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AN EVALUATION OF THE URBAN DESIGN STORM CONCEPT

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ABSTRACT

AN EVALUATION OF THE URBAN DESIGN STORM CONCEPT

This report describes an evaluation of the assumption commonly employed in drainage design that the return period of the rainfall used to design a system is the same as the peak flow produced by that rainfall. Specifically, the sensitivity of the frequency response of four catchments to design storm parameters is examined. Parameters include, hyetograph shape, antecedent soil moisture and rainfall duration. A continuous simulation model is used to compute simulated historical frequency responses for three different long term rainfall records. Design storms are also developed from depth-duration-frequency analyses of the rainfall data. Comparisons are made on frequency graphs. It is concluded that an appropriate choice of design storm parameters can produce a design which yields peak flows of the desired return period.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTATION

A^I, A^Q	=	pipe or channel flow area corresponding to uniform flow at discharges I and Q respectively
COV	=	covariance operator
DLYPER	=	potential daily rate of deep percolation
EVP	=	potential daily evaporation
EVPAN	=	daily pan evaporation
EVPT	=	potential daily evapotranspiration
FCAP	=	field capacity of soil
F_M	=	inter-stage objective function movement
f	=	infiltration capacity, Rosenbrock objective function
f_c	=	infiltration capacity for saturated soil
f_c'	=	deep percolation rate
f_i	=	potential infiltration capacity at any time after the beginning of rainfall
f_o	=	infiltration capacity for dry soil
f_o'	=	initial infiltration capacity for a specific event
g	=	lower bound
g', h'	=	inner boundary definitions
H	=	maximum soil moisture storage used in Boneyard study
h	=	soil moisture storage, Rosenbrock upper bound
I	=	reach inflow discharge
IAIA	=	impervious area initial abstraction
IAIAMAX	=	maximum impervious area initial abstraction
i	=	objective function index
i_j	=	effective rainfall rate during internal j
j	=	objective function index
k	=	Horton decay coefficient, autocorrelation index
L	=	reach length

m	=	rank
N	=	number of years, total number of non-zero precipitation depths
n	=	number of storm events used for calibration
PAIAMAX	=	maximum pervious area initial abstraction
PAIA, PAIA'	=	pervious area initial abstraction after and before accounting for daily evaporation
PANRAT	=	ratio of actual potential to pan evaporation
Q	=	discharge from pipe reach
Q_c, Q_o	=	computed and observed values of runoff hydrograph
Q_n	=	runoff at the end of time period n
Q_o'	=	peak of observed runoff hydrograph
R	=	objective function
RAIN	=	daily rainfall
$RVOL_c$, $RVOL_o$	=	computed and observed runoff volumes
r_k	=	serial correlation coefficient
S	=	reach storage volume
SMSMAX	=	maximum value for soil moisture storage
SMS, SMS', SMS"	=	final daily soil moisture storage, value before accounting for evapotranspiration and value before accounting for evapotranspiration and deep percolation, respectively
T	=	return period
TEVPT	=	daily evapotranspiration
TRANRAT	=	ratio of daily transpiration
t	=	time, autocorrelation index
V	=	Rosenbrock search vector
VAR	=	variance operator
W	=	Rosenbrock search vector
X	=	decision variable
X^N	=	normalized decision variable

X_D^N	=	normalized decision vector intra-stage movement
X_M^N	=	normalized decision vector inter-stage function
x	=	non-zero rainfall depth
x_t, X_{t+k}	=	logged and non-logged non-zero rainfall depths
α	=	constant of proportionality between deep percolation rate and soil moisture storage (for Boneyard study), Rosenbrock parameter
α_r	=	fraction of daily rainfall which can infiltrate
β	=	factor to account for runoff contribution of supplemental impervious area, Rosenbrock parameter
γ	=	Rosenbrock parameter
Δ	=	Rosenbrock parameter
Δt	=	time increment
Δ_{n-j+1}	=	incremental area contributing to runoff at time period n-j+1
ε	=	boundary zone parameter
η_L	=	lower boundary penetration
η_u	=	upper boundary penetration
η_L^N	=	normalized lower boundary penetration
η_U^N	=	normalized upper boundary penetration
θ	=	Rosenbrock parameter
ν	=	net distance moved in previous stage
ρ	=	orthonormal search directions
$\hat{\rho}$	=	new orthonormal search directions
ϕ	=	initial soil moisture storage for Horton infiltration model for a specific event, Rosenbrock parameter

Chapter 1 INTRODUCTION

1.1 Problem Statement

Traditionally the design process for water resources systems has included the choice and use of a so-called "design storm." That is, a precipitation event, either historical or artificial, is identified and the system under study is designed to accommodate that event. For most systems, and those associated with urban areas such as storm drainage systems in particular, one basic parameter used in the selection of the design storm is its average return period or frequency. Once the return period is identified for the design storm it is usually assumed that the performance of the system will retain that same frequency. In other words, it is assumed that the probability of the design capacity being exceeded is the same as the probability of the magnitude of the design storm being exceeded. The original decision concerning which design storm frequency to be used is based on this assumption as are all the economic implications associated with this decision.

The validity of the above assumption has not been proven. In fact it is easy to demonstrate that it is theoretically false. However, the design storm is a frequently used concept in present day design practice and in many cases where the use of a complex mathematical simulation model is not practical it is the only realistic alternative. The important question from an engineering viewpoint is to what degree actual urban watersheds depart from this assumption and what variables in the design process affect the departure. Once this is answered the economic implications of the decision concerning design storm frequency can be assessed and improved design storm procedures can be adopted.

Billions of dollars each year are devoted in small parcels to urban drainage projects throughout the United States. These projects usually are not large when compared to reservoir construction, for example, but there are so many that the total national economic effort is significant. The technology used in urban drainage design is thus repeatedly used and the benefits from improvements in the technology will be felt because of this frequency of use. However, it is because of the scale of the projects on an individual basis that technological progress is slow to be developed and implemented. Local governments or the engineering firms to whom the work is contracted generally cannot afford to spend time and money on new major technology. The problem of the uncertainty concerning the relationship between design storm frequency and system performance is directly related to government productivity because the decision regarding design frequency is really a statement of acceptable risk of system capacity being exceeded. That is, an economic and/or political analysis by public decision makers indicates that a prescribed risk level is acceptable. This risk level is then assigned to the design storm and the resulting design is assumed to preserve this risk level. Any significant deviation in the actual risk level achieved from the original assumed value presumably would effect the original decision if this deviation were known. At the present time there is very little information available to guide the decision maker in this regard.

The importance of this study in the area of planning as well as design is pointed out by McPherson[1].

> A monumental question in the use of urban hydrology models is the choice of storms to be applied. Storm definitions used for deriving river basin extremes are irrelevant because urban sewer systems are expected to be overtaxed much more frequently than major river structures whose failures could be catastrophic. In terms of actual objective functions, the mean frequencies of occurrence of flow peaks and volumes and quality constituent amounts is the issue, not the frequencies of the input rainfall. Furthermore, because there are inherent non-linearities in most methods for processing inputs for linear models, and dynamic models are non-linear by definition, the statistics of the rainfall input array may differ appreciably from those of some or all of the arrays for runoff and quality characteristics. Attempting to assign a mean frequency of probable occurrence to a "design storm" is meaningless because of statistical non-homogeneity of rainfall, runoff and quality, and such an approach neglects the effects of prior storms on the

1. Superscripted numbers refer to References.

runoff from a given storm. Preferred inputs for modern planning models are reasonable lengths of actual rainfall records, perhaps at least spanning ten to twenty years. It seems more reasonable to route rainfall data of local record through a model to arrive at output parameter frequencies than to synthesize a storm of some assumed probability. Use of meteorological expedients can conceivably be unnecessarily hazardous and the results obtained thereby can be extremely misleading. Because the cost of running the more elegant design/analysis models per storm event is high, many defenders of these models champion acceptance of a "design storm" as an expedient to save time and money, but at the expense of credibility of results. This is not to suggest that all catchments of a jurisdiction should be analyzed using twenty years of continuous rainfall records on a SWMM-type model. Rather, such a long record should be applied to a catchment near the reference weather station to segregate those storms of design importance. Because only the unusual occurrences are of design interest, there may be perhaps only two dozen or so actual storms of concern. To be consistent, any project sufficiently important to call for the use of a SWMM-type model should also be important enough to apply a few storms rather than a single synthetic storm. Thus, the handful of storms selected on the basis of simulated catchment response become a family of design storms for use in connection with other catchments in the jurisdiction. Officials in charge of urban drainage facilities are hard-put to explain an artificial, synthetic storm's frequency to irate citizens who have been flooded or to a territorial official regulating over-flows. Defense against storms of record is rather direct, and in the opinion of the writer the only realistic option open to a public official. The temptation to use artificial confections as input data should be resisted.

1.2 Objectives of the Research

The overall objective of the study is to evaluate the relationship between the return period of design storms and the corresponding return period of the resulting peak runoff. Urban sewered catchments are used and return periods are limited to 25 years.

The design storm parameters of specific interest are temporal distribution of the rainfall, i.e. the hyetograph shape, the antecedent soil moisture condition and the duration of the design storm. How these parameters effect the peak runoff and its return period are of primary interest.

These findings form the basis of recommendations for design procedures.

1.3 Scope

The design storm approach is used in many types of design problems. However, this study is limited to small urban catchments which are sewered to some extent and which have significant percentages of impervious area.

The return period range is limited to a maximum of 25 years since this includes the values most commonly used for design and extension to 100 years for example would be very costly.

Peak discharge is the dependent variable under consideration. Budget limitations required this restriction along with the recognition that it is the variable of principal interest in design. Water quality parameters are not appropriate in the context of a design storm approach.

1.4 Related Research

Previous studies on this problem have not been numerous, probably because of lack of data. Ideally one would need independent long term measurements of rainfall and outflow from a system. A frequency analysis of the historical outflow could then be made and compared with the calculated outflow from design storms with various return periods. The development of simulation models has made feasible the generation of a simulated record of outflow from a historical rainfall record.

Sieker[2] reported a study using data from a 54 hectare residential area near Hamburg, Germany. He used a linear storage simulation model and uniform intensity design storms. He concluded that for a given return period the design storms produced lower peak flows than the natural event with the difference increasing with increasing return period.

Desbordes[3] has reported the activities of the Laboratory of Mathematical Hydrology at the Montpellier Sciences University in France. He has developed an urban runoff model based on the instantaneous unit hydrograph but with a variable lag. Although no results were reported, Desbordes recognized the utility of models in evaluating the design storm approach.

Perhaps the most extensive work to date has been reported by

Marsalek [4]. He used a 23 ha residential catchment using the EPA Storm Water Management Model as a simulator. Two types of design storms were studies and the effects of detention storage were examined as well. In general it was found that for a given return period the design storms produced peak flows which were higher than the simulated peaks from historical rainfall. Prior to Marsalek's work the most recent effort was done by Veres at Purdue University as part of a graduate course [5]. Although the results are as yet unpublished the work involved the application of the ILLUDAS model to a particular residential catchment in Chicago, Illinois for which the necessary data are available. The results of this study show that for a given return period the peak runoff from the design storm was 2.5 to 22 percent higher than the true peak runoff for the same return period as established by the model for return periods from 2 to 200 years. A historical rainfall record of 35 years was used and variations in antecedent conditions was not considered. In terms of frequency the results show that a 10 year frequency design storm resulted in a peak runoff frequency of about 14 years and a 50 year design storm can result in a 117 year peak runoff.

One of the most interesting related studies was the John Hopkins University Storm Drainage Research Project which involved data gathering from 20 catchments from 0.2 to 150 acres. Schaake, Geyer and Knapp[6] examined approximately 5 years of rainfall-runoff data from several catchments. Frequency curves were plotted and it was observed that the frequency distributions were not the same although it was concluded that from a practical standpoint the assumption of equal design storm and peak runoff frequencies is valid for return periods under 5 years. However it must be emphasized that long-term runoff records were not available for this study.

In a discussion,[7] Irish presented evidence that the frequency of design storms is not equal to the corresponding flood frequency. Although the discussion is not directed at urban catchments the qualitative argument presented is valid. He pointed out the work by Alexander et. al[8] which agrees qualitatively with the results of Shaake et. al[6] and Veres[5], namely that the slope of the runoff frequency curve is greater than the rainfall frequency curve when plotted on an appropriate linearized scale. This means that as the design storm frequency increases the runoff frequency increases more rapidly. It is the changes in antecedent conditions as well as storm temporal patterns which Irish stated as major causes of this effect.

In May of 1979 a seminar on the design storm concept was held at École Polytechnique, Montreal, Canada. The proceedings of that seminar[9] contains the most concentrated discussion of the current state-of-the-art.

The work by Packman and Kidd in England was presented at this seminar and was subsequently published.[10] Their work involved the development of design storm parameters for use in England which produced good agreement between return period of design rainfall and peak runoff. The parameters were developed using model simulation and a procedure similar to that employed in this study.

Chapter 2 PROCEDURE

2.1 General Approach

The approach used in this study is to employ a simulation model as a substitute for field data collection. This was necessary because of a lack of long term runoff measurements from urban catchments. A continuous simulation model was developed and used to develop simulated historical runoff records from various catchments. A frequency analysis of these flow peaks served as a basis for comparison with the peaks from various design storms.

Continuous long term rainfall data for three different locations were obtained from the USDA Science and Education Administration. Data from each site was analyzed to define the rainfall events. This was done by performing an auto-correlation analysis using 15 minute lag increments. The lag for which the correlation coefficient fell to an arbitrary low value was used as the criteria for the length of zero rainfall time separating independent events.

A depth-duration-frequency analysis of each rainfall record was performed. This formed the basis for generating the design storms.

Each of the catchments under study was represented by the simulation model and calibrated using local rainfall and runoff data. The catchments were chosen because of their land use and availability of calibration data. The long-term historical rainfall data was then applied to the catchments and the simulated historical peak runoff values were obtained via the model. Although this procedure may appear questionable at first, it is quite valid for the purposes of this study. The computed runoff values are not viewed as estimates of actual runoff which occurred at the various catchments sites, but as estimates of runoff which would result if the long term rainfall had occurred at each site. This serves as a basis for comparison with runoff from design storms generated from the same rainfall record, and this comparison is the objective of the study.

In order to economize on computer time, it was recognized that only the rainfall events producing the largest runoff peaks were of direct interest, although the entire record was needed for continuous soil moisture accounting. Therefore a screening model or procedure was developed which permitted the identification of rainfall events which had a reasonable probability of producing a significant peak runoff. Only these events were processed through the runoff computation portion of the model.

A frequency analysis based on the annual exceedance time series of the peak runoff values was performed for each combination of catchment and rainfall data set. The design storms with various temporal patterns, durations, return periods, and antecedent soil moisture conditions were then processed through the model on a single event basis and compared with the simulated historical results.

Figure 2-1 shows a flow chart which describes the overall procedure. A more detailed discussion of some of the steps follows.

2.2 Screening Procedure

The screening procedure was introduced in order to eliminate the computation of surface runoff hydrographs from insignificant events. This was possible within the continuous simulation context because the soil moisture accounting was done independent of runoff simulation. For each set of rainfall data a depth-duration-frequency analysis was performed. Then for each catchment under consideration a duration was identified which was near the time of concentration. For this duration the 1-yr return period depth was determined from the rainfall analysis. A value of approximately 60 percent of this depth was used as a criterion for runoff simulation. If any event had a depth greater than this value in any period equal to the chosen duration, this event was simulated.

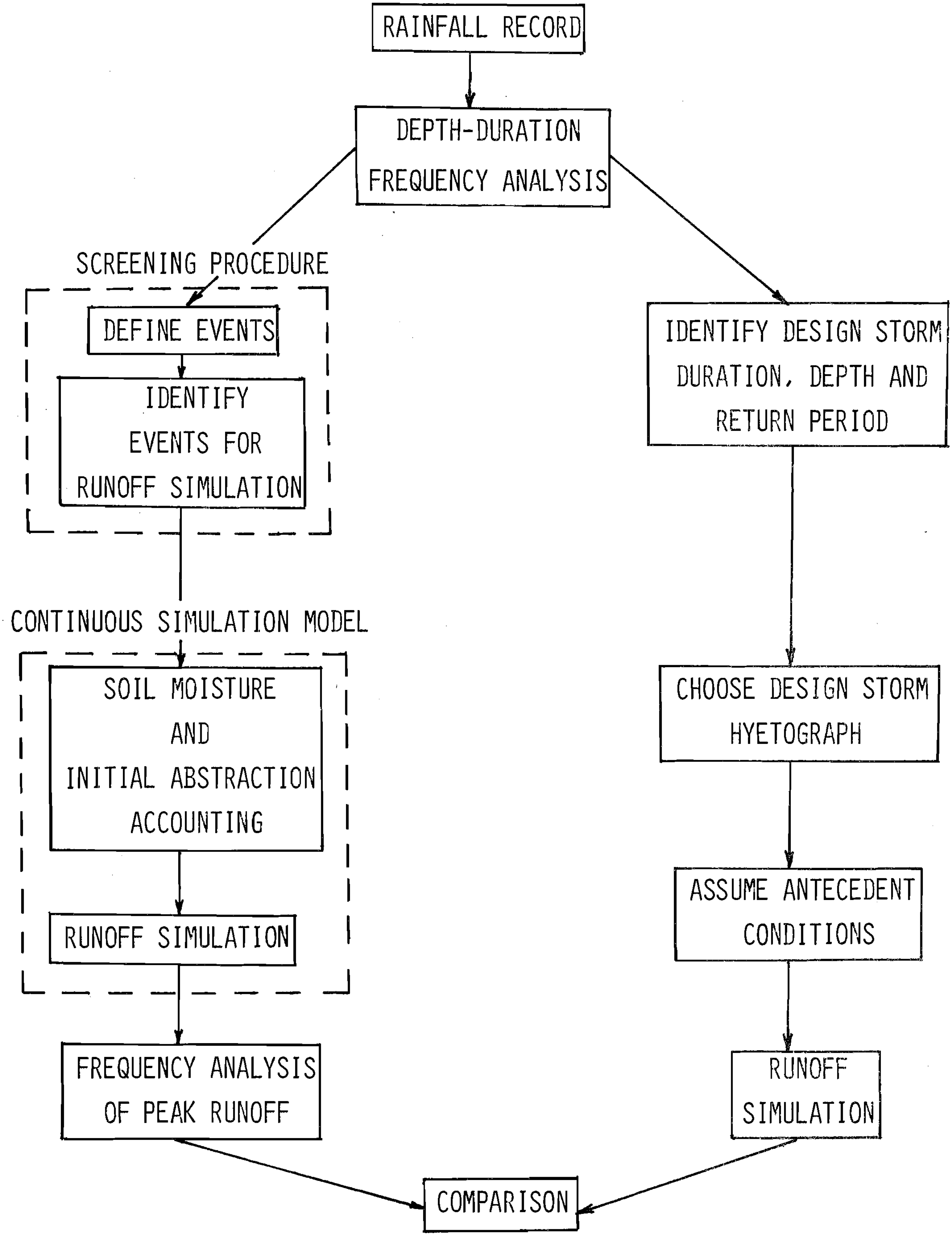

Fig. 2-1 Procedural Flow Chart

This procedure eliminated many minor events from simulation. However it was sufficiently conservative so as to include several times the number of events which composed the annual exceedance time series used in the frequency analysis of the runoff peaks. It is quite unlikely that a rainfall event that did not satisfy the runoff simulation criterion would result in a runoff peak which would appear in the frequency analysis of the peaks. If this did occur the event would certainly have a return period very close to 1.0 yr and thus not effect the overall distribution.

2.3 Frequency Analysis

Frequency analysis was used to analyze and describe each set of rainfall data and also to describe the peak runoff from the rainfall data as well as the design storms.

A conventional depth-duration-frequency analysis was used for each set of rainfall data. Various durations were identified and a minimum zero rainfall period criterion was established to define events. For each event, the maximum rainfall depth in any time period equal to the chosen duration was identified. The resulting partial duration series was then truncated to an annual exceedance series and plotting positions or return periods were assigned using the plotting position formula

$$T = N/m \tag{2-1}$$

where T = return period in yrs, N = number of yrs of record and m = rank. This process was repeated for various durations and the results plotted on semi-log paper (see Chapter 6).

The runoff peaks were also analyzed using an annual exceedance series with Eq. 2-1 as the plotting position formula.

2.4 Design Storms

Three basic types of temporal distributions were used for the design storms: uniform, triangular with various patterns, and a distribution developed by Huff[13] to describe central Illinois thunderstorms. The latter is an advanced pattern and is given in dimensionless tabular format in Table 2-1.

TABLE 2-1. Huff First-Quartile Point Rainfall Distribution for East Central Illinois

$t/_{duration}$	P/P_{total}
8.3	0.21
16.7	0.44
25.0	0.59
33.3	0.68
41.7	0.75
50.0	0.80
58.3	0.84
66.7	0.87
75.0	0.90
83.3	0.94
91.7	0.97
100.0	1.00

Chapter 3 CONTINUOUS SIMULATION MODEL

The simulation model used in this study (11) is based on the Illinois Urban Drainage Area Simulator (ILLUDAS)[12]. In its usual form, ILLUDAS is a single event, distributed, deterministic model that can be used either for sewer system design or for runoff simulation from an existing system.

ILLUDAS was modified in several respects to operate in the continuous mode. The largest change was the modification of the rainfall abstraction component to permit continuous accounting of soil moisture and potential initial abstractions. The hydrograph routing procedure was changed and a model parameter calibration procedure was developed. These components are described in the following sections of this chapter.

3.1 Runoff Hydrograph Computation

This component of the continuous model is the same as the original single event model. A detailed description has been published by Terstriep and Stall[12] and therefore only a summary is presented here.

Each sub-basin is divided into three area types: directly connected impervious, contributing pervious and supplemental impervious. Supplemental impervious areas are those which drain onto pervious areas, such as roof drains, rather than flowing directly into the sewer inlet. Runoff hydrographs for the paved areas and for the combined pervious and supplemental paved areas are separately computed using the time-area method and then added. The general equation for a hydrograph ordinate is:

$$Q_n = \sum_{j=1}^{n} i_j \Delta A_{n-j+1} \qquad (3\text{-}1)$$

where Q_n = runoff at the end of time period n; i_j = effective rainfall rate during interval j; and ΔA_{n-j+1} = incremental area contributing to runoff at time period n-j+1.

The time-area curves for pervious and impervious areas are assumed to be linear with maximum ordinates given by the respective total contributing areas and the associated times of concentration. The latter can be specified by the user or computed by the program internally. For this study the times were independently computed.

The effective rainfall values are determined by subtracting the abstractions from the total rainfall. The supplemental impervious area runoff contribution is computed by increasing the total rainfall hyetograph ordinates for the pervious area. The pervious time-area curve is then used in Eq. 3-1 to compute the runoff hydrograph ordinates.

Hydrograph routing in the original version of ILLUDAS was performed utilizing a simple single step reservoir routing technique where the relationship between storage and discharge is given by Manning's equation for the pipe or channel segment. A modification of this procedure was introduced in the continuous model and is described below. Surcharging is treated by temporary storage at the upstream inlet of excess capacity flow and then subsequently released at capacity rate.

3.2 Daily Soil Moisture and Initial Abstraction Accounting

The addition of soil moisture and initial abstraction accounting procedures represents a significant modification to the single event model. The purpose of these procedures is to provide the necessary antecedent information, if the runoff simulation for a specific rainfall event is desired.

The accounting model can be viewed as three reservoirs in which storage is updated at the end of each day: an upper layer soil moisture reservoir, an initial pervious area abstraction reservoir, and an initial impervious area abstraction reservoir. This is shown schematically in Fig. 3-1. The soil moisture reservoir represents the equivalent depth of water stored in the soil, and the initial abstraction reservoirs represent the value of the initial abstraction at the beginning of any event which is to be simulated. Each of the sub-basins in the catchment being modeled has a set of these reservoirs. The following description applies to any single sub-basin and is repeated for all sub-basins.

The soil moisture reservoir is, in general, subject to increased moisture due to rainfall in excess of initial pervious area abstractions and decreases due to both evapotranspiration and deep percolation in the event that the field capacity of the soil is exceeded. The accounting is made in a series of steps. First, the soil moisture storage is increased due to rainfall. It is assumed that only a fraction of the daily rainfall, α_r, is available for infiltration. Furthermore, there is an upper limit on soil moisture storage at which saturation occurs, SMSMAX. The effect of rainfall is given by:

$$SMS''_i = \text{Min}\{[SMS_{i-1} + \text{Max}(RAIN_i - PAIA_{i-1}, 0.0)\cdot\alpha_r\cdot\beta], SMSMAX\} \quad (3\text{-}2)$$

in which SMS''_i = soil moisture storage depth at the end of day i before accounting for evaportranspiration and deep percolation; SMS_{i-1} = soil moisture storage depth at the end of the previous day; $RAIN_i$ = total daily rainfall depth; $PAIA_{i-1}$ = pervious area initial abstraction at end of previous day; α_r = fraction of daily rainfall which can infiltrate (a calibration parameter); β = 1 + supplemental impervious area/contributing pervious area; and SMSMAX = upper limit for soil moisture storage corresponding to saturated conditions (a calibration variable).

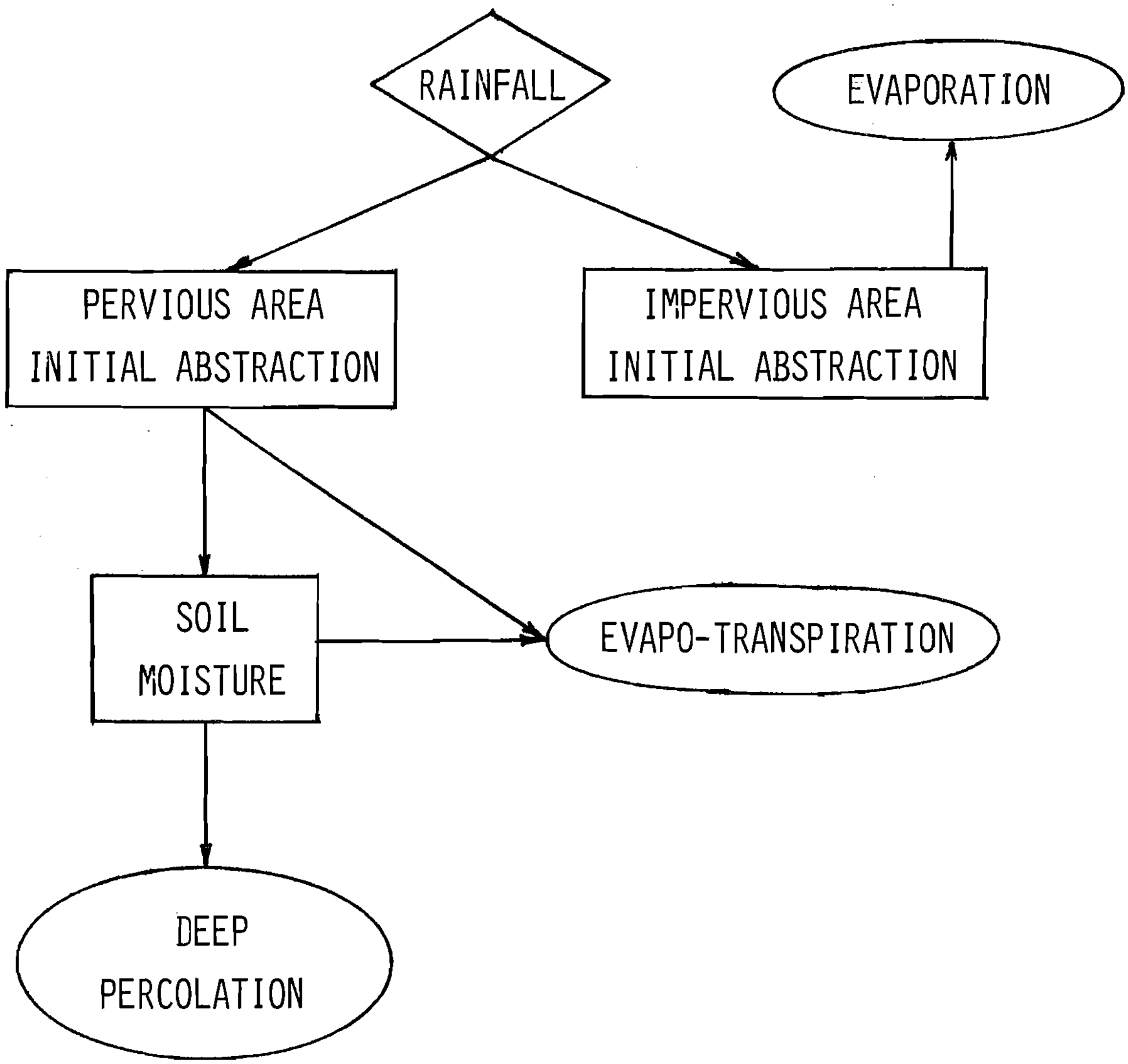

Fig. 3-1 Soil Moisture and Abstraction Reservoir Schematic

In the event that SMS_i'' exceeds the field capacity of the soil deep percolation occurs and the soil moisture storage must be further modified:

$$SMS_i' = \text{Max}(SMS_i'' - DLYPER, FCAP) \qquad (3\text{-}3)$$

in which SMS_i' = soil moisture storage before accounting for evapotranspiration; DLYPER = daily amount of potential deep percolation (a calibration parameter); and FCAP = field capacity of the soil (a calibration parameter), i.e., the soil moisture at which gravity drainage will begin if further increase in soil moisture occurs.

The next step is to account for both evapotranspiration from the soil moisture reservoir and evaporation from the initial abstraction reservoirs. Potential values are given by:

$$EVP_i = EVPPAN_i \cdot PANRAT \qquad (3\text{-}4)$$

$$EVPT_i = EVP_i(1 + TRANRAT) \qquad (3\text{-}5)$$

in which EVP_i and $EVPT_i$ = potential evaporation and evapotranspiration values respectively; $EVPPAN_i$ = daily pan evaporation (input data); PANRAT = ratio of actual to pan evaporation values (a calibration parameter); and TRANRAT = ratio of daily potential transpiration to actual potential evaporation (a calibration parameter). Since part of the potential evapotranspiration is satisfied by evaporation from the pervious area initial abstraction reservoir, these two are interrelated. First, rainfall is applied to the pervious area initial abstraction reservoir:

$$PAIA'_i = Max(PAIA_{i-1} - RAIN_i, 0.0) \quad (3\text{-}6)$$

in which $PAIA'_i$ = pervious area initial abstraction for day i before accounting for daily evaporation; and $PAIA_{i-1}$ is the net value of pervious area initial abstraction at the end of the previous day. Daily evaporation is then applied, but a maximum value of PAIA in introduced as well.

$$PAIA_i = Min(PAIA'_i + EVP_i, PAIAMAX) \quad (3\text{-}7)$$

in which PAIAMAX = upper limit of PAIA (a calibration parameter). The impervious area initial abstractions are treated in a similar fashion:

$$IAIA_i = Min\{[Max(IAIA_{i-1} - RAIN_i, 0.0) + EVP_i], IAIAMAX\} \quad (3\text{-}8)$$

in which IAIA = impervious area initial abstractions; and IAIAMAX = upper limit of IAIA (a calibration parameter).

The soil moisture reservoir can then be adjusted for evapotranspiration. First, the potential evapotranspiration is corrected for the evaporation from the pervious area initial abstraction reservoir.

$$EVPT_i = Max\{[EVPT'_i - (PAIA_i - PAIA'_i)], 0.0\} \quad (3\text{-}9)$$

The actual evapotransportation is assumed to be proportional to the fractional soil saturation.

$$TEVPT_i = EVPT_i \cdot (SMS'_i/SMSMAX) \quad (3\text{-}10)$$

in which $TEVPT_i$ = total daily evapotranspiration from the soil moisture reservoir. The final value for soil moisture storage is thus:

$$SMS_i = SMS_i' - TEVPT_i \quad (3\text{-}11)$$

Equations 3-7, 3-9 and 3-11 give the updated daily values for the respective variables and the procedure is repeated for the next day.

3.3 Hydrograph Routing

The original routing procedure used in ILLUDAS was replaced by three optional procedures in the development of the model. The first is a simple hydrograph time-shift process in which the inflow hydrograph is translated without change of shape through the reach. The translation velocity is taken as that associated with the maximum inflow assuming local uniformity to compute the flow area. If the translation time is less than the user-specified time increment for calculations, a parabolic interpolation scheme is used to obtain flow values at the proper time increment. After shifting, the hydrograph is again interpolated at the user-specified time interval.

The second routing procedure is a hydrologic scheme based upon the usual expression for continuity:

$$\frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2} = \frac{S_2 - S_1}{\Delta t} \quad (3\text{-}12)$$

in which I_1 and I_2 = the inflow values for the reach at the beginning and end, respectively, of time interval Δt; Q_1 and Q_2 = the respective outflow values; and S_1 and S_2 = the respective storage values.

The solution of Eq. 3-12 requires a second relationship between I, Q, and S. Two different relationships are used. The first requires an implicit solution for Q_2:

$$S_2 - S_1 = [A_2^I + A_2^Q - (A_1^I + A_1^Q)]L/2 \qquad (3\text{-}13)$$

in which A_2^I = flow area evaluated using the inflow I at the end of the time interval assuming uniform flow described by Manning's equation; A_2^Q = flow area evaluated in the same way using the outflow at the end of the time interval; A_1^I and A_1^Q = flow areas evaluated using I and Q at the beginning of the time interval and L = the length of the reach. The simultaneous solution of Eqs. 3-12 and 3-13 requires an implicit procedure for which an accelerated bracketing scheme is used.

The second relationship is a simplification of Eq. 3-13 in which it is assumed that $A_2^Q = A_2^I$, which leads to:

$$S_2 - S_1 = [2A_2^I - (A_1^I + A_1^Q)]L/2 \qquad (3\text{-}14)$$

The combination of Eqs. 3-14 and 3-12 permits an explicit solution for Q_2. As in the time-shift method, if the estimated travel time in the reach is less than the value of Δt specified by the user, a parabolic interpolation is performed at the travel time interval, and after routing, a second interpolation is done to obtain the values at intervals of Δt. This procedure avoids instabilities in the numerical procedure.

For all three methods, if the inflow exceeds the capacity of the pipe, the inflow is assumed to be detained temporarily at that point until the inflow falls below the capacity; at that time, the detained flow is added at a rate so that the inflow remains at capacity until the detained volume is depleted.

For small drainage systems or shorter reaches, experience indicates that the time-shift routing procedure yields results which are very close to those using either of the hydrologic routing procedures with a significant savings of computer time, particularly when compared to the implicit approach. Therefore, the time-shift routing was used for all work in this report.

3.4 Runoff Event Simulation

The transition to the runoff simulation for a specific rainfall event utilizes the daily soil moisture and initial abstraction accounting.

It was decided to retain the Horton infiltration model utilized in the single event version of ILLUDAS given by:

$$f = f_c + (f_o - f_c)e^{-kt} \tag{3-15}$$

in which f = infiltration capacity at any time t; f_o = infiltration capacity for dry soil; f_c = infiltration capacity under saturated soil conditions; and k = a decay coefficient. All of these parameters can be determined in the overall model calibration procedure as discussed in Chapter 5 or the results from independent infiltration data can be used.

The value of f_o to be used at the beginning of a specific event to be simulated, designated by f_o', depends on the soil moisture at that time, which is based on the daily accounting process. Figure 3-2 shows the Horton model. The area between the capacity curve and the line $f = f_c$ is analogous to the maximum soil moisture storage in the daily accounting procedure, SMSMAX. This area can easily be shown to be given by $(f_o - f_c)/k$. For any value of soil moisture storage at time t, SMS_t, there is a corresponding analogous area above $f = f_c$ and to the left of the time corresponding to f_o', identified as ϕ in Fig. 3-2.

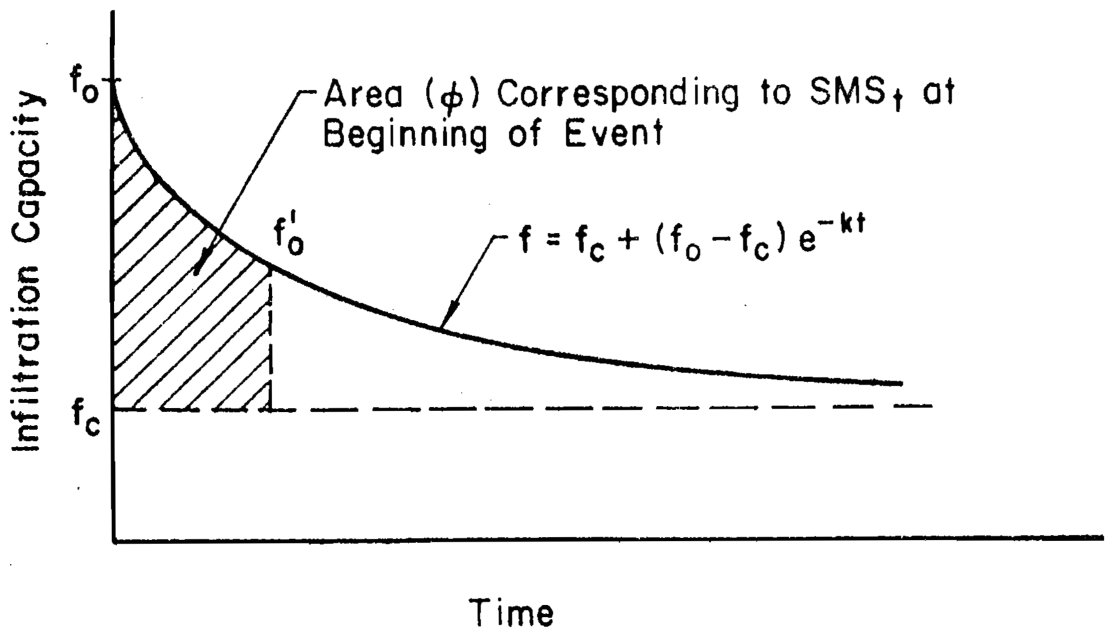

Fig. 3-2 Infiltration Model

$$\phi = \frac{f_o - f_c}{k} - \frac{f'_o - f_c}{k} = \frac{f_o - f'_o}{k} \qquad (3\text{-}16)$$

To evaluate f'_o, it is assumed that ϕ is proportional to the percentage of maximum soil moisture that exists at that time as determined in the daily accounting procedure.

$$\frac{\phi}{((f_o - f_c)/k)} = \frac{SMS_t}{SMSMAX} \qquad (3\text{-}17)$$

Thus, the initial value of the infiltration capacity is given by:

$$f'_o = f_c + (f_o - f_c)(1 - \frac{SMS_t}{SMSMAX}) \qquad (3\text{-}18)$$

The value of SMS_t is based on the value of SMS_i, the soil moisture storage at the end of the current day. If t equals the hour during the day at which the event begins, then:

$$SMS_t = SMS_{i-1} + (SMS_i - SMS_{i-1}) \frac{t}{24} \qquad (3\text{-}19)$$

The value of f'_o is, therefore, determined by substituting the value of SMS_t obtained from Eq. 3-19 into Eq. 3-18.

The values for the pervious and impervious initial abstractions at the beginning of the event are determined using the Eq. 3-19 proportioning scheme ; that is, the values of the variables at the end of the day and the previous day are utilized in a relationship analogous to Eq. 3-19 with SMS replaced by the respective abstraction variables.

If more than one event is simulated during any day, Eq. 3-19 is simply applied again with t set equal to the beginning time for the second event.

It should be pointed out that the daily accounting procedure is conducted independently of the runoff simulation. There is no connection between the Horton Infiltration capacity at the end of an event and the corresponding value of SMS at that time. The daily accounting values are used only to compute the values of the initial abstractions and infiltration rate at the beginning of each simulated event.

Figure 3-3 is a flow chart showing the various steps in the continuous simulation process.

3.5 Initial Version of Model

In the first phase of this study, a different version of a continuous ILLUDAS was used. This version was somewhat simpler than the version described above and was used to study the Boneyard Creek catchment only. It is described in Appendix A.

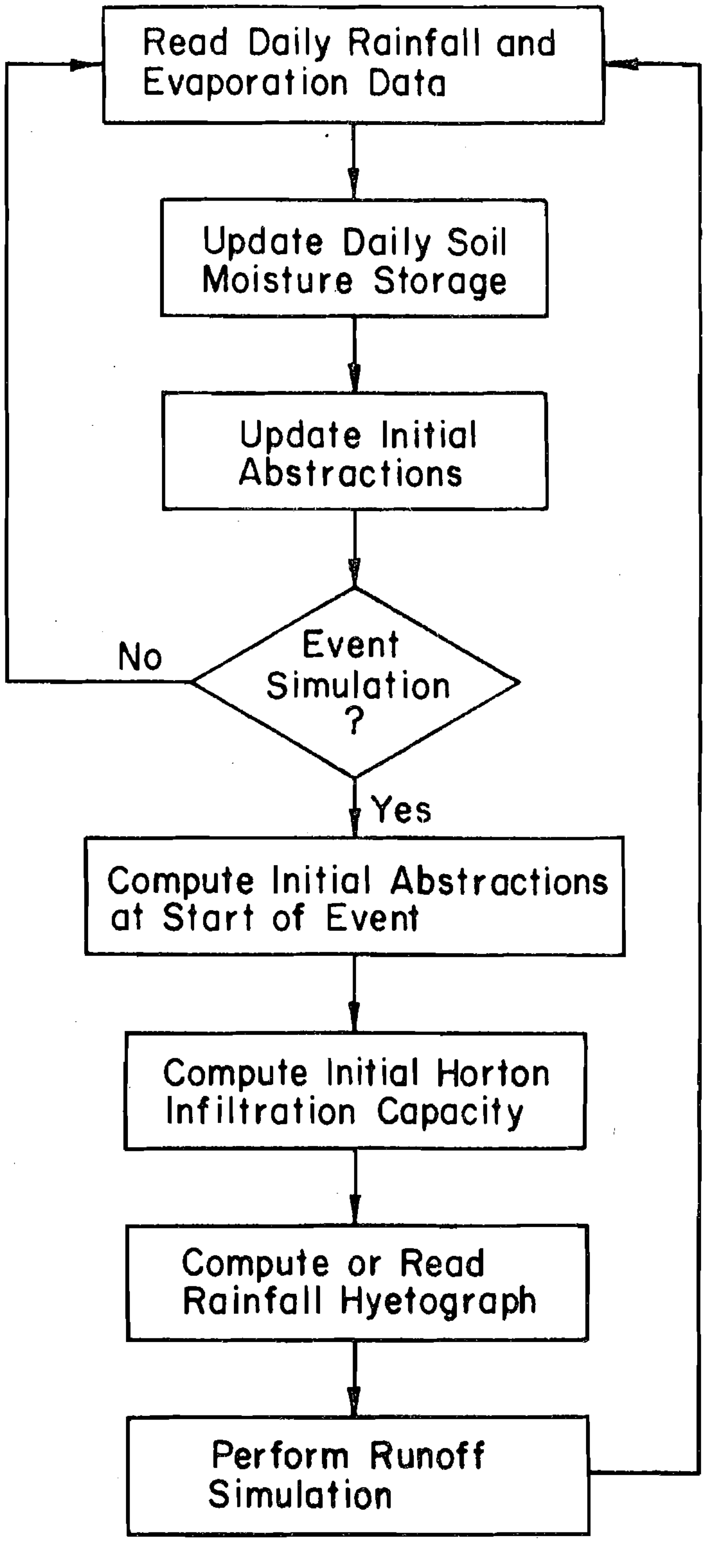

Fig. 3-3 Continuous Simulation Flow Chart

Chapter 4. RAINFALL AND CATCHMENT DATA

4.1 Rainfall Data

Four sets of rainfall data were used in the continuous simulation model for computing simulated historical runoff data. The data used for calibration of the model for each catchment is described in Chapter 5.

The first phase of this study was done using data collected by the Illinois State Water Survey using a special raingage network. The Survey provided 13 years of this data reduced to 15 min increments. Three additional rainfall data sets were obtained from USDA Science and Education Administration. These data were from three research sites and were on computer tape in the form of break-point mass curve values, i.e., time and depth values when the slope of the rainfall mass curve changes. This format permits the development of a continuous rainfall record with incremental depth values at arbitrary time increments.

Table 4-1 shows a summary of the rainfall data.

TABLE 4-1 Rainfall Data

Location	Years	Months Included* Each Year	Events Before Screening	Events After Screening
Champaign-Urbana, IL	1949-61	March-November		118
Coshocton, Ohio	1951-75	March-November	1621	105
McCreddie, Missouri	1941-74	March-November		209
Albuquerque, New Mexico	1941-72	March-November		135

4.2 Rainfall Event Criterion

There is no single standard procedure for defining independent rainfall events. The procedure adopted was to perform an autocorrelation analysis on a portion of each long term rainfall data set. The correlation coefficient was computed by

$$r_k = \frac{COV(x_t, x_{t+k})}{[VAR(x_t)\ VAR(x_{t+k})]^{0.5}} \qquad (4\text{-}1)$$

where r_k = correlation coefficient for a lag of k time periods, x_t and x_{t+k} = lagged and non-lagged 5 min rainfall depth values. The covariance in Eq. 4-1 is evaluated as

$$COV(x_t, x_{t+k}) = \frac{1}{N-k-1}\sum_{t=1}^{n-k} x_t x_{t+k} - \frac{1}{(N-k-1)(N-k)}\sum_{t=1}^{N-k} x_t \sum_{t=1}^{N-k} x_{t-k} \qquad (4\text{-}2)$$

where N = total number of non-zero depth values used in the analysis. The variance in Eq. 4-1 is computed by

$$VAR(x) = \frac{1}{N-k-1}\sum_{t=1}^{N-k} x^2 - \frac{1}{(N-k-1)(N-k)}\left[\sum_{t=1}^{N-k} x\right]^2 \qquad (4\text{-}3)$$

A portion of each of the three SEA data sets were selected for analysis The Champaign-Urbana data were analyzed previously by Morris[14]. Five minute depth values were determined and lag time periods of 15-min multiples were used. The results of the analyses are shown in Fig. 4-1. The McCreddie data indicate a definite local minimum correlation

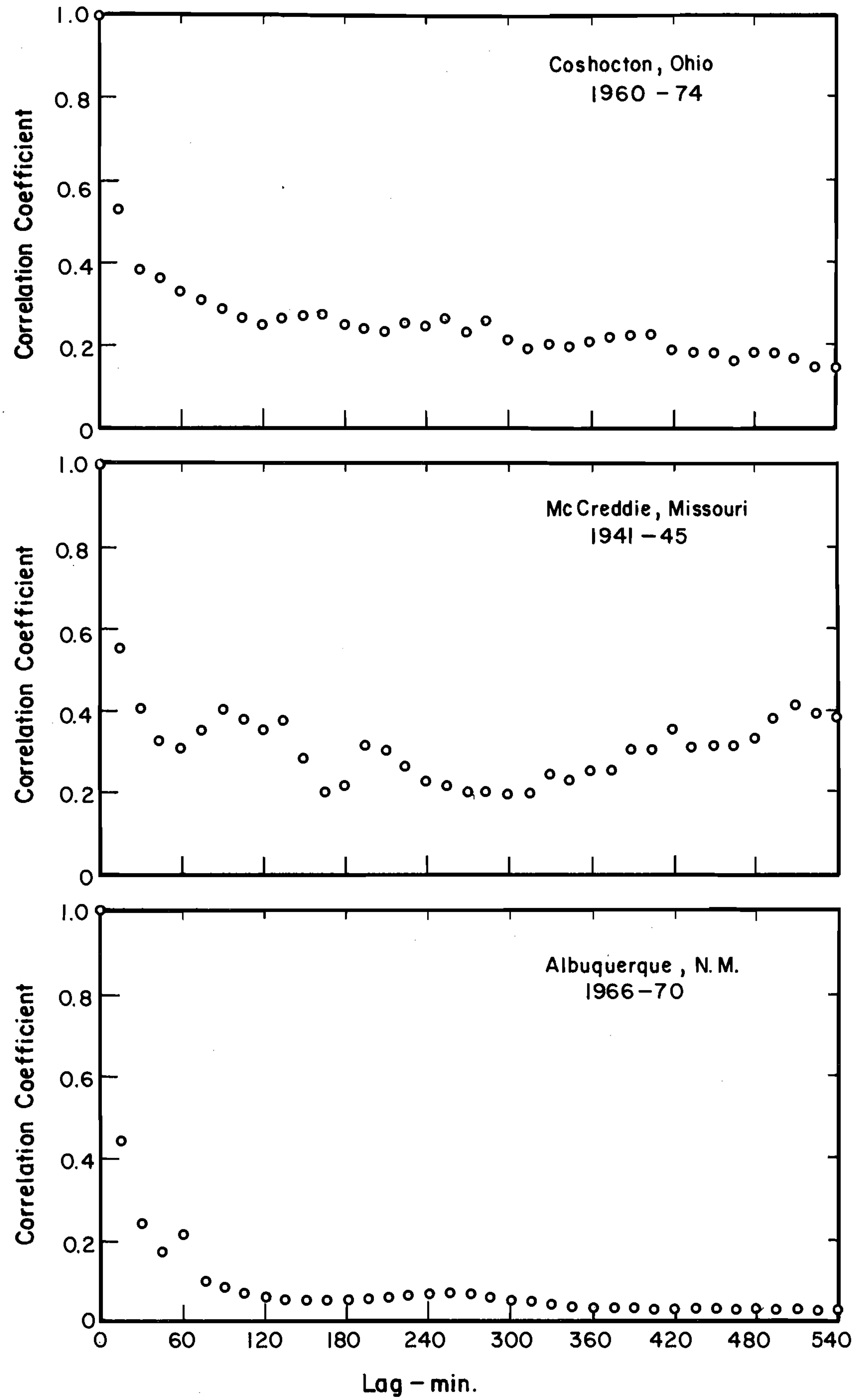

Fig. 4-1 Rainfall Autocorrelation

at 300-min. The other sets show a gradual decline in correlation. The Albuquerque correlation falls more rapidly than the others indicating shorter duration rainfall. It was concluded that a 300-min zero rainfall criterion was adequate for all three data sets, but no statistical significance tests were done. The analyses by Morris of the Champaign-Urbana data indicated a 270 min criterion and this value was therefore used.

4.3 Depth-Duration-Frequency Analysis of Rainfall Data

After rainfall events were defined, a frequency analysis for various durations was performed on each data set following the procedure described in Section 2.2.

The results of these analyses are summarized in Tables 4-2 through 4-5.

TABLE 4-2 Depth-Frequency Analysis for Champaign Rainfall

Return Period yrs	Depth in.	Duration min
1	1.34	105
2	1.62	105
5	2.04	105
10	2.33	105
25	2.73	105

TABLE 4-3 Frequency Analysis for Coshocton Rainfall

Return Period yrs	Dept (in.) for Specified Duration 15 min	20 min	25 min	30 min	60 min
1	0.68	0.76	0.84	0.88	1.05
2	0.76	0.87	0.94	1.01	1.24
5	0.87	1.00	1.09	1.17	1.49
10	0.95	1.11	1.19	1.30	1.68
15	1.00	1.17	1.26	1.37	1.78
20	1.04	1.21	1.30	1.43	1.86
25	1.06	1.24	1.34	1.47	1.92

TABLE 4-4 Frequency Analysis for McCreddie Rainfall

Return Period yrs	Depth (in.) for Specified Duration 15 min	20 min	25 min	30 min	45 min	60 min
1	0.66	0.74	0.81	0.91	0.98	1.07
2	0.79	0.93	1.03	1.10	1.26	1.36
5	0.97	1.18	1.33	1.35	1.65	1.75
10	1.10	1.36	1.55	1.55	1.94	2.05
15	1.18	1.48	1.68	1.66	2.11	2.23
20	1.24	1.55	1.77	1.74	2.23	2.35
25	1.28	1.61	1.85	1.80	2.32	2.45
30	1.32	1.66	1.91	1.85	2.40	2.52
34	1.34	1.70	1.95	1.88	2.45	2.58

TABLE 4-5 Frequency Analysis for Albuquerque Rainfall

Return Period yrs	Depth (in.) for Specified Duration 15 min	20 min	25 min	30 min	45 min	60 min
1	0.35	0.39	0.44	0.46	0.51	0.58
2	0.49	0.55	0.61	0.64	0.71	0.77
5	0.68	0.77	0.83	0.89	0.98	1.03
10	0.82	0.93	1.00	1.08	1.19	1.22
15	0.91	1.02	1.11	1.19	1.31	1.34
20	0.97	1.09	1.18	1.27	1.39	1.42
25	1.01	1.14	1.23	1.33	1.46	1.48
30	1.05	1.18	1.28	1.38	1.51	1.54

4.4 Catchment Descriptions

Four urban catchments were used in this study. The basic data for these are summarized in Table 4.6. The Boneyard Creek catchment was used in the first phase of the study and was tested only with Champaign-Urbana rainfall. The other catchments were tested with the remaining three rainfall data sets.

TABLE 4-6 Catchment Data

Catchment	Land Use*	Drainage Area (ac)	Data Source
Boneyard Creek, IL	1, 2, 3	2,290	Illinois State Water Survey
Gray Haven, MD	1	23.3	Johns Hopkins University
Dade County, FL	2	14.7	U.S. Geological Survey
Broward County, FL	3	20.0	U.S. Geological Survey

*Land Use Key: 1 = single family residential; 2 = apartment; 3 = commercial

4.4.1 Boneyard Creek Urban Catchment

The Boneyard Creek watershed includes portions of Champaign, Urbana and the University of Illinois campus. It is fully urbanized, containing parks, residential and commercial areas. Figure 4-2 shows a map of the area which includes the rain gage system and the location of the USGS gaging station which defined the downstream end of the watershed used in this study.

The system was modeled using 83 sewer reaches and 25 open channel reaches as shown in Fig. 4-3. All sewers with a diameter of 15 in. or greater were included. The details of the representation are given in Appendix B.

4.4.2 Gray Haven Residential Catchment

The Gray Haven catchment in Baltimore, MD is a residential sewered catchment and was modeled using 10 pipes. Figure 4-4 shows a

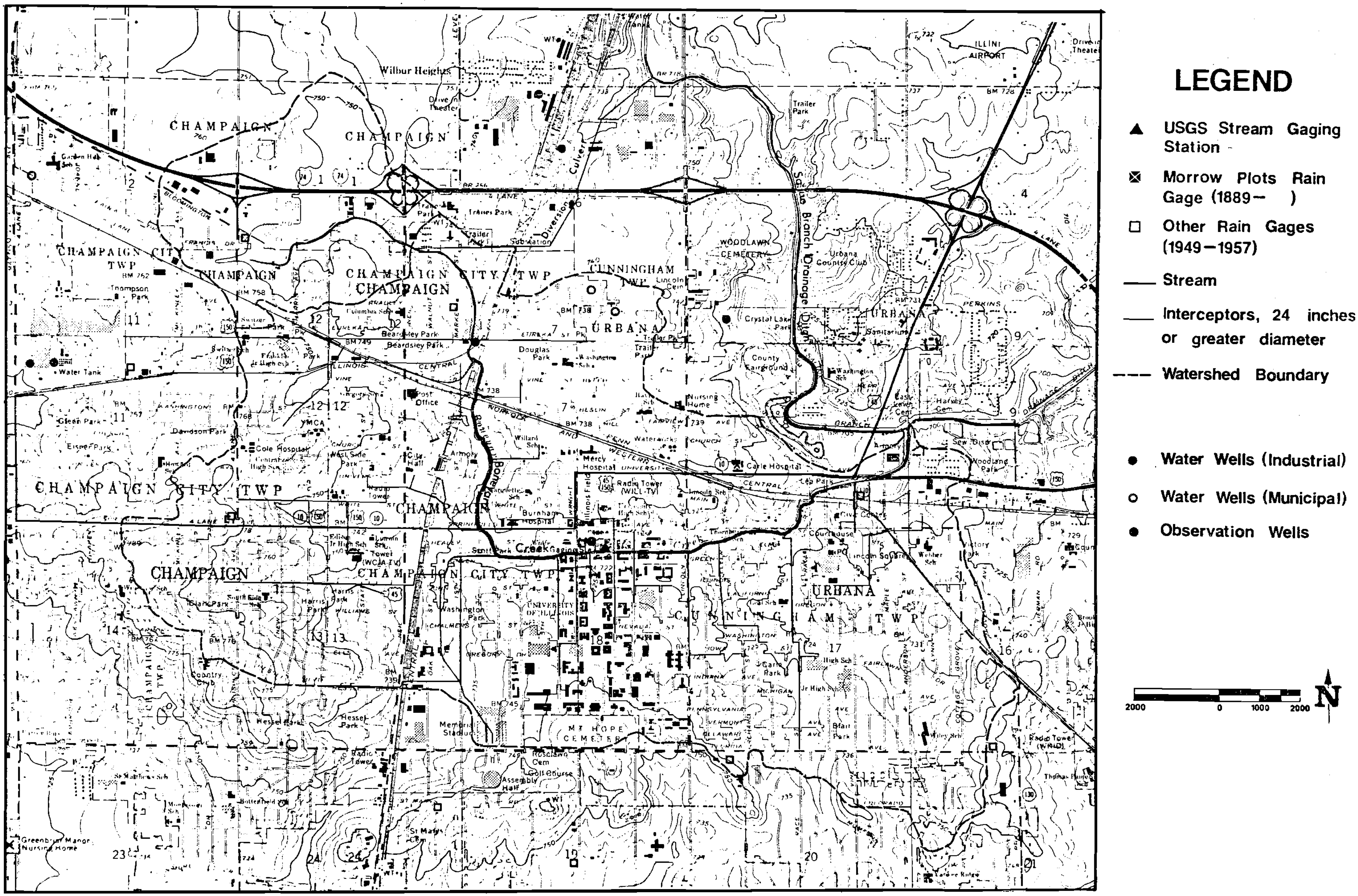

Fig. 4-2 Boneyard Creek Catchment

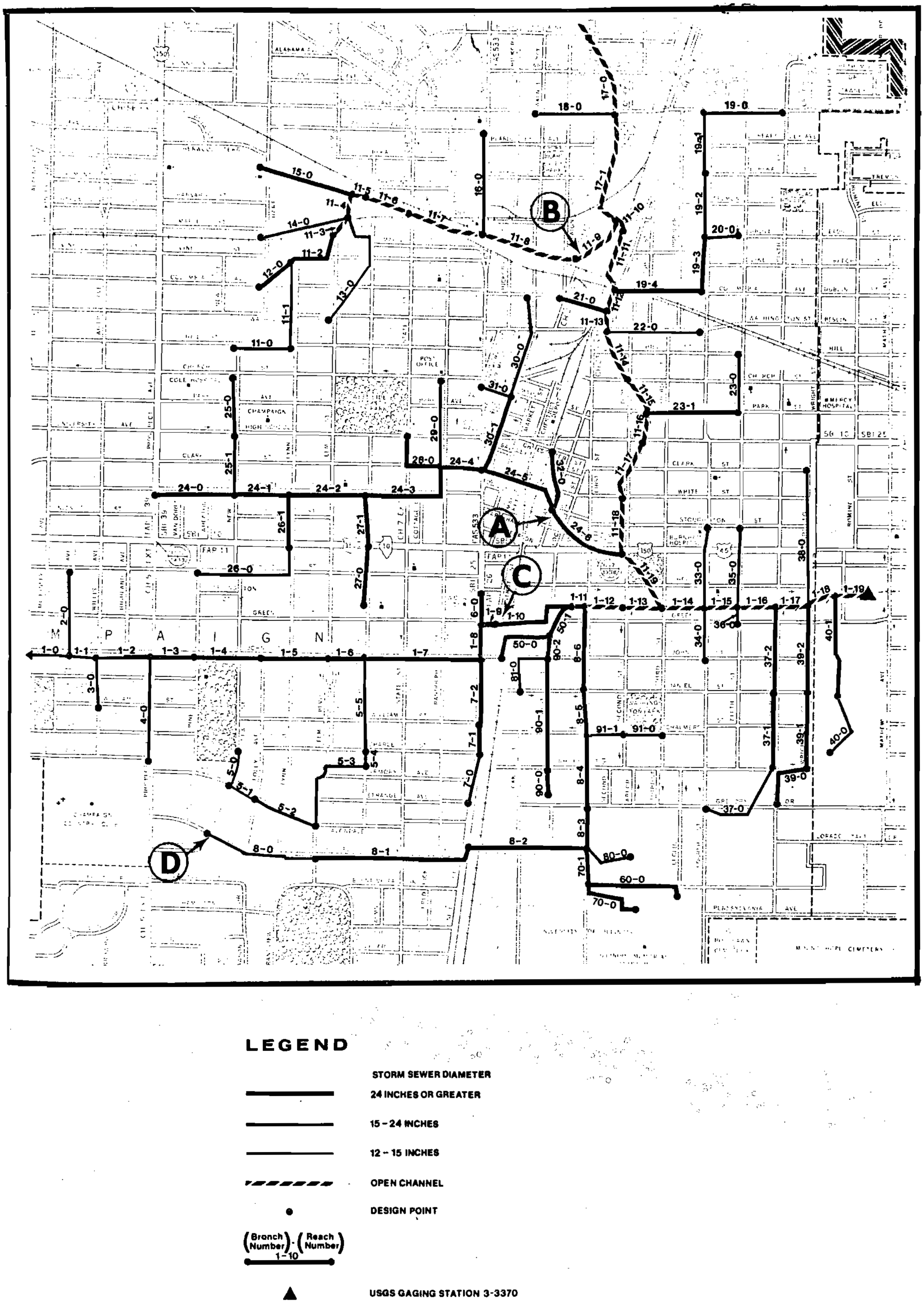

Fig. 4-3 Boneyard Creek Drainage System

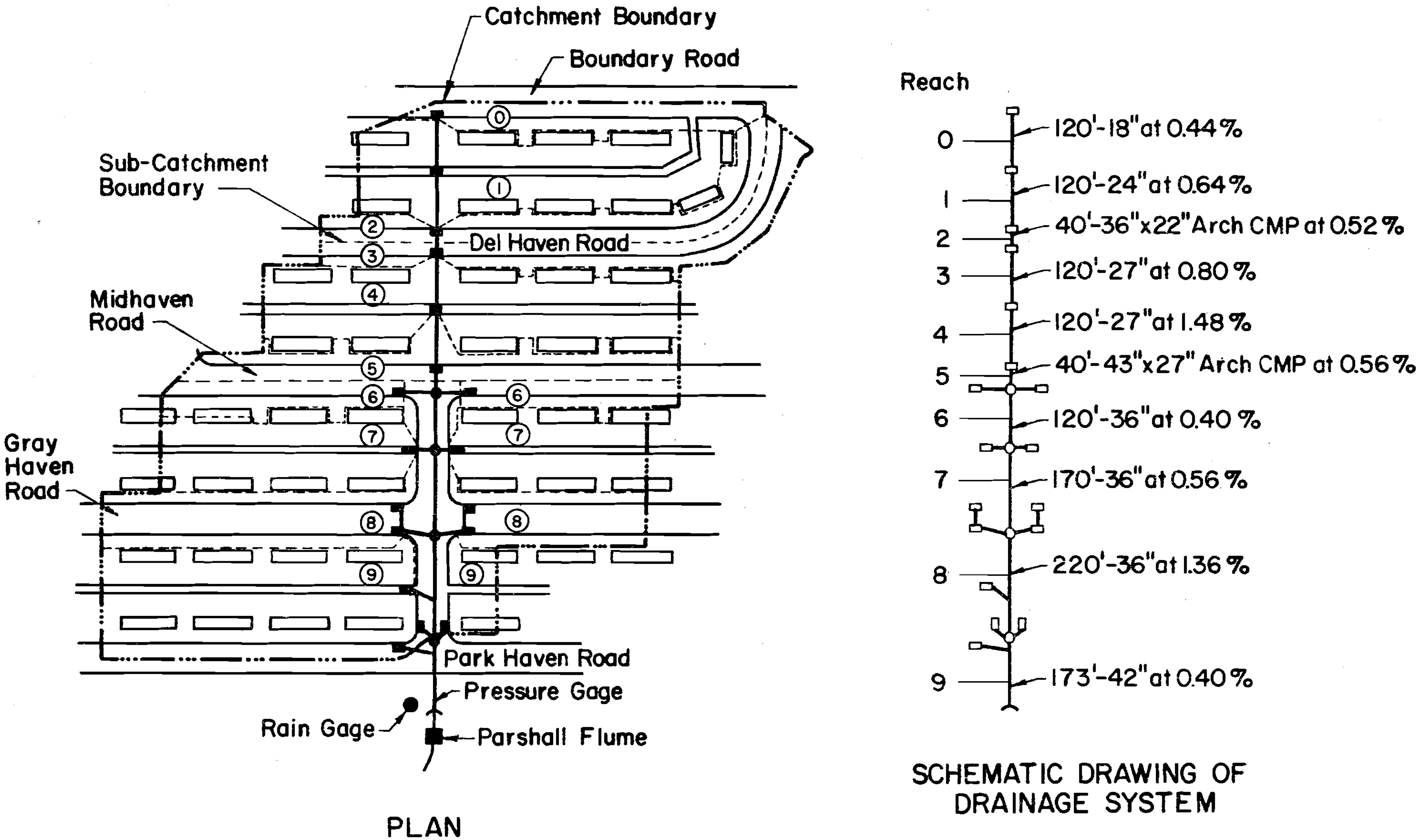

Fig. 4-4 Gray Haven Residential Catchment

schematic of the catchment along with the sewer system. Appendix C contains the detailed representation.

The site was monitored by a single tipping bucket raingage and a Parshall flume. The pervious areas are grassed and underlain by a sandy soil. Ground slopes are gentle, averaging about 0.5 percent.

4.4.3 <u>Dade County Residential Catchment</u>

The Dade County catchment is a multifamily residential area (apartments) which was monitered for rainfall, runoff and water quality from May 1977 to June 1978 by the U.S. Geological Survey[15].

The impervious area is 10.4 ac or 70.7 percent of the total area. The soil, which is covered by grass, is Perrine marl with a very low infiltration capacity (SCS hydrologic soil group D). The streets have no curbs or gutters, but are formed with the center of the street acting as a swale. Downspouts discharge onto lawns. The storm sewer system is shown in Fig. 4-5 and has a 48 in. diameter outfall. The pipes are corrugated metal and circular[16, 17].

Rainfall was measured at two locations as shown in Fig. 4-4 and discharge was measured at the outlet using an electro-magnetic velocity meter installed in the pipe. All data were coordinated in time and recorded in 1 min time intervals.

The representation of the catchment is given in Appendix D.

4.4.4 <u>Broward County Commercial Catchment</u>

This catchment is a shopping center located in Ft. Lauderdale, which was monitered by the U.S. Geological Survey from May 1975 to June 1977[18]. The catchment is unique among those used in this study in that it is 98 percent impervious, with significant roof and parking lot area.

The site was monitored by a single raingage and flow meter at the outlet as shown in Fig. 4-6. All pipes are concrete and circular. Roof downspouts are directly connected to the sewer system[16, 17].

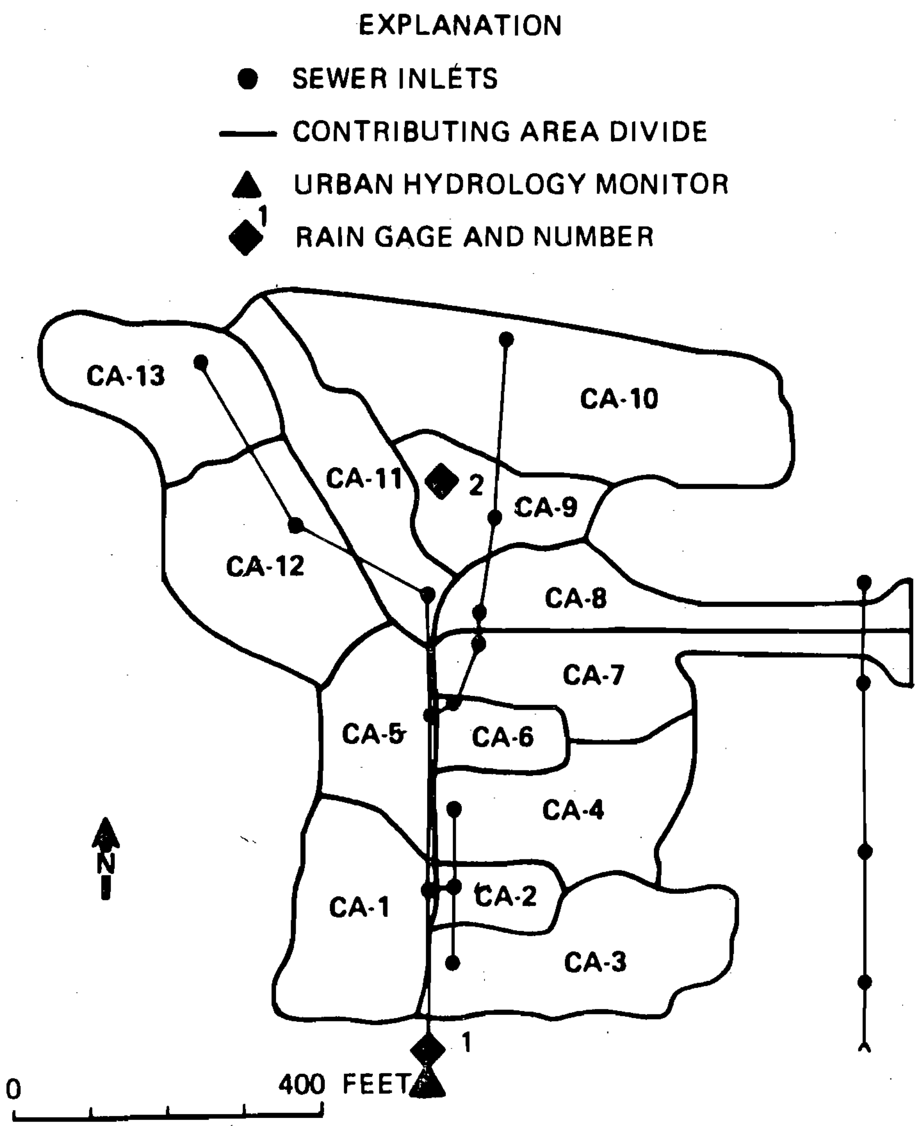

Fig. 4-5 Dade County Residential Catchment

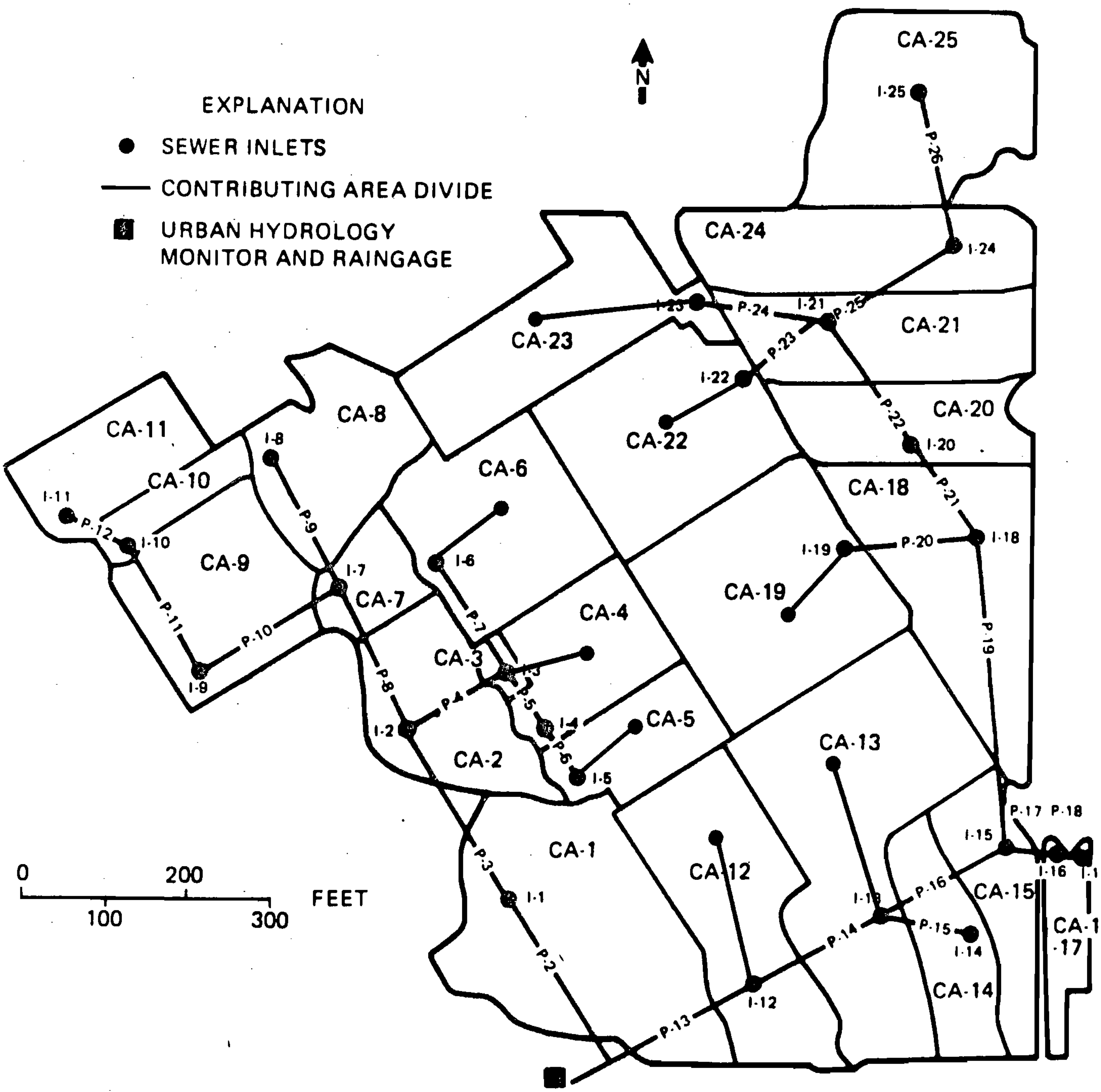

Fig. 4-6 Broward County Commercial Catchment

Chapter 5 MODEL CALIBRATION

5.1 General Procedure

Calibration is a very important aspect of the application of any model. There is no uniformly accepted calibration procedure since this may vary depending on the use of the model or the type or quantity of calibration data. The procedure described herein was developed because it can incorporate any number of parameters and recognizes that more than one calibration criterion may be useful.

The first version of the continuous model was calibrated more or less by trial and this was used for the Boneyard Creek watershed study. The calibration of the second version, which was used for the other three catchments shown in Table 4-1, is described below.

For the second version of the simulation model, the calibration process has two components. First, the definitions and descriptions of the sub-basins and pipe system must be described. This means that the boundaries and areas (i.e., impervious, pervious, and supplemental impervious) of the sub-basins must be specified, as well as the inlet times for these areas. In addition, the size, slope, roughness, and length of all pipes and channels must be provided.

The second calibration component consists of the determination of the various parameters related to the soil moisture and initial abstraction accounting and infiltration as discussed previously. Table 5-1 summarizes these parameters as well as listing their values for catchments to be subsequently discussed. This calibration component was performed using an optimization procedure developed by Rosenbrock[19]. A discussion of the technique is presented in Appendix F. Basically, the process involves the establishment of an objective function and an orderly sensitivity search through the various calibration parameters. Once the parameters to which the objective function

TABLE 5-1 Model Calibration Parameters

Parameter	Description	Gray Haven Catchment	Dade Co. Catchment	Broward Co. Catchment
f_o	Horton infiltration capacity for dry soil (in.hr)	8.21	9.81	
f_c	Horton infiltration capacity for saturated soil (in./hr)	1.97	0.83	
k	Horton decay constant (hr^{-1})	3.96	4.98	
PAIAMAX	Maximum pervious area initial abstraction (in.)	0.20	0.35	
IAIAMAX	Maximum impervious area initial abstraction (in.)	0.10	0.17	0.05
SMSMAX	Maximum soil moisture storage (in.)	4.73	3.36	
DLYPER	Daily rate of deep percolation (in./day)	0.04	0.29	
FCAP	Field capacity of soil (in.)	2.89	1.34	
α_r	Fraction of daily rainfall which can infiltrate	1.00	0.88	
PANRAT	Ratio of daily evaporation to pan evaporation	0.90	0.90	0.90
TRANRAT	Ratio of daily transpiration to evaporation	0.12	0.12	0.12

is most sensitive are identified, a series of stages occur in which systematic changes in each parameter are made utilizing the history of results gained in prior stages. The process incorporates constraints (i.e., limiting values on the parameters) by imposing a weighted penalty to the objective function as the parameter limits are approached. Successive stages are evaluated until the improvement in the value of the objective function drops below a prescribed value.

The calibration data required are daily rainfall, daily pan evapoation, event rainfall, and corresponding runoff hydrographs. Two separate objective functions are used. The first involves the runoff volume:

$$R = \text{Min} \sum_{i=1}^{n} \ell n \left[\frac{RVOL_{c_i}}{RVOL_{o_i}} \right]^2 \tag{5-1}$$

in which $RVOL_{c_i}$ = computed runoff volume for storm i; $RVOL_{o_i}$ = corresponding observed value; n = number of storm events used for calibration; and R = value of the objective function.

The second objective function involves the shape of the runoff hydrograph with heavier weight given to the peak discharge:

$$R = \text{Min}\left[\sum_{i=1}^{n} \sum_{j} \frac{Q_{c_{ij}}}{Q'_{o_i}} (Q_{c_{ij}} - Q_{o_{ij}})^2 \right] \tag{5-2}$$

in which Q'_{o_i} = observed runoff hydrograph peak for storm i; and $Q_{c_{ij}}$ and $Q_{o_{ij}}$ are the computed and observed runoff hydrograph ordinates for event i and time interval j.

The reason for utilizing two objective functions is that each is based on a specific runoff hydrograph property. Equation 5-1 optimizes the model parameters on the basis of agreement between observed and computed runoff volumes, while Eq. 5-2 utilizes hydrograph shape agreement, with emphasis on the peak region.

The last six parameters in Table 5-1 are utilized in the daily soil moisture accounting procedure, and thus are related primarily to runoff volume rather than hydrograph shape. Therefore, Eq. 5-1 serves as a reasonable objective function for these parameters. The first five parameters in Table 5-1 relate to both hydrograph volume and shape. Of these, the Horton infiltration parameters are judged to have more influence on runoff volume than hydrograph shape, particularly for large events. Their importance is, of course, in part a function of the percentage of pervious area in the catchment. Therefore, Eq. 5-1 was used to evaluate the Horton parameters. The initial abstraction parameters can have a stronger effect on the hydrograph peak, particularly for small events, because they are concentrated at the beginning of each event and thus can strongly influence the effective rainfall hyetograph, which in turn has a direct influence on the hydrograph shape. Therefore, Eq. 5-2 is appropriate for calibrating PAIAMAX and IAIAMAX.

The general calibration procedure can be summarized as follows:

1. Using Eq. 5-1 as the objective function, all parameters in Table 5-1 were evaluated except PAIAMAX and IAIAMAX using the optimization procedure. During this step the latter two parameters are held constant at initial estimated values. A reasonable estimate of these constant values is PAIAMAX = 0.2 in. (5 mm) and IAIAMAX = 0.1 in. (2.5 mm).
2. Using the resulting parameter values obtained from step 1 as fixed, Eq. 5-2 was used as the objective function to calibrate PAIAMAX and IAIAMAX.
3. Using the values of all parameters obtained from steps 1 and 2 as initial values, step 1 was repeated holding the initial abstraction parameters constant.

5.2 Boneyard Creek Catchment Calibration

The study of this catchment was done using an earlier version of the model as discussed previously. The calibration of this catchment, therefore, was not done using the procedure described above.

The model was calibrated using 6 min rainfall data collected by the Illinois State Water Survey from 1949-1965. The Thiessen method was used to compute average 6 min areal values from the basic network data. Runoff data were obtained from the USGS gaging station shown in Fig. 4-2.

Initial estimates of model parameters which were physically reasonable were used and modified by trial and error. It was found that calibration could be improved for large events by limiting the flow in reaches 11-18 and 11-19 in Fig. 4-3 to 100 and 250 cfs respectively. This limitation accounts for the limitation on inflow to the main channel by some of the local storm sewer pipes which had low capacities and caused local street flooding. These limits were justified from field observations and independent channel capacity calculations. The model parameter values are shown in Table 5-2.

TABLE 5-2 Boneyard Catchment Model Parameters

Parameter	Description	Value
f_o	Initial infiltration capacity	8.0 in./hr
f_c	Saturated infiltration capacity	0.5 in./hr
α	Constant of proportionality between deep percolation rate and soil moisture storage	0.129 hr^{-1}
H	Maximum soil moisture storage	3.87 in.
	Field capacity or minimum soil moisture storage	1.16 in.
	Maximum impervious area initial abstraction	0.1 in.
	Maximum pervious area initial abstraction	0.2 in.

Table 5-3 shows the results of nine calibration events and Fig. 5-1 shows four of the observed and computed hydrographs.

TABLE 5-3 Boneyard Catchment Calibration Summary

Event Date	AMC[1]	Total Rain in.	Runoff Volume (in.) Observed	Computed	Obs/Comp	Runoff Peak (cfs) Observed	Computed	Obs/Comp
10/26/60	2	0.65	0.10	0.13	0.77	185	214	0.86
11/15/60	1	0.84	0.16	0.17	0.94	223	205	1.09
11/28/60	1	0.36	0.06	0.06	1.00	143	158	0.91
03/04/61	2	0.69	0.12	0.14	0.86	235	269	0.87
06/06/61	1	1.96	0.42	0.47	0.89	479	524	0.91
09/23/61	2	0.39	0.07	0.07	1.00	175	144	1.22
05/10/62	4	0.65	0.16	0.17	0.94	247	324	0.76
04/19/64	2	1.16	0.28	0.25	1.12	234	248	0.94
04/20/64	4	3.08	1.19	0.78	1.53	507	442	1.15

1. AMC = antecedent soil moisture condition as defined in Ref (2).

5.3 <u>Gray Haven Catchment Calibration</u>

Rainfall and runoff data for Gray Haven were obtained as part of the Johns Hopkins Storm Drainage Project as summarized by Tucker[18]. Rainfall and runoff data at 1 minute intervals were used. For the daily soil moisture accounting, daily rainfall values from the National Weather Service gage at Baltimore airport were used as well as daily NWS pan evaporation data from Beltsville. The calibration events and results are summarized in Table 5-4.

The calibration was performed in several stages, based in the steps previously outlined. Using all of the calibration events in Table 5-4, Eq. 5-1 as the objective function, and PAIAMAX and IAIAMAX held constant at 0.2 in. and 0.1 in. respectively, the remaining parameters were evaluated using the optimization procedure. Next, the initial abstraction parameters were evaluated using Eq. 5-2 as the objective function with the remaining

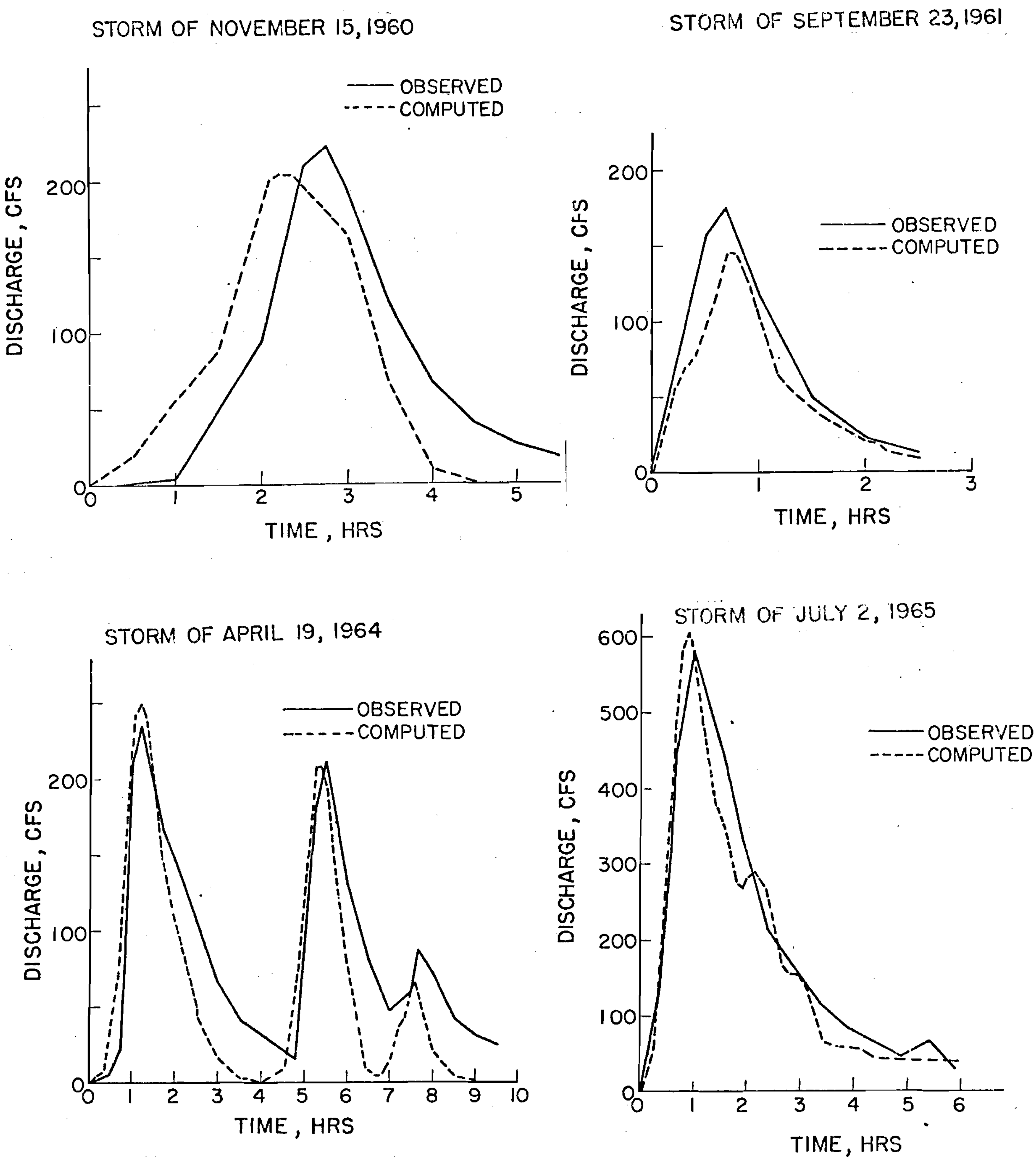

Fig. 5-1 Boneyard Creek Calibration Hydrographs

parameters held constant at the values determined in the first step. The calibration events used for this step are denoted by an asterik in Table 5-4. They are relatively small in magnitude and it was judged that the initial abstraction parameters would be more sensitive to these events. In the third step all of the parameters except PAIAMAX and IAIAMAX were again evaluated using Eq. 5-1 starting with the final values in the first step and holding the initial abstraction parameters at the values determined in the second step. This third step did not result in large changes in parameters values.

A model adjustment was made to account for sewer surcharging. ILLUDAS temporarily stores surcharge flow at the upstream end of the pipe reach. No parallel surface flow is permitted. It was believed that this was not appropriate for Gray Haven, and therefore, several of the pipes at the downstream end of the drainage system were increased in size to eliminate the surcharging which was first indicated by the model during the two largest calibration events only.

Finally, some slight adjustments to the entry times were made to improve the agreement between the rising limbs of the observed and simulated hydrographs. This latter stage was done subjectively without the use of the optimization procedure.

It should be pointed out that several of the small events were poorly predicted, particularly in terms of runoff volume as shown in Table 5-4. It is believed that this is due to the inability of the abstraction component of the model to accurately deal with events in which most of the rainfall becomes abstractions. On the other hand, the model does a reasonable job with the larger events and, if these are the events of interest, then the model can be used with confidence.

TABLE 5-4 Gray Haven Catchment Calibration Summary

Event Date	Rainfall Depth (in.)	Rainfall Duration (min)	Runoff Volume (in.) Observ.	Comp.	Observ./ Comp.	Runoff Peak (cfs) Observ.	Comp.	Observ./ Comp.
6/05/63	2.20	53.0	1.51	1.51	1.00	80.8	81.3	0.99
6/10/63	2.18	44.0	1.47	1.28	1.15	77.6	79.0	0.98
6/14/63	1.43	62.0	0.61	0.61	1.00	30.9	30.4	1.02
6/20/63	1.41	44.0	0.59	0.60	0.99	29.6	32.6	0.91
6/29/63	1.18	160.0	0.53	0.44	1.20	27.3	26.1	1.05
8/01/63	0.29	11.0	0.08	0.04	2.00	5.8	6.9	0.84
8/13/63	0.60	58.0	0.19	0.18	1.07	11.2	14.3	0.78
8/14/63	2.13	109.0	1.05	0.92	1.13	34.7	32.3	1.07
8/19/63	2.18	109.0	1.10	1.01	1.09	35.0	34.8	1.01
6/22/64[a]	0.43	51.0	0.12	0.10	1.10	9.1	13.5	0.67
7/08/64-I[a]	1.24	227.0	0.45	0.46	0.98	16.8	18.2	0.92
7/08/64-II[a]	0.43	100.0	0.22	0.12	1.77	12.4	13.4	0.93
7/13/64[a]	0.24	26.0	0.07	0.004	16.40	2.1	4.2	0.50
9/29/64[a]	0.22	12.0	0.07	0.01	7.18	6.5	1.5	4.33
7/16/65[a]	0.30	32.0	0.05	0.04	1.19	5.3	1.4	3.79
7/29/65[a]	0.31	37.0	0.07	0.05	1.48	6.6	6.7	0.99
8/02/65[a]	0.99	60.0	0.37	0.36	1.03	30.3	28.4	1.07
8/20/65[a]	0.31	23.0	0.08	0.05	1.69	4.3	6.9	0.62
9/03/65[a]	0.47	35.0	0.12	0.12	1.00	7.6	9.5	0.80
8/12/66	0.75	46.0	0.38	0.24	1.57	19.3	13.2	1.46

[a]Events using Eq. 5-2 as objective function remaining parameters held constant at values determined in previous step.

Figure 5-2 shows four examples of computed and observed hydrographs together with the rainfall hyetograph for four of the calibration events in Table 5-4. The June 10, 1963 event is one of the largest, showing good agreement between computed and observed peaks but somewhat less sensitivity to rainfall variation around the computed peak. The August 14, 1963 and July 8, 1963 hydrographs show more complex rainfall events. They illustrate the response of the model to multi-peaked hyetographs. The first two computed peaks of the July 8, 1964 event indicate that the abstractions may be underestimated during the earlier portion of the event while the main peak is predicted much better. The September 3, 1965 event is small and is not well simulated. Again, this is attributed to the need for a much more sophisticated abstraction model to accurately simulate small rainfall events. Appendix C contains plots of all calibration events.

This calibration exercise emphasizes an important point. The more calibration data that are used, the greater the chances of showing up some weaknesses in the model being calibrated. Excellent calibration can generally be obtained if only a few events are used. As the spectrum of events increases so does the users awareness of the deficiencies in the model. This knowledge should then be applied to yield an intelligent application.

5.4 Dade County Residential Catchment Calibration

The Dade County catchment was calibrated using data for 16 events. The results are shown in Table 5-5 and the hydrographs are shown in Appendix D. The parameter optimization procedure described earlier was used.

5.5 Broward County Commercial Catchment Calibration

The Broward County catchment was calibrated using 25 events. The results are summarized in Table 5-4. The hydrographs are shown in Appendix E. It was necessary to increase the diameter of some of the pipes to account for parallel surface flow in the parking lot since the model does not have a surface routing component. Since there was essentially no pervious area the optimization procedure was not followed in this case.

It should be noted in Table 5-4 that the smaller events have the largest modelling percentage error. This is probably because the abstractions form a significant portion of the total rainfall in such cases and a much more detailed model would be required to improve the simulation.

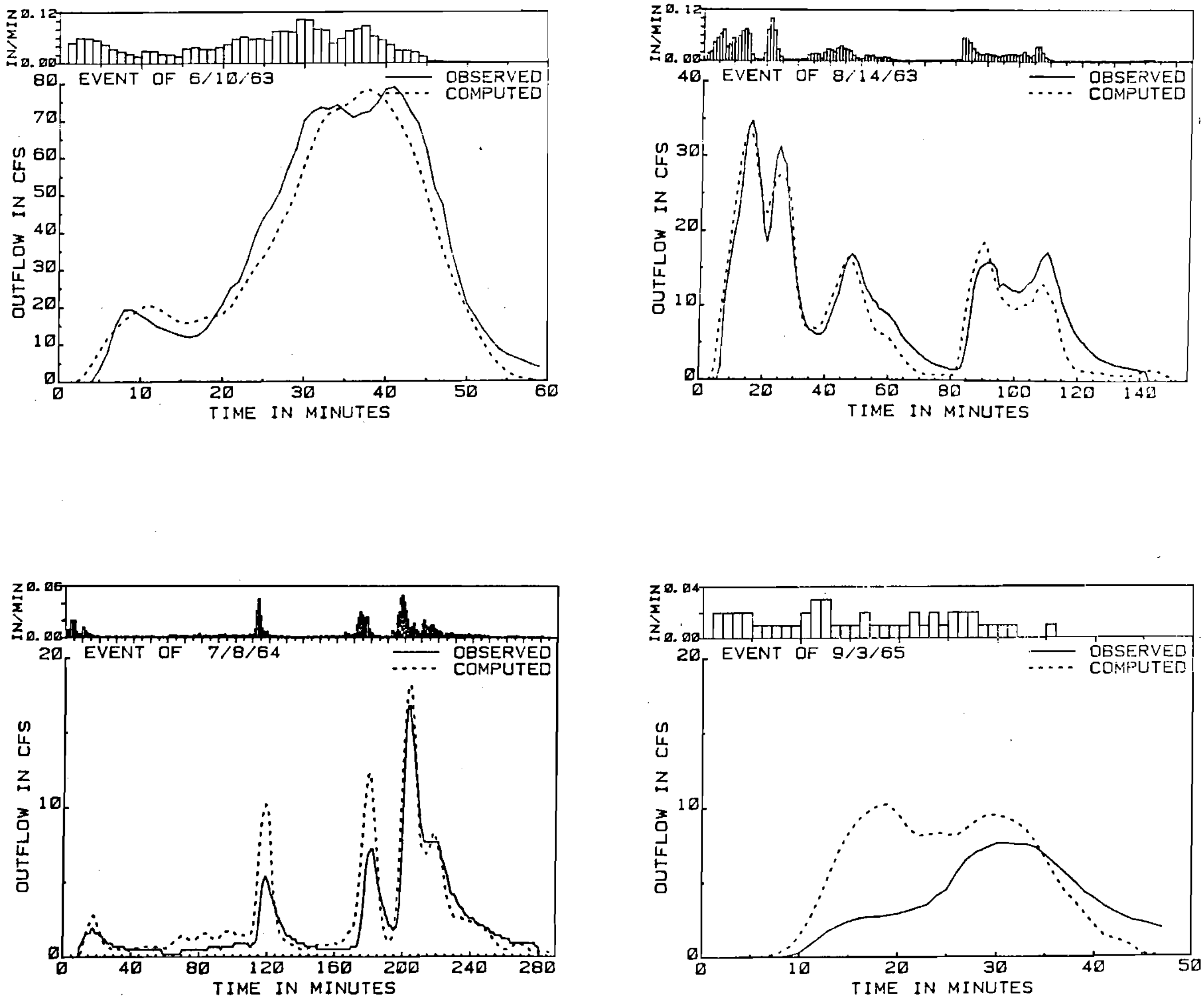

Fig. 5-2 Gray Haven Calibration Hydrographs

In particular an improved initial abstraction component would be useful (which would not allocate all such abstractions at the beginning of the event).

Despite the errors shown in Table 5-6 the model is adequate for the purposes of this study.

TABLE 5-5 Dade County Catchment Calibration Summary

Event Date	Rainfall Depth (in.)	Rainfall Duration (min)	Runoff Volume (in.) Obser.	Comp.	Observ./Comp.	Runoff Peak (cfs) Observ.	Comp.	Obser./Comp.
5/04/77	2.85	335	2.00	1.47	1.36	20.7	20.4	1.01
5/11/77	1.17	50	0.67	0.73	0.92	30.4	31.6	0.96
5/11/77	2.08	120	1.43	1.39	1.03	26.5	23.3	1.14
6/1/77	1.86	240	1.19	0.88	1.35	15.6	19.4	0.80
7/15/77	1.67	165	0.68	0.77	0.88	15.3	15.6	0.98
8/08/77	0.53	65	0.22	0.17	1.29	11.9	12.7	0.94
8/08/77	1.00	235	0.55	0.53	1.04	13.0	18.6	0.70
8/12/77	1.50	365	0.90	0.67	1.34	16.3	15.2	1.07
12/6/77	0.80	145	0.31	0.30	1.03	15.6	13.9	1.12
1/19/78	0.73	295	0.29	0.27	1.07	10.0	12.9	0.78
2/18/78	2.02	390	0.71	0.88	0.81	11.0	15.8	0.70
3/03/78	1.56	265	0.42	0.66	0.64	14.0	15.3	0.92
4/23/78	0.74	100	0.34	0.27	1.26	14.3	13.9	1.03
5/18/78	0.75	230	0.24	0.27	0.89	8.0	7.7	1.04
5/26/78	0.61	80	0.26	0.21	1.24	10.5	11.7	0.90
6/12/78	1.01	30	0.45	0.42	1.07	24.0	26.2	0.92

Table 5-6 Broward County Catchment Calibration Summary

Event Date	Rainfall Depth (in.)	Rainfall Duration (min)	Runoff Volume (in.) Observ.	Comp.	Observ./ Comp.	Runoff Peak (cfs) Observ.	Comp.	Observ./ Comp.
06/03/75	1.29	180	1.04	1.24	0.87	42.9	63.7	0.67
06/17/75	0.54	180	0.58	0.49	1.18	26.5	26.6	1.00
06/23/75	1.74	310	1.80	1.69	1.07	52.5	48.0	1.09
08/07/75	0.35	30	0.35	0.30	1.17	24.6	27.9	0.88
09/07/75	0.33	30	0.24	0.28	0.86	22.1	30.5	0.72
02/01/76	0.38	150	0.40	0.33	1.21	10.7	15.7	0.68
02/25/76	0.87	430	0.74	0.82	0.90	10.6	12.9	0.82
02/28/76	0.73	130	0.71	0.68	1.04	23.7	24.5	0.97
06/07/76	1.65	265	1.62	1.60	1.01	51.7	52.4	0.99
06/23/76	1.13	325	1.14	1.08	1.06	22.5	19.2	1.17
07/07/76	1.67	255	1.53	1.62	0.94	38.6	44.2	0.87
07/09/76	0.48	170	0.54	0.43	1.26	17.3	15.6	1.11
07/25/76	0.17	20	0.13	0.12	1.08	5.1	9.3	0.55
08/11/76	0.21	85	0.16	0.16	1.00	13.8	16.4	0.84
08/18/76	1.47	450	1.32	1.42	0.93	27.6	21.9	1.26
09/14/76	1.06	45	1.07	1.01	1.06	37.6	40.8	0.92
10/09/76	0.44	285	0.33	0.39	0.85	18.8	28.1	0.67
11/17/76	0.38	45	0.27	0.33	0.82	10.3	19.0	0.54
12/13/76	1.93	210	2.04	1.88	1.09	45.4	41.4	0.87
01/29/77	0.29	15	0.32	0.24	1.33	22.6	26.0	1.05
02/08/77	0.85	490	0.85	0.80	1.06	30.4	34.4	0.88
04/13/77	1.41	345	1.29	1.36	0.95	34.0	36.1	0.94
04/24/77	0.32	125	0.31	0.27	1.15	20.0	23.0	0.87
05/09/77	1.00	130	0.83	0.95	0.87	36.1	53.3	0.68
06/09/77	2.16	475	2.36	2.11	1.12	41.1	39.8	1.03

Chapter 6 RESULTS

For each of the four catchments a historical peak runoff frequency analysis was made and various design storms were then simulated as described in Chapter 2. The specific procedure varied somewhat with each catchment, therefore the results for each are presented and then a general discussion of all results is presented.

6.1 Boneyard Creek Catchment

The 13 year historical rainfall record was processed through the first version of the model and a frequency analysis performed.

The design storm duration chosen was 105 min since this duration produced, in general, maximum outflows for a given return period and hyetograph shape. Only two hyetograph shapes were used in the analysis: Huff and uniform distributions. The two extreme soil moisture conditions (dry and saturated) were used.

Figure 6-1 shows the results for flow at the gaging station, illustrating the sensetivity to the design storm parameters.

Because of the size of the catchment, the response of four sub-catchments of smaller size and varying land use was investigated. Table 6-1 summarizes the sub-catchment characteristics and they are identified in Fig. 4-3.

TABLE 6-1 Boneyard Creek Sub-Catchment Data

Designation	Lane Use	Area (ac)	Drainage
A	commercial, residential	370	all sewered
B	residential	291	sewers and channels
C	residential	501	all sewered
D	residential	4.7	all sewered

The results are shown in Figs. 6-2 through 6-5. The historical simulated peaks shown in these figures result from the same rainfall as used for Fig. 6-1 and the design storms all have 105 min duration. Note in Fig. 6-2 that the antecedent soil moisture apparently has no effect for the Huff distribution and for the uniform distribution above a 5 yr return period. This is also seen for sub-catchment C, Fig. 6-4. Examination of the flow in individual pipes showed that significant surcharging existed. This limits the outflow from the sub-catchment and masks the effect of antecedent soil moisture. In the case of sub-catchment A the pipe immediately upstream of the outlet pipe was surcharging for all but the 1 and 2 yr design storms with the uniform distribution. For sub-catchment C, 14 of the 22 sewers were surcharging for the 1 yr Huff design storm and 21 of the 22 were surcharging for the 25 yr design storm with dry antecedent soil moisture.

To investigate the effect of surcharging, the entire catchment drainage system was redesigned using the design mode of ILLUDAS. A 5 yr Huff distribution design storm was used with saturated initial soil conditions. The results for the total catchment are shown in Fig. 6-6. Comparison with Fig. 6-1 shows the new simulated historical peaks are about the same for a 1 yr return period but increase rapidly with return period Only the Huff distribution design storm was investigated for sensitivity for this new design and the results for sub-catchments A and C are shown in Figs. 6-7 and 6-8. For both sub-catchments the effect of antecedent soil moisture can now be seen as well as the higher flows associated with the reduction in surcharging. The sharp break in the saturated design storm curve in Fig. 6-8 is due again to surcharging which occurred for return periods above the 5 yr design.

Even though a saturated soil moisture condition was used for the new design, Figs. 6-6, 6-7 and 6-8 show that the dry antecedent soil produced a result which agrees rather well with the historical data. This indicates that the combination of Huff distribution and saturated soil produced a very conservative design.

6.2 Gray Haven Catchment

The time of concentration for this catchment was estimated as 15 min and the result using Coshocton rainfall data with 15 min design storm duration shown in Fig. 6-9 and for a 30 min duration in Fig. 6-10. The design storm data are shown for the two extreme antecedent soil moisture conditions: dry (AMC=1) and saturated (AMC=4). The initial abstraction values used for all design storms are given in Table 5-1.

In order to more clearly see the effect of the design storm hyetograph, expected values of AMC for each combination of catchment and rainfall data base were computed. This was done by determining the numerical value of AMC on a scale of 1 to 4 at the beginning of each of the simulated historical events. For each event the average of the AMC for all of the sub-catchments with pervious area was determined and then these were averaged for all events to compute the expected value. Table 6-2 shows the results for the Gray Haven and Dade County catchments. The Broward County catchment contained essentially no pervious area so the computation was not made for this catchment. The result for Gray Haven is shown in Fig. 6-11.

TABLE 6-2 Expected Antecedent Soil Moisture

Rainfall Data	Gray Haven	Dade County
Coshocton	2.287	1.951
McCreddie	2.440	1.989
Albuquerque	1.251	1.294

Figures 6-12 and 6-13 show the results for the McCreddie rainfall data, which is somewhat similar in character to the Coshocton rainfall.

Albuquerque rainfall is quite different from the other two rainfall locations. Note in Table 6-2 that the expected antecedent soil moisture is low and, also, the rainfall depth is lower for a given duration and return period for the Albuquerque rainfall record. Figures 6-14 and 6-15 show the results for this rainfall.

6.3 Dade County Catchment

The time of concentration of this catchment was estimated as 30 min. Figure 6-16 shows the result for this duration, while Figs. 6-17 and 6-18 show the results for 15 and 60 min duration design storms respectively. This catchment is characterized by surcharging which limits the outlet flow to approximately 32 cfs. This results in a flattening of frequency curve which eliminates the sensitivity to design hyetograph shape. Figure 6-19 shows the result for the expected AMC for Coshocton rainfall.

The results for McCreddie rainfall are shown in Figs. 6-20 and 6-21 and for Albuquerque rainfall in Figs. 6-22 and 6-23.

6.4 Broward County Catchment

This catchment has essentially no pervious area and therefore the results do not include the effect of AMC. The estimated time of concentration was 15 min and the result for Coshocton rainfall is shown in Fig. 6-24 for 15 min design storms and in Fig. 6-25 for 30 min design storms. Results for 15 min design storms for McCreddie and Albuquerque rainfall are shown in Figs. 6-26 and 6-27 respectively.

6.5 General Discussion of Results

6.5.1 Design Storm Hyetograph Sensitivity

The hyetograph shape and antecedent soil moisture are interrelated with respect to their effect on frequency response. However, some general observations can be made. First, it is clear that the uniform distribution produces the lowest peak flow and that in almost every case these peaks are much lower than the historical for any return period. There are some cases where a combination of saturated AMC and uniform distribution produce results which are close to the historical peaks, but this is unusual and is not a recommended combination.

The delayed triangular design hyetograph produces the highest peaks in most cases, while in a few, the Huff distribution results are slightly higher. The reason for the delayed triangular distribution producing rather consistent high peaks is that the period of maximum rainfall intensity occurs later in the event when the initial abstraction have been satisfied and the infiltration capacity is lower, thereby producing a high peak effective rainfall intensity. However, the delayed distribution is not typical of natural thunderstorm rainfall in general and this is reflected in the high peaks shown in most of the results. In a study by Voorhees[21], expected values for the peak time for a triangular rainfall distribution were formed to be advanced, with a typical peak value at 20-30 percent of the duration.

The Huff distribution is shown to be the most variable in terms of its relationship to the other hyetographs. This is due to its advanced pattern. For relatively short duration design storms the highest event distractions coincide with the advanced peak of the Huff hyetograph. As the duration is increased these high abstractions are satisfied more by the pre-peak intensity rainfall and thus the peak intensity is not effected as much for the longer durations. Therefore, higher effective rainfall intensities (relative to the other distributions) can occur for relatively longer duration Huff distributions. Compare, for example, the relative position of the Huff distribution in Fig. 6-17 for a 15 min design storm to that in Fig. 6-18 for a 60 min duration. For dry AMC the Huff peak is close to the uniform distribution for 1 and 2 year return periods in

Fig. 6-17 (15 min duration), while for the same AMC and a 60 min duration (Fig. 6-18) the Huff peak is above all the other peaks including the delayed triangular distribution.

In order to obtain an overall perspective on hyetograph shape sensitivity the figures showing the results using expected AMC for the Gray Haven and Dade County catchments can be used along with the Broward County catchment figures. A qualitative judgement of the best fit distribution for each combination of rainfall data and catchment is given in Table 6-3.

TABLE 6-3 Best Fit Hyetographs

Rainfall	Gray Haven	Dade County	Broward County
Coshocton	sym. triang.	Huff	Huff
McCreddie	Huff	Huff	Huff
Albuquerque	Huff	sym. triang.	Huff

Based on the results shown, it appears that a reasonable design storm hyetograph distribution for general use would be an advanced type. An advanced triangular shape would possibly produce acceptable results, with the peak time determined from the characteristics of the local rainfall. These conclusions are obviously limited to the three rainfall data sets used in this study and other studies have indicated a delayed pattern may be most appropriate for other locals (see Marsalek[4]).

6.5.2 Antecedent Soil Moisture Sensitivity

This parameter is equally as important as hyetograph shape in terms of frequency response sensitivty for the three catchments with pervious areas. It is clear from observing the various figures that in general the extreme conditions span the historical frequency response and that an intermediate value would be appropriate. For this reason the expected

AMC values were computed. For the Coshocton and McCreddie data the expected values were about 2 or 30 percent of soil saturation, whereas for the Albuquerque rainfall a value of 1.2 or 7 percent of saturation was found. When these values of AMC were used the frequency response generally was reasonable, with the historical data falling within the range of design storm values for the various hyetographs (see Figs. 6-11, 6-13, 6-15, 6-19, 6-21, 6-23, and 6-25.

It can be concluded that the use of some type of expected antecedent soil moisture condition is acceptable for design storm use, and that extremes should be avoided. This is acheived by analyzing local soil moisture conditions for the basin to be designed. Obviously, the effect of soil moisture decreases as the imperviousness of the basin increases. The limiting case is portrayed by the Broward County catchment which is almost completely impervious and thus completely insensitive to antecedent soil moisture conditions.

6.5.3 Design Storm Duration Sensitivity

The use of the time of concentration as a criterion for choosing design storm duration is common. The reasoning is that this gives an opportunity for all sub-catchments to contribute to flow and that longer durations would result in lower peaks because of the nature of the general depth-duration relationship.

This criterion was investigated by varying the duration for the Coshocton rainfall only. For the Gray Haven catchment with an estimated time of concentration of 15 min, a 30 min design storm resulted in lower peaks as seen in Fig. 6-10. For the Dade County catchment with an estimated 30 min time of concentration, the 15 min design storm result (Fig. 6-17) was very close to the 30 min result (Fig. 6-16) for most hyetographs. However, a 60 min duration (Fig. 6-18) produced substantially lower peaks and is clearly not appropriate. For the Broward County catchment with a 15 min estimated time of concentration (Fig. 6-24), a 30 min duration produced lower results, but they still spanned the historical data.

These results indicate that the use of a duration near the estimated time of concentration is appropriate. Some variation from this, perhaps ± 25 percent may not produce significant change in the frequency response.

6.5.4 Initial Abstraction Sensitivity

Initial abstraction is not a parameter of primary interest since it is established by calibration. Its importance can vary depending on how it is treated in the model. In the ILLUDAS simulation model used in this study, initial abstractions are satisfied before any rainfall is available for runoff production. This treatment is not realistic, since it is unreasonable to expect such a process to occur in nature. Initial abstractions include interception and depression storage, both of which are satisfied gradually rather than entirely at the beginning of an event. This treatment is a recognized weakness in the model. Improvement is a research project in itself.

A change in initial abstractions will have a decreasing effect on runoff peak as the return period of the design storm increases, i.e. as the percentage of total rainfall which becomes runoff increases. Thus the one and two year events will be more sensitive than the 10 and 25 year events.

In this study the initial abstractions were established for each catchment during the calibration procedure and these values were held constant for all design storms.

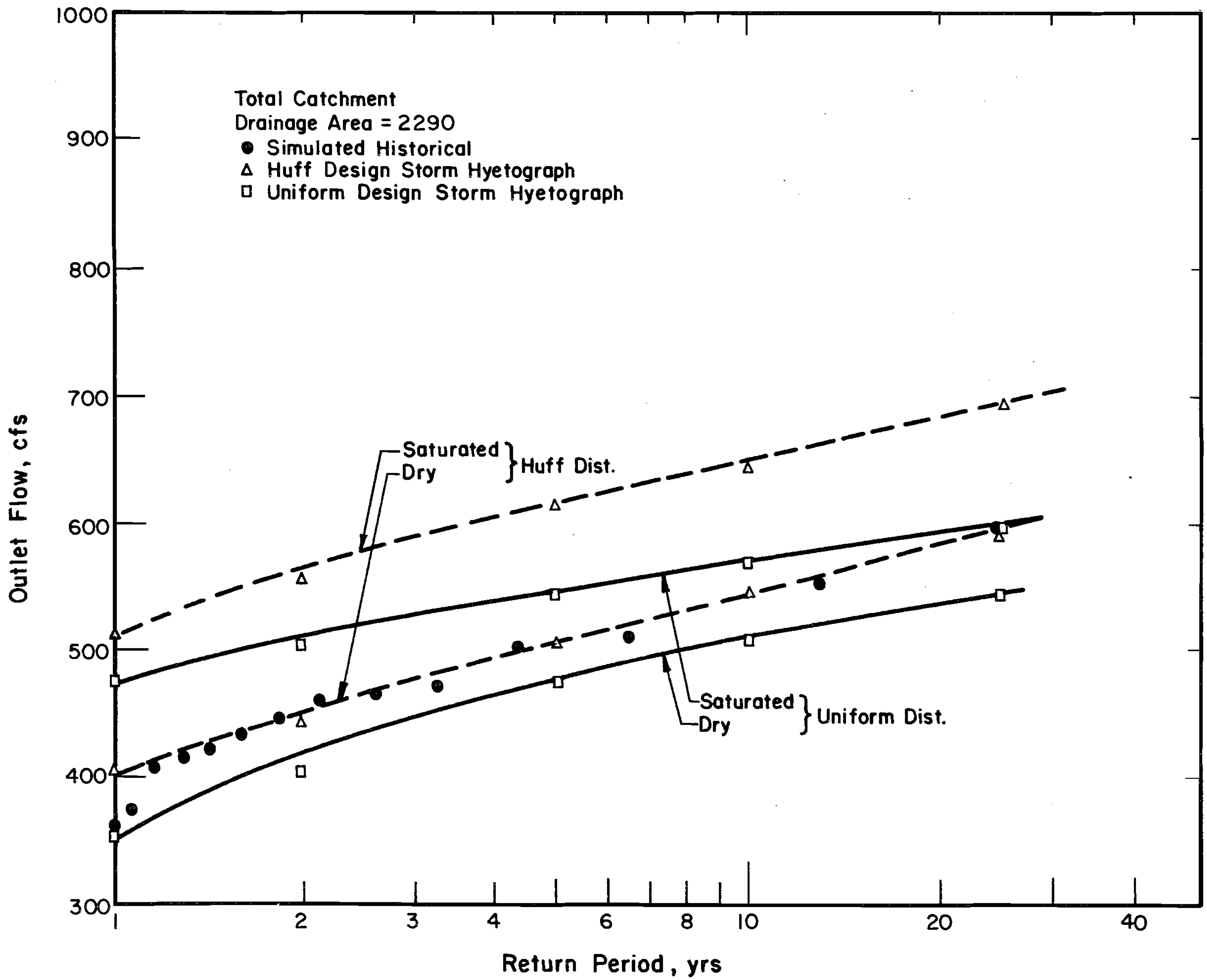

Fig. 6-1 Boneyard Creek Frequency Response - Total Area

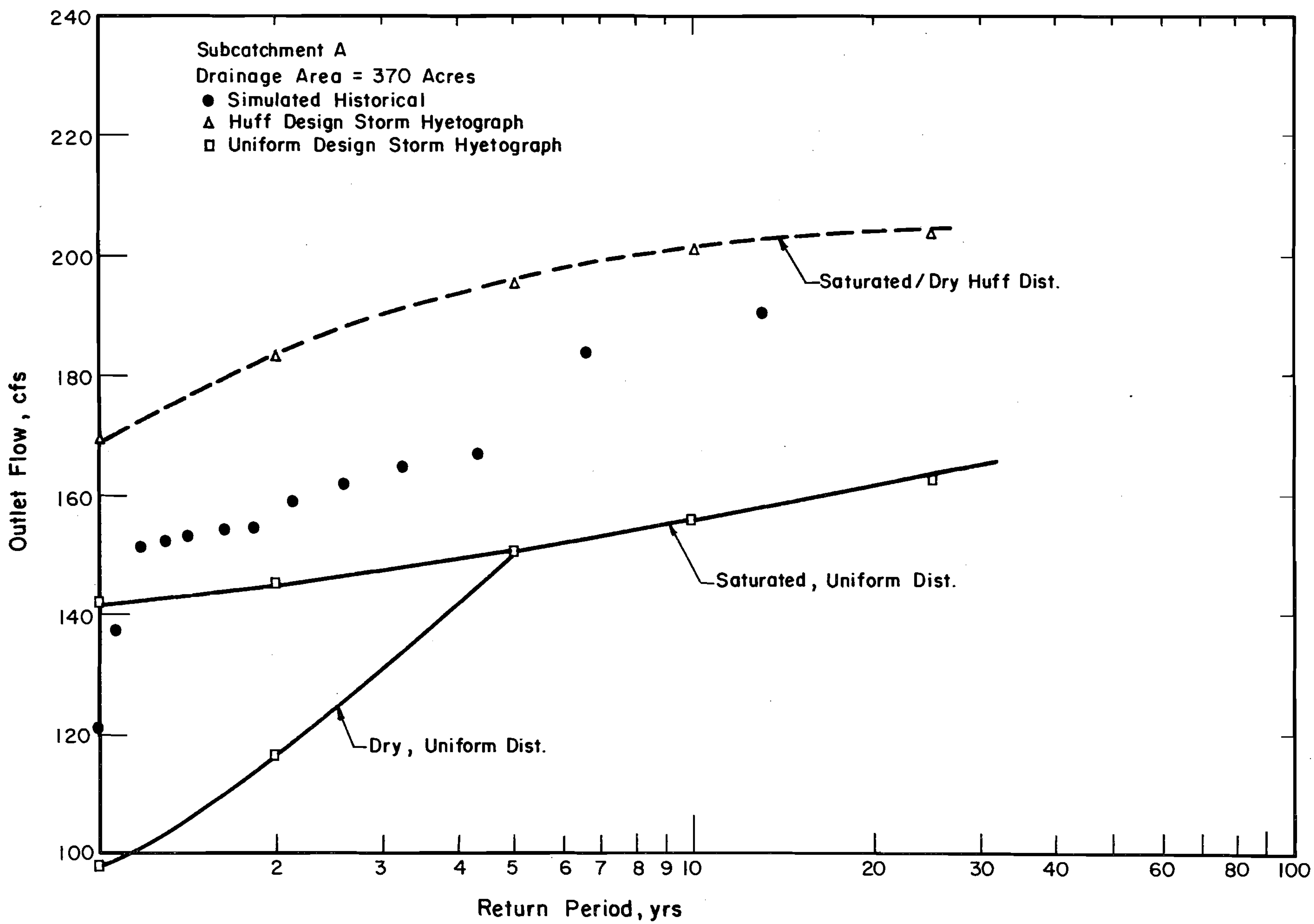

Fig. 6-2 Boneyard Creek Frequency Response - Subcatchment A

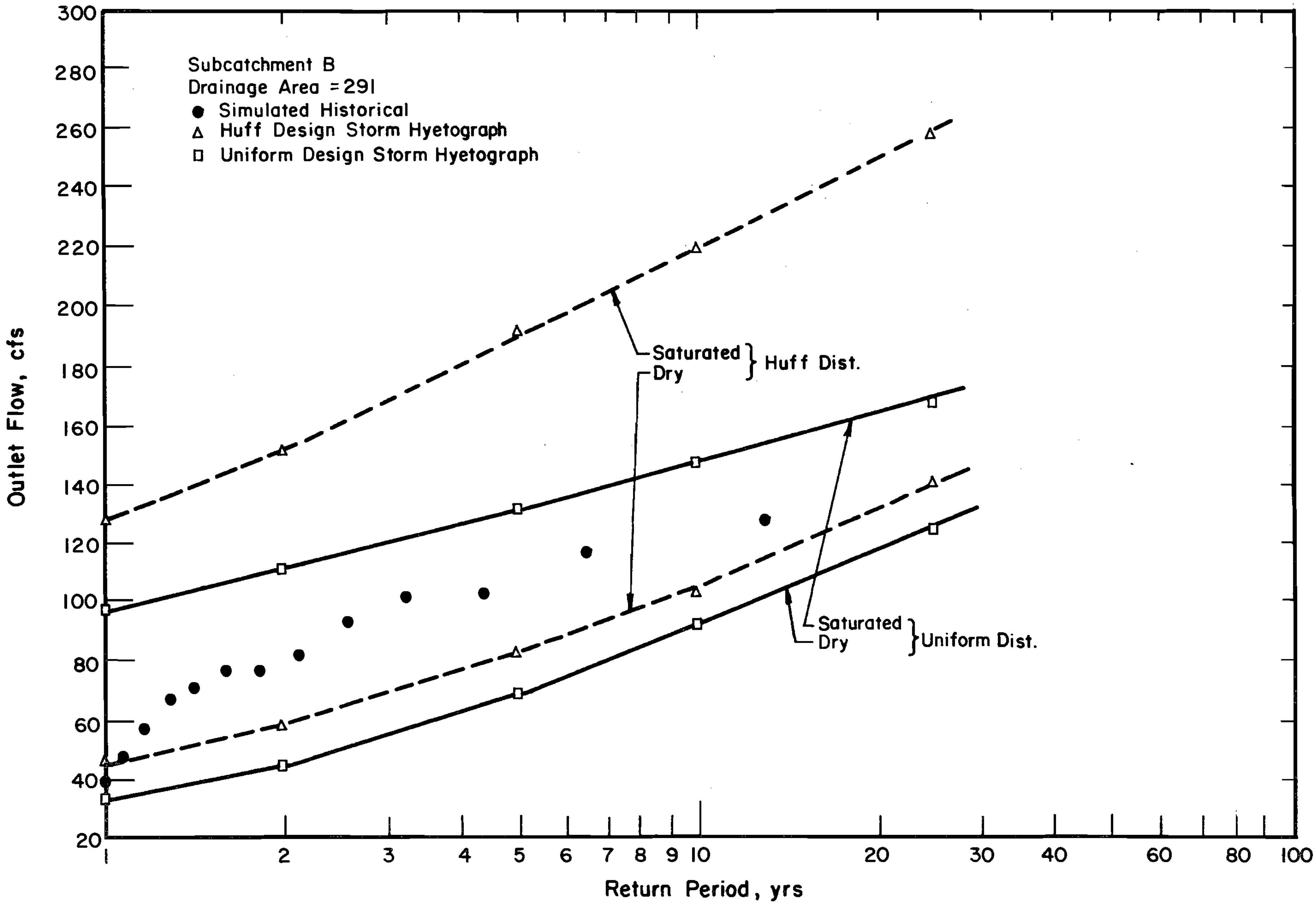

Fig. 6-3 Boneyard Creek Frequency Response - Subcatchment B

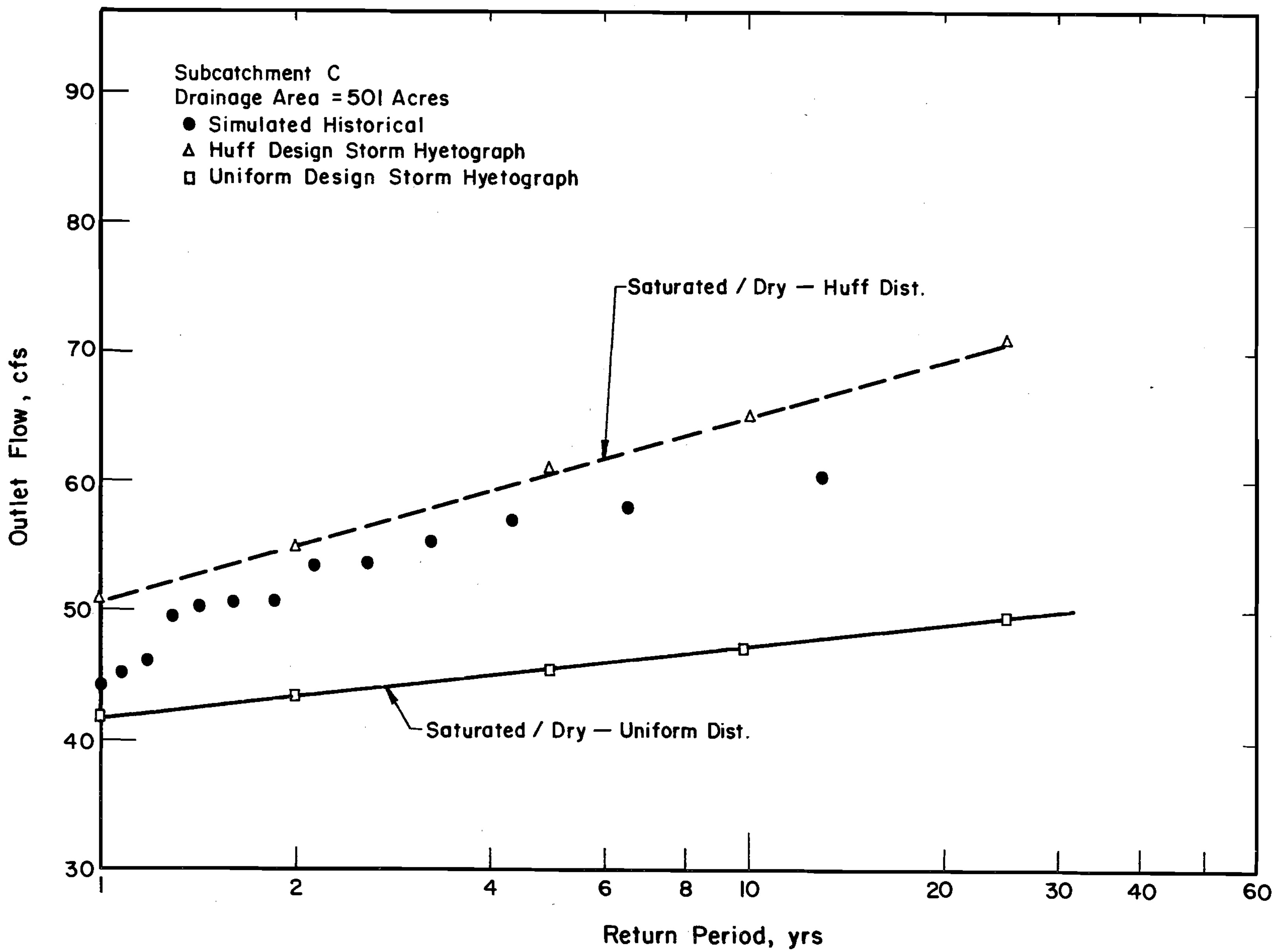

Fig. 6-4 Boneyard Creek Frequency Response - Subcatchment C

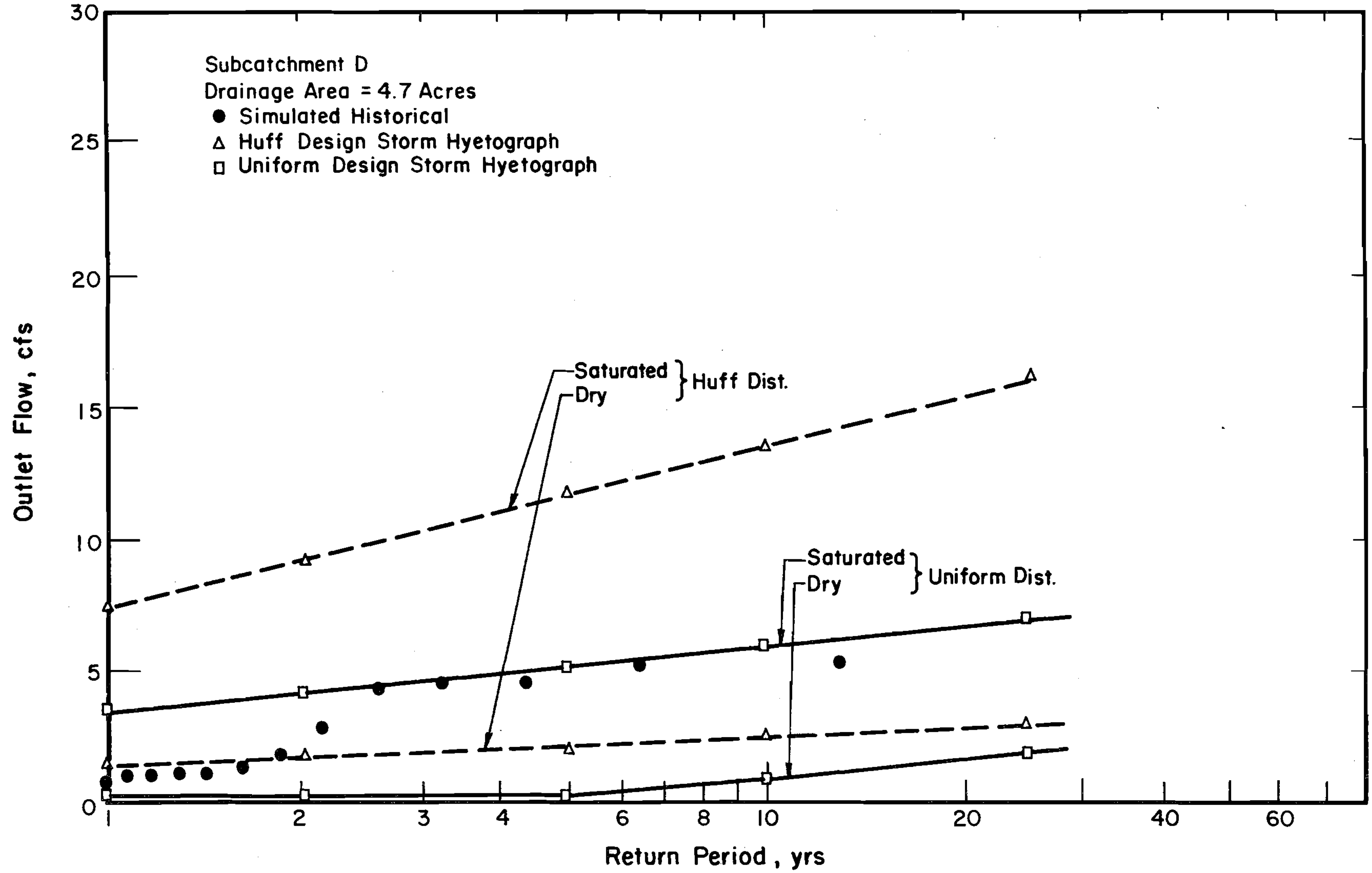

Fig. 6-5 Boneyard Creek Frequency Response - Subcatchment D

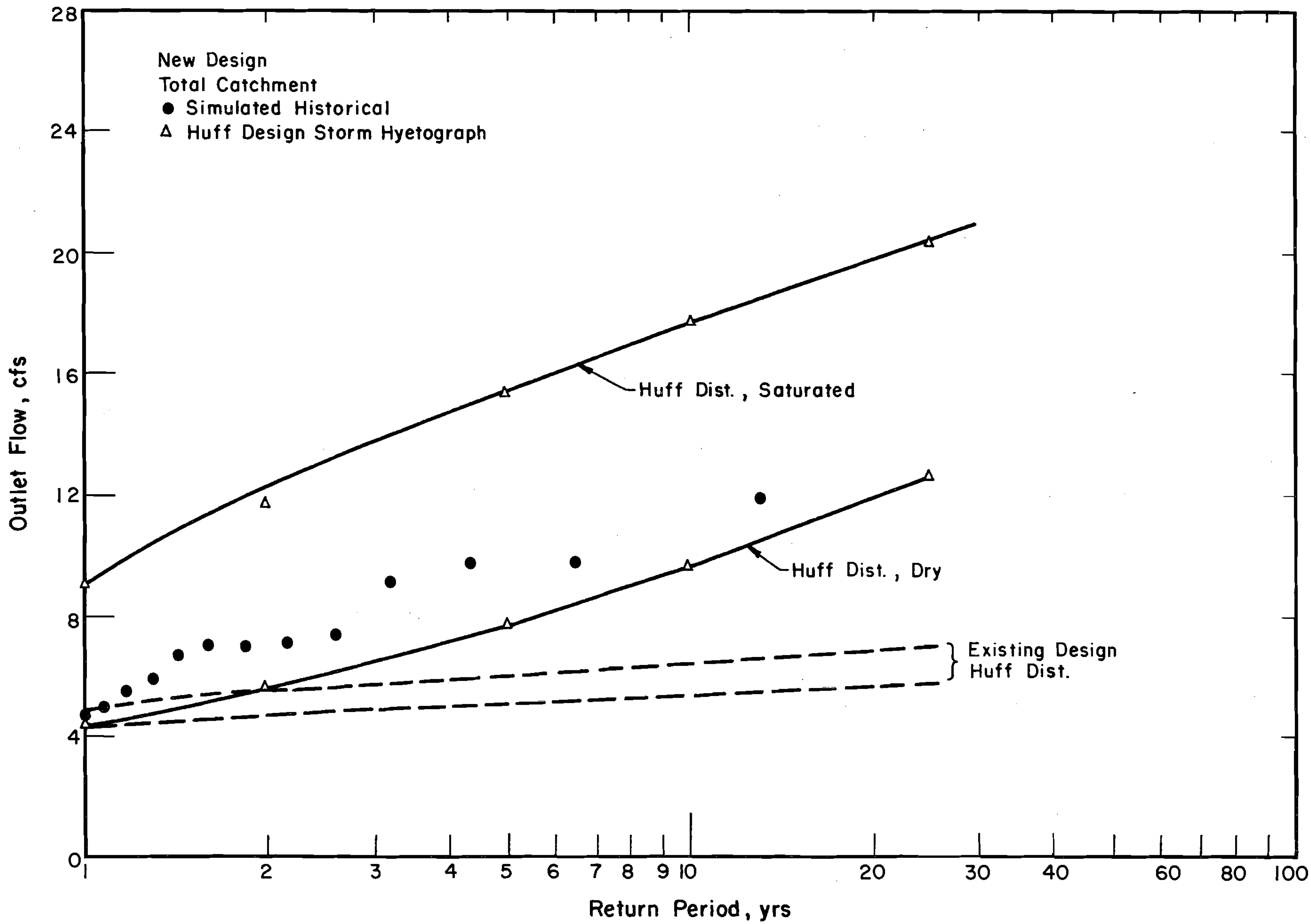

Fig. 6-6 Boneyard Creek Frequency Response - New Design - Total Area

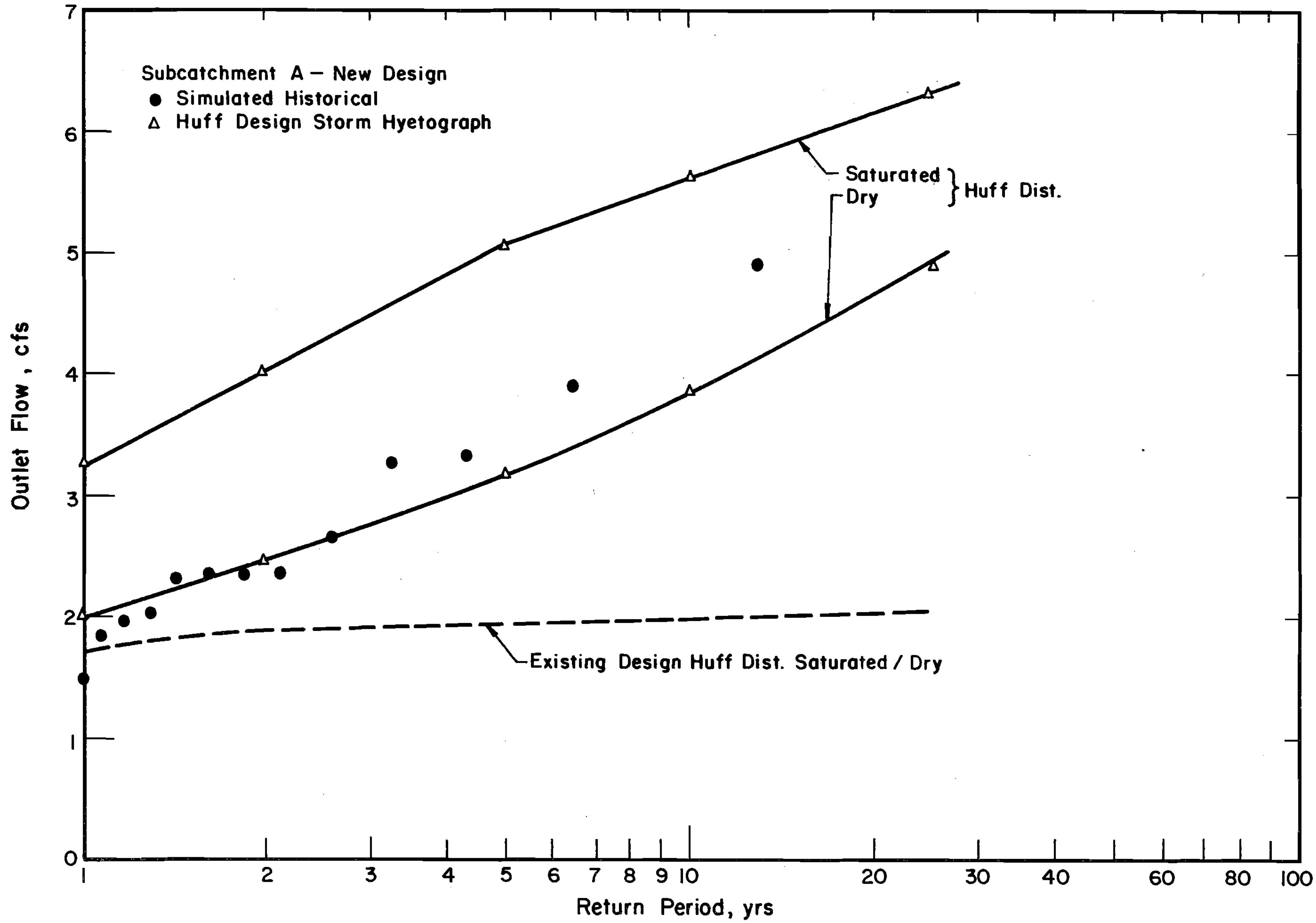

Fig. 6-7 Boneyard Creek Frequency Response - Subcatchment A

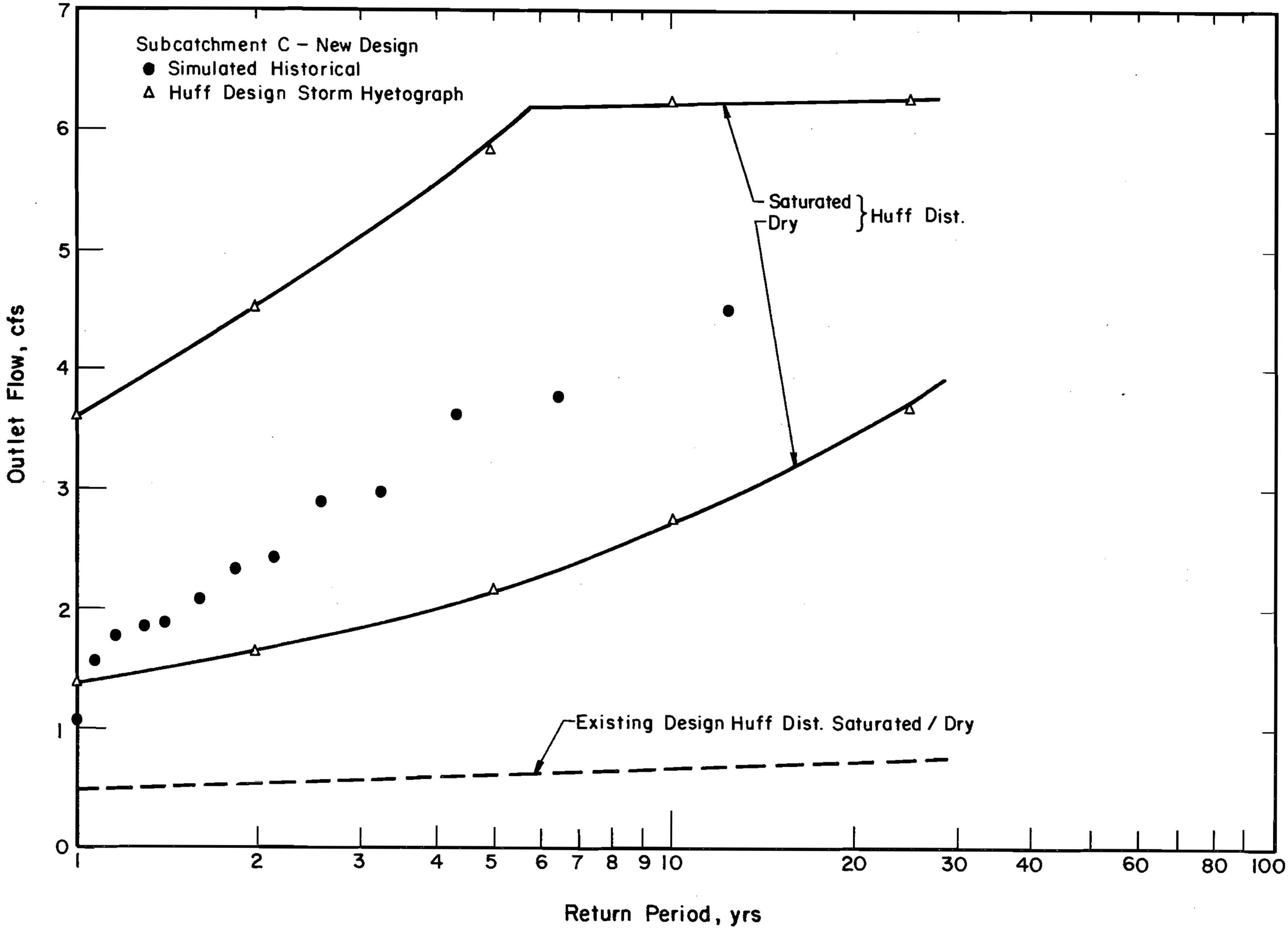

Fig. 6-8 Boneyard Creek Frequency Response - Subcatchment C

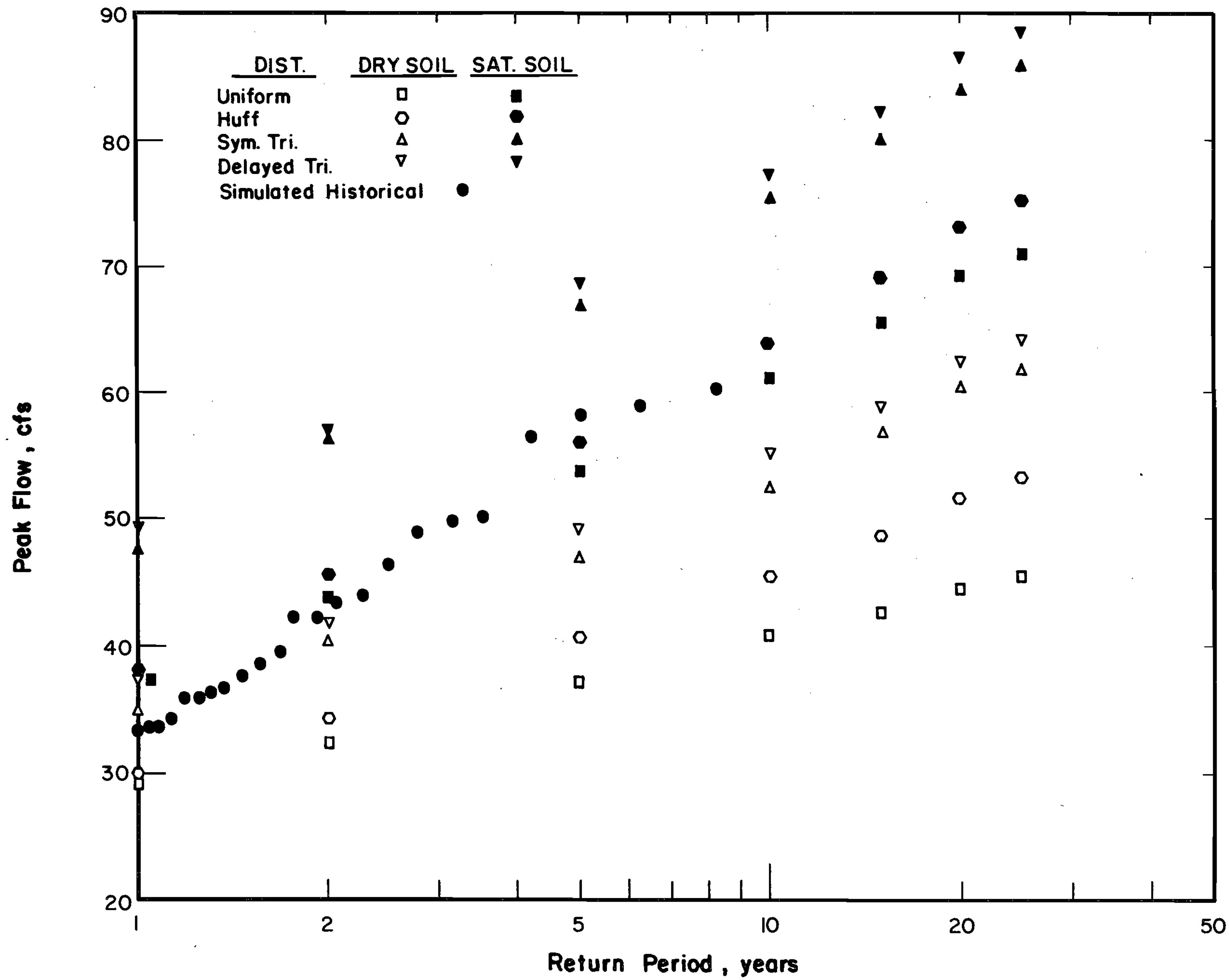

Fig. 6-9 Gray Haven Frequency Response - Coshocton Rainfall - 15 Minute Design Storms

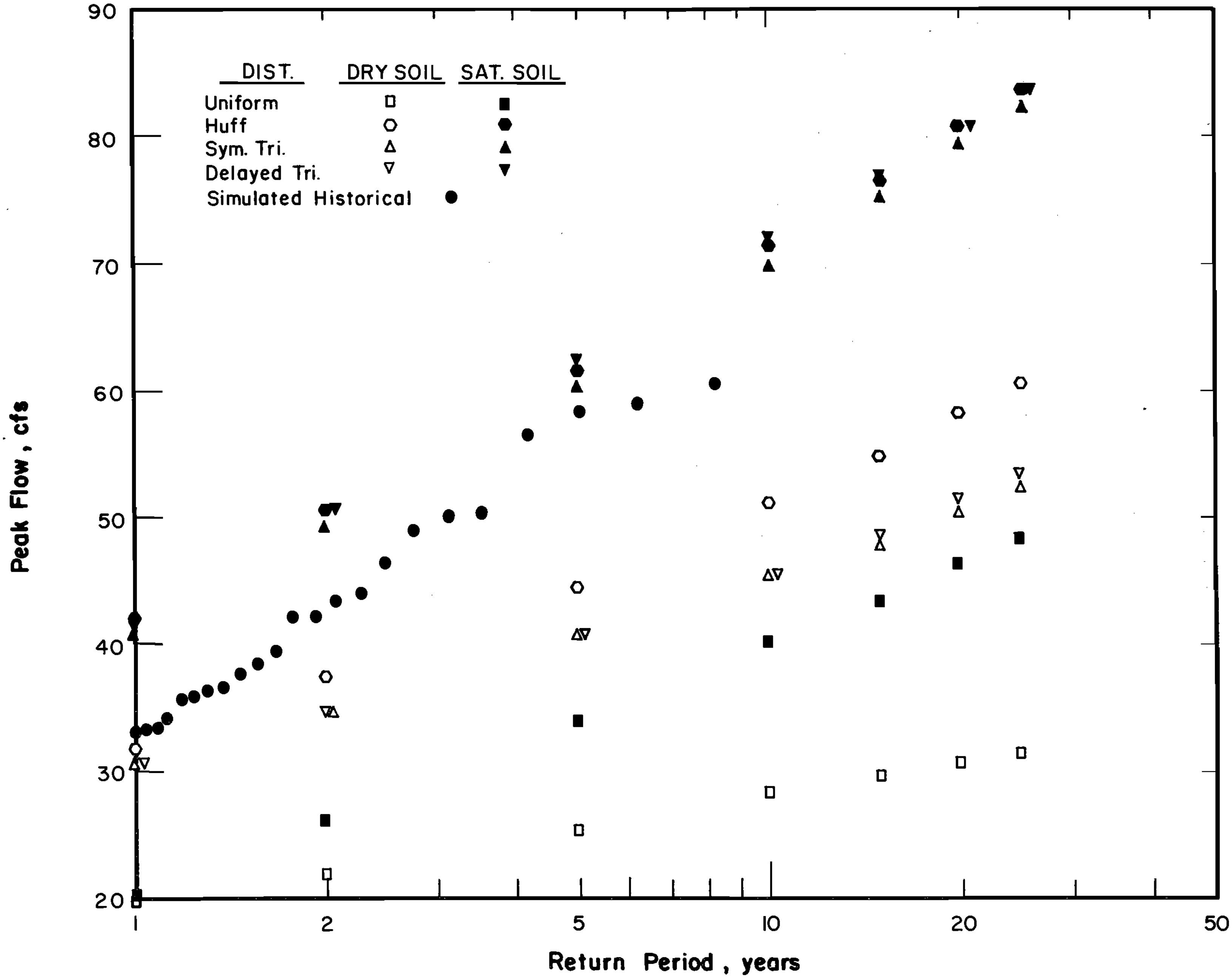

Fig. 6-10 Gray Haven Frequency Response - Coshocton Rainfall - 30 Minute Design Storms

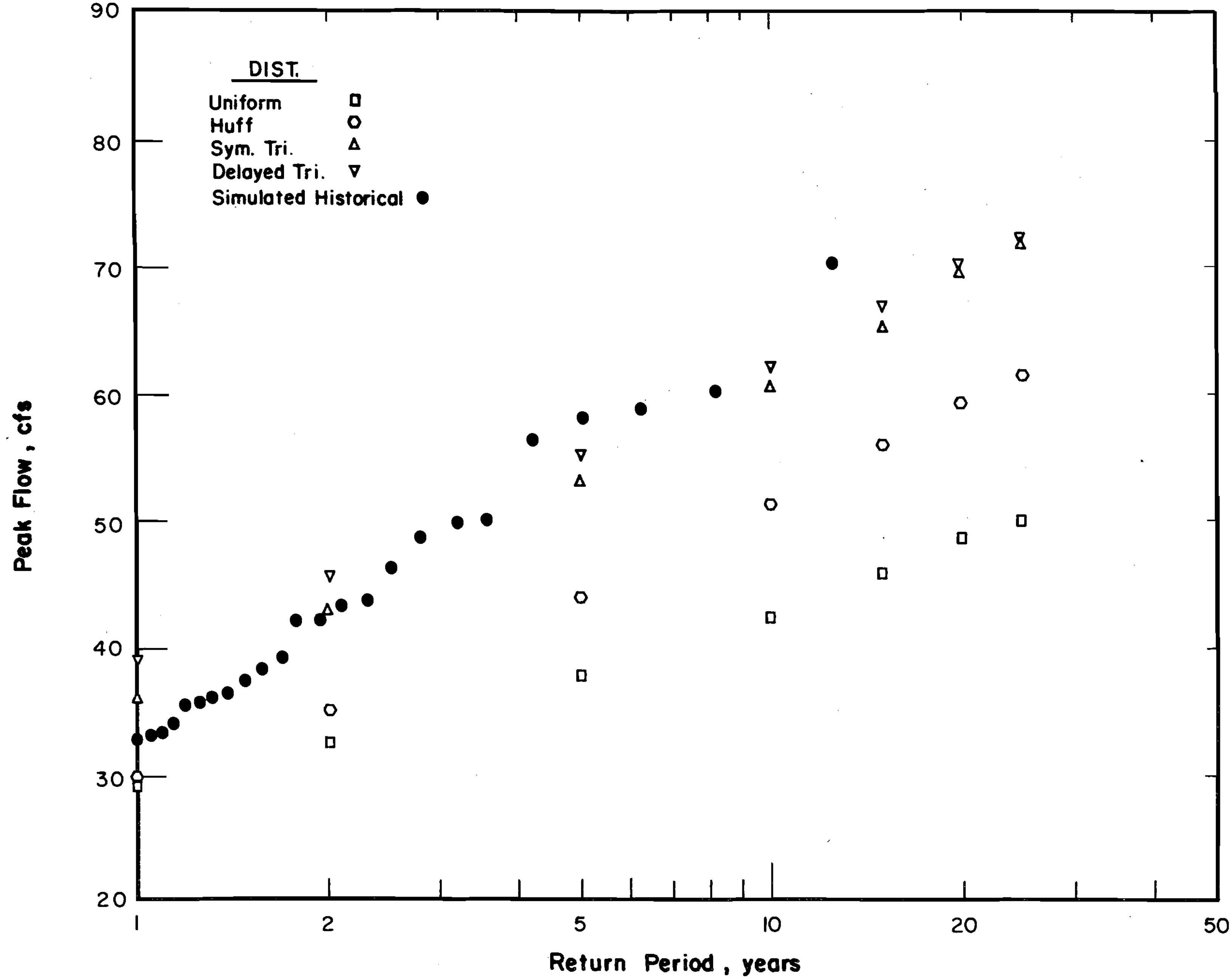

Fig. 6-11 Gray Haven Frequency Response - Coshocton Rainfall - 15 Minute Design Storms - Expected AMC

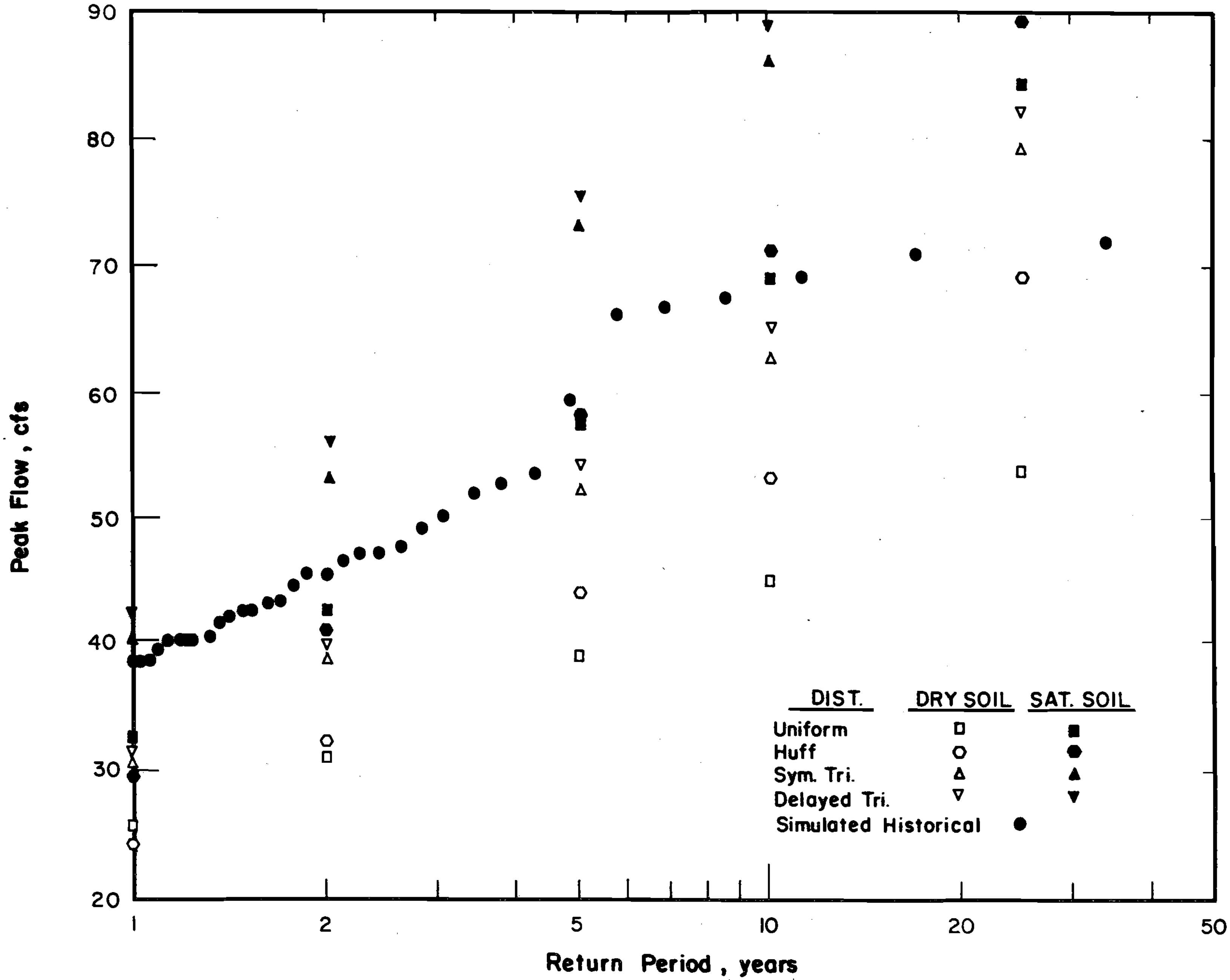

Fig. 6-12 Gray Haven Frequency Response - McCreddie Rainfall - 15 Minute Design Storms

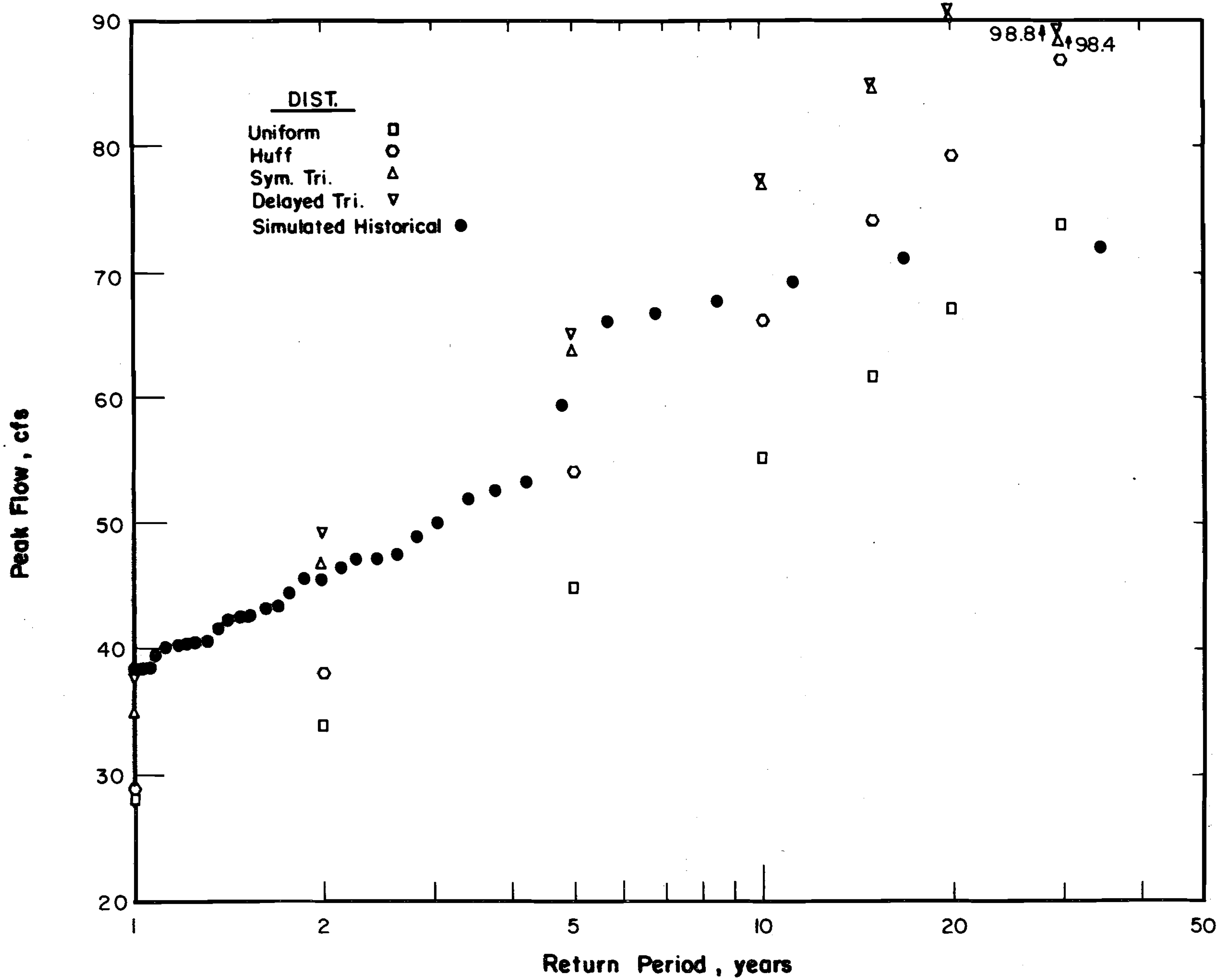

Fig. 6-13 Gray Haven Frequency Response - McCreddie Rainfall - 15 Minute Design Storms - Expected AMC

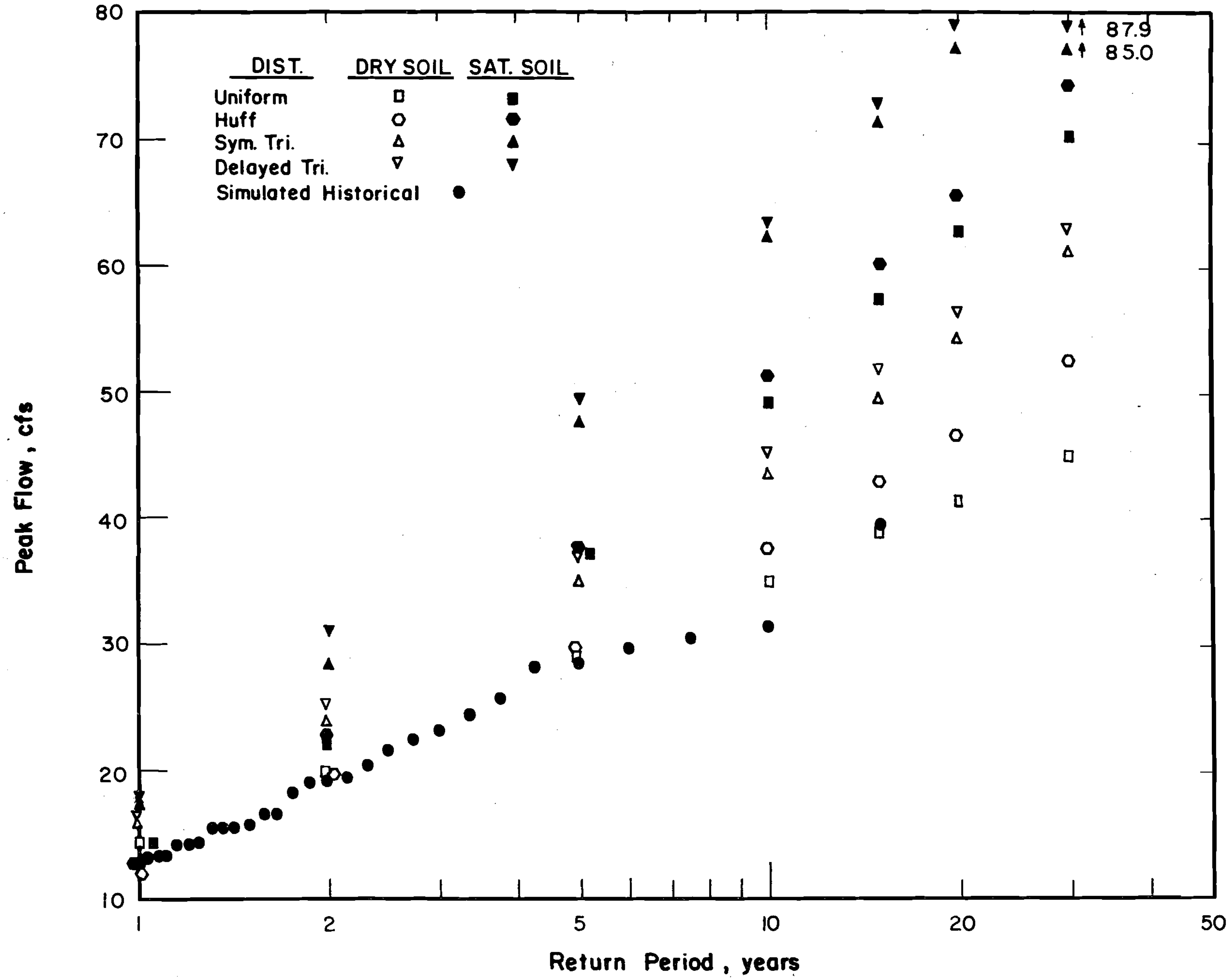

Fig. 6-14 Gray Haven Frequency Response - Albuquerque Rainfall - 15 Minute Design Storms

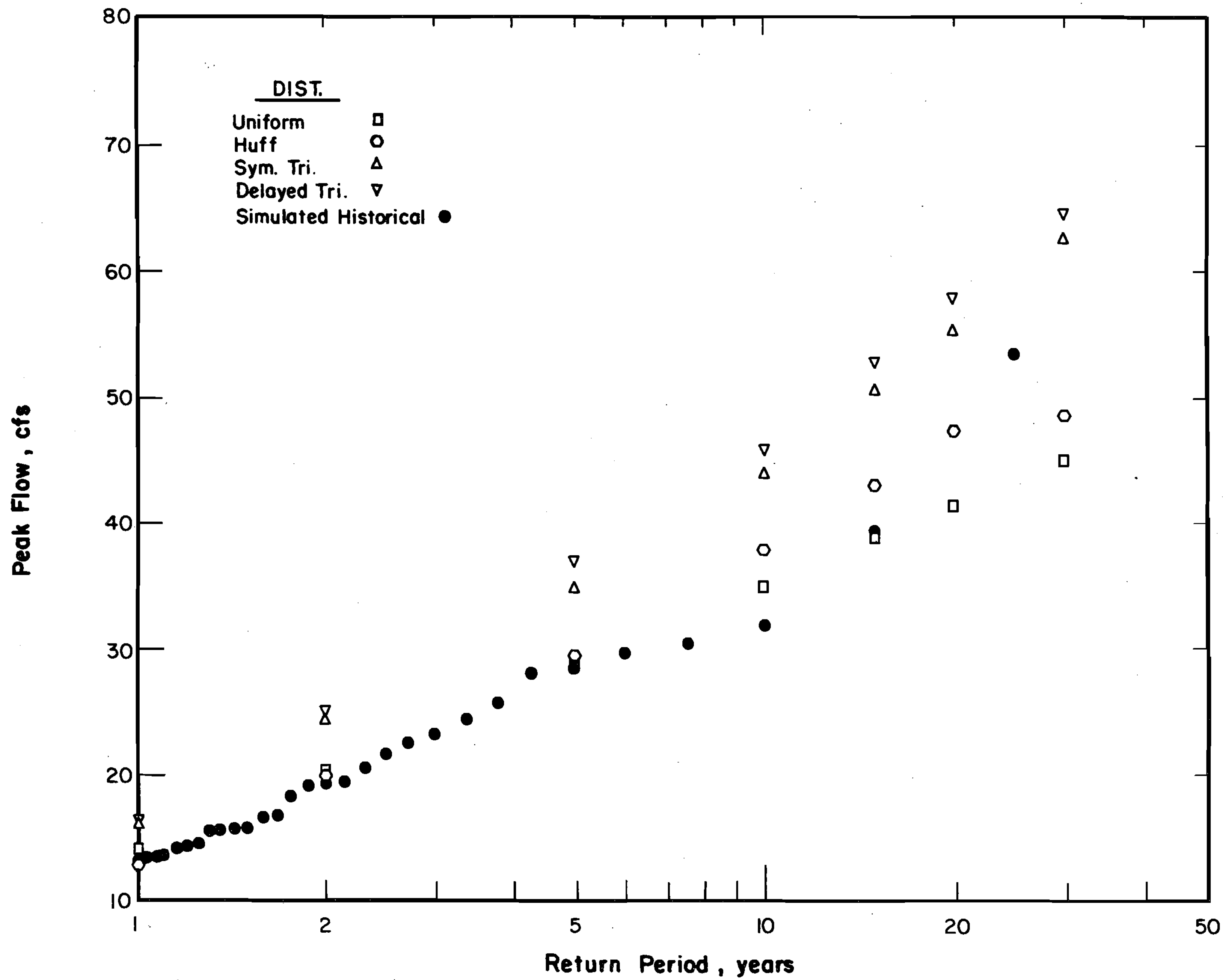

Fig. 6-15 Gray Haven Frequency Response - Albuquerque Rainfall - 15 Minute Design Storms - Expected AMC

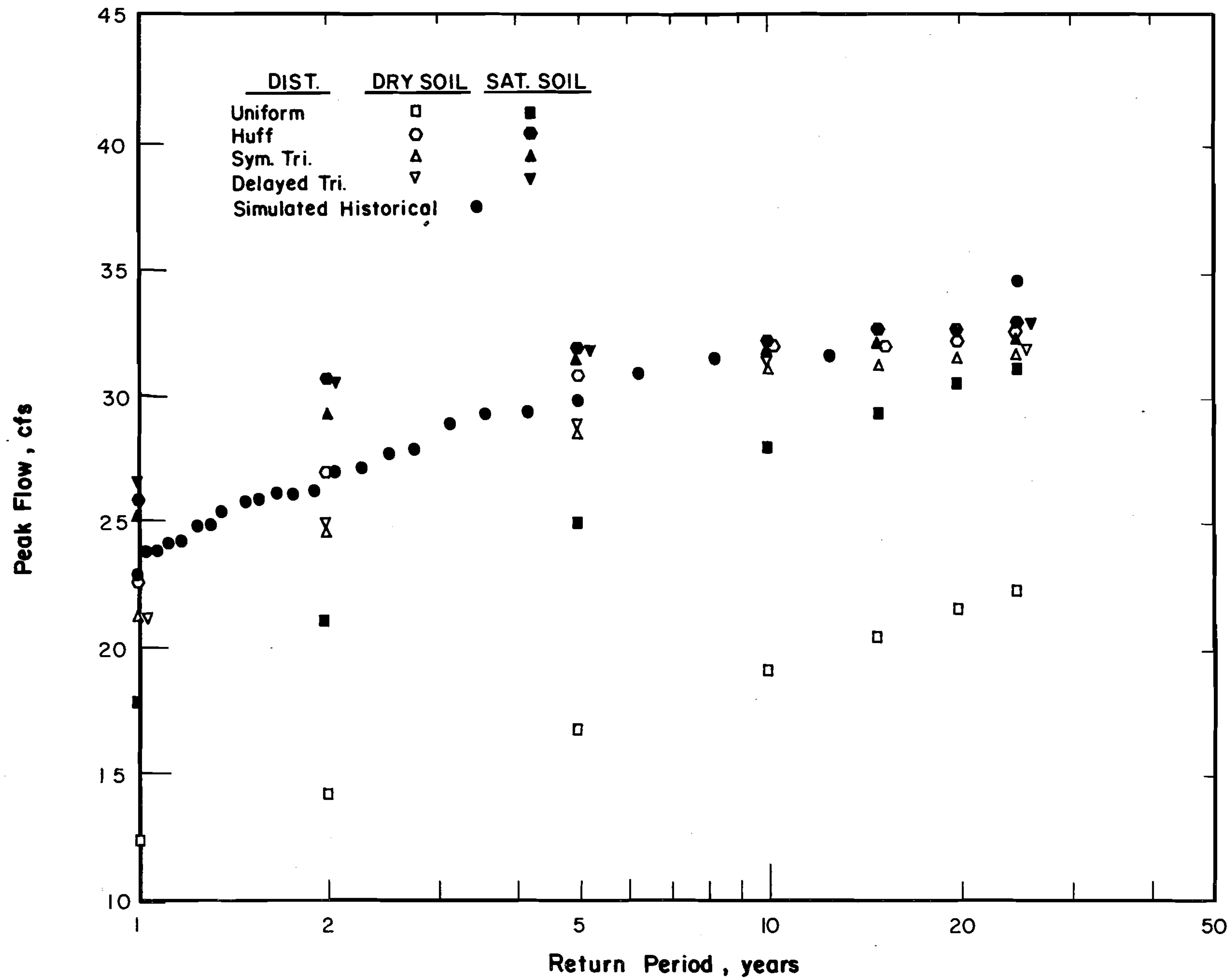

Fig. 6-16 Dade County Frequency Response - Coshocton Rainfall - 30 Minute Design Storms

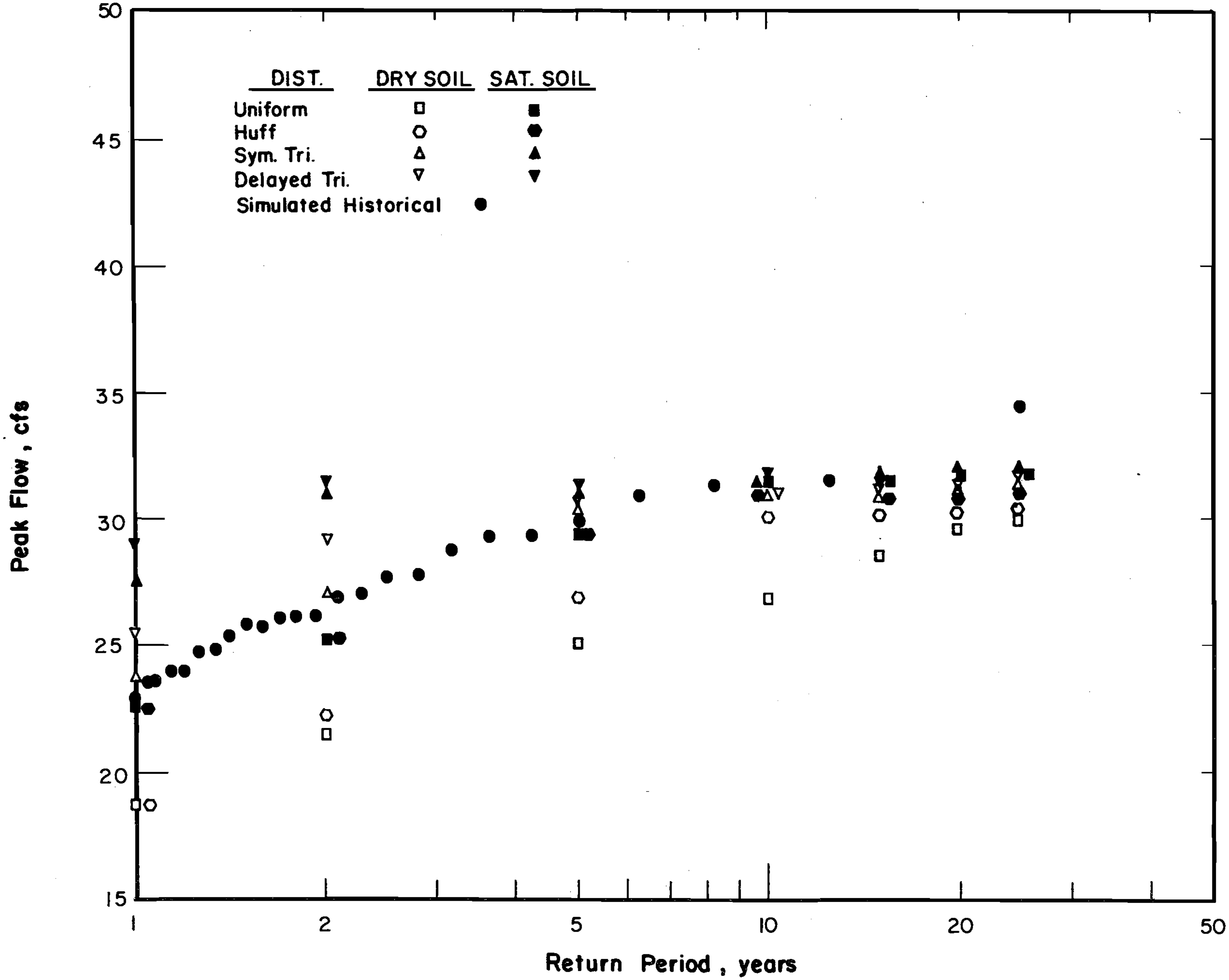

Fig. 6-17 Dade County Frequency Response - Coshocton Rainfall - 15 Minute Design Storms

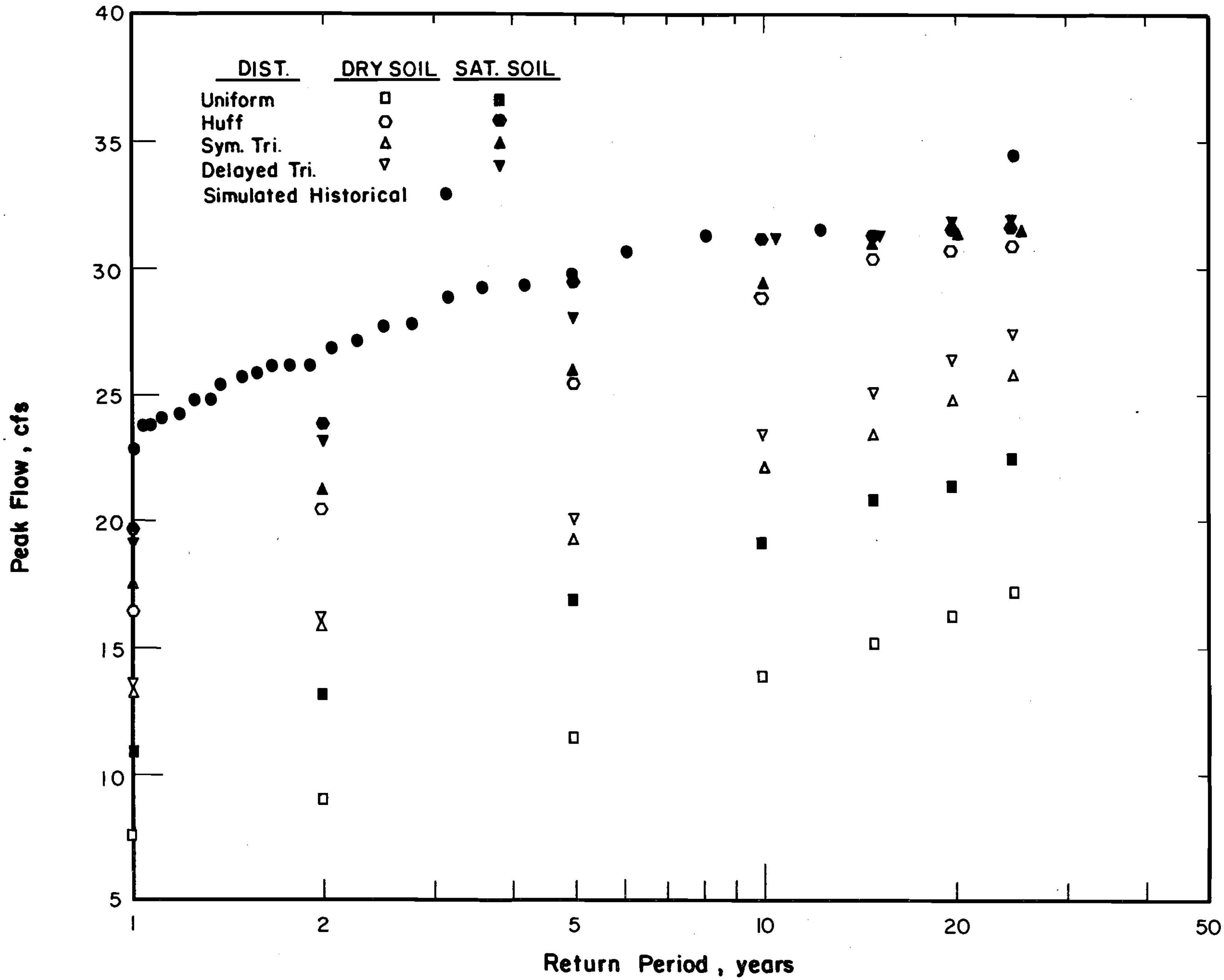

Fig. 6-18 Dade County Frequency Response - Coshocton Rainfall - 60 Minute Design Storms

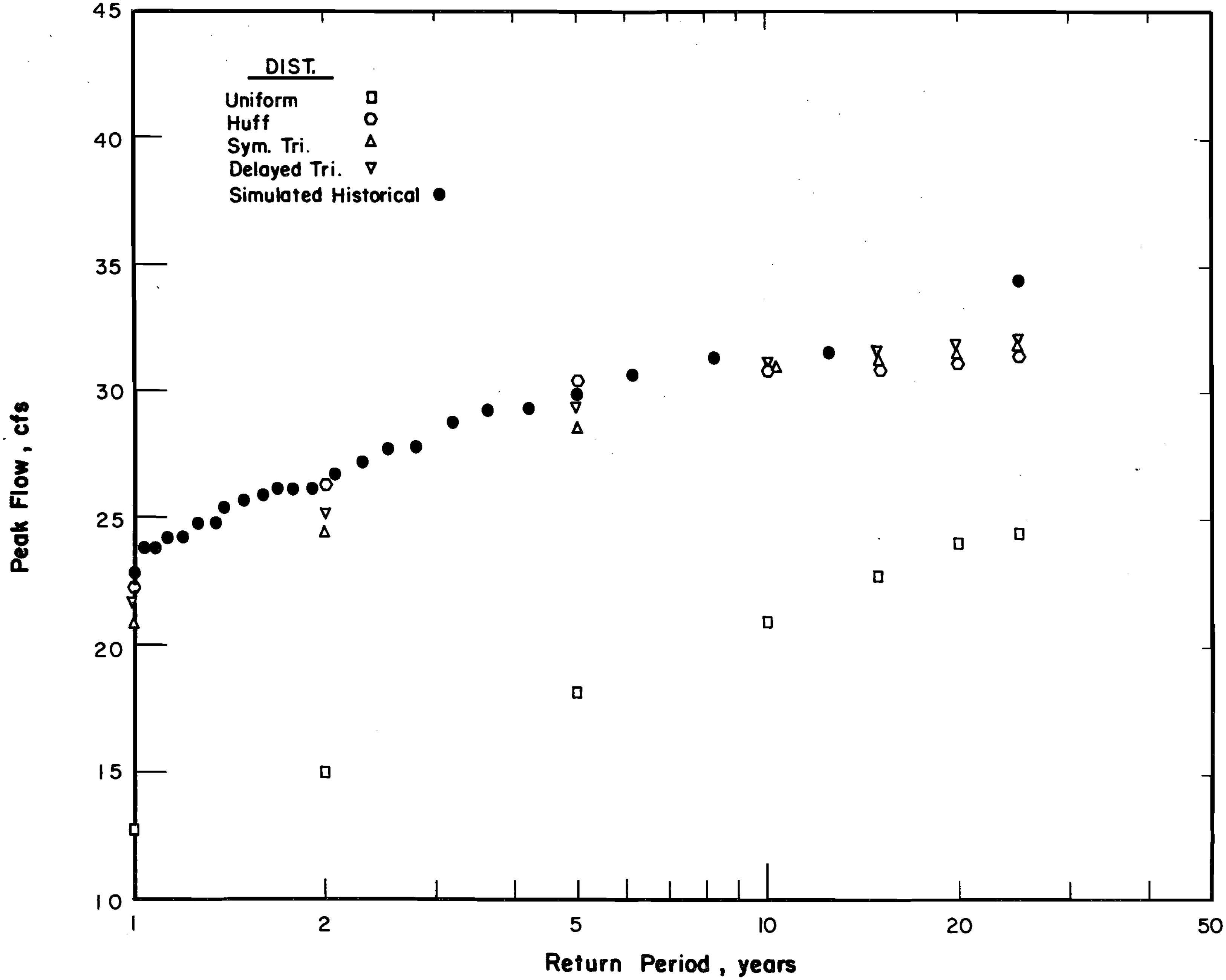

Fig. 6-19 Dade County Frequency Response - Coshocton Rainfall - 30 Minute Design Storms - Expected AMC

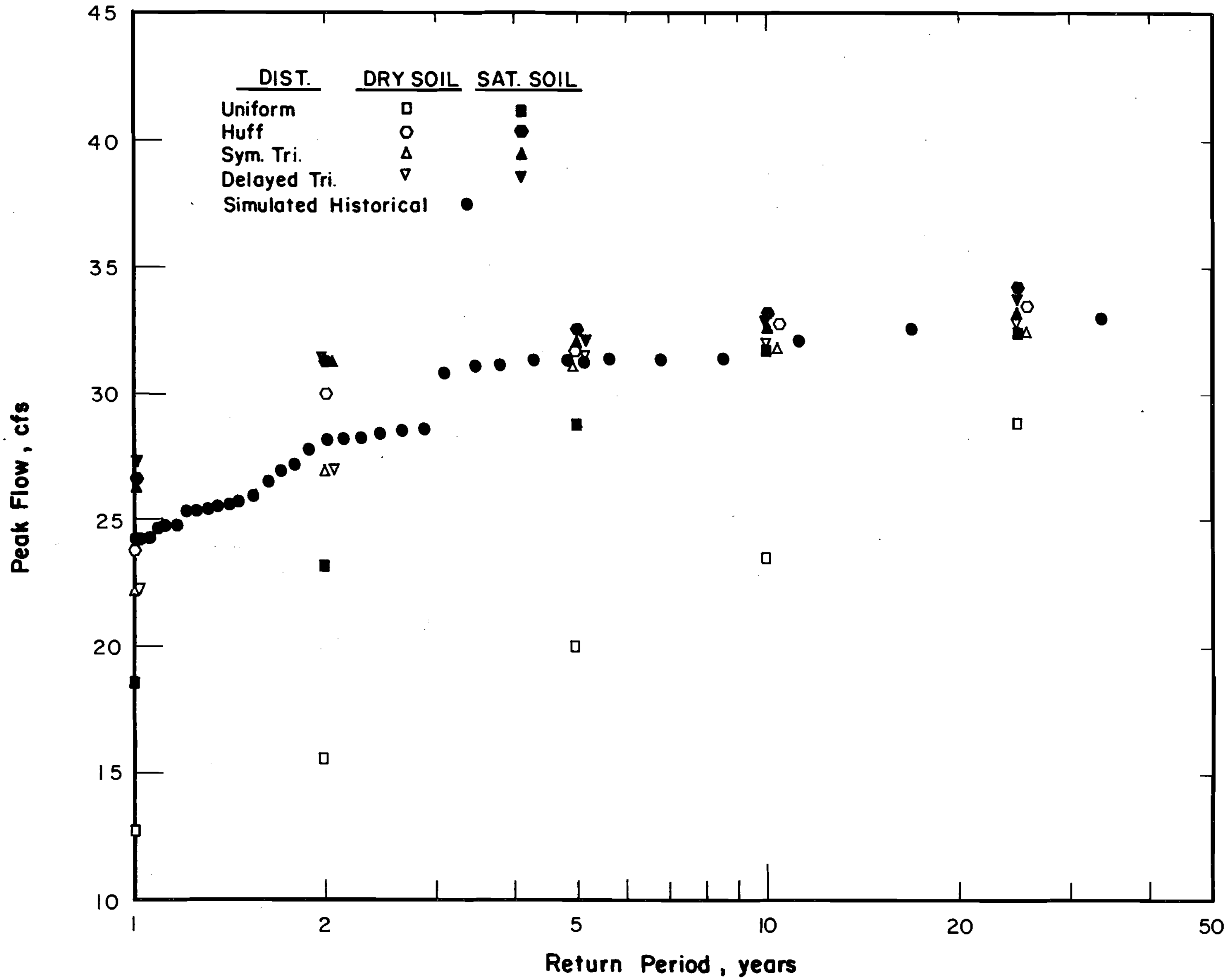

Fig. 6-20 Dade County Frequency Response - McCreddie Rainfall - 30 Minute Design Storms

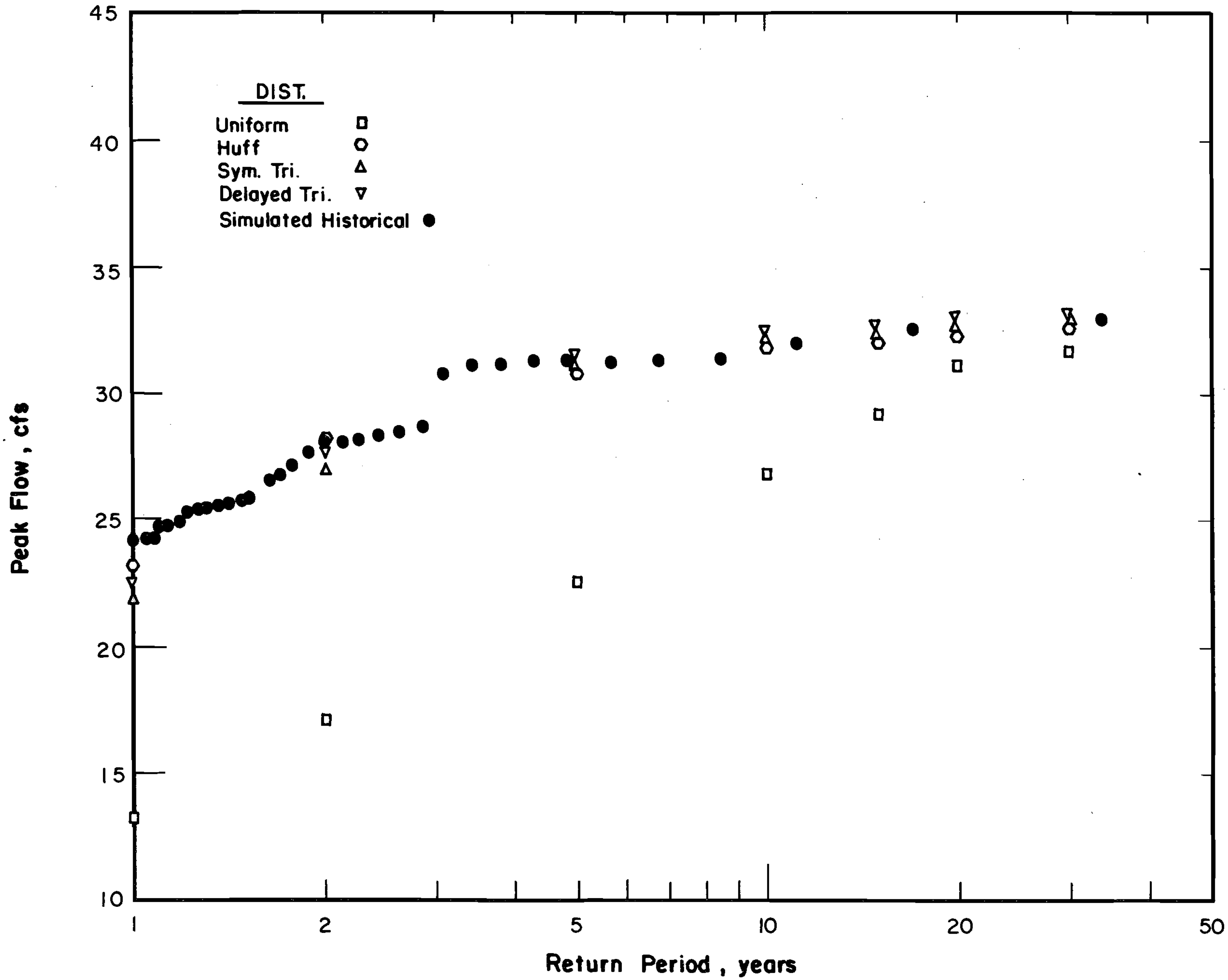

Fig. 6-21 Dade County Frequency Response - McCreddie Rainfall - 30 Minute Design Storms - Expected AMC

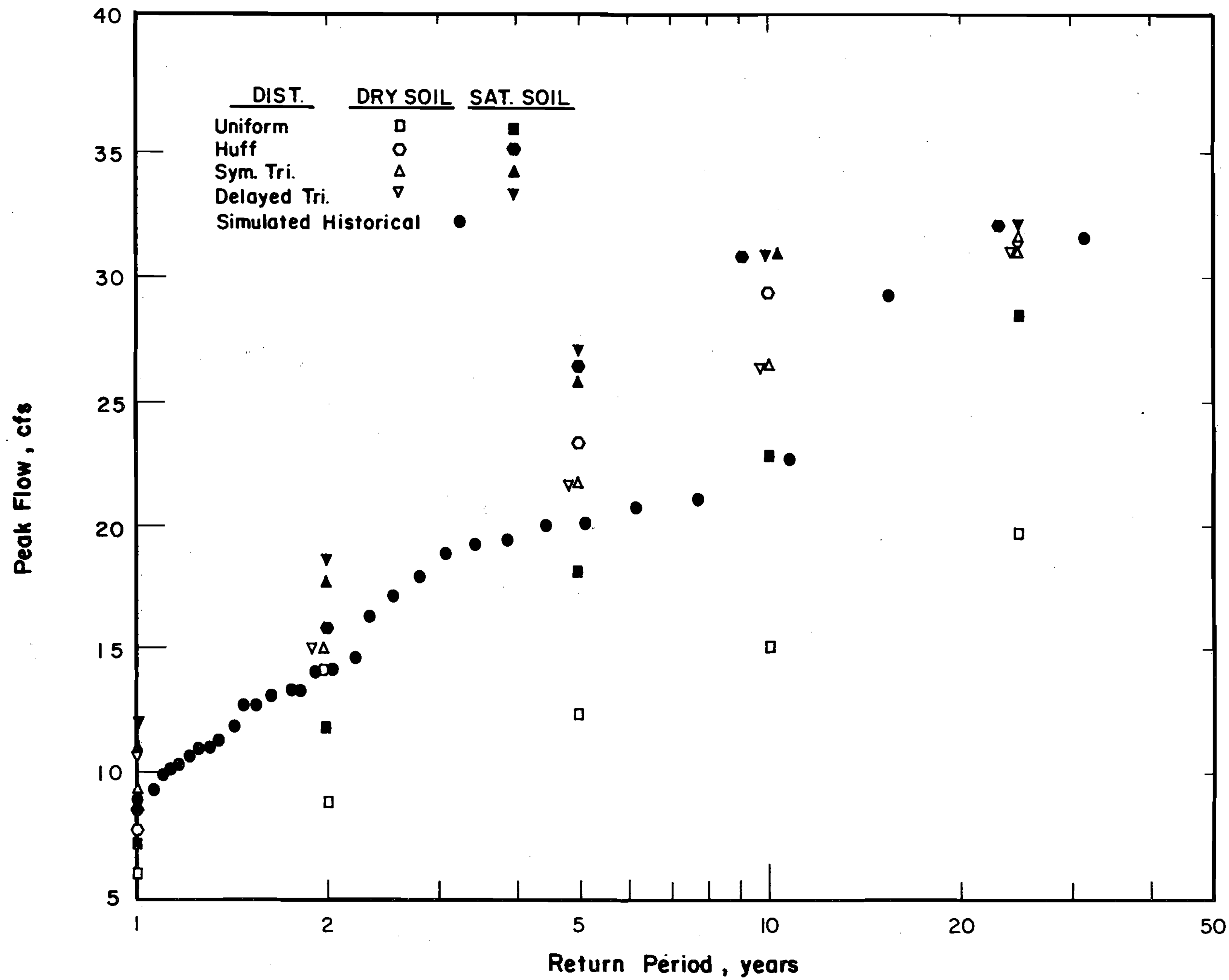

Fig. 6-22 Dade County Frequency Response - Albuquerque Rainfall - 30 Minute Design Storms

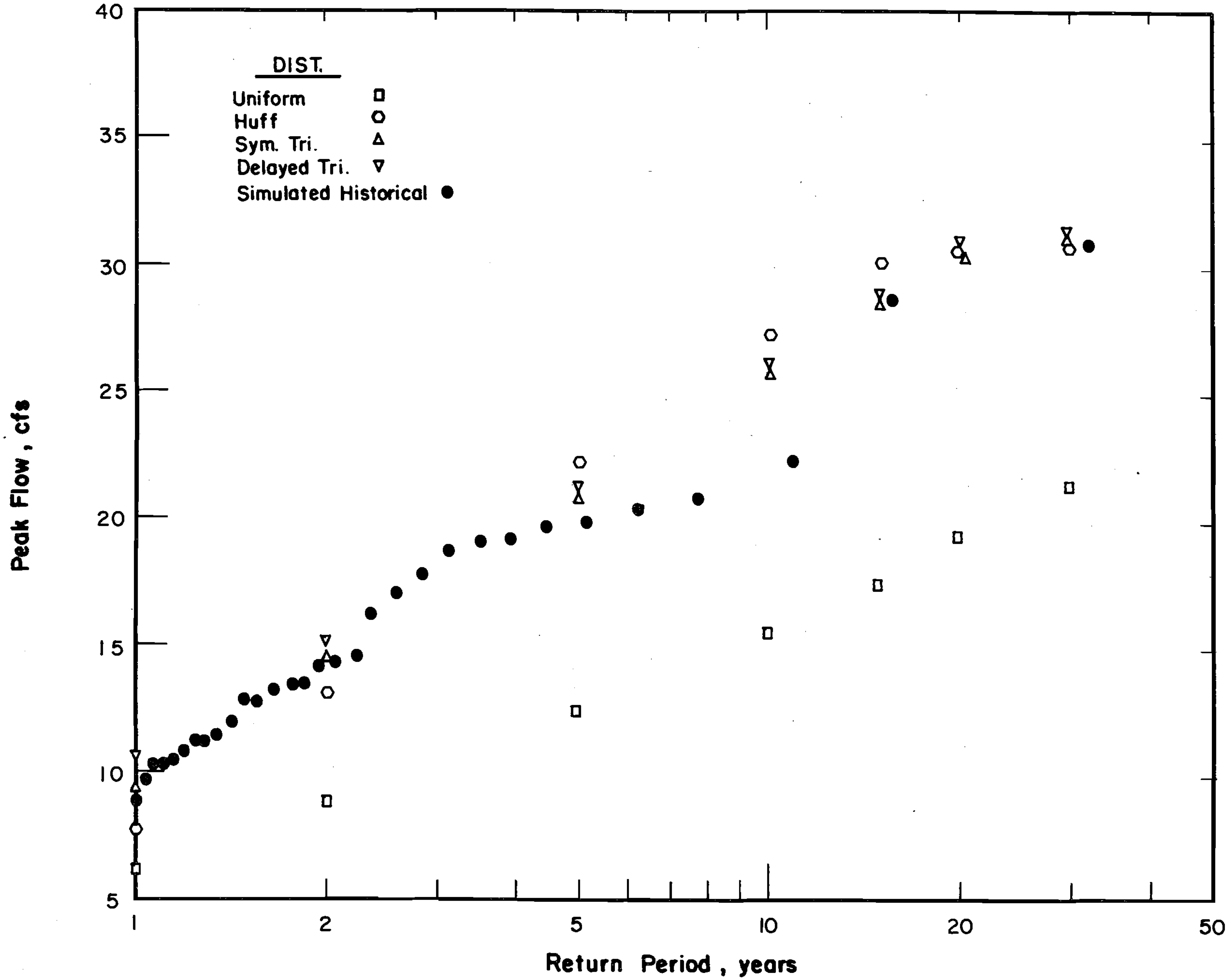

Fig. 23 Dade County Frequency Response - Albuquerque Rainfall - 30 Minute Design Storms - Expected AMC

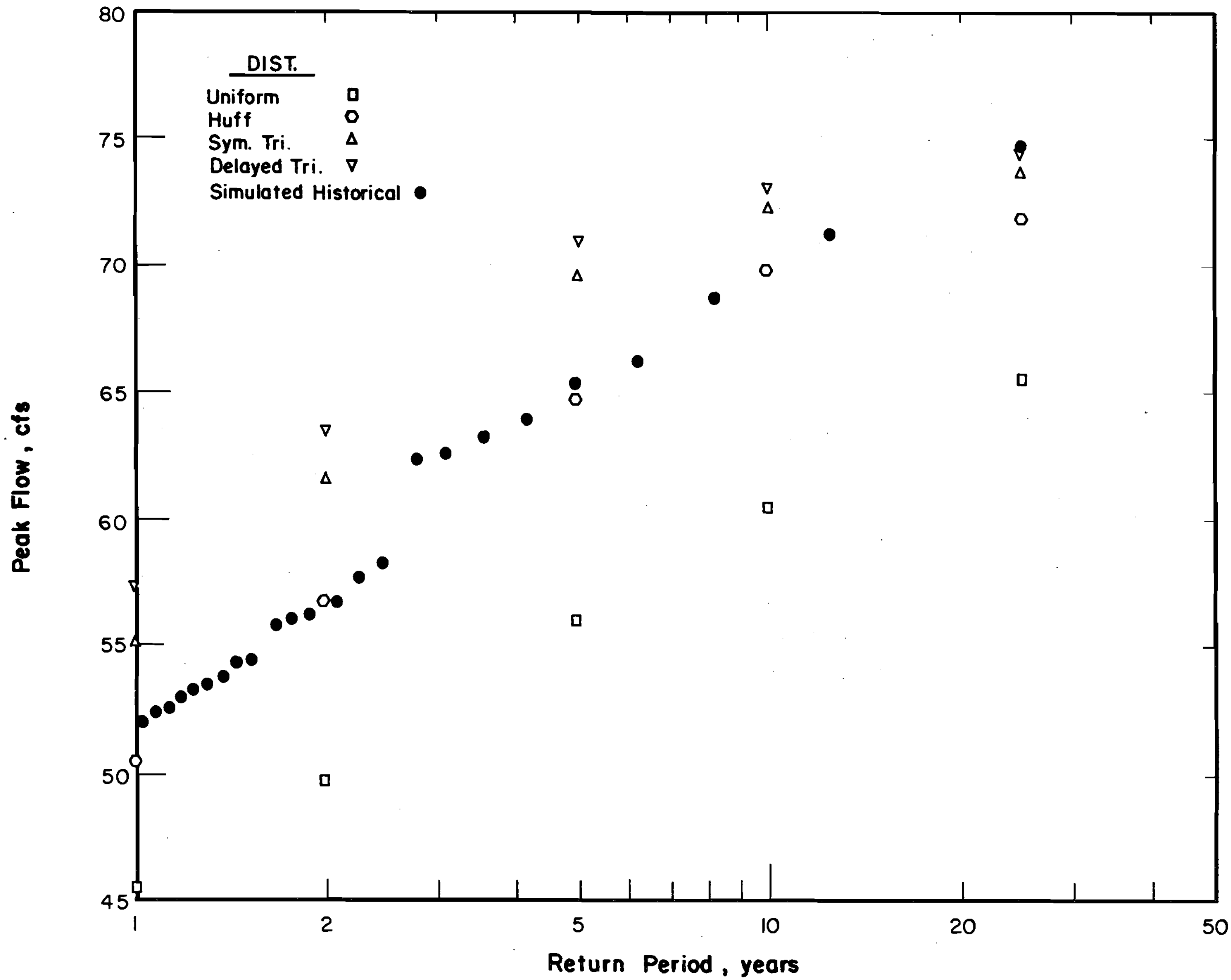

Fig. 6-24 Broward County Frequency Response - Coshocton Rainfall -
15 Minute Design Storms

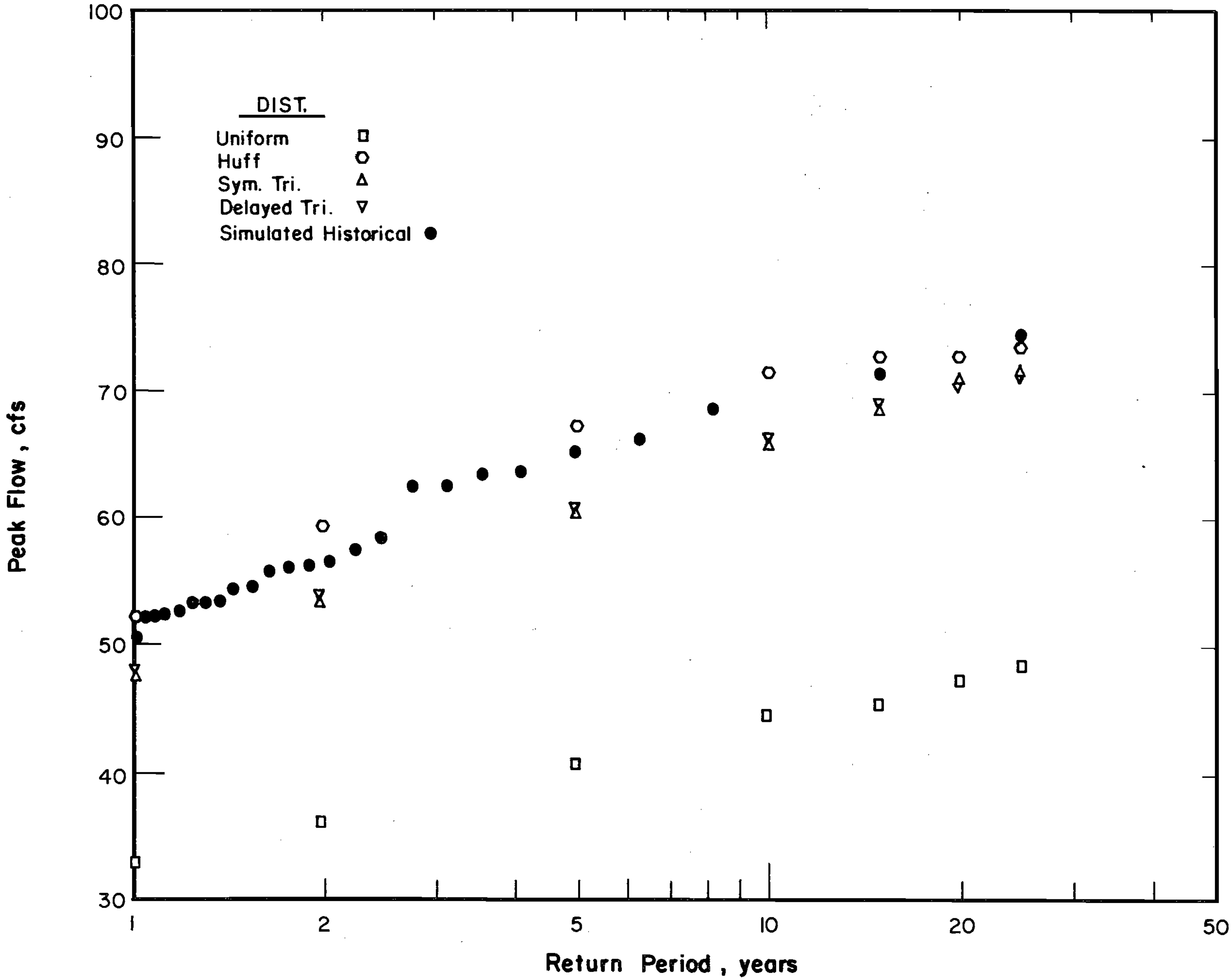

Fig. 6-25 Broward County Frequency Response - Coshocton Rainfall - 30 Minute Design Storms

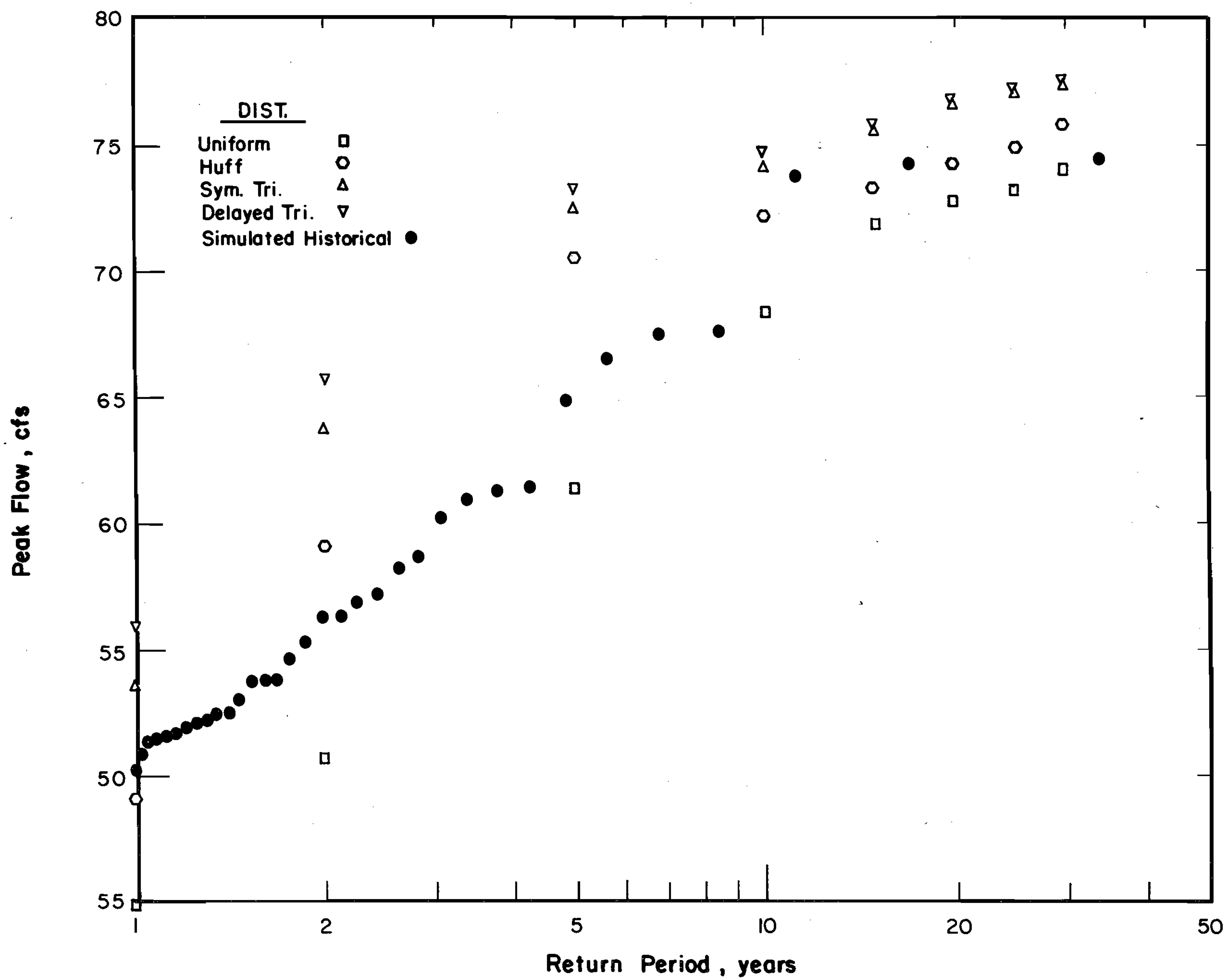

Fig. 6-26 Broward County Frequency Response - McCreddie Rainfall - 15 Minute Design Storms

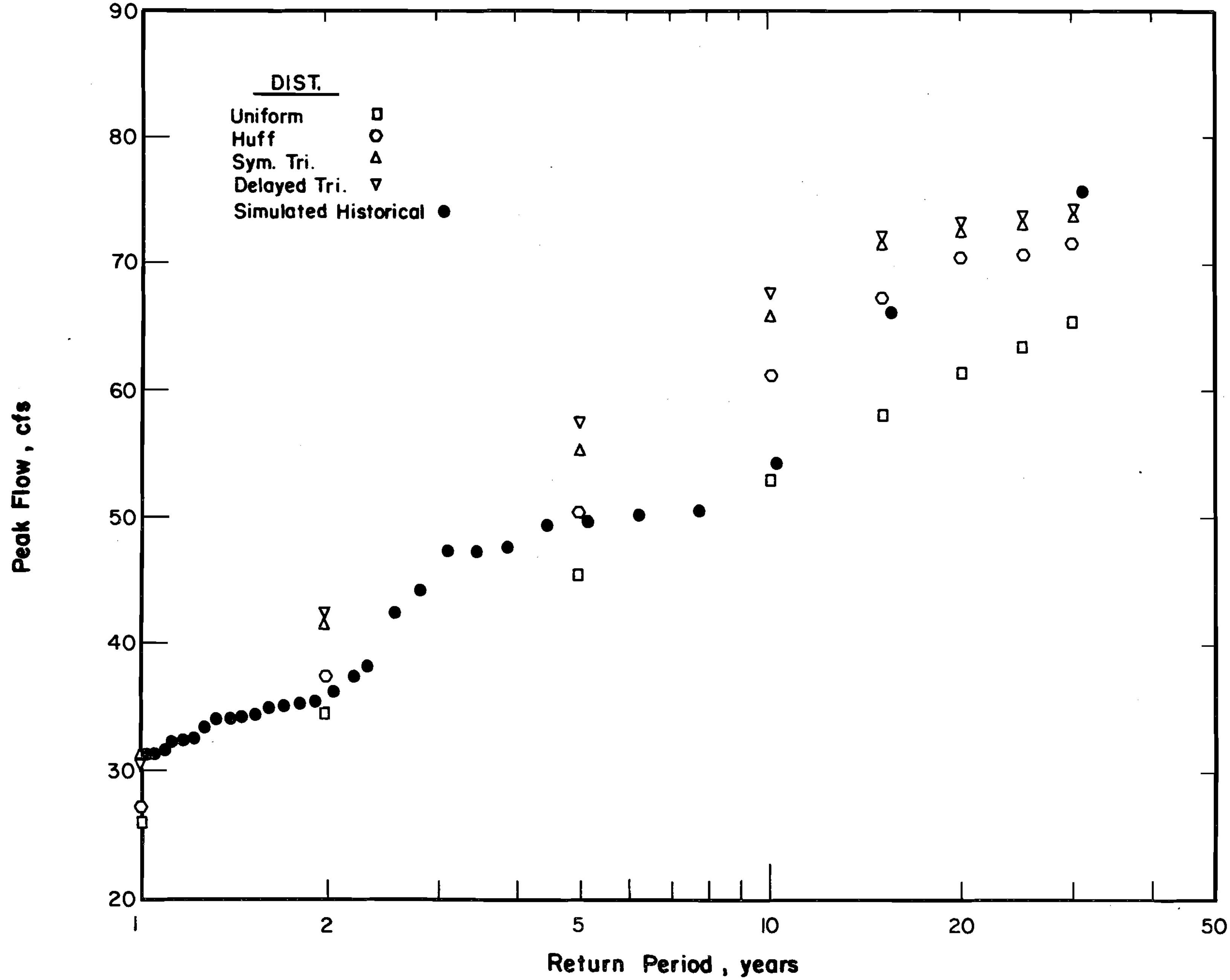

Fig. 6-27 Broward County Frequency Response - Albuquerque Rainfall - 15 Minute Design Storms

Chapter 7 CONCLUSIONS

The following conclusions are made based on this study:

1. For an urban catchment, a reasonable choice of design storm hyetograph, antecedent soil moisture and storm duration can be chosen to produce a peak flow frequency response which provides the same return period as the design storm rainfall.
2. A design storm hyetograph with an advanced pattern is most appropriate. Although the Huff distribution proved generally most suitable for the specific cases examined in this study, a triangular distribution with an advanced peak would likely serve as well.
3. The use of some type of average or expected antecedent soil moisture condition should be used. This should be determined using local rainfall data and soil characteristics.
4. The time of concentration of the catchment serves as a good guide to determine the duration of the design storm to be used. Significantly longer durations will result in low peak flows for a given return period.
5. The above conclusions are based on a limited study. Although reasonable consistency was observed for the various catchments and rainfall data studied, a more extensive analysis is needed in order to make firm, specific recommendations of a non-local nature.

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APPENDIX A

Continuous Simulation Model Used for Boneyard Creek

The use of ILLUDAS as a continuous or semi-continuous simulator required modifications to the infiltration model. The original ILLUDAS infiltration model employs the Horton equation

$$f_i = f_c + (f_o - f_c)e^{-kt} \tag{A-1}$$

where f_i = the potential infiltration capacity at any time after the beginning of rainfall, f_o and f_c are the initial and final values of infiltration capacity and k is a decay coefficient. Both f_o and f_c are functions of soil type as is k. The initial value of f_i for any event depends on the antecedent soil moisture which then determines an effective value of t in Eq. A-1 corresponding to the actual starting time of the event.

ILLUDAS was modified so that a continuous soil moisture balance accounting is performed. The soil moisture at the beginning of an event then dictates the initial value of f_i in Eq. A-1.

The infiltration model can be viewed as a reservoir system in which the storage is the soil moisture in the upper soil layer. Inflow to the reservoir is given by the infiltration capacity f_i or the rainfall rate, which ever is less. Outflow during an event is the deep percolation rate f_c', which is not constant but is assumed to be proportional to the total soil moisture storage, h, at any time.

$$f_c' = \alpha h \tag{A-2}$$

where α = constant of proportionality and f_c' and h are functions of time.

When the soil is saturated $f_c' = f_c$ in Eq. A-1.

The continuity equation for the soil reservoir is therefore given by

$$f_i - f_c' = f_i - \alpha h = \frac{dh}{dt} \tag{A-3}$$

and the modified Horton equation is given by

$$f_i = f_c' + (f_o - f_c')e^{-kt} \tag{A-4}$$

Solving Eq. (A-4) for $f_i - f_c'$ and substituting into Eq. A-3 gives

$$\frac{dh}{dt} = (f_o - \alpha h)e^{-kt} \tag{A-5}$$

and

$$\int_0^h \frac{dh}{f_o - \alpha h} = \int_0^t e^{-kt}\, dt \tag{A-6}$$

which results in

$$h = \frac{f_o}{\alpha} \{1\text{-EXP}\ [-\frac{\alpha}{k}\ (1 - e^{-kt})]\} \tag{A-7}$$

and solving for t gives

$$t = -\frac{1}{k}\ell n\ [\frac{k}{\alpha}\ \ell n(\frac{f_o - \alpha h}{f_o}) + 1] \tag{A-8}$$

The maximum total soil moisture storage, H, can be obtained by setting

$t = \infty$ in Eq. A-7

$$H = \frac{f_o}{\alpha}\ [1\text{-EXP}(-\ \frac{\alpha}{k})] \tag{A-9}$$

If values of f_o, f_c and k are known, the coefficient α can be found by

recognizing in Eq. A-2 that if h = H then $f_c' = f_c$

$$f_c = \alpha H \tag{A-10}$$

and from Eq. 9

$$f_c = f_o \, [1-\mathrm{EXP}(-\frac{\alpha}{k})] \tag{A-11}$$

which can be solved for α to obtain

$$\alpha = -k \, \ell n(1- \frac{f_c}{f_o}) \tag{A-12}$$

In summary to this point, if the value of h at the beginning of an event is known, Eq. A-8 is used to determine the value of t used in Eq. A-4 to determine the initial value of f_i. As long as the rainfall intensity exceeds f_i, Eqs. A-2, A-7 and A-4 can be used to compute subsequent values of f_i and t corresponds to real time.

However, if the rainfall rate i drops below f_i the soil moisture storage input rate is limited to i and therefore t in Eq. A-4 no longer corresponds to real time. In this case the continuity equation for the soil reservoir over a time interval Δt can be written as

$$\Delta h = i\Delta t - f_c' \Delta t \tag{A-13}$$

where i = average rainfall intensity during Δt, f_c' = average rate of deep percolation and Δh = change in soil moisture storage. Assuming

$$f_c' = \alpha \, (h+ \frac{\Delta h}{2}) \tag{A-14}$$

where h = soil moisture storage at the beginning of the time interval, substitution into Eq. A-13 gives

$$\Delta h = \frac{\Delta t(i-\alpha h)}{1 + \frac{\alpha \Delta t}{2}} \tag{A-15}$$

The soil moisture storage at the end of the time interval is h + Δh and the equivalent time on the infiltration capacity curve can be found using Eq. A-8. The value of f_i at the end of the time interval is then determined using Eqs. A-2 and A-4.

The above procedure applies during a storm event. Between events deep percolation continues to reduce soil moisture at a rate given by Eq. 4-2. In addition an evapotranspiration component is incorporated. This abstraction is taken as a constant rate depending on the month.

Furthermore, in recognition of the fact that deep percolation due to gravity, f_c', will not completely deplete soil moisture because of capillary forces, a lower limit on the effect of f_c' on h was imposed. This limit, or field capacity, is taken as a percentage of maximum soil moisture, H, depending on the soil type. Once h reaches this limit f_c' has no further effect on h, although evapotranspiration continues to deplete h.

The other abstractions accounted for in the model are interception and depression storage, sometimes termed initial losses. Maximum initial losses of 0.1 in. for impervious surfaces and 0.2 in. on grass were used. These were accounted for continuously by applying constant monthly evaporation and evapotranspiration rates, respectively, between events.

APPENDIX B

Boneyard Creek Urban Catchment Data

Pipe[1]	Impervious Area ac	Imperv. Area Entry Time min	Pervious Area ac	Perv. Area Entry Time min	Suppl. Imperv. Area ac	Length ft.	Type[2]	Slope	Existing Diameter in.	Redesign Diameter in.	Manning's n
1-0	2.1	8.0	2.0	18.5	2.9	560	C	.0055	18	27	.015
2-0	3.8	11.0	3.0	22.3	3.4	1010	C	.010	18	27	.015
1-1	4.0	11.0	7.0	22.3	4.8	420	C	.016	21	36	.015
3-0	2.2	11.0	5.0	21.5	3.0	600	C	.0085	18	27	.015
1-2	3.1	14.0	8.0	24.5	6.7	670	C	.007	24	54	.015
4-0	1.8	8.0	3.0	18.5	4.0	1250	C	.0135	15	24	.015
1-3	7.2	21.0	12.0	32.3	7.4	500	C	.0075	30	72	.015
1-4	2.1	7.0	4.0	17.1	3.7	750	C	.0075	30	72	.015
1-5	2.7	6.0	3.0	15.6	3.8	860	C	.0075	30	72	.015
1-6	4.3	8.0	7.0	17.6	7.5	440	C	.005	33	84	.015
5-0	.8	6.0	4.0	16.5	2.9	450	C	.020	12	21	.015
5-1	2.0	7.0	6.0	20.3	3.6	320	C	.006	12	36	.015
5-2	1.2	6.0	3.0	19.3	1.7	850	C	.006	15	42	.015
5-3	1.4	6.0	3.0	17.7	2.4	1300	C	.009	15	42	.015
5-4	1.4	8.0	4.0	17.6	2.3	200	C	.009	15	42	.015
5-5	2.0	16.0	5.0	27.3	2.7	1100	C	.005	18	54	.015
1-7	2.2	9.0	3.0	18.6	3.0	1290	C	.005	33	96	.015
6-0	20.6	10.0	1.0	19.6	1.2	700	C	.005	18	42	.015
7-0	3.9	10.0	6.0	19.6	4.4	610	C	.005	10	36	.015
7-1	2.5	7.0	4.0	16.6	2.5	1110	C	.005	24	42	.015
1-8	17.5	6.0	7.0	15.6	7.0	200	C	.005	33	96	.015
8-0	.7	6.0	3.0	19.3	.9	1320	C	.0152	21	21	.015

Pipe[1]	Impervious Area ac	Imperv. Area Entry Time min	Pervious Area ac	Perv. Area Entry Time min	Suppl. Imperv. Area ac	Length ft.	Type[2]	Slope	Existing Diameter in.	Redesign Diameter in.	Manning's n
8-1	1.2	6.0	5.0	19.3	1.3	1740	C	.0144	24	27	.015
8-2	2.5	6.0	4.0	15.6	1.4	2430	C	.005	12	36	.015
1-9	9.5	14.0	0.0	0.0	0.0	750	C	.005	48	108	.015
9-0	5.8	6.0	0.0	0.0	0.0	720	C	.006	24	27	.015
9-1	4.8	12.0	0.0	0.0	0.0	220	C	.005	24	36	.015
9-2	8.1	6.0	3.0	13.0	1.4	1070	C	.005	30	42	.015
9-3	5.7	14.0	1.0	21.0	.5	1300	C	.005	33	48	.015
9-4	5.2	9.0	3.0	17.0	4.5	240	C	.002	39	72	.015
1-10	.8	6.0	0.0	0.0	.5	550	C	.005	66	108	.015
1-11	5.8	6.0	1.0	14.6	1.9	180	T	.005	-	0	.070
10-0	.9	6.0	1.0	14.6	1.4	890	C	.008	18	21	.015
10-1	3.6	8.0	4.0	16.6	5.8	1550	C	.0065	24	36	.015
1-12	2.1	6.0	2.0	14.6	2.1	420	T	.005	-	0	.070
1-13	.9	6.0	0.0	0.0	1.1	410	T	.005	-	0	.070
11-0	1.3	6.0	2.0	15.8	2.6	610	C	.010	15	24	.015
11-1	1.1	6.0	2.0	15.6	1.5	970	C	.020	15	24	.015
12-0	3.0	9.0	4.0	18.8	4.3	400	C	.005	24	36	.015
11-2	2.0	6.0	3.0	15.6	2.6	840	C	.005	24	48	.015
11-3	1.0	6.0	2.0	15.6	1.8	240	T	.005	-	0	.070
13-0	1.1	6.0	2.0	15.6	1.7	1610	C	.009	12	21	.015
14-0	1.1	8.0	2.0	17.8	2.1	1100	C	.007	15	21	.015
11-4	3.4	13.0	6.0	22.6	3.5	210	T	.005	-	0	.070
15-0	1.6	8.0	3.0	17.8	5.8	1160	C	.007	30	30	.015
11-5	.1	6.0	0.0	0.0	0.0	180	T	.004	-	0	.080
11-6	2.1	11.0	3.0	21.8	3.7	450	T	.004	-	0	.090

Pipe[1]	Impervious Area ac	Imperv. Area Entry Time min	Pervious Area ac	Perv. Area Entry Time min	Suppl. Imperv. Area ac	Length ft.	Type[2]	Slope	Existing Diameter in.	Redesign Diameter in.	Manning's n
11-7	3.2	6.0	5.0	16.4	4.2	790	T	.003	-	0	.090
16-0	2.3	8.0	7.0	18.8	2.8	1090	C	.010	18	27	.015
11-8	11.6	6.0	4.0	16.8	3.8	1220	T	.003	-	0	.080
11-9	10.1	6.0	4.0	16.8	5.1	550	T	.004	-	0	.080
17-0	3.4	21.0	4.0	31.8	5.9	900	T	.002	-	0	.090
18-0	.9	6.0	1.0	16.8	.9	810	C	.006	15	21	.015
17-1	4.6	13.0	6.0	23.8	6.2	1300	T	.002	-	0	.090
11-10	11.3	18.0	3.0	28.8	3.6	160	T	.002	-	0	.080
11-11	1.1	6.0	1.0	17.9	3.5	780	T	.002	-	0	.080
19-0	2.9	7.0	4.0	19.8	5.2	900	C	.005	15	36	.015
19-1	2.0	6.0	2.0	17.9	3.6	680	C	.005	15	42	.015
19-2	1.7	8.0	2.0	19.9	3.5	700	C	.006	15	42	.015
20-0	1.3	6.0	1.0	17.9	3.7	400	C	.005	15	27	.015
19-3	1.3	6.0	1.0	17.9	2.6	630	C	.005	24	48	.015
19-4	2.9	10.0	3.0	21.9	4.0	1070	C	.005	30	54	.015
11-12	1.8	6.0	2.0	17.9	3.6	290	T	.0033	-	0	.080
21-0	7.8	6.0	0.0	0.0	0.0	450	C	.006	24	30	.015
11-13	.4	6.0	0.0	0.0	1.5	230	T	.0033	-	0	.080
22-0	1.1	6.0	1.0	17.9	1.6	1170	C	.006	12	21	.015
11-14	5.9	6.0	3.0	17.9	4.0	700	T	.0033	-	0	.080
11-15	2.6	7.0	1.0	18.9	1.6	400	T	.0033	-	0	.080
23-0	4.5	9.0	4.0	20.9	3.6	620	C	.005	20	36	.015
23-1	2.4	8.0	2.0	19.9	3.0	1120	C	.011	24	36	.015
11-16	5.3	7.0	2.0	18.9	2.2	400	T	.0033	-	0	.080
11-17	18.0	9.0	0.0	0.0	.8	700	T	.0033	-	0	.080

Pipe[1]	Impervious Area ac	Imperv. Area Entry Time min	Pervious Area ac	Perv. Area Entry Time min	Suppl. Imperv. Area ac	Length ft.	Type[2]	Slope	Existing Diameter in.	Redesign Diameter in.	Manning's n
11-18	12.9	6.0	3.0	16.8	3.1	500	T	.0033	-	0	.080
24-0	6.8	10.0	13.0	21.3	9.1	960	C	.014	24	36	.015
25-0	1.7	8.0	2.0	17.6	2.1	650	C	.020	15	21	.015
25-1	2.4	10.0	4.0	19.6	3.2	730	C	.011	20	30	.015
24-1	2.0	8.0	6.0	17.6	7.7	600	C	.008	34	54	.015
26-0	.8	6.0	1.0	15.6	1.3	1400	C	.011	15	18	.015
26-1	3.7	9.0	6.0	18.6	7.7	580	C	.007	24	36	.015
24-2	3.9	7.0	5.0	16.6	4.7	920	C	.008	38	60	.015
27-0	.5	6.0	1.0	15.6	.7	680	C	.010	24	24	.015
27-1	2.0	6.0	0.0	0.0	1.6	640	C	.005	24	27	.015
24-3	2.3	6.0	3.0	15.6	2.9	1170	C	.009	42	72	.015
28-0	3.1	10.0	2.0	19.6	1.9	680	C	.007	24	24	.015
29-0	10.0	11.0	1.0	20.6	1.5	1000	C	.011	18	30	.015
24-4	15.3	6.0	5.0	15.6	4.6	480	C	.005	54	84	.015
30-0	15.0	11.0	2.0	20.6	2.3	1170	C	.006	15	42	.015
31-0	8.6	6.0	0.0	0.0	0.0	380	C	.010	15	27	.015
30-1	22.8	6.0	0.0	0.0	0.0	950	C	.010	24	54	.015
24-5	19.5	7.0	0.0	0.0	0.0	970	C	.050	54	96	.015
32-0	7.5	6.0	0.0	0.0	0.0	590	C	.010	24	27	.015
24-6	19.4	6.0	0.0	0.0	0.0	980	C	.010	60	96	.015
11-19	13.7	7.0	3.0	17.2	3.1	900	T	.0025	-	0	.070
1-14	2.1	6.0	2.0	14.6	4.6	550	T	.002	-	0	.070
33-0	1.4	6.0	1.0	14.6	1.3	870	C	.020	18	18	.015
34-0	4.0	9.0	3.0	17.6	5.2	620	C	.024	15	27	.015
1-15	2.0	6.0	1.0	14.6	2.8	470	T	.002	-	0	.070

Pipe[1]	Impervious Area ac	Imperv. Area Entry Time min	Pervious Area ac	Perv. Area Entry Time min	Suppl. Imperv. Area ac	Length ft.	Type[2]	Slope	Existing Diameter in.	Redesign Diameter in.	Manning's n
35-0	.9	6.0	1.0	16.8	1.9	800	C	.0125	15	18	.015
36-0	4.2	10.0	2.0	18.6	2.8	220	C	.045	15	21	.015
1-16	1.3	6.0	1.0	15.4	1.6	360	T	.002	-	0	.070
37-0	2.3	6.0	1.0	14.6	1.6	1010	C	.005	15	24	.015
37-1	6.0	6.0	3.0	17.3	0.0	830	C	.005	24	36	.015
37-2	6.6	6.0	1.0	14.6	.7	1080	C	.021	24	36	.015
1-17	9.2	7.0	2.0	15.6	.9	450	T	.002	-	0	.06
38-0	4.1	10.0	5.0	20.8	4.0	1550	C	.013	15	27	.015
39-0	7.6	6.0	4.0	18.1	0.0	540	C	.005	30	36	.015
39-1	4.3	6.0	0.0	0.0	0.0	830	C	.010	34	36	.015
39-2	2.9	6.0	1.0	14.6	.3	1090	C	.020	39	30	.015
1-18	10.5	6.0	2.0	14.6	.8	300	T	.002	-	0	.06
40-0	3.5	6.0	8.0	19.2	0.0	680	C	.015	18	24	.015
40-1	2.8	6.0	7.0	19.2	0.0	1070	C	.014	24	30	.015
1-19	10.0	6.0	13.0	18.1	0.0	360	T	.002	-	0	.06

[1] See Fig. 4-2

[2] C = circular pipe; T = tropezoidal channel

APPENDIX C

Gray Haven Residential Catchment Data

Subbasin[1]	Impervious Area ac	Imperv. Area Entry Time min	Pervious Area ac	Perv. Area Entry Time min	Suppl. Imperv. Area ac	Reach[1]	Length ft.	Slope	Diam. in.
0	0.38	9.0	0.56	15.0	0.05	0	120	.0044	18
1	1.24	9.0	1.43	16.0	0.30	1	120	.0064	27
2	.60	11.0	0.72	17.0	0.06	2	40	.0052	30
3	.60	11.0	0.72	17.0	0.06	3	120	.0080	30
4	1.55	7.0	1.14	14.0	0.38	4	120	.0148	36
5	0.56	7.0	0.90	13.0	0.07	5	40	.0056	42
6	0.58	8.0	0.69	14.0	0.06	6	120	.0040	48
7	1.33	8.0	1.56	15.0	0.34	7	170	.0056	48
8	1.47	9.0	1.67	15.0	0.15	8	220	.0136	42
9	1.99	9.0	1.82	16.0	0.32	9	173	.0140	48

Manning's n = .015 for all pipes

[1] see Fig. 4-3

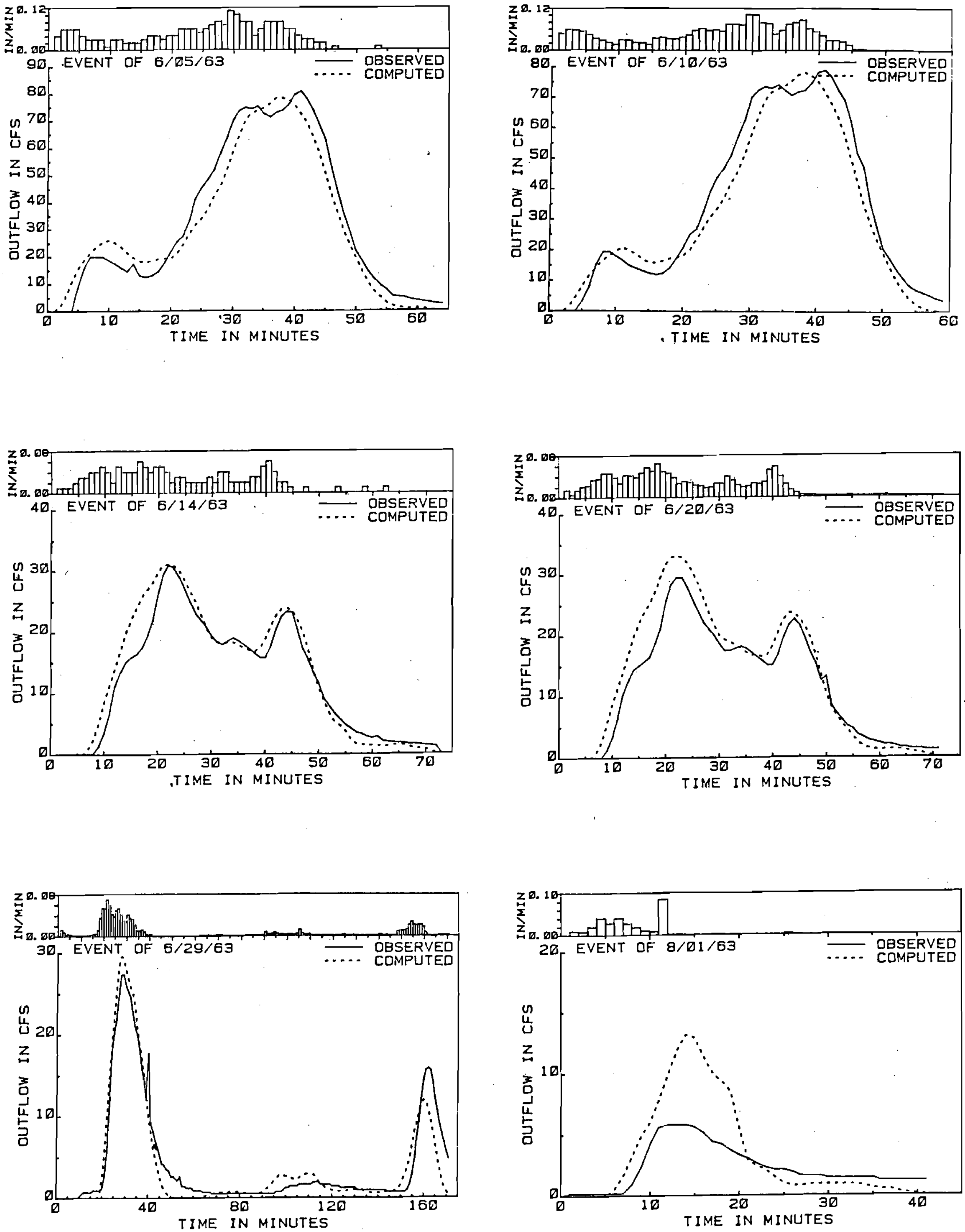

Figure C-1 Gray Haven Catchment Calibration Hydrographs

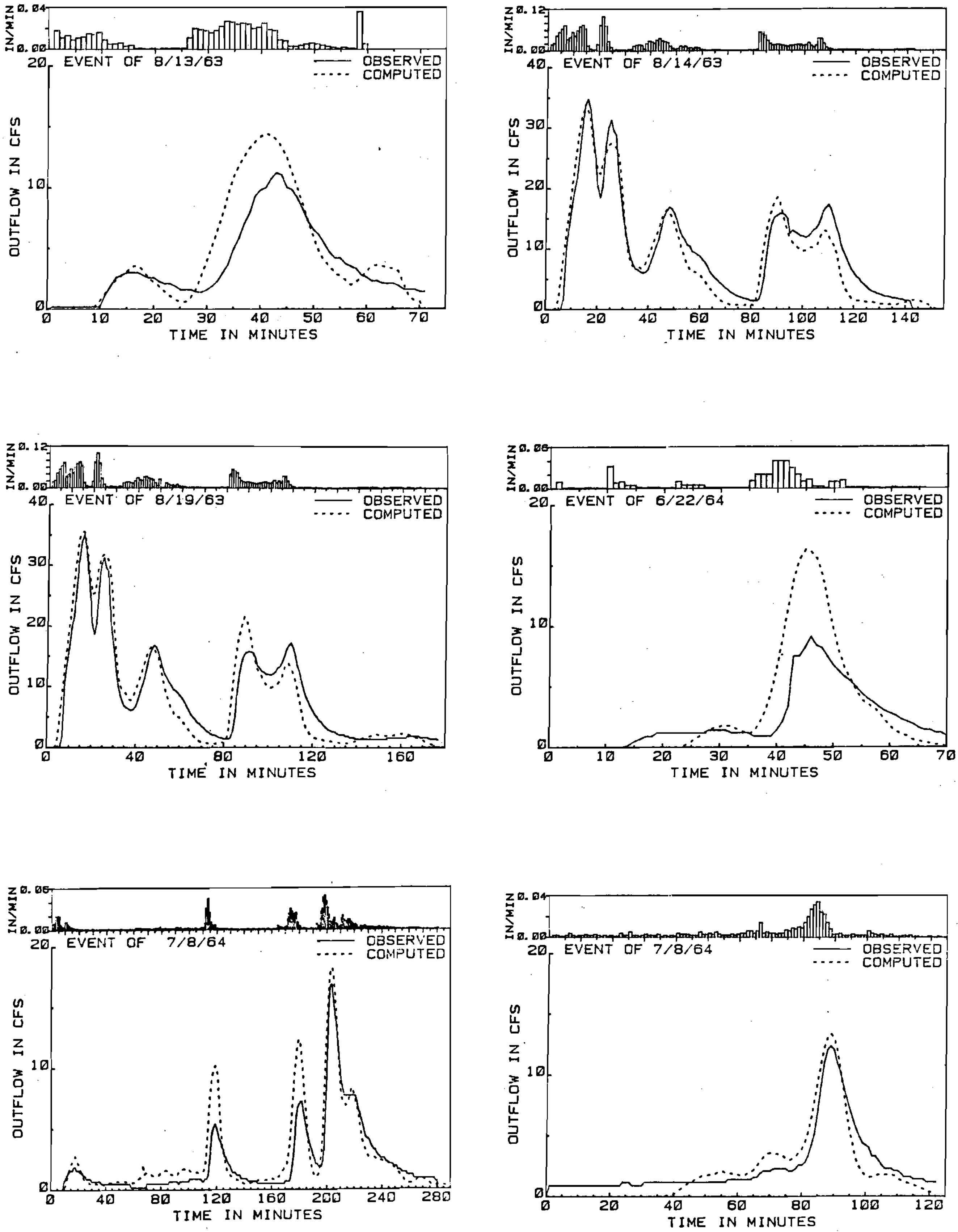

Figure C-1 Gray Haven Catchment Calibration Hydrographs

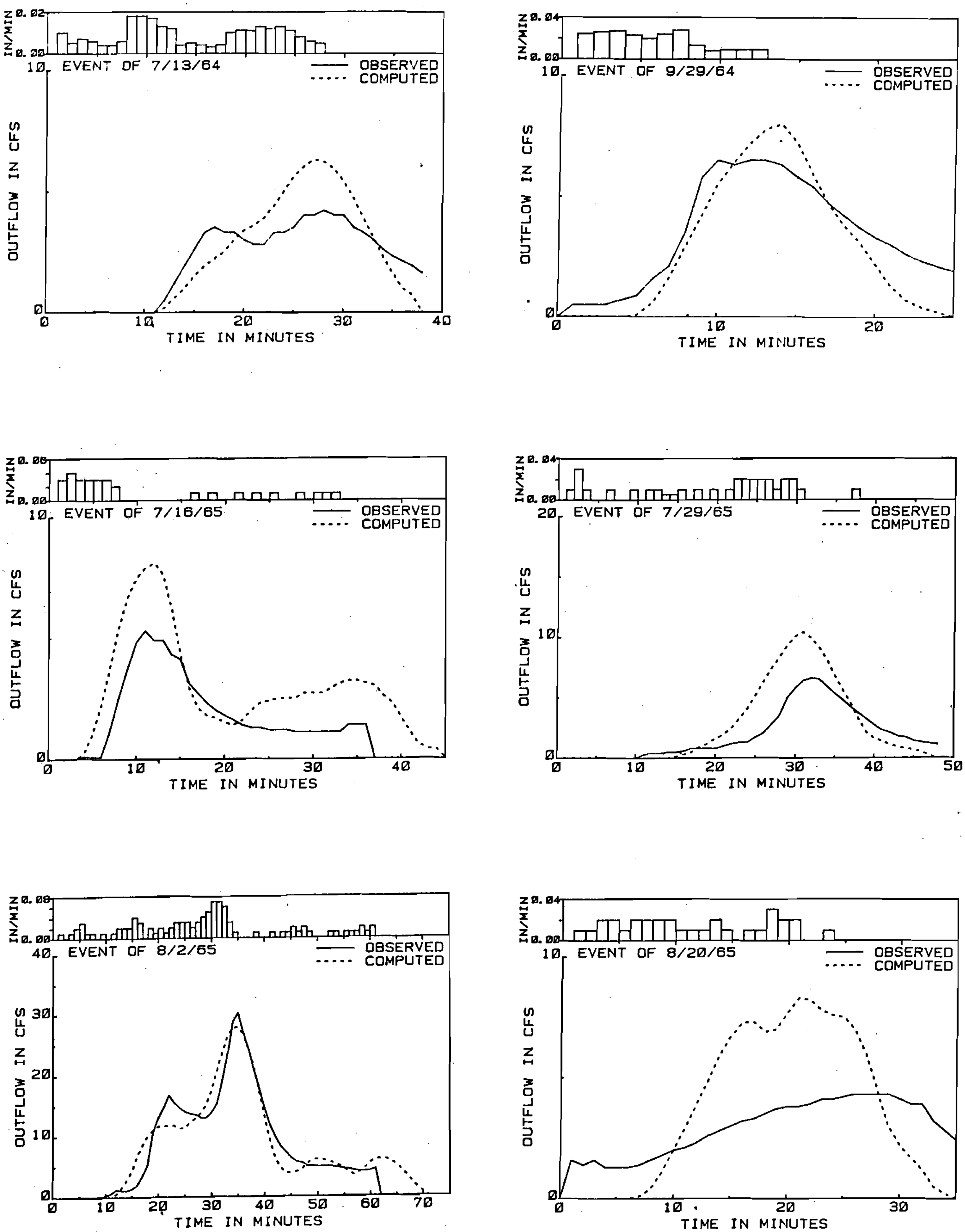

Figure C-1 Gray Haven Catchment Calibration Hydrographs

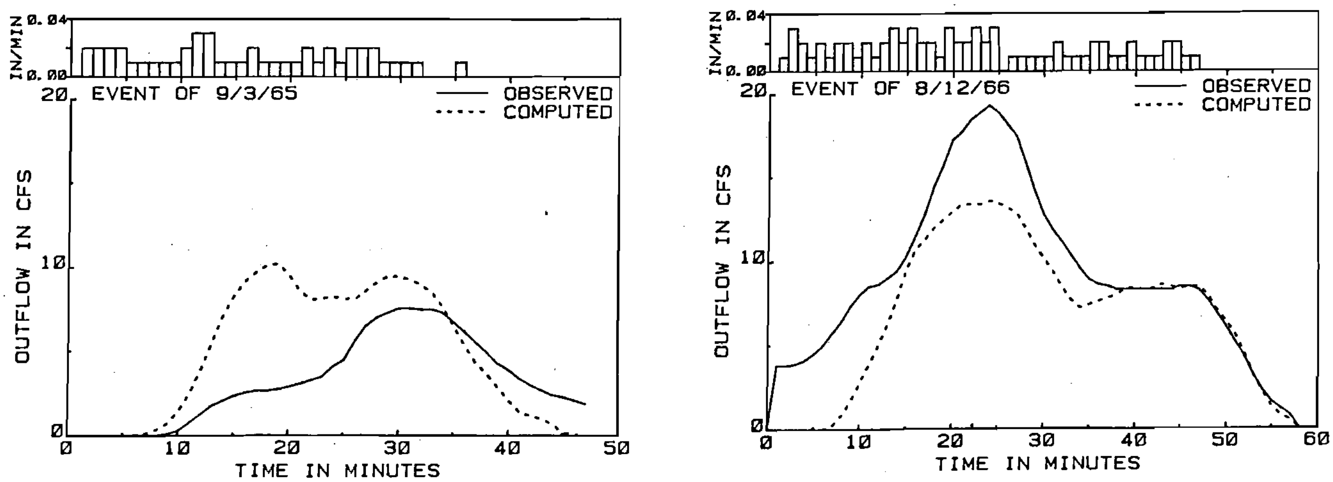

Figure C-1 Gray Haven Catchment Calibration Hydrographs

APPENDIX D

Dade County Residential Catchment Data

Sub-basin[1]	Imperv. Area ac	Pervious Area ac	Suppl. Imperv. Area ac	Pipe[1]	Length ft	Slope	Diam. in.
CA13	0.522	0.399	0.123	P013	115	.682	21
				P13A	205	.237	30
CA12	0.952	0.276	0.200	P012	110	.078	21
				P12A	175	.237	30
CA11	0.323	0.568	0	P011	165	.237	30
CA10	1.428	0.614	0.369	P010	210	.148	24
CA9	0.584	0.184	0.108	P009	165	.382	27
CA8	0.384	0.246	0.153	P008	40	.238	30
CA7	0.737	0.307	0.230	P007	90	.722	36
CA6	0.169	0.031	0.184	P006	40	.290	36
CA5	0.308	0.154	0.154	P005	240	.163	36
CA4	0.476	0.276	0.353	P004	105	.038	18
CA3	0.538	0.691	0.154	P003	105	.076	18
CA2	0.123	0.046	0.092	P002	32	.297	18
CA1	0.415	0.292	0.261	P001	220	.505	48

Manning's n = .015 for all pipes

Impervious area entry time = 5.5 for all sub-basins

Pervious area entry time = 28.5 for all sub-basins

[1] See Fig. 4-4

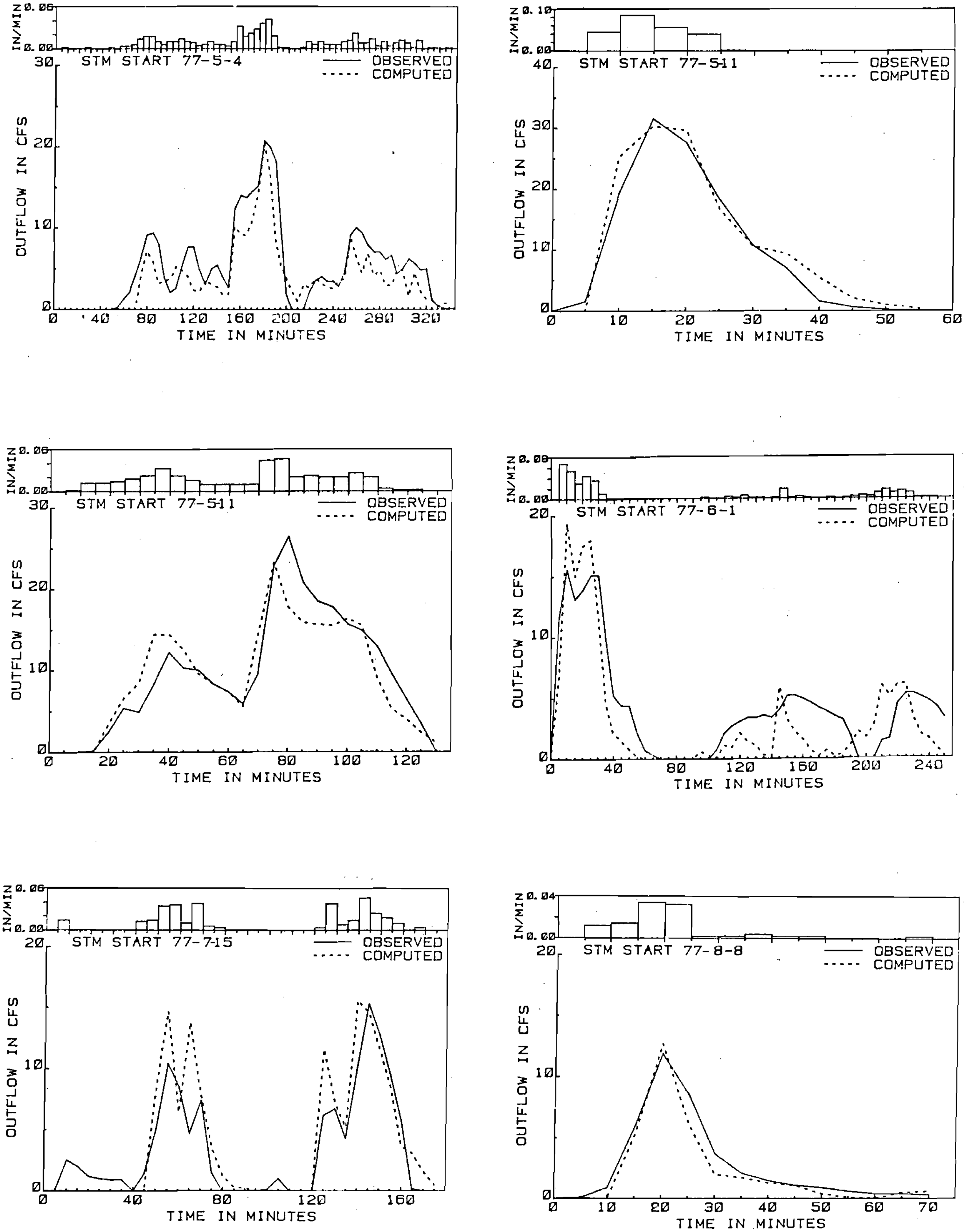

Figure D-1 Dade County Catchment Calibration Hydrographs

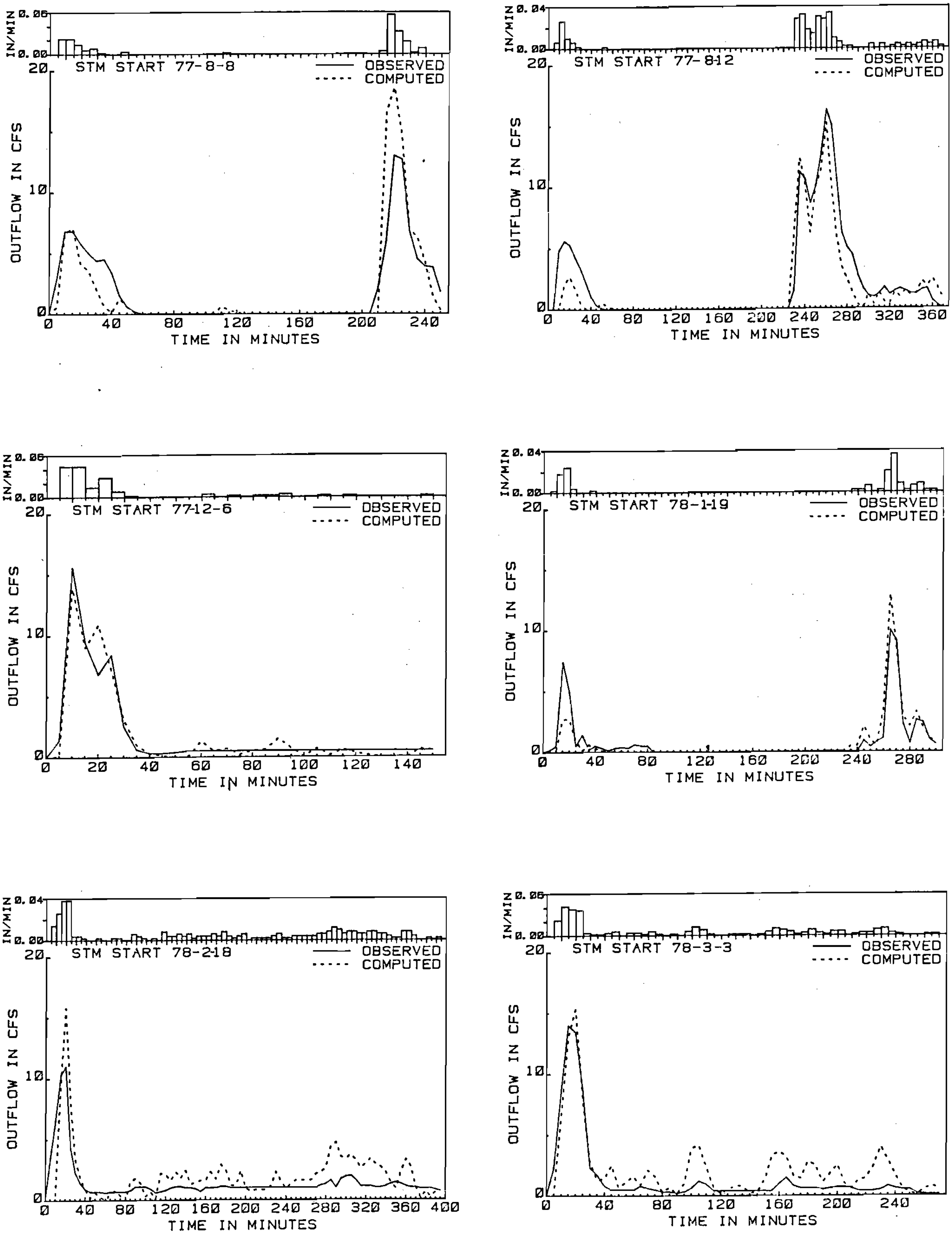

Figure D-1 Dade County Catchment Calibration Hydrographs

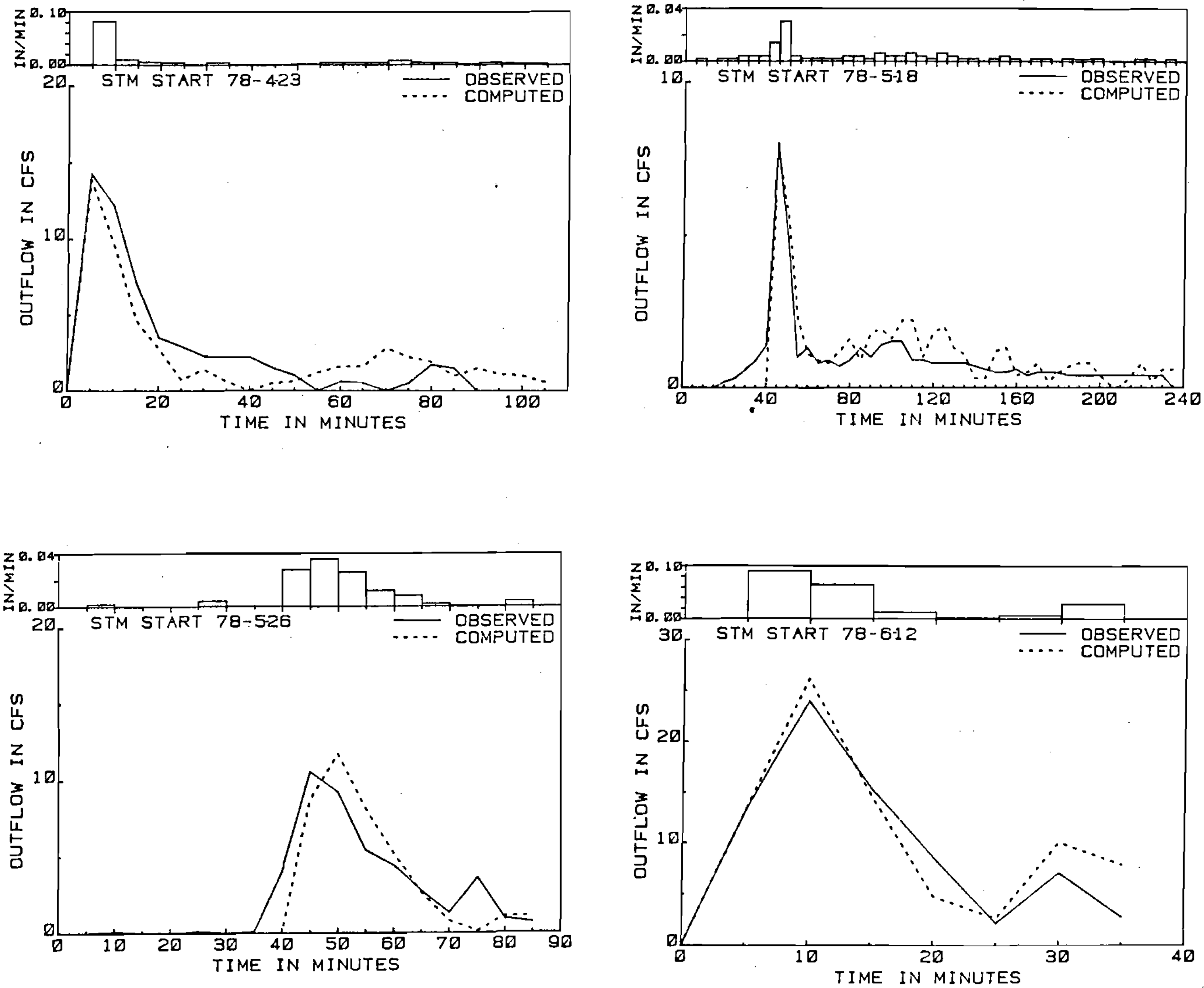

Figure D-1 Dade County Catchment Calibration Hydrographs

APPENDIX E

Broward County Commercial Catchment Data

Subcatchment[1]	Impervious Area ac	Entry Time min	Pipe[1]	Length ft	Diameter in.
CA25	1.186	6.6	P-26	180	12
CA24	0.893	8.2	P-25	188	21
CA23	1.028	8.4	P-24a	216	42
			P-24	160	12
CA22	1.211	8.6	P-23a	95	42
			P-23	125	12
CA21	0.819	7.5	P-22	180	27
CA20	0.598	5.6	P-21	128	30
CA19	1.435	8.6	P-20a	108	42
			P-20	136	12
CA18	1.171	8.3	P-19	360	36
CA17	0.103	7.2	P-18	32	18
CA16	0.157	7.6	P-17	75	18
CA15	0.498	7.6	P-16	184	36
CA14	0.529	6.1	P-15	114	18
CA13	1.846	8.4	P-14a	216	42
			P-14	172	42
CA12	1.151	7.6	P-13a	189	42
			P-13	203	36
CA11	0.511	4.5	P-12	78	12
CA10	0.222	6.0	P-11	175	18
CA9	0.904	7.1	P-10	197	21
CA8	0.762	7.9	P-9	167	12
CA7	0.278	4.2	P-8	203	27
CA6	0.999	7.6	P-7a	96	42
			P-7	145	10
CA5	0.489	7.1	P-6a	81	42
			P-6	67	10
CA4	0.647	7.6	P-5a	96	42
			P-5	85	10
CA3	0.067	5.7	P-4	146	15
CA2	0.776	7.2	P-3	220	30
CA1	1.708	5.7	P-2	228	36
			Outlet	80	42

Manning's n = .012 for all pipes
Slope = .002 for all pipes

[1] See Fig. 4-5

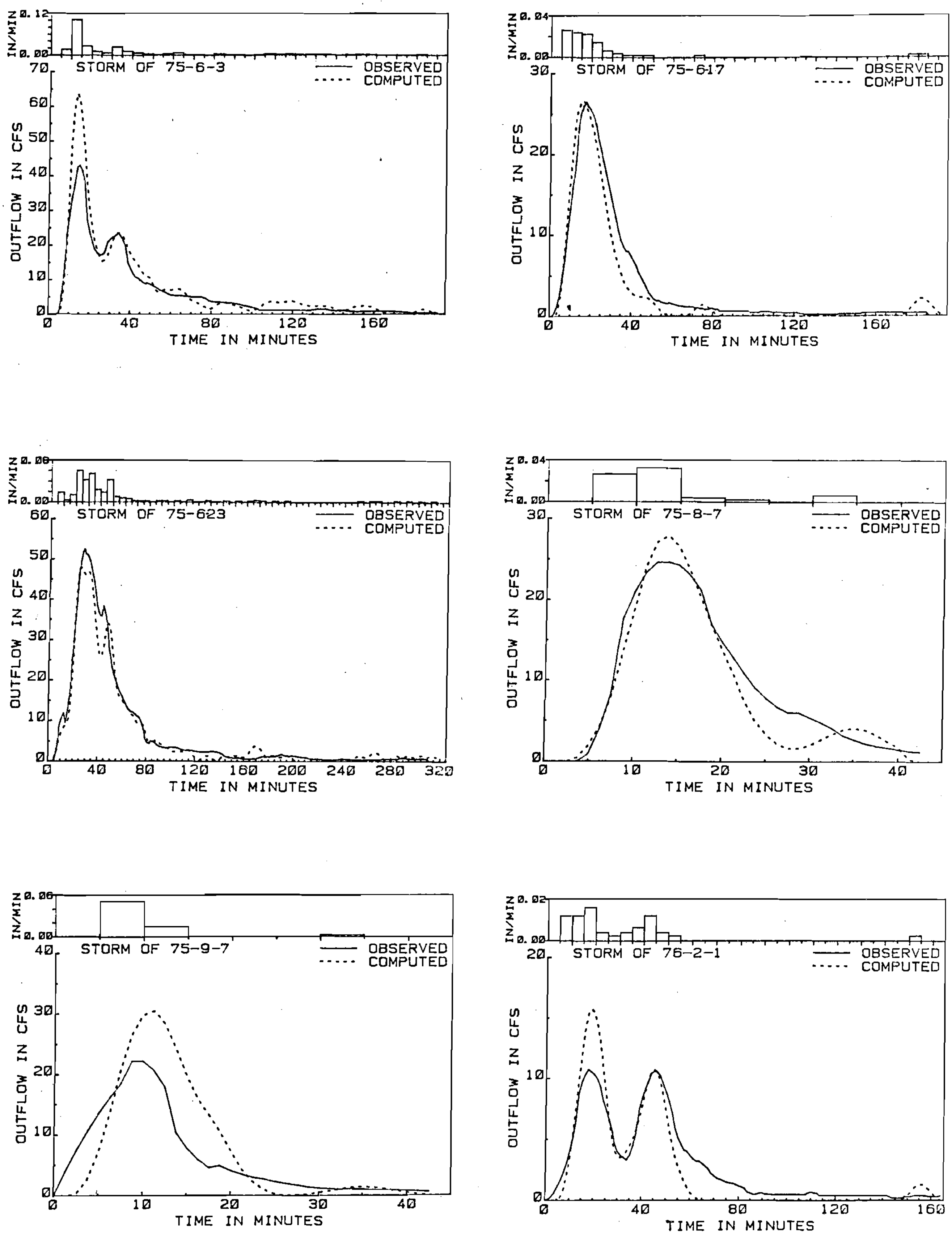

Figure E-1 Broward County Catchment Calibration Hydrographs

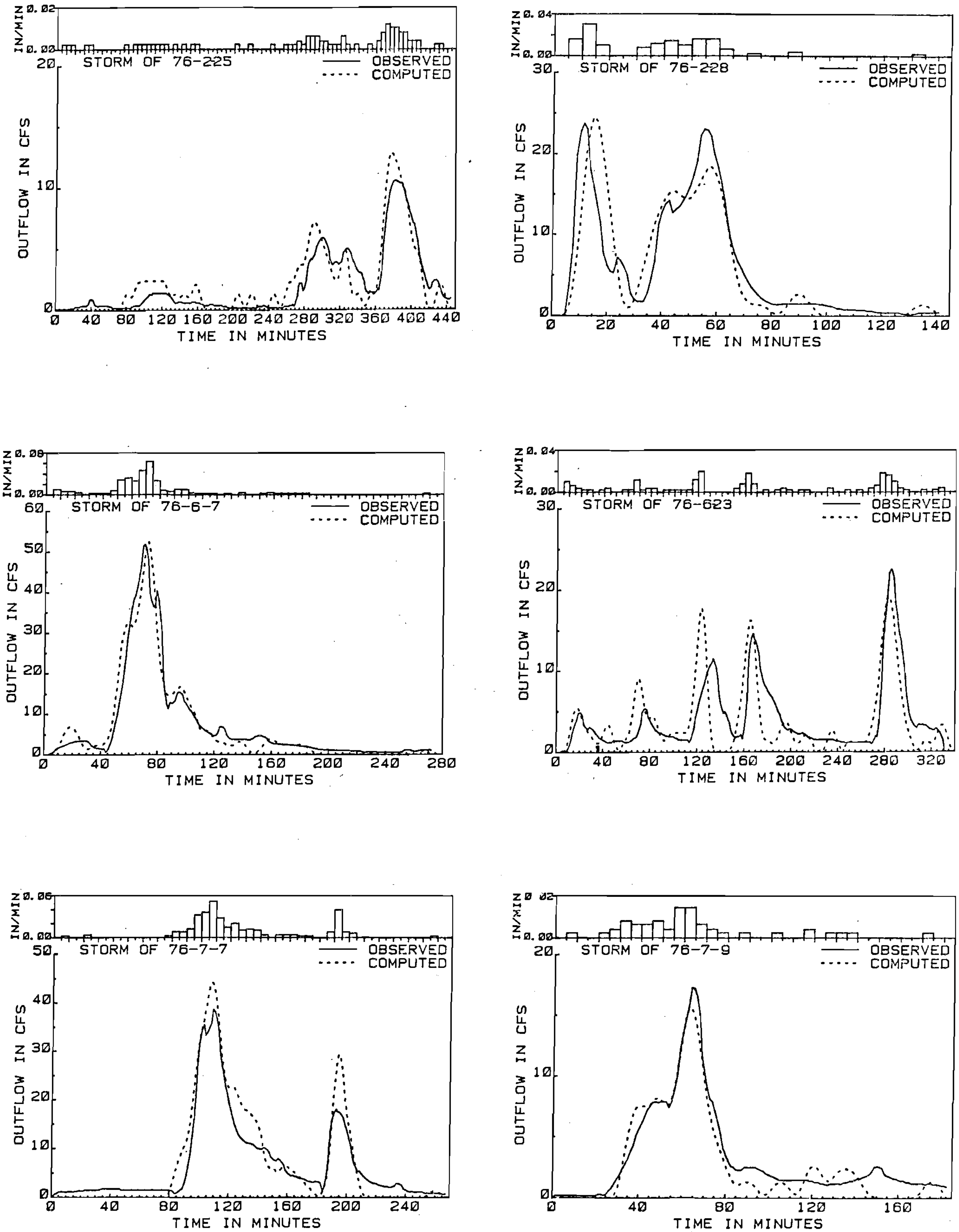

Figure E-1 Broward County Catchment Calibration Hydrographs

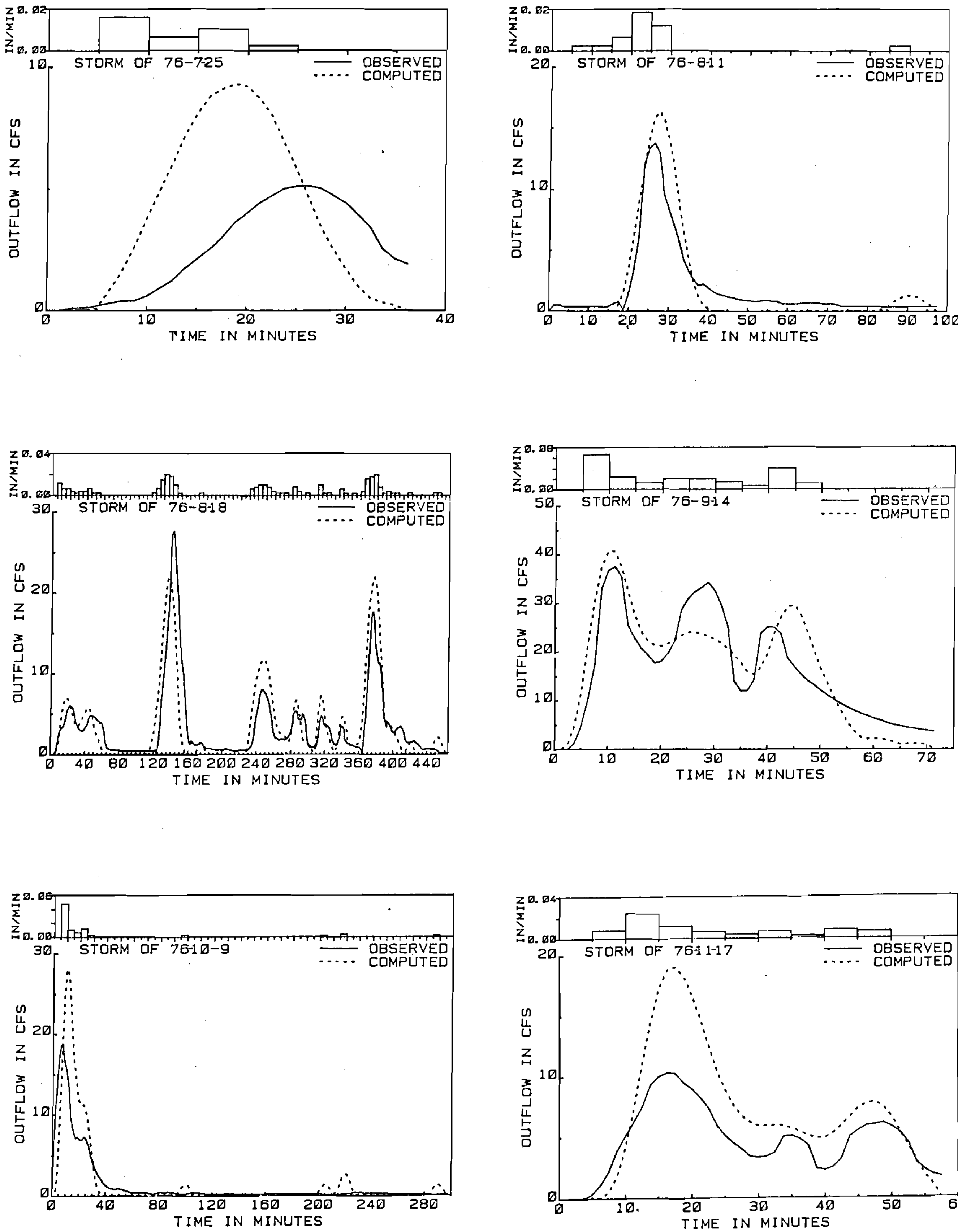

Figure E-1 Broward County Catchment Calibration Hydrographs

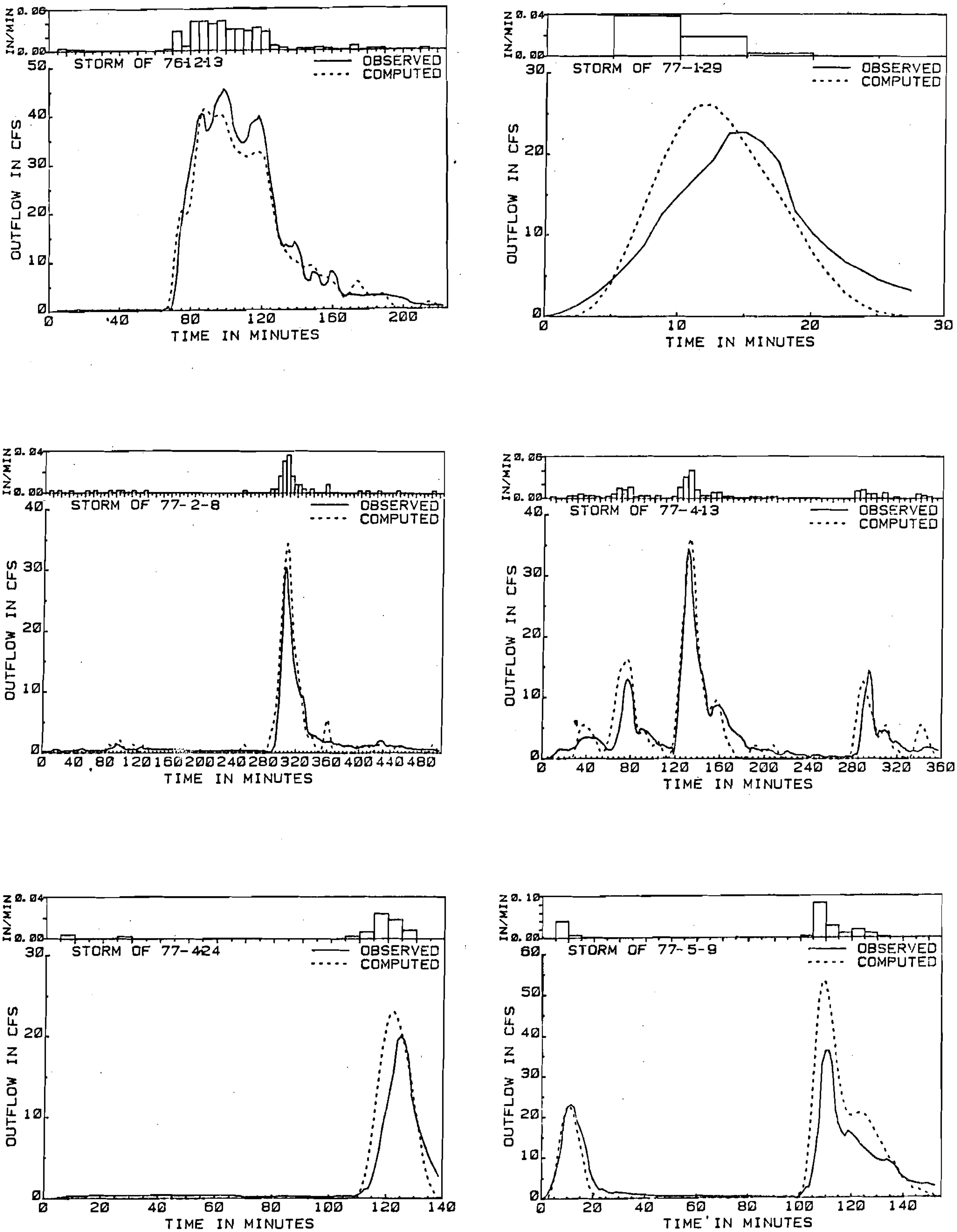

Figure E-1 Broward County Catchment Calibration Hydrographs

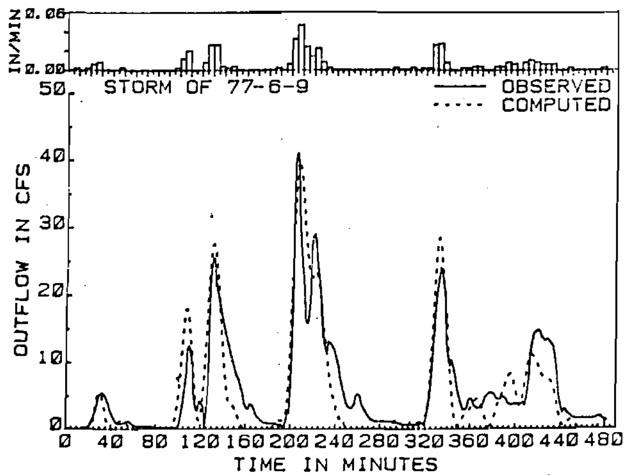

Figure E-1 Broward County Catchment Calibration Hydrographs

APPENDIX F

Rosenbrock Optimization

The optimization procedure developed by Rosenbrock for the design of economical chemical processes and has been applied by the USGS[22], Manley[23], and Rao and Han[24] to hydrologic models. The non-linear optimization consists of a search in a n-dimensional space for the best set of n decision variables formed by n-orthogonal vectors (directions) with decision variable bounds. New Orthogonal directions are obtained based upon movements along the n-directions of a current stage. Only in the first (exploratory) stage are the orthogonal directions coincidental with the n-variable directions.

Movement within each stage is made along orthogonal directions. Initially, a step of specified length is attempted in one of the orthogonal directions. This movement is considered successful if the new value of the objective function is an improvement over the previous best value. If successful, this orthogonal direction stepsize is increased by a factor α, conversely, if unsuccessful, the orthogonal direction stepsize is reversed and decreased by a factor β. This process is repeated in each of the orthogonal directions until success followed by failure is generated in each of the orthogonal directions at which time a new stage (or new set of orthogonal directions and step sizes) is generated. Initial stage stepsizes are obtained by applying a fraction, γ, to the orthogonal direction vectors.

In the exploratory or first stage, the mutually orthonomal search directions are the unit vectors in the decision variable directions. After the exploratory stage has been completed the construction of a new set of orthogonal search directions is performed. Let ν^j, $j = 1,\ldots,n$, where n is the number of decision variables, denote the net distance moved in the previous stage in the j^{th} search direction. Now define U vectors as

$$U^1 = \nu^1 \rho^1 + \nu^2 \rho^2 + \dots + \nu^n \rho^n \tag{F-1}$$

$$U^2 = \nu^2 \rho^2 + \dots + \nu^n \rho^n$$

$$\vdots$$

$$U^n = \nu^n \rho^n$$

where $\rho^1, \dots, \rho^n$ are the n mutually orthonormal search directions from the stage just completed. Note that U^1 is the vector joining the initial and final points of the stage just completed and that it is assumed to be a "promising" direction. The next step is to find a new set of orthonormal vectors for the next stage. This is performed by applying the Gram-Schmidt orthogonalization procedure. If all ν^j are non-zero then the vectors U^j, j = 1,..., n, are linearly independent. A set of vectors can then be obtained as

$$W^j = U^j - \sum_{k=1}^{j-1} [(U^j)^T \rho^k]\rho^k, \quad j=1,\dots,n \tag{F-2}$$

where $(U^j)^T$ is the transpose of the U^j vector. The W^j vectors can then be used to obtain the new unit length search directions for the next stage as

$$\hat{\rho}^j = \frac{W^j}{||W^j||}, \quad j=1,\dots,n \tag{F-3}$$

where $||W^j||$ is the vector length of W^j. These $\hat{\rho}$ vectors thus obtained serve as the new set of n mutually orthonomal search directions for the next stage. The $\hat{\rho}^j$ vectors are multiplied by γ to start the next stage search.

Bounds are handled by defining boundary zones for the decision variable(s) as illustrated in Fig. F-1. Boundary zones are denoted by the shaded area. Define the i^{th} bound

$$g_i \leq x_i \leq h_i \tag{F-4}$$

where g_i and h_i are constants. In addition define constants g_i', h_i', and ε such that

$$g_i - g_i' = h_i - h_i' = \varepsilon(h_i - g_i) \tag{F-5}$$

Where ε is a small constant. For the lower boundary zone (see Fig. F-1) the depth of penetration can be defined as

$$\eta_{L_i} = \frac{g_i + \varepsilon(h_i-g_i)-x_i}{\varepsilon(h_i-g_i)} \tag{F-6}$$

and for the upper boundary zone

$$\eta_{U_i} = \frac{X_i + \varepsilon(h_i-g_i)-g_i}{\varepsilon(h_i-g_i)} \tag{F-7}$$

The decision variables can be normalized by the bounds by

$$X_i^N = \frac{X_i-g_i}{h_i-g_i} \tag{F-8}$$

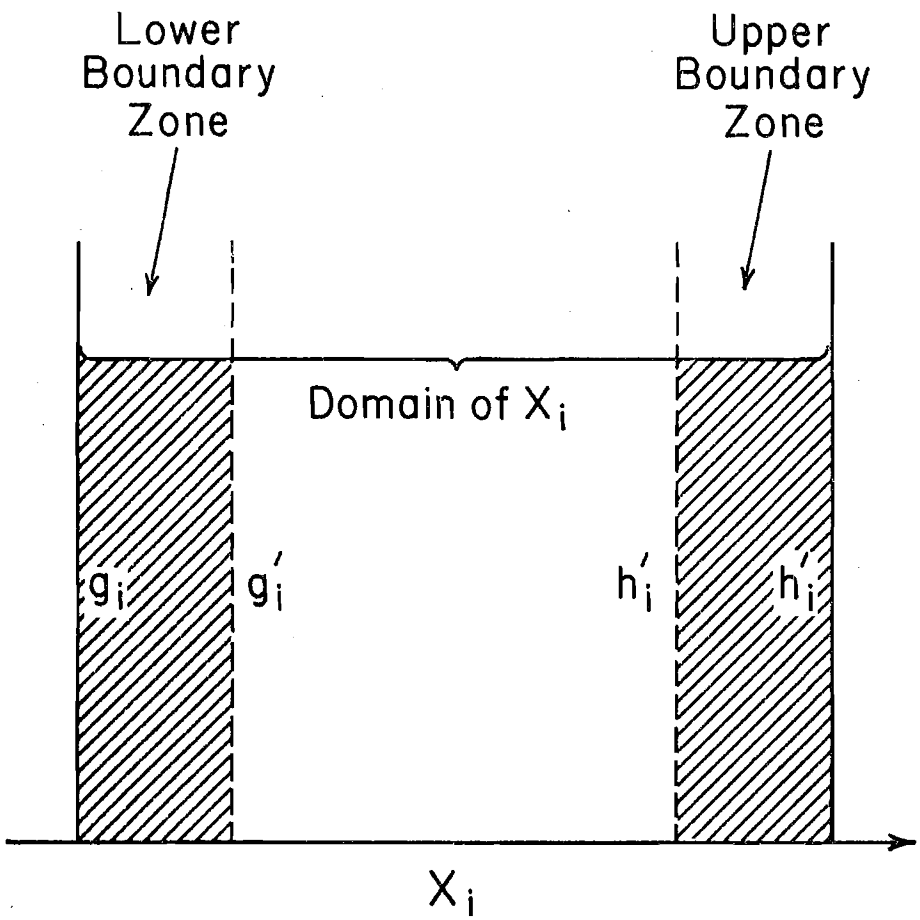

Fig. 1 Rosenbrock's Method of Handling Bounds

X_i^N then varies from 0 to 1 for all i. Using this transformation in Eq. F-6 and F-7, the depths of penetration into boundary zones can be expressed as

$$\eta_{L_i}^N = (\varepsilon - X_i^N)/\varepsilon \qquad \text{(F-9)}$$

and

$$\eta_{U_i}^N = (X_i^N + \varepsilon - 1)/\varepsilon \qquad \text{(F-10)}$$

The bounded search is carried out as in the unconstrained version except for each objective function evaluation some additional steps must be performed. Let $\hat{X}^N$ denote the normalized decision vector defining the next point at which f (the objective function) is to be evaluated according to the unconstrained method. The additional steps are summarized by Avriel[25]:

1) If $\hat{X}^N$ is feasible, call the move to $\hat{X}^N$ a failure and continue as in the unconstrained version.

2) If $\hat{X}^N$ is feasible and does not lie in any boundary zone, follow the unconstrained version.

3) If $\hat{X}^N$ is in a boundary zone, modify the function value $f(\hat{X}^N)$ as follows: Set the index j equal to the first component of the vector and reset $f(\hat{X}^N)$ to a revised f defined as

$$\bar{f}(\hat{X}^N) = f(\hat{X}^N) - [f(\hat{X}^N) - f^+][3\eta_j - 4\eta_j^2 + \eta_j^3] \qquad \text{(F-11)}$$

wherein f^+ is the current lowest value of f at feasible points not in the boundary zones. Now increase j to the second component of $\hat{X}^N$ that lies in a boundary zone and recompute $\bar{f}$ by replacing $f(\hat{X}^N)$ by $\bar{f}(\hat{X}^N)$ in Eq. F-11.

Ending criteria can be defined for the Rosenbrock search by checking the intra-stage movement of the decision vector. If movement is less than some small prescribed value the algorithm can be terminated. This intra-stage normalized movement can be defined as

$$X_D^N = [\sum_i (X_i^N - X_i^{N+})^2]^{0.5} \quad \text{(F-12)}$$

with X_i^{N+} is the i^{th} normalized decision variable value for the current best objective function. Additionally, at the end of each stage, a check for the movement of both the decision vector and the objective function is done. Concurrent small prescribed movements of both the decision vector and objective function for a given stage will also cause termination. These movements can be defined by

$$X_M^N = [\sum_i (X_i^{N*} - X_i^{N*-1})^2]^{0.5} \quad \text{(F-13)}$$

and

$$F_M = | f^* - f^{*-1} | \quad \text{(F-14)}$$

where X_i^{N*} is the normalized i^{th} decision variable value for the best objective function, f^*, found in the present stage; and X_i^{N*-1} is the i^{th} decision variable value for the best objective function, f^{*-1}, found in the previous stage.

Parameters can be defined to cause search termination. These are defined as ϕ, Δ, and θ and termination of the algorithm occurs if

$$X_D^N \leq \phi \quad \text{(F-15)}$$

or

$$\{X_M^N \leq \Delta \text{ and } F_M \leq \theta\}$$

The total number of required parameters for the algorithm is then seven, namely α, β, ε, γ, ϕ, Δ, and θ. Table F-1 gives the values of these parameters used in the optimization routine for this study.

TABLE F-1 Modified Rosenbrock Optimization Parameters

Parameter	Value	
α	3.0	acceleration/deceleration
β	0.5	parameters
γ	0.05	initial stage stepsize parameter
ε	0.0001	boundary definition parameter
ϕ	0.001	
Δ	0.1	ending criteria
θ	0.1	parameters

Appendix G

USER'S GUIDE FOR CONTINUOUS SIMULATION MODEL

Seven files supply the input for the continuous ILLUDAS model. Table G-1 lists these input files along with a general description of the purpose of each. Some or all of these files must be supplied depending on the type of run of the model. The type of run is set in the CNTRL file.

TABLE G-1 Input Files

File name	Description
CNTRL	Sets basic information for run such as number of years of simulation, type of run, parameter settings, etc.
DLYRN	Daily rainfall for simulation/calibration
DLYEV	Daily pan evaporation
STMSRT	Number of events on each day of simulation/calibration
RFALL	Detailed event rainfall data
DISCH	Observed event discharge hydrographs for calibration or comparison
BASIN	ILLUDAS description of modelled basin

Three files are used for output from the model. Table G-2 describes these files.

TABLE G-2 Output Files

File Name	Description
RESULT	Detailed event simulation/calibration results
PEAKS	Summary of event simulation
UNDER	Output file for under-dimensional events for subsequent execution

Card Number	Card Column	Format	Description	Variable Name	Default Value

**** File CNTRL ****

Card Number	Card Column	Format	Description	Variable Name	Default Value
C-1	-	LD* (integer)	Maximum no. of incremental rainfall depths in any event	NDIM	None
	-	LD (integer)	Maximum number of branches into and out of any node	MAXBR	None
C-2	-	LD (real)	ILLUDAS soil group specification. A value of 1 (clay) to 4 (sand) on a continuous scale. This is used to determine internal default values for soil moisture accounting values. A value must be specified even if default values are not used.	GROUP	None
	-	LD (real)	Antecedent soil moisture condition on continuous scale from 1 (dry) to 4 (saturated). A value must still be placed here but is not used. This item will be taken out in the future.	AMC	None
C-3	-	LD (logical)	Specify false (F)	GRAPH	None
	-	LD (logical)	Observed discharge hydro data supplied	DIS	None
	-	LD (logical)	Pan-evaporation data supplied	EVPRTN	None
	-	LD (logical)	Surface and reach routing	RTNG	None
	-	LD (logical)	Calibration run	CALIB	None
	-	LD (logical)	Simulation run	SIMUL	None
	-	LD (logical)	Not used specify false	OPTDES	None
	-	LD (logical)	Design storm execution run	DESSTM	None
	-	LD (logical)	Not used specify false	CRTOBS	None
	-	LD (logical)	Runoff volume objective function for calibration	OBJVOL	None

* - List-directed or free input format

Card Number	Card Column	Format	Description	Variable Name	Default Value
C-3	-	LD (logical)	Peak event discharge objective function used for calibration.	OBJQP	None
	-	LD (logical)	Runoff hydrograph shape objective function used for calibration.	OBJSHP	None
			NOTE: Only one objective function (OBJVOL, OBJQP or OBJSHP) should be used.		
	-	LD (logical)	Detailed printout to RESULT file	PRNT	None
	-	LD (logical)	Internal default values of soil moisture parameters to be used.	INTERN	None
C-4	-	LD (logical)	Number of years of simulation/ calibration; this item is not required if design storm simulation is performed (DESSTM = .TRUE.)	NYRS ($\leq$ 25)	None
C-5	-	LD (integer)	Start year of simulation/calibration expressed as for example "81" for "1981"	YRST(.) YRST(.)	None None
	-	LD (integer)	Start month of simulation/ calibration (Jan = 1, etc.)	STMØ(.)	None
	-	LD (integer)	Start day of simulation/ calibration	DYST(.)	None
	-	LD (integer)	End year of simulation/calibration (should = YRST(.)) expressed as "69" for "1969"	YRED(.)	None
	-	LD (integer)	End month of simulation/ calibration	EDMØ(.)	None
	-	LD (integer)	End day of simulation/ calibration	DYED(.)	None
			NOTE: As with card C-4, C-5, is not required when design storm simulation is performed. Repeat card C-5 for each year of simulation until there is a total of NYRS card C-5's.		
C-6	-	LD (real)	Maximum impervious area initial abstraction (in.)	PVDAB	None
	-	LD (real)	Maximum pervious area initial abstraction (in.)	GRDAB	None

Card Number	Card Column	Format	Description	Variable Name	Default Value
C-7	-	LD (real)	Horton dry infiltration capacity (in./hr)	FO	None
		LD	Horton saturated infiltration capacity (in./hr)	FC	None
		LD (real)	Horton decay coefficient (hr^{-1})	KIF	None
		LD (real)	Maximum daily soil moisture storage (in.)	C	None
		LD (real)	Fraction of daily rainfall which infiltrates (dimensionless)	DRR	None
		LD (real)	Fraction of maximum daily soil moisture storage which is field capacity (no gravity drainage) (dimensionless)	FCAP	None
		LD (real	Daily deep percolation rate (in./day)	DLYPER	None
		LD (real)	Pervious area entry time (min), this item used only if calibration of this item for whole basin is done. In order to calibrate this item source program must be changed in subroutine ILLUDAS.	GNT	None
		LD (real)	Impervious area entry time (min), this item used only if calibration of this item for whole basin is done. In order to calibrate this item source program must be changed in subroutine ILLUDAS.	PNT	None
		LD (real)	Reach Manning's n, this item used only if it is to be calibrated. In order to calibrate this item source program must be changed in subrouting ILLUDAS.	RFF	None
		LD (real)	Antecedent soil moisture condition for simulation/calibration start and any record gaps. Specified on a continuous scale of 1 to 4.	AMC	None

Card Number	Card Column	Format	Description	Variable Name	Default Value
C-7	-	8LD (real)	All these variables were included for design storm optimization. They are not used in this program but values must be specified arbitrarily for the present source program. NOTE: Card C-7 is not required if internal parameter setting (Card C-3, INTERN = .TRUE.) is specified.	DUR, AP, PEX, QEX, PST, QST, PSTST, QSTST	None
C-8	-	21LD (Integer)	Sequence of optimization of parameters for calibration (and only for calibration, this card is not used for simulation or design storm generation). The sequence is defined corresponding to the seq sequence of parameters defined on Cards C-6 and C-7. There must be sequence numbers for all parameters to be calibrated. If a parameter is not to be calibrated a "0 (zero)" should be entered as its sequence number. For example if the three Horton parameters are to be calibrated (and no others) this card could be entered as "1 2 3 18* 0" for the twenty-one parameters and the search sequence would start with FO, then FC, and finally KIF.	OPTNO(.)	None
C-9	-	LD (real)	Frequency expressed as a return period in years of design storm	FREQ	0
	-	LD (real)	Design storm duration (min)	DURA	None
	-	LD (real)	Design storm rainfall depth (in.)	TRAIN	None
	-	LD (integer)	Hyetograph designation 1 - Uniform 2 - Huff 3 - Triangular 4 - Beta 5 - Bi-Beta (not available)	HYETO	None
	-	LD (real)	Design storm antecedent Moisture condition on continuous scale from 1 to 4	AMC	None
	-	LD (real)	Pipe design mode 1 - design pipes blank or 0 - no design	DESIN	0

Card Number	Card Column	Format	Description	Variable Name	Default Value
C-9	-	LD (real)	Simulation mode 1 - simulation (existing system) blank or 0 - no evaluation NOTE: Only one mode (DESIN or EVAL) should be specified as 1	EVAL	0
	-	LD (real)	Debugging print-out 1 - print-out blank or 0 - no debug print-out	DEBUG	0
	-	LD (integer)	Reach routing option 1 - time-shift 2 - explicit hydrologic 3 - implicit hydrologic	IDXRTE	1
	-	LD (real)	Simulation time increment (min)	DTOUT	None
			NOTE: Card C-9 only required for design storm generation. As many C-9 cards can be repeated as desired to generate different design storm runs. Only files RFALL (used only for basin I.D.), BASIN, and CNTRL one required for design storm simulation.		

**** File DLYRN ****

Card Number	Card Column	Format	Description	Variable Name	Default Value
D-1		LD (integer)	Year of daily rainfall data, this item should be equal to each of the YRST(.)'s specified on the card C-5's (expressed as "1981")	YEAR1	None
D-2	1-4 5-8 61-64	16F4.2	Daily rainfall depths (in.) the no. of these to be specified is computed from the C-5 cards. Repeat this card until all daily rainfall depths have been specified for year YEAR1.	RAIN(.)	None
			NOTE: Repeat the D-1 and D-2 cards for each year of simulation or calibration. DLYRN is not a required file if design storm simulation is being performed.		

Card Number	Card Column	Format	Description	Variable Name	Default Value
			**** File DLYEV ****		
DE-1	-	LD (integer)	Year of daily pan-evaporation data, this item should be equal to each of the YRST(.)'s specified on the card C-5's (expressed as "1981")	YEAR2	None
DE-2	1-4 5-8 61-64	16I4	Daily pan-evaporation (in.), the no. of these to be specified is computed from the C-5 cards. Repeat this card until all daily pan-evaporation has been specified for year YEAR2.		
			NOTE: Repeat the DE-1 and DE-2 cards for each year of simulation/calibration. DLYEV is not a required file if design storm generation is being performed. If EVPRTN = .FALSE. on card C-3 internal average monthly pan-evaporation data for Urbana, IL are used to approximate these values and thus file DLYEV is not required.		
			**** File STMSRT ****		
S-1	-	LD (integer)	Year of no. of events for each day data, this item should be equal to each of the YRST(.)'s specified on the card C-5's (expressed as "1981"0.	YEAR3	None
S-2	1-4 5-8 61-64	16I4	Number of events occurring on a simulation/calibration day. The no. of these to be input is computed from the C-5 cards. Repeat this card until all the days for year YEAR1 have their no. of events defined. If no events occur on a given day a zero is entered.	NSTM(.)	None

Card Number	Card Column	Format	Description	Variable Name	Default Value
			****** File DISCH ******		
Q-1	-	LD (real)	Time increment (min) at which the observed outlet discharge hydrograph is specified	DISTIM	None
	-	LD (integer)	Number of observed discharges to be specified	NØBS	None
	-	LD (real)	Observed event discharge hydrograph volume (ft^3)	VOLBOS	None
Q-2	-	LD (real)	Observed event discharge hydrograph values (cfs), NOBS in number.	QOBS(.)	None
			NOTE: Repeat Q-1 and Q-2 cards for all events corresponding to all events in the RFALL file. DISCH is only required for calibration.		
			****** File RFALL ******		
R-1	1-80	20A4	Basin and ppt. record description up to 80 characters	XNAME(.)	BLANK
R-2	12-13	I2	Event starting year (example "81" for "1981")	IYR	None
	14-15	I2	Event starting month (Jan = 1, etc.)	MTH	None
	16-17	I2	Event starting day of month	IDY	None
	20-24	F5.0	Event starting time in military time (example 3:00 PM would be "1500")	ST	None
	42-46	F5.0	Event ending time in military time	ENDTIM	None
R-3	1-10	F10.0	*Run identification* - An identification number of run to delineate separate runs of the same basin and/or storm.	XID	0.0
	11-20	F10.0	*Design mode* - A positive number indicates design mode for sizing all or some of the sewers; otherwise a zero or blank entry assumes a non-design mode.	DESIN	0.0

Card Number	Card Column	Format	Description	Variable Name	Default Value
R-3	21-30	F10.0	*Simulation mode* - A positive number indicates simulation (evaluation) mode of existing network.	EVAL	0.0
	31-40	F10.0	Debugging print-out option 1 - print-out blank or 0 - no debug print-out	DEBUG	0.0
	41-50	I10	Reach routing option 1 - time shift 2 - explicit hydrologic 3 - implicit hydrologic	IDXRTE	1
R-4	1-10	F10.0	Total area of basin in acres	AREA	0.0
	41-50	F10.0	Smallest pipe diameter in inches to be used for system design (this item not specified for simulation).	DIMIN	8.0
	51.60	F10.0	Manning's 'n' value for system design (this item not specified for simulation/calibration).	RUFFN	0.0
R-5	1-10	F10.0	A non-zero entry specifies that rainfall depth increments will be specified	XRN	0.0
	11-20	F10.0	The number of rainfall depth increments to be specified	XRI	0.0
	21-25	F5.0	Rainfall input time increment (min)	DTIN	None
	26-30	F5.0	Runoff simulation time increment (min)	DTOUT	None
	31-40	F10.0	Hyetograph designation (XRN = 0.0) 1 - Uniform 2 - Huff 3 - Triangular 4 - Beta	XHY	None
	41-50	F10.0	Duration in minutes. This is for input reference. The duration is re-computed from XRI and DTIN from this card.	DURA	None
	51-60	F10.0	Return period in years. Only specified if XHY≠ 0	FREQ	0.0
	61-70	F10.0	Total rainfall in inches. This is for input reference only. It is recomputed in the program.	TRAIN	0.0

Card Number	Card Column	Format	Description	Variable Name	Default Value
R-6	1-10 11-20 71-80	8F10.0	Incremental rainfall depths for this event. Repeat this card until all the rainfall for this event has been entered.	RR(.)	0.0
			<u>NOTE</u>: <u>Repeat</u> cards R-1 through R-6 for each event until all event rainfalls have been entered.		
			**** File BASIN ****		
B-1	1-3	F3.0	*Branch* - The branch number, a numeric between 1 and 999, which is the first part of an identifying number assigned to each sewer or channel. The numerical value of the branch numbers does not influence the order in which ILLUDAS is applied to the basin since this is determined by the order in which the reach cards appear in the input deck.	BRAN (70)	None
	4-6	F3.0	*Reach* - The reach number is a numeric designation to identify the sewer or channel in the branch and is the second portion of the identifying number assigned to each sewer or channel. The uppermost sewer of each branch must be assigned a reach number of zero. This number is increased by 1 for each consecutive downstream sewer in a particular branch.	REACH	None
	7-9	F3.0	*Terminating branch* - The branch number that terminates at the confluence.	ENDBR	0.0
	10-12	F3.0	*Continuing branch* - The branch number that continues through the confluence.	CONBR	0.0
			<u>NOTE</u>: ENDBR and CONBR should be left blank unless there is a branch termination, then they are the only entries on this card and no card B-2 is used.		

Card Number	Card Column	Format	Description	Variable Name	Default Value
B-1	13-15	I3	*Option* - This item is used to define the mode (simulation or design) to be used for this sewer. It may contain a blank which returns control of the option mode specified on Card Set 2 or it may contain a 1 or a 2. A 1 calls the design mode in which ILLUDAS will select a large enough pipe to pass the design hydrograph. A 2 calls the simulation mode in with ILLUDAS will route the hydrograph through the existing pipe and print out the accumulated storage if the pipe is undersize.	IRUN	(As that specified by type of run card)
	16-20	F5.0	*Sewer length* - This is the length in feet of this particular sewer or channel.	DIST	None
	21-25	F5.0	*Slope* - This is the average invert slope in percent, that is, feet drop per 100 feet, for this sewer.	SLP	None
	26-30	F5.0	*Manning's n* - This item gives Mannings roughness factor of the pipe or open channel if this reach is part of an existing system. If this sewer is in design mode, ILLUDAS will use the value specified in columns 51-60 in Card R-4 (if design storm generation is performed RUFFN and DIMIN are set internally).	RUFF	0.0
	31	I1	*Cross section* - For the design mode this location sould be left blank since ILLUDAS uses only circular sections for new designs. For the simulation mode this location will contain a 1, 2, or 3 indicating whether the existing cross section of the sewer is circular, rectangular, or trapezoidal, respectively.	ISECT	1
	32-35	F4.0	*Pipe diameter* - In simulation mode if this sewer is an existing circular section, the user must enter the diameter in inches in this location. The user must reduce other odd-shaped sections such as oval, horseshoe, or egg-shaped to equivalent circular sections and indicate these by a 1 in column 31 and the equivalent diameter here. For the design mode leave this location blank.	DIAM	None

Card Number	Card Column	Format	Description	Variable Name	Default Value
B-1	36-40	F5.0	*Rectangular section height* - In the simulation mode this location should contain the height in feet of a rectangular cross section. If the cross section is trapezoidal this item will indicate the bank-full depth in feet. For the design mode leave this space blank.	HR	None
	41-45	F5.0	*Width* - As in the preceeding item, this location serves two mutally exclusive functions. It may contain the width in feet of a rectangular section, or the bottom-width in feet of a trapezoidal section. For design option leave this location blank.	WR	None
	46-50	F5.0	*Section side slope* - This location is used only in simulation mode for trapezoidal cross sections and contains the lateral or side-slope of the trapezoid expressed as the feet of rise per foot of run. For design mode leave this location blank.	SS	None
	51-55	F5.0	*Allowable sewer discharge* - The user may limit the flow in a particular sewer by specifying here the maximum allowable discharge for the sewer in cfs.	QALOW	None
	56-60	F5.0	*Rainfall ratio* - The user may change the total rainfall being applied to this particular subbasin by entering here the desired total rainfall divided by the total rainfall specified on Card R-5.	FREQR	1.0
	61-65	F5.0	*Available storage* - If the user wishes to incorporate detention storage into the design, specify the amount of storage in 1000 cubic feet to be provided at the entrance to this particular sewer.	STORE	0.0
	66-68	A3	*End test* - The word END should appear in this location on the last sewer in the basin.	TEST	0

Card Number	Card Column	Format	Description	Variable Name	Default Value
B-1	69-70	I2	*Print hydrograph* - The ordinates of the design hydrograph entering any sewer can be printed in tabular form on the computer output by entering a positive integer in this location.	HYD	0
B-2	1-3	F3.0	Branch no. of reach which this sub-basin runoff enters	CBRAN (70)	None
	4-6	F3.0	Reach no. in the branch which this sub-basin runoff enters	CREACH	0
	7-15	F7.0	Total drainage area for this hydrograph in acres.	BA	None
	16-20	F5.0	Directly connected impervious area in acres.	CPA	None
	21-23	F3.0	Percent of total area which is directly connected impervious area. This is an alternate to the previous value (CPA). Both should not be specified.	PCPA	None
	24-28	F5.0	Supplemental impervious area in acres. This is the area which flows onto previous areas before reaching the inlet.	SPA	None
	29-31	F3.0	Percent of total area which is supplemental impervious. This is an alternate to specifying the previous item (SPA). Both should not be specified.	PSPA	None
	32-36	F5.0	Impervious area entry time in minutes. This is the time of concentration at the inlet for the impervious area. It is determined by the user.	PENT	None
	37-41	F5.0	The length in ft of the longest impervious area flow path to the inlet. If the previous item (PENT) is specified this item is left blank.	PL	None
	42-46	F5.0	The slope (in percent) of the impervious area flow path. If PENT is specified this should be left blank.	PS	None

Card Number	Card Column	Format	Description	Variable Name	Default Value
B-2	47-51	F5.0	The pervious area in acres contributing to runoff.	CGA	None
	52-54	F3.0	The percent of the total area which is pervious area. This is an alternate to the pervious item (CGA). Both should not be specified.	PCGA	None
	55-59	F5.0	Pervious area entry time in minutes. This is the time of concentration at the inlet for the pervious area. It is determined by the user.	GENT	None
	60-64	F5.0	The length in ft of the longest pervious area flow path to the inlet of the previous item (GENT) is specified this item is left blank. A decimal point is required.	GL	None
	65-69	F5.0	The slope (in percent) of the pervious area flow path. If GENT is specified this item is left blank. A decimal point is required.	GS	None
	72-76	F5.0	A rainfall factor which can be used to adjust all rainfall hyetograph ordinates for this inlet. If no adjustment is needed leave blank. A decimal point is required.	FREQR	1.0
	77-80	I4	If the inlet hydrograph and associated information is required in the output, enter a 1 anywhere in columns 77-80. Otherwise leave blank.	HYD	0

NOTE: Repeat cards B-1 and B-2 until all reaches, sub-basins and confluences for the basin have been described.

Default Parameters Used by Program When

INTERN = .TRUE. on Card C-3

PVDAB = 0.1 (in.)

GRDAB = 0.2 (in.)

* FO = 12 - 2 x GROUP, GROUP $\leq$ 2 (in./hr)

FO = 7 - 2 x (GROUP-2), GROUP > 2 (in./hr)

FC = Exp (.805 - .715 x GROUP) (in./hr)

KIF = 2.0 (hr^{-1})

** C = FO (1 - Exp (-ALPHA/k)/ALPHA (in.)

DRR = 0.9

FCAP = 0.4

DLYPER = 0.1 (in./day)

AMC = 2.0

* GROUP is the hydrologic soil group on a continuous scale from 1 to 4.

** ALPHA = -KIF (ℓn (1-FC/FO))

Appendix H
Listing of Continuous Simulation Model

```
C....  THE CONTINUOUS ILLINOIS URBAN DRAINAGE SIMULATOR FOR 3/1-11/30 INCLUSIVE.
C....    WITH MODIFIED ROSENBROCK OPTIMIZATION OF PARAMEIFR VECTOR
C....    CIVIL ENGINFFRING DEPT.  7/79
C....    H. L. VOORHEES
      PROGRAM MAIN(CNTRL,OUTPUT,DLYRN,DLYEV,STMSRT,RFALL,DISCH,BASIN
     $,RESULT,PFAKS,UNDER,INPUT,
     $TAPE1=DLYRN,TAPE2=DLYEV,TAPE3=STMSRT,TAPE4=RFALL,
     $TAPE5=DISCH,TAPE6=BASIN,TAPE7=RESULT,TAPE8=PEAKS,TAPE9=UNDER,
     $TAPE10=OUTPUT,TAPE11=CNTRL,TAPE12=INPUT)
C*****************************************************************************
C....  DEFINITION OF MAX DIMENSIONING FOR ILLUDAS AND ITS SUBRS
      DIMENSION AA(520),AR(520),GAD(520)
      DIMENSION PASR(520),GGR(520),GR(520),Q(4,521)
      DIMENSION RI(520),RR(520),QOBS(520)
      DIMENSION RRX(520),QT(520),SR(520),TMPGR(5200),TMPQ(5200),TEMP(520
     $)
      DIMENSION QXOBS(520),TYPE(520),XOBCA(520),QCOM(520),XCOM(520)
C*****************************************************************************
      CALL INPT(NDIM,MAXBR,NDP1,ND10)
      CALL RSNBRCK
C     CALL FLEXI
C     CALL MGRG
     $(NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCON,TEMP,XCOM)
      STOP
      END
C     PROGRAM TEST(INPUT,OUTPUT)
C     PROGRAM FLEXI (INPUT,OUTPUT,TAPE10=INPUT)
      BLOCK DATA AREDIS
C
C
      COMMON /AOQO/ AO(51),QO(51),HO(51)
      DATA AO/0.00000000, .00005260, .00041978, .00141116, .00332652,
     1 .00645107, .01105094, .01736901, .02562104, .03599230, .04863465,
     2 .06366413, .08115911, .10115911, .12366413, .14863465, .17599230,
     3 .20562104, .23736901, .27105094, .30645107, .34332652, .38141116,
     4 .42041978, .46005260, .50000000, .53994740, .57958022, .61858884,
     5 .65667348, .69354893, .72894906, .76263099, .79437896, .82400770,
     6 .85136535, .87633587, .89884089, .91884089, .93633587, .95136535,
     7 .96400770, .97437896, .98263099, .98894906, .99354893, .99667348,
     8 .99858884, .99958022, .99994740,1.00000000/
      DATA QO/0.00000000, .00000100, .00002012, .00011584, .00039926,
     1 .00103766, .00225361, .00432056, .00755523, .01230744, .01894770,
     2 .02785327, .03939321, .05391291, .07171900, .09306491, .11813796,
     3 .14704829, .17982015, .21638599, .25658341, .30015533, .34675325,
     4 .39594361, .44721701, .50000000, .55366899, .60756595, .66101521,
     5 .71334091, .76388446, .81202145, .85717751, .89884250, .93658279,
     6 .97005104, .99899317,1.02325424,1.04277704,1.05760388,1.06787124,
     71.07380380,1.07570612,1.07395264,1.06897632,1.06125665,1.05130715,
     81.03966306,1.02686954,1.01317073,1.00000000/
      DATA HO/0.00000000, .00098664, .00394265, .00885637, .01570842,
     1 .02447174, .03511176, .04758647, .06184666, .07783604, .09549150,
     2 .11474338, .13551569, .15772645, .18128801, .20610737, .23208660,
     3 .25912316, .28711035, .31593772, .34549150, .37565506, .40630934,
     4 .43733338, .46860474, .50000000, .53139526, .56266662, .59369066,
     5 .62434494, .65150850, .68406228, .71288965, .74087684, .76791340,
     6 .79389263, .81871199, .84227355, .86448431, .88525662, .90450850,
     7 .92216396, .93815334, .95241353, .96488824, .97552826, .98429158,
     8 .99114363, .99605735, .99901336,1.00000000/
      END
      SUBROUTINE INITX(X,MAXOPT,NE,NI,G,H)
      DIMENSION X(50),G(50),H(50),OPTNO(25)

      DIMENSION XM(25),PARM(25),GG(25),HH(25)
      COMMON/ZZZZST/NOBJ,NCNST,M1,M2
      COMMON /OPT/PAR(25),FOO,FC,KIF,C,RR,FCAP,PVDAB,GRDAB,DLYPER,
     1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FO
      COMMON /LOGIC/PRNT,DESSTM,OPTDES,SIMUL,CRTOBS,CALIB,EVPRTN
     1,DIS,GRAPH,RTNG,OBJVOL,OBJQP,OBJSHP
      INTEGER EO,FO,OPTNO
      LOGICAL PRNT,DESSTM,OPTDES,SIMUL,CRTOBS,CALIB
      REAL KIF
C
C....       * INITIAL OPTIMIZATION ROUTINE *
C
C....  PLACE ELEVEN PARAMETERS IN X-ARRAY
      NE=0
      NI=0
      NOBJ=NCNST=0
      M1=NE
      M2=NI
      X(1)=FOO$X(2)=FC $X(3)=KIF $X(4)=C $X(5)=RR
      X(6)=FCAP$ X(7)=PVDAB  $ X(8)=GRDAB  $ X(9)=DLYPER
      X(10)=GNT $ X(11)=PNT $X(12)=RFF
      X(13)=AMC $ X(14)=DUR $X(15)=AP $ X(16)=PEX
      X(17)=QEX $ X(18)=PST $ X(19)=QST $ X(20)=PSTST $ X(21)=QSTST
      IF(.NOT.OPTDES.AND..NOT.CALIB) RETURN
      EO=21
      PRINT*,' INPUT THE SEQUENCE OF OPTIMIZATION'
      PRINT6691,(PAR(IOP),IOP=1,EO)
 6691 FORMAT(9(1X,A3))
      READ(11,*) (OPTNO(I),I=1,EO)
C....  PLACE PARAMETERS IN X-ARRAY AS DETERMINED BY OPTNO-ARRAY
      DO 901 I=1,EO
      PARM(I)=PAR(I)
      XM(I)=X(I)
      GG(I)=G(I)
  901 HH(I)=H(I)
      MAXOPT=0
      DO 903 I=1,EO
      IF(OPTNO(I).GT.MAXOPT) MAXOPT=OPTNO(I)
      IF(OPTNO(I).GT.0) X(OPTNO(I))=XM(I)
      IF(OPTNO(I).GT.0) G(OPTNO(I))=GG(I)
      IF(OPTNO(I).GT.0) H(OPTNO(I))=HH(I)
  903 IF(OPTNO(I).GT.0) PAR(OPTNO(I))=PARM(I)
      IF(MAXOPT.EQ.EO) GO TO 803
      FO=MAXOPT
      ILO=MAXOPT+1
      DO 907 I=1,EO
      IF(OPTNO(I).EQ.0) X(ILO)=XM(I)
      IF(OPTNO(I).EQ.0) PAR(ILO)=PARM(I)
      IF(OPTNO(I).EQ.0) H(ILO)=HH(I)
      IF(OPTNO(I).EQ.0) G(ILO)=GG(I)
  907 IF(OPTNO(I).EQ.0) ILO=ILO+1
  803 CONTINUE
       PRINT 1030
      DO 65 I=1,EO
      IF(I.LE.FO)OPTNO(I)=I
      IF(I.GT.FO) OPTNO(I)=0
      IF(OPTNO(I).GT.0) PRINT 789,I,PAR(I),X(I),OPTNO(I)
  789 FORMAT(I10,5X,A4,F10.4,' + ','(',I2,')')
   65 IF(OPTNO(I).LE.0) PRINT 799, I,PAR(I),X(I)
  799 FORMAT(I10,5X,A4,F10.4,' - ')
C
C....        CHECK IF INITIAL PARAMETER VALUE WITHIN OUTER BOUNDARY
C....        VALUES
C

      DO 45 I=1,EO
          XX=X(I)
          IF (XX.LE.G(I)) GO TO 40
          IF (XX.GE.H(I)) GO TO 40
          GO TO 45
C
C....                      IF PARAMETER VALUES NOT WITHIN BOUNDARY VAL
C....                      PRINT ERROR MESSAGE
C
   40      PRINT 1055, I,G(I),X(I),H(I)
          STOP
   45 CONTINUE
      RETURN
C
 1030 FORMAT(1H1,' INITIAL PARAMETER VALUES AND OPT DESCRIPTION.',/)
 1055 FORMAT (1H ,38HFAILURE OF BOUNDARY CHECK OF PARAMETER,I3,3F10.3)
      END
      SUBROUTINE OBJF(X,F,NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM,NP)
      DIMENSION RAIN(366),EVAPT(366),NODYMO(12),NSTM(366),AEVAPT(12)
      COMMON /DATA/ SMS(366),IDYST(25),STMO(25),DYST(25),IDYED(25),EDMO(
     $25),DYED(25),YRST(25),YRFD(25),PANRAT,TRANRAT,QB,NRCH
     $,RAIN(366),EVAPT(366),NODYMO(12),NSTM(366),AEVAPT(12),NYRS
      DIMENSION X(50)
C*****************************************************************************
C....  DEFINITION OF MAX DIMENSIONING FOR ILLUDAS AND ITS SUBRS
      DIMENSION AA(NDIM),AR(NDIM),GAD(NDIM)
      DIMENSION PASR(NDIM),GGR(NDIM),GR(NDIM),Q(MAXBR,NDP1)
      DIMENSION RI(NDIM),RR(NDIM),QOBS(NDIM)
      DIMENSION RRX(NDIM),QT(NDIM),SR(NDIM),TMPGR(ND10),TMPQ(ND10),TEMP(
     $NDIM)
      DIMENSION QXOBS(NDIM),TYPE(NDIM),XOBCA(NDIM),QCOM(NDIM),XCOM(NDIM)
      DIMENSION IDD(4),IMM(4)
C*****************************************************************************
      COMMON /OPT/PAR(25),FO,FC,KIF,C,DRR,FCAP,PVDAB,GRDAB,DLYPER,
     1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
      COMMON /LOGIC/PRNT,DESSTM,OPTDES,SIMUL,CRTOBS,CALIB,EVPRTN
     1,DIS,GRAPH,RTNG,OBJVCL,OBJQP,OBJSHP
C     COMMON /INF/FO,FC,KIF,DDELT,ALPHA,FCAP,C,DLYPER
      COMMON /INF/DDELT,ALPHA
      COMMON /MOIST/TSMS(20,20),FACTOR(20,20),DIRT(20,20),IBX(35),
     +IRX(35),TMFSMS(35),HYETO
      COMMON/ZZZZST/NOBJ,NCNST,M1,M2
       INTEGER YRST,STMO,DYST,YRFD,EDMO,DYED,OPTNO
      INTEGER YEAR1,YEAR2,YEAR3,HYETO,FOO
      REAL KIF
      LOGICAL GRAPH,DIS,INTERN,DYUNDER,RTNG,STP,OPTDES,ANS
      LOGICAL EVPRTN,CALIB,SIMUL,DESSTM,OBJVOL
      LOGICAL OBJQP,PRNT,CRTOBS,OBJSHP
C     NOBJ=NOBJ+1
C     DO 7993 IJX=1,NP
C     IF(PAR(IJX).EQ.3H FO) FO=X(IJX)
C     IF(PAR(IJX).EQ.3H FC) FC=X(IJX)
C     IF(PAR(IJX).EQ.3HKIF) KIF=X(IJX)
C     IF(PAR(IJX).EQ.3H  C)C=X(IJX)
C     IF(PAR(IJX).EQ.3HDRR)DRR=X(IJX)
C     IF(PAR(IJX).EQ.3HFCP) FCAP=X(IJX)
C     IF(PAR(IJX).EQ.3HPVD) PVDAB=X(IJX)
C     IF(PAR(IJX).EQ.3HGRD)GRDAB=X(IJX)
C     IF(PAR(IJX).EQ.3HDLY) DLYPER=X(IJX)
C     IF(PAR(IJX).EQ.3HGNT) GNT=X(IJX)
C     IF(PAR(IJX).EQ.3HPNT) PNT=X(IJX)
C     IF(PAR(IJX).EQ.3HRFF) RFF=X(IJX)
C     IF(PAR(IJX).EQ.3HAMC) AMC=X(IJX)
C     IF(PAR(IJX).EQ.3HDUR) DUR=X(IJX)
C     IF(PAR(IJX).EQ.3H AP)  AP=X(IJX)
```

```
C      IF(PAR(IJX).EQ.3HPEX) PEX=X(IJX)
C      IF(PAR(IJX).EQ.3HQEX) QEX=X(IJX)
C      IF(PAR(IJX).EQ.3H P*) PST=X(IJX)
C      IF(PAR(IJX).EQ.3H Q*) QST=X(IJX)
C      IF(PAR(IJX).EQ.3HP**) PSTST=X(IJX)
C7993 IF(PAR(IJX).EQ.3HQ**) QSTST=X(IJX)
C....  OUTPUT PARAMETER VECTOR TO TERMINAL AND RESULT FILE
C      IF(FOO.EQ.0) GO TO 1209
C      IF(.NOT.CALIB.AND..NOT.OPTDES) GO TO 1209
C      WRITE(7,7321)
C      WRITE(7,8995) NOBJ
C      WRITE(10,8995) NOBJ
C      DO 8393 IP=1,FOO
C      WRITE(7,8394) PAR(IP),X(IP)
C8393 WRITE(10,8394) PAR(IP),X(IP)
 8394 FORMAT(A10,' = ',F10.4,/,1X,40(1H*))
 8995 FORMAT(/,40(1H*),/,'  PARAMETER VALUES OF INTERFST FOR SIMULATION
     $LOOP ',I5)
 1209 CONTINUE
C....  REWIND THE DAILY PPT & EVP, AND STORM I.D. FILES
      IF(NYRS.EQ.1) GO TO 7879
      REWIND 1
      IF(EVPRTN)REWIND 2
      REWIND 3
C.....  WRITESIMULATION NUMBER(K)
C.... REWIND STORM AND DISCHARGE DATA FILES
 7879 REWIND 4
      REWIND 5
C....  START OF SIMULATION LOOP
      F=0.0
      STP=.FALSE.
      DO 38 NYR=1,NYRS
C....  SET THE INITIAL PAVED AND GRASSED AREA ABSTRACTIONS
      DEPG=GRDAB $ ABSTRT=PVDAB
      IF(.NOT.DESSTM) GO TO 3938
      NOSTM=1
      IST=1
      IED=1
      RAIN(1)=EVAPT(1)=0.0
      NSTM(1)=1
      GO TO 9652
C....  SET THE INITIAL SOIL MOISTURE STORAGES FOR EACH RFACH
 3938 DO 893 I=1,NRCH
      IF(FACTOR(IBX(I),IRX(I)).EQ.0.0) TSMS(IBX(I),IRX(I))=0.0
      IF(FACTOR(IBX(I),IRX(I)).EQ.0.0)GO TO 893
      TSMS(IBX(I),IRX(I))=(AMC-1.0)*C/3.0
      IF(NYR.EQ.1) GO TO 893
      IF(IDYED(NYR-1).EQ.365.OR.IDYED(NYR-1).EQ.366.AND.IDYST(NYR).EQ.1)
     $TSMS(IBX(I),IRX(I))=SMS(IDYED(NYR-1))
  893 CONTINUE
C....  READ DAILY RAIN AND PAN EVAPORATION DATA FOR NYR.
      IF(NYRS.EQ.1.AND.NOBJ.GT.1) GO TO 9652
      READ(1,*)YEAR1
      IF(EVPRTN)READ(2,*)YEAR2
      IF(.NOT.EVPRTN)YEAR2=YEAR1
      READ(03,*)YEAR3
      IF(YEAR1.NE.YRST(NYR)+1900) STP=.TRUE.
      IF(YEAR2.NE.YRST(NYR)+1900) STP=.TRUE.
      IF(YEAR3.NE.YRST(NYR)+1900) STP=.TRUE.
      IF(STP) PRINT*,' DATA FILES UNSYNCHRONIZED ',YFAR1,YEAR2,YEAR3
      IF(STP) STOP
      YEAR=FLOAT(YEAR1)
      IST=IDYST(NYR)
      IED=IDYED(NYR)
      READ(1,11220) (RAIN(I),I=IST,IED)
11220 FORMAT(16F4.2)
      IF(EVPRTN)READ(2,*) (EVAPT(I),I=IST,IED)
      IF(EVPRTN)GO TO 7878
C....  PLACE AVERAGE DAILY EVAPORATION IN EVAPT-ARRAY
      ILOW=1
      DO 9051 IMO=1,12
      IDYS=NODYMO(IMO)
      IF(((YRST(NYR))/4)*4.EQ.(YRST(NYR)).AND.IMO.EQ.2) IDYS=IDYS+1
      IUP=ILOW+IDYS-1
      DO 9050 IDY=ILOW,IUP
 9050 EVAPT(IDY)=AEVAPT(IMO)
 9051 ILOW=IUP+1
 7878 CONTINUE
      READ(03,11222) (NSTM(I11),I11=IST,IED)
11222 FORMAT(16I4)
 9652 DO 30 I=IST,IED
      DRAIN=RAIN(I)
C....  EVAPORATION IS EXPRESSED IN INCHES/DAY
      EVPPAN=EVAPT(I)
      IF(NSTM(I)) 50,50,40
   40 NOSTM=NSTM(I)
      DYUNDER=.FALSE.
      DO 7781 ILT=1,NOSTM
      CALL  ILLUDAS(PKOBS,PKCOM,
     +ABSTRT,QB,NRCH,RUFF,NOSTM,ILT,EVPPAN,PANRAT,TRANRAT,PREVEND,
     $DYUNDER,VOLCOM,VOLOBS,FINC,DEPG,YEAR,DRR,
     $PTRAIN,NDIM,NDP1,AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,
     $RRX,QXOBS,TYPE,XOBCA,QCOM,XCOM,QT,SR,TMPGR,TMPQ,TEMP,ND10,MAXBR,
     $I,NODYMO,DURA)
      IF(CALIB.OR.OPTDES)F=F+FINC
      IF(CALIB.OR.OPTDES)WRITE(7,1237) FINC,F
 7781 CONTINUE
      IF(DESSTM) GO TO 30
 1237 FORMAT('  INCREMENTAL OBJECTIVE FUNCTION = ',F15.5,
     +'  ACCUMULATED OBJECTIVE FUNCTION = ',F15.5)
      DRAIN=ABS(RAIN(I))
   50 CALL DLYACCT(DRAIN,EVPPAN,NRCH,PANRAT,TRANRAT,DEPG,ABSTRT,I,
     $SMST)
C.....  PLACE THE END OF DAY SOIL MOISTURE STORAGE IN THE SMS ARRAY
C....  NOTE: THIS IS THE SMS OF THE LAST SUB-BASIN
      SMS(I)=SMST
   30 CONTINUE
C....   WRITETHE END OF DAY SMS FOR LAST REACH FOR ACCTING CHECK
C....  THIS IS DONE FOR EACH DAY IN THE YEAR 'NYR'
C....   WRITEHEADING
      IF(DESSTM) GO TO 5
      IF(.NOT.PRNT) GO TO 38
              WRITE(7,6733) YRST(NYR)+1900
 6733 FORMAT('1',' SOIL MOISTURF RECORD FOR LAST REACH FOR',I5,/,
     $1X,4('  DAY  RAIN  EVP NST  SMS'))
      NDYS=IED-IST+1
      NDYS04=NDYS/4
      IF(NDYS.GT.NDYS04*4) NDYS04=NDYS04+1
      IS=IST
      DO 9955 NL=1,NDYS04
      IE=MINO(IS+3,IED)
      DO 9953 IJ=IS,IE
      IDMO=1
      DO 9954 IM=1,12
      ISMO=IDMO

      IDMO=IDMO+NODYMO(IM)-1
      IF(IM.EQ.2.AND.(YRST(NYR)/4)*4.EQ.YRST(NYR))IDMO=IDMO+1
      IF(IJ.GE.ISMO.AND.IJ.LE.IDMO) GO TO 9952
      IDMO=IDMO+1
 9954 CONTINUE
 9952 IDD(IJ+1-IS)=IJ+1-ISMO
 9953 IMM(IJ+1-IS)=IM
      WRITE(7,6731)(IMM(IJ+1-IS),IDD(IJ+1-IS),RAIN(IJ),EVAPT(IJ),NSTM(IJ
     $),SMS(IJ),IJ=IS,IE)
 6731 FORMAT(1X,3(1H!,I2,'/',I2,2F5.2,I4,F5.1),(1H!,I2,'/',I2,2F5.2,I4,F
     $5.1,1H!))
 9955 IS=IE+1
   38 CONTINUE
C      IF(CALIB.OR.OPTDES)WRITE(7,7321)
 7321 FORMAT(' ********************************************')
C....  FND OF SIMULATION LOOP
    5 IF(.NOT.CALIB.AND..NOT.OPTDES) STOP
      RETURN
       END
      SUBROUTINE ILLUDAS(PKOBS,PKCOM,
     +ABSTRT,QB,NRCH,RUFF,NOSTM,ILT,EVPPAN,PANRAT,TRANRAT,PREVEND,
     $DYUNDER,VOLOUT,VOLOBS,FINC,DEPG,YEAR,RRAT,
     $PTRAIN,NDIM,NDP1,A,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,
     $RRX,QXOBS,TYPE,XOBCA,QCOM,XCOM,QT,SR,TMPGR,TMPQ,TEMP,ND10,MAXBR,
     $IDAY,NODYMO,DURA)
      DIMENSION A(NDIM),AR(NDIM),GAD(NDIM),QT(NDIM),SR(NDIM)
      DIMENSION TMPGR(ND10),TMPQ(ND10),TEMP(NDIM)
      DIMENSION PASR(NDIM),GGR(NDIM),GR(NDIM),PQ(10), PV(10), Q(MAXBR,ND
     $P1)
      DIMENSION RI(NDIM),RR(NDIM), STORM(20), XNAMF(20),QOBS(NDIM)
      DIMENSION DIA(24),           MODE(2),XSEC(3),RTNG(3),RRX(NDIM)
      DIMENSION QXOBS(NDIM),TYPE(NDIM),XOBCA(NDIM),QCOM(NDIM),XCOM(NDIM)
      DIMENSION LOGINT(35),RCHINT(20),NODYMO(12)
      COMMON ECAP,FLAREA,EVEL,AO(51),QO(51),LSTSCT
C      COMMON /INF/FO,FC,KIF,DTOUT,ALPHA1,FCAP,C,DLYPER
      COMMON /INF/DTOUT,ALPHA1
      COMMON /OPT/PAR(25),FO,FC,KIF,C,DRR,FCAP,PVDAB,GRDAB,DLYPER,
     1GMT,PMT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
      COMMON /MOIST/TSMS(20,20),FACTOR(20,20),DIRT(20,20),IBX(35),
     +IRX(35),TMPSMS(35),HYETO
      COMMON /LOGIC/PRNT,DESSTM,OPTDES,SIMUL,CRTOBS,CALIB,EVPRTN
     1,DIS,GRAPH,RTING,OBJVOL,OBJQP,OBJSHP
      REAL KIF
      INTEGER HYD,HYETO,RAIN
      LOGICAL SRCHRG,BSNDBG,GRAPH,DIS,DYUNDER,RTING,LOGINT
      LOGICAL  PRNT,DESSTM,DIS,OPTDES,SIMUL,CRTOBS
      LOGICAL OBJVOL,OBJQP,OBJSHP,CALIB,EVPRTN,GRAPH,RTING
      DATA END/3HEND/
      DATA PREDI/12.0/
      DATA DIA/8.,10.,12.,15.,18.,21.,24.,27.,30.,36.,42.,48.,54.,60.,72
     1.,84.,96.,108.,120.,132.,144.,156.,168.,180./
      DATA MODE/5HDSGN ,5HSMLTN/
      DATA RTNG/5HTSHFT,5HEXPLT,5HIMPLT/
      DATA XSEC/3HCIR,3HRCT,3HTRP/
      MAXA=NDIM
      LT=4
      ALPHA=DLYPER/24.0/FC
      MT=6
 9903 NREACH=0
      TOTIN=TOTINF=0.0
C....  INITIALIZE INITIAL-BRANCH REACH LOGICAL ARRAY
C....   NO OF RFACHES,BRANCHES <= 20; BRAN ,REACH < 20
      DO 1 I=1,NRCH
    1 LOGINT(I)=.FALSE.

      DO 7855 I=1,NDIM
 7855 RR(I)=RRX(I)=0.0
      REWIND MT
      IF(DESSTM) GO TO 7857
       READ(LT,1040) XNAME,(STORM(I),I=1,2),IYR,MTH,IDY,STORM(3),ST,
     $STORM(4),STORM(5),ENDTIM
       READ(LT,1050) XID,DESIN,EVAL,DEBUG,IDXRTE
       READ(LT,1055) AREA,              DIMIN,RUFFN
       READ(LT,1060) XRN,XRI,DTIN,DTOUT,XHY,DURA,FREQ,TRAIN
      RAIN=INT(XRN)
      IF(.NOT.OPTDES)HYETO=INT(XHY)
      IF(OPTDES) RAIN=0
      GO TO 8758
 7857 REWIND LT
      IYR=0 $ MTH=0 $IDY=0 $ ST=0 $ ENDTIM=0
      AREA=0.0 $ XID=0.0 $ RAIN=0
      PRINT*,'FREQ,DURA,TRAIN,HYETO,AMC,DESIN,EVAL,DEBUG,IDXRTE,DTOUT'
      READ(11,*)FREQ,DURA,TRAIN,HYETO,AMC,DESIN,EVAL,DEBUG,IDXRTE,DTOUT
      IF(EOF(11).NE.0.0) RETURN
```

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      DTIN=DTOUT
      DIMIN=8.0
      RUFFN=0.014
      IF(EOF(11).NE.0.0) RETURN
      DO 3301 I11=1,NRCH
 3301 TSMS(IBX(I11),IRX(I11))=(AMC-1.)*C/3.0
      DO 4401 IO=1,5
 4401 STORM(IO)=8H
      IF(HYETO.EQ.1) STORM(4)=10HUNIFORM
      IF(HYETO.EQ.2) STORM(4)=10HHUFF
      IF(HYETO.EQ.3) STORM(4)=10HTRIANGULAR
      IF(HYETO.EQ.4) STORM(4)=10HBETA
      IF(HYETO.EQ.5) STORM(4)=10HBI-MODAL B
      IF(HYETO.EQ.5) STORM(5)=7HETA
      READ(LT,1040) XNAME
      GO TO 8757
C.... COMPUTE THE STARTING DAY FROM INPUT DATA
 8758 IDYST=0
      IST=MTH
      DO 2222 I=1,IST
      IF(I.EQ.MTH) GO TO 3333
      IDYST=IDYST+NODYMO(I)
      IF(I.EQ.2.AND.((IYR)/4)*4.EQ.(IYR))
     $IDYST=IDYST+1
 2222 CONTINUE
 3333 IDYST=IDYST+IDY
      IF(IDYST.NE.IDAY) PRINT*,' SIMULATION DAY AND DAY FROM RFALL DON'
     $T MATCH, SIMULATION DAY = ',IDAY,' STORM DAY = ',IDYST
      IF(IDYST.NE.IDAY) STOP
      IF(IYR.NE.INT(YEAR-1900.))PRINT*,' SIMULATION YEAR AND YEAR FROM R
     $FALL FILE DON'T MATCH, SIMULATION YR=',INT(YEAR),', STORM YEAR = '
     $,IYR+1900
      IF(IYR.NE.INT(YEAR-1900.))STOP
C
 8757 IF(IDXRTE.EQ.0) IDXRTE=1
      BSNDBG=.FALSE.
      IF(DEBUG.GT.0) BSNDBG=.TRUE.
      IF(PRNT)
     + WRITE(7,1040) XNAME,(STORM(I),I=1,2),IYR,MTH,IDY,STORM(3),ST,
     $STORM(4),STORM(5),ENDTIM
C.... OUTPUT THE BEGINING OF DAY SOIL MOISTURE STORAGES
      IF(ILT.EQ.1.AND.PRNT)WRITE(7,891)
  891 FORMAT('      BEGINNING OF DAY SOIL MOISTURE STORAGE BY REACH ',/,
     +5('  B  R     SMS '))
      IF(ILT.EQ.1.AND.PRNT)
     $WRITE(7,894) (IBX(I)-1,IRX(I)-1,TSMS(IBX(I),IRX(I)),I=1,NRCH)
  894 FORMAT(5(2I3,F10.3))
      IF (DESIN.NE.0.0.AND.EVAL.NE.0.0) GO TO 20
      IF (DESIN.EQ.0.0.AND.EVAL.EQ.0.0) GO TO 35
      IF (DESIN.EQ.0.0) GO TO 30
      GO TO 25
   20  WRITE(7,1070)
   25 IRUNB=1
      GO TO 40
   30 IRUNB=2
      GO TO 40
   35  WRITE(7,1075)
      IRUNB=1
   40 CONTINUE
      NRI=INT(XRI)
      IFREQ=FREQ
      IID=XID
      IF (HYETO.GT.0.AND.RAIN.GT.0) GO TO 50
      IF(OPTDES) GO TO 67852
      IF (RAIN.EQ.0) GO TO 55
67852 READ(LT,*) (RR(J),J=1,NRI)
C.... TRUNCATE INPUT HYETOGRAPH WHEN TRAILING ZEROES OCCUR
      DO 993 I=1,NRI
      K=NRI-(I-1)
      IF(RR(K).GT.0.001) GO TO 4931
  993 CONTINUE
      WRITE(7,2789)
 2789 FORMAT(' EXC TERM DUE TO A ZERO OR NEGLIGABLE RAINFALL MASS INPUT'
     $)
      STOP
 4931 NRI=K
      IF((NRI-1)*INT(DTIN/DTOUT).GT.NDIM) GO TO 4809
      IF(ABS(DTIN-DTOUT).LE.1E-04)GO TO 3092
C.... UNIFORM TIME INTERVAL RAINFALL INTERPOLATION
      IUP=1
      DO 7664 I=2,NRI
      ILOW=IUP+1
      IUP=ILOW+INT(DTIN/DTOUT)-1
      DO 7664 J=ILOW,IUP
 7664 RRX(J)=RR(I)*DTOUT/DTIN
C.... PLACE INTERPOLATED UNIFORM RFALL ARRAY IN RR-ARRAY
 7553 DO 7554 I=2,IUP
 7554 RR(I)=RRX(I)
      NRI=IUP
 3092 XNRI=NRI
C.... COMPUTE THE TOTAL RAINFALL
      TRAIN=0.0
      DO 7983 I=1,NRI
 7983 TRAIN=TRAIN+RR(I)
      DURA=(XNRI-1.0)*DTOUT
      GO TO 3809
 4809 IF(NRI.LE.NDIM) DTOUT=DTIN
      IF(NRI.LE.NDIM) GO TO 3809
      WRITE(9,1040) XNAME,(STORM(I),I=1,2),IYR,MTH,IDY,STORM(3),ST,
     $STORM(4),STORM(5),ENDTIM
      WRITE(9,3045) XID,DESIN,EVAL,DEBUG,IDXRTE
 3045 FORMAT(4F10.0,I10)
      WRITE(9,5005) AREA,ARSTRT,DEPG,DIMIN,RUFFN
 5005 FORMAT(F10.2,2F10.3,10X,F10.2,F10.4)
      WRITE(9,3060) RAIN,NRI,DTIN,DTOUT,HYETO,DURA
 3060 FORMAT(F10.0,I10,F5.1,F5.1,F10.0,F10.1)
      WRITE(9,3080) (RR(I),I=1,NRI)
 3080 FORMAT(10F8.3)
      IF(ILT.EQ.1)WRITE(9,894) (IBX(I)-1,IRX(I)-1,TSMS(IBX(I),IRX(I)),I=
     $1,NRCH)
C.... WRITEA MESSAGE TO RESULT FILE TO REMIND USER THAT
C.... DIMENSIONING WAS TOO SMALL FOR SIMULATION OF THIS
C.... PARTICULAR STORM
      IF(PRNT)
     + WRITE(7,5000) NDIM
 5000 FORMAT(' NO. OF RFS > ',I5,', STORM ECHOED TO FILE UNDER...')
      DYUNDER=.TRUE.
      RETURN
 3809 CONTINUE
      IF(OPTDES) GO TO 67831
      GO TO 60
   50  WRITE(7,1085)
      STOP
   55 CONTINUE
      IF(HYETO.EQ.3)READ(11,*) AP
      IF(HYETO.EQ.4)READ(11,*)PEX,QEX
67831 CALL RHYETO (TRAIN,DURA,DTOUT,RR,NRI,NDIM,SR,HYETO,AP,PEX,QEX,
     $PST,QST,PSTST,QSTST,PRNT)
   60 CONTINUE
      IF(PRNT)
     +  WRITE(7,1090)
      IF(PRNT)
     +  WRITE(7,1095) (RR(J),J=1,NRI)
      IF(PRNT)
     +  WRITE(7,1100)
      IF(PRNT)
     +  WRITE(7,1105)
      IF(PRNT)
     +  WRITE(7,1110) IID,AREA,DTIN,DTOUT,BSNDBG,RTNG(IDXRTE)
      IF(PRNT)
     +  WRITE(7,1115)
      IF(PRNT)
     +  WRITE(7,1120)
      IF(PRNT)
     + WRITE(7,1125) TRAIN,IFREQ,DURA,    ARSTRT,DEPG
      IF(PRNT)
     + WRITE(7,1130)
      IF(PRNT)
     +WRITE(7,3399)
 3399 FORMAT(1X,131(1H=))
      PREDI=DIMIN
      DTOUTHR=DTOUT/60.0
      NEND=0
      DO 65 L=1,NDIM
          GR(L)=0.0
   65     CONTINUE
      DO 70 M=1,MAXRR
          Q(M,NDP1)=0.0
   70     CONTINUE
      TGAR=0.0
      TGA=0.0
      TSPA=0.0
      TPAR=0.0
      TC=0.0
      TCPA=0.0
      TVOL=TSMX=0.0
   75 CONTINUE
      VOL=0
      OUTLET=0
      SURMAX=0
      SMX=0
      READ(MT,1140) BRAN,REACH,ENDBR,CONRR,IRUN,DIST,SLP,RUFF,ISECT,DIA
     1M,HR,WR,SS,QFLOW,FREQR,STORE,TEST,HYD
C.... CHECK TO SEE WHAT MODE IS TO BE USED FOR THIS REACH
      IF (DEBUG.GT.0.0) HYD=1
      IF (IRUN.NE.0) GO TO 80
      IRUN=IRUNB
   80 CONTINUE
C.... CHECK FOR A CONFLUENCE, IF NOT PROCESS THIS REACH FOR SURFACE
C.... RUNOFF AND ROUTING.
      IF (ENDBR.EQ.0.0) GO TO 510
C$$$$$$$$$$$$$$$$$CONFLUENCE COMPUTATION SECTION$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
  503 IF(.NOT.RTING.AND.TEST.NE.END) GO TO 75
      IF(.NOT.RTING.AND.TEST.EQ.END) GO TO 5691
      DO 515 M=1,MAXRR
          IF (Q(M,NDP1).EQ.CONRR) GO TO 520
  515     CONTINUE
      WRITE(7,1260)
      STOP
  520 IB=M
      DO 525 M=1,MAXRR
          IF (Q(M,NDP1).EQ.ENDBR) GO TO 530
  525     CONTINUE
      WRITE(7,1265)
      STOP
  530 IEND=M
      DO 535 N=1,NDIM
          Q(IB,N)=Q(IB,N)+Q(IEND,N)
  535     CONTINUE
C
      Q(IEND,NDP1)=0.0
  540 LAST=1
      DO 550 N=1,NDIM
          IF (Q(IB,N).GT.0.0) GO TO 545
          GO TO 550
  545     LAST=N
  550     CONTINUE
      IF (TEST.EQ.END) GO TO 7369
      GO TO 75
C$$$$$$$$$$$$$$$$$CONFLUENCE COMPUTATION SECTION$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
  510 IF (BRAN.GT.0.0) GO TO 120
      WRITE(7,1160)
      STOP
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  120  READ(MT,1145) CBRAN,CREACH,BA,CPA,PCPA,SPA,PSPA,PENT,PL,PS,CGA,PC
      1GA,GFNT,GL,GS
       IF(CBRAN.NE.BRAN.OR.CRFACH.NE.REACH)
      $PRINT*,' BRANCH OR RFACH DO NOT MATCH ON THE REACH AND SUB-BASIN C
      $ARDS.'
       IF(CBRAN.NE.BRAN.OR.CREACH.NE.REACH) STOP
C      GENT=GNT
C      PENT=PNT
       RUFF=RFF
       NRFACH=NREACH+1
       IF (FREOR.EQ.1.0) GO TO 95
       IF (FREOR.NE.0.0) GO TO 85
       FREQR=1.0
       GO TO 95
   85 DO 90 IJ=1,NRI
          RR(IJ)=RR(IJ)*FREQR
   90     CONTINUE
       IF(PRNT)
     + WRITE(7,1150) FREQR
   95 CONTINUE
       CPA=AMAX1(CPA,BA*PCPA*0.01)
       SPA=AMAX1(SPA,BA*PSPA*0.01)
       CGA=AMAX1(CGA,BA*PCGA*0.01)
       IF (PENT+PL.EQ.0.0) GO TO 115
       IF (PENT.NE.0.0) GO TO 115
       IF (CPA.EQ.0.0) GO TO 115
       CALL PAVENT (PENT,PL,PS,CPA,PRNT)
  115 CONTINUE
       IF(CGA.EQ.0.0) GO TO 227
       IF (GENT+GL.EQ.0.0) GO TO 220
       IF (GENT.NE.0.0) GO TO 225
       CALL GRENT (GENT,CGA,GL,GS,PENT,PRNT)
       GO TO 226
  220 GENT=20.0
       IF(PRNT)
     + WRITE(7,1175)
       GO TO 226
  225 CONTINUE
C....  FOR LATERAL PERVIOUS TO CPA
  226 CONTINUE
       GENT=GENT+PENT/2.0
  227 TGA=TGA+CGA
       TSPA=TSPA+SPA
       TCPA=TCPA+CPA
C      IF(CGA+CPA.EQ.0.0) GO TO 228
       TOTIN=TOTIN+(CGA+SPA+CPA)*TRAIN/12.*43560.
C      PRINT*,' TOTIN=',TOTIN
       CALL SRFRNFF
      $(GR,GRPK,PKIN,CPA,CGA,SPA,NRI,RR,TSMS,KIF,C,PTRAIN,PRFVEND,ST,
      $FCAP,DLYPER,EVPPAN,PANRAT,ABSTRT,PVDAB,TRANRAT,DEPG,FO,FC,
      $DTCUT,PENT,MAXA,HYD,BRAN,RFACH,NOSTM,NRFACH,TOTIN,TOTINF,ALPHA,
      $GENT,GAD,RTING,NDIM,GGR,AR,RI,PASR,A,RRAT,TKAIN,ILT,GRDAB,
      $DTOUTHR,NEND,PRNT)
  228 IF(.NOT.RTING) GO TO 4050
       PKIN=GRPK
       LAST=NEND
C
C.... TEST FOR MID BRANCH OR INITIAL REACH.
C
       IF(.NOT.LOGINT(INT(BRAN))) RCHINT(INT(BRAN))=REACH
       IF(.NOT.LOGINT(INT(BRAN))) LOGINT(INT(BRAN))=.TRUE.
C      PRINT*,' RCHINT(',INT(BRAN),')=',RCHINT(INT(BRAN)),'  REACH = ',RE
C     $ACH
       IF(REACH.NE.RCHINT(INT(BRAN))) GO TO 295
       GO TO 345
C
C.... COMBINE PREVIOUS ROUTED HYDROGRAPH WITH NEW SURFACE HYDROGRAPH
C
  295 CONTINUE
C      PRINT*,' AT LABEL 295'
       DO 500 M=1,MAXBR
          IF (Q(M,NDP1).EQ.BRAN) GO TO 305
  500     CONTINUE
       WRITE(7,1190)
       STOP
  305 IB=M
       GRPK=0
       DO 320 N=1,NDIM
          GR(N)=GR(N)+Q(IB,N)
          IF(GR(N).GT.0.01) LAST=N
          IF (GRPK-GR(N)) 310,315,315
  310     GRPK=GR(N)
  315     CONTINUE
  320     CONTINUE
       IF (HYD) 330,330,325
  325  IF(PRNT) WRITE(7,1195)
       IF(PRNT)
     + WRITE(7,1200) (GR(J),J=1,LAST)
  330 IF (DIAM) 335,335,340
  335 TDIAM=PREDI
C
C
       GO TO 390
  340 TDIAM=DIAM
       IF (IRUN.EQ.1) TDIAM=DIMIN
       GO TO 390
  345 CONTINUE
       IF (DIAM) 370,370,350
  350 TDIAM=DIAM
       IF (IRUN.EQ.1.AND.DIMIN.LT.8.0) DIMIN=8.0
       IF (IRUN.EQ.1.AND.DIMIN.LT.8.0.AND.PRNT)  WRITE(7,1015)
       FLG1=0.0
       DO 355 I=1,22
  355     IF (DIMIN.EQ.DIA(I)) FLG1=1.0
       IF (FLG1.EQ.1.0) GO TO 375
       DIFF=1000.0
       ICHOOS=1
       DO 360 I=1,24
          IF (ABS(DIMIN-DIA(I)).GT.DIFF) GO TO 360
          DIFF=ABS(DIMIN-DIA(I))
          ICHOOS=I
  360     CONTINUE
       DIMIN=DIA(ICHOOS)
       IF (FLG1.EQ.1.0.AND.PRNT)  WRITE(7,1020) DIMIN
  370 TDIAM=DIMIN
  375 DO 380 M=1,MAXBR
          IF (Q(M,NDP1).EQ.0.0) GO TO 385
  380     CONTINUE
       WRITE(7,1205)
       STOP
  385 IB=M
       Q(IB,NDP1)=BRAN
       GO TO 390
C
C.... FIND GROSS HYDROGRAPH PEAK
C
  390 GRPK=GR(1)
       DO 400 J=2,NDIM
          IF (GRPK-GR(J)) 395,400,400
  395     GRPK=GR(J)
  400     CONTINUE
       PKDES=GRPK
       IF (STORE.EQ.0.0) GO TO 405
       IF (QALOW.EQ.0.0) GO TO 415
       IF(PRNT)
     + WRITE(7,1210)
       QALOW=0.0
       GO TO 415
  405 IF (QALOW.EQ.0.0) GO TO 425
       IF (QALOW-GRPK) 410,425,425
  410 CALL LIMITQ (GR,GRPK,LAST,QALOW,DTOUT,BRAN,REACH,VOL,NDIM,QT,PRNT)
       GO TO 420
  415 CALL DETEN (GR,GRPK,LAST,STORE,DTOUT,BRAN,RFACH,VOL,NDIM,
      $QT,PRNT)
  420 CONTINUE
       OUTLET=GRPK
       SMX=STORE*1000.0
C
C.... PRINT 903,BRAN,REACH,SMX,GRPK,VOL
C
  425 IF(.NOT.RTING) GO TO 4050
       GO TO (430,450,450), IRUN
C$$$$$$$$$$$$$$$$$$$$$$PIPE SIZING SECTION FOR DESIGN MODE$$$$$$$$$$$$$$$$$$$$$$$
  430 CONTINUE
       INCR=0
  435 QFB=0.0081*TDIAM*TDIAM/RUFFN*(TDIAM/48.0)**.667*(SLP/100.0)**.50
C      PRINT*,' TDIAM=',TDIAM,' RUFFN=',RUFFN,'SLP=',SLP,GRPK
       VFB=QFB/(TDIAM*TDIAM*3.141592654/576.)
       IF (QFB-GRPK) 440,445,445
  440 CONTINUE
       IF (INCR.GT.24)  WRITE(7,1025)
       IF (INCR.GT.24) STOP
       INCR=INCR+1
       TDIAM=DIA(INCR)
       GO TO 435
  445 CONTINUE
C$$$$$$$$$$$$$$$$$$$$$$PIPE SIZING SECTION FOR DESIGN MODE$$$$$$$$$$$$$$$$$$$$$$$
C
C
  450 CONTINUE
       CALL ROUTE (GR,IB,DTOUT,RUFF,SLP,DIAM,DIST,LAST,SURMAX,Q,VOL,HYD,I
      1SECT,HR,WR,SS,GRPK,BRAN,REACH,IDXRTE,IRUN,RUFFN,TDIAM,QFB,SRCHRG,
      2ROUGH,NDIM,HD10,NDP1,TMPGR,TMPQ,IFMP,MAXBR,QT,PRNT,TSHIFT)
       IF(BRAN.EQ.1.0) TC=TC+TSHIFT
       IF(BRAN.EQ.1.0.AND.REACH.EQ.0.0) TC=TC+GENT*60.0
       TVOL=TVOL+VOL
       TSMX=TSMX+SMX
C      IF(HYD.NE.0) WRITE(7,1130)
       IF (QALOW.NE.0.0.OR.STORE.NE.0.0) GO TO 455
       GO TO (460,465,465), IRUN
  455 GO TO (470,475,475), IRUN
  460 IF(PRNT)
      $ WRITE(7,1215) MODE(IRUN),BRAN,REACH,DIST,ROUGH,SLP/100.,XSEC(ISEC
      1T),TDIAM,CPA,PENT,CGA,SPA,GENT,QFB,PKIN,PKDES,OUTLET,VOL,SMX
      2,TSHIFT/60.,SRCHRG
       IF (DIAM.GE.TDIAM.AND.PRNT)  WRITE(7,1225)DIAM
       GO TO 480
  465 IF(PRNT)
      $  WRITE(7,1215) MODE(IRUN),BRAN,RFACH,DIST,ROUGH,SLP/100.,XSEC(ISE
      1CT),DIAM,CPA,PENT,CGA,SPA,GENT,ECAP,PKIN,PKDES,OUTLET,VOL,SMX
      2,TSHIFT/60.,SRCHRG
       GO TO 480
  470 IF(PRNT)
      $ WRITE(7,1215) MODE(IRUN),BRAN,REACH,DIST,ROUGH,SLP/100.,XSEC(ISEC
      1T),TDIAM,CPA,PENT,CGA,SPA,GENT,QFB,PKIN,PKDES,OUTLET,VOL,SMX
      2,TSHIFT/60.,SRCHRG
       GO TO 480
  475 IF(PRNT)
      $ WRITE(7,1215) MODE(IRUN),BRAN,REACH,DIST,ROUGH,SLP/100.,XSEC(ISEC
      1T),DIAM,CPA,PENT,CGA,SPA,GENT,ECAP,PKIN,PKDES,OUTLET,VOL,SMX
      2,TSHIFT/60.,SRCHRG
  480 CONTINUE
C
C.... PRINT 1301,BRAN,REACH,ISECT,DIAM,HR,WR,SLP,RUFF,DEPTH,SURMAX
C.... FIND PEAK OF DISCHARGE HYDROGRAPH
C
C      PRINT*,(Q(IB,IW),IW=1,LAST)
       QPK=0
       DO 490 ID=1,LAST
          IF (Q(IB,ID)-QPK) 490,490,485
  485     QPK=Q(IB,ID)
  490     CONTINUE
```

```
C
 4050 PRFDI=TDIAM
      IRUN=IRUNB
      IF (FREOR.EQ.1.0) GO TO 300
      DO 195 IJ=1,NRI
           RR(IJ)=RR(IJ)/FREOR
  195      CONTINUE
  300 CONTINUE
      IF (TEST.NE.END) GO TO 75
C
C.... PRINT DISCHARGE HYDRO
C....  WRITE(7,402)
C.... WRITE(7,403)PENT,RUFF,DTOUT,FREOR
C
C$$$$$$$$$$$$$$$$$$$$$$$$$CHFCK FOR CONFLUENCES AT END OF LAST RFACH$$$$$$$$$$$$$$$
 7369  RFAD(MT,2140) ENDBR,CONDR
 2140 FORMAT(6X,2F3.0)
      IF(EOF(MT).NE.0.0) GO TO 5691
      GO TO 503
C$$$$$$$$$$$$$$$$$$$$$$$$$CHFCK FOR CONFLUENCES AT END OF LAST RFACH$$$$$$$$$$$$$$$
C
C$$$$$$$$$$$$$$$$$$$$$$$$$OUTFALL HYDRO OUTPUT PROCESSING$$$$$$$$$$$$$$$$$$$$$$$$$$
 5691 VOLOUT=AMAX1(TOTIN-ABSTRT/12.*43560.*TCPA-DEPG/12.*43560.*TGA,0.0)
     $-TOTINF
      TOTABS=AMIN1(TRAIN,ABSTRT)*43560.*TCPA/12.+
     $AMIN1(TRAIN*(TGA+TSPA)/AMAX1(TGA,1.E-10),DEPG)*43560.*TGA/12.
      IF(.NOT.RTING) GO TO 9333
      IF(PRNT)
     +WRITE(7,3399)
      IF(PRNT)
     + WRITE(7,1155) TCPA,TGA,TSPA
      IF(PRNT)
     +WRITE(7,6611) TVOL,TSMX
      IF(PRNT) WRITE(7,6641) TC/60.0
 6641 FORMAT(' TIME OF CONCENTRATION FOR THIS STORM = ',F10.3)
      PKCOM=0.0
      OFLLVOL=0.0
      DO 505 MM=1,LAST
      Q(IB,MM)=Q(IB,MM)+QB
      IF(Q(IB,MM).GT.PKCOM) PKCOM=Q(IB,MM)
      OFLLVOL=OFLLVOL+Q(IB,MM)*DTOUT*60.
  505      CONTINUE
      IF(DIS) GO TO 9333
      IF(PRNT)
     $WRITE(7,1250)-VOLOUT,-12.*VOLOUT/(TCPA+TGA+TSPA)/43560.,
     $OFLLVOL,12.*OFLLVOL/(TCPA+TGA+TSPA)/43560.,
     +  VOLOUT,(12.*VOLOUT/(TCPA+TGA+TSPA)/43560.),
     $TOTINF,12.*TOTINF/(TCPA+TGA+TSPA)/43560.,
     $TOTABS,12.*TOTABS/(TCPA+TGA+TSPA)/43560.,
     $VOLOUT+TOTINF+TOTABS,12.*(VOLOUT+TOTINF+TOTABS)/(TCPA+TGA+TSPA)
     $/43560.,
     $(TCPA+TGA+TSPA)*43560.*TRAIN/12.,TRAIN
      IF(PRNT)
     +WRITE(7,2030) VOLOUT
 2030 FORMAT(//,' OUTFALL HYDROGRAPH(CFS)   RUNOFF VOLUME(CF) = ',
     $F15.2)
      IF(PRNT)
     +WRITE(7,2031) (Q(IB,M),M=1,LAST)
 2031 FORMAT(10F8.1)
      PREVEND=ENDTIM
      PTRAIN=TRAIN
      IF(CRTOBS) WRITE(5,*) DTOUT,LAST,VOLOUT
      IF(CRTOBS) WRITE(5,*) (Q(IB,M),M=1,LAST)
      WRITE(08,8888) IYR,MTH,IDY,ST,VOLOUT,TVOL,PKCOM,TC/60.0
 8888 FORMAT(3I2,F5.0,4F10.3)
      IF(DESSTM)GO TO 9903
      RETURN
C.... READ IN OBSERVED DICHARGES
 9333 READ(5,*) DISTIM,NOBS,VOLOBS
   77 FORMAT(42X,F3.0,/,I5,F15.0)
      READ(5,*) (QOBS(I),I=1,NOBS)
   74 FORMAT(10F8.0)
C     CVOLOB=0.0
C     DO 5623 I=1,NOBS
C5623 CVOLOB=CVOLOB+QOBS(I)*60.*DISTIM
C     IF(ABS(CVOLOB-VOLOBS).GT.50.0) WRITE(7,*) ' VOLOBS NOT = CVOLOBS '
C     VOLOBS=CVOLOB
      IF(RTING) GO TO 8083
 9988 FINC=ABS(VOLOUT-VOLOBS)
C     WRITE(7,*) '  VOLCOM= ',VOLOUT,' VOLOBS= ',VOLOBS
C     PRINT*, '  VOLCOM= ',VOLOUT,' VOLOBS= ',VOLOBS
      PREVEND=ENDTIM
      PTRAIN=TRAIN
      WRITE(08,8888) IYR,MTH,IDY,ST,VOLOUT,TVOL,PKCOM,TC/60.0
      RETURN
 8083 CONTINUE
      XOBCA(1)=0.0
       DO 81 I=2,NOBS
   81 XOBCA(I)=XOBCA(I-1)+DTOUT
      QCOM(1)=XCOM(1)=0.0
      DO 99 I=2,LAST
      XCOM(I)=XCOM(I-1)+DTOUT
   99 QCOM(I)=Q(IB,I)
      IF(DISTIM.EQ.DTOUT)GO TO 79
C.... INTERPOLATE QOBS ARRAY AT DTOUT INTERVALS FROM DTIN INTERVALS.
      CALL INTERP(DISTIM,NOBS,QOBS,DTOUT,NXOBS,QXOBS,NDIM,NDIM,PRNT,.FAL
     $SE.)
C.... REPLACE QOBS ARRAY WITH INTERPOLATED QXOBS ARRAY
      QOBS(1)=XOBCA(1)=0.0
      DO 63 I=2,NXOBS
      XOBCA(I)=XOBCA(I-1)+DTOUT
   63 QOBS(I)=QXOBS(I)
      NOBS=NXOBS
   79 CONTINUE
      PKOBS=0.0
      DO 78 I=1,NOBS
   78 IF(QOBS(I).GT.PKOBS) PKOBS=QOBS(I)
      IF(NOBS.GE.LAST) GO TO 87
      NOBSP1=NOBS+1
      DO 89 I=NOBSP1,LAST
   89 QOBS(I)=0.0
   87 CONTINUE
      TYPE(1)=4H*
      J=INT(DTIN/DTOUT)+1
      DO 93 I=2,LAST
      TYPE(I)=4H
      IF(I.EQ.J)TYPE(I)=4H*
      IF(Q(IB,I).EQ.PKCOM) TYPE(I)=4H<C
      IF(QOBS(I).EQ.PKOBS) TYPE(I)=4H<O
      IF(Q(IB,I).EQ.PKCOM.AND.QOBS(I).EQ.PKOBS) TYPE(I)=4H<C*O
   93 IF(I.EQ.J) J=J+INT(DTIN/DTOUT)
      IF(PRNT)
     $WRITE(7,1250)VOLOBS,12.*VOLOBS/(TCPA+TGA+TSPA)/43560.,
     $OFLLVOL,12.*OFLLVOL/(TCPA+TGA+TSPA)/43560.,
     +  VOLOUT,(12.*VOLOUT/(TCPA+TGA+TSPA)/43560.),
     $TOTINF,12.*TOTINF/(TCPA+TGA+TSPA)/43560.,
     $TOTABS,12.*TOTABS/(TCPA+TGA+TSPA)/43560.,
     $VOLOUT+TOTINF+TOTABS,12.*(VOLOUT+TOTINF+TOTABS)/(TCPA+TGA+TSPA)
     $/43560.,
     $(TCPA+TGA+TSPA)*43560.*TRAIN/12.,TRAIN
 1252 FORMAT(/,'  TIME   OBS-RF   CAL-Q   OBS-Q ',/,
     $     '  (MIN)   (INS)    (CFS)   (CFS)')
      IF(PRNT)
C    + WRITE(7,1255) (FLOAT(M-1)*DTOUT,RR(M),Q(IB,M),QOBS(M),TYPE(M),
C    $M=1,LAST)
     +CALL COLUMN(RR,Q,QOBS,TYPE,LAST,7,DTOUT,NDIM,NDP1,MAXBR,IB)
      IF(PRNT)
     + WRITE(7,4488)
 4488 FORMAT(8X,'99999999')
      F3INC=0.0
      DO 8811 I=1,LAST
 8811 F3INC=F3INC+(QCOM(I)/PKOBS)*ABS(QCOM(I)-QOBS(I))
      F2INC=ABS(QPK-PKOBS)
      F1INC=ABS(VOLOUT-VOLOBS)
C     PRINT*,'  F1INC = ',F1INC,'  F2INC = ',F2INC,'  F3INC = ',
C    $F3INC
      IF(PRNT)
     +WRITE(7,*)'  F1INC = ',F1INC,'  F2INC = ',F2INC,'  F3INC = ',
     $F3INC
      PREVEND=ENDTIM
      PTRAIN=TRAIN
C      SET FINC IF NO OBJECTIVE FUNCTION IS SET OR PASSED
      FINC=999999.
      IF(OBJVOL) FINC=F1INC
      IF(OBJQP) FINC=F2INC
      IF(OBJSHP) FINC=F3INC
      WRITE(08,8888) IYR,MTH,IDY,ST,VOLOUT,TVOL,QPK,TC/60.0
      RETURN
C
C
 1005 FORMAT (32H   TIME SHIFT ROUTING ACTIVATED.)
 1010 FORMAT (3X,A2,36HPLICIT HYDROLOGIC ROUTING ACTIVATED.)
 1015 FORMAT (45H MINIMUM PIPE DIA SPECIFIED < 8-IN, 8-IN USED)
 1020 FORMAT (51H CLOSEST COMMERCIALLY AVAILABLE PIPE SIZE CHOSEN AS,F10
     1.2,8H INCHES.)
 1025 FORMAT (49H PIPE SIZING > 180-IN; PROBABLE INPUT DATA ERROR.)
 1040 FORMAT (20A4,/,1X,A6,A4,I2,I2,I2,A2,F5.0,A10,A7,F5.0)
 1045 FORMAT (///,20A4,/,1X,3A6,F5.0,4A4,1X,F5.0//)
 1046 FORMAT (20A4,/,1X,3A6,F5.0,4A4,1X,F5.0)
 1050 FORMAT (1F10.0,I10)
 1055 FORMAT (1F10.0,30X,2F10.0)
 1060 FORMAT (F10.0,F10.0,2F5.0,F10.0,4F10.0)
 1065 FORMAT (21H  THE JOB IS FINISHED)
 1070 FORMAT (54H DESIGN AND EVALUATION BOTH SPECIFIED - DESIGN ASSUMED)
 1075 FORMAT (52H NEITHER DESIGN NOR EVAL SPECIFIED - DESIGN ASSUMED )
 1080 FORMAT (10F8.0)
 1085 FORMAT (48H RAINFALL PROVIDED OR STANDARD DISTRIBUTION ??? )
 1090 FORMAT (10H RAINFALL PATTERN )
 1095 FORMAT (10F8.3)
 1100 FORMAT ('0      RUN NUMBER   BASIN AREA   TIME INCREMENT',
     1'   TIME INCREMENT                 BASIN   BASIN')
 1105 FORMAT (  '                            ACRES     INPUT(MINS)',
     1'       OUTPUT(MINS)                DEBUG   ROUTING',/)
 1110 FORMAT (I13,F15.1,2F13.2,26X,L1,5X,A3,//)
 1115 FORMAT (73H         TOTAL RAIN   FREQUENCY   DURATION    AMC   PAVED
     1 ABS.   GRASS ABS.)
 1120 FORMAT (70H             INCHES        YEARS       MINUTES          INCHES
     1            INCHES,/)
 1130 FORMAT(//,' MODE   BR  RCH  LENGTH    N  SLP  SCTN',
     +' DMTR DCPA PENT  CGA SPA  GENT CAPAC-Q INLT-Q DSGN-Q  LTD-Q  ',

     +'RORD-DET  ROSTD-DET TSHIFT SURCH')
 1125 FORMAT (9X,F5.2,6X,I5,7X,F6.1,8X,F11.2,F14.2,//)
 1140 FORMAT (4F3.0,I3,2F5.0,F5.0,I1,F4.0,6F5.0,1A3,I2,10X)
 1145 FORMAT (2F3.0,F9.0,F5.0,F3.0,F5.0,F3.0,4F5.0,F3.0,3F5.0,11X)
 1150 FORMAT (36H RAINFALL MULTIPLIED BY A FACTOR OF ,F5.2,15H FOR THIS
     1REACH)
 1155 FORMAT (5X,24HACCUM CONTRIBUTING AREAS,15(1H>),F5.1,5X,F5.1,F5.1)
 6611 FORMAT(1H+,64X,5X,'ACCUM DETENTION>>>>>>>>>>>>>>',E10.4,1X,E10.4)
 1160 FORMAT ('  BRANCH < = 0.0 AND ENDBR = 0.0')
 1175 FORMAT (45H GRASS ENT ASSUMED = 20 MIN.  GIVE MORE DATA )
 1190 FORMAT (37H PREVIOUS BRANCH HYDROGRAPH NOT FOUND)
 1195 FORMAT (41H UPSTREAM ROUTED PLUS SURFACE HYDROGRAPH.)
 1200 FORMAT (10F8.1)
 1205 FORMAT (21H NO BRANCHES ARE FREE)
 1210 FORMAT (53H BOTH STORAGE AND LIMITED Q REQUESTED - STORAGE USED )
 1215 FORMAT (1X,A5,F4.0,F5.0,1X,F6.0,F6.3,F5.3,3X,A3,F5.0,5F5.1
     1,1F7.1,2X,2E10.3,2X,F5.2,L6,/,1X,131(1H-))
 1220 FORMAT (44H                        REQUIRED PIPE =          ,F5.0,F8.2,
     1F6.2,F10.2,F9.2,F13.2,//)
 1225 FORMAT (10X,  '***EXISTING PIPE HAS ADEQUATE CAPACITY***',
     +/,10X,'   WITH DIAMETER OF ',F5.0,' INCHES')
 1230 FORMAT (63H
     1          ,F10.2,F9.2,F13.2,//)
 1235 FORMAT (F8.0,F4.0,F6.0,F5.2,F6.3,3F5.2,F5.0,F8.2,F6.2,F10.2,F9.2,F
```

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     113.2,/)
 1240 FORMAT (44H                    REQUIRED PIPE =           ,F5.0,F8.2,
     1F6.2,F10.2,9X,F12.1,F13.0,//)
 1245 FORMAT (63H
     1          ,F10.2,9X,F12.1,F13.0,//)
 1250 FORMAT(///,' *****EVENT SUMMARY******** ',/,' OBSERVED RUNOFF VOLUM
     1E ',F16.0,' (',F7.3,')',/,
     6' OUTFALL DISCHARGE VOLUME ',F14.0,' (',F7.3,')',//,
     1                               ' COMPUTED RUNOFF VOLUME ',F16.0,
     $' (',F7.3,')',
     1                          /,' COMPUTED INFILTRATION VOLUME ',F10.0,'
     $ (',F7.3,')',/,
     2' COMPUTED ABSTRACTION VOLUME ',F11.0,' (',F7.3,')',/,
     3'                               ---------- --------_',/,
     4' RAINFALL VOLUME FROM ABOVE ',F12.0,' (',F7.3,')',/,
     5' CONTRIBUTING AREA RAINFALL ',F12.0,' (',F7.3,')')
 1255 FORMAT (F8.1,F8.3,2F8.1,1X,A4)
 1260 FORMAT (35H CONTINUING BRANCH RECORD NOT FOUND)
 1265 FORMAT (29H ENDD BRANCH RECORD NOT FOUND)
 1270 FORMAT (38H  TROUBLE FINDING UPSTREAM HYDROGRAPH )
      END
      FUNCTION BETAX(Z,W)
      BETAX=EXP(ALGAMA(Z))*EXP(ALGAMA(W))/EXP(ALGAMA(Z+W))
      RETURN
      END
      SUBROUTINE RHYETO (TRAIN,DURA,DTOUT,RR,NRI,NDIM,SR,HYETO,AP,PEX,QE
     $X,PST,QST,PSTST,QSTST,PRNT)
      REAL RR(NDIM),PCTT(17),PCTR(17),SR(NDIM)
      INTEGER XRI,HYETO
      LOGICAL PRNT
      DATA PCTR/0.,9.6,21.,32.7,43.,51.2,58.3,63.1,67.2,
     $70.6,73.5,79.5,84.2,88.5,92.5,96.3,100./
C
C                            HYETO OPTIONS
C          1=UNIFORM  2=HUFF MEDIAN  3=TRIANGULAR  4=BETA  5=BI-MODAL BETA
C
C
      GO TO (3,1,2,4,5), HYETO
    1 X=-4.
      IF(PRNT)

     +WRITE(7,998)
  998 FORMAT('*****HUFF DISTR(MEDIAN PT CURVE)*****')
      DO 8 I=1,11
           X=X+4.0
           PCTT(I)=X
    8      CONTINUE
      DO 10 I=12,17
           PCTT(I)=PCTT(I-1)+10.
   10      CONTINUE
      XRI=DURA/DTOUT+1.1
      SR(1)=0
      X=0
      DO 30 I=2,XRI
           X=X+DTOUT
           PX=(X/DURA)*100.
           DO 15 J=1,17
                IF (PX-PCTT(J)) 20,25,15
   15           CONTINUE
           GO TO 30
   20      SR(I)=(PCTR(J-1)+(PCTR(J)-PCTR(J-1))/(PCTT(J)-PCTT(J-1))*(PX-
     1     PCTT(J-1)))*TRAIN*.01
           GO TO 30
   25      SR(I)=PCTR(J)*TRAIN*.01
   30      CONTINUE
      JJ=XRI
      NRI=JJ
      RR(1)=0.0
      DO 35 J=2,JJ
           RR(J)=SR(J)-SR(J-1)
   35      CONTINUE
C
C.... PRINT 9,(RR(J),J=1,JJ)
C
C     RETURN
      GO TO 9999
    2 TOT=0.0
      IF(PRNT)
     +WRITE(7,889) AP
  889 FORMAT('*****TRI DISTR(AO=',F5.3,')*****')
      TIME=0.0
      RR(1)=0.0
      NRI=INT(DURA/DTOUT)+2
      TO=0.0
      DO 200 I=2,NRI
      TIME=TIME+DTOUT
      TOM=TO
      TO=TIME/DURA
      IF(TO.GT.1.0) TO=1.0
      IF(AP.GT.0.0)DO=(TO**2)/AP
      IF(TO.GT.AP.OR.AP.EQ.0.0)  DO=AP-((TO**2)-2.*TO+2.*AP-(AP**2))/(1.
     &-AP)
      IF(AP.GT.0.0)DOM=(TOM**2)/AP
      IF(TOM.GT.AP.OR.AP.EQ.0.0) DOM=AP-((TOM**2)-2.*TOM+2.*AP-(AP**2))/
     &(1.-AP)
      RR(I)=(DO-DOM)*TRAIN
  200 IF(RR(I).LT.0.0) RR(I)=0.0
C     RETURN
      GO TO 9999
    3 NRI=INT(DURA/DTOUT)+1
      IF(PRNT)
     +WRITE(7,779)
  779 FORMAT('*****UNIFORM DISTR*****')
      RR(1)=0.0
      DO 400 I=2,NRI
  400 RR(I)=TRAIN/FLOAT(NRI-1)
C     RETURN
      GO TO 9999
C
    4 NRI=INT(DURA/DTOUT)+2
      IF(PRNT)
     +WRITE(7,1998) PEX,QEX
 1998 FORMAT(' *****BETA DISTR( P = ',F10.3,'  Q = ',F10.3,')*****')
      B=BETAX(PEX,QEX)
      PRINT*,'  BETA = ',B
      RR(1)=0.0
      TIME=0.0
      TT=DTOUT/10.
      DO 500 I=2,NRI
      TIME=TIME+DTOUT
      TMP=0.0
      TO=(TIME-DTOUT)/DURA
      DO 7601 IRB=1,10
      TO=TO+TT/DURA
      IF(TO.GT.1.0) GO TO 7602
 7601 TMP=TMP+TO**(PEX-1.)*(1.+1E-20-TO)**(QEX-1.)
 7602 RIAVG=TMP*TRAIN/DURA/10./B
  500 RR(I)=RIAVG*DTOUT
C     RETURN
      GO TO 9999
    5  WRITE(7,33333)
33333 FORMAT(' *****BI-MODAL BETA NOT AVAILABLE YET*****')
      STOP
 9999 CONTINUE
C... CHECK DESIGN STORM TOTAL DEPTH TO SEE IF IT IS CONSISTENT
      TR=0.0
      DO 3092 I=1,NRI
 3092 TR=TR+RR(I)
      IF(ABS(TRAIN-TR).GT.0.020) PRINT*,' INCONSISTENT DESIGN STORM ',TR
     $AIN,TR
C     IF(ABS(TRAIN-TR).GT.0.020) STOP
      RETURN
      END
      SUBROUTINE STATUS(GRAPH,DIS,EVPRTN,RTNG,CALIB,SIMUL,OPTDES,DESSTM,
     $CRTOBS,OBJVOL,OBJQP,OBJSHP,PRNT,NSIM,NN,HYETO,INTERN)
      DIMENSION IER(10)
      LOGICAL GRAPH,DIS,INTERN,RTNG,STP,OPTDES
      LOGICAL EVPRTN,CALIB,SIMUL,OPTDES,DESSTM,OBJVOL
      LOGICAL OBJQP,PRNT,CRTOBS,OBJSHP
      INTEGER HYETO
      DATA IER/10*0/
      STP=.FALSE.
      IU=10
      NER=0
      IF((CALIB.OR.SIMUL).AND.(OPTDES.OR.DESSTM.OR.CRTOBS))
     $IER(1)=1
      IF(CALIB.AND.SIMUL.AND.IER(1).EQ.0) IER(1)=1
      IF(OPTDES.AND.DESSTM.AND.IER(1).EQ.0) IER(1)=1
      IF(OPTDES.AND.CRTOBS.AND.IER(1).EQ.0) IER(1)=1
      IF(CRTOBS.AND.DESSTM.AND.IER(1).EQ.0) IER(1)=1
      IF(.NOT.CALIB.AND..NOT.SIMUL.AND..NOT.OPTDES.AND..NOT.DESSTM.
     $AND..NOT.CRTOBS) IER(2)=2
      IF(SIMUL.OR.DESSTM.OR.CRTOBS) GO TO 10
      IF((OBJVOL.OR.OBJQP).AND.OBJSHP) IER(3)=3
      IF(OBJVOL.AND.OBJQP.AND.IER(3).EQ.0) IER(3)=3
      IF(.NOT.OBJVOL.AND..NOT.OBJQP.AND..NOT.OBJSHP) IER(4)=4
   10 IF((CALIB.OR.OPTDES).AND..NOT.DIS) IER(5)=5
      IF(GRAPH) IER(7)=7
      DO 40 I=1,10
      IF(IER(I).NE.0) STP=.TRUE.
   40 IF(IER(I).NE.0) WRITE(IU,50) IER(I)
   50 FORMAT('   PROGRAM STATUS ERROR NO.',I3,'.')
      IF(STP) STOP
C....  DETERMINE WHICH DIMENSIONLESS HYETO IS TO BE USED
      IF(OPTDES) PRINT*,' INPUT HYETO TYPE(1-UNIFORM,2-HUFF,3-
     $TRI,4-BETA,5-BIMODAL BETA)'
      IF(OPTDES) READ(11,*)HYETO
      IF(.NOT.OPTDES.AND..NOT.CALIB) GO TO 20
C....  SET NN FOR OBJECTIVE FUNCTION USED
      IF(OBJVOL) NN=1
      IF(OBJQP) NN=2
      IF(OBJSHP) NN=3
       NSIM=100
      GO TO 30
   20 CONTINUE
      NSIM=1
   30 CONTINUE
C....  SET SURFACE/PIPE ROUTING STATUS
C    NOTE:  IF SIMULATION RTNG CAN BE EITHER F OR T AS READ-IN.
      IF((CALIB.OR.OPTDES).AND.(OBJQP.OR.OBJSHP)) RTNG=.TRUE.
      IF((CALIB.OR.OPTDES).AND.OBJVOL) RTNG=.TRUE.
      IF(DESSTM.OR.CRTOBS) RTNG=.TRUE.
      IF((CALIB.OR.OPTDES).AND.OBJVOL) RTNG=.FALSE.
C....  DETERMINE PRINTING STATUS
      IF(SIMUL) PRNT=.TRUE.
      IF(CALIB) PRNT=.FALSE.
      IF(DESSTM) PRNT=.TRUE.
C     IF(OPTDES) PRNT=.FALSE.
      IF(CRTOBS) PRNT=.FALSE.
C.... DETERMINE OBSERVED EVAPORATION DATA STATUS
C....  NOTE:  CALIB,SIMUL,OPTDES, AND CRTOBS ALL MAY HAVE EVAPORATION OR NOT
      IF(DESSTM) EVPRTN=.FALSE.
C....  SUMMARIZE PROGRAM RUN STATUS
      WRITE(IU,100)
  100 FORMAT(15X,'*****RUN STATUS SUMMARY*****')
      IF(CALIB) WRITE(IU,60)
   60 FORMAT('  CALIBRATION RUN(WITH OBSERVED DISCHARGES) ')
      IF(OPTDES) WRITE(IU,70)
   70 FORMAT('  DESIGN STORM OPTIMIZATION WITH OBSERVED/SIMULATED DISCHA
     $RGES ')
      IF(SIMUL) WRITE(IU,80)
   80 FORMAT('  SIMULATION                                   ')
      IF(DESSTM) WRITE(IU,90)
   90 FORMAT('  DESIGN STORM GENERATION ')
      IF(DESSTM) WRITE(IU,91)
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   91 FORMAT('    ONLY FILES REQUIRED ARE 'RFALL', 'CNTRL', AND 'BASIN''
     $)
      IF(CRTOBS)WRITE(IU,110)
  110 FORMAT('  SIMULATION TO CREATE DISCHARGES FOR DESIGN STORM OPTIMIZ
     $ATION')
      IF(OPTDES)WRITE(IU,170) HYETO
  170 FORMAT('     HYETOGRAPH TEMPORAL DISTRIBUTION ',I1,' USED')
      IF(INTERN) WRITE(IU,120)
  120 FORMAT('     INITIAL PARAMETER SETTING INTERNAL BY SOIL GROUP')
      IF(.NOT.INTERN) WRITE(IU,130)
  130 FORMAT('     INITIAL PARAMETER SETTING READ-IN')
      IF((OPTDES.OR.CALIB).AND.OBJVOL)WRITE(IU,140)
  140 FORMAT('     RUNOFF VOLUME OBJECTIVE FUNCTION USED')
      IF((OPTDES.OR.CALIB).AND.OBJOP)WRITE(IU,150)
  150 FORMAT('     PEAK DISCHARGE OBJECTIVE FUNCTION USED')
      IF((OPTDES.OR.CALIB).AND.OBJSHP)WRITE(IU,160)
  160 FORMAT('     HYDROGRAPH SHAPE OBJECTIVE FUNCTION USED')
      IF(PRNT) WRITE(IU,180)
  180 FORMAT('     DETAILED PRINT-OUT TO 'RESULT' FILE')
      IF(.NOT.PRNT) WRITE(IU,190)
  190 FORMAT('     DETAILED PRINT-OUT TO 'RESULT' FILE SUPPRESSED')
      WRITE(IU,200) NSIM
  200 FORMAT('     MAX NO. OF SIMULATION LOOPS = ',I3)
      IF(RTNG) WRITE(IU,210)
  210 FORMAT('     SURFACE/PIPE ROUTING ACTIVATED')
      IF(.NOT.RTNG) WRITE(IU,220)
  220 FORMAT('     SURFACE/PIPE ROUTING UNACTIVE')
      WRITE(IU,230)
  230 FORMAT(6X,'         *****END OF RUN STATUS SUMMARY*****')
      RETURN
      END
      SUBROUTINE RSNBRCK(NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM)
      DIMENSION XB(25),FAIL(25,100),ALP(25),XDEL(25,25),XO(25)
      DIMENSION DEL(25,25),XMIN(25),UU(25,25),W(25,25),NTRY(25)
      DIMENSION X(25),SUCFAL(25),L(25),U(25)
C*****************************************************************************
C.... DEFINITION OF MAX DIMENSIONING FOR ILLUDAS AND ITS SUBRS
      DIMENSION AA(NDIM),AR(NDIM),GAD(NDIM)
      DIMENSION PASR(NDIM),GGR(NDIM),GR(NDIM),Q(MAXBR,NDP1)
      DIMENSION RI(NDIM),RR(NDIM),QOBS(NDIM)
      DIMENSION RRX(NDIM),QT(NDIM),SR(NDIM),TMPGR(ND10),TMPQ(ND10),TEMP(
     $ND10)
      DIMENSION QXOBS(NDIM),TYPE(NDIM),XOBCA(NDIM),QCOM(NDIM),XCOM(NDIM)
C*****************************************************************************
      COMMON/ZZZZST/NOBJ,NCNST,M1,M2
      COMMON /RSN/N,FPLUS,FEX,FXN,L(25),U(25)
      LOGICAL FAIL,SUCFAL
      REAL L
      ALFHA=3.0
      BETA=0.5
C     CALL BOUNDS(L,U)
C     CALL INITX(X,N,NC,MI,L,U)
C     FPLUS=FCAP=FMIN=1.E99
C     PRINT*,' '
C      PRINT *,' INITIAL STARTING POINT VECTOR = ',(X(IND),IND=1,N)
      CALL OBJF(X,FXN,NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM,N)
      CALL NORM(X)
      FMIN=FXN+EXTRA(X)
      PRINT *,' OBJ FXN = ',FMIN-FEX,'   PENALTY FXN = ',FEX
      PRINT*,' '
      FPLUS=FCAP=FMIN
      DO 333 J=1,N
      ALP(J)=0.0
      I=J
  333 XMIN(I)=XB(I)=X(I)
      DO 4 J=1,N
      DO 4 I=1,N
      DEL(J,I)=XDEL(J,I)=0.0
    4 IF(J.EQ.I) DEL(J,I)=XDEL(J,I)=1.0
      NSTAGE=1
      NOBJ=0
C     EPS=0.1/.66666666666666666
      EPS=0.05
C....  PERFORM EXPLORATORY STAGE
C   5 EPS=EPS*.6666666666666
C   5 IF(NSTAGE.EQ.1) GO TO 6
C     EPS=0.0
C     DO 9900 I=1,N
C     PRINT*,XMIN(I),XO(I)
C9900 EPS=EPS+(XMIN(I)-XO(I))**2
C     EPS=AMAX1(0.05,EPS)
      PRINT *,'  EPS = ',EPS
      IF(EPS.LT.0.0000000001) RETURN
    5 CONTINUE
    6 DO 1 J=1,N
      XO(J)=XMIN(J)
      DO 1 I=1,N
    1 XDEL(J,I)=DEL(J,I)=XDEL(J,I)*EPS
      J=0
      NSTAGE=NSTAGE+1
      FEXMIN=0.0
      DO 3 J=1,N
      FAIL(J,1)=FAIL(J,2)=.TRUE.
      SUCFAL(J)=.FALSE.
    3 NTRY(J)=2
    2 J=J+1
      IF(J.GT.N) J=1
      DO 10 I=1,N
   10 X(I)=XB(I)+XDEL(J,I)
      CALL UNNORM(X)
      CALL UNNORM(XB)
      PRINT *,' START OF ITERATION BASE PT = ',(XB(IND),IND=1,N)
      PRINT *,' INCREMENT NORM. VECTOR ',J,' = ',(XDEL(J,IND),IND=1,N)
      PRINT *,' AT POINT ',(X(IND),IND=1,N)
      NTRY(J)=NTRY(J)+1
      CALL NORM(XB)
      CALL OBJF(X,FXN,NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM,N)
      CALL NORM(X)
      FUN2=FXN+EXTRA(X)
      PRINT *,' OBJ FXN = ',FUN2-FEX,'   EXTRA = ',FEX
      IF(FUN2.LE.FMIN) PRINT *,' SUCCESS!!!'
      IF(FUN2.GT.FMIN) PRINT *,' FAILURE???'
      PRINT *,' '
      IF(FUN2.LE.FMIN) 100,200
  100 FAIL(J,NTRY(J))=.FALSE.
      DO 301 I=1,N
      XB(I)=XB(I)+XDEL(J,I)
      XMIN(I)=X(I)
      IF(XDEL(J,I).NE.0.0) NZI=I
      IF(XDEL(J,I).NE.0.0)ALP(J)=ALP(J)+XDEL(J,NZI)/DEL(J,NZI)
  301 XDEL(J,I)=XDEL(J,I)*ALPHA
      FMIN=FUN2
      FEXMIN=FEX
      GO TO 2
  200 FAIL(J,NTRY(J))=.TRUE.
      DO 50 I=1,N
   50 XDEL(J,I)=-BETA*XDEL(J,I)
      DO 60 JJ=1,N
      IF(FAIL(JJ,NTRY(JJ)).AND..NOT.FAIL(JJ,NTRY(JJ)-1))
     $SUCFAL(JJ)=.TRUE.
   60 CONTINUE
      DO 998 JJJ=1,N
  998 IF(.NOT.SUCFAL(JJJ)) GO TO 2
      DO 89 I=1,N
   89 UU(1,I)=0.0
      DO 90 J=1,N
      DO 90 I=1,N
   90 UU(1,I)=W(1,I)=UU(1,I)+ALP(J)*DEL(J,I)
      TW=0.0
      DO 106 I=1,N
  106 TW=TW+UU(1,I)**2
      DO 107 I=1,N
  107 XDEL(1,I)=UU(1,I)/SQRT(TW)
      DO 105 J=2,N
      DO 105 I=1,N
  105 UU(J,I)=UU(J-1,I)-ALP(J-1)*DEL(J-1,I)
      NM1=N-1
      DO 206 J=2,N
      TW=0.0
      DO 207 I=1,N
      W(J,I)=UU(J,I)
      DO 208 K=1,NM1
      UTDELK=0.0
      DO 401 IO=1,N
  401 UTDELK=UTDELK+UU(J,IO)*XDEL(K,IO)
  208 W(J,I)=W(J,I)-UTDELK*XDEL(K,I)
  207 TW=TW+W(J,I)**2
      DO 209 II=1,N
  209 XDEL(J,II)=DEL(J,II)=W(J,II)/SQRT(TW)
  206 CONTINUE
      DO 901 I=1,N
  901 DEL(1,I)=XDEL(1,I)
      PRINT *,' ALP-VECTOR '
      PRINT *,ALP(1),ALP(2)
      PRINT *,'  U-VECTORS'
      PRINT *,(UU(1,I),I=1,2)
      PRINT *,(UU(2,I),I=1,2)
      PRINT *,'  W-VECTORS'
      PRINT *,(W(1,I),I=1,2)
      PRINT *,(W(2,I),I=1,2)
      PRINT *,'  XDEL-VECTORS'
      PRINT *,(XDEL(1,I),I=1,2)
      PRINT *,(XDEL(2,I),I=1,2)
      PRINT *,'  DEL-VECTORS'
      PRINT *,(DEL(1,I),I=1,2)
      PRINT *,(DEL(2,I),I=1,2)
      DO 306 I=1,N
      XB(I)=XMIN(I)
  306 ALP(I)=0.0
      PRINT*,' OBJ FXN = ',FMIN-FEXMIN,'  AT NORM. (',
     $(XMIN(IP),IP=1,N),')'
      CALL UNNORM(XMIN)
      PRINT*,' OBJ FXN = ',FMIN-FEXMIN,'  AT UNNORM. (',
     $(XMIN(IP),IP=1,N),')'
      CALL NORM(XMIN)
      PRINT*,' NO. OF STAGES = ',NSTAGE-1,'  NO. OF FXN EVAL = ',
     $NOBJ
C....  PLACE OPT ENDING CRITERIA HERE
      IF(NSTAGE.EQ.200) RETURN
      PRINT*,' '
      GO TO 5
      END
C     *BUILD LIBRARY
C     *TYPE RFL
C     *B,*,REL/INPT,INFLTN,DELS,THE,TIMEA,GRENF,INTEN,DETEN
C     *B,*,REL/PAVENT,RHYETO,LIMITQ,ROUTE,CAREA,SRFRNFF,INTERP,DLYACCT
C     *B,*,REL/SETPAR,STATUS,REPORT,RSNBRCK,EXTRA,NORM,UNNORM,POLY,FLEXI,FEASBL,ST
ART
C     *B,*,REL/WRITEX
C     *B,*,REL/SUMR,PROBLEM,REPORT,BOUNDS,OBJF,ILLUDAS
      SUBROUTINE INPT(NDIM,MAXBR,NDP1,ND10)
      COMMON /DATA/ SMS(366),IDYST(25),STMO(25),DYST(25),IDYED(25),EDMO(
     $25),DYED(25),YRST(25),YRED(25),PANRAT,TRANRAT,QB,NRCH
     $,RAIN(366),EVAPT(366),NODYMO(12),NSTM(366),AEVAPT(12),NYRS
      COMMON /LOGIC/PRNT,DESSTM,OPTDES,SIMUL,CRTOBS,CALIB,EVPRTN
     1,DIS,GRAPH,RTNG,OBJVOL,OBJOP,OBJSHP
      COMMON /OPT/PAR(25),FO,FC,KIF,C,DRR,FCAP,PVDAB,GRDAB,DLYPER,
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      1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
C      COMMON /INF/FO,FC,KIF,DDELT,ALPHA,FCAP,C,DLYPER
       COMMON /INF/DDELT,ALPHA
       COMMON /MOIST/TSMS(20,20),FACTOR(20,20),DIRT(20,20),IBX(35),
      +IRX(35),THPSMS(35),HYETO
        INTEGER YRST,STMO,DYST,YRED,EDMO,DYED,OPTNO
       INTEGER YEAR1,YEAR2,YEAR3,HYETO,FOO
       REAL KIF
       LOGICAL GRAPH,DIS,INTERN,DYUNDER,RTNG,STP,OPTDES,ANS
       LOGICAL EVPRTN,CALIB,SIMUL,DESSTM,OBJVOL
       LOGICAL OBJQP,PRNT,CRTOBS,OBJSHP
       DATA NODYMO/31,28,31,30,31,30,31,31,30,31,30,31/
       DATA PAR/3H FO,3H FC,3HKIF,3H  C,3HDRR,3HFCP,3HPVD,3HGRD,3HDLY,
      $3HGNT,3HPNT,3HRFF,3HAMC,3HDUR,3H AP,3HPEX,3HQEX,3H P*,3H Q*,
      $3HP**,3HQ**/
C....  ARRAY AEVAPT IS THE AVERAGE DAILY PAN EVAPORATION FOR EACH MONTH
       DATA AEVAPT/.0097,.0214,.0548,.1446,.2063,.2380,.2597,
      +.2448,.1968,.1410,.0133,.0032/
       NAMELIST/PARA/FO,FC,KIF,C,DRR,FCAP,PVDAB,GRDAR,DLYPER
      $,GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,
      $PANRAT,TRANRAT,QB
       PRINT*,' INPUT THE PROGRAM DIMENSIONING '
       READ(11,*)NDIM,MAXBR
       NDP1=NDIM+1
       ND10=NDIM*10
       PRINT*,' INPUT THE SOIL GROUP(1-4) AND THE AMC(1-4) '
       READ(11,*)GROUP,AMC
C          READ IN LOGICAL PROGRAM PARAMETERS
       PRINT*,'GRAPH,DIS,EVPRTN,RTNG,CALIB,SIMUL,OPTDES,DESSTM,CRTOBS,OBJ
      $VOL,OBJQP,OBJSHP,PRNT,INTERN'
        READ(11,*) GRAPH,DIS,EVPRTN,RTNG,CALIR,SIMUL,OPTDES,DESSTM,CRTOBS
      $,OBJVOL,OBJOP,OBJSHP,PRNT,INTERN
       CALL STATUS(GRAPH,DIS,EVPRTN,RTNG,CALIB,SIMUL,OPTDES,DESSTM,
      $CRTOBS,OBJVOL,OBJOP,OBJSHP,PRNT,NSIM,NN,HYETO,INTERN)
       IF(DESSTM) GO TO 2388
       PRINT*,' INPUT THE NO. OF YEARS OF SIMULATION  '
       READ(11,*)NYRS
       DO 9944 I=1,NYRS
       PRINT*,' INPUT THE STARTING YEAR, MONTH, & DAY OF SIMULATION '
       PRINT*,'  FOR ',I,' YEAR.'
       READ(11,*)YRST(I),STMO(I),DYST(I)
       PRINT*,' INPUT THE ENDING YEAR, MONTH, & DAY OF SIMULATION '
       READ(11,*)YRED(I),EDMO(I),DYED(I)
       IF(YRST(I).NE.YRED(I)) PRINT*,' YRST .NE. YRED '
 9941  IF(YRST(I).NE.YRED(I)) STOP
C....  COMPUTE THE STARTING DAY AND ENDING DAY FOR EACH YEAR
       DO 8832 NYR=1,NYRS
       IDYST(NYR)=0
       IST=STMO(NYR)
       DO 2 I=1,IST
       IF(I.EQ.STMO(NYR)) GO TO 3
       IDYST(NYR)=IDYST(NYR)+NODYMO(I)
       IF(I.EQ.2.AND.((YRST(NYR))/4)*4.EQ.(YRST(NYR)))
      $IDYST(NYR)=IDYST(NYR)+1
    2  CONTINUE
    3  IDYST(NYR)=IDYST(NYR)+DYST(NYR)
       IDYED(NYR)=0
       IED=EDMO(NYR)
       DO 6 I=1,IED
       IF(I.EQ.EDMO(NYR)) GO TO 7
       IDYED(NYR)=IDYED(NYR)+NODYMO(I)
        IF(I.EQ.2.AND.((YRED(NYR))/4)*4.EQ.(YRED(NYR)))
      $IDYED(NYR)=IDYED(NYR)+1
    6  CONTINUE
    7  IDYED(NYR)=IDYED(NYR)+DYED(NYR)
 8832  CONTINUE
C....  INITIALIZE FOR GCS PLOT OUTPUT
 2388  IF(GRAPH) CALL USTART
C....  INITIALIZE PARAMETERS
       IF(INTERN) 8042,8043
C....  NOTE: BASIN CAN ONLY HAVE ONE SET OF PARAMETERS
 8012  CALL SETPAR(FO,FC,ALPHA,FCAP,TFCP,C,TMAX,GROUP,KIF
      +,QB,DLYPER,PANRAT,TRANRAT,RUFF)
       GO TO 8045
C....  INPUT THE INITIAL STREET ABSTRACTION AND GRASSED AREA ABS.
 8043  PRINT*,' INPUT THE INITIAL PAVED AND GRASSED AREA ABSTRACTIONS '
       READ(11,*)PVDAR,GRDAR
       PRINT*,'FO,FC,KIF,C,DRR,FCAP,DLYPER,GNT,PNT,
      $RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST'
       READ(11,*)FO,FC,KIF,C,DRR,FCAP,DLYPER,GNT,PNT,RFF,
      $AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST
       PANRAT=.9 $ TRANRAT=.12
       QB=0.0
 8045  CONTINUE
       WRITE(10,PARA)
       WRITE(7,PARA)
       NRCH=0
 2569  ENBR=0.
       READ(6,2069)IBR,IRCH,ENDBR,TEST
 2069  FORMAT(2I3,F3.0,56X,A3)
       IF(ENDBR.NE.0.0) GO TO 2569
       BA=SPA=CGA=0.0
       READ(6,2669) BA,SPA,PSPA,CGA,PCGA,GROUP
 2669  FORMAT(6X,F9.0,8X,F5.0,F3.0,15X,F5.0,F3.0,15X,F2.0)
       IF(SPA.NE.0.0) GO TO 3269
       SPA=BA*PSPA*0.01
 3269  CONTINUE
       IF(CGA.NE.0.0) GO TO 3369
       CGA=BA*PCGA*0.01
 3369  CONTINUE
       NRCH=NRCH+1$IRX(NRCH)=IRCH+1$IBX(NRCH)=IBR+1
       IF(CGA.EQ.0.0) FACTOR(IBX(NRCH),IRX(NRCH))=0.0
       IF(CGA.EQ.0.0) GO TO 301
       FACTOR(IBX(NRCH),IRX(NRCH))=(CGA+SPA)/CGA
  301  IF(TEST.EQ.3HEND) GO TO 1234
       GO TO 2569
 1234  WRITE(7,3344)
 3344  FORMAT(' FACTOR ARRAY ECHO',/,5('  B  R     FACTOR'))
       WRITE(7,896) (IBX(I)-1,IRX(I)-1,FACTOR(IBX(I),IRX(I)),I=1,NRCH)
  896  FORMAT(5(2I3,F10.4),/)
       RETURN
       END
       SUBROUTINE INFLTN(NRI,FI,DEPG,NGSR,SPASR,AR,PASR,NOSTM,NREACH,
      $CPA,SPA,CGA,TOTIN,TOTINF,TRAIN,ALPHA,NDIM,PRNT)
       DIMENSION  PASR(NDIM),AR(NDIM)
C      COMMON /INF/FO,FC,K,DELT,ALPHA1,FCAP,TOTAL,DLYPER
       COMMON /INF/DELT,ALPHA1
       COMMON /OPT/PAR(25),FO,FC,K,C,DRR,FCAP,PVDAR,GRDAB,DLYPER,
      1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
       COMMON /MOIST/TSMS(20,20),FACTOR(20,20),DIRT(20,20),IBX(35),
      +IRX(35),TMPSMS(35)
       REAL K
       LOGICAL PRNT
C      FCAP=(FO-FC)*0.1*(1.+GROUP)/K
C      TOTAL=(FO-FC)/K
C      DIFF=TOTAL-FCAP
C.... DYSDRN REPRESENTS THE NUMBER OF DAYS REQUIRED TO DRAIN THE SOIL MANTLE
C.... FROM SATURATION TO FIELD CAPACITY.
C.... THE RANGE OF THIS PARAMETER IS USSUALLY FROM 2.5-3.0 DAYS DEPENDING
C.... ON THE SOIL TYPE.
C      DYSDRN=3.0
C....  ALPHA REPRESENTS THE HYSTERISIS OF THE DEEP PERCOLATION BEING
C....  LESS WHEN THE MOISTURE CONTENT IS DECREASING(NO INFILTRATION) COMPARED TO
C....  THE DEEP PERCOLATION WHEN THE MOISTURE CONTENT IS INCREASED(INFILTRATON).
C      ALPHA=(DIFF/DYSDRN)/(FC*24.0)
C      PRINT*,' FCAP=',FCAP,' TOTAL=',TOTAL,' DIFF=',DIFF,' ALPHA=',ALPHA
       DEPVOL=DEPG
       T=THE(FI)
       SPASR=0.0
       NGSR=0
       DO 10 I=1,NRI,1
       IF(AR(I)-DEPVOL) 100,200,200
  100  DEPVOL=DEPVOL-AR(I)
       AR(I)=0.0
       GO TO 300
  200  AR(I)=AR(I)-DEPVOL
       DEPVOL=0.0
  300  CONTINUE
       DELF=DELS(T)/(DELT/60.)
       DELR=AR(I)/(DELT/60.)
C....  NEXT 2 STATEMENTS TRANSFORM POINT PERVIOUS SUPPLY TO AREAL SUPPLY
C      IF(DELR.LE.DELF) PASR(I)=DELR/(2.*DELF)
C      IF(DELR.GT.DELF) PASR(I)=DELR-(DELF/2.0)
       PASR(I)=AMAX1(DELR-DELF,0.0)
       DELF=AR(I)-PASR(I)*(DELT/60.)
C      PRINT*,'I=',I,'DELF=',DELF
       SPASR=SPASR+PASR(I)*DELT/60.
       IF(DELF.GT.0.0)FI=FI+DELF
C....  IF NO INFILTRATION OCCURS DRAIN SOIL MANTLE
       IF(PASR(I).GT.0.01) NGSR=I
       T=THE(FI)
       TOTINF=TOTINF+CGA*43560.*DELF/12.0
   10  IF(DELF.LE.0.0.AND.FI-FC*T.GT.FCAP*(FO-FC)/KIF)
      $FI=FI-ALPHA*FC*DELT/60.
C....  RESET SOIL MOISTURE FOR SUBSEQUENT STORMS WHICH START ON SAME DAY.
       IF(NOSTM.EQ.1) RETURN
       TMPSMS(NREACH)=FI-FC*T
       RETURN
       END
       FUNCTION DELS(T)
C      COMMON /INF/FO,FC,K,DELT,ALPHA,FCAP,C,DLYPER
       COMMON /INF/DELT,ALPHA
       COMMON /OPT/PAR(25),FO,FC,K,C,DRR,FCAP,PVDAB,GRDAB,DLYPER,
      1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
       REAL K
       DT=DELT/60.
       TPDT=T+DT
       DELS=FC*TPDT-FC*T-(FO-FC)*EXP(-K*TPDT)/K+(FO-FC)*EXP(-K*T)/K
       RETURN
       END
       FUNCTION THE(FI)
C....  COMPUTATION OF EQUIVALENT TIME ON HORTON INFILTRATION CURVE
C....  USING THE INTERVAL BI-SECTION METHOD.
C      COMMON /INF/FO,FC,K,DELT,ALPHA,FCAP,C,DLYPER
       COMMON /INF/DELT,ALPHA
       COMMON /OPT/PAR(25),FO,FC,K,C,DRR,FCAP,PVDAB,GRDAB,DLYPER,
      1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
       REAL K
       IF(FI.LE.0.0) FI=0.0
       IF(FI.EQ.0.0) THE=0.0
       IF(FI.EQ.0.0) RETURN
       TU=10.0
       FU=FI-FC*TU+(FO-FC)*EXP(-K*TU)/K-(FO-FC)/K
       IF(FU.GT.0.0) THE=10.0
       IF(FU.GT.0.0) RETURN
       TL=0.0
   10  FU=FI-FC*TU+(FO-FC)*EXP(-K*TU)/K-(FO-FC)/K
       FL=FI-FC*TL+(FO-FC)*EXP(-K*TL)/K-(FO-FC)/K
       TI=(TU+TL)/2.0
       FTI=FI-FC*TI+(FO-FC)*EXP(-K*TI)/K-(FO-FC)/K
       IF(ABS(FTI/ABS(FTI)-FU/ABS(FU)).LE.0.001) TU=TI
       IF(ABS(FTI/ABS(FTI)-FU/ABS(FU)).GT.0.001) TL=TI
       IF(ABS(FTI).GT.0.01) GO TO 10
       THE=TI
       RETURN
       END
       SUBROUTINE TIMEA (A,ENT,DTOUT,NAI,MAXA,CA,NDIM,PRNT)
       DIMENSION A(NDIM)
       LOGICAL PRNT
C
C.... COMPUTE AND STORE TIME AREA CURVE
C
```

```
    5 AAS=ENT/DTOUT
      TAAS=AAS+1.0
      NAI=TAAS
      IF (NAI.EQ.1) GO TO 20
      ASUM=0
      NIX=NAI-1
      DO 10 N=1,NIX
           A(N)=CA/AAS
   10      ASUM=ASUM+A(N)
      A(NAI)=CA-ASUM
      NAX=NAI+1
      DO 15 N=NAX,MAXA
   15      A(N)=0
      GO TO 30
   20 A(1)=CA
      DO 25 N=2,MAXA
   25      A(N)=0
   30 CONTINUE
C
C.... PRINT 70
C.... PRINT 80,(A(N),N=1,NAI)
C
      RETURN
C
      END
      SUBROUTINE GRENT (GENT,GA,GLENG,GSLP,ENT,PRNT)
C
      LOGICAL PRNT
      GENT=0.83*(.40*GLENG/(GSLP/100.)**0.5)**.467
C
C
C
C....  FOLLOWING CARD USED FOR SERIES OVERLAND FLOW SYSTEM
C....   ,NOT USED FOR PARALLEL SYSTEM.
C     GENT=GENT+ENT
C
C
      RETURN
C
C
      END


      SUBROUTINE INTEN (RI,ABSTRT,NRI,DTOUTHR,NDIM,PRNT)
      DIMENSION RI(NDIM)
      LOGICAL PRNT
      SUB=0.0
      DO 5 J=1,NRI
           SUB=SUB+RI(J)
           IF (ABSTRT-SUB) 10,10,5
    5      RI(J)=0.0
      IF(PRNT)
     + WRITE(7,1005)
      GO TO 20
   10 CONTINUE
      RI(J)=SUB-ABSTRT
      DO 15 K=1,NRI
           RI(K)=RI(K)/DTOUTHR
   15      CONTINUE
   20 CONTINUE
C
C.... PRINT 70,(RI(J),J=1,NRI)
C
      RETURN
C
C
 1005 FORMAT (51H  ABSTRAT GREATER THAN RAINFALL IN SUBROUTINE INTEN)
      END
      SUBROUTINE DETEN (GR,GRPK,LAST,STORF,DTOUT,BRAN,REACH,VOL,NDIM,
     $QT,PRNT)
      DIMENSION GR(NDIM),QT(NDIM)
      LOGICAL PRNT
      DTMAX=STORE*1000.0
      DTOUTSC=DTOUT*60.0
C
C.... PRINT 200,GRPK
C
      QOUT=0.0
      QINC=GRPK/50.0
    5 J=0
      VOLMAX=0
      MIKE=LAST
      DO 10 K=1,NDIM
           QT(K)=0
   10      CONTINUE
      VOL=0
      QOUT=QOUT+QINC
      IF (QOUT) 40,40,15
   15 J=J+1
      AVAIL=GR(J)+VOL/DTOUTSC
      DIFF=AVAIL-QOUT
      IF (DIFF) 20,20,25
   20 QT(J)=AVAIL
      VOL=0
      GO TO 35
   25 QT(J)=QOUT
      VOL=DIFF*DTOUTSC
      IF (VOLMAX.GT.VOL) GO TO 30
      VOLMAX=VOL
   30 IF (VOL.GT.DTMAX) GO TO 5
   35 CONTINUE
C
C.... PRINT 300,J,QOUT,AVAIL,DIFF,GR(J),QT(J),VOL,VOLMAX,DTMAX
C
      IF (J.LT.LAST) GO TO 15
      IF (VOL.LT.5.0) GO TO 45
      MIKE=MIKE+1
      IF (MIKE.GT.(NDIM-1)) GO TO 45
      GR(MIKE)=0.0
      GO TO 15
   40  IF(PRNT) WRITE(7,1005)
   45 GRPK=QOUT
      VOL=VOLMAX
      LAST=MIKE
      DO 50 K=1,LAST
           GR(K)=QT(K)
   50      CONTINUE
C
C.... PRINT 201,GRPK
C
      RETURN
C
C
 1005 FORMAT (33H NO SOLUTION IN SUBROUTINE DETEN )
      END
      SUBROUTINE PAVENT (PENT,PL,PS,CPA,PRNT)
      LOGICAL PRNT
C
C....  APPROX. BY KERBY(1959) FOR L <= 1200 FT
C....   ASSUME N=0.40
      PENT=0.83*(.02*PL/(PS/100.)**0.5)**.467
C
C
      RETURN
C
C
    5 FORMAT (24H IMPERVIOUS ENTRY TIME= ,F6.1,4H MIN)
      END
      SUBROUTINE RHYETO (TRAIN,DURA,DTOUT,RR,NRI,NDIM,SR,HYETO,AP,PEX,DE
     $X,PST,QST,PSTST,QSTST,PRNT)
      REAL RR(NDIM),PCTT(17),PCTR(17),SR(NDIM)
      INTEGER XRI,HYETO
      LOGICAL PRNT
      DATA PCTR/0.,9.6,21.,32.7,43.,51.2,58.3,63.1,67.2,
     $70.6,73.5,79.5,84.2,88.5,92.5,96.3,100./
C
C                             HYETO OPTIONS
C        1=UNIFORM  2=HUFF MEDIAN  3=TRIANGULAR  4=BETA  5=BI-MODAL BETA
C
C
C
      GO TO (3,1,2,4,5), HYETO
    1 X=-4.
      IF(PRNT)
     +WRITE(7,998)
  998 FORMAT('*****HUFF DISTR(MEDIAN PT CURVE)*****')
      DO 8 I=1,11
           X=X+4.0
           PCTT(I)=X
    8      CONTINUE
      DO 10 I=12,17
           PCTT(I)=PCTT(I-1)+10.
   10      CONTINUE
      XRI=DURA/DTOUT+1.1
      SR(1)=0
      X=0
      DO 30 I=2,XRI
           X=X+DTOUT
           PX=(X/DURA)*100.
           DO 15 J=1,17
                IF (PX-PCTT(J)) 20,25,15
   15           CONTINUE
           GO TO 30
   20      SR(I)=(PCTR(J-1)+(PCTR(J)-PCTR(J-1))/(PCTT(J)-PCTT(J-1))*(PX-
     1     PCTT(J-1)))*TRAIN*.01
           GO TO 30
   25      SR(I)=PCTR(J)*TRAIN*.01
   30      CONTINUE
      JJ=XRI
      NRI=JJ
      RR(1)=0.0
      DO 35 J=2,JJ
           RR(J)=SR(J)-SR(J-1)
   35      CONTINUE
C
C.... PRINT 9,(RR(J),J=1,JJ)
C
      RETURN
    2 TOT=0.0
      IF(PRNT)
     +WRITE(7,889) AP
  889 FORMAT('*****TRI DISTR(AO=',F5.3,')*****')
      TIME=0.0
      RR(1)=0.0
      NRI=INT(DURA/DTOUT)+1
      DO 200 I=2,NRI
      TIME=TIME+DTOUT
      TO=TIME/DURA
      DO=(TO**2)/AP
      IF(TO.GT.AP) DO=AP-((TO**2)-2.*TO+2.*AP-(AP**2))/(1.-AP)
      IF(TO.GT.1) DO=1.0
      RR(I)=(DO*TRAIN-TOT)
      IF(RR(I).LT.0.0) RR(I)=0.0
  200 TOT=TOT+RR(I)
      RETURN
    3 NRI=INT(DURA/DTOUT)+1
      IF(PRNT)
     +WRITE(7,779)
  779 FORMAT('*****UNIFORM DISTR*****')
      RR(1)=0.0
      DO 400 I=2,NRI
  400 RR(I)=TRAIN/FLOAT(NRI-1)
      RETURN
C
```

```
    4 NRI=INT(DURA/DTOUT)+1
      IF(PRNT)
     +WRITE(7,1998) PEX,QEX
 1998 FORMAT(' *****BETA DISTR( P = ',F10.3,'  Q = ',F10.3,')*****')
      B=BETAX(PEX,QEX)
      RR(1)=0.0
      TIME=0.0
      DO 500 I=2,NRI
      TIME=TIME+DTOUT
      T2=TIME/DURA
      T1=(TIME-DTOUT/2.0)/DURA
      TO=(TIME-DTOUT)/DURA
      TMP=TO**(PEX-1.)*(1.-TO)**(QEX-1.)
      TMP=TMP+T1**(PEX-1.)*(1.-T1)**(QEX-1.)
      TMP=TMP+T2**(PEX-1.)*(1.-T2)**(QEX-1.)
      RIAVG=TMP*TRAIN/DURA/3./B
  500 RR(I)=RIAVG*DTOUT
      RETURN
    5  WRITE(7,33333)
33333 FORMAT(' *****BI-MODAL BETA NOT AVAILABLE YET*****')
      STOP
      END

      SUBROUTINE LIMITQ (GR,GRPK,LAST,QALOW,DTOUT,BRAN,REACH,VOL,NDIM,
     $QT,PRNT)
      DIMENSION GR(NDIM),QT(NDIM)
      LOGICAL PRNT
      DTOUTSC=DTOUT*60.0
C
C.... PRINT 200,(GR(J),J=1,LAST)
C
      QOUT=QALOW
      J=0
      VOLMAX=0
      MIKE=LAST
      DO 5 K=1,NDIM
           QT(K)=0.0
    5      CONTINUE
      VOL=0.0
   10 J=J+1
      AVAIL=GR(J)+VOL/DTOUTSC
      DIFF=AVAIL-QOUT
      IF (DIFF) 15,15,20
   15 QT(J)=AVAIL
      VOL=0
      GO TO 25
   20 QT(J)=QOUT
      VOL=DIFF*DTOUTSC
      IF (VOLMAX.GT.VOL) GO TO 25
      VOLMAX=VOL
   25 CONTINUE
      IF (J.LT.LAST) GO TO 10
      IF (VOL.LT.5.0) GO TO 30
      MIKE=MIKE+1
      IF (MIKE.GT.(NDIM-1)) GO TO 30
      GR(MIKE)=0.0
      GO TO 10
   30 GRPK=QOUT
      VOL=VOLMAX
      LAST=MIKE
      DO 35 K=1,LAST
           GR(K)=QT(K)
   35      CONTINUE
C
C.... PRINT 201,(GR(J),J=1,LAST)
C
      RETURN
C
      END
      SUBROUTINE ROUTE (GR,IB,DTOUT,RUFF,SO,DIAM,LENG,LAST,SURCH,Q,VOL,H
     1YD,ISECT,HR,WR,SS,GRPK,BRAN,REACH,IDXRTE,IRUN,RUFFN,TDIAM,QFB,SRCH
     2RG,ROUGH,NDIM,ND10,NDP1,TMPGR,TMPQ,TEMP,MAXBR,QT,PRNT,TRAVTIM)
      DIMENSION GR(NDIM),Q(MAXBR,NDP1),TMPGR(ND10),TMPQ(ND10), TEMP(NDIM
     $),QT(NDIM)
      COMMON CAPAC,FLAREA,VELOC,AO(51),QO(51),LSTSCT
      COMMON /AOQO/ AOP(51),QOP(51),HO(51)
      REAL LENG,LS
      INTEGER HYD
      LOGICAL SRCHRG,DEBUG,DESIGN,SIMUL,BEGIN,PRNT
      IF(GRPK.GT.0.01) GO TO 8901
      DO 8903 I=1,NDIM
 8903 Q(IB,I)=0.0
      LAST=NDIM
      SRCHRG=.FALSE.
      SURCH=0.0
      RETURN
 8901 SLOP=SO/100.
      AVOL=0.0
      IEND=LAST
      LSTSCT=300
      SRCHRG=.FALSE.
      SIMUL=SRCHRG
      DESIGN=SIMUL
      DEBUG=DESIGN
      IF (HYD.NE.0) DEBUG=.TRUE.
      IF (IRUN.EQ.1) DESIGN=.TRUE.
      IF (IRUN.EQ.2) SIMUL=.TRUE.
      IF (DESIGN) ROUGH=RUFFN
      IF (DESIGN) CAPAC=QFB
      IF (DESIGN) FLAREA=3.141592654*TDIAM*TDIAM/(144.*4)
      IF (DESIGN) VELOC=CAPAC/FLAREA
      IF (DESIGN) ISECT=1
      IF (SIMUL) ROUGH=RUFF
      IF (SIMUL) DIA=DIAM
      IF(ROUGH.LE.0.0) WRITE(7,3)
    3 FORMAT(' MANNINGS ROUGHNESS COEFFICIENT ZERO IN SUBR ROUTE-EXC END
     +ED.')
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```
      IF(ROUGH.LE.0.0) STOP
      DO 5 I=1,NDIM
           TEMP(I)=0.0
    5      Q(IB,I)=0.0
      DO 7 I=1,ND10
           TMPQ(I)=0.0
    7      TMPGR(I)=TMPQ(I)
      VOLIN=0.0
      DO 10 I=1,IEND
   10      VOLIN=VOLIN+GR(I)*DTOUT*60.
      IF (DEBUG.AND.PRNT.AND.ISECT.EQ.1.OR.ISECT.EQ.2)  WRITE(7,1015) GR
     $PK
      IF (DEBUG.AND.PRNT)  WRITE(7,1020) VOLIN
      IF (DESIGN) GO TO 30
      GO TO (25,15,40), ISECT
   15 FLAREA=HR*WR
      HRAD=FLAREA/(2.*HR+2.*WR)
      VELOC=1.486*HRAD**(2./3.)*SQRT(SLOP)/ROUGH
      CAPAC=VELOC*FLAREA
      I=1
      DEPTH=0.0
      QO(1)=DEPTH
      AO(1)=QO(1)
   20 I=I+1
      IF (I.EQ.51) GO TO 65
      DEPTH=0.02*HR+DEPTH
      AO(I)=AO(I-1)+0.02
      QO(I)=AO(I)**(5./3.)*((2.*HR+2.*WR)/(2.*DEPTH+WR))**(2./3.)
      GO TO 20
   25 DIA=DIA/12.
      FLAREA=DIA**2*3.141592654/4.0
      VELOC=1.486*(DIA/4.0)**(2./3.)*SQRT(SLOP)/ROUGH
      CAPAC=FLAREA*VELOC
   30 IF (LSTSCT.EQ.1) GO TO 70
      DO 35 I=1,51
           AO(I)=AOP(I)
           QO(I)=QOP(I)
   35      CONTINUE
      GO TO 70
   40 LS=1./SS
      TEMPHR=0.0
   45 TEMPHR=TEMPHR+0.5
C
      HRAD=TEMPHR*(WR+TEMPHR*LS)/(WR+2.*SQRT(1.+LS*LS)*TEMPHR)
      FLAREA=TEMPHR*(WR+TEMPHR*LS)
      CAPAC=(1.486/ROUGH)*FLAREA*HRAD**(2./3.)*SQRT(SLOP)
      VELOC=CAPAC/FLAREA
C
      IF (CAPAC.LT.GRPK) GO TO 45
      DEPTH=0.02*TEMPHR
      I=1
      AO(1)=0.0
      QO(1)=0.0
   50 I=I+1
      AO(I)=AO(I-1)+0.02
      IF (I.EQ.51) GO TO 65
   55 FXN=AO(I)-(DEPTH*(WR+DEPTH*LS))/(TEMPHR*(WR+TEMPHR*LS))
      IF (ABS(FXN).LT.0.05) GO TO 60
      DFXNDD=-(WR+2.*DEPTH*LS)/(TEMPHR*(WR+TEMPHR*LS))
      DEPTH=DEPTH-FXN/DFXNDD
      GO TO 55
   60 PO=(WR+2.*SQRT(1.+LS*LS)*DEPTH)/(WR+2.*SQRT(1.+LS*LS)*TEMPHR)
      QO(I)=AO(I)**(5./3.)/PO**(2./3.)
      GO TO 50
   65 AO(51)=1.
      QO(51)=1.
   70 IF (DEBUG.AND.PRNT)  WRITE(7,1025) CAPAC
      BEGIN=.FALSE.
      DO 75 I=1,NDIM
           IF (BEGIN) GO TO 80
           IF (GR(I).GT.0.01.AND..NOT.BEGIN) ISTART=I
           IF (GR(I).GT.0.01) BEGIN=.TRUE.
   75      CONTINUE
   80 CONTINUE
      IF (DEBUG.AND.PRNT)  WRITE(7,1005) (GR(I),I=1,IEND)
      IF (GRPK.GT.CAPAC) SRCHRG=.TRUE.
C
C.... WRITE(7,501) SRCHRG
C
      IF (.NOT.SRCHRG) GO TO 95
      SURCH=0.0
      DO 90 I=ISTART,IEND
           IF (CAPAC-GR(I)) 85,90,90
   85      SURCH=SURCH+(GR(I)-CAPAC)*DTOUT*60.
   90      CONTINUE
      CALL LIMITQ(GR,GRPK,IEND,CAPAC,DTOUT,BRAN,REACH,PVOL,NDIM,QT,PRNT)
      VOL=AMAX1(VOL,PVOL)
   95 CONTINUE
      IF (DEBUG.AND.PRNT.AND.SRCHRG.AND.ISECT.EQ.1.OR.ISECT.EQ.2)  WRITE
     $(7,1030)
     1(GR(I),I=1,IEND)
C
      TRAVTIM=LENG/(GRPK/CAREA(GRPK))
      IF (TRAVTIM.LE.DTOUT*60./10.0) GO TO 100
      GO TO 110
  100  IF(PRNT) WRITE(7,1010)
      DO 105 I=1,IEND
  105      Q(IB,I)=GR(I)
      IQEND=IEND
      VOLOUT=VOLIN
      IF (DEBUG.AND.PRNT)  WRITE(7,1035) TRAVTIM
      GO TO 160
  110 IF (DEBUG.AND.PRNT)  WRITE(7,1035) TRAVTIM
C
      DT=TRAVTIM/60.
C
      IF (TRAVTIM/60.0.LT.DTOUT) GO TO 115
      GO TO 120
```

```
  115 CALL INTERP (DTOUT,IEND,GR,DT,IENDP,TMPGR,NDIM,ND10,PRNT,SRCHRG)
      IFND=IENDP
      GO TO 130
  120 XNDX=(TRAVTIM/60.)/DTOUT
      NDX=INT(XNDX)
      IF (XNDX-FLOAT(NDX).GE.0.5) NDX=NDX+1
      DO 125 I=1,IFND
  125     TMPGR(I)=GR(I)
      DT=DTOUT
C
  130 DT=DT*60.0
C
      ISHIFT=1
      IF (TRAVTIM-DTOUT*60..GE.1E-04) ISHIFT=NDX
      DO 135 I=ISTART,IFND
  135     TMPQ(I+ISHIFT)=TMPGR(I)
      IQEND=IEND+ISHIFT
      IF (IDXRTE.EQ.1) GO TO 150
C
      J=ISTART-1
      IF (TRAVTIM.GE.DTOUT*60.) J=ISTART+NDX-1
  140 J=J+1
      O2=TMPQ(J+1)
      ITER=1
      CAREA1=CAREA(TMPGR(J))
      CAREA2=CAREA(TMPQ(J))
      CAREA3=CAREA(TMPGR(J+1))
      ALPHA=(DTOUT*60./DT)
      PREVF=0.0
      IF (IDXRTE.EQ.2) O2=TMPGR(J)+TMPGR(J+1)-TMPQ(J)+(CAREA2-CAREA3)*LE
     1NG/DT
      IF (O2.GT.CAPAC) O2=CAPAC
      IF (O2.LT.0.0) O2=0.0
      TMPQ(J+1)=O2
      IF (J+1.GT.IQEND) GO TO 150
      IF (IDXRTE.EQ.2) GO TO 140
C
      CONST=TMPGR(J)+TMPGR(J+1)-TMPQ(J)+(CAREA1+CAREA2-CAREA3)*LENG/DT
      CONST=CONST
  145 F=CONST-CAREA(O2)*LENG/DT-O2
C
      IF (PREVF.LT.0.0.AND.F.GT.0.0) ALPHA=ALPHA*2.0
      IF (PREVF.GT.0.0.AND.F.LT.0.0) ALPHA=ALPHA*2.0
      IF (PREVF.LT.0.0.AND.F.LT.0.0) ALPHA=ALPHA*0.666
      IF (PREVF.GT.0.0.AND.F.GT.0.0) ALPHA=ALPHA*0.666
      IF (ABS(F).LE.0.1) TMPQ(J+1)=O2
      IF (ABS(F).LE.0.1) GO TO 140
      IF (ITER.GE.100)  WRITE(7,1040) F,TMPGR(J),O2
      O2=O2+F/ALPHA
      PREVF=F
      IF (O2.GT.CAPAC) O2=CAPAC
      IF (O2.LT.0.0) O2=0.0
      IF (ABS(O2-CAPAC).LE.1E-04.AND.F.GT.0.0) XVOL=XVOL+F
      IF (ABS(O2-CAPAC).LE.1E-04.AND.F.GT.0.0) GO TO 140
      IF (O2.EQ.0.0.AND.F.LT.0.0) GO TO 140
      ITER=ITER+1
      IF (ITER.GT.100)  WRITE(7,1045) ITER
      IF (ITER.GT.150) WRITE(7,1050)
      IF (ITER.GT.150) STOP
      GO TO 145
  150 CONTINUE
C
      CALL INTERP (DT/60,IQEND,TMPQ,DTOUT,IQENDP,TEMP,ND10,NDIM,PRNT,SRC
     $HRG)
      IQEND=IQENDP
      VOLOUT=0.0
      DO 155 I=1,IQEND
          Q(IB,I)=TEMP(I)
  155     VOLOUT=VOLOUT+Q(IB,I)*DTOUT*60.
  160 IF (DEBUG.AND.PRNT)  WRITE(7,1055) VOLOUT
      IF (DEBUG.AND.PRNT)  WRITE(7,1060) (Q(IB,I),I=1,IQEND)
      IF (DESIGN) CAPAC=0.0
      IF (DESIGN) VELOC=0.0
      LSTSCT=ISECT
      LAST=IQEND
      RETURN
C
C
 1005 FORMAT (34H DESIGN HYDRO BEFORE CAPACITY LTD ,/,10F8.1,49(/,10F8.1
     1))
 1010 FORMAT (49H  TRAVEL TIME SO SMALL THAT ROUTED =DESIGN HYDRO.)
 1015 FORMAT (38H PEAK Q BEFORE REACH CAP. REDUCTION = ,F10.1,5H.CFS.)
 1020 FORMAT (35H CONTINUITY CHECK--INFLOW VOLUME = ,F15.1)
 1025 FORMAT (21H CAPACITY OF REACH = ,F10.1,15H IN SUBR ROUTE.)
 1030 FORMAT (51H DESIGN HYDRO AFTER REDUCTION FOR REACH CAPACITY   ,/,1
     10F8.1,49(/,10F8.1))
 1035 FORMAT (29H TRAVEL TIME FOR THIS REACH =,F10.2,9H SECONDS.)
 1040 FORMAT (19H ZEROED CONT FXN = ,F10.2,18H PRESENT INFLOW = ,F10.2,4
     16H PRESENT OUTFLOW FOR WHICH CONTINUITY FAILS = ,F10.2)
 1045 FORMAT (75H EXCESSIVE ITERATIONS IN ROUTE FOR IMPLICIT METHOD ITER
     1ATIONS PRESENTLY AT ,I5,1H.)
 1050 FORMAT (81H TERMINATION DUE TO EXCESSIVE ITERATIONS OF IMPLICIT ME
     1THOD IN SUBROUTINE ROUTE!!)
 1055 FORMAT (36H CONTINUITY CHECK--OUTFLOW VOLUME = ,F15.1)
 1060 FORMAT (20H ROUTED DESIGN HYDRO,/,10F8.1,49(/,10F8.1))
      END
      FUNCTION CAREA (Q)
      COMMON CAPAC,FLAREA,VELOC,AO(51),QO(51),LSTSCT
      RATIO=Q/CAPAC
      IF (ABS(RATIO-QO(51)).LE.1E-04) CAREA=FLAREA
      IF (ABS(RATIO-QO(51)).LE.1E-04) RETURN
      IF (ABS(RATIO).LE.1E-04) CAREA=0.0
      IF (ABS(RATIO).LE.1E-04) RETURN
      IF (RATIO.LE.QO(2)) I=2
      IF (RATIO.LE.QO(2)) GO TO 10
      DO 5 I=2,51
          IF (ABS(RATIO-QO(I)).LT.ABS(RATIO-QO(I-1)).AND.ABS(RATIO-QO(I
     1    )).LT.ABS(RATIO-QO(I+1))) GO TO 10
    5     CONTINUE
       WRITE(7,1005) Q
       WRITE(7,1010) RATIO
      IF (RATIO.GT.QO(51)) I=51
      IF (RATIO.GT.QO(51)) RATIO=1.0
      IF (RATIO.LT.0.0) I=2
      IF (RATIO.LT.0.0) RATIO=0
   10 CONTINUE
      Y1=AO(I-1)
      Y2=AO(I)
      Y3=AO(I+1)
      X1=QO(I-1)
      X2=QO(I)
      X3=QO(I+1)
      A=(Y1-Y3-(Y2-Y3)*(X1-X3)/(X2-X3))/(X1**2-X3**2-(X1-X3)*(X2+X3))
      B=(Y2-Y3)/(X2-X3)-(X2+X3)*A
      C=Y3-X3*(X3*A+B)
      CAREA=(A*RATIO**2+B*RATIO+C)*FLAREA
C
C.... PRINT *,A,B,C,RATIO,CAREA,I,X1,X2,X3,Y1,Y2,Y3,
C.... QO(I+1),AO(I+1)
C
      RETURN
C
C
 1005 FORMAT (46H DISCHARGE OUT OF RANGE OF AO VS QO CURVE Q = ,F10.1)
 1010 FORMAT (23H DISCHARGE RATIO(QO) = ,F10.5)
      END
       SUBROUTINE SRFRNFF
     $(GR,GRPK,PKIN,CPA,CGA,SPA,NRI,RR,TSMS,KIF,C,PTRAIN,PREVEND,ST,
     $FCAP,DLYPER,EVPPAN,PANRAT,ABSTRT,PVDAB,TRANRAT,DEPG,FO,FC,
     $DTOUT,PENT,MAXA,HYD,BRAN,REACH,NOSTM,NREACH,TOTIN,TOTINF,ALPHA,
     $GENT,GAD,RTING,NDIM,GGR,AR,RI,PASR,A,RRAT,TRAIN,ILT,GRDAB,
     $DTOUTHR,NEND,PRNT)
       DIMENSION GR(NDIM),RR(NDIM),TSMS(20,20),GAD(NDIM),GGR(NDIM),AR(NDI
     $M)
     $,RI(NDIM),PASR(NDIM),A(NDIM)
       INTEGER HYD
       REAL KIF
       LOGICAL RTING,PRNT
C$$$$$$$$$$$$$$$$$$$$SURFACE RUNOFF COMPUTATION SECTION$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C.... FOR AREA =0 IN MID BRANCH
C
      DO 290 J=1,NDIM
          GR(J)=GGR(J)=0.0
  290     CONTINUE
      GRPK=0.0
      PKIN=0.0
      NGSR=NEND=NGEND=0
      IF (CPA+CGA+SPA.LE.0.0) RETURN
      IF (CGA.LE.0.0.AND..NOT.RTING) RETURN
      IF(RTING.AND.CGA.LE.0.0) GO TO 133
C.... CHANGE THE RAINFALL SUPPLY RATE TO REFLECT SPA CONTRIBUTION
  130 DO 210 I=1,NRI,1
          AR(I)=RR(I)*(CGA+SPA)/CGA
  210     CONTINUE
C....  DETERMINE FI FOR THIS REACH TO INITIALIZE INFLTN ROUTINE
      SLMSTR=TSMS(INT(BRAN)+1,INT(REACH)+1)*(FO-FC)/KIF/C
      IF(ILT.EQ.1) PTRAIN=0.0
      IF(ILT.EQ.1) PREVEND=0.0
C....  DETERMINE THE EVAPOTRANSPIRATION BETWEEN STORMS STARTINS ON SAME DAY.
C....  DETERMINE THE HOURS BETWEEN PREVIOUS STORM END AND PRESENT
C....   STORM START FOR MULTIPLE STORM STARTS ON THE SAME DAY
      HOURS=ST/60.-(40./60.)*AINT(ST/100.)
     $-PREVEND/60.+(40./60.)*AINT(PREVEND/100.)
      DAYS=HOURS/24.0
C     PRINT*,ST,PREVEND
C     PRINT*,' DAYS = ',DAYS
C....  PLACE RR*100%  OF THE DAILY RAINFALL INTO THE SOIL
      SLMSTR=AMIN1(TSMS(INT(BRAN)+1,INT(REACH)+1)+PTRAIN*(CGA+SPA)
     $/CGA*RRAT,C)
C     PRINT*,SLMSTR,TSMS(INT(BRAN)+1,INT(REACH)+1),PTRAIN,CGA,SPA
C    $,RRAT,C
C....  DRAIN SOIL IF SLMSTR IS GT FCAP
      IF(SLMSTR-FCAP*C.GT.0.001)SLMSTR=AMAX1(SLMSTR-DLYPER*DAYS,FCAP*C)
C     PRINT*,FCAP,EVPPAN,PANRAT,DAYS
      EVP=EVPPAN*PANRAT*DAYS
      ABSTRT=AMIN1(AMAX1(ABSTRT-PTRAIN,0.0)+EVP,PVDAB)
      EVPT=EVP+EVP*TRANRAT
C....  FILL GRASSED ABSTRACTION RESEVOIR WITH RAIN
      DEPGP=AMAX1(DEPG-PTRAIN,0.0)
C....  DEPLETE GRASSED ABSTRACTION RESEVOIR WITH EVAPORATION
      DEPGPP=AMIN1(DEPGP+EVP,GRDAB)
C     PRINT*,' EVPPAN= ',EVPPAN,' EVP= ',EVP
C....  ADJUST THE EVAPOTRANSPIRATION FROM THE SOIL DUE TO INITIAL ABS
      EVPT=AMAX1(0.0,EVPT+DEPGP-DEPGPP)
      DEPG=DEPGPP
      EVPT=EVPT*SLMSTR/C
      SLMSTR=AMAX1(0.0,SLMSTR-EVPT)
      SLMSTR=(SLMSTR/C)*(FO-FC)/KIF
C     PRINT*,SLMSTR,C,FO,FC,KIF
      TMX=-ALOG(1.0-KIF*SLMSTR/(FO-FC))/KIF
      FI=TMX*FC+SLMSTR
      CALL INFLTN(NRI,FI,DEPG,NGSR,SPASR,AR,PASR,NOSTM,NREACH,
     $CPA,SPA,CGA,TOTIN,TOTINF,TRAIN,ALPHA,NDIM,PRNT)
C     PRINT*,' GRASSED AREA SUPPLY RATE ',(PASR(I7),I7=1,NGSR)
      IF(.NOT.RTING) RETURN
C     PRINT*,' ABSTRT= ',ABSTRT,' DEPG = ',DEPG
  133 IF (CPA) 135,135,145
  135 DO 140 N=1,NDIM
          GR(N)=0.0
  140     CONTINUE
      GO TO 180
  145 CALL TIMEA (A,PENT,DTOUT,NAI,MAXA,CPA,NDIM,PRNT)
      DO 150 N=1,NRI
```

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          RI(N)=RR(N)
  150     CONTINUE
      CALL INTEN (RI,ABSTRT,NRI,DTOUTHR,NDIM,PRNT)
C
C.... COMPUTE GROSS PAVED AREA HYDROGRAPH BY CONVOLUTION OF LINEAR(W.R.T.
C....  TIME) TIME-AREA CURVE
C
      NEND=NRI+NAI-1
      DO 165 L=1,NRI
          N=L-1
          DO 160 J=1,NAI
              N=N+1
              DGR=RI(L)*A(J)
              GR(N)=GR(N)+DGR
  160         CONTINUE
  165     CONTINUE
      IF (HYD) 175,175,170
  170  IF(PRNT) WRITE(7,1165) BRAN,REACH
 1165 FORMAT (//,27H IMPERVIOUS AREA HYDROGRAPH,2F10.1)
      IF(PRNT)
     + WRITE(7,1170) (GR(J),J=1,NEND)
 1170 FORMAT (9F8.1)
  175 IF (CGA) 260,260,180
  180 CONTINUE
      IF (NGSR) 260,260,215
  215 CONTINUE
      CALL TIMEA (GAD,GENT,DTOUT,NGAI,MAXA,CGA,NDIM,PRNT)
      NGEND=NGAI+NGSR-1
C.... COMPUTE GROSS PERVIOUS AREA HYDROGRAPH BY CONVOLUTION OF LINEAR(W.R.T.
C....  TIME) TIME-AREA CURVE
      DO 240 L=1,NGSR
          N=L-1
          DO 235 J=1,NGAI
              N=N+1
              GDGR=PASR(L)*GAD(J)
              GGR(N)=GGR(N)+GDGR
  235         CONTINUE
  240     CONTINUE
      IF (HYD) 250,250,245
  245  IF(PRNT) WRITE(7,1180)
 1180 FORMAT (24H GRASSED AREA HYDROGRAPH)
      IF(PRNT)
     + WRITE(7,1185) (GGR(J),J=1,NGEND)
 1185 FORMAT (9F8.1)
  250 IF (NGEND-NEND) 260,260,255
  255 NEND=NGEND
  260 GRPK=GR(1)
C.... COMBINE THE SURFACE IMPERVIOUS AND PERVIOUS HYDROS AT DESIGN PT
      DO 265 I=1,NEND
          GR(I)=GR(I)+GGR(I)
      GRPK=AMAX1(GRPK,GR(I))
  265     CONTINUE
C$$$$$$$$$$$$$$$$$$$SURFACE RUNOFF COMPUTATION SECTION$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      RETURN
      END
      SUBROUTINE INTERP (DFROM,ENDFROM,ARRFROM,DTO,K,ARRTO,RNGFROM,RNGTO
     1,PRNT,FLAG)
      DIMENSION ARRFROM(1), ARRTO(1)
      INTEGER ENDFROM,RNGTO,RNGFROM
      LOGICAL PRNT,FLAG
      TOTO=DTO
      ARRTO(1)=0.0
      K=2
      IF (ENDFROM.GT.RNGFROM)  WRITE(7,1005)
      IF (ENDFROM.GT.RNGFROM)  WRITE(7,1015)
      IF (ENDFROM.GT.RNGFROM) STOP
   10 IF (TOTO.LE.DFROM) JP=2
      IF (TOTO.LE.DFROM) GO TO 20
      IF (TOTO-FLOAT(ENDFROM-1)*DFROM.GT.1E-04) GO TO 25
      JKLOW=INT(TOTO/DFROM)-1
      IF (JKLOW.LE.2) JKLOW=2
      DO 15 JK=JKLOW,ENDFROM
          IF (JK.EQ.ENDFROM) JP=ENDFROM-1
          IF (JK.EQ.ENDFROM) GO TO 20
          IF (ABS(FLOAT(JK-1)*DFROM-TOTO).LE.ABS(FLOAT(JK-2)*DFROM-TOTO
     1    ).AND.ABS(FLOAT(JK-1)*DFROM-TOTO).LE.ABS(FLOAT(JK)*DFROM-TOTO
     2)) JP=JK
          IF (ABS(FLOAT(JK-1)*DFROM-TOTO).LE.ABS(FLOAT(JK-2)*DFROM-TOTO
     1    ).AND.ABS(FLOAT(JK-1)*DFROM-TOTO).LE.ABS(FLOAT(JK)*DFROM-TOTO
     2)) GO TO 20
   15     CONTINUE
   20 Y1=ARRFROM(JP-1)
      Y2=ARRFROM(JP)
      Y3=0
      IF (JP.NE.ENDFROM) Y3=ARRFROM(JP+1)
      IF(ABS(AMAX1(ABS(Y1-Y2),ABS(Y2-Y3),ABS(Y1-Y3))).LE.0.001)
     +ARRTO(K)=(Y1+Y2+Y3)/3.0
      IF(ABS(AMAX1(ABS(Y1-Y2),ABS(Y2-Y3),ABS(Y1-Y3))).LE.0.001)  GO TO 6
     +7
      X1=FLOAT(JP-1)*DFROM-DFROM
      X2=FLOAT(JP-1)*DFROM
      X3=FLOAT(JP-1)*DFROM+DFROM
      A=(Y1-Y3-(Y2-Y3)*(X1-X3)/(X2-X3))/(X1**2-X3**2-(X1-X3)*(X2+X3))
      B=(Y2-Y3)/(X2-X3)-(X2+X3)*A
      C=Y3-X3*(X3*A+B)
      ARRTO(K)=A*TOTO**2+B*TOTO+C
      IF (ARRTO(K).LT.0.0) ARRTO(K)=0.0
      IF(ARRTO(K).EQ.0.0) GO TO 67
      IF(.NOT.FLAG) GO TO 67
C.....  RESTRICT INTERPOLATED VALUE TO HIGHEST DATA PT IF LOCAL OPT.
      IF(A.EQ.0.0) GO TO 67
      XMAX=-B/2./A
      IF(XMAX.LT.X1.OR.XMAX.GT.X3) GO TO 67
      IF(A.LT.0.0.AND.ARRTO(K).GT.AMAX1(Y1,Y2,Y3)) ARRTO(K)=AMAX1(Y1,Y2,
     $Y3)
      IF(A.GT.0.0.AND.ARRTO(K).LT.AMIN1(Y1,Y2,Y3)) ARRTO(K)=AMIN1(Y1,Y2,
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     $Y3)
   67 CONTINUE
C     IF(TOTO.EQ.7.50.OR.TOTO.EQ.42.50.AND.ARRFROM(3).EQ.3.95)
C     $PRINT*,' JP=',JP,' Y1=',Y1,' Y2=',Y2,' Y3=',Y3,' X1=',X1,
C     $' X2=',X2,' X3=',X3,' A=',A,' B=',B,' C=',C,' ARRTO(',K,')=',ARRTO(K)
C     $,' TOTO=',TOTO,' ENDFROM=',ENDFROM,' DFROM=',DFROM,' DTO=',DTO,
C     $' JKLOW=',JKLOW,' XMAX=',XMAX
      IF(K.EQ.RNGTO) RETURN
      K=K+1
      TOTO=TOTO+DTO
      GO TO 10
   25 ARRTO(K)=0.0
      RETURN
C
 1005 FORMAT (1H0,50H INTERPOLATED-FROM ARRAY OUT OF RANGE IN INTERP...)
 1010 FORMAT (1H0,48H INTERPOLATED-TO ARRAY OUT OF RANGE IN INTERP...)
 1015 FORMAT (1H0,37H     EXECUTION TERMINATED INTERP.....)
      END
      SUBROUTINE DLYACCT(RAIN,EVPPAN,NRCH,PANRAT,TRANRAT,DEPG,ABSTRT,NEX
     $NEV,SMS)
C     COMMON /INF/FO,FC,K,DELT,ALPHA,FCAP,C,DLYPER
      COMMON /INF/DELT,ALPHA
      COMMON /OPT/PAR(25),FO,FC,K,C,RR,FCAP,PVDAB,GRDAB,DLYPER,
     1GNT,PNT,RFF,AMC,DUR,AP,PEX,QEX,PST,QST,PSTST,QSTST,FOO
      COMMON /MOIST/TSMS(20,20),FACTOR(20,20),DIRT(20,20),IBX(35),
     +IRX(35),TMPSMS(35)
C....  SUBROUTINE FOR DAILY MOISTURE ACCOUNTING
      DO 10 I=1,NRCH
      SMS=TSMS(IBX(I),IRX(I))
      IF(FACTOR(IBX(I),IRX(I)).EQ.0.0) GO TO 10
C....  PLACE RR*100%  OF THE DAILY RAINFALL INTO THE SOIL
      SMS=AMIN1(SMS+AMAX1(RAIN-DEPG,0.0)*FACTOR(IBX(I),IRX(I))*RR,C)
C....  DRAIN SOIL IF SMS IS GT FCAP
      IF(SMS-FCAP*C.GT.0.001)SMS=AMAX1(SMS-DLYPER,FCAP*C)
      EVP=EVPPAN*PANRAT
      ABSTRT=AMIN1(AMAX1(ABSTRT-RAIN,0.0)+EVP,PVDAB)
      EVPT=EVP+EVP*TRANRAT
C....  FILL GRASSED ABSTRACTION RESEVOIR WITH RAIN
      DEPGP=AMAX1(DEPG-RAIN,0.0)
C....  DEPLETE GRASSED ABSTRACTION RESEVOIR WITH EVAPORATION
      DEPGPP=AMIN1(DEPGP+EVP,GRDAB)
C....  ADJUST THE EVAPOTRANSPIRATION FROM THE SOIL DUE TO INITIAL ABS
      EVPT=AMAX1(0.0,EVPT+DEPGP-DEPGPP)
      DEPG=DEPGPP
      EVPT=EVPT*SMS/C
      SMS=AMAX1(0.0,SMS-EVPT)
      TSMS(IBX(I),IRX(I))=SMS
   10 CONTINUE
C     WRITE(7,*)' DAY = ', NOBJ ,' RAIN = ',RAIN,' EVPT=',EVPT,' DEPG=
C    +',DEPG,' ABSTRT = ',ABSTRT,' SMS= ',SMS
C     PRINT*,' RAIN=',RAIN,' EVPPAN=',EVPPAN,' IDAY=',NOBJ
C     PRINT*,' SMS= ',SMS
      RETURN
      END
      SUBROUTINE SETPAR(FO,FC,ALPHA1,FCAP,
     +TFCP,C,TMAX,
     +GROUP,KDCY,QB,DLYPER,PANRAT,TRANRAT,RUFF)
C     DIMENSION TSMS(20,20)
      REAL KDCY
      KDCY=2.0
      IF(GROUP.LE.2.0)FO=12.0-2.0*GROUP
      IF(GROUP.GT.2.0) FO=7.0-2.0*(GROUP-2.0)
      FC=EXP(.804719-.715009*GROUP)
      ALPHA=-KDCY*ALOG(1.-FC/FO)
      C=FO*(1.-EXP(-ALPHA/KDCY))
     +/ALPHA
      FCAP=(FO-FC)*0.1*(1.+GROUP)/KDCY
      TFCP=-ALOG(KDCY*ALOG((FO-ALPHA*FCAP
     +)/FO
     +)/
     +ALPHA+1.0)/KDCY
      TMAX=-ALOG(KDCY*ALOG((FO-ALPHA*(C
     +-0.01))/FO
     +)/
     +ALPHA+1.0)/KDCY
      QB=0.0
....  DYSDRN IS THE NUMBER OF DAYS IT TAKES THE SATURATED BASIN SOIL TO
....  DRAIN TO FIELD CAPACITY
      DYSDRN=3.0
      ALPHA1=((C-FCAP)/DYSDRN)/(FC*24.0)
....  PANRAT IS THE FRACTION OF POTENTIAL EVAPORATION TO PAN EVAPORATION
      PANRAT=0.9
....  TRANRAT IS THE ADDITIONAL FRACTION OF POTENTIAL EVAPORATION
....  WHICH IS TRANSPIRATION(THIS IS USED TO COMPUTE POTENTIAL
....  EVAPOTRANSPIRATION)
      TRANRAT=0.1
      RUFF=0.015
      RETURN
      END
      SUBROUTINE STATUS(GRAPH,DIS,EVPRTN,RTNG,CALIB,SIMUL,OPTDES,DESSTM,
     $CRTOBS,OBJVOL,OBJQP,OBJSHP,PRNT,NSIM,NN,HYETO,INTERN)
      DIMENSION IER(10)
      LOGICAL GRAPH,DIS,INTERN,RTNG,STP,OPTDES
      LOGICAL EVPRTN,CALIB,SIMUL,OPTDES,DESSTM,OBJVOL
      LOGICAL OBJQP,PRNT,CRTOBS,OBJSHP
      INTEGER HYETO
      DATA IER/10*0/
      STP=.FALSE.
      IU=10
      NER=0
      IF((CALIB.OR.SIMUL).AND.(OPTDES.OR.DESSTM.OR.CRTOBS))
     $IER(1)=1
      IF(CALIB.AND.SIMUL.AND.IER(1).EQ.0) IER(1)=1
      IF(OPTDES.AND.DESSTM.AND.IER(1).EQ.0) IER(1)=1
      IF(OPTDES.AND.CRTOBS.AND.IER(1).EQ.0) IER(1)=1
      IF(CRTOBS.AND.DESSTM.AND.IER(1).EQ.0) IER(1)=1
      IF(.NOT.CALIB.AND..NOT.SIMUL.AND..NOT.OPTDES.AND..NOT.DESSTM.
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     $AND..NOT.CRTOBS) IER(2)=2
      IF(SIMUL.OR.DESSTM.OR.CRTOBS) GO TO 10
      IF((OBJVOL.OR.OBJQP).AND.OBJSHP) IER(3)=3
      IF(OBJVOL.AND.OBJQP.AND.IER(3).EQ.0) IER(3)=3
      IF(.NOT.OBJVOL.AND..NOT.OBJQP.AND..NOT.OBJSHP) IER(4)=4
   10 IF((CALIB.OR.OPTDES).AND..NOT.DIS) IER(5)=5
      IF(GRAPH) IER(7)=7
      DO 40 I=1,10
      IF(IER(I).NE.0) STP=.TRUE.
   40 IF(IER(I).NE.0) WRITE(IU,50) IER(I)
   50 FORMAT('   PROGRAM STATUS ERROR NO.',I3,'.')
      IF(STP) STOP
C.... DETERMINE WHICH DIMENSIONLESS HYETO IS TO BE USED
      IF(OPTDES) PRINT*,' INPUT HYETO TYPE(1-UNIFORM,2-HUFF,3-
     $TRI,4-BETA,5-BIMODAL BETA)'
      IF(OPTDES) READ(11,*)HYETO
      IF(.NOT.OPTDES.AND..NOT.CALIB) GO TO 20
C.... SET NN FOR OBJECTIVE FUNCTION USED
      IF(OBJVOL) NN=1
      IF(OBJQP) NN=2
      IF(OBJSHP) NN=3

       NSIM=100
      GO TO 30
   20 CONTINUE
      NSIM=1
   30 CONTINUE
C.... SET SURFACE/PIPE ROUTING STATUS
C    NOTE:  IF SIMULATION RTNG CAN BE EITHER F OR T AS READ-IN.
      IF((CALIB.OR.OPTDES).AND.(OBJQP.OR.OBJSHP)) RTNG=.TRUE.
      IF((CALIB.OR.OPTDES).AND.OBJVOL) RTNG=.TRUE.
      IF(DESSTM.OR.CRTOBS) RTNG=.TRUE.
      IF((CALIB.OR.OPTDES).AND.OBJVOL) RTNG=.FALSE.
C.... DETERMINE PRINTING STATUS
      IF(SIMUL) PRNT=.TRUE.
      IF(CALIB) PRNT=.FALSE.
      IF(DESSTM) PRNT=.TRUE.
      IF(OPTDES) PRNT=.FALSE.
      IF(CRTOBS) PRNT=.FALSE.
C.... DETERMINE OBSERVED EVAPORATION DATA STATUS
C.... NOTE:  CALIB,SIMUL,OPTDES, AND CRTOBS ALL MAY HAVE EVAPORATION OR NOT
      IF(DESSTM) EVPRTN=.FALSE.
C.... SUMMARIZE PROGRAM RUN STATUS
      WRITE(IU,100)
  100 FORMAT(15X,'*****RUN STATUS SUMMARY*****')
      IF(CALIB) WRITE(IU,60)
   60 FORMAT('  CALIBRATION RUN(WITH OBSERVED DISCHARGES) ')
      IF(OPTDES) WRITE(IU,70)
   70 FORMAT('  DESIGN STORM OPTIMIZATION WITH OBSERVED/SIMULATED DISCHA
     $RGES ')
      IF(SIMUL) WRITE(IU,80)
   80 FORMAT('  SIMULATION                                 ')
      IF(DESSTM) WRITE(IU,90)
   90 FORMAT('  DESIGN STORM GENERATION ')
      IF(DESSTM) WRITE(IU,91)
   91 FORMAT('     ONLY FILES REQUIRED ARE 'RFALL', 'CNTRL', AND 'BASIN''
     $)
      IF(CRTOBS)WRITE(IU,110)
  110 FORMAT('  SIMULATION TO CREATE DISCHARGES FOR DESIGN STORM OPTIMIZ
     $ATION')
      IF(OPTDES)WRITE(IU,170) HYETO
  170 FORMAT('     HYETOGRAPH TEMPORAL DISTRIBUTION ',I1,' USED')
      IF(INTERN) WRITE(IU,120)
  120 FORMAT('     INITIAL PARAMETER SETTING INTERNAL BY SOIL GROUP')
      IF(.NOT.INTERN) WRITE(IU,130)
  130 FORMAT('     INITIAL PARAMETER SETTING READ-IN')
      IF((OPTDES.OR.CALIB).AND.OBJVOL)WRITE(IU,140)
  140 FORMAT('     RUNOFF VOLUME OBJECTIVE FUNCTION USED')
      IF((OPTDES.OR.CALIB).AND.OBJQP)WRITE(IU,150)
  150 FORMAT('     PEAK DISCHARGE OBJECTIVE FUNCTION USED')
      IF((OPTDES.OR.CALIB).AND.OBJSHP)WRITE(IU,160)
  160 FORMAT('     HYDROGRAPH SHAPE OBJECTIVE FUNCTION USED')
      IF(PRNT) WRITE(IU,180)
  180 FORMAT('     DETAILED PRINT-OUT TO 'RESULT' FILE')
      IF(.NOT.PRNT) WRITE(IU,190)
  190 FORMAT('     DETAILED PRINT-OUT TO 'RESULT' FILE SUPPRESSED')
      WRITE(IU,200) NSIM
  200 FORMAT('     MAX NO. OF SIMULATION LOOPS = ',I3)
      IF(RTNG) WRITE(IU,210)
  210 FORMAT('     SURFACE/PIPE ROUTING ACTIVATED')
      IF(.NOT.RTNG) WRITE(IU,220)
  220 FORMAT('     SURFACE/PIPE ROUTING UNACTIVE')
      WRITE(IU,230)
  230 FORMAT(6X,'         *****END OF RUN STATUS SUMMARY*****')
      RETURN
      END
       SUBROUTINE COLUMN(RF,Q,QOBS,TYPE,NPTS,IU,DTOUT,
     $NDIM,NDP1,MAXBR,IB)
C      PROGRAM COLUMN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
       DIMENSION INDEX(4),Q(MAXBR,NDP1),FMT(13),RF(NDIM),QOBS(NDIM),TYPE(
     $NDIM)
       DIMENSION DATPR(2),DATSKP(2)
       DATA FMT(1),COMMA,COLSKP/4H (1X,1H,,3H5X,/
       DATA DATSKP(1),DATSKP(2)/10HF6.2,A7,2A,4H8,A4/
       DATA RPAREN,DATPR(1),DATPR(2)/1H),10HF6.2,F7.3,,
     $8H?F8.1,A4/
       DATA BLANK/10H          /
C      NPTS=14
C      DO 9 I=1,NPTS
C      T(I)=FLOAT(I)
C      TYPE(I)=4H   *
C    9 RF(I)=Q(I)=QOBS(I)=FLOAT(I)
       WRITE(IU,1000)
 1000 FORMAT('1',/,1X,4('  TIME   RAIN  COMP-Q   OBS-Q    '),
     $/,1X,4(' (MIN)    (IN)    (CFS)    (CFS)     '))
       NC=4
C      WRITE(IU,200) FMT(1),LPAREN
  200 FORMAT(A2)
      NR=NPTS/NC
      IF(NPTS.GT.NR*NC) NR=NR+1
      DO 20 J=1,NR
      IX=0
      IFMT=1
      DO 10 I=1,NC
      IX=IX+1
      IF(IX.GT.1)INDEX(IX)=INDEX(IX-1)+NR
      IF(IX.EQ.1) INDEX(IX)=J
C     IFMT=IFMT+1
C     FMT(IFMT)=COLSKP
      IFMT=IFMT+1
      FMT(IFMT)=DATPR(1)
      IF(INDEX(IX).GT.NPTS) FMT(IFMT)=DATSKP(1)
      IFMT=IFMT+1
      FMT(IFMT)=DATPR(2)
      IF(INDEX(IX).GT.NPTS) FMT(IFMT)=DATSKP(2)
C     IF(INDEX(IX).GT.NPTS) T(INDEX(IX))=BLANK
      IF(INDEX(IX).GT.NPTS) Q(IB,INDEX(IX))=BLANK
      IF(INDEX(IX).GT.NPTS) RF(INDEX(IX))=BLANK
      IF(INDEX(IX).GT.NPTS) QOBS(INDEX(IX))=BLANK
      IF(INDEX(IX).GT.NPTS) TYPE(INDEX(IX))=BLANK
      IFMT=IFMT+1
      FMT(IFMT)=COMMA
   10 IF(I.EQ.NC) FMT(IFMT)=RPAREN
C     WRITE(IU,*) (INDEX(III),III=1,NC)
C     WRITE(IU,100) FMT
  100 FORMAT(14A10)
   20 WRITE(IU,FMT)((FLOAT(INDEX(IX)-1)*DTOUT,RF(INDEX(IX)),Q(IB,INDEX(I
     $X)),QOBS(INDEX(IX)),TYPE(INDEX(IX))),IX=1,NC)
      RETURN
      END
      SUBROUTINE REPORT(X,F)
      DIMENSION X(25)
      COMMON/ZZZZST/NOBJ,NCNST,M1,M2
      PRINT *,NOBJ,' OBJECTIVE FUNCTION EVALUATIONS'
      NCNST=NCNST*(M1+M2)
      PRINT *,NCNST,' CONSTRAINT EVALUATIONS'
      RETURN
      END
      SUBROUTINE RSNBRCK(NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM)
      DIMENSION XB(25),FAIL(25,100),ALP(25),XDEL(25,25),XO(25)
      DIMENSION DEL(25,25),XMIN(25),UU(25,25),W(25,25),NTRY(25)
      DIMENSION X(25),SUCFAL(25),L(25),U(25)
C*******************************************************************************
C.... DEFINITION OF MAX DIMENSIONING FOR ILLUDAS AND ITS SUBRS
      DIMENSION AA(NDIM),AR(NDIM),GAD(NDIM)
      DIMENSION PASR(NDIM),GGR(NDIM),GR(NDIM),Q(MAXBR,NDP1)
      DIMENSION RI(NDIM),RR(NDIM),QOBS(NDIM)
      DIMENSION RRX(NDIM),QT(NDIM),SR(NDIM),TMPGR(ND10),TMPQ(ND10),TEMP(
     $ND10)
      DIMENSION QXOBS(NDIM),TYPE(NDIM),XOBCA(NDIM),QCOM(NDIM),XCOM(NDIM)
C*******************************************************************************
      COMMON/ZZZZST/NOBJ,NCNST,M1,M2
      COMMON /RSN/N,FPLUS,FEX,FXN,L(25),U(25)
      LOGICAL FAIL,SUCFAL
      REAL L
      ALPHA=3.0
      BETA=0.5
      CALL BOUNDS(L,U)
      CALL INITX(X,N,NC,MI,L,U)
      FPLUS=FCAP=FMIN=1.E99
      PRINT*,' '
       PRINT *,' INITIAL STARTING POINT VECTOR = ',(X(IND),IND=1,N)
      CALL OBJF(X,FXN,NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM,N)
      CALL NORM(X)
      FMIN=FXN+EXTRA(X)
      PRINT *,' OBJ FXN = ',FMIN-FEX,'   PENALTY FXN = ',FEX
      PRINT*,' '
      FPLUS=FCAP=FMIN
      DO 333 J=1,N
      ALP(J)=0.0
      I=J
  333 XMIN(I)=XB(I)=X(I)
      DO 4 J=1,N
      DO 4 I=1,N
      DEL(J,I)=XDEL(J,I)=0.0
    4 IF(J.EQ.I) DEL(J,I)=XDEL(J,I)=1.0
      NSTAGE=1
      NOBJ=0
C     EPS=0.1/.6666666666666666
      EPS=0.05
C....   PERFORM EXPLORATORY STAGE
C   5 EPS=EPS*.6666666666666
C   5 IF(NSTAGE.EQ.1) GO TO 6
C     EPS=0.0
C     DO 9900 I=1,N
C     PRINT*,XMIN(I),XO(I)
C9900 EPS=EPS+(XMIN(I)-XO(I))**2
C     EPS=AMAX1(0.05,EPS)
      PRINT *,'  EPS = ',EPS
      IF(EPS.LT.0.0000000001) RETURN
    5 CONTINUE
    6 DO 1 J=1,N
      XO(J)=XMIN(J)
      DO 1 I=1,N
    1 XDEL(J,I)=DEL(J,I)=XDEL(J,I)*EPS
      J=0
      NSTAGE=NSTAGE+1
      FEXMIN=0.0
      DO 3 J=1,N
      FAIL(J,1)=FAIL(J,2)=.TRUE.
```

```
      SUCFAL(J)=.FALSE.
    3 NTRY(J)=2
    2 J=J+1
      IF(J.GT.N) J=1
      DO 10 I=1,N
   10 X(I)=XB(I)+XDEL(J,I)
      CALL UNNORM(X)
      CALL UNNORM(XB)
      PRINT *,' START OF ITERATION BASE PT = ',(XB(IND),IND=1,N)
      PRINT *,' INCREMENT NORM. VECTOR ',J,' = ',(XDEL(J,IND),IND=1,N)
      PRINT *,' AT POINT ',(X(IND),IND=1,N)
      NTRY(J)=NTRY(J)+1
      CALL NORM(XB)
      CALL OBJF(X,FXN,NDIM,MAXBR,NDP1,ND10,
     1AA,AR,GAD,PASR,GGR,GR,Q,RI,RR,QOBS,RRX,QT,SR,TMPGR,TMPQ,
     2QXOBS,TYPE,XOBCA,QCOM,TEMP,XCOM,N)
      CALL NORM(X)
      FUN2=FXN+EXTRA(X)
      PRINT *,' OBJ FXN = ',FUN2-FEX,'   EXTRA = ',FEX
      IF(FUN2.LE.FMIN) PRINT *,' SUCCESS!!!'
      IF(FUN2.GT.FMIN) PRINT *,' FAILURE???'
      PRINT *,' '
      IF(FUN2.LE.FMIN) 100,200
  100 FAIL(J,NTRY(J))=.FALSE.
      DO 301 I=1,N
      XB(I)=XB(I)+XDEL(J,I)
      XMIN(I)=X(I)
      IF(XDEL(J,I).NE.0.0) NZI=I
      IF(XDEL(J,I).NE.0.0)ALP(J)=ALP(J)+XDEL(J,NZI)/DEL(J,NZI)
  301 XDEL(J,I)=XDEL(J,I)*ALPHA
      FMIN=FUN2
      FEXMIN=FEX
      GO TO 2
  200 FAIL(J,NTRY(J))=.TRUE.
      DO 50 I=1,N
   50 XDEL(J,I)=-BETA*XDEL(J,I)
      DO 60 JJ=1,N
      IF(FAIL(JJ,NTRY(JJ)).AND..NOT.FAIL(JJ,NTRY(JJ)-1))
     $SUCFAL(JJ)=.TRUE.
   60 CONTINUE
      DO 998 JJJ=1,N
  998 IF(.NOT.SUCFAL(JJJ)) GO TO 2
       DO 89 I=1,N
   89 UU(1,I)=0.0
      DO 90 J=1,N
      DO 90 I=1,N
   90 UU(1,I)=W(1,I)=UU(1,I)+ALP(J)*DEL(J,I)
      TW=0.0
      DO 106 I=1,N
  106 TW=TW+UU(1,I)**2
      DO 107 I=1,N
  107 XDEL(1,I)=UU(1,I)/SQRT(TW)
      DO 105 J=2,N
      DO 105 I=1,N
  105 UU(J,I)=UU(J-1,I)-ALP(J-1)*DEL(J-1,I)
      NM1=N-1
      DO 206 J=2,N
      TW=0.0
      DO 207 I=1,N
      W(J,I)=UU(J,I)
      DO 208 K=1,NM1
      UTDELK=0.0
      DO 401 IQ=1,N
  401 UTDELK=UTDELK+UU(J,IQ)*XDEL(K,IQ)
  208 W(J,I)=W(J,I)-UTDELK*XDEL(K,I)
  207 TW=TW+W(J,I)**2
      DO 209 II=1,N
  209 XDEL(J,II)=DEL(J,II)=W(J,II)/SQRT(TW)
  206 CONTINUE
       DO 901 I=1,N
  901 DEL(1,I)=XDEL(1,I)
      PRINT *,' ALP-VECTOR '
      PRINT *,ALP(1),ALP(2)
      PRINT *,'  U-VECTORS'
      PRINT *,(UU(1,I),I=1,2)
      PRINT *,(UU(2,I),I=1,2)
      PRINT *,'  W-VECTORS'
      PRINT *,(W(1,I),I=1,2)
      PRINT *,(W(2,I),I=1,2)
      PRINT *,'  XDEL-VECTORS'
      PRINT *,(XDEL(1,I),I=1,2)
      PRINT *,(XDEL(2,I),I=1,2)
      PRINT *,'  DEL-VECTORS'
      PRINT *,(DEL(1,I),I=1,2)
      PRINT *,(DEL(2,I),I=1,2)
      DO 306 I=1,N
      XB(I)=XMIN(I)
  306 ALP(I)=0.0
      PRINT*,' OBJ FXN = ',FMIN-FEXMIN,'  AT NORM. (',
     $(XMIN(IP),IP=1,N),')'
      CALL UNNORM(XMIN)
      PRINT*,' OBJ FXN = ',FMIN-FEXMIN,'  AT UNNORM. (',
     $(XMIN(IP),IP=1,N),')'
      CALL NORM(XMIN)
      PRINT*,' NO. OF STAGES = ',NSTAGE-1,'  NO. OF FXN EVAL = ',
     $NOBJ
C....  PLACE OPT ENDING CRITERIA HERE
      IF(NSTAGE.EQ.200) RETURN
      PRINT*,' '
      GO TO 5
      END
      FUNCTION EXTRA(X)
      DIMENSION X(25)
      COMMON /RSN/N,FPLUS,FEX,FXN
      LOGICAL FEAS,LBZONE,UBZONE
      REAL NUJ1
      FFX=EXTRA=0.0
      EPSIL=.0001
      FEAS=.FALSE.
      DO 10 J=1,N
      IF(X(J).LT.0.0.OR.X(J).GT.1.0) FXN=1.E99
   10 IF(X(J).LT.0.0.OR.X(J).GT.1.0) RETURN
      FEAS=.TRUE.
      LBZONE=UBZONE=.FALSE.
      DO 20 J=1,N
      IF(X(J).GE.0.0.AND.X(J).LE.0.0+EPSIL*(1.0-0.0))LBZONE=.TRUE.
      IF(X(J).LE.1.0.AND.X(J).GE.1.0-EPSIL*(1.0-0.0))UBZONE=.TRUE.
      IF(LBZONE.OR.UBZONE) J1=J
   20 IF(LBZONE.OR.UBZONE) GO TO 30
      IF(FXN.LT.FPLUS) FPLUS=FXN
      RETURN
   30 IF(LBZONE) NUJ1=(EPSIL-X(J1))/EPSIL
      IF(UBZONE) NUJ1=(X(J1)+EPSIL-1.0)/EPSIL
      FEX=EXTRA=FEX-(FXN-FPLUS)*(3.*NUJ1-4.*NUJ1**2+2.*NUJ1**3)
      PRINT *,'  FEX = ',FEX
      J1=J1+1
      IF(J1.GT.N) GO TO 50
      LBZONE=UBZONE=.FALSE.
      DO 40 J=J1,N
      IF(X(J).GE.0.0.AND.X(J).LE.EPSIL*(1.0-0.0))LBZONE=.TRUE.
      IF(X(J).LE.1.0.AND.X(J).GE.1.0-EPSIL*(1.0-0.0))UBZONE=.TRUE.
      IF(LBZONE.OR.UBZONE) J1=J
   40 IF(LBZONE.OR.UBZONE) GO TO 30
   50 CONTINUE
      RETURN
      END
C     SUBROUTINE BOUNDS(G,H)
C     DIMENSION G(25),H(25)
C      G(1)=-10.$ H(1)=10.
C      G(2)=-10.$ H(2)=10.
C      G(3)=-10.$ H(3)=10.
C      G(4)=-10.$ H(4)=10.
C     RETURN
C     END
C     SUBROUTINE OBJF(X,F)
C     DIMENSION X(25),B(20)
C     COMMON /RSN/N,FPLUS,FEX,FXN,L(25),U(25)
C     REAL L
C     DATA B/75.1963666677,-3.8112755343,.1269366345
C    1,-.0020567665,.000010345,-6.8306567613,.0302344793,
C    2-.0012813448,.0000352559,.0000002266,.2564581253,
C    3-.003460403,.0000135139,-28.1064434908,-.0000052375,
C    4-.0000000063,.0000000007,.0003405462,-.0000016638,
C    5-2.8673112392/
C      NOBJ=NOBJ+1
C....  C.F. WOOD
C      F=100.*(X(2)-X(1)**2)**2+(1.-X(1))**2
C    $+90.*(X(4)-X(3)**2)**2+(1.-X(3))**2+10.1*
C    $((X(2)-1.)**2+(X(4)-1.)**2)+19.8*(X(2)-1.)*(X(4)-1.)
C      RETURN
C....  H.H. ROSENBROCK
C      F=100.*(X(2)-X(1)*X(1))**2+(1.-X(1))**2
C      RETURN
C....  G.K. BARNES
C      F=B(1)+B(2)*X(1)+B(3)*(X(1)**2)+B(4)*(X(1)**3)
C    1+B(5)*(X(1)**4)+B(6)*X(2)+B(7)*X(1)*X(2)
C    2+B(8)*((X(1)**2))*X(2)+B(9)*((X(1)**3))*X(2)
C    3+B(10)*((X(1)**4))*X(2)+B(11)*(X(2)**2)
C    4+B(12)*(X(2)**3)+B(13)*(X(2)**4)+B(14)/(X(2)+1.)
C    5+B(15)*((X(1)**2))*((X(2)**2))+B(16)*((X(1)**3))
C    6*((X(2)**2))+B(17)*((X(1)**3))*((X(2)**3))
C    7+B(18)*X(1)*((X(2)**2))+B(19)*X(1)*((X(2)**3))
C    8+B(20)*EXP(.0005*X(1)*X(2))
C      F=-F
C      RETURN
C      END
C     SUBROUTINE INITX(X,N)
C     DIMENSION X(25)
C     N=4
C     X(1)=-3.0
C     X(2)=-1.0
C     X(3)=-3.0
C     X(4)=-1.0
C     RETURN
C     END
      SUBROUTINE NORM(X)
      COMMON /RSN/N,FPLUS,FEX,FXN,L(25),U(25)
      DIMENSION X(25)
      REAL L
      DO 1 I=1,N
    1 X(I)=(X(I)-L(I))/(U(I)-L(I))
      RETURN



      END
      SUBROUTINE UNNORM(X)
      DIMENSION X(25)
      COMMON /RSN/N,FPLUS,FEX,FXN,L(25),U(25)
      REAL L
      DO 1 I=1,N
    1 X(I)=X(I)*(U(I)-L(I))+L(I)
      RETURN
      END
      FUNCTION POLY(FXNA,FXNB,FXNC,A,B,C)
      XNUM=(B*B-C*C)*FXNA+(C*C-A*A)*FXNB+(A*A-B*B)
     $*FXNC
      DEN=2.*((B-C)*FXNA+(C-A)*FXNB+(A-B)*FXNC)
      POLY=XNUM/DEN
      RETURN
      END
```