THE UNIVERSITY OF MANITOBA

A LINEAR RESERVOIR SIMULATION MODEL OF WILSON CREEK WATERSHED

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

WINNIPEG, MANITOBA

MAY 1980

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SYNOPSIS

This study has investigated whether a simple mathematical model could be used to produce useful results in flood event simulation. A simplified computer model of the Wilson Creek Watershed that simulates hourly streamflow due to rainfall has been developed. The sequential development of the model is discussed, along with the effect of the various model parameters.

Physically, the model can be thought of as two stacked linear reservoirs with outflows corresponding to the hydrograph components direct runoff and spring flow. Input to the model consists of initial soil moisture content and hourly rainfall data. The model ignores the effects of evaporation, evapotranspiration and interception, assuming them to be negligible in the overall water balance during a rainstorm. The parameters that define the storage and outflow characteristics of each reservoir were determined by minimizing the least squares deviation of the percentage error between the recorded and simulated flood peaks and volumes. Five storms with peak discharges varying from 300 cfs to 1350 were selected for calibration of the model. To verify the model five additional storms were simulated.

The model was found to be capable of a reasonable reproduction of observed streamflow hydrographs. However, an anomaly was encountered in the reproduction of two of the storms. This anomaly requires further study.

ACKNOWLEDGEMENTS

I wish to express my appreciation to Professor C. Booy for his advice throughout this study and critical review of the manuscript. The comments received from the members of my thesis committee, Mr. G.H. MacKay and Dr. I. Goulter, have been gratefully appreciated. Mr. J.E. Thomlinson's, Manager of the Wilson Creek Watershed, interpretation of the water data has been invaluable.

I would like to express my most sincere appreciation to my wife, Sandy, and daughter, Shelley, for their patience through the completion of this thesis.

Finally, I wish to express my gratitude to my parents for instilling in me the value of education that has guided my endeavours.

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CHAPTER I

INTRODUCTION

1.1 SCOPE OF STUDY

The purpose of this study has been to determine whether a simple mathematical model could be used to produce useful results in flood event simulation. Many hydrologic models, for instance the Sanford Model, have been developed to provide a complete time history of runoff for engineering purposes. A considerable knowledge of the basin hydrology is needed to use these models and several trial runs are necessary to obtain a reasonable reproduction of recorded streamflow. A complete reproduction of runoff is not always needed. The design of engineering structures and flood forecasting is served sufficiently by reproduction of the flood hydrographs resulting from individual rainfall events.This allows a considerable simplification of the model. Experimental data from the Wilson Creek Experimental Watershed have been used to develop such a model.

1.2 DESCRIPTION OF WATERSHED

The Wilson Creek Experimental Watershed is a basin of 8.5 square miles. It is shown on Figure 1. The Wilson Creek Watershed is located on the eastern slopes of the Riding Mountain National Park in Township 20, Range 16 W.P.M. some 150 miles northwest of Winnipeg. The topography of the Watershed is typical of watersheds of the Manitoba Escarpment, which forms a semi-continuous break in topography along a line across the southwestern corner of the Province. The upper portion of the Watershed is located on a relatively flat plateau at an elevation of 2,400 feet. From this plateau the land drops rapidly to an elevation of 1,100 feet in a distance of about four miles. The latter portion of the Watershed is deeply incised by gullies and ravines. The main streams are cut into bedrock shale in valleys that are four to five hundred feet deep.

A surface of unconsolidated glacial drift deposits overlies the shale bedrock formations throughout most of the Watershed. The upper portion of the Watershed is covered with open decadent forest of hardwoods and spruces interspersed with areas of browsed shrub cover. The lower portion of the Watershed is dominated by stands of white birch and aspen.

The climate in this area is sub-humid. The average annual precipitation is about 18 inches of which approximately 14 inches falls as rain during the months of April to October. Throughout the Manitoba Escarpment intense thunderstorms are frequent in the summer. These storms are usually centered over the uplands and often quite local. Rainfall intensities up to four inches per hour have been recorded for short periods of time over the small drainage area of the Watershed. These intensive rainfalls, rather than snowmelt, produce the major flood events on the Watershed (1).

1.3 PREVIOUS STUDIES

A mathematical model of the Wilson Creek Watershed that simulated hourly streamflow from rainfall and evaporation data was developed in 1970 by M. Sydor (2). This model included the simulation of interception, evaporation and evapotranspiration. Basically, the model consisted of three linear reservoirs in series, the outflows represented the hydrograph components: direct runoff, spring flow or interflow and base flow. The synthesized runoff hydrograph was transferred to the downstream end of the Wilson Creek Experimental Watershed by the Muskingum Flood Routing Method taking into account the observed time of travel.

In the development of this model three typical rainstorms were selected for reproduction. The storage capacities and initial amounts in storage prior to the storms were based upon physical observations of the Watershed. The base flow recession coefficients of the groundwater reservoir were determined by conventional hydrograph separation. The parameters that defined the outflow and storage coefficients of the direct runoff and spring flow were optimized to produce a minimum least squares deviation from the observed hydrographs.

The study concluded that the optimized reservoir coefficients produced an adequate simulation of streamflow. In two out of the three storms studied the agreement between actual and synthesized flows was good. However, a third storm revealed an inadequacy of the model in that the direct runoff as modelled did not properly reproduce the storage in ponds, reservoirs, and sloughs from a previous storm. It was recommended that the observed anomaly be given further study.

CHAPTER II

MATHEMATICAL REPRESENTATION OF THE HYDROLOGIC PROCESS

2.1 INTRODUCTION

The development of a mathematical model that simulates streamflow is made much simpler if components of the model can be identified with corresponding natural hydrologic features of the watershed. This also enables the transfer of the model to other watersheds where similar features and conditions exist. Therefore, the study has endeavoured to develop a simple mathematical model in which the components parallel the main natural processes. This chapter describes the hydrologic processes and their conceptual representation. In accordance with the purpose of the study, namely to develop the simplest model that would actually reproduce hourly streamflow, these hydrological processes were drastically simplified.

2.2 HYDROLOGIC PROCESSES

During the initial part of a storm much of the precipitation is intercepted by the vegetative cover, stored and subsequently evaporated. This volume of water is referred to as the interception storage. Once the interception storage capacity is met, the amount of water reaching the soil surface is equal to the rainfall less any evaporation from the vegetative cover. The interception storage capacity of a well-developed forest canopy is estimated to range from 0.03 to 0.06 inches (3). While the interception may be a significant factor in an annual water balance, in major storm events it is of little importance and it may be neglected for the present purpose.

Part of the water which reaches the ground infiltrates into the soil. Infiltration is the movement of water through the soil surface into the soil. It is distinguished from percolation, which is the movement of water through the soil. The water enters the soil surface due to the combined influence of gravity and capillary forces. Both forces also cause percolation. The capillary forces divert the downward-moving gravity water into capillary pores. As the capillary pores at the surface are filled their intake capacity is reduced, and as a result, the infiltration capacity decreases. The infiltration capacity is the maximum rate at which water can enter the soil. Normally, the infiltration capacity decreases gradually with time. The water at the surface cannot infiltrate at a greater rate than it is transmitted downward. Normally, soils are stratified and the subsoil layers are usually less permeable than the surface soil. Thus the infiltration rate is eventually limited to the rate of percolation through the least pervious subsoil stratum reached by the expanding zone of saturation.

When the rainfall intensity exceeds the infiltration capacity, the rainfall excess begins to fill surface depressions. The rainwater retained in puddles and ponds is termed depression storage. When a depression is filled further inflow is balanced by outflow, plus infiltration and evaporation. Once the depressions are filled overland flow begins. The water held in depressions at the end of the rain is either evaporated or absorbed by the soil through infiltration. Depression storage is usually lumped with interception and is treated as an initial loss with respect to storm runoff. Experience suggests that for most basins, the depression storage capacity will be between 0.5 and 2.0 inches (4).

The entire part of storm precipitation which does not appear either as infiltration or as overland flow during or immediately following the storm, is called surface retention. Surface retention includes interception, depression storage, and evaporation, but does not include water temporarily stored en route to the stream.

Evaporation and transpiration (water exuded in the form of vapor by plants) is also taking place during the rainfall period, but at a very limited rate, since the lower atmosphere is saturated or nearly saturated. In this study this component is neglected.

2.3 COMPONENTS OF STREAMFLOW

The water which constitutes streamflow may travel to the stream channel by several paths from the point where it first reached the earth surface. The water that does not infiltrate into the soil flows over the soil surface and reaches the stream soon after its occurrence as rainfall. The balance of the water infiltrates through the soil surface and flows beneath the surface to the stream channel. This water moves more slowly than the surface water and contributes to the sustained flow of the stream after the rainfall has ceased.

The water which travels over the soil surface is referred to as overland flow. Overland flow is the excess precipitation produced by a high-intensity of rainfall which exceeds the infiltration capacity once the detention and interception requirements are met. When surface depressions are filled, surface water begins to move down the slopes following micro-channels which coalesce with others growing larger and larger until the water reaches the main channels. In major runoff events, of interest in design and flood forecasting, overland flow is the most important element in the formation of the flood hydrograph. For many small and moderate storms overland flow may be quite small, since overland flow over a permeable soil can only occur when the rainfall rate exceeds the infiltration capacity. For such storms, overland flow may occur only from relatively impermeable surfaces within the watershed. Usually, the total impervious area is a small percentage of the basin area. Hence, significant amounts of overland flow occur only as a result of high-intensity rainfalls.

Runoff is called interflow if it, after infiltrating into the soil, moves laterally through the upper soil layers until it is intercepted by a stream channel. This water does not percolate down to the groundwater table and become part of the typical groundwater flow system. The proportion of total runoff which occurs as interflow depends on the geology of the basin. A porous surface soil cover underlain by a relatively impervious strata a short distance below the soil surface favours substantial quantities of interflow, whereas a uniform permeable soil encourages downward percolation to the groundwater table. Interflow is probably more significant in storms of moderate intensity, while overland flows is more associated with high-intensity storms.

In the Wilson Creek Watershed, the unconsolidated glacial deposits in which interflow occurs is underlain by shale bedrock formations. The movement of water through the shale fractures that occurs during a storm is referred to as spring flow. In many locations along the shale slopes and stream channels numerous springs occur, which flow freely when heavy rainfall occurs in the watershed. It is assumed that fractures in the shale form interceptors to the vertical and lateral movement within the underlying rock and thus feed the springs. Spring flow is distinguished from groundwater flow proper in that it moves independently of the groundwater table.

The precipitation that infiltrates the soil surface and percolates downward until it reaches the groundwater table may eventually discharge into the stream as base flow, if the water table intersects the stream channel of the basin. The groundwater contribution to the streamflow can increase over several orders of magnitude in a short time. Nevertheless, the maximum contribution to the flow is minor when we deal with major runoff events.

The final component of streamflow is the precipitation that falls directly on the water surface of lakes and streams. This component of streamflow is known as channel precipitation.

2.4 REPRESENTATION OF HYDROLOGIC PROCESSES BY A SERIES OF STORAGE RESERVOIRS

When precipitation falls on a watershed, the water on its way to the stream is temporarily stored either above or below ground and then released. Each area or material the water passes through thus acts as a storage reservoir which retains some of the water for awhile and then releases it partly or entirely to a lower reservoir. The entire watershed can thus be thought of as a series of reservoirs stacked one above the other as shown on Figure 2.

The first reservoir is formed by the vegetative cover. The vegetative cover provides interception storage. Once the interception storage capacity has been reached, the water, minus any evaporation, is passed on to the soil surface.

The soil surface acts as the second reservoir; it will be called the surface reservoir. This reservoir is filled by the water released from the interception storage. The surface reservoir allows part of its storage to be released as overland flow and part to infiltrate into the soil zone below. For overland flow to occur, the flow from the interception storage must exceed the infiltration rate of the soil surface and the depression storage capacity of the soil surface must be satisfied.

Immediately below the surface reservoir is the field reservoir. The field reservoir represents the soil moisture held in the surface deposits. Infiltration from the soil surface acts as input to the field reservoir. The amount of infiltrated water stored in the field reservoir depends on the soil moisture deficit. This is by definition the field capacity (the moisture that cannot drain by gravity from an initially saturated soil) minus the soil moisture content. Once the field capacity of the soil is reached the field reservoir allows part of its storage to be depleted by interflow and part to percolate into the soil layer below. Storage in the field reservoir is also depleted by evapotranspiration.

The fractured shale formations in the Wilson Creek Watershed are represented by a fourth reservoir; it will be called the spring reservoir. The spring reservoir allows part of its storage to be released as spring flow and part to deep percolation.

The groundwater reservoir is the lowest reservoir in the stacked system. This reservoir receives deep percolation water from the spring reservoir. Water stored in the groundwater reservoir is released as base flow to the stream channel and deep percolation to the lower zone as a system loss. The losses take into account the groundwater flow both vertically downward and flow below the Wilson Creek Weir. The groundwater reservoir represents the long term groundwater storage of the complete watershed and is released very slowly.

2.5 LINEAR RESERVOIRS

The rate of outflow from each of the reservoirs discussed in section 2.4 towards the stream channel and the lower lying reservoir is dependent on the amount of water stored in the reservoir. The actual relationship is very complex however, in this study it was assumed that the storage-outflow relationship is linear, so that the storage is directly proportional to the outflow:

$$S(t) = KO(t)$$

The constant K has the dimension of time. It is a measure of the delay imposed by the reservoir on the hydrograph. If the above relationship is combined with the storage equation

$$I(t) - O(t) = \frac{d}{dt} S(t)$$

one gets:

$$I(t) - O(t) = \frac{Kd}{dt} O(t)$$

which can be written in operational form as

$$(1 + KD)\ O(t) = I(t)$$

where D is the differential operator. This equation has the solution

$$O(t)e^{t/K} = \frac{1}{K} \int I(t)e^{t/K}\, dt + \text{constant} \quad \ldots\ldots\ldots\ldots \quad (1)$$

For any given inflow this equation can be solved either analytically or numerically. The case where the inflow into the reservoir has ceased equation (1) can be solved by simple integration. Assuming the limits $I = o$ and $O = S/K$ at $t = o$ equation (1) becomes

$$O = \frac{S}{K}\, e^{-t/K} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Thus the response of a linear reservoir to the termination of inflow is an exponential decay function. A similar equation may be derived for two linear reservoirs placed in series.

For two unequal linear reservoirs, the outflow from the first reservoir is expressed by equation (2). In routing the flow, this outflow is considered as the inflow to the second reservoir. Using equation (2) as the input function and with τ being the variable, the integral of

$$O(\tau) = \int_{o}^{t} u(t-\tau)\ I(\tau)d\tau$$

gives the outflow from the second reservoir as

$$O = \int_{o}^{t} \frac{Se^{-\tau/K1}}{K1} \frac{e^{-(t-\tau)/K2}}{K2} d\tau$$

$$= S\left(\frac{e^{-t/K1}}{K2 - K1} + \frac{e^{-t/K2}}{K1 - K2}\right)$$

Thus the outflow from the second reservoir is a combination exponential decay function.

2.6 ASSUMPTIONS

To simplify the conceptional model as much as possible in compliance with the aim of the study, the following assumptions were made:

a) As the moisture content of the atmosphere is at, or near, saturation during the rainfall period, evaporation and evapotranspiration takes place at a very limited rate and was therefore neglected.

b) As the interception storage capacity of the vegetative cover, estimated to be less than 0.10 inches, is considered to be negligible in the overall water balance of high-intensity rainfalls, interception losses were neglected.

c) Direct runoff produced by rainfall on impervious portions of the basin directly connected to, or adjacent to the channel system, were neglected. It is estimated that less than two percent of the rainfall occurs directly on the channel or is translated directly to the channel. This component of runoff normally occurs prior to the peak discharge and does not contribute significantly to the volume of runoff.

d) The component of base flow was assumed to remain constant through the storm event. Base flow represents the long term storage of the complete watershed and does not fluctuate rapidly.

e) Direct runoff was taken as the sum of overland flow and interflow. The distinction between overland flow and interflow is to some extent arbitrary in any case. Water may start out as overland flow, infiltrate into the soil surface and then complete its trip to the stream as overland flow. Therefore, the total flow in Wilson Creek was assumed to be comprised of three components: 1) direct runoff from the surface deposits of glacial till; 2) spring flow from the subsurface shale bedrock fractures; and 3) base flow from the groundwater system.

CHAPTER III

HYDROGRAPHS STUDIED

3.1 HYDROMETEOROLOGICAL DATA

Precipitation and streamflow records, as well as records of numerous other hydrometeorological data, have been kept for the Wilson Creek Experimental Watershed since 1959. A large amount of data is thus available for analysis. For this study five rainfall events that produced relatively large volumes of runoff were selected for development of the Model.

3.1.1 Precipitation

The areal average of the hourly precipitation was calculated for each storm by means of the Thiessen polygon method using the data of eight recording rain gauges. In this method rainfall at each point of the basin is taken as the rainfall in the nearest rain gauge. Areas nearest to a particular gauge form polygons that are fixed by the geometry of the rain gauge network and the drainage basin. To determine the mean rainfall, each rain gauge observation is multiplied by a coefficient determined as the area of the particular polygon divided by the total area. This procedure was convenient for the storms used in this study since the network is fixed. The calculated mean hourly precipitation multiplied by the drainage area of the watershed represents the volume of the inflow to the Model.

3.1.2 Soil Moisture

The antecedent soil moisture content prior to each storm was estimated from the soil moisture surveys taken weekly in the summer at seven points in the Watershed. A one-inch tube sampler is used to take a soil sample at increments of six inches to a depth of three feet. An experienced operator estimates the moisture content of each sample by touch, which is then recorded. The difference in water content of the soil between the field capacity and the permanent wilting point is about three inches per foot of soil (5). The permanent wilting point is that soil water content at which the soil cannot supply water at a sufficient rate to maintain turgor, and the plant permanently wilts.

The soil moisture estimates have been useful in determining the depth of storm rainfall necessary to produce a significant runoff. Although the method does not provide accurate values of soil moisture content, it has given reliable estimates and helped to explain why some heavy rainstorms have produced relatively little runoff. For example, the 40-hour storm of August 5 to 7, 1966, produced 4.6 inches of rainfall, a maximum hourly intensity of 1.4 inches, and a peak flow of 120 cubic feet per second at the Wilson Creek Weir. By contrast, the 48-hour storm of June 25 to 27, 1969, which produced 4.9 inches of rainfall, a maximum hourly intensity of 0.7 inches, gave a peak flow of 700 cubic feet per second. Although the precipitation of the two storms was similar, there was a great difference in the runoff, presumably because of the moisture content of the soil before the storms. Soil moisture tests before the storms indicated that the soil could absorb more than two inches in the 1966 storm and only 0.75 of an inch in the 1969 storm (5).

3.1.3 Streamflow

Streamflow from the 5400.7 acre Wilson Creek Experimental Watershed is measured at the Wilson Creek Weir. In 1960 Bald Hill and Ridge

Dams were constructed on the headwaters of Wilson Creek. As a result, outflow from 716.2 acres of the Watershed is controlled by the dams. The model developed in this study simulates runoff from the portion of the Watershed which excludes the drainage area of the dams. The recorded outflow from the dams was, however, added to the simulated streamflow hydrographs before being compared with the recorded discharge at the Wilson Creek Weir.

3.2 STORM EVENTS

Five rainfall events with peak discharges ranging from 300 cfs to 1580 cfs were selected for the development of the Model. The five events were selected because of their significant volumes of runoff and availability of soil moisture data, which allowed an estimate of soil moisture conditions prior to the storms. The storms which represent five out of the six largest discharges recorded in the Wilson Creek Experimental Watershed since its inception in 1959, reflect a range of antecedent soil moisture conditions and rainfall intensities and durations. A description of the five storms is as follows:

Event 69-6-1:

From June 25th to 27th, 1969, during a 48-hour period, an average of 4.93 inches of rain fell on the Wilson Creek Watershed. The average maximum hourly rainfall intensity of the storm over the Watershed was 0.41 inches. Prior to the storm, the soil moisture deficit of the Watershed was estimated to be 0.76 inches. At the Wilson Creek Weir a maximum instantaneous discharge of 700 cfs was recorded. A day later at 2100 cst on June 28th an additional 1.51 inches of rain fell during the ensuring 25.5 hours. A secondary peak discharge of 311 cfs was recorded at the Wilson

Creek Weir. The average maximum hourly rainfall intensity of the second storm was 0.16 inches. In this study both storm events have been combined to determine the Model's response to a sequence of rainfall events.

Event 74-5-1:

On May 11th, 1974, an instantaneous peak discharge of 298 cfs was recorded at the Wilson Creek Weir. This was the result of a 22.25 hour rainstorm in which an average of 2.42 inches of rain fell on the Watershed. The soil moisture conditions of the Watershed were at field capacity prior to the storm. The average maximum hourly rainfall intensity of the storm was 0.16 inches.

Event 75-8-2:

From August 23rd to 25th, 1975, during a 53-hour period, an average of 3.06 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.57 inches. At the Wilson Creek Weir a maximum instantaneous discharge of 330 cfs was recorded. The soil moisture deficit prior to the storm was estimated to be 0.76 inches.

Event 75-9-1:

The largest storm ever recorded in Manitoba began over the Wilson Creek Watershed on September 19th, 1975 at 3:30 p.m. During the next 59.5 hours, an average of 9.86 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.74 inches. At the Wilson Creek Weir, a maximum instantaneous discharge of 1580 cfs was recorded. This is the largest discharge ever recorded on Wilson Creek. The soil moisture deficit prior to the storm was estimated to be 0.35 inches.

Event 77-7-1:

During a 21.5 hour period from July 10th to 11th, 1977, an average of 5.39 inches of rain fell on the Watershed. The maximum hourly rainfall intensity of the storm was 0.96 inches. A maximum discharge of 540 cfs was recorded at the Wilson Creek Weir. The soil moisture deficit prior to the storm was estimated to be 1.10 inches.

The five storms have been summarized in Table 1 for comparison purposes.

TABLE 1

SUMMARY OF STORM EVENTS

Storm Event	Duration of Rainfall in Hours	Average Rainfall In Inches	Maximum Hourly Rainfall Inches/Hour	Initial Soil Moisture Deficit in Inches	Maximum Instantaneous Discharge in cfs
69-6-1(a)	48	4.93	0.41	0.76	700
69-6-1(b)	25.5	1.51	0.16	0.00	311
74-5-1	22.25	2.42	0.16	0.00	298
75-8-2	53	3.06	0.57	0.76	330
75-9-1	59.5	9.86	0.74	0.35	1580
77-7-1	21.5	5.39	0.96	1.10	540

CHAPTER IV

MODEL DEVELOPMENT

4.1 CRITERIA OF GOODNESS-OF-FIT

In the sequential development of the mathematical model, the agreement between simulated and observed streamflow hydrographs was checked by means of an objective function. This function, which is to be minimized, measures the goodness-of-fit. Many such objective functions are possible. For the purpose of this study, the two most important components of the streamflow hydrograph are the peak discharge and the runoff volume. An objective function was developed that measures the deviation between the simulated and recorded peak discharge and volume using the Principle of Least Squares. This Principle can be stated as follows: The most probable value of a quantity is obtained from a set of measurements by choosing the value which minimizes the sum of squares of the deviation of these measurements. The resultant objective function which is minimized is as follows:

$$F(x) = \sum_{i=1}^{N} \left(\frac{(PSi-PRi)}{PRi} \times 100 \right)^2 + \sum_{i=1}^{N} \left(\frac{(VSi-VRi)}{VRi} \times 100 \right)^2$$

Where:

PRi - is the recorded maximum hourly discharge in cfs;

PSi - is the simulated maximum hourly discharge in cfs;

VRi - is the volume of the recorded streamflow hydrograph in cfs-hours;

VSi - is the volume of the simulated streamflow hydrograph in cfs-hours; and

N - is the total number of storms analyzed.

4.2 OPTIMIZATION PROCEDURE

A systematic search for the optimal value of the storage constants of the linear reservoirs was incorporated in the model. The Direct Pattern Search was employed to optimize the model reservoir constants so as to minimize the objective function. The Pattern Search does not rely on the evaluation of partial derivates but adjusts the parameters stepwise to successively improve trial solutions. The Pattern Search method was introduced by R. Hooke and T.A. Jeeves in 1961. A detailed description of the method is contained in Appendix A.

4.3 MODEL DEVELOPMENT

This section discusses the sequential development of the hourly streamflow simulation model. A model incorporating only a single linear reservoir representing the hydrograph component direct runoff was examined first, as the study's objective was to develop the simplest model possible. However, the results discussed below indicated that at least two linear reservoirs stacked one above the other and representing the hydrograph components direct runoff and spring flow would be needed.

4.3.1 The Single Reservoir Model

In the single linear reservoir model only direct runoff from the surface deposits of glacial till represented by the field reservoir is simulated. The simplest model is one in which direct runoff begins once the field capacity of the field reservoir is reached. The initial soil moisture content of the field reservoir prior to each storm was estimated by the soil moisture deficit readings (field capacity minus the soil moisture deficit). The soil moisture deficit readings allows for an approximation of conditions in the Watershed prior to the storm. This simplistic model referred to as Model A may be represented mathematically as:

When $S_t \leq FC$ $\quad D_t = 0$

When $S_t > FC$ $\quad D_t = (S_t - FC)AREA/KD$

Where:

S_t - is the storage volume of the field reservoir in inches at time period t;

D_t - is the direct runoff in cfs at time period t;

FC - is the field capacity of the field reservoir in inches;

KD - is the storage constant of the field reservoir in hours which relates the volume of storage to the direct runoff; and

AREA - is the drainage area in acres of the Wilson Creek Experimental Watershed, excluding Baldhill and Ridge Dams.

These equations were combined with the storage equation, shown on page 10, to mathematically represent the movement of water through the entire Watershed. For the five storms described in section 3.2, the optimal storage constant KD, for Model A, based on minimization of the objective function was determined to be 69.94 hours. The minimum value of the objective function was 21,849. The hourly streamflow hydrographs simulated by Model A are shown on Figures B-1 to B-5, Appendix B.

The peak discharge simulated by Model A was significantly underestimated in all five storms and the rising and recession limbs of the simulated hydrographs were too flat. Also the initial increase in streamflow, simulated by Model A, occurred before an increase in the recorded streamflow hydrographs. It was felt that if an additional parameter representing the depression storage capacity of the Watershed was incorporated into the field reservoir, a large amount of the initial precipitation would be absorbed. This would delay the start of runoff and steepen the slope of the rising and recession limb of the hydrograph. A second linear reservoir model, referred to as Model B, was developed on this premise.

Model B may be represented mathematically as:

$$\text{When} \quad S_t \leq FC + DS \qquad D_t = 0$$

$$\text{When} \quad S_t > FC + DS \qquad D_t = (S_t-(FC+DS))AREA/KD$$

Where DS is the estimated average depression storage capacity of the Watershed in inches. The depression storage capacity is defined as the moisture level above field capacity which direct runoff begins.

Using the five storms, the optimal value of KD and DS for Model B were determined to be 11.00 hours and 1.53 inches respectively. The minimum value of the objective function F(x) was reduced from 21,849 to 5,259. The hourly streamflow hydrographs simulated by Model B are shown on Figures B-1 to B-5, Appendix B. The effect of including the depression storage capacity was that the start of direct runoff was delayed to coincide with that of the observed streamflow hydrographs. Peak discharges were also significantly increased resulting in the simulated hydrographs taking on the general shape of the recorded streamflow hydrographs. However, the recession limb of the simulated hydrographs was still too flat. This resulted in too great a volume. To overcome this problem two reservoirs stacked one above the other will be investigated next.

4.3.2 The Two Reservoir Model

In the two reservoir model, the outflow from the field reservoir corresponds to direct runoff and that of the spring reservoir to spring flow. Assuming that the rate at which water is lost from the field reservoir could be increased by a second outflow component, percolation was added to the field reservoir. The addition of percolation would hopefully lead to an increase in the steepness of the hydrograph recession limb rectifying the problem experienced in Model B. The percolation would act as inflow to the spring reservoir.

In Model C, percolation from the field reservoir was assumed to begin once the field capacity is reached. The field reservoir fills until the depression storage capacity is reached at which time direct runoff begins. The field reservoir of Model C may be represented mathematically as:

When $S_t < FC$	$D_t = 0$ and $P_t = 0$
When $FC < S_t \leq FC+DS$	$D_t = 0$ and
	$P_t = (S_t - FC)AREA/KP$
When $S_t \geq FC + DS$	$D_t = (S_t - (FC+DS))AREA/KD$ and
	$P_t = (S_t - FC)AREA/KP$

Where:

P_t - is the percolation rate in cfs at time period t; and

KP - is the storage constant of the field reservoir, in hours, which relates the volume of storage to the percolation rate.

The downward percolation from the field reservoir acts as input to the spring reservoir. The spring reservoir represents the fissured shale bedrock formations in the Watershed. The spring reservoir of Model C has incorporated storage losses to the groundwater system by deep percolation. For simplicity the rate of deep percolation was assumed constant. When the downward percolation exceeds the maximum deep percolation rate the excess acts as input to the spring reservoir which is mathematically represented by:

$$SF_t = SS_t \times AREA/KS$$

Where:

SF_t - is the spring flow in cfs at time period t;

SS_t - is the storage volume of the spring reservoir in inches at time period t; and

KS - is the storage constant of the spring reservoir in hours, which relates the volume of storage to the spring flow.

A schematic of Model C is shown on Figure 3. In the Model, the depression storage capacity and the maximum deep percolation rate are fixed for each computer run. The optimization program then adjusts the storage constants KD, KP and KS until a "best fit" of the hydrographs is attained.

Model C resulted in a significant improvement in the simulated hydrographs. This improvement was almost totally attributable to the modified field reservoir which takes into account depression storage and percolation. To demonstrate this, the maximum deep percolation rate was set at 0.5 inches per hour, which resulted in zero spring flow. For the case of zero spring flow the best fit, F(x) of 2,462, was obtained for a depression storage capacity of 1.2 inches. The resultant optimal values of KD and KP were 11.51 hours and 107.35 hours respectively. The simulated direct runoff hydrographs of Model C are shown on Figures B-6 and B-10, Appendix B. Generally the hydrographs simulated by Model C show good agreement with the rising and recession limbs and peak discharge of the recorded hydrographs. As the field reservoir of Model C adequately simulates the direct runoff component of the hydrograph and meets the study's criteria of developing a simple model, the field reservoir of Model C has been used in all subsequent Models developed.

The effect of the spring reservoir of Model C was then assessed by fixing the depression storage capacity at 1.2 inches and adjusting the maximum deep percolation rate for succeeding runs. For all values of the maximum deep percolation rate selected, the optimized value of KS was greater than 1,000 hours. This resulted in negligible spring flow from the spring reservoir and results similar to the case of zero spring flow. These results were considered to be unacceptable. The remainder of the Model's development was devoted to modifications of the spring reservoir.

Two additional spring reservoirs were subsequently developed. In both cases, the field reservoir of Model C was used to simulate percolation, which acts as inflow to the spring reservoir. In the spring reservoir component of Model D, the deep percolation rate was assumed to be proportional to the storage of the spring reservoir. This differs from Model C where the deep percolation rate was assumed to be a constant loss. Finally in Model E, an attempt was made to incorporate into the spring reservoir of Model D a parameter representing an initial volume of water absorbed by the soil particles of the shale fractures before spring flow and deep percolation can begin.

In the spring reservoir of Model D deep percolation was assumed to be proportionate to the storage of the spring reservoir. Deep percolation begins immediately upon the spring reservoir filling and increases until the maximum deep percolation rate is reached at which time spring flow begins. The spring reservoir of Model E may be represented mathematically as:

When $SS_t \leq SDP$ $\quad DP_t = SS_t \times AREA/KDP$ and

$SF_t = 0$

When $SS_t > SDP$ $\quad DP_t = SDP \times AREA/KDP$ and

$SF_t = (SS_t - SDP) AREA/KS$

Where: SDP - is the storage volume of the spring reservoir in inches at which the maximum deep percolation rate is reached;

DP_t - is the deep percolation rate in cfs at time period t;

KDP - is the storage constant of the spring reservoir in hours which relates the volume of storage to the deep percolation rate.

A schematic of Model D is shown on Figure 4. Like Model C, the depression storage capacity and the maximum deep percolation rate are fixed for each run and the optimization program then adjusts the storage constants KD, KP, KDP, and KS until a "best fit" of the hydrographs is attained.

The revised spring reservoir of Model D, decreased the minimum objective function to 2,357. For the optimal maximum deep percolation rate of 0.01 inches per hour, the optimized values of KD, KP, KDP and KS significantly improved the hydrograph's shape. This significant improvement was not indicated by the objective function. The optimum value of KS of 78.0 resulted in an increase in the portion of the spring reservoir's storage released to spring flow, thus improving the agreement between the simulated and recorded hydrographs for flows less than 60 cfs. The optimal values of KD and KP of 10.10 hours and 48.39 hours respectively, which were less than the values obtained for Model C, increased the slope of the recession limb of the direct runoff component of the hydrograph. As shown by a visual inspection of the simulated hydrographs of Model D on Figures B-6 to B-10, Appendix B, a major improvement in the fit of the recession limb of the simulated hydrographs with the recorded hydrographs has occurred, even though the objective function did not indicate a significant improvement. Although this improvement in hydrograph shape was not recognized by the objective function, it was felt that changing the objective function would not significantly improve the study results.

The final spring reservoir developed considers an initial volume of percolation from the field reservoir absorbed by the soil particles of the shale fractures, before spring flow, and deep percolation begins. It was felt this initial volume of water must be absorbed before outflow from the shale fractures can begin. In this model both spring flow and deep percolation were assumed to begin once the initial soil moisture deficit of the spring reservoir was satisfied. This deficit is called the spring capacity. The spring reservoir of Model F may be represented mathematically as:

When $SS_t \leq SC$ $\quad DP_t = 0$ and $SF_t = 0$

When $SS_t > SC$ $\quad DP_t = (SS_t - SC)AREA/KDP$ and

$$SF_t = (SS_t - SC)AREA/KS$$

Where SC is the spring capacity of the spring reservoir in inches.

A schematic of Model E is shown on Figure 5. In Model E, the depression storage capacity, maximum deep percolation rate, and spring capacity are fixed for each run, whereas the optimization program adjusts the storage constants KD, KP, KDP and KS until a "best fit" of the hydrographs is attained.

In Model E it was observed that increasing the value of the spring capacity resulted in a decreased value of the objective function. A spring capacity of 0.60 inches reduced the minimum objective function F(x) to 1,145. The hydrographs simulated by Model E for a spring capacity of 0.60 inches are shown on Figures B-11 to B-15. The reduction in the objective function was totally accounted for by the improvement in storm 74-5-1. This improvement was based on the assumption that storm 74-5-1 was initially at spring capacity. This assumption was based on the fact that as the initial soil moisture content of storm 74-5-1 was at field capacity the spring reservoir could have similarly been at spring capacity. In storm 75-8-1 it was also observed that the spring capacity had the effect of delaying the start of spring flow, which caused a distinct secondary peak. The larger the value of the spring capacity the more pronounced the secondary peak became. Because of the abnormality of the secondary peak of storm 75-8-1, and the improvement in only storm 74-5-1, which was based on an unsubstantiated assumption, the idea of an initial soil moisture deficit developed in the spring reservoir of Model E was given no further consideration.

In summary, of the five models previously discussed, Model D is considered to simulate best the five storms studied. A schematic diagram of the field reservoir and spring reservoir of Model D with the corresponding linear functions is shown on Figure 4.

CHAPTER V

DISCUSSION

5.1 GOODNESS-OF-FIT OF MODEL

The hydrographs that have been studied indicate good agreement in four out of the five storms reproduced by Model D. The fifth storm, Event 74-5-1, reveals an inadequacy of Model D and the variability that occurs in the physical watershed response.

Storm Event 69-6-1 shows good agreement between the recorded and simulated flows. As shown on Figure 6, the characteristic hydrograph shape of the two sequential rainfall events is reasonably reproduced. The largest discrepancy occurs in the peak discharge of the second rainfall event, which is underestimated by approximately 70 cfs or 23 percent.

Storm Event 74-5-1 shows the largest discrepancy of the five storms studied. The peak discharge and volume are underestimated by 21.6 percent and 29.2 percent respectively, as shown on Figure 7.Storm 74-5-1 is the only event studied in which the rising limb of the simulated hydrograph does not precede that of the recorded flow. It would appear that the discrepancy lies in the initial soil moisture conditions. This discrepancy can perhaps be explained as follows: Spring runoff had occurred approximately two weeks earlier. The depression storage capacity of the Watershed is probably still partially full. Event 74-5-1 being of a moderate rainfall intensity, the partially full depression storage capacity would significantly effect the start of runoff and thus the runoff volume and peak. As Model D does not attempt to recognize initial depression storage in the Watershed because of the lack of actual physical observations, the runoff hydrograph would have been underestimated.

Storm Events 75-8-2 and 75-9-1 indicate the best agreement between the recorded and simulated flow. In Event 75-8-2 the peak discharge and runoff volume were reproduced within 8 percent and 1 percent respectively, as shown on Figure 8. Similarly, in Event 75-9-1 the peak discharge and runoff volume were reproduced within 1 percent and 10 percent respectively, as shown on Figure 9. For both high-intensity rainfall events initial soil moisture conditions were below field capacity.

Storm Event 77-7-1 indicates good agreement between the recorded and simulated flows, as shown by Figure 10. The peak discharge and runoff volume were overestimated by 16 percent and 21 percent respectively. Like Event 69-6-1 the volume of runoff under the rising limb has been overestimated.

In the Model's development, it was realized that there was something unique about storm 74-5-1. A review of the hydrometeorologic data found no conclusive reason to discard this storm. It was felt that including storm 74-5-1 in calibration of the Model did not have a significant effect on the parameters because of the goodness-of-fit attained for the four other storms. Because storm 74-5-1 was used in the development of the Model, five additional storms, discussed in the following section, have been used for verification of the Model D.

5.2 VERIFICATION OF MODEL

Five additional hydrographs were synthesized to verify Model D. In Model D, the field reservoir is represented by the equations:

When $S_t \leq FC$ $\quad D_t = 0$ and $P_t = 0$

When $FC < S_t \leq FC + DS$ $\quad D_t = 0$ and

$P_t = (S_t - FC)AREA/KP$

When $S_t > FC + DS$ $\quad D_t = (S_t - (FC+DS))AREA/KD$ and

$P_t = (S_t - FC)AREA/KP$

and the spring reservoir by the equations:

When $SS_t \leq SDP$ $\quad DP_t = SS_t \times AREA/KDP$ and

$SF_t = 0$

When $SS_t > SDP$ $\quad DP_t = SDP \times AREA/KDP$ and

$SF_t = (SS_t - SDP)AREA/KS$

The parameters used in the verification of Model D are those calibrated from the five storms previously discussed in section 5.1. The optimal storage constants KD, KP, KDP and KS determined from these five storms are 10.10 hours, 48.39 hours, 6.00 hours and 78.0 hours respectively. The corresponding depression storage capacity and maximum deep percolation rate are 10.2 inches and 0.01 inches per hour respectively.

In two of the five storms used for verification of Model D the simulated hydrographs were overestimated in excess of 100 percent. A description of the five storms used for verification and the hydrographs synthesized by Model D are discussed as follows:

Event 63-6-2

During a 26.5 hour period from June 9th to 10th, 1963, an average of 2.55 inches of rain fell on the Wilson Creek Watershed. The average maximum hourly rainfall intensity of the storm was 0.34 inches. The soil moisture deficit prior to the storm was estimated to be 0.23 inches. At the Wilson Creek Weir a maximum instantaneous discharge of 218 cfs was recorded.

As shown by Figure 11, there is reasonable agreement between the simulated and recorded hydrographs. The peak discharge was overestimated by approximately 12 percent and the runoff volume was underestimated by 33 percent.

Event 65-9-1

From September 3rd to 5th, 1965, during a 32-hour period, an average of 4.41 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.41 inches. The soil moisture deficit prior to the storm was 0.70 inches. The peak discharge recorded at the Wilson Creek Weir was 111 cfs.

As shown by Figure 12, Model D significantly overestimated the runoff. The peak discharge and runoff volume were overestimated by approximately 320 and 215 percent respectively. However, the start of the simulated direct runoff coincided with the increase in the recorded streamflow.

It is felt that as the start of the simulated and recorded runoff of storm 65-9-1 coincided, the field reservoir of Model D adequately represents the depression storage capacity of the Watershed. From examining the storms used in this study, the recorded rainfall for storm 65-9-1 should have produced a significantly greater runoff. For instance, storm 69-6-1 with a similar rainfall and antecedent soil moisture conditions produced three times the runoff. It was postulated that the problem with storm 65-9-1 could be in the hydrometeorological data. As a result, the hydrometeorological of storm 65-9-1 was reviewed in detail. The results of this review are discussed in section 5.3.

Event 65-9-2

During a 60-hour period from September 15th to 18th, 1965, an average of 3.29 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.16 inches. A peak discharge of 150 cfs was recorded at the Wilson Creek Weir. Initial soil moisture readings were not available for Event 65-9-2. Therefore, annual soil moisture readings for September were examined to estimate the initial conditions. Between Events 65-9-1 and 65-9-2 there were eleven consecutive days without precipitation. Soil moisture deficit readings for September indicate that the soil moisture content would decline on the average by 0.60 inches during such a period. Therefore, a soil moisture deficit of 0.60 was assumed to estimate the conditions prior to Event 65-9-2.

As shown on Figure 13, there is good agreement between the simulated and recorded hydrographs. The peak discharge and runoff volume were reproduced within 1 percent and 12 percent respectively.

Event 66-8-1

From June 4th to 6th, 1966, during a 51-hour period, an average of 6.06 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.84 inches. The soil moisture deficit prior to the storm was estimated to be 2.20 inches. A peak discharge of 114 cfs was recorded at the Wilson Creek Weir.

As shown by Figure 14, the runoff produced by the rainfall from Event 66-8-1 was significantly overestimated by Model D. The peak discharge and volume of runoff were overestimated by 226 and 83 percent respectively.

As in Event 65-9-1 the start of direct runoff simulated by Model D coincided with the increase in recorded flow. Also from examining the storms used in this study, the recorded rainfall of storm 66-8-1, like storm 65-9-1, should have produced a significantly greater runoff. A detailed review of the hydrometeorologic data of storms 66-8-1 and 65-9-1 was conducted. This review is discussed in section 5.3.

Event 71-6-1

During a 51-hour period from June 4th to 6th, 1971, an average of 6.06 inches of rain fell on the Wilson Creek Watershed. The average maximum hourly rainfall intensity of the storm was 0.51 inches. A maximum instantaneous discharge of 850 cfs was recorded at the Wilson Creek Weir. For 1971 there is no soil moisture data, as an experimental NEA neutron probe used to estimate moisture content was improperly calibrated. Therefore, the initial soil moisture deficit of 1.10 inches was estimated from extrapolation of conditions in 1976. In 1976 precipitation and evaporation for the month of May was approximately equivalent to that of 1971. The estimated soil moisture deficit of 1.10 inches is considered a reasonable estimate, as the start of runoff and the magnitude and timing of the first peak discharge agree with the recorded runoff.

As shown by Figure 15, there is good agreement between the simulated and recorded hydrographs of Event 71-6-1. The hourly peak discharge and volume of runoff were reproduced within 9 percent.

5.3 COMPARISON OF HYDROMETEOROLOGIC DATA

A detail analysis of storm Events 65-9-1 and 66-8-1 has been undertaken to explain the large discrepancies between the recorded and simulated hydrographs. From examination of all ten storms, the recorded runoff hydrographs of Events 65-9-1 and 66-8-1 do not appear to agree with the recorded hourly rainfall intensities. Therefore, the basic hydrometeorological data used in the Model has been analyzed.

First, the recorded streamflow data was checked. Although there could be some uncertainty in the observed runoff hydrographs, due to errors in the discharge rating curve, this error is not estimated to be in the order of 100 percent as indicated by the simulated hydrographs. The accuracy of a discharge measurement is normally within 5 to 10 percent of the true flow (6). Also, as a check on the recorded streamflow measurements, the recorded streamflow for Wilson Creek and Packhorse Creek were compared. Comparison of Events 65-9-1, 65-9-2 and 66-8-1 indicated agreement in the proportionate runoff volume of the two creeks for the period of the simulated hydrographs. However, the comparison of the peak discharges of the two creeks indicated that the peak discharge on Wilson Creek was proportionally less in Events 65-9-1 and 66-8-1 than the other events studied, as shown in Table 2. No apparent reason could be found to explain this variance in the peak discharges of the two creeks for events 65-9-1 and 66-8-1.

TABLE 2

COMPARISON OF WILSON CREEK AND PACKHORSE CREEK

RECORD PEAK DISCHARGE

EVENT	PEAK DISCHARGE IN CFS WILSON CREEK	PEAK DISCHARGE IN CFS PACKHORSE CREEK	RATIO OF PEAK DISCHARGE
63-6-2	218	103	0.472
65-9-1	111	67	0.599
65-9-2	150	73	0.486
66-8-1	114	76	0.665
69-6-1	694	182	0.260
71-6-1	733	223	0.304
74-5-1	298	87	0.296
75-8-2	260	N/A	-
75-9-1	1580	480 Est.	0.308
77-7-1	540	N/A	-

Est - Estimated (7)

The second source of error between the recorded and simulated hydrographs was thought to be in the precipitation data. The wide spatial relationships in precipitation which occur throughout the Watershed during a storm have been approximated by the average hourly precipitation, as estimated by the Theissen polygon method. However, the rainfall isoyhets of Event 65-9-1 and 66-8-1 do not exhibit any characteristic differences from the other eight storms studied. Also, the rainfall network is considered to be adequate to measure variations in precipitation throughout the Watershed. Therefore, the precipitation data used in the Model was not considered to be the problem.

The third possible error considered was due to the initial soil moisture estimates. The Model has been applied to a wide range of initial soil moisture conditions in the storms studied. As the start of the simulated runoff in Events 65-9-1 and 66-8-1 coincides closely with the increase in recorded streamflow, the initial soil moisture estimates were not considered to be the major source of the error. The effect of the initial soil moisture conditions on the runoff are discussed in detail in the following section.

Finally, seasonal variations in any of the hydrometeorological data discussed previously are not considered to be the source of the error as the Model has been applied successfully in other storms during the period from May to September.

In summary, this review of the hydrometeorological data appears to find no apparent reason for the discrepancy in the two storms modeled.

5.4 EFFECT OF INITIAL SOIL MOISTURE

Soil moisture surveys are taken weekly in the summer. Changes in the soil moisture deficit of up to 0.70 inches can occur in periods without precipitation as indicated in 1973. To assess the effect of the variability in initial soil moisture conditions on Model D, a sensitivity analysis was conducted by varying the initial soil moisture condition of each storm studied by 0.20 inches. The results indicated that for the larger storms, such as 75-9-1 and 71-6-1, varying the initial soil moisture had an almost negligible effect on the peak discharge. For the moderate storms, Events 77-1-1 and 65-9-1, the change in initial soil moisture conditions of 0.20 inches changed the peak discharge by approximately 9 percent. In the balance of the storms studied the change in initial soil moisture conditions had the most severe effect by changing the peak discharge by 15 to 20 percent.

In two of the storms studied, Events 65-9-2 and 77-7-1, it was necessary to estimate the initial soil moisture conditions. As indicated by the preceding sensitivity analysis, the greatest uncertainty in the simulated hydrographs would appear to be in Event 65-9-2.

CONCLUSIONS

A relatively simple computer model using two stacked linear reservoirs could be used with good success to simulate hourly streamflow hydrographs due to rainfall for the Wilson Creek Watershed. The Model was kept very simple. The effects of evaporation, evapotranspiration and interception were ignored.

For the five storms used for verification of the Model there was good agreement to the actual streamflow in three cases. In the other two instances, the Model overestimated the runoff. No simple reason for this could be found. The recorded runoff hydrographs of the two storms, Events 65-9-1 and 66-8-1 do not appear to agree with the recorded hourly rainfall intensities. A examination of the hydrometeorological data could not explain this discrepancy. Additional studies are required to resolve the difference between recorded and simulated runoff of the two events.

The criteria of the goodness-of-fit developed in this study has been successfully applied in optimizing the storage constants of the linear reservoirs and in the comparison of the individual simulation runs. At times, however, it has been necessary to visually examine the simulated hydrographs for improvements in the shape of the hydrographs, which the objective function could not account for. Further studies could compare various objective functions to best define the criteria of the goodness-of-fit for hydrologic modeling.

Further studies could investigate the application of the Model to other watersheds. An attempt has been made to identify the Model components with the corresponding hydrologic processes in order that the Model could be applied to other watersheds where similar features and conditions exists. If the Model is to be applied to other watersheds, a minimum of three rainfall events should be used in calibration of the Model. In further studies, an optimization technique, other than the Direct Pattern Search, should be considered. In this study it was necessary to calibrate six parameters simultaneously. With six parameters, the Direct Pattern Search was found to be very inefficient and expensive to use. Therefore, the depression storage capacity and the maximum deep percolation rate were fixed for each run, and the Direct Pattern Search was then used to calibrate the storage constants. This has also resulted in an inefficient approach to optimization as the depression storage capacity and the maximum deep percolation rate had to be manually adjusted between successive runs.

The Model developed in this study has shown that initial soil moisture conditions can significantly effect the runoff hydrograph produced from rainfall events. In the Wilson Creek Watershed soil moisture surveys are taken at weekly intervals. However, in most watersheds soil moisture data is not available. If the Model is to be applied to other watersheds along the Manitoba Escarpment, studies should be undertaken to determine whether the soil moisture conditions could be estimated from available meteorological data. The data gathered from the Wilson Creek Watershed could be used for such a study.

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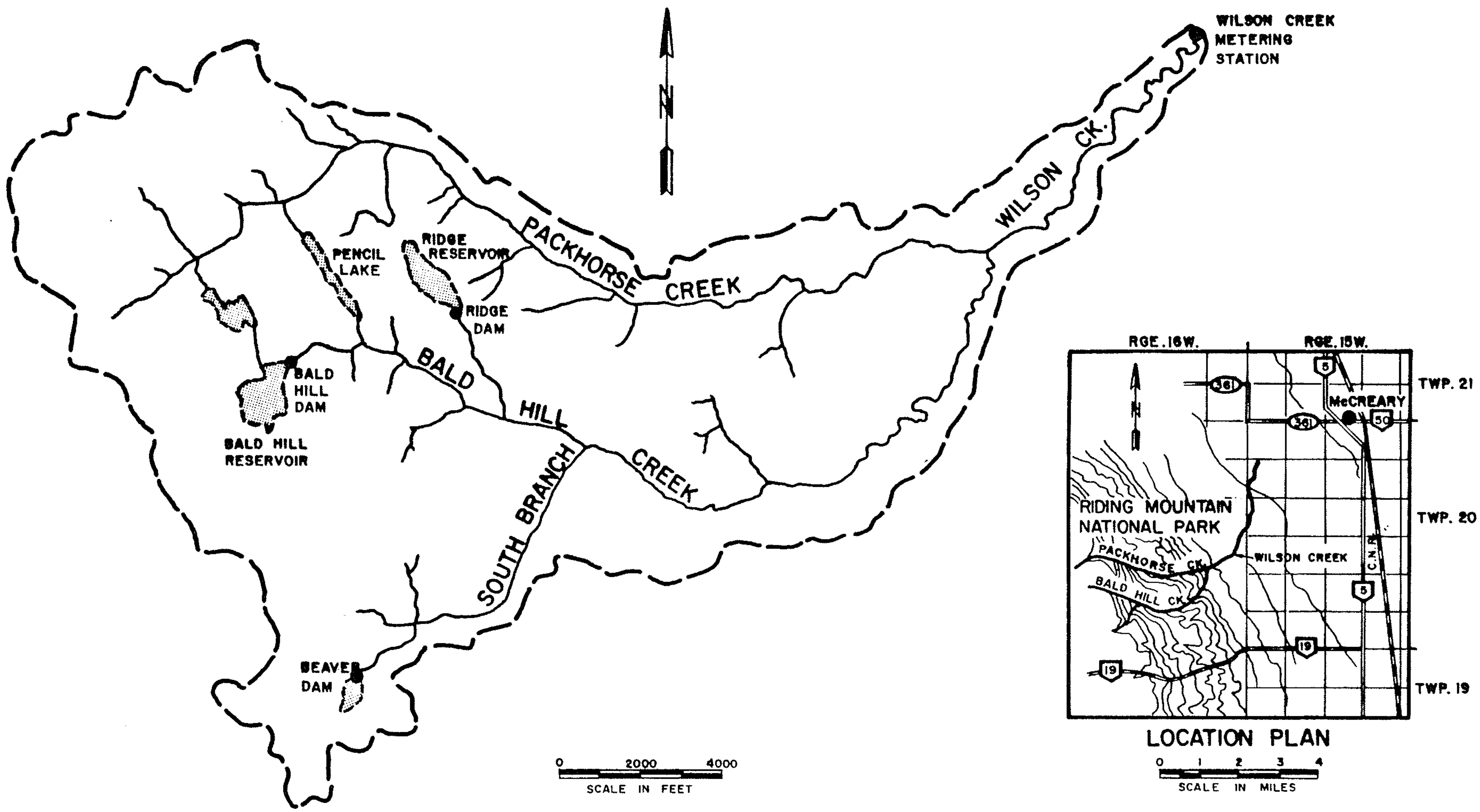


LOCATION PLAN OF WILSON CREEK WATERSHED

FIGURE 1

MODEL REPRESENTATION OF HYDROLOGIC PROCESS

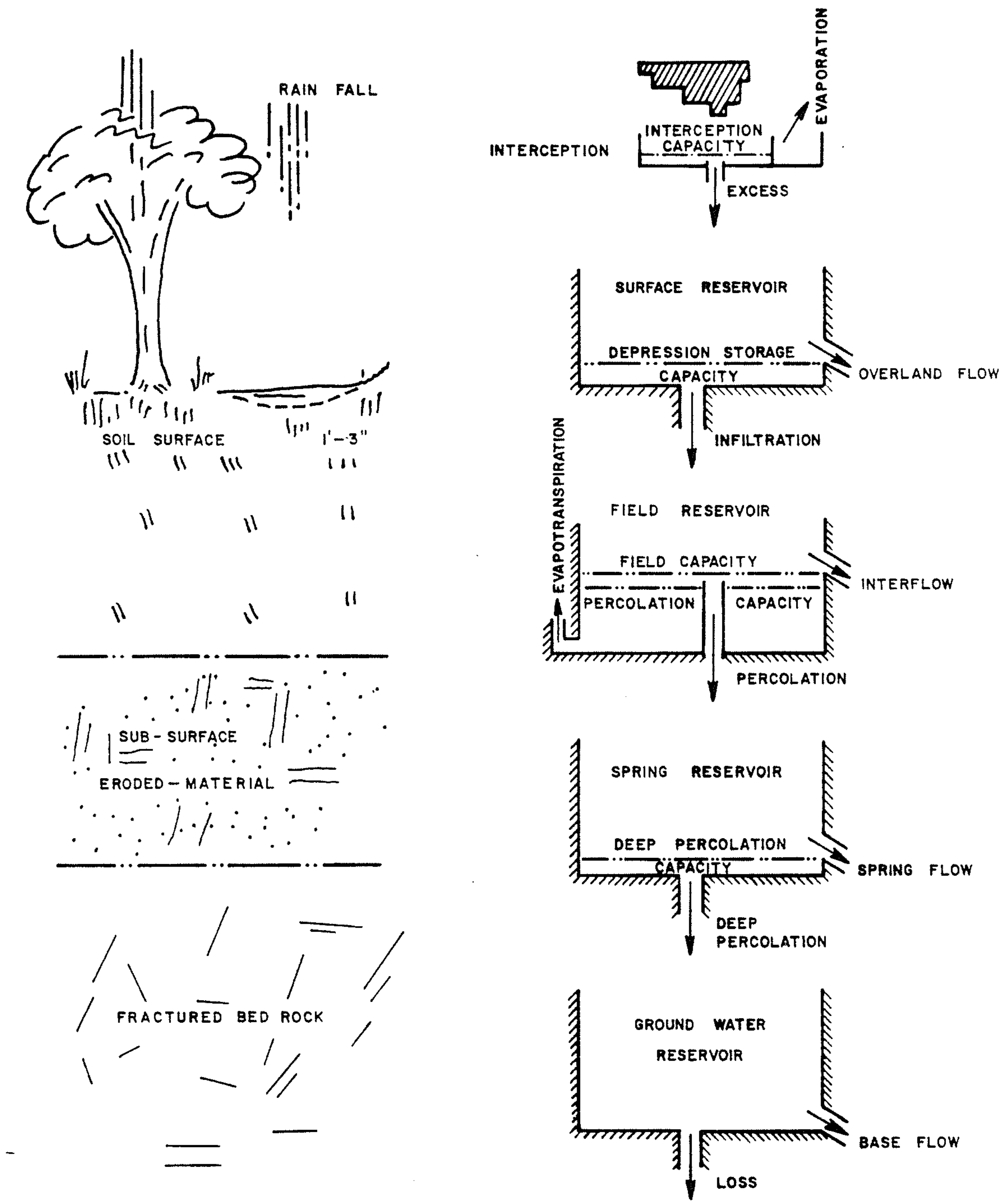


FIGURE 2

THE UNIVERSITY LIBRARIES

SCHEMATIC OF LINEAR RESERVOIR MODEL 'C'

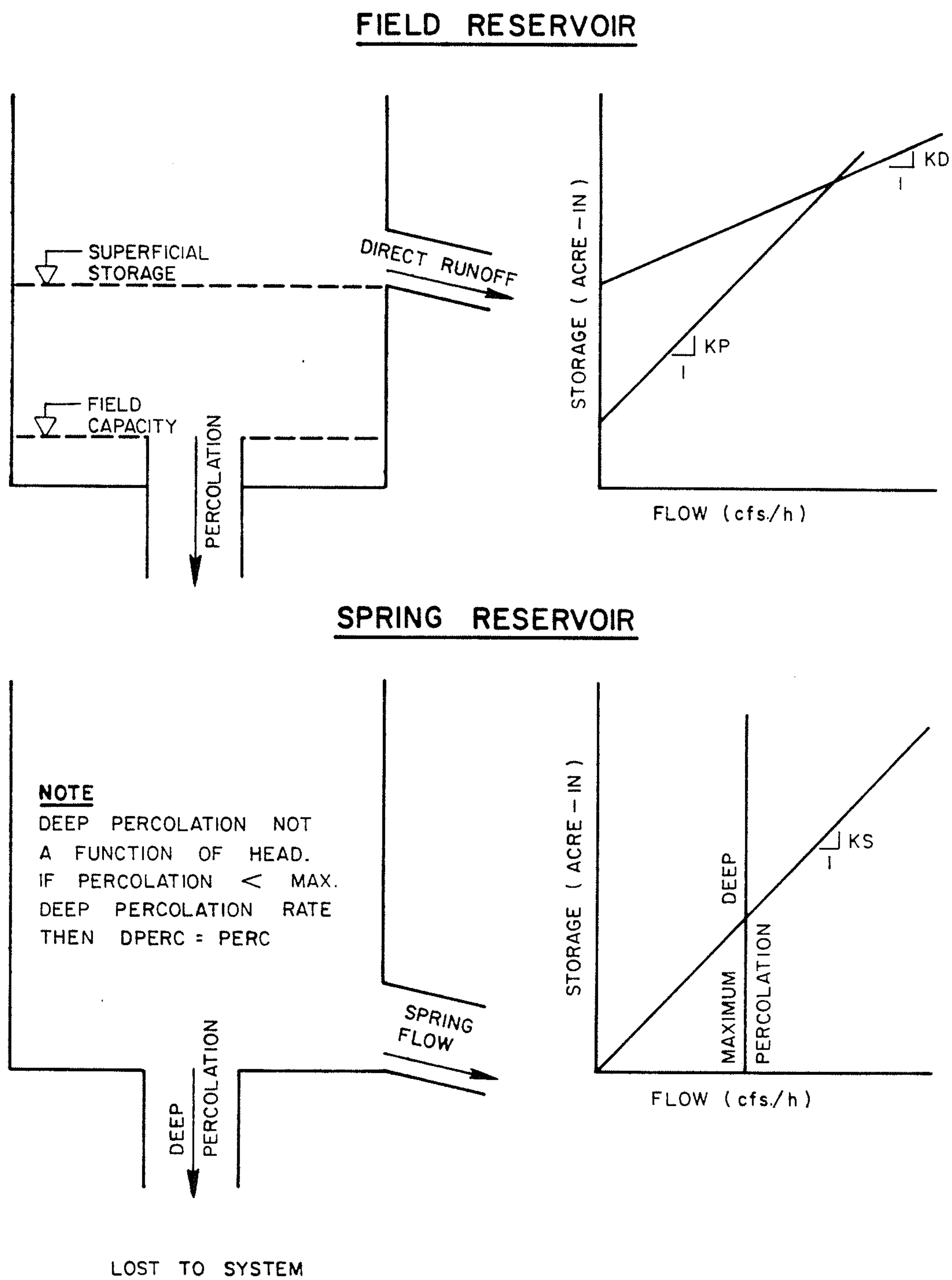
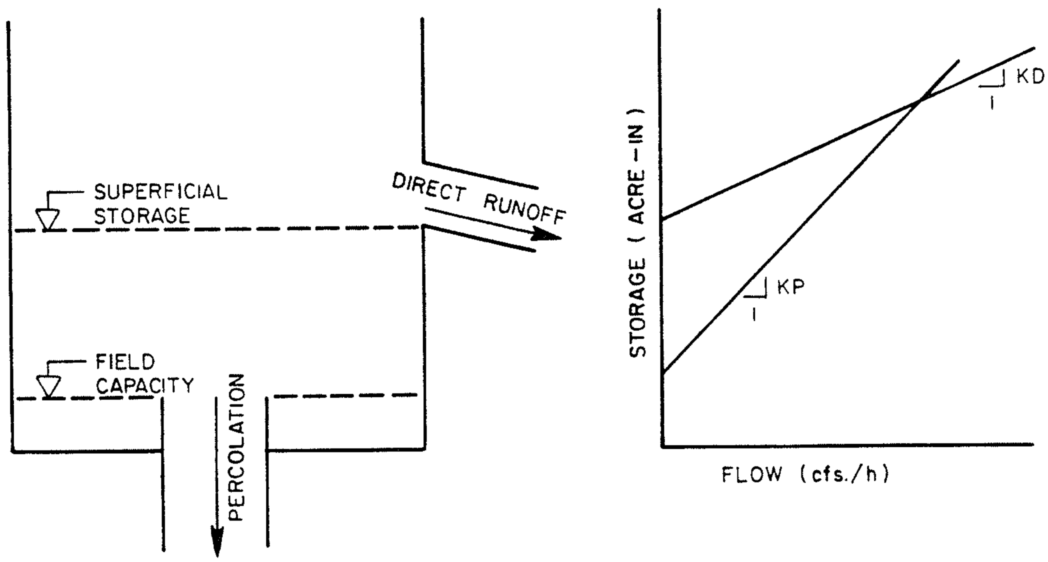


FIGURE 3

SCHEMATIC OF LINEAR RESERVOIR MODEL 'D'

FIELD RESERVOIR



SPRING RESERVOIR

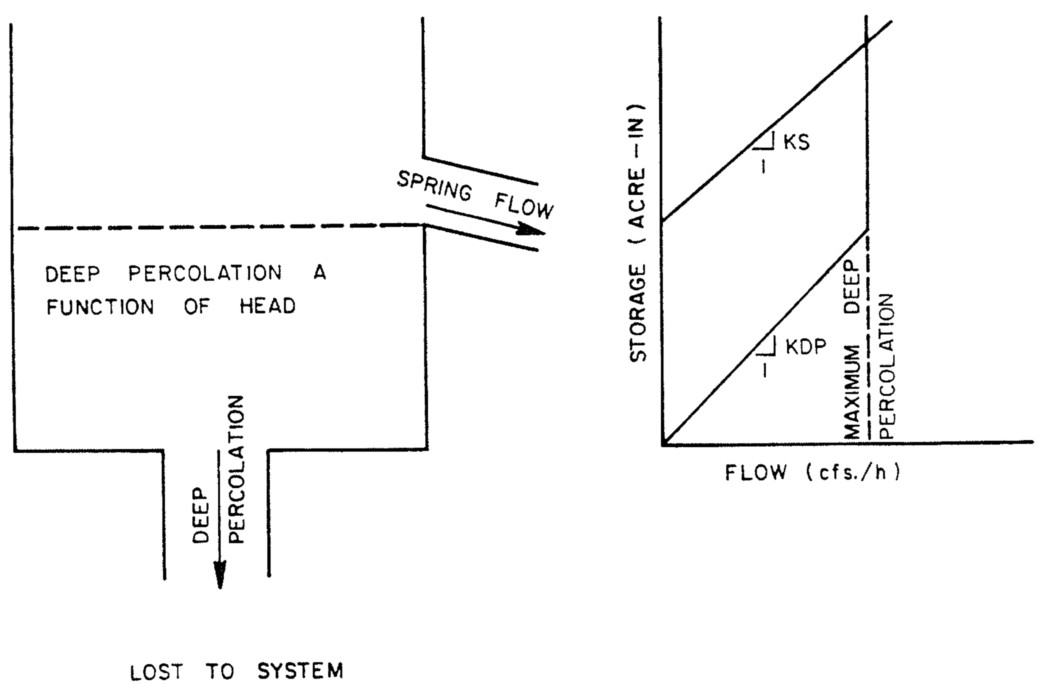


FIGURE 4

SCHEMATIC OF LINEAR RESERVOIR MODEL 'E'

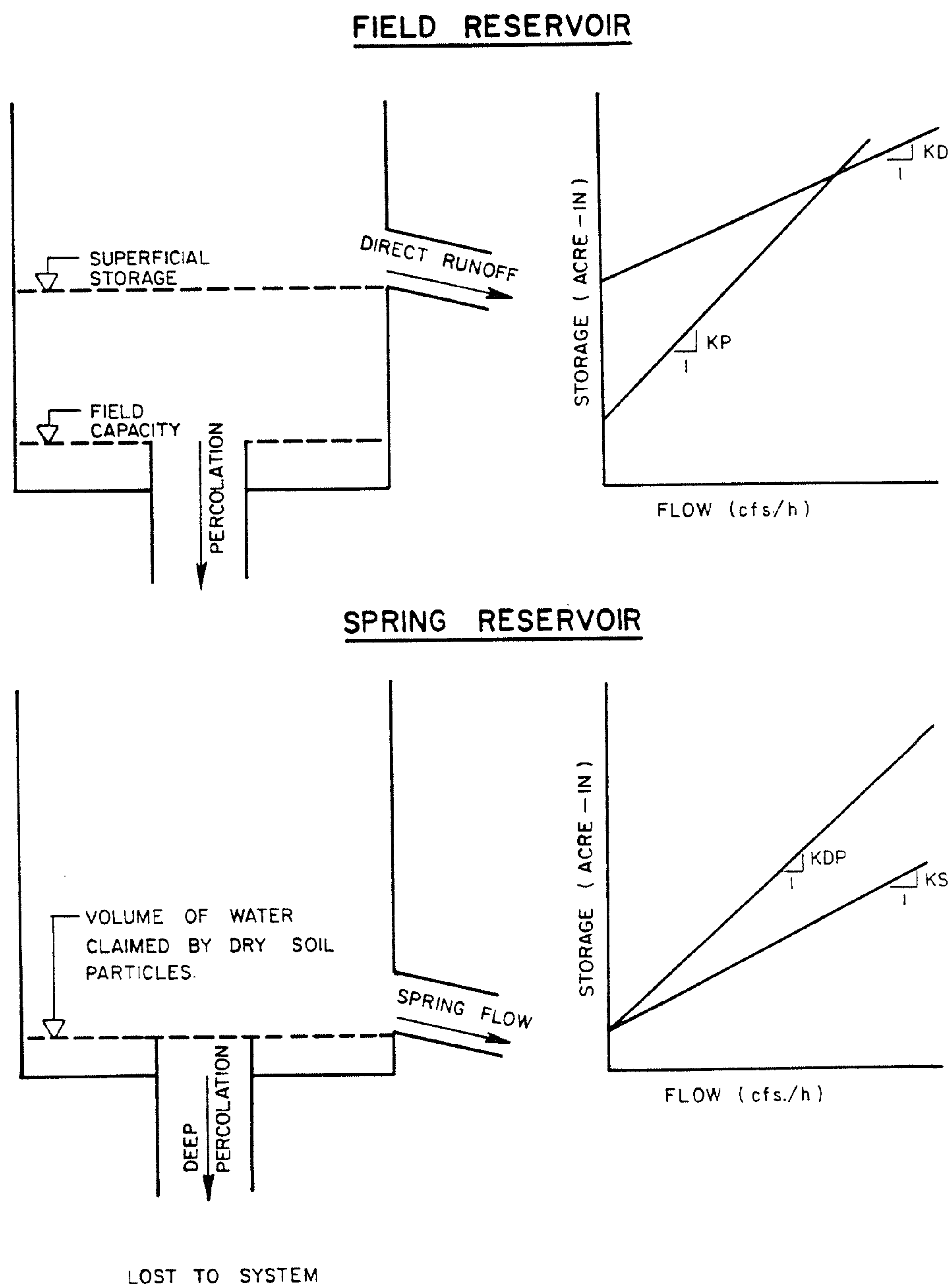
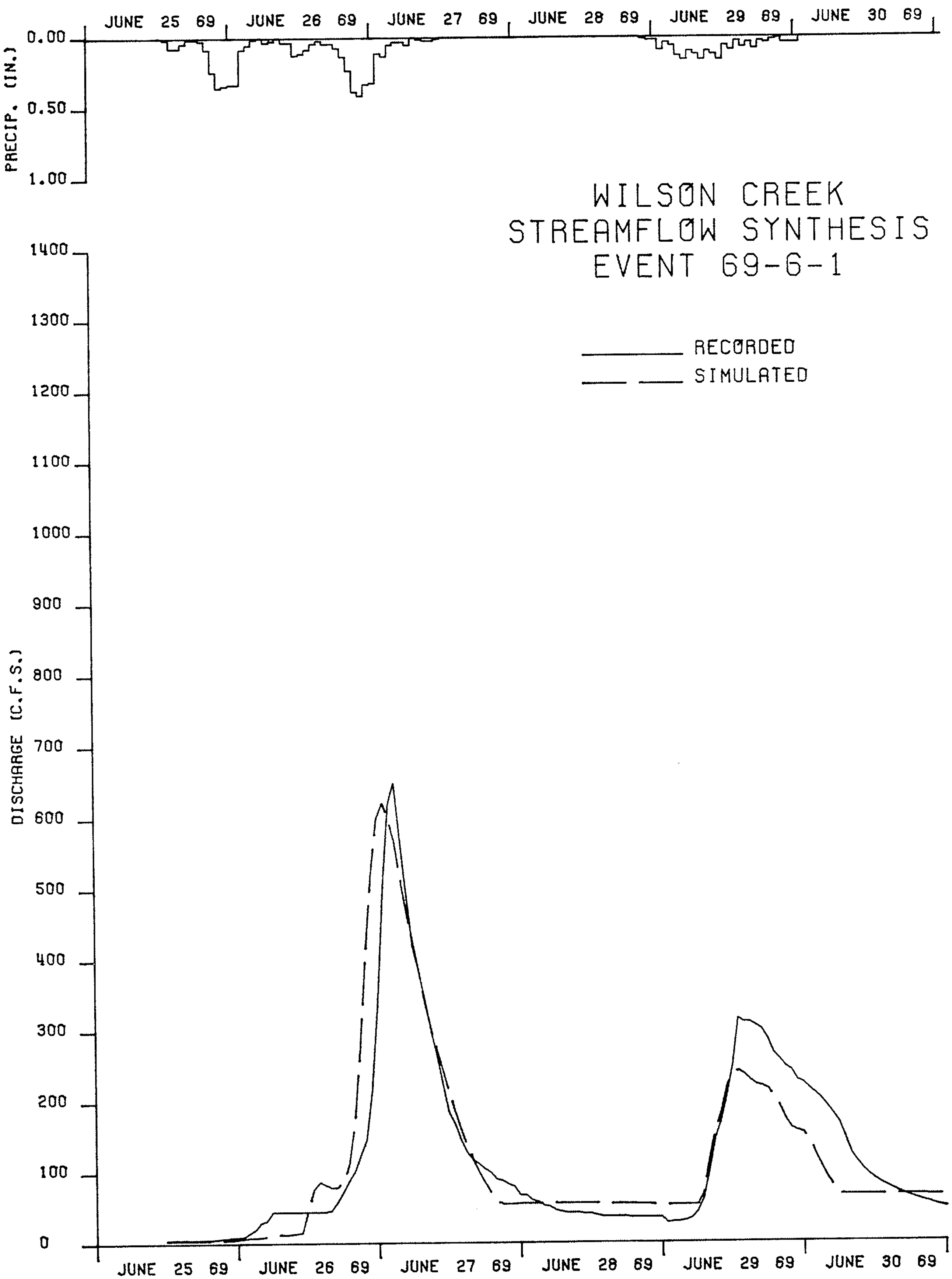


FIGURE 5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JUNE 26 69
JUNE 27 69
JUNE 28 69
JUNE 29 69
JUNE 30 69
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 69-6-1
RECORDED
SIMULATED
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
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JUNE 25 69
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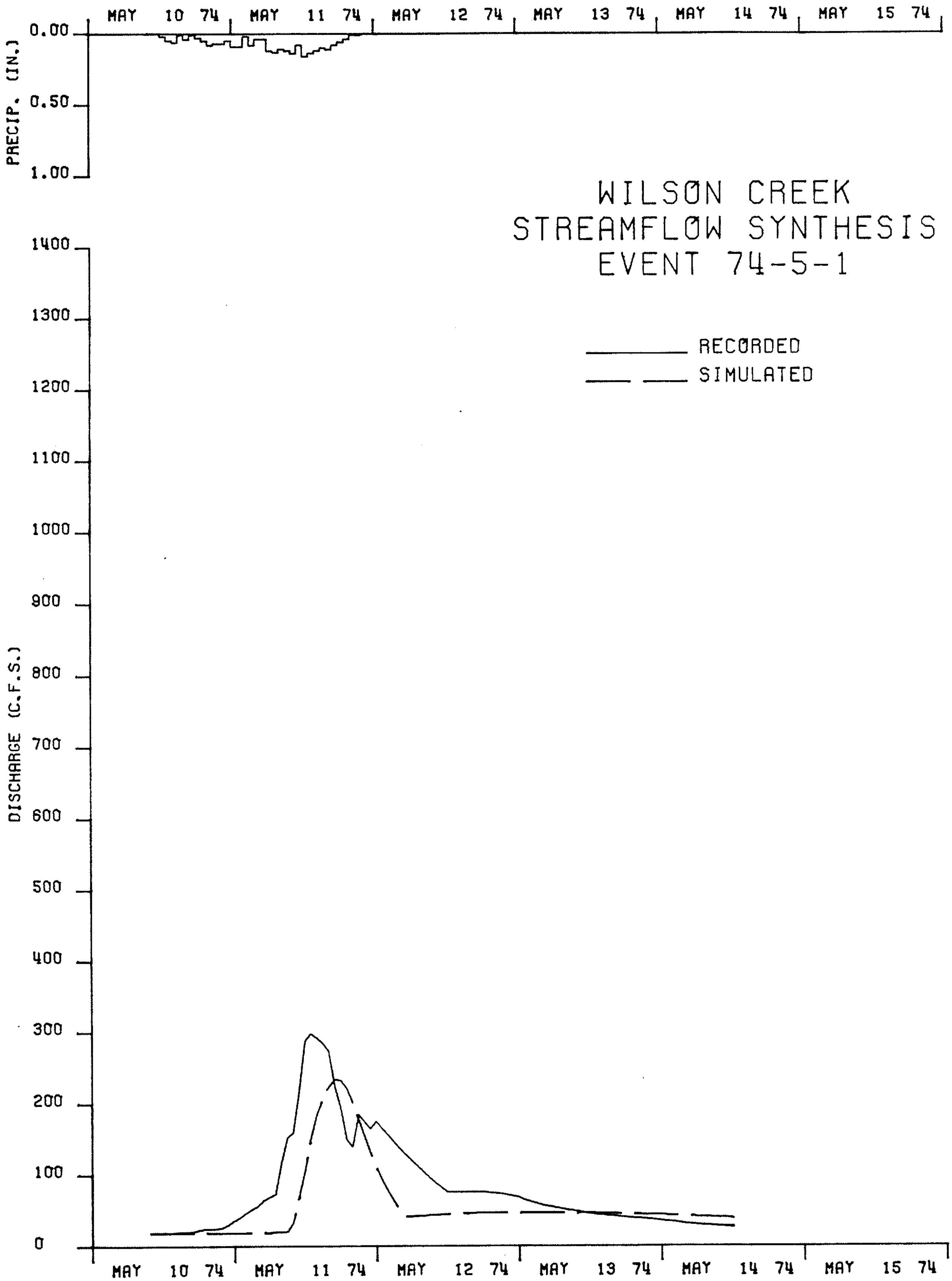
JUNE 29 69
JUNE 30 69

FIGURE 6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MAY 12 74
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PRECIP. (IN.)
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1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 74-5-1
RECORDED
SIMULATED
DISCHARGE (C.F.S.)
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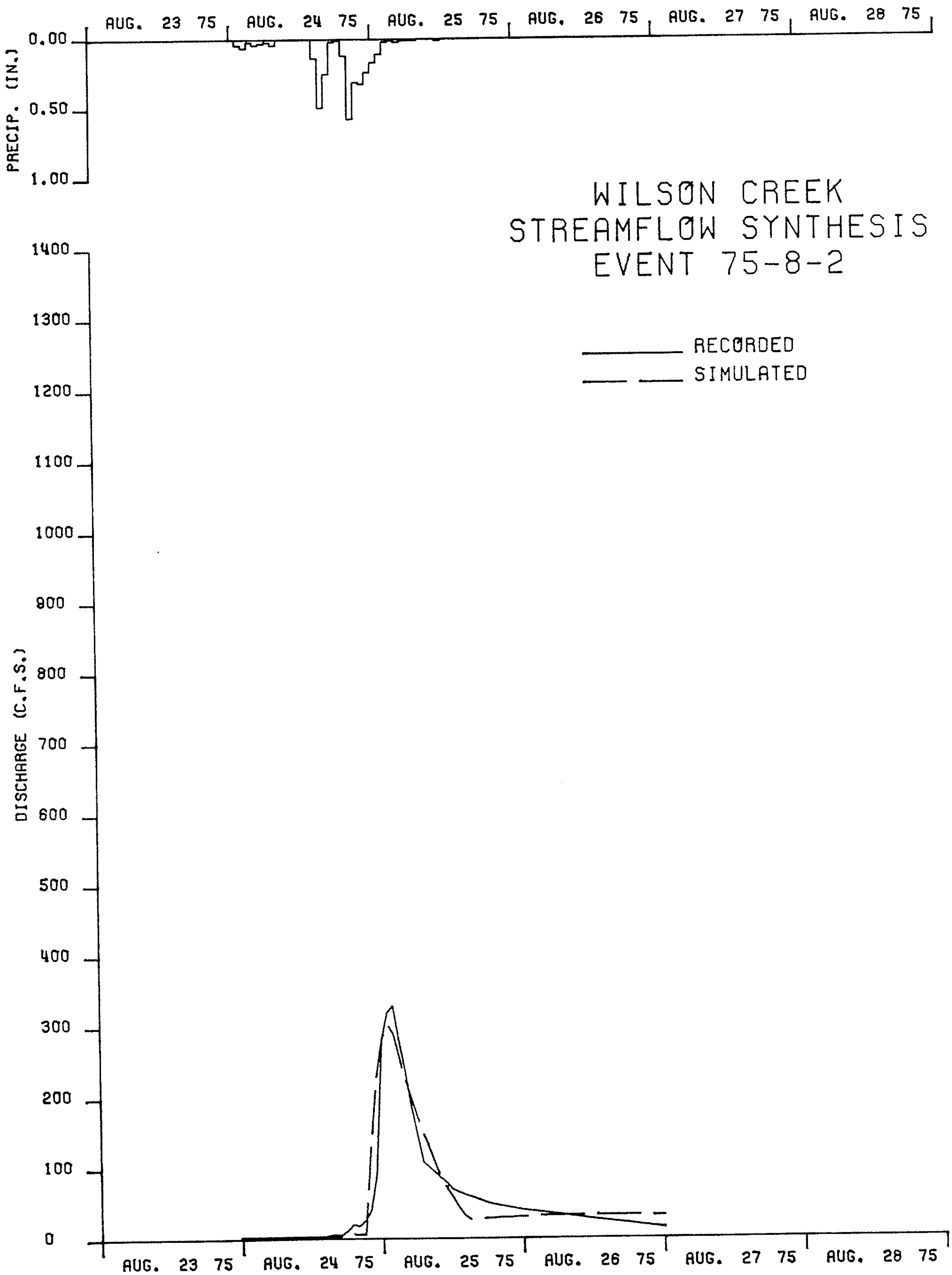
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE 7



AUG. 23 75
AUG. 24 75
AUG. 25 75
AUG. 26 75
AUG. 27 75
AUG. 28 75
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1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-8-2
RECORDED
SIMULATED
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)
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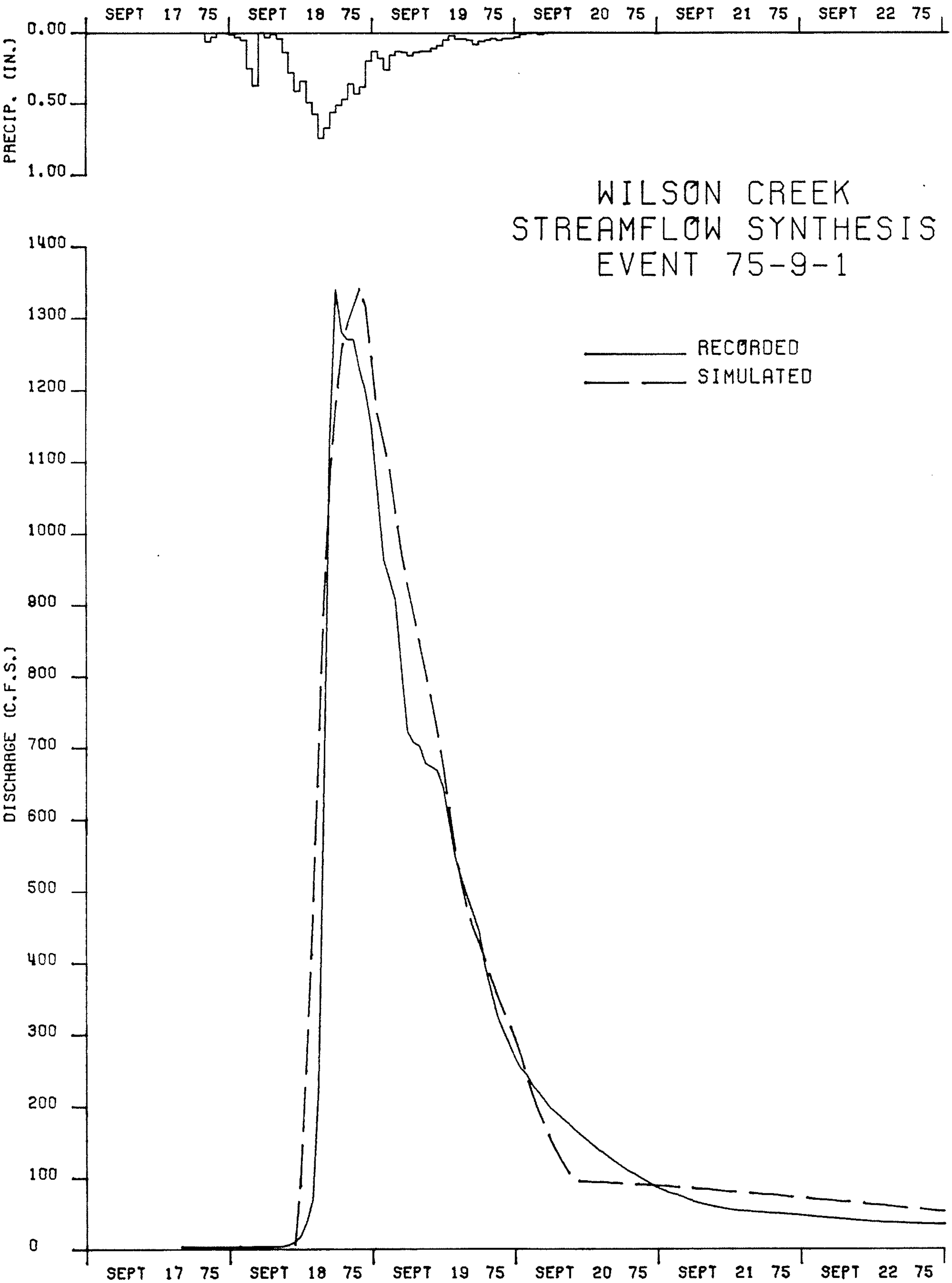
AUG. 24 75
AUG. 25 75
AUG. 26 75
AUG. 27 75
AUG. 28 75

FIGURE 8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SEPT 21 75
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0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-9-1
RECORDED
SIMULATED
DISCHARGE (C.F.S.)
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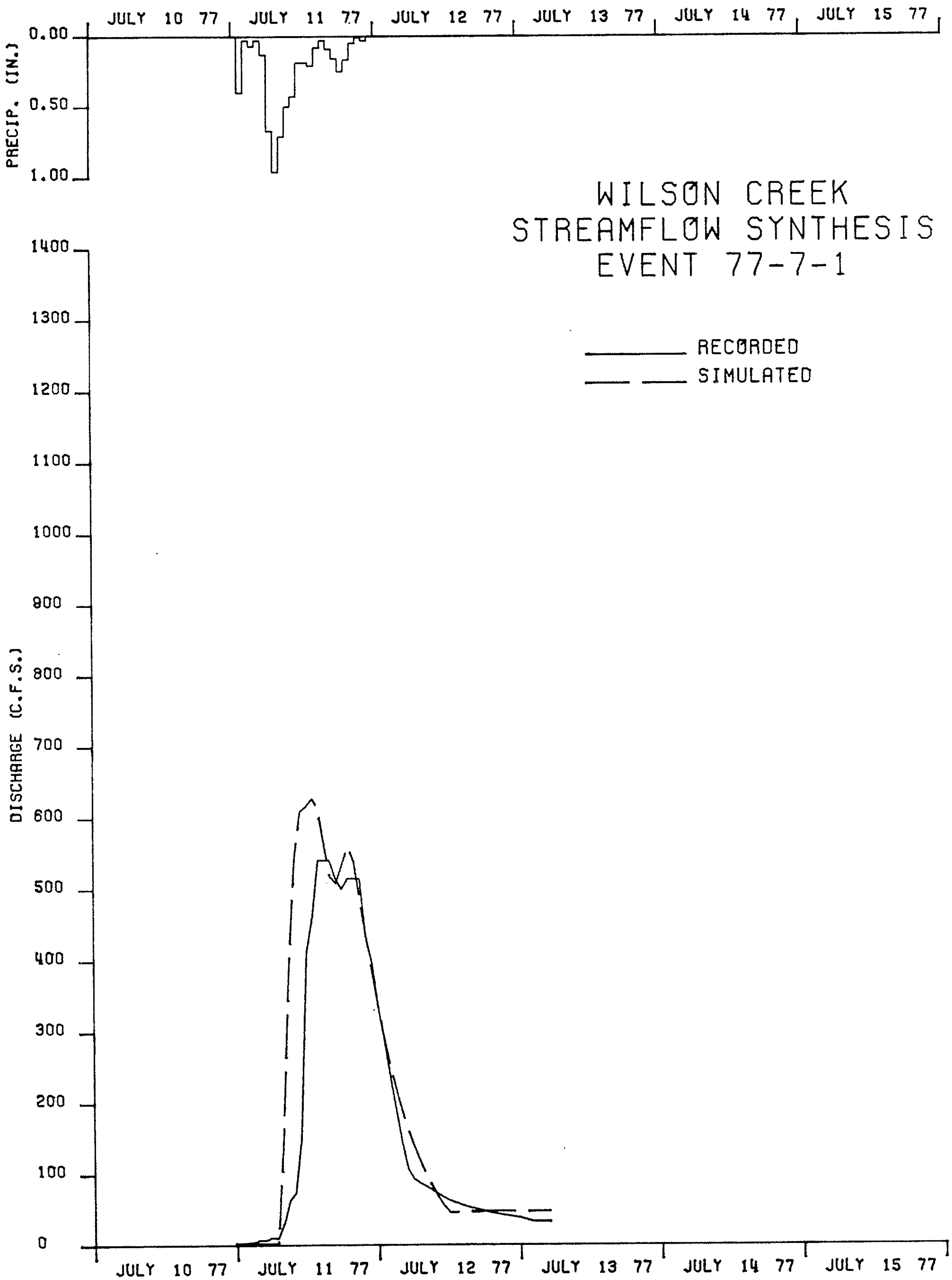
1300
1200
1100
1000
800
800
700
600
500
400
300
200
100
0

FIGURE 9



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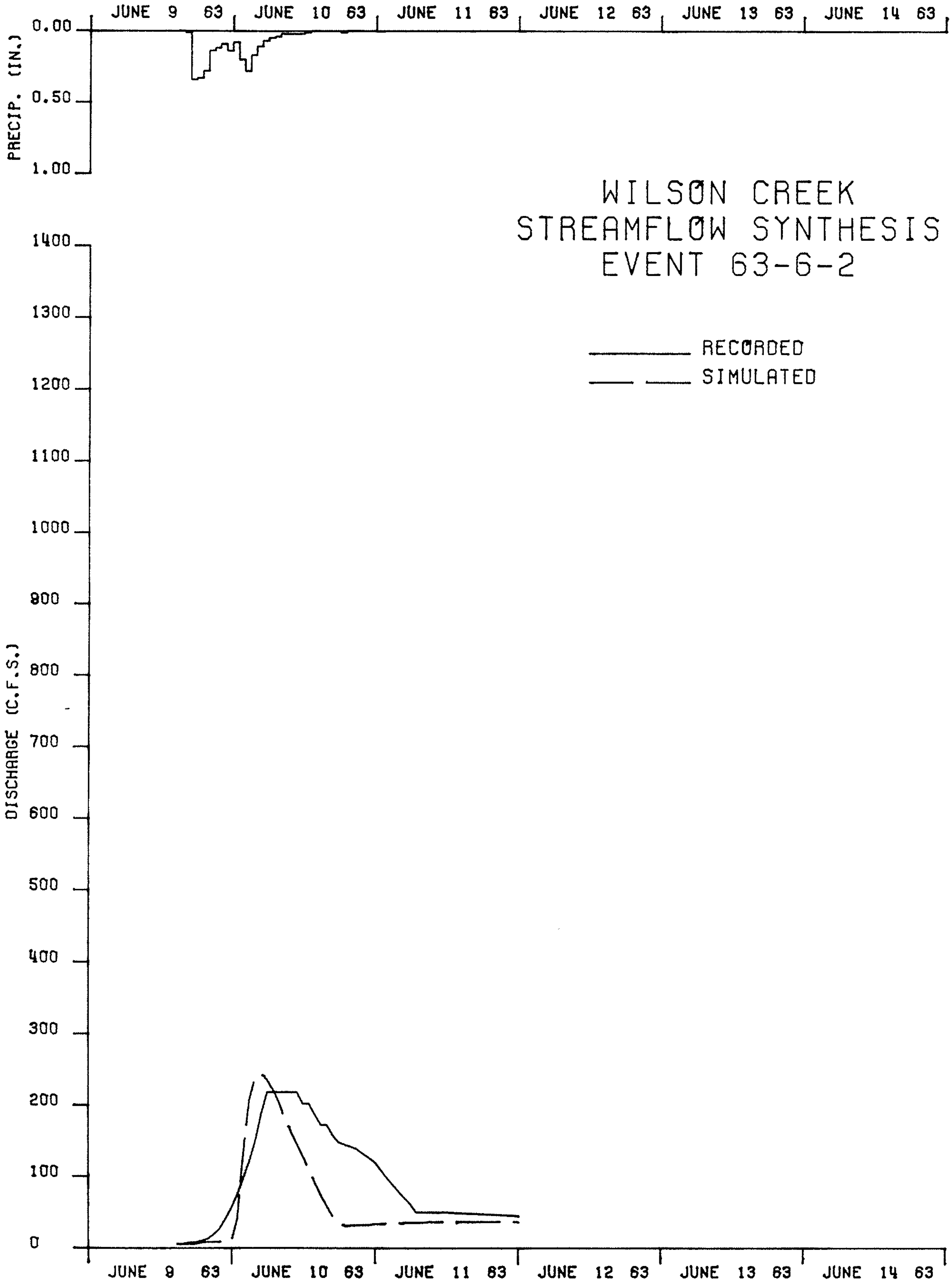
JULY 11 77
JULY 12 77
JULY 13 77
JULY 14 77
JULY 15 77
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 77-7-1
RECORDED
SIMULATED
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)
JULY 10 77
JULY 11 77
JULY 12 77
JULY 13 77
JULY 14 77
JULY 15 77

FIGURE 10



JUNE 9 63
JUNE 10 63
JUNE 11 63
JUNE 12 63
JUNE 13 63
JUNE 14 63
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 63-6-2
RECORDED
SIMULATED
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)

FIGURE 11

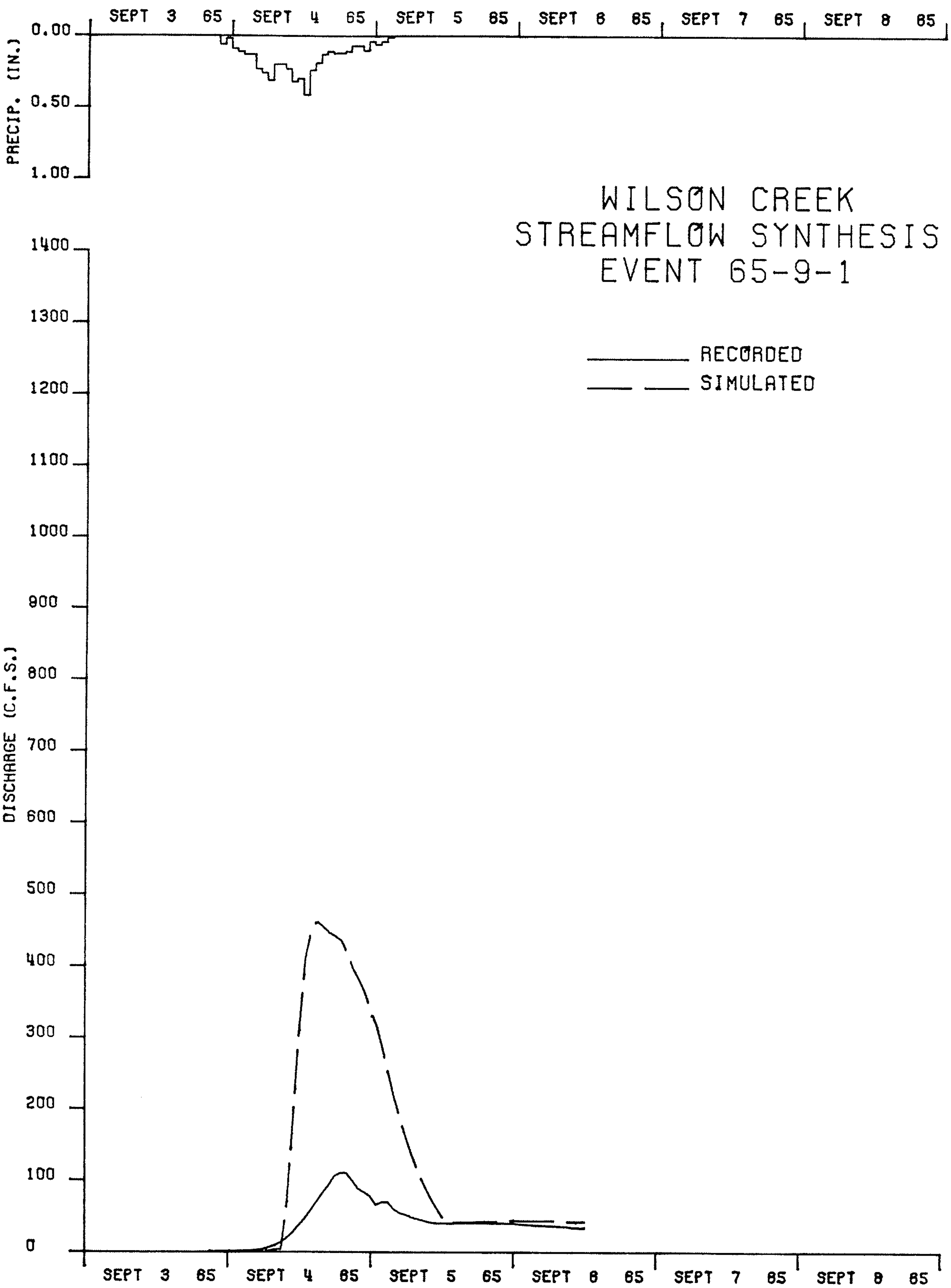
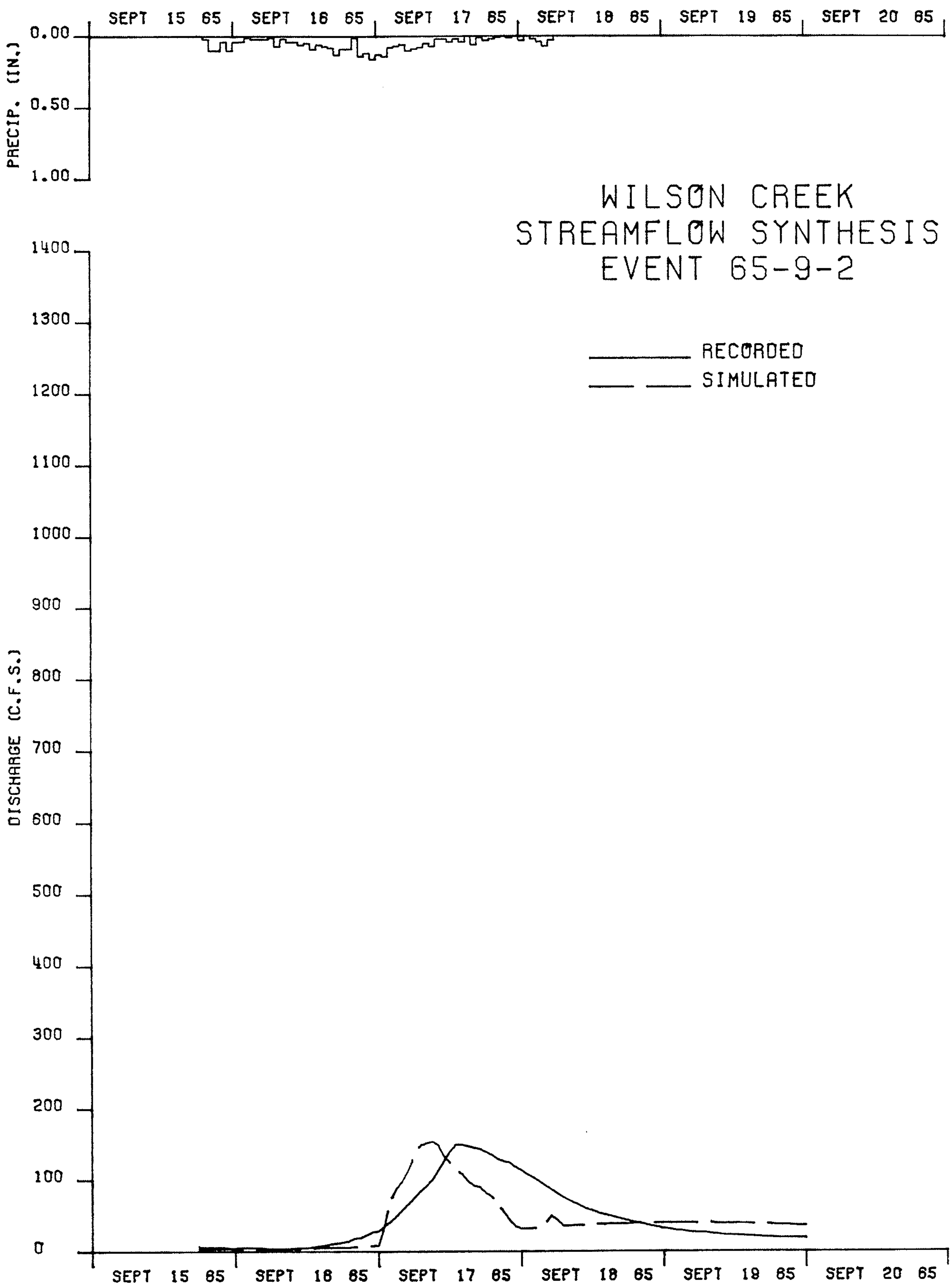

SEPT 3 65 SEPT 4 65 SEPT 5 65 SEPT 6 65 SEPT 7 65 SEPT 8 65
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 65-9-1
RECORDED
SIMULATED
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)
SEPT 3 65 SEPT 4 65 SEPT 5 65 SEPT 6 65 SEPT 7 65 SEPT 8 65

FIGURE 12



WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 65-9-2
RECORDED
SIMULATED
PRECIP. (IN.)
0.00
0.50
1.00
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
SEPT 15 65
SEPT 16 65
SEPT 17 65
SEPT 18 65
SEPT 19 65
SEPT 20 65

FIGURE 13

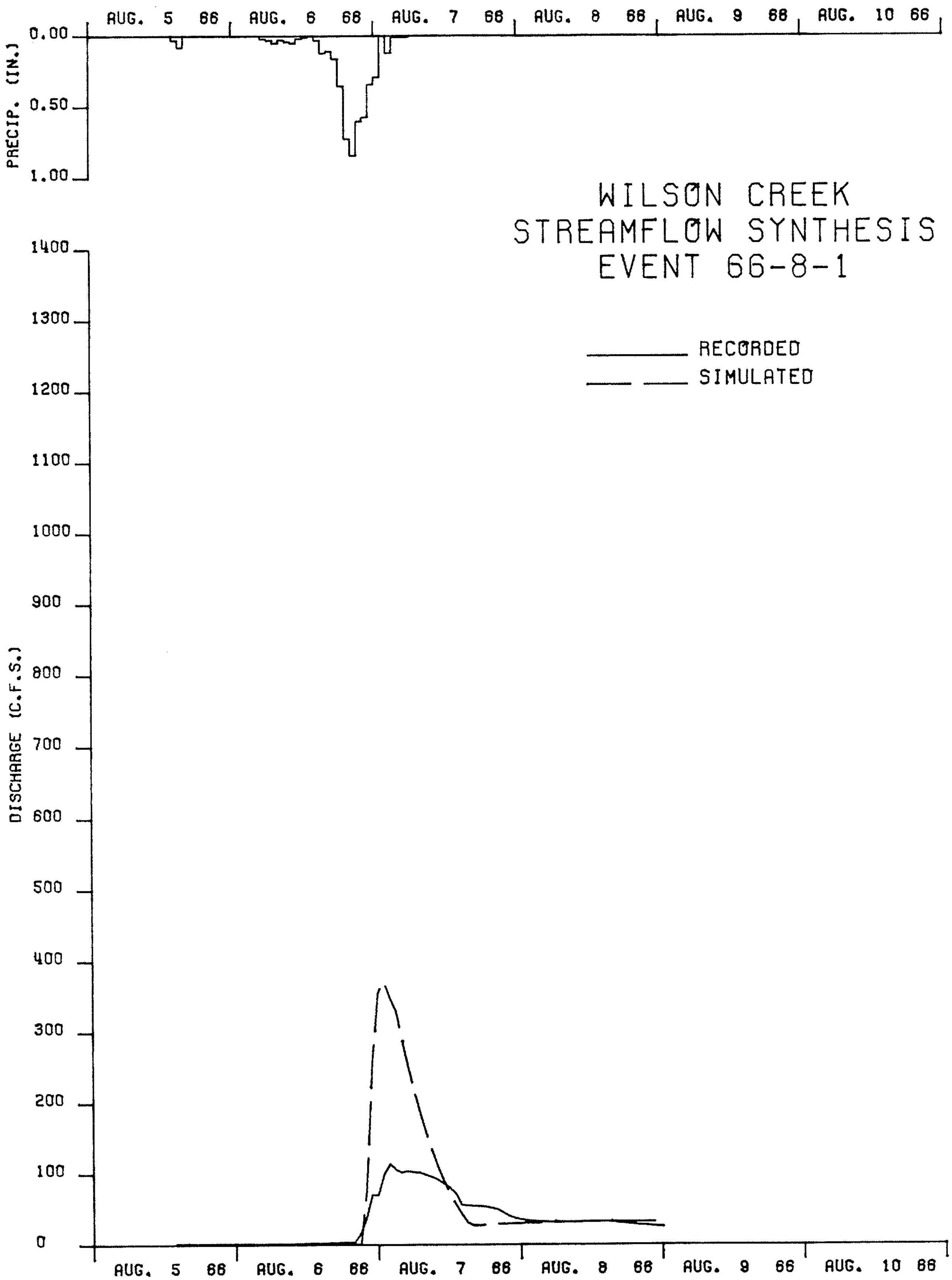

AUG. 5 66
AUG. 6 66
AUG. 7 66
AUG. 8 66
AUG. 9 66
AUG. 10 66
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 66-8-1
RECORDED
SIMULATED
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)

FIGURE 14

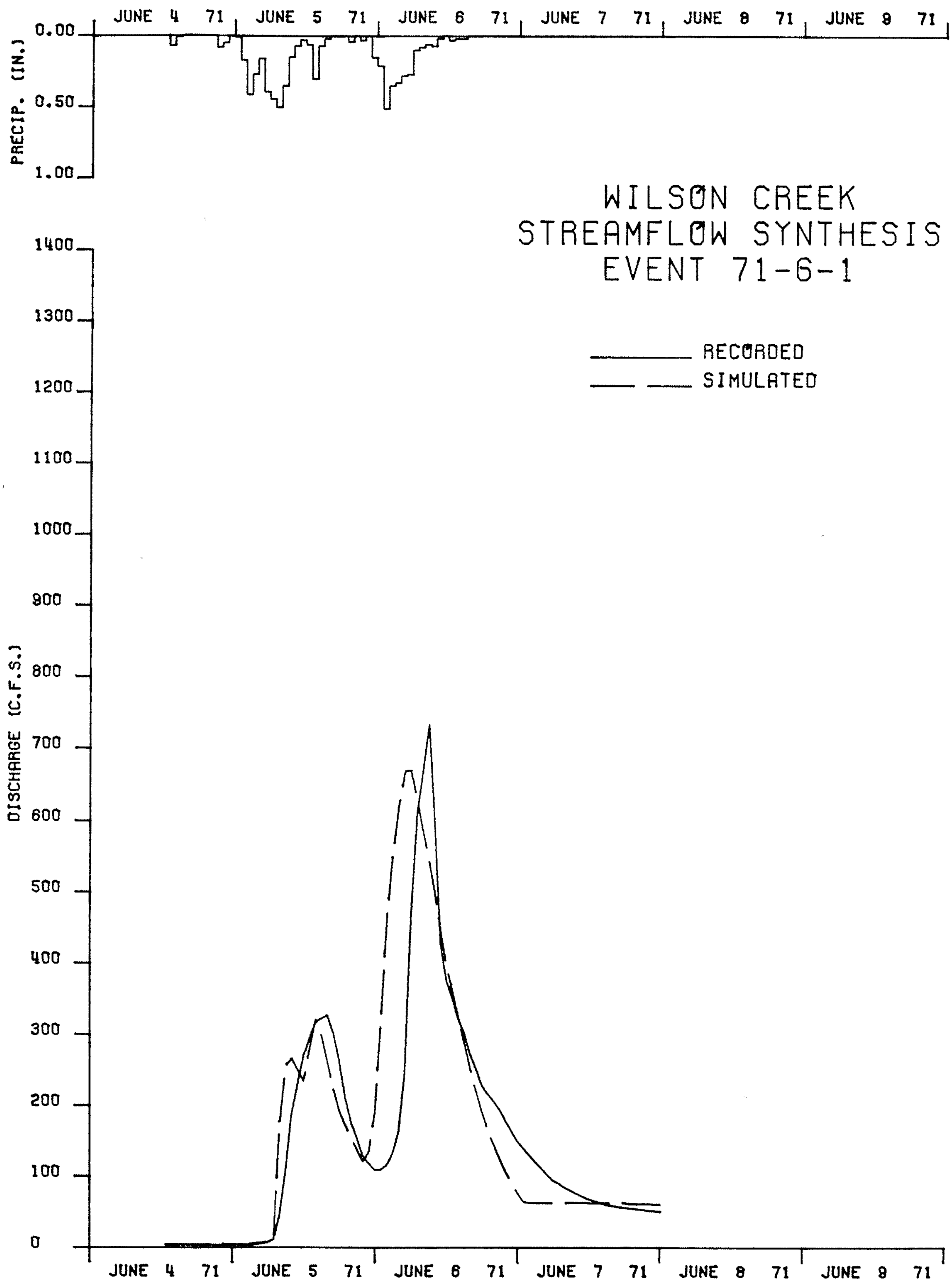

WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 71-6-1
RECORDED
SIMULATED
PRECIP. (IN.)
0.00
0.50
1.00
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
JUNE 4 71
JUNE 5 71
JUNE 6 71
JUNE 7 71
JUNE 8 71
JUNE 9 71

FIGURE 15

A P P E N D I X A

PATTERN SEARCH METHOD

PATTERN SEARCH METHOD

INTRODUCTION

The Direct Pattern Search Method has been employed in this study to optimize the model reservoir constants so as to minimize the objective function. The Pattern Search Method is part of a group of techniques which are titled "Direct Search Methods". The direct search does not rely on the evaluation of partial derivatives, but on the sequential examination of trial solutions. Each solution is compared with the best one obtained up to that time.

The Pattern Search Method was introduced in 1961 by Hooke and Jeeves (1). The Pattern Search is an easily programmed accelerating climbing technique with ridge-following properties.

The program used in this study has been obtained from the 1970 Graudate Thesis entitled "Computer Simulation Model of Wilson Creek Watershed" (2). The original program for the pattern search strategy was written by P.A. McDonald of the Department of Electrical Engineering of the University of Manitoba, in the Fortran IV language (the program in ALGOL can be found in references 4 and 5). This program was changed somewhat in 1970 by D. Alterman to accommodate the specific situation that occurs in the Wilson Creek Watershed. The following is a description of the Pattern Search Method Program as obtained from Appendix D of the 1970 thesis.

The general idea of the Pattern Search Method can be summarized in the following way. There is no sophisticated mathematical theory behind this method; it will be advisable to refer to the various references in order to gain a more detailed understanding of the method.

The program minimizes an objective function "F" subject to a set of variables, i.e. to find the minimum of $F(X_1, X_2, \ldots X_n)$. This task is achieved by changing the argument by trial and error until the minimum of the function "F" is obtained. To set the minimum in the most efficient way, it is necessary to establish a BASE POINT. The Base Point should be the closest point to the optimum known to the user. The Base Point is determined by assuming a set of values for the argument. The program will be explained with the aid of the following example and Figure A-1.

Assume a two-dimensional function where the Base Point is at $X_1 = 8$, $X_2 = 5$ and $F(X) = 138$. The problem now is what direction is to be taken from this point. We refer to a routine whose aim is to "Explore" the best direction for the movement. We call it E-routine. The argument will be re-defined and this function is F (t). We increase or decrease the co-ordinates by the value of a pre-given step length and evaluate the function each time. The change of co-ordinates is done with one variable at a time.

The move in the co-ordinate system is considered a "Success" if it decreases the value of F (t), or "Failure" if it does not decrease the value of F (t). Assume the step length is equal to 2. (See Diagram A-1). Therefore:

Step 1. $F(t_1 = 8+2,\ t_2 = 5) = 154$ Failure

Step 2. $F(t_1 = 8-2,\ t_2 = 5) = 137$ Success

Step 3. $F(t_1 = 6,\ t_2 = 5+2) = 126$ Success

This "set" of movement has determined the "Pattern". Now, the PATTERN MOVE has been determined. Every coefficient will change by a given amount:

$$t_i = 2\, t_i - X_i$$

(Remember that X_i is the Base Point co-ordinates and t_i is the exploration movement co-ordinates).

This Pattern Move set a temporary Base Point, while the permanent base point has been moved to the "Best" point found in the exploration routine.

<u>The Pattern Move</u>:

$$t_1 = 2 \times 6 - 8 = 4$$

$$t_2 = 2 \times 7 - 5 = 9$$

<u>The new Permanent Base Point</u>:

$$F\ (X_1 = 6,\ X_2 = 7) = 126$$

<u>The Temporary Base Point</u>:

$$F\ (t_1 = 4,\ t_2 = 9) = ?$$

It does not matter, in this stage, what is the functional value at the Temporary Base Point. We refer to the Exploration routine to find out where the next movement should be.

<u>CASE A</u>:

Assume that the functional value at the Temporary Base Point is given as the following:

$F\ (t_1 = 4,\ t_2 = 9) = 130$ i.e. No improvement over the Permanent Base Point.

<u>The Exploration Movement</u>:

Step 1. $F\ (t_1 = 4 - 2,\ t_2 = 9) = 193$ Failure

(We do start with $t_1 = 4 - 2$ because the reduction of this co-ordinate proved to be a success in the previous Exploration routine).

Step 2. $F(t_1 = 4+2,\ t_2 = 9) = 129.5$ Failure

Step 3. $F(t_1 = 6,\ t_2 = 9+2) = 120.0$ Success

This last step is point 6 in diagram A-1. Point 6 is "lower" than the Permanent Base Point. We therefore set it as the new Permanent Base Point. The new Temporary Base Point is determined as before.

<u>CASE B</u>:

$F(t_1 = 4,\ t_2 = 9) = 130$ Failure

Step 1. $F(t_1 = 4-2,\ t_2 = 9) = 193$ Failure

Step 2. $F(t_1 = 4+2,\ t_2 = 9) = 129.5$ Failure

Step 3. $F(t_1 = 6,\ t_2 = 9+2) = 128$ Failure

Point 6 is higher than the Permanent Base Point. The Temporary Base Point is not an improvement over the permanent one. Therefore, this movement is abandoned. We have to return to the Permanent Base Point and start the exploration again from there. If now, during this exploration routine we find a better point which determines a pattern move, we can then continue. But, if we again fail to find a better point we should decrease the step length (Δ) by a pre-given factor ρ. That is,

$$\Delta = \rho \times \Delta \qquad (\text{where } \rho < 1)$$

and we continue with the optimization, but with a smaller step length. This way the search is done in a more concentrated area.

It was found that working with six variables, the exploration routine would change one variable only. This change will sometimes produce only a slight improvement in the function. This result is not considered a satisfactory improvement. It must be considered as if no improvement has occurred. To avoid this type of development, two more constraints have been introduced.

a) J, which is an indication of the number of successful movements in the E - process.

b) DELTAFN - (delta function) - which is the value of a satisfactory improvement to the objective function. As the step length decreases DELTAFN should decrease by the same factor. So, if for example in the E - routine, only one variable has changed, J will be equal to one. If, for example, this change produced a value of F (t) = 122 and the previous Base Point was F (X) = 120, this will constitute a satisfactory improvement only if DELTAFN > 2. However, if DELTAFN $\leq$ 2 we regard this case as if no improvement has occurred.

The optimization will be terminated by one of these cases:

1. N, the number of function evaluations exceeds a pre-determined value. In this case, the output will fall under the title "CONVERGENCE = FALSE".
2. The step length size is less than the predetermined value LAMBDA. In this case the output will fall under the title "CONVERGENCE = TRUE".

<u>The Computer Program</u>:

The Pattern Search Program consists of two subroutines:

1. Subroutine HJMIN
2. Subroutine E

The latter is the Exploration routine.

<u>Variable Names</u>:

K or NV	Number of co-ordinate Variables.
RHO	Reduction factor for step size.

LAMBDA	"Minimum" step length.
SL	Initial step length.
DELTA	Current step size.
H	The functional value before a move is being taken.
SPHI	F (t), the functional value for a move.
SPSI	F (X), the functional value at the Permanent Base Point.
PHI (i)	t, the point resulting from the current move.
PSI (i)	X, the correct Permanent Base Point.
THETA	The previous Permanent Base Point.
CONV.	The logical variable which is true if successful convergence is obtained and false otherwise.
LIMIT	Maximum number of function evaluations to be permitted.
VALUE	Name of a user supplied function sub-program which evaluates the objective function .

Program Use Procedure:

In the MAIN Program there should be the following declaration statements:

```
LOGICAL     CONV
REAL        LAMBDA
DIMENSION   X(k) (k is the number of variables)
EXTERNAL    F
DATA        X/0.1,0.1, ..../,SL,RHO,LAMBDA/.1,.5,1.E-2/
```

To optimize the function HJMIN, it should be called in the following manner:

```
CALL HJMIN(X,NV,Z,SL,RHO,LAMBDA,150,CONV.,TRUE.,F)
```

The function to be optimized is to be given in a Function Subroutine.

A listing of the main program and sub-routines, for minimization of the objective function $F(X) = 100 (X_2 - X_1)^2 + (1 - X_1)^2$ is shown on Pages 66 to 71 inclusive.

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1. R. Hooke and T.A. Jeeves, Direct Search Solution of Numerical and Statistical Problems, J.ACM, Vol. 8, pp. 212-229, April 1961.

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3. D.J. Wilde and C.S. Beightler, Foundation of Optimization. Englewood Cliffs, N.J.: Prentice-Hall, 1967.

4. A.F. Kaupe, Jr., Algorithm 178: Direct Search, Commun. ACM, Vol. 6, pp. 313-314, June 1963.

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6. J.W. Bandler, Optimization Methods for Computer Aided Design, IEEE Transactions on Microwave Theory and Techniques, V MTT-17, No. 8, pp. 543-544, August 1969.

7. P.A. MacDonald, Locating the Minimum of Function by Pattern Search, Numerical Application Group, Department of Electrical Engineering, University of Manitoba, April 1969.

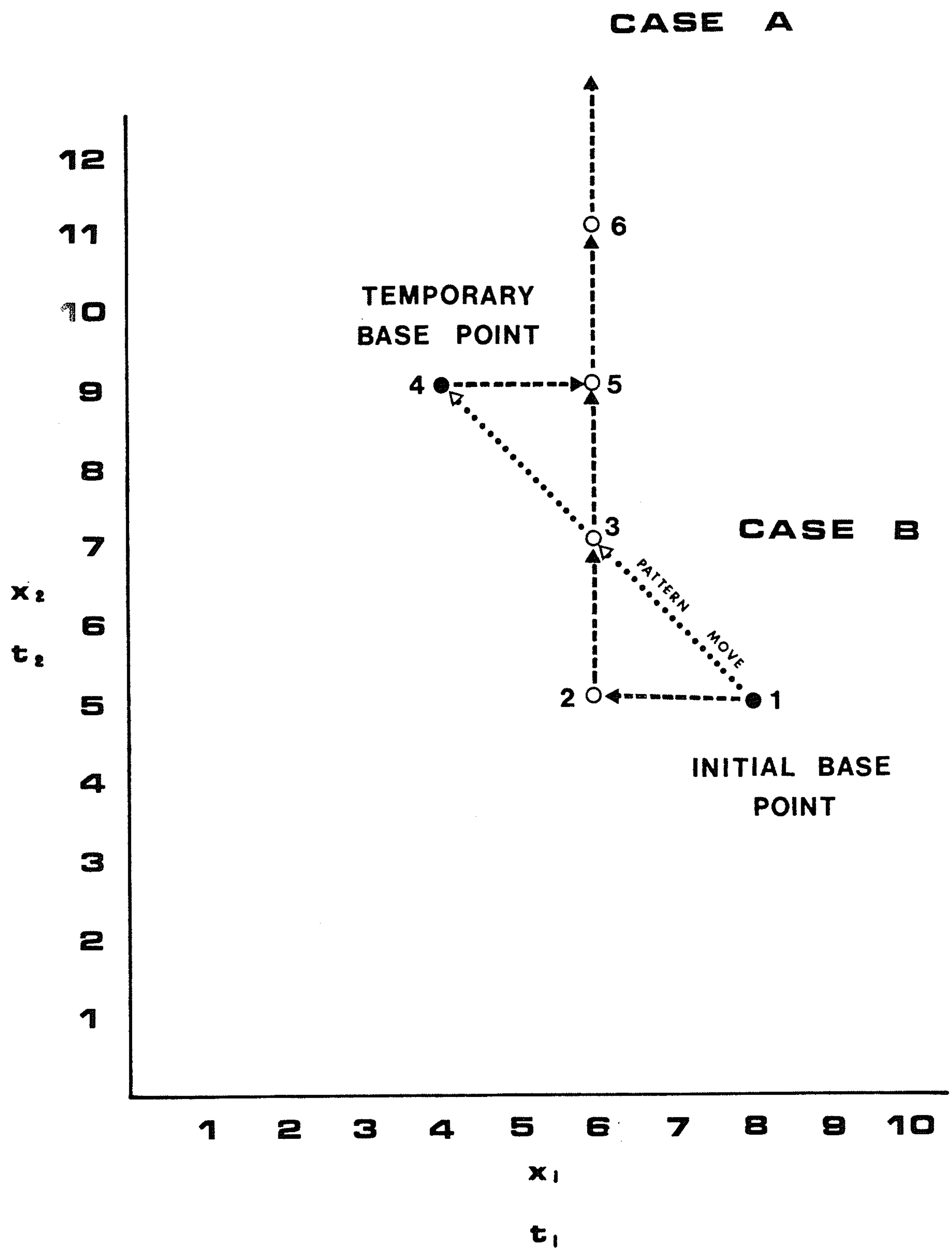

CASE A
CASE B
TEMPORARY BASE POINT
INITIAL BASE POINT
PATTERN MOVE
1
2
3
4
5
6
12
11
10
9
8
7
6
5
4
3
2
1
x_2
t_2
1 2 3 4 5 6 7 8 9 10
x_1
t_1

FIGURE A-1

REQUESTED OPTIONS: XREF

OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF TERM IBM FLAG(I)

```
                C      SAMPLE: MAIN PROGRAM TO ILLUSTRATE USE OF SUBPROGRAM HJMIN
ISN 0002               LOGICAL CONV
ISN 0003               REAL LAMBDA
ISN 0004               DIMENSION X(4)
ISN 0005               K=2
ISN 0006               DATA X/10.,10.,10.,10./,SL,RHO,LAMBDA/5.,.1,1.E-4/
ISN 0007               WRITE(6,10) SL,RHO,LAMBDA
ISN 0008            10 FORMAT(' INITIAL STEP LENGTH = ',F10.3/' REDUCTION FACTOR =     ',F
                      &10.3/' MINIMUM STEP LENGTH = ',F10.4///)
ISN 0009               WRITE(6,15)
ISN 0010            15 FORMAT('  BASE',8X,'X1',8X,'X2',6X,'F(X)',6X,'STEP LENGTH',/,' POI
                      &NT',35X,'X1',8X,'X2',/)
ISN 0011               CALL HJMIN(X,K,Z,SL,RHO,LAMBDA,250,CONV)
ISN 0012               WRITE(6,20)
ISN 0013            20 FORMAT ('X='6F10.3)
ISN 0014               WRITE(6,30) Z,CONV
ISN 0015            30 FORMAT (' F(X)= 'F13.6,5X,'CONVERGENCE= 'L2)
ISN 0016               STOP
ISN 0017               END
```

```
LEVEL 2.3.0 (JUNE 78)                    OS/360  FORTRAN H EXTENDED              DATE 79.291/13.11.15        PAGE   1
REQUESTED OPTIONS: XREF
OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF TERM IBM FLAG(I)
                  C      SAMPLE FUNCTION SUBPROGRAM
   ISN 0002              FUNCTION F(X)
   ISN 0003              REAL X(4)
   ISN 0004              F=100*(X(2)-X(1))**2+(1-X(1))**2
   ISN 0005              RETURN
   ISN 0006              END
```

```
REQUESTED OPTIONS: XREF

OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF TERM IBM FLAG(I)

  ISN 0002              SUBROUTINE HJMIN(PSI, K, SPSI, SL, RHO, LAMBDA, LIMIT, CONV)
                  C----
                  C---- THIS IS AN OPTIMIZATION PROGRAM BASED ON THE PATTERN SEARCH
                  C---- METHOD OF HOOKE AND JEEVES.
                  C---- SEE D.J.WILDE AND C.S.BEIGHTLER, FOUNDATIONS OF OPTIMIZATION.
                  C---- ENGLEWOOD CLIFFS, N.J. : PRENTICE-HALL,1967
                  C---- THIS 'DIMENSION' DECLARATION IS FOR 4 VARIABLES .
                  C
                  C           VARIABLES
                  C           ---------
                  C
                  C     NAME             DESCRIPTION
                  C
                  C     K OR V         NUMBER OF VARIABLES BEING OPTIMIZED
                  C     RHO            REDUCTION FACTOR FOR STEP LENGTH
                  C     LAMBDA         MINIMUM STEP LENGTH
                  C     SL             INITIAL STEP LENGTH
                  C     DELTA          CURRENT STEP LENGTH
                  C     H              FUNCTIONAL VALUE BEFORE A MOVE IS BEING TAKEN
                  C     SPHI           FUNCTIONAL VALUE FOR A MOVE
                  C     SPSI           FUNCTIONAL VALUE AT THE PERMANENT BASE POINT
                  C     PHI(I)         POINT RESULTING FROM THE CURRENT MOVE
                  C     PSI(I)         CURRENT PERMANENT BASE POINT
                  C     THETA          PREVIOUS PERMANENT BASE POINT
                  C     CONV.          A LOGICAL VARIABLE WHICH IS TRUE IF SUCCESSFUL
                  C                    CONVERGENCE IS OBTAINED AND FALSE OTHERWISE
                  C     LIMIT          MAXIMUM NUMBER OF FUNCTION EVALUATIONS PERMITTED
                  C     VALUE          SUBPROGRAM WHICH EVALUATES THE OBJECTIVE FUNCTION
                  C
  ISN 0003              DIMENSION PSI(4), PHI(4), S(4), X(4)
  ISN 0004              REAL LAMBDA
  ISN 0005              LOGICAL CONV
  ISN 0006              COMMON / LOCAL / M, N, H, PHI, S, J
  ISN 0007              DLTAFN = 0.0001
  ISN 0008              M = K
  ISN 0009              DELTA = SL
  ISN 0010              DO 10 I = 1, K
  ISN 0011           10 S(I) = DELTA
                  C---- EVALUATE FUNCTION AT INITIAL BASE POINT
                  C
  ISN 0012              SPSI = F(PSI)
  ISN 0013              N = 1
  ISN 0014           20 H = SPSI
  ISN 0015              DO 30 I = 1, K
  ISN 0016           30 PHI(I) = PSI(I)
                  C---- MAKE EXPLORATORY MOVES
                  C
  ISN 0017              CALL E
                  C
  ISN 0018              IF (N .GT. LIMIT) GO TO 90
                  C---- PRESENT FUNCTIONAL VALUE BELOW THAT AT BASE POINT?
                  C
  ISN 0020              IF (H .GE. SPSI .OR. J .EQ. 1 .AND. (SPSI - H) .LT. DLTAFN) GO TO
                       X70
```

```
ISN 0022          40 DO 50 I = 1, K
ISN 0023             IF (PHI(I) .GT. PSI(I) .AND. S(I) .LT. 0. .OR. PHI(I) .LE. PSI(I)
                    X.AND. S(I) .GE. 0.) S(I) = - S(I)
                C---- SET NEW BASE POINT AND MAKE PATTERN MOVE
                C
ISN 0025             THETA = PSI(I)
ISN 0026             PSI(I) = PHI(I)
ISN 0027             PHI(I) = 2. * PHI(I) - THETA
                C----  THIS IS A CONSTRAINT.  CHANGE ACCORDING TO YOUR NEEDS.
ISN 0028          50 IF (PHI(I) .LE. 1.) PHI(I) = PSI(I)
ISN 0030             SPSI = H
ISN 0031             SPHI = F(PHI)
ISN 0032             N = N + 1
ISN 0033             IF (N .GT. LIMIT) GO TO 90
ISN 0035             H = SPHI
                C---- MAKE EXPLORATORY MOVES
                C
ISN 0036             CALL E
                C
ISN 0037             IF (N .GT. LIMIT) GO TO 90
                C---- IS PRESENT FUNCTIONAL VALUE BELOW THAT OF BASE POINT?
                C
ISN 0039             IF (J .EQ. 1 .AND. (SPSI - H) .LT. DLTAFN .AND. (SPSI - H) .GT. 0.
                    X) GO TO 70
ISN 0041             IF (H .GE. SPSI) GO TO 20
ISN 0043             DO 60 I = 1, K
ISN 0044             IF (ABS(PHI(I) - PSI(I)) .GT. 0.5 * DELTA) GO TO 40
ISN 0046          60 CONTINUE
                C---- IS STEP SIZE SMALL ENOUGH?
                C
ISN 0047          70 IF (DELTA .LT. LAMBDA) GO TO 130
                C---- DECREASE STEP SIZE
                C
ISN 0049             DELTA = RHO * DELTA
ISN 0050             DO 80 I = 1, K
ISN 0051          80 S(I) = RHO * S(I)
ISN 0052             DLTAFN = RHO * DLTAFN
ISN 0053             GO TO 20
ISN 0054          90 CONV = .FALSE.
ISN 0055             IF (H .GE. SPSI) GO TO 110
ISN 0057             SPSI = H
ISN 0058             DO 100 L = 1, K
ISN 0059         100 PSI(L) = PHI(L)
ISN 0060         110 CONTINUE
ISN 0061             WRITE (6,120) N
ISN 0062         120 FORMAT (6X,20H NO CONCLUSION AFTER,I4,21H FUNCTION EVALUATIONS)
ISN 0063             RETURN
                C
ISN 0064         130 CONV = .TRUE.
ISN 0065             WRITE (6,140) N
ISN 0066         140 FORMAT (6X,24H CONVERGENCE OBTAINED IN,I4,23H FUNCTIONAL EVALUATIO
                    &NS)
ISN 0067             RETURN
                C
ISN 0068             END
```

```
LEVEL 2.3.0 (JUNE 78)                OS/360  FORTRAN H EXTENDED              DATE 79.291/13.11.22          PAGE   1
REQUESTED OPTIONS: XREF
OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF TERM IBM FLAG(I)
                  C
  ISN 0002              SUBROUTINE E
                  C---- MAKE EXPLORATORY MOVES ABOUT A GIVEN POINT
                  C
  ISN 0003              REAL PHI(4),S(4)
  ISN 0004              COMMON / LOCAL / K, N, H, PHI, S, J
                  C---- INCREASE COORDINATE
                  C
  ISN 0005              J = 0
  ISN 0006              DO 60 I = 1, K
  ISN 0007              PHI(I) = PHI(I) + S(I)
                  C---- THIS IS A CONSTRAINT.  CHANGE ACCORDING TO YOUR NEEDS.
  ISN 0008              IF (PHI(I) .LE. 0.) GO TO 20
  ISN 0010              SPHI = F(PHI)
  ISN 0011              N = N + 1
                  C---- SUCCESSFUL MOVE?
                  C
  ISN 0012              IF (SPHI .LT. H) GO TO 40
                  C---- DECREASE COORDINATE
                  C
  ISN 0014           20 S(I) = - S(I)
  ISN 0015              PHI(I) = PHI(I) + 2. * S(I)
                  C---- THIS IS A CONSTRAINT.  CHANGE ACCORDING TO YOUR NEEDS.
  ISN 0016              IF (PHI(I) .LE. 0.) GO TO 30
  ISN 0018              SPHI = F(PHI)
  ISN 0019              N = N + 1
                  C---- SUCCESSFUL MOVE?
                  C
  ISN 0020              IF (SPHI .LT. H) GO TO 40
                  C---- RESET COORDINATE
                  C
  ISN 0022           30 PHI(I) = PHI(I) - S(I)
  ISN 0023              GO TO 60
                  C---- RETAIN NEW COORDINATE AND FUNCTIONAL VALUE
                  C
  ISN 0024           40 CONTINUE
  ISN 0025              H = SPHI
  ISN 0026              J = J + 1
  ISN 0027           60 CONTINUE
  ISN 0028           71 WRITE(6,81) N,(PHI(I),I=1,K),H,(S(I),I=1,K)
  ISN 0029           81 FORMAT(1X,I5,8F10.4)
  ISN 0030              RETURN
  ISN 0031              END
```

INITIAL STEP LENGTH = 5.000
REDUCTION FACTOR = 0.100
MINIMUM STEP LENGTH = 0.0001

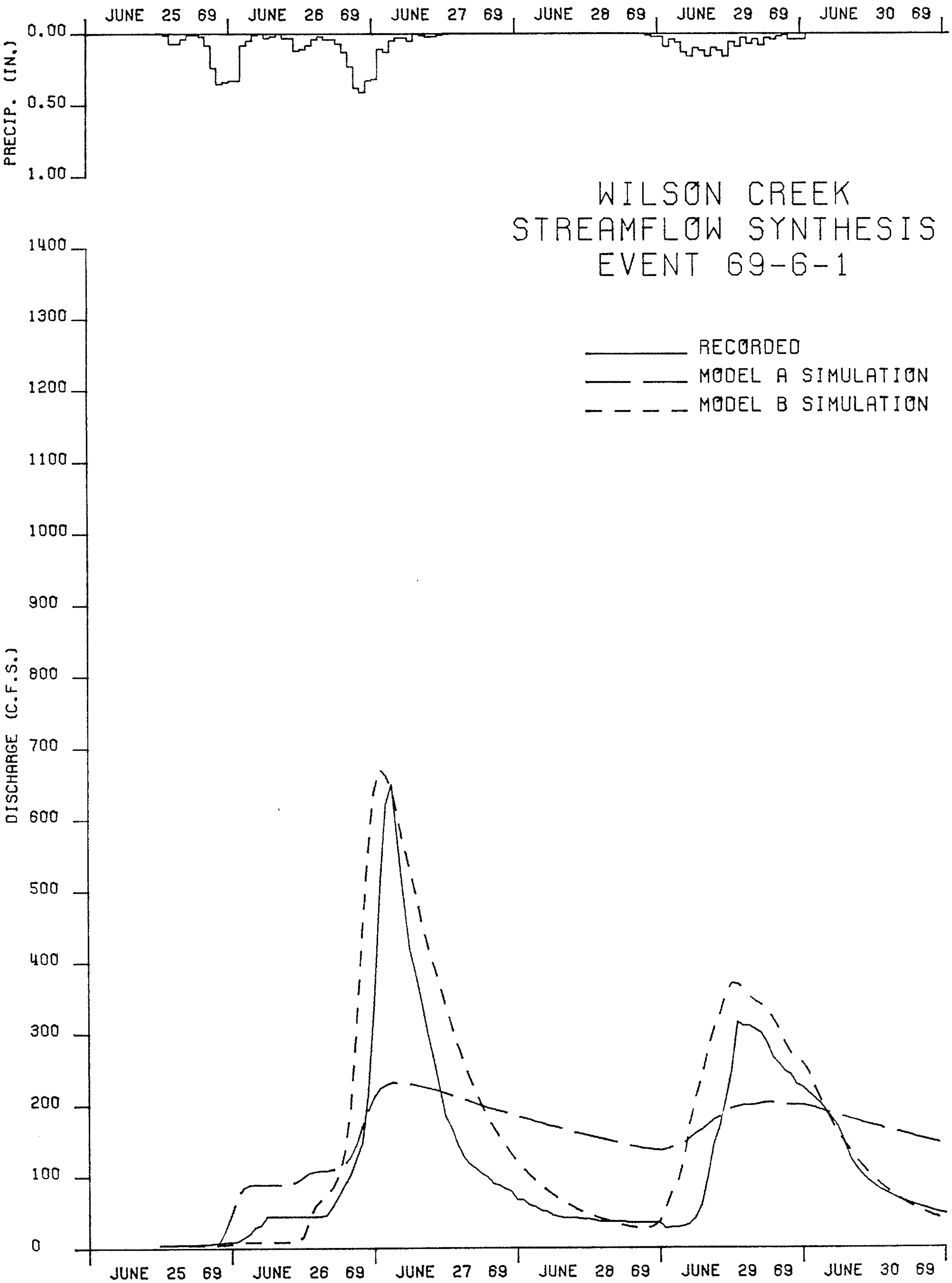
BASE POINT	X1	X2	F(X)	STEP LENGTH X1	STEP LENGTH X2
5	10.0000	10.0000	81.0000	-5.0000	-5.0000
9	10.0000	10.0000	81.0000	0.5000	0.5000
13	9.9500	9.9500	80.1025	-0.0500	-0.0500
16	9.8500	9.8500	78.3224	-0.0500	-0.0500
19	9.7000	9.7000	75.6897	-0.0500	-0.0500
22	9.5000	9.5000	72.2495	-0.0500	-0.0500
25	9.2500	9.2500	68.0618	-0.0500	-0.0500
28	8.9499	8.9499	63.2015	-0.0500	-0.0500
31	8.5999	8.5999	57.7587	-0.0500	-0.0500
34	8.1999	8.1999	51.8384	-0.0500	-0.0500
37	7.7499	7.7499	45.5607	-0.0500	-0.0500
40	7.2498	7.2498	39.0605	-0.0500	-0.0500
43	6.6998	6.6998	32.4879	-0.0500	-0.0500
46	6.0998	6.0998	26.0078	-0.0500	-0.0500
49	5.4498	5.4498	19.8004	-0.0500	-0.0500
52	4.7497	4.7497	14.0605	-0.0500	-0.0500
55	3.9997	3.9997	8.9982	-0.0500	-0.0500
60	3.2497	3.2497	5.0611	0.0500	0.0500
65	2.4997	2.4997	2.2490	0.0500	0.0500
70	1.7496	1.7496	0.5619	0.0500	0.0500
75	1.7496	1.7496	0.5619	0.0500	0.0500
79	1.7446	1.7446	0.5545	-0.0050	-0.0050
82	1.7346	1.7346	0.5397	-0.0050	-0.0050
85	1.7196	1.7196	0.5178	-0.0050	-0.0050
88	1.6996	1.6996	0.4895	-0.0050	-0.0050
91	1.6746	1.6746	0.4551	-0.0050	-0.0050
94	1.6446	1.6446	0.4155	-0.0050	-0.0050
97	1.6096	1.6096	0.3716	-0.0050	-0.0050
100	1.5696	1.5696	0.3245	-0.0050	-0.0050
103	1.5246	1.5246	0.2752	-0.0050	-0.0050
106	1.4746	1.4746	0.2253	-0.0050	-0.0050
109	1.4196	1.4196	0.1761	-0.0050	-0.0050
112	1.3596	1.3596	0.1293	-0.0050	-0.0050
115	1.2946	1.2946	0.0868	-0.0050	-0.0050
120	1.2296	1.2296	0.0527	0.0050	0.0050
125	1.1646	1.1646	0.0271	0.0050	0.0050
130	1.0996	1.0996	0.0099	0.0050	0.0050
135	1.0346	1.0346	0.0012	0.0050	0.0050
140	1.0346	1.0346	0.0012	0.0050	0.0050
144	1.0341	1.0341	0.0012	-0.0005	-0.0005
147	1.0331	1.0331	0.0011	-0.0005	-0.0005
150	1.0316	1.0316	0.0010	-0.0005	-0.0005
153	1.0296	1.0296	0.0009	-0.0005	-0.0005
156	1.0271	1.0271	0.0007	-0.0005	-0.0005
161	1.0246	1.0246	0.0006	0.0005	0.0005
166	1.0221	1.0221	0.0005	0.0005	0.0005
171	1.0195	1.0195	0.0004	0.0005	0.0005
176	1.0170	1.0170	0.0003	0.0005	0.0005
181	1.0145	1.0145	0.0002	0.0005	0.0005
186	1.0120	1.0120	0.0001	0.0005	0.0005
191	1.0095	1.0095	0.0001	0.0005	0.0005
196	1.0070	1.0070	0.0000	0.0005	0.0005
201	1.0045	1.0045	0.0000	0.0005	0.0005
206	1.0019	1.0019	0.0000	0.0005	0.0005
211	1.0019	1.0019	0.0000	0.0005	0.0005
215	1.0019	1.0019	0.0000	-0.0001	-0.0001

CONVERGENCE OBTAINED IN 215 FUNCTIONAL EVALUATIONS

$\bar{\bar{F}}(X)$= 0.000004 CONVERGENCE= T

A P P E N D I X B

SIMULATED HYDROGRAPHS



JUNE 25 69
JUNE 26 69
JUNE 27 69
JUNE 28 69
JUNE 29 69
JUNE 30 69
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 69-6-1
RECORDED
MODEL A SIMULATION
MODEL B SIMULATION
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)

FIGURE B-1

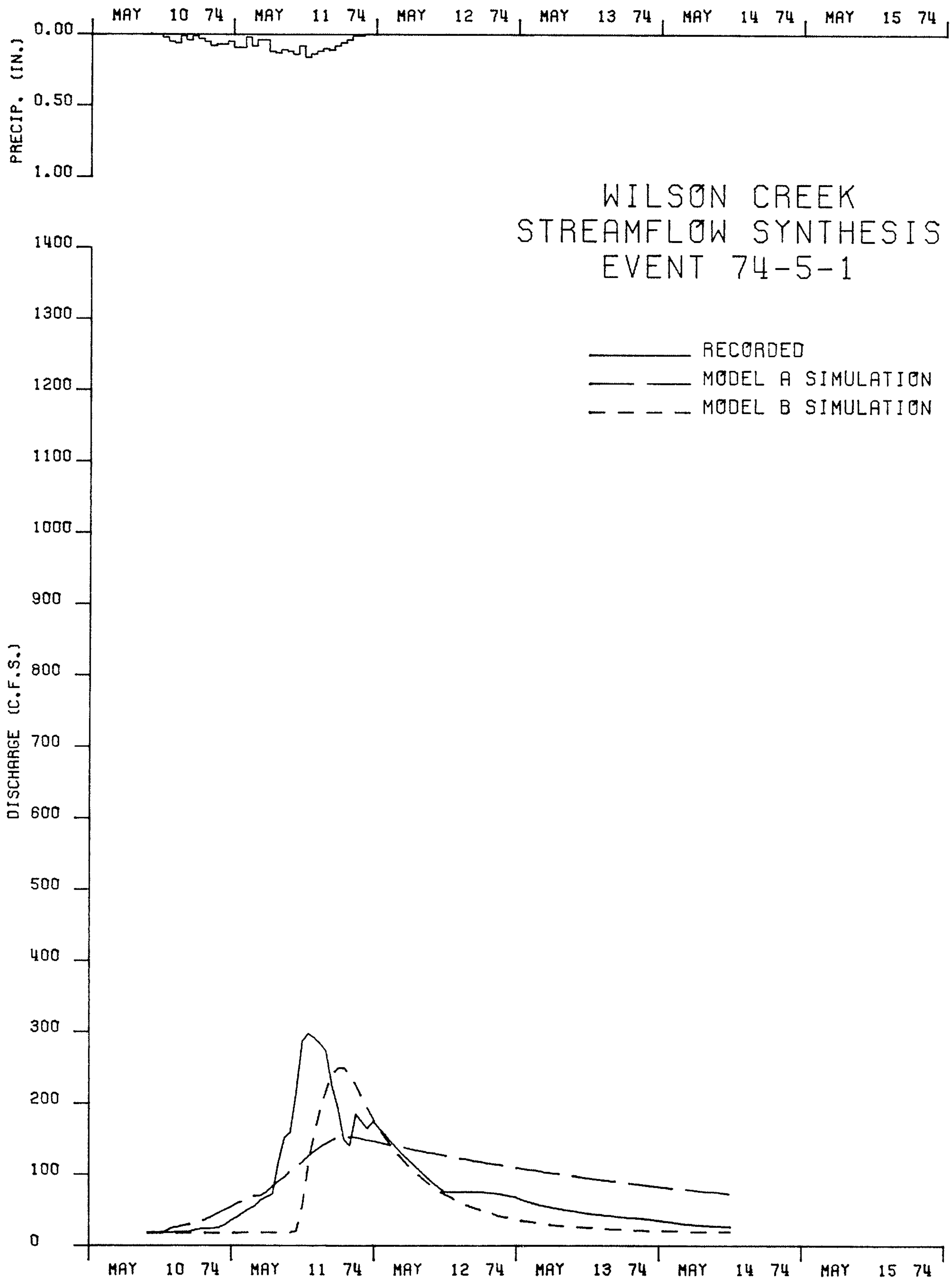
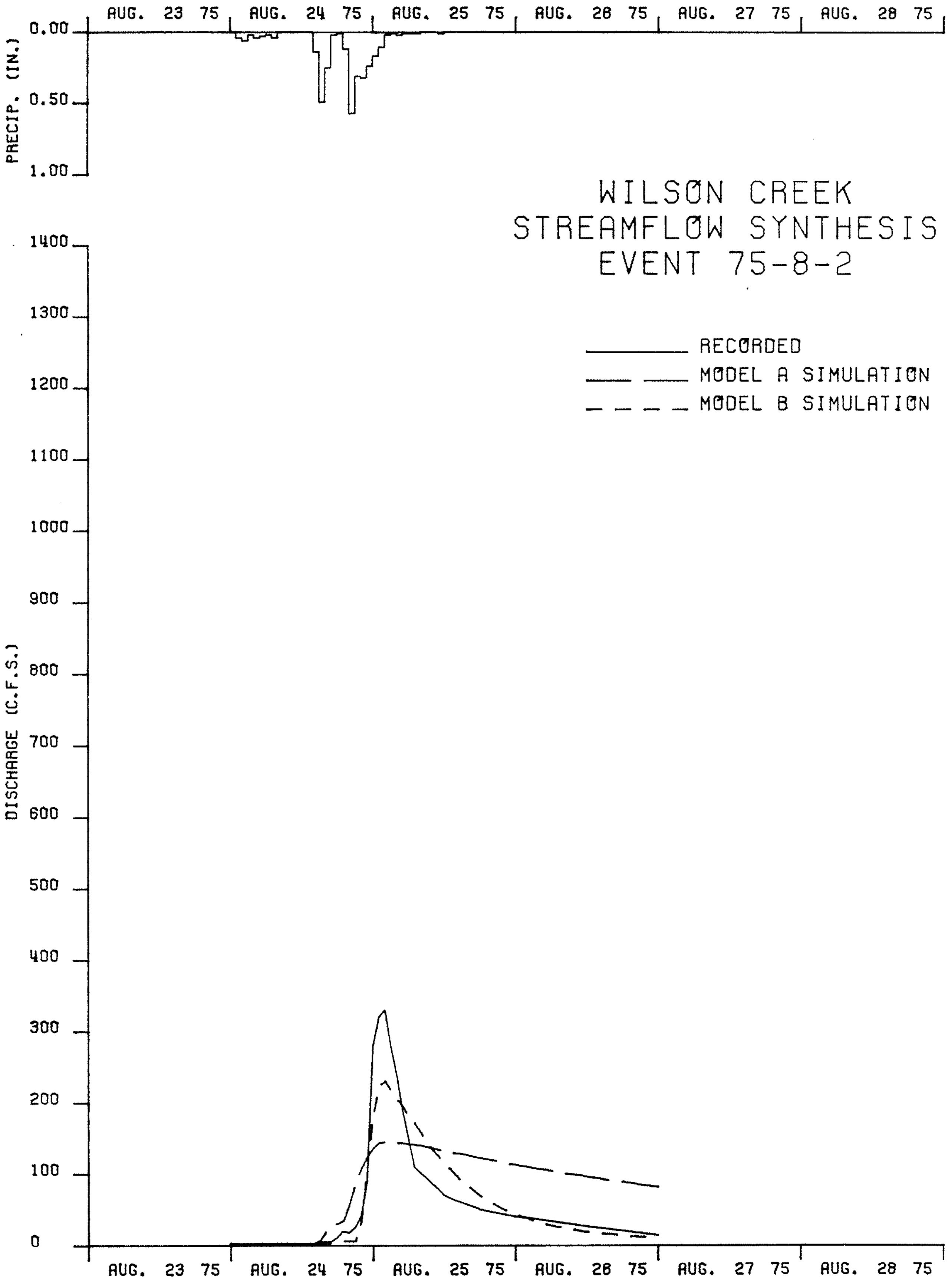
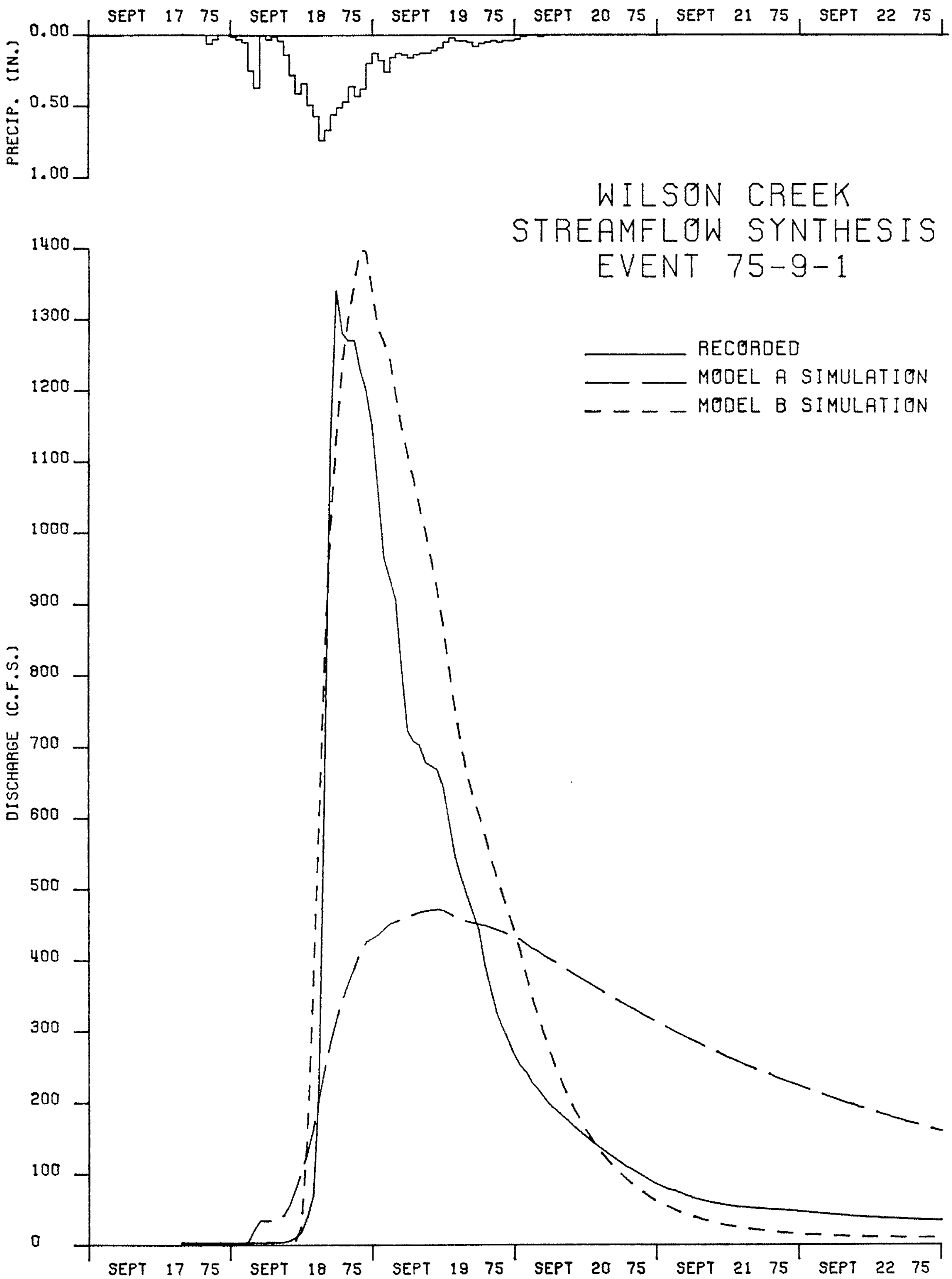

MAY 10 74
MAY 11 74
MAY 12 74
MAY 13 74
MAY 14 74
MAY 15 74
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 74-5-1
RECORDED
MODEL A SIMULATION
MODEL B SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-2



AUG. 23 75
AUG. 24 75
AUG. 25 75
AUG. 26 75
AUG. 27 75
AUG. 28 75
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-8-2
RECORDED
MODEL A SIMULATION
MODEL B SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-3



SEPT 17 75
SEPT 18 75
SEPT 19 75
SEPT 20 75
SEPT 21 75
SEPT 22 75
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-9-1
RECORDED
MODEL A SIMULATION
MODEL B SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-4

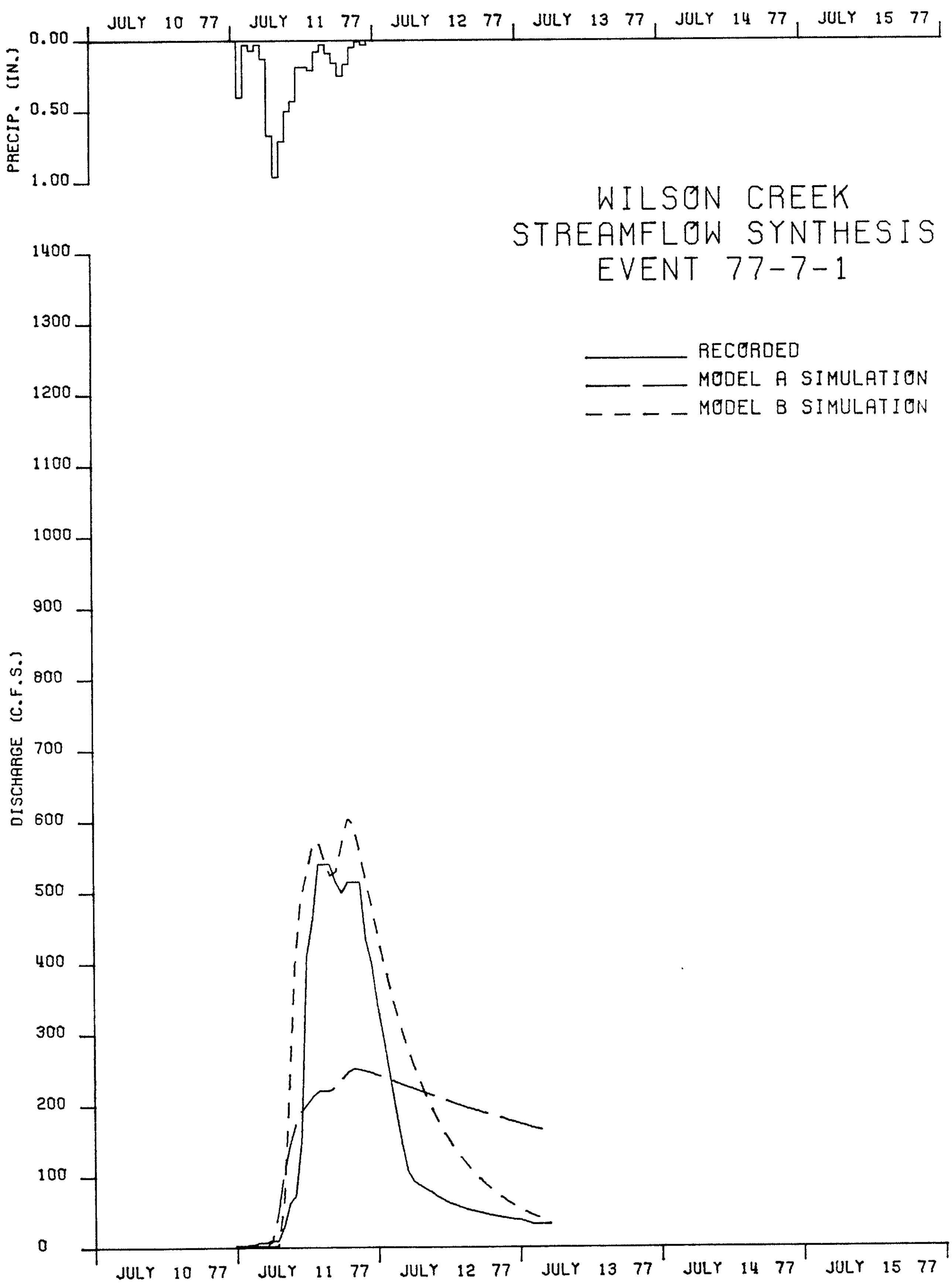
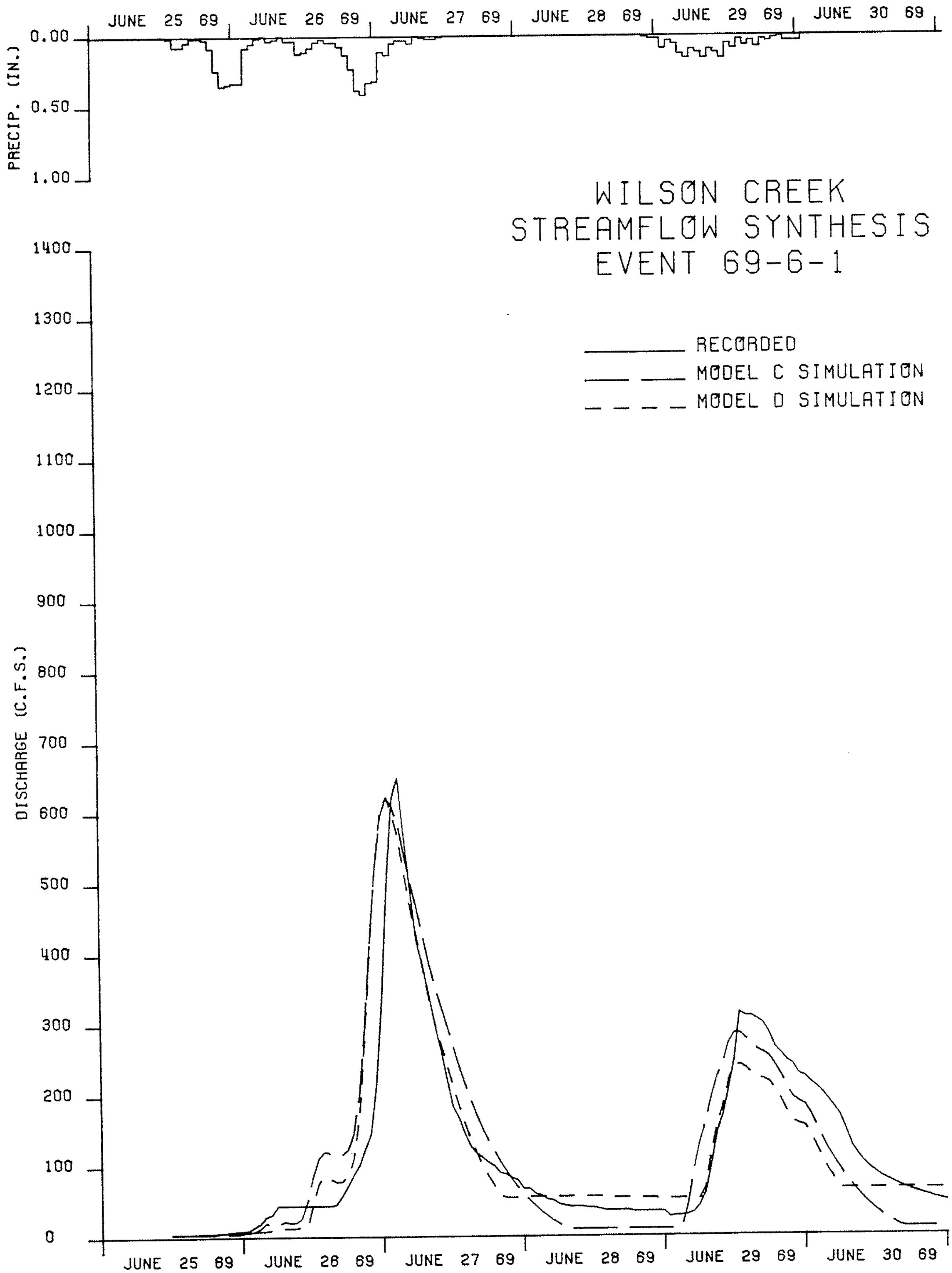

JULY 10 77
JULY 11 77
JULY 12 77
JULY 13 77
JULY 14 77
JULY 15 77
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 77-7-1
RECORDED
MODEL A SIMULATION
MODEL B SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
JULY 10 77
JULY 11 77
JULY 12 77
JULY 13 77
JULY 14 77
JULY 15 77

FIGURE B-5



JUNE 25 69
JUNE 26 69
JUNE 27 69
JUNE 28 69
JUNE 29 69
JUNE 30 69
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 69-6-1
RECORDED
MODEL C SIMULATION
MODEL D SIMULATION
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)
JUNE 25 69
JUNE 26 69
JUNE 27 69
JUNE 28 69
JUNE 29 69
JUNE 30 69

FIGURE B-6

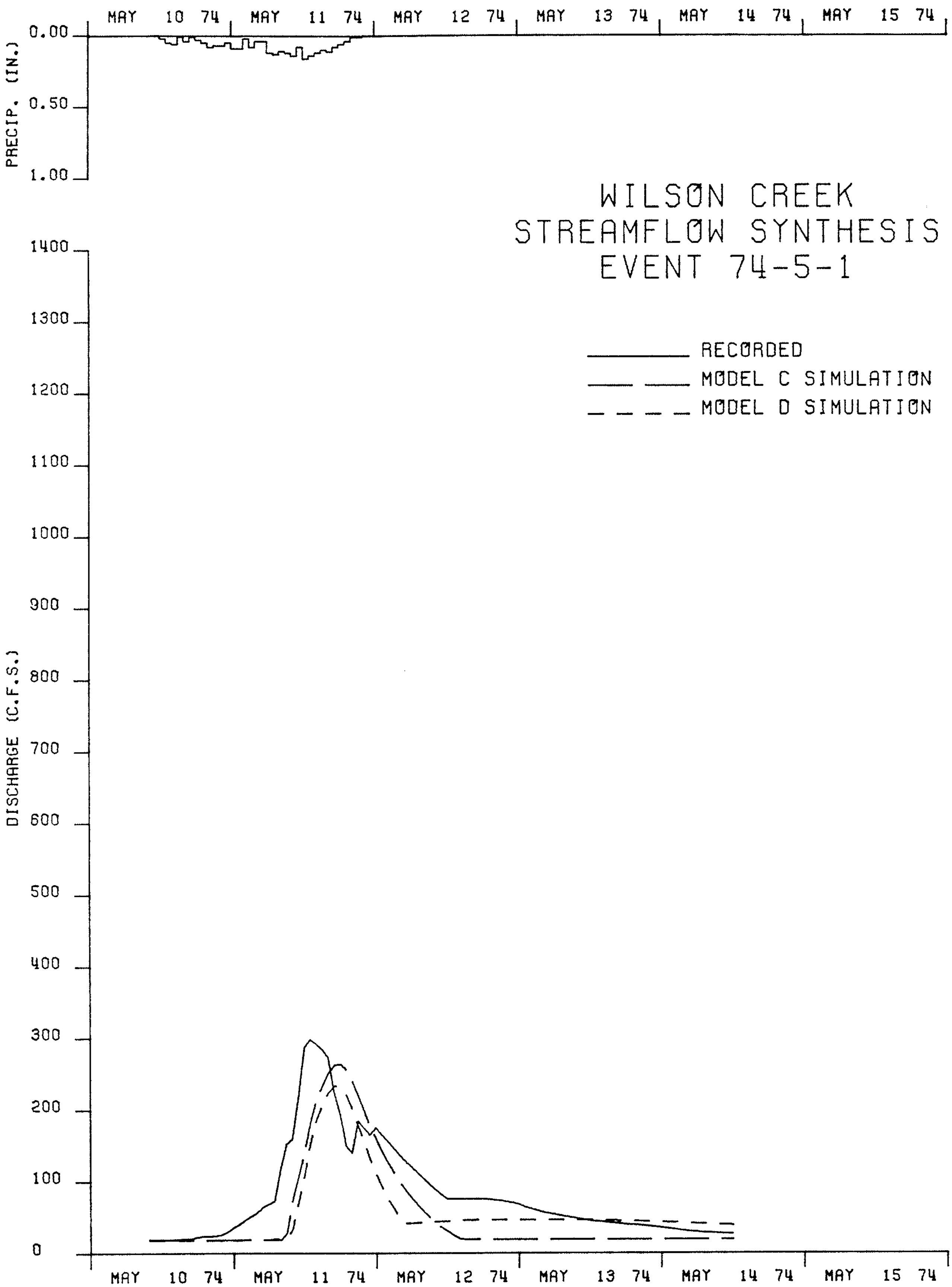
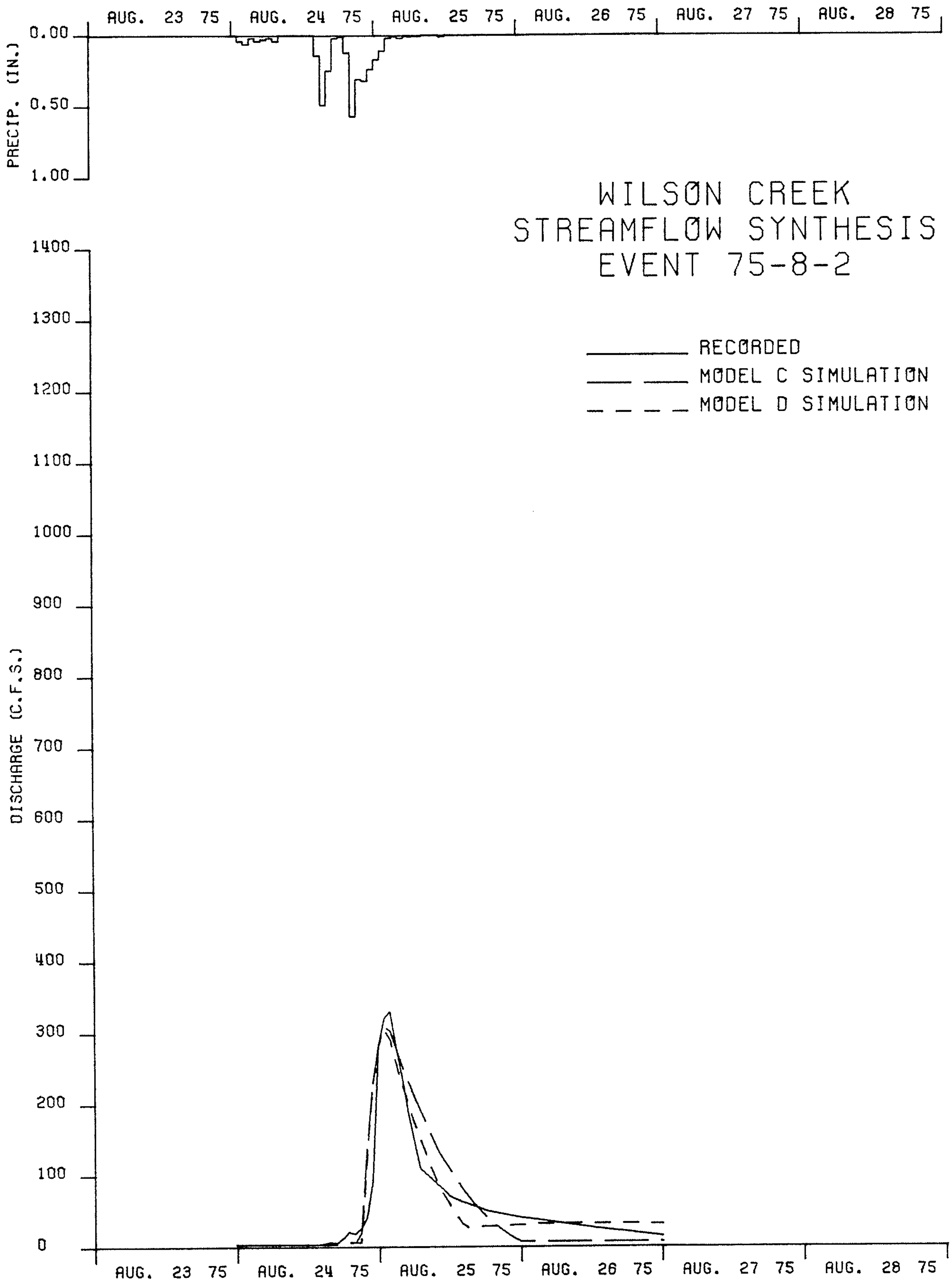

MAY 10 74
MAY 11 74
MAY 12 74
MAY 13 74
MAY 14 74
MAY 15 74
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 74-5-1
RECORDED
MODEL C SIMULATION
MODEL D SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-7



AUG. 23 75
AUG. 24 75
AUG. 25 75
AUG. 26 75
AUG. 27 75
AUG. 28 75
PRECIP. (IN.)
0.00
0.50
1.00
WILSØN CREEK
STREAMFLØW SYNTHESIS
EVENT 75-8-2
RECØRDED
MØDEL C SIMULATIØN
MØDEL D SIMULATIØN
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-8

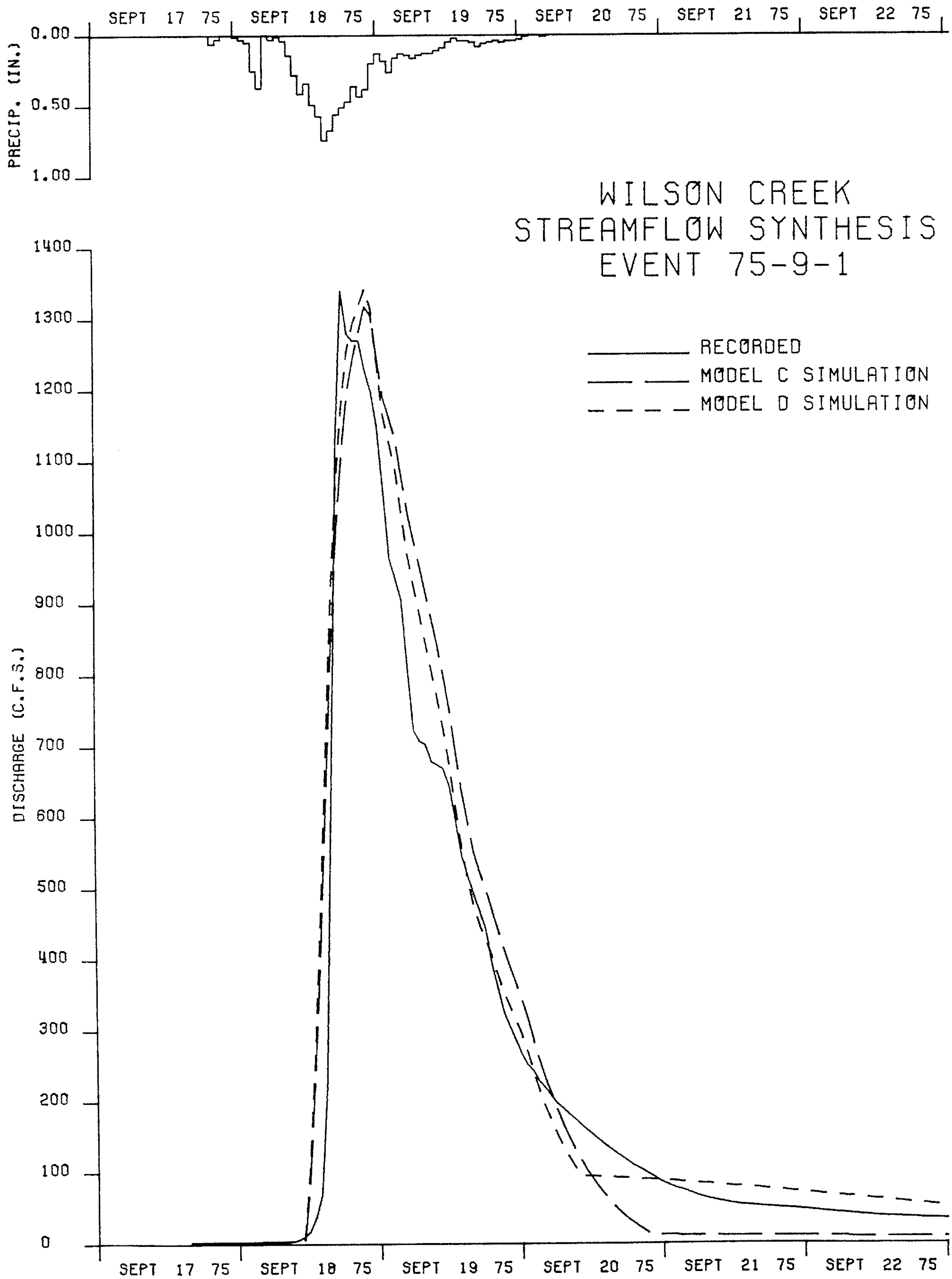

WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-9-1
RECORDED
MODEL C SIMULATION
MODEL D SIMULATION
PRECIP. (IN.)
0.00
0.50
1.00
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
SEPT 17 75
SEPT 18 75
SEPT 19 75
SEPT 20 75
SEPT 21 75
SEPT 22 75

FIGURE B-9

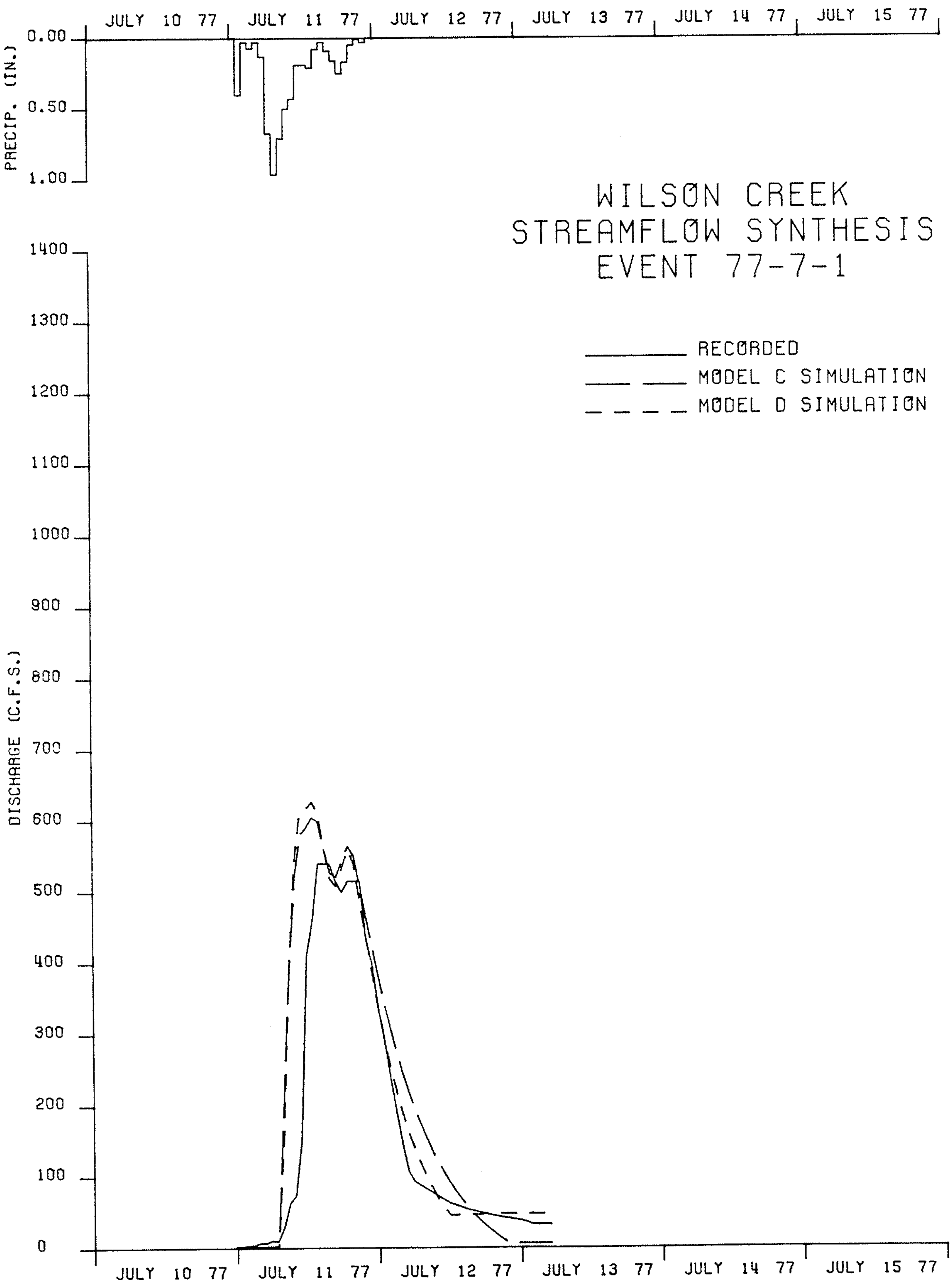
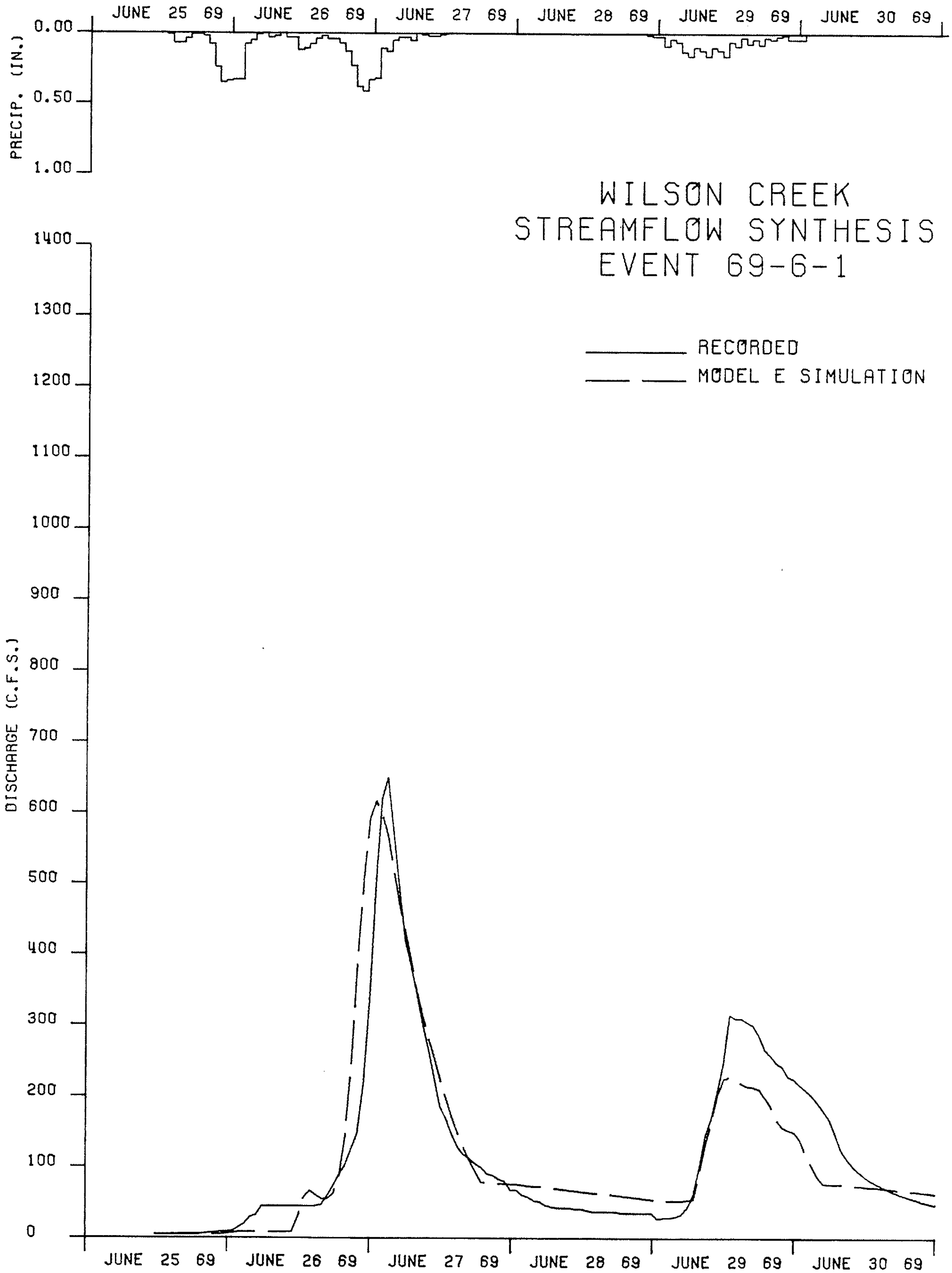

JULY 10 77
JULY 11 77
JULY 12 77
JULY 13 77
JULY 14 77
JULY 15 77
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 77-7-1
RECORDED
MODEL C SIMULATION
MODEL D SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-10



JUNE 25 69
JUNE 26 69
JUNE 27 69
JUNE 28 69
JUNE 29 69
JUNE 30 69
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 69-6-1
RECORDED
MODEL E SIMULATION
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)

FIGURE B-11

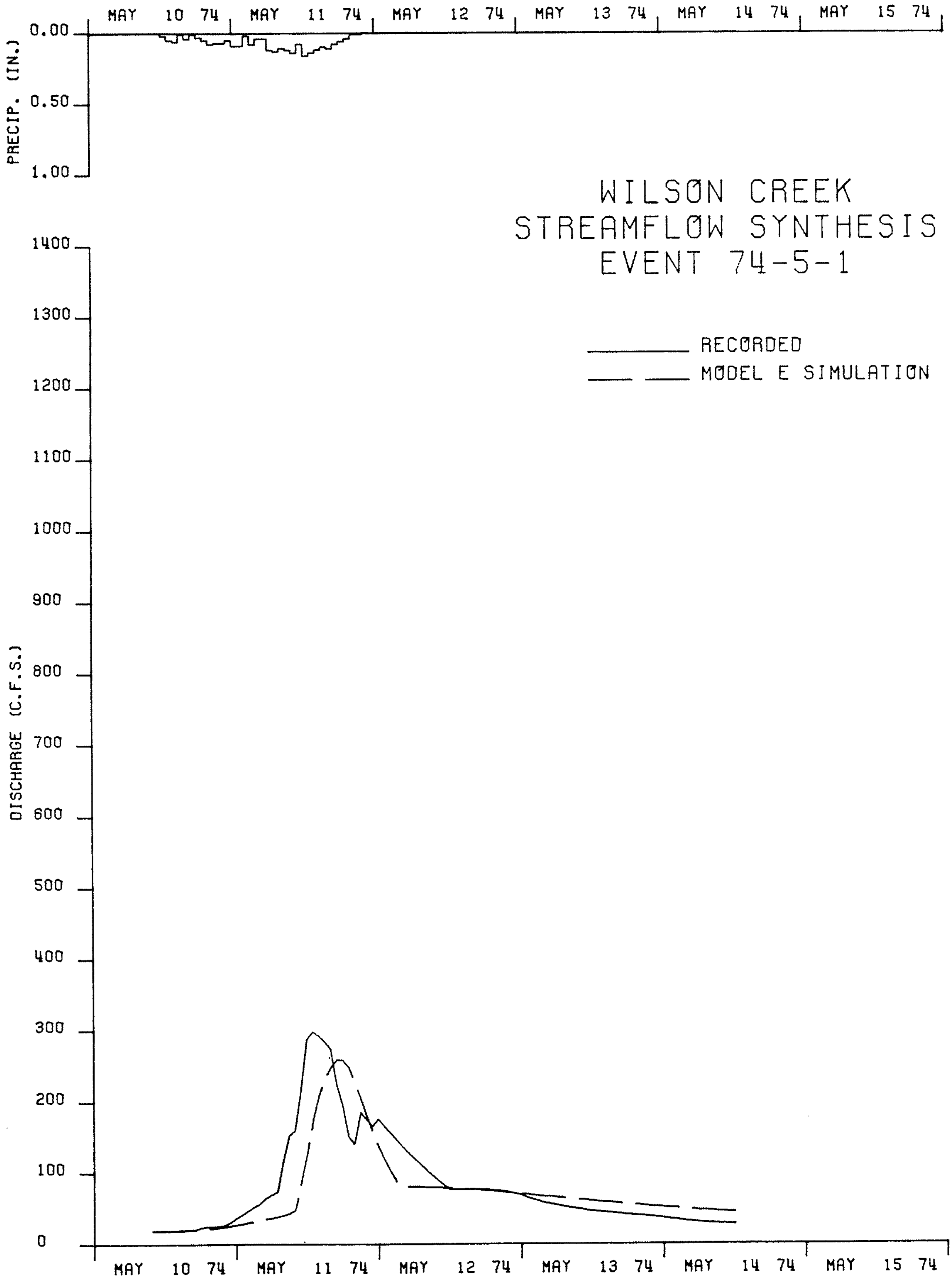
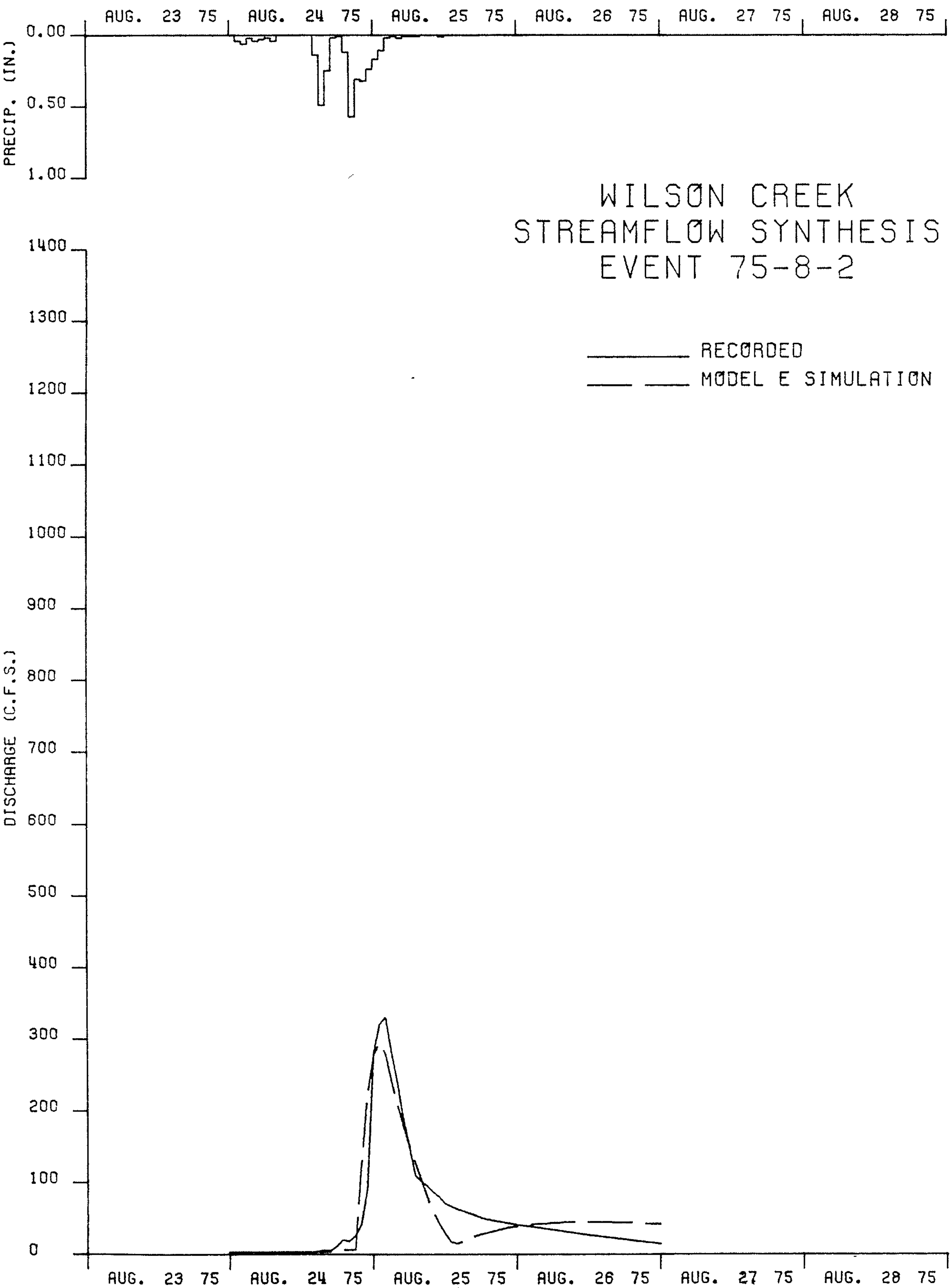

MAY 10 74
MAY 11 74
MAY 12 74
MAY 13 74
MAY 14 74
MAY 15 74
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 74-5-1
RECORDED
MODEL E SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-12



AUG. 23 75
AUG. 24 75
AUG. 25 75
AUG. 26 75
AUG. 27 75
AUG. 28 75
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-8-2
RECORDED
MODEL E SIMULATION
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)

FIGURE B-13

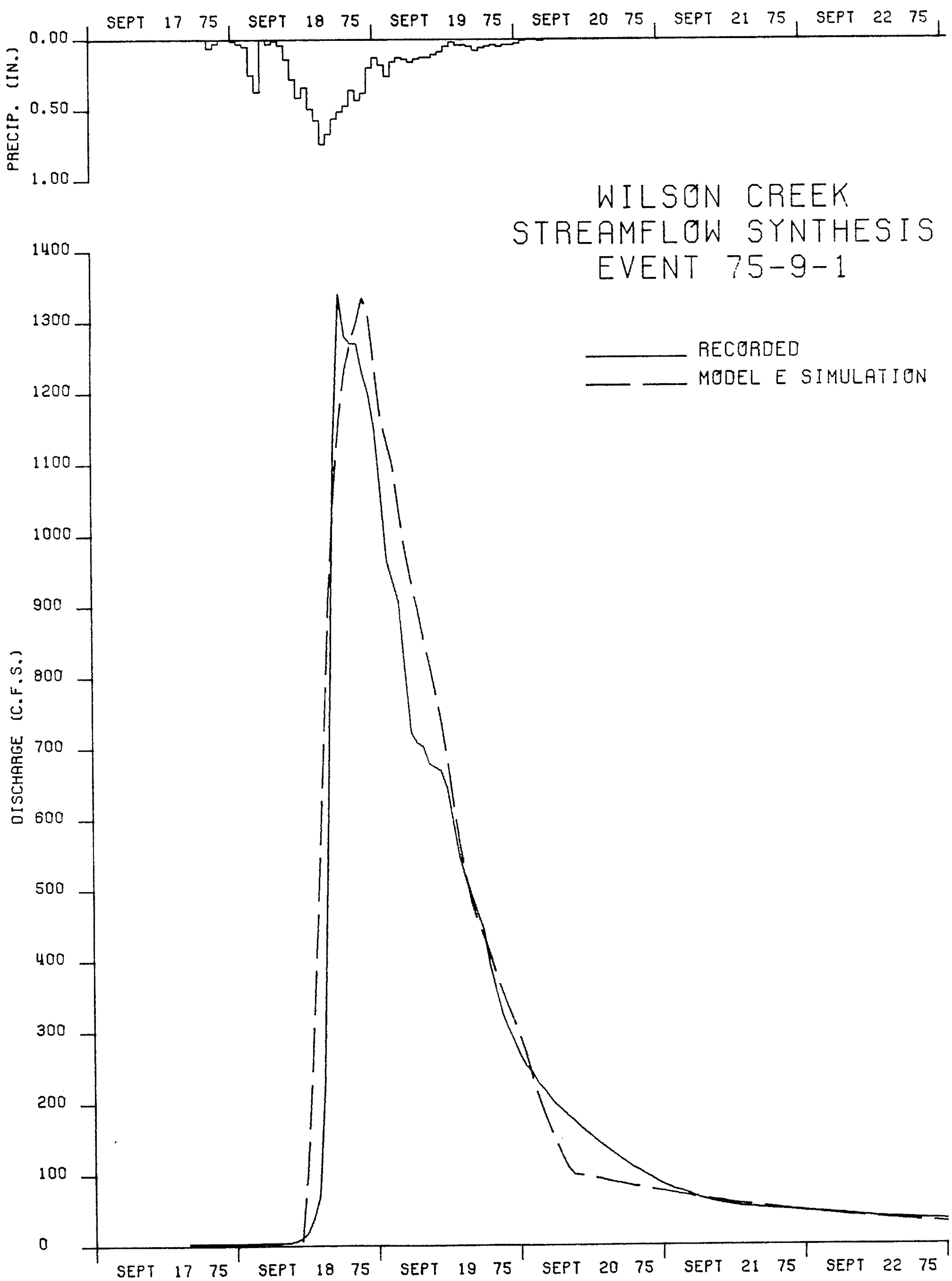

SEPT 17 75
SEPT 18 75
SEPT 19 75
SEPT 20 75
SEPT 21 75
SEPT 22 75
PRECIP. (IN.)
0.00
0.50
1.00
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 75-9-1
RECORDED
MODEL E SIMULATION
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-14

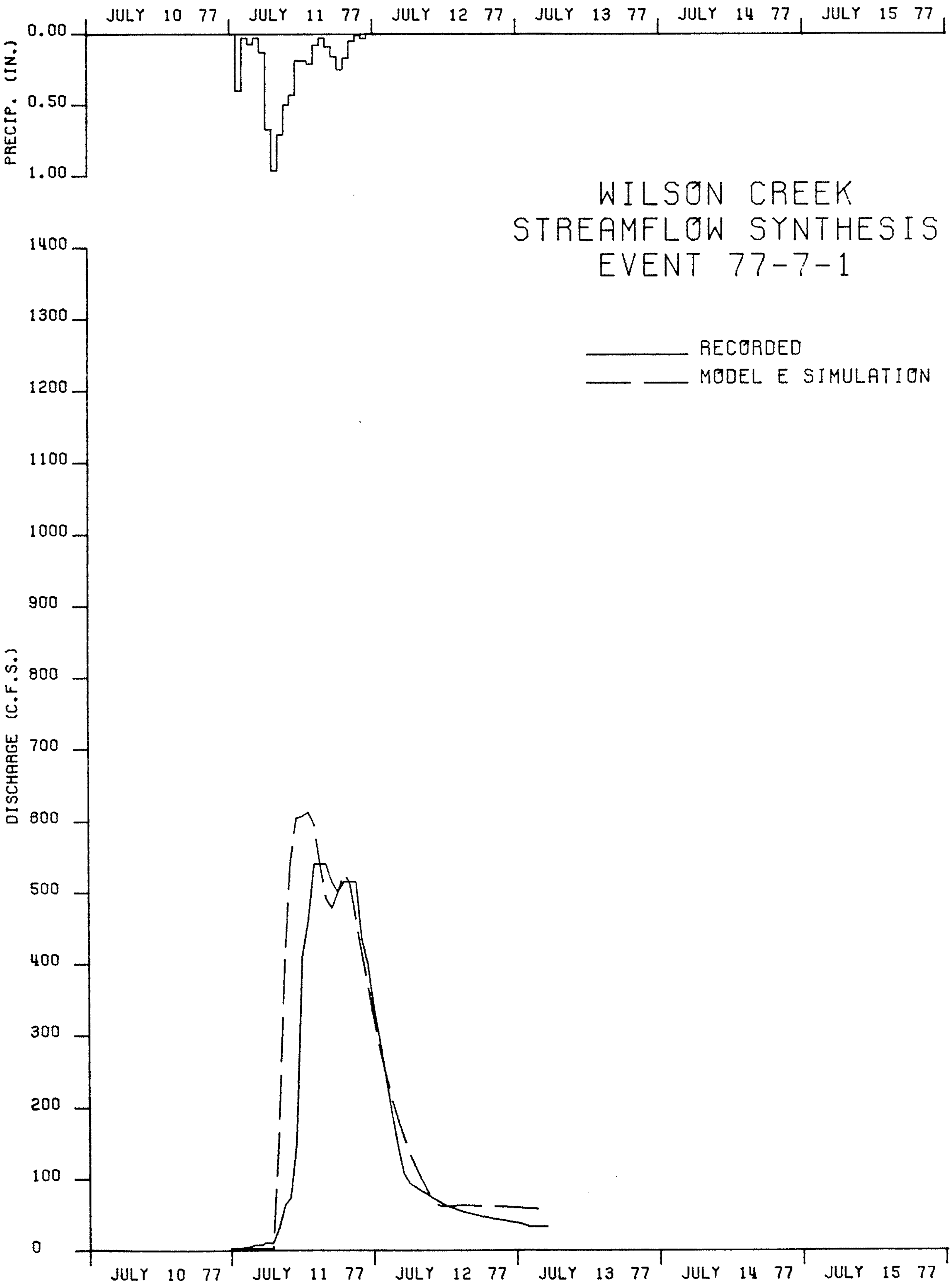

JULY 10 77
JULY 11 77
JULY 12 77
JULY 13 77
JULY 14 77
JULY 15 77
0.00
0.50
1.00
PRECIP. (IN.)
WILSON CREEK
STREAMFLOW SYNTHESIS
EVENT 77-7-1
RECORDED
MODEL E SIMULATION
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE (C.F.S.)

FIGURE B-15

A P P E N D I X C

MODEL PROGRAM

MODEL PROGRAM

INTRODUCTION

A listing of the computer simulation model referred to as Model D is provided on Pages 94 to 111. The program has been broken-up into various subroutines. These subprograms are called up by the main program when required to perform certain operations. The subroutines are as follows:

FIELD: routes the precipitation inflow through the field reservoir to determine percolation flow and direct runoff;

INTERF: routes the percolation flow from the field reservoir through the spring reservoir to determine the deep percolation and spring flow;

E and HJMIN: optimization subprograms of the Direct Pattern Search, discussed in Appendix A;

F(X) function subroutine containing the criteria of Goodness-of-Fit;

VOLUME determines the volume of a streamflow hydrograph;

VMAX1 determines the maximum hourly peak discharge of a storm.

Capacity

1. The maximum allowable number of variables which may be optimized is four.
2. The maximum duration of a storm event is fifteen days.
3. The maximum number of storms which can be optimized at once is seven.

Input

A sample input is shown on Pages 112 to 114. This data is described as follows with the restriction that all values marked INTEGER must appear right justified with no decimal point and that other values may appear right justified with no decimal point or within the field and with a decimal point.

1. Initial Condition Card

Columns	Description
1-5	Integer, number of storms
6-15	Drainage area of Watershed in acres
16-20	Integer, number of variables to be optimized
	Initial estimate of linear reservoir constants:
21-30	KD, storage constant of field reservoir in hours which relates the volume of storage to direct runoff
31-40	KP, storage constant of field reservoir in hours which relates the volume of storage to the rate of percolation
41-50	KS, storage constant of spring reservoir in hours which relates the volume of storage to spring flow
51-60	KDP, storage constant of spring reservoir in hours which relates the volume of storage to the rate of deep percolation.

2. Constant Value Card

Columns	Description
1-10	Field capacity of Watershed in inches
11-20	Total storage capacity of Watershed in inches, includes the field capacity and the depression storage capacity

21-30 Maximum percolation rate in inches per hour

31-40 Maximum deep percolation rate in inches per hour

41-50 Soil moisture capacity of spring reservoir in inches

3. Output Option Card

Columns	Description
1-5	Integer, punch code for simulated streamflow hydrograph
	if 0, no punched output
	if 1, punched output

4. Job Description Card

Columns	Description
1-80	Alpha-numeric description of the simulation run.

Data Decks

For each storm a data deck is required consisting of the following cards.

5. Storm Identification Card

Columns	Description
1-80	Alpha-numeric description of the storm

6. Storm Length Specification Card

Columns	Description
1-5	Integer, duration of storm in days
6-10	Integer, initial hour storm started
11-15	Integer, final hour of storm

7. Precipitation Description Card

Columns	Description
1-80	Alpha-numeric description of the storm precipitation

8. <u>Precipitation Data Deck</u>

The length of this deck is twice the duration of the storm as specified on Storm Length Specification Card, the AM data is placed on the first card followed by the PM data.

Columns	Description
1-4	Integer, year
5-6	Integer, month
7-8	Integer, day
9	Alpha-numeric, A or P, designating whether data is AM or PM
	Hourly precipitation in inches for hours
21-25	1 or 13
26-30	2 or 14
76-80	12 or 24

9. <u>Recorded Streamflow Description Card</u>

Columns	Description
1-80	Alpha-numeric description of recorded hourly streamflow hydrograph

10. <u>Recorded Streamflow Data Deck</u>

The recorded hourly streamflow hydrograph is input in the same format as previously described for the Precipitation Data Deck

11. <u>Initial Storm Condition Card</u>

Columns	Description
1-10	Initial soil moisture deficit of field reservoir in inches
11-20	Initial soil moisture capacity of spring reservoir in inches

Output

A sample printed output of the simulation run to optimize the reservoir storage constants of Model D is shown on pages 115 to 131 inclusive.

```
      PROGRAM BASIN(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE7)
C         VARIABLES
C         ---------
C     NAME               DESCRIPTION                                    UNIT
C
C     STORM              REFERENCE NUMBER OF STORM EVENT
C     AREA               DRAINAGE AREA OF WATERSHED                     ACRES
C     SOIL               INITIAL SOIL MOISTURE DEFICIT BELOW FIELD      IN
C                        CAPACITY
C     PRECIP             AVG AREAL HOURLY PRECIPITATION                 IN/HR
C     ACCUM              ACCUMULATIVE HOURLY PRECIPITATION              IN
C     FCAP               FIELD CAPACITY,SATURATION POINT OF SOIL,       IN
C                        POINT AT WHICH PERCOLATION BEGINS
C     SCAP               TOTAL STORAGE CAPACITY OF SOIL,INCLUDES        IN
C                        SOIL MOISTURE DEFICIT & SUPERFICAL STORAGE
C     SPRCAP             SOIL MOISTURE CAPACITY OF SPRING RESEVOIR      IN
C                        ,POINT AT WHICH DEEP PERCOLATION AND SPRING
C                        FLOW BEGIN
C     SSOIL              INITIAL SOIL MOISTURE CAPACITY OF SPRING       IN
C                        RESERVOIR
C     INFILT             INFILTRATION RATE                              IN/HR
C     EXCESS             EXCESS PRECIPITATION                           IN/HR
C     DISCHG             RECORDED DISCHARGE WILSON CREEK                CFS
C     BALDHL             RECORDED HOURLY OUTFLOW FROM BALDHILL          CFS
C                        RESERVOIR
C     BASE               BASEFLOW                                       CFS
C     INFLOW             INFLOW TO LINEAR RESERVOIR                     CFS
C     DIRECT             COMBINED SURFACE & ROOT ZONE FLOW              CFS
C     PERCOL             PERCOLATION RATE                               CFS
C     DPERC              DEEP PERCOLATION RATE                          CFS
C     MAXPER             MAXIMUN PERCOLATION RATE                       IN/HR
C     MAXDPR             MAXIMUN DEEP PERCOLATION RATE                  IN/HR
C     SPRING             SPRING FLOW                                    CFS
C     OUTFLW             SIMULATED OUTFLOW FROM LINEAR RESERVOIR        CFS
C                        SYSTEM
C     QPDIS              RECORDED PEAK DISCHARGE                        CFS
C     QPOUT              PEAK OUTFLOW FROM LINEAR RESERVOIR SYSTEM      CFS
C     VOLDIS             VOLUME OF RECORDED STORM HYDROGRAPH
C     VOLOUT             VOLUME OF SIMULATED STORM HYDROGRAPH
C
C     KD                 DIRECT FLOW STORAGE CONSTANT
C     KP                 PERCOLATION STORAGE CONSTANT
C     KS                 SPRING FLOW STORAGE CONSTANT
C     KDP                DEEP PERCOLATION STORAGE CONSTANT
C
C     HOUR               HOURS 1-24
C     DAY                DAY 1-31
C     MONTH              MONTH 1-12
C     YEAR               YEAR OF STORM
C
C     NV                 NUMBER OF VARIABLES TO BE OPTIMIZED
C     NSTORM             NUMBER OF STORMS
C     MSTART             STARTING MONTH OF STORM
C     NDSRT              STARTING DAY OF STORM
C     NHSRT              FIRST HOUR OF STORM
C     NDAY               DURATION OF STORM HYDROGRAPH IN DAYS
C                        MAXIMUM OF 15 DAYS
```

```
C       NH              DURATION OF STORM HYDROGRAPH IN HOURS
C                       MAXIMUM OF 360 HOURS
C       NHSLT           LAST HOUR OF STORM
C
C       CODE1 = 0       OUTPUT SIMULATED HYDROGRAPH NOT PUNCHED
C             = 1       OUTPUT SIMULATED HYDROGRAPH PUNCHED
C
      REAL PRECIP(7,15,24),INFLOW(7,15,24),OUTFLW(7,15,24),PNAME(7,20),
     &QNAME(7,20),DISCHG(7,15,24),X(4),STORM(7,2),BALDHL(7,15,24),
     &EXCESS(7,15,24),BASE(7),INFILT,AREA,SOIL(7),BNAME(7,20),
     &DIRECT(7,15,24),PERCOL(7,15,24),SPRING(7,15,24),DPERC(7,15,24)
      REAL QPOUT(7),QPDIS(7),STORMX(2),VOLOUT(7),VOLDIS(7)
      REAL PRCP(360),Q(360),QO(360)
      REAL KD,KP,KS,KDP,FCAP,SCAP,MAXPER,MAXDP
      REAL SPRCAP,SSOIL(7)
      REAL DESCRP(20)
      INTEGER NDAY(7),NHSRT(7),NHLST(7),NHSRT1(7),NSTORM
      INTEGER YEAR(7),MONTH(7,12),DAY(7,31)
      INTEGER PNHSRT,PNDSRT,PMSRT,PYEAR
      INTEGER CODE1
      REAL LAMBDA
      LOGICAL CONV
      COMMON /TIME/ NHSRT1,NHLST,NDAY,NSTORM
      COMMON /COEFF/ KD,KP,KS,KDP,INFILT
      COMMON /RAIN/ AREA,SOIL,PRECIP,EXCESS,FCAP,SCAP,MAXPER,MAXDP
      COMMON /FLOW/ INFLOW,OUTFLW,DISCHG,BASE,BALDHL,DIRECT,DPERC,
     &PERCOL,SPRING
      COMMON /BETA/ STORMX,NH,Q,QO,PRCP,PNHSRT,PNDSRT,PMSRT,PYEAR
      COMMON /CRITER/ QPDIS,QPOUT,VOLDIS,VOLOUT
      COMMON /SHALE/ SPRCAP,SSOIL
      DATA SL,RHO,LAMBDA/2.00,0.5,0.20/,X/0.,0.,0.,0./
C
      READ(5,21) NSTORM,AREA,NV,KD,KP,KS,KDP,INFILT
      READ(5,23) FCAP,SCAP,MAXPER,MAXDP,SPRCAP
      READ(5,22) CODE1
C
      READ(5,105) DESCRP
      DO 5 K=1,NSTORM
C
C     ZERO ARRAYS
C
      DO 1 I=1,15
      DO 1 J=1,24
      EXCESS(K,I,J)=0.0
      PRECIP(K,I,J)=0.0
      INFLOW(K,I,J)=0.0
      DIRECT(K,I,J)=0.0
      PERCOL(K,I,J)=0.0
      DPERC(K,I,J)=0.0
      SPRING(K,I,J)=0.0
      BALDHL(K,I,J)=0.0
      OUTFLW(K,I,J)=0.0
    1 DISCHG(K,I,J)=0.0
C
      READ(5,24)(STORM(K,I),I=1,2)
      READ(5,22) NDAY(K),NHSRT(K),NHLST(K)
      NHSRT1(K)=NHSRT(K)
```

```
C
C      READ IN RECORDED HOURLY PRECIPITATION ,DISCHARGE FOR WILSON CR.
C      AND OUTFLOW FROM BALDHILL RESERVOIR
C
       READ(5,24)(PNAME(K,I),I=1,20)
       MDAY=NDAY(K)
       DO 10 I=1,MDAY
    10 READ(5,20) YEAR(K),MONTH(K,I),DAY(K,I),(PRECIP(K,I,J),J=1,24)
C
       READ(5,24)(QNAME(K,I),I=1,20)
       DO 15 I=1,MDAY
    15 READ(5,20) YEAR(K),MONTH(K,I),DAY(K,I),(DISCHG(K,I,J),J=1,24)
C
       READ(5,24)(BNAME(K,I),I=1,20)
       DO 16 I=1,MDAY
    16 READ(5,20) YEAR(K),MONTH(K,I),DAY(K,I),(BALDHL(K,I,J),J=1,24)
C
       QPDIS(K)=VMAX1(DISCHG,K)
       VOLDIS(K)=VOLUME(DISCHG,K)
C
C
       READ(5,23) SOIL(K),BASE(K),SSOIL(K)
C
     5 CONTINUE
C
C      WRITE OUT HEADING
C
       WRITE(6,104)
       WRITE(6,106) DESCRP
       WRITE(6,112) FCAP,SCAP
       WRITE(6,113) MAXDP
       WRITE(6,115) SPRCAP
       WRITE(6,109)
       WRITE(6,110)
       X(1)=KD
       X(2)=KP
       X(3)=KS
       X(4)=KDP
       CALL HJMIN(X,NV, Z, SL, RHO, LAMBDA, 350, CONV)
C
       WRITE(6,111)(QPDIS(K),K=1,NSTORM)
C
       DO 30 K=1,NSTORM
C
       WRITE(6,107) (STORM(K,I),I=1,2)
       WRITE(6,108) SOIL(K),MAXPER,BASE(K)
       WRITE(6,116) SSOIL(K)
       N1=NHSRT(K)
       N2=24
       NH=0
       WRITE(6,101)
       WRITE(6,102)
       MDAY=NDAY(K)
C
       DO 100 I=1,MDAY
       IF(I.GT.1) N1=1
       IF(I.EQ.NDAY(K)) N2=NHLST(K)
```

```
      DO 100 J=N1,N2
      NH=NH+1
      Q(NH)=OUTFLW(K,I,J)
      QO(NH)=DISCHG(K,I,J)
      PRCP(NH)=PRECIP(K,I,J)
  100 WRITE(6,103) DAY(K,I),J,PRECIP(K,I,J),EXCESS(K,I,J),INFLOW(K,I,J),
     &DIRECT(K,I,J),PERCOL(K,I,J),DPERC(K,I,J),SPRING(K,I,J),BALDHL(K,I,
     &J),BASE(K),OUTFLW(K,I,J),DISCHG(K,I,J)
C
      WRITE(6,114) VOLDIS(K),VOLOUT(K)
C
C     INITIALIZE VARIABLES FOR SUBROUTINE GRAPHH
C
      PNHSRT=NHSRT(K)
      PNDSRT=DAY(K,1)
      PMSRT=MONTH(K,1)
      PYEAR=YEAR(K)
      DO 17 I=1,2
   17 STORMX(I)=STORM(K,I)
C
      CALL GRAPHH
C     PUNCHED OUT SIMULATED HYROGRAPH
C
      IF(CODE1.EQ.0) GO TO 30
      WRITE(7,24)(STORM(K,I),I=1,2)
      DO 18 I=1,MDAY
      WRITE(7,25) YEAR(K),MONTH(K,I),DAY(K,I),(OUTFLW(K,I,J),J=1,12)
      WRITE(7,26) YEAR(K),MONTH(K,I),DAY(K,I),(OUTFLW(K,I,J),J=13,24)
   18 CONTINUE
C
C
   30 CONTINUE
C
   20 FORMAT(I4,2I2,12X,12F5.0/20X,12F5.0)
   21 FORMAT(I5,F10.2,I5,6F10.2)
   22 FORMAT(5I5)
   23 FORMAT(8F10.0)
   24 FORMAT(20A4)
   25 FORMAT(I4,2I2,1HA,11X,12F5.0)
   26 FORMAT(I4,2I2,1HP,11X,12F5.0)
  101 FORMAT(1H-,1X,3HDAY,1X,4HHOUR,3X,7HPRECIP.,3X,7HPRECIP.,4X,6HINFLO
     &W,4X,6HDIRECT,4X,6HPERCOL,6X,4HDEEP,4X,6HSPRING,2X,8HBALDHILL,2X,8
     &HBASEFLOW,1X,9HSIMULATED,2X,8HOBSERVED/,24X,6HEXCESS,14X,6HRUNOFF,
     &6X,4HFLOW,4X,6HPERCOL,6X,4HFLOW,16X,4HFLOW,6X,4HFLOW)
  102 FORMAT(17X,3HIN.,7X,3HIN.,7X,3HCFS,7X,3HCFS,7X,3HCFS,7X,3HCFS,7X,3
     &HCFS,7X,3HCFS,7X,3HCFS,7X,3HCFS,7X,3HCFS/)
  103 FORMAT(2X,I3,2X,I3,2F10.3,10F10.2)
  104 FORMAT(1H1,1H-,40X,33HLINEAR RESERVOIR SIMULATION MODEL/,46X,22HWI
     &LSON CREEK WATERSHED/)
  105 FORMAT(20A4)
  106 FORMAT(20X,20A4///)
  107 FORMAT(1H1,3X,7H EVENT ,2A4/)
  108 FORMAT(10X,32HINITIAL SOIL MOISTURE DEFICIT = ,F5.2,7H INCHES/,10X
     &,27HMAXIMUM PERCOLATION RATE = ,F5.2,8H IN./HR./,10X,11HBASEFLOW =
     & ,F5.2,4H CFS/)
  109 FORMAT(45X,35HPATTERN SEARCH TO OPTIMIZE FUNCTION/)
  110 FORMAT(5H BASE,5X,2HKD,5X,2HKP,5X,2HKS,4X,3HKDP,5X,31HSIMULATED PE
     &AK DISCHARGE IN CFS,7X,8HFUNCTION,9X,11HSTEP LENGTH/,6H POINT,27X,
     &8H  69-6-1,8H  74-5-1,8H  75-8-1,8H  75-9-1,8H  77-7-1,6X,5HVALUE,
     &6X,2HS1,6X,2HS2,6X,2HS3,6X,2HS4//)
  111 FORMAT(7X,13HRECORDED PEAK,13X,5F8.2)
  112 FORMAT(10X,16HFIELD CAPACITY =,F5.2,7H INCHES/,10X,24HTOTAL STORAG
     &E CAPACITY =,F5.2,7H INCHES)
  113 FORMAT(10X,31HMAXIMUM DEEP PERCOLATION RATE =,F5.3,8H IN./HR.)
  114 FORMAT(1H-,,10X,26HVOLUME OF RECORDED STORM =,F10.1,8H CFS.HR./,11
     &X,27HVOLUME OF SIMULATED STORM =,F9.1,8H CFS.HR./)
  115 FORMAT(10X,44HSOIL MOISTURE CAPACITY OF SPRING RESERVOIR =,F5.2,7H
     & INCHES//)
  116 FORMAT(10X,51HINITIAL SOIL MOISTURE CONTENT OF SPRING RESERVOIR =,
     &F5.2,7H INCHES//)
C
      STOP
      END
```

```
C
C     FUNCTION SUBROUTINE
C     -------------------
C     PURPOSE:
C             CALCULATES EXCESS PRECIPITATION AND ROUTES INFLOW
C             THROUGH A LINEAR RESERVOIR SYSTEM
C
      FUNCTION F(X)
      REAL PRECIP(7,15,24),EXCESS(7,15,24),SOIL(7),DPERC(7,15,24)
      REAL INFLOW(7,15,24),OUTFLW(7,15,24),DISCHG(7,15,24),BASE(7),
     &QPDIS(7),QPOUT(7),DIRECT(7,15,24),PERCOL(7,15,24),SPRING(7,15,24),
     &VOLDIS(7),VOLOUT(7)
      REAL KD,KP,KS,KDP,X(4),BALDHL(7,15,24),INFILT,AREA
      REAL FCAP,SCAP,STOR,MAXPER,MAXDP
      INTEGER NHSRT1(7),NHLST(7),NDAY(7),NSTORM
      COMMON /TIME/ NHSRT1,NHLST,NDAY,NSTORM
      COMMON /COEFF/ KD,KP,KS,KDP,INFILT
      COMMON /RAIN/ AREA,SOIL,PRECIP,EXCESS,FCAP,SCAP,MAXPER,MAXDP
      COMMON /FLOW/ INFLOW,OUTFLW,DISCHG,BASE,BALDHL,DIRECT,DPERC,
     &PERCOL,SPRING
      COMMON /CRITER/ QPDIS,QPOUT,VOLDIS,VOLOUT
C
      KD=X(1)
      KP=X(2)
      KS=X(3)
      KDP=X(4)
      SUM=0.
C
      DO 10 K=1,NSTORM
      STOR=FCAP-SOIL(K)
      ACCUM=STOR
      N1=NHSRT1(K)
      N2=24
      MDAY=NDAY(K)
C
      DO 20 I=1,MDAY
      IF(I.GT.1) N1=1
      IF(I.EQ.NDAY(K)) N2=NHLST(K)
      DO 20 J=N1,N2
      ACCUM=ACCUM+PRECIP(K,I,J)
      IF(ACCUM.LT.FCAP) GO TO 30
      IF(ACCUM-PRECIP(K,I,J).LE.FCAP) GO TO 40
      EXCESS(K,I,J)=PRECIP(K,I,J)-INFILT
      GO TO 50
   30 EXCESS(K,I,J)=0.
      GO TO 50
   40 EXCESS(K,I,J)=(ACCUM-FCAP)-INFILT
   50 IF(EXCESS(K,I,J).LT.0.) EXCESS(K,I,J)=0.
   20 INFLOW(K,I,J)=EXCESS(K,I,J)*AREA
C
C     ROUTE INFLOW THROUGH LINEAR FIELD RESERVOIR
C
      CALL FIELD(K,AREA,FCAP,SCAP,STOR,MAXPER)
C
C     ROUTE PERCOLATION FLOW FROM FIELD RESERVOIR THROUGH
C     INTERFLOW RESERVOIR
C
      CALL INTERF(K,MAXDP,AREA)
C
      QPOUT(K)=VMAX1(OUTFLW,K)
      VOLOUT(K)=VOLUME(OUTFLW,K)
C
      SUM=SUM+(((QPDIS(K)-QPOUT(K))/QPDIS(K))*100.)**2.0+(((VOLDIS(K)-VO
     &LOUT(K))/VOLDIS(K))*100.)**2.0
C
   10 CONTINUE
      F=SUM
C
      RETURN
      END
```

```
C
      SUBROUTINE FIELD(K,AREA,FCAP,SCAP,STOR,MAXPER)
C
C     PURPOSE:
C             ROUTES INFLOW THROUGH A LINEAR FIELD RESERVOIR
C
      REAL INFLOW(7,15,24),OUTFLW(7,15,24),DISCHG(7,15,24),BASE(7),
     &QPDIS(7),QPOUT(7),DIRECT(7,15,24),PERCOL(7,15,24),SPRING(7,15,24),
     &VOLDIS(7),VOLOUT(7)
      REAL KD,KP,KS,KDP,X(4),BALDHL(7,15,24),INFILT,AREA,DPERC(7,15,24)
      REAL SCAP,STOR,MAXPER,VALUE,PMAX,S0,S1,S2
      INTEGER NHSRT1(7),NHLST(7),NDAY(7),NSTORM
      COMMON /TIME/ NHSRT1,NHLST,NDAY,NSTORM
      COMMON /COEFF/ KD,KP,KS,KDP,INFILT
      COMMON /FLOW/ INFLOW,OUTFLW,DISCHG,BASE,BALDHL,DIRECT,DPERC,
     &PERCOL,SPRING
      COMMON /CRITER/ QPDIS,QPOUT,VOLDIS,VOLOUT
C
      S1=0.0
      S2=0.0
      S0=(SCAP-FCAP)*AREA
      PMAX=AREA*MAXPER
      N1=NHSRT1(K)
      N2=24
      I1=1
      J1=NHSRT1(K)-1
      MDAY=NDAY(K)
C
      DO 10 I=1,MDAY
      I2=I
      IF(I.GT.1) N1=1
      IF(I.EQ.NDAY(K)) N2=NHLST(K)
      DO 10 J=N1,N2
      J2=J
      IX=1
      IF(J1.EQ.0) INFLOW(K,I1,J1)=0.0
      IF(S1.GT.S0) GO TO 20
   90 IF(PERCOL(K,I1,J1).GE.PMAX) GO TO 30
      S2=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KP)))/(1.
     &+1./(2.*KP))
      IX=IX+1
      S2A=S2
      GO TO 40
C
   30 S2=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1-PMAX/2.)/(1.+1./(2.*
     &KP))
      IX=IX+1
      S2A=S2
   40 IF(S2.GT.S0.AND.IX.LE.3) GO TO 20
      IF(IX.GE.4) GO TO 100
      PERCOL(K,I,J)=S2/KP
      DIRECT(K,I,J)=0.0
      IF(PERCOL(K,I,J).LE.PMAX) GO TO 50
      PERCOL(K,I,J)=PMAX
      IF(PERCOL(K,I1,J1).GE.PMAX) GO TO 60
      S2= ((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KP))-PMAX
     &/2.
```

```
      S2A=S2
      GO TO 70
   60 S2= (INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.-PMAX+S1
      S2A=S2
   70 IF(S2.LE.S0) GO TO 50
C
   20 IF(PERCOL(K,I1,J1).GE.PMAX) GO TO 80
      S2=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KD)-1./(2
     &.*KP))+S0/KD)/(1.+1./(2.*KD)+1./(2.*KP))
      S2B=S2
      IX=IX+1
      IF(S2.LT.S0.AND.IX.LE.3) GO TO 90
      IF(IX.GE.4) GO TO 100
      PERCOL(K,I,J)=S2/KP
      DIRECT(K,I,J)=(S2-S0)/KD
      IF(PERCOL(K,I,J).LE.PMAX) GO TO 50
      PERCOL(K,I,J)=PMAX
      S2=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KD)-1./(2
     &.*KP))-PMAX/2.+S0/KD)/(1.+1./(2.*KD))
      S2B=S2
      IF(S2.LT.S0.AND.IX.LE.3) GO TO 90
      IF(IX.GE.4) GO TO 100
      DIRECT(K,I,J)=(S2-S0)/KD
      GO TO 50
C
   80 S2=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KD))+S0/K
     &D-PMAX/2.)/(1.+1./(2.*KD)+1./(2.*KP))
      S2B=S2
      IF(S2.LT.S0.AND.IX.LE.3) GO TO 90
      IF(IX.GE.4) GO TO 100
      PERCOL(K,I,J)=S2/KP
      DIRECT(K,I,J)=(S2-S0)/KD
      IF(PERCOL(K,I,J).LE.PMAX) GO TO 50
      PERCOL(K,I,J)=PMAX
      S2=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KD))+S0/K
     &D-PMAX)/(1.+1./(2.*KD))
      S2B=S2
      IF(S2.LT.S0.AND.IX.LE.3) GO TO 90
      IF(IX.GE.4) GO TO 100
      DIRECT(K,I,J)=(S2-S0)/KD
      GO TO 50
C
  100 CONTINUE
      S2=(S2A+S2B)/2.0
      PERCOL(K,I,J)=S2/KP
      DIRECT(K,I,J)=(S2-S0)/KD
      IF(PERCOL(K,I,J).LE.PMAX) GO TO 105
      IF(PERCOL(K,I1,J1).GE.PMAX) GO TO 110
      S2A=((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KP))-PMAX
     &/2.
      S2B=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KD)-1./(
     &2.*KP))-PMAX/2.+S0/KD)/(1.+1./(2.*KD))
      S2=(S2A+S2B)/2.0
      GO TO 120
C
  110 S2A=(INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.-PMAX+S1
      S2B=(((INFLOW(K,I1,J1)+INFLOW(K,I2,J2))/2.)+S1*(1.-1./(2.*KD))+S0/
     &KD-PMAX)/(1.+1./(2.*KD))
      S2=(S2A+S2B)/2.0
  120 PERCOL(K,I,J)=PMAX
      DIRECT(K,I,J)=(S2-S0)/KD
  105 CONTINUE
      IF(DIRECT(K,I,J).LT.0.) DIRECT(K,I,J)=0.0
   50 CONTINUE
      I1=I2
      J1=J2
      S1=S2
   10 CONTINUE
C
      RETURN
      END
```

```
      C
            SUBROUTINE INTERF(K,MAXDP,AREA)
      C
      C     PURPOSE:
      C             ROUTES PERCOLATION FLOW FROM THE FIELD RESERVOIR THROUGH
      C             A LINEAR INTERFLOW RESERVOIR TO DETERMINE SPRING FLOW
      C
            REAL INFLOW(7,15,24),OUTFLW(7,15,24),DISCHG(7,15,24),BASE(7),
           &QPDIS(7),QPOUT(7),DIRECT(7,15,24),PERCOL(7,15,24),SPRING(7,15,24),
           &VOLDIS(7),VOLOUT(7)
            REAL KD,KP,KS,KDP,X(4),BALDHL(7,15,24),INFILT,AREA,DPERC(7,15,24)
           &,MAXDP,DPMAX
            REAL SPRCAP,SSOIL(7),EXPERC(7,15,24)
            INTEGER NHSRT1(7),NHLST(7),NDAY(7),NSTORM
            COMMON /TIME/ NHSRT1,NHLST,NDAY,NSTORM
            COMMON /COEFF/ KD,KP,KS,KDP,INFILT
            COMMON /FLOW/ INFLOW,OUTFLW,DISCHG,BASE,BALDHL,DIRECT,DPERC,
           &PERCOL,SPRING
            COMMON /CRITER/ QPDIS,QPOUT,VOLDIS,VOLOUT
            COMMON /SHALE/ SPRCAP,SSOIL
      C
            DO 1 I=1,15
            DO 1 J=1,24
          1 EXPERC(K,I,J)=0.0
      C
            ACCUM=SSOIL(K)*AREA
            SPR=SPRCAP*AREA
      C
            SS1=0.0
            SS2=0.0
            DPMAX=AREA*MAXDP
            SS0=DPMAX*KDP
            N1=NHSRT1(K)
            N2=24
            I1=1
            J1=NHSRT1(K)-1
            MDAY=NDAY(K)
      C
            DO 10 I=1,MDAY
            I2=I
            IF(I.GT.1) N1=1
            IF(I.EQ.NDAY(K)) N2=NHLST(K)
            DO 10 J=N1,N2
            ACCUM=ACCUM+PERCOL(K,I,J)
            IF(ACCUM.LT.SPR) GO TO 130
            IF(ACCUM-PERCOL(K,I,J).LE.SPR) GO TO 140
            EXPERC(K,I,J)=PERCOL(K,I,J)
            GO TO 150
        130 EXPERC(K,I,J)=0.
            GO TO 150
        140 EXPERC(K,I,J)=ACCUM-SPR
        150 IF(EXPERC(K,I,J).LT.0.) EXPERC(K,I,J)=0.0
            J2=J
            IX=1
            IF(J1.EQ.0) EXPERC(K,I1,J1)=0.0
            IF(SS1.GT.SS0) GO TO 20
         90 IF(DPERC(K,I1,J1).GE.DPMAX) GO TO 30
```

```
      SS2=(((EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.)+SS1*(1.-1./(2.*KDP)))/
     *(1.+1./(2.*KDP))
      IX=IX+1
      SS2A=SS2
C
      GO TO 40
   30 SS2=(((PERCOL(K,I1,J1)+PERCOL(K,I2,J2))/2.)+SS1-DPMAX/2.)/(1.+1./2
     @*KDP)
      IX=IX+1
      SS2A=SS2
   40 IF(SS2.GT.SS0.AND.IX.LE.3) GO TO 20
      IF(IX.GE.4) GO TO 100
      DPERC(K,I,J)=SS2/KDP
      SPRING(K,I,J)=0.0
      GO TO 50
C
   20 IF(DPERC(K,I1,J1).GE.DPMAX) GO TO 80
      SS2=(((EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.)+SS1*(1.-1./(2.*KS)-1./
     *(2*KDP))-DPMAX/2.+SS0/KS)/(1.+1./(2.*KS))
      SS2B=SS2
      IF(SS2.LT.SS0.AND.IX.LE.3) GO TO 90
      IF(IX.GE.4) GO TO 100
      SPRING(K,I,J)=(SS2-SS0)/KS
      DPERC(K,I,J)=DPMAX
      GO TO 50
   80 SS2=(((EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.)+SS1*(1.-1./(2.*KS))+SS
     @0/KS-DPMAX)/(1.+1./(2.*KS))
      SS2B=SS2
      IF(SS2.LT.SS0.AND.IX.LE.3) GO TO 90
      IF(IX.GE.4) GO TO 100
      SPRING(K,I,J)=(SS2-SS0)/KS
      DPERC(K,I,J)=DPMAX
      GO TO 50
C
  100 CONTINUE
      SS2=(SS2A+SS2B)/2.0
      DPERC(K,I,J)=SS2/KDP
      SPRING(K,I,J)=(SS2-SS0)/KS
      IF(DPERC(K,I,J).LE.DPMAX) GO TO 105
C
      IF(DPERC(K,I1,J1).GE.DPMAX) GO TO 110
      SS2A=((EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.)+SS1*(1.-1./(2.*KDP))-
     *DPMAX/2.
      SS2B=(((EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.)+SS1*(1.-1./(2.*KS)-1.
     */(2.*KDP))-DPMAX/2.+SS0/KS)/(1.+1./(2.*KS))
      SS2=(SS2A+SS2B)/2.0
      GO TO 120
  110 SS2A=(EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.-DPMAX+SS1
      SS2B=(((EXPERC(K,I1,J1)+EXPERC(K,I2,J2))/2.)+SS1*(1.-1./(2.*KS))+S
     *S0/KS-DPMAX)/(1.+1./(2.*KS))
      SS2=(SS2A+SS2B)/2.0
  120 DPERC(K,I,J)=DPMAX
      SPRING(K,I,J)=(SS2-SS0)/KS
  105 IF(SPRING(K,I,J).LT.0) SPRING(K,I,J)=0.0
   50 CONTINUE
      OUTFLW(K,I,J)=DIRECT(K,I,J)+SPRING(K,I,J)+BASE(K)+BALDHL(K,I,J)
      I1=I2
      J1=J2
      SS1=SS2
   10 CONTINUE
C
      RETURN
      END
```

```
      C
            SUBROUTINE E
      C---- MAKE EXPLORATORY MOVES ABOUT A GIVEN POINT
      C
            REAL INFLOW(7,15,24),OUTFLW(7,15,24),DISCHG(7,15,24),BASE(7),
           &QPDIS(7),QPOUT(7),DIRECT(7,15,24),PERCOL(7,15,24),SPRING(7,15,24),
           &BALDHL(7,15,24),DPERC(7,15,24),VOLDIS(7),VOLOUT(7)
            REAL PHI(4),S(4)
            INTEGER NHSRT1(7),NHLST(7),NDAY(7),NSTORM
            COMMON / LOCAL / K, N, H, PHI, S, J
            COMMON /TIME/ NHSRT1,NHLST,NDAY,NSTORM
            COMMON /FLOW/ INFLOW,OUTFLW,DISCHG,BASE,BALDHL,DIRECT,DPERC,
           &PERCOL,SPRING
            COMMON /CRITER/ QPDIS,QPOUT,VOLDIS,VOLOUT
      C---- INCREASE COORDINATE
      C
            J = 0
            DO 60 I = 1, K
            PHI(I) = PHI(I) + S(I)
      C---- THIS IS A CONSTRAINT.  CHANGE ACCORDING TO YOUR NEEDS.
            IF (PHI(I) .LE. 0.) GO TO 20
            SPHI = F(PHI)
            N = N + 1
      C---- SUCCESSFUL MOVE?
      C
            IF (SPHI .LT. H) GO TO 40
      C---- DECREASE COORDINATE
      C
         20 S(I) = - S(I)
            PHI(I) = PHI(I) + 2. * S(I)
      C---- THIS IS A CONSTRAINT.  CHANGE ACCORDING TO YOUR NEEDS.
            IF (PHI(I) .LE. 0.) GO TO 30
            SPHI = F(PHI)
            N = N + 1
      C---- SUCCESSFUL MOVE?
      C
            IF (SPHI .LT. H) GO TO 40
      C---- RESET COORDINATE
      C
         30 PHI(I) = PHI(I) - S(I)
            GO TO 60
      C---- RETAIN NEW COORDINATE AND FUNCTIONAL VALUE
      C
         40 CONTINUE
            H = SPHI
            J = J + 1
         60 CONTINUE
         71 WRITE(6,81) N,(PHI(I),I=1,K),(QPOUT(I),I=1,NSTORM),H,(S(I),I=1,K)
         81 FORMAT(I5,4F7.2,5F8.2,F11.5,4F8.3)
            RETURN
            END
```

```
      C
             SUBROUTINE HJMIN(PSI, K, SPSI, SL, RHO, LAMBDA, LIMIT, CONV)
      C----                                                                    0030
      C----  THIS IS AN OPTIMIZATION PROGRAM BASED ON THE PATTERN SEARCH       0040
      C----  METHOD OF HOOKE AND JEEVES.                                       0050
      C----  SEE D.J.WILDE AND C.S.BEIGHTLER, FOUNDATIONS OF OPTIMIZATION.     0060
      C----  ENGLEWOOD CLIFFS, N.J. : PRENTICE-HALL,1967                       0070
      C----  THIS 'DIMENSION' DECLARATION IS FOR 4 VARIABLES .                 0080
      C
      C          VARIABLES
      C          ---------
      C      NAME             DESCRIPTION
      C
      C      K OR V         NUMBER OF VARIABLES BEING OPTIMIZED
      C      RHO            REDUCTION FACTOR FOR STEP LENGTH
      C      LAMBDA         MINIMUM STEP LENGTH
      C      SL             INITIAL STEP LENGTH
      C      DELTA          CURRENT STEP LENGTH
      C      H              FUNCTIONAL VALUE BEFORE A MOVE IS BEING TAKEN
      C      SPHI           FUNCTIONAL VALUE FOR A MOVE
      C      SPSI           FUNCTIONAL VALUE AT THE PERMANENT BASE POINT
      C      PHI(I)         POINT RESULTING FROM THE CURRENT MOVE
      C      PSI(I)         CURRENT PERMANENT BASE POINT
      C      THETA          PREVIOUS PERMANENT BASE POINT
      C      CONV.          A LOGICAL VARIABLE WHICH IS TRUE IF SUCCESSFUL
      C                     CONVERGENCE IS OBTAINED AND FALSE OTHERWISE
      C      LIMIT          MAXIMUM NUMBER OF FUNCTION EVALUATIONS PERMITTED
      C      VALUE          SUBPROGRAM WHICH EVALUATES THE OBJECTIVE FUNCTION
      C
             DIMENSION PSI(4), PHI(4), S(4), X(4)                              0090
             REAL LAMBDA                                                       0100
             LOGICAL CONV                                                      0110
             COMMON / LOCAL / M, N, H, PHI, S, J                               0120
             DLTAFN = 0.10
             M = K                                                             0160
             DELTA = SL                                                        0170
             DO 10 I = 1, K                                                    0180
          10 S(I) = DELTA                                                      0190
      C----  EVALUATE FUNCTION AT INITIAL BASE POINT                           0200
      C                                                                        0210
             SPSI = F(PSI)
             N = 1                                                             0230
          20 H = SPSI                                                          0240
             DO 30 I = 1, K                                                    0250
          30 PHI(I) = PSI(I)                                                   0260
      C----  MAKE EXPLORATORY MOVES                                            0270
      C                                                                        0280
             CALL E
      C                                                                        0300
             IF (N .GT. LIMIT) GO TO 90                                        0310
      C----  PRESENT FUNCTIONAL VALUE BELOW THAT AT BASE POINT?                0320
      C                                                                        0330
             IF (H .GE. SPSI .OR. J .EQ. 1 .AND. (SPSI - H) .LT. DLTAFN) GO TO 0340
            X70                                                                0350
          40 DO 50 I = 1, K                                                    0360
             IF (PHI(I) .GT. PSI(I) .AND. S(I) .LT. 0. .OR. PHI(I) .LE. PSI(I) 0370
            X.AND. S(I) .GE. 0.) S(I) = - S(I)                                 0380
```

```
C---- SET NEW BASE POINT AND MAKE PATTERN MOVE
C
      THETA = PSI(I)
      PSI(I) = PHI(I)
      PHI(I) = 2. * PHI(I) - THETA
C----  THIS IS A CONSTRAINT.  CHANGE ACCORDING TO YOUR NEEDS.
   50 IF (PHI(I) .LE. 1.) PHI(I) = PSI(I)
      SPSI = H
      SPHI = F(PHI)
      N = N + 1
      IF (N .GT. LIMIT) GO TO 90
      H = SPHI
C---- MAKE EXPLORATORY MOVES
C
      CALL E
C
      IF (N .GT. LIMIT) GO TO 90
C---- IS PRESENT FUNCTIONAL VALUE BELOW THAT OF BASE POINT?
C
      IF (J .EQ. 1 .AND. (SPSI - H) .LT. DLTAFN .AND. (SPSI - H) .GT. 0.
     X) GO TO 70
      IF (H .GE. SPSI) GO TO 20
      DO 60 I = 1, K
      IF (ABS(PHI(I) - PSI(I)) .GT. 0.5 * DELTA) GO TO 40
   60 CONTINUE
C---- IS STEP SIZE SMALL ENOUGH?
C
   70 IF (DELTA .LT. LAMBDA) GO TO 130
C---- DECREASE STEP SIZE
C
      DELTA = RHO * DELTA
      DO 80 I = 1, K
   80 S(I) = RHO * S(I)
      DLTAFN = RHO * DLTAFN
      GO TO 20
   90 CONV = .FALSE.
      IF (H .GE. SPSI) GO TO 110
      SPSI = H
      DO 100 L = 1, K
  100 PSI(L) = PHI(L)
  110 CONTINUE
      WRITE (6,120) N
  120 FORMAT (6X,20H NO CONCLUSION AFTER,I4,21H FUNCTION EVALUATIONS)
      RETURN
C
  130 CONV = .TRUE.
      WRITE (6,140) N
  140 FORMAT (6X,24H CONVERGENCE OBTAINED IN,I4,23H FUNCTIONAL EVALUATIO
     &NS)
      RETURN
C
      END
```

```
C
C                                                                       00002
C     GRAPHING  SUBROUTINE
C     -----------  --------  ----------                                 00004
C                                                                       00005
C     PURPOSE:                                                          00007
C             PLOTTING ON THE LINE PRINTER HOURLY
C             FLOWS & PRECIPITATION
C                                                                       00011
C     SUBROUTINES CALLED                                                00012
C             NONE                                                      00013
C                                                                       00018
C     VARIABLES                                                         00019
C             STORM  - REFERNCE NUMBER OF STORM EVENT
C             NH     - # OF HOURS OF PLOTTING
C             NHSRT  - STARTING HOUR
C             NDSRT  - STARTING DAY                                     00023
C             MSTART - STARTING MONTH                                   00024
C             NYEAR  - YEAR OF PLOT                                     00025
C             P1     - ARRAY CONTAINING OUTFLOWS FROM LINEAR RESFRVOIR
C             P2     - ARRAY CONTAINING OBSERVED FLOWS
C             P3     - ARRAY CONTAINING PRECIPATION
C                                                                       00031
C                                                                       00032
C     COMMON DECLARATION                                                00033
C             ALL VALUES ARE PASSED IN LABELLED COMMON BETA             00034
C             I.E. INSERT THE FOLLOWING DECLARATION IN YOUR CALLING     00035
C                 ROUTINE                                               00036
C                                                                       00037
C     DIMENSION  P1(360),P2(360),P3(360),STORM(6)
C     COMMON /BETA/ STORM,NH,P1,P2,P3,NHSRT,NDSRT,MSTART,NYEAR
C                                                                       00040
C                                                                       00067
C             SYMBOLS PRINTED AS PLOT POSITION                          00069
C                                                                       00070
C                 O  - OUTFLOW                                          00072
C                 *  - OBSERVED FLOW                                    00073
C                 P  - PRECIPITATION                                    00074
C                                                                       00077
C             TITLES                                                    00079
C                                                                       00080
C                 1  - OUTFLOW(O) & OBSERVED FLOW(*)
C                 2  - PRECIP(P) IN INCHES
C                                                                       00086
C                                                                       00091
      SUBROUTINE GRAPHH
C                                                                       00104
C                                                                       00105
      DIMENSION AX(3),ISPAN(3),ISTEP(3),ISTRT(3),PLOT(121),
     1SAVE(121),SCALE(13),STP(3),STRT(3),ISCAL(3),NDAY(12),MONTH(12),
     2P1(360),P2(360),P3(360),STORM(2)
      COMMON /BETA/ STORM,NH,P1,P2,P3,NHSRT,NDSRT,MSTART,NYEAR
      DATA NDAY/31,29,31,30,31,30,31,31,30,31,30,31/                    00109
      DATA MONTH/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,3HAUG,3HSEP,3
     &HOCT,3HNOV,3HDEC/
      DATA BLANK,PER,ASTRK,ALTRP,ALTRO/1H ,1H.,1H*,1HP,1HO/
      NV=3
```

```
              NV1=NV
      C                                                                 00115
      C                                                                 00116
              PRINT 9,STORM
              PRINT 301                                                 00118
      C                                                                 00119
              DO 10 I=1,121                                             00120
              PLOT(I)=BLANK                                             00121
           10 SAVE(I)=BLANK                                             00122
      C                                                                 00123
      C                                                                 00124
      C                INITIATE STANDARD PLOT VARIABLES                 00125
      C                                                                 00126
              NS=0                                                      00127
              ISCAL(1)=1                                                00128
              ISCAL(2)=2                                                00129
              ISTRT(1)=0                                                00131
              ISTRT(2)=0                                                00132
              ISTRT(3)=120
              ISPAN(1)=0                                                00135
              ISPAN(2)=120                                              00136
              ISPAN(3)=-40
              AX(1)=ALTRO
              AX(2)=ASTRK                                               00140
              AX(3)=ALTRP
           38 JPJ=0                                                     00184
              DO 200 J=1,NV                                             00185
              IF(JPJ.GT.0)GO TO 40                                      00186
              AMIN=99999999.                                            00187
              AMAX=-99999999.                                           00188
      C                USE SAME SCALE AS FOLLOWING VARIABLE IF ISPAN IS ZERO 00189
           40 JPJ=0                                                     00190
              IF(ISPAN(J).EQ.0) GO TO 45                                00191
              NS=NS+1                                                   00192
              IF(ISCAL(NS).EQ.2) PRINT 303
              IF(ISTRT(J).GE.0) GO TO 45                                00196
      C                NEGATIVE ISTRT SETS ZERO SCALE LIMIT             00197
              AMIN=0.                                                   00198
              ISTRT(J)=-ISTRT(J)                                        00199
      C                CENTER AND PRINT SCALE TITLE                     00200
      C                FIND EXTREME VALUES                              00201
           45 DO 100 K=1,NH
              GO TO (50,60,70),J
           50 TEMP=P1(K)                                                00204
              GO TO 90                                                  00205
           60 TEMP=P2(K)                                                00206
              GO TO 90                                                  00207
           70 TEMP=P3(K)                                                00208
           90 IF(TEMP.GT.AMAX) AMAX=TEMP                                00211
              IF(TEMP.LT.AMIN) AMIN=TEMP                                00212
          100 CONTINUE                                                  00213
              IF(ISPAN(J).NE.0) GO TO 105                               00214
              JPJ=1                                                     00215
              GO TO 200                                                 00216
      C                DETERMINE INCREMENT FOR 10 SPACES                00217
          105 TMP=ISPAN(J)/10                                           00218
              IF(TMP.LT.0) TMP=-TMP                                     00219
```

```
      IF(AMAX.EQ.0.0.AND.AMIN.EQ.0.0) AMAX=0.1
      IF(AMAX.LE.AMIN)AMAX=1.01*AMIN
      IF (AMAX .LT. 0.0 .AND. AMIN.LT. 0.0)  AMAX = 0.0
      RATIO=(AMAX-AMIN)/TMP
      STEP=1.
      IFMT=1
  110 IF(RATIO.LE..5) GO TO 120
      IF(RATIO.GT.5.) GO TO 130
      IF(RATIO.LE.2..AND.RATIO.GT.1.) STEP=2.*STEP
      IF(RATIO.LE.4..AND.RATIO.GT.2.) STEP=4.*STEP
      IF(RATIO.GT.4.) STEP=5.*STEP
      GO TO 140
  120 STEP=STEP*.1
      RATIO=RATIO*10.
      IFMT=IFMT+1
      GO TO 110
  130 STEP=STEP*10.
      RATIO=RATIO*.1
      GO TO 110
C                 LOCATE AND ASSIGN SCALE VALUES, PRINT SCALE
  140 ITP=AMIN/STEP
      TMP=ITP
      TMP=(TMP-.01)*STEP
      IF(AMIN.LT.TMP) ITP=ITP-1
      ITMP=AMAX/STEP
      TMP=ITMP
      TMP=(TMP+.01)*STEP
      IF(AMAX.GT.TMP) ITMP=ITMP+1
      IF(IFMT.GT.2) IFMT=2
      ITEMP=1
      IF(ISPAN(J).LT.0) ITEMP=-ITEMP
      DO 145 L=1,13
  145 SCALE(L)=0.
      LX=ISTRT(J)/10+1
      TEMP=ITP
      TEMP=TEMP*STEP
      ITMP=ITMP-ITP+1
      DO 150 L=1,ITMP
      IF(LX.GT.13) GO TO 160
      IF(LX.LT.1) GO TO 160
      SCALE(LX)=TEMP
      LX=LX+ITEMP
  150 TEMP=TEMP+STEP
  160 GO TO (170,175),IFMT
  170 PRINT 6,(SCALE(LX),LX=1,13)
      GO TO 195
  175 PRINT 8,(SCALE(LX),LX=1,13)
C                 STORE SCALE INCREMENTS AND LOCATIONS
  195 STP(J)=STEP*.1
      TMP=ITP
      STRT(J)=TMP*STEP
      ISTEP(J)=1
      IF(ISPAN(J).LT.0) ISTEP(J)=-1
      DO 197 K=1,J
      IF(ISPAN(K).NE.0) GO TO 197
      STP(K)=STP(J)
      STRT(K)=STRT(J)
```

```
              ISTEP(K)=ISTEP(J)                                              00279
              ISTRT(K)=ISTRT(J)                                              00280
              ISPAN(K)=ISPAN(J)                                              00281
          197 CONTINUE                                                       00282
          200 CONTINUE                                                       00283
C                  DRAW SCALE LINES                                          00284
              LX=1                                                           00285
              DO 205 L=1,13                                                  00286
              PLOT(LX)=PER                                                   00287
              SAVE(LX)=PER                                                   00288
          205 LX=LX+10                                                       00289
C                  COMPUTE LOCATION OF EACH POINT AND PLOT                   00290
              M=NHSRT
              I = MSTART                                                     00291
              N = NDSRT                                                      00292
              DO 300 K=1,NH
              DO 260 J=1,NV                                                  00294
              GO TO (210,220,230),J
          210 TEMP=P1(K)                                                     00296
              GO TO 250                                                      00297
          220 TEMP=P2(K)                                                     00298
              GO TO 250                                                      00299
          230 TEMP=P3(K)                                                     00300
          250 ITMP=(TEMP-STRT(J))/STP(J)+.5                                  00303
              LX=ISTRT(J)+ITMP*ISTEP(J)+1                                    00304
              IF(LX.GT.121) LX=121                                           00305
              IF(LX.LT.1) LX=1                                               00306
              IF  (J.LT.3)  GO TO 850
              IF(P3(K).EQ.0.) GO TO 762
              DO 654 LXX=LX,121                                              00308
              IF(J.EQ.3 .AND. PLOT(LXX).EQ.AX(1))  GO TO 654
              IF(J.EQ.3 .AND. PLOT(LXX).EQ.AX(2))  GO TO 654
              PLOT(LXX) = AX(J)
          654 CONTINUE
              GO TO 762                                                      00311
        850   PLOT(LX) = AX(J)                                               00312
        762   CONTINUE                                                       00313
          260 CONTINUE                                                       00314
           17 FORMAT(1X,A3,2I4,121A1)
              IF(M.NE.12) GO TO 7821
              PRINT 17,MONTH(I),N,M,(PLOT(L),L=1,121)
              GO TO 246                                                      00318
         7821 PRINT 5,M,(PLOT(L),L=1,121)                                    00319
          246 CONTINUE                                                       00320
              IF(M.EQ.24) GO TO 247
              M=M+1
              GO TO 265
          247 M=1
              IF(I.NE.2) GO TO 48                                            00321
              IF((NYEAR/4)*4.NE.NYEAR) GO TO 44                              00322
              NDAY1=29                                                       00323
              GO TO 46                                                       00324
           44 NDAY1=28                                                       00325
              GO TO 46                                                       00326
           48 NDAY1=NDAY(I)                                                  00327
           46 IF(N.NE.NDAY1) GO TO 6321                                      00328
              I = I+ 1                                                       00329
              N = 0                                                          00330
         6321 CONTINUE                                                       00331
              N = N + 1                                                      00332
          265 CONTINUE
              DO 270 L=1,121                                                 00333
          270 PLOT(L)=SAVE(L)                                                00334
          300 CONTINUE                                                       00335
              RETURN                                                         00336
            5 FORMAT(8X,I4,121A1)
            6 FORMAT(7X,F6.0,12F10.0)
            7 FORMAT(7X,F6.1,12F10.1)
            8 FORMAT(7X,F6.2,12F10.2)
            9 FORMAT(1H1,50X,14H STORM NUMBER ,2A4/)
          301 FORMAT(2X,4HDATE,2X,4HTIME,15X,49H          OUTFLOW(O) AND OBSERV
             &ED FLOW(*) IN CFS)
          303 FORMAT(100X,33H     PRECIPITATION(P) IN INCHES    )
              END                                                            00346
```

```
C
      FUNCTION VOLUME(HYDRO,K)
C
C     FUNCTION TO DETERMINE THE VOLUME UNDER AN STORM HYDROGRAPH
C
C     HYDRO          ARRAY OF STORM HYDROGRAPHS
C     NDAY           DURATION OF STORM HYDROGRAPH IN DAYS
C     NHSRT1         FIRST HOUR OF STORM
C     NHLST          LAST HOUR OF STORM
C
      REAL HYDRO(7,15,24)
      INTEGER NDAY(7),NHSRT1(7),NHLST(7),NSTORM
      COMMON /TIME/ NHSRT1,NHLST,NDAY,NSTORM
C
      VOLUME=0.0
      N1=NHSRT1(K)
      N2=24
      MDAY=NDAY(K)
C
      DO 10 I=1,MDAY
      IF(I.GT.1) N1=1
      IF(I.EQ.NDAY(K)) N2=NHLST(K)
      DO 10 J=N1,N2
   10 VOLUME=VOLUME+HYDRO(K,I,J)
C
      RETURN
      END
```

```
C
      FUNCTION VMAX1(X,K)
C     FUNCTION TO DETERMINE THE MAXIMUN VALUE OF THE KTH ELEMFNT OF AN
C     ARRAY
C
C     X             ARRAY
C     K             ELEMENT OF ARRAY
C     VMAX1         MAXIMUN VALUE OF KTH ELEMENT OF ARRAY
C
      DIMENSION X(7,15,24)
      VMAX1=X(K,1,1)
C
      DO 102 I=1,15
      DO 102 J=1,24
      IF(X(K,I,J).GT.VMAX1) VMAX1=X(K,I,J)
  102 CONTINUE
      RETURN
      END
```

```
    5   4684.5      4 10.02       46.60      76.5      6.0
  9.0       10.2          0.25     0.01
    0
  LINEAR RESERVOIR OPTIMIZATION                                      MAR 79
1969-6-1
    7   12    24
STORM 69-6-1 HOURLY PRECIPITATION IN INCHES DURATION 48 HOURS
1969 625A
1969 625P              .01  .07  .07  .04  .01  .01  .02  .08  .24  .35  .34  .33
1969 626A              .33  .08  .05  .01  .00  .03  .02  .00  .03  .03  .12  .11
1969 626P              .08  .04  .02  .04  .04  .07  .13  .23  .38  .41  .33  .32
1969 627A              .11  .13  .05  .03  .03  .05  .00  .01  .02  .02  .01
1969 627P
1969 628A
1969 628P                                                          .01  .02  .02
1969 629A              .09  .04  .06  .13  .16  .10  .12  .16  .10  .12  .16  .06
1969 629P              .09  .03  .07  .04  .08  .03  .04  .02  .01  .04  .04  .04
1969 630A
1969 630P
1969 7 1A
1969 7 1P
STORM 69-6-1 HOURLY DISCHARGE IN CFS AT WILSON CREEK WEIR
1969 625A                                                                    4.2
1969 625P              4.0  4.2  4.3  4.5  4.7  4.7  5.0  5.2  6.0  6.7  7.7  8.0
1969 626A              9.0 14.2 19.3 28.5 31.7 44.0 44.0 44.0 44.0 44.0 44.0 44.0
1969 626P             44.0 44.0 44.0 46.0 58.0 72.3 88.0  102  125  146  216  335
1969 627A              498  620  650  571  493  420  385  345  301  267  225  185
1969 627P              169  146  128  118  112  105 99.6 90.5 88.0 83.0 79.5 67.8
1969 628A             67.8 60.3 58.0 53.0 51.3 46.0 44.0 42.3 42.3 42.3 40.7 40.7
1969 628P             39.0 37.0 37.0 37.0 37.0 37.0 35.0 35.0 35.0 35.0 35.0 35.0
1969 629A             27.0 28.5 28.5 30.0 33.3 42.3 60.3 99.6  146  169  207  248
1969 629P              316  311  311  306  301  287  267  258  248  243  229  225
1969 630A              217  210  202  192  181  169  148  125  113  103 94.4 88.0
1969 630P             82.0 77.5 73.5 69.5 66.0 62.7 59.9 57.2 54.7 52.2 50.1 48.0
1969 7 1A             46.0 44.0 42.1 40.3 38.8 37.3 35.7 34.4 33.1 32.0 31.0 30.0
1969 7 1P             29.5 29.0 28.4 28.0 27.6 27.3 27.0 26.7 26.4 26.1 25.9 25.7
STORM 69-6-1 OUTFLOW BALDHILL RESERVOIR IN CFS
1969 625A                                                                   0.20
1969 625P             0.20 0.20 0.22 0.26 0.26 0.26 0.26 0.26 0.36 0.58 1.01 1.63
1969 626A             3.29 3.59 3.85 4.03 4.14 4.23 4.30 4.37 4.43 4.47 4.52 4.55
1969 626P             4.59 4.62 4.64 4.67 4.70 4.73 4.75 4.79 4.81 4.85 4.89 4.96
1969 627A             5.04 5.14 5.24 5.31 5.38 5.43 5.48 5.52 5.56 5.58 5.59 5.62
1969 627P             5.64 5.65 5.66 5.67 5.69 5.69 5.69 5.70 5.71 5.71 5.72 5.72
1969 628A             5.72 5.72 5.73 5.73 5.73 5.73 5.74 5.74 5.74 5.74 5.74 5.74
1969 628P             5.74 5.74 5.74 5.74 5.74 5.74 5.74 5.74 5.74 5.74 5.73 5.73
1969 629A             5.73 5.73 5.73 5.73 5.74 5.74 5.74 5.75 5.75 5.76 5.76 5.77
1969 629P             5.78 5.79 5.80 5.81 5.82 5.83 5.84 5.84 5.85 5.86 5.87 5.87
1969 630A             5.87 5.87 5.88 5.88 5.89 5.89 5.89 5.89 5.90 5.90 5.90 5.91
1969 630P             5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91
1969 7 1A             5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91 5.91
1969 7 1P             5.91 5.91 5.90 5.90 5.90 5.90 5.90 5.89 5.89 5.89 5.89 5.89
     0.76       4.0
1974-5-1
    5   10    12
STORM 74-5-1  HOURLY PRECIPITATION IN INCHES   DURATION 34 HOURS
1974 510A                                                                    .02
1974 510P              .05  .06  .01  .04  .01  .03  .05  .08  .07  .07  .05  .09
1974 511A              .09  .02  .08  .04  .04  .12  .13  .11  .12  .14  .08  .16
1974 511P              .14  .12  .10  .11  .08  .06  .04  .01  .01
1974 512A
1974 512P
1974 513A
1974 513P
1974 514A
1974 514P
STORM 74-5-1  HOURLY DISCHARGE IN CFS AT WILSON CREEK WEIR
1974 510A                                                         18.4 18.4 18.4
1974 510P             18.4 18.4 19.1 19.8 19.8 22.0 23.5 23.5 24.2 25.7 29.1 35.3
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1974 511A             40.0  46.0  51.2  55.5  63.7  68.6  72.3   117   152   159   216   287
1974 511P              298   292   284   274   225   195   150   140   185   175   165   175
1974 512A              165   156   146   137   128   120   112   104    96    89  82.0  75.9
1974 512P             75.9  75.9  75.9  75.9  75.9  75.9  75.1  74.4  73.6  72.2  70.5  68.6
1974 513A             65.0  62.3  60.0  57.8  56.0  54.4  52.8  51.3  49.9  48.7  47.4  46.0
1974 513P             45.0  44.3  43.4  42.7  41.8  41.0  40.2  39.6  38.8  38.0  37.1  36.2
1974 514A             35.0  34.0  32.8  31.7  30.8  30.0  29.4  29.0  28.5  28.1  27.7  27.4
1974 514P
STORM 74-5-1 OUTFLOW BALDHILL RESERVOIR IN CFS
1974 510A                                                                4.98  4.98  4.98
1974 510P             4.98  4.98  4.98  4.98  4.98  4.99  4.99  4.99  4.99  4.99  4.99  5.01
1974 511A             5.07  5.08  5.08  5.09  5.11  5.12  5.14  5.16  5.18  5.21  5.23  5.25
1974 511P             5.29  5.31  5.33  5.34  5.35  5.37  5.39  5.40  5.41  5.42  5.43  5.44
1974 512A             5.45  5.46  5.47  5.48  5.49  5.49  5.50  5.50  5.51  5.51  5.52  5.52
1974 512P             5.53  5.53  5.54  5.55  5.56  5.57  5.57  5.58  5.58  5.59  5.59  5.59
1974 513A             5.59  5.60  5.60  5.60  5.61  5.61  5.61  5.61  5.61  5.61  5.61  5.61
1974 513P             5.62  5.62  5.62  5.63  5.63  5.63  5.63  5.63  5.63  5.63  5.63  5.63
1974 514A             5.63  5.63  5.63  5.63  5.63  5.63  5.63  5.63  5.63  5.63  5.64  5.64
1974 514P
           0      13.42
1975-8-1
    4   24   24
STORM 75-8-1 HOURLY PRECIPITATION IN INCHES   DURATION 53 HOURS
1975 823A
1975 823P
1975 824A              .04   .06   .02   .04   .03   .02   .04
1975 824P                    .14   .49   .25   .02   .01   .12   .57   .31   .32   .24   .17
1975 825A              .11   .02   .01   .02   .01   .01   .01                     .01
1975 825P
1975 826A
1975 826P
STORM 75-8-1  HOURLY DISCHARGE IN CFS AT WILSON CREEK WEIR
1975 823A
1975 823P
1975 824A                                                                              2.7
1975 824P              2.7   2.7   2.7   3.0   3.0   3.0   3.0   3.0   3.0   3.0   2.7   2.7
1975 825A              2.7   2.7   4.3   6.0   5.3  11.5  20.5  18.0  25.6  40.5  90.0   280
1975 825P              320   330   280   240   190   150   110   102  95.0  87.0  80.0  71.0
1975 826A             67.0  63.3  60.3  57.5  54.5  51.4  49.3  47.5  46.1  44.4  42.9  41.4
1975 826P             40.2  39.1  38.0  36.9  35.8  34.5  33.3  32.2  31.0  29.8  28.5  27.3
                      26.2  25.3  24.2  23.3  22.2  21.1  20.0  19.0  18.0  17.0  16.0  15.0
STORM 75-8-1 OUTFLOW BALDHILL RESERVOIR IN CFS
1975 823A
1975 823P
1975 824A                                            0.12  0.26  0.18  0.14  0.08
1975 824P
1975 825A                                      1.78  2.66  2.81  2.91  3.03  3.28  3.48  3.69
1975 825P             3.90  4.00  4.08  4.16  4.20  4.23  4.25  4.26  4.28  4.30  4.31  4.31
1975 826A             4.31  4.31  4.31  4.30  4.30  4.30  4.29  4.29  4.28  4.28  4.27  4.27
1975 826P             4.27  4.27  4.27  4.27  4.27  4.27  4.27  4.27  4.27  4.27  4.27  4.27
          0.76      2.7  4.26  4.26  4.26  4.25  4.25  4.25  4.24  4.24  4.24  4.23  4.23  4.23
1975-9-1
    6   16   24
STORM 75-9-1 HOURLY PRECIPITATION IN INCHES, DURATION 59.5 HOURS
1975 917A
1975 917P
1975 918A                                                  .06   .03   .00   .00   .01
1975 918P              .03   .05   .25   .37   .00   .03   .01   .04   .14   .28   .41   .34
1975 919A              .49   .57   .74   .67   .56   .51   .47   .36   .43   .38   .20   .13
1975 919P              .18   .26   .16   .13   .14   .16   .14   .13   .13   .11   .09   .05
1975 920A              .02   .04   .04   .05   .08   .06   .05   .04   .05   .04   .04   .03
1975 920P              .01   .00   .00   .01
1975 921A
1975 921P
1975 922A
1975 922P
STORM 75-9-1 HOURLY DISCHARGE IN CFS AT WILSON CREEK WEIR
1975 917A
1975 917P                                    2.7   2.7   2.7   2.7   2.7   2.7   2.7   2.7   2.7
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1975 918A              2.7  2.7  2.7  2.7  2.7  2.7  2.7 3.25 3.75 5.66 10.0 18.0
1975 918P             37.9 69.3  229  647 1130 1340 1280 1270 1270 1230 1200 1150
1975 919A             1060  965  936  907  810  723  708  703  679  674  669  645
1975 919P              596  547  518  493  469  444  395  361  327  307  288  268
1975 920A              253  244  229  220  209  198  191  183  176  168  161  154
1975 920P              147  140  134  128  122  116  110  106  101   96   91 85.9
1975 921A             82.3 79.0 76.6 72.4 73.9 67.3 65.0 63.0 61.0 59.3 57.8 56.1
1975 921P             55.0 54.2 53.5 52.9 52.2 51.6 51.0 50.4 50.0 49.2 48.7 48.0
1975 922A             47.3 46.5 45.8 45.0 44.1 43.5 42.7 41.9 41.2 40.4 39.8 39.0
1975 922P             38.8 38.2 37.9 37.5 37.1 36.8 36.5 36.1 35.8 35.5 35.2 35.0
STORM 75-9-1 OUTFLOW BALDHILL RESERVOIR IN CFS
1975 917A
1975 917P                             1.34 1.34 1.34 1.34 1.34 1.34 1.34 1.34 1.34
1975 918A             1.34 1.41 1.47 2.52 2.53 2.61 2.63 2.70 2.83 3.04 3.36 3.70
1975 918P             4.00 4.25 4.62 4.85 5.08 5.23 5.48 5.57 5.66 5.78 5.84 5.89
1975 919A             5.94 5.98 6.01 6.03 6.04 6.09 6.10 6.12 6.16 6.22 6.49 6.69
1975 919P             6.88 6.94 7.23 7.39 7.55 7.78 7.94 8.07 8.26 8.48 8.70 8.86
1975 920A             9.03 9.14 9.30 9.8710.1610.4410.6010.7510.9111.0511.2011.30
1975 920P            11.2811.2511.2011.1211.0510.9810.8910.8010.7010.6010.5110.44
1975 921A            10.3010.1510.00 9.89 9.75 9.60 9.46 9.32 9.21 9.08 8.97 8.66
1975 921P             8.81 8.78 8.71 8.67 8.62 8.58 8.54 8.50 8.47 8.43 8.40 8.37
1975 922A             8.32 8.29 8.26 8.22 8.19 8.17 8.14 8.11 8.08 8.05 8.01 7.98
1975 922P             7.95 7.91 7.88 7.83 7.80 7.76 7.70 7.65 7.70 7.65 7.60 7.56
      0.35      1.36
1977-7-1
   4  24    5
STORM 77-7-1 HOURLY PRECIPITATION IN INCHES  DURATION 21.5 HOURS
1977 710A
1977 710P
1977 711A              .40  .03  .07  .03  .13  .67  .96  .71  .50  .43  .19  .19
1977 711P              .21  .08  .03  .09  .16  .25  .17  .05  .01  .03
1977 712A
1977 712P
1977 713A
1977 713P
STORM 77-7-1  HOURLY DISCHARGE IN CFS AT WILSON CREEK WEIR
1977 710A
1977 710P
1977 711A                                                                    2.0
1977 711P              2.0  2.8  4.2  6.8  7.0 10.3  9.7 30.0 62.7 72.7  149  410
1977 712A              460  540  540  540  515  500  515  515  515  435  400  340
1977 712P              294  243  193  148  108 93.8 88.0   83   78 72.5 67.7 62.7
1977 713A             59.9 56.9 54.2 52.0 50.0 48.0 46.2 44.6 43.0 41.8 40.2 39.0
1977 713P             36.4 33.3 33.3 33.3 33.3
STORM 77-7-1 OUTFLOW BALDHILL RESERVOIR IN CFS
1977 710A
1977 710P                                                                   1.03
1977 711A             1.03 1.06 1.06 1.06 1.10 1.13 1.90 2.70 3.13 3.54 3.89 4.16
1977 711P             4.31 4.47 4.58 4.65 4.71 4.74 4.78 4.82 4.86 4.90 4.93 4.94
1977 712A             4.95 4.96 4.98 4.98 4.98 4.98 4.98 4.97 4.97 4.97 4.96 4.95
1977 712P             4.94 4.92 4.89 4.86 4.84 4.82 4.80 4.78 4.75 4.73 4.71 4.69
1977 713A             4.74 4.65 4.64 4.62 4.60
1977 713P
       1.1      0.97
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LINEAR RESERVOIR SIMULATION MODEL
WILSON CREEK WATERSHED

LINEAR RESERVOIR OPTIMIZATION MAR 79

FIELD CAPACITY = 9.00 INCHES
TOTAL STORAGE CAPACITY =10.20 INCHES
MAXIMUM DEEP PERCOLATION RATE = .010 IN./HR.
SOIL MOISTURE CAPACITY OF SPRING RESERVOIR = 0.00 INCHES

PATTERN SEARCH TO OPTIMIZE FUNCTION

BASE POINT	KD	KP	KS	KDP	SIMULATED PEAK DISCHARGE IN CFS 69-6-1	74-5-1	75-8-1	75-9-1	77-7-1	FUNCTION VALUE	STEP LENGTH S1	S2	S3	S4
9	10.02	46.60	74.50	6.00	622.31	232.07	304.78	1344.55	628.90	2358.34793	-2.000	-2.000	-2.000	-2.000
18	10.02	46.60	74.50	6.00	620.94	231.11	303.11	1343.23	626.90	2358.34793	2.000	2.000	2.000	2.000
26	10.02	46.60	74.50	6.00	622.31	232.07	304.78	1344.55	628.90	2358.34793	-2.000	-2.000	-2.000	-2.000
34	10.02	47.60	75.50	6.00	623.27	233.11	304.73	1346.75	628.95	2357.53992	1.000	1.000	1.000	1.000
43	10.02	47.60	75.50	6.00	623.27	233.11	304.73	1346.75	628.95	2357.53992	1.000	-1.000	-1.000	1.000
51	10.02	47.60	75.50	6.00	623.95	233.58	305.57	1347.40	629.94	2357.53992	-1.000	1.000	1.000	-1.000
59	10.02	47.10	75.50	6.00	622.32	232.30	304.32	1345.16	628.36	2357.48793	.500	-.500	-.500	.500
68	10.02	47.10	75.50	6.00	622.32	232.30	304.32	1345.16	628.36	2357.48793	.500	.500	.500	.500
76	10.02	47.10	75.50	6.00	622.66	232.54	304.76	1345.49	628.86	2357.48793	-.500	-.500	-.500	-.500
84	10.02	47.35	75.50	6.00	622.97	232.83	304.74	1346.14	628.89	2357.41963	.250	.250	.250	.250
93	10.02	47.35	75.50	6.00	622.97	232.83	304.74	1346.14	628.89	2357.41963	.250	-.250	.250	.250
101	10.02	47.35	75.50	6.00	623.13	232.95	304.96	1346.30	629.14	2357.41963	-.250	.250	-.250	-.250
109	10.02	47.35	75.63	6.00	622.97	232.84	304.79	1346.13	628.94	2357.41691	.125	-.125	.125	.125
	CONVERGENCE OBTAINED IN 109 FUNCTIONAL EVALUATIONS													
	RECORDED PEAK				650.00	298.00	330.00	1340.00	540.00					

EVENT 1969-6-1

INITIAL SOIL MOISTURE DEFICIT = .76 INCHES
MAXIMUM PERCOLATION RATE = .25 IN./HR.
BASEFLOW = 4.00 CFS

INITIAL SOIL MOISTURE CONTENT OF SPRING RESERVOIR = 0.00 INCHES

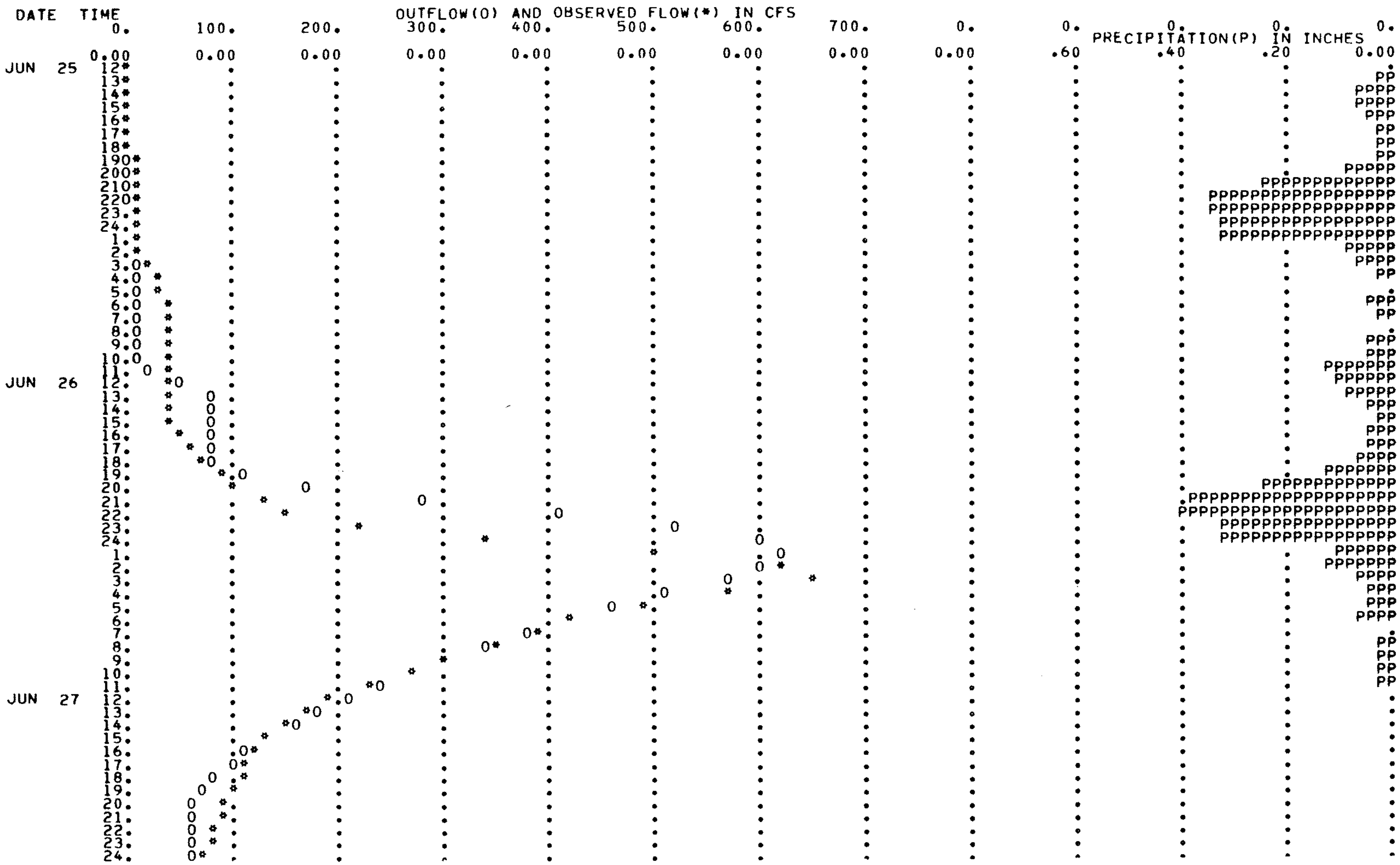
DAY	HOUR	PRECIP. IN.	PRECIP. EXCESS IN.	INFLOW CFS	DIRECT RUNOFF CFS	PERCOL FLOW CFS	DEEP PERCOL CFS	SPRING FLOW CFS	BALDHILL CFS	BASEFLOW FLOW CFS	SIMULATED FLOW CFS	OBSERVED CFS
25	12	0.000	0.000	0.00	0.00	0.00	0.00	0.00	.20	4.00	4.20	4.20
25	13	.010	0.000	0.00	0.00	0.00	0.00	0.00	.20	4.00	4.20	4.00
25	14	.070	0.000	0.00	0.00	0.00	0.00	0.00	.20	4.00	4.20	4.20
25	15	.070	0.000	0.00	0.00	0.00	0.00	0.00	.22	4.00	4.22	4.30
25	16	.040	0.000	0.00	0.00	0.00	0.00	0.00	.26	4.00	4.26	4.50
25	17	.010	0.000	0.00	0.00	0.00	0.00	0.00	.26	4.00	4.26	4.70
25	18	.010	0.000	0.00	0.00	0.00	0.00	0.00	.26	4.00	4.26	4.70
25	19	.020	0.000	0.00	0.00	0.00	0.00	0.00	.26	4.00	4.26	5.00
25	20	.080	0.000	0.00	0.00	0.00	0.00	0.00	.26	4.00	4.26	5.20
25	21	.240	0.000	0.00	0.00	0.00	0.00	0.00	.36	4.00	4.36	6.00
25	22	.350	.140	655.83	0.00	6.85	.52	0.00	.58	4.00	4.58	6.70
25	23	.340	.340	1592.73	0.00	30.21	3.24	0.00	1.01	4.00	5.01	7.70
25	24	.330	.330	1545.89	0.00	62.37	9.73	0.00	1.63	4.00	5.63	8.00
26	1	.330	.330	1545.89	0.00	93.37	20.02	0.00	3.29	4.00	7.29	9.00
26	2	.080	.080	374.76	0.00	111.49	32.46	0.00	3.59	4.00	7.59	14.20
26	3	.050	.050	234.23	0.00	115.53	44.69	0.00	3.85	4.00	7.85	19.30
26	4	.010	.010	46.85	0.00	116.05	46.85	.75	4.03	4.00	8.78	28.50
26	5	0.000	0.000	0.00	0.00	114.11	46.85	1.63	4.14	4.00	9.77	31.70
26	6	.030	.030	140.54	0.00	113.20	46.85	2.49	4.23	4.00	10.72	44.00
26	7	.020	.020	93.69	0.00	113.28	46.85	3.33	4.30	4.00	11.63	44.00
26	8	0.000	0.000	0.00	0.00	111.89	46.85	4.15	4.37	4.00	12.52	44.00
26	9	.030	.030	140.54	0.00	111.02	46.85	4.94	4.43	4.00	13.37	44.00
26	10	.030	.030	140.54	0.00	111.64	46.85	5.73	4.47	4.00	14.20	44.00
26	11	.120	.120	562.14	0.00	116.65	46.85	6.53	4.52	4.00	15.05	44.00
26	12	.110	.110	515.30	30.84	125.25	46.85	7.42	4.55	4.00	46.82	44.00
26	13	.080	.080	374.76	58.04	131.00	46.85	8.39	4.59	4.00	75.02	44.00
26	14	.040	.040	187.38	66.70	132.83	46.85	9.40	4.62	4.00	84.72	44.00
26	15	.020	.020	93.69	61.14	131.66	46.85	10.40	4.64	4.00	80.18	44.00
26	16	.040	.040	187.38	56.23	130.62	46.85	11.37	4.67	4.00	76.26	46.00
26	17	.040	.040	187.38	56.28	130.63	46.85	12.32	4.70	4.00	77.30	58.00
26	18	.070	.070	327.92	62.93	132.04	46.85	13.27	4.73	4.00	84.93	72.30
26	19	.130	.130	608.99	88.67	137.48	46.85	14.25	4.75	4.00	111.67	88.00
26	20	.230	.230	1077.44	146.74	149.77	46.85	15.33	4.79	4.00	170.87	102.00
26	21	.380	.380	1780.11	253.30	172.32	46.85	16.63	4.81	4.00	278.74	125.00
26	22	.410	.410	1920.65	387.38	200.70	46.85	18.25	4.85	4.00	414.48	146.00
26	23	.330	.330	1545.89	495.16	223.50	46.85	20.18	4.89	4.00	524.23	216.00
26	24	.320	.320	1499.04	570.80	239.51	46.85	22.34	4.96	4.00	602.10	335.00
27	1	.110	.110	515.30	589.33	243.43	46.85	24.60	5.04	4.00	622.97	498.00
27	2	.130	.130	608.99	563.86	238.04	46.85	26.83	5.14	4.00	599.83	620.00
27	3	.050	.050	234.23	528.07	230.47	46.85	28.94	5.24	4.00	566.25	650.00
27	4	.030	.030	140.54	474.32	219.09	46.85	30.89	5.31	4.00	514.52	571.00
27	5	.030	.030	140.54	422.29	208.08	46.85	32.68	5.38	4.00	464.35	493.00
27	6	.050	.050	234.23	380.60	199.26	46.85	34.31	5.43	4.00	424.34	420.00
27	7	0.000	0.000	0.00	337.05	190.04	46.85	35.80	5.48	4.00	382.33	385.00
27	8	.010	.010	46.85	289.65	180.01	46.85	37.14	5.52	4.00	336.31	345.00
27	9	.020	.020	93.69	252.06	172.06	46.85	38.35	5.56	4.00	299.97	301.00
27	10	.020	.020	93.69	220.96	165.48	46.85	39.45	5.58	4.00	270.00	267.00
27	11	.010	.010	46.85	191.21	159.18	46.85	40.45	5.59	4.00	241.25	225.00
27	12	0.000	0.000	0.00	160.44	152.67	46.85	41.35	5.62	4.00	211.41	185.00
27	13	0.000	0.000	0.00	130.97	146.44	46.85	42.16	5.64	4.00	182.77	169.00
27	14	0.000	0.000	0.00	104.86	140.91	46.85	42.88	5.65	4.00	157.39	146.00
27	15	0.000	0.000	0.00	81.73	136.02	46.85	43.52	5.66	4.00	134.91	128.00

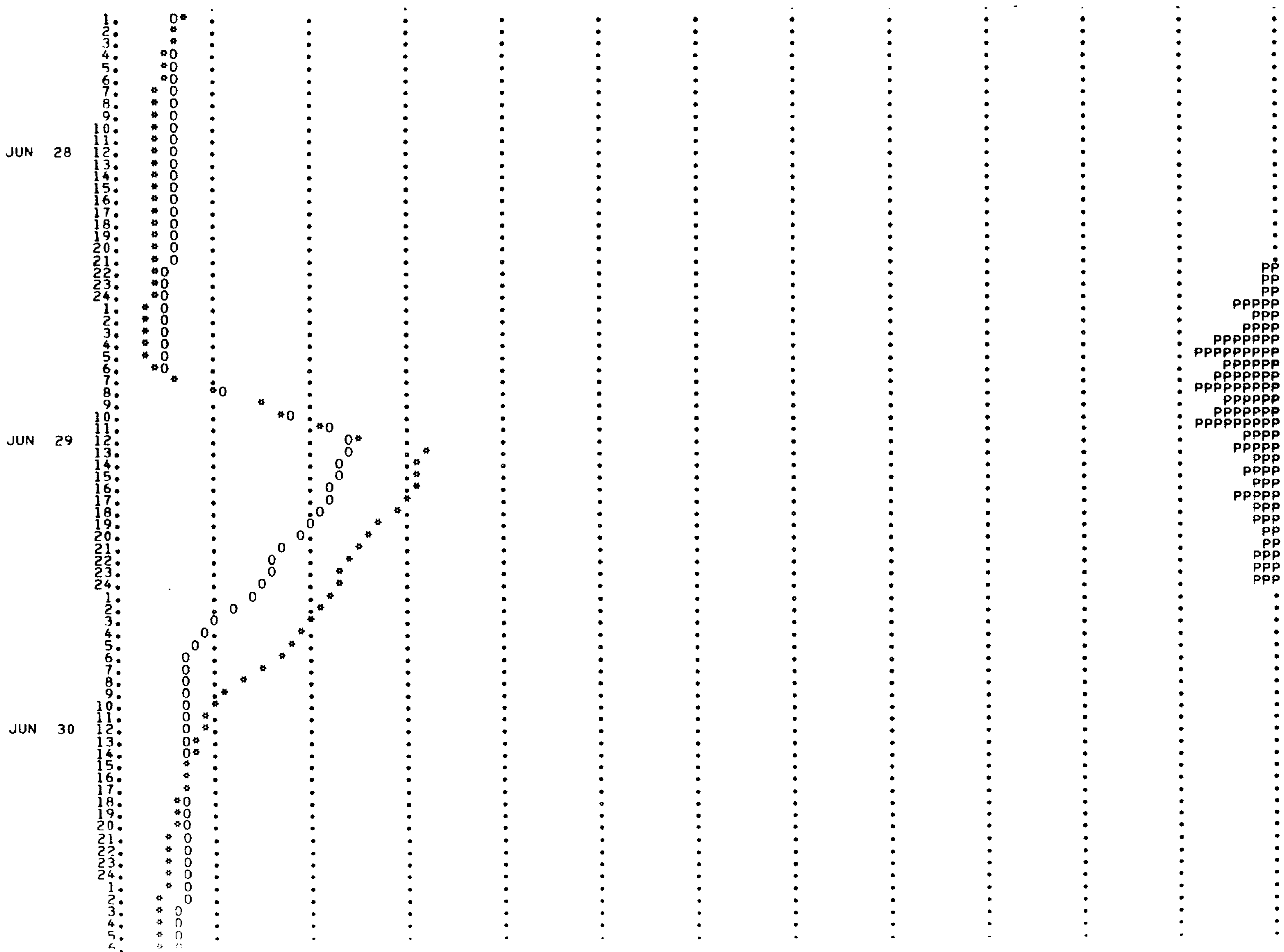
27	16	0.000	0.000	0.00	61.24	131.68	46.85	44.09	5.67	4.00	115.00	118.00
27	17	0.000	0.000	0.00	43.09	127.84	46.85	44.60	5.69	4.00	97.37	112.00
27	18	0.000	0.000	0.00	27.00	124.43	46.85	45.05	5.69	4.00	81.74	105.00
27	19	0.000	0.000	0.00	12.75	121.42	46.85	45.46	5.69	4.00	67.90	99.60
27	20	0.000	0.000	0.00	.12	118.75	46.85	45.83	5.70	4.00	55.65	90.50
27	21	0.000	0.000	0.00	0.00	116.26	46.85	46.15	5.71	4.00	55.86	88.00
27	22	0.000	0.000	0.00	0.00	113.83	46.85	46.44	5.71	4.00	56.15	83.00
27	23	0.000	0.000	0.00	0.00	111.46	46.85	46.70	5.72	4.00	56.42	79.50
27	24	0.000	0.000	0.00	0.00	109.13	46.85	46.92	5.72	4.00	56.64	67.80
28	1	0.000	0.000	0.00	0.00	106.85	46.85	47.10	5.72	4.00	56.82	67.80
28	2	0.000	0.000	0.00	0.00	104.61	46.85	47.26	5.72	4.00	56.98	60.30
28	3	0.000	0.000	0.00	0.00	102.43	46.85	47.38	5.73	4.00	57.11	58.00
28	4	0.000	0.000	0.00	0.00	100.29	46.85	47.48	5.73	4.00	57.21	53.00
28	5	0.000	0.000	0.00	0.00	98.19	46.85	47.54	5.73	4.00	57.27	51.30
28	6	0.000	0.000	0.00	0.00	96.14	46.85	47.58	5.73	4.00	57.31	46.00
28	7	0.000	0.000	0.00	0.00	94.13	46.85	47.59	5.74	4.00	57.33	44.00
28	8	0.000	0.000	0.00	0.00	92.16	46.85	47.57	5.74	4.00	57.31	42.30
28	9	0.000	0.000	0.00	0.00	90.24	46.85	47.53	5.74	4.00	57.27	42.30
28	10	0.000	0.000	0.00	0.00	88.35	46.85	47.46	5.74	4.00	57.20	42.30
28	11	0.000	0.000	0.00	0.00	86.50	46.85	47.37	5.74	4.00	57.11	40.70
28	12	0.000	0.000	0.00	0.00	84.70	46.85	47.26	5.74	4.00	57.00	40.70
28	13	0.000	0.000	0.00	0.00	82.93	46.85	47.12	5.74	4.00	56.86	39.00
28	14	0.000	0.000	0.00	0.00	81.19	46.85	46.96	5.74	4.00	56.70	37.00
28	15	0.000	0.000	0.00	0.00	79.50	46.85	46.79	5.74	4.00	56.53	37.00
28	16	0.000	0.000	0.00	0.00	77.83	46.85	46.59	5.74	4.00	56.33	37.00
28	17	0.000	0.000	0.00	0.00	76.21	46.85	46.38	5.74	4.00	56.12	37.00
28	18	0.000	0.000	0.00	0.00	74.62	46.85	46.14	5.74	4.00	55.88	37.00
28	19	0.000	0.000	0.00	0.00	73.06	46.85	45.89	5.74	4.00	55.63	35.00
28	20	0.000	0.000	0.00	0.00	71.53	46.85	45.62	5.74	4.00	55.36	35.00
28	21	0.000	0.000	0.00	0.00	70.03	46.85	45.34	5.74	4.00	55.08	35.00
28	22	.010	.010	46.85	0.00	69.06	46.85	45.04	5.74	4.00	54.78	35.00
28	23	.020	.020	93.69	0.00	69.09	46.85	44.74	5.73	4.00	54.47	35.00
28	24	.020	.020	93.69	0.00	69.60	46.85	44.45	5.73	4.00	54.18	35.00
29	1	.090	.090	421.61	0.00	73.53	46.85	44.19	5.73	4.00	53.92	27.00
29	2	.040	.040	187.38	0.00	78.36	46.85	43.99	5.73	4.00	53.72	28.50
29	3	.060	.060	281.07	0.00	81.61	46.85	43.85	5.73	4.00	53.58	28.50
29	4	.130	.130	608.99	0.00	89.21	46.85	43.78	5.73	4.00	53.51	30.00
29	5	.160	.160	749.52	0.00	101.54	46.85	43.84	5.74	4.00	53.58	33.30
29	6	.100	.100	468.45	0.00	112.14	46.85	44.05	5.74	4.00	53.79	42.30
29	7	.120	.120	562.14	9.79	120.79	46.85	44.39	5.74	4.00	63.92	60.30
29	8	.160	.160	749.52	59.22	131.25	46.85	44.85	5.75	4.00	113.82	99.60
29	9	.100	.100	468.45	98.61	139.59	46.85	45.42	5.75	4.00	153.78	146.00
29	10	.120	.120	562.14	124.69	145.11	46.85	46.08	5.76	4.00	180.53	169.00
29	11	.160	.160	749.52	161.02	152.79	46.85	46.81	5.76	4.00	217.59	207.00
29	12	.060	.060	281.07	179.98	156.81	46.85	47.62	5.77	4.00	237.37	248.00
29	13	.090	.090	421.61	181.35	157.10	46.85	48.44	5.78	4.00	239.57	316.00
29	14	.030	.030	140.54	175.95	155.95	46.85	49.24	5.79	4.00	234.98	311.00
29	15	.070	.070	327.92	166.76	154.01	46.85	50.02	5.80	4.00	226.57	311.00
29	16	.040	.040	187.38	160.82	152.75	46.85	50.76	5.81	4.00	221.39	306.00
29	17	.080	.080	374.76	157.76	152.10	46.85	51.48	5.82	4.00	219.06	301.00
29	18	.030	.030	140.54	152.84	151.06	46.85	52.18	5.83	4.00	214.85	287.00
29	19	.040	.040	187.38	139.67	148.28	46.85	52.84	5.84	4.00	202.36	267.00
29	20	.020	.020	93.69	125.80	145.34	46.85	53.46	5.84	4.00	189.10	258.00
29	21	.010	.010	46.85	106.90	141.34	46.85	54.03	5.85	4.00	170.77	248.00
29	22	.040	.040	187.38	94.56	138.73	46.85	54.54	5.86	4.00	158.96	243.00
29	23	.040	.040	187.38	90.24	137.82	46.85	55.03	5.87	4.00	155.13	229.00
29	24	.040	.040	187.38	86.41	137.01	46.85	55.49	5.87	4.00	151.77	225.00
30	1	0.000	0.000	0.00	74.20	134.42	46.85	55.93	5.87	4.00	140.00	217.00
30	2	0.000	0.000	0.00	54.57	130.27	46.85	56.32	5.87	4.00	120.76	210.00
30	3	0.000	0.000	0.00	37.17	126.59	46.85	56.65	5.88	4.00	103.70	202.00
30	4	0.000	0.000	0.00	21.76	123.32	46.85	56.93	5.88	4.00	88.57	192.00
30	5	0.000	0.000	0.00	8.11	120.44	46.85	57.17	5.89	4.00	75.17	181.00
30	6	0.000	0.000	0.00	0.00	117.92	46.85	57.37	5.89	4.00	67.26	169.00
30	7	0.000	0.000	0.00	0.00	115.45	46.85	57.54	5.89	4.00	67.43	148.00
30	8	0.000	0.000	0.00	0.00	113.04	46.85	57.66	5.89	4.00	67.55	125.00
30	9	0.000	0.000	0.00	0.00	110.68	46.85	57.76	5.90	4.00	67.66	113.00
30	10	0.000	0.000	0.00	0.00	108.37	46.85	57.83	5.90	4.00	67.73	103.00
30	11	0.000	0.000	0.00	0.00	106.10	46.85	57.86	5.90	4.00	67.76	94.40

30	12	0.000	0.000	0.00	0.00	103.88	46.85	57.86	5.91	4.00	67.77	88.00
30	13	0.000	0.000	0.00	0.00	101.71	46.85	57.84	5.91	4.00	67.75	82.00
30	14	0.000	0.000	0.00	0.00	99.59	46.85	57.79	5.91	4.00	67.70	77.50
30	15	0.000	0.000	0.00	0.00	97.51	46.85	57.71	5.91	4.00	67.62	73.50
30	16	0.000	0.000	0.00	0.00	95.47	46.85	57.60	5.91	4.00	67.51	69.50
30	17	0.000	0.000	0.00	0.00	93.47	46.85	57.47	5.91	4.00	67.38	66.00
30	18	0.000	0.000	0.00	0.00	91.52	46.85	57.31	5.91	4.00	67.22	62.70
30	19	0.000	0.000	0.00	0.00	89.61	46.85	57.13	5.91	4.00	67.04	59.90
30	20	0.000	0.000	0.00	0.00	87.73	46.85	56.93	5.91	4.00	66.84	57.20
30	21	0.000	0.000	0.00	0.00	85.90	46.85	56.71	5.91	4.00	66.62	54.70
30	22	0.000	0.000	0.00	0.00	84.11	46.85	56.47	5.91	4.00	66.38	52.20
30	23	0.000	0.000	0.00	0.00	82.35	46.85	56.20	5.91	4.00	66.11	50.10
30	24	0.000	0.000	0.00	0.00	80.63	46.85	55.92	5.91	4.00	65.83	48.00
1	1	0.000	0.000	0.00	0.00	78.94	46.85	55.62	5.91	4.00	65.53	46.00
1	2	0.000	0.000	0.00	0.00	77.29	46.85	55.30	5.91	4.00	65.21	44.00
1	3	0.000	0.000	0.00	0.00	75.68	46.85	54.96	5.91	4.00	64.87	42.10
1	4	0.000	0.000	0.00	0.00	74.10	46.85	54.61	5.91	4.00	64.52	40.30
1	5	0.000	0.000	0.00	0.00	72.55	46.85	54.24	5.91	4.00	64.15	38.80
1	6	0.000	0.000	0.00	0.00	71.03	46.85	53.85	5.91	4.00	63.76	37.30
1	7	0.000	0.000	0.00	0.00	69.55	46.85	53.45	5.91	4.00	63.36	35.70
1	8	0.000	0.000	0.00	0.00	68.09	46.85	53.04	5.91	4.00	62.95	34.40
1	9	0.000	0.000	0.00	0.00	66.67	46.85	52.61	5.91	4.00	62.52	33.10
1	10	0.000	0.000	0.00	0.00	65.28	46.85	52.17	5.91	4.00	62.08	32.00
1	11	0.000	0.000	0.00	0.00	63.91	46.85	51.72	5.91	4.00	61.63	31.00
1	12	0.000	0.000	0.00	0.00	62.58	46.85	51.26	5.91	4.00	61.17	30.00
1	13	0.000	0.000	0.00	0.00	61.27	46.85	50.78	5.91	4.00	60.69	29.50
1	14	0.000	0.000	0.00	0.00	59.99	46.85	50.30	5.91	4.00	60.21	29.00
1	15	0.000	0.000	0.00	0.00	58.73	46.85	49.80	5.90	4.00	59.70	28.40
1	16	0.000	0.000	0.00	0.00	57.51	46.85	49.29	5.90	4.00	59.19	28.00
1	17	0.000	0.000	0.00	0.00	56.31	46.85	48.78	5.90	4.00	58.68	27.60
1	18	0.000	0.000	0.00	0.00	55.13	46.85	48.25	5.90	4.00	58.15	27.30
1	19	0.000	0.000	0.00	0.00	53.98	46.85	47.72	5.90	4.00	57.62	27.00
1	20	0.000	0.000	0.00	0.00	52.85	46.85	47.18	5.89	4.00	57.07	26.70
1	21	0.000	0.000	0.00	0.00	51.74	46.85	46.63	5.89	4.00	56.52	26.40
1	22	0.000	0.000	0.00	0.00	50.66	46.85	46.08	5.89	4.00	55.97	26.10
1	23	0.000	0.000	0.00	0.00	49.60	46.85	45.52	5.89	4.00	55.41	25.90
1	24	0.000	0.000	0.00	0.00	48.57	46.85	44.95	5.89	4.00	54.84	25.70

VOLUME OF RECORDED STORM = 16858.8 CFS.HR.
VOLUME OF SIMULATED STORM = 17143.7 CFS.HR.

STORM NUMBER 1969-6-1




JUN 28
JUN 29
JUN 30

EVENT 1974-5-1

INITIAL SOIL MOISTURE DEFICIT = 0.00 INCHES
MAXIMUM PERCOLATION RATE = .25 IN./HR.
BASEFLOW = 13.42 CFS

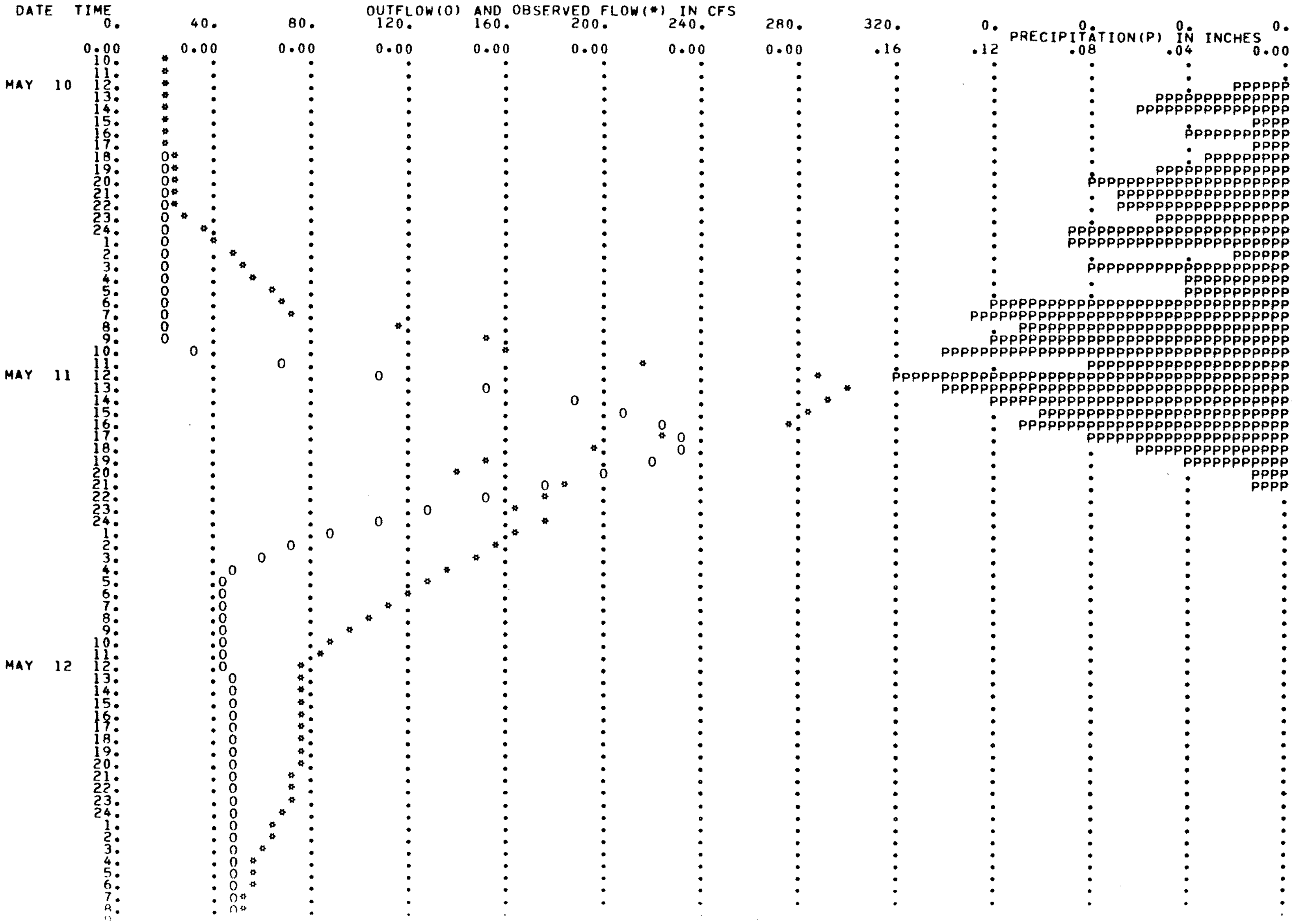
INITIAL SOIL MOISTURE CONTENT OF SPRING RESERVOIR = 0.00 INCHES

DAY	HOUR	PRECIP. IN.	PRECIP. EXCESS IN.	INFLOW CFS	DIRECT RUNOFF CFS	PERCOL FLOW CFS	DEEP PERCOL CFS	SPRING FLOW CFS	BALDHILL CFS	BASEFLOW FLOW CFS	SIMULATED FLOW CFS	OBSERVED CFS
10	10	0.000	0.000	0.00	0.00	0.00	0.00	0.00	4.98	13.42	18.40	18.40
10	11	0.000	0.000	0.00	0.00	0.00	0.00	0.00	4.98	13.42	18.40	18.40
10	12	.020	.020	93.69	0.00	.98	.07	0.00	4.98	13.42	18.40	18.40
10	13	.050	.050	234.23	0.00	4.39	.47	0.00	4.98	13.42	18.40	18.40
10	14	.060	.060	281.07	0.00	9.68	1.46	0.00	4.98	13.42	18.40	18.40
10	15	.010	.010	46.85	0.00	12.90	2.94	0.00	4.98	13.42	18.40	19.10
10	16	.040	.040	187.38	0.00	15.08	4.61	0.00	4.98	13.42	18.40	19.80
10	17	.010	.010	46.85	0.00	17.21	6.35	0.00	4.98	13.42	18.40	19.80
10	18	.030	.030	140.54	0.00	18.81	8.11	0.00	4.99	13.42	18.41	22.00
10	19	.050	.050	234.23	0.00	22.33	9.99	0.00	4.99	13.42	18.41	23.50
10	20	.080	.080	374.76	0.00	28.23	12.30	0.00	4.99	13.42	18.41	23.50
10	21	.070	.070	327.92	0.00	34.98	15.21	0.00	4.99	13.42	18.41	24.20
10	22	.070	.070	327.92	0.00	41.10	18.66	0.00	4.99	13.42	18.41	25.70
10	23	.050	.050	234.23	0.00	46.12	22.43	0.00	4.99	13.42	18.41	29.10
10	24	.090	.090	421.61	0.00	52.01	26.45	0.00	5.01	13.42	18.43	35.30
11	1	.090	.090	421.61	0.00	59.73	30.89	0.00	5.07	13.42	18.49	40.00
11	2	.020	.020	93.69	0.00	63.87	35.55	0.00	5.08	13.42	18.50	46.00
11	3	.080	.080	374.76	0.00	67.43	40.10	0.00	5.08	13.42	18.50	51.20
11	4	.040	.040	187.38	0.00	71.89	44.56	0.00	5.09	13.42	18.51	55.50
11	5	.040	.040	187.38	0.00	74.31	46.85	.18	5.11	13.42	18.71	63.70
11	6	.120	.120	562.14	0.00	80.59	46.85	.58	5.12	13.42	19.12	68.60
11	7	.130	.130	608.99	0.00	91.14	46.85	1.08	5.14	13.42	19.64	72.30
11	8	.110	.110	515.30	0.00	100.98	46.85	1.71	5.16	13.42	20.29	117.00
11	9	.120	.120	562.14	0.00	110.13	46.85	2.46	5.18	13.42	21.06	152.00
11	10	.140	.140	655.83	10.18	120.87	46.85	3.33	5.21	13.42	32.14	159.00
11	11	.080	.080	374.76	46.34	128.53	46.85	4.31	5.23	13.42	69.30	216.00
11	12	.160	.160	749.52	82.79	136.24	46.85	5.38	5.25	13.42	106.84	287.00
11	13	.140	.140	655.83	128.30	145.87	46.85	6.55	5.29	13.42	153.56	298.00
11	14	.120	.120	562.14	159.81	152.54	46.85	7.80	5.31	13.42	186.35	292.00
11	15	.100	.100	468.45	178.91	156.58	46.85	9.12	5.33	13.42	206.78	284.00
11	16	.110	.110	515.30	193.63	159.69	46.85	10.46	5.34	13.42	222.85	274.00
11	17	.080	.080	374.76	202.26	161.52	46.85	11.82	5.35	13.42	232.84	225.00
11	18	.060	.060	281.07	198.88	160.81	46.85	13.16	5.37	13.42	230.84	195.00
11	19	.040	.040	187.38	187.08	158.31	46.85	14.47	5.39	13.42	220.36	150.00
11	20	.010	.010	46.85	165.59	153.76	46.85	15.71	5.40	13.42	200.13	140.00
11	21	.010	.010	46.85	139.95	148.34	46.85	16.88	5.41	13.42	175.65	185.00
11	22	0.000	0.000	0.00	115.02	143.06	46.85	17.95	5.42	13.42	151.81	175.00
11	23	0.000	0.000	0.00	90.73	137.92	46.85	18.95	5.43	13.42	128.53	165.00
11	24	0.000	0.000	0.00	69.21	133.37	46.85	19.87	5.44	13.42	107.94	175.00
12	1	0.000	0.000	0.00	50.15	129.33	46.85	20.71	5.45	13.42	89.73	165.00
12	2	0.000	0.000	0.00	33.26	125.76	46.85	21.50	5.46	13.42	73.64	156.00
12	3	0.000	0.000	0.00	18.29	122.59	46.85	22.24	5.47	13.42	59.42	146.00
12	4	0.000	0.000	0.00	5.03	119.79	46.85	22.92	5.48	13.42	46.85	137.00
12	5	0.000	0.000	0.00	0.00	117.28	46.85	23.56	5.49	13.42	42.47	128.00
12	6	0.000	0.000	0.00	0.00	114.83	46.85	24.16	5.49	13.42	43.07	120.00
12	7	0.000	0.000	0.00	0.00	112.43	46.85	24.72	5.50	13.42	43.64	112.00
12	8	0.000	0.000	0.00	0.00	110.08	46.85	25.24	5.50	13.42	44.16	104.00
12	9	0.000	0.000	0.00	0.00	107.78	46.85	25.73	5.51	13.42	44.66	96.00
12	10	0.000	0.000	0.00	0.00	105.53	46.85	26.17	5.51	13.42	45.10	89.00
12	11	0.000	0.000	0.00	0.00	103.32	46.85	26.59	5.52	13.42	45.53	82.00
12	12	0.000	0.000	0.00	0.00	101.16	46.85	26.96	5.52	13.42	45.90	75.90
12	13	0.000	0.000	0.00	0.00	99.05	46.85	27.31	5.53	13.42	46.26	75.90

12	14	0.000	0.000	0.00	0.00	96.98	46.85	27.62	5.53	13.42	46.57	75.90
12	15	0.000	0.000	0.00	0.00	94.95	46.85	27.91	5.54	13.42	46.87	75.90
12	16	0.000	0.000	0.00	0.00	92.97	46.85	28.16	5.55	13.42	47.13	75.90
12	17	0.000	0.000	0.00	0.00	91.03	46.85	28.38	5.56	13.42	47.36	75.90
12	18	0.000	0.000	0.00	0.00	89.12	46.85	28.58	5.57	13.42	47.57	75.90
12	19	0.000	0.000	0.00	0.00	87.26	46.85	28.74	5.57	13.42	47.73	75.10
12	20	0.000	0.000	0.00	0.00	85.44	46.85	28.89	5.58	13.42	47.89	74.40
12	21	0.000	0.000	0.00	0.00	83.65	46.85	29.00	5.58	13.42	48.00	73.60
12	22	0.000	0.000	0.00	0.00	81.90	46.85	29.09	5.59	13.42	48.10	72.20
12	23	0.000	0.000	0.00	0.00	80.19	46.85	29.16	5.59	13.42	48.17	70.50
12	24	0.000	0.000	0.00	0.00	78.52	46.85	29.20	5.59	13.42	48.21	68.60
13	1	0.000	0.000	0.00	0.00	76.87	46.85	29.23	5.59	13.42	48.24	65.00
13	2	0.000	0.000	0.00	0.00	75.27	46.85	29.23	5.60	13.42	48.25	62.30
13	3	0.000	0.000	0.00	0.00	73.70	46.85	29.20	5.60	13.42	48.22	60.00
13	4	0.000	0.000	0.00	0.00	72.16	46.85	29.16	5.60	13.42	48.18	57.80
13	5	0.000	0.000	0.00	0.00	70.65	46.85	29.10	5.61	13.42	48.13	56.00
13	6	0.000	0.000	0.00	0.00	69.17	46.85	29.02	5.61	13.42	48.05	54.40
13	7	0.000	0.000	0.00	0.00	67.73	46.85	28.93	5.61	13.42	47.96	52.80
13	8	0.000	0.000	0.00	0.00	66.31	46.85	28.81	5.61	13.42	47.84	51.30
13	9	0.000	0.000	0.00	0.00	64.92	46.85	28.68	5.61	13.42	47.71	49.90
13	10	0.000	0.000	0.00	0.00	63.57	46.85	28.53	5.61	13.42	47.56	48.70
13	11	0.000	0.000	0.00	0.00	62.24	46.85	28.37	5.61	13.42	47.40	47.40
13	12	0.000	0.000	0.00	0.00	60.94	46.85	28.19	5.61	13.42	47.22	46.00
13	13	0.000	0.000	0.00	0.00	59.66	46.85	27.99	5.62	13.42	47.03	45.00
13	14	0.000	0.000	0.00	0.00	58.42	46.85	27.79	5.62	13.42	46.83	44.30
13	15	0.000	0.000	0.00	0.00	57.20	46.85	27.57	5.62	13.42	46.61	43.40
13	16	0.000	0.000	0.00	0.00	56.00	46.85	27.33	5.63	13.42	46.38	42.70
13	17	0.000	0.000	0.00	0.00	54.83	46.85	27.09	5.63	13.42	46.14	41.80
13	18	0.000	0.000	0.00	0.00	53.69	46.85	26.83	5.63	13.42	45.88	41.00
13	19	0.000	0.000	0.00	0.00	52.56	46.85	26.56	5.63	13.42	45.61	40.20
13	20	0.000	0.000	0.00	0.00	51.46	46.85	26.28	5.63	13.42	45.33	39.60
13	21	0.000	0.000	0.00	0.00	50.39	46.85	25.98	5.63	13.42	45.03	38.80
13	22	0.000	0.000	0.00	0.00	49.34	46.85	25.68	5.63	13.42	44.73	38.00
13	23	0.000	0.000	0.00	0.00	48.31	46.85	25.37	5.63	13.42	44.42	37.10
13	24	0.000	0.000	0.00	0.00	47.30	46.85	25.05	5.63	13.42	44.10	36.20
14	1	0.000	0.000	0.00	0.00	46.31	46.85	24.72	5.63	13.42	43.77	35.00
14	2	0.000	0.000	0.00	0.00	45.34	46.85	24.38	5.63	13.42	43.43	34.00
14	3	0.000	0.000	0.00	0.00	44.39	46.85	24.04	5.63	13.42	43.09	32.80
14	4	0.000	0.000	0.00	0.00	43.46	46.85	23.68	5.63	13.42	42.73	31.70
14	5	0.000	0.000	0.00	0.00	42.56	46.85	23.32	5.63	13.42	42.37	30.80
14	6	0.000	0.000	0.00	0.00	41.67	46.85	22.95	5.63	13.42	42.00	30.00
14	7	0.000	0.000	0.00	0.00	40.80	46.85	22.58	5.63	13.42	41.63	29.40
14	8	0.000	0.000	0.00	0.00	39.94	46.85	22.20	5.63	13.42	41.25	29.00
14	9	0.000	0.000	0.00	0.00	39.11	46.85	21.81	5.63	13.42	40.86	28.50
14	10	0.000	0.000	0.00	0.00	38.29	46.85	21.41	5.63	13.42	40.46	28.10
14	11	0.000	0.000	0.00	0.00	37.49	46.85	21.02	5.64	13.42	40.08	27.70
14	12	0.000	0.000	0.00	0.00	36.71	46.85	20.61	5.64	13.42	39.67	27.40

VOLUME OF RECORDED STORM = 8025.1 CFS.HR.
VOLUME OF SIMULATED STORM = 5693.1 CFS.HR.

STORM NUMBER 1974-5-1



EVENT 1975-8-2

INITIAL SOIL MOISTURE DEFICIT = .76 INCHES
MAXIMUM PERCOLATION RATE = .25 IN./HR.
BASEFLOW = 2.70 CFS

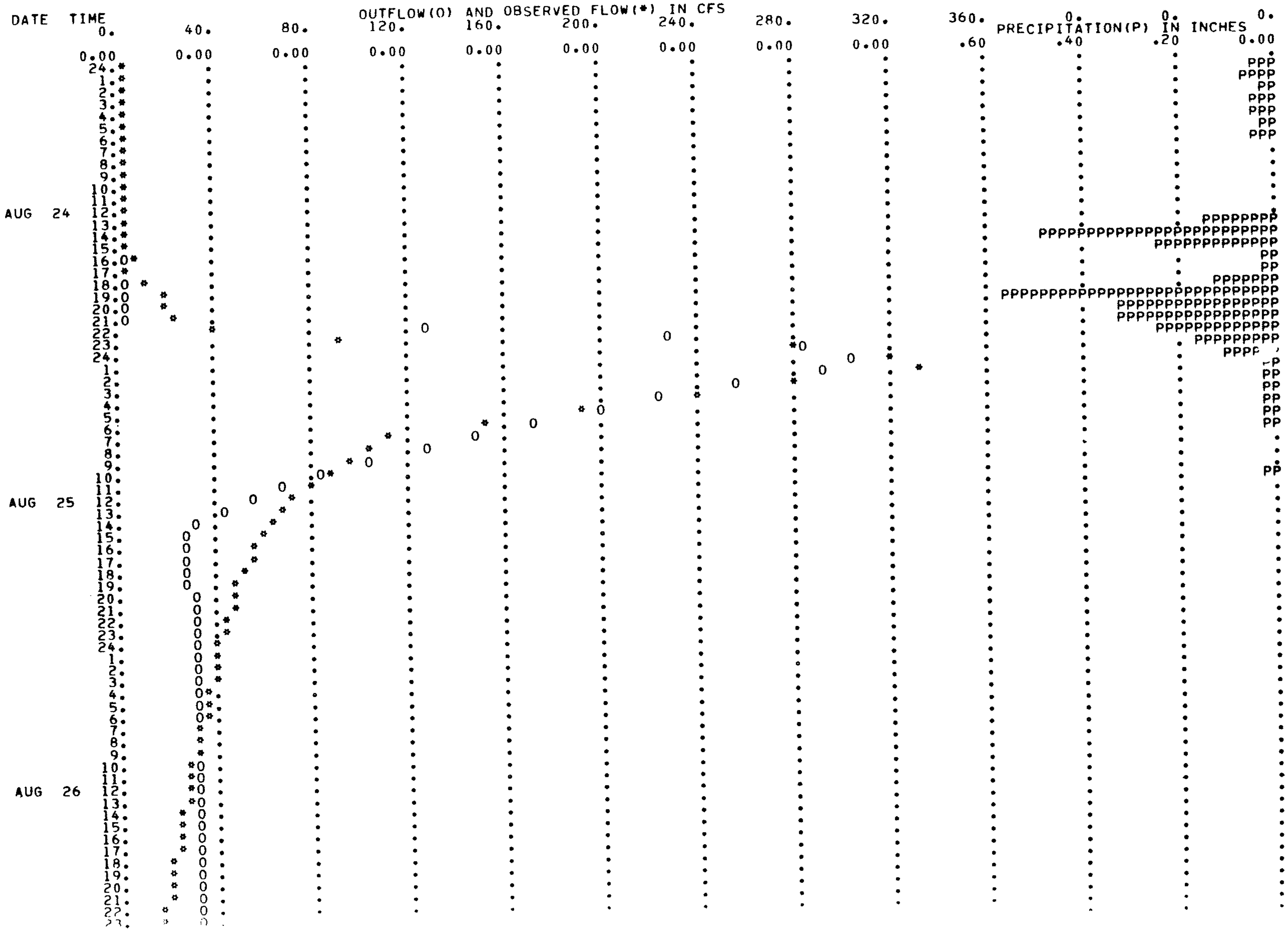
INITIAL SOIL MOISTURE CONTENT OF SPRING RESERVOIR = 0.00 INCHES

DAY	HOUR	PRECIP. IN.	PRECIP. EXCESS IN.	INFLOW CFS	DIRECT RUNOFF CFS	PERCOL FLOW CFS	DEEP PERCOL CFS	SPRING FLOW CFS	BALDHILL CFS	BASEFLOW FLOW CFS	SIMULATED FLOW CFS	OBSERVED CFS
23	24	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	1	.040	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	2	.060	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	3	.020	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	4	.040	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	5	.030	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	6	.020	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	7	.040	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	8	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	9	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	10	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	3.00
24	11	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	12	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	13	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	14	.140	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70
24	15	.490	.120	562.14	0.00	5.87	.44	0.00	0.00	2.70	2.70	4.30
24	16	.250	.250	1171.13	0.00	23.86	2.62	0.00	0.00	2.70	2.70	6.00
24	17	.020	.020	93.69	0.00	36.58	6.79	0.00	1.78	2.70	4.48	5.30
24	18	.010	.010	46.85	0.00	37.28	11.34	0.00	2.66	2.70	5.36	11.50
24	19	.120	.120	562.14	0.00	42.87	15.68	0.00	2.81	2.70	5.51	20.50
24	20	.570	.570	2670.17	0.00	75.75	22.26	0.00	2.91	2.70	5.61	18.00
24	21	.310	.310	1452.20	0.00	117.24	33.47	0.00	3.03	2.70	5.73	25.60
24	22	.320	.320	1499.04	121.51	144.43	46.85	.12	3.28	2.70	127.61	40.50
24	23	.240	.240	1124.28	219.92	165.26	46.85	1.54	3.48	2.70	227.64	90.00
24	24	.170	.170	796.37	274.05	176.71	46.85	3.15	3.69	2.70	283.59	280.00
25	1	.110	.110	515.30	293.35	180.80	46.85	4.84	3.90	2.70	304.79	320.00
25	2	.020	.020	93.69	277.38	177.42	46.85	6.51	4.00	2.70	290.59	330.00
25	3	.010	.010	46.85	241.19	169.76	46.85	8.09	4.08	2.70	256.07	280.00
25	4	.020	.020	93.69	209.13	162.98	46.85	9.56	4.16	2.70	225.55	240.00
25	5	.010	.010	46.85	180.72	156.96	46.85	10.92	4.20	2.70	198.54	190.00
25	6	.010	.010	46.85	153.35	151.17	46.85	12.18	4.23	2.70	172.47	150.00
25	7	.010	.010	46.85	129.10	146.04	46.85	13.36	4.25	2.70	149.41	110.00
25	8	0.000	0.000	0.00	105.41	141.03	46.85	14.45	4.26	2.70	126.83	102.00
25	9	0.000	0.000	0.00	82.22	136.12	46.85	15.47	4.28	2.70	104.67	95.00
25	10	0.000	0.000	0.00	61.67	131.77	46.85	16.41	4.30	2.70	85.08	87.00
25	11	.010	.010	46.85	45.67	128.38	46.85	17.29	4.31	2.70	69.97	80.00
25	12	0.000	0.000	0.00	31.49	125.38	46.85	18.11	4.31	2.70	56.62	71.00
25	13	0.000	0.000	0.00	16.73	122.26	46.85	18.89	4.31	2.70	42.63	67.00
25	14	0.000	0.000	0.00	3.65	119.49	46.85	19.61	4.31	2.70	30.27	63.30
25	15	0.000	0.000	0.00	0.00	117.00	46.85	20.29	4.31	2.70	27.30	60.30
25	16	0.000	0.000	0.00	0.00	114.55	46.85	20.93	4.30	2.70	27.93	57.50
25	17	0.000	0.000	0.00	0.00	112.16	46.85	21.53	4.30	2.70	28.53	54.50
25	18	0.000	0.000	0.00	0.00	109.81	46.85	22.09	4.30	2.70	29.09	51.40
25	19	0.000	0.000	0.00	0.00	107.52	46.85	22.61	4.29	2.70	29.60	49.30
25	20	0.000	0.000	0.00	0.00	105.27	46.85	23.10	4.29	2.70	30.09	47.50
25	21	0.000	0.000	0.00	0.00	103.07	46.85	23.55	4.28	2.70	30.53	46.10
25	22	0.000	0.000	0.00	0.00	100.92	46.85	23.96	4.28	2.70	30.94	44.40
25	23	0.000	0.000	0.00	0.00	98.81	46.85	24.34	4.27	2.70	31.31	42.90
25	24	0.000	0.000	0.00	0.00	96.74	46.85	24.69	4.27	2.70	31.66	41.40
26	1	0.000	0.000	0.00	0.00	94.72	46.85	25.01	4.27	2.70	31.98	40.20
26	2	0.000	0.000	0.00	0.00	92.74	46.85	25.30	4.27	2.70	32.27	39.10
26	3	0.000	0.000	0.00	0.00	90.80	46.85	25.55	4.27	2.70	32.52	38.00

26	4	0.000	0.000	0.00	0.00	88.91	46.85	25.78	4.27	2.70	32.75	36.90
26	5	0.000	0.000	0.00	0.00	87.05	46.85	25.99	4.27	2.70	32.96	35.80
26	6	0.000	0.000	0.00	0.00	85.23	46.85	26.16	4.27	2.70	33.13	34.50
26	7	0.000	0.000	0.00	0.00	83.45	46.85	26.31	4.27	2.70	33.28	33.30
26	8	0.000	0.000	0.00	0.00	81.70	46.85	26.43	4.27	2.70	33.40	32.20
26	9	0.000	0.000	0.00	0.00	80.00	46.85	26.53	4.27	2.70	33.50	31.00
26	10	0.000	0.000	0.00	0.00	78.32	46.85	26.61	4.27	2.70	33.58	29.80
26	11	0.000	0.000	0.00	0.00	76.69	46.85	26.66	4.27	2.70	33.63	28.50
26	12	0.000	0.000	0.00	0.00	75.08	46.85	26.69	4.27	2.70	33.66	27.30
26	13	0.000	0.000	0.00	0.00	73.52	46.85	26.70	4.26	2.70	33.66	26.20
26	14	0.000	0.000	0.00	0.00	71.98	46.85	26.69	4.26	2.70	33.65	25.30
26	15	0.000	0.000	0.00	0.00	70.47	46.85	26.66	4.26	2.70	33.62	24.20
26	16	0.000	0.000	0.00	0.00	69.00	46.85	26.61	4.25	2.70	33.56	23.30
26	17	0.000	0.000	0.00	0.00	67.56	46.85	26.54	4.25	2.70	33.49	22.20
26	18	0.000	0.000	0.00	0.00	66.15	46.85	26.46	4.25	2.70	33.41	21.10
26	19	0.000	0.000	0.00	0.00	64.77	46.85	26.36	4.24	2.70	33.30	20.00
26	20	0.000	0.000	0.00	0.00	63.41	46.85	26.24	4.24	2.70	33.18	19.00
26	21	0.000	0.000	0.00	0.00	62.09	46.85	26.10	4.24	2.70	33.04	18.00
26	22	0.000	0.000	0.00	0.00	60.79	46.85	25.95	4.23	2.70	32.88	17.00
26	23	0.000	0.000	0.00	0.00	59.52	46.85	25.78	4.23	2.70	32.71	16.00
26	24	0.000	0.000	0.00	0.00	58.27	46.85	25.60	4.23	2.70	32.53	15.00

VOLUME OF RECORDED STORM = 3878.8 CFS.HR.
VOLUME OF SIMULATED STORM = 3917.6 CFS.HR.

STORM NUMBER 1975-8-2



EVENT 1975-9-1

INITIAL SOIL MOISTURE DEFICIT = .35 INCHES
MAXIMUM PERCOLATION RATE = .25 IN./HR.
BASEFLOW = 1.36 CFS

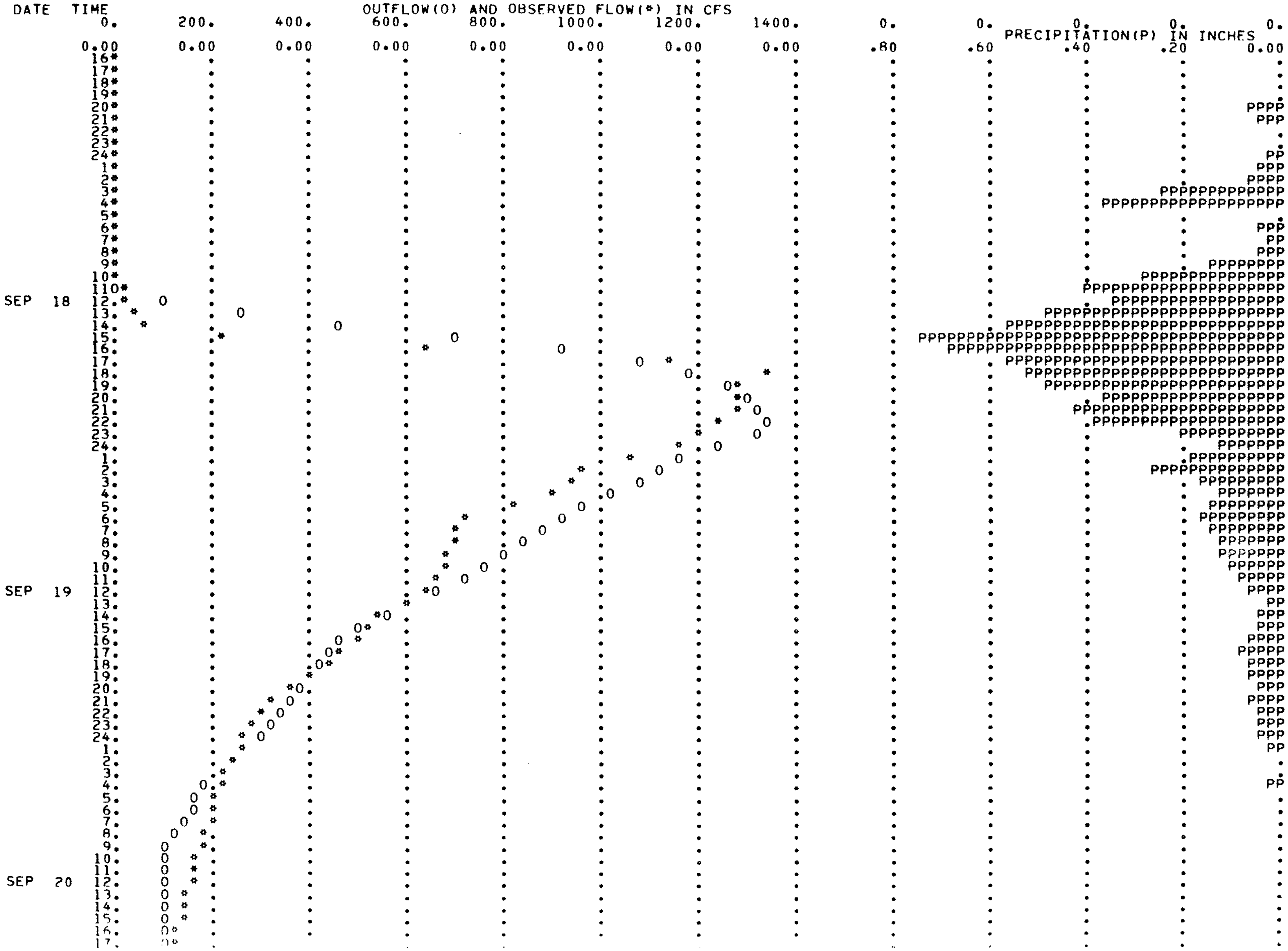
INITIAL SOIL MOISTURE CONTENT OF SPRING RESERVOIR = 0.00 INCHES

DAY	HOUR	PRECIP. IN.	PRECIP. EXCESS IN.	INFLOW CFS	DIRECT RUNOFF CFS	PERCOL FLOW CFS	DEEP PERCOL CFS	SPRING FLOW CFS	BALDHILL CFS	BASEFLOW FLOW CFS	SIMULATED FLOW CFS	OBSERVED CFS
17	16	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	17	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	18	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	19	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	20	.060	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	21	.030	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	22	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	23	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
17	24	.010	0.000	0.00	0.00	0.00	0.00	0.00	1.34	1.36	2.70	2.70
18	1	.030	0.000	0.00	0.00	0.00	0.00	0.00	1.41	1.36	2.77	2.70
18	2	.050	0.000	0.00	0.00	0.00	0.00	0.00	1.47	1.36	2.83	2.70
18	3	.250	.080	374.76	0.00	3.92	.30	0.00	2.52	1.36	3.88	2.70
18	4	.370	.370	1733.27	0.00	25.86	2.50	0.00	2.53	1.36	3.89	2.70
18	5	0.000	0.000	0.00	0.00	43.43	7.35	0.00	2.61	1.36	3.97	2.70
18	6	.030	.030	140.54	0.00	43.99	12.84	0.00	2.63	1.36	3.99	2.70
18	7	.010	.010	46.85	0.00	45.03	17.62	0.00	2.70	1.36	4.06	3.25
18	8	.040	.040	187.38	0.00	46.54	21.87	0.00	2.83	1.36	4.19	3.75
18	9	.140	.140	655.83	0.00	54.38	26.19	0.00	3.04	1.36	4.40	5.66
18	10	.280	.280	1311.66	0.00	73.80	31.91	0.00	3.36	1.36	4.72	10.00
18	11	.410	.410	1920.65	0.00	106.03	40.66	0.00	3.70	1.36	106.64	18.00
18	12	.340	.340	1592.73	101.03	140.10	46.85	.55	4.00	1.36	268.64	37.90
18	13	.490	.490	2295.41	261.29	174.01	46.85	1.99	4.25	1.36	463.49	69.30
18	14	.570	.570	2670.17	453.98	214.79	46.85	3.90	4.62	1.36	692.16	229.00
18	15	.740	.740	3466.53	679.81	262.58	46.85	6.37	4.85	1.36	917.56	647.00
18	16	.670	.670	3138.62	901.93	309.58	46.85	9.43	5.08	1.36	1078.45	1130.00
18	17	.560	.560	2623.32	1059.04	342.83	46.85	12.97	5.23	1.36	1186.40	1340.00
18	18	.510	.510	2389.10	1162.97	364.82	46.85	16.84	5.48	1.36	1262.94	1280.00
18	19	.470	.470	2201.72	1235.21	380.11	46.85	20.89	5.57	1.36	1298.12	1270.00
18	20	.360	.360	1686.42	1266.15	386.66	46.85	25.04	5.66	1.36	1320.96	1270.00
18	21	.430	.430	2014.34	1284.74	390.59	46.85	29.20	5.78	1.36	1346.13	1230.00
18	22	.380	.380	1780.11	1305.62	395.01	46.85	33.36	5.84	1.36	1318.08	1200.00
18	23	.200	.200	936.90	1273.43	388.20	46.85	37.45	5.89	1.36	1238.37	1150.00
18	24	.130	.130	608.99	1189.79	370.50	46.85	41.33	5.94	1.36	1163.51	1060.00
19	1	.180	.180	843.21	1111.29	353.89	46.85	44.93	5.98	1.36	1126.04	965.00
19	2	.260	.260	1217.97	1070.39	345.23	46.85	48.31	6.01	1.36	1088.66	936.00
19	3	.160	.160	749.52	1029.74	336.63	46.85	51.54	6.03	1.36	1027.05	907.00
19	4	.130	.130	608.99	965.08	322.95	46.85	54.58	6.04	1.36	968.18	810.00
19	5	.140	.140	655.83	903.38	309.89	46.85	57.41	6.09	1.36	922.82	723.00
19	6	.160	.160	749.52	855.33	299.72	46.85	60.04	6.10	1.36	882.73	708.00
19	7	.140	.140	655.83	812.75	290.71	46.85	62.51	6.12	1.36	840.74	703.00
19	8	.130	.130	608.99	768.42	281.33	46.85	64.84	6.16	1.36	801.47	679.00
19	9	.130	.130	608.99	726.94	272.55	46.85	67.01	6.22	1.36	762.39	674.00
19	10	.110	.110	515.30	685.78	263.84	46.85	69.03	6.49	1.36	719.26	669.00
19	11	.090	.090	421.61	640.50	254.26	46.85	70.91	6.69	1.36	667.84	645.00
19	12	.050	.050	234.23	587.15	242.97	46.85	72.63	6.88	1.36	606.87	596.00
19	13	.020	.020	93.69	524.46	229.70	46.85	74.17	6.94	1.36	550.53	547.00
19	14	.040	.040	187.38	466.71	217.48	46.85	75.52	7.23	1.36	505.25	518.00
19	15	.040	.040	187.38	419.95	207.59	46.85	76.70	7.39	1.36	467.23	493.00
19	16	.050	.050	234.23	380.73	199.29	46.85	77.75	7.55	1.36	442.41	469.00
19	17	.080	.080	374.76	354.80	193.80	46.85	78.70	7.78	1.36	422.74	444.00
19	18	.060	.060	281.07	334.04	189.41	46.85	79.56	7.94	1.36	398.68	395.00
19	19	.050	.050	234.23	309.02	184.11	46.85	80.36				

19	20	.040	.040	187.38	282.45	178.49	46.85	81.07	8.07	1.36	372.95	361.00
19	21	.050	.040	234.23	258.91	173.51	46.85	81.70	8.26	1.36	350.23	327.00
19	22	.040	.040	187.38	238.05	169.10	46.85	82.26	8.48	1.36	330.15	307.00
19	23	.040	.040	187.38	217.37	164.72	46.85	82.76	8.70	1.36	310.19	288.00
19	24	.030	.030	140.54	196.84	160.38	46.85	83.19	8.86	1.36	290.25	268.00
20	1	.010	.010	46.85	172.04	155.13	46.85	83.55	9.03	1.36	265.98	253.00
20	2	0.000	0.000	0.00	143.46	149.08	46.85	83.84	9.14	1.36	237.79	244.00
20	3	0.000	0.000	0.00	115.93	143.25	46.85	84.04	9.30	1.36	210.63	229.00
20	4	.010	.010	46.85	93.74	138.56	46.85	84.17	9.87	1.36	189.14	220.00
20	5	0.000	0.000	0.00	74.08	134.40	46.85	84.25	10.16	1.36	169.85	209.00
20	6	0.000	0.000	0.00	54.46	130.25	46.85	84.26	10.44	1.36	150.52	198.00
20	7	0.000	0.000	0.00	37.08	126.57	46.85	84.23	10.60	1.36	133.26	191.00
20	8	0.000	0.000	0.00	21.68	123.31	46.85	84.15	10.75	1.36	117.93	183.00
20	9	0.000	0.000	0.00	8.03	120.42	46.85	84.03	10.91	1.36	104.33	176.00
20	10	0.000	0.000	0.00	0.00	117.90	46.85	83.87	11.05	1.36	96.28	168.00
20	11	0.000	0.000	0.00	0.00	115.44	46.85	83.69	11.20	1.36	96.25	161.00
20	12	0.000	0.000	0.00	0.00	113.03	46.85	83.47	11.30	1.36	96.13	154.00
20	13	0.000	0.000	0.00	0.00	110.66	46.85	83.23	11.28	1.36	95.87	147.00
20	14	0.000	0.000	0.00	0.00	108.35	46.85	82.96	11.25	1.36	95.57	140.00
20	15	0.000	0.000	0.00	0.00	106.09	46.85	82.66	11.20	1.36	95.22	134.00
20	16	0.000	0.000	0.00	0.00	103.87	46.85	82.34	11.12	1.36	94.82	128.00
20	17	0.000	0.000	0.00	0.00	101.70	46.85	81.99	11.05	1.36	94.40	122.00
20	18	0.000	0.000	0.00	0.00	99.57	46.85	81.62	10.98	1.36	93.96	116.00
20	19	0.000	0.000	0.00	0.00	97.49	46.85	81.23	10.89	1.36	93.48	110.00
20	20	0.000	0.000	0.00	0.00	95.46	46.85	80.82	10.80	1.36	92.98	106.00
20	21	0.000	0.000	0.00	0.00	93.46	46.85	80.38	10.70	1.36	92.44	101.00
20	22	0.000	0.000	0.00	0.00	91.51	46.85	79.92	10.60	1.36	91.88	96.00
20	23	0.000	0.000	0.00	0.00	89.60	46.85	79.45	10.51	1.36	91.32	91.00
20	24	0.000	0.000	0.00	0.00	87.72	46.85	78.95	10.44	1.36	90.75	85.90
21	1	0.000	0.000	0.00	0.00	85.89	46.85	78.44	10.30	1.36	90.10	82.30
21	2	0.000	0.000	0.00	0.00	84.09	46.85	77.91	10.15	1.36	89.42	79.00
21	3	0.000	0.000	0.00	0.00	82.34	46.85	77.37	10.00	1.36	88.73	76.60
21	4	0.000	0.000	0.00	0.00	80.62	46.85	76.80	9.89	1.36	88.05	72.40
21	5	0.000	0.000	0.00	0.00	78.93	46.85	76.23	9.75	1.36	87.34	73.90
21	6	0.000	0.000	0.00	0.00	77.28	46.85	75.64	9.60	1.36	86.60	67.30
21	7	0.000	0.000	0.00	0.00	75.67	46.85	75.03	9.46	1.36	85.85	65.00
21	8	0.000	0.000	0.00	0.00	74.09	46.85	74.42	9.32	1.36	85.10	63.00
21	9	0.000	0.000	0.00	0.00	72.54	46.85	73.79	9.21	1.36	84.36	61.00
21	10	0.000	0.000	0.00	0.00	71.02	46.85	73.14	9.08	1.36	83.58	59.30
21	11	0.000	0.000	0.00	0.00	69.54	46.85	72.49	8.97	1.36	82.82	57.80
21	12	0.000	0.000	0.00	0.00	68.08	46.85	71.83	8.66	1.36	81.85	56.10
21	13	0.000	0.000	0.00	0.00	66.66	46.85	71.15	8.81	1.36	81.32	55.00
21	14	0.000	0.000	0.00	0.00	65.27	46.85	70.47	8.78	1.36	80.61	54.20
21	15	0.000	0.000	0.00	0.00	63.90	46.85	69.78	8.71	1.36	79.85	53.50
21	16	0.000	0.000	0.00	0.00	62.57	46.85	69.08	8.67	1.36	79.11	52.90
21	17	0.000	0.000	0.00	0.00	61.26	46.85	68.37	8.62	1.36	78.35	52.20
21	18	0.000	0.000	0.00	0.00	59.98	46.85	67.65	8.58	1.36	77.59	51.60
21	19	0.000	0.000	0.00	0.00	58.73	46.85	66.92	8.54	1.36	76.82	51.00
21	20	0.000	0.000	0.00	0.00	57.50	46.85	66.19	8.50	1.36	76.05	50.40
21	21	0.000	0.000	0.00	0.00	56.30	46.85	65.46	8.47	1.36	75.29	50.00
21	22	0.000	0.000	0.00	0.00	55.12	46.85	64.71	8.43	1.36	74.50	49.20
21	23	0.000	0.000	0.00	0.00	53.97	46.85	63.96	8.40	1.36	73.72	48.70
21	24	0.000	0.000	0.00	0.00	52.84	46.85	63.21	8.37	1.36	72.94	48.00
22	1	0.000	0.000	0.00	0.00	51.74	46.85	62.45	8.32	1.36	72.13	47.30
22	2	0.000	0.000	0.00	0.00	50.66	46.85	61.69	8.29	1.36	71.34	46.50
22	3	0.000	0.000	0.00	0.00	49.60	46.85	60.92	8.26	1.36	70.54	45.80
22	4	0.000	0.000	0.00	0.00	48.56	46.85	60.15	8.22	1.36	69.73	45.00
22	5	0.000	0.000	0.00	0.00	47.55	46.85	59.38	8.19	1.36	68.93	44.10
22	6	0.000	0.000	0.00	0.00	46.55	46.85	58.60	8.17	1.36	68.13	43.50
22	7	0.000	0.000	0.00	0.00	45.58	46.85	57.82	8.14	1.36	67.32	42.70
22	8	0.000	0.000	0.00	0.00	44.63	46.85	57.04	8.11	1.36	66.51	41.90
22	9	0.000	0.000	0.00	0.00	43.69	46.85	56.25	8.08	1.36	65.69	41.20
22	10	0.000	0.000	0.00	0.00	42.78	46.85	55.47	8.05	1.36	64.88	40.40
22	11	0.000	0.000	0.00	0.00	41.89	46.85	54.68	8.01	1.36	64.05	39.80
22	12	0.000	0.000	0.00	0.00	41.01	46.85	53.89	7.98	1.36	63.23	39.00
22	13	0.000	0.000	0.00	0.00	40.15	46.85	53.10	7.95	1.36	62.41	38.80
22	14	0.000	0.000	0.00	0.00	39.32	46.85	52.31	7.91	1.36	61.58	38.20
22	15	0.000	0.000	0.00	0.00	38.49	46.85	51.52	7.88	1.36	60.76	37.90
22	16	0.000	0.000	0.00	0.00	37.69	46.85	50.72	7.83	1.36	59.91	37.50
22	17	0.000	0.000	0.00	0.00	36.90	46.85	49.93	7.80	1.36	59.09	37.10
22	18	0.000	0.000	0.00	0.00	36.13	46.85	49.14	7.76	1.36	58.26	36.80
22	19	0.000	0.000	0.00	0.00	35.38	46.85	48.35	7.70	1.36	57.41	36.50
22	20	0.000	0.000	0.00	0.00	34.64	46.85	47.56	7.65	1.36	56.57	36.10
22	21	0.000	0.000	0.00	0.00	33.91	46.85	46.77	7.70	1.36	55.83	35.80
22	22	0.000	0.000	0.00	0.00	33.20	46.85	45.98	7.65	1.36	54.99	35.50
22	23	0.000	0.000	0.00	0.00	32.51	46.85	45.19	7.60	1.36	54.15	35.20
22	24	0.000	0.000	0.00	0.00	31.83	46.85	44.41	7.56	1.36	53.33	35.00

VOLUME OF RECORDED STORM = 31580.0 CFS.HR.
VOLUME OF SIMULATED STORM = 35039.3 CFS.HR.

STORM NUMBER 1975-9-1



EVENT 1977-7-1

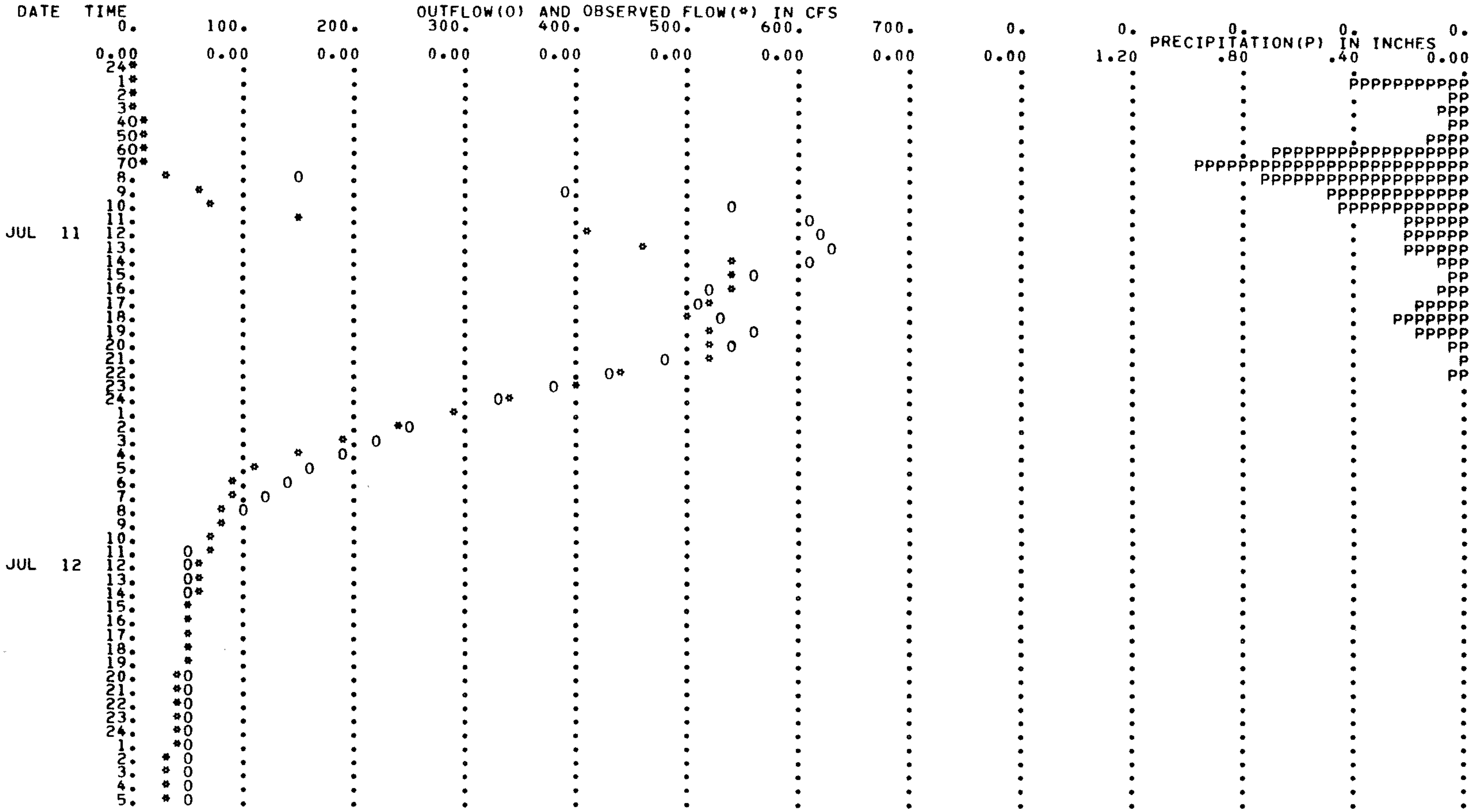
INITIAL SOIL MOISTURE DEFICIT = 1.10 INCHES
MAXIMUM PERCOLATION RATE = .25 IN./HR.
BASEFLOW = .97 CFS

INITIAL SOIL MOISTURE CONTENT OF SPRING RESERVOIR = 0.00 INCHES

DAY	HOUR	PRECIP. IN.	PRECIP. EXCESS IN.	INFLOW CFS	DIRECT RUNOFF CFS	PERCOL FLOW CFS	DEEP PERCOL CFS	SPRING FLOW CFS	BALDHILL CFS	BASEFLOW FLOW CFS	SIMULATED FLOW CFS	OBSERVED CFS
10	24	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.03	.97	2.00	2.00
11	1	.400	0.000	0.00	0.00	0.00	0.00	0.00	1.03	.97	2.00	2.00
11	2	.030	0.000	0.00	0.00	0.00	0.00	0.00	1.06	.97	2.03	2.80
11	3	.070	0.000	0.00	0.00	0.00	0.00	0.00	1.06	.97	2.03	4.20
11	4	.030	0.000	0.00	0.00	0.00	0.00	0.00	1.06	.97	2.03	6.80
11	5	.130	0.000	0.00	0.00	0.00	0.00	0.00	1.10	.97	2.07	7.00
11	6	.670	.230	1077.43	0.00	11.26	.85	0.00	1.13	.97	2.10	10.30
11	7	.960	.960	4497.12	0.00	69.27	6.80	0.00	1.90	.97	2.87	9.70
11	8	.710	.710	3326.00	149.93	150.45	22.36	0.00	2.70	.97	153.60	30.00
11	9	.500	.500	2342.25	388.38	200.91	45.50	0.00	3.13	.97	392.48	62.70
11	10	.430	.430	2014.34	537.92	232.55	46.85	2.13	3.54	.97	544.56	72.70
11	11	.190	.190	890.05	602.08	246.13	46.85	4.63	3.89	.97	611.57	149.00
11	12	.190	.190	890.05	606.02	246.96	46.85	7.20	4.16	.97	618.34	410.00
11	13	.210	.210	983.75	613.91	248.63	46.85	9.74	4.31	.97	628.94	460.00
11	14	.080	.080	374.76	596.66	244.98	46.85	12.24	4.47	.97	614.34	540.00
11	15	.030	.030	140.54	541.70	233.35	46.85	14.61	4.58	.97	561.86	540.00
11	16	.090	.090	421.61	495.21	223.52	46.85	16.80	4.65	.97	517.63	540.00
11	17	.160	.160	749.52	482.68	220.86	46.85	18.88	4.71	.97	507.24	515.00
11	18	.250	.250	1171.13	506.85	225.98	46.85	20.95	4.74	.97	533.51	500.00
11	19	.170	.170	796.37	530.46	230.97	46.85	23.06	4.78	.97	559.28	515.00
11	20	.050	.050	234.23	507.30	226.07	46.85	25.15	4.82	.97	538.23	515.00
11	21	.010	.010	46.85	451.51	214.27	46.85	27.09	4.86	.97	484.43	515.00
11	22	.030	.030	140.54	397.67	202.87	46.85	28.86	4.90	.97	432.40	435.00
11	23	0.000	0.000	0.00	347.76	192.31	46.85	30.46	4.93	.97	384.13	400.00
11	24	0.000	0.000	0.00	296.94	181.56	46.85	31.90	4.94	.97	334.75	340.00
12	1	0.000	0.000	0.00	251.90	172.03	46.85	33.19	4.95	.97	291.02	294.00
12	2	0.000	0.000	0.00	212.01	163.58	46.85	34.34	4.96	.97	252.28	243.00
12	3	0.000	0.000	0.00	176.66	156.10	46.85	35.38	4.98	.97	217.99	193.00
12	4	0.000	0.000	0.00	145.34	149.48	46.85	36.31	4.98	.97	187.60	148.00
12	5	0.000	0.000	0.00	117.60	143.61	46.85	37.14	4.98	.97	160.69	108.00
12	6	0.000	0.000	0.00	93.02	138.40	46.85	37.89	4.98	.97	136.85	93.80
12	7	0.000	0.000	0.00	71.24	133.80	46.85	38.56	4.98	.97	115.75	88.00
12	8	0.000	0.000	0.00	51.94	129.71	46.85	39.17	4.97	.97	97.05	83.00
12	9	0.000	0.000	0.00	34.85	126.09	46.85	39.72	4.97	.97	80.51	78.00
12	10	0.000	0.000	0.00	19.70	122.89	46.85	40.22	4.97	.97	65.86	72.50
12	11	0.000	0.000	0.00	6.28	120.05	46.85	40.67	4.96	.97	52.88	67.70
12	12	0.000	0.000	0.00	0.00	117.54	46.85	41.08	4.95	.97	47.00	62.70
12	13	0.000	0.000	0.00	0.00	115.08	46.85	41.45	4.94	.97	47.36	59.90
12	14	0.000	0.000	0.00	0.00	112.68	46.85	41.79	4.92	.97	47.68	56.90
12	15	0.000	0.000	0.00	0.00	110.32	46.85	42.09	4.89	.97	47.95	54.20
12	16	0.000	0.000	0.00	0.00	108.02	46.85	42.36	4.86	.97	48.19	52.00
12	17	0.000	0.000	0.00	0.00	105.76	46.85	42.59	4.84	.97	48.40	50.00
12	18	0.000	0.000	0.00	0.00	103.55	46.85	42.79	4.82	.97	48.58	48.00
12	19	0.000	0.000	0.00	0.00	101.39	46.85	42.96	4.80	.97	48.73	46.20
12	20	0.000	0.000	0.00	0.00	99.27	46.85	43.10	4.78	.97	48.85	44.60
12	21	0.000	0.000	0.00	0.00	97.19	46.85	43.20	4.75	.97	48.92	43.00
12	22	0.000	0.000	0.00	0.00	95.16	46.85	43.29	4.73	.97	48.99	41.80
12	23	0.000	0.000	0.00	0.00	93.17	46.85	43.34	4.71	.97	49.02	40.20
12	24	0.000	0.000	0.00	0.00	91.23	46.85	43.36	4.69	.97	49.02	39.00
13	1	0.000	0.000	0.00	0.00	89.32	46.85	43.37	4.74	.97	49.08	36.40
13	2	0.000	0.000	0.00	0.00	87.45	46.85	43.34	4.65	.97	48.96	33.30
13	3	0.000	0.000	0.00	0.00	85.63	46.85	43.29	4.64	.97	48.90	33.30
13	4	0.000	0.000	0.00	0.00	83.84	46.85	43.22	4.62	.97	48.81	33.30
13	5	0.000	0.000	0.00	0.00	82.08	46.85	43.13	4.60	.97	48.70	33.30

VOLUME OF RECORDED STORM = 8861.3 CFS.HR.
VOLUME OF SIMULATED STORM = 10966.0 CFS.HR.

STORM NUMBER 1977-7-1



A P P E N D I X D

PLOT PROGRAM

PLOT PROGRAM

INTRODUCTION

This program plots, on the Calcomp Plotter, the recorded hourly rainfall, recorded hourly streamflow and the synthesized streamflow hydrographs. The "Main" program plots the streamflow hydrographs and subroutine Rain is used to plot the hourly rainfall data. A listing of the program is provided on Pages 136 to 139 inclusive.

Capacity

This program plots a maximum of six days data.

Input

A sample input is shown on Page 140. This data is described as follows with the restriction that all values marked INTEGER must appear right justified with no decimal point and that other values may appear right justified with no decimal point or within the field and with a decimal point.

1. Event Number Card

Columns	Description
1-12	Storm Event Number

2. Plate Number Card

Columns	Description
1-12	Figure number which is to appear on the bottom right hand corner of graph

3. Plot Length Specification Card

Columns Description

1-5	Integer, duration of storm in days
6-10	Integer, initial hour storm started
1-15	Integer, final hour of storm on the last day of the data.

4. Precipitation Description Card

Columns	Description
1-80	Alpha-numeric description of the storm precipitation

5. Precipitation Data Deck

The length of this deck is twice the duration of the storm, as specified on the Plot Length Specification Card. The AM data is placed on a first card followed by the PM data.

Columns	Description
1-4	Integer, year
5-6	Integer, month
7-8	Integer, day
9	A or P, designating whether data is AM or PM
	Hourly precipitation in inches for hours
21-25	1 or 13
26-30	2 or 14
76-80	12 or 24

6. Recorded Streamflow Description Card

Columns	Description
1-80	Alpha-numeric description of recorded hourly streamflow hydrograph

7. Recorded Streamflow Data Deck

The recorded hourly streamflow hydrograph is input in the same format as previously described for the Daily Precipitation Data Deck.

8. Synthesized Streamflow Description Card

Columns	Description
1-80	Alpha-numeric description of synthesized hourly streamflow hydrograph.

9. Synthesized Streamflow Deck

Synthesized hourly streamflow hydrograph is input in the same format as previously described for the Daily Precipitation Data Deck.

Output

A sample of the plotted output of the plot program is shown on Page 141.

```
REQUESTED OPTIONS: XREF

OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF TERM IBM FLAG(I)

                   C
                   C      NAME            DESCRIPTION
                   C      ----            -----------
                   C
                   C      DISCH          ACTUAL RECORDED HYDROGRAPH
                   C      HYDRO          SYNTHESIZED HYDROGRAPH
                   C      PREC           HOURLY PRECIPITATION
                   C      EVENT          EVENT NUMBER
                   C      FIGURE         FIGURE NUMBER
                   C
                   C      NMSRT          STARTING MONTH OF STORM
                   C      NHSRT          STARTING HOUR OF STORM
                   C      NDSRT          STARTING DAY OF STORM
                   C      NDAY           DURATION OF STORM IN DAYS
                   C      NHSLT          LAST HOUR OF STORM
                   C      NH             DURATION OF STORM IN HOURS
                   C
                   C
ISN 0002                  REAL DISCH(6,24),HYDRO(6,24),PREC(6,24)
ISN 0003                  REAL DISCH1(146),HYDRO1(146),PREC1(146),TIME(146)
ISN 0004                  REAL PNAME(20),DNAME(20),HNAME(20)
ISN 0005                  REAL EVENT(3),FIGURE(3)
ISN 0006                  INTEGER YEAR(6),MONTH(6),DAY(6),MONS(12),DATE(12)
                   C
ISN 0007                  DATA MONS/4HJAN.,4HFEB.,4HMAR.,4HAPR.,4HMAY ,4HJUNE,4HJULY,4HAUG.,
                         &4HSEPT,4HOCT.,4HNOV.,4HDEC./
ISN 0008                  DATA DATE/31,28,31,30,31,30,31,31,30,31,30,31/
                   C
ISN 0009                  CALL PLOTS(0,0,8)
ISN 0010                  CALL PLOT(1.5,1.3,-3)
                   C
                   C      READ IN RECORDED HOURLY PRECIPITATION AND,ACTUAL RECORDED
                   C      AND SYNTHESIZED HYDROGRAPHS
                   C
ISN 0011                5 READ(5,1,END=99) EVENT
ISN 0012                  READ(5,1) FIGURE
                   C
ISN 0013                  READ(5,10) NDAY,NHSRT,NHLST
                   C
ISN 0014                  READ(5,21)(PNAME(I),I=1,20)
ISN 0015                  DO 20 I=1,NDAY
ISN 0016               20 READ(5,22) YEAR(I),MONTH(I),DAY(I),(PREC(I,J),J=1,24)
ISN 0017                  READ(5,21)(DNAME(I),I=1,20)
ISN 0018                  DO 30 I=1,NDAY
ISN 0019               30 READ(5,22) YEAR(I),MONTH(I),DAY(I),(DISCH(I,J),J=1,24)
ISN 0020                  READ(5,21)(HNAME(I),I=1,20)
ISN 0021                  DO 40 I=1,NDAY
ISN 0022               40 READ(5,22) YEAR(I),MONTH(I),DAY(I),(HYDRO(I,J),J=1,24)
                   C
ISN 0023                  N1=NHSRT
ISN 0024                  N2=24
ISN 0025                  NH=0
ISN 0026                  DO 50 I=1,NDAY
```

```
  ISN 0027              IF(I.GT.1) N1=1
  ISN 0029              IF(I.EQ.NDAY) N2=NHLST
  ISN 0031              DO 50 J=N1,N2
  ISN 0032              NH=NH+1
  ISN 0033              TIME(NH)=NH+NHSRT-1
  ISN 0034              PREC1(NH)=PREC(I,J)
  ISN 0035              DISCH1(NH)=DISCH(I,J)
  ISN 0036           50 HYDRO1(NH)=HYDRO(I,J)
                  C
  ISN 0037              DISCH1(NH+1)=0.0
  ISN 0038              DISCH1(NH+2)=200.0
  ISN 0039              HYDRO1(NH+1)=0.0
  ISN 0040              HYDRO1(NH+2)=200.0
  ISN 0041              TIME(NH+1)=0.0
  ISN 0042              TIME(NH+2)=24.0
                  C
  ISN 0043              IF(NDAY.EQ.6) GO TO 60
  ISN 0045              NX=6-NDAY
  ISN 0046              DO 70 I=1,NX
  ISN 0047              I1=NDAY+I
  ISN 0048              IX=I1-1
  ISN 0049              DAY(I1)=DAY(IX)+1
  ISN 0050              ID=MONTH(IX)
  ISN 0051              IF(DAY(I1).LE.DATE(ID)) GO TO 80
  ISN 0053              DAY(I1)=1
  ISN 0054              MONTH(I1)=ID+1
  ISN 0055              GO TO 70
  ISN 0056           80 MONTH(I1)=MONTH(IX)
  ISN 0057           70 YEAR(I1)=YEAR(IX)
                  C
  ISN 0058           60 CONTINUE
                  C
  ISN 0059              ELEV=0.0
  ISN 0060              YAXIS=-0.5
  ISN 0061              XAX=0.0
  ISN 0062              YAX=0.0
                  C
  ISN 0063              DO 100 I=1,15
  ISN 0064              YAXIS=YAXIS+0.5
  ISN 0065              CALL NUMBER(-0.4,YAXIS,.07,ELEV,0.,-1)
  ISN 0066          100 ELEV=ELEV+100.0
                  C
  ISN 0067              CALL PLOT(-0.1,YAXIS,3)
  ISN 0068              CALL PLOT(0.0,YAXIS,2)
                  C
  ISN 0069              DO 105 I=1,14
  ISN 0070              YAXIS=YAXIS-0.5
  ISN 0071              CALL PLOT(0.0,YAXIS,2)
  ISN 0072              CALL PLOT(-0.1,YAXIS,3)
  ISN 0073          105 CALL PLOT(0.0,YAXIS,2)
  ISN 0074              CALL SYMBOL(-0.5,3.0,.07,19HDISCHARGE (C.F.S.) ,90.,19)
                  C
  ISN 0075              XAXIS=0.0
  ISN 0076              CALL PLOT(XAXIS,-0.1,3)
  ISN 0077              CALL PLOT(XAXIS,0.0,2)
                  C
  ISN 0078              DO 110 I=1,6
  ISN 0079              XAXIS=XAXIS+1.0
```

```
ISN 0080              CALL PLOT(XAXIS,0.0,2)
ISN 0081              CALL PLOT(XAXIS,-0.1,3)
ISN 0082              CALL PLOT(XAXIS,0.0,2)
ISN 0083          110 CONTINUE
            C
ISN 0084              DO 120 I=1,6
ISN 0085              M=MONTH(I)
ISN 0086              I1=I-1
ISN 0087              XS=I1+0.15
ISN 0088              CALL SYMBOL(XS,-0.2,.07,MONS(M),0.,4)
ISN 0089              XS=XS+0.4
ISN 0090              FPN=DAY(I)
ISN 0091              CALL NUMBER(XS,999.,.07,FPN,0.,-1)
ISN 0092              XS=XS+0.25
ISN 0093              FPN=YEAR(I)
ISN 0094              CALL NUMBER(XS,999.,.07,FPN,0.,-1)
ISN 0095          120 CONTINUE
            C
ISN 0096              CALL SYMBOL(3.6,7.3,0.15,12HWILSON CREEK,0.,12)
ISN 0097              CALL SYMBOL(3.0,7.05,0.15,20HSTREAMFLOW SYNTHESIS,0.,20)
ISN 0098              CALL SYMBOL(3.6,6.8,0.15,EVENT,0.,12)
ISN 0099              CALL PLOT(3.5,6.25,3)
ISN 0100              CALL PLOT(4.2,6.25,2)
ISN 0101              CALL SYMBOL(4.3,6.25,0.09,8HRECORDED,0.,8)
ISN 0102              CALL PLOT(3.5,6.05,3)
ISN 0103              CALL PLOT(3.8,6.05,2)
ISN 0104              CALL PLOT(3.9,6.05,3)
ISN 0105              CALL PLOT(4.2,6.05,2)
ISN 0106              CALL SYMBOL(4.3,6.05,0.09,9HSIMULATED,0.,9)
            C
ISN 0107              CALL LINE(TIME,DISCH1,NH,1,0,0)
ISN 0108              CALL DDASH(TIME,HYDRO1,NH,0.3,0.3,0.1)
            C
ISN 0109              CALL SYMBOL(5.0,-0.9,0.10,FIGURE,0.,12)
            C
ISN 0110              CALL RAIN(NHSRT,NH,PREC1,MONTH,DAY,YEAR,MONS)
            C
ISN 0111              CALL PLOT(8.5,-8.5,-3)
ISN 0112              GO TO 5
            C
ISN 0113           99 CALL PLOT(11.,-8.,999)
            C
ISN 0114            1 FORMAT(3A4)
ISN 0115           10 FORMAT(8I5)
ISN 0116           21 FORMAT(20A4)
ISN 0117           22 FORMAT(2X,3I2,12X,12F5.0/20X,12F5.0)
            C
            C
ISN 0118              STOP
ISN 0119              END
```

```
REQUESTED OPTIONS: XREF

OPTIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF ALC NOANSF TERM IBM FLAG(I)

                  C
                  C
                  C
   ISN 0002             SUBROUTINE RAIN(NHSRT,NH,PREC1,MONTH,DAY,YEAR,MONS)
   ISN 0003             DIMENSION PREC1(146)
   ISN 0004             INTEGER YEAR(6),MONTH(6),DAY(6),MONS(12)
                  C
   ISN 0005             CALL PLOT(0.,7.5,3)
   ISN 0006             CALL PLOT(0.,8.5,-2)
                  C
   ISN 0007             ELEV=0.0
   ISN 0008             YAXIS=0.5
                  C
   ISN 0009             DO 10 I=1,3
   ISN 0010             YAXIS=YAXIS-0.5
   ISN 0011             CALL NUMBER(-0.4,YAXIS,.07,ELEV,0.,2)
   ISN 0012             ELEV=ELEV+0.5
   ISN 0013          10 CONTINUE
                  C
   ISN 0014             CALL PLOT(-0.1,YAXIS,3)
   ISN 0015             CALL PLOT(0.0,YAXIS,2)
                  C
   ISN 0016             DO 105 I=1,2
   ISN 0017             YAXIS=YAXIS+0.5
   ISN 0018             CALL PLOT(0.0,YAXIS,2)
   ISN 0019             CALL PLOT(-0.1,YAXIS,3)
   ISN 0020         105 CALL PLOT(0.0,YAXIS,2)
                  C
   ISN 0021             CALL SYMBOL(-0.5,-0.90,.07,13HPRECIP. (IN.),90.,13)
   ISN 0022             XAXIS=0.0
   ISN 0023             CALL PLOT(XAXIS,0.1,3)
   ISN 0024             CALL PLOT(XAXIS,0.0,2)
                  C
   ISN 0025             DO 110 I=1,6
   ISN 0026             XAXIS=XAXIS+1.0
   ISN 0027             CALL PLOT(XAXIS,0.0,2)
   ISN 0028             CALL PLOT(XAXIS,0.1,3)
   ISN 0029             CALL PLOT(XAXIS,0.0,2)
                  C
   ISN 0030         110 CONTINUE
                  C
   ISN 0031             DO 120 I=1,6
   ISN 0032             M=MONTH(I)
   ISN 0033             I1=I-1
   ISN 0034             XS=I1+0.15
   ISN 0035             CALL SYMBOL(XS,0.1,.07,MONS(M),0.,4)
   ISN 0036             XS=XS+0.4
   ISN 0037             FPN=DAY(I)
   ISN 0038             CALL NUMBER(XS,999.,.07,FPN,0.,-1)
   ISN 0039             XS=XS+0.25
   ISN 0040             FPN=YEAR(I)
   ISN 0041             CALL NUMBER(XS,999.,.07,FPN,0.,-1)
   ISN 0042         120 CONTINUE
                  C
                  C
   ISN 0043             XHOUR=FLOAT(NHSRT)/24.
                  C
   ISN 0044             DO 20 I=1,NH
   ISN 0045             IF(I.EQ.1) CALL PLOT(XHOUR,0.,3)
   ISN 0047             CALL PLOT(XHOUR,-PREC1( I),2)
   ISN 0048             XHOUR1=(NHSRT+I)/24.
   ISN 0049             CALL PLOT (XHOUR1,-PREC1(I),2)
   ISN 0050             IF(J.EQ.NH) CALL PLOT(XHOUR1,0.0,2)
   ISN 0052             XHOUR=XHOUR1
   ISN 0053          20 CONTINUE
                  C
   ISN 0054             RETURN
   ISN 0055             END
```

EVENT 75-8-2
FIGURE B-13
4 24 24

STORM 75-8-2 HOURLY PRECIPITATION IN INCHES DURATION 53 HOURS

1975 823A												
1975 823P												
1975 824A	.04	.06	.02	.04	.03	.02	.04					
1975 824P		.14	.49	.25	.02	.01	.12	.57	.31	.32	.24	.17
1975 825A	.11	.02	.01	.02	.01	.01	.01				.01	
1975 825P												
1975 826A												
1975 826P												

STORM 75-8-2 HOURLY DISCHARGE IN CFS AT WILSON CREEK WEIR

1975 823A												
1975 823P												2.7
1975 824A	2.7	2.7	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.7	2.7
1975 824P	2.7	2.7	4.3	6.0	5.3	11.5	20.5	18.0	25.6	40.5	90.0	280
1975 825A	320	330	280	240	190	150	110	102	95.0	87.0	80.0	71.0
1975 825P	67.0	63.3	60.3	57.5	54.5	51.4	49.3	47.5	46.1	44.4	42.9	41.4
1975 826A	40.2	39.1	38.0	36.9	35.8	34.5	33.3	32.2	31.0	29.8	28.5	27.3
1975 826P	26.2	25.3	24.2	23.3	22.2	21.1	20.0	19.0	18.0	17.0	16.0	15.0

STORM 75-8-2 SIMULATED DISCHARGE RUN D3

1975 823A	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1975 823P	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.
1975 824A	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
1975 824P	3.	3.	3.	3.	4.	5.	6.	6.	6.	125.	223.	277.
1975 825A	295.	278.	241.	208.	179.	151.	127.	103.	79.	59.	43.	29.
1975 825P	17.	15.	18.	22.	25.	28.	30.	32.	34.	36.	38.	39.
1975 826A	40.	41.	42.	43.	43.	44.	44.	45.	45.	45.	45.	45.
1975 826P	45.	45.	45.	44.	44.	44.	44.	43.	43.	42.	42.	42.

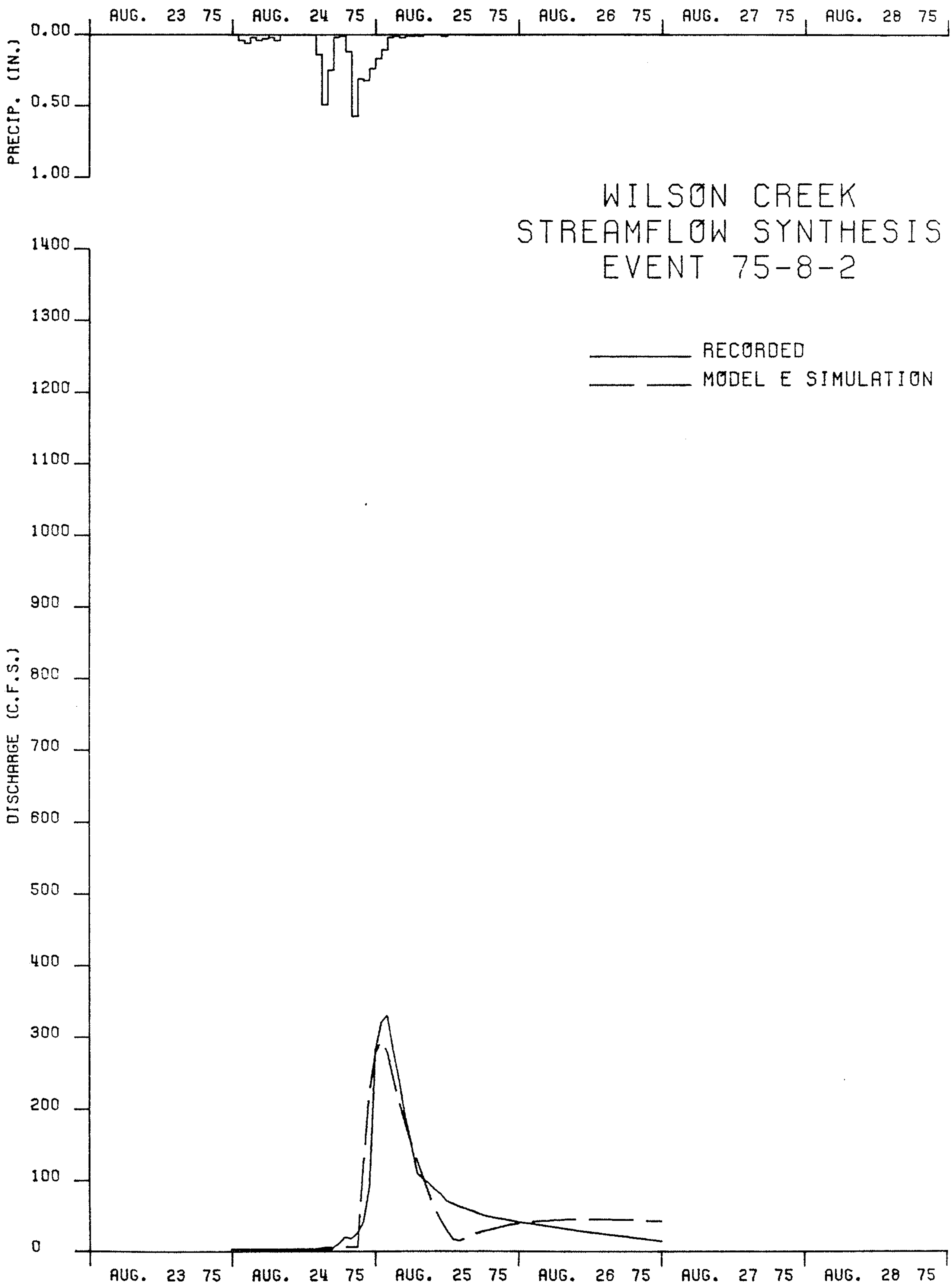

AUG. 23 75
AUG. 24 75
AUG. 25 75
AUG. 26 75
AUG. 27 75
AUG. 28 75
PRECIP. (IN.)
0.00
0.50
1.00
WILSØN CREEK
STREAMFLØW SYNTHESIS
EVENT 75-8-2
RECØRDED
MØDEL E SIMULATIØN
DISCHARGE (C.F.S.)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

FIGURE B-13