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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.

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

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

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

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

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

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.

REFERENCES

1. Amorocho, J. and A. Brandstetter. The representation of storm precipitation fields near ground level. J. of Geophys. Res. 72: 1145, 1967.

2. Brooks, Jr., B. P. and J. C. McWhorter. Depth of area rainfall from point rainfall. Paper No. 69-218 presented at the annual meeting of the American Society of Agricultural Engineers, Purdue University, West Lafayette, Indiana, June 1969.

3. Das, S. C. The fitting of truncated type III curves to daily rainfall data. Australian Journal of Physics, 8:298, 1955.

4. DeCoursey, D. G. Use of Multiple Discriminant Analyses to Evaluate the Effects of Land Use Change on the Yield of a Watershed. Ph. D. dissertation, Georgia Institute of Technology, 1970.

5. Fogel, M. M. and L. Duckstein. Point rainfall frequencies in convective storms. Water Resources Research, 5(6): 1229-1237, Dec. 1969.

6. Friedman, D. G. The estimation of rainfall probabilities. The Travelers Weather Research Center, Hartford, Connecticut, 1957.

7. Gupta, V.L. Brief reports, selection of frequency distribution models. Water Resources Research, 6: 1193, 1970.

8. Holtan, H. N. Watershed modeling from a research viewpoint. Proceedings of Agricultural Research Service and Soil Conservation Service on Watershed Modeling Workshop at Tucson, Arizona, pp. 4-1, 4-5, March, 1970.

9. Huff, F. A. Rainfall gradients in warm season rainfall. J. Applied Meteorol.; 6(2): 435-437, 1967.

10. Huff, F. A. Climatological assessment of natural precipitation characteristics for use in weather modification. J. Applied Meteorol.; 8(3): 401-410, 1969a.

11. Huff, F. A. Spatial correlation of storm, monthly and seasonal precipitation. J. Applied Meteorol.; 8(4): 542-550, 1969b.

12. Huff, F. A. Spatial distribution of rainfall rates. Water Resources Research, 6(1): 254-259, 1970.

13. Kotz, S. and J. Neumann. On the distribution of precipitation amounts for periods of increasing length: Addendum. J. of Geophys. Res., 69: 800, 1964.

14. Manning, H. L. Confidence limits of expected monthly rainfall. Research Memoir, Empire Cotton Growing Corporation, London, 1951.

15. Manning, H. L. The statistical assessment of rainfall probability and its application in Uganda agriculture. Proc. Royal Soc. Series B, 144: 460, 1956.

16. Markovic, R. D. Probability functions of best fit to distributions of annual precipitation and runoff. Hydrology papers, Colorado State University, Fort Collins, Colorado, 1956.

17. McCulloch, J.A.W. and M. Booth. Estimation of basin precipitation by regression equation. Water Resources Research, 6(6): 1753-1758, Dec. 1970.

18. Mooley, D. A. and H. L. Crutcher. An application of the Gamma distribution function to Indian rainfall. ESSA Technical Report E055, p. 47, 1968.

19. Muller, R. B., J. G. Gervais and R. W. Shaw. The effect of precipitation on the level of Lake Michigan/Huron. Meteorological Branch, Canada Department of Transport, Toronto, Canada, CIR-4264, TEC-576, p. 37, 1965.

20. Neyman, J. and E. L. Scott. Note on techniques of evaluation of single rain simulation experiments. 5th Berkeley Symposium, 5: 371, 1967.

21. Pattison, A. Synthesis of Rainfall Data. Ph.D. dissertation, Department of Civil Engineering, Stanford University, Stanford, California, 1964.

22. Senn, H. V. and G. F. Andrews. Feasibility of real-time cumulative rainfall measurements using radar raingages. Rosenstiel School of Marine and Atmospheric Science, Univ. of Miami, Miami, Fla.; July 1971.

23. Skees, P. and L. R. Shenton. Comments on the statistical distribution of rainfall per period under various transformations. Paper presented at the satellite symposium on statistical hydrology, Tucson, Arizona, August-September 1971.

24. Solomon, S. Relationship between precipitation, evaporation and runoff in tropical equatorial regions. Water Resources Research, 3(1): 163-172, 1967.

25. Solomon, S. I., J. P. Denouvilliez, E. J. Chart, J. A. Woodley and C. Cadou. The use of a square grid system for computer estimation of precipitation, temperature, and runoff. Water Resources Research, 4(5): 919-929, 1968.

26. Thom, H.C.S. A statistical method of evaluating augmentation of precipitation by cloud seeding. Final report of the advisory committee on weather control, 2:5, 1957.

27. Thom, H.C.S. A note on the Gamma distribution. Monthly Weather Review, 86:117, 1958.

28. Thom, H.C.S. Approximate convolution of Gamma and Mixed Gamma distributions. Monthly Weather Review, 6:883-886, 1968.

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

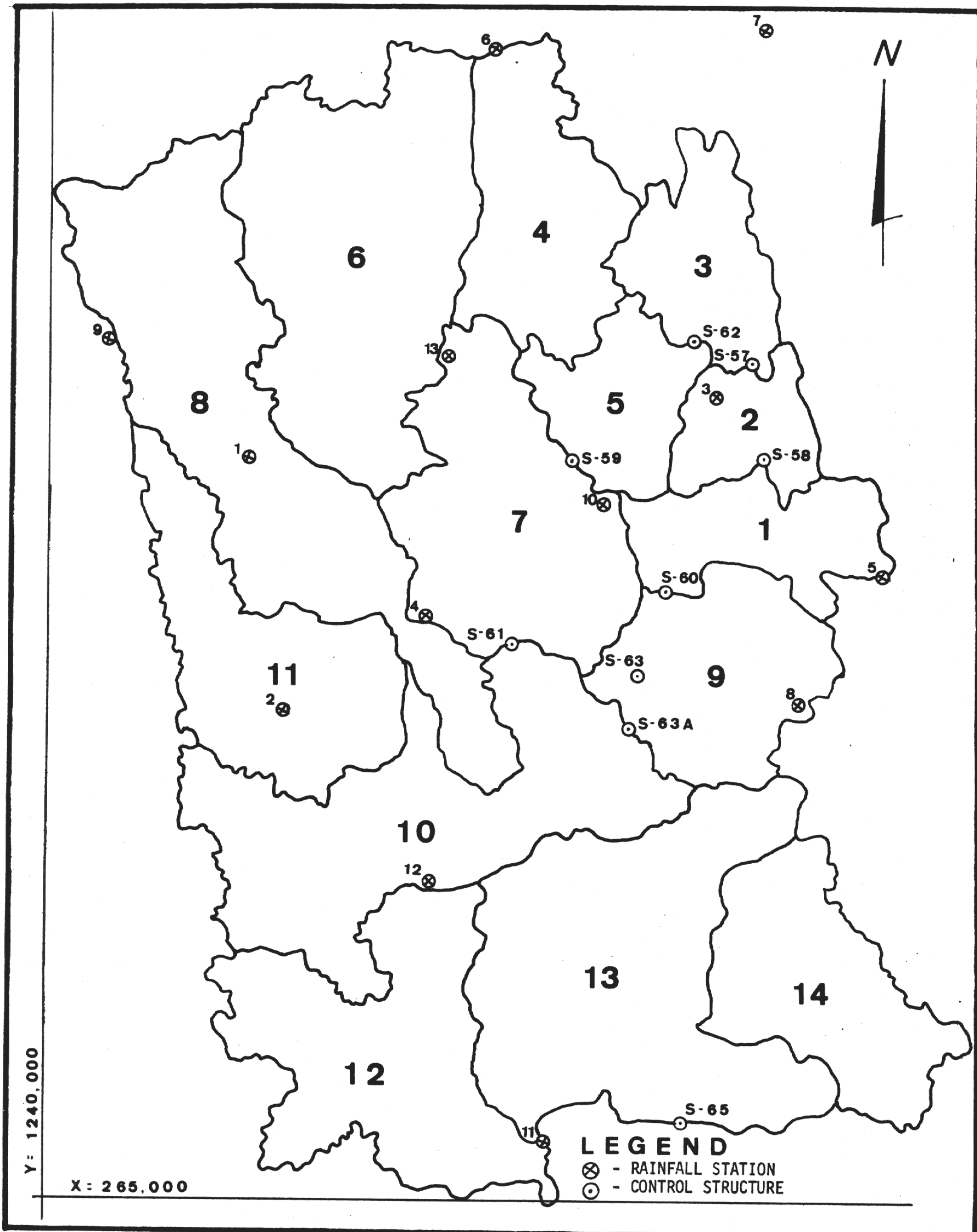
Rainfall Station	JUNE		JULY		AUGUST		SEPTEMBER	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
(1)	1.125 1.500	0.353 1.000	4.600 3.052	3.042 1.928	5.625 4.750	4.047 1.658	2.778 3.000	1.664 1.362
(2)	1.000 1.750	0.000 0.753	4.846 3.267	2.911 1.907	3.762 3.937	3.284 2.999	2.923 2.923	1.656 1.934
(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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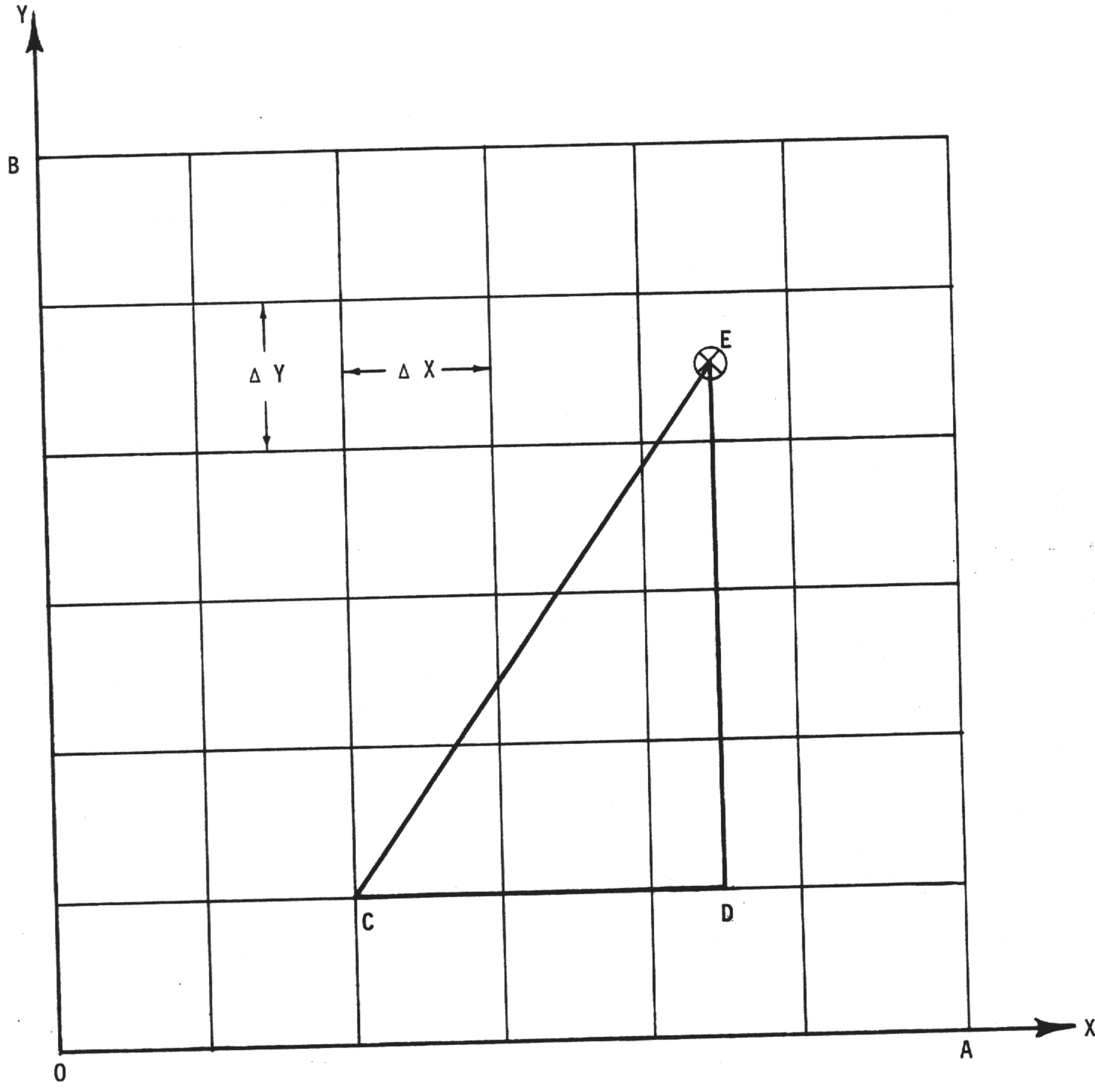
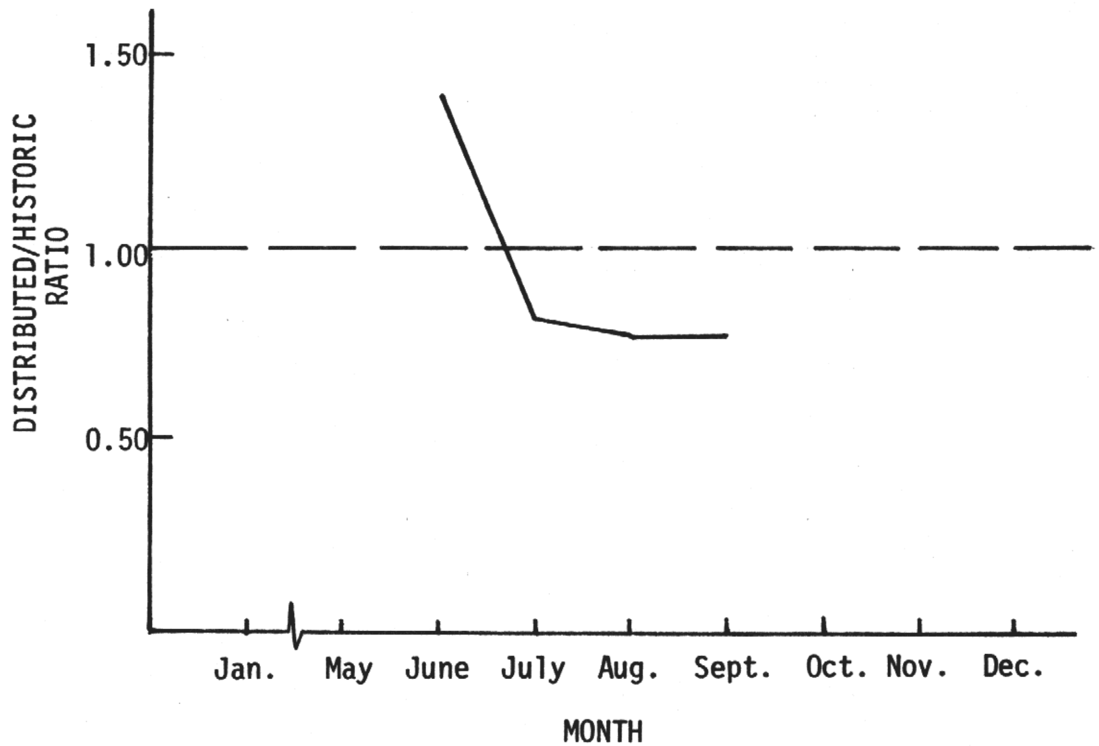
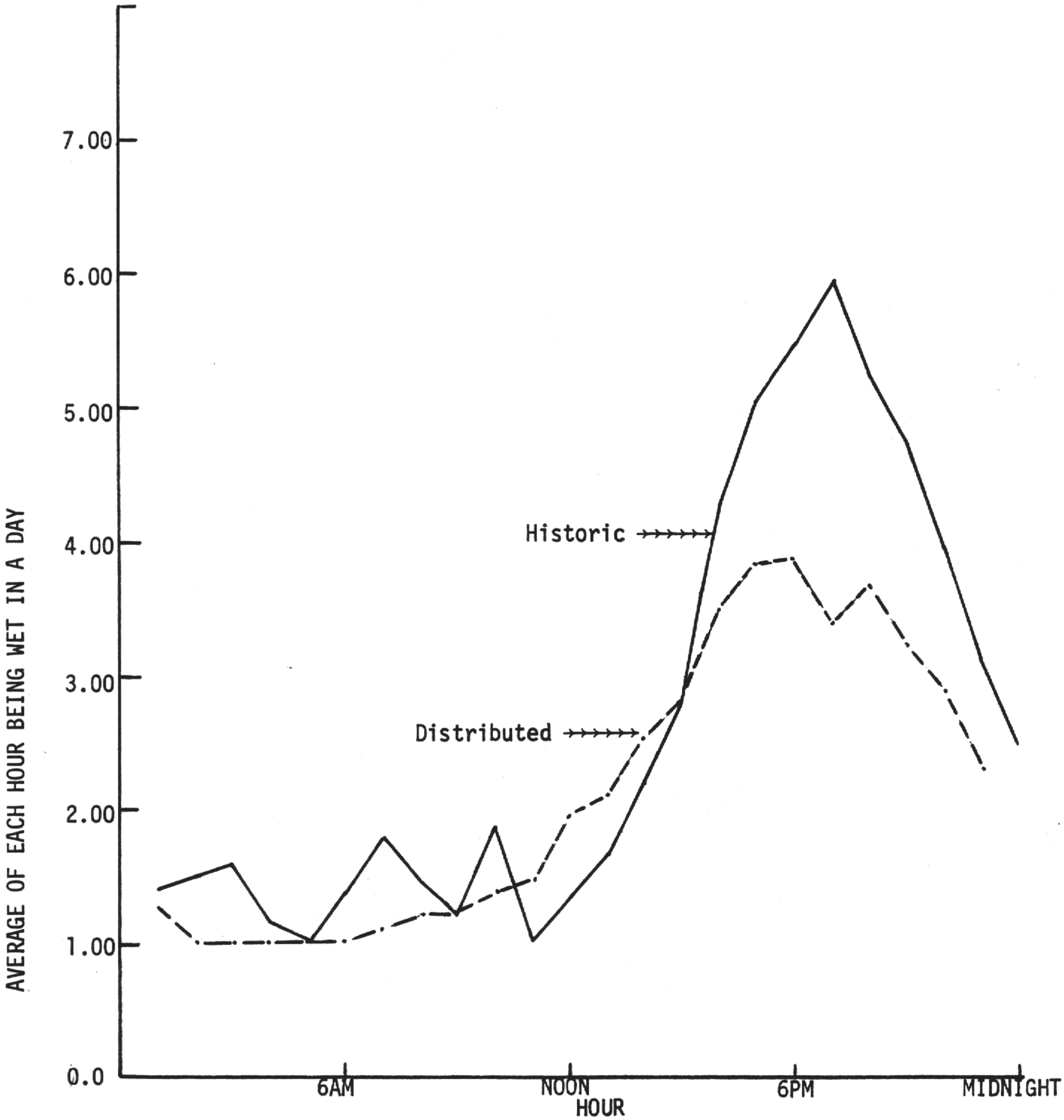
LEGEND
⊗ - RAINFALL STATION
⊙ - CONTROL STRUCTURE
X: 265,000
Y: 1240,000



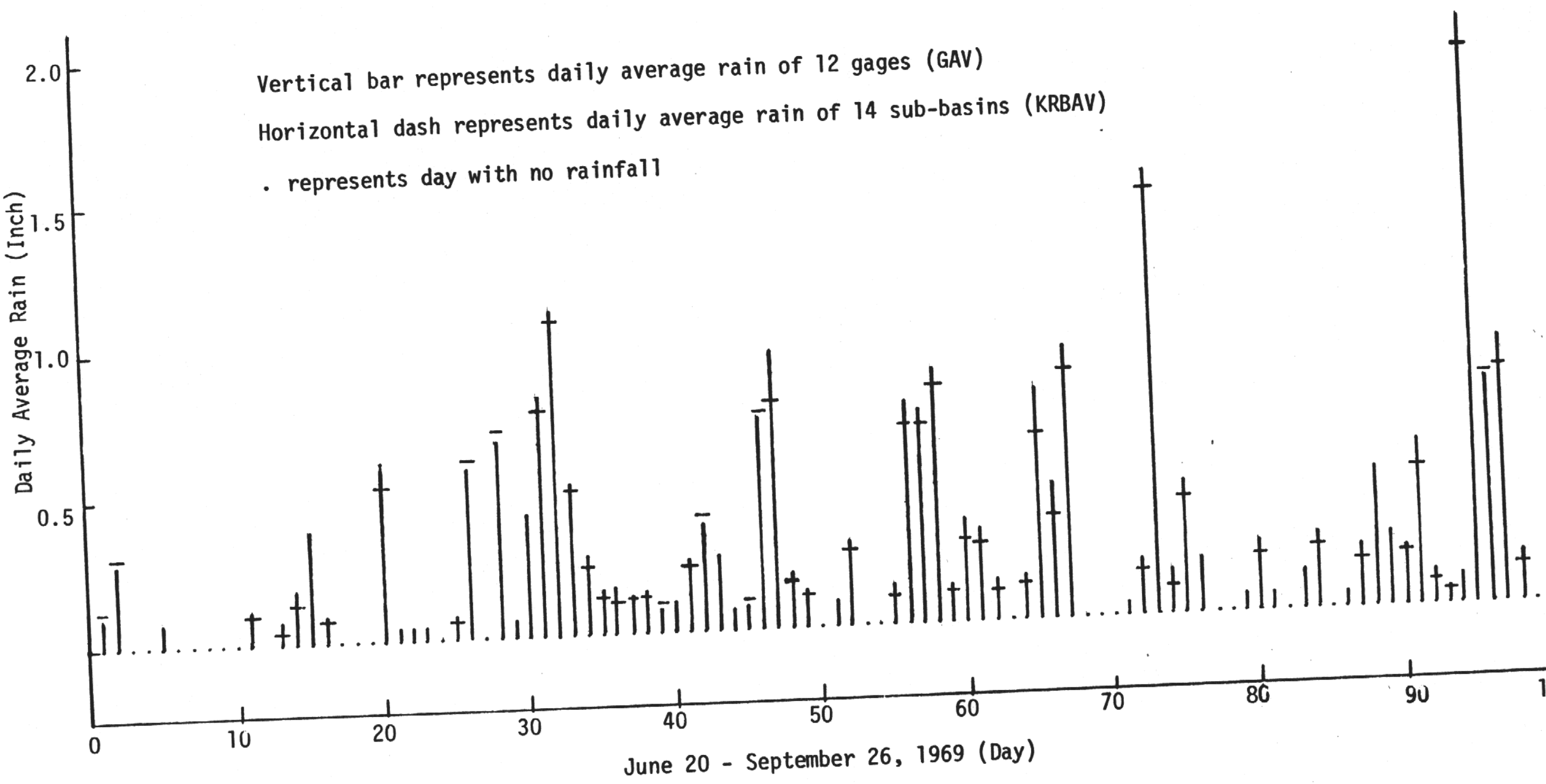
COMPUTATION OF RADIUS OF INFLUENCE



RATIO OF DISTRIBUTED TO HISTORIC TOTAL WET HOUR COUNTS



AVERAGE OF EACH HOUR DURING THE DAY BEING WET



COMPARISON OF KRBAV AND GAV VALUES

DRAFT

MEMORANDUM

Date: March 1, 1972

TO: Director, Department of Engineering

FROM: N. N. Khanal

SUBJECT: Hydrologic Data for Phase II of the Economic Model Study

This memorandum will summarize the work done on analysis of the hydrologic variables for the second phase of the economic model study for the Kissimmee River Basin.

Basin Yield: - Basin yield was computed simply as the difference between the basin rainfall and the total loss from the basin (seepage, infiltration, evaporation and interception). In order to cover the whole drainage area of the Kissimmee River Basin fairly well by raingages, the following stations, listed in Table 1, were used. Ten years (1961-1970) of daily rainfall values from these stations were used in this study.

Table 1. Rainfall Stations and Station Names

Station	Station Name
1.	Avon Park
2.	Bithlo
3.	Cornwell
4.	Fort Drum
5.	Lake Hart
6.	Isleworth
7.	Indian Lake Estates
8.	Kissimmee II
9.	Lake Alfred
10.	Lake Placid
11.	Mountain Lake
12.	Nittaw
13.	Okeechobee H.G. #6
14.	Orlando W.B.

The daily rainfall values were summed-up to monthly values for each station. The simple average values from these fourteen stations were used as the basin rainfall values. The average monthly rainfall values are presented in Table 2.

Table 2. Average Monthly Rainfall Values for Kissimmee River Basin for each Month of the Year

	MONTH											
YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1961	2.01	2.12	2.42	1.58	2.99	5.65	3.97	7.24	3.08	1.73	0.73	0.62
1962	.90	1.32	2.59	1.47	2.76	9.40	6.32	8.03	6.54	.87	2.81	.74
1963	1.81	5.68	1.98	.79	5.32	4.98	3.91	4.72	6.07	.89	5.38	2.71
1964	3.93	3.85	2.75	2.34	3.61	4.08	7.45	9.54	7.65	1.83	.62	1.58
1965	1.22	3.97	3.22	1.83	.98	7.64	9.22	6.36	5.77	4.65	.99	2.27
1966	4.96	5.38	1.51	2.14	5.23	8.48	6.45	8.30	7.02	2.57	.41	.98
1967	.83	4.00	.81	.23	1.58	9.19	8.70	7.97	5.04	1.02	.28	2.35
1968	.65	1.98	1.48	.56	6.55	14.76	7.43	5.33	5.25	5.04	2.21	.41
1969	2.39	1.85	6.40	2.28	3.10	5.58	6.10	8.45	7.32	7.27	2.31	4.05
1970	3.61	3.18	5.29	.52	3.45	5.44	7.60	5.08	3.97	2.70	.41	.95
Mean	2.32	3.34	2.84	1.37	3.55	7.52	6.71	7.10	5.77	2.85	1.61	1.67
Std. Dev.	1.50	1.52	1.84	.76	1.72	3.07	1.75	1.67	1.44	2.14	1.60	1.16

The 55-year yearly average for the State of Florida is 52.77" (1), 52.80" is the 30-year yearly average for Kissimmee Station (2) and the 10-year yearly average (1961-1970) for the whole Kissimmee River Basin is 46.64".

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(1) Tannehill, Iva Ray. 1956. Drought, Its Causes and Effects.

(2) Butson, K. D. and R. M. Prine. April 1968. Weekly Rainfall Frequencies in Florida. Agr. Exp. Station, Univ. of Florida, Gainesville.

A plot of the 55-year monthly average for Florida and the 10-year monthly average for the whole Kissimmee River Basin is shown in Figure 1. It can be seen that the 10-year monthly average follows the same trend as the 55-year monthly average trend for Florida.

Weighted average values for each rainfall station covering up to S-65 was also used to compute the basin runoff. The percentage weights of each of the rainfall stations up to S-65 is presented below in Table 2A.

Table 2A. Percentage weights of each of the rainfall stations up to S-65

Station Name	Percentage Weight
Lake Alfred	3.40
Lake Kissimmee	27.50
Isleworth	9.10
Orlando	4.90
Bithlo	0.40
Lake Hart	16.70
Indian Lake Estates	26.20
Mountain Lake	11.80
	100.00

Basin Rainfall = .034* Lake Alfred + .275* Lake Kissimmee + .091* Isleworth +.490* Orlando +.004* Bithlo + .167* Lake Hart + .262* Indian Lake Estates + .118* Mountain Lake (1)

The basin rainfall up to S-65, estimated by use of equation (1) is presented in Table 2B.

* A comparison of Table 2 and 2B shows that the mean monthly values from Table 2B are a bit lower than those from Table 2, which is expected. Table 2B will not be used to compute yield values, as the mean of the ten yearly values is much lower than the normal yearly mean.

FIG. 1. AVERAGE BASIN RAINFALL FROM 9 STATIONS LOCATED ABOVE S-65, & 14 STATIONS LOCATED ABOVE LAKE OKEECHOBEE

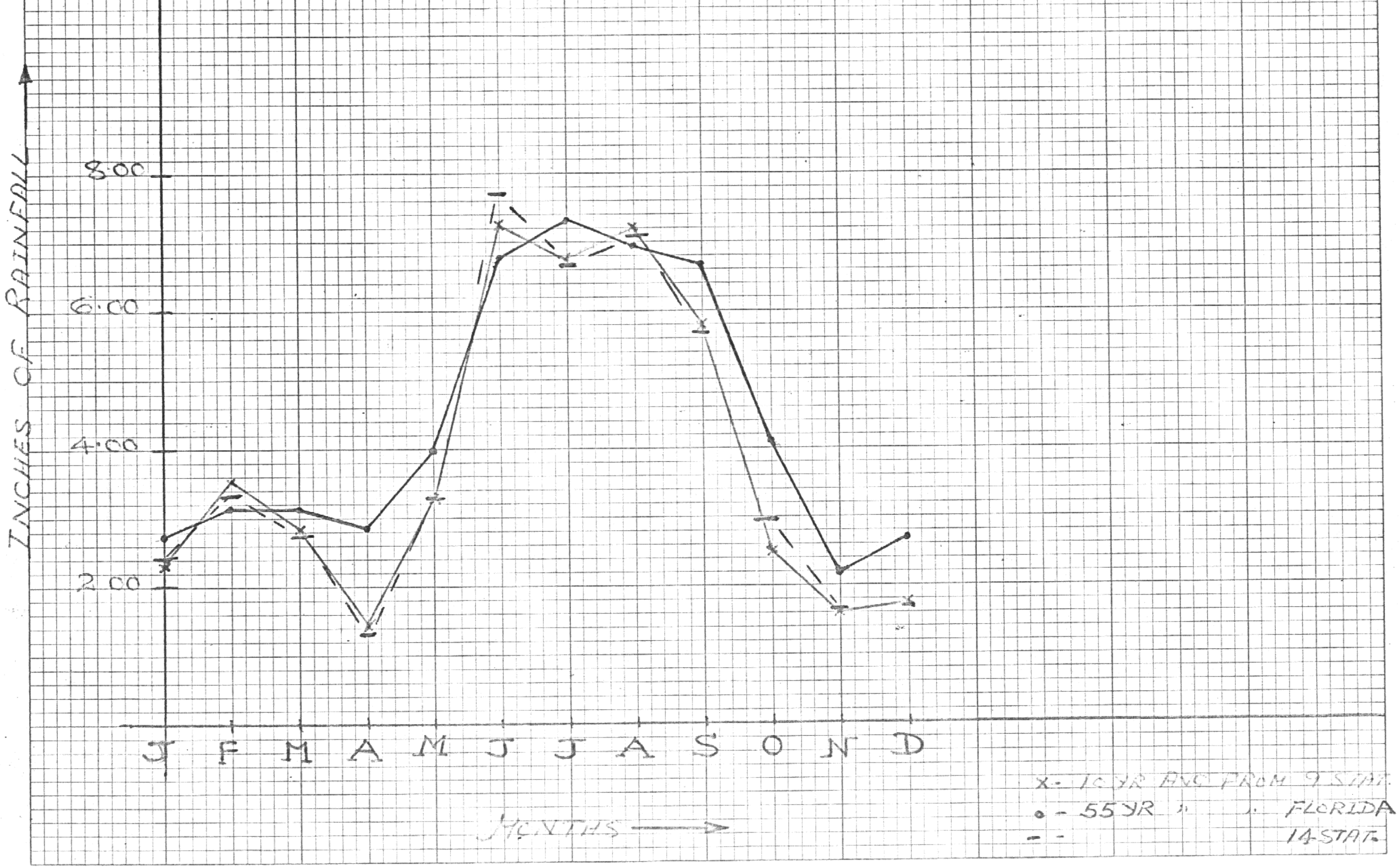


Table 2B. Weighted Average Monthly Rainfall Values up to S-65 for the Kissimmee River Basin

YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1961	1.50	2.40	1.90	1.20	2.40	4.75	3.30	3.70	1.90	.85	.50	1.25
1962	.55	1.05	1.45	.70	3.90	4.55	6.85	6.10	6.55	1.00	2.75	1.00
1963	1.60	6.75	1.55	1.05	5.40	3.70	2.75	3.60	3.75	1.35	4.90	2.45
1964	4.20	3.00	3.10	2.80	3.30	2.40	9.50	12.90	9.60	1.25	.60	1.35
1965	1.60	4.10	2.80	1.55	1.50	8.55	9.45	6.65	5.75	4.30	1.15	2.45
1966	5.35	6.65	1.50	1.95	5.10	8.90	5.10	7.65	6.70	1.65	.15	1.35
1967	.80	4.10	.60	.10	.60	8.50	10.50	8.35	5.15	.60	.10	2.70
1968	.30	2.00	1.15	.30	4.05	12.90	6.35	3.90	4.65	3.45	2.00	.35
1969	2.90	1.90	6.10	2.40	2.65	4.95	6.20	9.15	9.72	7.30	2.30	4.40
1970	2.40	3.00	5.00	.60	3.90	4.90	7.55	4.45	3.10	2.40	.50	1.25
MEAN	2.12	3.49	2.51	1.26	3.28	6.41	6.75	6.64	5.69	2.41	1.49	1.85

In order to derive the basin yield (runoff) from basin rainfall, the Corps of Engineers monthly rainfall-total loss curve was used.* The curve for each month of the year is presented in Figures 2, 3 and 4. Functional equations, both logarithmic and linear in form, were fitted to the curve. The equations for logarithmic and linear fittings are presented in Tables 3 and 4.

Table 3. Monthly Total Loss Equation Fitted to Corps of Engineers Rainfall-Total Loss Curve. (Logarithmic Form).

Month	Monthly Loss $Y = a \cdot x^b$
January	$2.15 \times R'fall^{.226}$
February	$1.24 \times R'fall^{.612}$
March	$1.54 \times R'fall^{.529}$
April	$1.94 \times R'fall^{.510}$
May	$1.35 \times R'fall^{.728}$
June	$2.35 \times R'fall^{.487}$
July	$2.54 \times R'fall^{.425}$
August	$2.34 \times R'fall^{.476}$
September	$2.35 \times R'fall^{.417}$
October	$1.96 \times R'fall^{.466}$
November	$1.45 \times R'fall^{.588}$
December	$1.20 \times R'fall^{.691}$

*(see Pg. 6)

Table 4. Monthly Total Loss Equation Fitted to Corps of Engineers Rainfall-Total Loss Curve (Linear Form).

Month	Monthly Loss (Y = a+b x)
January	.927 + .429 x R'fall
February	1.132 + .455 x R'fall
March	1.220 + .504 x R'fall
April	1.720 + .457 x R'fall
May	1.530 + .530 x R'fall
June	2.220 + .520 x R'fall
July	2.600 + .470 x R'fall
August	1.890 + .580 x R'fall
September	2.460 + .370 x R'fall
October	1.970 + .360 x R'fall
November	1.110 + .470 x R'fall
December	.740 + .530 x R'fall

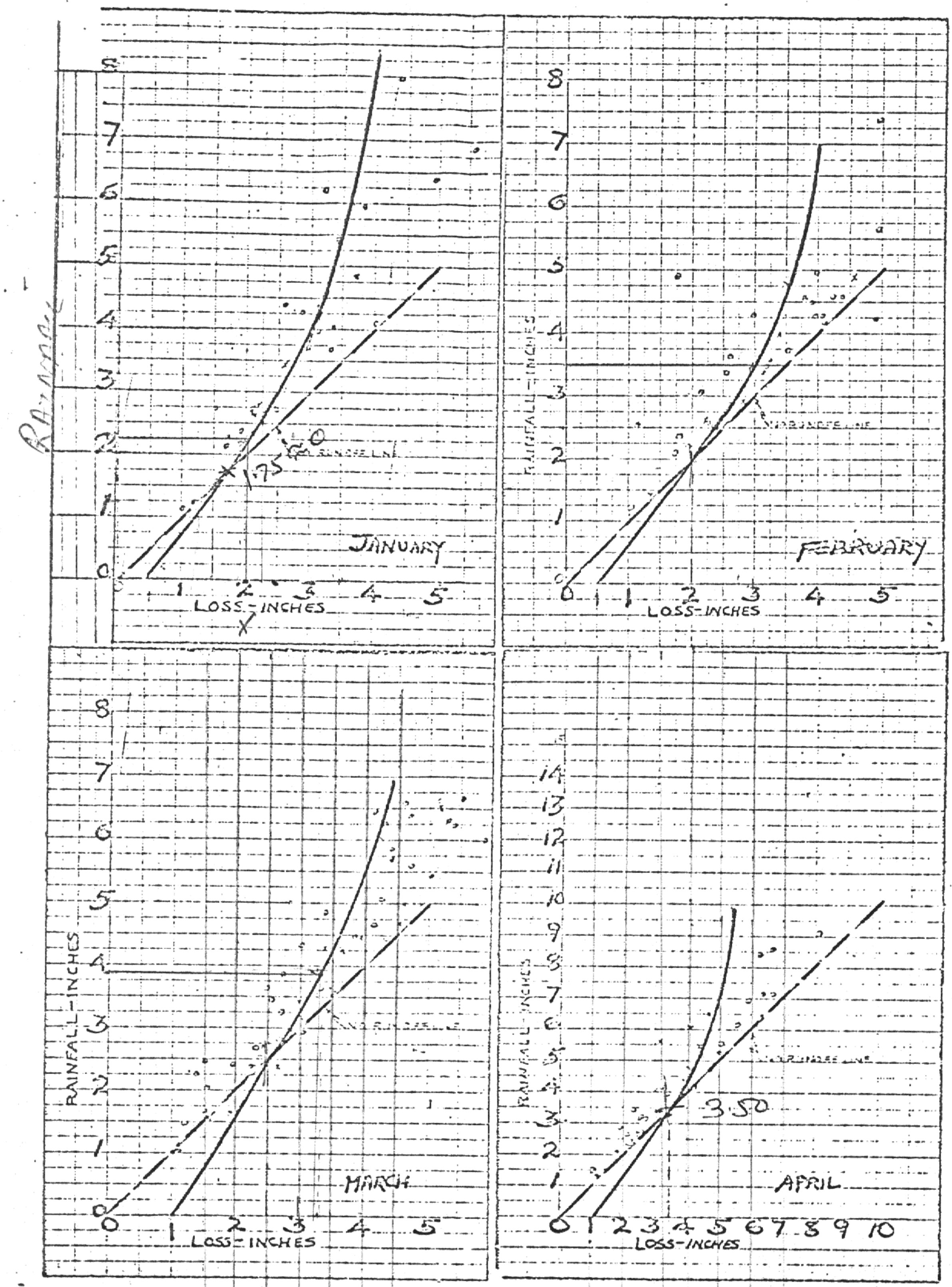
*(from page 5)
Desigm Memorandum, Part VI, Supp. 8, "General Studies and Reports, Rainfall Excess Evaluation."

The R square, δ, standard error and F test values for both fittings are presented in Table 5.

Table 5. Statistical Properties of the Logarithmic and Linear Equation Fitting for Corps of Engineers Rainfall - Total Loss Curve.

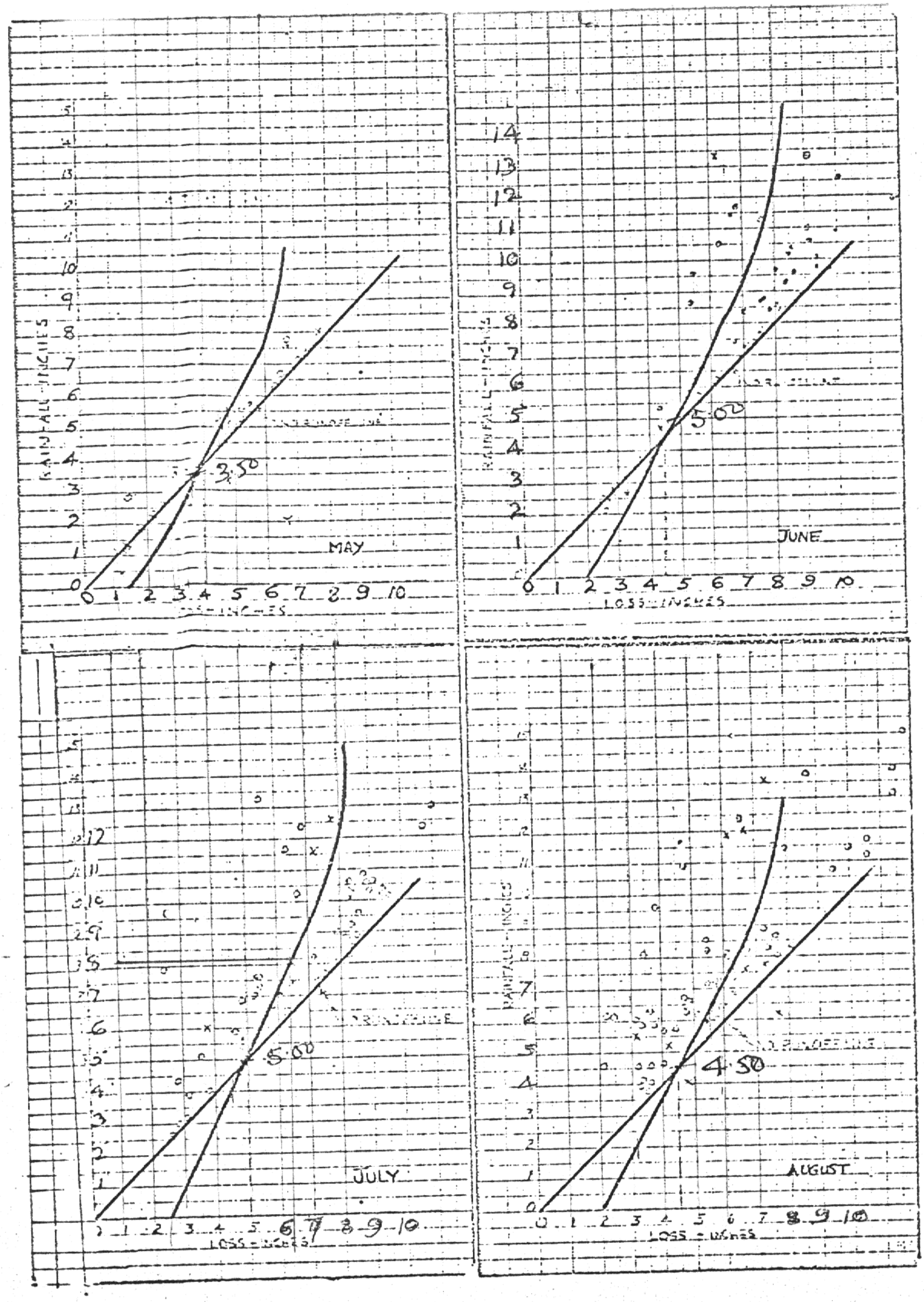
Months	R Square	δ	Std. Error	F(95%)	R Square	δ	Std. Error	F(95%)
January	.882	.248	.031	52.64	.940	.300	.038	122.48
February	.983	.059	.035	296.08	.930	.280	.054	69.94
March	.998	.015	.010	2634.01	.990	.090	.023	473.14
April	.988	.042	.021	584.53	.960	.270	.035	169.43
May	.923	.162	.073	97.24	.920	.490	.054	96.16
June	.987	.043	.018	693.58	.990	.160	.015	1060.75
July	.969	.060	.023	314.88	.990	.110	.009	2289.33
August	.972	.061	.061	209.30	.990	.060	.010	3271.13
September	.986	0.38	.015	749.26	.960	.280	.023	252.62
October	.992	.032	.012	1302.33	.960	.240	.020	317.53
November	.992	.037	.037	699.80	.960	.210	.040	139.29
December	.991	.047	.047	463.43	.960	.200	.047	127.30

Both the equations were used to generate basin yield on a monthly basis. The monthly basin yield values generated by use of the logarithmic and linear equations are presented in Tables 6 and 7.



TOTAL LOSS

FIG 2. Total Rainfall-Loss



MAY
3.50
RAINFALL INCHES
LOSS INCHES
JUNE
5.00
LOSS INCHES
JULY
5.00
LOSS INCHES
AUGUST
4.50
RAINFALL INCHES
LOSS INCHES

Fig 3.

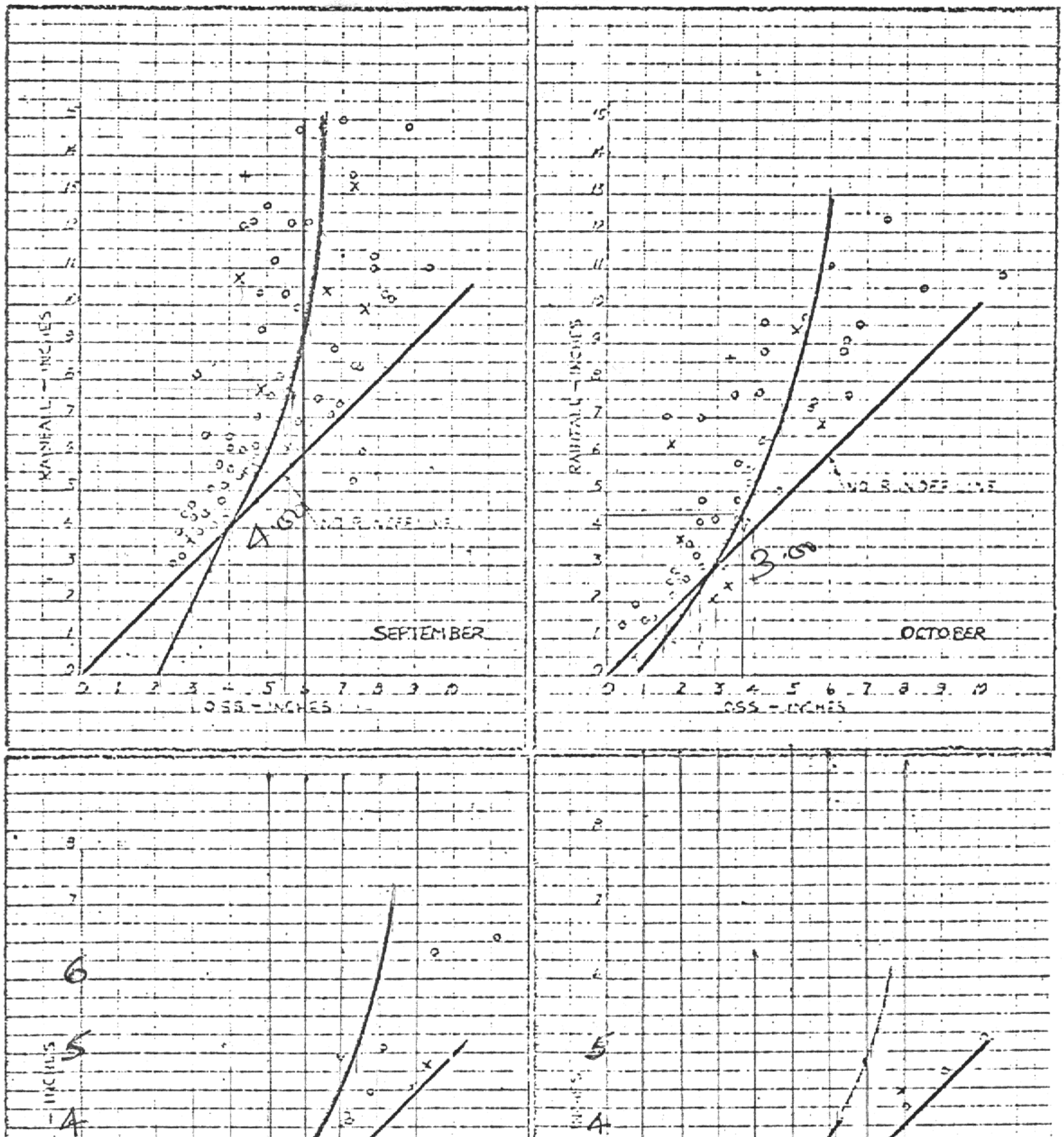

SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
RAINFALL — INCHES
LOSS — INCHES
NO RUNOFF LINE
4.00
3.00
2.00
1.50

Fig 4.

Table 6. Monthly Yield Values for Kissimmee River Basin by Use of the Logarithmic Loss Equation $Y = ax^b$ (D.A. 1,600 sq. miles, or 1,024,000 Acre Feet).

YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1961	0	13	0	0	0	15	0	104	0	0	0	0	132
1962	0	0	3	0	0	208	64	146	119	0	12	0	551
1963	0	183	0	0	65	0	0	0	92	0	126	27	493
1964	85	87	8	0	14	0	130	180	200	0	0	0	704
1965	0	92	30	0	0	112	229	61	75	54	0	13	666
1966	159	162	0	0	62	155	71	158	147	0	0	0	914
1967	0	94	0	0	0	193	198	143	36	0	0	15	679
1968	0	8	0	0	106	515	125	8	47	74	0	0	883
1969	0	3	195	0	2	12	53	168	164	198	0	76	871
1970	62	56	134	0	10	6	135	0	0	0	0	0	403
MEAN	30.6	69.8	37.0	0	25.9	121.6	100.5	96.8	88.0	32.6	13.8	13.1	
Std. Dev.	54.8	66.0	69.3	0	37.8	160.3	76.2	82.8	64.7	64.1	39.3	23.9	

Table 7. Monthly Yield Values for Kissimmee River Basin by Use of the Linear Loss Equation $Y = a+b \cdot x$

YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1961	84	2	0	0	0	43	0	97	0	0	0	0	226
1962	0	0	5	0	0	205	61	126	141	0	30	0	568
1963	9	172	0	0	79	16	0	7	116	0	145	43	587
1964	112	82	10	0	11	0	115	182	200	0	0	0	712
1965	0	88	32	0	0	125	191	66	100	85	0	25	712
1966	162	153	0	0	75	159	67	134	167	0	0	0	917
1967	0	89	0	0	0	188	167	124	61	0	0	29	658
1968	0	0	0	0	127	416	110	27	72	106	4	0	862
1969	37	0	166	0	0	40	51	140	183	227	8	59	911
1970	96	51	119	0	5	35	118	20	3	0	0	0	447
MEAN	50.0	63.7	33.2	0	29.7	122.7	88.0	91.3	105.1	41.8	18.7	15.6	
Std. Dev.	59.7	64.4	59.5	0	46.3	125.8	63.4	60.1	69.5	76.4	45.3	22.1	

The LP model is designed to accept the yield values on a seasonal basis. The year is divided into four seasons, or periods; season, or period 1, being the months of June, July, August and September. Period 2 is October and November. Period 3 is December and January. Period 4 is February, March, April and May. The yield into the Kissimmee River Basin for these four periods for each year is presented in Table 8.

Table 8. Seasonal Yield into the Kissimmee River Basin From Logarithmic Fitting

YEAR	June, July August & September PERIOD 1	October, November PERIOD 2	December January PERIOD 3	February, March April & May PERIOD 4
	Yield (1000 Ac. Ft.)			
1961	119	0	0	13
1962	537	12	0	3
1963	92	126	27	248
1964	510	0	85	109
1965	477	54	13	122
1966	531	0	159	224
1967	570	0	15	94
1968	695	74	0	114
1969	397	198	76	200
1970	141	0	62	200
MEAN	406.9	46.4	43.7	132.7
Std. Dev.	212.59	68.38	51.80	84.56

Table 9. Seasonal Yield into the Kissimmee River Basin from Linear Fitting

YEAR	June, July August & September PERIOD 1	October November PERIOD 2	December January PERIOD 3	February, March April & May PERIOD 4
	Yield (1000 Ac. Ft.)			
1961	140	0	0	2
1962	533	30	0	5
1963	139	145	52	251
1964	495	0	112	103
1965	482	85	25	120
1966	527	0	162	228
1967	540	0	29	89
1968	625	110	0	127
1969	474	235	96	166
1970	176	0	96	175
MEAN	413.1	60.5	57.2	126.6
Std. Dev.	181.4	81.5	56.4	82.9

The difference in the mean yield values arrived at from both logarithmic and linear equations is very close, the difference being about 18,000 acre feet. Therefore, it can be concluded that either one of the seasonal yield values can be used in the L. P. Model.

Storage Computations:

A list of the lakes which are within the Kissimmee River Basin is presented below. They are:

Lake Kissimmee
Lake Hatchineha
Cypress Lake
Lake Tohopekaliga
East Lake Tohopekaliga
Lake Hart
Lake Mary Jane
Lake Myrtle
Lake Alligator
Lake Gentry
Lake Marian
Lake Jackson
Lake Tiger
Lake Rosalie
Lake Marion
Lake Weohyakapka

The U. S. G. S. publishes the daily stages for these lakes. Ten years (1961 - 1970) of end-of-month stages were used for the storage computation. Lagendre Polynomial equations for storage, as a function of stage, were fitted for each of the lakes listed above. The equations developed for each of the lakes are presented in Table 10 below.

Table 10. Lagendre Polynomial Equation Fitted for Each Storage as a Function of Stage.

Lakes	Functional Equation
Kissimmee	Stor = 725.24 - 6078.5 x Stage + 19038.0 x Stage^2 - 26472 x Stage^3 + 13855.0 x Stage^4.
Hatchineha	Stor = -674.0 + 5799.2 x Stage - 18633.0 x Stage^2 - 26495.0 x Stage^3 - 14059 x Stage^4 .
Cypress	Stor = 1266.0 - 10945.0 x Stage + 35439.0 x Stage^2 - 50903.0 x Stage^3 + 27417 x Stage^4 .
Tohopekaliga	Stor = -699.22 + 5240.4 x Stage - 14702.0 x Stage^2 + 18258.0 x Stage^3 - 8437.2 x Stage^4 .

East Tohopekaliga	$Stor = 266.67 + 1817.55 \times Stage - 4660.0 \times Stage^2 + 5293.5 \times Stage^3 - 2230 \times Stage^4.$
Hart	$Stor = 4.79 + 39.76 \times Stage - 121.48 \times Stage^2 + 160.97 \times Stage^3 - 77.20 \times Stage^4.$
Mary Jane	$Stor = 51.81 - 373.95 \times Stage + 1011.9 \times Stage^2 - 1218.3 \times Stage^3 + 551.66 \times Stage^4.$
Myrtle	$Stor = 21.84 - 152.10 \times Stage + 397.80 \times Stage^2 - 463.81 \times Stage^3 + 203.85 \times Stage^4.$
Alligator	$Stor = 5.94 - 51.50 \times Stage + 167.26 \times Stage^2 - 242.7 \times Stage^3 + 134.10 \times Stage^4.$
Gentry	$Stor = -90.13 + 532.02 \times Stage - 1144.5 \times Stage^2 + 1048.8 \times Stage^3 - 335.33 \times Stage^4.$
Tiger	$Stor = 39.54 - 318.4 \times Stage + 957.0 \times Stage^2 - 1278.2 \times Stage^3 + 645.2\ Stage^4.$
Rosalie	$Stor = -2.4 + 10.3 \times Stage - 7.3 \times Stage^2 - 24.1 \times Stage^3 + 39.26 \times Stage^4.$
Marion	$Stor = -293.91 \times 1708.8 \times Stage - 3716.0 \times Stage^2 + 3577.6 \times Stage^3 - 1283.3 \times Stage^4.$
Weohyakapka	$Stor = 324.15 - 2191.0 \times Stage + 5531.8 \times Stage^2 - 6195.0 \times Stage^3 + 2606.0 \times Stage^4.$
Marian	$Stor = 383.37 - 2763.2 \times Stage + 7452.0 \times Stage^2 - 8918.0 \times Stage^3 + 4002.7 \times Stage^4.$
Jackson	$Stor = -412.72 + 2095.7 \times Stage - 8080.7 \times Stage^2 + 9692.5 \times Stage^3 - 4344.5 \times Stage^4.$
Istokpoga	$Stor = -623560.0 + 89302 \times Stage - 5297.1 \times Stage^2 + 166.54 \times Stage^3 - 2.93 \times Stage^4 + .03 \times Stage^5 - 0001.0 \times Stage^6.$

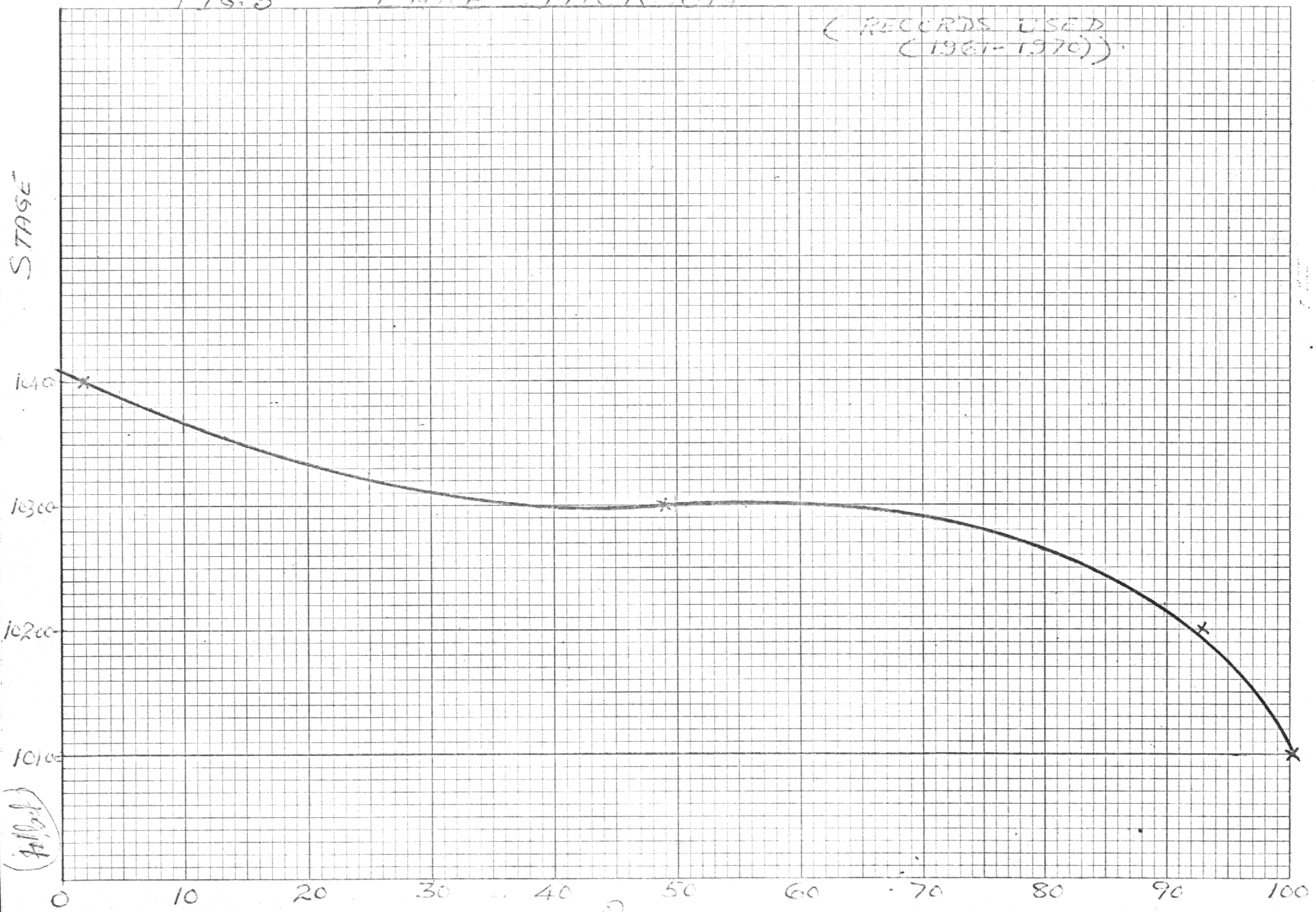
Where

Stage = original stage/100.0 in feet

Stor = computed storage

Actual Stor = computed storage x 100,000 Ac. Ft.

FIG. 5 LAKE JACKSON



% OF TIME

Total Basin Storage

Total basin storage for the entire Kissimmee Basin was estimated by combining the storage of each individual lake at different frequency levels. Stage - frequency curves prepared by the District were utilized for the computation.

Table II. Lake Stages at Difference Frequency Levels

Lakes	Frequency % of Time					
	1	5	10	25	50	90
Kissimmee	55.6	54.2	53.2	51.8	50.4	47.1
Hatchineha	56.4	55.0	53.9	52.4	53.3	48.7
Cypress	56.8	55.5	54.6	53.9	52.5	50.0
Tohopekaliga	58.0	56.4	55.8	54.8	53.4	50.8
East Tohopekaliga	60.8	59.8	58.8	57.4	55.9	53.8
Hart	63.8	62.0	61.1	60.1	59.2	57.9
Mary Jane	63.8	62.0	61.1	60.4	60.0	59.0
Myrtle	63.3	62.4	61.9	61.0	60.3	59.1
Alligator	66.0	65.3	65.0	64.3	63.3	61.4
Gentry	62.0	61.2	60.9	59.7	58.7	57.0
Marion	67.6	67.0	66.8	66.4	66.1	65.5
Marian	61.0	60.5	60.3	59.8	59.5	59.2
Jackson	104.0	103.9	103.7	103.2	103.0	102.2
Rosalie	55.9	54.9	54.8	54.3	53.2	52.0
Tiger*						
Weohyakapka	62.8	62.4	62.2	61.9	61.5	60.2
Istokpoga	41.8	40.8	40.0	39.0	38.4	37.0

*No stage record available for Lake Tiger; therefore, it was combined with Kissimmee lake stages.

The stages listed in Table 11 were converted to storages by use of the polynomial equation and are presented in Table 12.

Table 12. Lake Storage at Different Frequency Levels

Lakes	Frequency % 1	5	10	25	50	90
Kissimmee, Hatchineha, Cypress, Tiger	700	560	484	400	328	184
Tohopekaliga	222	182	160	130	108	65
East Tohopekaliga	172	154	140	123	104	80
Hart	7	7	7	7	7	7
Mary Jane	13	10	7	6	6	6
Myrtle	4	3	3	3	2	2
Alligator	47	40	38	35	32	25
Gentry	17	15	15	14	12	9
Marion	27	26	24	23	23	21
Marian	65	64	63	62	60	48
Jackson	8	7	6	5	4	4
Rosalie	66	58	58	56	47	45
Weohyakapka	73	70	68	67	64	52
Istokpoga	250	217	185	155	149	100
Total	1,676	1,413	1,258	1,186	946	648

Individual storage - duration curves for Kissimmee, Hatchineha and Cypress combined, Lake Tohopekaliga, East Tohopekaliga, Istokpoga and Weohyakapka were drawn and are presented in Figure 6. The total storage-duration curve for the whole Kissimmee Basin was also drawn and is presented in Figure 7.

FIG. 6 IND. LAKE STORAGE AT DIFF. FREQ LEVELS

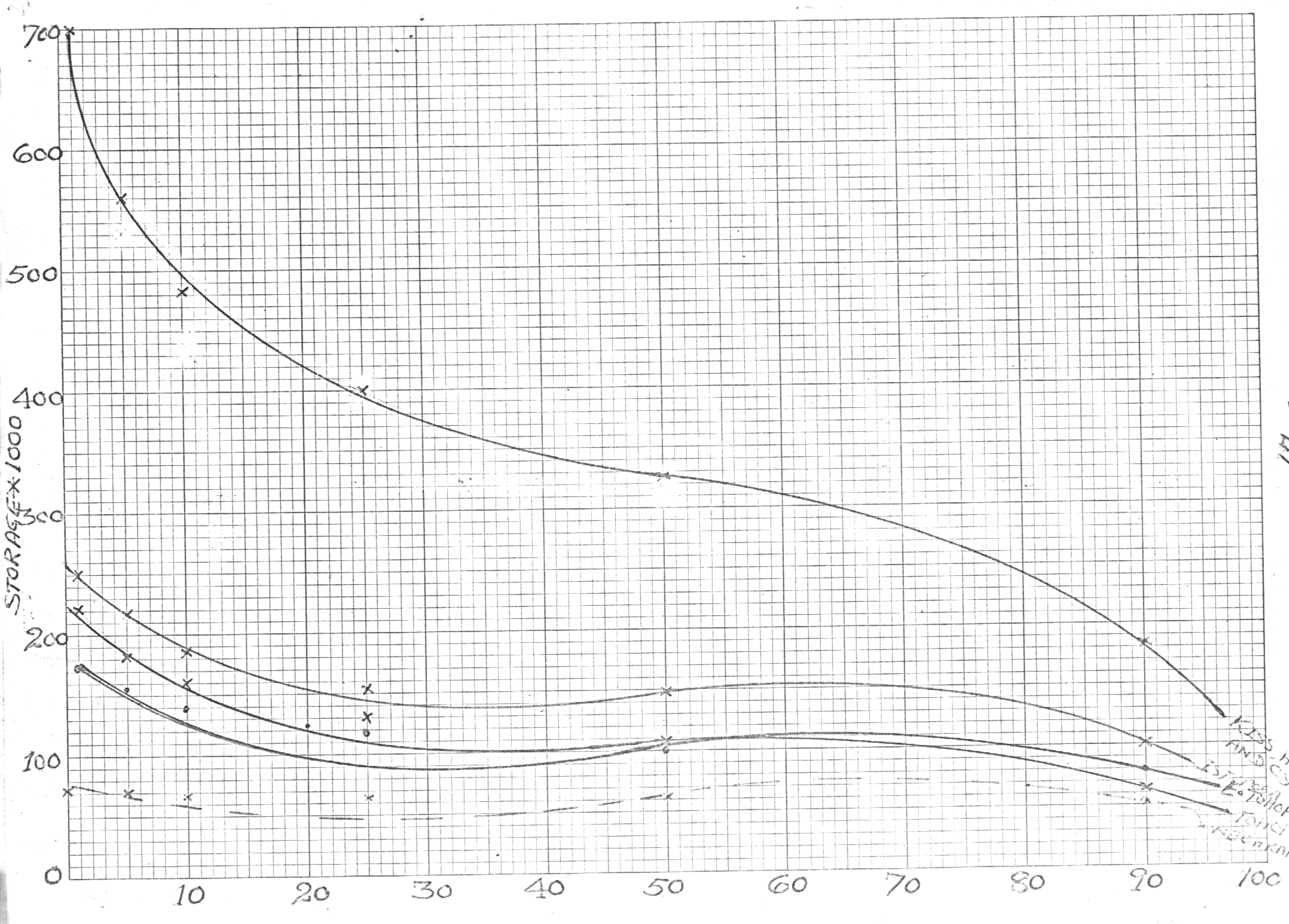
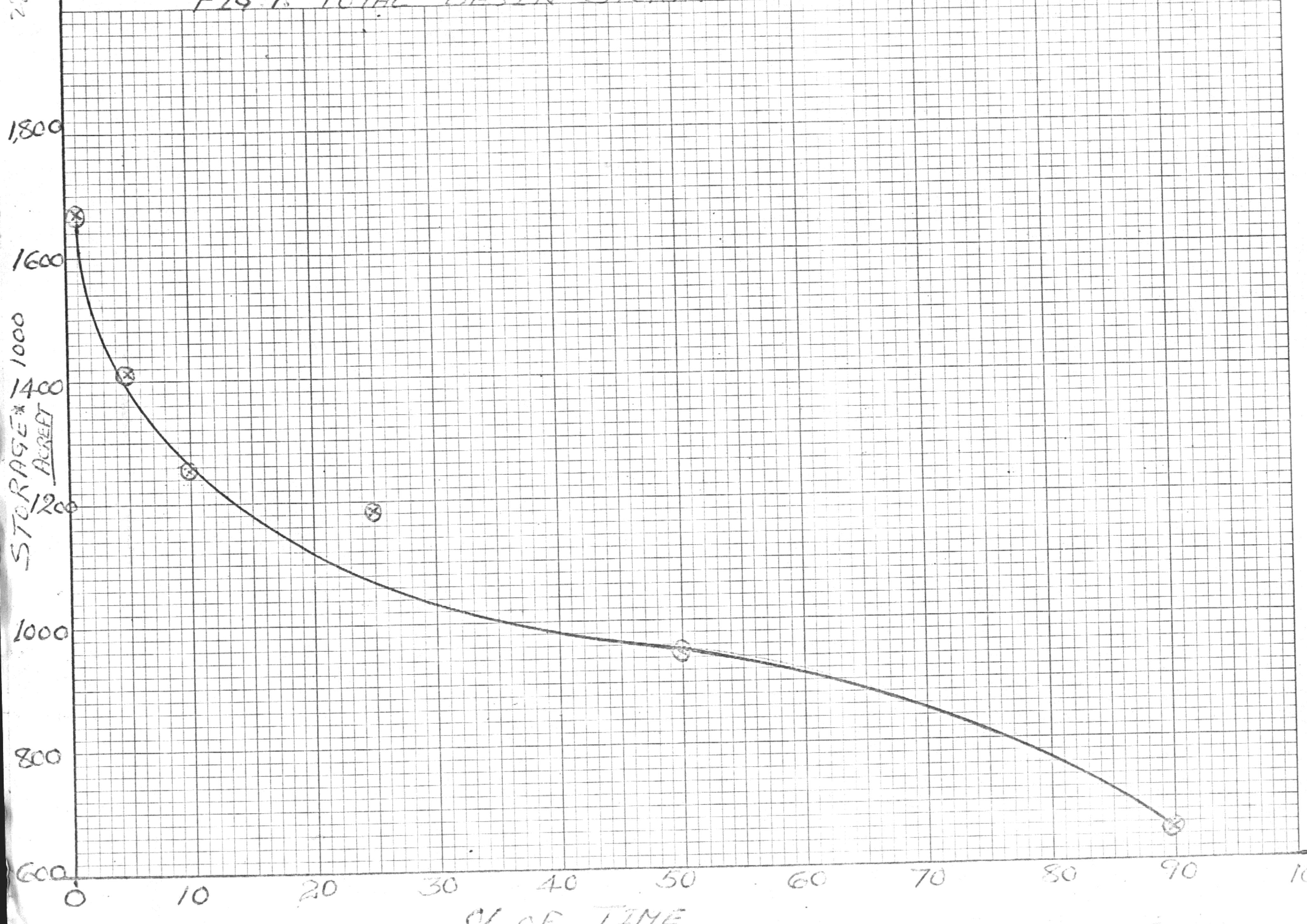


FIG 7. TOTAL BASIN STORAGE FOR THE WHOLE KISS BASIN



Top of regulation is the lake level where the maximum allowable storage occurs. In order to estimate the maximum allowable basin storage, top of regulation stage from each individual lake was converted to storage by use of the polynomial equation listed in Table 10. Top of regulation stage for each lake is listed in Table 13.

Table 13. Top of Regulation Stages and Associated Storages.

Lake	Top of Regulation (Stage)	Top of Regulation (Storage) X 1000 Acre Ft.
Kissimmee) Hatchineha) Cypress)	52.5	440
Tohopekaliga	55.0	144
East Tohopekaliga	58.0	130
Hart	61.0	7
Mary Jane	61.0	7
Myrtle	63.0	4
Alligator	64.0	43
Gentry	62.0	17
Marion *		23
Marian *		60
Jackson *		4
Rosalie *		47
Weohyakapka		64
Istokpoga	40.0-39.5	185
		1,175

*Lakes Marion, Marian, Jackson and Rosalie have no control structures, so 50% frequency level was taken as the top of regulation stage for which top of regulation storage was computed.

Top of regulation storage, and 50 and 90 percent frequency storages were used as the maximum allowable, mean and minimum storages for the whole Kissimmee Basin. These storages are presented in Table 14. (See Figure 8).

Table 14. Maximum Allowable, Mean and Minimum Storages for the Kissimmee River Basin (1,000 acre feet).

Maximum Storage	Mean Storage	Minimum Storage
1,175	945	650

Flood Damage Computation

In order to arrive at the dollar figures from flood damage in the Kissimmee River Basin, the following lakes with the highest frequencies were supplied to the Planning Department. Based on the 1 ft. contour interval map of the River Basin and the current agricultural land use, flood damage in terms of dollars was estimated. The lakes, highest stages, and the damage in dollars are presented in Table 15.

Table 15. Lakes, Stages and the Damage in Dollars

Lake	Stages and Damages (1000 Ac. Ft. and $1000)				
Kissimmee	53(140)	54(155)	55(170)	56(185)	57(200)
Istokpoga	39(50)	40(100)	41(200)	42(425)	43(500)
Tohopekaliga	55(0)	56(225)	57(575)	60(1,200)	
East Tohopekaliga	58(0)	60(350)	63(1,500)	65(2,500)	
Gentry	62(0)	63(25)	65(100)		
Alligator	64(0)	65(65)	68(450)	70(750)	
Hart & Mary Jane	61(0)	62(25)	63(125)	65(350)	

( ) Damage in $1,000.

Fig. 8 Maximum, Mean and Minimum Storage
Kissimmee Basin

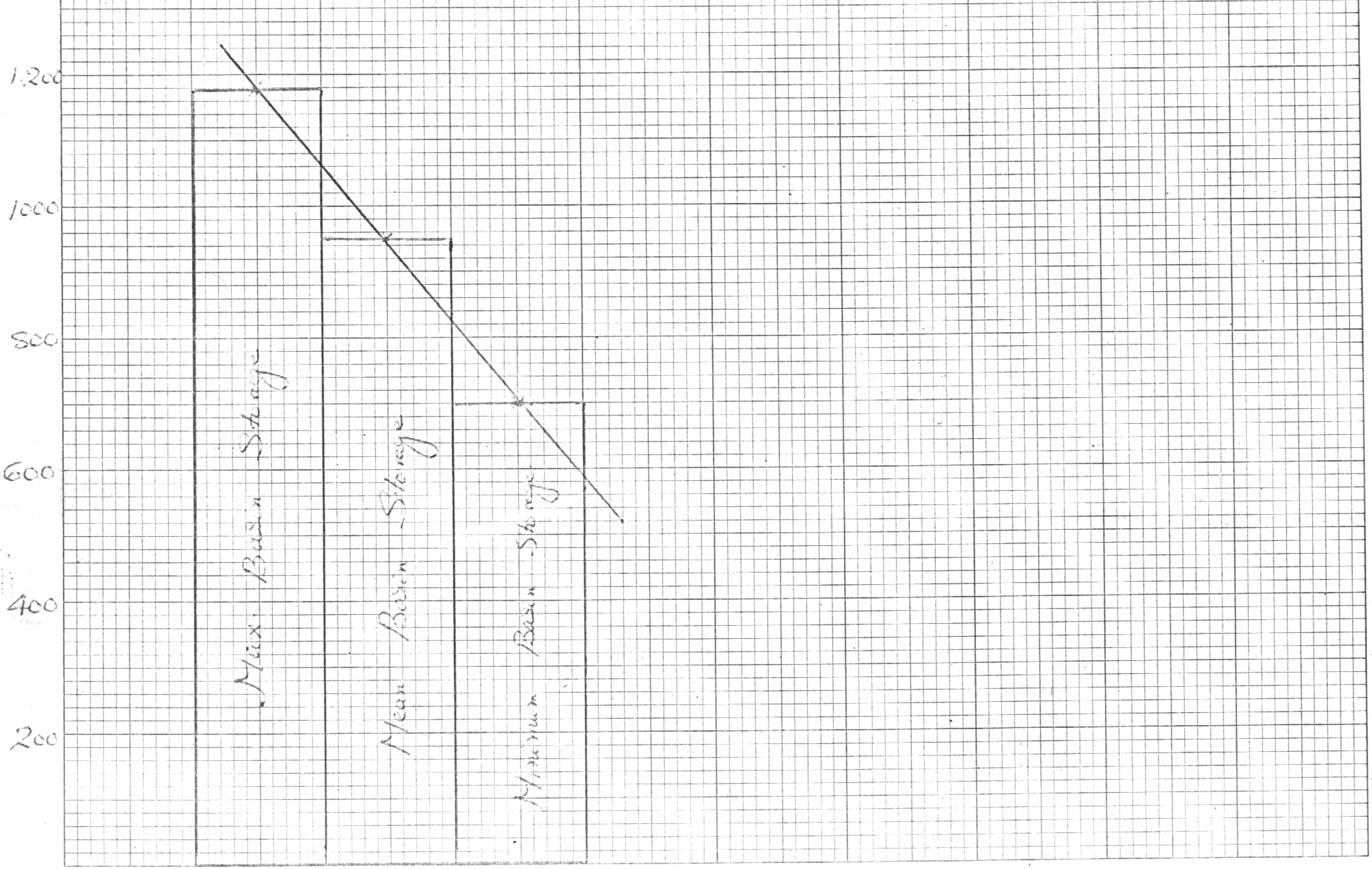


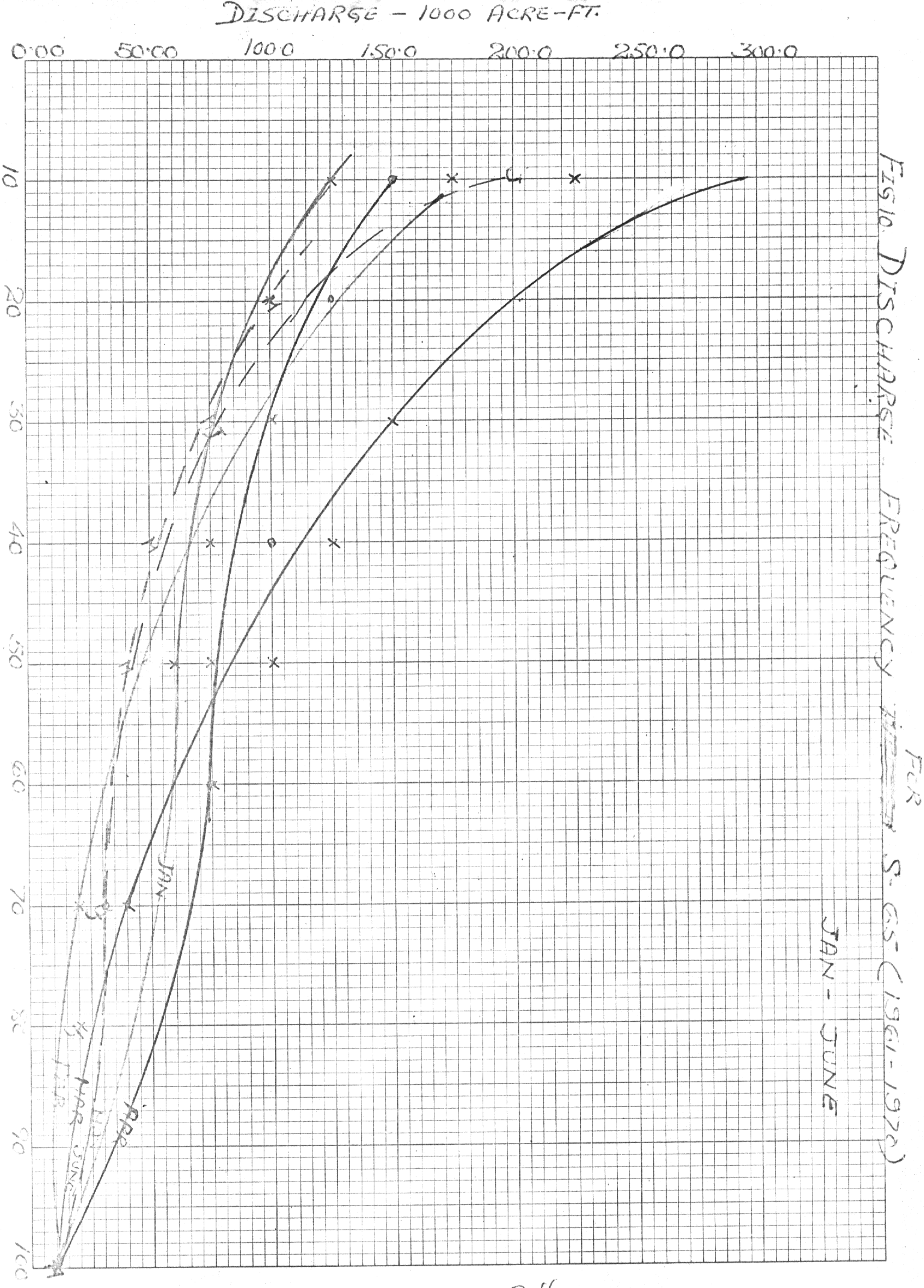
Table 16. Damage $ = f (Stage/Storage) fitted to each of the lakes presented above.

Lakes	Damage Equation
Istokpoga	Damage ($) = -4767500.0 + 122500.0 x Stage R^2 = .949, F = 56.71, δ = 51.437 Std. error = 16266.0
Kissimmee	Damage ($) = -655.0 + 15 x Stage R^2 = 1.00, F = 9999.0
Tohopekaliga	$ = -1235.0 + 8.78 x Storage R^2 = 0.983, F = 122.3, δ = 81.26, Std. error = .794
East Tohopekaliga	$ = -2878 + 21.17 x Storage R^2 = .988, δ = 157.7, F = 166.94 Std. error = 1.638
Alligator	$ = -664.42 + 17.53 x Storage R^2 = 0.966, δ = 78.66, F = 57.65 Std. error = 2.309
Gentry	$ = -144.57 + 8.44 x Storage R^2 = .999, δ = 993, F = 5489.4 Std. error = .1139
Hart & Mary Jane	$ - -304.22 + 38.40 x Storage R^2 = 0.967, δ = 35.38, F = 58.91 Std. error = 5.004

Table 17. Mandatory Release - Discharge Through S-65

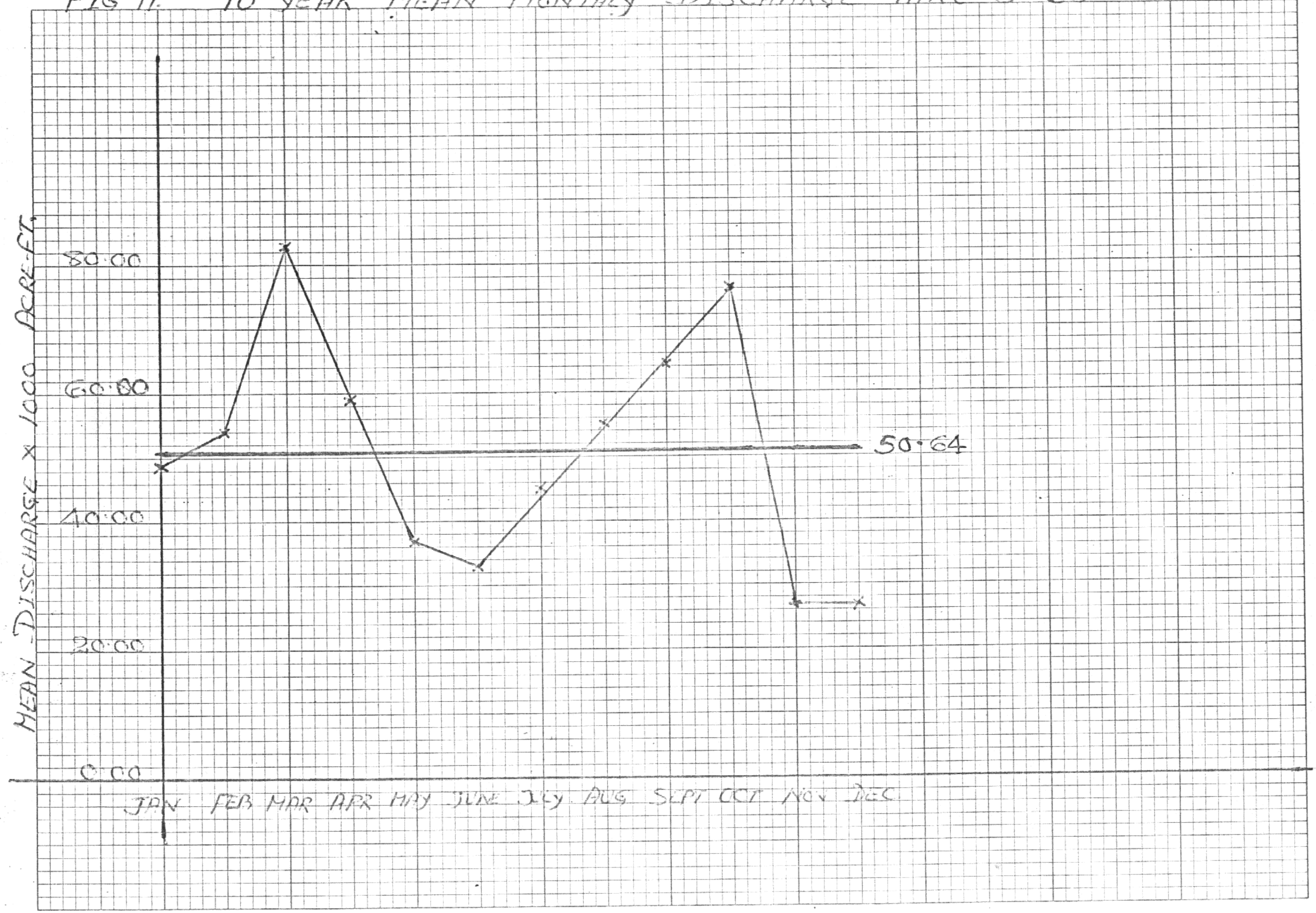
YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1961	97	71	67	55	41	30	30	26	30	25	18	13
1962	9	6	5	3	1	1	1	2	6	20	19	17
1963	13	12	31	30	24	24	29	27	26	30	32	40
1964	67	154	143	84	66	47	27	27	101	96	15	14
1965	42	60	90	55	21	18	59	92	77	80	45	29
1966	42	90	219	144	90	67	72	114	109	100	27	9
1967	9	7	8	10	31	23	14	88	108	54	11	11
1968	11	10	10	8	8	80	195	168	118	36	15	12
1969	60	18	151	122	77	35	2	2	60	310	89	115
1970	136	76	109	80	10	12	25	10	6	15	3	8
MEAN	48.6	50.4	83.3	59.1	36.9	33.7	45.4	55.6	64.1	76.6	27.4	26.8
Std. Dev.	42.6	48.8	72.6	48.6	30.9	24.6	57.1	56.5	44.2	87.8	24.6	32.5

FIG. 9. DISCHARGE - FREQ. FOR S-65 (1961-70)
JULY - DECEMBER



DISCHARGE - 1000 ACRE-FT.
0.00
50.00
100.0
150.0
200.0
250.0
300.0
10
20
30
40
50
60
70
80
90
100
JAN
MAR
APR
JUNE
FIG 10. DISCHARGE FREQUENCY FOR S-65 (1961-1972)
JAN - JUNE

FIG 11. 10 YEAR MEAN MONTHLY DISCHARGE THRU S-65



Mandatory Releases

Based on the discharge duration curve for S-65, 90% discharge-duration was taken as the mandatory discharge through the Kissimmee River Basin. Monthly mandatory discharge is presented in Table 18.

Table 18. Mandatory Discharge Through the Kissimmee River Basin.

Month	M. Discharge x 1000 Acre Feet
January	27
February	10
March	15
April	34
May	22
June	22
July	25
August	24
September	17
October	15
November	20
December	20
TOTAL	251

Water Balance

In order to check the accuracy of the various hydrologic variables that were used in this study, a water balance for the Upper Kissimmee River Basin was made. The inflow to the basin was derived from the rainfall-runoff curve fitted to logarithmic and linear functional equations. The outflow from the basin is the measured discharge through S-65. In the first water balance only 9 lakes (Tohopekaliga, East Tohopekaliga, Kissimmee, Hatchineha, Cypress, Alligator, Gentry, Hart and Mary Jane) were included. The difference between the monthly change in storage levels together with the difference between inflow and outflow is presented in Tables 19 and 20. For the water balance presented in Table 20 four more lakes (Marion, Marian, Rosalie and Weohyakapka) were included in order to minimize the difference between the change in storage levels and inflow and outflow. The lake stages were converted to lake storages by use of the polynomial equations. The maximum difference between the storage volume and inflow and outflow is 204,000 acre feet. Corps of Engineers Part II, Supp. 5, gives a figure of 7,100 acre ft/foot change of lake level for East Chain of Lakes; 38,000 for West Chain of Lakes, and 78,000 for Kissimmee, Hatchineha and Cypress. Together they total 125,000 acre feet. Therefore, the maximum error which occurred once in 10 years is 1 1/2 ft. of change in storage for all the lakes.

This error resulted by using the rainfall-runoff relationship used by the Corps of Engineers. Other errors are within the 1 foot change of lake level limit.

Table 19. Water Balance of Kissimmee River Basin up to S-65 (Includes Lakes Tohopekaliga, East Tohopekaliga, Kissimmee, Cypress, Hatchineha, Alligator, Gentry, Hart, and Mary Jane).

YEAR		JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1961	A	-54	-31	-44	-43	-59	-32	-13	-11	-5	-37	-31	-22
	B	-97	-53	-67	-55	-41	-7	-30	73	-30	-25	-18	-13
1962	A	-7	-12	-13	-25	-18	25	15	43	71	-16	1	-17
	B	-9	-6	-5	-3	-1	94	76	137	175	-20	-4	-17
1963	A	-2	87	65	-39	1	8	-3	-2	28	-17	102	35
	B	7	173	-31	-30	32	-7	-29	-27	83	-30	143	4
1964	A	90	49	-123	-121	-47	-51	5	103	152	-56	-15	-1
	B	69	-88	-111	-84	-66	-47	69	150	98	-96	-15	-13
1965	A	-41	-2	-35	-68	-45	27	74	27	-17	53	-7	-6
	B	-42	30	-60	-55	-21	108	153	-13	12	-8	-45	5
1966	A	67	127	-68	-138	-168	1	25	65	16	-16	-30	-11
	B	129	84	-219	-144	2	112	-49	3	76	-100	-27	-9
1967	A	-7	24	-19	-60	-71	50	68	94	-9	-52	-27	-1
	B	-9	104	-8	-10	-31	195	213	86	-71	-54	-11	28
1968	A	-18	-9	-23	-25	-13	264	69	-137	-39	27	46	1
	B	-11	-3	-10	-8	60	368	-48	-148	-62	69	2	-12
1969	A	7	-30	21	-98	-90	-37	1	50	122	60	43	-23
	B	-3	-16	-7	-122	-77	-15	44	159	159	-147	-89	-10
1970	A	-48	-17	-31	-118	-33	-3	47	22	1	-16	-16	-16
	B	-51	-8	-5	-80	-4	5	41	-5	-6	-15	-3	-8

A - Calculated difference in monthly storage.
B - Difference; inflow to the basin, outflow from Structure 65.

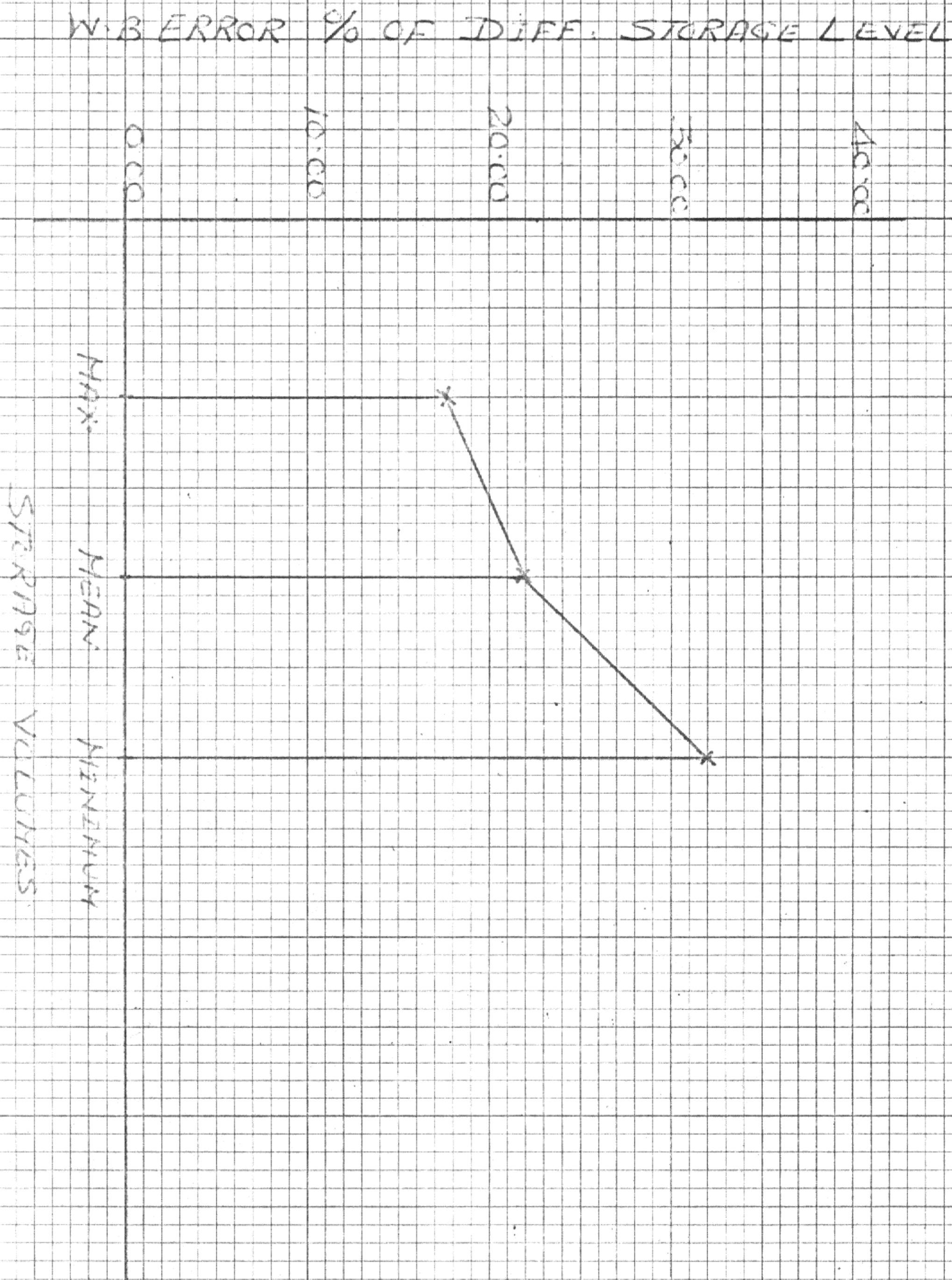
Table 20. A Water Balance for the Kissimmee River Basin up to S-65. (Includes Lakes Tohopekaliga, East Tohopekaliga, Kissimmee, Cypress, Hatchineha, Alligator, Gentry, Hart, Mary Jane, Marion, Marian, Rosalie, and Weohyakapka).

YEAR		JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1961	A	-50	-31	-45	-69	-64	-32	-7	15	-8	-42	-34	-24
	B	-97	-53	-67	-55	-41	-7	-30	73	-30	-25	-18	-13
1962	A	-7	-12	-12	-26	-23	40	14	57	80	-27	0	-20
	B	-9	-6	-5	-3	-1	94	76	137	175	-20	-4	-17
1963	A	-1	103	60	-51	7	21	-4	-6	32	-24	104	34
	B	7	173	-31	-30	32	-7	-29	-27	83	-30	143	4
1964	A	102	54	-90	-88	-49	-57	8	131	149	-67	-22	1
	B	69	-88	-111	-84	-66	-47	69	150	98	-96	-15	-13
1965	A	-49	1	-55	-62	-54	45	96	31	-17	55	-21	-9
	B	-42	30	-60	-55	-21	108	153	-13	12	-8	-45	5
1966	A	78	149	-80	-150	-66	4	33	74	10	-23	-37	-16
	B	129	84	-219	-144	2	112	-49	3	76	-100	-27	-9
1967	A	-8	25	-25	-71	-80	15	78	116	-6	-61	-33	0
	B	-9	104	-8	-10	-31	195	213	86	-71	-54	-11	28
1968	A	-20	-10	-27	-43	-12	306	76	-148	-34	26	43	-5
	B	-11	-3	-10	-8	60	368	-48	-148	-62	69	2	-12
1969	A	10	-33	36	-108	-100	-35	2	73	129	57	36	-22
	B	-3	-16	-7	-122	-77	-15	44	159	159	-147	-89	-10
1970	A	-53	-20	-25	-129	-42	-6	54	25	-2	-16	-19	-17
	B	-51	-8	-5	-80	-4	5	41	-5	-6	-15	-3	-8

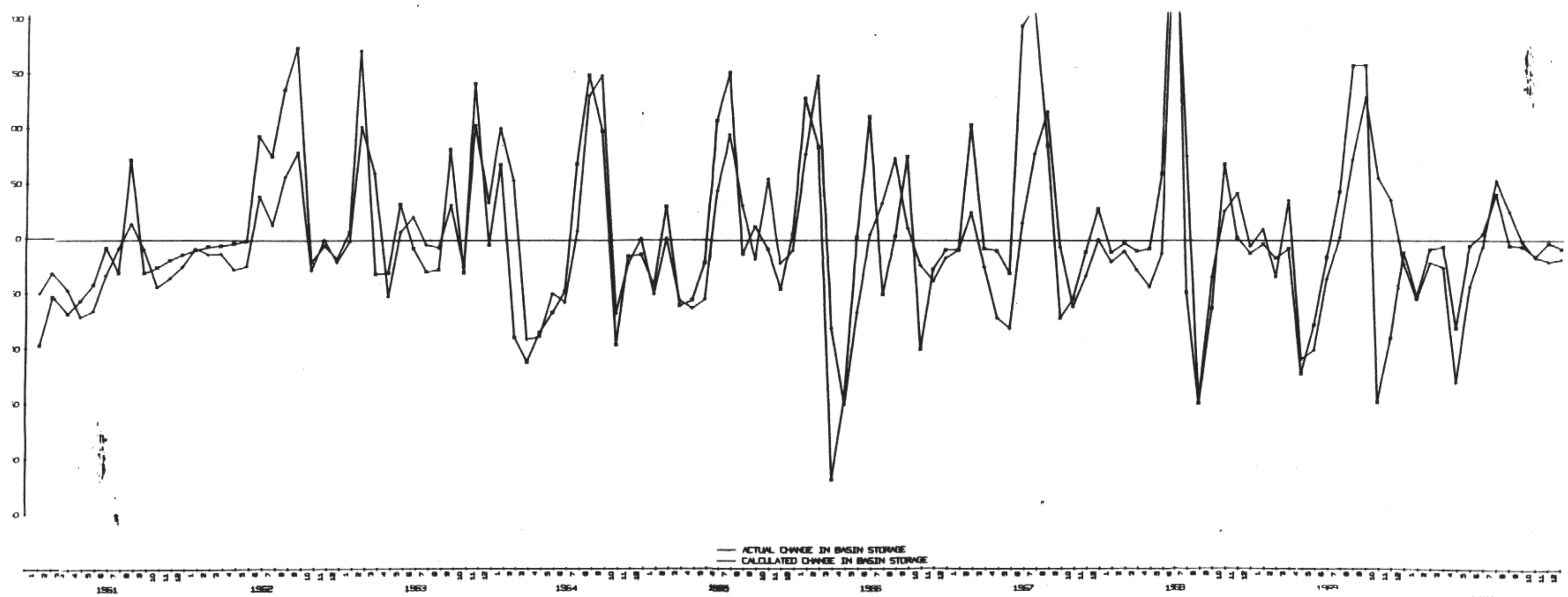
A - Calculated difference in monthly storage.
B - Difference - inflow to the Basin, outflow from Structure 65.

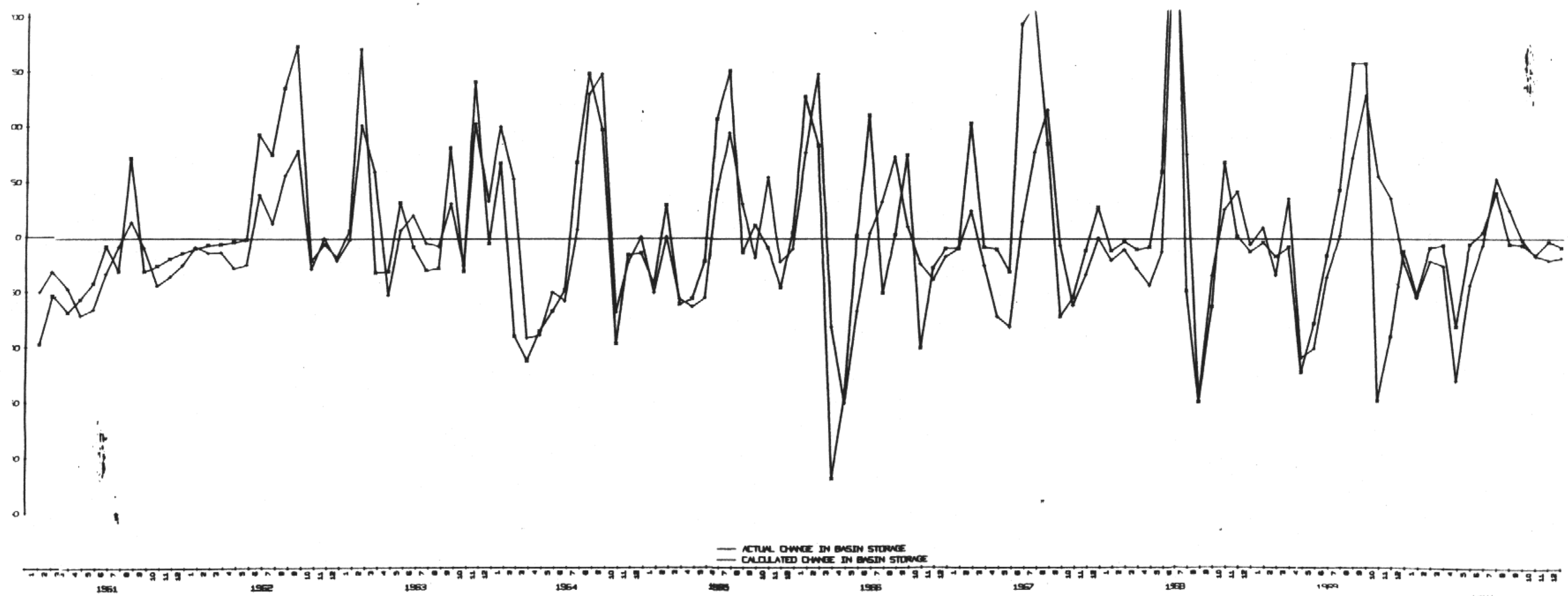
Conclusion: The seasonal basin yield, mandatory discharge together with the minimum, mean and maximum storage for the whole Kissimmee Basin is estimated to be:

	Period I (June, July, Aug., Sept.)	Period II (Oct., Nov.)	Period III (Dec., Jan.)	Period IV (Feb., Mar., April, May
Yield (1000 ac.ft.)	413.10	60.5	57.2	126.6
Mandatory Discharge (1000 ac. ft.)	88.0	35.0	47.0	91.0
Storage (1000 ac. ft.)	Maximum 1,175	Mean 945	Minimum 650	



W.B ERROR % OF DIFF. STORAGE LEVEL
0.00
10.00
20.00
30.00
40.00
MAX.
MEAN
MINIMUM
STORAGE VOLUMES


ACTUAL CHANGE IN BASIN STORAGE
CALCULATED CHANGE IN BASIN STORAGE
1961
1962
1963
1964
1965
1966
1967
1968
1969



ACTUAL CHANGE IN BASIN STORAGE
CALCULATED CHANGE IN BASIN STORAGE
1961
1962
1963
1964
1965
1966
1967
1968
1969