78	.80	.95
Lake Myrtle	3	2.00	.83	.66	.71
Kirchoff Property	4	1.50	.76	.74	.76
Holopaw	5	1.00	.69	.73	.72
Taft	6	3.00	.96	.73	.60
Beeline Hwy.	7	2.00	.95	.72	.68
Pine Island	8	.50	.52	.50	.70
Chapman's Farm	9	1.50	.82	.81	.85
St. Cloud Airpark	10	1.75	.81	.67	.59
Forestry Tower	11	1.20	1.06	.98	.89
Snively's Ranch	12	1.33	.93	1.55	.91

Table 5. Mean and Standard Deviation of Wet Hours Count

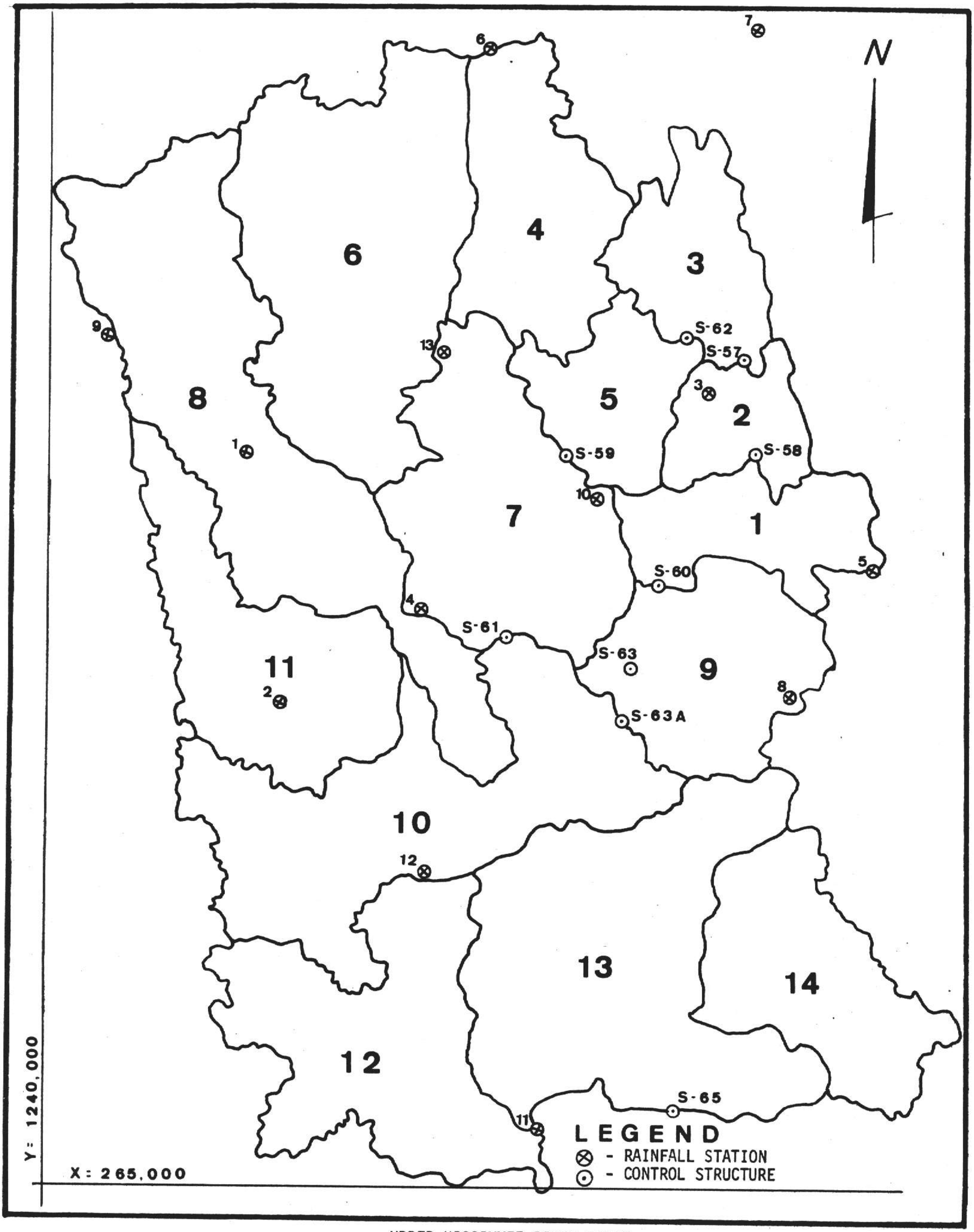
Rainfall Station	JUNE		JULY		AUGUST		SEPTEMBER	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
(1)	1.125 1.500	0.353 1.000	4.600 3.052	3.042 1.928	5.625 4.750	4.047 1.658	2.778 3.000	1.664 1.362
(2)	1.000 1.750	0.000 0.753	4.846 3.267	2.911 1.907	3.762 3.937	3.284 2.999	2.923 2.923	1.656 1.934
(3)	1.000 1.143	0.000 0.377	3.470 2.882	2.065 1.363	3.800 3.333	3.707 2.023	2.857 3.307	1.768 1.931
(4)	1.000 1.500	0.000 0.756	4.500 2.500	2.236 1.505	3.353 2.470	2.370 1.374	2.800 2.909	1.740 2.119
(5)	1.000 1.667	0.000 0.577	3.000 2.071	1.414 0.917	3.381 2.736	3.057 1.851	2.500 3.071	1.503 1.591
(6)	1.000 1.000	0.000 0.000	3.928 2.789	2.129 1.512	2.928 2.727	1.639 1.272	2.000 2.166	1.000 0.983
(7)	1.000 1.111	0.000 0.333	4.500 3.157	3.006 2.034	4.733 3.600	3.198 1.764	2.714 3.000	1.521 2.236
(8)	1.000 1.142	0.000 0.378	4.600 2.400	2.354 1.502	1.667 1.800	0.707 0.447	2.150 2.000	0.933 1.134
(9)	1.000 1.333	0.000 0.499	3.286 2.714	2.234 1.540	4.500 2.933	3.398 1.709	3.750 2.857	1.484 1.875
(10)	1.000 1.000	0.000 0.000	3.800 2.555	1.971 1.293	5.066 4.250	4.043 2.050	2.889 2.214	2.054 1.051
(11)	1.000 1.250	0.000 0.500	4.181 2.579	2.561 1.923	3.307 3.818	1.931 2.182	2.842 2.888	1.833 2.298
(12)	1.000 1.000	0.000 0.000	4.750 2.789	2.562 2.123	3.166 2.682	2.289 1.961	1.642 1.750	1.081 0.965

Upper and lower rows of numbers in each square refer to historic and distributed values, respectively.

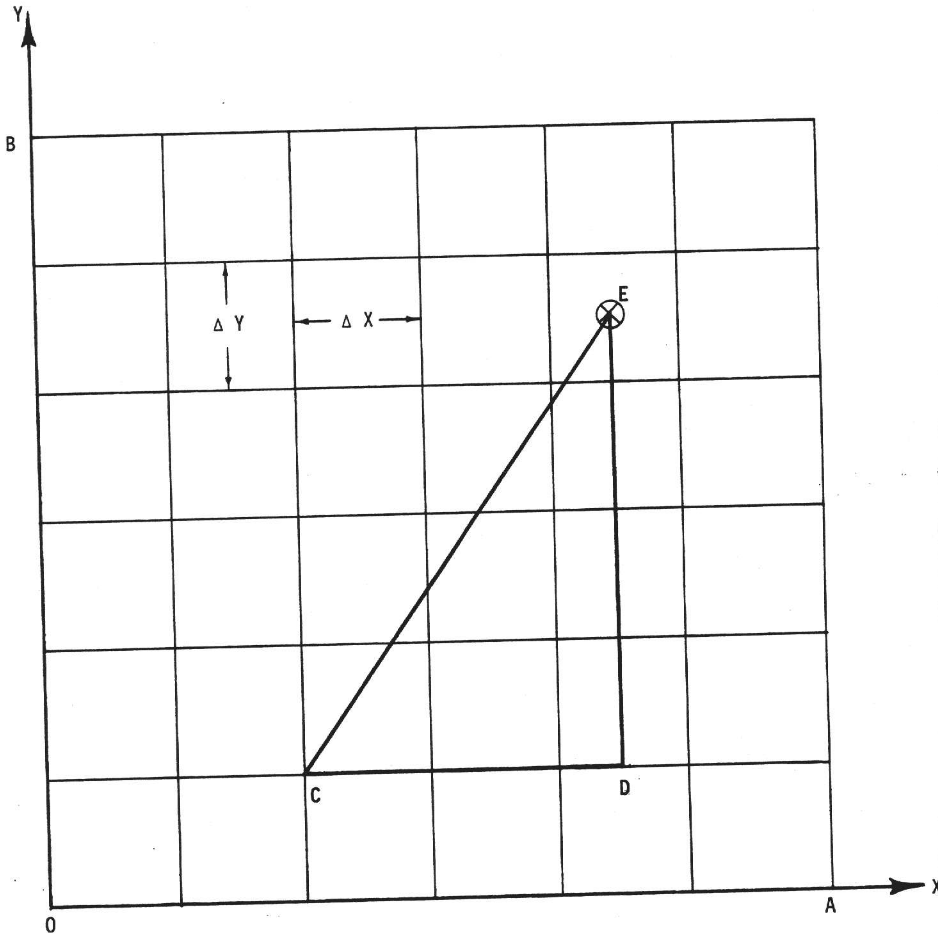
Table 6. Average of each Hour During a Day Being Wet

Hour	JUNE		JULY		AUGUST		SEPTEMBER	
	Hist.	Distri-buted	Hist.	Distri-buted	Hist.	Distri-buted	Hist.	Distri-buted
1AM	0.00	0.00	2.00	1.25	1.22	0.00	1.40	0.00
2	0.00	0.00	5.00	1.00	1.12	0.00	1.45	1.00
3	0.00	1.00	3.00	1.00	1.20	1.00	1.67	1.00
4	0.00	0.00	1.50	1.00	1.00	1.00	1.17	0.00
5	0.00	1.00	0.00	1.50	1.00	1.00	1.00	0.00
6	0.00	1.00	0.00	1.00	1.00	1.00	1.67	1.00
7	0.00	1.00	1.00	1.00	1.67	1.33	3.00	1.00
8	1.00	1.00	1.67	1.50	1.67	1.00	1.25	1.00
9	1.00	1.00	1.33	1.12	1.25	1.25	1.25	1.00
10	1.33	1.00	1.25	1.66	1.25	1.25	1.00	1.28
11	1.00	1.00	1.00	1.88	1.17	1.50	1.00	1.28
NOON	1.00	1.00	1.00	2.33	1.60	2.00	1.70	2.00
1PM	1.00	1.33	1.75	2.72	1.30	2.11	2.72	1.43
2	1.00	1.25	1.91	3.58	2.20	2.72	2.72	1.60
3	1.00	1.40	2.75	4.09	3.00	2.82	3.33	2.10
4	1.00	1.40	4.25	4.16	6.63	4.18	3.50	3.00
5	1.00	1.50	6.16	4.08	7.33	4.83	2.91	4.41
6	0.00	1.57	5.83	3.91	7.00	5.17	3.20	3.83
7	1.00	1.30	6.41	4.08	7.25	4.00	4.58	2.91
8	1.00	1.50	6.16	3.16	5.75	5.17	4.25	3.80
9	2.00	1.50	6.17	2.58	5.00	4.10	3.66	3.63
10	1.00	1.00	5.66	2.40	3.83	3.45	3.08	2.91
11	1.00	1.50	4.36	2.33	2.81	2.36	2.72	2.40
MIDNIGHT	1.00	1.00	2.75	2.91	2.66	2.36	2.16	3.50

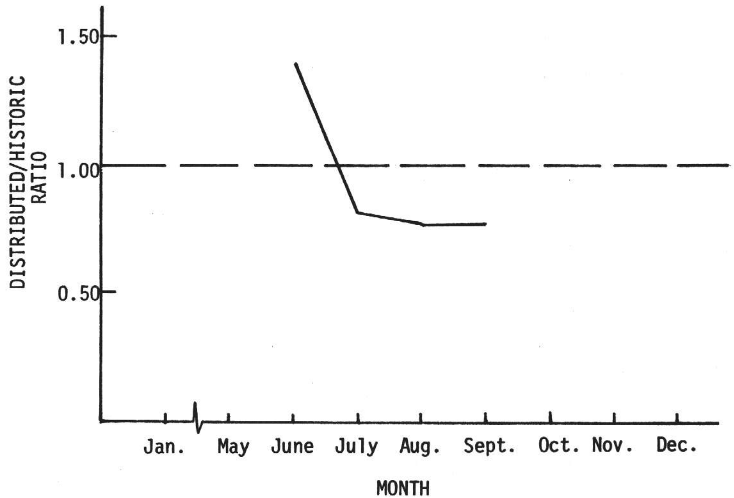
LIST OF FIGURES



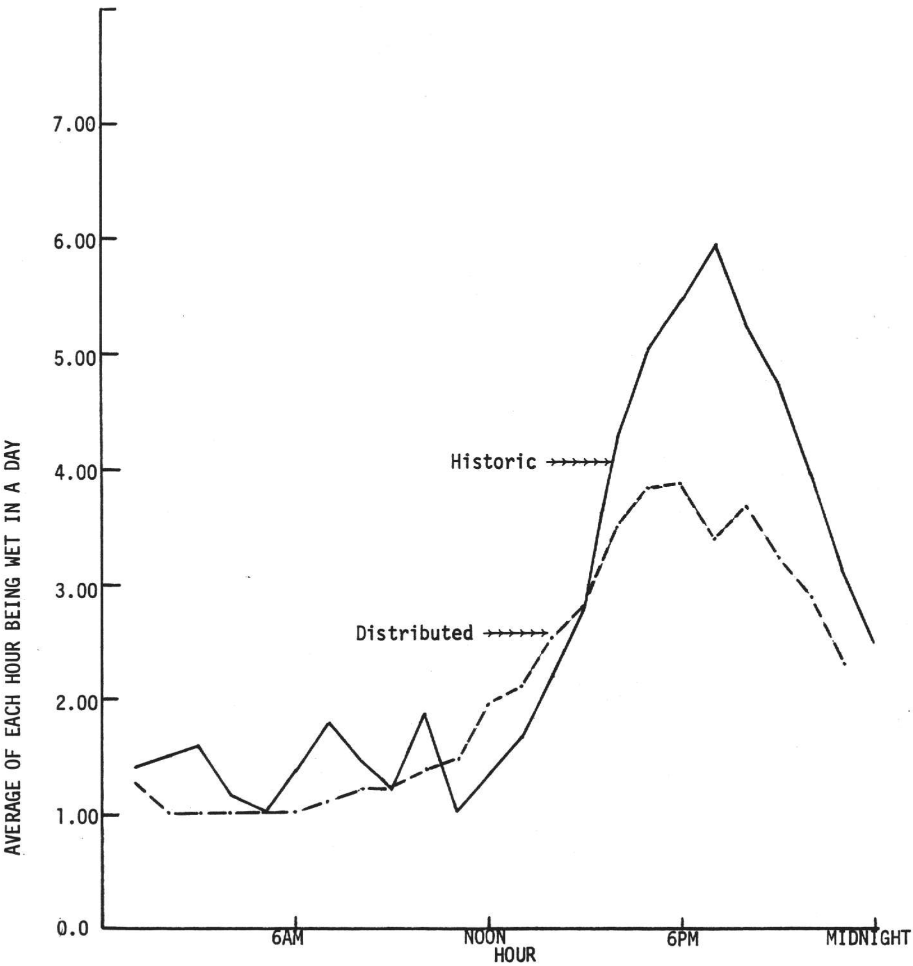
UPPER KISSIMMEE RIVER BASIN



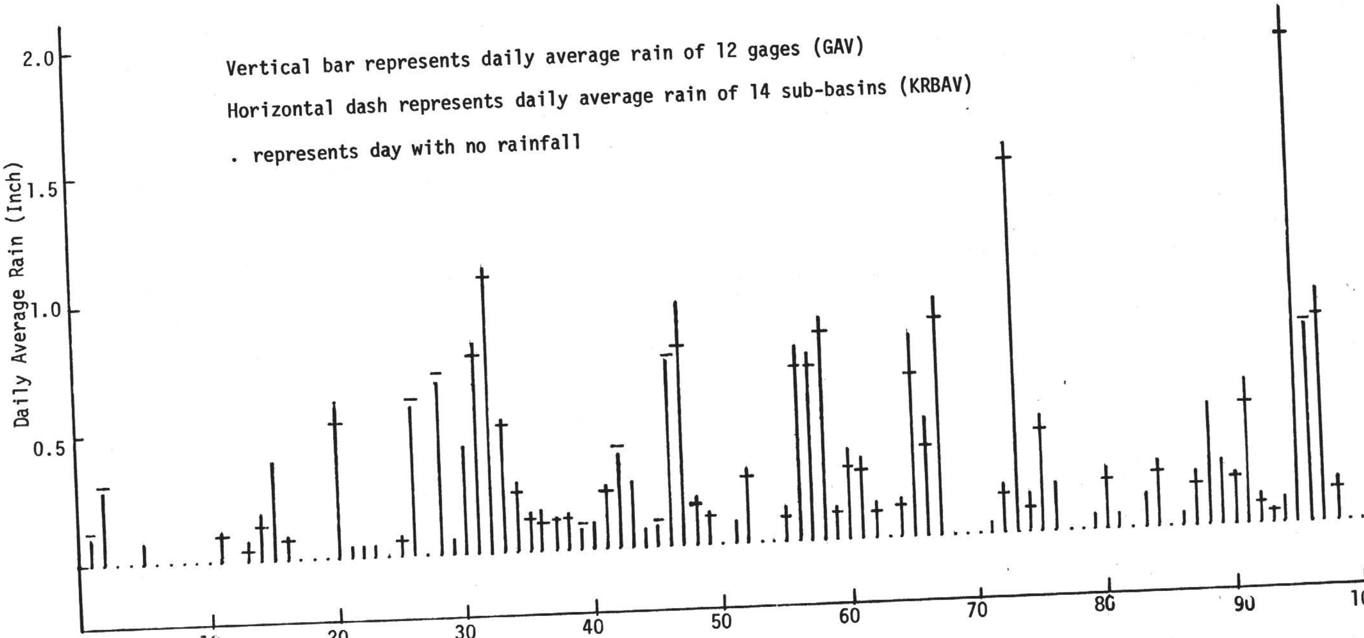
COMPUTATION OF RADIUS OF INFLUENCE



RATIO OF DISTRIBUTED TO HISTORIC TOTAL WET HOUR COUNTS



AVERAGE OF EACH HOUR DURING THE DAY BEING WET



June 20 - September 26, 1969 (Day)

COMPARISON OF KRBAV AND GAV VALUES