UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROGRESS REPORT ON STUDY OF
MAGNITUDE AND FREQUENCY OF FLOODS
ON SMALL DRAINAGE AREAS IN FLORIDA

By W. C. Bridges

U.S. GEOLOGICAL SURVEY

Open-File Report 77-478

Prepared in cooperation with

FLORIDA DEPARTMENT OF TRANSPORTATION

CONTENTS

ILLUSTRATIONS

PROGRESS REPORT ON STUDY OF MAGNITUDE AND FREQUENCY OF FLOODS ON SMALL DRAINAGE AREAS IN FLORIDA

By

W. C. Bridges

ABSTRACT

Long-term flood records for small basins, especially those basins of less than 10 square miles, are almost nonexistent in Florida. In July 1967 a program was begun to develop a data base to extend short-term flood-peak records for small basins by use of the U.S. Geological Survey rainfall/runoff model. Concurrent rainfall and runoff data, for a 5- to 7-year period, were used to calibrate a model for eight rainfall/runoff gaging stations. The standard error of estimate ranged from 25 to 50 percent. Twenty other rainfall/runoff stations are ready for calibration.

The Caney Creek station was calibrated, and the annual peaks simulated for 1902-68 were used as input to develop a flood-frequency curve using a log-Pearson Type III distribution.

INTRODUCTION

Because of the increase in the number of highways being constructed in recent years, more knowledge of the flood-frequency characteristics of small watersheds is needed for the design of safe and economical highway drainage structures. In the hydraulic design of such structures, one of the first considerations is the magnitude and frequency of the design flood or the maximum peak flow that can safely pass through

1

the structure. The most desirable basis for a selection of the design
discharge is a flood-frequency analysis of a long-term record of floods
that have occurred at or near the site. With more than 50 percent of
the Florida Highway bridge construction funds being spent to build
bridges and culverts on small basins, there exists a great need for
reliable flood-frequency information for small basins.

In 1958 the Florida Department of Transportation and the Geological
Survey began a cooperative program to install crest-stage gages to
obtain data on the annual maximum stage and discharge at selected sites
in Florida. The purpose of this program was to provide a data base of
annual peaks to be used in a statewide flood-frequency report.

A crest-stage gage consists of a length of 2-in (inch) pipe set in
a vertical position in the stream channel and records the peak stage of
the stream. There are 41 crest-stage stations, 25 stations are on
streams whose drainage areas are 50 mi^2 or less. Only four of the
crest-stage stations are on streams whose drainage areas are less than
10 mi^2. Drainage areas range from 2.95 to 1,720 mi^2.

In Florida, as in most states, the emphasis had been on data
collection for basins larger than 50 mi^2. Very little data are avail-
able for smaller basins, expecially those of less than 10 mi^2, for which
records of more than 10 years in length are almost nonexistent. Records
of less than 10 years now available are insufficient to develop frequency
curves for an individual site or on a regional basis.

To meet this need for flood-frequency data on small basins the
Geological Survey and the Florida Department of Transportation expanded
the cooperative program in July 1967 to develop a data base and to extend
short-term flood peak records on small basins using the U.S. Geological
Survey Rainfall/Runoff Model (Dawdy, Lichty, and Bergman, 1972).

Five rainfall/runoff gaging stations were established in December 1968. By July 1969 a total of 20 rainfall/runoff gaging stations were in the network. During July and September 1970 the rainfall/runoff gaging station network was expanded to 27 stations. At the request of the cooperator six urban rainfall/runoff gaging stations were added to the network in July 1971 which made a total of 33 rainfall/runoff gaging stations. Because of variable backwater problems three of the stations were discontinued, leaving a network of 30 rainfall/runoff stations.

Drainage areas for the rainfall/runoff gaging stations vary from 0.06 to 19.9 mi^2, and their distribution is as follows:

Drainage area (mi^2)	0-0.5	0.5-1	1-2	2-5	5-10	10-20
Number of stations	1	3	5	8	9	4

Drainage areas for the crest-stage and regular gaging stations (on streams whose drainage areas are less than 50 mi^2) range from 2.95 to 49.1 mi^2, and their distribution is as follows:

Drainage area (mi^2)	1-2	2-5	5-10	10-20	20-30	30-40	40-50
Number of stations	0	1	5	11	20	13	8

Figure 1 is a map showing the location of the rainfall/runoff gaging stations and crest-stage or regular gaging stations on streams whose drainage areas are 50 mi^2 or less. Of these, 36 percent are on streams whose drainage areas are 10 mi^2 or less.

The purpose of this report is to describe the general characteristics of the rainfall/runoff model and to summarize the modeling results using one example. A flow chart of the work elements of the project is shown in figure 2.

Figure I. Location of gaging stations whose drainage areas are 50 square miles or less.

4

DATA COLLECTION

A. STAGE
B. RAINFALL
C. DISCHARGE MEASURE.
D. PROCESSING OF DIGITAL TAPES

COMPUTER PROCESSING

1. Storm rainfall
2. Flood runoff

EDIT DATA

1. Computer program
2. Visual check

CALIBRATION OF USGS RAINFALL-RUNOFF MODEL

INPUT DATA

A. Selected flood events (20 to 30)
   1. Discharge intervals (15-minutes)
   2. Rainfall (15-minutes)
B. Daily data
   1. Rainfall (period of record used in A)
   2. Evaporation (period of record used in A)

OUTPUT DATA

Parameter values for rainfall-runoff

LONG-TERM NATIONAL WEATHER SERVICE DATA

A. STORM RAINFALL
   1. Obtain rainfall data for 3 or 4 major rainfall events each year for period of record
   2. Tabulate data to 5-minute intervals for NWS stations at:
      a. Pensacola, Fla.
      b. Jacksonville, Fla.
      c. Tampa, Fla.
      d. Thomasville, Ga.
B. DAILY RAINFALL
   Tabulate period of record for:
      a. Pensacola, Fla.
      b. Jacksonville, Fla.
      c. Tampa, Fla.
      d. Thomasville, Ga.
C. DAILY EVAPORATION
   Tabulate period of record for:
      a. Milton Experiment Station
      b. Gainesville, Fla.
      c. Lake Alfred Experiment Station

CARD PUNCHING

EDIT DATA

1. Computer programs
2. Visual check

SIMULATION OF LONG-TERM PEAK DISCHARGE DATA AT SITE

INPUT DATA

1. Parameter values as computed from calibration
2. Long-term weather station data
   a. Unit rainfall (to 5-minute intervals)
   b. Daily rainfall for period of record
   c. Daily evaporation for period of record

OUTPUT DATA

Simulated peak discharges (60-75 years)

FREQUENCY ANALYSIS AT INDIVIDUAL SITES

1. Select annual peak discharges from simulated long-term data
2. Obtain log-Pearson type III frequency curves

MULTIPLE REGRESSION ANALYSIS

1. For each small-stream site having a frequency distribution of simulated annual flood peak discharges, select 2-, 5-, 10-, 25-, 50-, and 100-year floods as dependant variable
2. For each site, use drainage area, stream slope, stream length, forest area, soil type, storage, etc., as independent variables
3. Use step forward regression to determine most significant parameters
4. Use step backward regression to develop predictive equations

REPORT

1. Equations having utility to highway design engineers in the form:

$$Q_t = a\, A^{a_1}\, B^{a_2} \ldots N^{a_n} \quad \underline{1/}$$

2. Supporting data:
   a. Storm rainfall
   b. Observed peak discharge and discharge volume
   c. Simulated peak discharge and volume
   d. Plot of observed peak discharge vs simulated peak discharge

$\underline{1/}$ Q_t = flood magnitude having a t-year recurrence interval

$A, B, \ldots N$ = drainage-basin indices

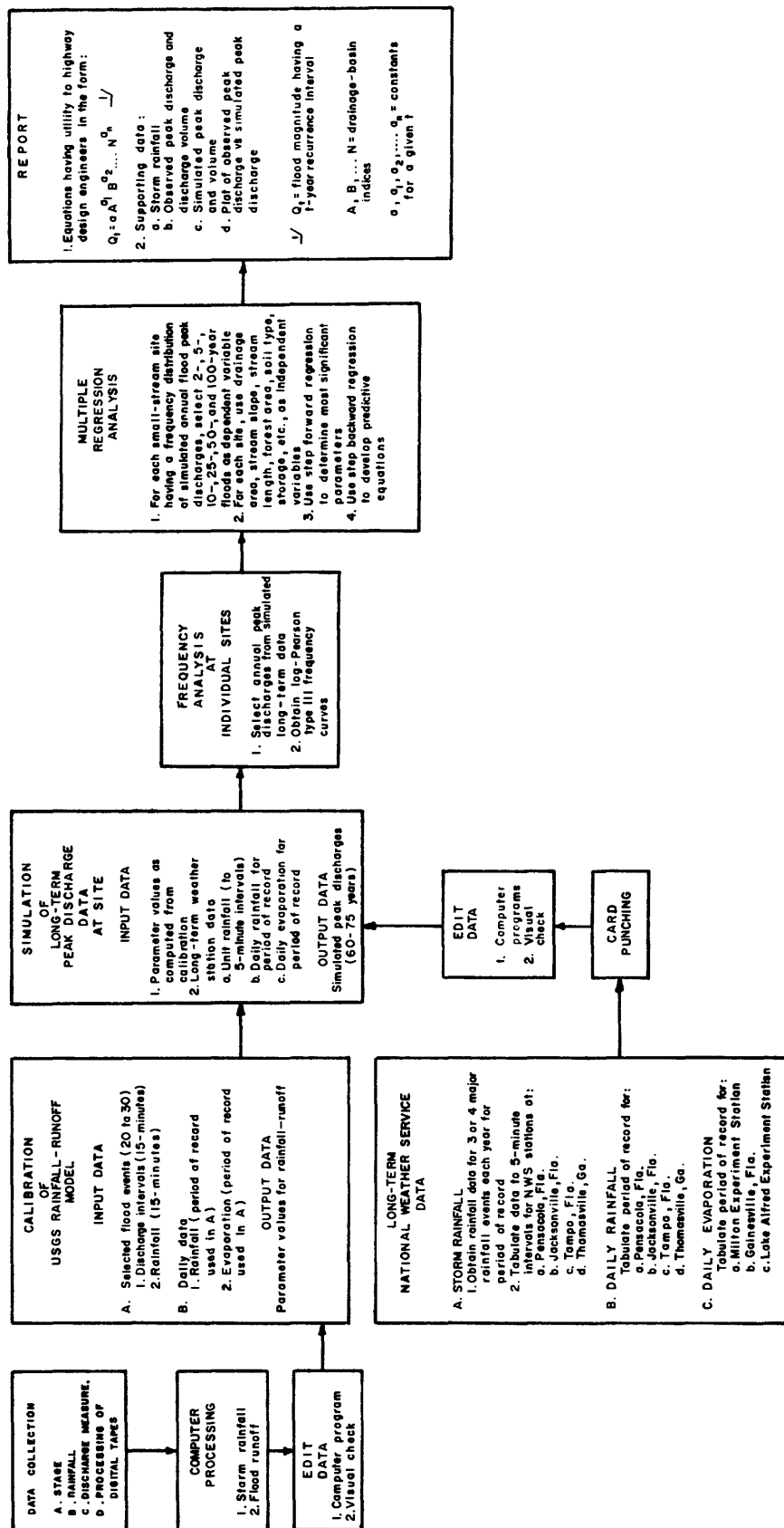$a, a_1, a_2, \ldots a_n$ = constants for a given t

FIGURE 2.--Flow chart of work elements of the small-streams flood-frequency study.

After model calibrations and peak simulations are completed (fig. 2), the next phase of the project will be to use the annual peaks from the crest-stage and regular gaging stations (with 10 or more years of record) and annual peaks from the rainfall/runoff gaging stations to develop statewide regional flood-frequencies. Individual frequency curves will be defined by mathematically fitting a log Pearson Type III distribution to the logarithms of the annual peaks using techniques recommended by the U.S. Water Resources Council (1976).

A technique using multiple regression analysis, described by Benson (1962; 1964), will be used to define regional relations between streamflow characteristics (dependent variable) and drainage-basin characteristics (independent variable). Flood estimating equations will be developed to determine the 2-, 5-, 10-, 25-, 50-, and 100-year frequency floods for ungaged sites.

Previous Studies

Flood studies by Pride (1958) and Barnes and Golden (1966) proposed flood estimating techniques which were applicable to streams having drainage areas larger than 10 mi^2. In these studies two regional curves were developed using the individual station data with the index flood method. The first curve showed the variation of peak discharge as a dimensionless ratio the mean annual flood, for a given recurrence interval. The second related the mean annual flood to the size drainage area alone, or to the size area and percentage of area in storage in lakes and swamps.

Acknowledgments

This study was conducted as part of a cooperative program with the Department of Transportation, State of Florida. Particular acknowledgment is given to William J. Rutledge, Jr., former Engineer of Drainage, for his interest in and support of this study.

DATA COLLECTION

Concurrent rainfall and discharge data are collected at 30 rainfall/runoff gaging stations. Each station is equipped with two digital recorders which simultansously record rainfall and stage. Of the 30 stations, 27 are equipped with 15-minute interval timers and 3 are equipped with 5-minute interval timers. The rainfall and stage parameters are digitally recorded on 16-channel paper tape for computer processing at a later date. Each rainfall/runoff gaging station is visited at 6- to 8-week intervals to

service the instruments, remove the punched paper tapes, and measure stream-
flow. Routine measurements of flow are made to define and check for
changes in the stage-discharge relation. In addition, speacial visits are
made as required to measure flood flows and to make surveys for indirect
measurement of extreme peak flows.

The punched-paper tapes of rainfall and stage are translated onto mag-
netic tape and stored in the U.S. Geological Survey computer file. These
data are then edited and prepared for use in the rainfall runoff model.
Data collection will continue until at least 25 significant floods have
occurred.

The annual maximum peak discharge for each crest-stage and regular
gaging station is entered into the peak-data computer file for later use
in developing flood-frequency curves.

RAINFALL/RUNOFF MODEL

Model Description

A rainfall/runoff simulation model has been developed by the U. S.
Geological Survey (Dawdy, Lichty, and Bergmann, 1972). This parametric
rainfall/runoff simulation model uses rainfall data and daily potential
evaporation data to predict flood volume and peak rates of runoff for
small drainage areas. The rainfall/runoff model simulates the flood hy-
drograph at the basin outlet, based on the basin's antecedent moisture
conditions and response to a specific rainfall. Three submodels of the
hydrologic cycle are linked to form the model: antecedent moisture, in-
filtration, and surface runoff.

The antecedent moisture component continually assesses the changes in soil moisture as a basis for determining the part of subsequent rainfall that becomes surface runoff. Assessment of moisture storage is made on a daily basis and on a unit-time basis during storm periods. The infiltration component determines the part of the rainfall that becomes rainfall excess or surface runoff. The surface-routing component distributes the rainfall excess to form the outflow hydrograph.

Each of the components is represented by equations describing the physical actions taking place in the basin. Embedded in these equations are 10 parameters, or mathematical constants, which define the interrelations among the variables in the equations. The 10 parameters utilized in the model are listed in table 1 along with descriptions of the parameters. The flow diagram in figure 3 demonstrates the relation between the components, parameters, and variables used by the model.

The antecedent moisture accounting component controls the gross movement of moisture within the soil. It includes four parameters as listed in table 1. Figure 4 is a schematic diagram of the soil moisture accounting procedure. The total moisture in storage in the soil column is divided into two parts. The first part is the unpatterned area which contains the BMS (base moisture storage) at a soil moisture varying from field capacity to wilting-point conditions. The second part is SMS (surface moisture storage) near saturation and is represented by the hachured area. It is assumed that the total infiltrated soil column is near saturation.

Table I. Identification and definition of the 10 input parameters used in the rainfall/runoff model.

| Parameter	Units	Definition and application
		Antecedent moisture component
EVC ----	----------	Coefficient to convert pan evaporation to potential evapotranspiration values.
RR -----	----------	Proportion of daily rainfall that infiltrates the soil.
BMSM ---	Inches ---	Soil moisture storage volume at field capacity.
DRN ----	----------	Drainage parameter for redistribution of soil moisture (fraction of KSAT).
		Infiltration component
PSP ----	Inches ---	Product of moisture deficit and suction at the wetted front for soil moisture at field capacity.
KSAT ---	Inches per hour -	The minimum (saturated) hydraulic conductivity used to determine infiltration rates.
RGF ----	----------	Ratio of the product of moisture deficit and suction at the wetted front for soil moisture at wilting point to that at field capacity.
		Surface runoff component (routing)
KSW ----	Hours ---	Time characteristic for linear reservoir routing.
TC -----	Minutes -	Length of the base of the triangular translation hydrograph.
TP/TC --	----------	Ratio of time to peak to base length of the triangular translation hydrograph.
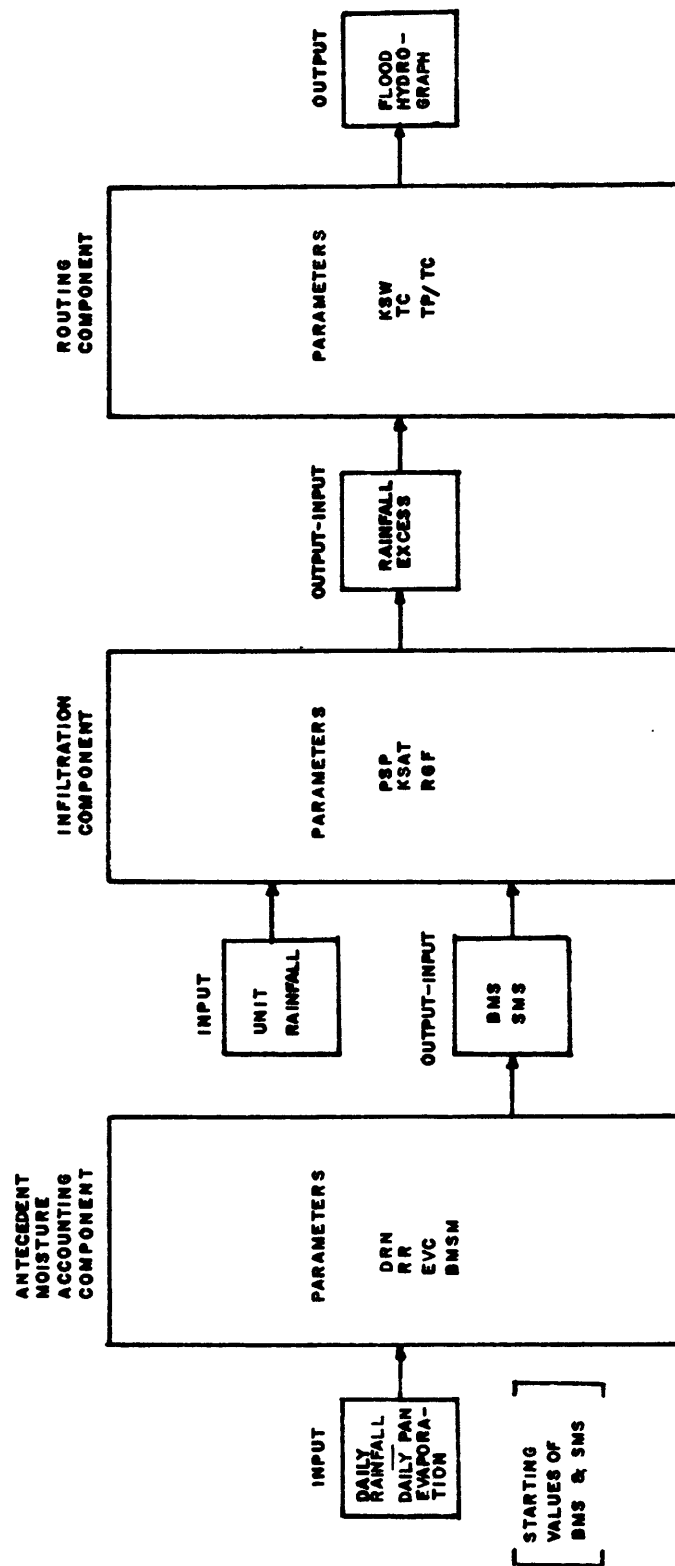
Figure 3. Schematic diagram of the U.S. Geological Survey rainfall/runoff model

11

SOIL-MOISTURE CONTENT

SMS

DEPTH BELOW SURFACE
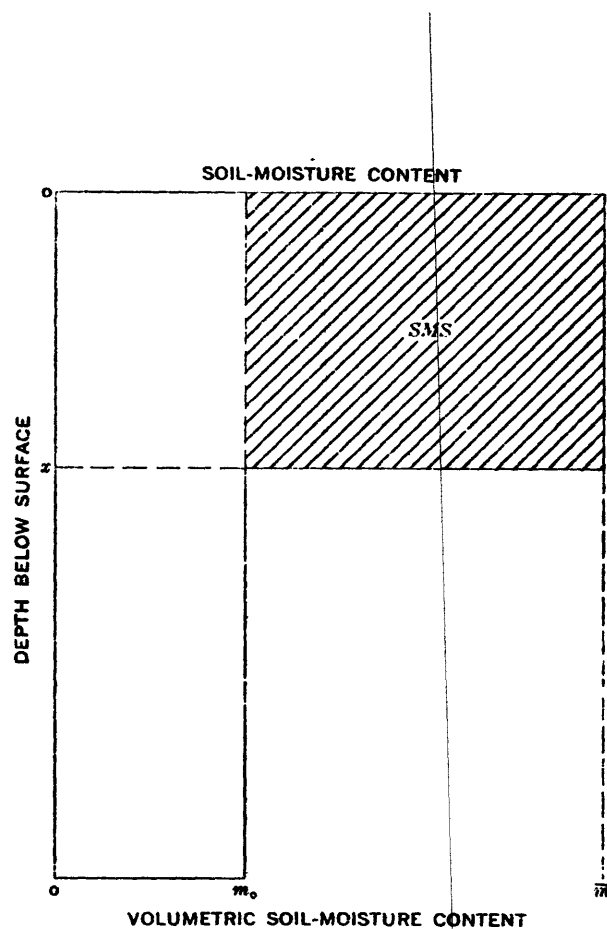
VOLUMETRIC SOIL-MOISTURE CONTENT

FIGURE 4.--Schematic diagram of the two-layered soil-moisture profile used with the infiltration equation in the model. The initial uniform soil-moisture content, stated as a proportion of total volume, is m_0, field capacity content is m, and the depth of the wetted layer is x. The amount of infiltrated moisture (SMS) is $(m-m_0) \cdot x$, and is shown as the hachured area. That portion of antecedent moisture contained in the wetted layer is $m_0 \cdot x$, and is shown as the unhachured area above the depth x in the profile. (Dawdy, Lichty, and Bergmann, 1972, p.6)

12

SMS portrays accumulated infiltration and during storm periods all the infiltration is added to SMS. BMS is used to compute the relative soil moisture deficit. Evapotranspiration demand is met from SMS as long as storage is greater than zero. (It is assumed that evapotranspiration losses occur at potential rate.) If storage in SMS is zero then evapotranspiration demand is met by BMS. Input to the antecedent moisture component is daily rainfall and daily pan evaporation. Output from the antecedent moisture component is the amount of BMS and infiltrated SMS.

The infiltration component is responsible for the division of rainfall into infiltration and surface runoff (rainfall excess). Input to the infiltration component are unit-time storm rainfall, BMS, and SMS. Parameters used in this component are PSP, KSAT, and RGF (table 1). Output is rainfall excess.

The surface routing component is responsible for routing the rainfall excess to the basin outlet. The routing component uses three parameters, KSW, TC, and TP/TC (table 1 and fig. 3). The Clark flood-routing method (Dawdy, Litchy, and Bergmann, 1972, p. 8) is used to translate the rainfall excess to a time-area curve and route it through a single linear storage reservoir to the basin outlet. Output for the surface routing component is the flood hydrograph.

13

Model Calibration

The ten parameter values which control the operation of the model must be evaluated for each site. The model uses a hill-climbing technique of parameter optimization. The optimization scheme compares the simulated record with the observed record, then changes one parameter value, repeats the computations, and compares the newly simulated record with the observed record. The process of individually changing parameter values and computing a new simulated record is repeated until a satisfactory comparison of simulated and observed record is obtained.

The model calibration process is divided into three phases; volume adjustment phase, routing phase, and combined phase. During the volume adjustment phase, the first seven parameters (table 1) controlling the moisture accounting and infiltration components of the model are adjusted to minimize the error in computing volumes of runoff. In the routing phase the other three parameters, controlling the surface routing component are adjusted to determine optimum values for reproducing flood peaks, given the correct volume of runoff. In the combined phase the three routing parameters are held constant and the initial seven parameters are adjusted to obtain the best reproduction of the observed peaks.

Calibration for a specific site requires concurrent data on streamflow, rainfall, and evaporation. Some assumptions made in the calibration process are:

1. That the rainfall recorded at a single rain gage is representative of that occurring throughout the basin.

2. That the input data are accurate.

3. That basin changes have not destroyed the homogeneity of flood records during the period used in the model calibration.

4. That the long-term rainfall and evaporation records available from other sites are applicable to the drainage basin.

After the first calibration run, a screening process is used to identify and eliminate those storms which show appreciable differences between the computed and observed runoff volume or peak discharge. Nonuniformity of rainfall over the basin and recorder malfunctions account for most of the differences between observed and simulated volumes and peaks. New calibration runs are made, using the screened data, to find the optimum set of parameter values.

HYDROLOGIC ANALYSIS

Model Studies

Preliminary model calibrations have been run on eight rainfall/ runoff gaging stations, 20 more are ready for calibration, and two stations lack adequate definition of the stage-discharge relationship.

Table 2 is a summary of the model parameters for the eight stations that have been calibrated. The standard error of estimate for these stations ranged from 25 to 50 percent. Additional storm data are now available and new model calibrations will be run in an attempt to reduce the standard error of estimate.

15

Table 2. Summary of model parameter values.

Rainfall/runoff station		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC	Standard error of estimate (percent)	Number of peaks
		Parameter values (See table1)											
02279517	Lateral ditch No.1 at Delray Beach	1.37	0.060	0.80	2.24	3.20	0.79	0.85	0.30	20.48	0.66	25.4	22
02301314	Mizelle Creek near Keysville	3.10	0.109	0.50	12.76	16.82	0.70	0.87	5.71	363	0.35	39.1	20
02326598	Caney Creek near Monticello	3.42	0.142	1.0	11.52	7.28	0.88	0.87	1.34	217	0.53	28.5	20
02358998	Hollman Branch near Altha	3.90	0.117	0.97	10.94	6.00	0.88	0.86	1.90	128	0.88	49.9	23
02365237	Fowler Branch near Leonia	1.51	0.095	0.32	16.68	5.12	0.78	0.85	6.91	335	0.99	44.6	16
02366859	Pate Branch near Freeport	2.52	0.106	0.07	13.75	2.40	0.70	0.79	5.70	475	0.56	34.2	25
02368300	Baggett Creek near Milligan	3.83	0.127	0.82	9.00	16.08	0.84	0.86	9.07	200	0.88	34.7	16
02370015	Muddy Branch near Beaver Creek	4.03	0.196	0.69	10.61	8.45	0.87	0.86	5.32	234	0.86	36.6	12

16

Use of the U.S. Geological Survey rainfall/runoff model will be
limited to the rainfall/runoff gaging stations. Flood frequency curves
for crest-stage and regular gaging stations, with 10 or more years
of record, will be developed by use of the log Pearson Type III
analysis (U.S. Water Resources Council, 1976).

Caney Creek Model

Caney Creek is the only rainfall/runoff gaging station for which
all of the following have been completed: 1) model calibrated; and
2) simulation of peaks from long-term rainfall record; flood frequency
curve developed using simulated peaks.

Three optimization runs were made to calibrate the model for
Caney Creek. After the first run the output was scanned and 20 of the
original 23 storm events were used in the second and third runs. Peaks
excluded from the calibration are March 30, 1972, October 27, 1972, and
August 6, 1973. These storm events were excluded because of nonrepresen-
tative rainfall. On March 30, 1972 and August 6, 1973 the rainfall was
concentrated more in the upper part of the basin whereas on October 27,
1972 the rainfall was more concentrated at the recording gage.

The final values used for the 10 parameters are shown in table 3.
A plot of the observed peak (ordinate) and the simulated peak (abscissa)
is shown in figure 5. The standard error of estimate for the third
optimization run was 28 percent.

For the calibrated model for Caney Creek, a long-term record of
rainfall and evaporation was used as input to generate a long-term record
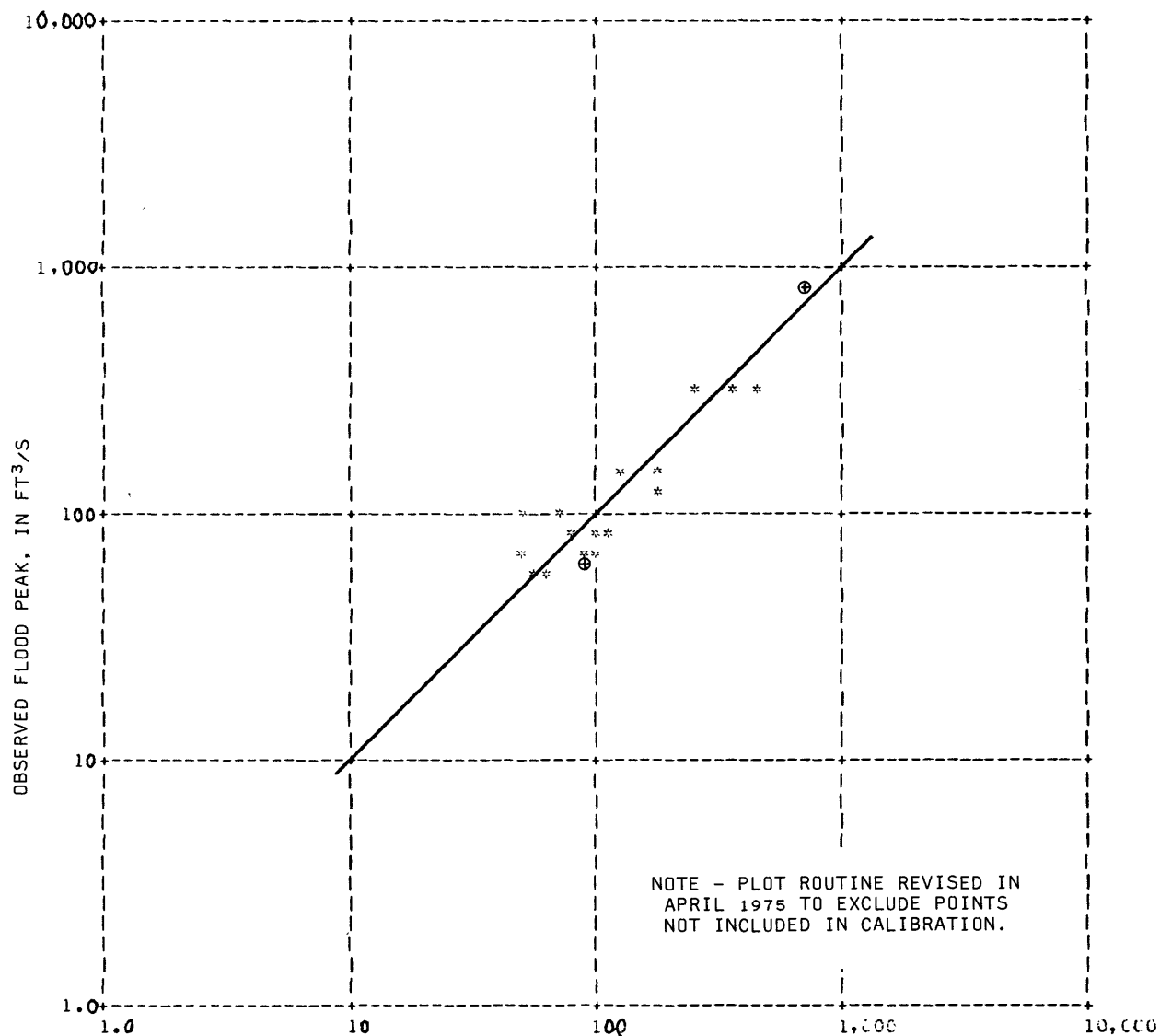of simulated flood peaks. Daily rainfall for 1902-63, and 5-minute

Table 3. Calibration results listing the 10 model parameters, observed runoff and peak discharge, and simulated runoff and peak discharge for 23 storms for Caney Creek.

USGS RAINFALL-RUNOFF MODEL CALIBRATION FOR   02326598 CANEY CK NR MONTICELLO, FLA (UNIT Q)
END OF ROUND--RESULTS OF LAST SUCCESSFUL TRIAL
PHASE 3 - OPTIMIZATION OF PEAK FLOW (TOTAL MODEL ERROR)

PEAK OBJECTIVE FUNCTION= 1.5886627E+00
ROOT MEAN SQ. ERROR LOG BASE 10(TOTAL ERROR)= 0.122220
PARAMETER VALUES ARE
PSP= 3.423
KSAT= 0.142
DRN= 1.000
RGF= 11.517
BMSM= 7.264
EVC= 0.882
RR= .870
KSAT= 1.336
TC= 217.250
TP= 115.007
TIME AREA HISTOGRAM 0.0450 0.0636 0.0816 0.0991 0.1171 0.1336 0.1212 0.1010 0.0807 0.0604 0.0402 0.0223

DATE	STORM RAINFALL	DIRECT RUNOFF	SIM DIRECT RUNOFF	PEAK DISCHARGE	SIM PEAK DISCHARGE
* 2/ 7/71	1.51	0.21	0.16	93	82
* 5/ 8/71	2.49	0.31	0.39	153	193
* 2/ 7/72	1.53	0.26	0.21	81	94
3/30/72	1.56	0.25	0.15	183	68
* 3/31/72	1.37	0.21	0.38	123	196
* 5/ 8/72	3.13	0.32	0.41	91	123
* 5/25/72	3.23	0.61	0.95	379	495
1/27/72	2.87	0.22	0.73	138	386
*11/25/72	2.33	0.27	0.27	160	139
*12/21/72	2.28	0.20	0.13	78	56
* 2/ 1/73	3.07	0.67	0.58	378	280
* 2/ 5/73	2.41	0.26	0.26	68	63
* 3/31/73	3.87	1.72	2.46	837	709
* 4/ 2/73	5.16	2.49	2.34	347	364
* 5/ 8/73	2.15	0.19	0.20	76	96
* 5/26/73	1.67	0.24	0.15	117	78
* 5/30/73	1.56	0.17	0.12	65	64
* 5/31/73	1.44	0.16	0.17	70	91
1/ 6/73	0.63	0.19	0.02	101	10
*12/26/73	3.63	0.42	0.34	89	102
*12/26/73	1.84	0.20	0.24	82	102
* 4/ 5/74	1.51	0.22	0.12	113	56
* 9/ 6/74	6.22	1.35	1.76	894	760

* Indicates those events used in calibration of model

18

NOTE – PLOT ROUTINE REVISED IN
APRIL 1975 TO EXCLUDE POINTS
NOT INCLUDED IN CALIBRATION.

NUMBER OF POINTS PLOTTED =   20   SIMULATED FLOOD PEAK, IN FT³/S
NUMBER OF MULTIPLE PTS.   =   2
NUMBER OF PTS. OFF GRID   =   0
NUMBER OF POINTS OMITTED =   3

⊕ MULTIPLE POINTS

FIGURE 5.--Graph of observed flood peak *versus* simulated flood peak.

19

unit rainfall for 267 selected storms for Pensacola, Florida, about 200 miles west of Caney Creek, were used as input data for the Caney Creek model. Daily pan evaporation record, 1963 to 1973, was available from the Milton Florida Experiment Station about 175 miles west. A computer program was used to fit a harmonic (sine-cosine) function which then generated a daily evaporation record from 1902 to 1962.

Simulated flood peaks for 1902-68 were generated and used as input to develop a flood frequency curve (see fig. 6) based on a log Pearson Type III distribution (U.S. Water Resources Council, 1976).
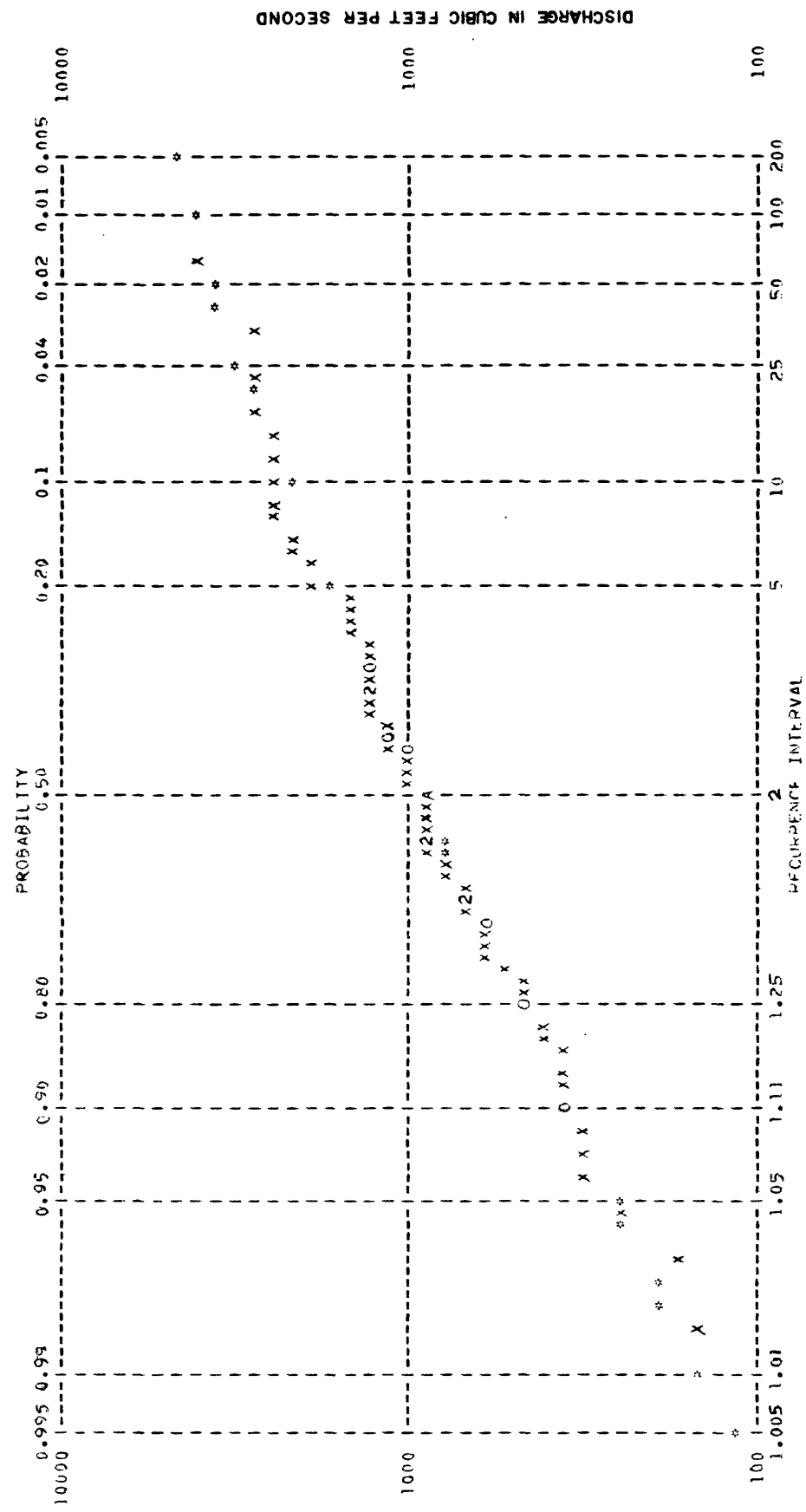
20

Figure 6. Graph of flood frequency curve for Caney Creek using simulated flood peaks 1902-68.

21

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