DRAFT of Final Report

Hydrologic and Water Quality Studies in Upper Taylor Creek and Chandler Slough Watersheds, Florida

by

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I. INTRODUCTION

For the Kissimmee-Okeechobee drainage area a water management scheme has been proposed based on detention of runoff, restrictions on surface water discharge rates, and routing of as much flow as possible through natural or manmade marshes. (Division of State Planning, 1976). With this in mind, this report is directed at examining the impact of drainage, principally agricultural, on hydrologic relationships and evaluting the storage and treatment capabilities of freshwater marshes. This research is sponsored by the South Florida Water Management District (SFWMD), formerly the Central and Southern Florida Flood Control District, and is a continuation of the previous effort, "Environment Resources Management Studies in the Kissimmee River Basin." (Huber, et al., 1976).

Upper Taylor Creek, in Okeechobee County, is selected as the drainage impact analyses study watershed since hydrologic data have been compiled since 1955 by the Agricultural Research Service and the United States Geological Survey. This area has undergone a transition from unimproved pasture with a natural creek bed to a regime dominated by improved pasture with a controlled channel. The investigations are presented in Chapter II and fall into two categories. First, hydrologic data are analyzed in order to describe the changes in hydrologic responses due to the drainage facilities, and second, hydrologic simulations with the Hydrologic Land-Use Model, HLAND, are used to analyze the influence of shifting land use and increasing drainage on water losses and runoff pathways. The HLAND Users Manuel is included as Appendix A to this report.

For the storage and treatment analyses of freshwater marshes, Chandler Slough Marsh is chosen as the study area because of the availability of recent water quality and quantity data from the SFWMD. Chandler Slough Marsh is also in Okeechobee County but is within the Kissimmee River Valley and is considered a flood plain marsh. The Chandler Slough Study is presented in Chapter III and is divided into flood peak attenuation analysis and evaluation of nutrient removal efficiency. The Storage/Treatment portion of the Storm Water Management Model, SWMM, (Huber, et al., 1975) is utilized to simulate the hydrologic and water quality aspects of Chandler Slough Marsh.

II. HYDROLOGIC ANALYSIS

INTRODUCTION

The objectives of this portion of the research are to examine the impact of drainage on hydrologic relationships, to quantify baseflow relationships with measured soil storage parameters and to quantify hydrologic-land use interactions. Upper Taylor Creek Watershed is selected as the study area for two reasons. One, this watershed has undergone transition from unimproved pasture, and two, data have been compiled, principally by the Agricultural Research Service (ARS) and U.S.G.S., since 1955. In addition, channel control structures were installed in the 1960's under a PL 566 program.

The Upper Taylor Creek Watershed is in Okeechobee County and covers about 100 square miles. The dominant soil within the basin is in the Myakka-Basinger association. Table 2.1 shows land-use hydrologic group breakdown for 1958 to 1972 and a map of Upper Taylor Creek Watershed is shown in figure 2.1.

DATA ANALYSIS

Daily mean streamflow, rainfall, pan evaporation and daily mean depth to groundwater are among the parameters which are available from the ARS Southern Branch (ARS Watershed Florida W-2 and W-3). Data examined prior to 1962 are referred to as "pre-control" and data examined after 1968 are referred to as "post-control". The purposes of data analyses are to describe changes in hydrologic relationships from the pre-control period to the post-control period and to quantify the baseflow relationship for uses in hydrologic simulation.

Groundwater Stage-Duration Curves

Composite groundwater stage duration curves for pre-control and post-control periods are shown in figure 2.2. The groundwater "stage" is the daily mean depth from ground surface to the water table of seven sampling wells. The post-control curve is a composite of 1969 through 1972 with annual precipitation of 66, 50, 49, and 42 inches. Pre-control is from 1969 through 1961 with annual precipitation of 61, 59, and 31 inches. Also figure 2.3 shows two single year curves, 1969 and 1960 where rainfall and runoff totals were about equal. As shown, there seems to be only slight variations in groundwater level frequencies between the two periods. A possible reason for this occurence is that control structures (drop spillways) are responsible for keeping the groundwater table higher near the stream channels which counteracts drawdown by ditching. See figure 2.1 where groundwater well locations are shown. (Note that all but sampling site 1 are near the stream channels with several sites just upstream from a control structure.)

Recession Curves

Figures 2.4 and 2.5 show flow (daily mean discharge), q_0, vs the following day's flow, q_1, for rainfree recession periods. A discharge relationship, * $q_t = q_0 K^t$, is derived from these curves where K is the inverse slope of the

* $q_t = q_0 K^t$ can be converted to the more familiar form:

$q_t = q_0 \exp [K't]$ where $K' = \ln(K)$.

TABLE 2.1 1958/1972 LAND USE - HYDROLOGIC GROUP BREAKDOWN AREA IN ACRES OF UPPER TAYLOR CREEK WATERSHED.

	HYDROLOGIC GROUP[A,B] 2	3	4	TOTAL
SCS HYDROLOGIC[B] SOIL GROUP	C	A/D	B/D	
LAND USE				
1. URBAN	0/0	179/2176	0/102	179/2278
2. CROPS & CITRUS	0/0	0/230	359/947	359/1177
3. IMPROVED PASTURE	77/589	13543/50433	1433/5325	15053/56347
4. UNIMPROVED PASTURE	256/0	37248/0	2560/0	40064/0
5. MARSH & FOREST	410/154	3763/1894	9036	8857/4710
TOTAL	743	54733	9036	64512/64512

[A]HYDROLOGIC GROUP 1 IS NOT REPRESENTED IN UPPER TAYLOR CREEK WATERSHED

[B]SEE "ENVIRONMENTAL RESOURCES MANAGEMENT STUDIES IN THE KISSIMMEE RIVER BASIN", HUBER, ET AL. FOR DEFINITION OR REFERENCES

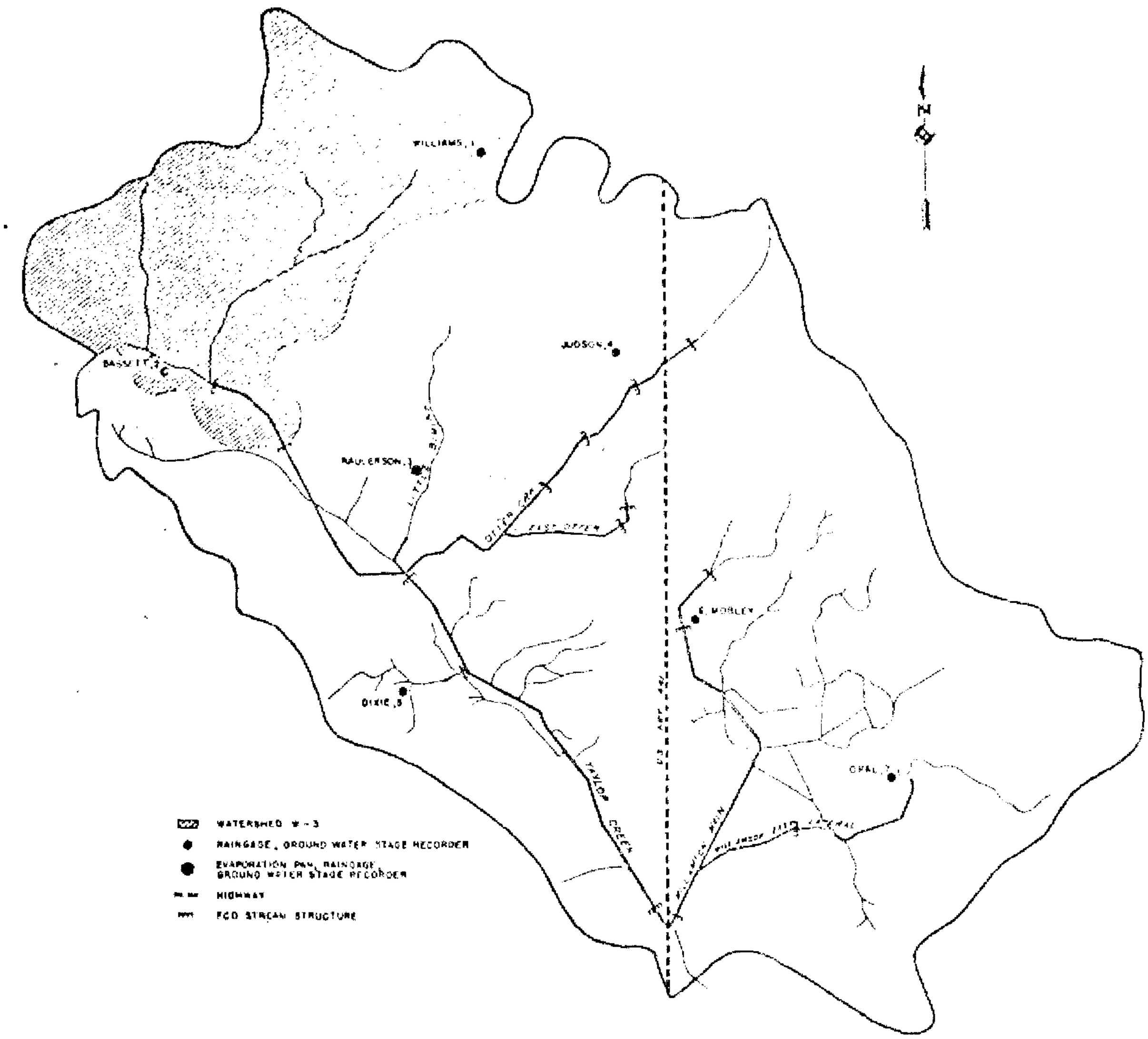


FIGURE 2.1 UPPER TAYLOR CREEK
FLORIDA WATERSHEDS W-2 AND W-3

from ARS, Annual Report, 1971, Soil and Water Conservation Division, Southern Branch, Fort Lauderdale.

FIGURE 2.2 STAGE-DURATION CURVES

Composite groundstage-duration curves for pre-control and post-control periods

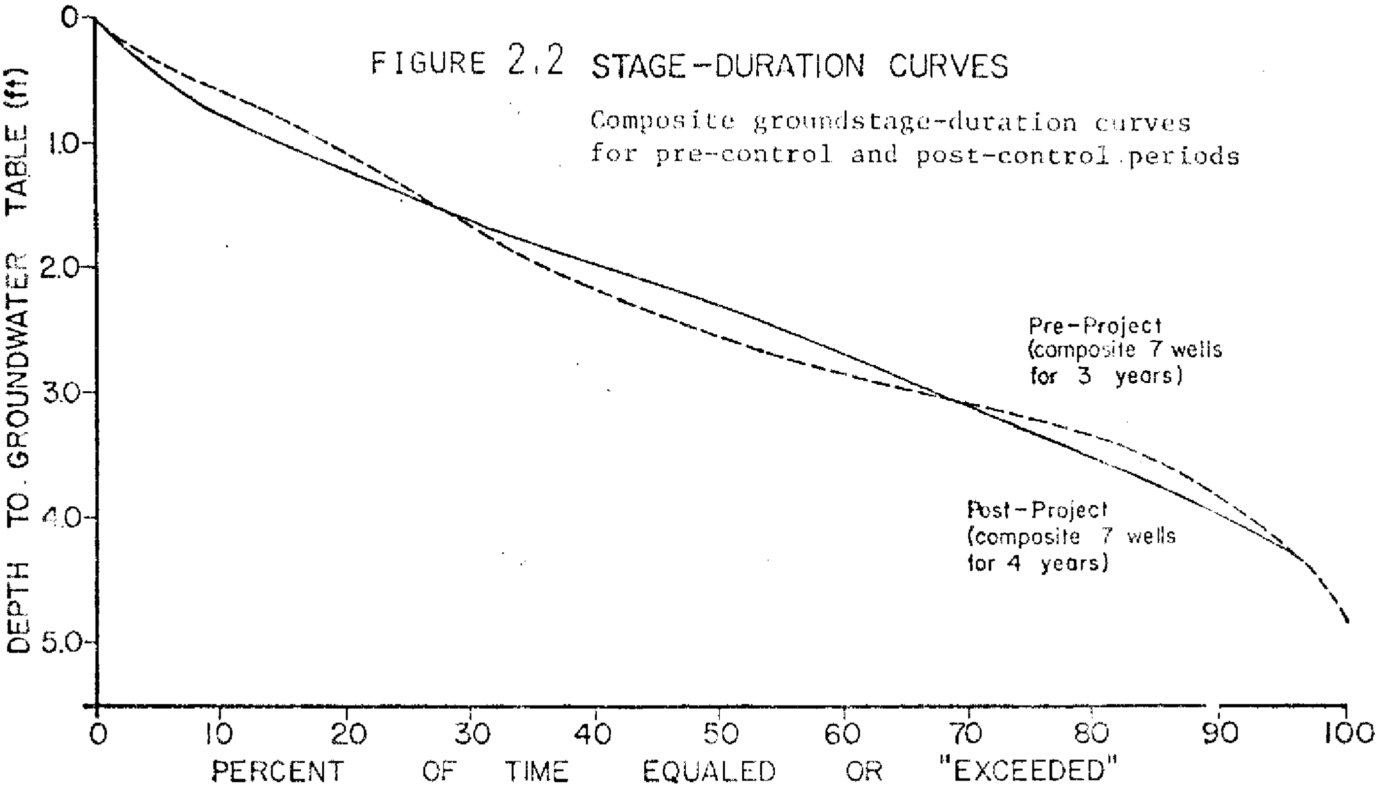
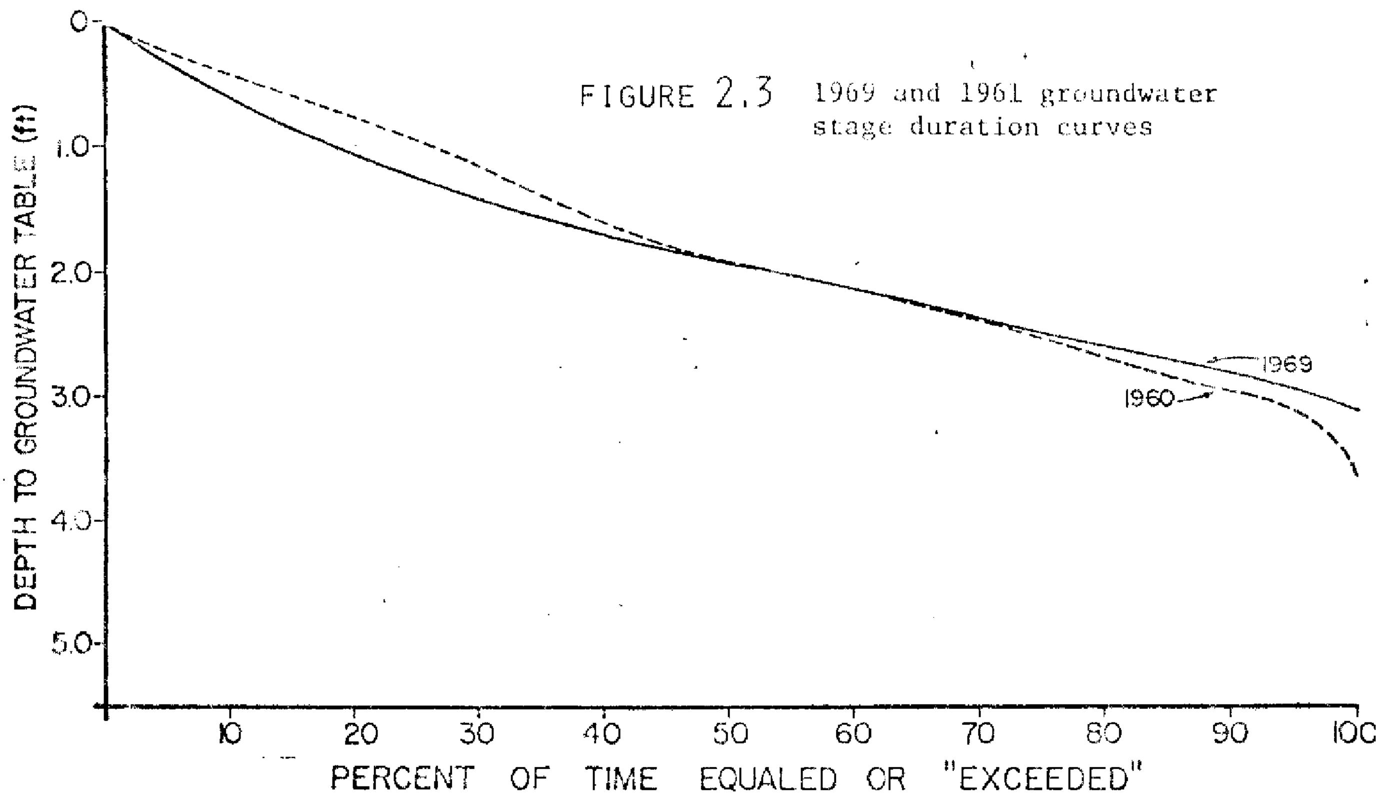


FIGURE 2.3 1969 and 1961 groundwater stage duration curves



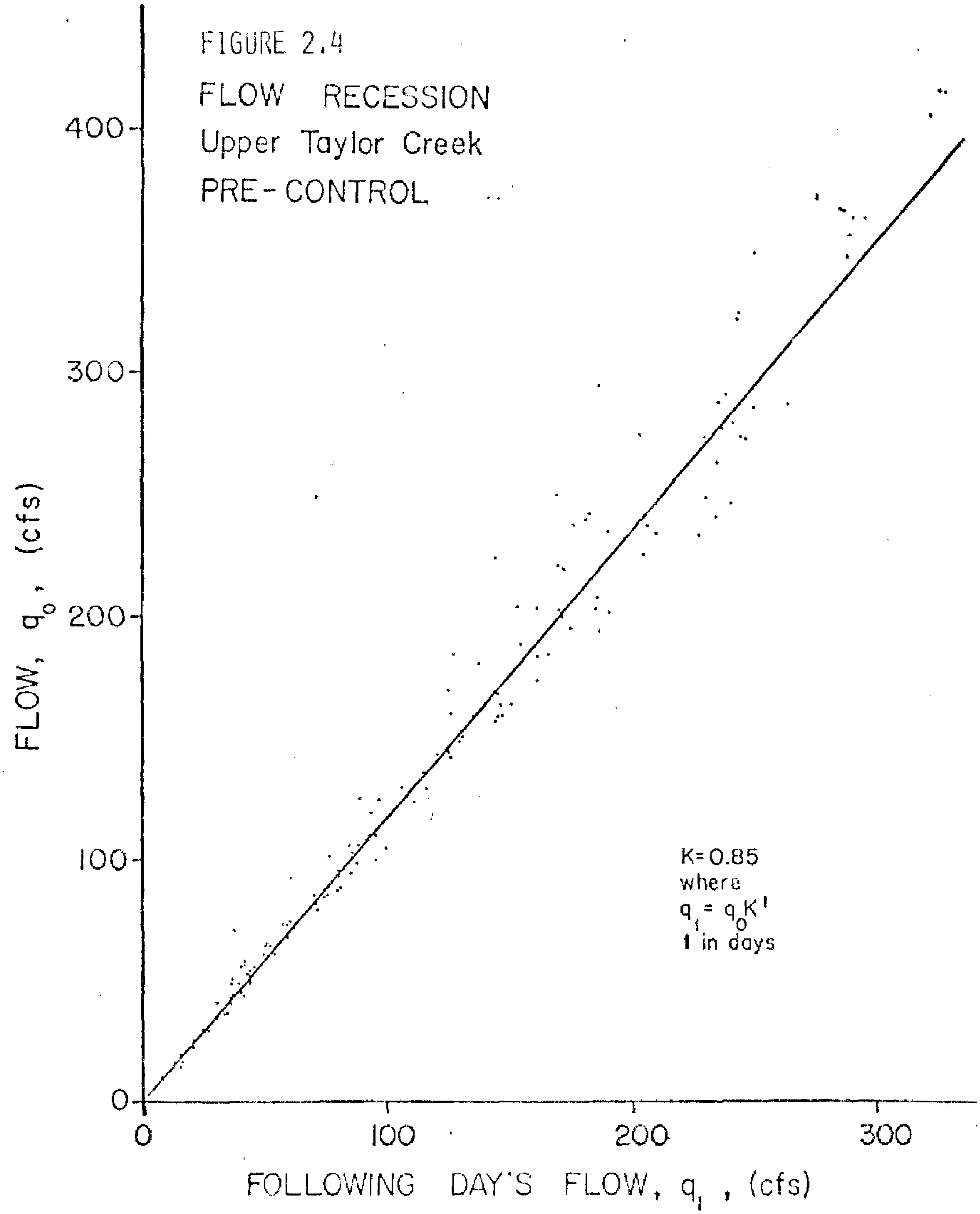


FIGURE 2.4
FLOW RECESSION
Upper Taylor Creek
PRE-CONTROL
K=0.85
where
q_t = q_o K^t
t in days
FLOW, q_o, (cfs)
400
300
200
100
0
0
100
200
300
FOLLOWING DAY'S FLOW, q_1, (cfs)

line. The value for the recession constant, K, is 0.85 in the pre-control period (figure 2.4). This K value also fits the data well in the lower regime of flow (i.e. less than 60 cfs on the ordinate) in the post-control period (figure 2.5). The recession relationship is not altered by drainage facilities in this range of flow. A K value of 0.7 fits the data in the remaining range of baseflow in figure 2.5. In this range of flow, between 300 - 60 cfs, recessions are faster in the post-control period. This faster recession is due to increased interception of subsurface flow by drainage ditches. The upper bound on baseflow is about 300 cfs since both lines envelop most data points above 300 cfs on the ordinate.

Figure 2.6 shows recession lines using streamstage plus depth to water table plus arbitrary datum, instead of flow. This parameter, H, is assumed to be proportional to soil moisture levels. A schematic diagram of this parameter is presented in figure 2.7. If q is a function of time and H is a function of time, given initial values for each, q as a function of H could be derived in the following form:

$$q_t/q_o = (H_t/H_o)^{K_1} + C \tag{2.1}$$

where K_1 and C are constants.

Results of plotting q_t/q_o vs. H_t/H_o on log-log paper produced a scatter diagram. Figure 2.6 does, however, show that the recession of this parameter, H, is not much different before and after control construction.

Streamflow vs. Depth to Groundwater Table

These curves are shown in figures 2.8 and 2.9. Rainfree recessions are again used. Depth to the water table is the average of all test wells within Upper Taylor Creek (see figure 2.1 for sites). For an individual rainfree periods, correlations are not as good. Once again, the faster recessions in the post-control period are evident. Breakpoints for pre-control are in the 300 - 700 cfs range and near 175 cfs for the post-control period.

Other Analyses Performed for Rainfree Recession Period

(not shown)

1. h_S vs. h_{GW}	semi-log
2. $\bar{q}$ vs $\bar{h}_{GW}$	semi-log
3. h_S vs. h_{GW}	arith.
4. h_{GW}/h_{GW_o} vs. h_S/h_{S_o}	arith.
5. h_S vs. h_{GW} per day	arith.
6. q vs. H/H_o	log-log
7. Total q vs. h_{GW}	arith.
8. $\bar{q}$ vs. $\bar{H}$	semi-log
9. q/q_o vs. H/H_o	log-log

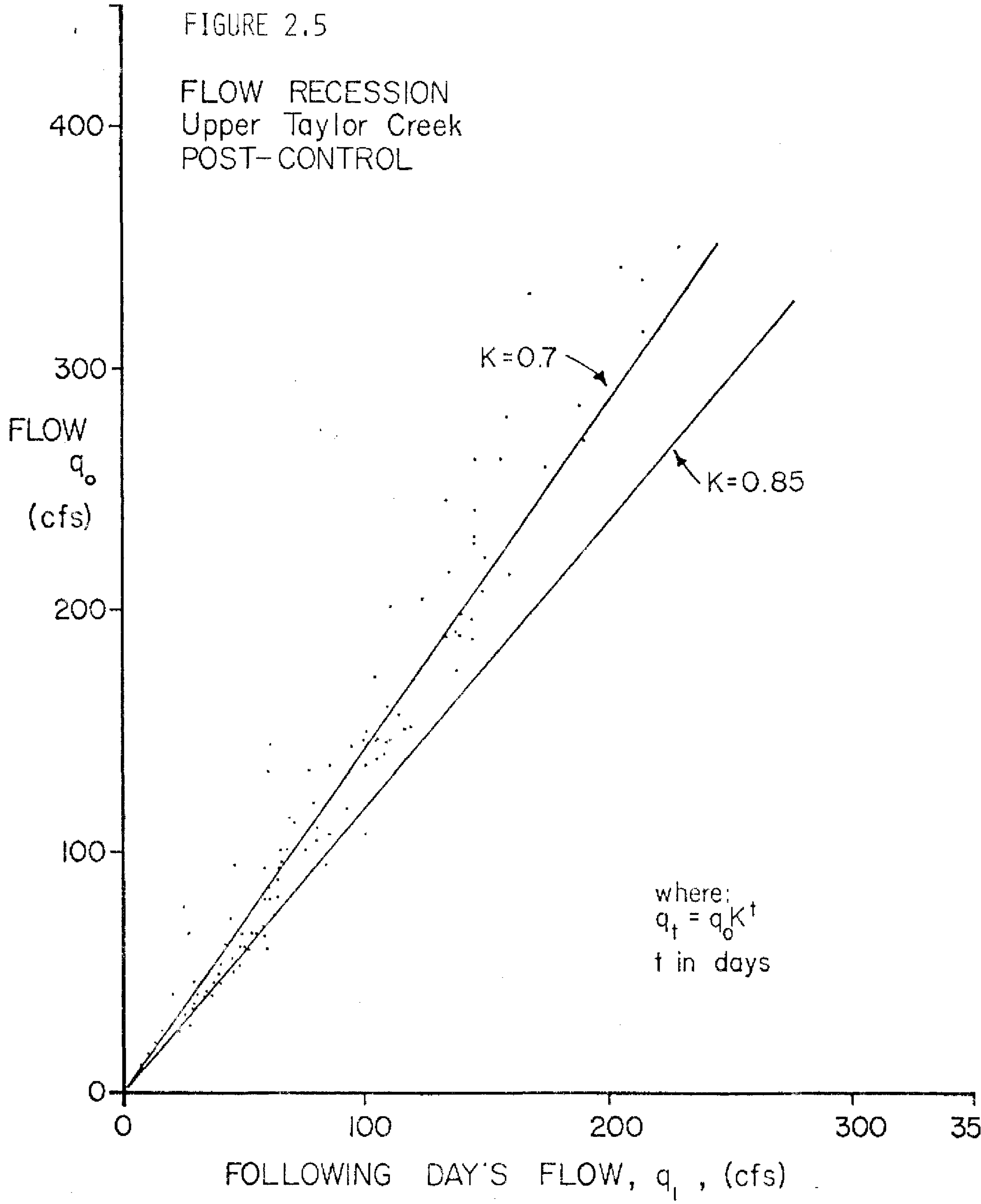


FIGURE 2.5
FLOW RECESSION
Upper Taylor Creek
POST-CONTROL
K=0.7
K=0.85
FLOW
q_o
(cfs)
400
300
200
100
0
0
100
200
300
35
FOLLOWING DAY'S FLOW, q_1, (cfs)
where:
$q_t = q_o K^t$
t in days

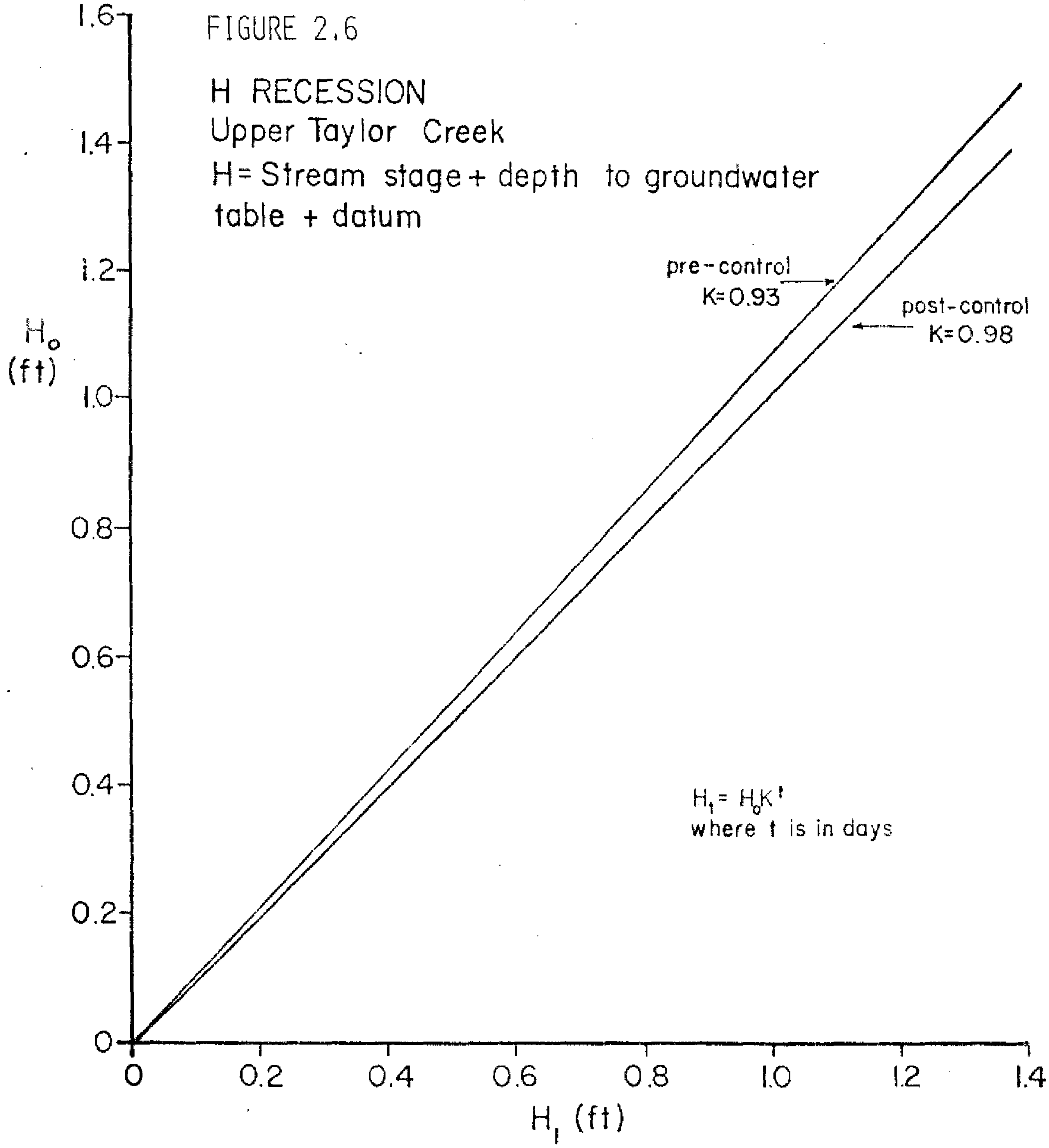


FIGURE 2.6
H RECESSION
Upper Taylor Creek
H = Stream stage + depth to groundwater table + datum
pre-control
K=0.93
post-control
K=0.98
$H_t = H_0 K^t$
where t is in days
H_0 (ft)
H_1 (ft)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

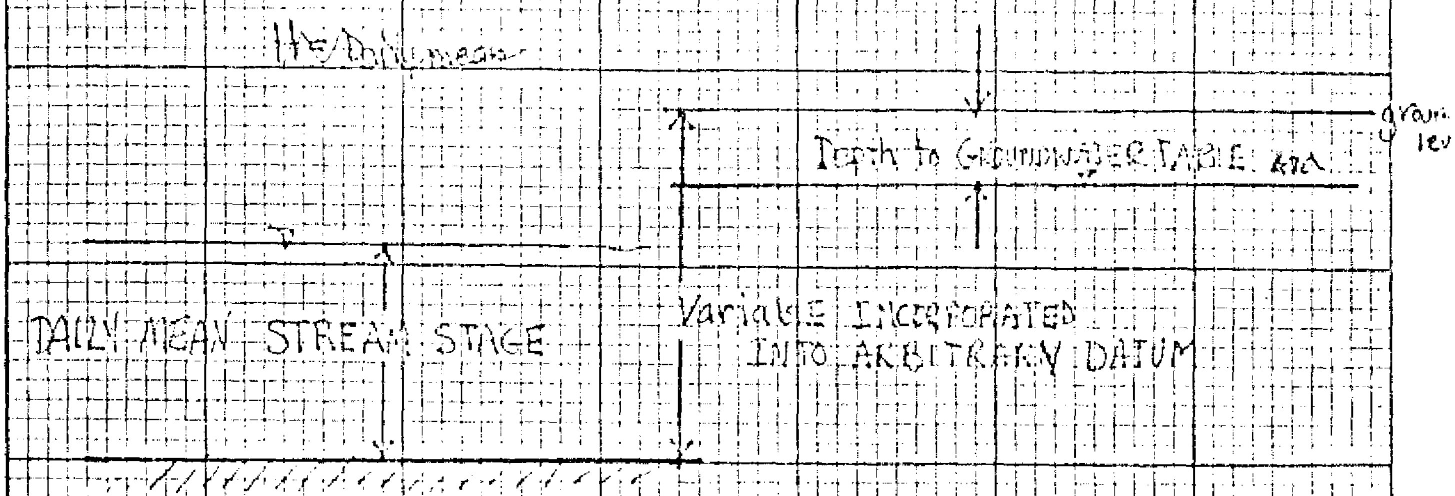


FIGURE 2.7 Schematic diagram of parameter, H.

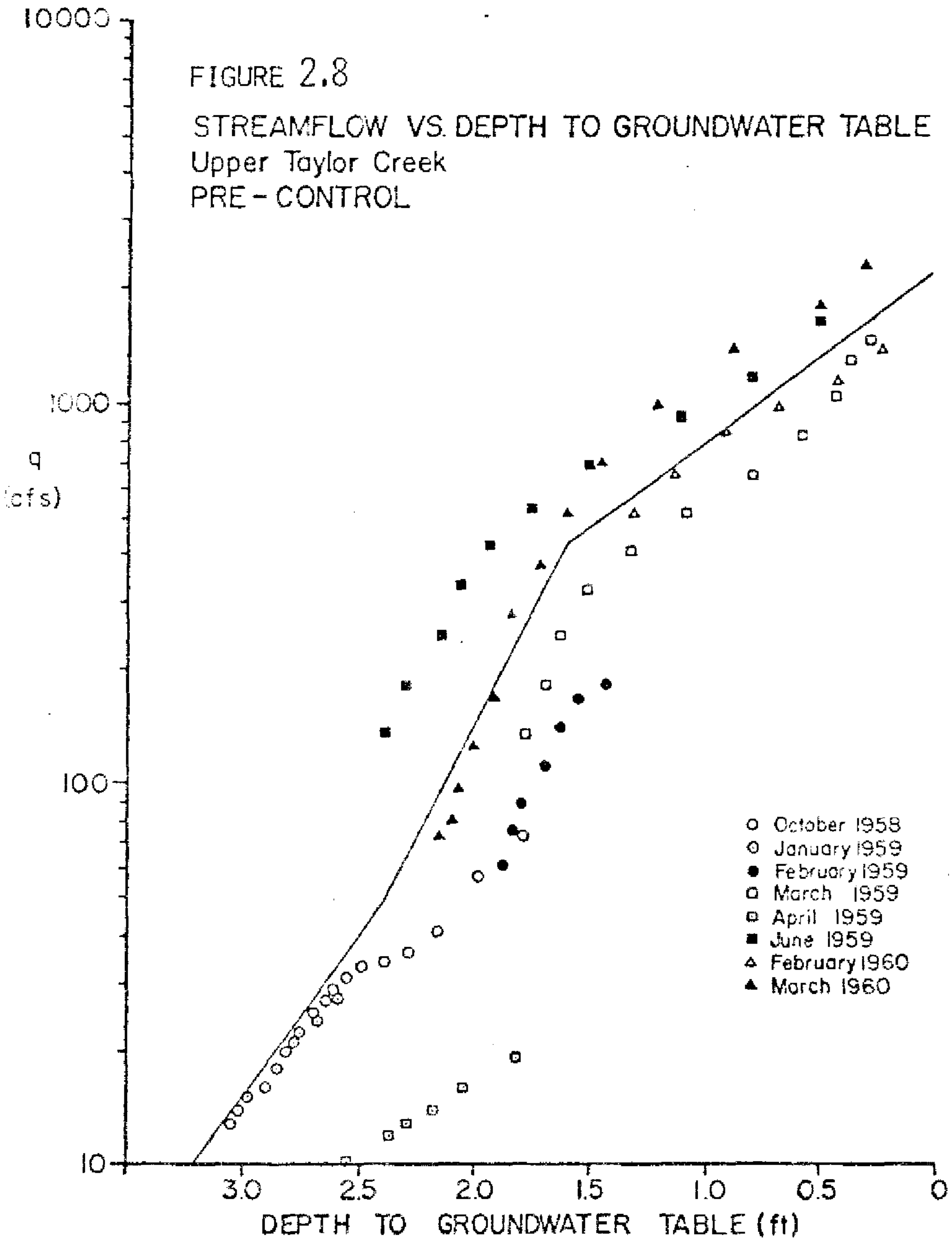


FIGURE 2.8
STREAMFLOW VS. DEPTH TO GROUNDWATER TABLE
Upper Taylor Creek
PRE-CONTROL
10000
1000
100
10
q
(cfs)
3.0
2.5
2.0
1.5
1.0
0.5
0
DEPTH TO GROUNDWATER TABLE (ft)
October 1958
January 1959
February 1959
March 1959
April 1959
June 1959
February 1960
March 1960

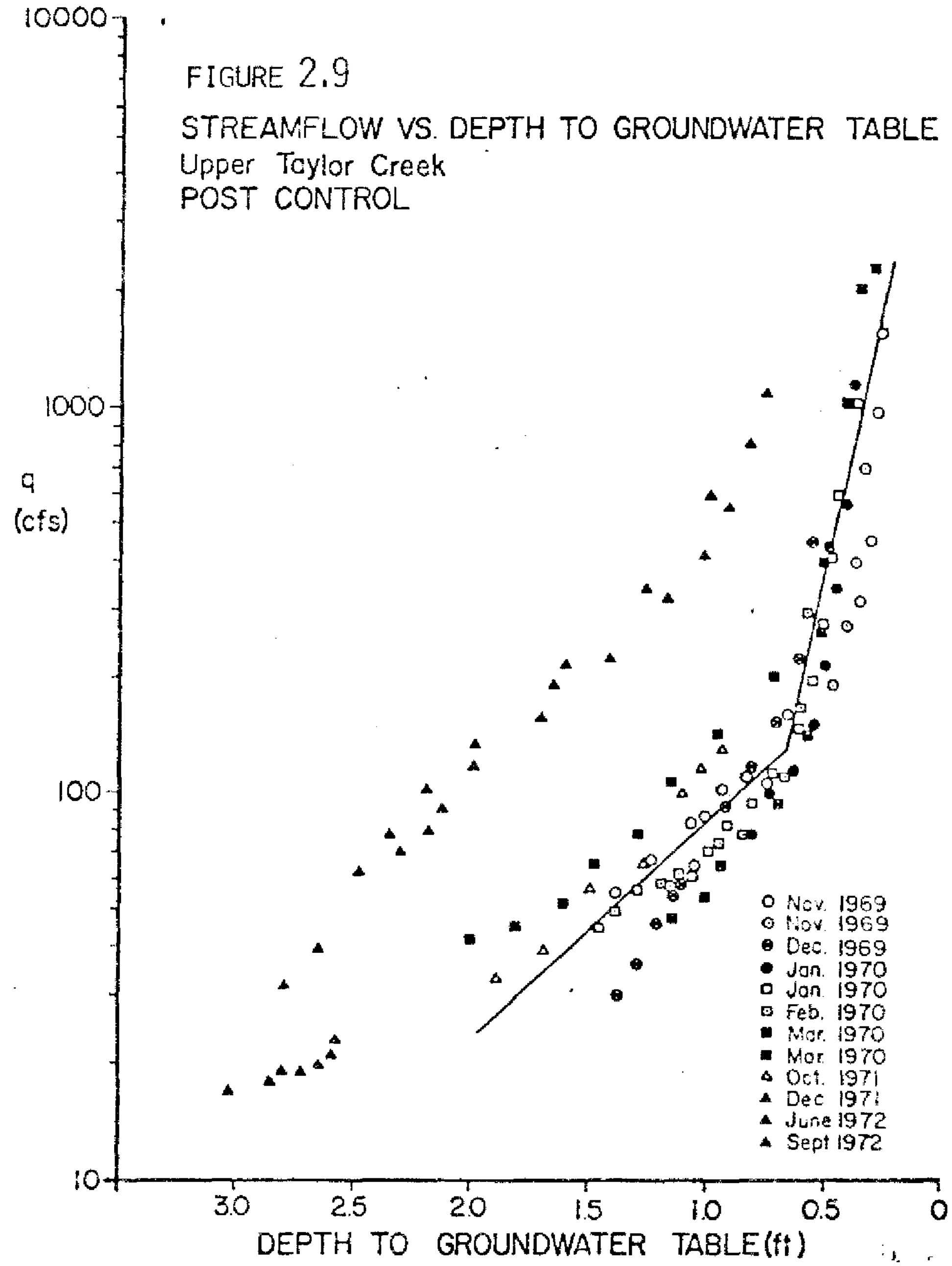


FIGURE 2.9
STREAMFLOW VS. DEPTH TO GROUNDWATER TABLE
Upper Taylor Creek
POST CONTROL
10000
1000
100
10
q
(cfs)
3.0
2.5
2.0
1.5
1.0
0.5
0
DEPTH TO GROUNDWATER TABLE (ft)
Nov. 1969
Nov. 1969
Dec. 1969
Jan. 1970
Jan. 1970
Feb. 1970
Mar. 1970
Mar. 1970
Oct. 1971
Dec 1971
June 1972
Sept 1972

10. q/q_o vs. H semi-log

11. q vs. H log-log

Results (of graphs not included)

For individual rainfree periods, baseflow vs. parameters sometimes produced good correlations but for several such periods, correlations were poor. The conclusion is that baseflow relationships for extended periods have not been quantified with these analyses. The graphs, at best, are useful only in a qualitative sense.

HYDROLOGIC SIMULATION

The main objective of hydrologic simulation with the Hydrologic-Land Use Model, HLAND, (Huber, et al. 1976; Bedient, 1975), is to analyze the effect of drainage on water losses and runoff through the use of continuous simulation before and after drainage facilities were installed in the Upper Taylor Creek Watershed. Other objectives are to establish and verify the baseflow relationship for the study area and to determine the effects of ditching on soil moisture storage levels. Simulations with HLAND are for two extended periods, the first from 1957 to 1961 where unimproved range was the dominant land use, and 1969 to 1973 where improved pasture dominated. Emphasis of simulation is to calibrate and verify HLAND for Upper Taylor Creek, then investigate the drainage facilities' influence on runoff pathways water losses, and storage parameters.

Baseflow-Soil Storage Relationship

Since hydrologic data analysis did not provide an adequate long-term baseflow relationship, HLAND simulation is used to predict storage changes using measured baseflow as in input. (Baseflow components of streamflow are found using hydrograph separation techniques.) This was done for five year periods (1957-1961 and 1969-1973) with a daily time step. A constant value correction factor was applied to the Thornthwaite ET depletion coefficients, DWL, so total measured and predicted streamflow volumes were within reasonable agreement. Then a regression fit was computed between monthly averaged soil storage levels and measured baseflow. In addition, adjustments were made to fit measured hydrographs with the predicted hydrographs during calibration. The baseflow relationships are presented in figure 2.10. In the lower range of baseflow, for soil storage values below 4.35 inches, there is more baseflow in the post-control period. This is due to the presence of stream structure (see figure 2.1 for structure locations), although soil mositure losses (i.e., evapotranspiration) in the post-control period are greater due to increased depletion coefficients. See figure 2.11 for a graphical depiction of the effect of changing depletion coefficients on water losses and Table 2.2 for the values of the depletion coefficients used in pre-control simulations. The relationships for 1957 through 1961 and 1969 through 1973 are as follows:

1957-1961 $BF = 0.95 \exp(0.9 \times STPU)$ for $4.4 < STPU \leq STPU_{max}$

$BF = 0.002 \exp(2.3 \times STPU)$ for $3.2 < STPU \leq 4.4$

$BF = 0.171 \exp(0.91 \times STPU)$ for $0 \leq STPU \leq 3.2$

$STPU_{max} = 7.73$ inches,

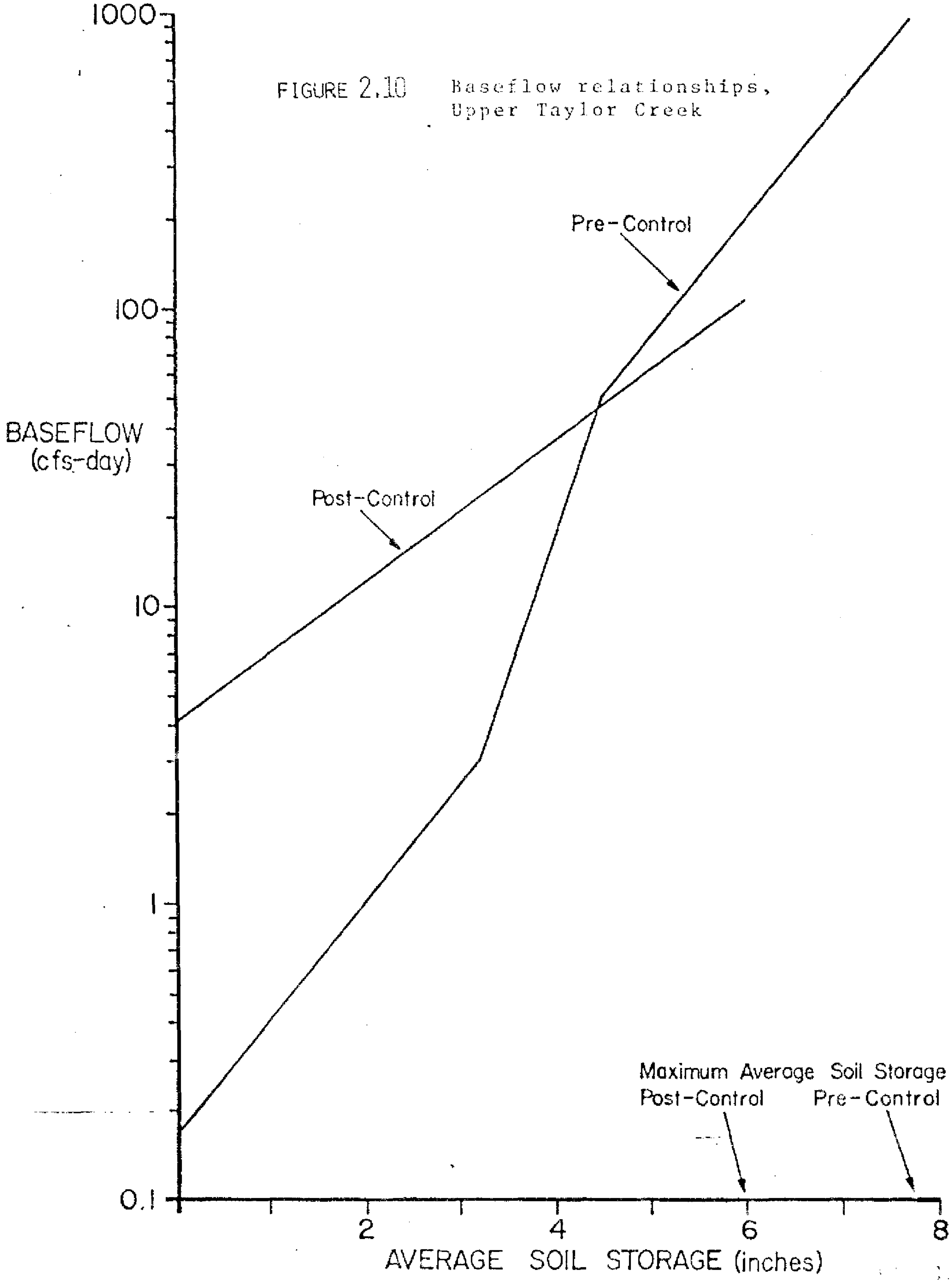
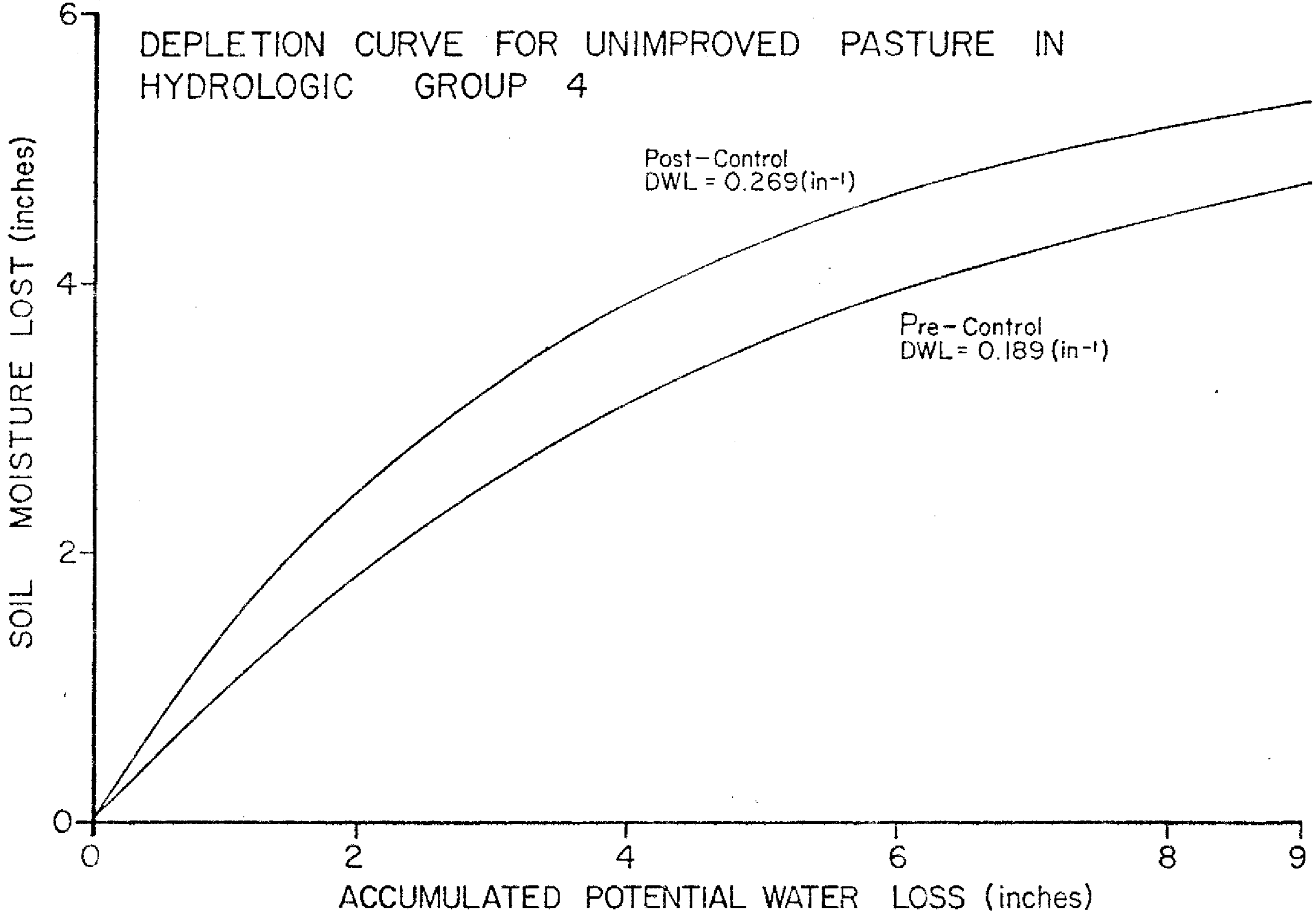


FIGURE 2.10 Baseflow relationships, Upper Taylor Creek

FIGURE 2.11



DEPLETION CURVE FOR UNIMPROVED PASTURE IN HYDROLOGIC GROUP 4
Post-Control
DWL = 0.269(in-1)
Pre-Control
DWL = 0.189 (in-1)
SOIL MOISTURE LOST (inches)
ACCUMULATED POTENTIAL WATER LOSS (inches)
0
2
4
6
8
9

1969-1973 $BF = 4.11 \exp(0.55 \times STPU)$ for $0 \leq STPU \leq STPU_{max}$

$STPU_{max} = 6.00$ inches,

where BF = Baseflow for entire watershed, cfs, and
STPU = Average Soil Moisture Storage Level, inches.

Effects of Drainage Facilities on Soil Moisture Levels

An analytic method which calculates the phreatic surface between parallel ditches is used to determine maximum soil storage levels of each land use-hydrologic group as a function of drainage density and soil characteristics.

The maximum soil moisture storage for an undrained soil profile is the depth of soil times the effective porosity. When drainage systems are installed the soil profile can retain the same maximum storage but this storage is quickly decreased due to lateral movement (interflow) into the drainage system. This subsurface flow becomes a component of direct (quick runoff since it is conveyed, ultimately, to the main stream through the lateral drainage network and can no longer contribute to baseflow except by reinfiltration.

Drainage density is defined as the length of all streams (natural or manmade) per unit drainage area (Horton, 1932). The average length of overland flow and the average ditch spacing is proportional to the reciprocal of drainage density, hence, as drainage density increases, both length of overland flow and ditch spacing decreases.

The effects of drainage are incorporated into two parameters in HLAND. First, maximum soil mositure storage levels, SM(J,K), for land use J and hydrologic group K, are decreased as drainage density increases. Whenever these levels are exceeded, surplus water is created. This surplus water includes subsurface flow, overland flow and water eventually lost by evaporation. The second parameter, CDET(J,K), is the fraction of surplus water that will remain on land per day, hence, direct runoff is delayed and attenuated by CDET. As drainage density increases, the CDET values decrease and surplus is removed faster. A current modification in HLAND allows surplus water remaining each day to be subject to evaporation and infiltration.

Previous HLAND simulation in Huber, et al., (1976) relied on SCS Runoff Curve Numbers (SCS, 1972) as a measure of the maximum soil moisture storages, SM(J,K). These curve numbers are determined empirically for hydrologic soil-cover complexes based on surface runoff occurring 24 hours or less after the rainfall event. Also, depending on the antecedent conditions, different curve numbers are used which makes their application to continuous simulation difficult. In the SCS procedures drained soil has a higher maximum storage value or maximum potential infiltration than undrained soil, therefore, less surface runoff. This surface runoff does not include the subsurface flow which will enter the drainage network through the highly permeable fine sands found in Taylor Creek Watershed and much of South Florida.

An analytic method is employed to find SM(J,K) values for each land use-hydrologic group, in lieu of curve number assignment. This method calculates the phreatic surface between parallel ditches as a function of drainage density and physical characteristics of the soil associations found in each hydrologic group. Representative values are chosen for saturated hydrualic conductivity, effective porosity, soil depth, and net accreation, then a steady state solution, equation 2.2 (Bear, 1972) is found for the free surface between the parallel ditches.

$$h(x) = [h_o^2 + N/K \ (L - x) \ x \ ]^{1/2} \tag{2.2}$$

where h_o = Soil depth - ditch depth, length,

N = Net Accreation, length/time,

K = Saturated hydraulic conductivity, length/time, and

$h(x)$ = Height of surface above impermeable layer a distance x between parallel ditches, length.

Equation 2.2 is integrated to determine the area under the phreatic surface and divided by the ditch spacing to yield an average depth to the water table. Using these procedures for all land use-hydrologic groups provides relative values for SM(J,K) which are presented in Table 2.3 for the various land use-hydrologic groups found in Upper Taylor Creek Watershed.

Discussion of Model's Performance and Results

Generally, HLAND will predict trends in streamflow without extensive calibration efforts. Measured and predicted hydrographs are shown in Appendix B. Low flow volumes are usually in good agreement which suggested that the baseflow relaitonships derived as described during calibration runs are adequate for modeling purposes. Since the model is based on water balance, discrepancies between measured and predicted streamflows are a result of inaccurate predictions of storage changes.

Indications are that short term evapotranspiration, ET, predictions and/or unaccounted for groundwater discharge (or recharge) are the factors influencing these variations. Note that one fourth inch of runoff over the watershed translates into about 260 cfs-day of streamflow, therefore, slight inaccuracies in moisture levels will produce the indicated discrepancies. Also, to be consistent with available inputs, the model makes no distinctions among intensities of rainfall nor among spatial variations beyond Theissen weights.

The predicted monthly and yearly direct, base, and total runoff components are presented in Table 2.4 - 2.14 along with measured total runoff for Upper Taylor Creek, 1958 land use is used for the pre-control period and 1972 land use is used for post-control (see Table 2.1). These tables illustrate the shift from baseflow to direct flow with increased agricultural development. Note that direct flow includes interflow. This shift of runoff pathways can be observed in the flow recession curves (figures 2.4 and 2.5) where there is a downward shift in flow regimes. The same type of effect can also be observed in the streamflow vs. depth to groundwater table curves (figures 2.8 and 2.9).

The mean ratio of annual baseflow to annual total flow is 0.91 (standard deviation, s, = 0.06) in the pre-control period and 0.54 (s = 0.08) in the post-control period. A decrease in baseflow is, primarily, accompanied by an increase in interflow although the mean annual total flow to annual precipitation ratio is depressed from 0.38 (s = 0.12) in the pre-control period to 0.27 (s = 0.12) in the post-control period. This implies that there is, also, an increase in the ET losses due to watershed alterations, at least for the two study periods. Mean annual ET are 34.91 inches (s = 2.24) and 36.75 inches (s = 1.51) for pre-control and post-control periods, respectively. These predictions are supported by the fact that predictions of ET by subtracting annual runoff from annual precipitation and neglecting storage changes are 34.57 inches and 36.64 inches, respectively.

Table 2.2 Depletion Coefficients, DWL Pre-Control/Post-Control Simulation Periods

(Inches^{-1})

Land Use	Hydrologic Group 2	Hydrologic Group 3	Hydrologic Group 4
1. Urban	0.181/0.258	0.205/0.293	0.409/0.584
2. Crops & Citrus	0.197/0.281	0.233/0.322	0.745/1.064
3. Improved Pasture	0.160/0.228	0.181/0.258	0.287/0.409
4. Unimproved Pasture	0.093/0.132	0.129/0.185	0.189/0.269
5. Marsh & Forest	0.082/0.117	0.114/0.163	0.166/0.238

Table 2.3 Maximum Soil Storage in Inches for Hydrologic Simulation[a]

Land Use	Hydrologic Group 2	Hydrologic Group 3	Hydrologic Group 4
1. Urban	6.13	5.38	2.66
2. Crops & Citrus	5.63	4.71	1.49
3. Improved Pasture	6.95	6.13	3.70
4. Unimproved Pasture	11.77	8.24	5.61
5. Marsh & Forest	11.84	8.45	5.76

[a] Calculation from "Procedures to Calculate Soil Storage Parameters for Use in HLAND for Modified Land Use", see Appendix C.

The mean annual precipitation for the pre-control period and post-control period are 52.26 (s = 12.68) and 52.48 (s = 8.62), respectively. The mean monthly average soil storages are 4.41 (s = 1.40) and 3.82 (s = 1.59) for the pre- and post-control periods, respectively.

SUMMARY

1. Upper Taylor Creek has undergone transition from unimproved range and marsh lands to a regime dominated by improved pasture; in addition, channel modifications and control structures have been installed in the 1960's through a PL 566 program.

2. There are only slight variations in observed groundwater level frequencies between the two study periods.

3. Streamflow recessions are faster in the post-control period. The faster recessions are probably due to increased interception of subsurface lateral flow by drainage facilities.

4. Hydrograph separation, flow recession data, and streamflow vs. depth to groundwater plots indicate shifts in runoff pathways where the upper limit of baseflow (daily mean discharge) is between 300 - 700 cfs for the pre-control period and near 200 cfs in the post-control period.

5. Monthly and yearly HLAND predictions of direct, base and total runoff components are presented in Tables 2.4 - 2.12 along with measured total runoff for Upper Taylor Creek. 1958 land use is used for the pre-control simulation and 1972 land use for the post-control simulation.

6. Results from HLAND indicate a major shift from baseflow to direct flow (including interflow) with increasing agricultural development. During the 1957-1961 period 91% of total flow is baseflow while only 54% is baseflow during the 1969-1973 period.

7. For the 1957-1961 and 1969-1975 periods, mean annual evapotranspiration losses increase from 34.91 to 36.75 inches; mean monthly soil moisture storages decrease from 4.41 inches to 3.82 inches; and the mean annual ratios of total runoff to rainfall are depressed from 0.38 to 0.27, respectively.

TABLE 2.4 SUMMARY OF YEARLY PRECIPITATION, PREDICTED EVAPOTRANSPIRATION, PREDICTED RUNOFF, MEASURED RUNOFF,
(ALL VALUES IN INCHES)

YEAR	RAINFALL	ET	PREDICTED RUNOFF	MEASURED RUNOFF
1957	60.02	36.05	21.69	20.95
1958	49.96	38.09	12.84	11.12
1959	61.15	34.70	26.28	25.16
1960	59.16	33.18	27.22	30.66
1961	31.02	32.55	0.49	0.58
TOTAL 1957- 1961	261.31	174.57	88.52	88.47
1969	65.76	36.83	28.89	30.15
1970	50.39	38.11	15.56	15.05
1971	49.36	34.34	13.87	13.77
1972	42.36	36.46	5.76	5.73
1973	49.51	37.94	11.60	9.50
TOTAL 1969-1973	257.38	183.73	75.68	74.20

TABLE 2. 5 UPPER TAYLOR CREEK 1957

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PRIDICTED RUNOFF BASE	DIRECT	TOTAL	MEASURED RUNOFF TOTAL
1	1.52	1.09	3.17	0.38	0.053	0.0	0.053	0.056
2	3.76	1.65	3.60	1.99	0.118	0.005	0.124	0.072
3	4.31	4.08	5.15	-1.01	1.227	0.018	1.246	0.690
4	5.61	3.90	4.91	0.78	0.926	0.004	0.929	0.891
5	7.37	4.40	5.61	1.07	1.865	0.032	1.897	2.194
6	4.91	4.21	5.18	-0.66	1.345	0.009	1.353	1.454
7	7.00	4.47	5.88	0.23	2.273	0.032	2.305	2.431
8	9.12	3.19	6.63	0.44	4.824	0.664	5.488	5.149
9	10.62	4.27	6.85	0.09	5.641	0.801	6.441	6.236
10	1.20	1.98	5.20	-2.13	1.352	0.0	1.353	1.425
11	0.48	1.59	3.47	-1.21	0.071	0.0	0.071	0.099
12	4.15	1.23	3.66	2.49	0.416	0.014	0.430	0.254
TOTAL OR AVERAGE	60.02	36.05	4.95	2.28	20.111	1.579	21.689	20.949

ALL VALUES ARE IN INCHES

TABLE 2. 6 UPPER TAYLOR CREEK 1958

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PREDICTED RUNOFF BASE	DIRECT	TOTAL	MEASURED RUNOFF TOTAL
1	6.06	2.17	6.06	0.71	2.950	0.228	3.178	2.417
2	1.01	2.35	4.83	2.18	0.832	0.0	0.832	0.448
3	6.08	2.55	5.21	1.99	1.512	0.020	1.532	1.948
4	1.79	3.79	4.57	2.69	0.691	0.0	0.691	0.471
5	3.80	3.22	3.87	0.35	0.228	0.001	0.229	0.165
6	5.27	3.35	3.11	1.85	0.063	0.007	0.070	0.095
7	6.82	5.78	5.59	-1.02	1.973	0.084	2.057	2.113
8	7.40	5.06	5.42	0.28	1.980	0.087	2.066	1.699
9	5.24	4.20	5.19	-0.18	1.221	0.003	1.223	1.170
10	3.43	3.04	4.64	-0.30	0.690	0.001	0.691	0.479
11	0.44	1.49	3.74	-1.20	0.156	0.0	0.156	0.138
12	2.62	1.09	3.28	1.41	0.114	0.002	0.116	0.125
TOTAL OR AVERAGE	49.96	38.09	4.63	-0.97	12.409	0.432	12.841	11.119

ALL VALUES ARE IN INCHES

TABLE 2. 7 UPPER TAYLOR CREEK 1959

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PREDICTED RUNOFF BASE	PREDICTED RUNOFF DIRECT	PREDICTED RUNOFF TOTAL	MEASURED RUNOFF TOTAL
1	3.26	1.53	4.50	1.40	0.674	0.017	0.691	0.473
2	0.71	1.56	4.60	-1.46	0.612	0.0	0.612	0.294
3	7.48	2.65	5.73	1.55	2.851	0.435	3.286	3.231
4	2.11	3.37	4.56	1.90	0.648	0.0	0.648	0.311
5	5.46	3.29	3.53	1.93	0.227	0.011	0.238	0.156
6	12.49	3.31	6.55	0.52	5.287	3.378	8.665	9.117
7	6.12	5.42	5.51	-0.93	1.632	0.001	1.633	1.395
8	3.91	4.46	4.67	1.39	0.734	0.0	0.734	0.734
9	6.39	2.72	5.33	1.87	1.748	0.040	1.788	2.700
10	8.55	2.47	6.06	1.37	4.037	0.680	4.717	4.473
11	3.32	2.59	6.04	-1.83	2.573	0.006	2.579	1.835
12	1.45	1.34	4.64	-0.58	0.684	0.0	0.684	0.390
TOTAL OR AVERAGE	61.15	34.70	5.14	0.18	21.708	4.468	26.276	25.157

ALL VALUES ARE IN INCHES

TABLE 2. 8 UPPER TAYLOR CREEK 1960

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

					PRIDICTED RUNOFF			MEASURED RUNOFF
MO	RAIN	ET	STOR	DELSTOR	BASE	DIRECT	TOTAL	TOTAL
1	0.34	1.29	3.93	-1.18	0.232	0.0	0.232	0.245
2	6.54	2.09	5.65	1.98	2.307	0.166	2.472	2.798
3	5.12	2.75	5.48	-0.39	2.275	0.433	2.755	3.453
4	2.26	3.01	4.26	-1.14	0.393	0.0	0.393	0.296
5	2.29	2.89	3.39	-0.69	0.082	0.0	0.082	0.097
6	10.15	4.61	5.31	2.71	2.398	0.426	2.824	2.724
7	8.92	5.04	5.44	1.68	1.955	0.243	2.198	2.147
8	4.41	4.33	5.89	-2.68	2.721	0.037	2.758	4.105
9	15.26	2.68	7.11	3.16	7.274	2.142	9.416	10.522
10	1.78	1.82	6.07	-3.37	3.306	0.028	3.334	3.999
11	1.36	1.67	4.61	-0.99	0.679	0.001	0.680	0.252
12	0.73	0.99	3.59	-0.03	0.072	0.0	0.072	0.026
TOTAL OR AVERAGE	59.16	33.18	5.07	-1.24	23.692	3.526	27.218	30.664

ALL VALUES ARE IN INCHES

TABLE 2. 9 UPPER TAYLOR CREEK 1961

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DEL STOR	PRIDICTED RUNOFF BASE	DIRECT	TOTAL	MEASURED RUNOFF TOTAL
1	1.98	2.18	3.62	-0.33	0.133	0.001	0.134	0.121
2	0.87	1.78	2.79	-0.93	0.022	0.0	0.022	0.043
3	1.60	2.07	1.98	-0.48	0.012	0.0	0.012	0.020
4	1.25	2.15	1.50	-0.91	0.008	0.0	0.008	0.011
5	4.60	2.05	0.95	2.54	0.006	0.005	0.011	0.007
6	4.38	4.54	3.24	-0.21	0.043	0.011	0.054	0.069
7	3.99	4.67	2.90	-0.71	0.027	0.003	0.030	0.060
8	6.15	3.99	3.00	2.07	0.077	0.021	0.098	0.085
9	1.81	4.09	3.19	-2.36	0.078	0.0	0.078	0.099
10	3.11	2.25	2.34	0.85	0.017	0.0	0.018	0.028
11	1.10	1.84	2.56	0.76	0.019	0.0	0.019	0.030
12	0.18	0.96	1.79	-0.79	0.010	0.0	0.010	0.011
TOTAL OR AVERAGE	31.02	32.55	2.48	-2.02	0.452	0.041	0.493	0.584

ALL VALUES ARE IN INCHES

TABLE 2.10 UPPER TAYLOR CREEK 1969

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PRIDICTED RUNOFF BASE	DIRECT	TOTAL	MEASURED RUNOFF TOTAL
1	2.04	2.09	4.50	-0.65	0.579	0.013	0.592	0.274
2	1.22	2.51	2.79	-1.49	0.201	0.0	0.201	0.154
3	8.39	2.13	4.88	3.00	0.883	2.381	3.264	4.285
4	1.69	4.31	3.72	-3.05	0.423	0.001	0.425	0.261
5	7.29	2.68	4.74	3.04	0.750	0.813	1.563	1.615
6	8.41	2.65	5.56	0.10	0.988	4.678	5.667	6.085
7	5.76	5.14	4.78	-0.52	0.686	0.054	0.740	0.824
8	9.38	4.64	5.64	0.42	1.065	3.246	4.311	4.576
9	5.52	3.48	5.48	0.60	0.950	0.487	1.438	1.674
10	10.48	3.65	5.60	0.84	1.050	4.943	5.993	5.857
11	3.83	1.52	5.77	-0.74	1.091	1.965	3.056	3.277
12	2.16	2.07	5.44	-1.55	0.957	0.681	1.637	1.270
TOTAL OR AVERAGE	65.76	36.88	4.92	0.0	9.622	19.264	28.886	30.151

ALL VALUES ARE IN INCHES

TABLE 2.11 UPPER TAYLOR CREEK 1970

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PREDICTED RUNOFF			MEASURED RUNOFF
					BASE	DIRECT	TOTAL	TOTAL
1	4.91	1.61	5.58	0.44	1.039	1.830	2.868	2.937
2	2.67	2.19	5.08	-0.46	0.720	0.218	0.938	1.137
3	7.03	2.20	5.15	1.43	0.845	2.554	3.398	3.577
4	0.14	3.98	3.66	-4.28	0.445	0.001	0.445	0.342
5	6.05	2.31	1.47	3.47	0.148	0.127	0.275	0.354
6	6.84	5.25	5.24	0.36	0.839	0.393	1.232	0.978
7	7.00	4.80	5.52	-0.01	0.991	1.226	2.217	2.337
8	5.69	4.32	5.49	-0.19	0.974	0.589	1.563	1.114
9	5.17	4.57	4.38	0.06	0.521	0.019	0.540	0.362
10	4.41	3.02	5.45	-0.26	0.960	0.688	1.648	1.469
11	0.05	2.66	3.37	-2.92	0.326	0.0	0.326	0.240
12	0.42	1.21	1.52	0.90	0.110	0.0	0.110	0.153
TOTAL OR AVERAGE	50.39	38.11	4.32	-3.28	7.917	7.645	15.562	15.050

ALL VALUES ARE IN INCHES

TABLE 2.12 UPPER TAYLOR CREEK 1971

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

					PRIDICTED RUNOFF			MEASURED RUNOFF
MO	RAIN	ET	STOR	DELSTOR	BASE	DIRECT	TOTAL	TOTAL
1	0.10	0.60	0.91	-0.58	0.078	0.0	0.078	0.132
2	3.43	1.55	1.40	1.82	0.100	0.008	0.108	0.216
3	1.27	2.51	1.66	-1.36	0.120	0.0	0.120	0.144
4	0.37	1.10	0.66	0.79	0.066	0.0	0.066	0.047
5	5.51	3.17	1.48	2.20	0.128	0.017	0.145	0.100
6	12.01	5.63	4.54	3.32	0.766	2.296	3.062	2.789
7	6.98	4.42	5.70	0.18	1.086	1.292	2.378	2.501
8	6.15	3.99	5.77	-0.01	1.129	1.055	2.184	2.323
9	6.00	3.62	5.60	-1.87	1.027	3.216	4.243	3.932
10	5.00	3.10	4.83	1.15	0.709	0.039	0.747	0.983
11	0.78	2.62	4.25	-2.37	0.513	0.016	0.529	0.307
12	1.70	2.04	2.65	-0.54	0.205	0.0	0.205	0.202
TOTAL OR AVERAGE	49.36	34.34	3.30	1.15	5.926	7.940	13.866	13.765

ALL VALUES ARE IN INCHES

TABLE 2.13 UPPER TAYLOR CREEK 1972

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PREDICTED RUNOFF BASE	PREDICTED RUNOFF DIRECT	PREDICTED RUNOFF TOTAL	MEASURED RUNOFF TOTAL
1	0.25	1.13	1.81	-1.01	0.129	0.0	0.129	0.143
2	2.35	1.76	2.15	0.44	0.145	0.0	0.145	0.160
3	4.53	1.71	1.58	2.47	0.115	0.230	0.345	0.161
4	1.17	3.77	2.42	-2.80	0.195	0.010	0.205	0.327
5	5.09	3.74	1.78	1.21	0.135	0.007	0.142	0.164
6	6.96	4.90	3.82	1.25	0.462	0.353	0.815	1.093
7	3.75	5.16	3.61	-1.81	0.363	0.041	0.403	0.358
8	10.69	4.17	2.73	4.71	0.287	1.524	1.810	1.021
9	0.83	3.64	4.62	-4.02	0.657	0.547	1.205	1.785
10	1.66	2.62	2.33	-1.13	0.174	0.0	0.174	0.218
11	3.37	1.69	2.21	1.47	0.164	0.009	0.173	0.140
12	1.75	2.18	2.67	-0.64	0.207	0.004	0.212	0.156
TOTAL OR AVERAGE	42.36	36.46	2.65	0.14	3.034	2.725	5.758	5.727

ALL VALUES ARE IN INCHES

TABLE 2.14 UPPER TAYLOR CREEK 1977

MONTHLY AND ANNUAL PRECIPITATION, ET, MEAN SOIL MOISTURE STORAGE (STOR), CHANGE IN SOIL STORAGE (DELSTOR), PREDICTED RUNOFF (BASE,DIRECT,TOTAL) AND MEASURED RUNOFF

MO	RAIN	ET	STOR	DELSTOR	PRIDICTED RUNOFF BASE	DIRECT	TOTAL	MEASURED RUNOFF TOTAL
1	3.57	1.76	3.06	1.52	0.266	0.022	0.290	0.311
2	1.69	2.31	3.83	-1.02	0.355	0.052	0.407	0.390
3	3.06	3.04	2.50	-0.18	0.191	0.004	0.195	0.325
4	1.30	2.92	2.03	-1.77	0.146	0.003	0.149	0.132
5	5.53	3.55	2.06	1.81	0.159	0.013	0.172	0.145
6	7.87	4.57	3.95	2.55	0.502	0.245	0.747	0.815
7	9.53	5.10	5.81	0.58	1.153	2.696	3.849	2.809
8	6.20	4.13	5.74	-0.21	1.111	1.170	2.282	1.770
9	4.34	3.20	5.66	-0.16	1.027	0.272	1.299	1.362
10	3.66	2.84	5.52	-0.54	0.991	0.372	1.363	1.099
11	1.19	2.57	4.52	-2.03	0.602	0.043	0.645	0.260
12	1.57	1.95	2.67	-0.59	0.206	0.0	0.206	0.078
TOTAL OR AVERAGE	49.51	37.94	3.95	-0.03	6.712	4.892	11.604	9.497

ALL VALUES ARE IN INCHES

III. ANALYSES OF STORAGE/TREATMENT CAPABILITIES OF A FRESHWATER MARSH

INTRODUCTION

The use of swamps, marshes and available depressions for storage and possible treatment of stormwater runoff has been suggested in recent years. Recent studies have quantified nutrient uptake by marshes and swamps (Shih and Hallett, 1974; McPherson, et al., 1976). The main objective of this chapter is to determine the ability of natural marshes to serve as quantity and quality control areas. For this purpose, the Chandler Slough Marsh is studied in detail because of availability of previous work and recent data.

DESCRIPTION OF CHANDLER SLOUGH

Chandler Slough Marsh is located within the Lower Kissimmee River Basin in Okeechobee County. The study area, shown in figure 3.1, is the portion of Chandler Slough between C-38 and U.S. 98, the downstream end of a drainage system which includes Gore Slough, Fish Slough, Cypress Slough, Ash Slough and Peat Marsh. The drainage area is approximately 74,000 acres of land dominated by improved pasture.

In order to properly evaluate the attenuation abilities and treatment efficiency of Chandler Slough Marsh, several fundamental hydrologic relationships are determined, particularly the stage-volume-discharge relationships. Hydrologic data used for the research include daily mean inflows at the North and South Bridge stations and daily mean stage record at Chandler Slough Marsh station, (see figure 3.1 for location). The stage-area-volume relationships in figure 3.2 are derived from transects of Chandler Slough Marsh supplied by the SFWMD.

Since the outlfow from Chandler Slough is not gauged, the stage-discharge relationship, figure 3.3, is estimated by plotting receding inflow vs. stage measured at the Chandler Slough Marsh station and fitting these data with a curve. The assumption here is that for slow recession periods, inflow is approximately equal to outflow. Note in figure 3.3 at stage 29 feet above MSL the inflow is minimal although there are still fluctuations in the stage below this level due to backwater from C-38 and secondary inflows and outflows (e.g., evaporation, seepage). To allow for this fluctuation, zero depth is set at 28 feet above MSL since the stage rarely is below this level, and 29 feet above MSL can be thought of as a "weir" height corresponding to the point at which actual outflow in the marsh begins. The following equation represents the depth-discharge function:

$$Q = 215\ (D-1)^{2.1} \qquad (3.1)$$

where Q = daily mean outflow, cfs,
D = depth above 28 ft MSL, ft, and
$Q = 0$ when $D \leq 1$

These hydrologic relationships are used in the Storage/Treatment portion of the Storm Water Management Model, Huber, et al., 1975, to simulate the hydrology of Chandler Slough Marsh. Verification of these relationships is achieved by comparing measured parameters with predicted parameters, as shown in figure 3.4 for stage in the marsh.

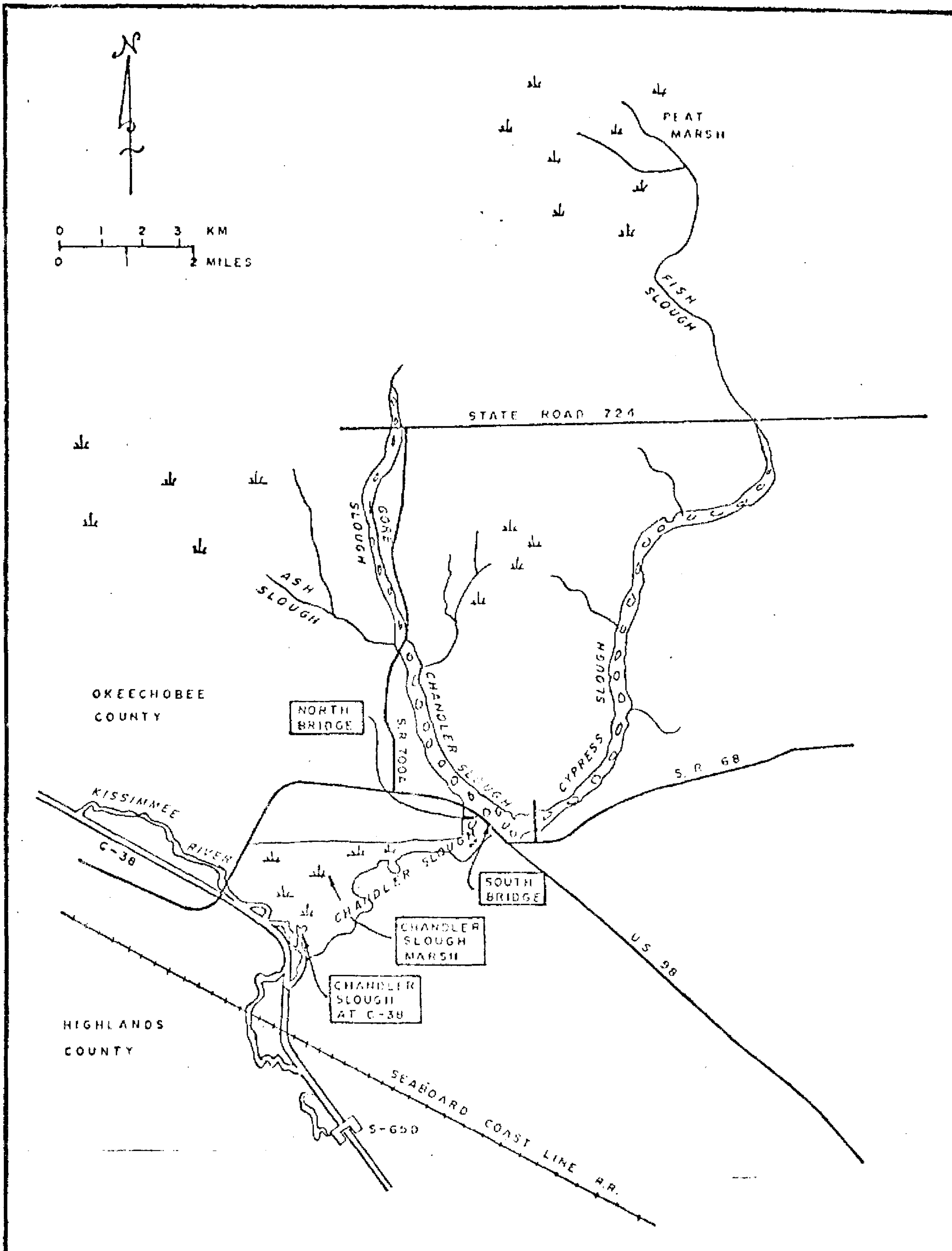
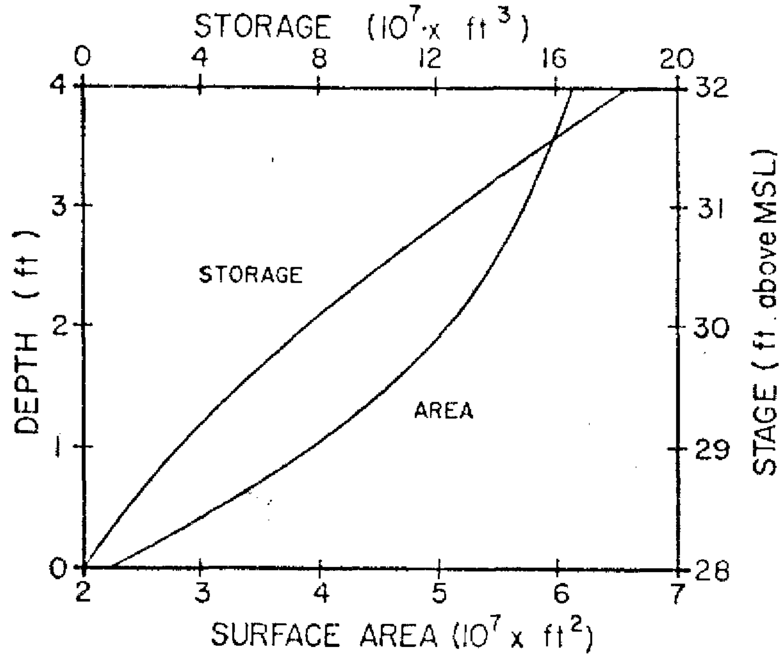


Figure 3.1 LOCATION OF CHANDLER SLOUGH DRAINAGE SYSTEM AND WATER SAMPLING STATIONS (from Federico, et al., 1978)

FIGURE 3.2 Stage-Area-Volume relationships for Chandler Slough Marsh



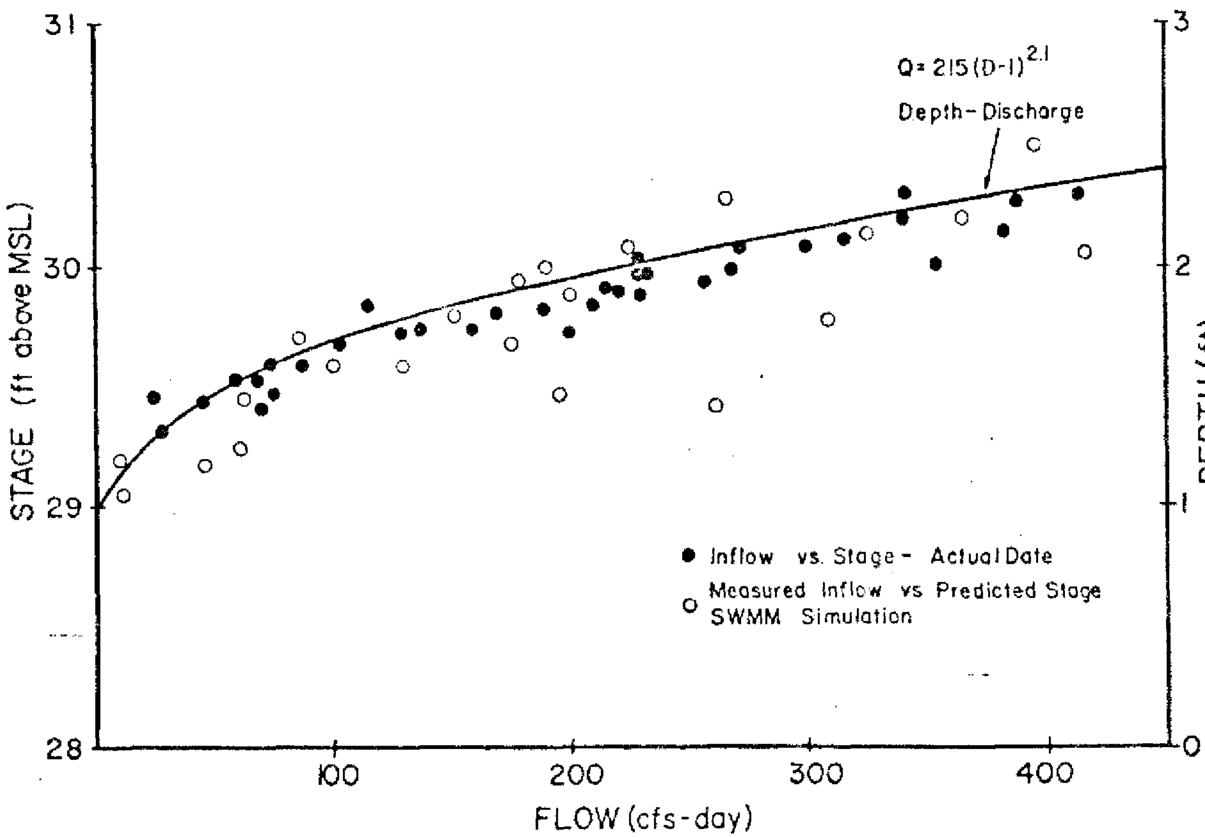


FIGURE 3.3 STAGE VS. FLOW AT CHANDLER SLOUGH MARSH STATION

FLOOD PEAK ATTENUATION

Flood attenuation is a function of storage capacity, with greater attenuation related to greater storage capacity. The effectiveness of a marsh in attenuating a given flood peak is related to the available storage (i.e., initial conditions) and the magnitude of the flood event. Also, decreasing the size of the marsh areas will effectively reduce storage time (residence time), implying, therefore, that a decrease in the amount of attenuation will also occur. In addition, it may be desirable from a quantity and/or quality standpoint to control the marsh's outflow and storage level. Attenuation factor is defined as the ratio of outflow peak discharge to inflow peak discharge. Therefore, analyses are performed to determine how the attenuation factor is related to the percent of a catchment area in marshes, initial storage, and stage-discharge function.

Since the hydrologic relationships for the marsh are known, it is desirable to keep the marsh area constant and vary the catchment size. In the simulation scheme, all the marsh area is assumed to be at the downstream end of the catchment. Also, to evaluate the effect of a control structure on the marsh outflow, two additional arbitrary depth-discharge relationships are modeled along with the uncontrolled (existing natural) relationship. Figure 3.5 shows the three cases simulated: 1) uncontrolled outflow, 2) broad-crested weir length 40 feet and weir height at 29 feet above MSL and, 3) broad-crested weir with weir length of 40 feet and weir height at 30 feet above MSL.

The motivation for the attenuation analysis is the relationship of Barnes and Golden (1966) for attenuation of the mean annual flood. They derive a curve for the reduction of the mean annual flood discharge in relation to the percent of the drainage area in lakes and swamps by comparing discharge records for drainage basins containing lakes and swamps with otherwise equivalent basins.

Since the entire Lower Kissimmee Basin has discharge records only at the upper and lower boundaries, it would be necessary to simulate on a long-term basis the hydrology of a lateral tributary in the Lower Kissimmee Basin to define the mean annual flood event for that lateral watershed. This could be accomplished by continuous simulation using HLAND, (Huber, et al., 1976; Bedient, 1975), although this would require simulating many years just to find the average mean annual flood.

Instead, a simpler method is employed to estimate the mean annual flood hydrograph. The method involves certain assumptions about the flood peak, the volume of the event, and the geometry of the hydrograph.

The flood peak is taken from the relationship of Barnes and Golden for the maximum mean annual flood peaks within the region which includes the Kissimmee River Basin:

$$Q_{peak} = 285\ A_d^{0.5},\quad 10 \le A_d \le 100 \qquad (3.2)$$

where Q_{peak} = mean annual flood peak, cfs, and

A_d = drainage area, sq. miles.

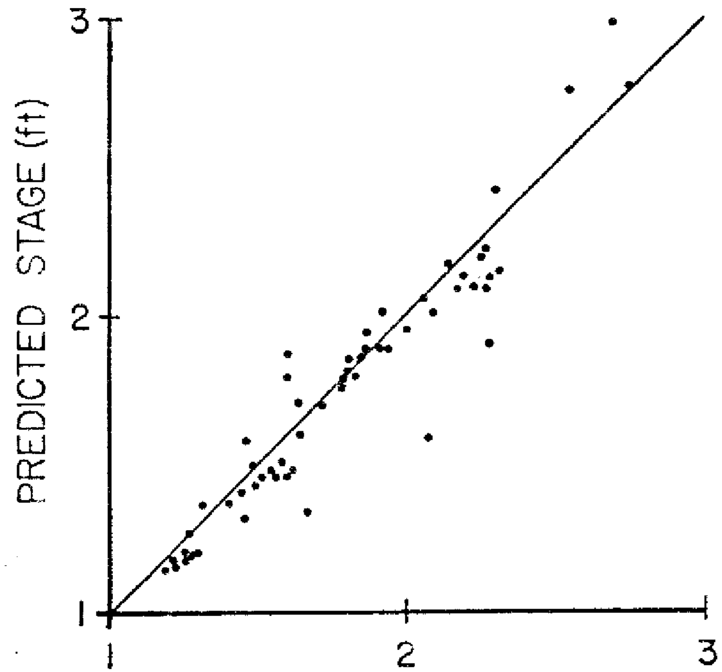


FIGURE 3.4 MEASURED STAGE (ft)

Measured Stage at Chandler Slough Marsh Station vs. Stage predicted by SWMM.

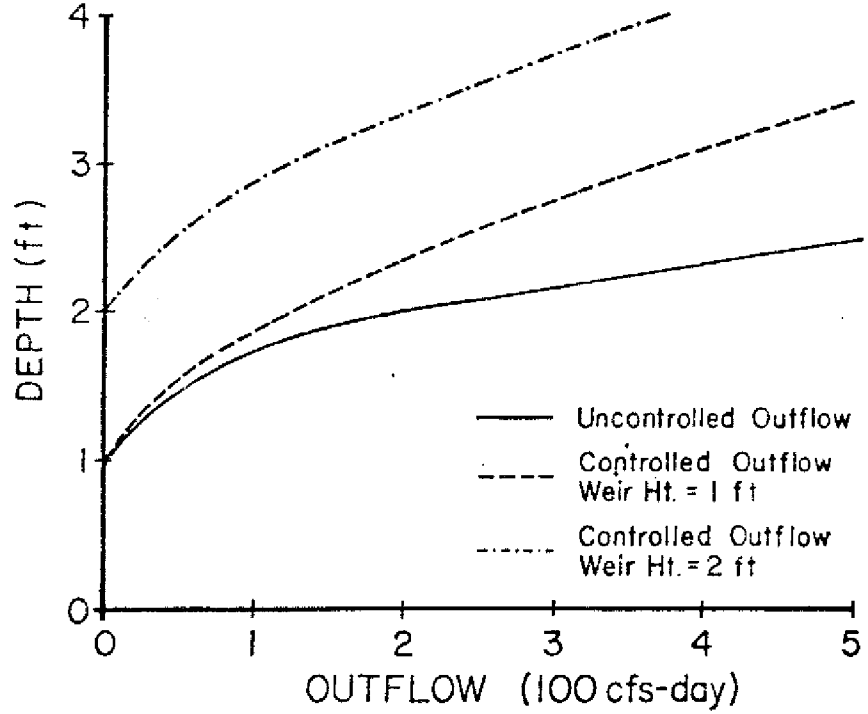


FIGURE 3.5 DEPTH VS. DISCHARGE

Depth vs. discharge for three cases simulated in the flood peak attenuation analysis.

This relationship is derived from data up to 1961 and is generalized for a large region, not just Chandler Slough drainage area. In addition, the mean annual flood peak may be higher now because of increased development in the basin. An example of how agricultural development influences discharge in the neighboring Taylor Creek Watershed is illustrated in figure 3.6.

The Barnes and Golden relationship provides the magnitude of the flood peak but says nothing about the total volume of the flood event nor the time to the peak. As the size of the catchment increases, both of these parameters increase.

Since the return period for the mean annual flood is 2.33 years, the maximum 24-hour rainfall to be expected once in 2 years is assumed to be the event which produces the mean annual flood. Actually, the 2 year maximum 24-hour rainfall may not be related to a flood with a simular return period, since the magnitude of a flood is controlled, to a large extent, by antecedent conditions. For the Chandler Slough area, the maximum 24-hour rainfall to be expected once in 2 years is 5.0 inches (Hershfield, 1961). This represents the maximum point value. The ratio of area rainfall (i.e., spatially averaged rainfall) to point to point rainfall for durations of 24 hours is between 0.93 to 0.99 for areas in the range of interest in this analysis (Eagleson, 1970). The area rainfall producing the mean annual flood is thus assumed to be 0.96 times the point rainfall.

To estimate the volume of runoff from the rainfall of 4.8 inches, the Runoff Curve Number Method (SCS, 1972) is used. Using the antecedent moisture conditions with the highest runoff potential, the Runoff Curve Number Method gives the runoff equal to 3.9 inches over the drainage area excluding the marsh area. Hence, the runoff which produces the flood event is estimated to be about 4 inches per acre, which probably is more extreme than the actual mean annual flood. To provide a lower bound for the mean annual flood volume, analysis is also performed using total runoff equal to 2 inches per acre. These two volume assumptions are made because data concerned with the return periods of total flood volumes are not available.

As for the time to the peak, T_p, a dimensionless triangular unit hydrograph figure 3.7, is employed. This hydrograph was developed from a large number of natural unti hydrographs from watersheds varying widely in size and geographical locations (SCS, 1972). Since the total flood volume and Q_{peak} are know for a given catchment size and 37.5% of the volume is under the rise limb of this unit hydrograph, T_p is as follows:

$$T_p = 2(.375\ \mathrm{Vol})/Q_{peak} \tag{3.3}$$

where Vol = total flood volume.

Knowing the peak and assuming the above mentioned characteristics, inflow hydrographs can be determined for various ratios of marsh area to catchment area. Two examples are shown in figure 3.8. Note that as the fraction in marsh, X, decreases (i.e., catchment area increases) the total volume and time to peak increase.

These inflow hydrographs are not necessarily related to the "true" mean annual flood except that they both share the same peak. Nevertheless, the hydrographs allow for a consistent evaluation of attenuation under various conditions.

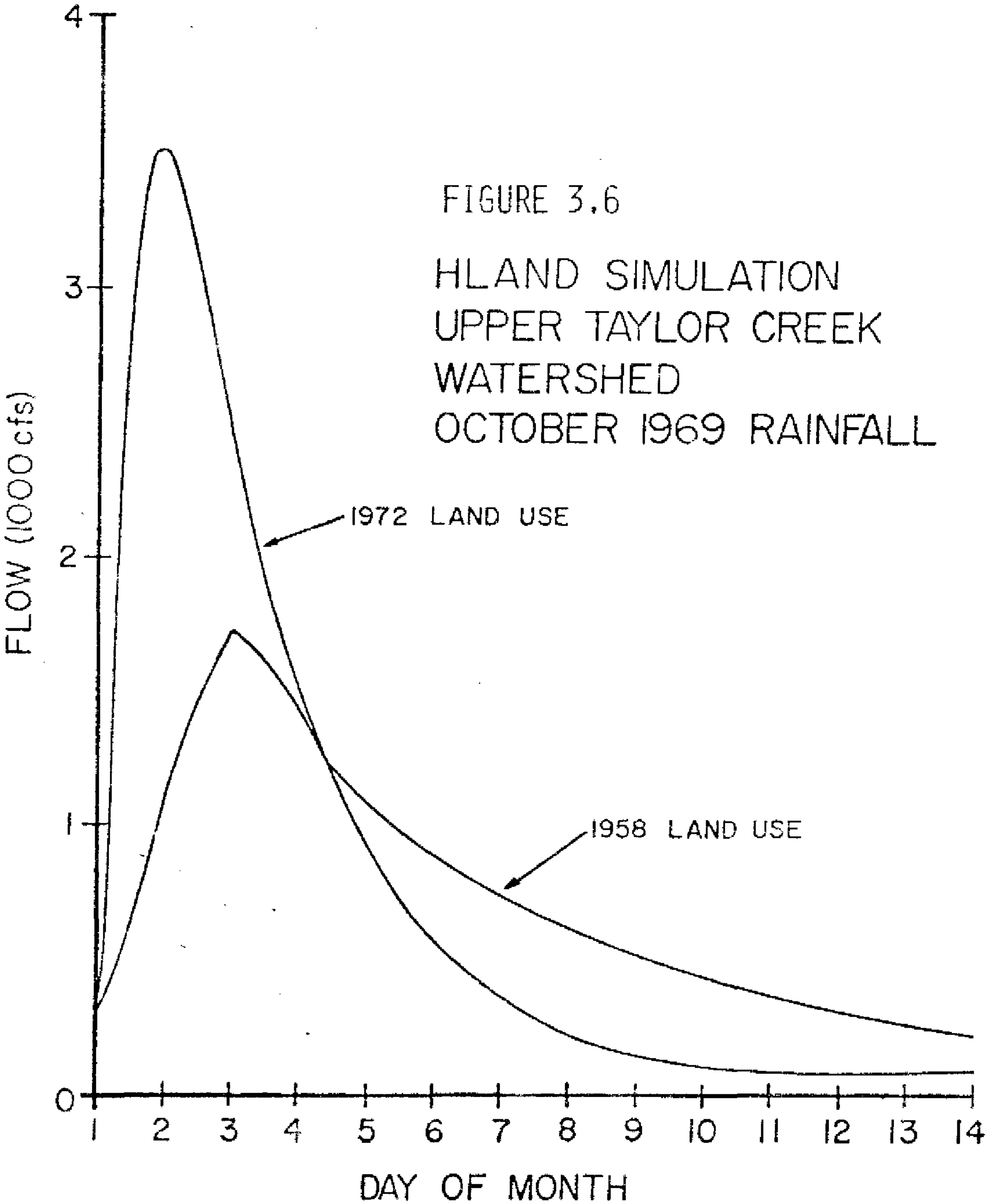


FIGURE 3.6

HLAND SIMULATION
UPPER TAYLOR CREEK
WATERSHED
OCTOBER 1969 RAINFALL

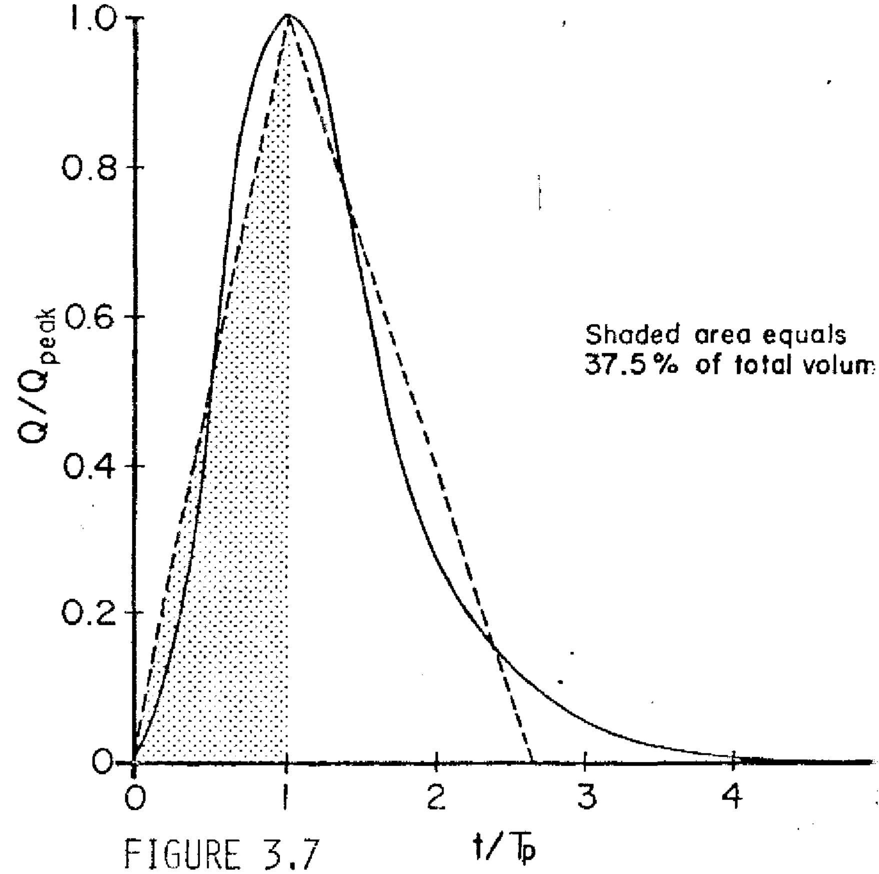


FIGURE 3.7

DIMENSIONLESS CURVILINEAR UNI
AND EQUIVALENT TRIANGULAR
HYDROGRAPHS (from SCS National
Engineering Handbook - Sec. 4
Hydrology 1972)

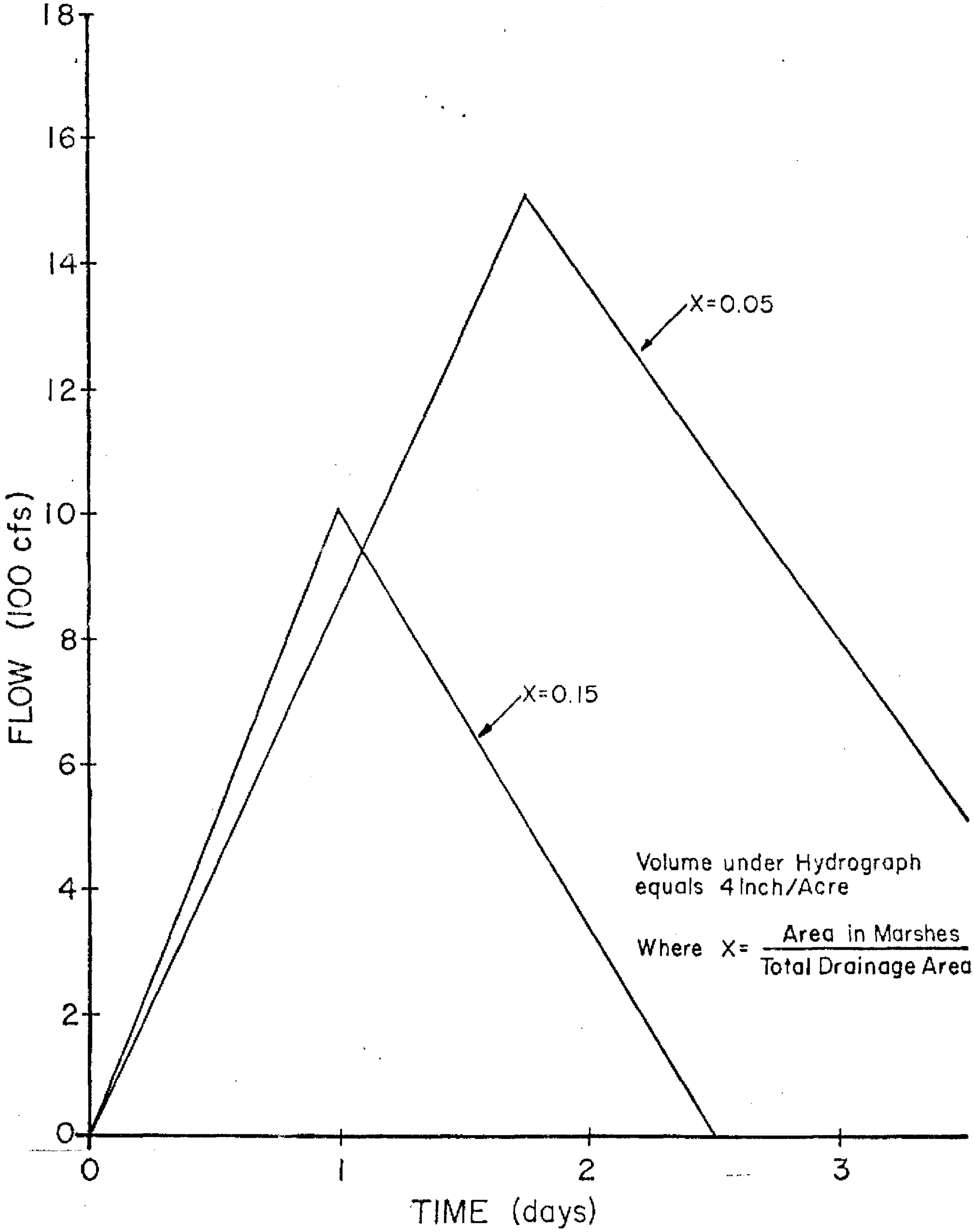


FIGURE 3.8 INFLOW HYDROGRAPHS

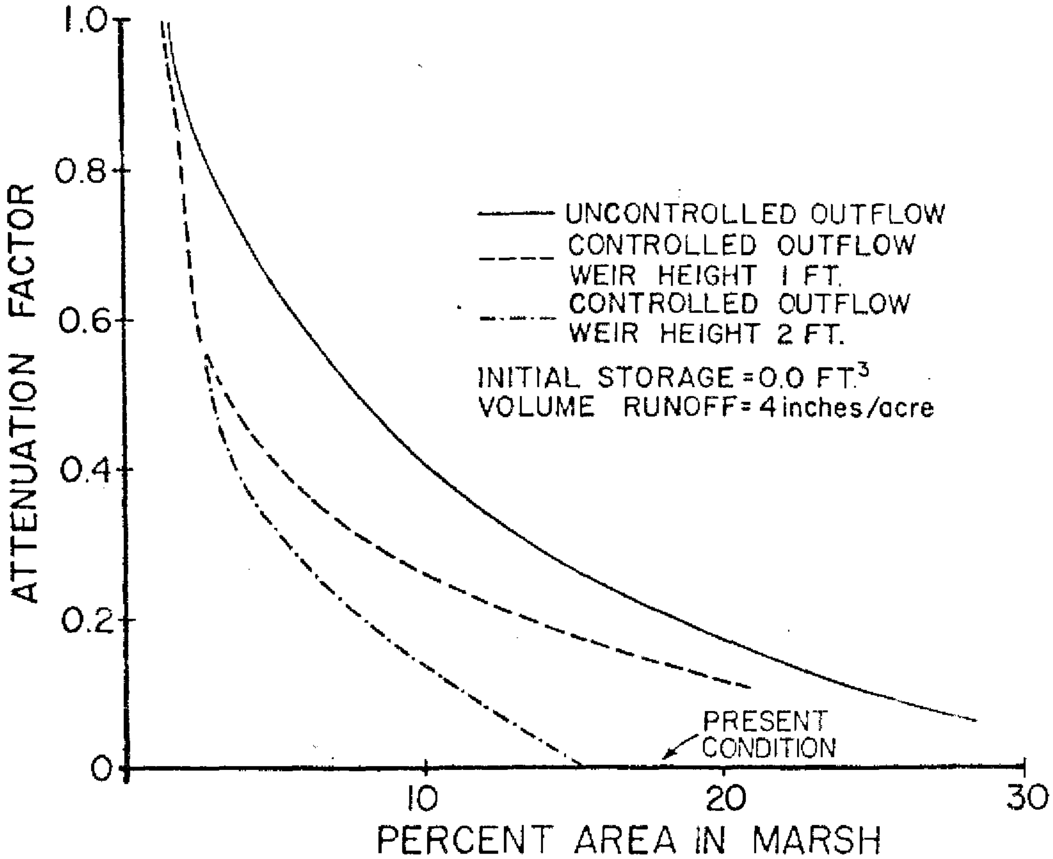


FIGURE 3.9A MAXIMUM FLOOD PEAK ATTENUATION VS. PERCENT AREA IN MARSH

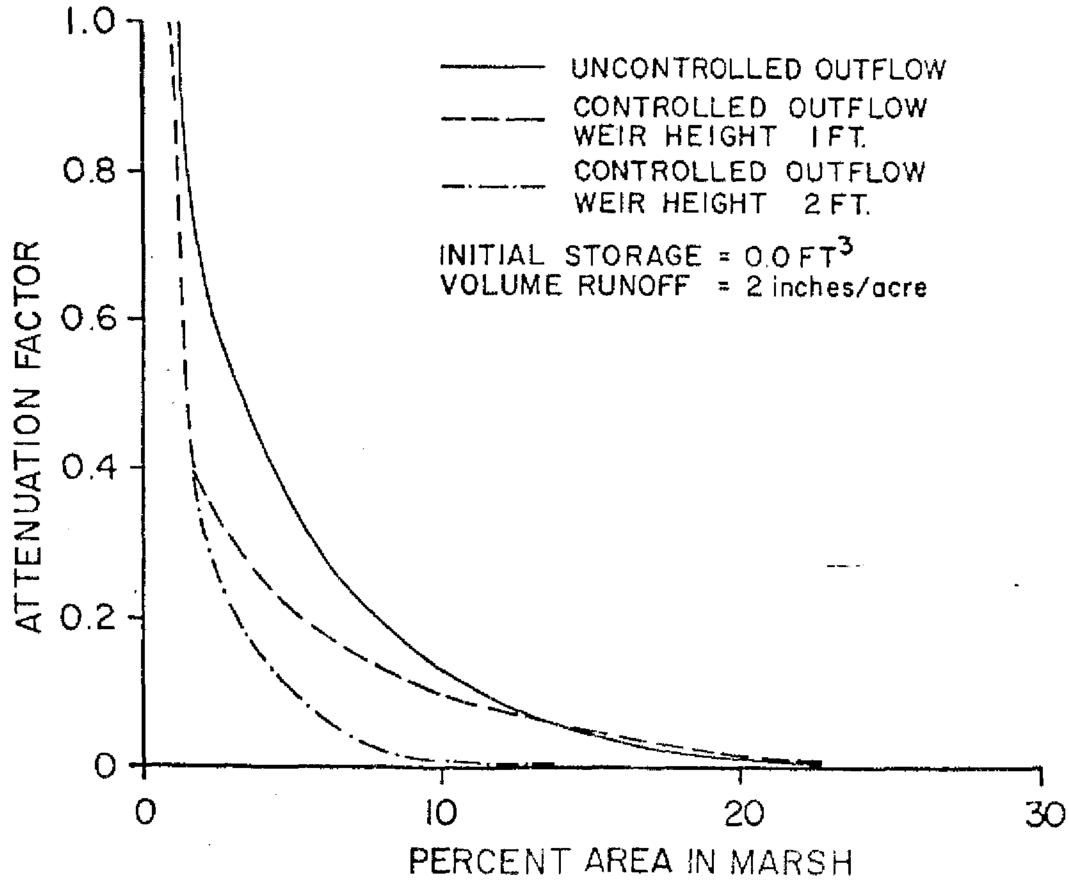
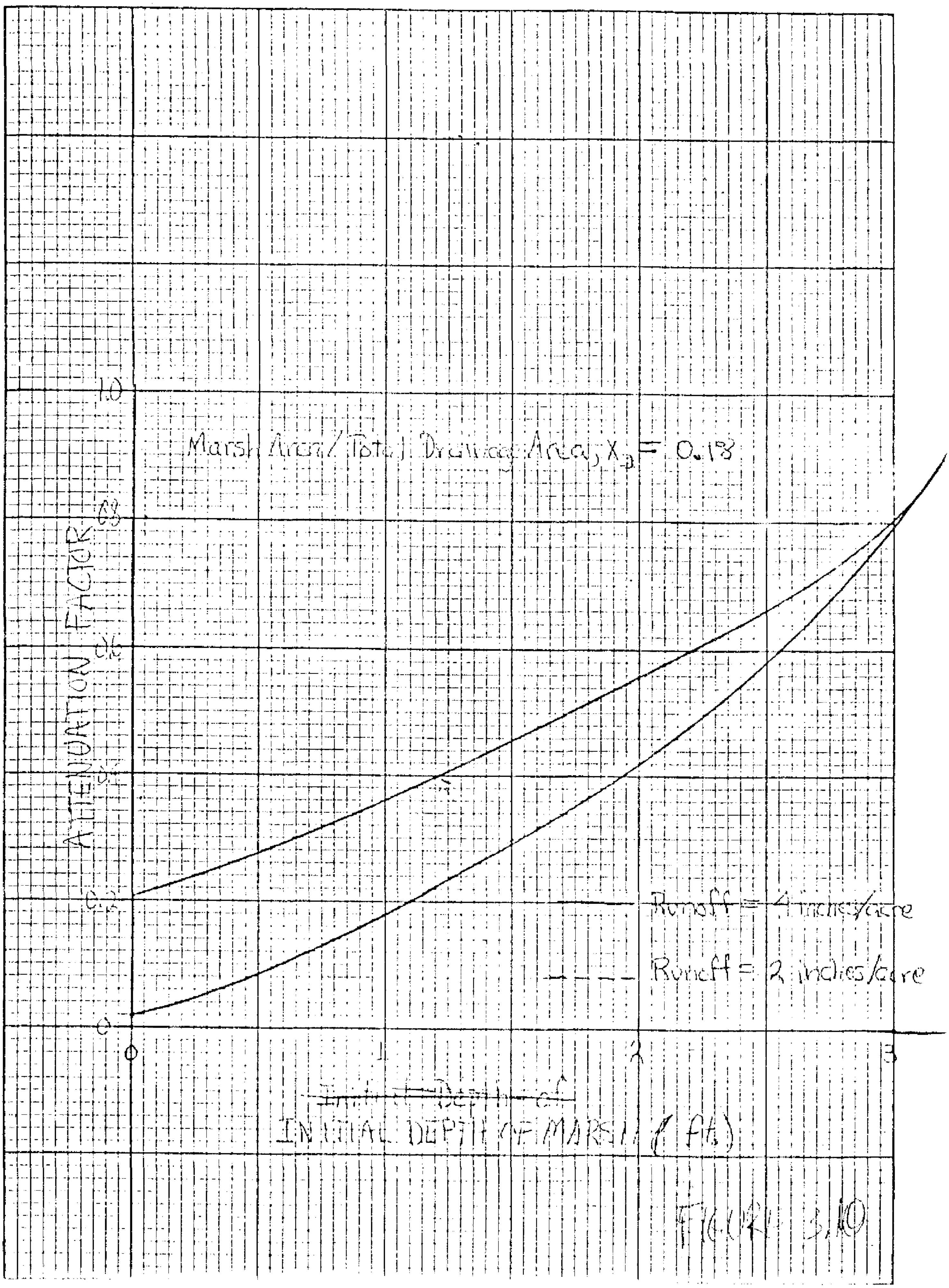


FIGURE 3.9B MAXIMUM FLOOD PEAK ATTENUATION



ATTENUATION FACTOR
1.0
0.8
0.6
0.2
0
Marsh Area / Total Drainage Area, X_D = 0.18
Runoff = 4 inches/acre
Runoff = 2 inches/acre
0
1
2
3
~~Initial Depth of~~
INITIAL DEPTH OF MARSH (Ft)

FIGURE 3.10

Since greater storage implies greater attenuation, maximum attenuation occurs when the initial depth of the marsh is zero. Maximum attenuation will rarely be realized since a major flood will rarely occur when the marsh depth is zero. For the marsh depth to be zero, the groundwater levels within the drainage basin would also have to be low. For the three cases modeled, maximum attenuation, as it relates to percent of catchment in marsh, is shown in figures 3.9a and 3.9b. The arrow represents the present condition of Chandler Slough-Cypress Slough Watershed with 18 percent of the catchment in marshes, which is less than half the area in marshes in 1958. At the 18 percent level the maximum attenuation factor (ratios of outflow peaks to inflow peaks) for the three cases are about 0.22, 0.14 and 0.0 (total capture), respectively, with the 4 inch per acre event and 0.02, 0.03 and 0.0, respectively, with the 2 inch per acre event. The conclusion drawn from this analysis is that control structures increase the single event attenuation achieved by the marsh although the control structures modeled lose their effectiveness when the marsh area decreases below about 5 percent.

Figure 3.10 shows the effect of initial condition of the marsh on its ability to reduce the flood peak for the present condition. As initial depth increases, available storage decreases and the attenuation factor increases. This figure also shows results for a more conservative estimate, 2 inches per area, of runoff. Here again, it is evident that a control structure with a gate is advantageous, since the marsh stage could be regulated to increase the marsh's ability to reduce the peak discharges. This may only consist of drawing down the marsh stage at the beginning of the wet season which may also be advantageous from a water quality standpoint.

EVALUATION OF TREATMENT EFFICIENCY

Mass Loading

Mass loadings to and from the Chandler Slough Marsh are calculated in order to determine the effectiveness of the marsh in nutrient removal. A water quality sampling program for the Chandler Slough area was initiated by the FCD in 1974 (Federico, et al., 1978). SFWMD personnel indicate that 1975 data are the most complete with regard to sampling around major runoff events, hence, 1975 is chosen to evaluate removal efficiency. Loadings for 1976 are also calculated although samples were not taken during May, the beginning of the 1976 wet season. Although a wide range of chemical parameters were sampled, only total phosphorus and chloride ion are included in the analysis discussed below, the former because of its significance in the eutrophication process and the latter because it is a conservative substance. Since outflow from Chandler Slough is not gauged and therefore must be generated by simulation, the conservative chloride ion serves as an indicator of the accuracy of outflow prediction. In addition, total inflow is taken as the sum of the two major tributaries, Chandler Slough at North Bridge and Cypress Slough at the South Bridge. All additional inflows and outflows, such as evaporation, seepage and rainfal, are assumed to be negligible and/or offsetting. More detailed water chemistry investigations in Chandler Slough Marsh, including description of sampling procedures are in Federico et al., 1978.

Water chemistry sampling locations include both North and South Bridges and a station at C-38 (see figure 3.1). Concentration data are shown in Table 3.1 for 1975 and 1976. Data are intermittent, therefore, concentrations for days without data were generated by linear interpolation between the previous and next available data points. Knowing the concentrations of the parameters and the measured inflows and predicted outflows, mass loadings to and from

Chandler Slough Marsh are found. Tables 3.2 and 3.3 show the monthly summary of influxes and effluxes of flow, total phosphorus and chloride ion in 1975 and 1976, respectively. The 1975 and 1976 annual precipitation totals (measured at Basinger) are approximately 33% and 17% below the mean annual precipitation of 52 inches (SCS, 1973).

The overall removal of total phosphorus is 6.73 percent indicating that the marsh in 1975 has low effectiveness in removal of this nutrient. There is an apparent removal of 4.97 percent of the conservative chloride ion which suggests dilution by the presence of additional inflows and thus even a lower actual removal of total phosphorus than indicated.

Pollutographs of inflow and outflow, figure 3.11, illustrate the "first flush" effect during June - July of 1975, where undoubtedly much of the previous year's deposition of total phosphorus is released. During the remaining portion of the wet season and in 1976 there is a net reduction in total phosphorus between the inflow and outflow loads. The pollutograph peak in June corresponds to the daily mean inflow and daily mean outflow hydrograph peak, which is the largest daily mean flow of 1975. During this event, detention times are on the order of one day and average velocities are on the order of 0.1 ft/sec, assuming a uniform velocity distribution across the marsh cross-section. From a water quality standpoint, additional attenuation of the above mentioned peak would be desirable since detention times would increase and velocities decrease, possibly decreasing the release of total phosphorus.

The 1976 calculations indicate an 8.60% net removal of chloride ion and a 34.76% net removal of total phosphorus. The high net removal of total phosphorus is suspect since the first wet season samples were not taken until June 11 and about 25% of 1976 rainfall (measured at Basinger) occurs in May. In addition, about 17% of the measured inflow into Chandler Slough Marsh occurs prior to these first samples. The question arises: "Is there a period in 1976 of net phosphorus release similar to the 17 day period in June and July 1975?" Inflows similar in magnitude to the "flushing" inflows of 1975 begin on June 10, 1976. Figure 3.12 shows a comparison between daily mean inflows and daily mean stage for the similar events in 1975 and 1976 where both periods include the largest daily mean inflows of each year. During the 1976 event and for the remainder of 1976 the marsh acts as a phosphorus sink (21% net removal between June 10 and June 16). This figure illustrates the importance of antecedent conditions (i.e., stage) on the treatment efficiencies of the marsh. The marsh state prior to the 1975 peak is about 0.8 ft. lower than the stage prior to the 1976 peak. In 1976, with the higher stage, an additional 180 acres are inundated.

If a major flushing event occurs in 1976 it would have to occur prior to June 10. About 8260 acre-ft of inflow to the marsh is recorded between May 17 and June 9 which is equivalent to about 1.5 inches of runoff over the drainage areas. The largest daily mean inflow during this period occurs on June 1 and is 726 acre-ft which is only one third the magnitude of the largest daily mean inflow that produced to 1975 net release. If this inflow is assumed to be adequate to flush the marsh and the most extreme conditions are assumed, e.g., all of the May 1976 import (2.20 metric tons) and all of the 1975 deposition (2.33 metric tons) are released, the net removal of total phosphorus for 1976 would 17.3 percent.

Table 3.1 Total Phosphorus and Chloride Ion Concentrations for Chandler Slough Marsh, 1975-76.

Not Included

Table 3.2 Summary of Flow, Total Phosphorus and Chloride Ion Imports and Exports for Chandler Slough Marsh 1975

Month	Flow (acre-ft) Inflow[a]	Flow (acre-ft) Outflow[b]	Total Phosphorus (metric tons) Import	Total Phosphorus (metric tons) Export	Chloride Ion (metric tons) Import	Chloride Ion (metric tons) Export
Jan.	30	80	0.00	0.00	2	2
Feb.	30	40	0.00	0.00	3	3
Mar.	0	0	0	0	0	0
Apr.	0	0	0	0	0	0
May	0	0	0	0	0	0
June	8410	6720	3.75	5.09	190	120
July	9590	9880	4.40	4.05	290	291
Aug.	2590	3390	1.14	0.69	67	98
Sept.	5740	4990	1.43	0.84	198	164
Oct.	13990	12550	2.68	1.80	541	466
Nov.	6400	8760	1.31	1.22	234	298
Dec.	110	410	0.01	0.04	3	15
TOTAL	46890	46730	14.72	13.73	1528	1452

	Flow	Total Phosphorus	Chloride Ion
Net Change	-160	-0.99	-76
% Net Removal	0.35	6.73	4.97

[a]inflow is the sum of North Bridge and South Bridge discharges

[b]computed by SWMM

Table 3.3 Summary of Flow, Total Phosphorus and Chloride Ion Imports and Exports for Chandler Slough Marsh 1976

Month	Flow (acre-ft)		Total Phosphorus (metric tons)		Chloride Ion (metric tons)	
	Inflow[a]	Outflow[b]	Import	Export	Import	Export
Jan.	10	0	0.00	0.00	0	0
Feb.	0	0	0	0	0	0
Mar.	0	0	0	0	0	0
Apr.	0	0	0	0	0	0
May	3710	2860	2.20	0.67	138	70
June	14590	15020	8.18	5.74	438	372
July	5720	5440	1.85	1.28	161	146
Aug.	16840	17060	7.55	5.03	418	426
Sept.	4380	5030	1.57	1.24	119	130
Oct.	3110	3060	1.05	0.65	105	116
Nov.	20	70	0.00	0.01	1	3
Dec.	80	10	0.01	0.00	3	0
TOTAL	48360	48590	22.41	14.62	1383	1264

Net Charge	+130	-7.79	-119
% Net Removal	-0.27	34.76	8.60

[a] inflow is the sum of North Bridge and South Bridge discharges

[b] computed by SWMM

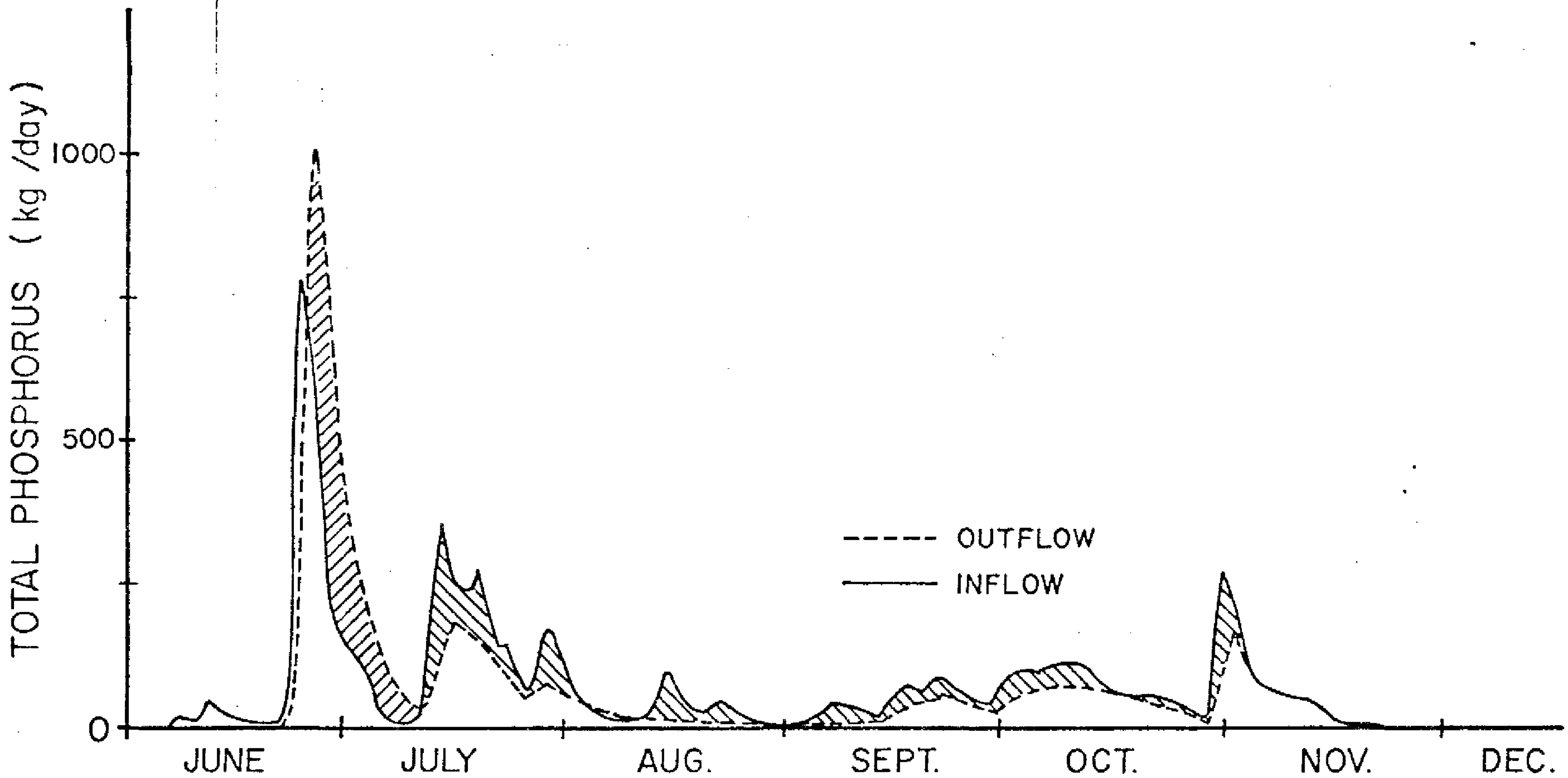
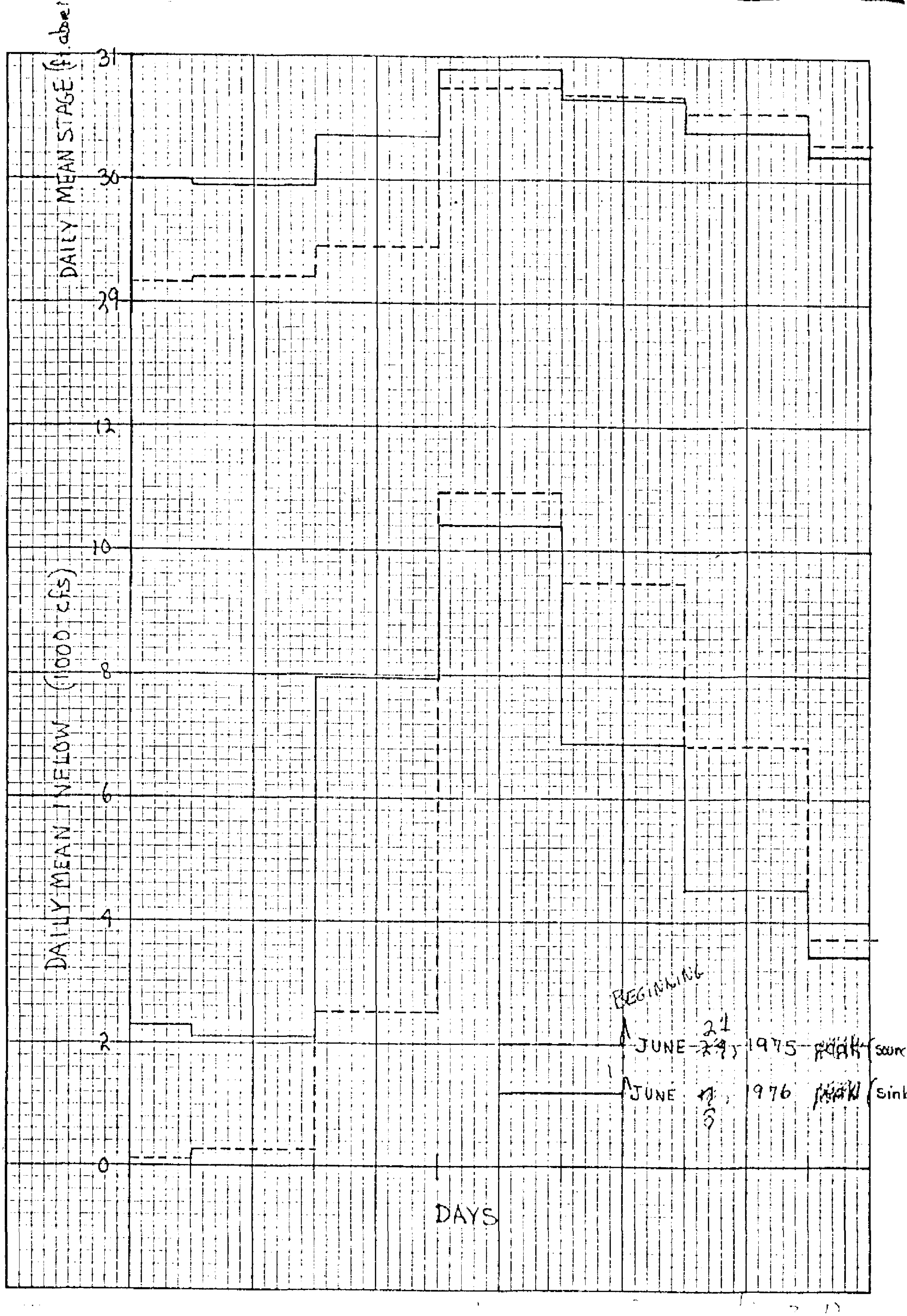


FIGURE 3.11 INFLOW AND OUTFLOW POLLUTOGRAPHS
CHANDLER SLOUGH MARSH 1975



DAILY MEAN STAGE
DAILY MEAN INFLOW (1000 cfs)
31
30
29
12
10
8
6
4
2
0
DAYS
BEGINNING
JUNE 21, 1975
JUNE 5, 1976

Water Quality Simulation

Water quality simulation is necessary to evaluate the effects of altering the hydrologic relationships on the marsh's ability to serve as a water quality control unit. The Storage/Treatment Block of SWMM (Huber, et al., 1975) is used to simulate Chandler Slough Marsh. Plug flow is assumed with nutrient removal following a simple first-order decay relationship.

Since the hydrology of Chandler Slough Marsh has already been calibrated in the mass loading and attenuation analyses, the calibration effort is directed at determining the first-order decay coefficient, K. It is realized that actual removal (and release) mechanisms involved complex interactions among physical, chemical and biological pathways but the first-order decay relationship will have to suffice since knowledge of the above pathways is limited and data are restrictive. The mass loads for total phosphorus derived from measured concentration data are assumed to represent the "actual" loads. Inflow loads to the model are equal to the combined loads calculated at the North and South Bridges; predicted outflow loads are then compared with "actual" outflow loads using various values for K. In addition, K is assumed to be temperature dependent and is expressed as

$$K = K_{20}(1.047)^{Te-20°} \qquad (3.4)$$

where Te = mean monthly temperature, °C, and
K_{20} = reaction coefficient at 20°C, hr^{-1}.

This allows the first-order decay coefficient seasonal variation.

A four month period commencing on August 1, 1975 is chosen as the calibration period because the marsh acts only as a phosphorus sink, apparent removal of chloride ion is small (1.3%) and the temperature is variable. Net release of total phosphorus is not allowed in the model.

Table 3.4 shows the pounds of total phosphorus released using K_{20} equal to 0.008, 0.007, and 0.006 per hour and the "actual" release during the calibration period. A K_{20} of 0.007 per hour (0.168 per day) yields the closest agreement with the "actual" release total. Therefore, this value is chosen to represent the first-order decay coefficient at 20°C for subsequent simulations of Chandler Slough Marsh. The mean monthly water temperatures for the Kissimmee-Everglades area between May and November range between 28.0 and 22.0°C and average about 25°C (Shih and Hallett, 1974). Hence, the average wet season K is about 0.2 day^{-1}. Comparisons between predicted and "actual" monthly loads during the calibration period are presented in Table 3.5.

The effects of controlling the outflow of Chandler Slough Marsh are evaluated using 1976 inflow and loading data. Simulations are performed using the broad crested weir formula as the depth-discharge relationship. Also, the predicted net removal of total phosphorus for 1976 with the "natural" depth-discharge relationships is 27.38%. Figure 3.13 summarizes the results using various combinations of weir lengths and weir heights. Percent removal, average stage and maximum stage for the 1976 wet season are plotted as functions of the weir parameters. This figure illustrates the trade-offs between flood control and water quality considerations. For instance, the highest weir height results in longer detention times and thus higher nutreint removal, but the higher stages result in more frequent inundation of surrounding areas.

Table 3.4 Predicted and actual release of total phosphorus (August-November, 1975) with various values of K_{20}.

K_{20}^{a} (hour^{-1})	Release of Total Phosphorus (lbs.) Predicted	Actual[b]	Percent Error
0.008	9630	10030	-3.99
0.007	10060	10030	+0.30
0.006	10550	10030	+5.18

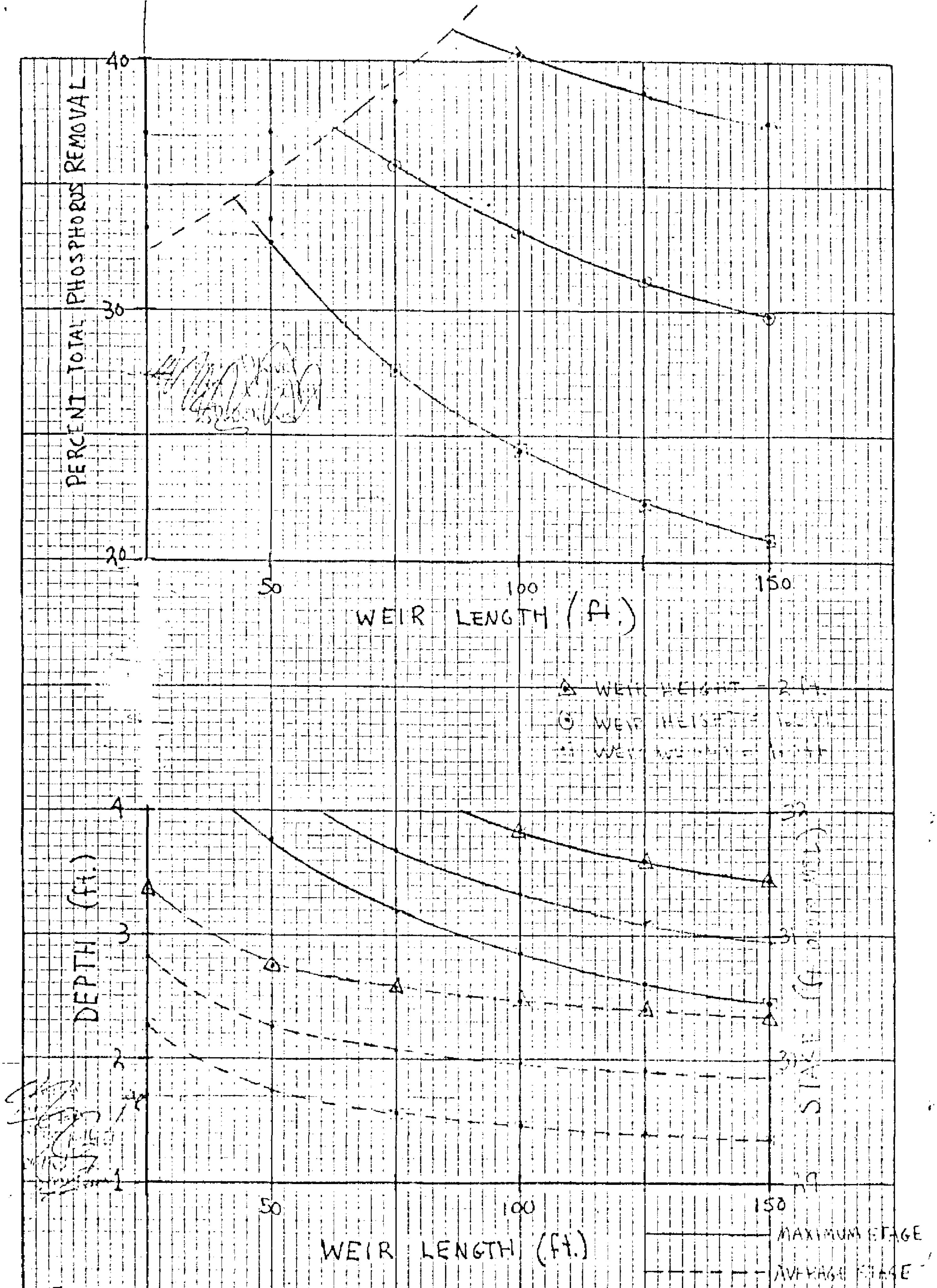
Table 3.5 Comparison between predicted and actual monthly release of total phosphorus (August-November, 1975) with $K_{20} = 0.007\ hr^{-1}$ (0.168 day^{-1}).

Month	Release of Total Phosphorus (lbs.)		Percent Error	Mean Monthly[c] Temperature (°C)
	Predicted	Actual[b]		
August	1560	1520	2.63	26.5
September	1880	1850	1.62	25.0
October	3790	3970	-4.53	22.0
November	2830	2690	5.20	22.0

[a] $K = K_{20}\ (1.047)^{T-20°}$.

[b] Actual values are derived from intermittent concentration values and predicted (SWMM) outflows.

[c] Mean monthly water temperatures for Kissimmee-Everglades area (Shih and Hallett, 1974).



PERCENT TOTAL PHOSPHORUS REMOVAL
40
30
20
50
100
150
WEIR LENGTH (ft.)
WEIR HEIGHT = 2 ft.
DEPTH (ft.)
4
3
2
1
50
100
150
WEIR LENGTH (ft.)
STAGE
MAXIMUM STAGE
AVERAGE STAGE

Figure 3.13

Detention times for Chandler Slough Marsh are approximated by:

$$T = STOR/Q \tag{3.5}$$

where T = detention time, sec,

$STOR$ = volume in storage, ft^3, and

Q = discharge rate, cfs.

Equation 3.5 represents the "instantaneous" detention time for a complete mix storage unit. Actual detention times, computed by the SWMM simulation using plug flow, are the number of time steps a plug or fraction of a plug remain in the storage unit. Nevertheless, the instantaneous detention time is useful to approximate the detention time because STOR and Q are expressed as functions of depth or stage.

The volume-depth relationship, illustrated in figure 3.2, is expressed as:

$$STOR = 3.12 \times 10^7 \ (D)^{1.264} \tag{3.6}$$

where D = marsh depth, ft.

Note that zero marsh depth is at about 28 feet above MSL.

The discharge-depth function, equation 3.1, for the present conditions (i.e., uncontrolled, no structures) is as follows:

$$Q(cfs) = 215 \ (D - 1)^{2.1} \tag{3.1}$$

The detention time, in days, for Chandler Slough Marsh, substituting equations 3.1 and 3.6 into equation 3.5, is thus approximately:

$$T = 1.68 \ (D)^{1.264} / \ (D - 1)^{2.1} \tag{3.7}$$

where D is greater than 1 foot.

For the fixed weir outlet, the detention time is:

$$T = 2.70 \times 10^{12} \ D^{1.264} / \ [3.33 \ WEIRL(D - WEIRHT)] \tag{3.8}$$

where $WEIRL$ = weir length, ft and

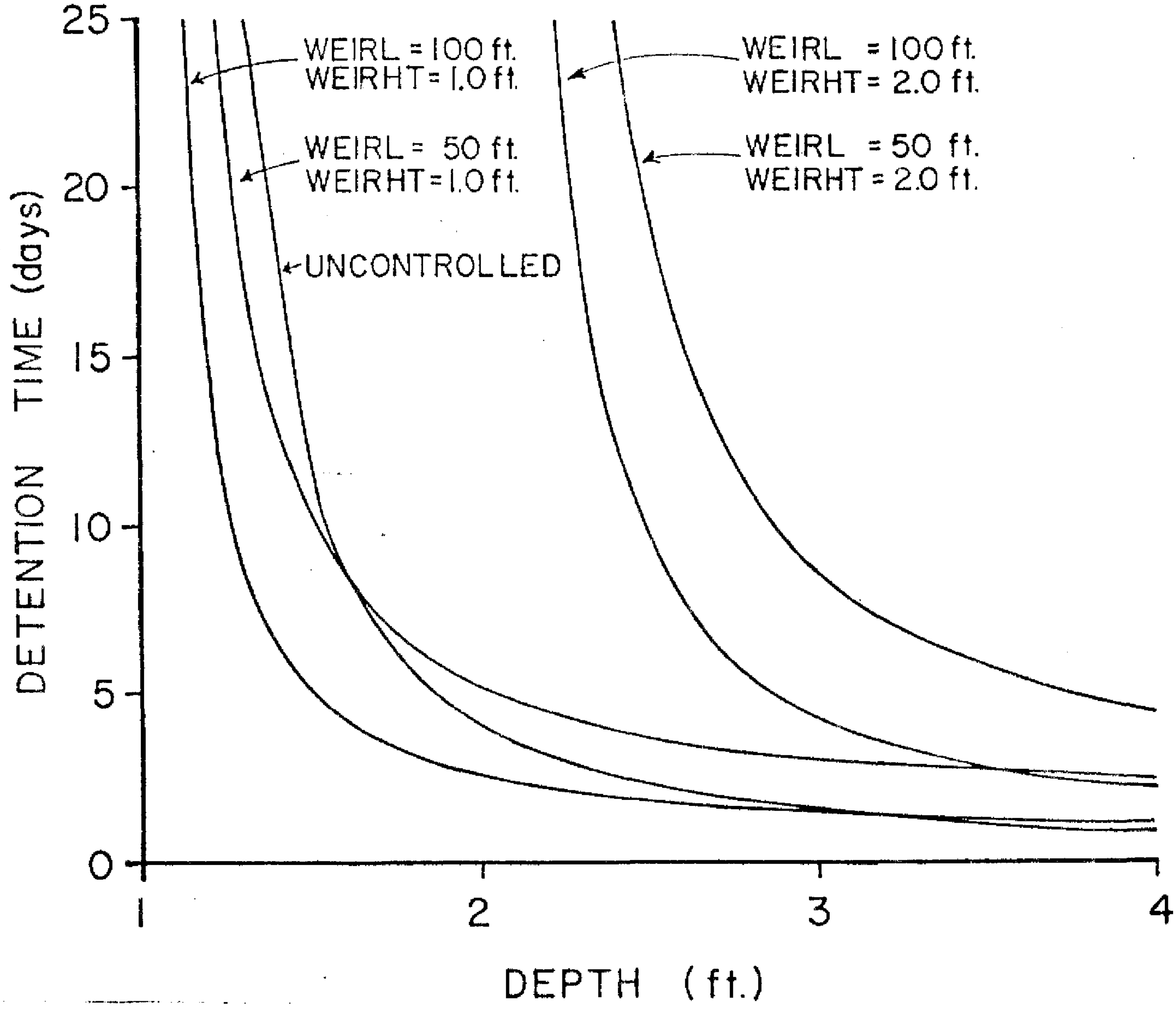
$WEIRHT$ = weir height, ft.

Detention times from equations 3.7 and 3.8 as they relate to depth for Chandler Slough Marsh are shown in figure 3.14 for present conditions and for several fixed weir outlets.

SUMMARY

The fraction of marsh area to catchment area determines the amount of flood attenuation. Fixed outlet structures can increase single event attenuation although they change the stage frequency thereby altering available storage. An outflow structure, such as a gated spillway, allows for stage regulation. The attenuation analysis assumes all marsh area is downstream of the catchment. Scattered upland detention areas may achieve greater attenuation.

FIGURE 3.14 Detention Times vs. Depth of Chandler Slough Marsh.



The mass calculations indicate Chandler Slough Marsh removes 4.97% and 8.60% of chlorides in 1975 and 1976 which suggests that there are additional inflows into the marsh other than the Chandler Slough (North Bridge) and the Cypress Slough (South Bridge) drainage systems.

Net total phosphorus removal for 1975 is between 2.1% and 6.7% with an "uptake" of as much as 2.3 metric tons. For 1976 net total phosphorus removal is between 17.3% and 34.8% with an "uptake" of between 6.3 and 7.8 metric tons.

There is considerable room for error in these water quality analyses. Since only about 30 days of concentration data are available for each wet season (1975 and 1976) with fewer (less than five) data points for the remainder of each year. Concentration values are estimated for the intermittent days by interpolating between data points.

The wet season equivalent first order decay coefficient for total phosphorus is found to be on the order of 0.2 day^{-1} which is equivalent to about 18% removal of total phosphorus per day of detention in the marsh.

The marsh in its present state may periodically release a large portion of accumulated phosphorus, as is the case in 1975. "Flushing" of the marsh is speculated to occur due to large inflows after a period of low water (i.e., large portions or all of the marsh area are dry). If this is the case, stage regulation with an outlet structure could minimize marsh dry out and possibly reduce release of phosphorus by increasing the hydroperiod. For instance, if the marsh depth and weir height are 2 feet and inflow ceases, it will take about 3.4 months and 5.1 months to reduce the depth to 1.0 foot and 0.5 foot, respectively, assuming a constant net loss of 3.5 inches per month.

The flushing of the marsh provides a means by which deposited material is removed. By altering the present cycle with an outlet structure, increased buildup of material may occur. A more effective method of reducing nutrient release into C-38 is probably to utilize upland marshes and sand ponds as control units in conjunction with the downstream marsh. By detaining surface runoff, these units will increase detention time and change the regime of much of the runoff from direct to subsurface pathways, thereby reducing inflow peaks and nutrient concentrations to the downstream marsh.

Fixed weir outlet structures are simulated for 1976 inflow and mass loading data. Their effects on phosphorus removal, average, and maximum wet season stage for 1976 are shown in figure 3.13. Increasing the weir height of the outlet structure will improve phosphorus removal by increasing storage and detention times. Also, phosphorus removals increase as weir lengths decrease. Both increasing the weir height and decreasing the weir length will increase the average and the maximum stage. For example, with a weir length and weir height of 100 ft. and 2 ft., respectively, the net 1976 total phosphorus removal is about 40% while the average and maximum 1976 wet season stages are 30.45 and 31.85 ft. above MSL. But with a weir length and weir height of 150 ft. and 1.5 ft., respectively, the net 1976 total phosphorus removal is about 30%, while the average and maximum 1976 wet season stages are 29.86 and 30.95 ft. above MSL.

The net total phosphorus removal predicted by SWMM is 27.4% and the average and maximum stages are 29.68 and 30.90 ft. above MSL for the 1976 wet season with natural outflow from Chandler Slough Marsh.

NOTATION

Chapter II

BF = Baseflow for entire watershed (cfs).

CDET = Fraction of surplus water remaining on land per day

DWL = ET depletion coefficient (mm^{-1}).

$H_t = h_S + h_{GW}$ + arbitrary datum at time t (ft).

h_{GW} = Daily mean depth to groundwater table (ft).

h_o = Soil depth - ditch depth (ft).

h_S = Stream stage measured at Taylor Creek at U.S. Hwy. 441 (ft).

h(x) = Height of phreatic surface above impermeable layer a distance x between parallel ditches (ft).

K, K', K_1, C = Constants.

K = Saturated hydraulic conductivity (length/time).

q_t = Daily mean discharge at time t (cfs).

S = Standard deviation.

SM = Maximum soil moisture storage (inches).

STPU = Average soil moisture storage level for the entire watershed (inches).

Chapter III

A_d = Drainage Area ($mile^2$).

D = Depth of marsh above 28 ft. MSL (ft).

K = First-order decay coefficient ($time^{-1}$).

K_{20} = K at 20°C. ($time^{-1}$).

Q = Daily mean outflow (cfs).

Q_{peak} = Mean annual flood peak (cfs).

STOR = Volume in storage (ft^3).

T = Detention time.

T_e = Mean monthly temperature (°C).

T_p = Time to peak of flood event.

Vol = Total flood volume (ft^3).

WEIRHT = Weir height (ft).

WEIRL = Weir length (ft).

X = Area in marshes/total drainage area.

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22. U.S. Dept. of Agriculture, USDAHL-70, Model of Watershed Hydrology, Tech. Bull. No. 1435, Washington, D.C., 1970.

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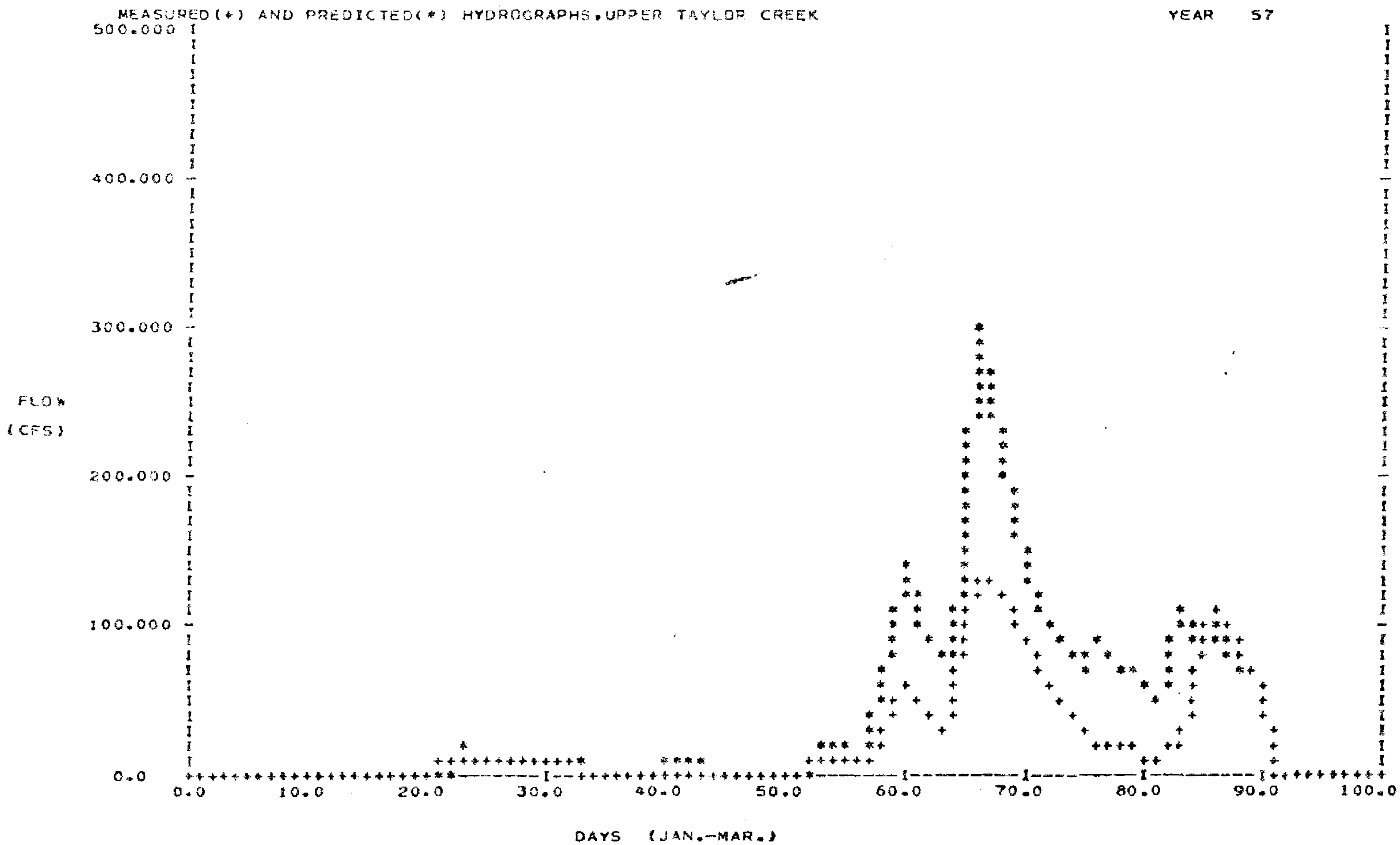
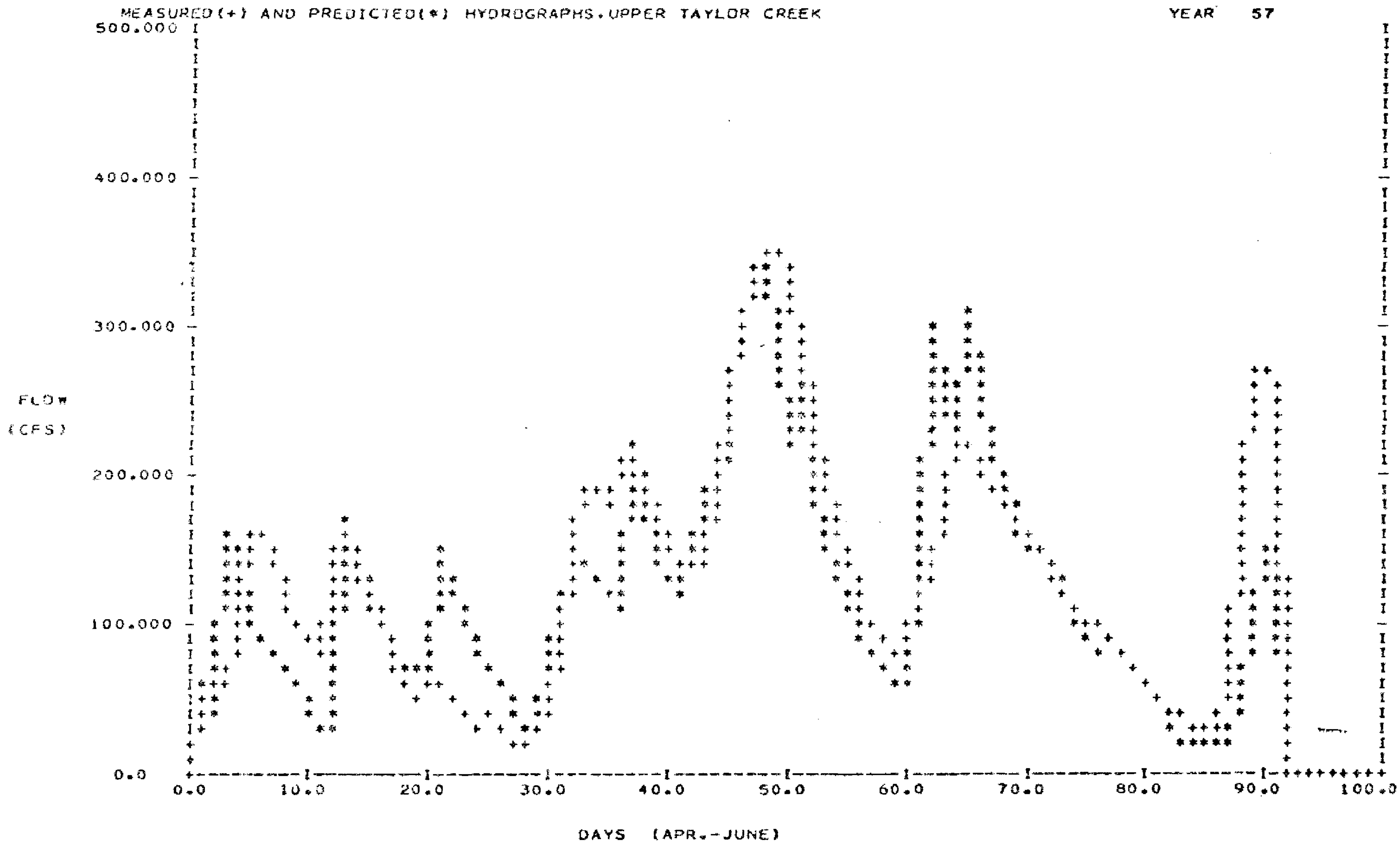
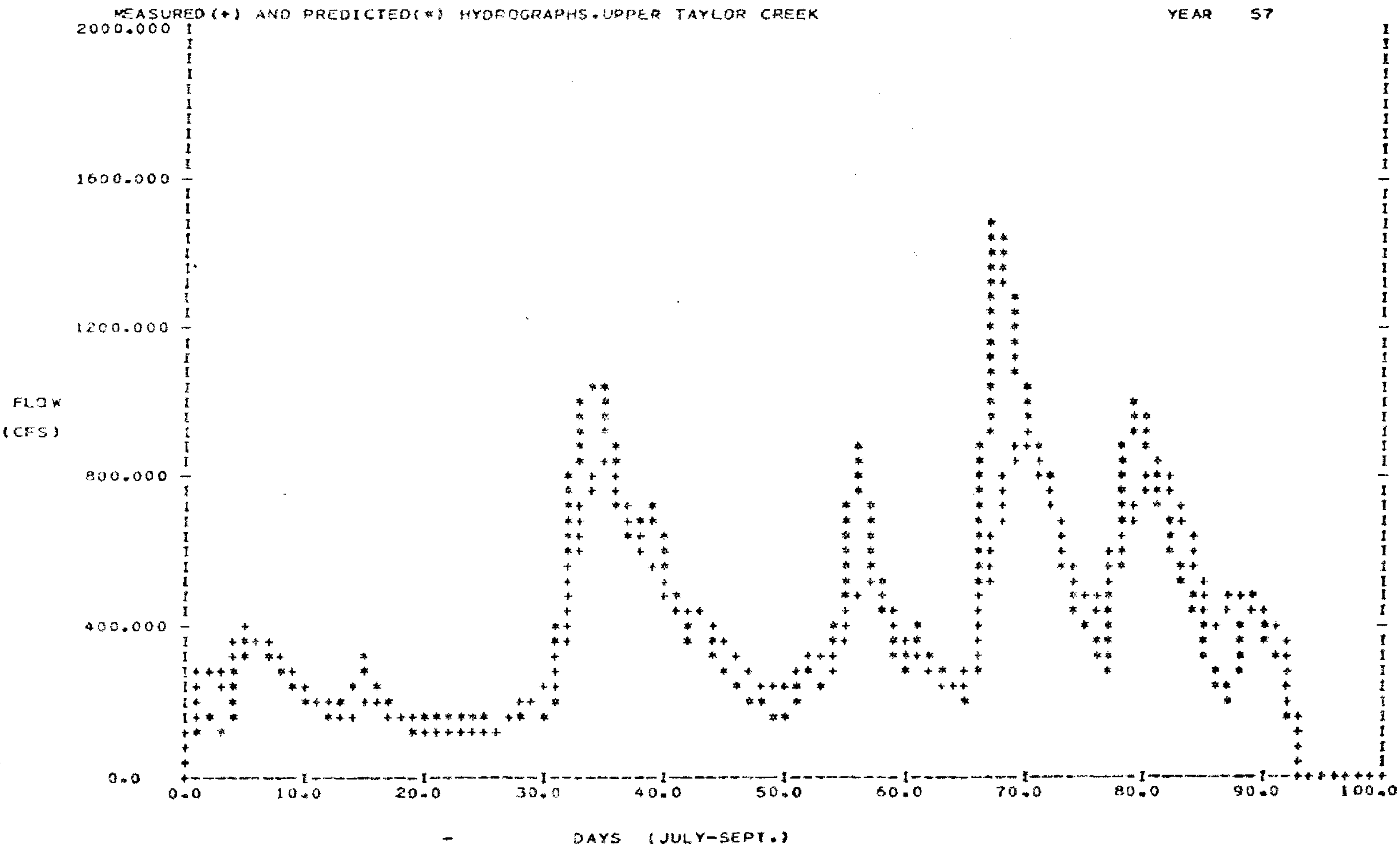
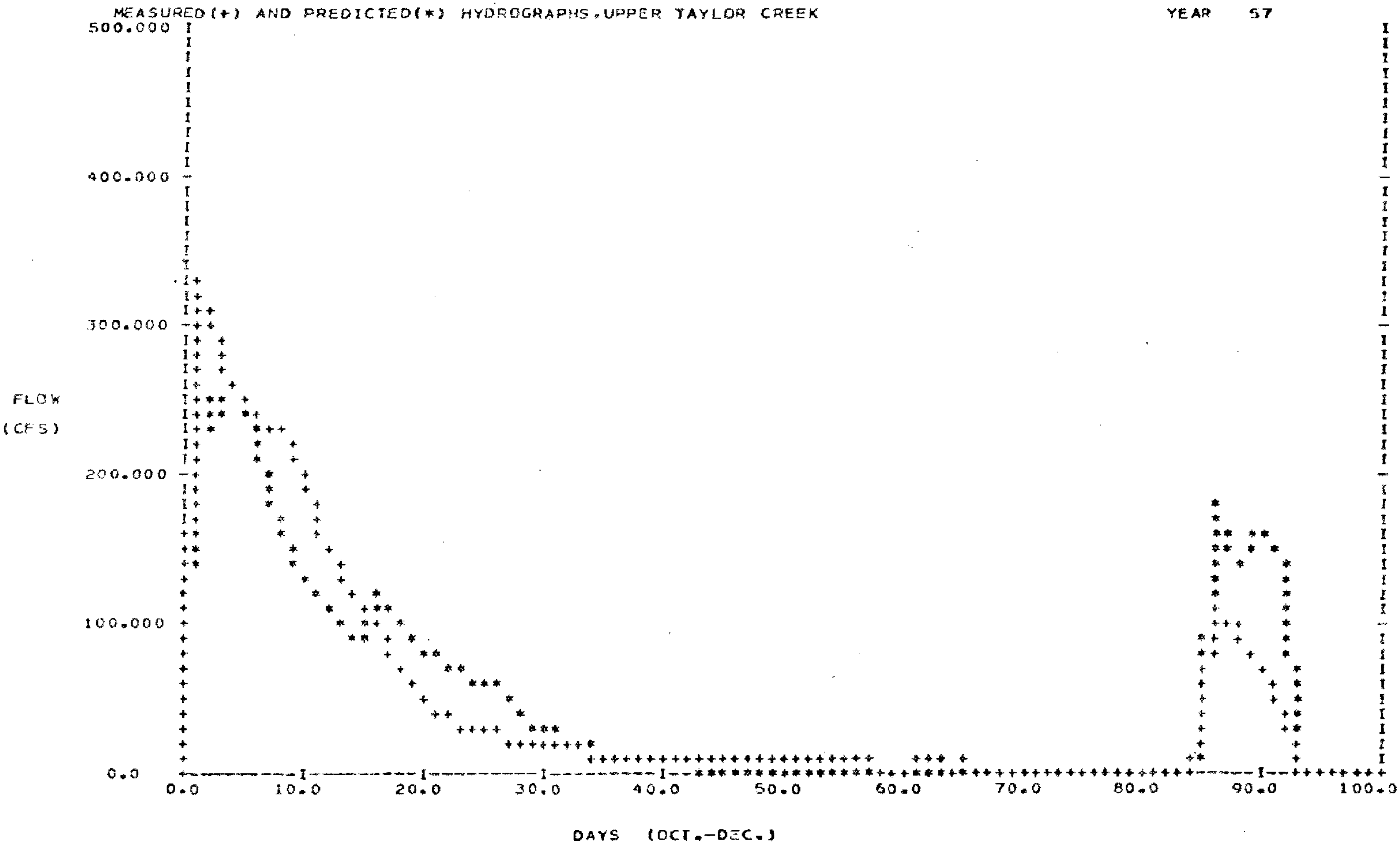
APPENDIX B

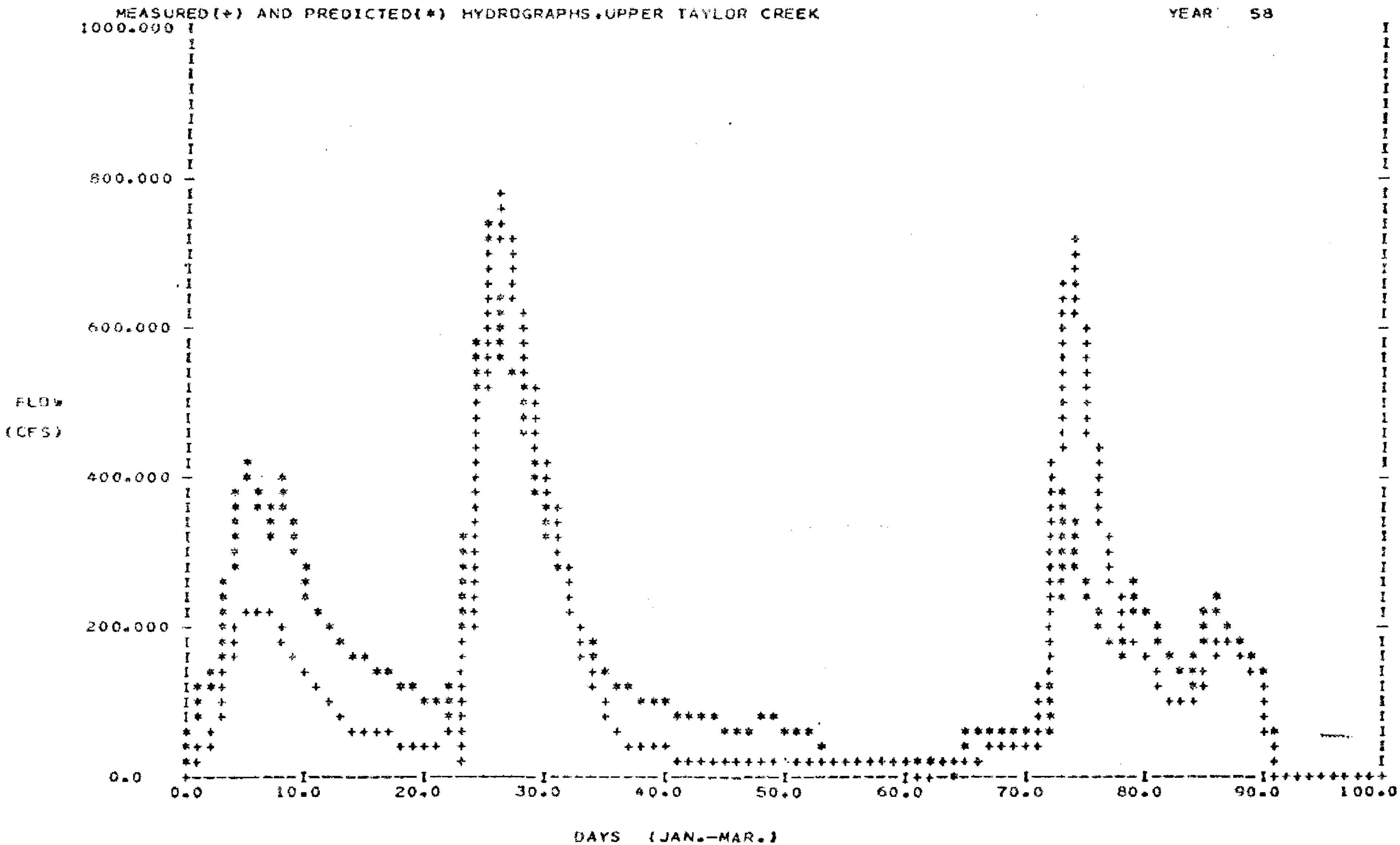
Measured and Predicted Hydrographs
Upper Taylor Creek 1957-1961 and
1969-1973

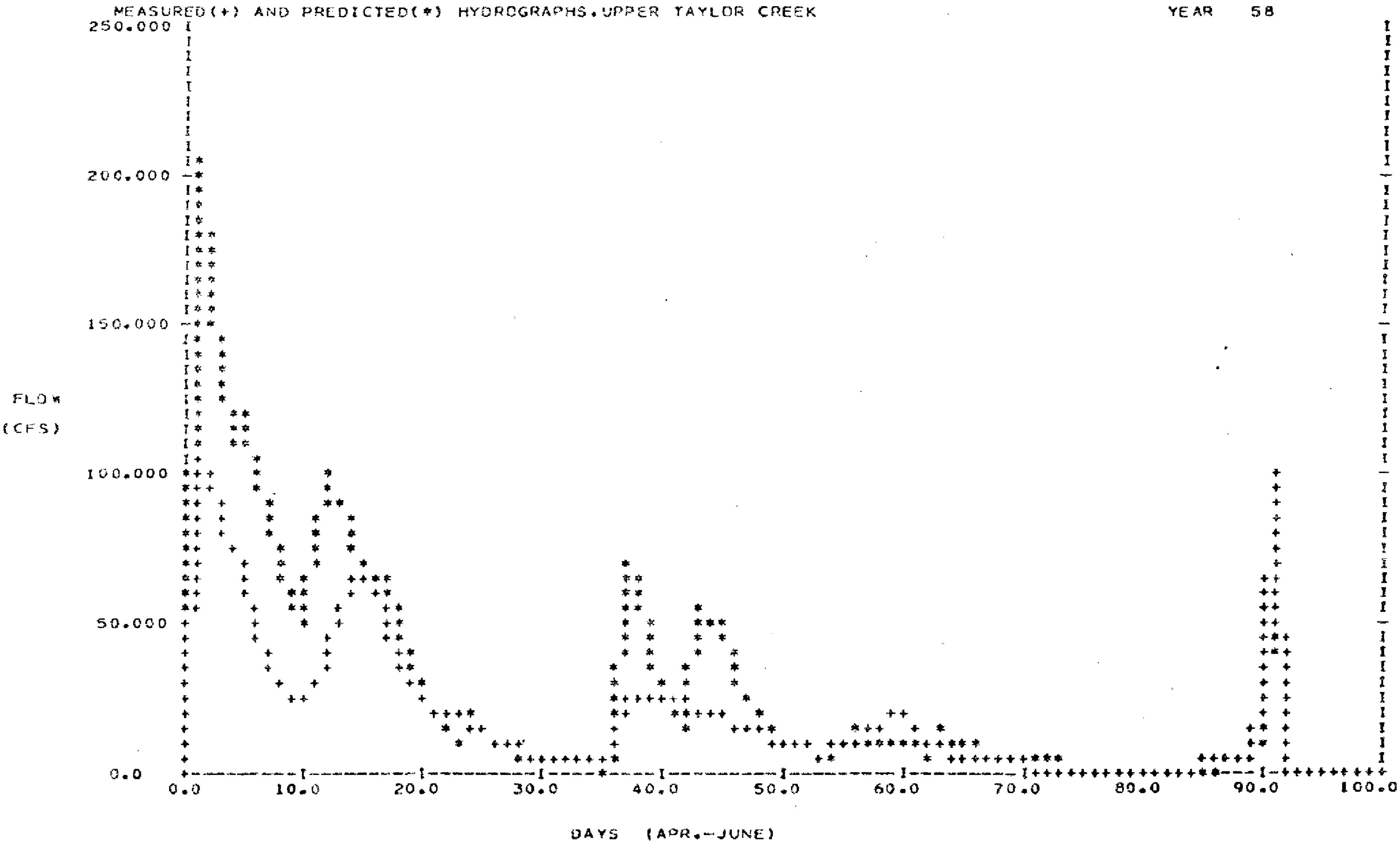

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 57
500.000
400.000
300.000
200.000
100.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JAN.-MAR.)

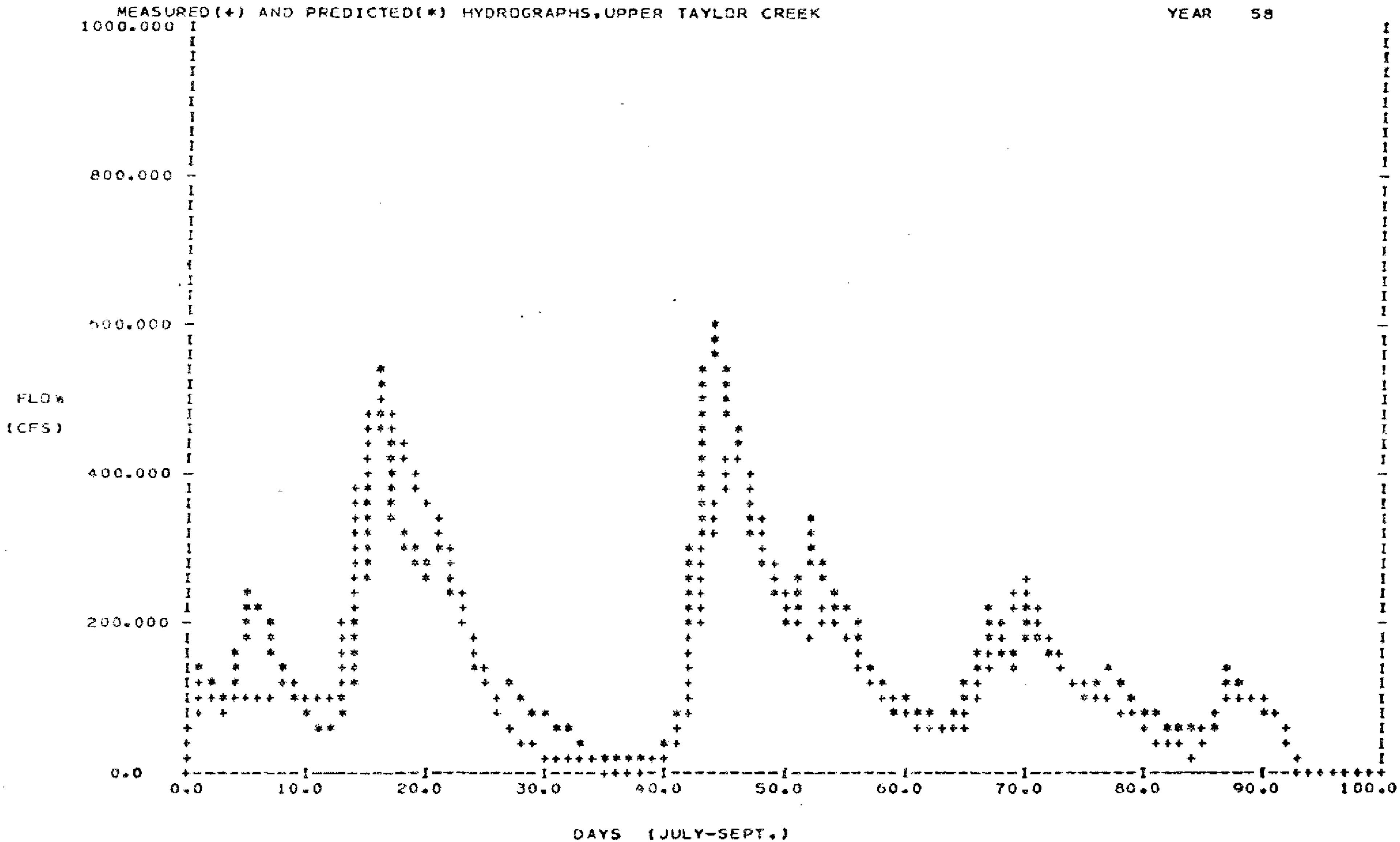

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 57
500.000
400.000
300.000
200.000
100.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

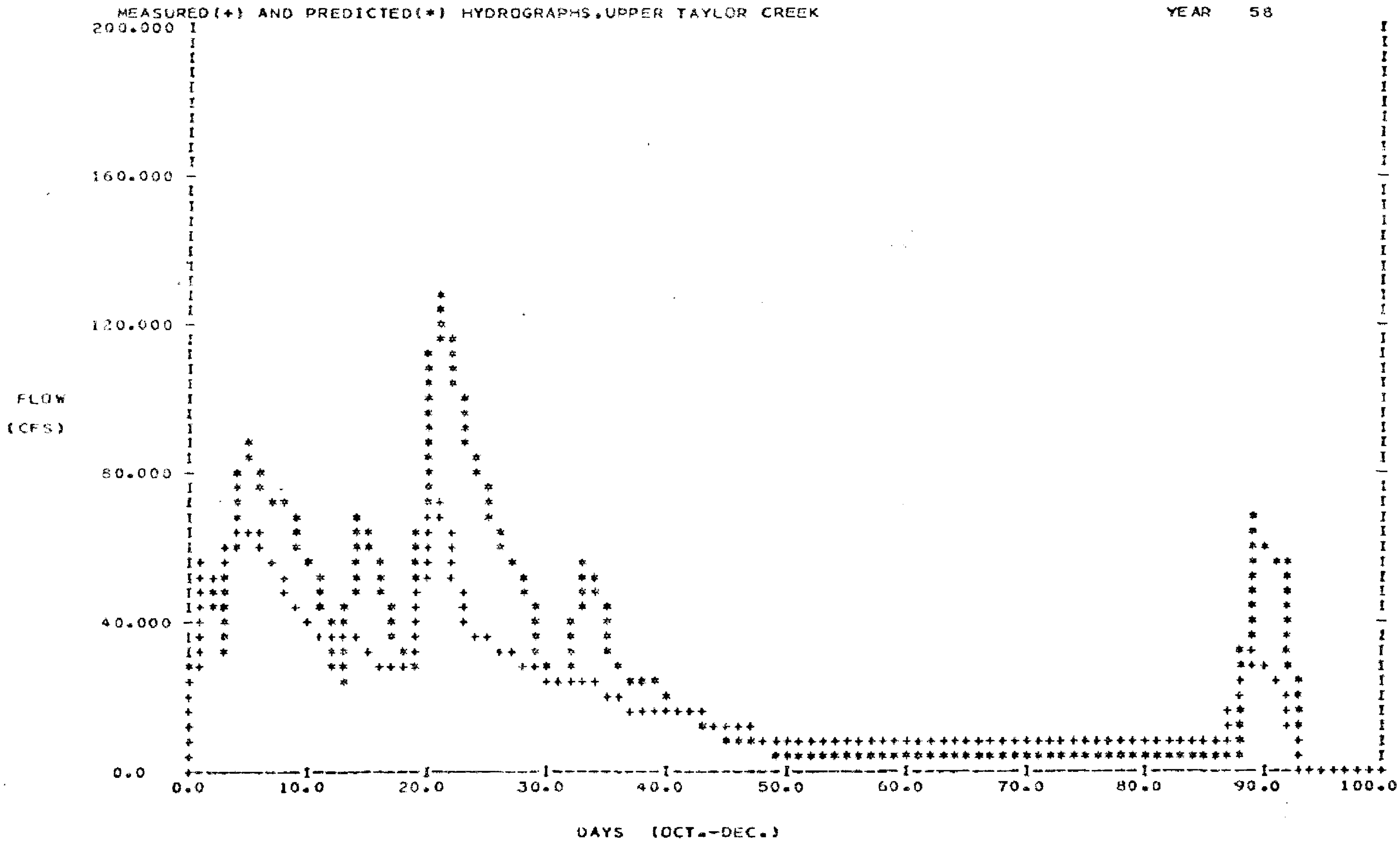

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 57
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 57
500.000
400.000
300.000
200.000
100.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (OCT.-DEC.)

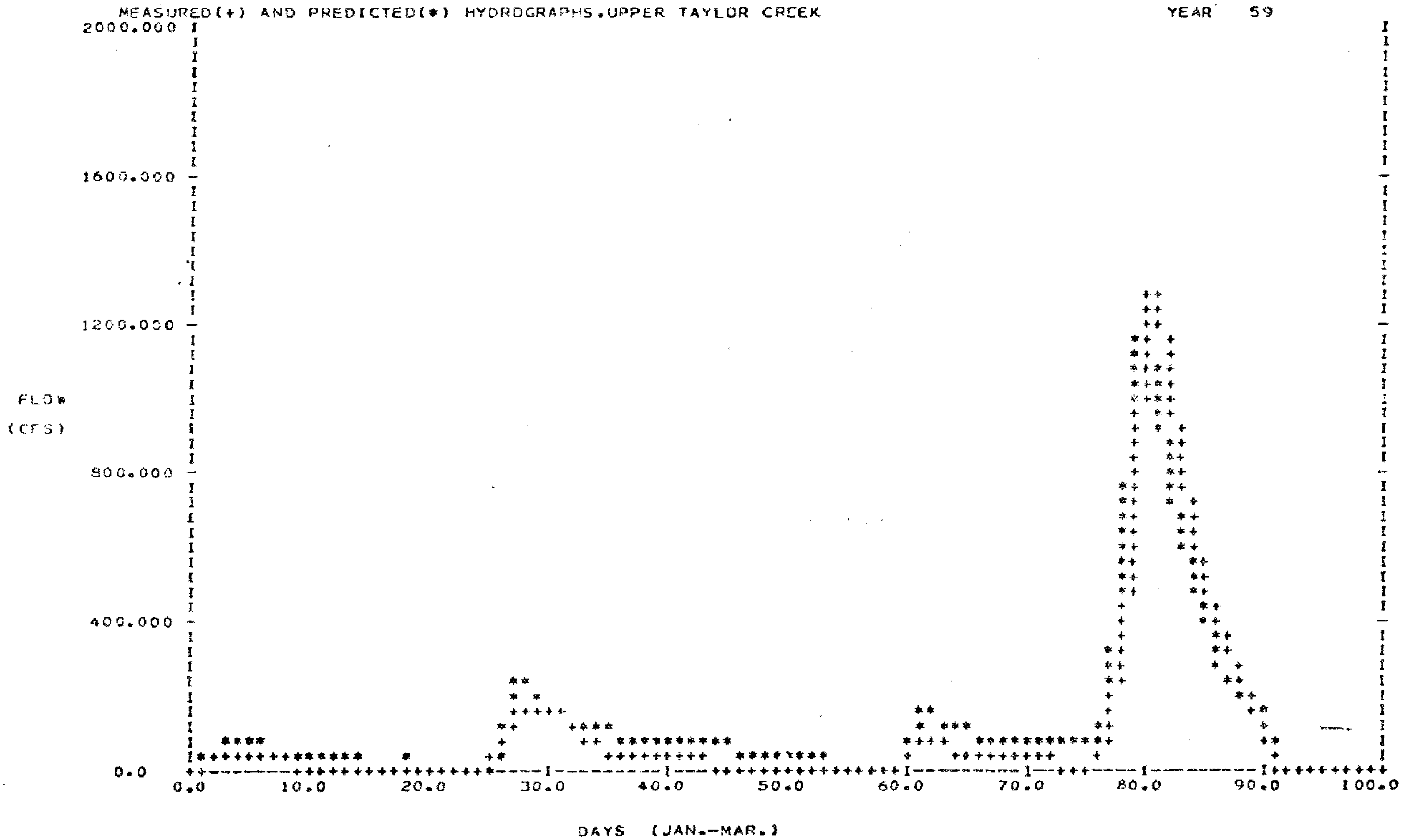

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 58
1000.000
800.000
600.000
400.000
200.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JAN.-MAR.)

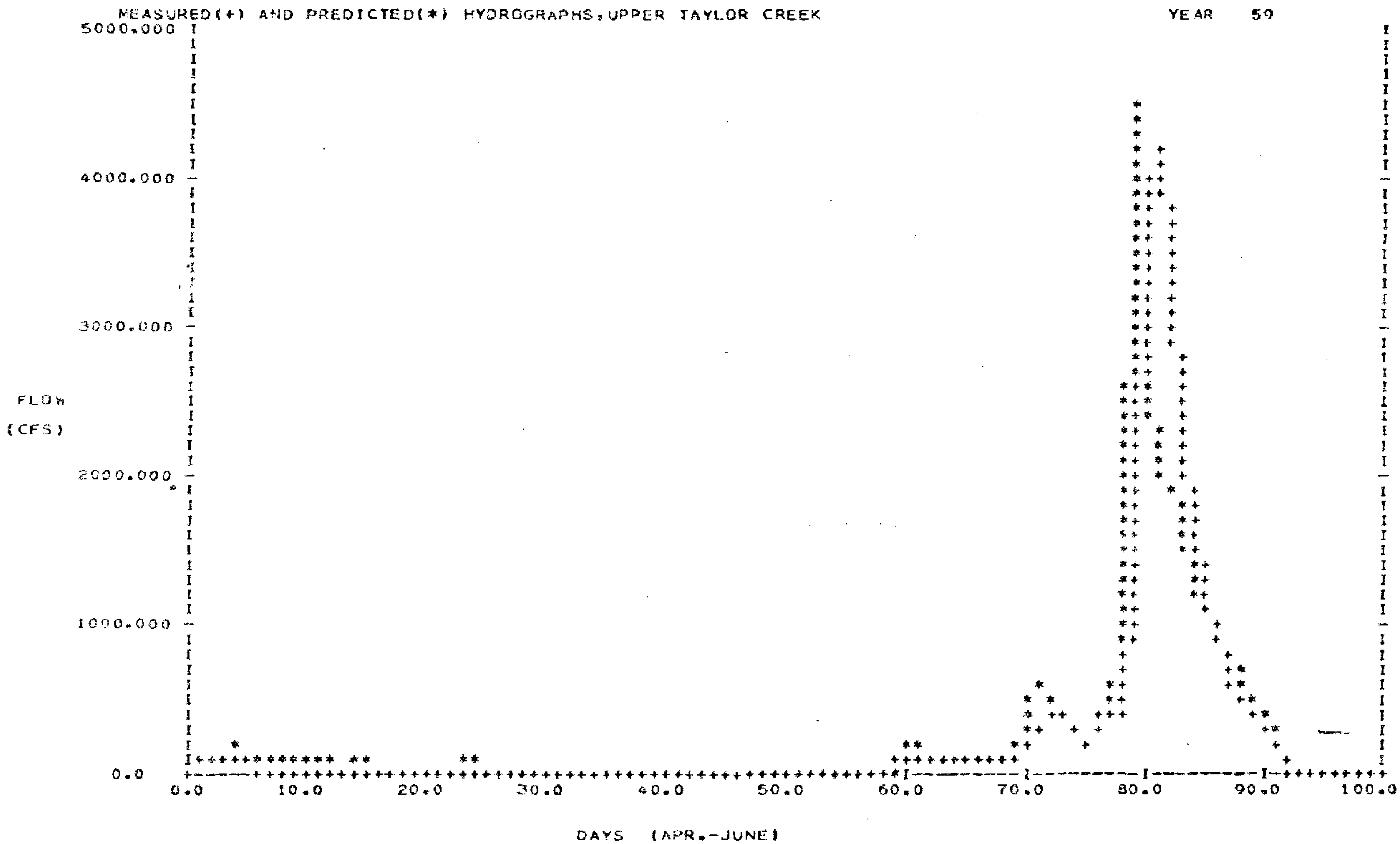

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 58
250.000
200.000
150.000
100.000
50.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

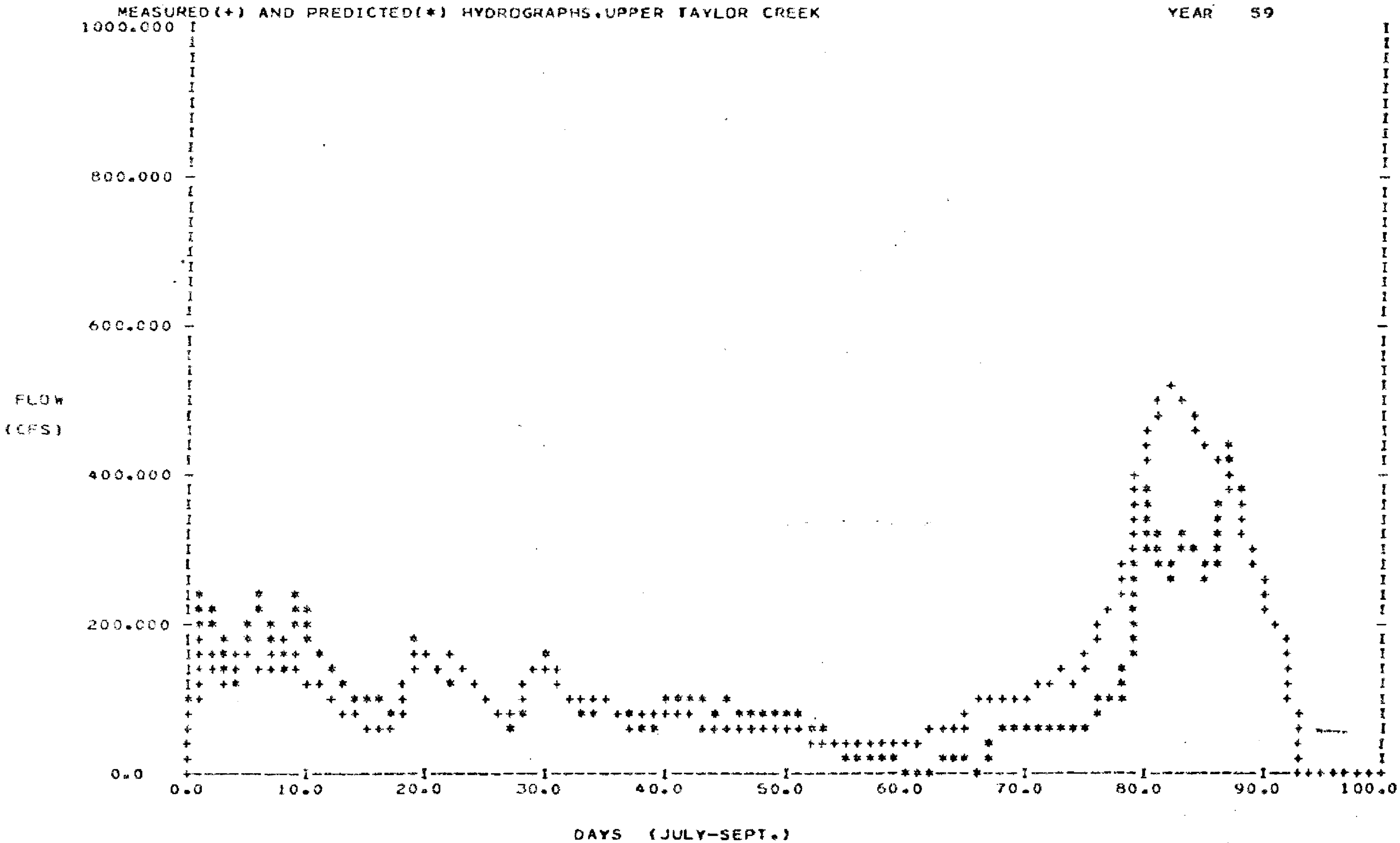

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 58
1000.000
800.000
600.000
400.000
200.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)



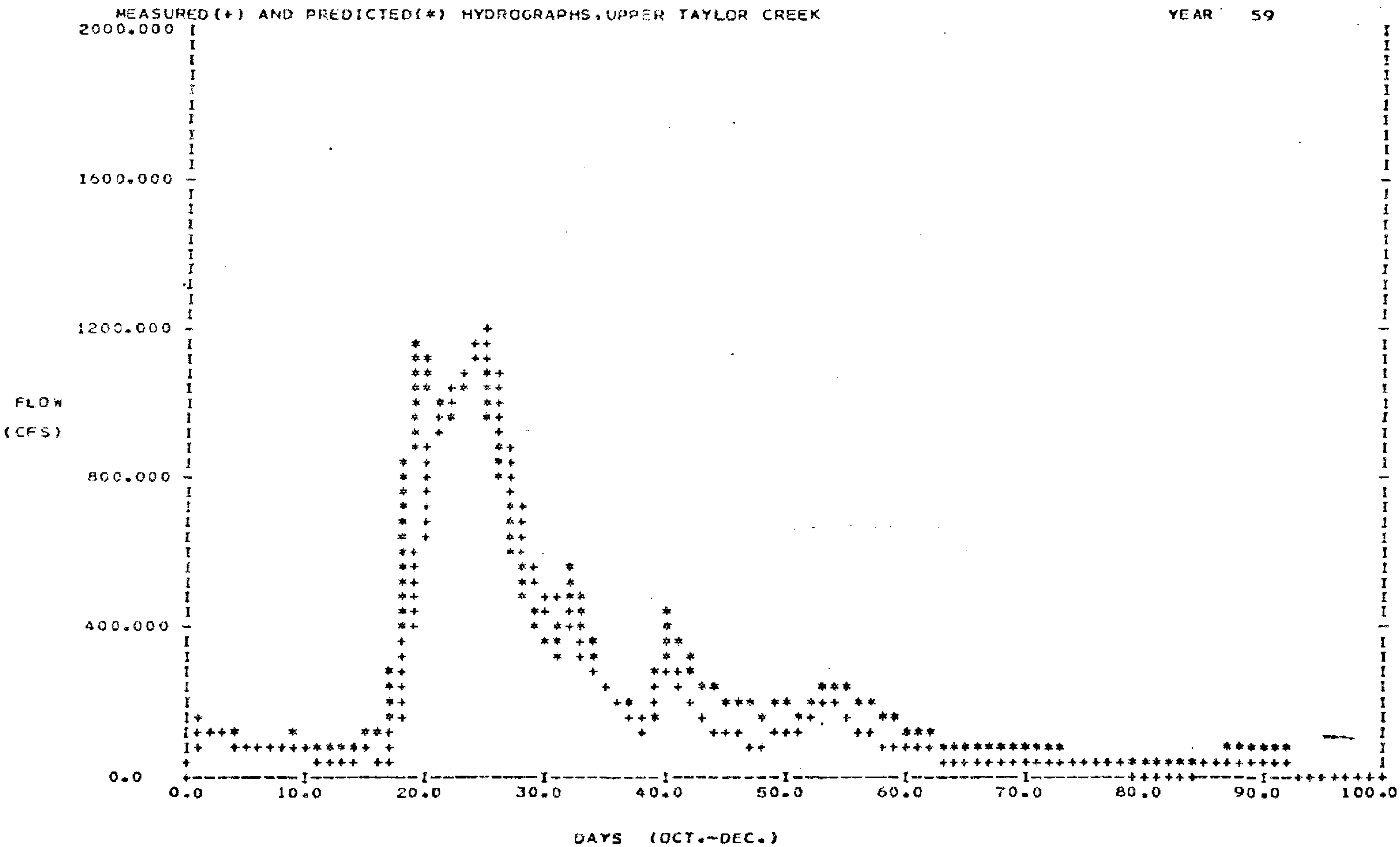
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 58
FLOW (CFS)
200.000
160.000
120.000
80.000
40.000
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (OCT.-DEC.)

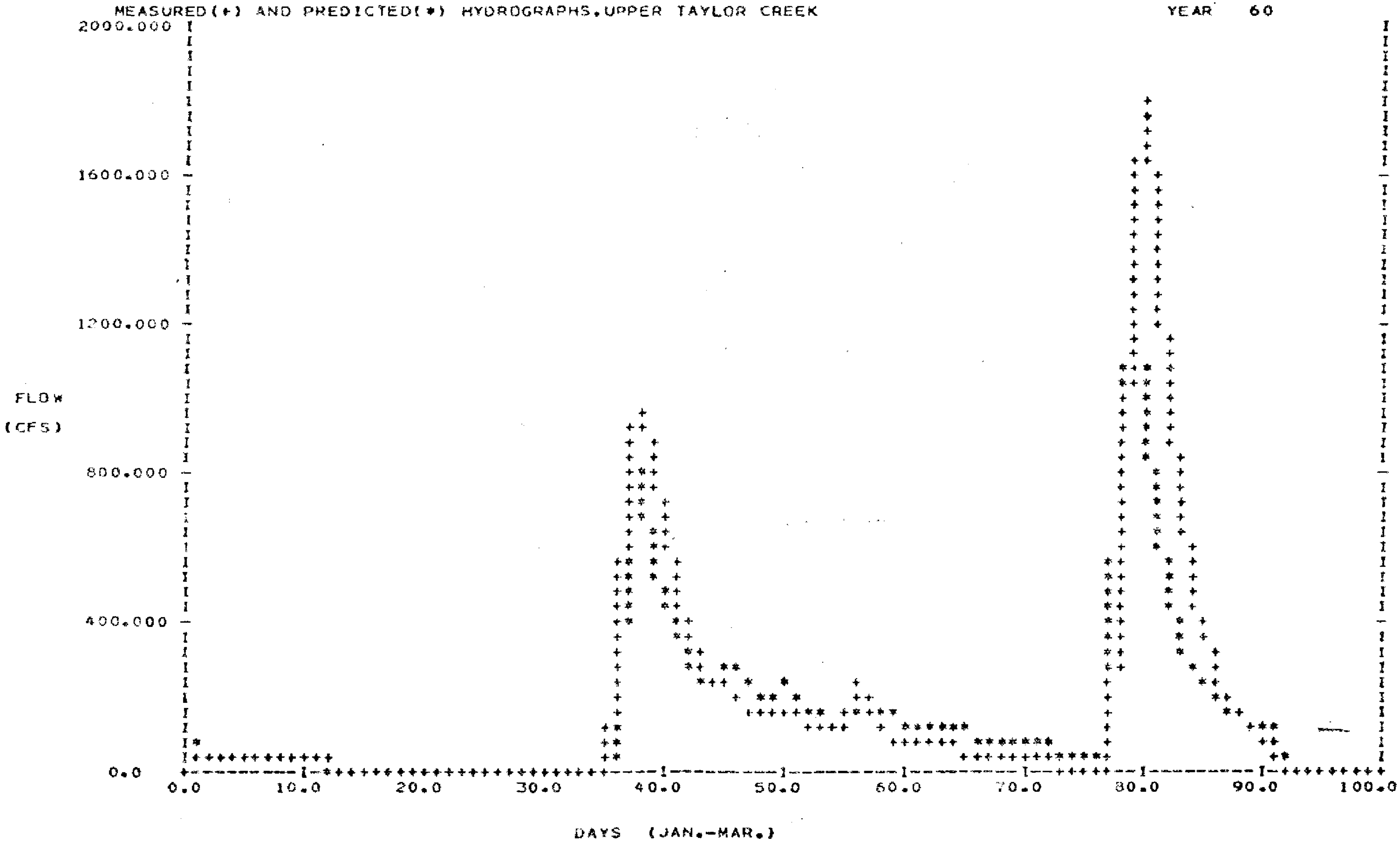

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 59
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JAN.-MAR.)

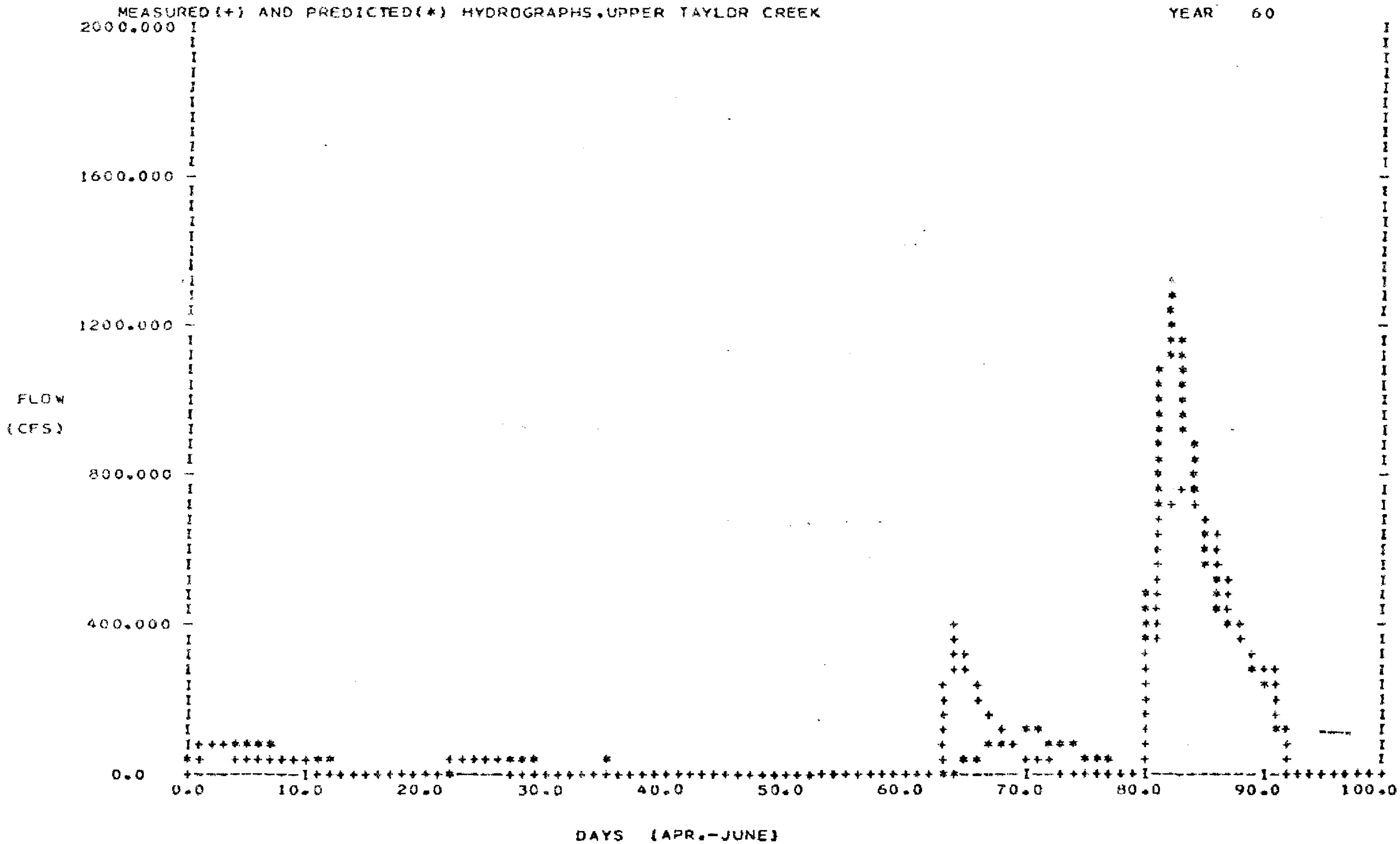

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 59
5000.000
4000.000
3000.000
2000.000
1000.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

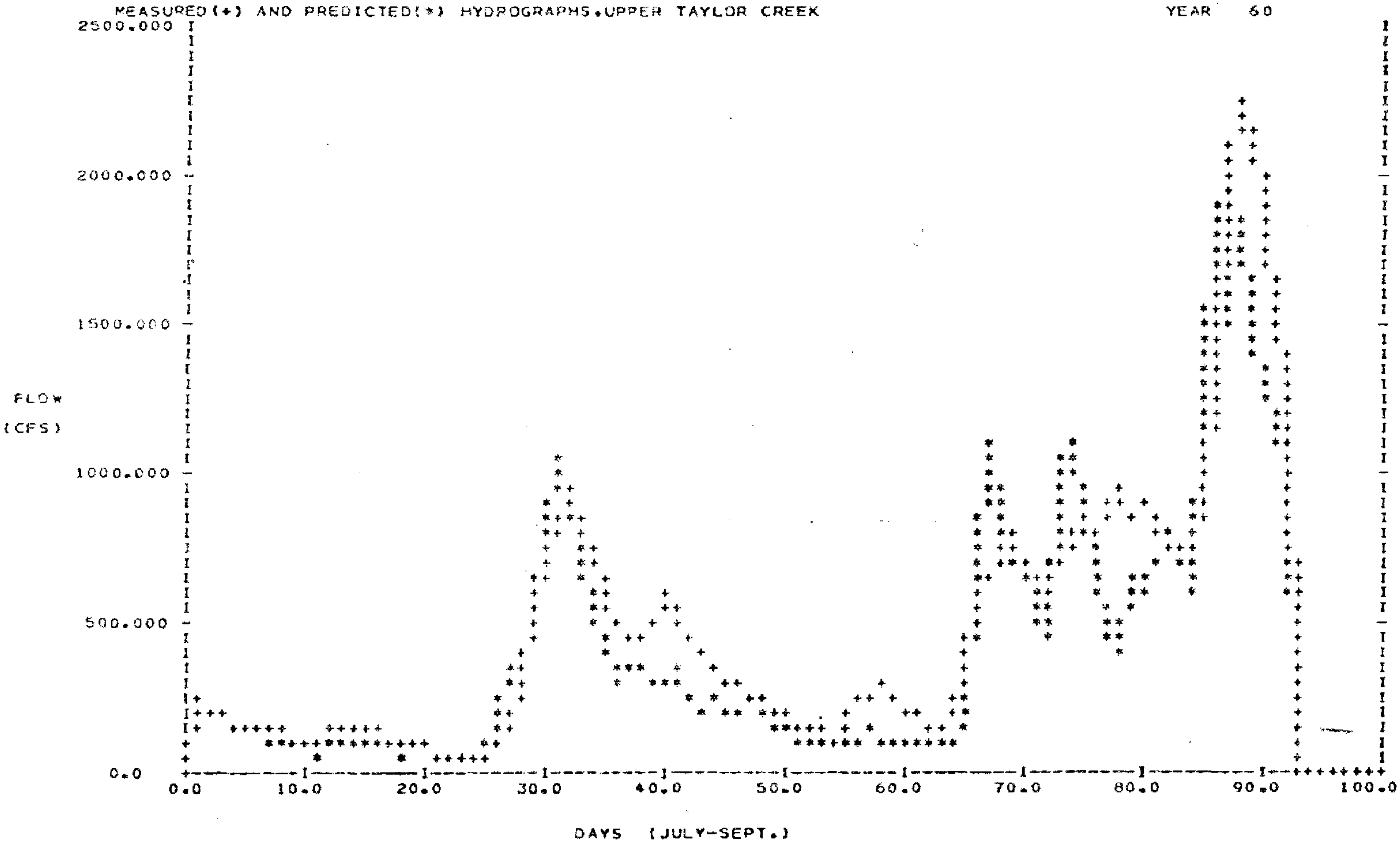


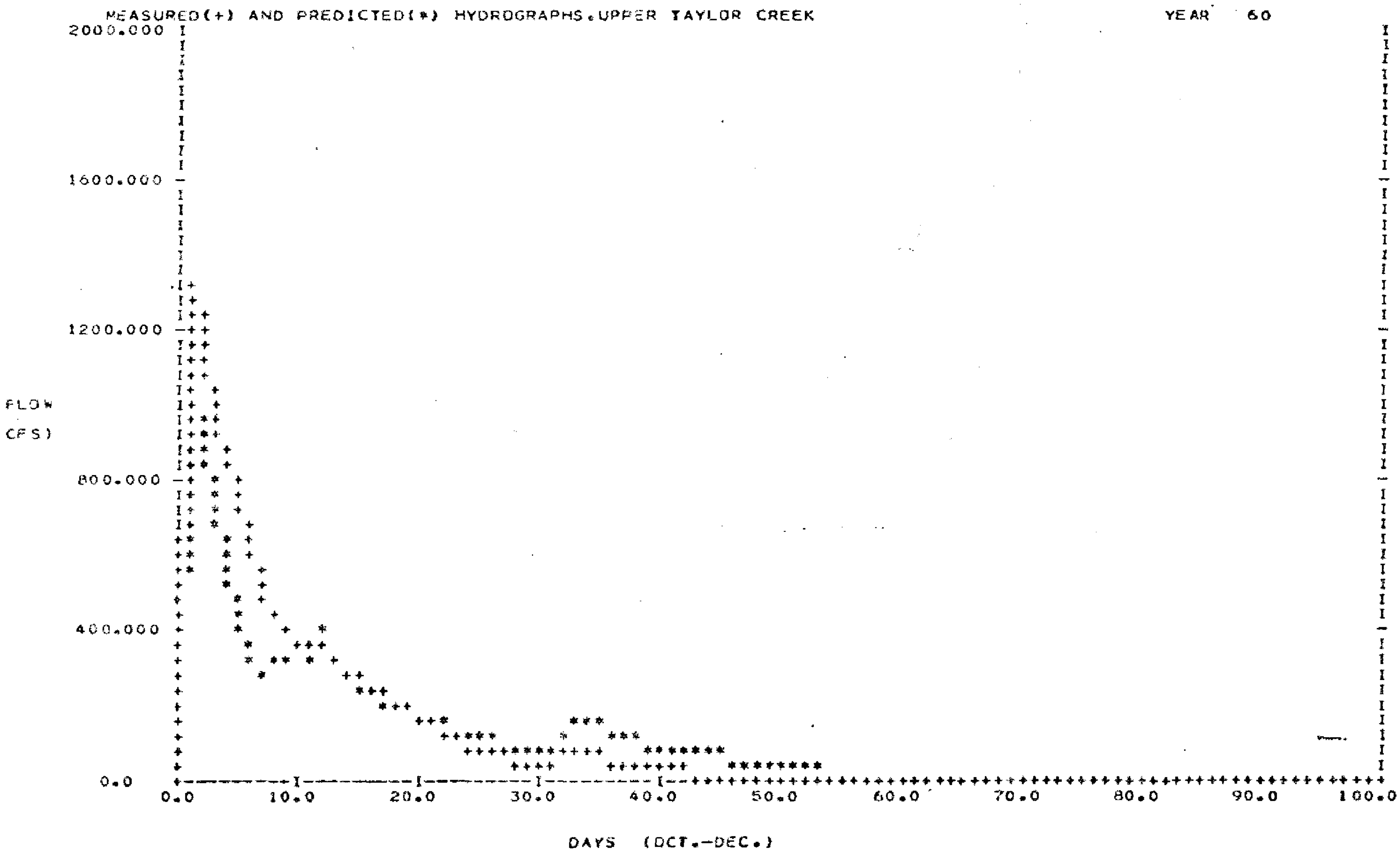
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 59
1000.000
800.000
600.000
400.000
200.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)

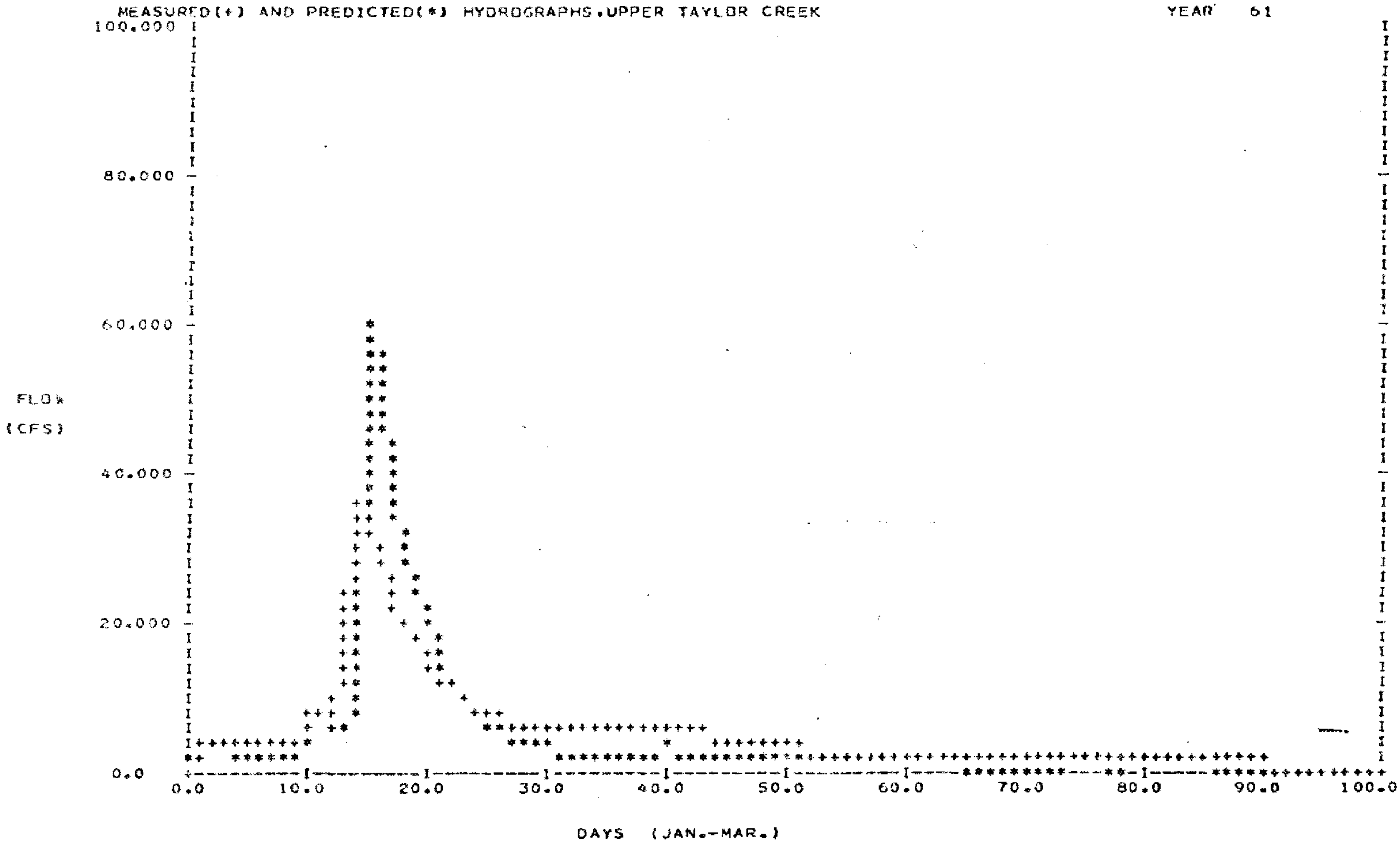

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS, UPPER TAYLOR CREEK
YEAR 59
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (OCT.-DEC.)


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 60
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JAN.-MAR.)

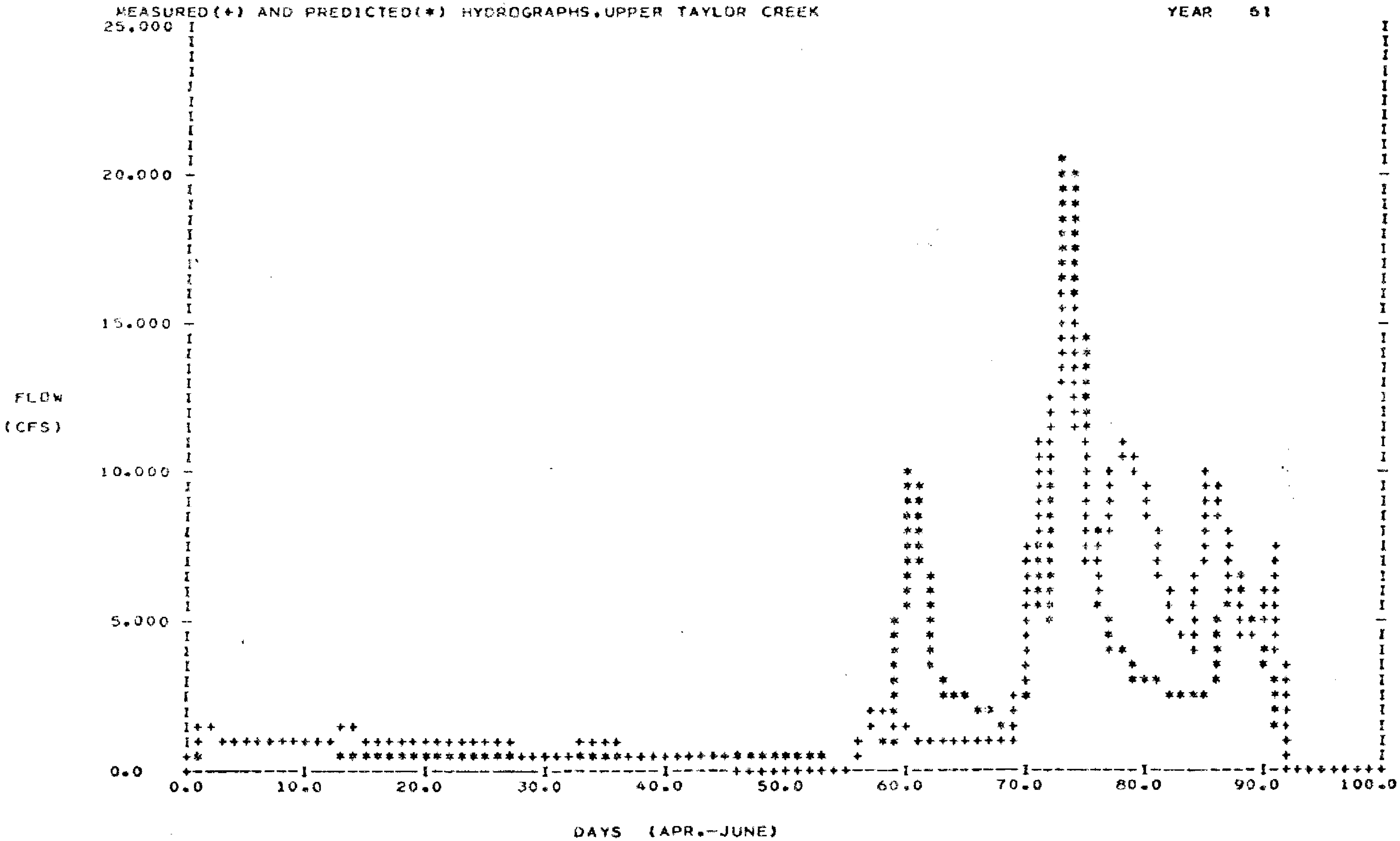

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 60
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

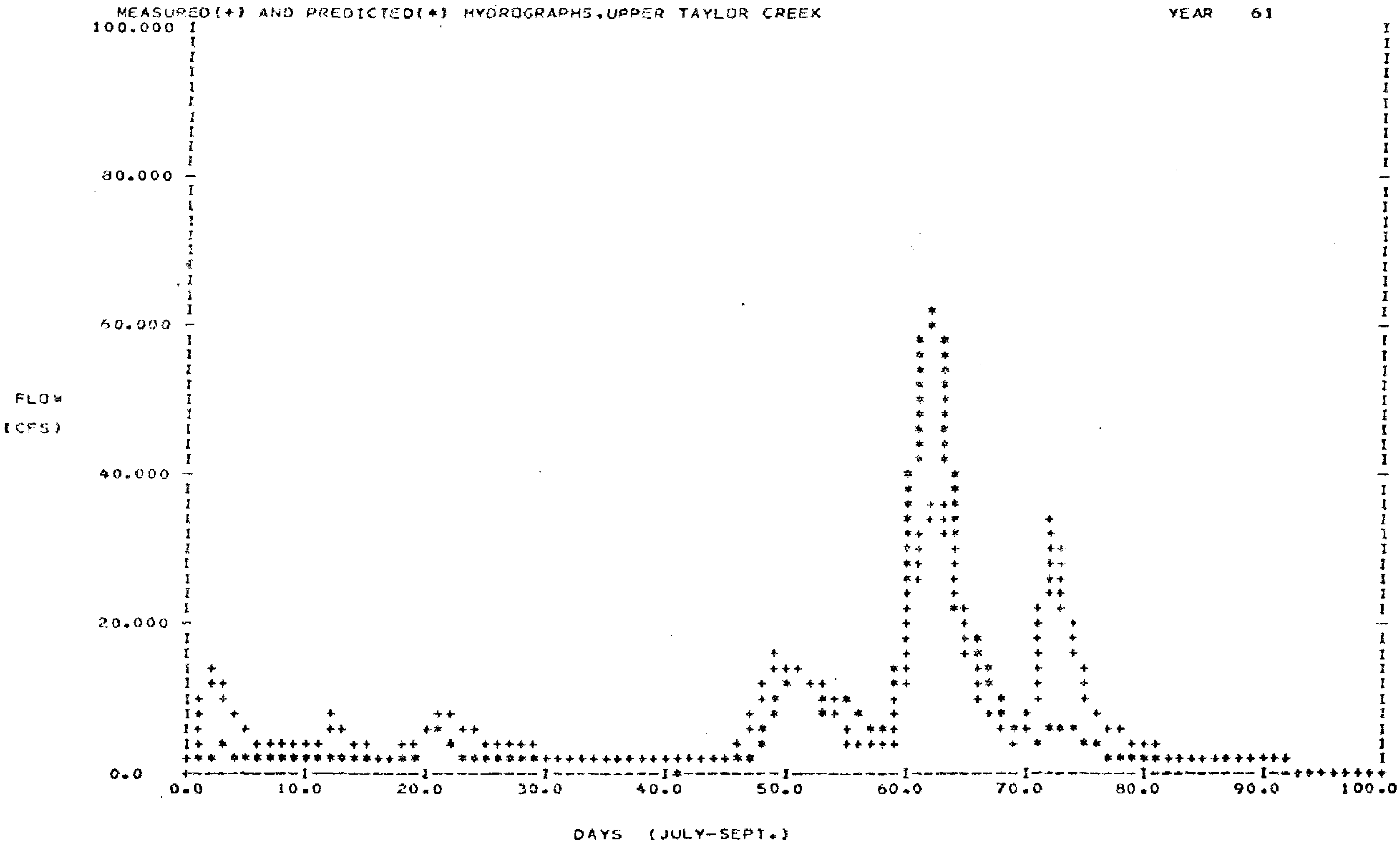

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 60
2500.000
2000.000
1500.000
1000.000
500.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)

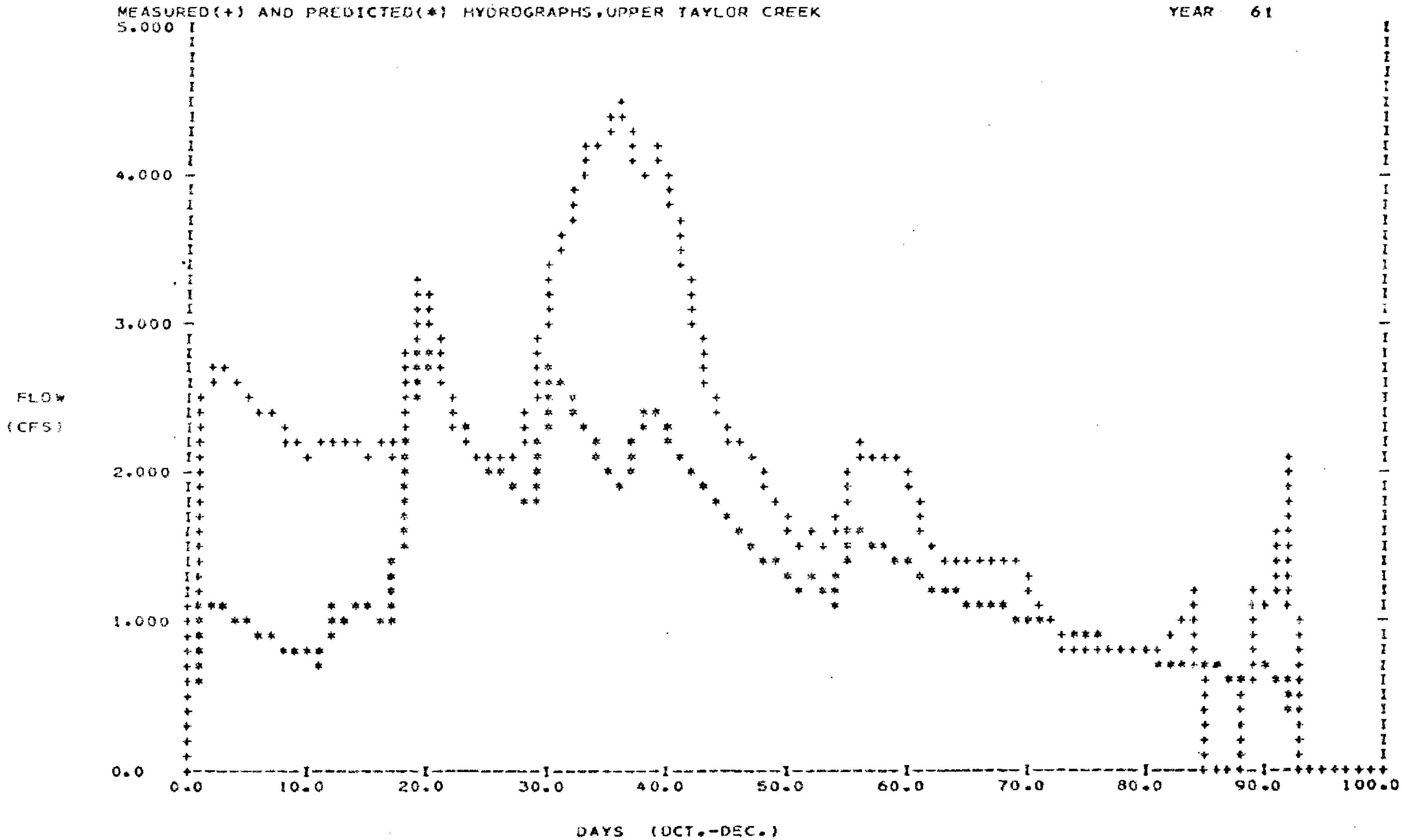

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 60
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (OCT.-DEC.)



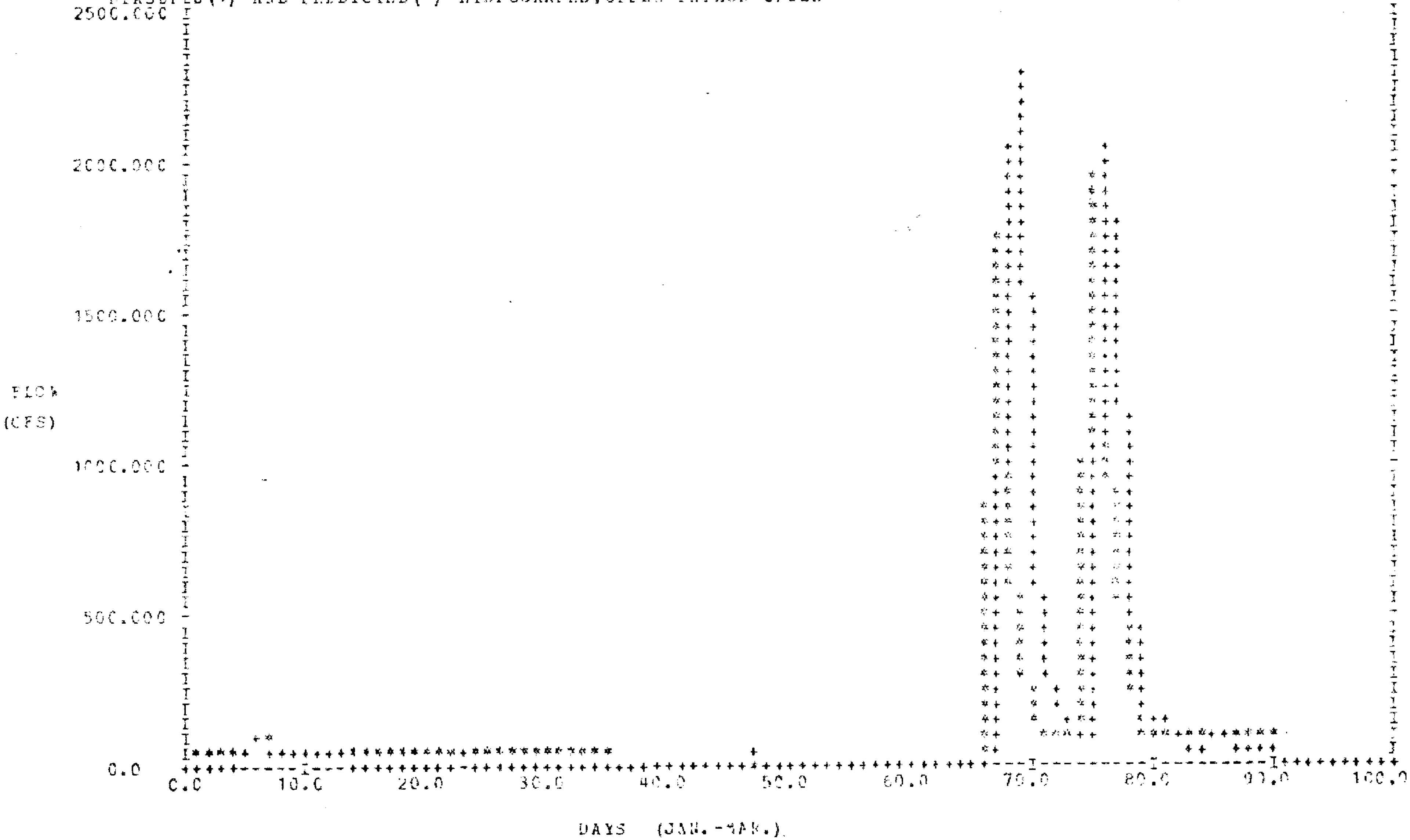
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 61
100.000
80.000
60.000
40.000
20.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JAN.-MAR.)


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 61
FLOW
(CFS)
25,000
20,000
15,000
10,000
5,000
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

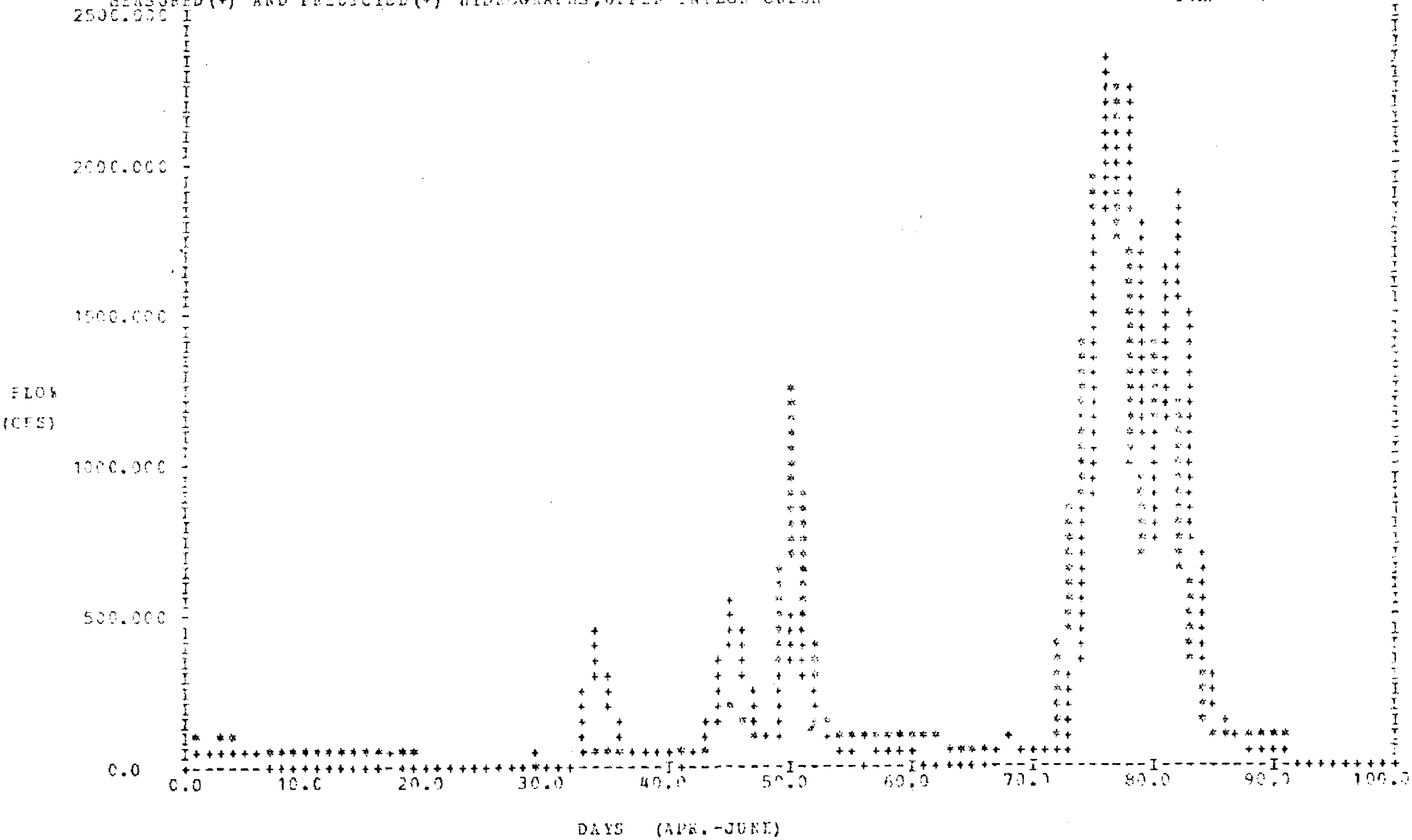

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS.UPPER TAYLOR CREEK
YEAR 61
100.000
80.000
60.000
40.000
20.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 61
FLOW
(CFS)
5.000
4.000
3.000
2.000
1.000
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (OCT.-DEC.)

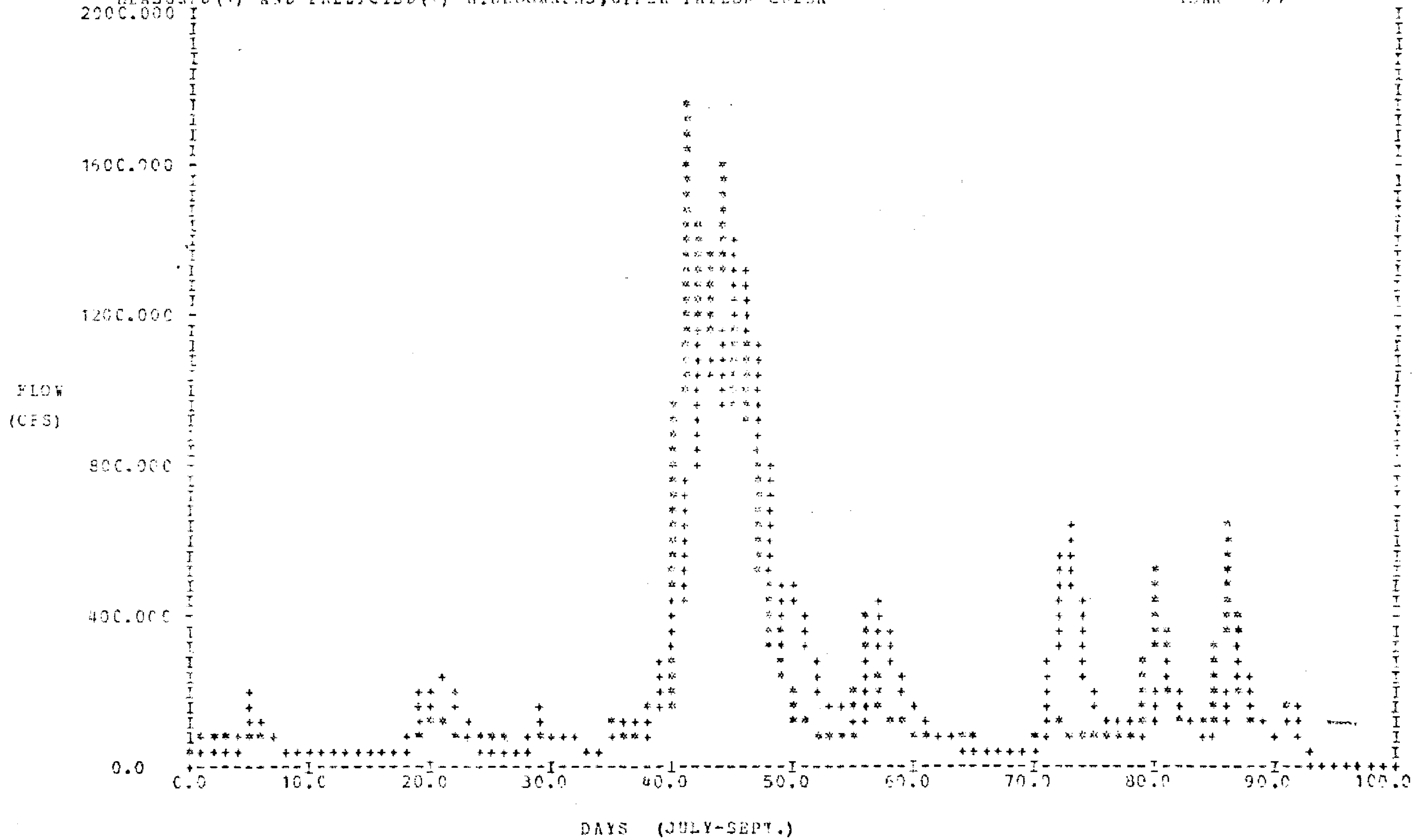
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS, UPPER TAYLOR CREEK YEAR 69

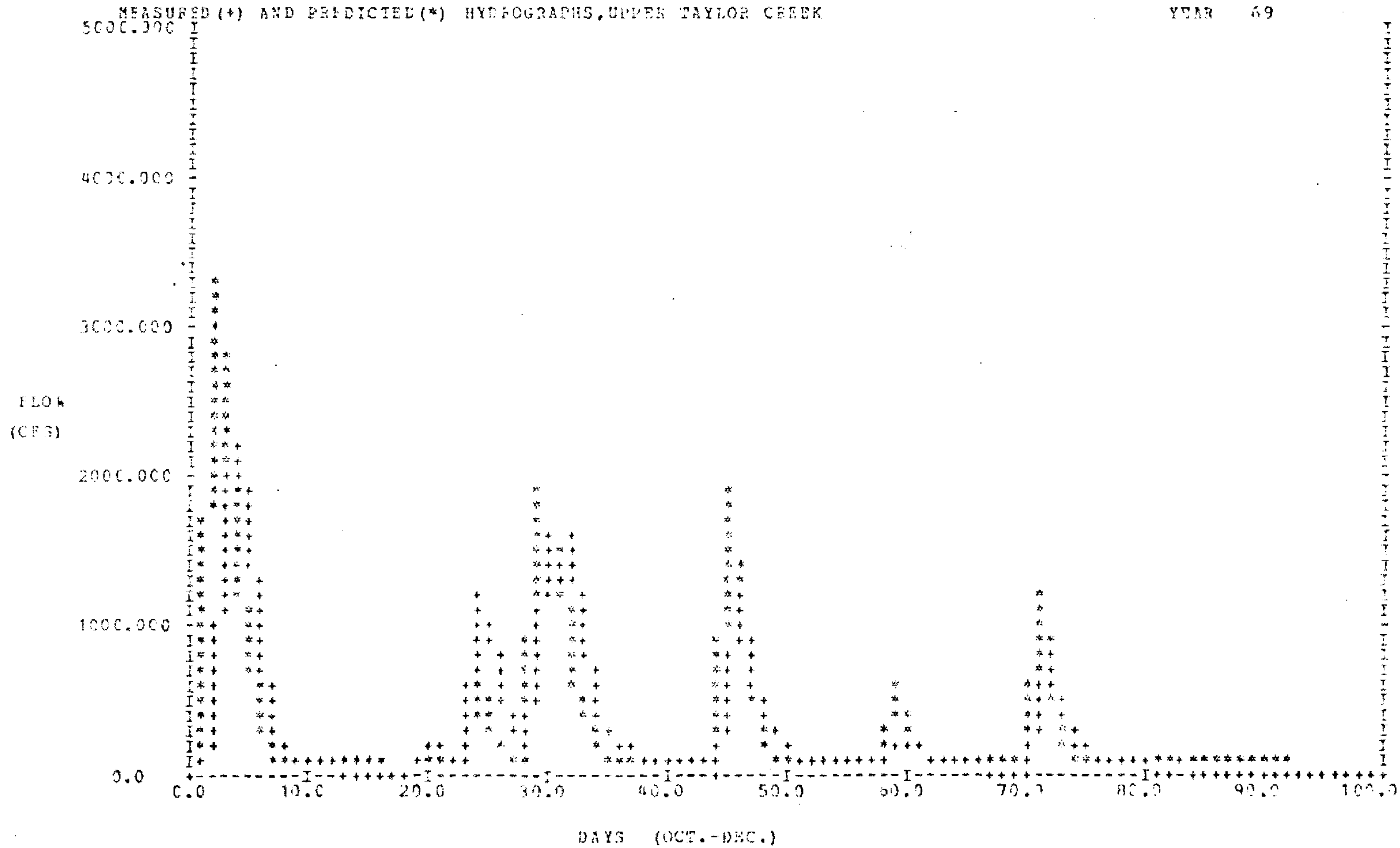


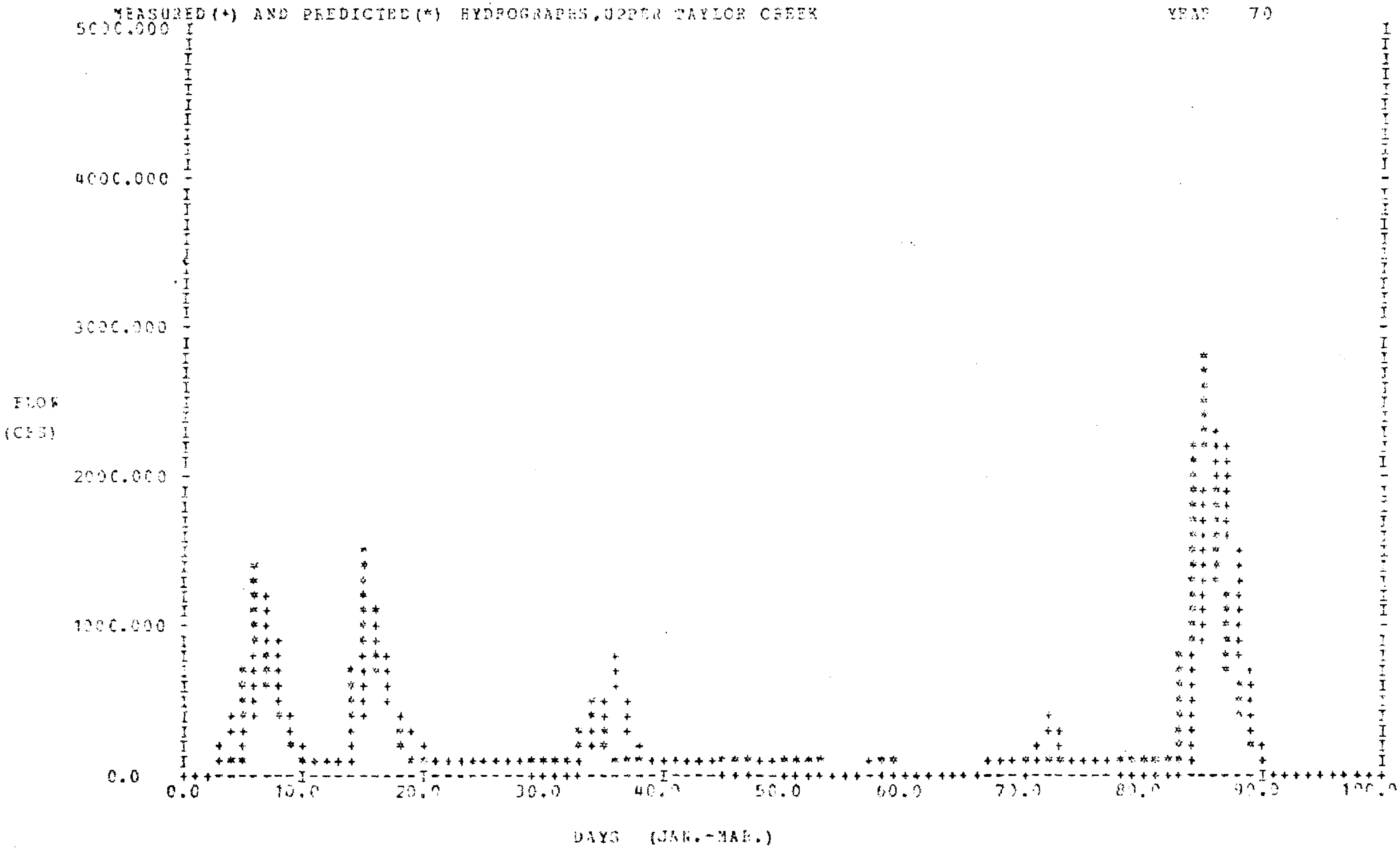
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK YEAR 69

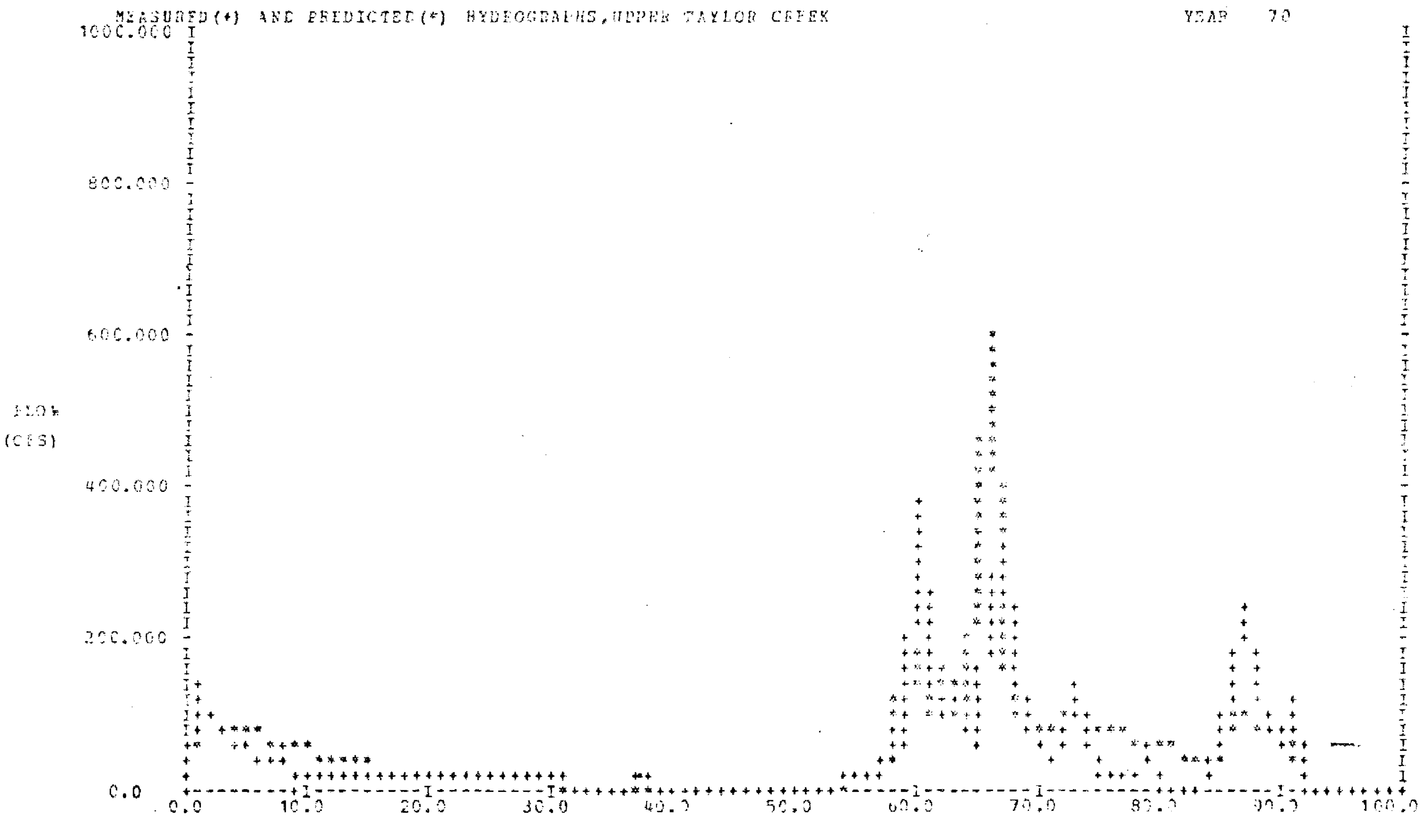


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS, UPPER TAYLOR CREEK YEAR 69

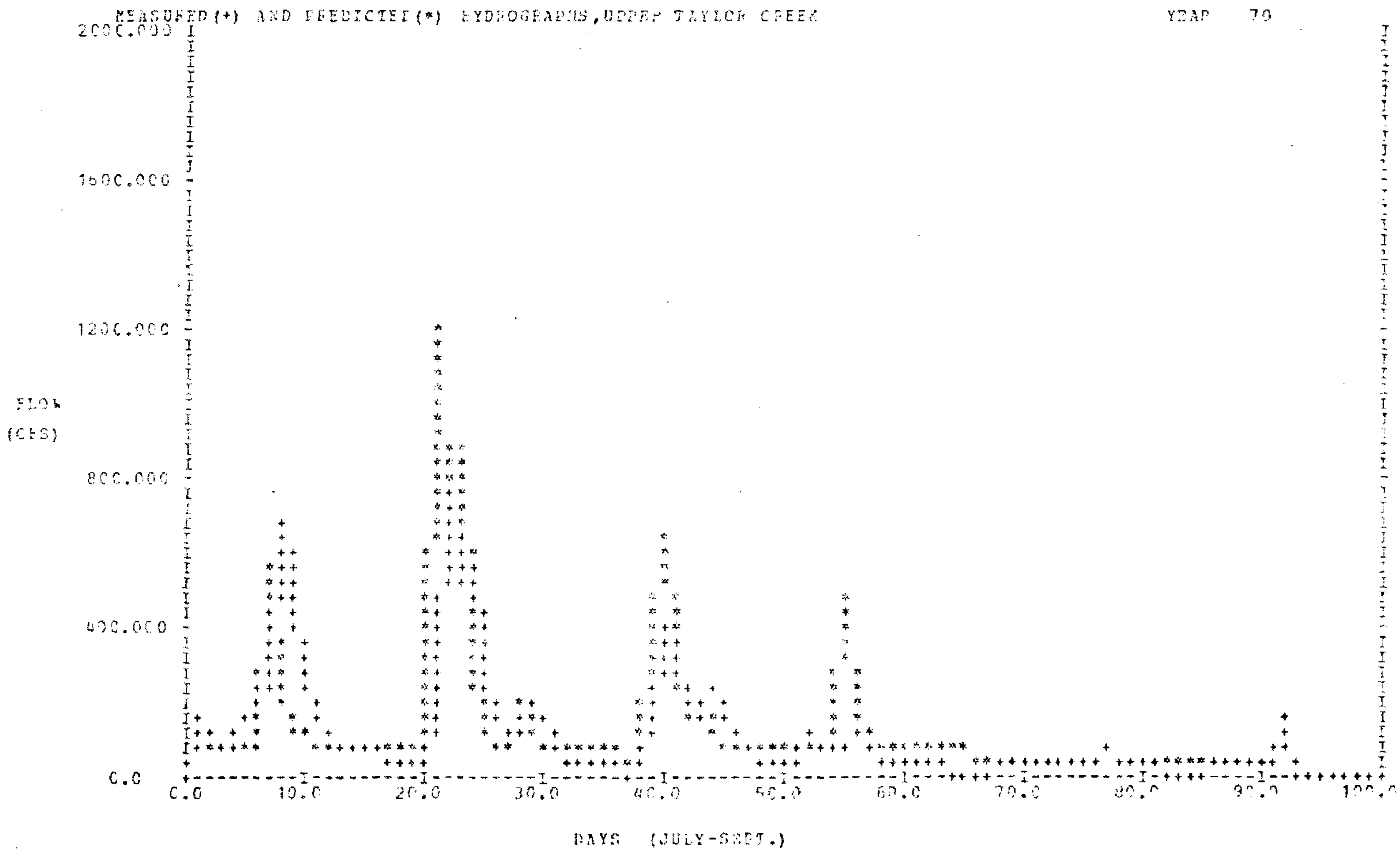



MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 69
5000.000
4000.000
3000.000
2000.000
1000.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (OCT.-DEC.)


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 70
5000.000
4000.000
3000.000
2000.000
1000.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JAN.-MAR.)

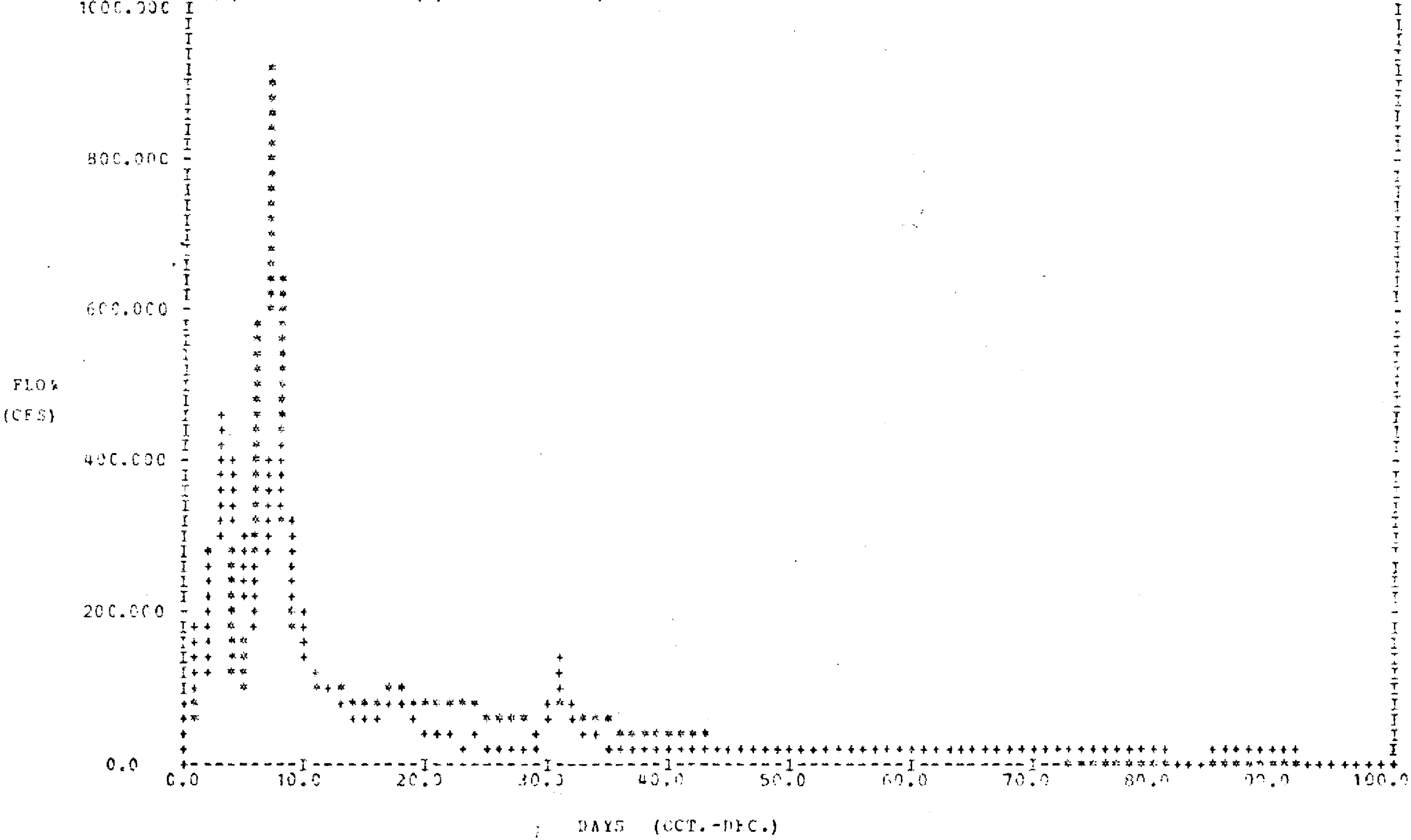


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 70
1000.000
800.000
600.000
400.000
200.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

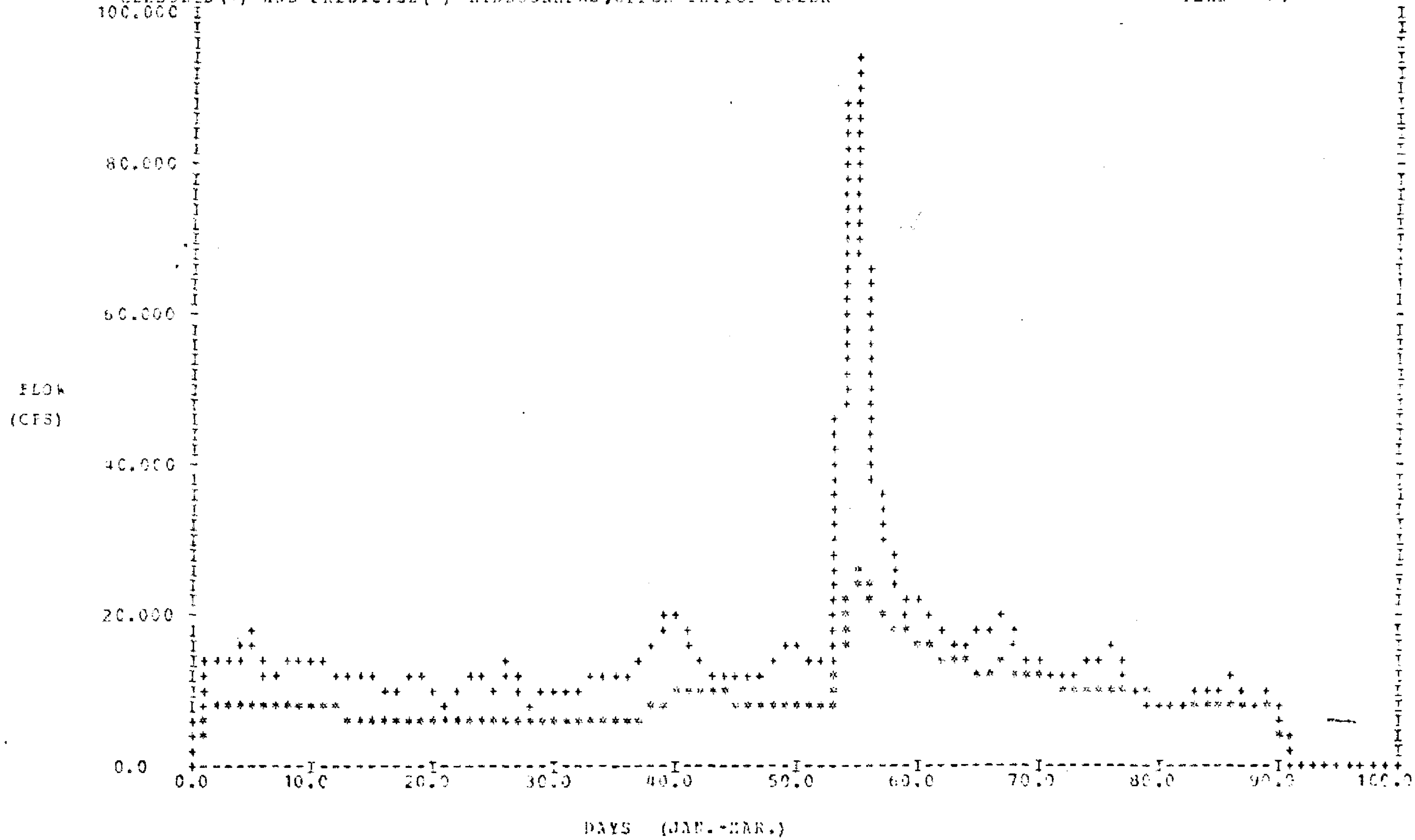


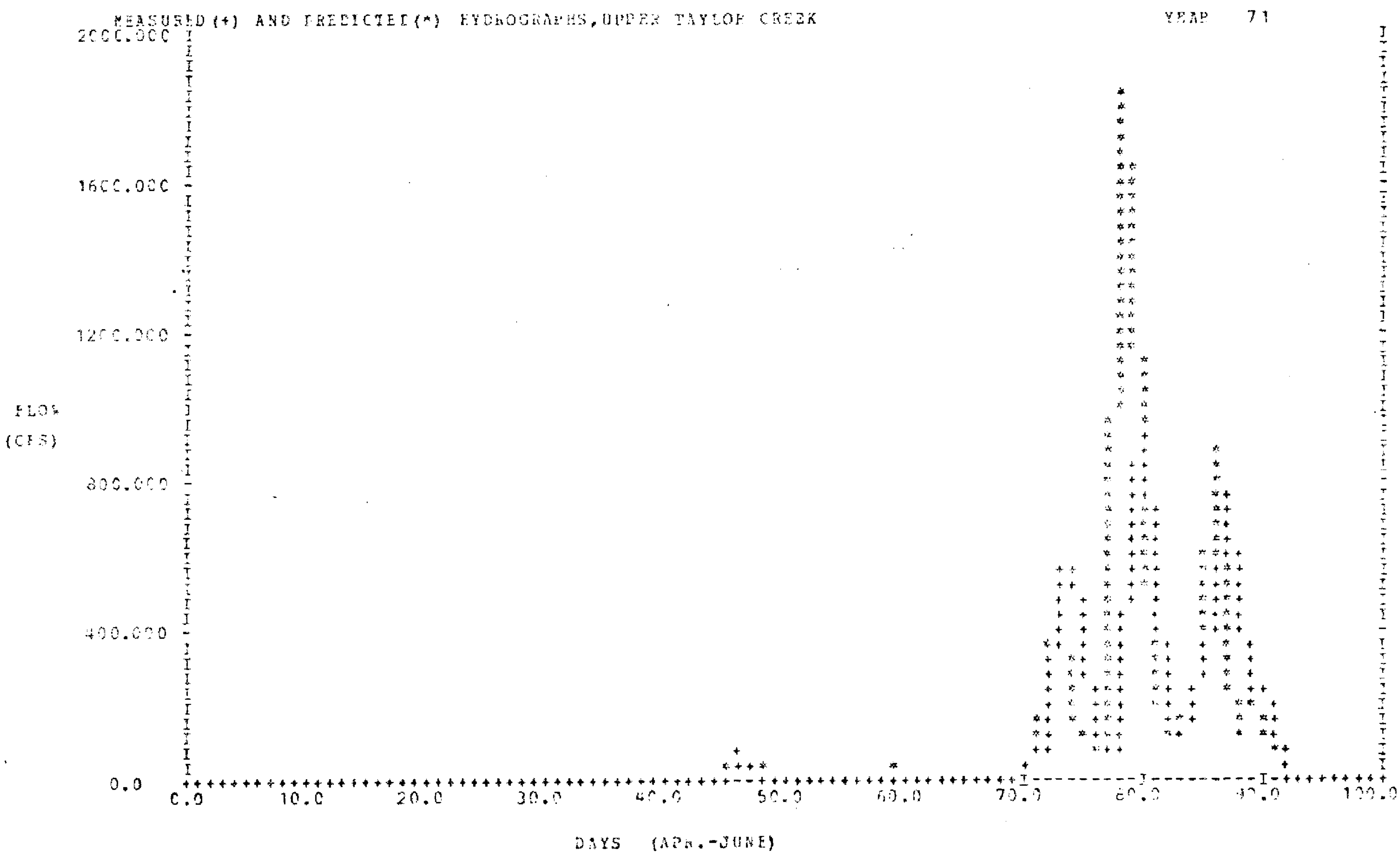
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 79
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)

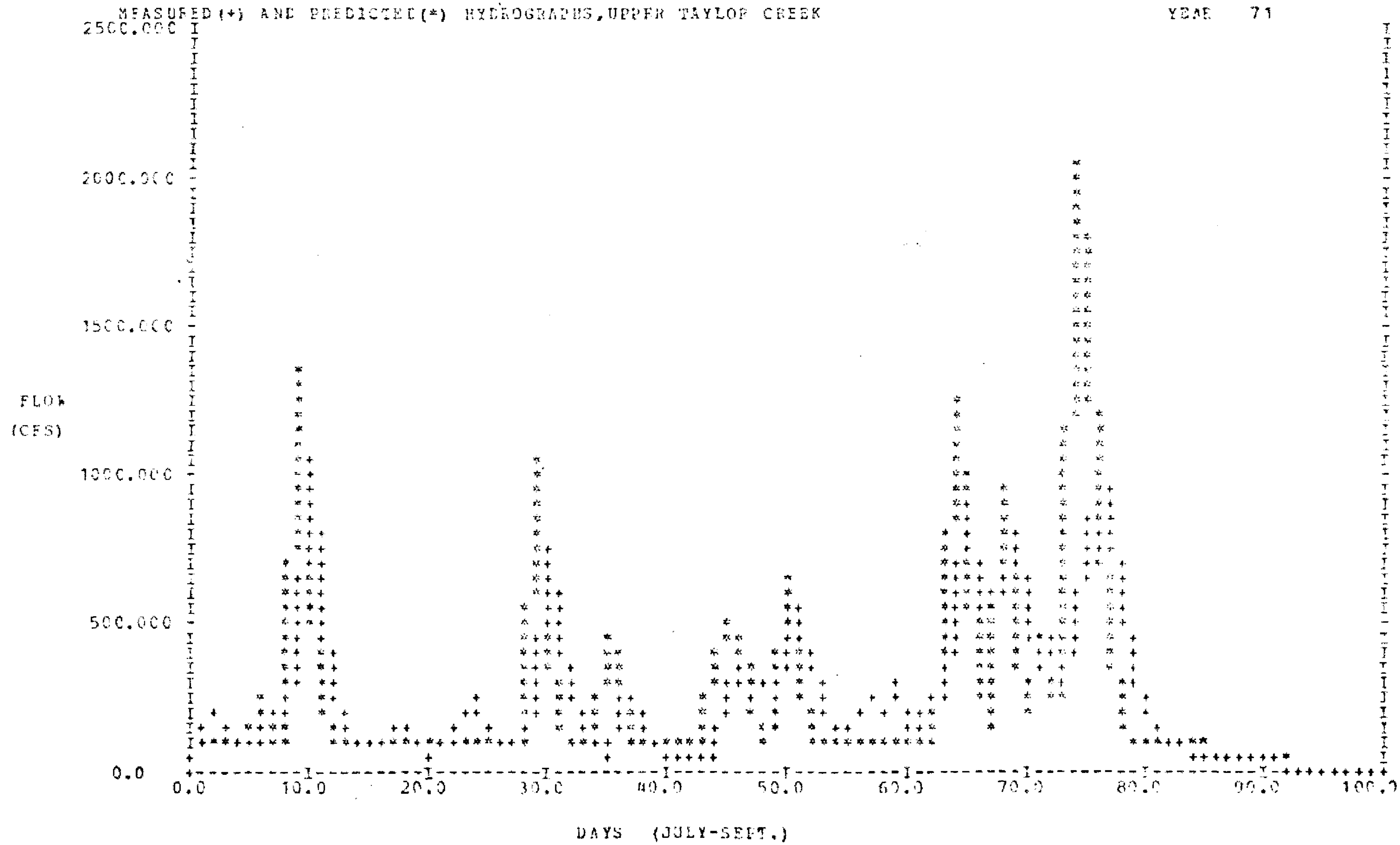
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK YEAR 70



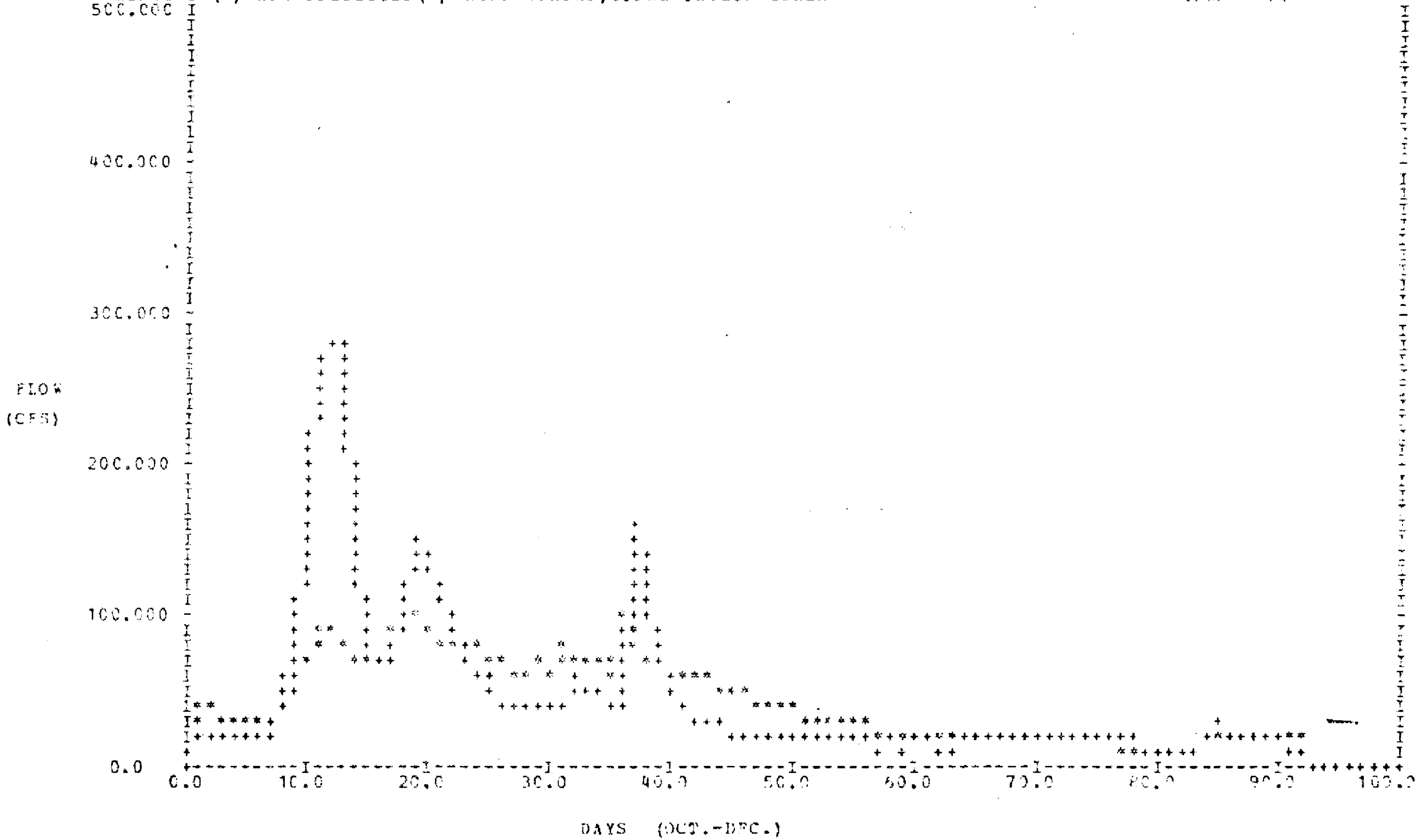
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK YEAR 71



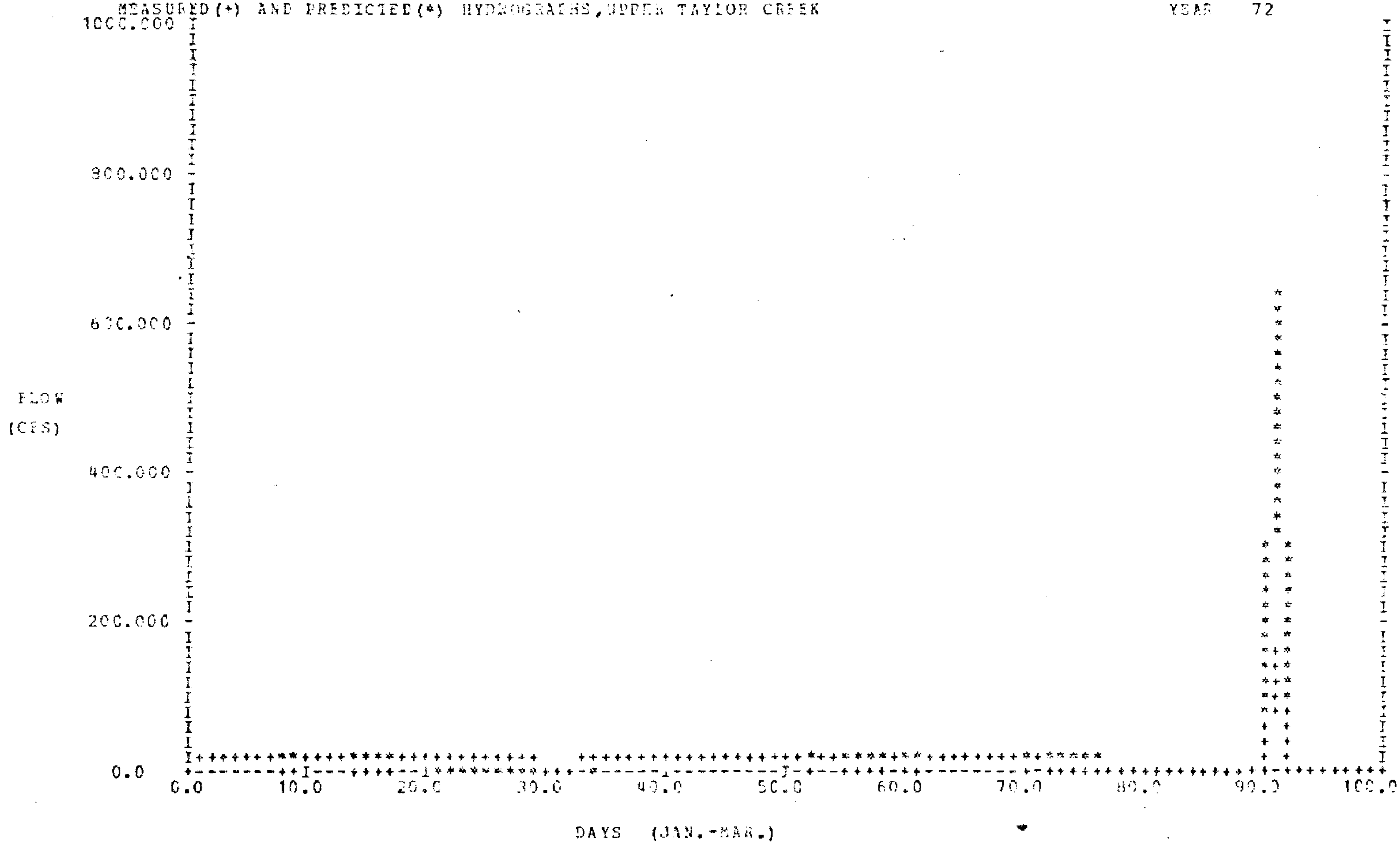

MEASURED (+) AND PREDICTED(*) HYDROGRAPHS, UPPER TAYLOR CREEK
YEAR 71
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

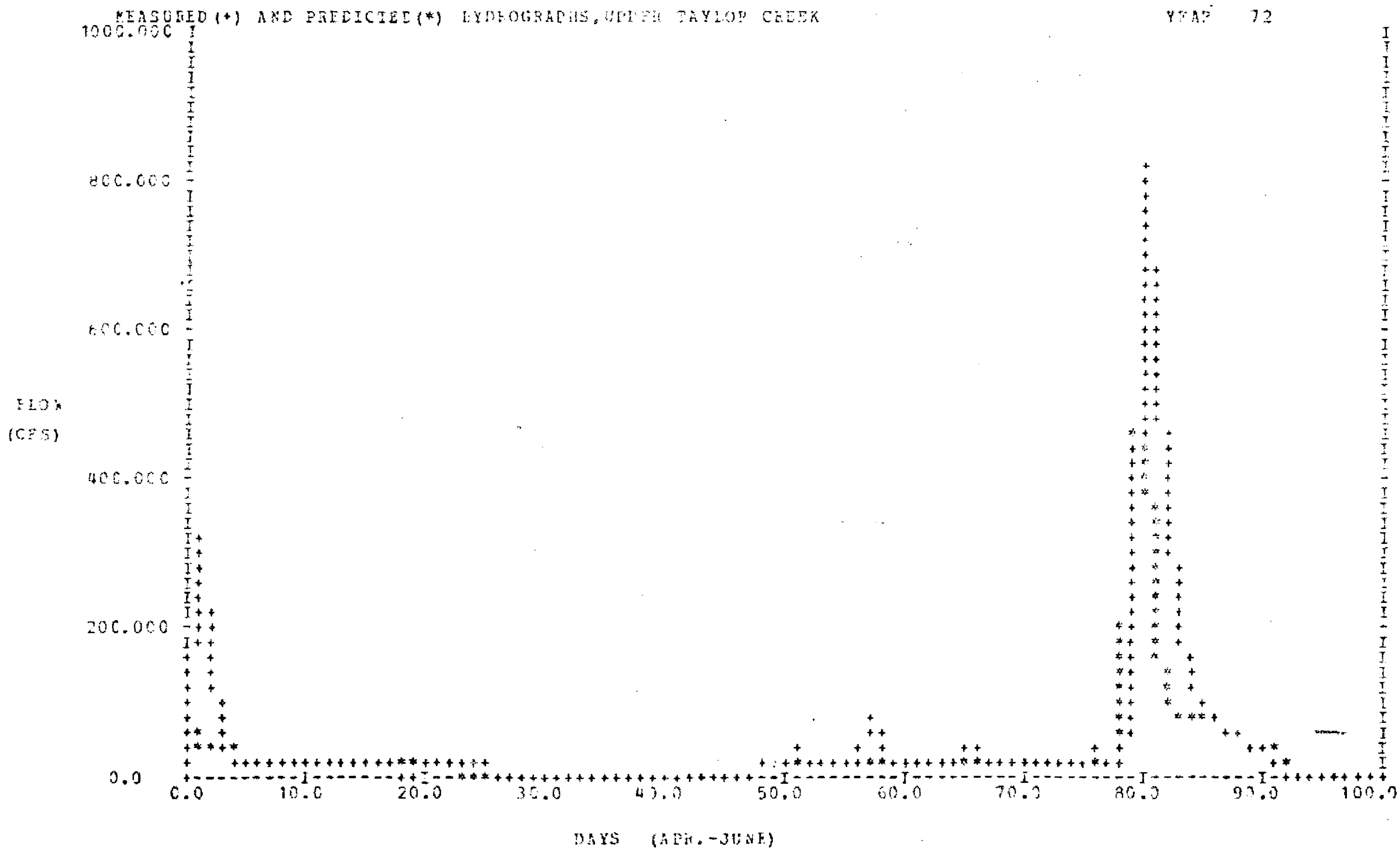

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 71
2500.000
2000.000
1500.000
1000.000
500.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK YEAR 71



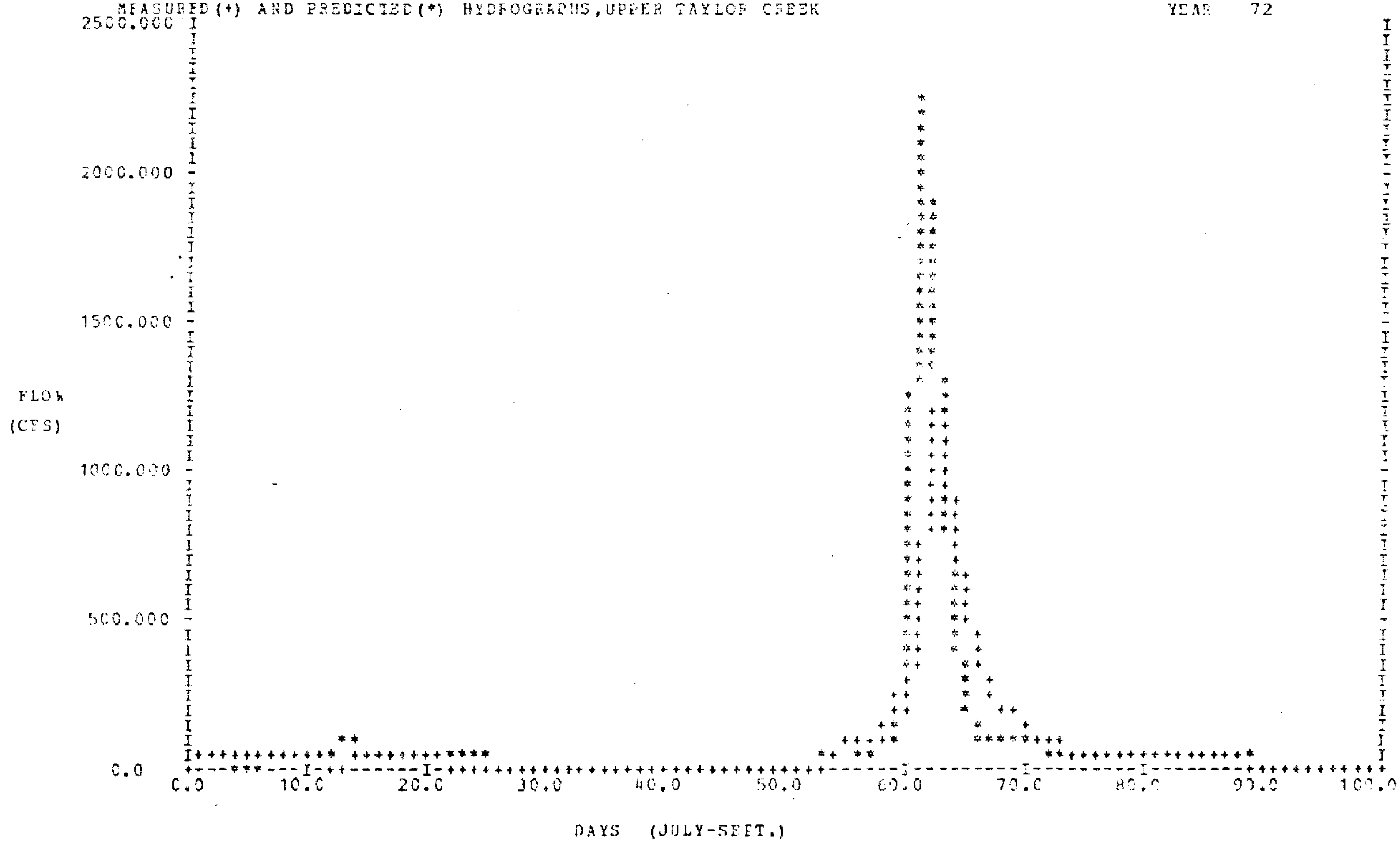
MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK YEAR 72



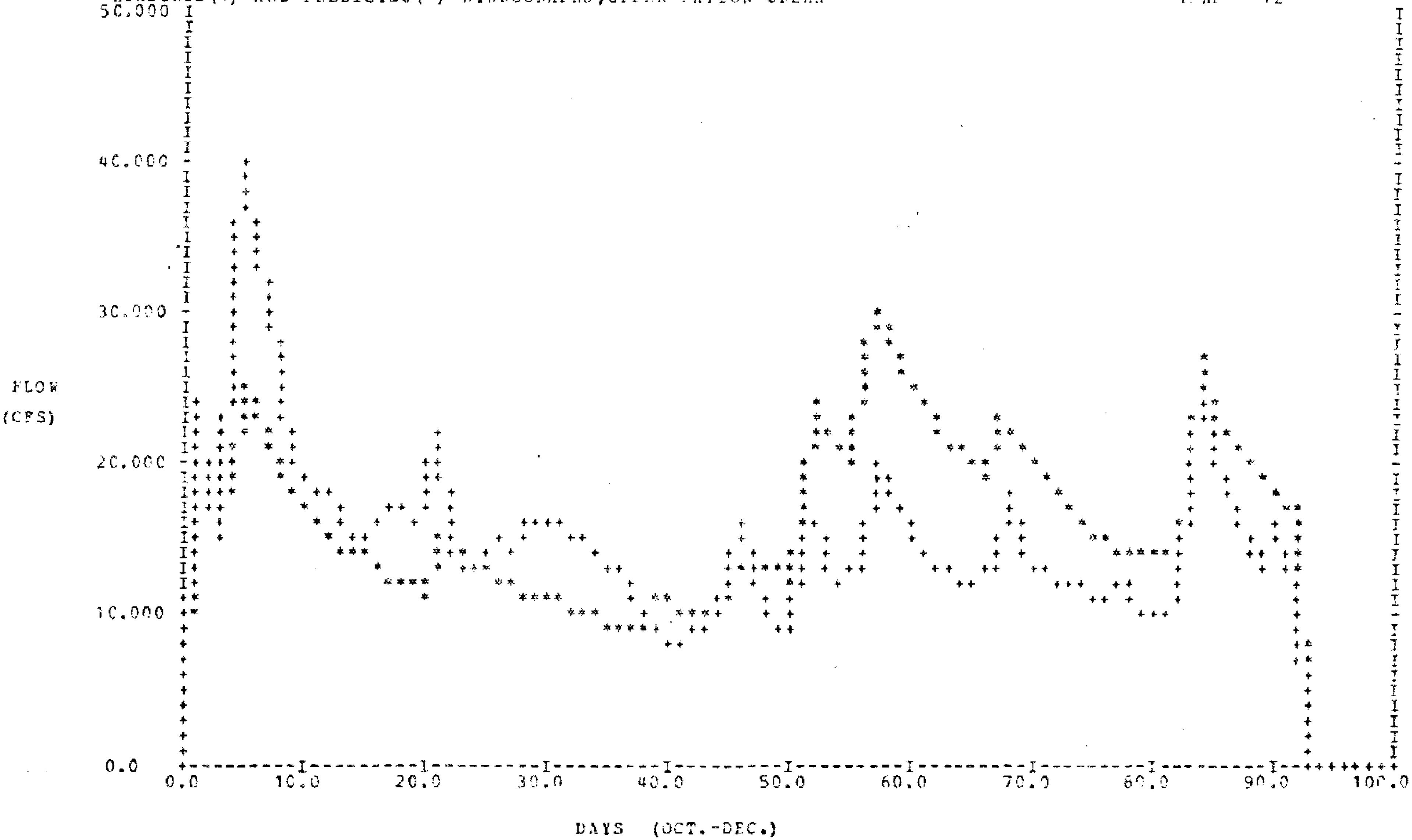


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 72
1000.000
800.000
600.000
400.000
200.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (APR.-JUNE)

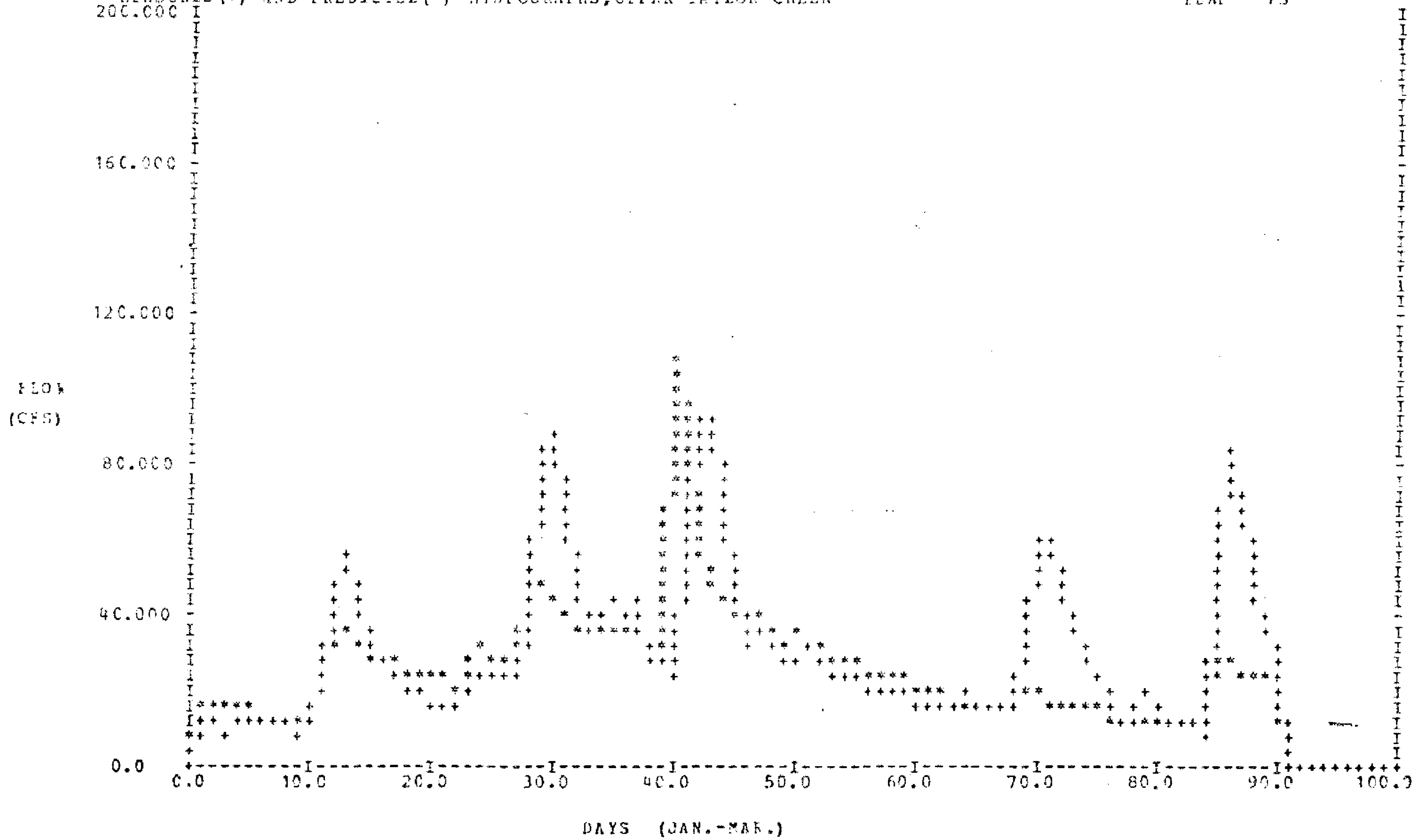
MEASURED (+) AND PREDICTED (*) HYDROGRAPHS, UPPER TAYLOR CREEK YEAR 72



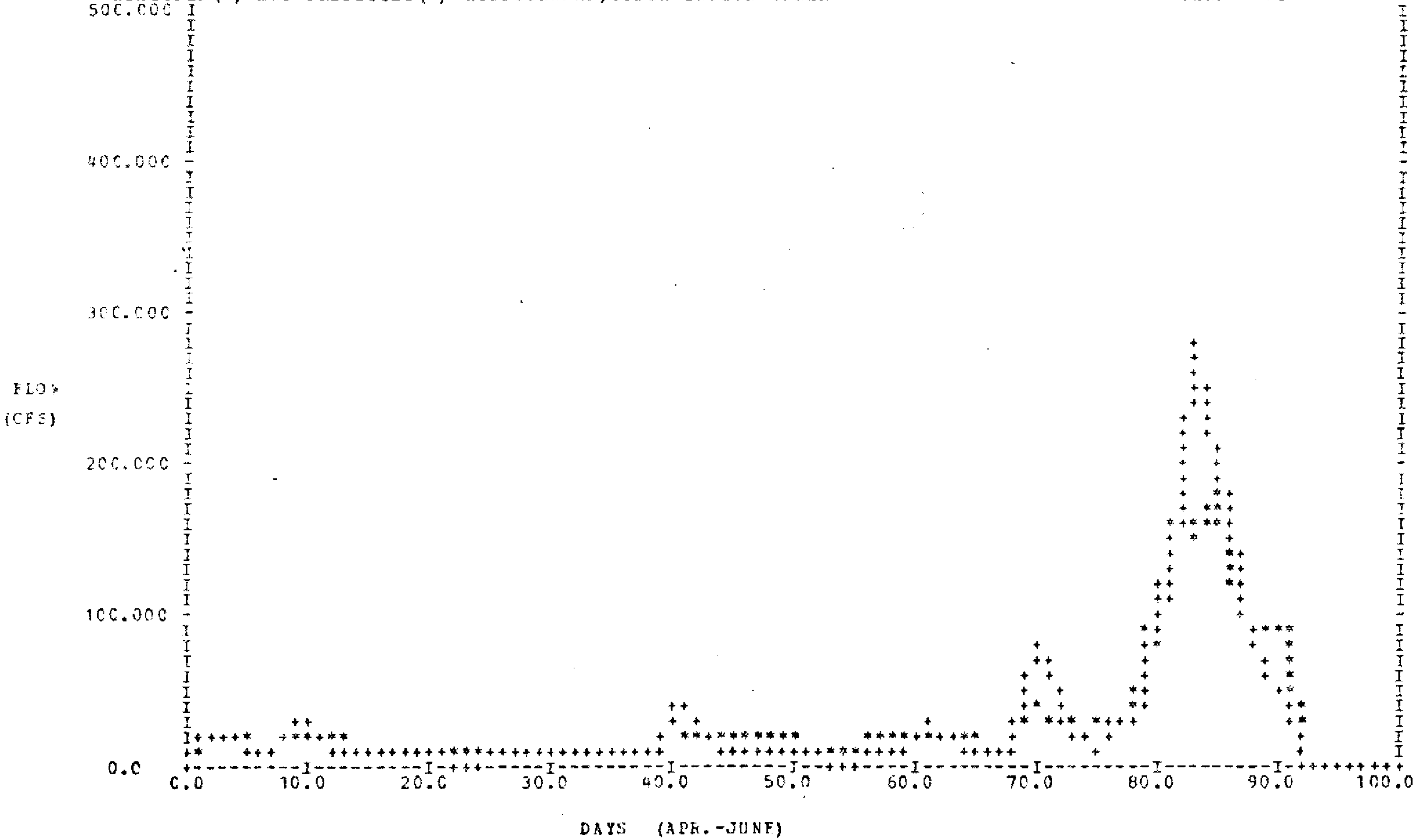
MEASURED (+) AND PREDICTED (*) HYDROGRAPHS, UPPER TAYLOR CREEK   YEAR 72

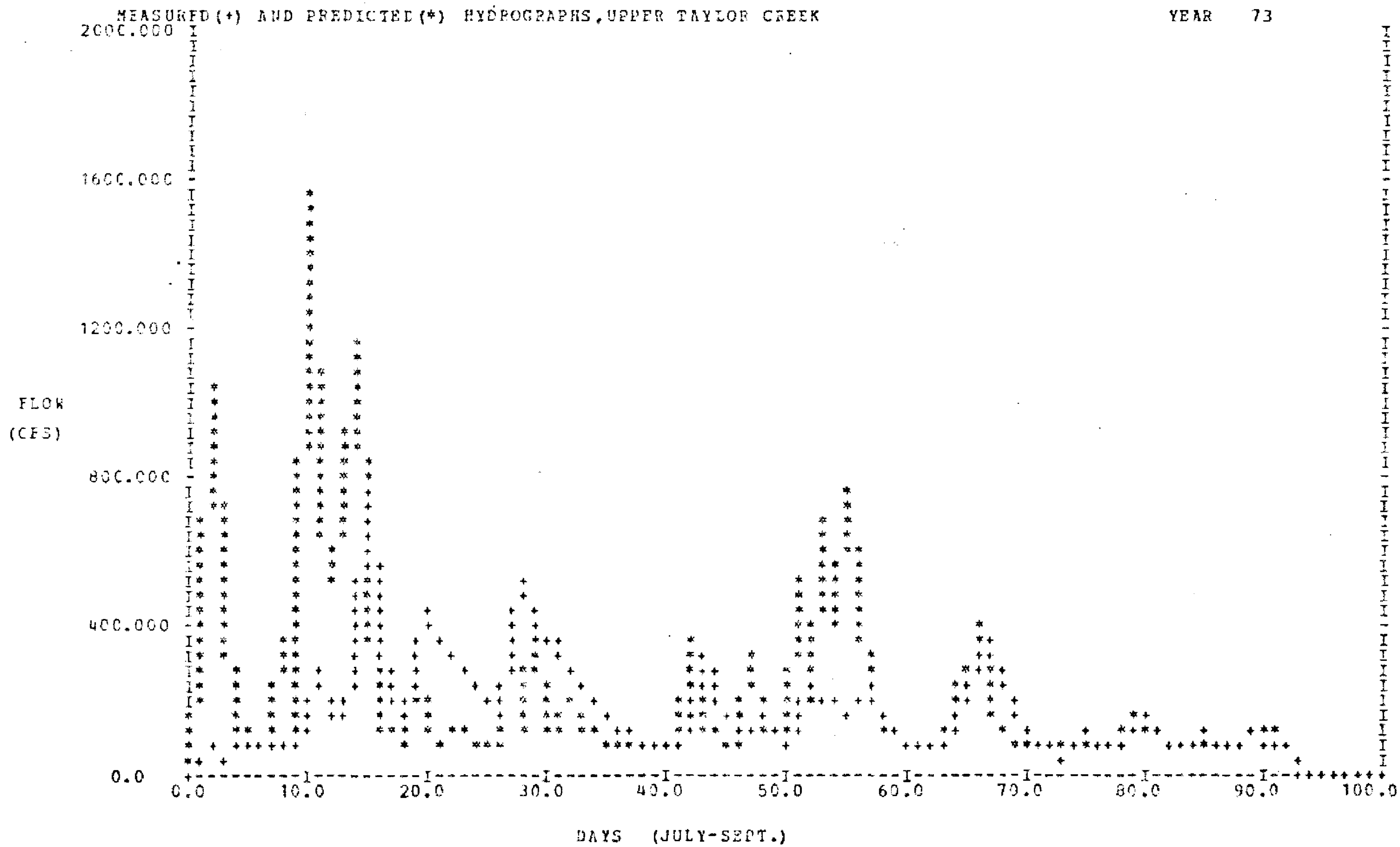


MEASURED(+) AND PREDICTED(*) HYDROGRAPHS, UPPER TAYLOR CREEK YEAR 73

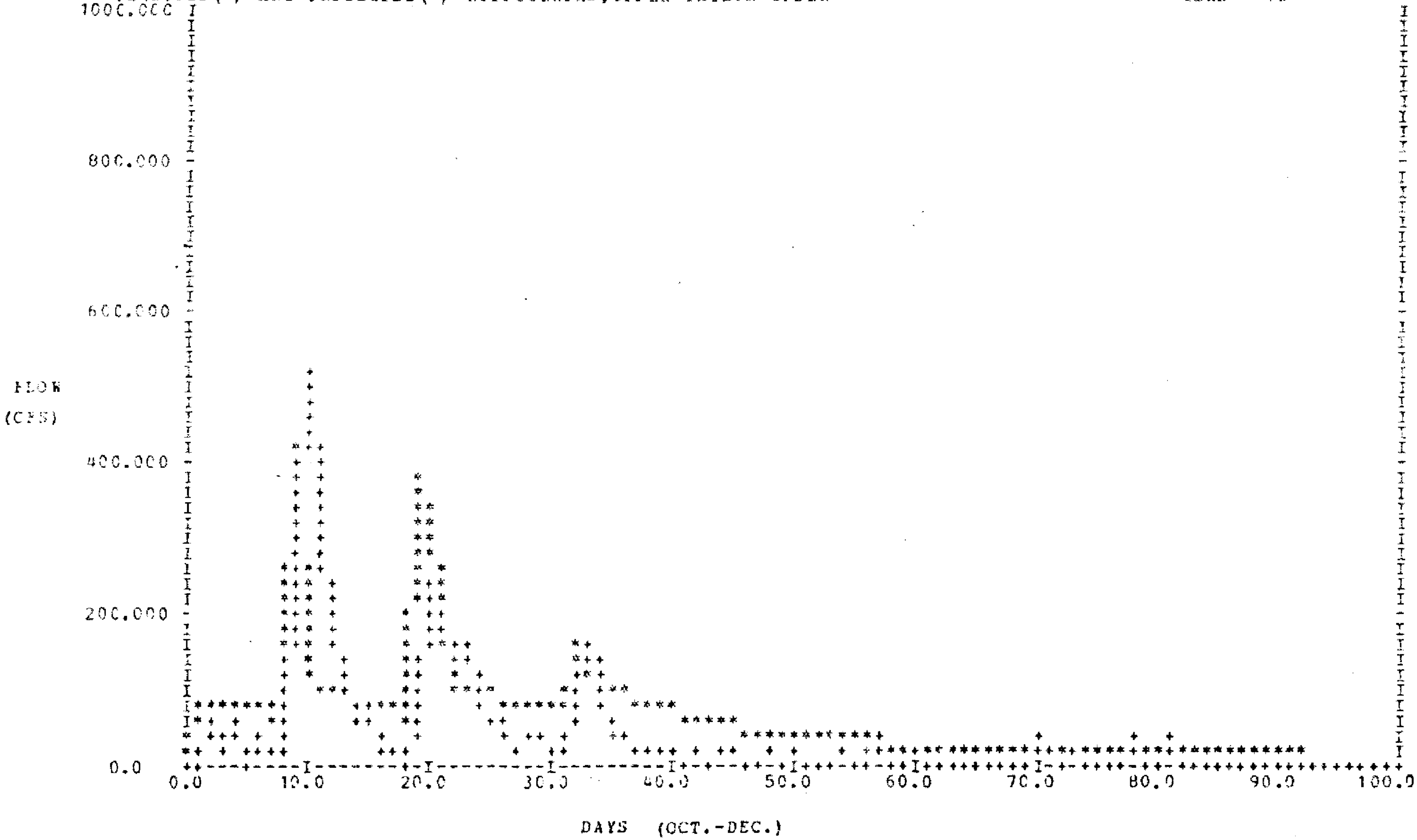


MEASURED (+) AND PREDICTED (*) HYDROGRAPHS, UPPER TAYLOR CREEK YEAR 73




MEASURED(+) AND PREDICTED(*) HYDROGRAPHS,UPPER TAYLOR CREEK
YEAR 73
2000.000
1600.000
1200.000
800.000
400.000
0.0
FLOW
(CFS)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
DAYS (JULY-SEPT.)

MEASURED(+) AND PREDICTED(*) HYDROGRAPHS, UPPER TAYLOR CREEK YEAR 73



APPENDIX C.

PROCEDURES TO CALCULATE SOIL STORAGE PARAMETERS FOR USE IN HLAND

INTRODUCTION

The following procedures are designed to determine the maximum soil moisture storages, SM(J,K), for use in the Hydrologic-Land Use Model, HLAND. SM values are found as functions of drainage densities and soil parameters, in lieu of the analogy to the SCS Curve Number procedures (see equation A-5). The depth to the impermeable barrier times the effective porosity is the maximum possible soil storage. Each land use, depending on its drainage density, has some fraction of this maximum soil storage. This method uses a steady state Dupuit equation for the free surface between parallel ditches.

Figure C-1 shows the idealized representation of the soil cross section. The soil profile is assumed to be homogeneous with respect to porosity, hydraulic conductivity and depth within each hydrologic soil group. The drainage network is assumed to be parallel with ditch depth and ditch spacing remaining constant for each land use. Parameters vary between hydrologic soil groups (e.g., values for hydrologic conductivities, effective porosities and soil depth are generally highest in SCS Hydrologic Soil Group A and lowest in Group D). Although most parameters must be estimated, the method gives relative indications of the effects of drainage densities on soil moisture parameters.

DEFINITION OF TERMS

H = Depth to impermeable layer (ft.) = Soil depth (ft.).

N = Net average accretion (inches/day).

K = Hydraulic conductivity (inches/day).

n_e = Effective porosity.

D_d = Drainage density (mile/sq. mile).

L = Ditch spacing (ft.) [neglect ditch width].

SM = Maximum soil moisture storage (inches).

d = Ditch depth (ft.).

h(x) = Height above the impermeable layer of the steady state phreatic surface at distance x from parallel ditch (ft.).

h_o = H - d (ft.).

L_{max} = Ditch length where $h(x=L_{max}/2) = H$ (ft.).

CN = Curve number.

PROCEDURES

STEP 1 Determine representative values for K, H, and n_e for the hydrologic soil group of interest.

STEP 2 Estimate N, d and D_d for the land use of interest. N = average runoff adjusted to the same units as K.

STEP 3 Find ditch spacing, L (ft) where $L = 5280 / D_d$.

STEP 4 The steady state equation for the shape of the phreatic surface (Bear, 1972) is as follows:

$$h(x) = [\ h_o^2 + N\ (\ L - x\ )\ x\ /\ K\ ]^{1/2} \tag{C.1}$$

Solving eq. C.1 for L_{max} when $h(x=L_{max}/2) = H$

$$L_{max} = [\ 4K\ (\ H^2 + h_o^2\ )\ /\ N\ ]^{1/2} \tag{C.2}$$

STEP 5 If ditch spacing, L, for the land use is less than or equal to L_{max}, then GO TO STEP 8. If L is greater than L_{max}, then GO TO STEP 6.

STEP 6 Integrate eq. C.1 from x=0 to $x=L_{max}$.

$$I = L_{max} h_o/2 + (K/N)^{1/2}\ (h_o^2 + NL_{max}^2/4K)\arcsin[\ A\ ] \tag{C.3}$$

where $I = \int h(x)dx$ from x=0 to $x=L_{max}$

$$A = [NL_{max}^2/(NL_{max}^2 + 4Kh_o^2)]^{1/2}$$

$$-\pi/2 \le \arcsin[\ A\ ] \le \pi/2$$

STEP 7 Find the average height of the phreatic surface, $\overline{h(x)}$, when $L > L_{max}$.

$$\overline{h(x)} = I/L + (L - L_{max})H/L \tag{C.4}$$

GO TO STEP 10.

STEP 8 Integrate eq. C.1 from x=0 to x=L. (same as eq. C.3 but with $L_{max} = L$).

STEP 9 Find the average height of the phreatic surface, $\overline{h(x)}$, when $L \le L_{max}$.

$$\overline{h(x)} = I/L \tag{C.5}$$

STEP 10 Determine the maximum soil moisture storage parameter, SM (inches).

$$SM = \overline{h(x)}\ n_e\ 12.0 \tag{C.6}$$

STEP 11 Convert SM to curve number form for input into HLAND.

$$CN = 1000/(SM + 10.0) \tag{C.7}$$

EXAMPLE 1

Determine SM for improved pasture in SCS Hydrologic Soil Group C with the drainage density equal to 11.7 mile/sq. mile.

STEP 1 K is estimated to be 320 inches/day.
n_e is estimated to be 0.18.
H is estimated to be 5.5 ft.

STEP 2 N ≈ average runoff = 0.0358 inches/day.
d is assumed to be 3 ft.

STEP 3 $L = 5280/D_d = 450$ ft.

STEP 4 $L_{max} = 926$ ft.

STEP 5 L is less than L_{max} therefore GO TO STEP 8.

STEP 8 I = 1419 ft^2

STEP 9 $\overline{h(x)} = 3.15$ ft.

STEP 10 SM = 6.8 inches.

STEP 11 CN = 59.

EXAMPLE 2

Same as example 1 except for unimproved pasture with drainage density = 1.7 $mi/mi.^2$

STEP 1 and STEP 2 same as example 1.

STEP 3 L = 3106 ft.

STEP 4 $L_{max} = 926.$ ft.

STEP 5 L is greater than L_{max} therefore GO TO STEP 6.

STEP 6 I = 4298 $ft.^2$

STEP 7 $\overline{h(x)} = 5.24$ ft.

STEP 10 SM = 11.33 inches.

STEP 11 CN = 47.