WATER YIELD TO KISSIMMEE RIVER BASIN BY USE OF THE FCD MODEL

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DRE-37

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INTRODUCTION

Significant advances have been made in the development of simulation models for synthesizing the hydrologic cycle by use of high-speed digital computers. Yet these models are still a series of empiricisms selected to provide a mathematical continuum from ridgetop to watershed outlet in terms of input information, which are readily available in one form or another. Nevertheless, these models are trying to reduce the entire system of watershed hydrology to a predictable pattern of physical probabilities that will account for the dispersion of water and its subsequent concentration in channel systems. (Holtan, H.N. and N.C. Lopez. USDAHL - 70 Model of Watershed Hydrology). Since so many approximations have to be used, the model concepts must be tested for different watershed, geographic and physical characteristics, as well as for varying climatic and meterological conditions.

The Central and Southern Florida Flood Control District has developed four sub-models in a continuing effort to operate its natural resources in optimal ways. These models are: (a) Synthesis Model to synthesize daily rainfall values. (b) Distributive Model to distribute the historic and/or synthesized rainfall values. (c) Physical Systems Model to simulate streamflows, and (d) Economic Model to allocate water to different uses in an optimal way. (Figure 1) These sub-models have been tested critically on an individual basis. The objective of this study is (a) to link these sub-models and develop a general model, (b) use the general model to the Kissimmee River Basin to generate the streamflow values, (c) compare the generated streamflow values against the historical values, and (d) use the streamflow values, if acceptable, to the economic model.

A description of the sub-models used in the general model, hereafter called the FCD Model, is described below:

SUB MODELS

Synthesis Model: This model is used to synthesize daily rainfall point values. It was decided to use the historical daily rainfall values in the general model for this study. So the synthesis model will not be described here. Those readers interested in the development of this model could refer to (2).

Distributive Model: The physical system model accepts rainfall values (input) at two-tenths of an hour intervals on real time scale. There are two ways in which two-tenths of an hour interval rainfall can be obtained to be used in the physical systems model: (1) the development of a stochastic model to distribute daily rainfall values to twenty-four hourly values, and then interpolate two successive hourly values into five two-tenths of an hourly values, and (2) direct transmission of rainfall information through remote sensing and telemetry systems from several raingaging stations in the basin to a central processing unit.

The physical systems model is intended to be used on a day-to-day basis for the operational purpose after the tests. For the real time operation of the system rainfall data will be transmitted on a regular basis through telemetry systems.

For the testing of the FCD Model, distribution of daily rainfall to twenty-four hourly values was made as follows:

Distribution of Daily Rainfall into Twenty-four Hourly Values. The development of relationships is based here essentially upon the work of Pattison (3). 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 one . 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.

$$\Pr\left[X_d = k \mid C_d+1 = c_d+1, \ldots, C_1 = c_1\right] = \left(\Pr\left[G_d = g_d \mid C_d+1 = c_d+1, \ldots, C_{d-1} = c_{d-1}\right]\right) \cdot \left(\Pr\left[X_d = k \mid G_d = g_d\right]\right)$$

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

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

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

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

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

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

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

$$H_{t+1} = A_{C_d} + B_{C_d} (H_t)$$

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

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

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

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 3. These data were used to estimate the probabilities, P_{ij}, coefficients A and B and standard deviations of e in Equation 2 for each daily rainfall class and daily rainfall persistence class. The coefficients and the frequencies are presented in Tables 3,4,5,6, and 7.

The mathematical relationships and the values of coefficients determined for Station 13, Kissimmee 2, were used to distribute daily rainfall values at the remaining eighteen raingaging stations in the whole Kissimmee River Basin. The daily rainfall falues were distributed for the period of June 20 through September 26, 1969, for the testing of the distributive model. 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% of the historic wet hour counts (3).

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 INCHES
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 EACH OF THE DAILY RAINFALL CLASS

Daily Rainfall Class	A	B	Standard Deviation
1	.0264	-.2820	.0256
2	.0486	-.2648	.0673
3	.0667	-.1938	.0679
4	.0803	-.2139	.0964
5	.1177	-.2340	.1163
6	.1255	-.0940	.1554
7	.1465	-.0701	.1923
8	.1682	-.0318	.2431
9	.2005	-.0647	.3053
10	.2489	.1619	.4922

TABLE 4 . PERCENT FREQUENCY INDICATED HOUR IS FIRST HOUR OF RAIN

FOR PERSISTENCE CLASS 1

Daily Rainfall Class, Whole Year 1952-1969

Hour of Start		1	2	3	4	5	6	7	8	9	10
A.M.	1	2	1	-	-	1	6	-	1	1	2
	2	5	-	-	1	2	5	-	2	2	4
	3	5	-	4	1	-	5	-	2	3	5
	4	8	-	4	2	-	5	1	3	3	5
	5	3	1	4	2	-	3	3	5	3	2
	6	5	2	3	2	-	6	4	5	3	2
	7	8	5	5	2	-	8	3	7	4	3
	8	10	6	3	2	1	5	4	7	3	5
	9	8	9	5	3	-	5	5	6	4	4
	10	10	9	9	4	-	5	5	8	3	5
	11	18	7	8	3	3	8	5	8	3	4
	12	21	11	9	3	8	12	8	12	3	6
P.M.	1	15	7	9	6	5	13	9	15	2	6
	2	24	14	7	11	8	14	8	14	2	8
	3	17	15	11	16	6	20	9	12	3	8
	4	26	19	11	13	9	22	11	11	6	8
	5	30	25	8	11	10	19	12	14	5	9
	6	27	14	10	9	13	23	11	15	5	9
	7	17	12	7	6	11	14	11	10	6	8
	8	18	11	8	5	11	12	10	11	4	7
	9	9	8	4	4	5	6	7	6	4	4
	10	7	8	3	5	3	9	5	5	3	5
	11	4	8	1	3	1	5	4	3	3	4
	12	7	4	-	1	1	1	4	5	2	2
		304	196	133	115	98	231	139	187	80	126

TABLE 5 . PERCENT FREQUENCY INDICATED HOUR IS FIRST HOUR OF RAIN

FOR PERSISTENCE CLASS 2

Daily rainfall Class Whole Year 1952 - 1969

Hour of Start		1	2	3	4	5	6	7	8	9	10
A.M.	1	20	9	3	8	3	6	5	5	2	6
	2	16	10	3	8	5	6	2	6	2	6
	3	13	8	5	7	6	7	2	5	1	7
	4	13	8	3	5	6	4	3	7	1	8
	5	4	3	2	5	4	5	3	7	2	8
	6	3	7	3	5	3	4	4	9	2	6
	7	5	3	5	6	2	3	2	8	2	4
	8	13	6	5	4	5	6	4	10	2	4
	9	18	6	1	2	4	4	4	11	2	5
	10	19	12	5	4	5	4	5	9	2	5
	11	8	8	7	7	3	5	7	9	2	5
	12	21	5	7	5	5	7	7	12	3	5
P.M.	1	11	7	8	10	9	6	12	15	4	7
	2	15	10	10	12	9	7	14	14	5	7
	3	16	11	11	9	14	11	9	18	5	8
	4	10	12	10	13	1-	17	13	18	6	8
	5	11	9	13	13	12	14	13	15	4	7
	6	10	11	11	9	9	10	10	15	3	4
	7	8	5	7	5	9	7	9	13	1	2
	8	8	3	4	5	4	5	5	11	-	3
	9	11	3	7	5	4	6	3	3	2	2
	10	2	3	6	4	4	4	4	2	1	3
	11	4	2	1	1	3	1	2	3	-	3
	12	4	-	-	3	1	1	2	2	-	2
		263	156	137	155	139	150	144	227	54	125

TABLE 6 . PERCENT FREQUENCY INDICATED HOUR IS FIRST HOUR OF RAIN

FOR PERSISTENCE CLASS 3

Daily Rainfall Class Whole Year 1952 - 1969

Hour of Start		1	2	3	4	5	6	7	8	9	10
A.M.	1	1	2	1	-	-	1	-	1	2	2
	2	-	3	2	2	-	1	1	1	2	2
	3	2	-	2	2	-	-	1	2	2	2
	4	-	1	1	2	-	1	2	2	2	3
	5	-	1	1	-	-	1	3	2	2	4
	6	1	5	-	-	-	3	3	2	1	4
	7	2	2	1	1	1	3	3	4	1	4
	8	3	4	1	2	1	3	4	4	2	4
	9	4	3	2	1	-	4	6	5	2	4
	10	5	2	2	-	1	7	7	6	2	5
	11	3	3	4	3	1	8	4	4	2	6
	12	4	5	6	4	4	14	6	7	2	7
P.M.	1	10	4	8	5	5	13	5	5	2	9
	2	13	10	8	5	8	16	10	12	4	7
	3	16	13	8	8	9	16	9	13	6	8
	4	14	18	9	11	6	18	12	13	9	8
	5	20	11	11	11	10	15	11	14	10	7
	6	29	9	18	8	11	14	13	13	7	5
	7	20	8	10	8	5	14	11	14	10	7
	8	18	13	9	10	4	16	8	12	6	5
	9	12	12	10	9	2	17	5	10	2	3
	10	10	11	6	5	5	10	6	8	5	4
	11	9	8	7	7	4	9	5	9	4	3
	12	17	7	4	7	4	7	3	6	3	2
		213	155	131	111	81	211	138	169	90	115

TABLE 7 . PERCENT FREQUENCY INDICATED HOUR IS FIRST HOUR OF RAIN

FOR PERSISTENCE CLASS 4

Daily Rainfall Class Whole Year 1952 - 1969

Hour of Start		1	2	3	4	5	6	7	8	9	10
A.M.	1	7	1	2	7	1	4	4	3	3	2
	2	4	1	3	5	1	3	4	4	5	5
	3	3	1	3	5	-	3	3	2	4	4
	4	2	2	1	5	-	3	3	2	4	5
	5	-	1	1	5	-	3	3	2	4	5
	6	-	3	1	6	1	3	2	1	3	3
	7	2	5	-	5	1	3	3	1	5	3
	8	7	7	1	4	1	3	3	3	4	5
	9	7	9	3	2	1	4	4	3	6	3
	10	9	3	3	3	1	6	5	4	5	4
	11	9	5	2	3	3	5	6	3	3	4
	12	12	9	3	6	4	12	9	10	3	8
P.M.	1	12	8	4	5	3	12	9	10	3	8
	2	12	11	7	9	6	15	6	14	5	8
	3	14	16	10	14	8	14	11	16	5	11
	4	16	17	9	13	9	13	16	19	11	12
	5	14	13	10	10	13	14	15	19	14	15
	6	13	21	15	14	12	12	19	21	9	17
	7	15	15	12	10	9	13	10	14	10	17
	8	15	10	6	8	6	15	6	10	9	13
	9	3	6	3	11	3	7	6	8	7	12
	10	2	1	3	6	3	8	5	6	7	12
	11	2	1	4	4	1	7	2	5	7	9
	12	6	2	4	2	1	5	3	7	6	7
		186	168	110	162	88	186	158	182	142	189

Physical Systems Model: Basically the physical systems model is used to: (a) determine the runoff entering into the system from an occurrence of rainfall, and (b) determine available storage in the zone of aeration or release of water from soil reservoir into the stream.

Basically, this sub-model involved using mathematical relationships for determining four broad hydrologic activities of the hydrologic cycle and they are: (a) infiltration, (b) water loses due to evaporation, transpiration and deep ground water percolation, (c) recovery of water into the stream channel from soil reservoir and overland flow, and (d) routing the water from channel to watershed outlet. Mathematical representations for each of the hydrologic activities is given below in (Figure 2).

Infiltration: The volume of water that infiltrates into the soil profile is found out by evaluating infiltration equations at the beginning and end of the time interval. Infiltration equations are those given by Holtan (4) as:

$$f = A(SA)^{1.4}, \quad SA \geq G$$

$$f = A(SA)^{1.4} + FC \qquad SA < G$$

where f = capacity rate of infiltration,

A = surface penetration index,

SA = storage currently available in the soil reservoir, and

G = total amount of gravitational water that could exist in a soil profile of selected depth,

FC = constant rate of infiltration after prolonged wetting in inches/hour.

Water Loss: The water that reached the ground surface but never appeared at the watershed outlet is considered as water loss. Such loss of water in this model is accounted for under three categories. A sum of losses at any time under the three categories constitutes the total water loss (WL). The three categories are:

i) Evaporation loss; This is attributed to fluctuations in depth to water table and the rate of such a loss is assumed to never exceed the pan evaporation rate. An equation used to represent this is:

$$E = C \left(1 - \frac{DWT}{DWTM}\right) \left(\frac{EP\ [NW]}{24}\right) (DT)$$

where E = evaporation loss (in)

C = a ratio of maximum evapotranspiration to maximum pan evaporation value = a constant

DWT = depth to water table (in)

DWTM = maximum depth to water table at which DWT will cease to contribute toward the value of E (in)

EP = pan evaporation (in/day)

NW = number of the week

DT = time increment (hr)

24 = a factor to convert day into hour

ii) Transpiration loss: This is attributed to existing vegetation and an equation to represent it is

$$T = C\ (GI\ [NW])\ \frac{EP[NW]}{24}\ (DT)$$

where T = transpiration loss (in), and

GI = an over-all growth index for existing vegetation.

iii) Deep percolation loss: This is given by an equation

$$DPL = (FC)\ (DT)$$

where DPL = deep percolation loss (in), and

FC = deep percolation rate (in/hr).

Recovery: The recovery of water into the stream channel is from two main sources, one from sub-surface flow and another from overland flow. Mathematical relationships used to estimate the sub-surface discharge into the stream channel is that based upon the basic continuity equation and a storage-outflow curve developed from typical recessions. These equations are

$$2(DELF) - Q_1\ (DT) + 2S_1 = C4$$

$$2S_2 + Q_2\ (DT) = C5$$

where subscripts $_1$ and $_2$ represent the beginning and end of the time interval, and

DELF = volume of water that infiltrated during a DT,

Q = sub-surface discharge into the stream channel, and

S = total available storage in soil profile of selected depth.

The sub-surface discharge into the stream channel at the end of a time interval, Q_2, is accepted when absolute difference between C4 and C5 is within a tolerance limit of 0.01. Such a value of Q_2 in equation 7 is obtained by an iterative procedure. The details about the derivation and utilization of equations 6 and 7 together with an iterative procedure used to obtain the value of Q_2 in equation 7 can be found in (4).

The total storage available at any time (t+1) in any of the reservoirs of a soil profile is represented by

$$(S_i)_{t+1} = (S_i)_t + [(f_i^R - f_i^D) - Q_i - WL_t] \text{ (DT)}$$

where i = reservoir number = 1, 2, ..., N

t = time

f_i^R = recharge rate to i^{th} reservoir,

f_i^D = downward depletion rate from i^{th} reservoir, and

Q_i = sub-surface discharge or lateral outflow into stream channel from the i^{th} reservoir.

An overland flow contribution to the stream channel is estimated by an equation of the form

$$OF = P - f, \quad VD = VDM, \quad P>f$$

where OF = overland flow

P = precipitation

VD = amount of water currently in sur ace depression storage, and

VDM = maximum volume of surface depression storage.

Routing: To obtain a time distribution of water at the watershed outlet, routing was done by Nash's (4) equation which assumed the existence of linear equal reservoirs. Nash's (4) equation is

$$U(o,t) = \frac{1}{K(N-1)!} \; \frac{t}{k}^{N-1} \; e^{-t/k}$$

where t = time

N = number of reservoirs = 1, 2, ..., N,

K = a time constant, and

e = naperian base.

The details about estimation of parameters involved in equations presented here are also available in (1).

This sub-model was tested on Taylor Creek which is 100 square miles in area, discharges into Lake Okeechobee, and is located north and west of Okeechobee, FLorida. The streamflow records were simulated, and the simulated streamflows were compared with the actual streamflows and they compare well.(4)

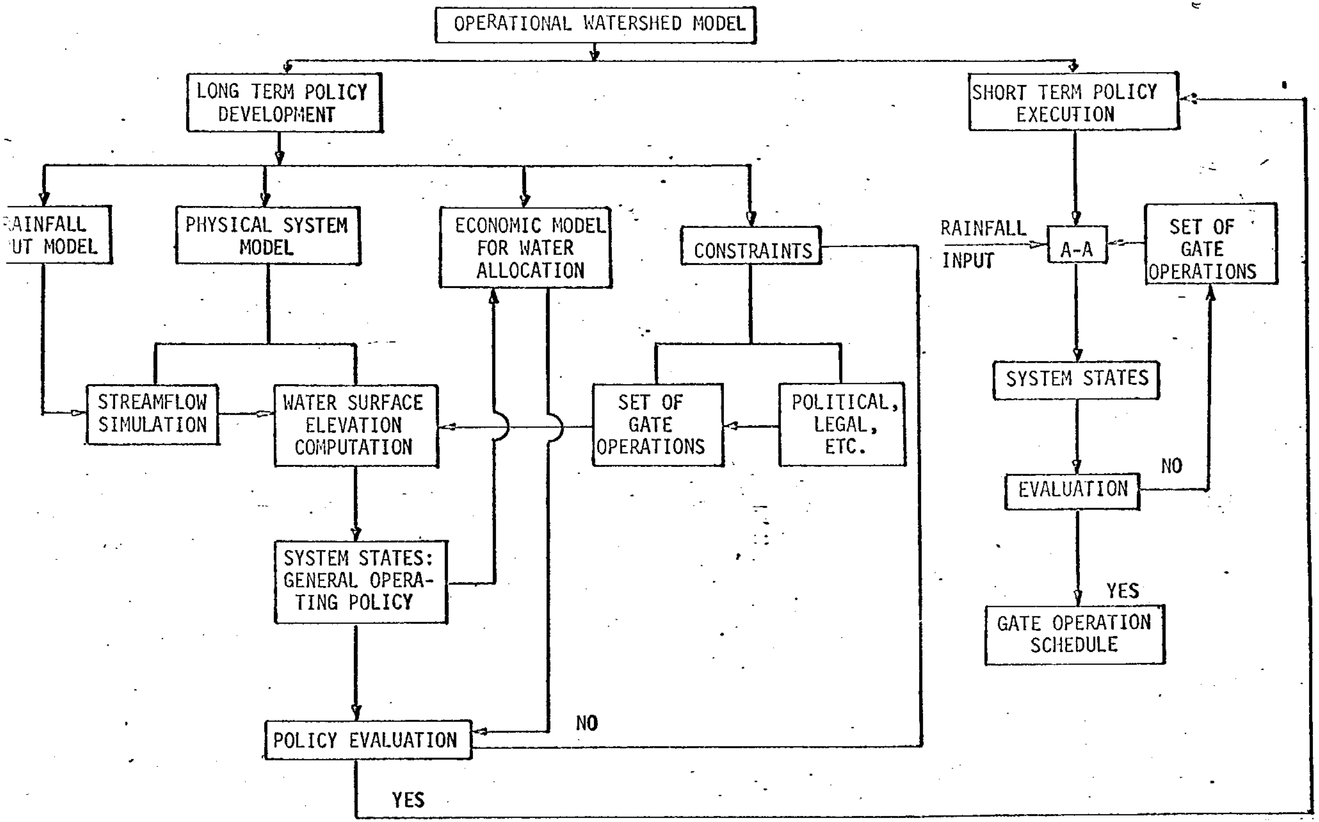


FIGURE 1 . . . SCHEMATIC FCD MODEL

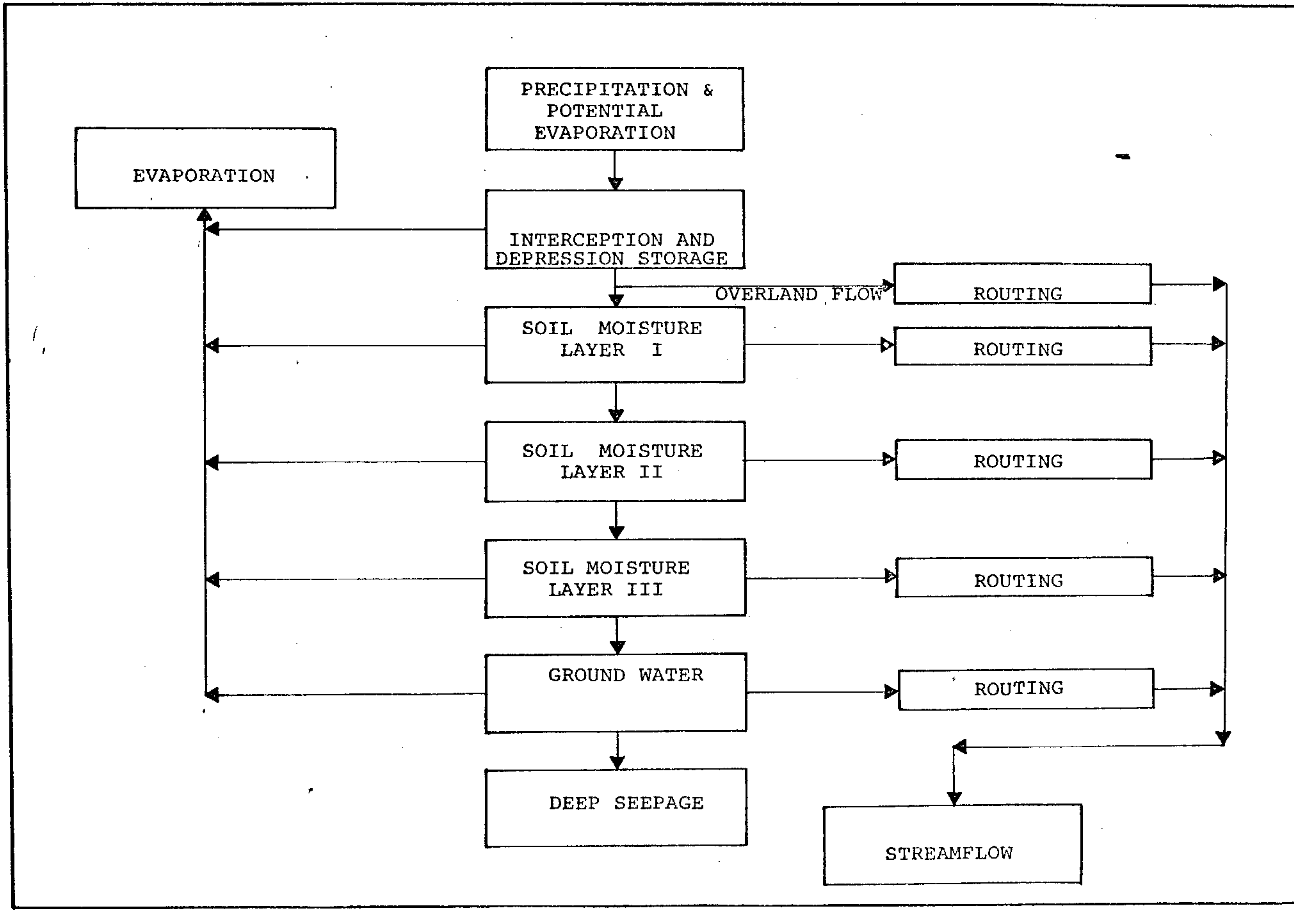


FIGURE 2 F. C. D.'S PHYSICAL SYSTEMS MODEL

APPLICATION OF THE FCD MODEL TO THE KISSIMMEE RIVER BASIN: The Kissimmee River Basin system of reservoirs, channels and spillways extend over approximately 3,000 square miles of the District's total area of 16,000 square miles. The District's responsibilities, in addition to flood prevention, include water conservation, water supply, public recreation and prevention of salt water intrusion into the ground water system.

Variation in areal distribution of precipitation was reduced by dividing the total watershed basin into nineteen sub-basins and applying the model to rainfall measurements on each sub-basin independently. An effort was made to have one rainfall station at each sub-basin or in the vicinity of it. This was not possible; so, some sub-basin rainfall stations which had been used previously had to be reused. Rainfall stations and the station names that were used in the FCD Model are presented in Tables 8,9,10,11 & 12.

A general map of the whole Kissimmee River Basin, divided into nineteen sub-basins, is presented in Figures 3 and 4 and the sub-basin drainage areas of the total basin is presented in Table 13.

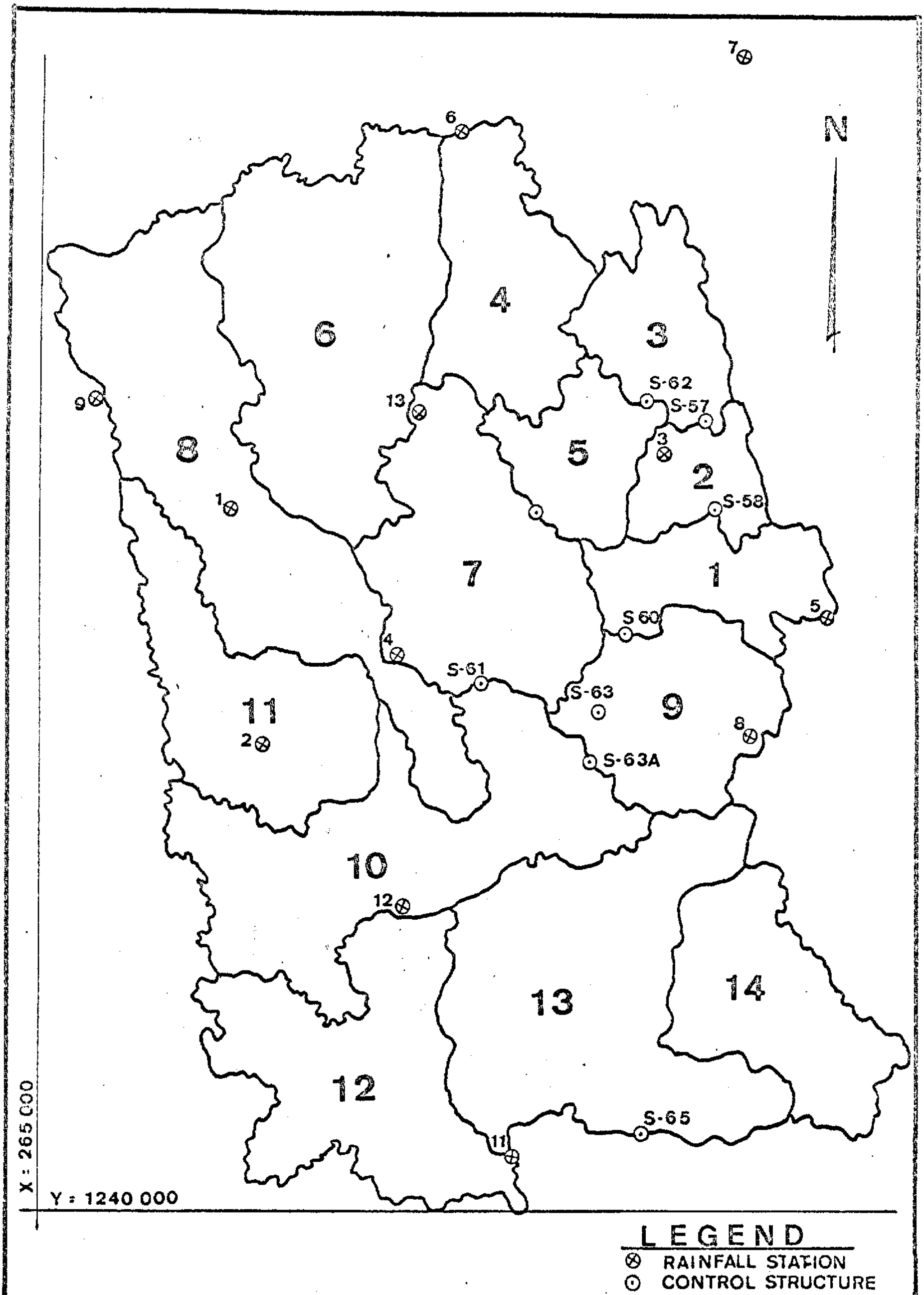


FIGURE 3 . UPPER KISSIMEE RIVER BASIN

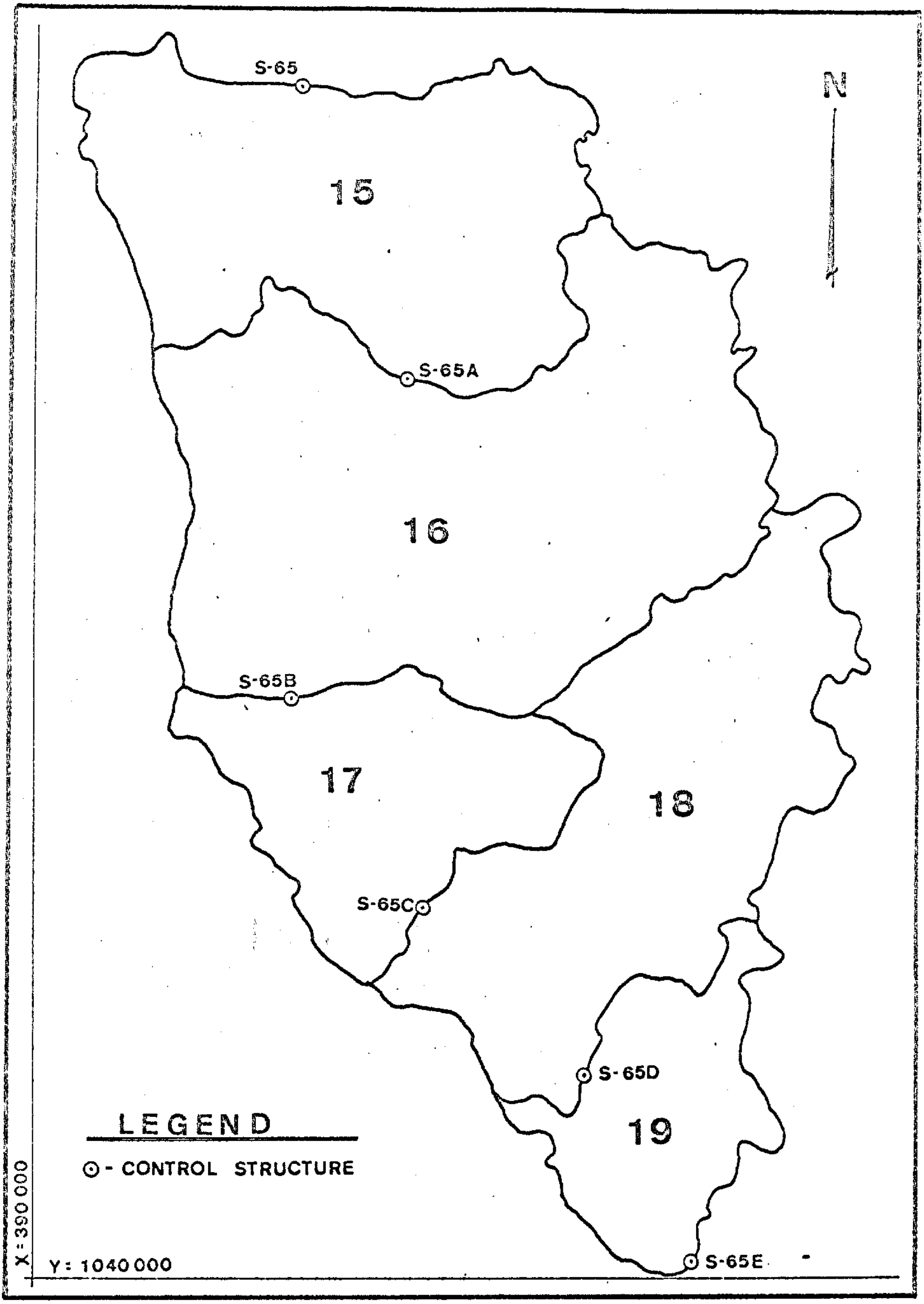


FIGURE 4 .. LOWER KISSIMMEE RIVER BASIN

The daily rainfall values from the stations presented in Tables 8,9,10,11 and 12 were distributed to twenty-four hourly values. Two consecutive hourly rainfall values were then interpolated to get five two-tenths of an hourly rainfall values. These two-tenths of an interval rainfall values were used as input to the FCD Model. The output from the model summed to daily values for each of the sub-basins. These daily values were also summed to seasonal values and are presented in Table 14.

Results: Ten years (1961-1970) of daily values for subsurface flow, surface flow, deep seepage, evapotranspiration loss, and end-of-day available storage were generated by use of the FCD Model.

Generated mean streamflow from the FCD Model is the summation of subsurface and surface flows. The yearly streamflow values summed from daily values for each of the sub-basins for the years 1961-1970 inclusive are presented in Table 14.

Istokpoga drainage basin is not included in the FCD Model For the Istokpoga drainage basin streamflow values were generated by use of the Corps of Engineers rainfall total loss curve.*

Monthly rainfall from four nearby stations (Avon Park, Cornwell, Desota, Placid) were averaged. The Corps of Engineers rainfall total loss curves were fitted to linear least square fitting. Then the monthly average values were subtracted from the monthly total loss values. If the difference was positive, then it was multiplied by the drainage area of the sub-basin. The monthly rainfall total loss curves are presented in Figures 5, 6, and 7. The statistical properties and the monthly equations (total loss rainfall) are presented in Tables 16 and 17. The seasonal yield from the Istokpoga sub-basin is presented in Table 15. The combined yield from the Istokpoga Basin together with the Kissimmee Basin yield is presented in Table 17a.

TABLE 8 . . . AVERAGE OF EIGHT STATIONS USED ON SUB-BASINS ONE, TWO AND NINE

Lake Hart

Orlando

Kissimmee II

Lake Alfred

Mountain Lake

Indian Lake Estates

Nittaw

Isleworth

TABLE 9 . . . RAINFALL STATIONS AND STATION NAMES USED IN THE FCD MODEL

YEARS 1961-1967

STATION	STATION NAME
1	Average of 8 Stations
2	Average of 8 Stations
3	Lake Hart
4	Orlando
5	Lake Hart
6	Isleworth
7	Kissimmee II
8	Isleworth
9	Average of 8 Stations
10	Mountain Lake
11	Lake Alfred
12	Mountain Lake
13	Indian Lake Estates
14	Nittaw
15	Indian Lake Estates
16	Fort Drum
17	Cornwell
18	Lake Placid
19	Okeechobee H.G. #6

TABLE 10 . . . RAINFALL STATIONS AND STATION NAMES USED IN THE FCD MODEL

YEAR 1968

STATION	STATION NAME
1	Average of 8 Stations
2	Average of 8 Stations
3	Myrtle Lake
4	Orlando
5	Lake Hart
6	Isleworth
7	Kissimmee II
8	Isleworth
9	Average of 8 Stations
10	Mountain Lake
11	Lake Alfred
12	S. Ranch
13	Indian Lake Estates
14	Nittaw
15	Indian Lake Estates
16	S65-B
17	Cornwell
18	S65-D
19	Okeechobee H.G. #6

TABLE 11 . . . RAINFALL STATIONS AND STATION NAMES USED IN THE FCD MODEL

STATION	STATION NAME
1	L73 S.R. 520
2	Beeline Highway
3	Lake Hart
4	Orlando
5	St. Cloud Airpark
6	Idleworth
7	Kissimmee II
8	Kissimmee Field Stat.
9	Lake Myrtle
10	Mountain Lake
11	Lake Alfred
12	Mountain Lake
13	Indian Lake Estates
14	Nittaw
15	S65-A
16	S65-B
17	S65-C
18	S65-D
19	S65-E

TABLE 12 . . . RAINFALL STATIONS AND STATION NAMES USED IN THE FCD MODEL

YEAR 1970

STATION	STATION NAME
1	L.R. 73 S.R. 520
2	Beeline Highway
3	Hart
4	Orlando
5	St. Cloud Airpark
6	Reedy Creek
7	Kissimmee II
8	Taft
9	Lake Myrtle
10	Mountain Lake
11	Lake Alfred
12	Mountain Lake
13	Indian Lake Estates
14	Nittaw
15	S65-A
16	S65-B
17	S65-C
18	S65-D
19	S65-E

TABLE 13. . . DRAINAGE AREA OF EACH SUB-BASIN FOR THE KISSIMMEE RIVER BASIN

Sub-basin	Goes to:	Structure #	D. Area Sq. Mi.
1		S-58	60.50
2		S-57	37.91
3		S-62	57/68
4		S-59	89.67
5		S-59	52.93
6		S-61	185.66
7		S-61	132.77
8		S-65	198.75
9		S-63A	89.22
10		S-65	119.63
11		S-65	109.85
12		S-65	197.78
13		S-65	197.78
14		S-65	94.70
15		S-65A	150.80
16		S-65B	229.76
17		S-65C	70.36
18		S-65D	163.44
19		S-65E	56.68

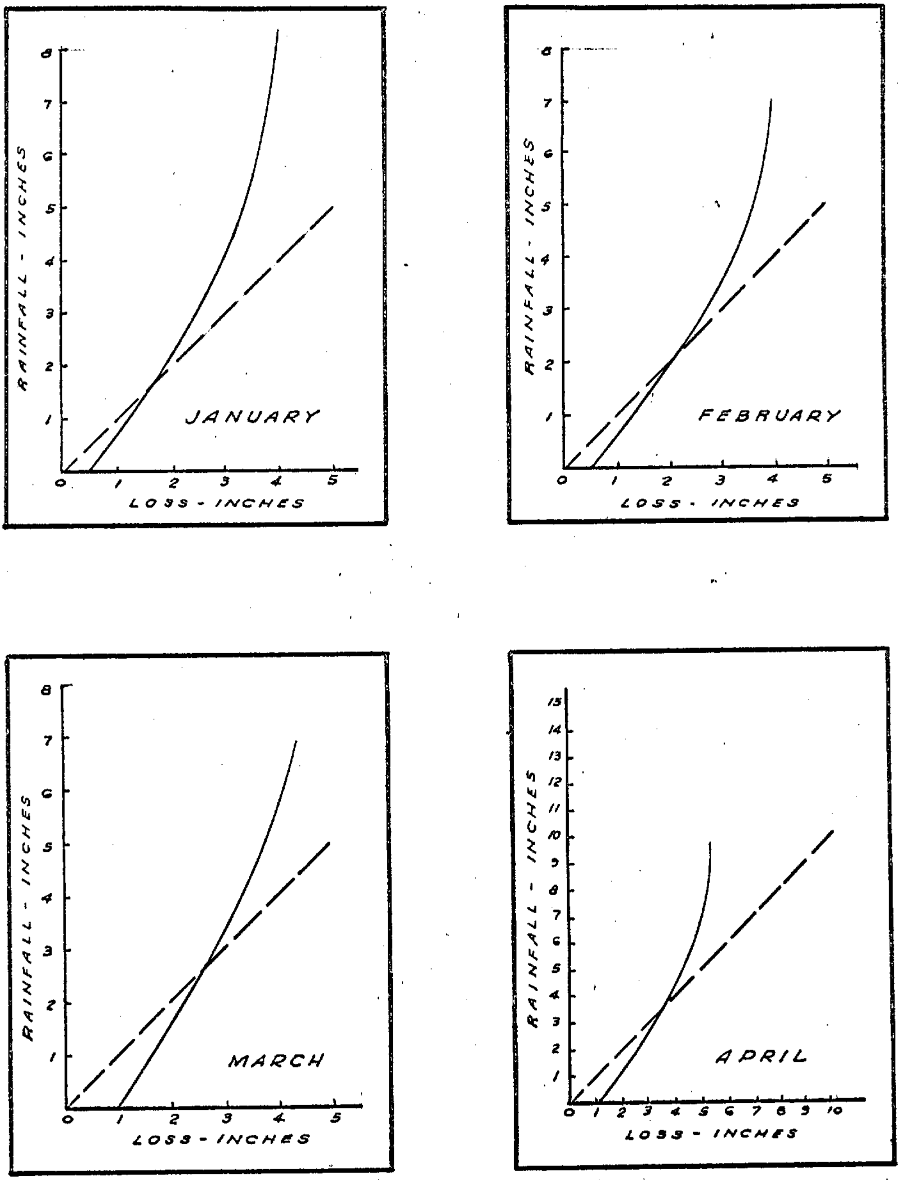


FIGURE 5

RAINFALL - TOTAL LOSS - INCHES

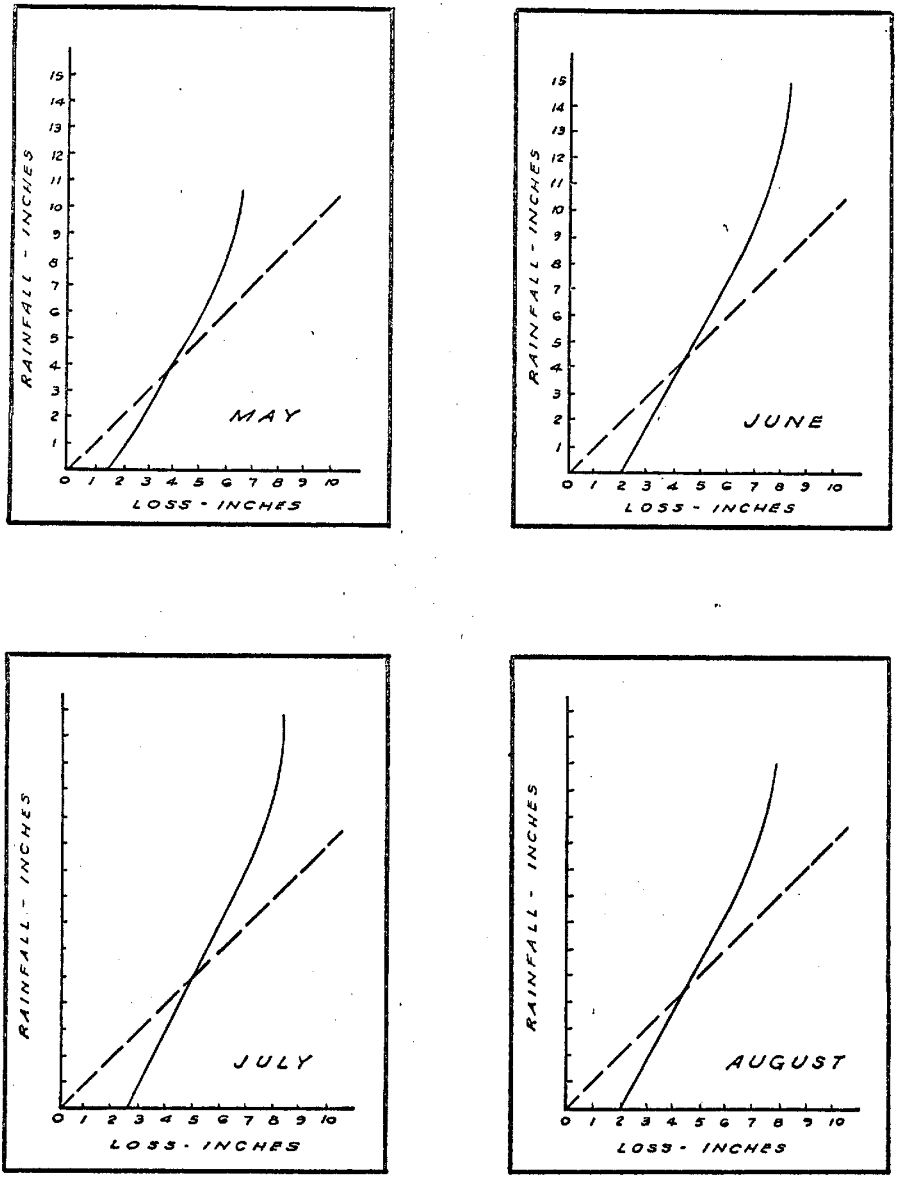


FIGURE 6

RAINFALL - TOTAL LOSS INCHES

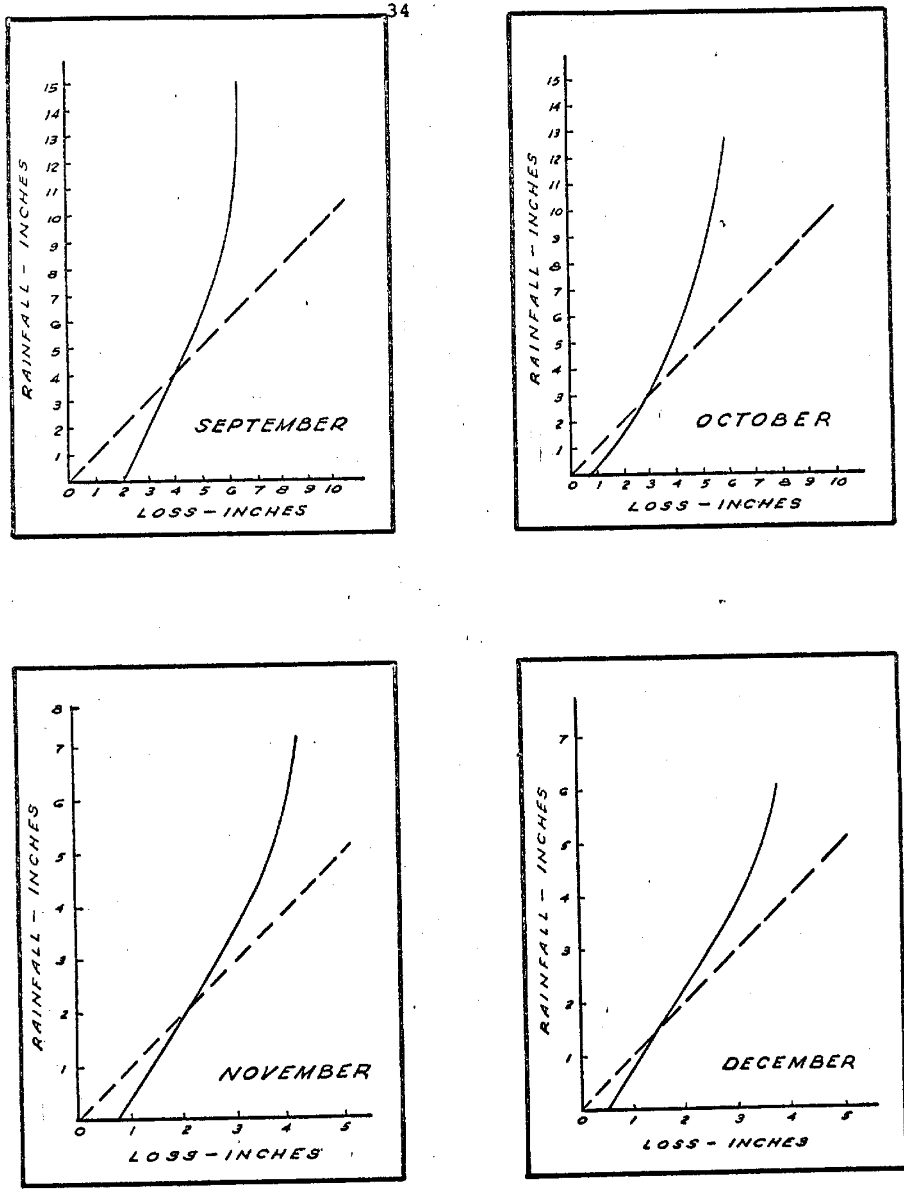


FIGURE 7

RAINFALL - TOTAL LOSS INCHES

TABLE 14 . . . YIELD IN 1000'S OF ACRE FEET FROM EACH OF THE THREE SUB-BASINS OF THE KISSIMMEE RIVER BASIN INCLUDING LAKE ISTÓKPOGA DRAINAGE AREA FOR EACH TIME PERIOD

YEAR	SUB-BASIN I				SUB-BASIN II				SUB-BASIN III				YEARLY BASIN TOT
	PERIODS				PERIODS				PERIODS				
	1	2	3	4	1	2	3	4	1	2	3	4	
1961	14	38	20	5	111	57	24	52	11	31	21	20	404
1962	3	87	149	26	10	129	115	30	.05	270	124	33	976
1963	99	23	96	46	104	73	79	54	52	136	61	43	866
1964	70	246	22	78	120	225	49	82	58	189	44	39	1222
1965	28	53	86	19	46	217	131	30	30	95	132	26	893
1966	139	191	58	40	178	148	81	43	94	131	73	30	1206
1967	30	115	17	2	30	209	61	23	17	50	37	7	598
1968	6	162	72	8	8	162	92	30	2	86	120	21	769
1969	46	131	193	97	75	162	222	87	51	98	259	61	1482
1970	72	29	25	70	90	67	43	67	65	10	33	59	630

Sub-basin I contains all the drainage area above structures S-61 and S-63A. Sub basin II contains all the drainage area above structure S-65 and Sub-basin III contains all the drainage area above Lake Okeechobee. Sub-basin I contains all the Sub-sub-basins 1,2,3,4, 5,6,7 and 9 listed in Table 13. Sub-basin II contains 8,10, 11,12,13 and 14 sub-sub-basins. Sub-basin III contains 15,16,17,18 and 19 sub-sub-basins.

TABLE 15 . . . YIELD IN 1000'S OF ACRE FT. FROM LAKE ISTOKPOGA SUB-BASIN OF THE KISSIMMEE RIVER BASIN

YEAR	FEB-MAY I	JUNE-SEPT II	OCT-NOV III	DEC-JAN IV	YEARLY TOTAL
1961	72	81	9	51	213
1962	17	305	65	13	400
1963	157	104	44	27	332
1964	87	176	27	41	331
1965	50	237	80	20	387
1966	141	334	49	69	593
1967	23	156	42	19	240
1968	46	296	74	14	430
1969	119	315	217	70	721
1970	126	146	10	78	360

TABLE.16 . MONTHLY TOTAL LOSS EQUATION FITTED TO CORPS OF ENGINEERS RAINFALL-TOTAL LOSS CURVE.

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

The R square, δ , standard error and F test values for the linear fitting are presented in Table 17.

TABLE 17 . . . STATISTICAL PROPERTIES OF THE LINEAR EQUATION FITTING FOR CORPS OF ENGINEERS RAINFALL - TOTAL LOSS CURVE.

MONTHS	R SQUARE	δ	STD. ERROR	F(95%)
January	.940	.300	.038	122.48
February	.930	.280	.054	69.94
March	.990	.090	.023	473.14
April	.960	.270	.035	169.43
May	.920	.490	.054	96.16
June	.990	.160	.015	1060.75
July	.990	.110	.009	2289.33
August	.990	.060	.010	3271.13
September	.960	.280	.023	252.62
October	.960	.240	.020	317.53
November	.960	.210	.040	139.29
December	.960	.200	.047	127.30

TABLE 17a . . . YIELD IN 1000'S OF ACRE FEET FROM EACH OF THE THREE SUB-BASINS OF THE KISSIMMEE RIVER BASIN INCLUDING LAKE ISTOKPOGA DRAINAGE AREA FOR EACH TIME PERIOD

YEAR	SUB-BASIN I				SUB-BASIN II				SUB-BASIN III				YEARL BASIN TO
	PERIODS				PERIODS				PERIODS				
	1	2	3	4	1	2	3	4	1	2	3	4	
1961	14	38	20	5	11	57	24	52	83	112	30	71	617
1962	3	87	149	26	10	129	115	30	27	575	189	46	1385
1963	99	23	96	46	104	73	79	54	209	241	105	70	1200
1964	70	246	22	78	120	225	49	82	145	365	71	80	1552
1965	28	53	86	19	46	217	131	30	80	332	212	45	1280
1966	139	191	58	40	178	148	81	43	235	465	124	99	1801
1967	30	115	17	2	30	209	61	23	42	206	79	26	840
1968	6	162	72	8	8	162	92	30	48	382	196	35	1197
1969	46	131	193	97	75	162	222	87	170	413	476	131	2203
1970	72	29	25	70	90	67	43	67	191	156	43	138	990

Yearly values of streamflow generated by use of the FCD Model together with the measured discharge from structure S-65E is presented in Table 1

TABLE 17b. . . YEARLY STREAMFLOW VALUES GENERATED FROM THE FCD MODEL TEGETHER WITH THE MEASURED DISCHARGE FROM S-65E

YEAR	GENERATED STREAMFLOW 1000'S OF ACRE FT.	MEASURED STREAMFLOW 1000'S OF ACRE FT.
1961	404	882
1962	976	500
1963	866	396
1964	1,222	1,046
1965	893	880
1966	1,206	1,552
1967	598	606
1968	769	1,269
1969	1,482	1,954
1970	630	1,389

A regression analysis was run between the backrouted observed and the computed runoff values. The equation used was $Q_{act} = a + b \cdot Q$ comp. The correlation coefficient "r" in addition to the intercept "a" and the regression coefficient "b" are as follows:

$r = 0.701$

$a = 95.42$

$b = 1.03$

It can be interpreted from the "r" value that the FCD Model is reliable 70 percent.

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 18 . . . 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	$\text{Stor} = 266.67 + 1817.55 \times \text{Stage} - 4660.0 \times \text{Stage}^2 + 5293.5 \times \text{Stage}^3 - 2230 \times \text{Stage}^4.$
Hart	$\text{Stor} = 4.79 + 39.76 \times \text{Stage} - 121.48 \times \text{Stage}^2 + 160.97 \times \text{Stage}^3 - 77.20 \times \text{Stage}^4.$
Mary Jane	$\text{Stor} = 51.81 - 373.95 \times \text{Stage} + 1011.9 \times \text{Stage}^2 - 1218.3 \times \text{Stage}^3 + 551.66 \times \text{Stage}^4.$
Myrtle	$\text{Stor} = 21.84 - 152.10 \times \text{Stage} + 397.80 \times \text{Stage}^2 - 463.81 \times \text{Stage}^3 + 203.85 \times \text{Stage}^4.$
Alligator	$\text{Stor} = 5.94 - 51.50 \times \text{Stage} + 167.26 \times \text{Stage}^2 - 242.7 \times \text{Stage}^3 + 134.10 \times \text{Stage}^4.$
Gentry	$\text{Stor} = -90.13 + 532.02 \times \text{Stage} - 1144.5 \times \text{Stage}^2 + 1048.8 \times \text{Stage}^3 - 335.33 \times \text{Stage}^4.$
Tiger	$\text{Stor} = 39.54 - 318.4 \times \text{Stage} + 957.0 \times \text{Stage}^2 - 1278.2 \times \text{Stage}^3 + 645.2\ \text{Stage}^4.$
Rosalie	$\text{Stor} = -2.4 + 10.3 \times \text{Stage} - 7.3 \times \text{Stage}^2 - 24.1 \times \text{Stage}^3 + 39.26 \times \text{Stage}^4.$
Marion	$\text{Stor} = -293.91 \times 1708.8 \times \text{Stage} - 3716.0 \times \text{Stage}^2 + 3577.6 \times \text{Stage}^3 - 1283.3 \times \text{Stage}^4.$
Weohyakapka	$\text{Stor} = 324.15 - 2191.0 \times \text{Stage} + 5531.8 \times \text{Stage}^2 - 6195.0 \times \text{Stage}^3 + 2606.0 \times \text{Stage}^4.$
Marian	$\text{Stor} = 383.37 - 2763.2 \times \text{Stage} + 7452.0 \times \text{Stage}^2 - 8918.0 \times \text{Stage}^3 + 4002.7 \times \text{Stage}^4.$
Jackson	$\text{Stor} = -412.72 + 2095.7 \times \text{Stage} - 8080.7 \times \text{Stage}^2 + 9692.5 \times \text{Stage}^3 - 4344.5 \times \text{Stage}^4.$
ISTOKPOGA	$\text{Stor} = 192.7 - 1851.0 \times \text{Stage} + 6546.5 \times \text{Stage}^2 - 10144.0 \times \text{Stage}^3 + 5918.2 \times \text{Stage}^4$

WHERE

Stage = original stage/100.0 in feet

Stor = computed storage

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

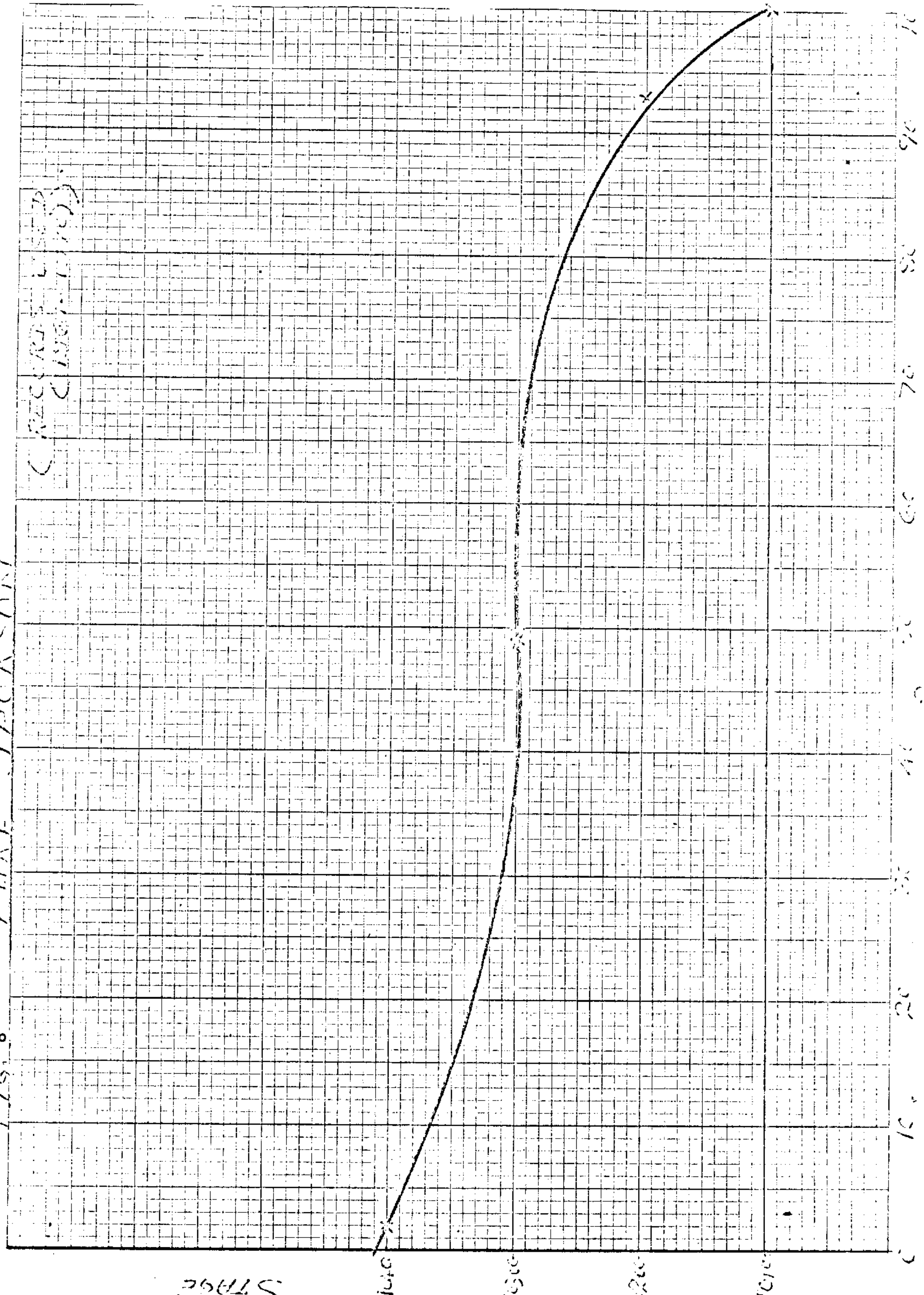


Fig. 8 LAKE JACKSON

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 19 . . . LAKE STAGES AT DIFFENENCE 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 20 . . . LAKE STORAGE AT DIFFERENT FREQUENCY LEVELS

	Frequency %					
Lakes	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	1,423	1,258	1,086	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 9. The total storage-duration curve for the whole Kissimmee Basin was also drawn and is presented in Figure 10.

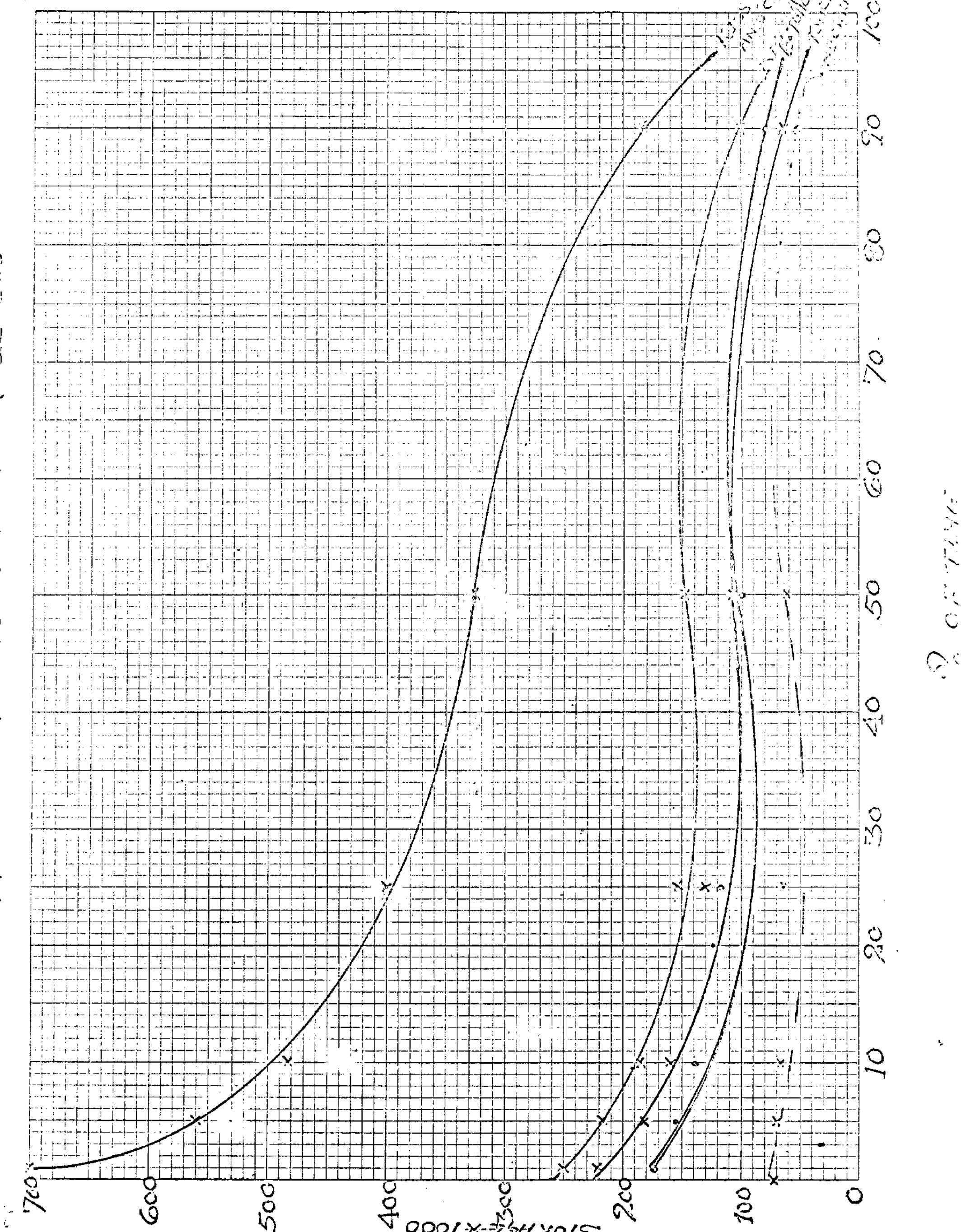
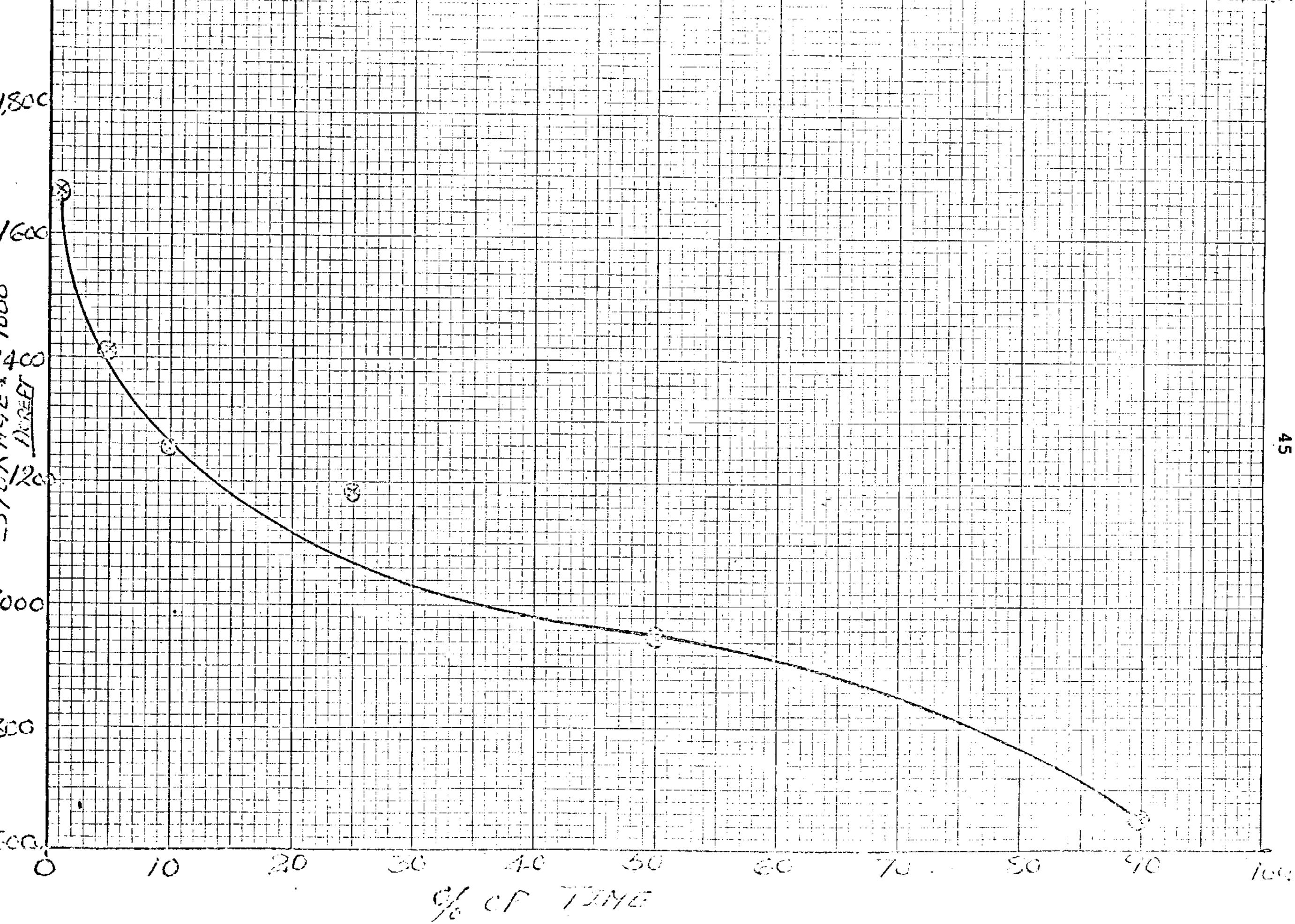

700
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100

FIG. 10 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

TABLE 21 . . . 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 22 . . . 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 23 . . . LAKES, STAGES AND 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.

TABLE 24 . . . 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 25 . . KISSIMMEE RIVER BASIN. DISCHARGE THROUGH S65-E MANDATORY RELEASE 1000'S OF ACRE FEET

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1961	178	129	113	90	64	46	58	69	63	33	22	17
1962	13	9	8	7	4	15	69	77	168	82	29	19
1963	17	23	52	30	25	32	35	28	36	45	34	38
1964	49	118	144	93	97	77	38	59	141	156	50	24
1965	45	52	105	68	28	24	63	115	118	126	96	40
1966	64	122	246	172	109	114	121	204	161	170	54	15
1967	12	14	106	6	24	29	33	104	146	102	15	15
1968	14	12	10	6	12	210	415	229	177	125	40	19
1969	90	28	219	164	109	97	22	87	119	615	176	228
1970	270	152	217	158	20	23	48	20	11	307	- 7	156
MEAN	75	66	122	79	49	67	91	99	114	176	52	57

MANDATORY RELEASES

Based on the monthly discharge figures from S-65E, the lowest monthly discharge for each month was taken as the mandatory discharge through the Kissimmee River Basin.

Monthly mandatory discharge is presented in Table 26.

TABLE 26 . . . MANDATORY DISCHARGE THROUGH THE KISSIMMEE RIVER BASIN

MONTH	M. DISCHARGE x 1000 ACRE FEET
January	15
February	10
March	10
April	10
May	10*
June	15
July	25
August	20
September	10
October	35
November	10
December	15

* Minimum discharge adjusted to the lowest 10,000 figure

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