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Systematic Development Of Methodologies In Planning Urban Water Resources For Medium Size Communities, Development Of An Extension Of Illudas Model For Continuous Simulation Of Urban Runoff Quantity And Discrete Simulation Of Runoff Quality

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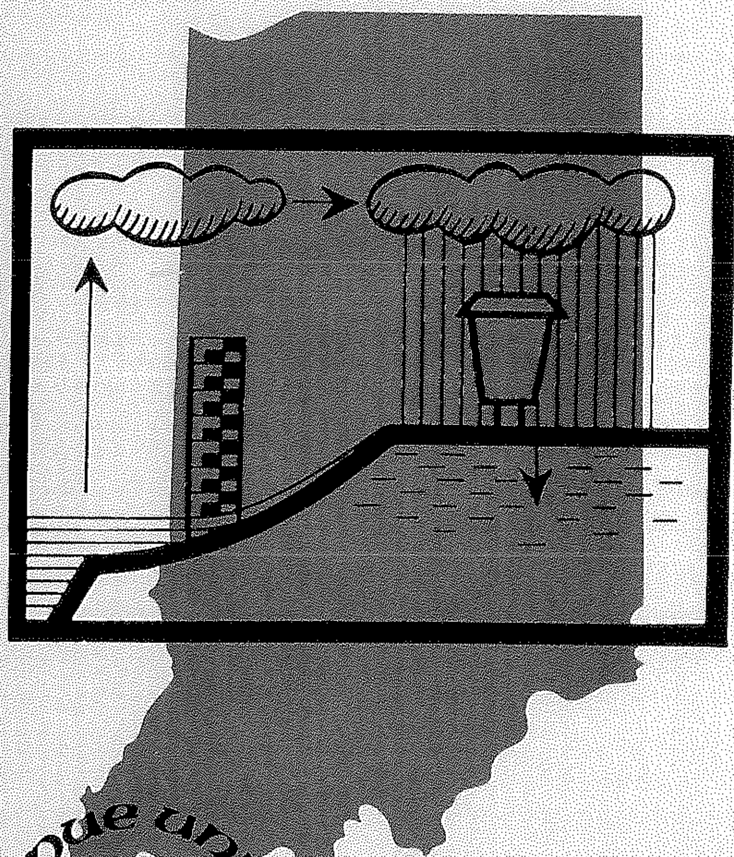

by

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July 1979

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

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ABSTRACT

The present study deals with the development of two short-time-interval simulation models: the first is a continuous simulation of the storm water runoff quantity, the second is a single event runoff quality simulation. Both models are extensions of the Illinois Urban Drainage Area Simulator, ILLUDAS, developed by the Illinois State Water Survey. Both models were verified on the Upper Ross-Ade Watershed in West Lafayette, Indiana.

A study of the sensitivity of the response of ILLUDAS to changes in the input parameters showed that the antecedent moisture condition is about equally as sensitive as the proper selection of the soil group. It was concluded that a time increment equal to the average inlet time of 5 minutes was the largest one giving acceptable hydrograph results for the watershed under study.

The ILLUDAS model, originally developed for the estimation of the runoff due to single rainfall events, was extended to allow for a continuous simulation of the urban runoff. This was done by adding the subroutine DRYAMC which calculates the total rainfall during the five days preceding the storm to determine the antecedent moisture condition at the beginning of each storm.

The single event rainfall-runoff model ILLUDAS was coupled with a modified version of the runoff quality model included in the program STORM, (Storage, Treatment, Overflow Runoff Model) developed by the

Hydrologic Engineering Center of the U.S. Corps of Engineers. In this fashion an integrated runoff quantity and equality model DRAINQUAL is obtained with the capability of simulating the pollutograph at a 5 minute time interval. The subroutine DIRT of the model STORM was modified to accommodate the 5-minute time step. Comparison with field measurements show that the model predicts the BOD and suspended solids pollutographs fairly well. At present the model DRAINQUAL is for single storm water quality simulation. It could be modified for continuous simulation by combining the quality subroutine with the continuous version of ILLUDAS and adding a subroutine simulating the pollutant accumulation on the watershed between rainfall events.

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1 Introduction

The design of urban storm drainage systems has been based largely on experience and on empirical relations such as the Rational Formula. This empirical approach is gradually being replaced by simulation models many of which make use of the computer. Tholin and Keifer (1960) developed the Chicago hydrograph method. It describes the overland flow, gutter routing, and lateral and main sewer routing to the basin outlet. It is a well validated method and takes into account the detailed physical phenomena of the entire urban runoff process. A version of this method which uses a time offset routing procedure was programmed for computer usage by Keifer et al (1970). Among the many other "desk top" methods we shall mention those developed by Eagleson (1962) and by Kaltenbach (1963). The Kaltenbach method is based on the total peak flow at the downstream point which is obtained by summing the routed inlet hydrograph ordinates. Eagleson proposed a unit hydrograph method. The characteristics of the hydrograph being correlated to the properties of the sewer system and drainage basin, it is possible to construct a synthetic unit hydrograph for ungaged basins. Both methods have been summarized by Jens and McPherson (1964). The instantaneous unit hydrograph model developed at Purdue University (Rao, et al, 1972) makes use of the single linear reservoir or the cascade of equal linear reservoirs, the parameters of which are correlated to the watershed characteristics (area and imperviousness) and to storm characteristics (volume of rainfall excess and duration). Extensive reviews of the progress in urban hydrologic modeling in the United States have been prepared by McPherson (1975, 1979a) and by Delleur and Dendrou (1979). Worldwide summaries of recent development in urban catchment research were prepared by McPherson and Zuidema (1977), and by McPherson (1979b).

Many of the recently developed methods require field data for calibration. Among these is the British Road Research Laboratory (RRL) model (Watkins, 1962), which estimates the urban runoff by considering only the impervious areas of the watershed directly connected to the storm drainage system (Terstriep and Stall, 1969). The Illinois Urban Drainage Area Simulators (ILLUDAS) developed by the Illinois State Water Survey (Terstriep and Stall, 1974) presents a design procedure for the hydrologic design of storm drainage system in urban areas which is an extension of the RRL method which includes the consideration of the pervious areas.

The ILLUDAS model is continuously being improved. In December 1978 the flow routing algorithms were expanded. This new version gives the user the choice of three routing options: a time shift of the entire hydrograph or a storage routing using an explicit or an implicit solution of the continuity equation. The water quality algorithms of SWMM are currently being adapted in a version known as QUAL-ILLUDAS (Terstriep et al., 1978; Terstriep 1979).

Various modifications of the ILLUDAS model have been reported in several countries. For example, an interactive mini-computer version of ILLUDAS has been developed by Patry et al. (1979) and has been tested in Canada.

Beyond these there is a group of computer based simulation models which are more complex. Among these are the University of Cincinnati Urban Runoff Model (UCUR); the Storage, Treatment, Overflow, Runoff Model (STORM) of the Hydrologic Engineering Center of the Corps of Engineers; the Storm Water Management Model (SWMM) of EPA; the Hydrocomp Simulation Program Model (HYDROCOMP); the SOGREAH Model; the DORSCH Model; the Battell-Northwest Model; the Massachausette Institute of Technology Model (MIT); and others. Some of these include water quality parameters and/or continuous simulation. Tables 1.1 and 1.2 (Lager, 1977) show a comparison of the models capabilities and performances.

1.2 Objectives

The present study is a part of a broad multi-disciplinary project on the development of methodologies and techniques in the comprehensive planning of the urban water resources of medium size communities (Delleur et al, 1976, 1979). The hydrology phase of this project includes the testing and improvement of urban drainage models. Sautier and Delleur (1978) reported on the sensitivity analysis of the runoff estimation of the model STORM. Padmanabhan and Delleur (1978) did an extensive statistical analysis of synthetic time series of runoff, suspended solids and BOD generated by the program STORM using 21 years of hourly rainfall data. The present report is concerned with the sensitivity analysis of the program ILLUDAS and with an extension of this program as a continuous simulation model adding also the capability of obtaining a short time interval simulation of the runoff quality.

TABLE 1.1 MODEL CHARACTERISTICS BY BRANDSTETTER
[after Lager, J. A., 1977]

	CATCHMENT HYDROLOGY							SEWER HYDRAULICS								WASTEWATER QUALITY									MISCELLANEOUS				
	MULTIPLE CATCHMENT INFLOWS	DRY-WEATHER FLOW	INPUT OF SEVERAL HYETOGRAPHS	SNOWMELT	RUNOFF FROM IMPERVIOUS AREAS	RUNOFF FROM PERVIOUS AREAS	WATER BALANCE BETWEEN STORMS	FLOW ROUTING IN SEWERS	UPSTREAM AND DOWNSTREAM FLOW CONTROL	SURCHARGING AND PRESSURE FLOW	DIVERSIONS	PUMPING STATIONS	STORAGE	PRINTS STAGE	PRINTS VELOCITIES	DRY-WEATHER QUALITY	STORMWATER QUALITY	QUALITY ROUTING	SEDIMENTATION AND SCOUR	QUALITY REACTIONS	WASTEWATER TREATMENT	QUALITY BALANCE BETWEEN STORMS	RECEIVING WATER FLOW SIMULATION	RECEIVING WATER QUALITY SIMULATION	CONTINUOUS SIMULATION	CAN CHOOSE TIME INTERVAL	DESIGN COMPUTATIONS	REAL-TIME CONTROL	COMPUTER PROGRAM AVAILABLE
BATTELLE-NORTHWEST	●	●	●		●	●		●			●		●	●	●	●	●	●			●					●	●	●	●
BRITISH ROAD RESEARCH LABORATORY	●	●	●		●			●															●			●			●
CHICAGO FLOW SIMULATION	●	●	●	●	●	●	●	●					●	●									●		●	●			●
CHICAGO HYDROGRAPH METHOD	●	●	●		●	●	●	●															●			●	●		●
COLORADO STATE UNIVERSITY	●	●			●			●	●					●	●														●
CORPS OF ENGINEERS				●	●	●	●				●		●				●			●		●			●				●
DORSCH CONSULT	●	●	●		●	●		●	●		●		●	●	●								●			●			
ENVIRONMENTAL PROTECTION AGENCY	●	●	●		●	●		●	●	●	●	●	●			●	●	●	●	●	●		●	●		●	●		●
HYDROCOMP	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●		●		●	●	●	●	●		●	
MASSACHUSETTE INSTITUTE OF TECHNOLOGY	●	●	●		●	●		●						●	●								●			●	●		
MINNEAPOLIS-ST. PAUL	●	●	●		●	●		●			●															●		●	●
SEATTLE	●	●	●		●	●	●	●	●	●	●	●	●	●												●		●	●
SOGREAH	●	●			●	●		●	●	●	●	●	●	●	●			●					●	●		●			
UNIVERSITY OF CINCINNATI	●				●	●		●															●			●			●
UNIVERSITY OF ILLINOIS	●	●		●	●	●		●	●		●	●	●	●	●											●	●		●
UNIVERSITY OF MASSACHUSETTS	●	●			●		●	●	●					●	●														●
WATER RESOURCES ENGINEERS	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●		●			●	●		●			
WILSEY AND HAM	●				●	●		●																		●	●		

TABLE 1.2 MODEL CHARACTERISTICS BY HUBER
[after Lager, J. A., 1977]

COMPARISON OF URBAN RUNOFF MODELS, MARCH 1974

Model	Surface Routing	Sewer Routing	Quality Routing	Degree of Sophistication of Surface Flow Routing	Degree of Sophistication of Sewer Flow Routing	Accurate Modeling of Surcharging	Flexibility of Modeling of Sewer Components	Explicit Modeling of In-System Storage	Treatment Modeling	Receiving Model Available	Degree of Calibration/Verification Required	Simulation Period	Availability	Documentation	Data Requirements
Rational Method	Peak Flows Only	Peak Flows Only	No	Low	Low	No	Low	No	NA	No	Usually not verified	Individual storms	Non-proprietary	Good	Low
Chicago	Yes	No	No	Moderate	NA	NA	NA	NA	NA	No	Moderate	Individual storms	Non-proprietary	Fair	Moderate
Unit Hydrograph	Yes	In combination with surface	No	Low	Low	No	Low	No	NA	No	High	Individual storms	Non-proprietary	Fair	Moderate
Unit Pulse	Yes	In combination with surface	No	Low-Moderate	Low-Moderate	No	Low	No	NA	No	High	Individual storms	Non-proprietary	Fair	Moderate
STORM	Yes	In combination with surface	Yes	Low	Low	No	Low	No	Yes	No	Low	Long term	Non-proprietary	Good	Moderate
RRL	Yes	Yes	No	Moderate	Low-Moderate	No	Low	No	NA	No	Moderate	Individual storms	Non-proprietary	Good	Moderate
MIT	Yes	No	No	High	NA	NA	NA	NA	NA	No	Moderate	Individual storms	Proprietary	Fair	Moderate
Battelle	Yes	Yes	Yes	Low	Moderate	No	Moderate	Yes	No	No	Moderate	Individual storms	Non-proprietary	Poor	Moderate
EPA-SWMM	Yes	Yes	Yes	High	Moderate	No	High	Yes	Yes	Yes	Moderate	Individual storms	Non-proprietary	Good	Extensive
WRE-SWMM	Yes	Yes	Yes	High	High	Yes	High	No	Yes	Yes	Moderate	Individual storms	Proprietary	Poor	Extensive
Cincinnati (UCUR)	Yes	Yes	Yes	High	Low	No	Low	No	No	No	Moderate	Individual	Non-proprietary	Fair	Extensive
Dorsch (HVM)	Yes	Yes	No	High	High	Yes	High	?	NA	Yes	Moderate	Individual storms	Proprietary	Poor	Extensive
SOGREAH	Yes	Yes	?	High	High	Yes	High	?	?	Yes	Moderate	Individual storms or separate	Proprietary	Poor	Extensive
Hydrocomp	Yes	Yes	Yes	Moderate	Moderate	No	Low	No	No	Yes	High	Individual storms or long term	Proprietary	Fair	Extensive
Illinois (ISS)	Yes	Yes	No	Moderate	High	No	Low	No	NA	No	Moderate	Individual storms	Non-proprietary	Good	Extensive

The specific objectives of the study are the following:

(1) To develop or extend deterministic urban runoff models using as input the recorded field data such as physical characteristics of the watershed and meteorological characteristics such as the rainfall duration and intensity, the duration of the antecedent dry period.

(2) To investigate the sensitivity of the runoff simulated by the ILLUDAS model due to changes in

i) the antecedent moisture condition

ii) the hydrologic soil group

iii) the time increment

(3) To study the possibility of adding a continuous simulation capability to the ILLUDAS model and to evaluate its performance.

(4) To develop an integrated rainfall-runoff-quality model by relating the water quality loading to the known storm and physiographic characteristics and to analyze the performance of the model.

The results of the present study are organized as follows. The data preparation and general description of the watershed are presented in Chapter 2. A brief review of the ILLUDAS model and a study of its limitations are discussed in Chapter 3. This chapter also deals with the sensitivity analysis. The modifications of the model for continuous simulation is discussed in Chapter 4. The results from several storms which are analyzed by using the above procedure are also included in Chapter 4. Chapter 5 is concerned with the development of an integrated rainfall-runoff-quality model. Numerical results of the model are also presented in Chapter 5. Conclusions are given in Chapter 6.

CHAPTER 2

DATA USED FOR ANALYSIS

2.1 Input Data Preparation

The hydrologic data of the Upper Ross-Ade watershed were used for the study of the ILLUDAS model. A Columbus-type deep-notch weir with a 6 foot crest length provided accurate flow measurement at the gaging site. Rainfall was collected at the weir site by a 16 inch diameter receiver located 8 feet above the ground. The rainfall and runoff data were recorded continuously on a 20 inch chart and digitized at one minute intervals for the years 1970 and 1974. The data for the year 1970 were used for the calibration of the model and those for 1974 were used for the verification of the model. The storms of June 21, July 19, September 11, and October 23, 1974 were used for comparison of the observed and computed outputs.

The quality data used in this study were collected in the Upper Ross-Ade watershed by McElroy and Bell (1974). The sampling equipment, installation and operation were described in detail by them. They discussed also the type of samples, sampling interval, sample volume, sample duration, sampling program and laboratory analyses selection. A 30 minute sampling interval was then chosen considering all the factors. The sampling interval significantly affects the shape of the pollutograph plots. Nevertheless, samples were collected from the Upper Ross-Ade watershed during the period October 1972 through May 1975 at an interval of 30 minutes. The dates of these storms, along with a listing of the laboratory analyses performed on them, can be found in the report by McElroy et al (1976). The pollutographs of June 21, July 19, and October 23, 1974 are selected for comparison with the computed results.

2.2 General Description of the Watershed

The Upper Ross-Ade watershed consists of 29 acres and is residential and relatively uniform in character. Of the 29 acres, 11 (or about 38 percent) are impervious. The basin has a definite valley-type configuration. Woodland Avenue which runs down the center of the valley has a slope of 1 to 3 percent, but some of the side streets are steeper. Yard slopes vary from nearly flat in the upper part of the basin to about 25 percent near the center of the basin (Figure 2.1).

Soils in the watershed vary from Crosby silt loam of hydrologic group C in the flood plain to Miami silt loam of hydrologic group B on the steeper portions of the watershed and Eel silt loam of hydrologic group C on the uplands. Almost half the roof drains have underground connections.

A set of detailed drainage system plans and profile drawings of the Upper Ross-Ade watershed was obtained from the City Engineer Office, West Lafayette, Indiana. Those drawings along with maps and aerial photos were used in this study. A schematic representation is shown in Figure 2.2. The length, slope, and diameter of each pipe segment are listed in Table 2.1.

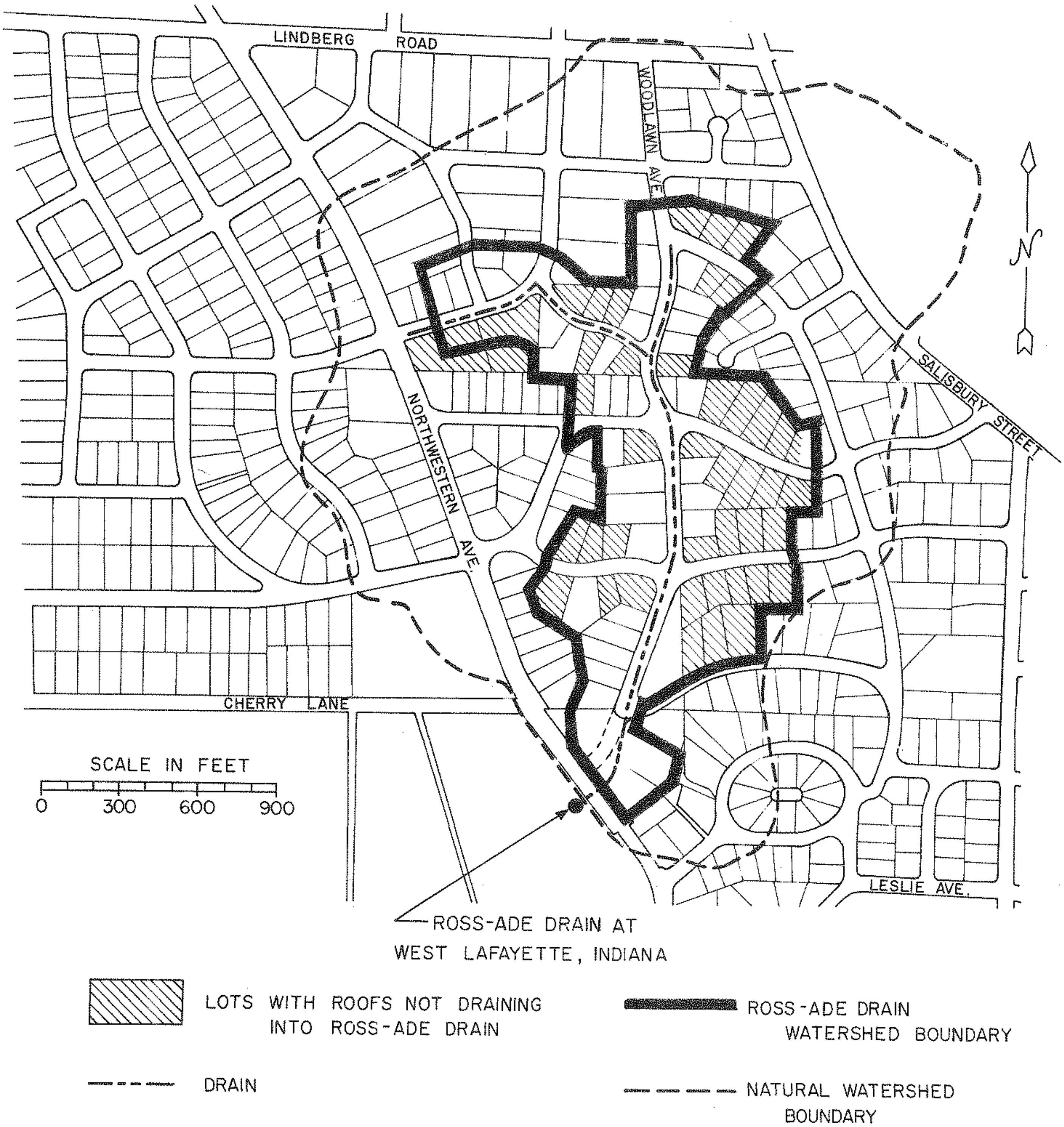

FIGURE 1 ROSS-ADE DRAIN UPPER WATERSHED

FIGURE 2.1 UPPER ROSS-ADE WATERSHED

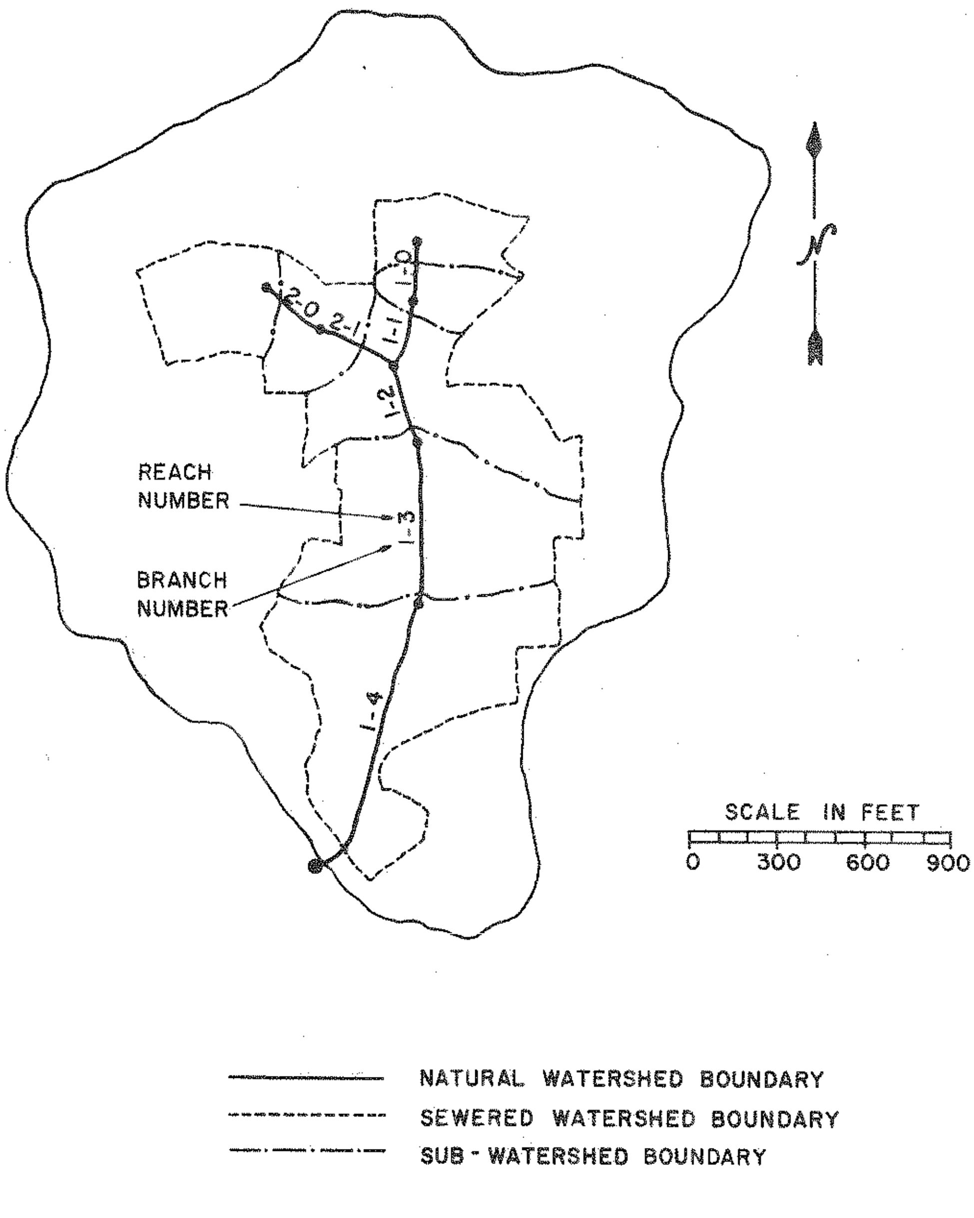

FIGURE 2.2 SCHEMATIC REPRESENTATION OF THE UPPER ROSS-ADE WATERSHED

TABLE 2.1 PHYSICAL CHARACTERISTICS OF PIPE SEGMENTS IN THE UPPER ROSS-ADE WATERSHED

Branch	Reach	Length [ft]	Slope [%]	Diameter [inches]
1	0	240	3.4	18
1	1	260	3.4	21
2	0	250	4.8	15
2	1	280	4.0	18
1	2	240	2.0	30
1	3	536	2.8	36
1	4	860	1.5	36

CHAPTER 3

SENSITIVITY ANALYSIS OF THE ILLUDAS MODEL

3.1 Introduction

The overall objective of urban runoff modeling is to aid in the decision making associated with the planning, design or operation of urban drainage systems. To achieve this broad objective three types of models are utilized describing the dynamics of the runoff, of the pollution washoff and of the flow in the sewer system with increasing detail; these are the planning, the design and the operation models.

The ILLUDAS model falls in the design model category along with many other urban runoff models, e.g. SWMM, SOGREAM, DORSCH. The ILLUDAS model was developed for the simulation of urban runoff from single storm events. It accounts for the details of the flow routing from the point of rainfall through the whole basin to the receiving waters. It calculates the runoffs from both grassed and paved areas. In the evaluation mode it is capable of accurately predicting the runoff at any point of the conveyance system. In the design mode it calculates the required channel or sewer-pipe sizes given the location, slopes, desired retention capacity, etc. ILLUDAS is a validated model which provides a useful technique for the hydrologic evaluation of an existing urban drainage system as well as for the design of new urban drainage systems. In the design mode several configurations of the sewer network and several locations and sizes of detention basins may be evaluated. In this manner ILLUDAS provides substantial assistance in the economic analysis of urban drainage systems.

ILLUDAS requires that the actual physical area be subdivided into subbasins served by identified sewer branches and reaches. The data needed include the rainfall pattern and amount, the antecedent moisture condition, the hydrologic soil group, and the paved and grassed area acreages (or the percentage of total area). In the evaluation mode, the pipe, culvert or open ditch dimensions, their lengths, slopes, Manning's n's, etc., are also needed. If the detention option is desired, the storage capacity may be specified at any point in the basin. As an additional option one may limit the flow through a given reach by specifying a small pipe size of a maximum discharge, and ILLUDAS will calculate the volume of detention storage accumulated. Maps, aerial photos and drainage systems drawings of the basin are needed to extract the branch, reach, and subbasin information. Even so, data requirements are considered moderate compared to some other models.

Contrary to the design models, the planning models are used for an overall estimation of the effectiveness and costs of the urban drainage systems. They generally utilize large time intervals and simulate for a long period of time. The model STORM is a good example of such a model. Planning models are capable of processing long periods of data. Design models instead reflect the dynamics of a system and emphasize the comprehensive analysis of singular events. These two models can be utilized in a complementary way, as will be shown in a subsequent chapter.

3.2 Limitations

As discussed earlier, the ILLUDAS model provides valuable information on the urban runoff quantity. It is well-documented and widely tested. However, there are two major limitations:

(a) There is no provision for continuous simulation;

(b) There is no runoff quality calculation, routing, and reaction.

A substantial portion of this report is concerned with the elimination of these two limitations. Chapter 4 of this report discusses the program modifications to accommodate a continuous simulation. The addition of a runoff quality model is discussed in Chapter 5. Before proceeding with these model extensions, the sensitivity analysis of the ILLUDAS model is studied in the following section.

3.3 Sensitivity Analysis of the ILLUDAS Model

The ILLUDAS model can be used as a design or as an evaluation model. In either mode, input data are required describing the storm event and the hydrologic characteristics of the basin. A sensitivity analysis is needed in order to gain a better insight into a system's behavior and into the effect of errors in certain input parameters on the model response. The conclusions are qualitatively general but the quantitative results of this study should not be transferred to other basins because of their uniqueness.

A series of computer runs using the design mode was made for the Upper Ross-Ade Watershed, West Lafayette, Indiana, for four return periods and 16 combinations of hydrologic soil groups and antecedent moisture conditions (AMC).

Four hydrologic soil groups were described by the U.S. Soil Conservation Service as follows:

A. These soils have a high infiltration rate. They are chiefly deep, well-drained sands and gravels (low runoff potential).

B. These soils have a moderate infiltration rate when thoroughly wet. They are chiefly moderately deep, well-drainaged soils of moderately course texture.

C. These soils have a slow infiltration rate when wet. They are soils with a layer that impedes downward movement of water and soils of moderately fine to fine texture.

D. These soils have a very slow infiltration rate. They are chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan at or near the surface, and shallow soils over nearly impervious material (high runoff potential).

Each antecedent moisture condition is based on the total rainfall that occurred during the five days preceding the storm. The values in the following table were used in this study.

ILLUDAS Number	Description	Total Rainfall During 5 Days Preceding Storm [inches]
1	Bone dry	0
2	Rather dry	0 to 0.5
3	Rather wet	0.5 to 1.0
4	Saturated	over 1

The basic data of four design storms, taken from Yarnell (1935) for West Lafayette, Indiana, are summarized as follows:

Return Period [years]	Total Rainfall [inches]	Duration [minutes]
2	1.10	30
5	1.40	30
10	1.60	30
25	1.85	30

The values of the parameters used in the sensitivity analysis are listed in Table 3.1. The branches and reaches characteristics can be found in Table 2.1.

3.3.1 Effect of the Antecedent Moisture Condition

In order to use the standard infiltration curves in ILLUDAS, it is necessary to evaluate the AMC. The sensitivity of the peak flows and of the pipe size (diameter) to changes in the AMC is described in the following two sections.

3.3.1.1 Effect of the Antecedent Moisture Condition on Peak Flow and Runoff Volume

Figure 3.1 shows the sensitivity of the peak flows to changes in the AMC for four different return periods and for the four soil groups. The graphs are plotted in terms of the percent of peak flows for AMC 4, for the four soil groups of A, B, C and D, and for return periods of 2, 5, 10 and 25 years. In general, the actual peak flows corresponding to 100 percent are not the same. Even so, the figures still show the sensitivity tendency.

The plots indicate that the sensitivity to changes in AMC decreases as the hydrologic soil group changes from A to D. Also, the sensitivity to a unit change in AMC decreases as the return period changes from 2 to 25 years for any given hydrologic soil group.

TABLE 3.1 VALUES USED FOR THE SENSITIVITY ANALYSIS OF THE ILLUDAS MODEL

Description of the Variable	Variable Name in the Program	Value Used	Units
New Design	DESIN	Positive Integer	-
Basin Area	AREA	29.1	
Paved Area Abstraction	ABSTRT	0.10	inches
Grassed Area Abstraction	DEPG	0.20	inches
Soil Group	ISOIL	1,2,3,4	-
Minimum Diameter	DIMIN	18.0	inches
Manning's n	RUFFN	0.013	-
Time Increment	DELT	1,2,3,4,5,6, 7,10,15,20, 30	minutes
Standard Rainfall Distribution	HUFF	Positive Integer	-
Duration	DURA	30.0	minutes
Return Period	FREQ	2,5,10,25	years
Total Rain	TRAIN	1.10, 1.40, 1.60, 1.85	inches
Antecedent Moisture Condition	AMC	1,2,3,4	-

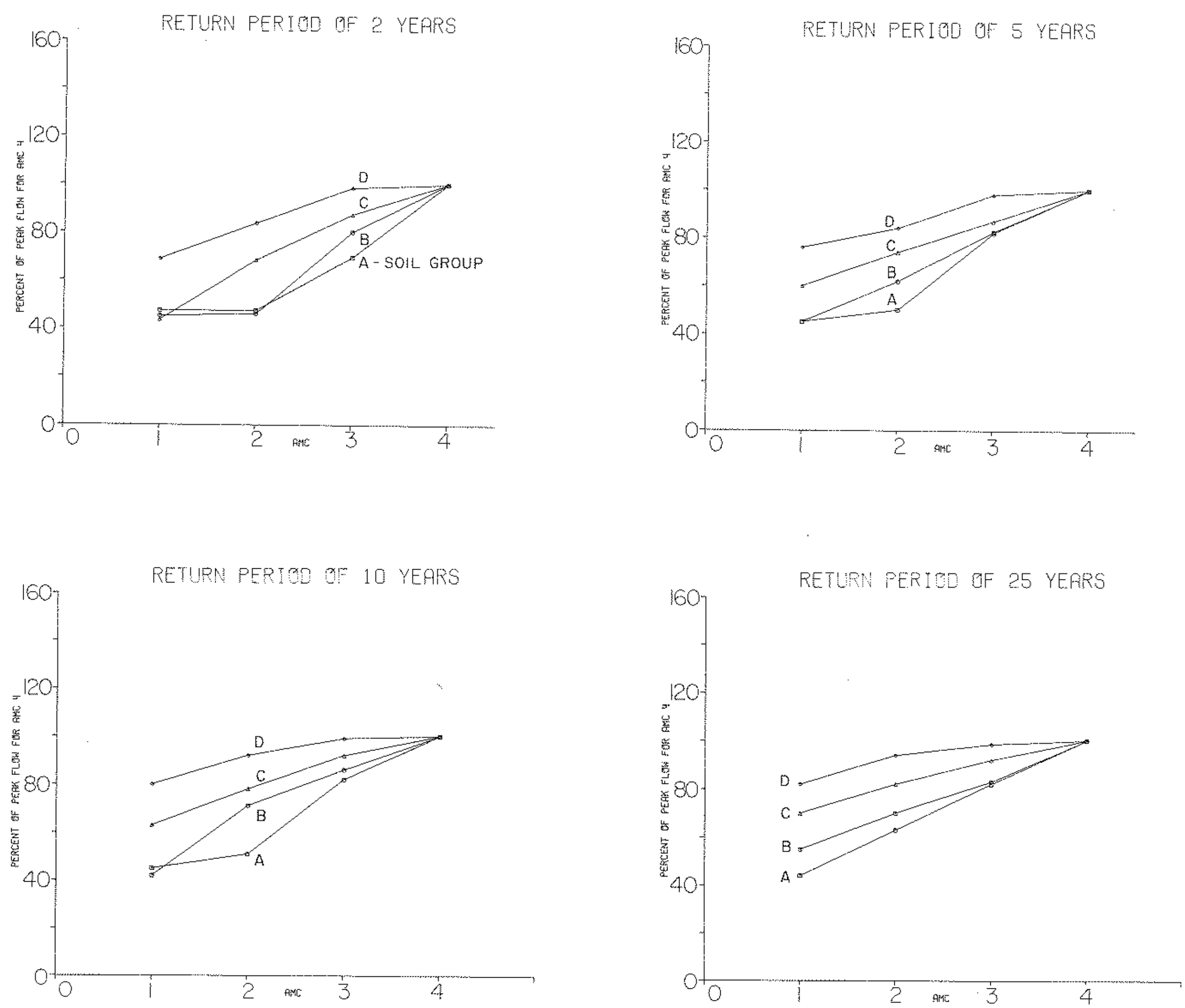

FIGURE 3.1 SENSITIVITY OF THE PEAK FLOWS TO CHANGES IN THE AMC

Table 3.2 summarizes the sensitivity of peak flows to AMC. It is obvious from Fig. 3.1 and Table 3.2 that an AMC change from 2 to 3 is critical in the basin studied as far as the peak flows are concerned.

Figure 3.2 shows the sensitivity of the hydrograph to changes in the AMC for the combinations of the return period of 5 and 10 years and of soil groups A and D. The time to peak does not change for each combination but the peak runoff and runoff volume increases as the AMC changes from 1 to 4. The percentage increase in peak flow and in runoff volume are listed in Table 3.3.

TABLE 3.2 SENSITIVITY OF THE PEAK FLOWS TO THE AMC

Return Period [years]	Range of Percent Change of Peak Flow per Unit AMC Increment	AMC which has Maximum Percent Change
2	0-38	2-3
5	2-35	2-3
10	2-32	2-3
25	2-20	2-3

3.3.1.2 <u>Effect of the Antecedent Moisture Condition on Pipe Size</u>

When ILLUDAS is used in the design mode, the pipe size is the variable of interest. It is expected that the pipe sizes are less sensitive than the peak flows to changes in AMC or in hydrologic soil group because each 3-inch size increment can accommodate a range of discharges. The downstream end reach 1-4 was investigated for four return periods and the four soil groups. Figure 3.3 shows the sensitivity of the pipe sizes to changes in the AMC. The results are summarized in Table 3.4.

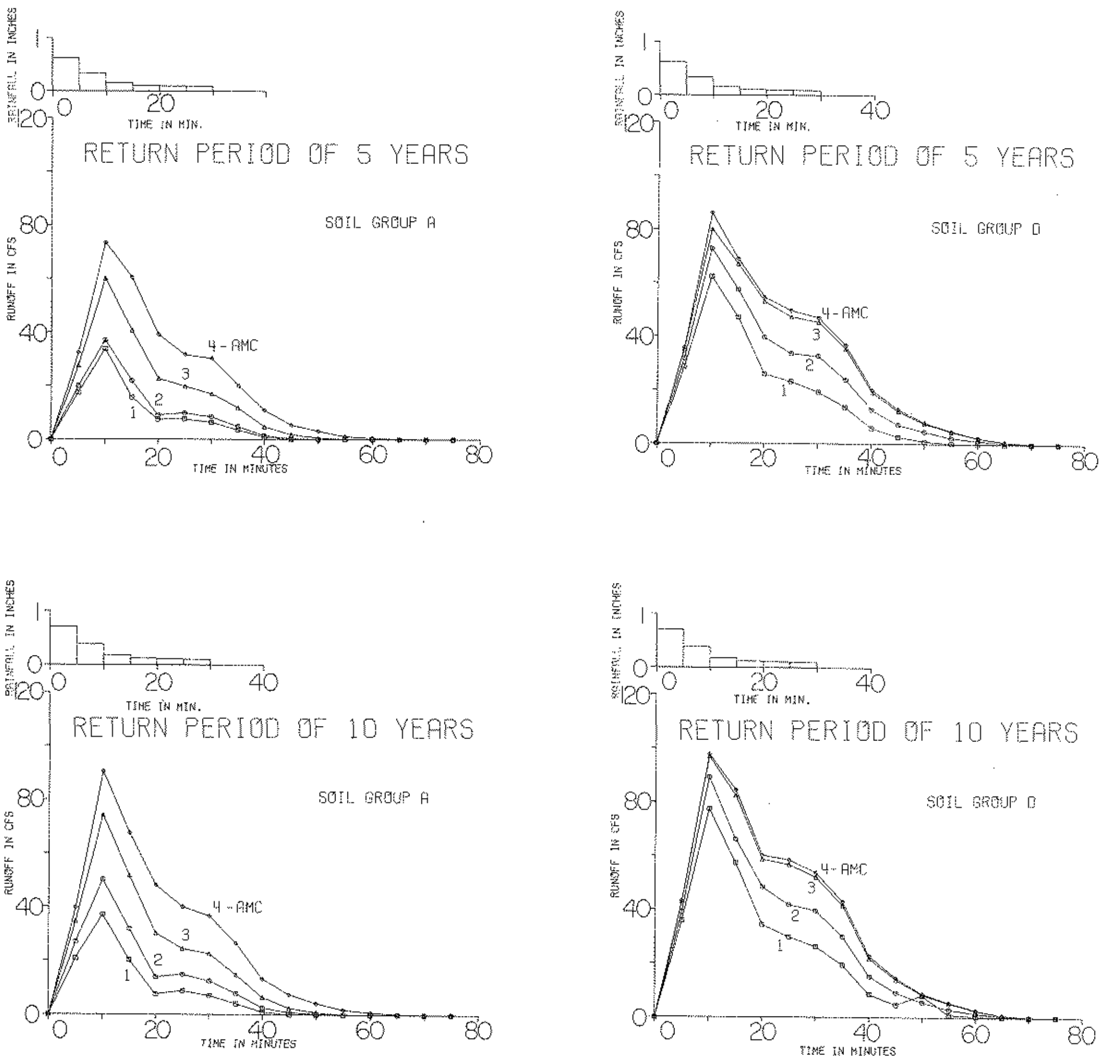

FIGURE 3.2 SENSITIVITY OF THE HYDROGRAPH TO CHANGES IN THE AMC FOR SOIL GROUPS A AND D

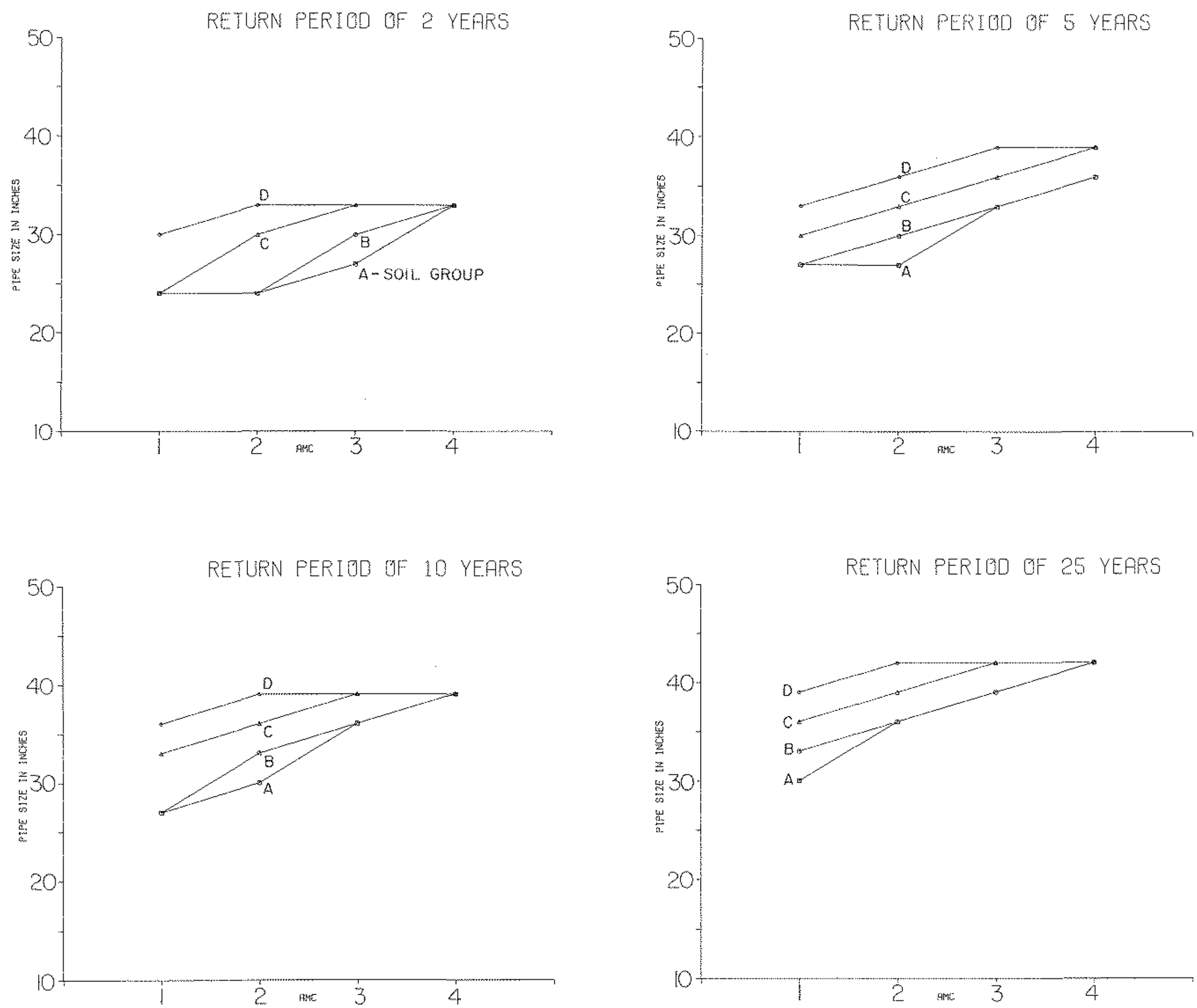

FIGURE 3.3 SENSITIVITY OF THE PIPE SIZES TO CHANGES IN THE AMC

TABLE 3.3 THE PERCENT INCREASE OF THE PEAK FLOW AND OF RUNOFF VOLUME WITH RESPECT TO AMC 1

Return Period [years]	Soil Group	AMC	Peak Flow [%]	Runoff Volume [%]
5	A	1 2 3 4	0 9.8 78.3 117.8	0 21.8 124.0 234.0
5	D	1 2 3 4	0 16.9 28.4 38.2	0 39.6 80.9 86.2
10	A	1 2 3 4	0 34.9 99.5 143.0	0 51.6 145.9 253.3
10	D	1 2 3 4	0 15.2 25.3 26.4	0 30.8 62.7 66.8

TABLE 3.4 SENSITIVITY OF THE PIPE SIZES TO THE AMC

Return Period [years]	Range of Pipe Size [inches]	AMC with Max. Change for Soil Groups A,B,C,D
2	24-33	1-2(C), 2-3(B), 3-4(A)
5	27-39	2-3(A)
10	27-39	1-2(B), 2-3(A)
25	30-42	1-2(A)

It can be seen from Fig. 3.3 and Table 3.4 that the maximum range in pipe sizes for a given return period is 12 inches. It is also observed that the pipe sizes decrease approximately uniformly as the AMC changes from 4 to 1 for a given soil group and for each return period.

3.3.2 Effect of the Hydrologic Soil Groups

It is interesting to study the sensitivity of hydrologic soil groups on peak flows and pipe sizes because the actual soil group is not always clearly defined. A series of computer runs in design mode were made for this purpose.

3.3.2.1 Effect of the Hydrologic Soil Group on Peak Flow and Runoff Volume

Figure 3.4 shows the sensitivity of peak flows to changes in the soil group for four different return periods and for the four antecedent moisture conditions. The graphs are presented in terms of the percent of the peak flows for soil group D, which is maximum for any given AMC and return period.

The plots show, for each return period, that the sensitivity to a unit change in soil group decreases as the AMC changes from 1 to 4. Table 3.5 provides a summary of the sensitivity of peak flows to soil groups. The table shows that, for shorter return periods (2 years and

TABLE 3.5 SENSITIVITY OF THE PEAK FLOWS TO THE SOIL GROUPS

Return Period [years]	Range of Percent Change of Peak Flow per Unit Soil Group Increment	Soil Group which has Maximum Percent Change
2	0-38	C-D
5	0-30	C-D
10	0-30	B-C
25	1-20	B-C

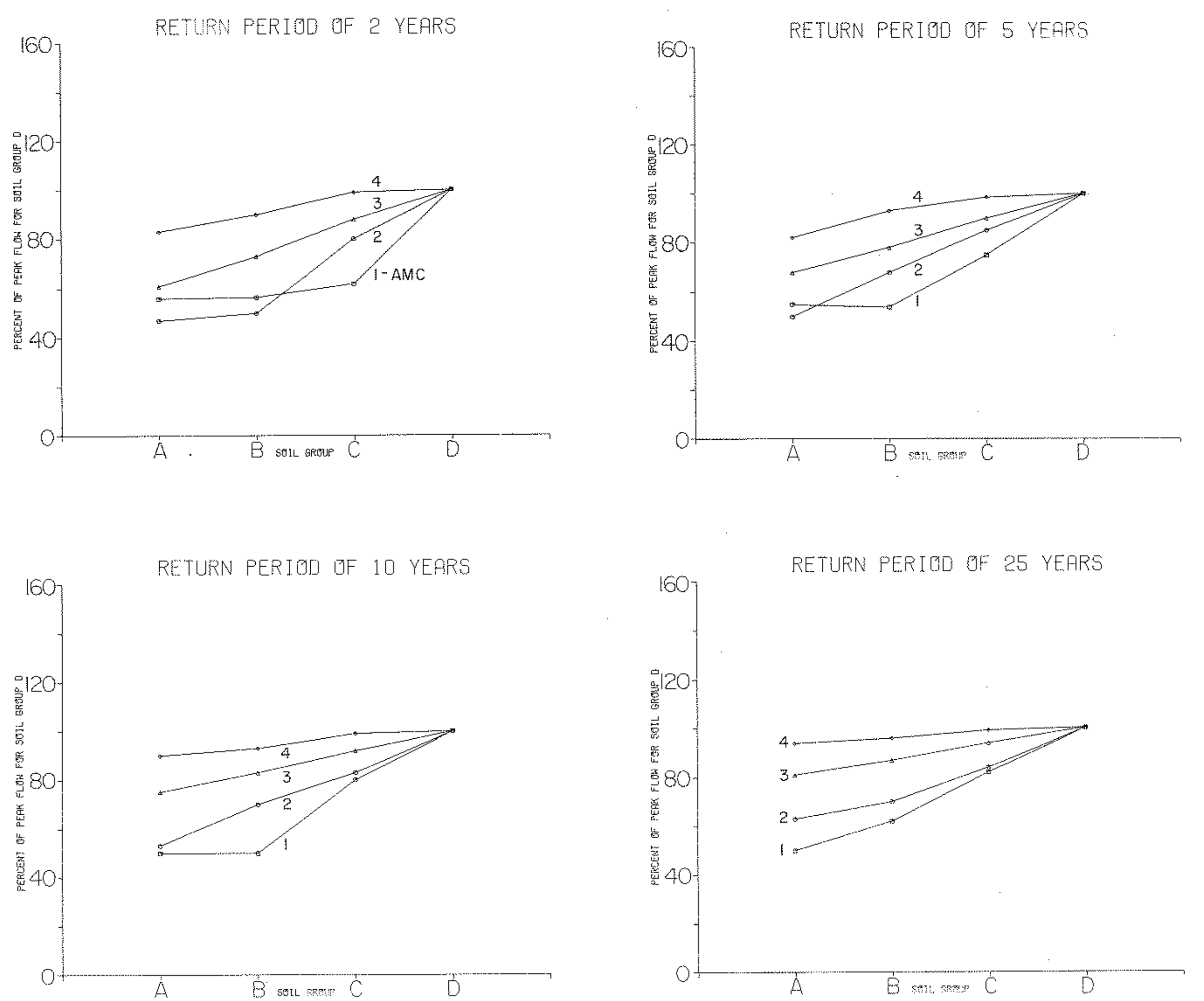

FIGURE 3.4 SENSITIVITY OF THE PEAK FLOWS TO CHANGES IN THE SOIL GROUPS

5 years), a change in soil group from C to D is critical whereas for larger return periods (10 years and 25 years), a change in soil group from B to C is the main concern.

Figure 3.5 shows the sensitivity of the hydrograph to changes in the soil groups for the combinations of the return period of 5 and 10 years and of AMC 1 and 4. The time to peak does not change for each combination but the peak runoff and runoff volume increase as the soil group changes from A to D. The percent increases are presented in Table 3.6.

3.2.2.2 Effect of the Hydrologic Soil Group on Pipe Size

Figure 3.6 shows the sensitivity of the pipe sizes to changes in the soil groups for the four AMC values and for four return periods. It is summarized in Table 3.7. From Fig. 3.6 and Table 3.7 it can be seen that the pipe sizes decrease as the soil group changes from D to A, and that the maximum range in pipe sizes for a given return period is 12 inches. A general conclusion on pipe size sensitivity would be that a unit change in either AMC or soil group would result in no more than an increase or decrease of 6 inches in the pipe size for a given return period.

3.3.3 Effect of the Time Increment

The time increment plays an important role in the ILLUDAS model. Generally, the time interval should be as short as the rainfall data will allow and generally not larger than 1/3 to 1/4 of the time of concentration of the basin. The time of concentration of the basin under study is about 30 minutes. The paved area inlet time calculated by ILLUDAS is nearly 4 minutes, and that of the grassed area is approximately 25 minutes. Increments of 1, 2, 3, 4, 5, 6, 7, 10, 15, 20 and 30 minutes were investigated.

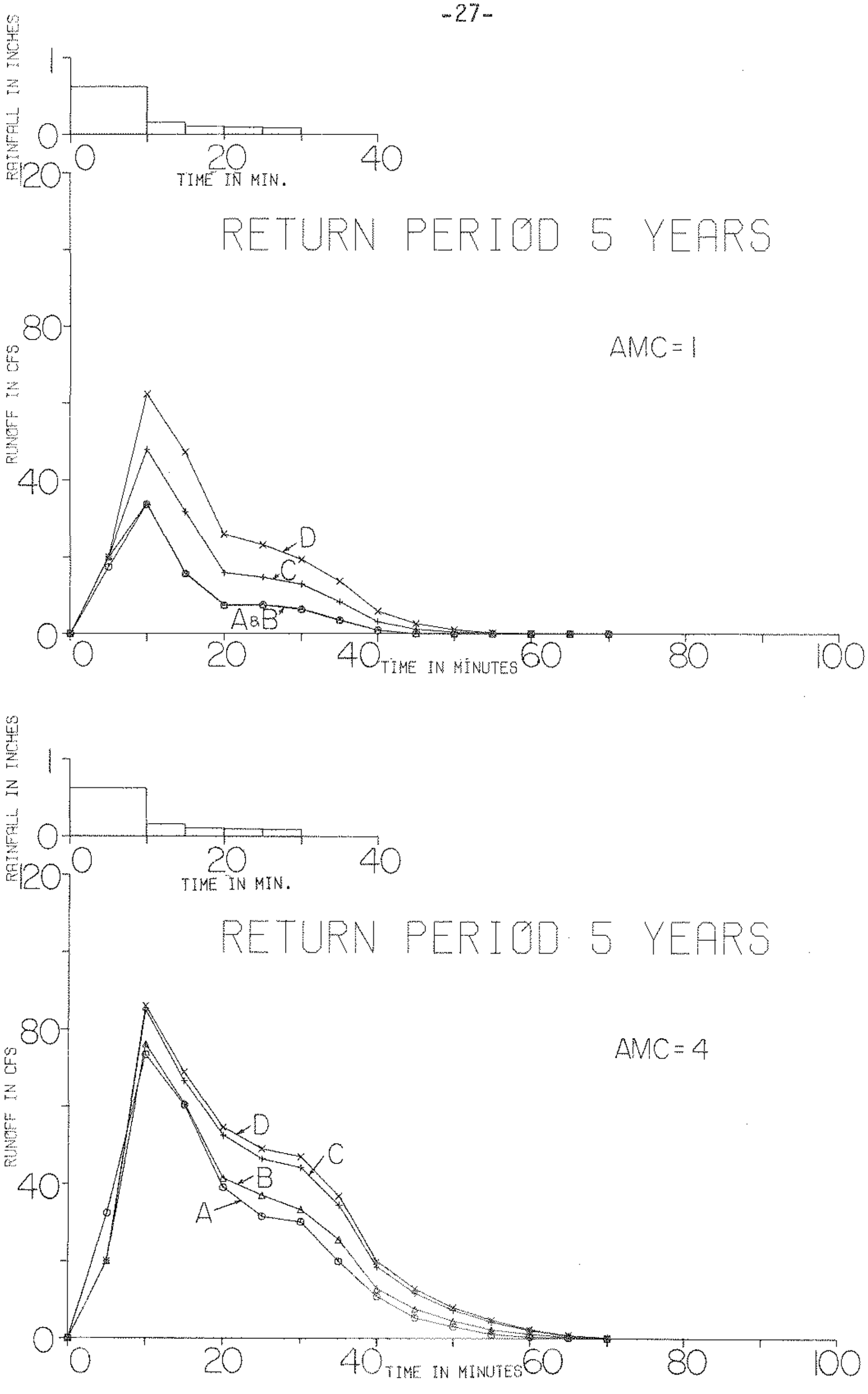

FIGURE 3.5 SENSITIVITY OF THE HYDROGRAPH TO CHANGES IN THE SOIL GROUP FOR AMC 1 AND 4

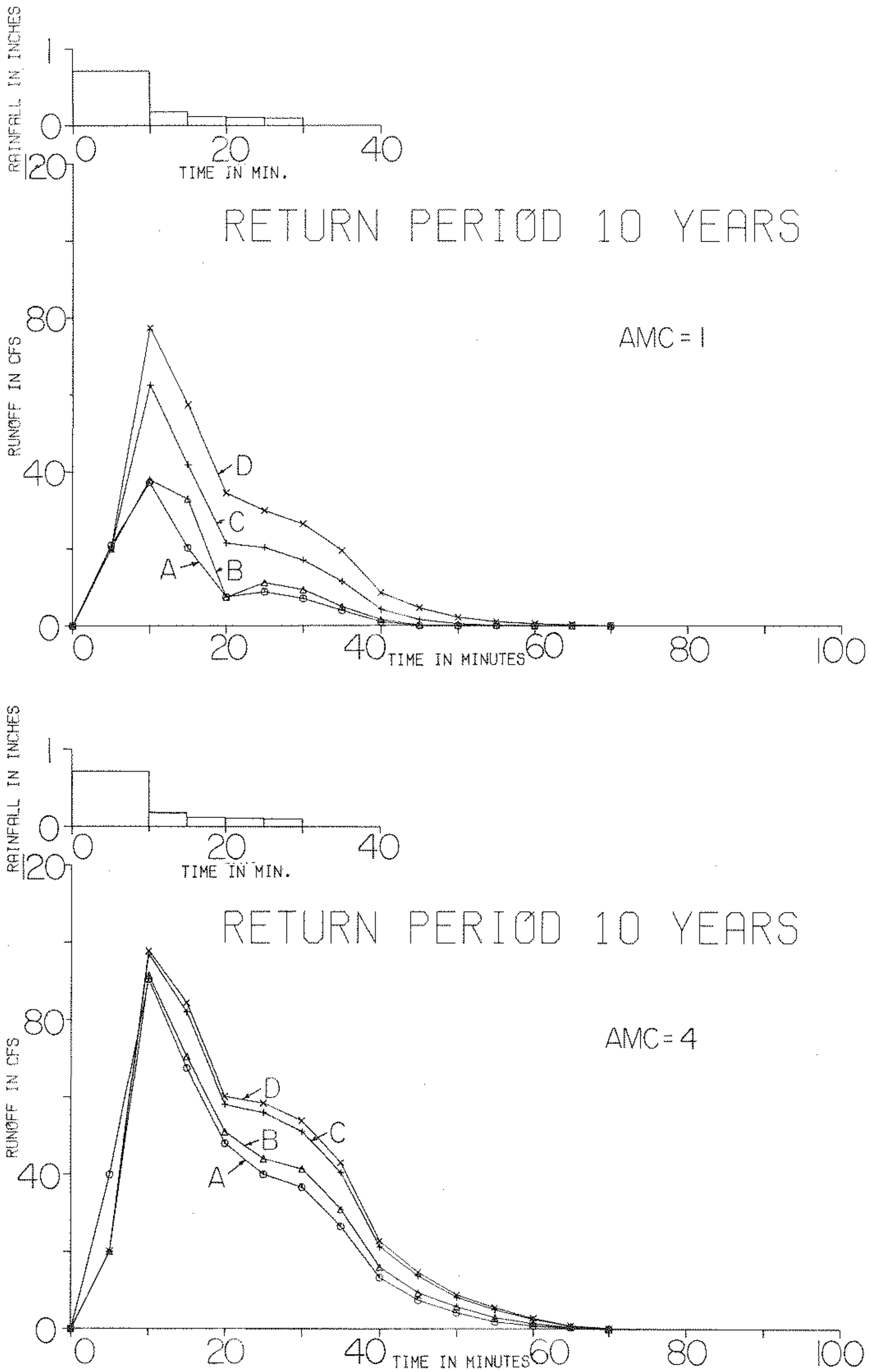

FIGURE 3.5 CONT'D

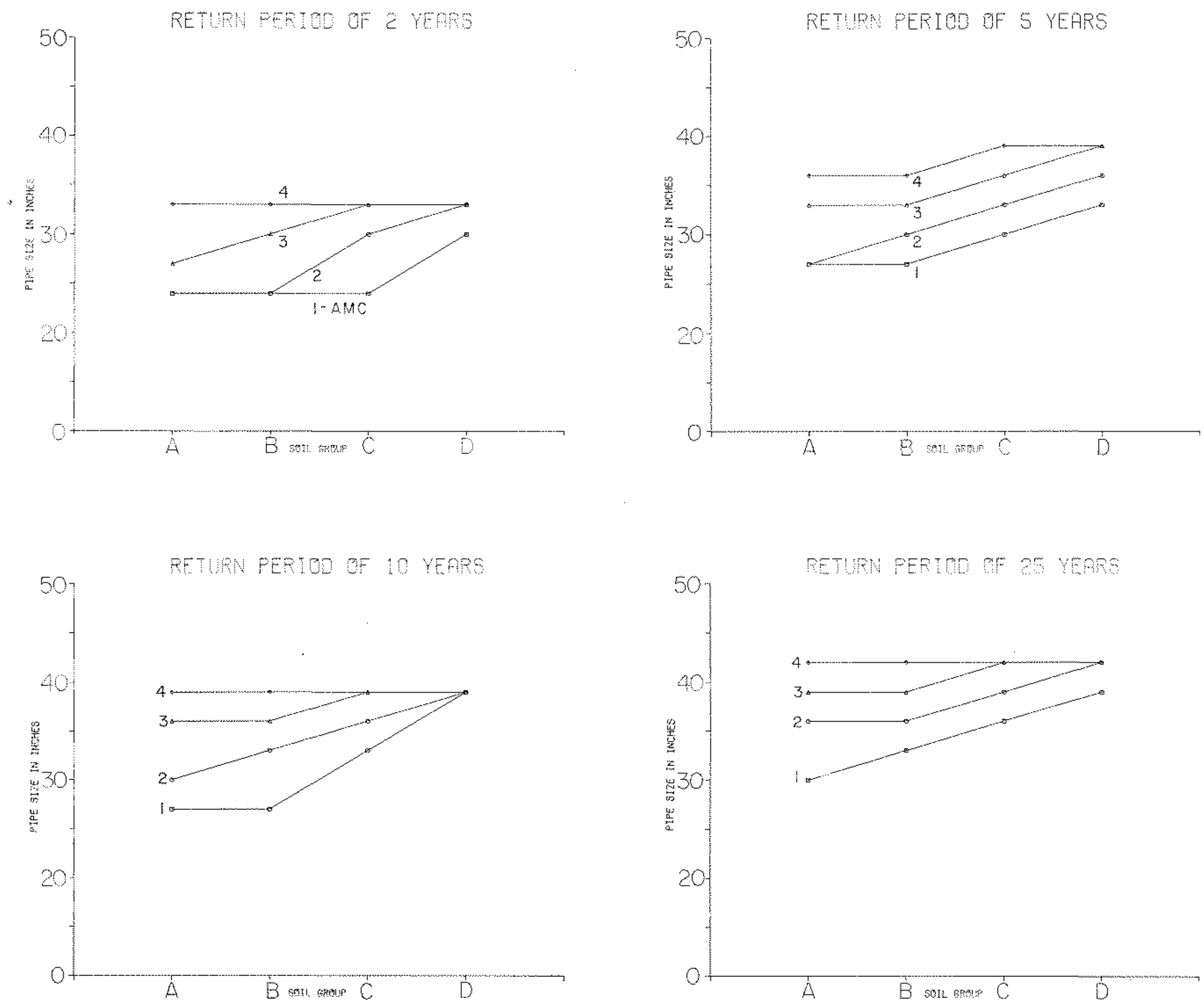

FIGURE 3.6 SENSITIVITY OF THE PIPE SIZES TO CHANGES IN THE SOIL GROUPS

TABLE 3.6 THE PERCENT INCREASE OF THE PEAK FLOW AND RUNOFF VOLUME WITH RESPECT TO SOIL GROUP A

Return Period [years]	AMC	Soil Group	Peak Flow [%]	Runoff Volume [%]
5	1	A	0	0
		B	0.3	0.9
		C	42.1	73.2
		D	84.9	148.7
5	4	A	0	0
		B	3.7	9.2
		C	15.7	32.8
		D	17.3	38.7
10	1	A	0	0
		B	1.9	20.9
		C	68.0	98.5
		D	108.1	179.2
10	4	A	0	0
		B	1.2	7.7
		C	7.2	26.9
		D	8.2	31.8

TABLE 3.7 SENSITIVITY OF THE PIPE SIZES TO THE SOIL GROUPS

Return Periods [years]	Range of Pipe Size [inches]	Soil Groups with Max. Change for AMC 1,2,3,4
2	24-33	B-C(2), C-D(1)
5	27-39	-
10	27-39	B-C(1), C-D(1)
25	30-42	-

3.3.3.1 Effect of the Time Increment on Peak Flow and Runoff Volume

Figures 3.7 and 3.8 show the sensitivity of the peak flows to changes in the time increments as a function of the AMC for soil Group C and as a function of the soil group for AMC of 1, respectively. Two conclusions can be drawn from those plots: (1) the sensitivity to changes in time increment decreases as the AMC changes from 1 to 4; (2) the sensitivity to changes in time increment decreases as the hydrologic soil group changes from A to D. It is shown that the calculated peak flow values are more sensitive to the time increment for $\Delta t > 5$ minutes and less sensitive to the time increment for $\Delta t < 5$ minutes in most cases.

Soil group A and AMC 1 is the combination which appears to be the most sensitive to changes in time increments. For this combination and a time increment of 5 min. the error in peak discharge varies with the return period from -15% to -18% with respect to the values for a 1 min. time increment. For a 4 min. time increment the errors reduce to -7% to -15%. From the point of view of the peak discharge the time increment of 5 min. appears to be the maximum tolerable.

Figure 3.9 shows the sensitivity of the hydrograph to changes in time increments of 1, 3, 5, 7, 10, 20, and 30 minutes. The time increment of 5 min. results in a peak value near that of the hydrographs for shorter time increments. For time increments larger than 5 minutes the hydrographs show a considerable deformation. The percentage changes are presented in Table 3.8.

3.3.3.2 Effect of the Time Increment on Pipe Size

Figures 3.10 and 3.11 show the sensitivity of the pipe sizes to changes in the time increments as a function of the AMC for soil group C as a function of the soil groups for the AMC 1, respectively.

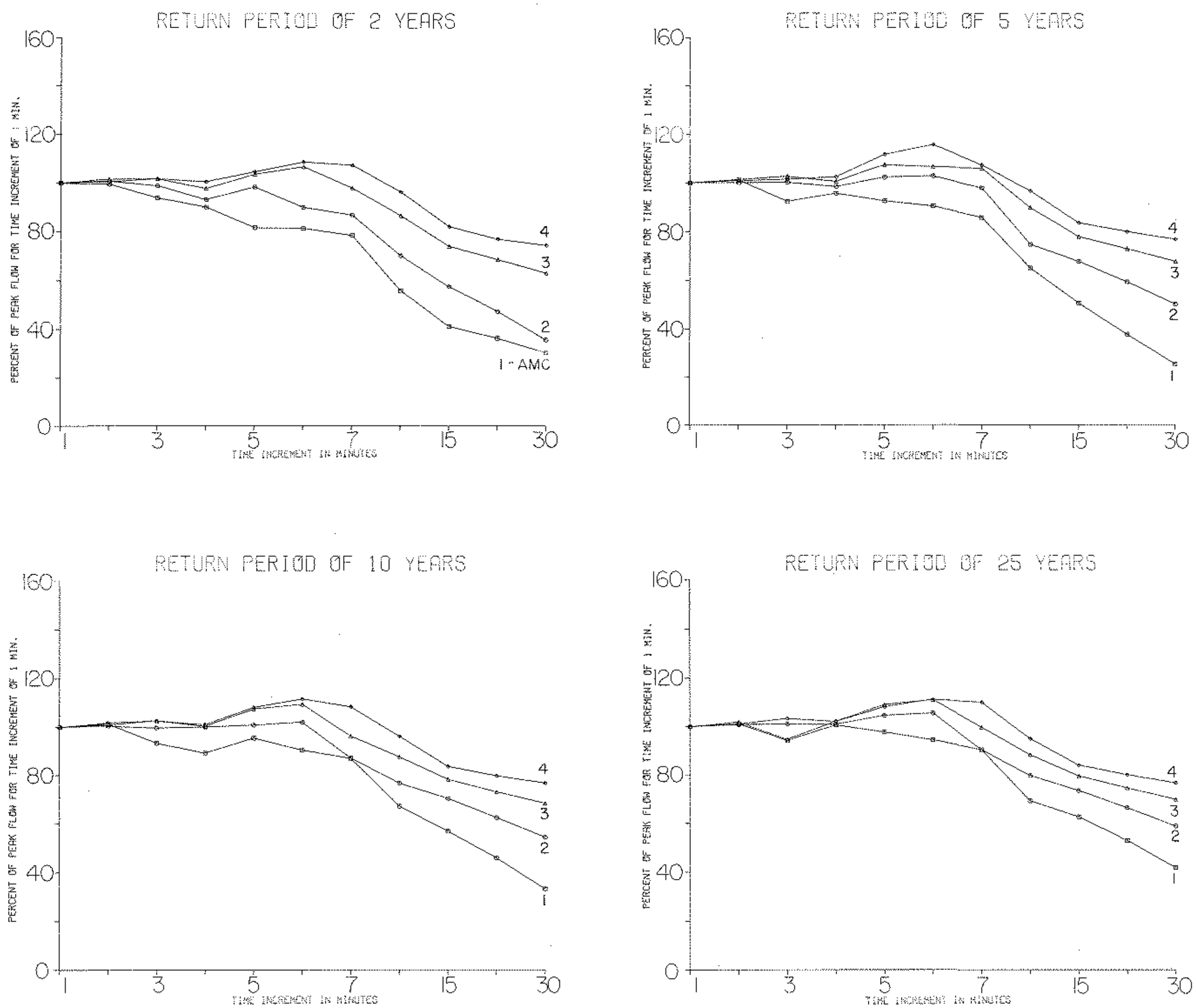

FIGURE 3.7 SENSITIVITY OF THE PEAK FLOWS TO CHANGES IN THE TIME INCREMENT AS A FUNCTION OF THE AMC FOR SOIL GROUP C

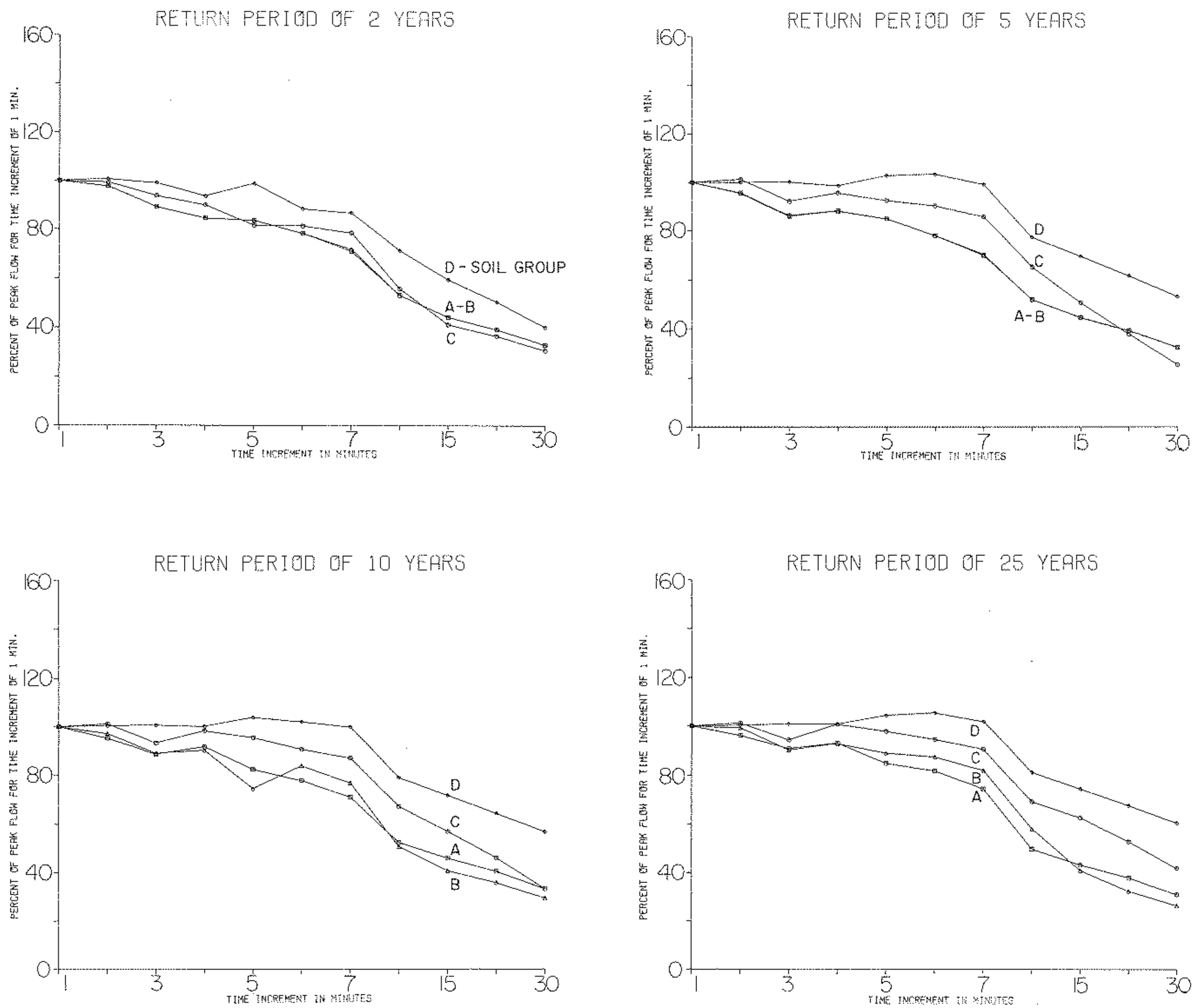

FIGURE 3.8 SENSITIVITY OF THE PEAK FLOWS TO CHANGES IN THE TIME INCREMENTS AS A FUNCTION OF THE SOIL GROUPS FOR AMC 1

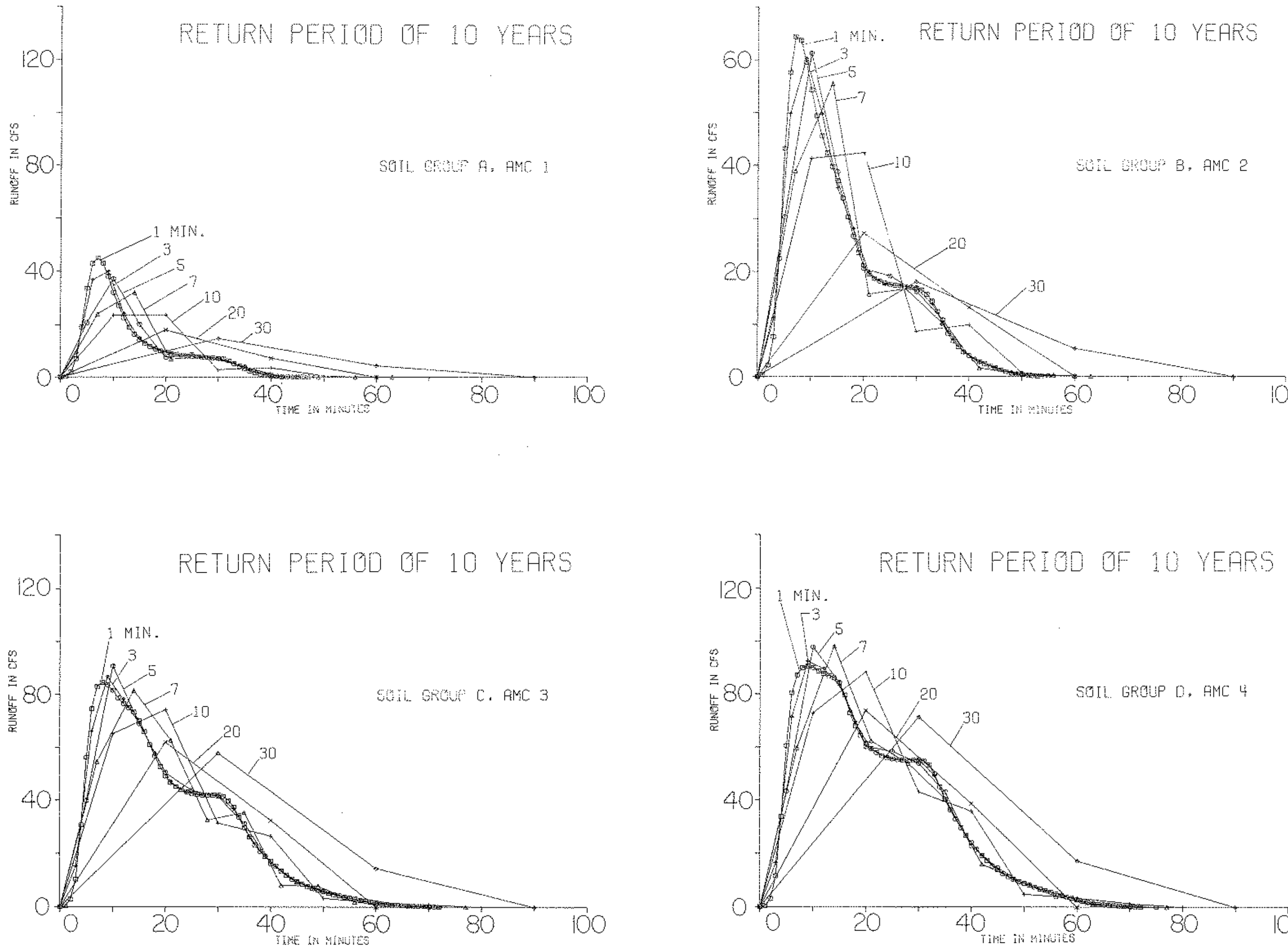

FIGURE 3.9 SENSITIVITY OF THE HYDROGRAPH TO CHANGES IN THE TIME INCREMENTS

TABLE 3.8 THE PERCENT CHANGE OF THE PEAK FLOW AND RUNOFF VOLUME FOR SEVERAL TIME INCREMENTS WITH RESPECT TO ONE MINUTE INCREMENT

Return Period [years]	AMC	Soil Group	Time Increment [min]	Peak Flow [%]	Runoff Volume [%]
10	1	A	1 3 5 7 10 20 30	0 -11.3 -17.5 -29.0 -47.7 -59.6 -66.7	0 0.03 0.07 - 2.1 1.2 - 4.3 9.3
10	2	B	1 3 5 7 10 20 30	0 - 6.5 - 4.8 -13.8 -34.2 -57.6 -71.9	0 - 0.03 - 0.02 - 3.9 1.3 -20.6 -30.7
10	3	C	1 3 5 7 10 20 30	0 2.5 7.3 - 3.6 -12.3 -26.8 -31.6	0 0 - 0.02 - 1.0 0.5 - 6.5 7.2
10	4	D	1 3 5 7 10 20 30	0 1.9 7.9 8.5 - 2.3 -18.5 -21.2	0 0 0.01 - 2.5 0.5 - 9.5 6.9

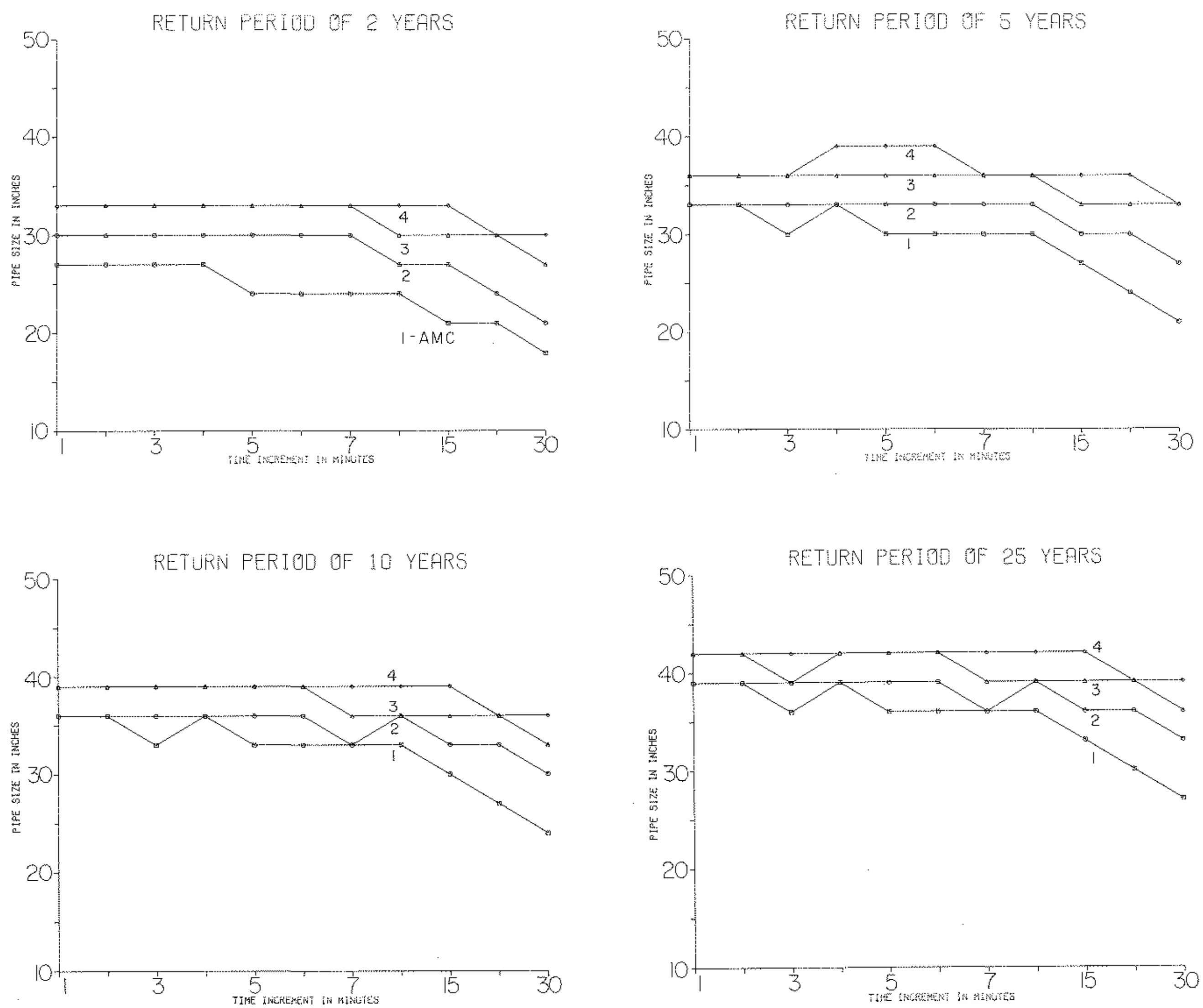

FIGURE 3.10 SENSITIVITY OF THE PIPE SIZES TO CHANGES IN THE TIME INCREMENTS AS A FUNCTION OF THE AMC FOR SOIL GROUP C

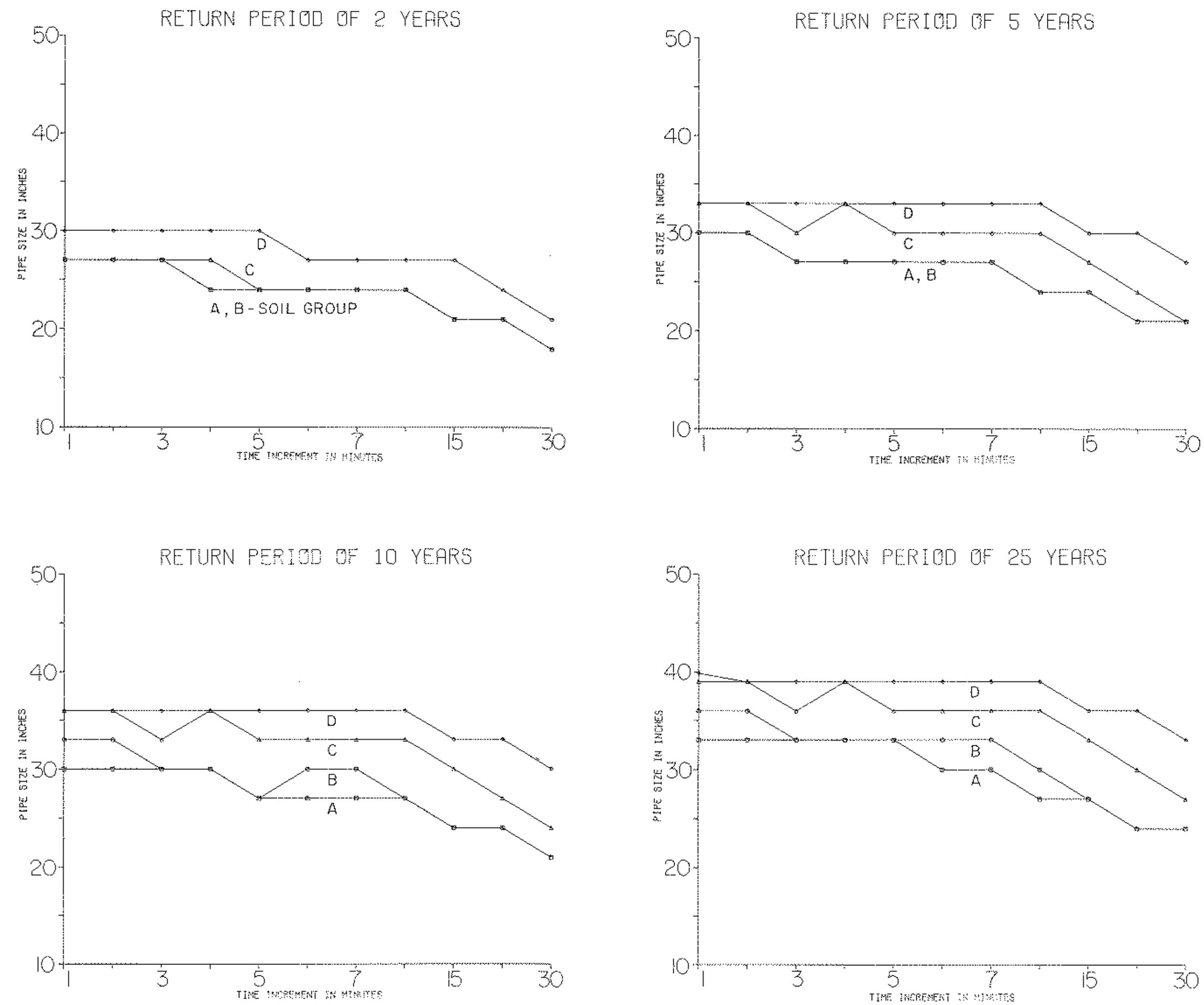

FIGURE 3.11 SENSITIVITY OF THE PIPE SIZES TO CHANGES IN THE TIME INCREMENTS AS A FUNCTION OF THE SOIL GROUPS FOR AMC 1

The effect of the time increment on pipe size is not as pronounced. Incorrect pipe sizes are obtained for time increments larger than 10 minutes. The maximum increase or decrease is of 3 inches in the pipe size for a unit change in either the AMC or the soil group for a given return period.

3.3.4 Summary of the Sensitivity Analysis

(1) The sensitivity of the peak flows to changes in the AMC increases as the soil group changes from D to A.

(2) The range of sensitivities to the soil groups and AMC are approximately the same.

(3) A change in the AMC from 2 to 3 and a change in the soil group from B to C for large design return periods and from C to D for small design return periods are critical.

(4) The time to peak for various combinations of soil group and AMC for different return period remains the same.

(5) The peak flow and runoff volume increase as the AMC changes from 1 to 4. This increase is particularly important between AMC 2 and 3 and between AMC 3 and 4 for soil group A. The peak flow and the run-off volume for constant soil group also increase as the soil group changes from A to D for constant AMC. This increase is particularly important between soil groups B and C and soil groups C and D, for AMC 1.

(6) The peak flows decrease markedly for time increments larger than 5 minutes and the pipe diameters decrease significantly for time increments larger than 10 minutes.

(7) A time increment should not exceed substantially the paved area inlet time. Hence a 5 minute time interval is chosen for further study.

CHAPTER 4

MODIFICATIONS OF THE ILLUDAS MODEL FOR CONTINUOUS SIMULATION

4.1 Introduction

The ILLUDAS model is best suited for a single design or observed storm. It utilizes the directly connected paved area concept of the Road Research Laboratory method (Terstriep and Stall, 1969) and also provides the grassed and nonconnected paved area component of runoff. Terstriep and Stall (1974) tested the ILLUDAS model in 21 urban and 2 rural basins. They concluded that the ILLUDAS model produced acceptable results in 14 of the 23 studied basins. Three other basins were considered marginal, three were indeterminate, and three were not acceptable.

It is well recognized that infiltration curves indigenous to the watershed under consideration are necessary and basic for accurate simulation of runoff events from that watershed. These infiltration curves are in turn dependent upon the antecedent moisture conditions. Four Standard Infiltration Curves for soils of hydrologic groups A, B, C and D have been devised for use in ILLUDAS. These curves were calculated from the Horton's equation as given by Musgrave and Horton (1964):

$$f = f_c + (f_o - f_c)e^{-kt} \qquad (1)$$

where: f_o is the initial rate of infiltration capacity [inches per hour]

e is base of natural logarithm

k is a constant depending primarily upon soils and vegetation

t is time since beginning of rainfall.

The shape factor k=2 in Eq. (1) is used in ILLUDAS. However, this is not meant to apply to soil with unique characteristics for which it is necessary to adjust the k-value. The choice of the soil group and the AMC fixes f_o, f_c and total infiltration amount and thus the infiltration curve. The use of the correct value of the soil group and the AMC is therefore extremely important for modeling.

It is felt that the dry period between storms needs to be emphasized for the proper determination of the AMC necessary for a continuous simulation of the runoff. A subroutine DRYAMC which calculates the total rainfall during the five days preceding the storm is added to determine the AMC at the beginning of each storm. With this modification the program ILLUDAS may be used for the continuous simulation of a long period of data rather than for a single storm event only. To achieve this goal, the dry period between storms in minutes, must be included in the input data. A simple block diagram of the modified ILLUDAS program is shown in Fig. 4.1. The listing of the modified ILLUDAS is given in Appendix A-1.

4.2 Calibration and Verification of the Modified Model

One approach in evaluating the parameters of a mathematical rainfall-runoff model for application to a given watershed is to estimate them from the available knowledge or from observed or physical properties of the watershed. This presumes that the model realistically represents the actual physical processes. The calibration is intended to reproduce the runoff in the best possible way (i.e., with the absolute least error) from the observed rainfall in the watershed under investigation.

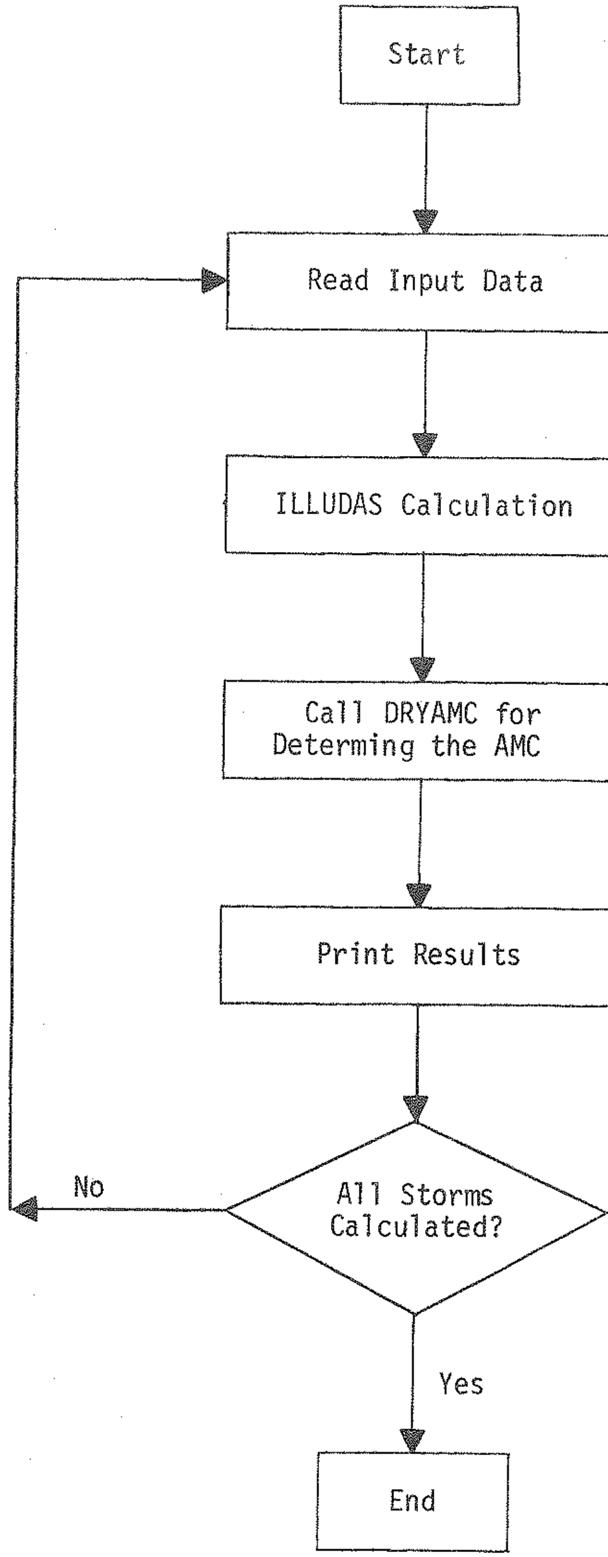

FIGURE 4.1 SIMPLE BLOCK DIAGRAM OF THE MODIFIED ILLUDAS PROGRAM

The modified ILLUDAS model was tested by using the data of the Upper Ross-Ade Watershed described in Chapter 2. A series of 132 storms recorded in 1970 and 154 storms in 1974 at 5 minute intervals as well as the dry periods between storms are the main inputs for calibration and verification, respectively. The actual calibration of the modified model is performed by keeping all other parameters as listed in Table 4.1, except the following two parameters: the paved area abstraction and the grassed area abstraction; both parameters account for surface wetting and depression storage. They are calibrated for the total yearly runoff. The final calibration is made on the basis of matching the calculated and observed total amounts of runoff. The values of the calibrated input data are:

the paved abstraction	0.1 inch
the grassed abstraction	0.2 inch

4.3 Evaluations of the Results of the Modified Model

A comparison is made of the observed runoffs with runoffs computed by means of the modified ILLUDAS model, and those estimated by the STORM model, as reported by Sautier and Delleur (1978) for continuous simulation from 4-9-70 through 11-29-70 and from 3-20-74 through 12-2-74. Tables 4.2 and 4.3 list the storms in the Upper Ross-Ade Watershed for the years 1970 and 1974, respectively, for which the observations and calculations are available. The storms which have observed rainfall and runoff as well as runoffs simulated by the modified ILLUDAS and STORM are particularly worth studying. There are 25 storms in 1970 and 6 storms in 1974 that meet this requirement. Tables 4.4 and 4.5 list the date of the storm, the observed rainfall,

TABLE 4.1 VALUES USED FOR THE CALIBRATION OF THE MODIFIED ILLUDAS MODEL

Description of the Variable	Variable Name in the Program	Value Used	Units
Evaluation	EVAL	Positive Integer	-
Number of Branches and Reaches	NBR	8	-
Number of the Storms of the Year	NSTORM	Positive Integer	-
Basin Area	AREA	29.1	acres
Paved Area Abstraction	ABSTRT	Calibrated Value	inches
Grassed Area Abstraction	DEPG	Calibrated Value	inches
Soil Group	ISOIL	3	-
Rainfall Provided	RAIN	Positive Number	-
No. of Increments	XRI	Positive Number	-
Minimum Diameter	DIMIN	18.0	inches
Manning's n	RUFFN	0.013	-
Time Increment	DELT	5	minutes
Antecedent Moisture Condition	AMC	Program Calculated	-
Dry Period Between Storms	TODUR	Non-negative Number	minutes

TABLE 4.2 AVAILABILITY OF STORM WATER RUNOFF AND SIMULATIONS FOR THE UPPER ROSS-ADE WATERSHED FOR THE YEAR 1970

<table>
<tr><th>No.</th><th>Date</th><th>Observed Rainfall</th><th>Observed Runoff</th><th>Calculated Runoff by ILLUDAS</th><th>Calculated Runoff by STORM</th></tr>
<tr><td>1</td><td>4-9</td><td>X</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>4-12</td><td>X</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>3</td><td>4-13</td><td>X</td><td>0</td><td>0</td><td rowspan="4">X</td></tr>
<tr><td>4</td><td>4-13</td><td>X</td><td>0</td><td>X</td></tr>
<tr><td>5</td><td>4-13</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>6</td><td>4-13</td><td>X</td><td>0</td><td>0</td></tr>
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<tr><td>14</td><td>4-23</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>15</td><td>4-27</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>16</td><td>4-30</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
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<tr><td>20</td><td>5-8</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>21</td><td>5-11</td><td>X</td><td>X</td><td>0</td><td rowspan="2">X</td></tr>
<tr><td>22</td><td>5-11</td><td>X</td><td>0</td><td>X</td></tr>
<tr><td>23</td><td>5-12</td><td>X</td><td>X</td><td>X</td><td rowspan="2">X</td></tr>
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<tr><td>30</td><td>5-14</td><td>X</td><td>0</td><td>X</td><td>0</td></tr>
</table>

Key: X - Data available   0 - Data not available

TABLE 4.2 CONT'D

<table>
<tr><th>No.</th><th>Date</th><th>Observed Rainfall</th><th>Observed Runoff</th><th>Calculated Runoff by ILLUDAS</th><th>Calculated Runoff by STORM</th></tr>
<tr><td>31</td><td>5-15</td><td>X</td><td>X</td><td>X</td><td>0</td></tr>
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<tr><td>55</td><td>7-20</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
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<tr><td>60</td><td>7-23</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>61</td><td>7-23</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>62</td><td>7-27</td><td>X</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>63</td><td>7-29</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
</table>

TABLE 4.2 CONT'D

No.	Date	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS	Calculated Runoff by STORM
64	7-30	X	X	X	0
65	8-19	X	0	0	
66	8-19	X	X	X	X
67	8-19	X	0	X	
68	9-3	X	X	0	0
69	9-3	X	0	0	0
70	9-3	X	0	0	0
71	9-4	X	X	X	X
72	9-6	X	0	0	0
73	9-6	X	X	0	0
74	9-12	X	0	0	0
75	9-13	X	0	0	
76	9-13	X	X	X	X
77	9-13	X	0	X	
78	9-13	X	X	X	
79	9-14	X	0	0	
80	9-14	X	X	X	X
81	9-14	X	0	0	
82	9-17	X	X	X	X
83	9-17	X	0	X	
84	9-18	X	0	0	0
85	9-18	X	0	0	0
86	9-18	X	0	0	0
87	9-18	X	0	0	0
88	9-18	X	0	0	0
89	9-18	X	0	0	0
90	9-20	X	0	0	0
91	9-21	X	X	0	X
92	9-22	X	X	X	
93	9-22	X	0	X	
94	9-22	X	0	0	X
95	9-22	X	0	X	
96	9-22	X	0	X	
97	9-22	X	0	0	

TABLE 4.2 CONT'D

<table>
<tr><th>No.</th><th>Date</th><th>Observed Rainfall</th><th>Observed Runoff</th><th>Calculated Runoff by ILLUDAS</th><th>Calculated Runoff by STORM</th></tr>
<tr><td>98</td><td>9-23</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>99</td><td>9-23</td><td>X</td><td>0</td><td>X</td><td>0</td></tr>
<tr><td>100</td><td>9-24</td><td>X</td><td>X</td><td>X</td><td>0</td></tr>
<tr><td>101</td><td>9-26</td><td>X</td><td>X</td><td>X</td><td rowspan="2">X</td></tr>
<tr><td>102</td><td>9-26</td><td>X</td><td>0</td><td>X</td></tr>
<tr><td>103</td><td>10-8</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>104</td><td>10-9</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>105</td><td>10-9</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>106</td><td>10-12</td><td>X</td><td>0</td><td>0</td><td rowspan="6">X</td></tr>
<tr><td>107</td><td>10-12</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>108</td><td>10-12</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>109</td><td>10-12</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>110</td><td>10-12</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>111</td><td>10-13</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>112</td><td>10-13</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>113</td><td>10-13</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>114</td><td>10-14</td><td>X</td><td>0</td><td>0</td><td rowspan="2">X</td></tr>
<tr><td>115</td><td>10-14</td><td>X</td><td>X</td><td>0</td></tr>
<tr><td>116</td><td>10-20</td><td>X</td><td>X</td><td>X</td><td>0</td></tr>
<tr><td>117</td><td>10-28</td><td>X</td><td>X</td><td>0</td><td rowspan="5">X</td></tr>
<tr><td>118</td><td>10-28</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>119</td><td>10-28</td><td>X</td><td>0</td><td>X</td></tr>
<tr><td>120</td><td>10-28</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>121</td><td>10-28</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>122</td><td>11-2</td><td>X</td><td>X</td><td>X</td><td rowspan="2">X</td></tr>
<tr><td>123</td><td>11-2</td><td>X</td><td>0</td><td>X</td></tr>
<tr><td>124</td><td>11-9</td><td>X</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>125</td><td>11-9</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>126</td><td>11-9</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>127</td><td>11-19</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>128</td><td>11-20</td><td>X</td><td>0</td><td>X</td><td>0</td></tr>
<tr><td>129</td><td>11-27</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>130</td><td>11-27</td><td>X</td><td>0</td><td>X</td><td>X</td></tr>
<tr><td>131</td><td>11-29</td><td>X</td><td>X</td><td>0</td><td>0</td></tr>
<tr><td>132</td><td>11-29</td><td>X</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Table 4.3 Availability of Storm Water Runoff and Simulation for the Upper Ross-Ade Watershed for the Year 1974

No.	Date	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS	Calculated Runoff by STORM
1	3-20	X	X	0	0
2	3-21	X	0	X	0
3	3-22	X	0	0	0
4	3-25	X	0	X	0
5	3-28	X	X	X	0
6	3-28	X	0	X	0
7	3-29	X	X	X	0
8	3-30	X	0	X	0
9	3-30	X	0	0	0
10	3-30	X	0	X	0
11	4-1	X	X	X	0
12	4-3	X	X	X	0
13	4-3	X	X	X	0
14	4-3	X	0	0	0
15	4-4	X	X	X	0
16	4-5	X	0	0	0
17	4-5	X	0	0	0
18	4-7	X	X	0	0
19	4-7	X	X	X	0
20	4-7	X	0	X	0
21	4-8	X	0	0	0
22	4-8	X	0	0	0
23	4-8	X	0	0	0
24	4-8	X	0	0	0
25	4-11	X	X	0	0
26	4-12	X	X	X	0
27	4-13	X	X	0	0
28	4-14	X	X	0	0
29	4-21	X	X	0	0
30	4-21	X	X	X	0

Key: X - Data available 0 - Data not available

TABLE 4.3 CONT'D

No.	Date	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS	Calculated Runoff by STORM
31	4-28	X	X	0	0
32	4-29	X	X	X	0
33	4-29	X	0	0	0
34	4-29	X	0	0	0
35	5-2	X	X	X	0
36	5-2	X	0	0	0
37	5-7	X	0	X	0
38	5-8	X	0	X	0
39	5-11	X	X	X	0
40	5-11	X	X	X	0
41	5-14	X	X	0	0
42	5-14	X	0	0	0
43	5-14	X	0	X	0
44	5-15	X	0	0	0
45	5-17	X	X	X	0
46	5-17	X	0	0	0
47	5-17	X	0	X	0
48	5-18	X	X	X	0
49	5-19	X	X	X	0
50	5-19	X	0	0	0
51	5-21	X	X	X	0
52	5-22	X	X	0	0
53	5-22	X	X	0	0
54	5-22	X	0	X	0
55	5-23	X	X	X	0
56	5-28	X	X	0	0
57	5-28	X	X	0	0
58	5-29	X	X	X	0
59	5-30	X	X	X	0
60	6-2	X	X	0	0
61	6-5	X	X	X	0
62	6-5	X	0	0	0
63	6-5	X	X	0	0
64	6-6	X	X	0	0

TABLE 4.3 CONT'D

No.	Date	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS	Calculated Runoff by STORM
65	6-6	X	X	X	0
66	6-7	X	0	0	0
67	6-7	X	X	X	0
68	6-8	X	X	0	0
69	6-8	X	0	0	0
70	6-8	X	X	0	0
71	6-11	X	X	0	0
72	6-11	X	X	X	0
73	6-13	X	X	0	0
74	6-14	X	X	X	0
75	6-14	X	0	X	0
76	6-15	X	0	0	0
77	6-16	X	X	0	0
78	6-19	X	X	X	0
79	6-20	X	X	0	0
80	6-21	X	X	X	X
81	6-22	X	X	0	0
82	6-22	X	0	X	0
82	6-22	X	0	X	0
83	6-22	X	0	X	0
84	6-22	X	0	X	0
85	6-25	X	X	0	0
86	6-26	X	X	0	0
87	7-19	X	X	X	X
88	7-22	X	X	0	0
89	7-22	X	0	0	0
90	7-22	X	X	0	0
91	7-27	X	X	0	0
92	8-1	X	X	0	0
93	8-1	X	0	0	0
94	8-7	X	X	0	0
95	8-7	X	0	0	0
96	8-7	X	0	0	0
97	8-9	X	X	X	0

TABLE 4.3 CONT'D

No.	Date	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS	Calculated Runoff by STORM
98	8-10	X	0	0	0
99	8-10	X	X	X	0
100	8-10	X	X	X	0
101	8-23	X	X	X	0
102	8-27	X	X	0	0
103	8-27	X	X	X	X
104	8-27	X	0	X	0
105	8-27	X	X	X	X
106	8-28	X	0	0	0
107	8-28	X	0	X	0
108	8-28	X	X	X	0
109	8-29	X	0	0	0
110	8-31	X	X	0	0
111	9-1	X	X	X	0
112	9-2	X	0	0	0
113	9-2	X	X	X	0
114	9-2	X	0	0	0
115	9-11	X	X	X	0
116	9-11	X	X	X	X
117	9-11	X	X	0	0
118	9-12	X	0	0	0
119	9-12	X	0	0	0
120	9-12	X	X	0	0
121	9-12	X	X	X	0
122	9-13	X	X	X	0
123	9-27	X	X	X	0
124	9-28	X	X	X	0
125	9-29	X	X	X	0
126	10-6	X	X	0	0
127	10-6	X	0	0	0
128	10-13	X	X	X	0
129	10-23	X	X	X	X
130	10-23	X	0	X	0
131	10-25	X	X	X	0

TABLE 4.3 CONT'D

No.	Date	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS	Calculated Runoff by STORM
132	10-25	X	0	0	0
133	10-29	X	X	X	0
134	10-29	X	X	0	0
135	10-29	X	0	0	0
136	10-29	X	X	X	0
137	10-29	X	0	0	0
138	11-1	X	X	0	0
139	11-3	X	X	X	0
140	11-3	X	0	0	0
141	11-3	X	0	X	X
142	11-3	X	0	0	0
143	11-4	X	X	X	0
144	11-4	X	X	0	0
145	11-4	X	X	X	0
146	11-5	X	0	0	0
147	11-6	X	0	X	0
148	11-9	X	X	0	0
149	11-23	X	X	0	0
150	11-24	X	X	0	0
151	11-24	X	X	0	0
152	11-27	X	X	0	0
153	12-2	X	0	0	0
154	12-2	X	X	X	0

TABLE 4.4 SUMMARY OF THE OBSERVED AND CALCULATED VALUES FOR THE STORMS IN 1970

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Date	Observed Rainfall [inches]	Observed Runoff [inches]	Calculated Runoff by ILLUDAS† [inches]	Error* ILLUDAS † [%]	Calculated Runoff by STORM [inches]	Error STORM [%]	Observed Runoff Coefficient	Calculated Runoff Coefficient by ILLUDAS†	Calculated Runoff Coefficient by STORM	Best Simulation
4-18	3.2456	1.1638	0.6270	-46.1	1.07	- 8.1	0.3586	0.1932	0.3297	S**
4-20	0.2456	0.0183	0.0216	18.0	0.02	9.3	0.0745	0.0879	0.0814	S
4-23	1.0754	0.1108	0.1525	37.6	0.10	- 9.7	0.1030	0.1418	0.0930	S
4-27	0.3482	0.0301	0.0497	65.1	0.01	-66.8	0.0864	0.1427	0.0287	I
4-30	0.3607	0.0331	0.0524	58.3	0.02	-39.6	0.0918	0.1453	0.0554	S
5-11	1.6325	0.2650	0.3045	14.9	0.30	13.2	0.1623	0.1865	0.1838	S
5-12	0.1886	0.0203	0.0135	-33.5	0.01	-50.7	0.1076	0.0716	0.0530	I
5-13	0.6692	0.1210	0.1126	- 6.9	0.08	-33.9	0.1808	0.1683	0.1195	I
5-24	0.5996	0.0484	0.0636	31.4	0.12	147.9	0.0807	0.1061	0.2001	I
6-1	0.9082	0.1688	0.1036	-38.6	0.08	-52.6	0.1859	0.1141	0.0881	I
6-14	0.3713	0.0316	0.0318	0.6	0.01	-68.4	0.0851	0.0856	0.0269	I
6-24	0.4507	0.0577	0.0719	24.6	0.03	-48.0	0.1280	0.1595	0.0666	I
7-8	0.4497	0.1170	0.0716	-38.8	0.03	-74.4	0.2602	0.1592	0.0667	I
7-18	2.2989	0.3338	0.5039	51.0	0.54	61.8	0.1452	0.2192	0.2349	I
8-19	0.8627	0.0893	0.1254	40.4	0.07	-21.6	0.1035	0.1454	0.0811	S
9-4	1.3385	0.2300	0.2485	8.0	0.21	- 8.7	0.1718	0.1857	0.1569	I
9-13	0.8578	0.0920	0.1073	16.6	0.07	-13.9	0.1073	0.1251	0.0816	I
9-14	0.2688	0.0202	0.0252	24.8	0.03	48.5	0.0751	0.0938	0.1116	I
9-17	0.7340	0.1130	0.1053	- 6.8	0.08	-29.2	0.1540	0.1435	0.1090	I
9-26	0.4314	0.0297	0.0437	47.1	0.03	1.0	0.0688	0.1013	0.0695	S
10-8	0.7814	0.0714	0.1323	85.3	0.07	- 2.0	0.0914	0.1693	0.0896	S
10-9	0.1692	0.0501	0.0137	-72.7	0.01	-80.4	0.2961	0.0810	0.0591	I
11-2	0.8559	0.0448	0.1185	164.5	0.10	123.2	0.0523	0.1385	0.1168	S
11-19	0.3743	0.0618	0.0532	-13.9	0.05	-19.1	0.1651	0.1421	0.1336	I
11-27	0.2408	0.0440	0.0196	-55.5	0.01	-77.3	0.1827	0.0814	0.0415	I

*Error [%] = $\frac{\text{calculated-observed}}{\text{observed}} \times 100$ **S = STORM; I = ILLUDAS† †Modified Version

TABLE 4.5 SUMMARY OF THE OBSERVED AND CALCULATED VALUES FOR THE STORMS IN 1974

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Date	Observed Rainfall [inches]	Observed Runoff [inches]	Calculated Runoff by ILLUDAS† [inches]	Error* ILLUDAS† [%]	Calculated Runoff by STORM [inches]	Error STORM [%]	Observed Runoff Coefficient	Calculated Runoff Coefficient by ILLUDAS†	Calculated Runoff Coefficient by STORM	Best** Simu-lation
6-21	0.6156	0.0962	0.1083	12.6	0.09	- 6.4	0.1563	0.1759	0.1462	S
7-19	0.6512	0.0730	0.1119	53.3	0.06	-17.8	0.1121	0.1718	0.0921	S
8-27	2.4341	0.5120	0.6205	21.2	0.13	-74.6	0.2103	0.2549	0.0534	I
9-11	0.8320	0.1536	0.1330	-13.4	0.08	-47.9	0.1846	0.1599	0.0962	I
10-23	0.3004	0.035	0.0299	-14.6	0.01	-71.4	0.1165	0.0995	0.0333	I
11-3	0.6189	-.100	0.0769	-23.1	0.05	-50.0	0.1616	0.1243	0.0808	I

$$\text{*Error [\%]} = \frac{\text{calculated-observed}}{\text{observed}} \times 100$$

**S = STORM; I = ILLUDAS†

†Modified Version

the observed runoff, the calculated runoff by the modified ILLUDAS, the percentage of error by the modified ILLUDAS, the calculated runoff by STORM, the percentage of error by STORM, the observed runoff coefficient, the calculated runoff coefficient by ILLUDAS, and the calculated runoff coefficient by STORM from column (1) through column (10). Column (11) indicates the better of the two models judged by comparing the percentage of error in the calculated runoff. Sixteen out of twenty-five storms in 1970 and four out of six storms in 1974, or 65% of the storms, are better simulated by the modified ILLUDAS than by STORM according to this criteria.

It is obvious that the modified ILLUDAS gives a better prediction of the runoff than STORM, based on a storm-by-storm analysis. The statistics of these selected storms in the two years analyzed (1970 and 1974) are examined to determine if they support this conclusion. Tables 4.6 through 4.9 show the calculated values of mean, standard deviation, and coefficient of variation of the 25 storms in 1970 and 6 storms in 1974 and the percentage of error of the total runoff and of the runoff coefficient. They show that the modified ILLUDAS model has a lesser percentage of error in the total runoff, mean runoff, and mean runoff coefficient for both 1970 and 1974. However, STORM has a lesser percentage of error in the standard deviation and coefficient of variation in 1970.

Four of the six storms analyzed in 1974 are plotted for comparison with the observed hydrographs in Figs. 4.2 and 4.3. Only a few points are shown for the hydrographs calculated by STORM as the time interval is one hour. The shapes of the hydrographs calculated by the modified ILLUDAS in reasonably good agreement with the observed hydrographs, and

TABLE 4.6 SUMMARY OF THE STATISTICS AND PERCENT ERROR OF TOTAL RUNOFF FOR THE 25 STORMS IN 1970

	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS†	Percent Error of ILLUDAS†	Calculated Runoff by STORM	Percent Error of STORM
Total [in]	19.7590	3.3660	3.1729	- 5.7	3.1500	-6.4
Mean(1)	0.7904	0.1346	0.1269	- 5.7	0.1260	-6.4
Standard Deviation(2)	0.7125	0.2291	0.1504	-34.4	0.2282	-0.4
Coefficient of Variation(3)	0.9015	1.7019	1.1846	-30.4	1.8108	6.4

(1) Mean = $\overline{Y} = \frac{\sum_{i=1}^{N} Y_i}{N}$, i - 1,2,3, ..., N

(2) Standard Deviation = $\sqrt{\text{variance} \times \frac{N}{N-1}}$ where: variance = $\frac{\sum Y_i^2}{N} - \frac{(\sum Y_i)^2}{N^2}$

(3) Coefficient of Variation = $\frac{\text{Standard Deviation}}{\text{Mean}}$

†Modified Version

TABLE 4.7 SUMMARY OF THE STATISTICS AND PERCENT ERROR OF RUNOFF COEFFICIENT FOR 25 STORMS IN 1970

	Observed Runoff Coefficient	Calculated Runoff Coefficient by ILLUDAS†	Percent Error of ILLUDAS†	Calculated Runoff Coefficient by STORM	Percent Error of STORM
Mean(1)	0.1407	0.1355	- 3.7	0.1071	-23.9
Standard(2) Deviation	0.0750	0.0399	-46.8	0.0696	- 7.2
Coefficient(3) of Variation	0.5327	0.2947	-44.7	0.6495	21.9

(1) $\text{Mean} = \overline{Y} = \frac{\sum_{i=1}^{N} Y_i}{N}$, i - 1,2,3, ..., N

(2) $\text{Standard Deviation} = \sqrt{\text{variance} \times \frac{N}{N-1}}$ where: $\text{variance} = \frac{\sum Y_i^2}{N} - \frac{(\sum Y_i)^2}{N^2}$

(3) $\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Mean}}$

† Modified Version

TABLE 4.8 SUMMARY OF THE STATISTICS AND PERCENT ERROR OF TOTAL RUNOFF FOR THE 6 STORMS IN 1974

	Observed Rainfall	Observed Runoff	Calculated Runoff by ILLUDAS†	Percent Error of ILLUDAS†	Calculated Runoff by STORM	Percent Error of STORM
Total [in]	5.4522	0.9698	1.0805	11.4	0.4200	-56.7
Mean(1)	9.9087	0.1616	0.1801	11.4	0.0700	-56.7
Standard Deviation(2)	0.7667	0.1760	0.2187	24.3	0.0405	-77.0
Coefficient of Variation(3)	0.8437	1.0886	1.2145	11.6	0.5785	-46.9

(1) Mean $= \bar{Y} = \frac{\sum_{i=1}^{N} Y_i}{N}$, i - 1,2,3, ..., N

(2) Standard Deviation $= \sqrt{\text{variance} \times \frac{N}{N-1}}$ where: variance $= \frac{\sum Y_i^2}{N} - \frac{(\sum Y_i)^2}{N^2}$

(3) Coefficient of Variation $= \frac{\text{Standard Deviation}}{\text{Mean}}$

† Modified Version

TABLE 4.9 SUMMARY OF THE STATISTICS AND PERCENT ERROR OF RUNOFF COEFFICIENT FOR THE 6 STORMS IN 1974

	Observed Runoff Coefficient	Calculated Runoff Coefficient by ILLUDAS†	Percent Error of ILLUDAS†	Calculated Runoff Coefficient by STORM	Percent Error of STORM
Mean(1)	0.1569	0.1644	4.8	0.0837	-46.7
Standard(2) Deviation	0.0382	0.0533	39.5	0.0390	2.1
Coefficient(3) of Variation	0.2432	0.3244	33.4	0.4660	91.6

(1) Mean $= \bar{Y} = \frac{\sum_{i=1}^{N} Y_i}{N}$, i - 1,2,3, ..., N

(2) Standard Deviation $= \sqrt{\text{variance} \times \frac{N}{N-1}}$ where: variance $= \frac{\sum Y_i^2}{N} - \frac{(\sum Y_i)^2}{N^2}$

(3) Coefficient of Variation $= \frac{\text{Standard Deviation}}{\text{Mean}}$

†Modified Version

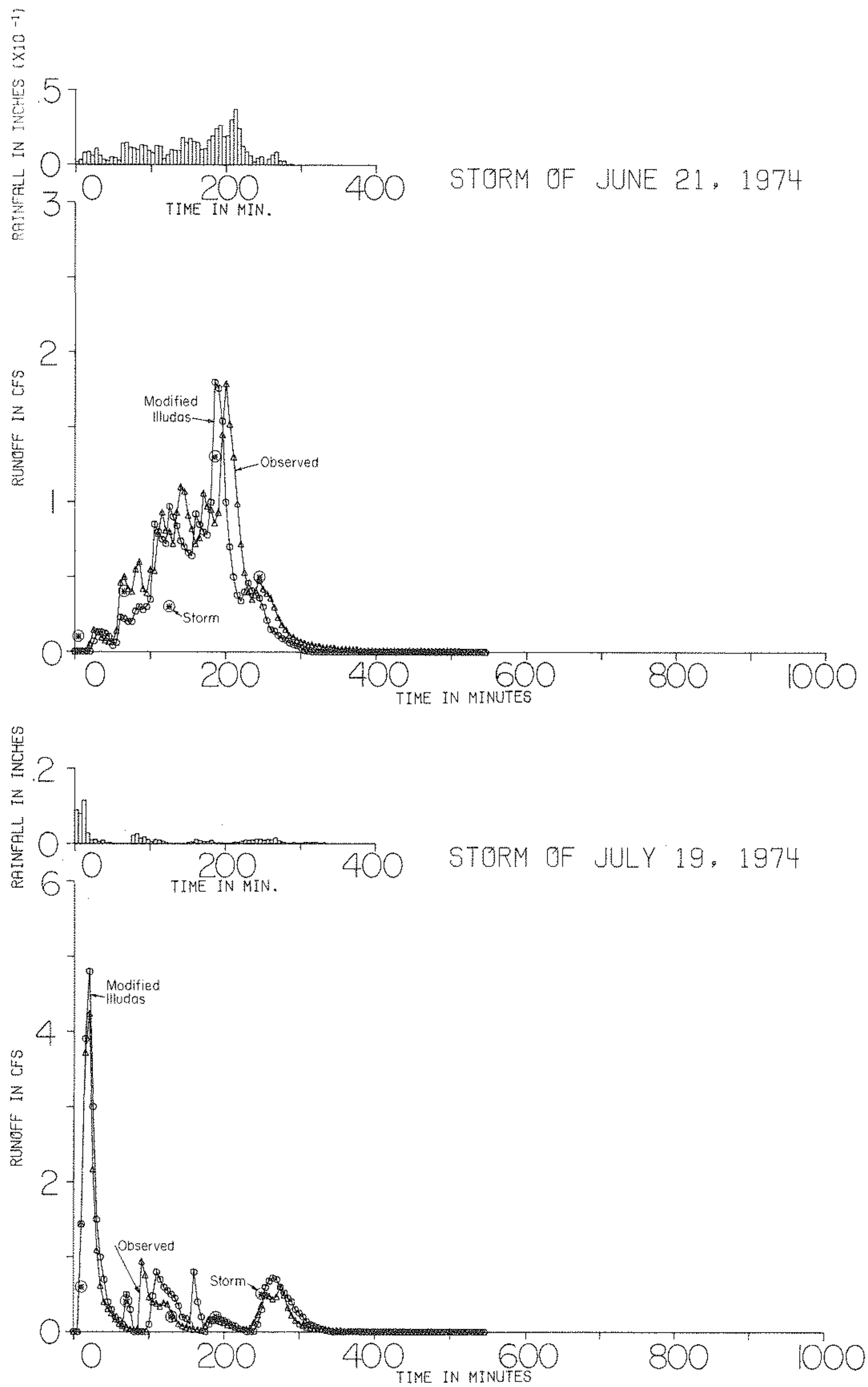


FIGURE 4.2 OBSERVED AND CALCULATED HYDROGRAPHS

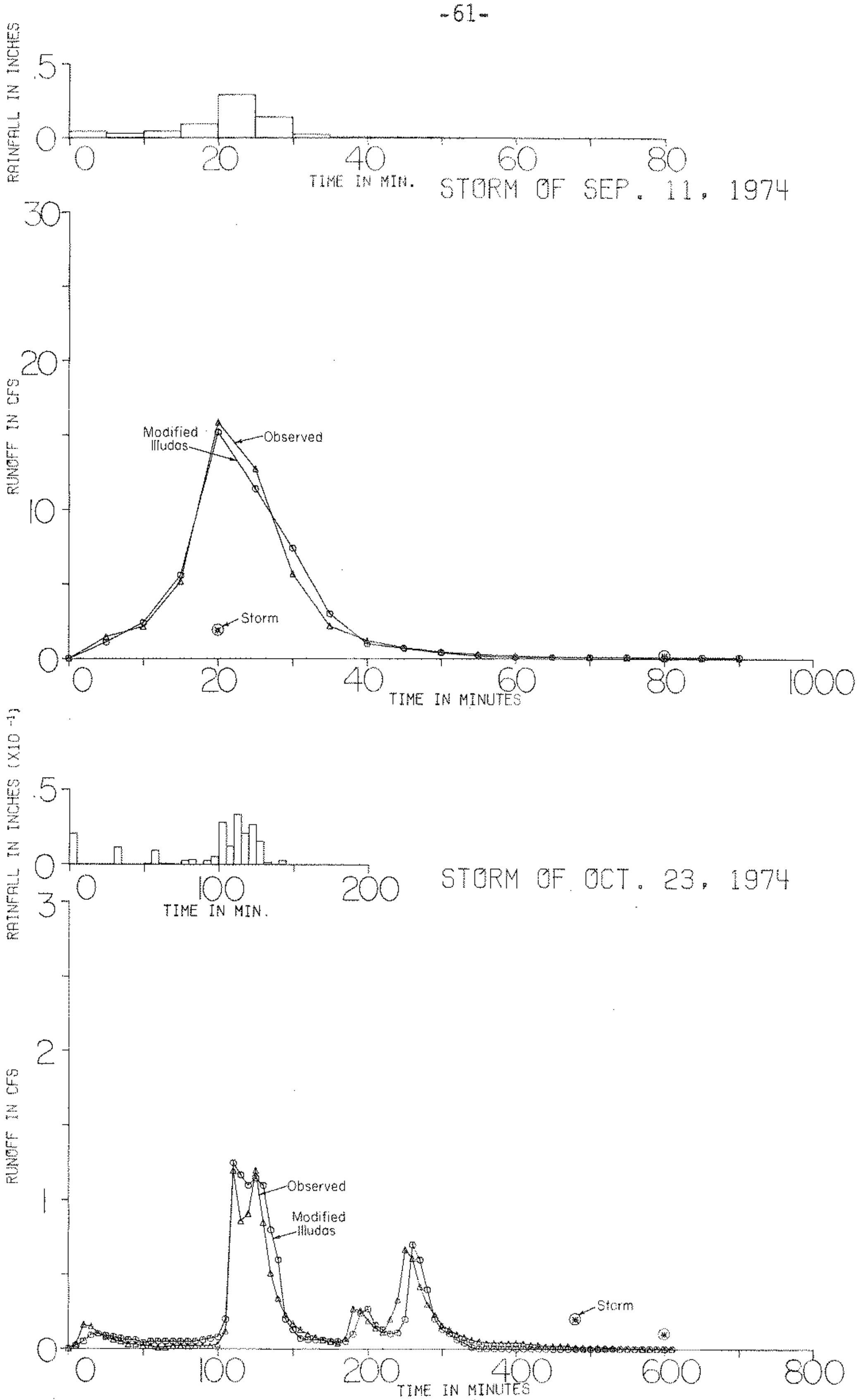


FIGURE 4.3 OBSERVED AND CALCULATED HYDROGRAPHS

the peak flow value and the time to peak are very close. Table 4.10 shows the observed and calculated values and the percent error of these four storms. The error in peak discharge is seen to be less than 13% and that in the time to peak less than 7.5%

4.4 Conclusions

(1) The ILLUDAS model was modified to account for the AMC at the beginning of each storm and to extend its capability to continuous simulation.

(2) The modified ILLUDAS model is a useful tool for understanding the physical characteristics of the storm runoff from urban watersheds.

(3) The total runoffs from the Upper Ross-Ade Watershed were computed for 25 selected storms in 1970 with a mean runoff error of -5.7% by the modified ILLUDAS and -6.4% by STORM. For 6 selected storms in 1974 the mean runoff errors were +11.4% and -56.7% by the modified ILLUDAS and STORM, respectively.

(4) The runoff coefficients were also calculated with a mean error of -3.7% and -23.9% by the modified ILLUDAS and STORM for the year 1970, and of 4.8% and -46.7% for the year 1974, respectively.

(5) For the tested data, the modified ILLUDAS estimates the peak flow with less than 13% error and calculates the time to peak perfectly except for the storm of June 21, for which the error in time to peak is -7.5%.

(6) The modified ILLUDAS model is applicable to complex storms. This is an advantage over the traditional unit hydrograph theory which requires simple observed hydrographs.

TABLE 4.10 THE OBSERVED AND CALCULATED PEAK FLOWS AND TIME TO PEAK VALUES AND THE PERCENT ERROR OF FOUR STORMS IN 1974

Date	Observed Peak Flow [cfs]	Calculated Peak Flow by ILLUDAS[†] [cfs]	Error of Peak Flow [%]	Observed Time to Peak [minutes]	Calculated Time to Peak [minutes]	Error of Time to Peak [%]
June 21	1.79	1.80	0.6	200	185	-7.5
July 19	4.24	4.80	13.2	20	20	0
Sept. 11	15.86	15.20	-4.2	20	20	0
Oct. 23	1.20	1.25	4.2	110	110	0

[†]Modified version

CHAPTER 5

AN INTEGRATED RAINFALL-RUNOFF-QUALITY MODEL

5.1 Introduction

The program STORM provides information on the urban runoff quantity and quality at the planning level of details. At the design level of details a simulation model is needed which provides a pollutograph with a level of detail comparable to that of the hydrographs generated by ILLUDAS. The purpose of this chapter is thus the development of an integrated runoff quantity and quality simulation model capable of yielding a detailed pollutograph of the storm runoff. To achieve this goal, the original rainfall-runoff model ILLUDAS is coupled with a modified version of the runoff quality model included in STORM.

It is well known that the ILLUDAS model is a validated design model which is capable of providing the entire hydrograph for a simple or complex storm. It can be used to analyze the existing system or to design new ones. It is typified by short time intervals (minutes)and short simulation time. On the other hand, the STORM model is a planning model which is considered as a good, relatively easy and useful tool for continuous quantity and quality simulation. It is typified by relatively large time intervals (hours) and long simulation time. To link these two different types of models together is a task which will be discussed in detail in the following sections.

5.2 Model DRAINQUAL for Small Interval Runoff Quality Prediction

As indicated in Chapter 2, the quality data were collected at 30 minute intervals in the Upper Ross-Ade watershed. However, it was felt that a smaller time interval in the model was necessary to provide a more accurate pollutograph. A 5 minute interval was selected to meet this requirement. The subroutine DIRT in the STORM model estimates the rate at which pollutants are washed off. It was modified and inserted into the ILLUDAS model. The program STORM provides a continuous simulation of the runoff quality at an hourly interval and some statistical information on washoff as well as overflows. It would be wasteful to simulate the stormwater runoff at short time intervals (5 minutes in this case) and then have an hourly quality prediction. It is also inefficient to combine the whole packages of STORM and ILLUDAS since this would require enormous memory in the computer system. For these reasons it was decided to modify the DIRT subroutine from an hourly interval to a 5 minute interval. This also leads to one of the objectives of the present study which is the capability of predicting the stormwater quality at a short time interval.

A general block diagram of the original ILLUDAS with the modified DIRT subroutine added (DRAINQUAL) is shown in Figure 5.1. The quantity of stormwater runoff at 5 minute intervals is first simulated by ILLUDAS, the simulated runoff then serves as the input to the quality calculation and the quality output with 5 minute intervals is computed. There are six stormwater quality parameters involved. They are the suspended and settleable solids, the biochemical oxygen demand, the total nitrogen, the orthophosphate and the total coliform. Only the suspended solids and the biochemical oxygen demand were considered in this study because of the

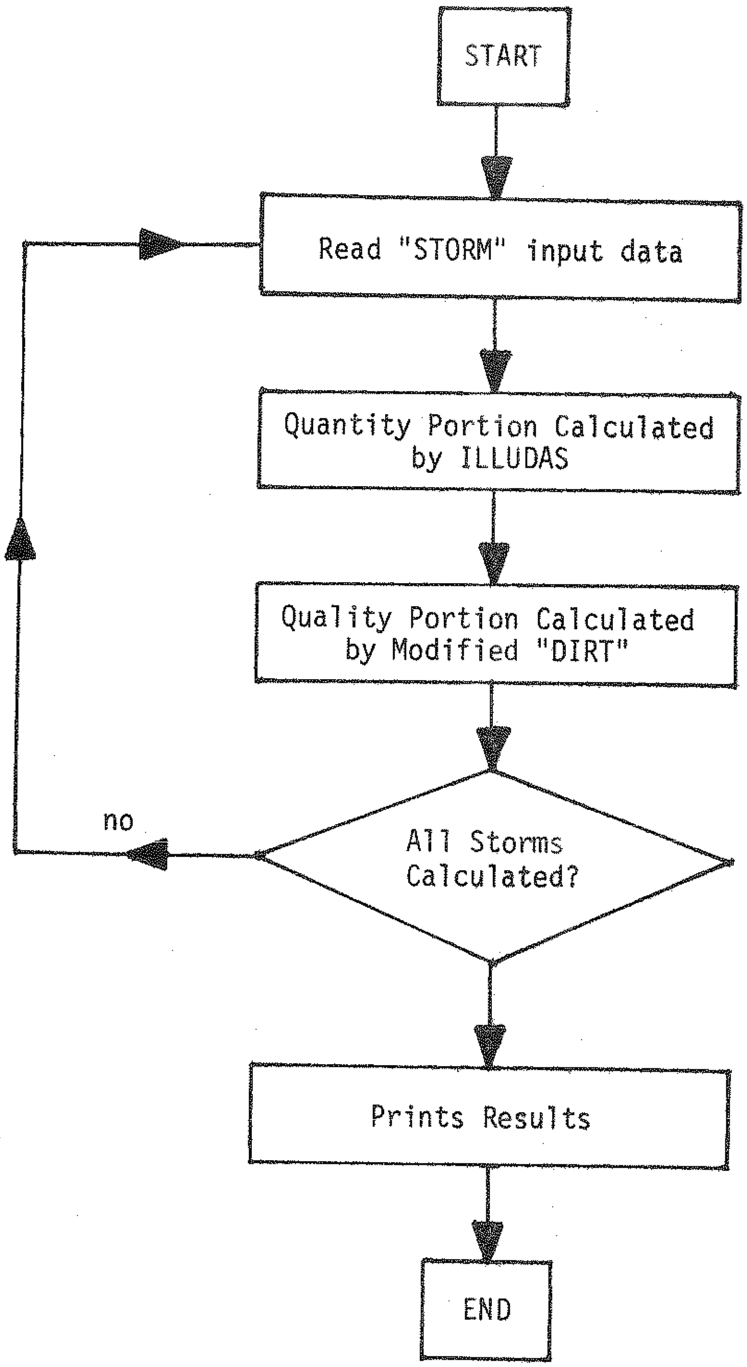


FIGURE 5.1 - GENERAL BLOCK DIAGRAM OF DRAINQUAL

limitation of the collected runoff quality data. There are two options to compute the quality of surface runoff in STORM, the dust and dirt method, and the daily pollutant accumulation method. The former was used in this study. The DRAINQUAL model as shown here is for single storm runoff quality simulation. The listing of the model DRAINQUAL is given in Appendix A-2.

5.3 Modification of DIRT

The expression used in STORM to calculate the rate at which pollutants are washed off the watershed assumes a first order reaction expression

$$\frac{dP}{dt} = -KP \tag{1}$$

where P is the total pounds of pollutant, K is the decay constant with the units of t^{-1} and t is time. Upon integration between the limits t = 0 and t = t the above equation becomes

$$P_t = P_o\, e^{-Kt} \tag{2}$$

where P_o and P_t are the pollutant loads initially and at time t, respectively. The pollutant washed off, M, is:

$$M = P_o - P_t = P_o(1 - e^{-Kt}) \tag{3}$$

Assuming that the rate of decay K (in.t^{-1}) is directly proportional to the runoff rate R_I (in. t^{-1}) then

$$K = k\, R_I \tag{4}$$

or

$$k = \frac{K}{R_I}\,, \qquad \left(\frac{1}{t} \cdot \frac{t}{in} = \frac{1}{in}\right) \tag{5}$$

It is observed that the units of k are independent of time. With this assumption, the amount of pollutant "p" washed off per unit time given by equation (3) becomes:

$$M_p = P_p\ (1 - e^{-kR_I t}) \qquad (6)$$

where: R_I = runoff rate in in/hr

k = washoff decay coefficient (1/inch)

P_p = total pounds of pollutant p at beginning of the storm

M_p = hourly rate of washoff of pollutants p, lbs/hr

taking the time t = 1 hour,

then

$$M_p = P_p\ (1 - e^{-kR_I}) \qquad (7)$$

which is the equation used in STORM. If it is assumed that a uniform runoff rate of $\frac{1}{2}$ inch per hour would wash 90 percent of the pollutants in one hour, then

$$1 - e^{-k \times 0.5 \times 1} = 0.90$$

and

$$k = -2\ \ln 0.1 = 4.6\ \text{in}^{-1}$$

Since the washoff decay coefficient k is independent of the time unit, its value is not affected by taking a time interval of 5 minutes, and remains numerically equal to 4.6 in^{-1}.

Taking t = 1 unit = 5 minutes, equation (6) becomes:

$$M_p = P_p\ (1 - e^{-kR_I}) \qquad (8)$$

where R_I = runoff rate in inches/5 minutes

k = 4.6 in^{-1} = washoff decay coefficient

P_p = total pounds of pollutant p at beginning of storm

M_p = rate of washoff of pollutant p, lbs/5 minutes

Thus a $\frac{1}{2}$ in/hr or $\frac{1}{24}$ in/5 minutes runoff rate would yield a rate of washoff in 5 minutes given by

$$M_p = P_p\,(1 - e^{-4.6 \times \frac{1}{24}}) = 0.17\ P_p \qquad (9)$$

and in one hour or 12 units of 5 minutes

$$M_p = P_p\,(1 - e^{-4.6 \times \frac{1}{24} \times 12}) = 0.90\ P_p \qquad (10)$$

as before.

Equation (7) must be modified, however, because not all of the dust and dirt on the watershed is available for inclusion in the runoff at a given time. The following set of equations is used to compute the hourly rate of washoff in STORM:

$$M_{sus}(t) = A_{sus} \cdot P_{sus}(t) \cdot \mathrm{EXPT} \qquad (11)$$

$$M_{set}(t) = A_{set} \cdot P_{set}(t) \cdot \mathrm{EXPT} \qquad (12)$$

where

$M_{sus}(t)$ = hourly rate of washoff of suspended solids

$M_{set}(t)$ = hourly rate of washoff of settleable solids

$$A_{sus} = 0.057 + 1.4R_I^{1.1} \qquad (13)$$

$$A_{set} = 0.028 + 1.0R_I^{1.8} \qquad (14)$$

$$\mathrm{EXPT} = (1 - e^{-4.6R_I\Delta t})/\Delta t, \text{ with } \Delta t = 1 \text{ hour} \qquad (15)$$

A_{sus} = availability of suspended solids in an hour

R_I = runoff rate in inch/hour

For a time interval of 5 minutes, the availabilities of suspended solids and of settleable solids become

$$A_{sus} = \frac{0.057}{12} + \frac{1.4}{12}\,(R_I \times 12)^{1.1}$$

$$A_{sus} = 0.00475 + 1.795\ R_I^{1.1} \qquad (16)$$

$$A_{set} = \frac{0.028}{12} + \frac{1}{12}(R_I \times 12)^{1.8} \quad (17)$$

$$A_{set} = 0.00233 + 7.300\ R_I^{1.8}$$

where A_{sus} = availability of suspended solids in 5 minutes

A_{set} = availability of settleable solids in 5 minutes

R_I = runoff rate in in/5 minutes.

As shown earlier in this section, the expression for EXPT remains the same, but with Δt = 1 time unit = 5 minutes.

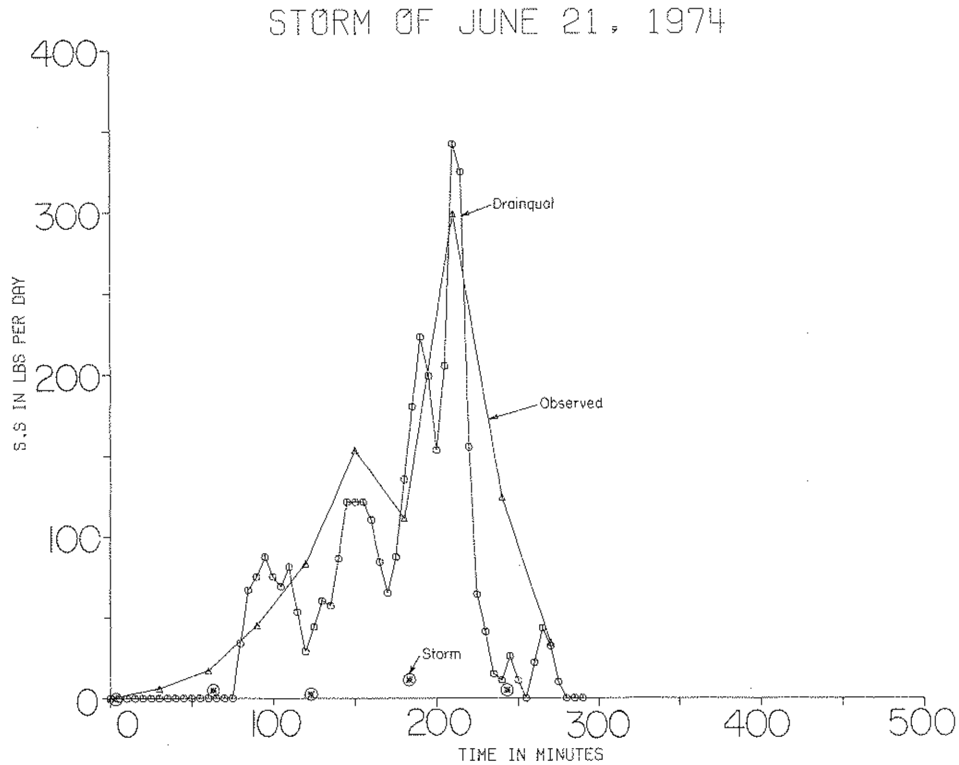
It was found in Storm Water Management Model Study (Metcalf and Eddy, Inc., et al., 1971) that the BOD associated with SS was about 10 percent of the suspended solids load and was about 2 percent of the settleable solids. Thus, correcting equation (1) for available suspended and settleable solids and adding the BOD found in the solids, the following equation is used in STORM:

$$M_{bod}(t) = P_{bod}(t) \cdot \text{EXPT} + 0.10\ A_{sus} + 0.02\ A_{set} \quad (18)$$

Equations (16), (17), and (18) were used in the modified DIRT subroutine.

5.4 Evaluations of the Results of the Combined Model DRAINQUAL

A set of three storms in the Upper Ross-Ade watershed in 1974 was selected (June 21, July 19, and October 23) for the evaluation of the combined model DRAINQUAL. The observed and computed pollutographs of BOD and SS are presented in Figs. 5.2, 5.3 and 5.4. DRAINQUAL model was calibrated using the pollutant load (pounds/day), not the concentration (mg/ℓ). The values used with units in this model are listed in Table 5.1. To determine the concentration of a pollutant, the pollutograph value in lbs/time is divided by the flow rate with an appropriate conversion factor.



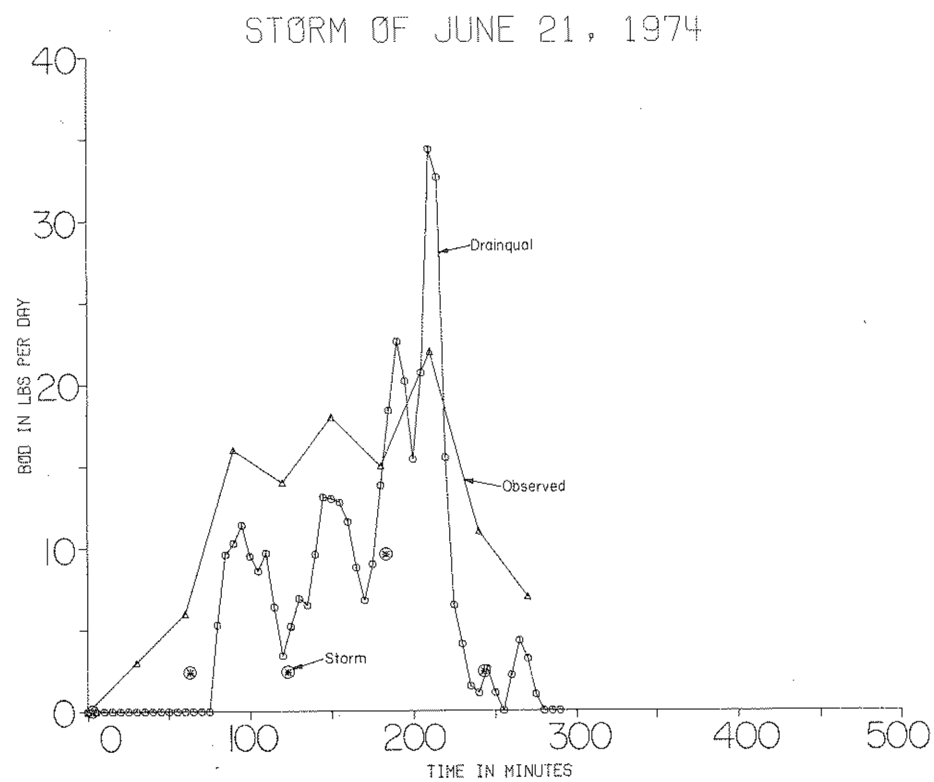
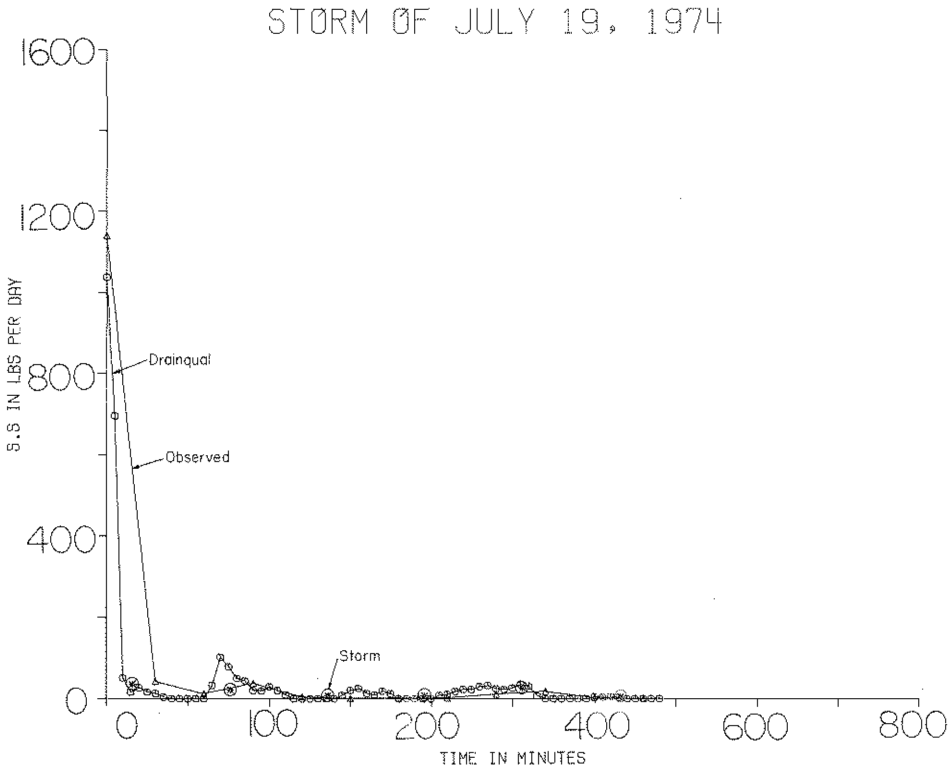


FIGURE 5.2 OBSERVED AND COMPUTED POLLUTOGRAPHS



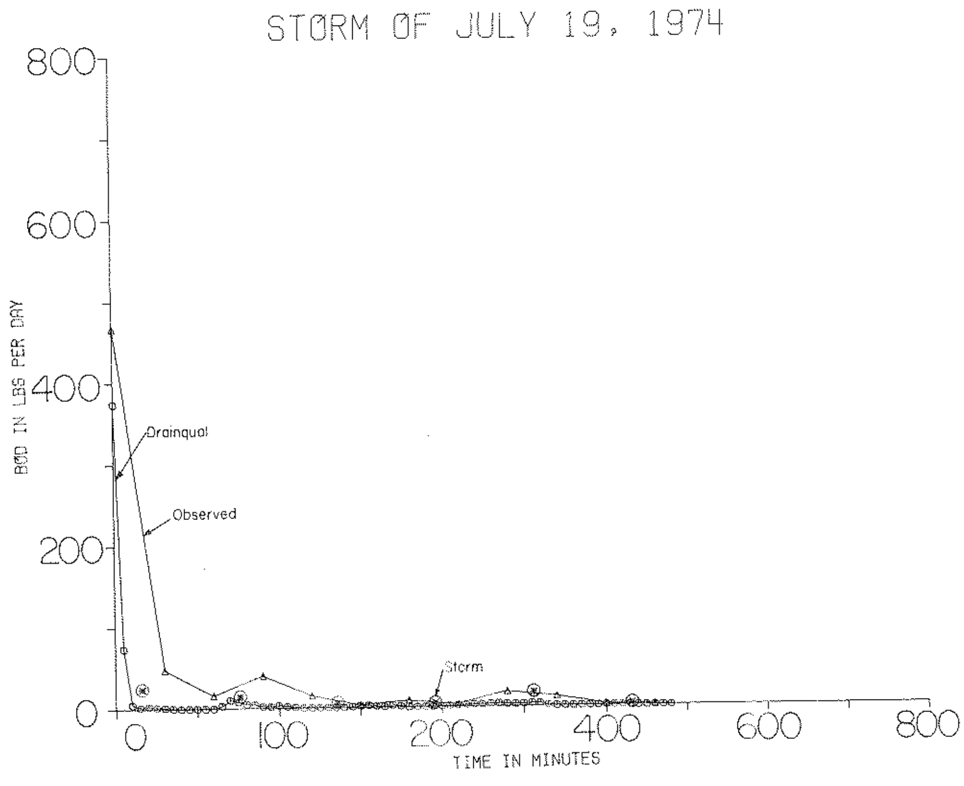
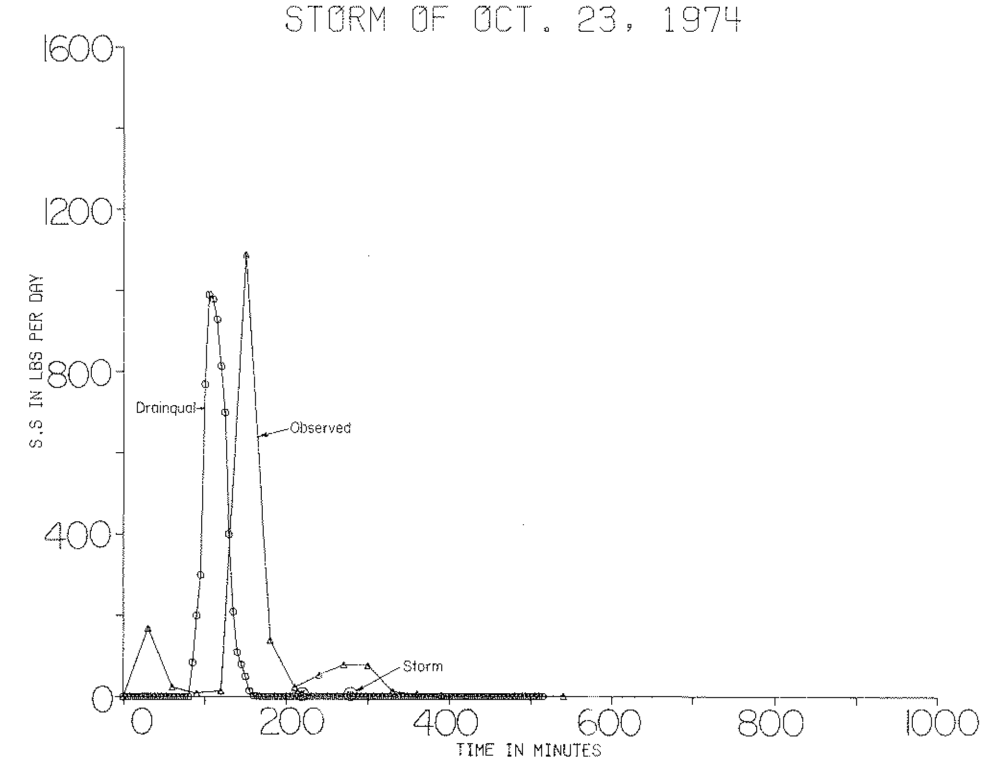


FIGURE 5.3 OBSERVED AND COMPUTED POLLUTOGRAPHS



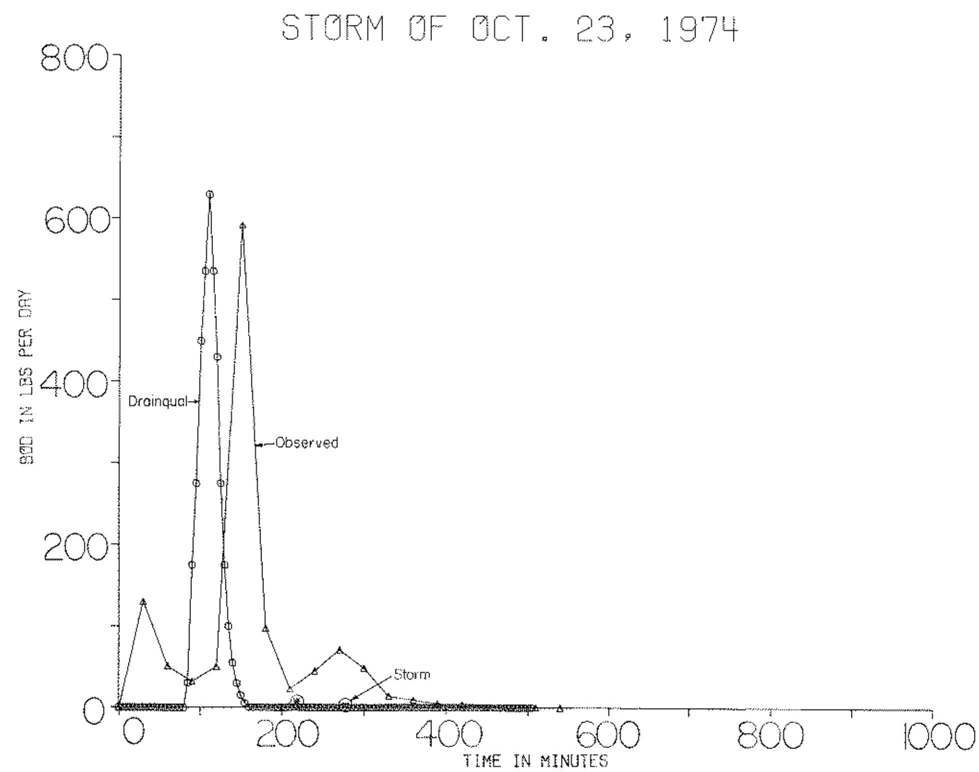


FIGURE 5.4 OBSERVED AND COMPUTED POLLUTOGRAPHS

TABLE 5.1 VALUES USED IN THE DRAINQUAL MODEL

Program Name	Description of the Variable	Variable Name Used in the Model	Value Used	Units
ILLUDAS	Paved Area Abstraction		0.10	inches
	Grassed Area Abstraction		0.20	inches
DIRT	Number of Subbasins	NWSHD	1	-
	No Snowmelt Computations	ISNO	0	-
	No Land Surface Erosion Computations	ISED	0	-
	Runoff Quality Computations will be made	IQUAL	1	-
	Hourly Pollutographs will be computed	IEVNT	1	-
	No Dry-Weather Flow Computation will be made	IODWF	0	-
	Length of Average Summer	NSUMR	90	days
	Number of Initial Hours of Overflow for which seperate quantity and quality reporting is desired	LEXT	3	hours
	Input Variables in English Units	METRIC	2	-
	Number of Land Uses	MXLG	1	-
	Washoff Decay Coefficient	EXPTE	4.6	-
	Street Sweeping Efficiency	REFF	0.7	-
	Pollutant Units	IPACUM	1	lbs/day/ 100 ft of gutter
	Area of Subbasin	AREA	29.0	acres
	Pan Evaporation Rate for Jan to Dec in that order	RECVRT	0.00,0.00, 0.00,0.15,0.14, 0.22,0.29,0.18, 0.14,0.11,0.02, 0.00	inches/day
	Infiltration Losses	LOSSEQ	2	-
	Percent Imperviousness of this land use	FIMP	38	-
	Length of Street Gutters	STLEN	360	ft/acre
	Land Use	LNDUSE	Single	-
	Number of Days Between Street Sweeping	NCLEAN	7	days
	Daily Rate of Accumulation of Dust and Dirt	DD	0.7	lbs/100' of gutter
	Suspended Solids per 100 lbs of Dust and Dirt	FRACTN(L,1)	33.3	lbs
	Settleable Solids per 100 lbs of Dust and Dirt	FRACTN(L,2)	1.1	lbs
	BOD per 100 lbs of Dust and Dirt	FRACTN(L,3)	1.5	lbs
	Rainfall Factor	RFU	1.0	-

The results show that the DRAINQUAL model has the ability to predict the stormwater quality fairly well. Even though the shapes of the observed and calculated pollutographs are not perfectly matched, the predicted values are following the observed pattern and the peak load values are fair. Tables 5.2, 5.3, and 5.4 show the time to peak, the peak load value, and the percent of error for the DRAINQUAL and the STORM models for all three storms. It is felt that the time to peak and peak load value are two important factors for designing. All three storms decisively show that the model has a better prediction ability for BOD and SS in the time to peak and the peak load value than STORM.

5.5 Conclusions

(1) By adding a runoff quality subroutine to the existing quantity calculations in the ILLUDAS program, the combined model DRAINQUAL provides the pollutographs to accompany the hydrographs for single storm events.

(2) Only two basic pollutants are considered in the present study because of the limited availability of data: the biochemical oxygen demand (BOD) and the suspended solids (SS). The time to peak and peak load for the three storms analyzed are calculated.

(3) The STORM model is used mostly as a planning model. The DRAINQUAL model is capable of calculating the runoff quality at short time intervals and can serve as a design model which may supplement STORM in preliminary designs.

(4) It will be interesting to compare the present results with those of other researchers models, such as the QUAL-ILLUDAS model in the process of development by the Illinois State Water Survey.

(5) By combining the quality subroutine with the continuous version of ILLUDAS and with the addition of a subroutine simulating the pollutants accumulation between rainfall events similar to that found in STORM it would be possible to obtain a continuous simulation of the runoff quality.

TABLE 5.2 OBSERVED AND COMPUTED RUNOFF QUALITY PARAMETERS FOR STORM OF JUNE 21, 1974

	Pollutant	Time to Peak [min]	Peak Load [#/day]
Observed	SS	210	299
	BOD	210	22
Computed by DRAINQUAL	SS	210	342.5
	BOD	210	34.4
Computed by STORM	SS	183	11.2
	BOD	183	9.6
Percent of Error of DRAINQUAL	SS	0	14.5
	BOD	0	56.4
Percent of Error of STORM	SS	-12.8	-96
	BOD	-12.8	-56.4

TABLE 5.3 OBSERVED AND COMPUTED RUNOFF QUALITY PARAMETERS FOR STORM OF JULY 19, 1974

	Pollutant	Time to Peak [min]	Peak Load [#/day]
Observed	SS	0	1140
	BOD	0	467
Computed by DRAINQUAL	SS	0	1037
	BOD	0	374
Computed by STORM	SS	16	36
	BOD	16	24
Percent of Error of DRAINQUAL	SS	0	-9.0
	BOD	0	-20
Percent of Error of STORM	SS	-	-96.8
	BOD	-	-94.9

TABLE 5.4 OBSERVED AND COMPUTED RUNOFF QUALITY PARAMETERS FOR STORM OF OCTOBER 23, 1974

	Pollutant	Time to Peak [min]	Peak Load [#/day]
Observed	SS	150	1090
	BOD	150	592
Computed by DRAINQUAL	SS	105	990
	BOD	105	630
Computed by STORM	SS	218	7.2
	BOD	218	7.2
Percent of Error of DRAINQUAL	SS	-30	-9.2
	BOD	-30	6.4
Percent of Error of STORM	SS	45	-99.3
	BOD	45	-98.8

CHAPTER 6

CONCLUSIONS

(1) From the sensitivity analysis it may be concluded that the time increment used in ILLUDAS should not exceed the paved area inlet time. The range of sensitivities to soil group and to antecedent moisture conditions are approximately the same. A change in the antecedent moisture content from 2 to 3 and a change in the soil group from B to C for large design return periods and from C to D for short design return periods are critical, and inappropriate choice of the antecedent moisture condition and soil group may result in substantial errors.

(2) The modified ILLUDAS model may be used as an improved design tool in urban water resources system because it has continuous simulation.

(3) It is known that STORM is generally used as a planning model which is able to generate data for a long period (e.g., 20 years) at a large time interval e.g., 1 hour). It does not give a detailed representation of the physical phenomena within the large time interval. For this reason a shorter time interval is needed, particularly for design purposes.

(4) The accuracy of urban runoff simulation is directly dependent upon the length of the rainfall interval used in the numerical scheme, thus the shorter the time interval, the better the simulation. In the watershed studied a 5 minute interval was used throughout and is short enough to reasonably define the hydrographs and pollutographs.

(5) The DRAINQUAL model was found to simulate the suspended solids and BOD with reasonable accuracy for short time intervals in single storm events. For the 3 storms tested the model DRAINQUAL had a better prediction ability for BOD and for SS than the model STORM.

(6) The calculated runoff quality results which are at 5 minute intervals were compared with observed quality data which are in 30 minute intervals. Because of the lack of runoff quality data at a shorter time interval, the need is indicated for more detailed runoff quality measurements.

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APPENDIX A-1

Program Listing of the Modified ILLUDAS

```
      PROGRAM ILLUDAS(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=
     *PUNCH,PLOT)
C        ILLUDAS -- THE ILLINOIS URBAN DRAINAGE AREA SIMULATOR
C                   ILLINOIS STATE WATER SURVEY
C                   MODIFIED FOR CONTINUOUS SIMULATION
C
      DIMENSION A(100),AR(500),AIF(6),BIF(6),CIF(6),DIF(6),GAD(50)
      DIMENSION GASR(500),GGR(500),GR(500),PQ(10),PV(10),Q(7,501)
      DIMENSION Q2ST(2,10),RI(500),RR(500),STORM(20),XNAME(20),XXX(502)
      DIMENSION BRAN(10),REACH(10),ENDBR(10),CONBR(10),IRUN(10),
     &DIST(10),SLP(10),RUFF(10),ISECT(10),DIAM(10),HR(10),WR(10),
     &SS(10),QALOW(10),FREQR(10),STORE(10),TEST(10),HYD(10)
      DIMENSION CBRAN(10),CREACH(10),BA(10),CPA(10),PCPA(10),SPA(10),
     &PSPA(10),PENT(10),PL(10),PS(10),CGA(10),PCGA(10),GENT(10),GL(10),
     &GS(10),IGROUP(10),QQQ(502),XRUN(502),RUN(502)
      REAL KIF
      COMMON TT,TTT,MDAY
      COMMON /HAN/ AMC
      COMMON/PLOTDAT/XL,IYL,XMIN,YMIN,XSCALE,YSCALE,XP,YP
      DATA MAXA/50/,PQ/.10,.20,.30,.40,.50,.60,.70,.80,.90,1.00/,PV/.16,
     *.27,.35,.43,.50,.58,.65,.71,.80,1.00/,IB/1/,
     *END/3HEND/,STOP/4HSTOP/,PREDI/12.0/
      DATA AIF/0.0,2.0,4.0,6.0,10.0,1.0/,BIF/0.0,1.5,3.0,4.0,8.0,0.5/
      DATA CIF/0.0,1.0,2.0,3.0,5.0,0.25/,DIF/0.0,0.7,1.5,2.0,3.0,0.1/
      DATA KIF/2.0/
      DELT=5
      LT=5
      READ(LT,11) NON
11    FORMAT(I10)
      READ(LT,12) (RUN(I),I=1,NON)
12    FORMAT(10F8.4)
      DO 13 I=1,NON
13    XRUN(I)=FLOAT(I)*DELT
      PRINT 20
20    FORMAT(*1     ILLUDAS ** ILLINOIS STATE WATER SURVEY ** *,/,
     **      ILLUDAS UPDATED  JULY 15 1976 *)
      LT=5
      NBR=8
      NSTORM=132
      TOTALV=0.0
      AMC=1.0
      GO TO 35
30    CONTINUE
      PRINT 31
31    FORMAT(*1*)
35    READ(LT,40)XNAME,STORM
      IF(EOF,LT)105,36
40    FORMAT(20A4)
 36   PRINT 50,XNAME,STORM
50    FORMAT( ///,20A4,/,20A4,//)
      READ(LT,60)XID,DESIN,EVAL
60    FORMAT (3F10.0)
      READ(LT,70)AREA,ABSTRT,DEPG,ISOIL,DIMIN,RUFFN
70    FORMAT(3F10.0,I10,2F10.0)
C     PRINT 7, AREA,ABSTRT,DEPG,ISOIL,DIMIN,RUFFN
80    FORMAT(3F12.3,I10,2F12.3)
      DO 381 I=1,NBR
      READ(LT,360) BRAN(I),REACH(I),ENDBR(I),CONBR(I),IRUN(I),DIST(I),
     $SLP(I),RUFF(I),ISECT(I),DIAM(I),HR(I),WR(I),SS(I),QALOW(I),
     $FREQR(I),STORE(I),TEST(I),HYD(I)
360   FORMAT(4F3.0,I3,3F5.0,I1,F4.0,6F5.0,1A3,I2,10X)
      READ(LT,380) CBRAN(I),CREACH(I),BA(I),CPA(I),PCPA(I),SPA(I),
     $PSPA(I),PENT(I),PL(I),PS(I),CGA(I),PCGA(I),GENT(I),
     $GL(I),GS(I),IGROUP(I)
380   FORMAT(2F3.0,F9.0,F5.0,F3.0,F5.0,F3.0,4F5.0,F3.0,3F5.0,I2,9X)
 381  CONTINUE
      TT=0.0
      TTT=0.0
  1   READ(LT,90)RAIN,XRI,DELT,HUFF,DURA,FREQ,TRAIN
90    FORMAT(7F10.0)
```

```
C      PRINT 21,RAIN,XRI,DELT,HUFF,DURA,FREQ,TRAIN,AMC
 100   FORMAT(8F12.4)
       IF(DESIN.NE.0.AND.EVAL.NE.0)GO TO 110
       IF(DESIN.EQ.0.AND.EVAL.EQ.0)GO TO 150
       IF(DESIN.EQ.0.0)GO TO 140
       GO TO 130
 105   CONTINUE
       PRINT 106
 106   FORMAT(*  THE JOB IS FINISHED*)
       STOP
 110   PRINT 120
 120   FORMAT(* DESIGN AND EVALUATION BOTH SPECIFIED - DESIGN ASSUMED*)
 130   IRUNB=1
       GO TO 170
 140   IRUNB=2
       GO TO 170
 150   PRINT 160
 160   FORMAT(* NEITHER DESIGN NOR EVAL SPECIFIED - DESIGN ASSUMED *)
       IRUNB=1
 170   CONTINUE
       NRI=XRI
       IFREQ=FREQ
       IMC=AMC
       IID=XID
       IF(HUFF.GT.0.AND.RAIN.GT.0)GO TO 190
       IF(RAIN.EQ.0.0)GO TO 210
       READ(LT,180)(RR(J),J=1,NRI)
 180   FORMAT(10F8.0)
       READ(LT,181)PK,MDAY,TODUR
   181 FORMAT(F10.0,I10,F10.0)
       TT=TT+TODUR
       IF(TT.GE.7200) TT=0.0
       TRAIN=0
       DO 185 K=1,NRI
       TRAIN=TRAIN+RR(K)
 185   CONTINUE
       IF(TT.EQ.0.0) GO TO 186
       TTT=TTT+TRAIN
       GO TO 187
 186   TTT=0.0
   187 DURA=(NRI-1)*DELT
       GO TO 220
 190   PRINT 200
 200   FORMAT(* RAINFALL PROVIDED OR STANDARD DISTRIBUTION &&& *)
       GO TO 1950
 210   CONTINUE
       CALL RHUFF(TRAIN,DURA,DELT,RR,NRI)
 220   CONTINUE
       PRINT 230
 230   FORMAT(* RAINFALL PATTERN *)
       PRINT 240,(RR(J),J=1,NRI)
 240   FORMAT(10F8.3)
       PRINT 241
   241 FORMAT( ' DURATION OF STORM   DRY PERIOD BETWEEN STORMS   TOTAL DUR
      $ATION ')
       PRINT 242, PK,MDAY,TODUR
   242 FORMAT(F10.0,15X,I10,8X,F10.0)
       PRINT 250
 250   FORMAT(*0      RUN NUMBER   BASIN AREA   TIME INCREMENT   SOIL GROU
      *P*)
       PRINT 260
 260   FORMAT(*                         ACRES         MINUTES      1234=ABCD
      * *,/)
       PRINT 270,IID,AREA,DELT,ISOIL
 270   FORMAT(I13,F15.1,F13.1,I13,//)
       PRINT 280
 280   FORMAT(*      TOTAL RAIN   FREQUENCY   DURATION    AMC   PAVED AB
      *S.   GRASS ABS.*)
       PRINT 290
 290   FORMAT(*         INCHES        YEARS       MINUTES          INCHES
```

```
     *       INCHES*,/)
      PRINT 300,TRAIN,IFREQ,DURA,IMC,ABSTRT,DEPG
300   FORMAT(9X,F6.3,6X,I5,7X,F6.1,I8,F11.2,F14.2,//)
      PRINT 310
310   FORMAT( //,*        B    R   LENG  SLP     N    HT    BW  V/H    DIA    CA
     *PAC    VEL     DESIGN     INLET     DETENTION     STORAGE *)
      PRINT 320
320   FORMAT(    *                   FT    PCT          FT    FT           INS     C
     *FS     FPS     Q-CFS      Q-CFS      CUBIC FT    REQUESTED *,//)
      PREDI=DIMIN
      DELTAT=DELT/60.0
      NEND=0
      DO 330 L=1,500
      GR(L)=0.0
330   CONTINUE
      DO 340 M=1,6
      Q(M,501)=0.0
340   CONTINUE
      TGAR=0.0
      TGA=0.0
      TSPA=0.0
      TPAR=0.0
      TCPA=0.0
      ILL=0
      IND=0
350   CONTINUE
      IND=IND+1
      NNSTORM=NSTORM+1
      IRAI=RAIN
      VOL=0
      OUTLET=0
      SURMAX=0
      SMX=0
361   IF(IRUN(IND).NE.0.0)GO TO 370
      IRUN(IND)=IRUNB
370   CONTINUE
      IF(ENDBR(IND).NE.0)GO TO 1790
 401  IF(IGROUP(IND).EQ.0) IGROUP(IND)=ISOIL
      IF(FREQR(IND).EQ.1.0)GO TO 440
      IF(FREQR(IND).NE.0)GO TO 410
      FREQR(IND)=1.0
      GO TO 440
410   DO 420 IJ=1,NRI
      RR(IJ)=RR(IJ)*FREQR
420   CONTINUE
      PRINT 430,FREQR(IND)
430   FORMAT(* RAINFALL MULTIPLIED BY A FACTOR OF *,F5.2,
     ** FOR THIS REACH*)
440   CONTINUE
      IF(CPA(IND).NE.0.0)GO TO 450
      CPA(IND)=BA(IND)*PCPA(IND)*0.01
450   IF(SPA(IND).NE.0.0)GO TO 460
      SPA(IND)=BA(IND)*PSPA(IND)*0.01
460   IF(CGA(IND).NE.0.0)GO TO 470
      CGA(IND)=BA(IND)*PCGA(IND)*0.01
470   IF(PENT(IND)+PL(IND).EQ.0.0)GO TO 480
      IF(PENT(IND).NE.0.0)GO TO 480
      IF(CPA(IND).EQ.0.0)GO TO 480
      CALL PAVENT(PENT(IND),PL(IND),PS(IND),CPA(IND))
480   CONTINUE
      TGA=TGA+CGA(IND)
      TSPA=TSPA+SPA(IND)
      TCPA=TCPA+CPA(IND)
      PRINT485,TCPA,TSPA,TGA
485   FORMAT(5X,*ACCUM CONTRIBUTING AREAS*,*    CPA=*,F7.1,*,    SPA=*,F7.
     *1,*,    CGA=*,F7.1)
      CALL CAPAC(ISECT(IND),DIAM(IND),HR(IND),WR(IND),SS(IND),SLP(IND),
     $RUFF(IND),ECAP,EVEL,EA)
490   CONTINUE
      IF(BRAN(IND).EQ.0.0)GO TO 500
```

```
      IF(CPA(IND)+CGA(IND)+SPA(IND))990,990,530
 500  CONTINUE
      IF(ENDBR(IND).EQ.0.0)GO TO 510
C  LABEL 600 IS FOR A CONFLUENCE
      GO TO 1790
 510  PRINT 520
 520  FORMAT (*  BRANCH AND ENDBR BOTH EQUAL ZERO*)
      GO TO 1930
 530  IF(CPA(IND))540,540,560
 540  DO 550 N=1,500
      GR(N)=0.0
 550  CONTINUE
      GO TO 670
 560  CALL TIMEA(A,PENT(IND),DELT,NAI,MAXA,CPA(IND))
 570  CONTINUE
      DO 580 N=1,NRI
      RI(N)=RR(N)
 580  CONTINUE
      CALL INTEN(RI,ABSTRT,NRI,DELTAT)
 590  CONTINUE
C
C     COMPUTE GROSS PAVED AREA HYDROGRAPH
      NEND=NRI+NAI-1
      DO 600 J=1,500
 600  GR(J)=0
      DO 620 L=1,NRI
      N=L-1
      DO 610 J=1,NAI
      N=N+1
      DGR=RI(L)*A(J)
      GR(N)=GR(N)+DGR
 610  CONTINUE
 620  CONTINUE
      IF(HYD(IND))660,660,630
 630  PRINT 640,BRAN(IND),REACH(IND)
 640  FORMAT (* PAVED AREA HYDROGRAPH*,2F10.1 )
      PRINT 650,(GR(J),J=1,NEND)
 650  FORMAT(9F8.1)
 660  IF(CGA(IND))950,950,670
 670  CONTINUE
      IGROU=IGROUP(IND)
      GO TO (680,690,700,710),IGROU
 680  FI=AIF(IMC)
      FO=AIF(5)
      FC=AIF(6)
      GO TO 720
 690  FI=BIF(IMC)
      FO=BIF(5)
      FC=BIF(6)
      GO TO 720
 700  FI=CIF(IMC)
      FO=CIF(5)
      FC=CIF(6)
      GO TO 720
 710  FI=DIF(IMC)
      FO=DIF(5)
      FC=DIF(6)
 720  CONTINUE
C     PRINT 406, NRI,IGROUP,IMC,CGA,SPA,DELTAT,DEPG,GL,GS,FI,FO,FC
 730  FORMAT ( 3I5,9F8.3)
C     PRINT 407,(RR(J),J=1,NRI)
 740  FORMAT (10F10.3)
      DO 750 I=1,NRI,1
      AR(I)=RR(I)*(CGA(IND)+SPA(IND))/CGA(IND)
 750  CONTINUE
      CALL SUPPLY (AR,DELTAT,FC,FI,FO,GASR,KIF,NRI,DEPG,NGSR,SGASR)
 760  CONTINUE
      IF(NGSR)950,950,770
 770  CONTINUE
      PRINT 780, (GASR(I),I=1,NGSR,1)
```

```
780   FORMAT (10F10.3)
      PRINT 790, SGASR
790   FORMAT (* GASR TOTAL *,F8.3 )
800   CONTINUE
      IF(GENT(IND)+GL(IND).EQ.0.0)GO TO 810
      IF(GENT(IND).NE.0.0) GENT(IND)=GENT(IND)+PENT(IND)
      IF(GENT(IND).NE.0.0)GO TO 830
      CALL GRENT(GENT(IND),CGA(IND),GL(IND),GS(IND),PENT(IND))
      GO TO 830
810   GENT=20.0
      PRINT 820
820   FORMAT(* GRASS ENT ASSUMED = 20 MIN.  GIVE MORE DATA *)
      GO TO 830
830   CONTINUE
      CALL TIMEA(GAD,GENT(IND),DELT,NGAI,MAXA,CGA(IND))
840   CONTINUE
      NGEND=NGAI+NGSR-1
      DO 850 J=1,500
850   GGR(J)=0.0
      DO 870 L=1,NGSR
      N=L-1
      DO 860 J=1,NGAI
      N=N+1
      GDGR=GASR(L)*GAD(J)
      GGR(N)=GGR(N)+GDGR
860   CONTINUE
870   CONTINUE
      IF(HYD(IND))910,910,880
880   PRINT 890
890   FORMAT (* GRASSED AREA HYDROGRAPH*)
      PRINT 900,(GGR(J),J=1,NGEND)
900   FORMAT(9F8.1)
910   IF(NGEND-NEND)930,930,920
920   NEND=NGEND
930   DO 940 I=1,NEND
      GR(I)=GR(I)+GGR(I)
940   CONTINUE
950   CONTINUE
      PRINT 960,CPA(IND),CGA(IND),SPA(IND),PENT(IND),GENT(IND)
960   FORMAT(5F10.4)
      GRPK = GR(1)
      DO 980 J=2,NEND
      IF(GRPK-GR(J))970,980,980
970   GRPK = GR(J)
980   CONTINUE
      PKIN=GRPK
      LAST=NEND
C  TEST FOR MID BRANCH (421)  OR INITIAL (426)
      IF(REACH(IND).NE.0.0)GO TO 1010
      GO TO 1140
C
C  FOR AREA =0 IN MID BRANCH
990   DO 1000 J=1,500
      GR(J)=0.0
1000  CONTINUE
      GRPK=0.0
      PKIN=0.0
      GO TO 1010
C
C  COMBINE PREVIOUS ROUTED HYDROGRAPH WITH NEW GROSS HYDROGRAPH
1010  CONTINUE
      DO 1020 M=1,6
      IF(Q(M,501).EQ.BRAN(IND))GO TO 1040
1020  CONTINUE
      PRINT 1030
1030  FORMAT(* PREVIOUS BRANCH HYDROGRAPH NOT FOUND*)
      GO TO 1930
1040  IB=M
      GRPK = 0
      DO 1070 N=1,500
```

```
      GR(N)=GR(N)+Q(IB,N)
      IF(GRPK-GR(N))1050,1060,1060
 1050 GRPK=GR(N)
 1060 CONTINUE
 1070 CONTINUE
      IF(HYD(IND))1110,1110,1080
 1080 PRINT 1090
 1090 FORMAT(* ROUTED PLUS SURFACE HYDROGRAPH *)
      PRINT 1100,(GR(J),J=1,LAST)
 1100 FORMAT(9F8.1)
 1110 IF(DIAM(IND))1120,1120,1130
 1120 TDIAM=PREDI
C  LABEL 450 IS FOR ROUTING
      GO TO 1210
 1130 TDIAM=DIAM(IND)
      IF(IRUN(IND).EQ.1)TDIAM=DIMIN
      GO TO 1210
 1140 CONTINUE
      IF(DIAM(IND))1160,1160,1150
 1150 TDIAM=DIAM(IND)
      IF(IRUN(IND).EQ.1)TDIAM=DIMIN
      GO TO 1170
 1160 TDIAM=DIMIN
 1170 DO 1180 M=1,6
      IF(Q(M,501).EQ.0.0)GO TO 1200
 1180 CONTINUE
      PRINT 1190
 1190 FORMAT(* NO BRANCHES ARE FREE*)
      GO TO 1930
 1200 IB=M
      Q(IB,501)=BRAN(IND)
      GO TO 1210
C
C  FIND GROSS HYDROGRAPH PEAK
 1210 GRPK =GR(1)
      DO 1230 J=2,500
      IF(GRPK-GR(J))1220,1230,1230
 1220 GRPK=GR(J)
 1230 CONTINUE
      PKDES=GRPK
      DO 1250 I=1,2
      DO 1240 J=1,10
      Q2ST(I,J) = 0.0
 1240 CONTINUE
 1250 CONTINUE
      IF(STORE(IND).EQ.0.0)GO TO 1280
      IF(QALOW(IND).EQ.0.0)GO TO 1310
 1260 PRINT 1270
 1270 FORMAT(* BOTH STORAGE AND LIMITED Q REQUESTED - STORAGE USED *)
      QALOW(IND)=0.0
      GO TO 1310
 1280 IF(QALOW(IND).EQ.0.0)GO TO 1340
      IF(QALOW(IND)-GRPK)1290,1340,1340
 1290 CALL LIMITQ(GR,GRPK,LAST,QALOW(IND),DELT,BRAN(IND),REACH(IND),VOL)
 1300 CONTINUE
      GO TO 1320
 1310 CALL DETEN(GR,GRPK,LAST,STORE(IND),DELT,BRAN(IND),REACH(IND),VOL)
 1320 CONTINUE
      OUTLET=GRPK
      SMX=STORE(IND)*1000.0
      PRINT 1330,BRAN,REACH,SMX,GRPK,VOL
 1330 FORMAT(F8.0,F4.0,*  FOR A*,F13.0,* CU FT BASIN -- OUTLET =*,
     *F7.1,* CFS ---  VOLUME = *, F12.1 )
 1340 IRU=IRUN(IND)
      GO TO (1350,1380,1380),IRU
 1350 QFB=0.0081*TDIAM*TDIAM/RUFFN*(TDIAM/48.0)**.667*(SLP(IND)/
     $100.0)**.50
      IF(QFB-GRPK)1360,1370,1370
 1360 TDIAM=TDIAM+3.0
      GO TO 1350
```

```
1370  CONTINUE
      GO TO 1460
1380  ISEC=ISECT(IND)
      GO TO (1450,1390,1410),ISEC
1390  CALL RECTAN(WR(IND),HR(IND),DIST(IND),RUFF(IND),GRPK,SLP(IND),
     $DELT,Q2ST)
1400  CONTINUE
      GO TO 1490
1410  DEPTH = 0
      SURMAX=0
      CALL TRAPA (WR(IND),SS(IND),DIST(IND),RUFF(IND),GRPK,SLP(IND),
     $DELT,Q2ST,DEPTH)
1420  CONTINUE
      GO TO 1430
1430  CALL ROUTE(GR,Q2ST,Q,IB,LAST,GRPK)
1440  CONTINUE
      GO TO 1510
C  COMPUTE QFB AND SFB
1450  QFB=0.0081*TDIAM*TDIAM/RUFF(IND)*(TDIAM/48.0)**.667*(SLP(IND)/
     $100.0)**.50
1460  CSA=3.1416*TDIAM*TDIAM/576.0
      SFB=CSA*DIST(IND)
      VFB=QFB/CSA
C
C  STORE PROPER Q VS Q+ IS/DELT  CURVE
      DO 1470 J=1,10
      Q2ST(1,J)=PQ(J)*QFB
1470  Q2ST(2,J)=Q2ST(1,J)+(2.0*PV(J)*SFB/(DELT*60.0))
1480  CONTINUE
1490  CALL ROUTCL (GR,Q2ST,Q,IB,LAST,GRPK,DELT,SURMAX)
1500  CONTINUE
      DEPTH=0.0
1510  CONTINUE
1520  FORMAT(F8.0,F4.0,F6.0,F5.2,F6.3,3F5.2,F5.0,F8.2,F6.2,
     *F10.2,9X,F12.1,F13.0,/)
1530  CONTINUE
      IF(QALOW(IND).NE.0.OR.STORE(IND).NE.0)GO TO 1540
      IRU=IRUN(IND)
      GO TO (1550,1570,1570),IRU
1540  IRU=IRUN(IND)
      GO TO (1590,1620,1620),IRU
1550  PRINT 1520,BRAN(IND),REACH(IND),DIST(IND),SLP(IND),RUFFN,HR(IND),
     $WR(IND),SS(IND),DIAM(IND),ECAP,EVEL,OUTLET,VOL,SMX
      PRINT 1560,TDIAM,QFB,VFB,PKDES,PKIN,SURMAX
1560  FORMAT(*                        REQUIRED PIPE =          *,F5.0,
     *F8.2,F6.2,F10.2,F9.2,F13.2,//)
      IF(DIAM(IND).GE.TDIAM)PRINT 1565
1565  FORMAT(10X,'****EXISTING PIPE HAS ADEQUATE CAPACITY***'//)
      GO TO 1640
1570  PRINT 1520,BRAN(IND),REACH(IND),DIST(IND),SLP(IND),RUFF(IND),
     $HR(IND),WR(IND),SS(IND),DIAM(IND),ECAP,EVEL,OUTLET,VOL,SMX
      PRINT 1580,PKDES,PKIN,SURMAX
1580  FORMAT(*
     *     *,F10.2,F9.2,F13.2,//)
      GO TO 1640
1590  PRINT 1600,BRAN(IND),REACH(IND),DIST(IND),SLP(IND),RUFFN,HR(IND),
     $WR(IND),SS(IND),DIAM(IND),ECAP,EVEL,PKDES,PKIN,SURMAX
1600  FORMAT(F8.0,F4.0,F6.0,F5.2,F6.3,3F5.2,F5.0,F8.2,F6.2,
     *F10.2,F9.2,F13.2,/)
      PRINT 1610,TDIAM,QFB,VFB,OUTLET,VOL,SMX
1610  FORMAT(*                        REQUIRED PIPE =          *,
     *F5.0,F8.2,F6.2,F10.2,9X,F12.1,F13.0,//)
      GO TO 1640
1620  PRINT 1600,BRAN(IND),REACH(IND),DIST(IND),SLP(IND),RUFF(IND),
     $HR(IND),WR(IND),SS(IND),DIAM(IND),ECAP,EVEL,PKDES,PKIN,SURMAX
      PRINT 1630,OUTLET,VOL,SMX
1630  FORMAT(*
     *     *,F10.2,9X,F12.1,F13.0,//)
1640  CONTINUE
C     PRINT 1301,BRAN(IND),REACH(IND),ISECT(IND),DIAM(IND),HR(IND),
```

```
C     $WR(IND),SLP(IND),RUFF(IND),DEPTH,SURMAX
1650  FORMAT( F8.0,F4.0,I5,F7.0,F7.1,F5.1,F5.2,F6.3,F7.1,F10.0,/)
1660  CONTINUE
C  FIND PEAK OF DISCHARGE HYDROGRAPH
1670  QPK=0
      DO 1690 ID=1,LAST
      IF(Q(IB,ID)-QPK)1690,1690,1680
1680  QPK=Q(IB,ID)
1690  CONTINUE
C
1700  PREDI=TDIAM
      IRUN(IND)=IRUNB
      IF(FREQR(IND).EQ.1.0)GO TO 1730
1710  DO 1720 IJ=1,NRI
      RR(IJ)=RR(IJ)/FREQR(IND)
1720  CONTINUE
1730  CONTINUE
      IF(TEST(IND).NE.END)GO TO 350
C
C  PRINT DISCHARGE HYDRO
1740  CONTINUE
C     WRITE (6,402)
1750  FORMAT(//,*     PENT  TIME   ROUGHNESS   TIME INCREMENT   FREQUENC
     *Y*,/)
C     WRITE(6,403)PENT,RUFF,DELT,FREQR
1760  FORMAT(8X,F5.1,7X,F5.4,9X,F5.0,10X,F5.0)
      VOLOUT=0.0
      DO 1761 M=1,LAST
      VOLOUT=VOLOUT+Q(IB,M)
1761  CONTINUE
      VOLOUT=VOLOUT*DELT*60.
      PRINT 1770,VOLOUT
1770  FORMAT(///,*   OUTFALL HYDROGRAPH IN CFS, ACCUMULATED RUNOFF IN CU
     * FT=*,F12.0)
      TOTALV=TOTALV+VOLOUT
      PRINT 1780, (Q(IB,M),M=1,LAST)
1780  FORMAT(10F8.2)
      PRINT 1789, TOTALV
1789  FORMAT(10X,'TOTAL RUNOFF FOR THE ENTIRE YEAR OF      =',E20.8)
      IF(IRAI.EQ.7) GO TO 1784
      GO TO 1785
1784  PRINT 1771, (XXX(JM),Q(IB,JM),JM=1,LAST)
1771  FORMAT(2(F10.4,10X))
      PRINT 1772, (XRUN(I),RUN(I),I=1,NON)
1772  FORMAT(2(F10.4,10X))
C     CALL NEWFRAM(XXX,Q,LAST,10.0,10.0,'TIME IN MINUTES','RUNOFF IN CFS
     $',15,13,10.0,10.0,'1970 UPPER ROSS ADE ILL',23)
C     CALL PLTCURV(XXX,Q,LAST,1,1,'ILLUDAS',7)
C     CALL PLTCURV(XRUN,RUN,NON,1,2,'OBSERVED',8)
C     CALL NEWFRAM(0.0,0.0,0,0.0,0.0,0,0,0,0,0.0,0.0,0,0)
1785  CALL DRYMAC(TT,TTT,MDAY)
      PRINT 1782, AMC
1782  FORMAT(X,'AMC=',F10.0)
      IF(IRAI.EQ.NSTORM) GO TO 1950
1781  CONTINUE
      GO TO 1
C  PRINT RESULTS FOR NEWLY DESIGNED REACH
C  COMBINE ROUTED HYDROS AT A CONFLUENCE
1790  DO 1800 M=1,6
      IF(Q(M,501).EQ.CONBR(IND))GO TO 1820
1800  CONTINUE
      PRINT 1810
1810  FORMAT(* CONTINUING BRANCH RECORD NOT FOUND*)
      GO TO 1930
1820  IB=M
      DO 1830 M=1,6
      IF(Q(M,501).EQ.ENDBR(IND))GO TO 1850
1830  CONTINUE
      PRINT 1840
1840  FORMAT(* ENDD BRANCH RECORD NOT FOUND*)
```

```
      GO TO 1930
1850  IEND=M
      DO 1860 N=1,500
      Q(IB,N)=Q(IB,N)+Q(IEND,N)
1860  CONTINUE
C     PRINT 1326
1870  FORMAT(* CONFLUENCE HYDRO  *)
C     PRINT 1327,(Q(IB,J,)J=1,200)
1880  FORMAT(10F10.4)
      Q(IEND,501)=0.0
      GO TO 1890
1890  LAST=1
      DO 1910 N=1,500
      IF(Q(IB,N).GT.0)GO TO 1900
      GO TO 1910
1900  LAST = N
1910  CONTINUE
1920  IF(TEST(IND).EQ.END)GO TO 30
      GO TO 350
1930  PRINT 1940
1940  FORMAT(*  TROUBLE FINDING UPSTREAM HYDROGRAPH *)
1950  CONTINUE
      END
      SUBROUTINE DRYMAC(TT,TTT,MDAY)
      COMMON /HAN/ AMC
      PRINT 21, TT,TTT,MDAY
21    FORMAT(X,2F10.3,I10)
      IF(TT.GE.7200.0) GO TO 1
      IF(TTT.EQ.0.0) AMC=1.0
      IF(TTT.GT.0.0.AND.TTT.LT.0.5) AMC=2.0
      IF(TTT.GE.0.5.AND.TTT.LE.1.0) AMC=3.0
      IF(TTT.GT.1.0) AMC=4.0
      GO TO 3
    1 IF(MDAY.GE.7200) GO TO 4
      IF(TTT.GT.0.0.AND.TTT.LT.0.5) AMC=2.0
      IF(TTT.GE.0.5.AND.TTT.LE.1.0) AMC=3.0
      IF(TTT.GT.1.0) AMC=4.0
      GO TO 3
    4 AMC=1.0
    3 PRINT 11, AMC
11    FORMAT(X,'AMC=',F10.0)
      RETURN
      END
      SUBROUTINE RECTAN (WR,VR,DIST,RUFF,GRPK,SLP,DELT,Q2ST)
C
C       FOR DISCHARGE STORAGE RELATION IN RECTANGULAR SECTION
C
      DIMENSION Q2ST(2,10)
C     WRITE(6,25) WR,VR,DIST,RUFF,GRPK,SLP,DELT
10    FORMAT (7F10.4)
      IH=0
      IC=0
      H=0
      DELTA=VR/10.0
20    IH=IH+1
      H=H+DELTA
      IC=IC+1
      IF(IC.EQ.10)GO TO 40
      CSA = WR*H
      P = WR+H+H
      Q = (1.486/RUFF)*CSA*((CSA/P)**.667)*(SLP/100.0)**0.5
      S = CSA*DIST
      V= Q/CSA
C     WRITE(6,26)P,Q,S,V
30    FORMAT(4F10.3)
      Q2ST(1,IH) =Q
      Q2ST(2,IH) = Q+(2*S)/(DELT*60.0)
      GO TO 20
40    Q2ST(1,IH) = Q
      Q2ST(2,IH) = Q+(2*S)/(DELT*60.0)
```

```
      WRITE (6,50)
 50   FORMAT (*    SUBROUTINE RECTAN  *)
      DO 70 I=1,2
 C    WRITE (6,15)(Q2ST(I,IH),IH=1,10)
 60   FORMAT (10F10.2)
 70   CONTINUE
      RETURN
      END
      SUBROUTINE TRAPA (W,V,DIST,RUFF,GRPK,SLP,DELT,Q2ST,DEPTH)
 C
 C         FOR DISCHARGE STORAGE RELATION IN TRAPAZOIDAL CHANNELS
 C
      DIMENSION Q2ST (2,10)
 C    WRITE(6,25) W,V,DIST,RUFF,GRPK,SLP,DELT,DEPTH
 10   FORMAT (8F10.4)
      IH = 0
      H = 0
 20   IH=IH+1
 30   H=H+1.0
      CSA = (W*H)+(H*H/V)
      P = W+((2.0*H)*(1.0+(1.0/(V*V)))**0.5)
      Q = (1.486/RUFF) * (CSA)*((CSA/P)**0.667)*(SLP/100.0)**00.5
      VEL=Q/CSA
      Q2ST(1,IH)=Q
      S=CSA*DIST
 C    WRITE(6,26)P,Q,S,VEL
 40   FORMAT(4F10.3)
      Q2ST(2,IH)=Q+(2.0*S)/(DELT*60.0)
      IF(Q-GRPK)50,50,70
 50   IF(IH.LT.10)GO TO 20
      IF(IH.EQ.10)GO TO 30
      PRINT 60
 60   FORMAT(* ERROR IN TRAPA SUBROUTINE*)
 70   DEPTH=H
 C    WRITE (6,10)
 80   FORMAT (*    SUBROUTINE  TRAPA  *)
      DO 100 I=1,2
 C    WRITE (6,21)(Q2ST(I,IH),IH=1,10)
 90   FORMAT (10F10.2)
 100  CONTINUE
      RETURN
      END
      SUBROUTINE ROUTE (GR,Q2ST,Q,IB,LAST,GRPK)
      DIMENSION GR(500),Q2ST(2,10),Q(7,501),QTEM(500),S(500)
 C
 C  DETERMINE THE SIGNIFICANT LENGTH OF THE HYDROGRAPH
 10   L=1
      IC = 1
 C    WRITE(6,57)(GR(IG),IG = 1,100)
 20   FORMAT(10F10.4)
      LAST=1
 30   DO 50 J=L,497
      IF(GR(J)-.001)60,60,40
 40   LAST=J+1
      IC = J+1
 50   CONTINUE
      GO TO 90
 60   DO 80 I=IC,498
      IF(GR(I)-.001)80,80,70
 70   L=I
      GO TO 30
 80   CONTINUE
 90   DO 100 IK=LAST,500
      GR(IK) = 0
 100  CONTINUE
 C  ROUTE GROSS HYDROGRAPH GR TO Q
 110  CONTINUE
 C    WRITE(6,1307)LAST
 120  FORMAT(*  GROSS HYDROGRAPH  LAST = *,I5)
 C    WRITE(6,1308)(GR(J),J=1,100)
```

```
130    FORMAT(10F10.4)
       TEST = 0.1*GRPK
       QTEM(1)=GR(1)
       DO 290 M=1,498
       IF(QTEM(M)-Q2ST(2,1))140,160,180
140    POR=QTEM(M)/Q2ST(2,1)
       IF(POR.GT.0.01)GO TO 150
       POR=0.0
150    Q(IB,M)=Q2ST(1,1)*POR
       S(M)=POR*Q2ST(2,1)-Q(IB,M)
       GO TO 240
160    J=1
170    Q(IB,M)=Q2ST(1,J)
       S(M)=Q2ST(2,J)-Q2ST(1,J)
       GO TO 240
180    DO 190 J=2,10
       IF(QTEM(M)-Q2ST(2,J))220,170,190
190    CONTINUE
200    CONTINUE
       Q2ST(2,10)=QTEM(M)
       Q(IB,M)=GRPK
       PRINT 210
210    FORMAT(* GEOMETRY OF SECTION CAUSED ROUTED PEAK TO EQUAL UPSTREAM
      * PEAK*)
       S(M)=QTEM(M)-GRPK
       GO TO 240
220    POR=(QTEM(M)-Q2ST(2,J-1))/(Q2ST(2,J)-Q2ST(2,J-1))
       Q(IB,M)=Q2ST(1,J-1)+POR*(Q2ST(1,J)-Q2ST(1,J-1))
       IF(Q(IB,M).GT.0.0001)GO TO 230
       Q(IB,M)=0.0
230    S(M)=(Q2ST(2,J-1)+POR*(Q2ST(2,J)-Q2ST(2,J-1)))-Q(IB,M)
       IF(S(M).GT.0.0001)GO TO 240
       S(M)=0.0
       GO TO 240
240    IF(M-LAST)280,250,250
250    IF(M.GT.498)GO TO 260
       IF(Q(IB,M)-.01)260,260,280
260    NO = M
       GO TO 300
C      WRITE (6,700) M,GR(M),GR(M+1),Q(IB,M),S(M)
270    FORMAT(I10,4F20.8)
280    QTEM(M+1)=GR(M+1)+GR(M)-Q(IB,M)+S(M)
290    CONTINUE
       NO = 499
300    LAST = NO
       IF(LAST-500)320,320,310
310    LAST = 500
320    CONTINUE
       DO 330 N=NO,500
       Q(IB,N)=0.
330    CONTINUE
C      WRITE (6,1324)LAST
340    FORMAT(* ROUTED HYDROGRAPH  LAST =  *,I5)
C      WRITE(6,1325)(Q(IB,J),J=1,LAST)
350    FORMAT(10F10.4)
       RETURN
       END
       SUBROUTINE SUPPLY (AR,DELTAT,FC,FI,FO,GASR,K,NRI,DEPG,NGSR,SGASR)
       DIMENSION GASR(500),AR(500)
       REAL K,IS
C      PRINT 105, DELTAT,FC,FI,FO,K,NRI,DEPG
105    FORMAT( 5F12.4,I10,F12.4 )
C      PRINT 4,(AR(I),I=1,NRI)
4      FORMAT (5F20.4)
       SGASR=0.0
       F1=FI
       MK=1
       AS=DEPG
       IS=0
       DO 150 I=1,NRI,1
```

```
      IF(MK)60,60,30
30    T=0.0
      TT=0.0
40    CONTINUE
      F=FC*T+((1.-EXP(-K*T))*(FO-FC))/K
      F=F-F1
      FP=FC+((FO-FC)*(K*EXP(-K*T)))/K
      T=T-F/FP
      IF(ABS(TT-T).LT.0.001)GO TO 50
      TT=T
      GO TO 40
50    CONTINUE
60    TN=T+DELTAT
      FN=FC*TN+((1.-EXP(-K*TN))*(FO-FC))/K
      FINC=FN-F1
      RINC=AR(I)
      DRUN=RINC-FINC
C     PRINT 5,FO,FC,F1,T,TN,FN,AS,DRUN
70    FORMAT (8F12.4)
      IF(DRUN)80,110,120
80    IS=DEPG-AS
      IF(ABS(DRUN)-IS)100,90,90
90    IS=0
      AS=DEPG
      GASR(I)=0.0
      F1=F1+RINC+IS
      MK=1
      GO TO 150
100   IS=IS+DRUN
      AS=DEPG-IS
      GASR(I)=0.0
      F1=FN
      T=TN
      MK=-1
      GO TO 150
110   F1=FN
      T=TN
      MK=-1
      GASR(I)=0.0
      GO TO 150
120   F1=FN
      T=TN
      MK=-1
      IF(DRUN-AS)140,130,130
130   GASR(I)=DRUN-AS
      AS=0.0
      GO TO 150
140   AS=AS-DRUN
      GASR(I)=0.0
      GO TO 150
150   CONTINUE
      J=NRI+1
      DO 160 I=J,500,1
      GASR(I)=0.0
160   CONTINUE
      NGSR=0
      DO 180 J=1,NRI
      IF(GASR(J).LT.0.001)GO TO 170
      NGSR=J
      SGASR=SGASR+GASR(J)
      GASR(J)=GASR(J)/DELTAT
      GO TO 180
170   GASR(J)=0.0
180   CONTINUE
C     PRINT 102
102   FORMAT( * GRASSED AREA SUPPLY RATE IN INCHES PER HOUR*)
C     PRINT 103,(GASR(I),I=1,NRI)
103   FORMAT (10F10.4)
210   RETURN
      END
```

```
      SUBROUTINE TIMEA (A,ENT,DELT,NAI,MAXA,CA)
      DIMENSION A(50)
C
C  COMPUTE AND STORE TIME AREA CURVE
10    AAS=ENT/DELT
      TAAS=AAS+1.0
      NAI=TAAS
      IF(NAI.EQ.1)GO TO 40
      ASUM=0
      NIX=NAI-1
      DO 20 N=1,NIX
      A(N)=CA/AAS
20    ASUM=ASUM+A(N)
      A(NAI)=CA-ASUM
      NAX=NAI+1
      DO 30 N=NAX,MAXA
30    A(N)=0
      GO TO 60
40    A(1)=CA
      DO 50 N=2,MAXA
50    A(N)=0
60    CONTINUE
C     PRINT 70
70    FORMAT (* TIME AREA*)
C     PRINT 80,(A(N),N=1,NAI)
80    FORMAT(10F10.4)
      RETURN
      END
      SUBROUTINE GRENT (GENT,GA,GLENG,GSLP,ENT)
      DATA AVSP/1.0/,C/0.050/
C        DETERMINE GRASSED AREA ENTRY TIME BY IZZARD EQUATIONS
      QEQ=AVSP * GLENG / 43200.
      CK=(0.0007* AVSP + C)/(GSLP/100.0) ** 0.333
      DET =CK * GLENG * QEQ ** 0.4
      GGENT = DET/(30.0 * QEQ)
      GENT = GGENT + ENT
      PRINT 10,GENT
10    FORMAT (* GRASSED ENTRY TIME= *,F6.1,* MIN*)
      RETURN
      END
      SUBROUTINE ROUTGL(GR,Q2ST,Q,IB,LAST,GRPK,DELT,SURMAX)
      DIMENSION GR(500),Q2ST(2,10),Q(7,501),QTEM(500),S(500)
C
C  DETERMINE THE SIGNIFICANT LENGTH OF THE HYDROGRAPH
10    L=1
      IC = 1
C     WRITE(6,57)(GR(IG),IG = 1,100)
20    FORMAT(10F10.4)
      LAST=1
30    DO 50 J=L,497
      IF(GR(J)-.001)60,60,40
40    LAST=J+1
      IC = J+1
50    CONTINUE
      GO TO 90
60    DO 80 I=IC,498
      IF(GR(I)-.001)80,80,70
70    L=I
      GO TO 30
80    CONTINUE
90    DO 100 IK=LAST,500
      GR(IK) = 0
100   CONTINUE
C  ROUTE GROSS HYDROGRAPH GR TO Q
110   CONTINUE
C     WRITE(6,1307)LAST
120   FORMAT(*  GROSS HYDROGRAPH  LAST = *,I5)
C     WRITE(6,1308)(GR(J),J=1,100)
130   FORMAT(10F10.4)
      QFB=Q2ST(1,10)
```

```
      SURCH=0.0
      SURMAX=0.0
      QTEM(1)=GR(1)
      S(1)=0.0
      DO 380 M=1,498
      IF(M.EQ.1) GO TO 190
      GRIN=(GR(M)+GR(M-1))/2.0
140   IF(GRIN-QFB)150,170,160
150   IF(SURCH.LT.0.01)GO TO 180
      GRIN=GRIN + SURCH/(DELT*60)
      SURCH=0.0
      GO TO 140
      SURCH=0.0
      GO TO 140
160   SURCH=SURCH+(GRIN-QFB)*DELT*60.0
      IF(SURMAX.GT.SURCH)GO TO 170
      SURMAX=SURCH
170   CONTINUE
      QTEM(M)=2.0*QFB+S(M-1)-Q(IB,M-1)
      GO TO 190
180   SURCH=0.0
      QTEM(M)=GRIN*2.0+S(M-1)-Q(IB,M-1)
190   EXCESS=QTEM(M)-Q2ST(2,10)
      IF(EXCESS)220,220,200
200   SURCH=SURCH+EXCESS*DELT*60.0
      QTEM(M)=Q2ST(2,10)
C     WRITE(6,240) EXCESS
210   FORMAT (*       EXCESS = *, F15.5 )
220   IF(QTEM(M)-Q2ST(2,1))230,250,270
230   POR=QTEM(M)/Q2ST(2,1)
      IF(POR.GT.0.01)GO TO 240
      POR=0.0
240   Q(IB,M)=Q2ST(1,1)*POR
      S(M)=POR*Q2ST(2,1)-Q(IB,M)
      GO TO 330
250   J=1
260   Q(IB,M)=Q2ST(1,J)
      S(M)=Q2ST(2,J)-Q2ST(1,J)
      GO TO 330
270   DO 280 J=2,10
      IF(QTEM(M)-Q2ST(2,J))310,260,280
280   CONTINUE
290   CONTINUE
      PRINT 300
300   FORMAT(* QFB WAS EXCEEDED IN ROUTCL *)
      J=10
      GO TO 260
310   POR=(QTEM(M)-Q2ST(2,J-1))/(Q2ST(2,J)-Q2ST(2,J-1))
      Q(IB,M)=Q2ST(1,J-1)+POR*(Q2ST(1,J)-Q2ST(1,J-1))
      IF(Q(IB,M).GT.0.0001)GO TO 320
      Q(IB,M)=0.0
320   S(M)=(Q2ST(2,J-1)+POR*(Q2ST(2,J)-Q2ST(2,J-1)))-Q(IB,M)
      IF(S(M).GT.0.0001)GO TO 330
      S(M)=0.0
      GO TO 330
330   IF(M-LAST)370,340,340
340   IF(M.GT.498)GO TO 350
      IF(Q(IB,M)-.01)350,350,370
350   NO = M
      GO TO 390
C     WRITE (6,700) M,GR(M),GR(M+1),Q(IB,M),S(M)
360   FORMAT(I10,4F20.8)
370   CONTINUE
380   CONTINUE
      NO = 499
390   LAST = NO
      IF(LAST-500)410,410,400
400   LAST = 500
410   CONTINUE
      DO 420 N=NO,500
```

```
      Q(IB,N)=0.
420   CONTINUE
C     PRINT 1324,LAST
430   FORMAT(* ROUTED HYDROGRAPH FROM ROUTCL LAST= *,I5)
C     PRINT 1325,(Q(IB,J),J=1,LAST)
440   FORMAT(10F10.4)
      RETURN
      END
      SUBROUTINE INTEN (RI,ABSTRT,NRI,DELTAT)
      DIMENSION RI(500)
      SUB=0.0
      DO 10 J=1,NRI
      SUB=SUB+RI(J)
      IF(ABSTRT-SUB)20,20,10
10    RI(J)=0.0
      PRINT 15
15    FORMAT (*  ABSTRAT GREATER THAN RAINFALL IN SUBROUTINE INTEN* )
      GO TO 60
20    CONTINUE
      RI(J)=SUB-ABSTRT
40    DO 50 K=1,NRI
      RI(K)=RI(K)/DELTAT
50    CONTINUE
60    CONTINUE
C     PRINT 70,(RI(J),J=1,NRI)
70    FORMAT(*  INTEN*,10F10.3)
      RETURN
      END
      SUBROUTINE CAPAC (ISECT,DIAM,H,W,SS,SLP,RUFF,ECAP,EVEL,EA)
C
C  SUBROUTINE TO COMPUTE CAPACITY OF EXISTING SECTIONS
C
      IF(ISECT.NE.0)GO TO 10
      ISECT=1
10    GO TO (20,40,50),ISECT
20    IF(DIAM.EQ.0)GO TO 30
      EA=0.00545*DIAM*DIAM
      P=0.2618*DIAM
      GO TO 60
30    ECAP=0
      EVEL=0
      EA=0
      GO TO 70
40    EA=H*W
      P=H+H+W+W
      GO TO 60
50    EA=(W*H)+(H*H/SS)
      P=W+((2.0*H)*(1.0+(1.0/(SS*SS)))**0.5)
60    EVEL=(1.486/RUFF)*(EA/P)**0.667*(SLP/100.0)**0.50
      ECAP=EVEL*EA
70    RETURN
      END
      SUBROUTINE DETEN(GR,GRPK,LAST,STORE,DELT,BRAN,REACH,VOL)
      DIMENSION GR(500),QT(500)
      DTMAX=STORE*1000.0
      DELTS=DELT*60.0
C     PRINT 200,GRPK
10    FORMAT(* GRPK IN TO DETEN= *,F10.4)
      QOUT=0.0
      QINC=GRPK/50.0
20    J=0
      VOLMAX=0
      MIKE=LAST
      DO 30 K=1,500
      QT(K)=0
30    CONTINUE
      VOL=0
      QOUT=QOUT+QINC
      IF(QOUT)100,100,40
40    J=J+1
```

```
      AVAIL=GR(J)+VOL/DELTS
      DIFF=AVAIL-QOUT
      IF(DIFF)50,50,60
50    QT(J)=AVAIL
      VOL=0
      GO TO 80
60    QT(J)=QOUT
      VOL=DIFF*DELTS
      IF(VOLMAX.GT.VOL)GO TO 70
      VOLMAX=VOL
70    IF(VOL.GT.DTMAX)GO TO 20
80    CONTINUE
C     PRINT 300,J,QOUT,AVAIL,DIFF,GR(J),QT(J),VOL,VOLMAX,DTMAX
90    FORMAT (I5,8F12.3)
      IF(J.LT.LAST)GO TO 40
      IF(VOL.LT.5.0)GO TO 120
      MIKE=MIKE+1
      IF(MIKE.GT.499)GO TO 120
      GR(MIKE)=0.0
      GO TO 40
100   PRINT 110
110   FORMAT(* NO SOLUTION IN SUBROUTINE DETEN *)
120   GRPK=QOUT
      VOL=VOLMAX
      LAST=MIKE
      DO 130 K=1,LAST
      GR(K)=QT(K)
130   CONTINUE
C     PRINT 201,GRPK
140   FORMAT (* GRPK OUT OF DETEN=*, F 10.4)
      RETURN
      END
      SUBROUTINE PAVENT (PENT,PL,PS,CPA)
C     PRINT 6,PENT,PL,PS,CPA
10    FORMAT(4F12.4)
      Q=CPA/4.0
      XN=0.02
      S=PS/100.0
      R=0.2
      V=(1.486/XN)*R**0.67*S**0.5
      PENT=PL/V/60.0+2.0
      PRINT 20,PENT
20    FORMAT(* PAVED ENTRY TIME= *,F6.1,* MIN*)
      RETURN
      END
      SUBROUTINE RHUFF(TRAIN,DURA,DELT,RR,NRI)
      REAL RR(500),PCTT(17),PCTR(17),SR(500)
      INTEGER XRI
      X=-4.
      DO 10 I=1,11
      X=X+4
      PCTT(I)=X
10    CONTINUE
      DO 20 I=12,17
      PCTT(I)=PCTT(I-1)+10.
20    CONTINUE
      PCTR(1)=0
      PCTR(2)=9.6
      PCTR(3)=21.0
      PCTR(4)=32.7
      PCTR(5)=43.
      PCTR(6)=51.2
      PCTR(7)=58.3
      PCTR(8)=63.1
      PCTR(9)=67.2
      PCTR(10)=70.6
      PCTR(11)=73.5
      PCTR(12)=79.5
      PCTR(13)=84.2
      PCTR(14)=88.5
```

```
      PCTR(15)=92.5
      PCTR(16)=96.3
      PCTR(17)=100.
      XRI=DURA/DELT+1.1
      SR(1)=0
      X=0
      DO 60 I=2,XRI
      X=X+DELT
      PX=(X/DURA)*100.
      DO 30 J=1,17
      IF(PX-PCTT(J))40,50,30
30    CONTINUE
      GO TO 60
40    SR(I)=(PCTR(J-1)+(PCTR(J)-PCTR(J-1))/(PCTT(J)
     *-PCTT(J-1))*(PX-PCTT(J-1)))*TRAIN*.01
      GO TO 60
50    SR(I)=PCTR(J)*TRAIN*.01
60    CONTINUE
      JJ=XRI
      NRI=JJ
      RR(1)=0.0
      DO 70 J=2,JJ
      RR(J)=SR(J)-SR(J-1)
70    CONTINUE
C     PRINT 9,(RR(J),J=1,JJ)
80    FORMAT (F12.4)
      RETURN
      END
      SUBROUTINE LIMITQ (GR,GRPK,LAST,QALOW,DELT,BRAN,REACH,VOL)
      DIMENSION GR(500),QT(500)
      DELTS=DELT*60.0
C     PRINT 200,(GR(J),J=1,LAST)
10    FORMAT(* GR INTO LIMITQ *,10F8.1)
      QOUT=QALOW
      J=0
      VOLMAX=0
      MIKE=LAST
      DO 20 K=1,500
      QT(K)=0.0
20    CONTINUE
      VOL=0.0
30    J=J+1
      AVAIL=GR(J)+VOL/DELTS
      DIFF=AVAIL-QOUT
      IF(DIFF)40,40,50
40    QT(J)=AVAIL
      VOL=0
      GO TO 60
50    QT(J)=QOUT
      VOL=DIFF*DELTS
      IF(VOLMAX.GT.VOL)GO TO 60
      VOLMAX=VOL
60    CONTINUE
      IF(J.LT.LAST)GO TO 30
      IF(VOL.LT.5.0)GO TO 70
      MIKE=MIKE+1
      IF(MIKE.GT.499)GO TO 70
      GR(MIKE)=0.0
      GO TO 30
70    GRPK=QOUT
      VOL=VOLMAX
      LAST=MIKE
      DO 80 K=1,LAST
      GR(K)=QT(K)
80    CONTINUE
C     PRINT 201,(GR(J),J=1,LAST)
90    FORMAT(* GR OUT OF LIMITQ *,10F8.1)
      RETURN
      END
```

APPENDIX A-2

Program Listing of DRAINQUAL

```
      PROGRAM ILLUDAS(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=
     *PUNCH,PLOT)
C       ILLUDAS -- THE ILLINOIS URBAN DRAINAGE AREA SIMULATOR
C                  ILLINOIS STATE WATER SURVEY
C                  MODIFIED FOR RUNOFF QUALITY SIMULATION
C
      DIMENSION A(100),AR(500),AIF(6),BIF(6),CIF(6),DIF(6),GAD(50)
      DIMENSION GASR(500),GGR(500),GR(500),PQ(10),PV(10),Q(7,501)
      DIMENSION Q2ST(2,10),RI(500),RR(500),STORM(20),XNAME(20)
      REAL KIF
      DATA MAXA/50/,PQ/.10,.20,.30,.40,.50,.60,.70,.80,.90,1.00/,PV/.16,
     *.27,.35,.43,.50,.58,.65,.71,.80,1.00/,IB/1/,
     *END/3HEND/,STOP/4HSTOP/,PREDI/12.0/
      DATA AIF/0.0,2.0,4.0,6.0,10.0,1.0/,BIF/0.0,1.5,3.0,4.0,8.0,0.5/
      DATA CIF/0.0,1.0,2.0,3.0,5.0,0.25/,DIF/0.0,0.7,1.5,2.0,3.0,0.1/
      DATA KIF/2.0/
      PRINT 20
20    FORMAT(*1     ILLUDAS ** ILLINOIS STATE WATER SURVEY ** *,/,
     **       ILLUDAS UPDATED  JULY 15 1976 *)
      LT=5
      GO TO 35
30    CONTINUE
      PRINT 31
31    FORMAT(*1*)
35    READ(LT,40)XNAME,STORM
      IF(EOF,LT)105,36
40    FORMAT(20A4)
 36   PRINT 50,XNAME,STORM
50    FORMAT( ///,20A4,/,20A4,//)
      READ(LT,60)XID,DESIN,EVAL
60    FORMAT (3F10.0)
      READ(LT,70)AREA,ABSTRT,DEPG,ISOIL,DIMIN,RUFFN
70    FORMAT(3F10.0,I10,2F10.0)
C     PRINT 7, AREA,ABSTRT,DEPG,ISOIL,DIMIN,RUFFN
80    FORMAT(3F12.3,I10,2F12.3)
      READ(LT,90)RAIN,XRI,DELT,HUFF,DURA,FREQ,TRAIN,AMC
90    FORMAT(8F10.0)
C     PRINT 21,RAIN,XRI,DELT,HUFF,DURA,FREQ,TRAIN,AMC
100   FORMAT(8F12.4)
      IF(DESIN.NE.0.AND.EVAL.NE.0)GO TO 110
      IF(DESIN.EQ.0.AND.EVAL.EQ.0)GO TO 150
      IF(DESIN.EQ.0.0)GO TO 140
      GO TO 130
105   CONTINUE
      PRINT 106
106   FORMAT(*  THE JOB IS FINISHED*)
      STOP
110   PRINT 120
120   FORMAT(* DESIGN AND EVALUATION BOTH SPECIFIED - DESIGN ASSUMED*)
130   IRUNB=1
      GO TO 170
140   IRUNB=2
      GO TO 170
150   PRINT 160
160   FORMAT(* NEITHER DESIGN NOR EVAL SPECIFIED - DESIGN ASSUMED *)
      IRUNB=1
170   CONTINUE
      NRI=XRI
      IFREQ=FREQ
      IMC=AMC
      IID=XID
      IF(HUFF.GT.0.AND.RAIN.GT.0)GO TO 190
      IF(RAIN.EQ.0.0)GO TO 210
      READ(LT,180)(RR(J),J=1,NRI)
180   FORMAT(10F8.0)
```

```
      TRAIN=0
      DO 185 K=1,NRI
      TRAIN=TRAIN+RR(K)
185   CONTINUE
      DURA=(NRI-1)*DELT
      GO TO 220
190   PRINT 200
200   FORMAT(* RAINFALL PROVIDED OR STANDARD DISTRIBUTION ^^^ *)
      GO TO 1950
210   CONTINUE
      CALL RHUFF(TRAIN,DURA,DELT,RR,NRI)
220   CONTINUE
      PRINT 230
230   FORMAT(* RAINFALL PATTERN *)
      PRINT 240,(RR(J),J=1,NRI)
240   FORMAT(10F8.3)
      PRINT 250
250   FORMAT(*0      RUN NUMBER   BASIN AREA   TIME INCREMENT   SOIL GROU
     *P*)
      PRINT 260
260   FORMAT(*                            ACRES          MINUTES       1234=ABCD
     * *,/)
      PRINT 270,IID,AREA,DELT,ISOIL
270   FORMAT(I13,F15.1,F13.1,I13,//)
      PRINT 280
280   FORMAT(*        TOTAL RAIN   FREQUENCY   DURATION    AMC    PAVED AB
     *S.   GRASS ABS.*)
      PRINT 290
290   FORMAT(*          INCHES         YEARS       MINUTES           INCHES
     *        INCHES*,/)
      PRINT 300,TRAIN,IFREQ,DURA,IMC,ABSTRT,DEPG
300   FORMAT(9X,F5.2,6X,I5,7X,F6.1,I8,F11.2,F14.2,//)
      PRINT 310
310   FORMAT( //,*        B    R    LENG   SLP    N    HT   BW  V/H    DIA    CA
     *PAC   VEL    DESIGN     INLET    DETENTION    STORAGE *)
      PRINT 320
320   FORMAT(     *                    FT     PCT          FT    FT          INS      C
     *FS     FPS    Q-CFS      Q-CFS      CUBIC FT   REQUESTED *,//)
      PREDI=DIMIN
      DELTAT=DELT/60.0
      NEND=0
      DO 330 L=1,500
      GR(L)=0.0
330   CONTINUE
      DO 340 M=1,6
      Q(M,501)=0.0
340   CONTINUE
      TGAR=0.0
      TGA=0.0
      TSPA=0.0
      TPAR=0.0
      TCPA=0.0
      ILL=0
350   CONTINUE
      VOL=0
      OUTLET=0
      SURMAX=0
      SMX=0
      READ(LT,360)BRAN,REACH,ENDBR,CONBR,IRUN,DIST,SLP,RUFF,ISECT,DIAM,H
     *R,WR,SS,QALOW,FREQR,STORE,TEST,HYD
360   FORMAT(4F3.0,I3,3F5.0,I1,F4.0,6F5.0,1A3,I2,10X)
      IF(IRUN.NE.0.0)GO TO 370
      IRUN=IRUNB
370   CONTINUE
      IF(ENDBR.NE.0)GO TO 1790
```

```
      READ(LT,380)CBRAN,CREACH,BA,CPA,PCPA,SPA,PSPA,PENT,PL,PS,CGA,PCGA,
     *GENT,GL,GS,IGROUP
380   FORMAT(2F3.0,F9.0,F5.0,F3.0,F5.0,F3.0,4F5.0,F3.0,3F5.0,I2,9X)
C     PRINT 6, BRAN,REACH,ENDBR,CONBR,DIST,SLP,RUFF,ISECT,DIAM,HR,WR,
C    1SS,FREQR,STORE,HYD
390   FORMAT(7F8.3,I3,6F8.3,I3)
C     PRINT 5, CBRAN,CREACH,BA,CPA,PCPA,SPA,PSPA,PENT,PL,PS,CGA,PCGA,
C    1GENT,GL,GS,IGROUP
400   FORMAT(15F8.3,I5)
      IF(IGROUP.EQ.0) IGROUP=ISOIL
      IF(FREQR.EQ.1.0)GO TO 440
      IF(FREQR.NE.0)GO TO 410
      FREQR=1.0
      GO TO 440
410   DO 420 IJ=1,NRI
      RR(IJ)=RR(IJ)*FREQR
420   CONTINUE
      PRINT 430,FREQR
430   FORMAT(* RAINFALL MULTIPLIED BY A FACTOR OF *,F5.2,
     ** FOR THIS REACH*)
440   CONTINUE
      IF(CPA.NE.0.0)GO TO 450
      CPA=BA*PCPA*0.01
450   IF(SPA.NE.0.0)GO TO 460
      SPA=BA*PSPA*0.01
460   IF(CGA.NE.0.0)GO TO 470
      CGA=BA*PCGA*0.01
470   IF(PENT+PL.EQ.0.0)GO TO 480
      IF(PENT.NE.0.0)GO TO 480
      IF(CPA.EQ.0.0)GO TO 480
      CALL PAVENT(PENT,PL,PS,CPA)
480   CONTINUE
      TGA=TGA+CGA
      TSPA=TSPA+SPA
      TCPA=TCPA+CPA
      PRINT485,TCPA,TSPA,TGA
485   FORMAT(5X,*ACCUM CONTRIBUTING AREAS*,*   CPA=*,F7.1,*,   SPA=*,F7.
     *1,*,   CGA=*,F7.1)
      CALL CAPAC(ISECT,DIAM,HR,WR,SS,SLP,RUFF,ECAP,EVEL,EA)
490   CONTINUE
      IF(BRAN.EQ.0.0)GO TO 500
      IF(CPA+CGA+SPA)990,990,530
500   CONTINUE
      IF(ENDBR.EQ.0.0)GO TO 510
C  LABEL 600 IS FOR A CONFLUENCE
      GO TO 1790
510   PRINT 520
520   FORMAT (*  BRANCH AND ENDBR BOTH EQUAL ZERO*)
      GO TO 1930
530   IF(CPA)540,540,560
540   DO 550 N=1,500
      GR(N)=0.0
550   CONTINUE
      GO TO 670
560   CALL TIMEA(A,PENT,DELT,NAI,MAXA,CPA)
570   CONTINUE
      DO 580 N=1,NRI
      RI(N)=RR(N)
580   CONTINUE
      CALL INTEN(RI,ABSTRT,NRI,DELTAT)
590   CONTINUE
C
C     COMPUTE GROSS PAVED AREA HYDROGRAPH
      NEND=NRI+NAI-1
      DO 600 J=1,500
```

```
 600   GR(J)=0
       DO 620 L=1,NRI
       N=L-1
       DO 610 J=1,NAI
       N=N+1
       DGR=RI(L)*A(J)
       GR(N)=GR(N)+DGR
 610   CONTINUE
 620   CONTINUE
       IF(HYD)660,660,630
 630   PRINT 640,BRAN,REACH
 640   FORMAT (* PAVED AREA HYDROGRAPH*,2F10.1 )
       PRINT 650,(GR(J),J=1,NEND)
 650   FORMAT(9F8.1)
 660   IF(CGA)950,950,670
 670   CONTINUE
       GO TO (680,690,700,710),IGROUP
 680   FI=AIF(IMC)
       FO=AIF(5)
       FC=AIF(6)
       GO TO 720
 690   FI=BIF(IMC)
       FO=BIF(5)
       FC=BIF(6)
       GO TO 720
 700   FI=CIF(IMC)
       FO=CIF(5)
       FC=CIF(6)
       GO TO 720
 710   FI=DIF(IMC)
       FO=DIF(5)
       FC=DIF(6)
 720   CONTINUE
C      PRINT 406, NRI,IGROUP,IMC,CGA,SPA,DELTAT,DEPG,GL,GS,FI,FO,FC
 730   FORMAT ( 3I5,9F8.3)
C      PRINT 407,(RR(J),J=1,NRI)
 740   FORMAT (10F10.3)
       DO 750 I=1,NRI,1
       AR(I)=RR(I)*(CGA+SPA)/CGA
 750   CONTINUE
       CALL SUPPLY (AR,DELTAT,FC,FI,FO,GASR,KIF,NRI,DEPG,NGSR,SGASR)
 760   CONTINUE
       IF(NGSR)950,950,770
 770   CONTINUE
C      PRINT 461, (GASR(I),I=1,NGSR,1)
 780   FORMAT (10F10.3)
C      PRINT 462, SGASR
 790   FORMAT (* GASR TOTAL *,F8.3 )
 800   CONTINUE
       IF(GENT+GL.EQ.0.0)GO TO 810
       IF(GENT.NE.0.0) GENT=GENT+PENT
       IF(GENT.NE.0.0)GO TO 830
       CALL GRENT(GENT,CGA,GL,GS,PENT)
       GO TO 830
 810   GENT=20.0
       PRINT 820
 820   FORMAT(* GRASS ENT ASSUMED = 20 MIN.  GIVE MORE DATA *)
       GO TO 830
 830   CONTINUE
       CALL TIMEA(GAD,GENT,DELT,NGAI,MAXA,CGA)
 840   CONTINUE
       NGEND=NGAI+NGSR-1
       DO 850 J=1,500
 850   GGR(J)=0.0
       DO 870 L=1,NGSR
```

```
      N=L-1
      DO 860 J=1,NGAI
      N=N+1
      GDGR=GASR(L)*GAD(J)
      GGR(N)=GGR(N)+GDGR
860   CONTINUE
870   CONTINUE
      IF(HYD)910,910,880
880   PRINT 890
890   FORMAT (* GRASSED AREA HYDROGRAPH*)
      PRINT 900,(GGR(J),J=1,NGEND)
900   FORMAT(9F8.1)
910   IF(NGEND-NEND)930,930,920
920   NEND=NGEND
930   DO 940 I=1,NEND
      GR(I)=GR(I)+GGR(I)
940   CONTINUE
950   CONTINUE
C     PRINT 59,CPA,CGA,SPA,PENT,GENT
960   FORMAT(5F10.4)
      GRPK = GR(1)
      DO 980 J=2,NEND
      IF(GRPK-GR(J))970,980,980
970   GRPK = GR(J)
980   CONTINUE
      PKIN=GRPK
      LAST=NEND
C  TEST FOR MID BRANCH (421)  OR INITIAL (426)
      IF(REACH.NE.0.0)GO TO 1010
      GO TO 1140
C
C  FOR AREA =0 IN MID BRANCH
990   DO 1000 J=1,500
      GR(J)=0.0
1000  CONTINUE
      GRPK=0.0
      PKIN=0.0
      GO TO 1010
C
C  COMBINE PREVIOUS ROUTED HYDROGRAPH WITH NEW GROSS HYDROGRAPH
1010  CONTINUE
      DO 1020 M=1,6
      IF(Q(M,501).EQ.BRAN)GO TO 1040
1020  CONTINUE
      PRINT 1030
1030  FORMAT(* PREVIOUS BRANCH HYDROGRAPH NOT FOUND*)
      GO TO 1930
1040  IB=M
      GRPK = 0
      DO 1070 N=1,500
      GR(N)=GR(N)+Q(IB,N)
      IF(GRPK-GR(N))1050,1060,1060
1050  GRPK=GR(N)
1060  CONTINUE
1070  CONTINUE
      IF(HYD)1110,1110,1080
1080  PRINT 1090
1090  FORMAT(* ROUTED PLUS SURFACE HYDROGRAPH *)
      PRINT 1100,(GR(J),J=1,LAST)
1100  FORMAT(9F8.1)
1110  IF(DIAM)1120,1120,1130
1120  TDIAM=PREDI
C  LABEL 450 IS FOR ROUTING
      GO TO 1210
1130  TDIAM=DIAM
```

```
      IF(IRUN.EQ.1)TDIAM=DIMIN
      GO TO 1210
 1140 CONTINUE
      IF(DIAM)1160,1160,1150
 1150 TDIAM=DIAM
      IF(IRUN.EQ.1)TDIAM=DIMIN
      GO TO 1170
 1160 TDIAM=DIMIN
 1170 DO 1180 M=1,6
      IF(Q(M,501).EQ.0.0)GO TO 1200
 1180 CONTINUE
      PRINT 1190
 1190 FORMAT(* NO BRANCHES ARE FREE*)
      GO TO 1930
 1200 IB=M
      Q(IB,501)=BRAN
      GO TO 1210
C
C  FIND GROSS HYDROGRAPH PEAK
 1210 GRPK =GR(1)
      DO 1230 J=2,500
      IF(GRPK-GR(J))1220,1230,1230
 1220 GRPK=GR(J)
 1230 CONTINUE
      PKDES=GRPK
      DO 1250 I=1,2
      DO 1240 J=1,10
      Q2ST(I,J) = 0.0
 1240 CONTINUE
 1250 CONTINUE
      IF(STORE.EQ.0.0)GO TO 1280
      IF(QALOW.EQ.0.0)GO TO 1310
 1260 PRINT 1270
 1270 FORMAT(* BOTH STORAGE AND LIMITED Q REQUESTED - STORAGE USED *)
      QALOW=0.0
      GO TO 1310
 1280 IF(QALOW.EQ.0.0)GO TO 1340
      IF(QALOW-GRPK)1290,1340,1340
 1290 CALL LIMITQ(GR,GRPK,LAST,QALOW,DELT,BRAN,REACH,VOL)
 1300 CONTINUE
      GO TO 1320
 1310 CALL DETEN(GR,GRPK,LAST,STORE,DELT,BRAN,REACH,VOL)
 1320 CONTINUE
      OUTLET=GRPK
      SMX=STORE*1000.0
C     PRINT 903,BRAN,REACH,SMX,GRPK,VOL
 1330 FORMAT(F8.0,F4.0,*  FOR A*,F13.0,* CU FT BASIN -- OUTLET =*,
     *F7.1,* CFS ---  VOLUME = *, F12.1 )
 1340 GO TO (1350,1380,1380),IRUN
 1350 QFB=0.0081*TDIAM*TDIAM/RUFFN*(TDIAM/48.0)**.667*(SLP/100.0)**.50
      IF(QFB-GRPK)1360,1370,1370
 1360 TDIAM=TDIAM+3.0
      GO TO 1350
 1370 CONTINUE
      GO TO 1460
 1380 GO TO (1450,1390,1410),ISECT
 1390 CALL RECTAN(WR,HR,DIST,RUFF,GRPK,SLP,DELT,Q2ST)
 1400 CONTINUE
      GO TO 1490
 1410 DEPTH = 0
      SURMAX=0
      CALL TRAPA (WR,SS,DIST,RUFF,GRPK,SLP,DELT,Q2ST,DEPTH)
 1420 CONTINUE
      GO TO 1430
 1430 CALL ROUTE(GR,Q2ST,Q,IB,LAST,GRPK)
```

```
1440  CONTINUE
      GO TO 1510
C  COMPUTE QFB AND SFB
1450  QFB=0.0081*TDIAM*TDIAM/RUFF*(TDIAM/48.0)**.667*(SLP/100.0)**.50
1460  CSA=3.1416*TDIAM*TDIAM/576.0
      SFB=CSA*DIST
      VFB=QFB/CSA
C
C  STORE PROPER Q VS Q+ IS/DELT  CURVE
      DO 1470 J=1,10
      Q2ST(1,J)=PQ(J)*QFB
1470  Q2ST(2,J)=Q2ST(1,J)+(2.0*PV(J)*SFB/(DELT*60.0))
1480  CONTINUE
1490  CALL ROUTCL (GR,Q2ST,Q,IB,LAST,GRPK,DELT,SURMAX)
1500  CONTINUE
      DEPTH=0.0
1510  CONTINUE
1520  FORMAT(F8.0,F4.0,F6.0,F5.2,F6.3,3F5.2,F5.0,F8.2,F6.2,
     *F10.2,9X,F12.1,F13.0,/)
1530  CONTINUE
      IF(QALOW.NE.0.OR.STORE.NE.0)GO TO 1540
      GO TO (1550,1570,1570),IRUN
1540  GO TO (1590,1620,1620),IRUN
1550  PRINT 1520,BRAN,REACH,DIST,SLP,RUFFN,HR,WR,SS,DIAM,ECAP,EVEL,OUTLE
     *T,VOL,SMX
      PRINT 1560,TDIAM,QFB,VFB,PKDES,PKIN,SURMAX
1560  FORMAT(*                         REQUIRED PIPE =            *,F5.0,
     *F8.2,F6.2,F10.2,F9.2,F13.2,//)
      IF(DIAM.GE.TDIAM)PRINT 1565
1565  FORMAT(10X,****EXISTING PIPE HAS ADEQUATE CAPACITY****//)
      GO TO 1640
1570  PRINT 1520,BRAN,REACH,DIST,SLP,RUFF,HR,WR,SS,DIAM,ECAP,EVEL,OUTLET
     *,VOL,SMX
      PRINT 1580,PKDES,PKIN,SURMAX
1580  FORMAT(*
     *      *,F10.2,F9.2,F13.2,//)
      GO TO 1640
1590  PRINT 1600,BRAN,REACH,DIST,SLP,RUFFN,HR,WR,SS,DIAM,ECAP,EVEL,PKDES
     *,PKIN,SURMAX
1600  FORMAT(F8.0,F4.0,F6.0,F5.2,F6.3,3F5.2,F5.0,F8.2,F6.2,
     *F10.2,F9.2,F13.2,/)
      PRINT 1610,TDIAM,QFB,VFB,OUTLET,VOL,SMX
1610  FORMAT(*                         REQUIRED PIPE =            *,
     *F5.0,F8.2,F6.2,F10.2,9X,F12.1,F13.0,//)
      GO TO 1640
1620  PRINT 1600,BRAN,REACH,DIST,SLP,RUFF,HR,WR,SS,DIAM,ECAP,EVEL,PKDES,
     *PKIN,SURMAX
      PRINT 1630,OUTLET,VOL,SMX
1630  FORMAT(*
     *      *,F10.2,9X,F12.1,F13.0,//)
1640  CONTINUE
C     PRINT 1301,BRAN,REACH,ISECT,DIAM,HR,WR,SLP,RUFF,DEPTH,SURMAX
1650  FORMAT( F8.0,F4.0,I5,F7.0,F7.1,F5.1,F5.2,F6.3,F7.1,F10.0,/)
1660  CONTINUE
C  FIND PEAK OF DISCHARGE HYDROGRAPH
1670  QPK=0
      DO 1690 ID=1,LAST
      IF(Q(IB,ID)-QPK)1690,1690,1680
1680  QPK=Q(IB,ID)
1690  CONTINUE
C
1700  PREDI=TDIAM
      IRUN=IRUNB
      IF(FREQR.EQ.1.0)GO TO 1730
1710  DO 1720 IJ=1,NRI
```

```
      RR(IJ)=RR(IJ)/FREQR
 1720 CONTINUE
 1730 CONTINUE
      IF(TEST.NE.END)GO TO 350
C
C  PRINT DISCHARGE HYDRO
 1740 CONTINUE
C     WRITE (6,402)
 1750 FORMAT(//,*     PENT  TIME   ROUGHNESS   TIME INCREMENT   FREQUENC
     *Y*,/)
C     WRITE(6,403)PENT,RUFF,DELT,FREQR
 1760 FORMAT(8X,F5.1,7X,F5.4,9X,F5.0,10X,F5.0)
      VOLOUT=0.0
      DO 1761 M=1,LAST
      VOLOUT=VOLOUT+Q(IB,M)
 1761 CONTINUE
      VOLOUT=VOLOUT*DELT*60.
      PRINT 1770,VOLOUT
 1770 FORMAT(///,*   OUTFALL HYDROGRAPH IN CFS, ACCUMULATED RUNOFF IN CU
     * FT=*,F12.0)
      PRINT 1780,(Q(IB,M),M=1,LAST)
 1780 FORMAT(9F8.1)
      GO TO 30
C  PRINT RESULTS FOR NEWLY DESIGNED REACH
C  COMBINE ROUTED HYDROS AT A CONFLUENCE
 1790 DO 1800 M=1,6
      IF(Q(M,501).EQ.CONBR)GO TO 1820
 1800 CONTINUE
      PRINT 1810
 1810 FORMAT(* CONTINUING BRANCH RECORD NOT FOUND*)
      GO TO 1930
 1820 IB=M
      DO 1830 M=1,6
      IF(Q(M,501).EQ.ENDBR)GO TO 1850
 1830 CONTINUE
      PRINT 1840
 1840 FORMAT(* ENDD BRANCH RECORD NOT FOUND*)
      GO TO 1930
 1850 IEND=M
      DO 1860 N=1,500
      Q(IB,N)=Q(IB,N)+Q(IEND,N)
 1860 CONTINUE
C     PRINT 1326
 1870 FORMAT(* CONFLUENCE HYDRO  *)
C     PRINT 1327,(Q(IB,J,)J=1,200)
 1880 FORMAT(10F10.4)
      Q(IEND,501)=0.0
      GO TO 1890
 1890 LAST=1
      DO 1910 N=1,500
      IF(Q(IB,N).GT.0)GO TO 1900
      GO TO 1910
 1900 LAST = N
 1910 CONTINUE
 1920 IF(TEST.EQ.END)GO TO 30
      GO TO 350
 1930 PRINT 1940
 1940 FORMAT(*  TROUBLE FINDING UPSTREAM HYDROGRAPH *)
 1950 CONTINUE
      END
      SUBROUTINE RECTAN (WR,VR,DIST,RUFF,GRPK,SLP,DELT,Q2ST)
C
C       FOR DISCHARGE STORAGE RELATION IN RECTANGULAR SECTION
C
      DIMENSION Q2ST(2,10)
```

```
C       WRITE(6,25) WR,VR,DIST,RUFF,GRPK,SLP,DELT
10      FORMAT (7F10.4)
        IH=0
        IC=0
        H=0
        DELTA=VR/10.0
20      IH=IH+1
        H=H+DELTA
        IC=IC+1
        IF(IC.EQ.10)GO TO 40
        CSA = WR*H
        P = WR+H+H
        Q = (1.486/RUFF)*CSA*((CSA/P)**.667)*(SLP/100.0)**0.5
        S = CSA*DIST
        V= Q/CSA
C       WRITE(6,26)P,Q,S,V
30      FORMAT(4F10.3)
        Q2ST(1,IH) =Q
        Q2ST(2,IH) = Q+(2*S)/(DELT*60.0)
        GO TO 20
40      Q2ST(1,IH) = Q
        Q2ST(2,IH) = Q+(2*S)/(DELT*60.0)
C       WRITE (6,11)
50      FORMAT (*    SUBROUTINE RECTAN  *)
        DO 70 I=1,2
C       WRITE (6,15)(Q2ST(I,IH),IH=1,10)
60      FORMAT (10F10.2)
70      CONTINUE
        RETURN
        END
        SUBROUTINE TRAPA (W,V,DIST,RUFF,GRPK,SLP,DELT,Q2ST,DEPTH)
C
C           FOR DISCHARGE STORAGE RELATION IN TRAPAZOIDAL CHANNELS
C
        DIMENSION Q2ST (2,10)
C       WRITE(6,25) W,V,DIST,RUFF,GRPK,SLP,DELT,DEPTH
10      FORMAT (8F10.4)
        IH = 0
        H = 0
20      IH=IH+1
30      H=H+1.0
        CSA = (W*H)+(H*H/V)
        P = W+((2.0*H)*(1.0+(1.0/(V*V)))**0.5)
        Q = (1.486/RUFF) * (CSA)*((CSA/P)**0.667)*(SLP/100.0)**00.5
        VEL=Q/CSA
        Q2ST(1,IH)=Q
        S=CSA*DIST
C       WRITE(6,26)P,Q,S,VEL
40      FORMAT(4F10.3)
        Q2ST(2,IH)=Q+(2.0*S)/(DELT*60.0)
        IF(Q-GRPK)50,50,70
50      IF(IH.LT.10)GO TO 20
        IF(IH.EQ.10)GO TO 30
        PRINT 60
60      FORMAT(* ERROR IN TRAPA SUBROUTINE*)
70      DEPTH=H
C       WRITE (6,10)
80      FORMAT (*   SUBROUTINE  TRAPA  *)
        DO 100 I=1,2
C       WRITE (6,21)(Q2ST(I,IH),IH=1,10)
90      FORMAT (10F10.2)
100     CONTINUE
        RETURN
        END
        SUBROUTINE ROUTE (GR,Q2ST,Q,IB,LAST,GRPK)
```

```
      DIMENSION GR(500),Q2ST(2,10),Q(7,501),QTEM(500),S(500)
C
C  DETERMINE THE SIGNIFICANT LENGTH OF THE HYDROGRAPH
10    L=1
      IC = 1
C     WRITE(6,57)(GR(IG),IG = 1,100)
20    FORMAT(10F10.4)
      LAST=1
30    DO 50 J=L,497
      IF(GR(J)-.001)60,60,40
40    LAST=J+1
      IC = J+1
50    CONTINUE
      GO TO 90
60    DO 80 I=IC,498
      IF(GR(I)-.001)80,80,70
70    L=I
      GO TO 30
80    CONTINUE
90    DO 100 IK=LAST,500
      GR(IK) = 0
100   CONTINUE
C  ROUTE GROSS HYDROGRAPH GR TO Q
110   CONTINUE
C     WRITE(6,1307)LAST
120   FORMAT(*  GROSS HYDROGRAPH  LAST = *,I5)
C     WRITE(6,1308)(GR(J),J=1,100)
130   FORMAT(10F10.4)
      TEST = 0.1*GRPK
      QTEM(1)=GR(1)
      DO 290 M=1,498
      IF(QTEM(M)-Q2ST(2,1))140,160,180
140   POR=QTEM(M)/Q2ST(2,1)
      IF(POR.GT.0.01)GO TO 150
      POR=0.0
150   Q(IB,M)=Q2ST(1,1)*POR
      S(M)=POR*Q2ST(2,1)-Q(IB,M)
      GO TO 240
160   J=1
170   Q(IB,M)=Q2ST(1,J)
      S(M)=Q2ST(2,J)-Q2ST(1,J)
      GO TO 240
180   DO 190 J=2,10
      IF(QTEM(M)-Q2ST(2,J))220,170,190
190   CONTINUE
200   CONTINUE
      Q2ST(2,10)=QTEM(M)
      Q(IB,M)=GRPK
      PRINT 210
210   FORMAT(* GEOMETRY OF SECTION CAUSED ROUTED PEAK TO EQUAL UPSTREAM
     * PEAK*)
      S(M)=QTEM(M)-GRPK
      GO TO 240
220   POR=(QTEM(M)-Q2ST(2,J-1))/(Q2ST(2,J)-Q2ST(2,J-1))
      Q(IB,M)=Q2ST(1,J-1)+POR*(Q2ST(1,J)-Q2ST(1,J-1))
      IF(Q(IB,M).GT.0.0001)GO TO 230
      Q(IB,M)=0.0
230   S(M)=(Q2ST(2,J-1)+POR*(Q2ST(2,J)-Q2ST(2,J-1)))-Q(IB,M)
      IF(S(M).GT.0.0001)GO TO 240
      S(M)=0.0
      GO TO 240
240   IF(M-LAST)280,250,250
250   IF(M.GT.498)GO TO 260
      IF(Q(IB,M)-.01)260,260,280
260   NO = M
```

```
      GO TO 300
C     WRITE (6,700) M,GR(M),GR(M+1),Q(IB,M),S(M)
270   FORMAT(I10,4F20.8)
280   QTEM(M+1)=GR(M+1)+GR(M)-Q(IB,M)+S(M)
290   CONTINUE
      NO = 499
300   LAST = NO
      IF(LAST-500)320,320,310
310   LAST = 500
320   CONTINUE
      DO 330 N=NO,500
      Q(IB,N)=0.
330   CONTINUE
C     WRITE (6,1324)LAST
340   FORMAT(* ROUTED HYDROGRAPH  LAST =  *,I5)
C     WRITE(6,1325)(Q(IB,J),J=1,LAST)
350   FORMAT(10F10.4)
      RETURN
      END
      SUBROUTINE SUPPLY (AR,DELTAT,FC,FI,FO,GASR,K,NRI,DEPG,NGSR,SGASR)
      DIMENSION GASR(500),AR(500)
      REAL K,IS
C     PRINT 105, DELTAT,FC,FI,FO,K,NRI,DEPG
10    FORMAT( 5F12.4,I10,F12.4 )
C     PRINT 4,(AR(I),I=1,NRI)
20    FORMAT (5F20.4)
      SGASR=0.0
      F1=FI
      MK=1
      AS=DEPG
      IS=0
      DO 150 I=1,NRI,1
      IF(MK)60,60,30
30    T=0.0
      TT=0.0
40    CONTINUE
      F=FC*T+((1.-EXP(-K*T))*(FO-FC))/K
      F=F-F1
      FP=FC+((FO-FC)*(K*EXP(-K*T)))/K
      T=T-F/FP
      IF(ABS(TT-T).LT.0.001)GO TO 50
      TT=T
      GO TO 40
50    CONTINUE
60    TN=T+DELTAT
      FN=FC*TN+((1.-EXP(-K*TN))*(FO-FC))/K
      FINC=FN-F1
      RINC=AR(I)
      DRUN=RINC-FINC
C     PRINT 5,FO,FC,F1,T,TN,FN,AS,DRUN
70    FORMAT (8F12.4)
      IF(DRUN)80,110,120
80    IS=DEPG-AS
      IF(ABS(DRUN)-IS)100,90,90
90    IS=0
      AS=DEPG
      GASR(I)=0.0
      F1=F1+RINC+IS
      MK=1
      GO TO 150
100   IS=IS+DRUN
      AS=DEPG-IS
      GASR(I)=0.0
      F1=FN
      T=TN
```

```
      MK=-1
      GO TO 150
110   F1=FN
      T=TN
      MK=-1
      GASR(I)=0.0
      GO TO 150
120   F1=FN
      T=TN
      MK=-1
      IF(DRUN-AS)140,130,130
130   GASR(I)=DRUN-AS
      AS=0.0
      GO TO 150
140   AS=AS-DRUN
      GASR(I)=0.0
      GO TO 150
150   CONTINUE
      J=NRI+1
      DO 160 I=J,500,1
      GASR(I)=0.0
160   CONTINUE
      NGSR=0
      DO 180 J=1,NRI
      IF(GASR(J).LT.0.001)GO TO 170
      NGSR=J
      SGASR=SGASR+GASR(J)
      GASR(J)=GASR(J)/DELTAT
      GO TO 180
170   GASR(J)=0.0
180   CONTINUE
C     PRINT 102
190   FORMAT( * GRASSED AREA SUPPLY RATE IN INCHES PER HOUR*)
C     PRINT 103,(GASR(I),I=1,NRI)
200   FORMAT (10F10.4)
210   RETURN
      END
      SUBROUTINE TIMEA (A,ENT,DELT,NAI,MAXA,CA)
      DIMENSION A(50)
C
C  COMPUTE AND STORE TIME AREA CURVE
10    AAS=ENT/DELT
      TAAS=AAS+1.0
      NAI=TAAS
      IF(NAI.EQ.1)GO TO 40
      ASUM=0
      NIX=NAI-1
      DO 20 N=1,NIX
      A(N)=CA/AAS
20    ASUM=ASUM+A(N)
      A(NAI)=CA-ASUM
      NAX=NAI+1
      DO 30 N=NAX,MAXA
30    A(N)=0
      GO TO 60
40    A(1)=CA
      DO 50 N=2,MAXA
50    A(N)=0
60    CONTINUE
C     PRINT 70
70    FORMAT (* TIME AREA*)
C     PRINT 80,(A(N),N=1,NAI)
80    FORMAT(10F10.4)
      RETURN
      END
```

```
      SUBROUTINE GRENT (GENT,GA,GLENG,GSLP,ENT)
      DATA AVSP/1.0/,C/0.050/
C        DETERMINE GRASSED AREA ENTRY TIME BY IZZARD EQUATIONS
      QEQ=AVSP * GLENG / 43200.
      CK=(0.0007* AVSP + C)/(GSLP/100.0) ** 0.333
      DET =CK * GLENG * QEQ ** 0.4
      GGENT = DET/(30.0 * QEQ)
      GENT = GGENT + ENT
      PRINT 10,GENT
10    FORMAT (* GRASSED ENTRY TIME= *,F6.1,* MIN*)
      RETURN
      END
      SUBROUTINE ROUTCL(GR,Q2ST,Q,IB,LAST,GRPK,DELT,SURMAX)
      DIMENSION GR(500),Q2ST(2,10),Q(7,501),QTEM(500),S(500)
C
C  DETERMINE THE SIGNIFICANT LENGTH OF THE HYDROGRAPH
10    L=1
      IC = 1
C     WRITE(6,57)(GR(IG),IG = 1,100)
20    FORMAT(10F10.4)
      LAST=1
30    DO 50 J=L,497
      IF(GR(J)-.001)60,60,40
40    LAST=J+1
      IC = J+1
50    CONTINUE
      GO TO 90
60    DO 80 I=IC,498
      IF(GR(I)-.001)80,80,70
70    L=I
      GO TO 30
80    CONTINUE
90    DO 100 IK=LAST,500
      GR(IK) = 0
100   CONTINUE
C  ROUTE GROSS HYDROGRAPH GR TO Q
110   CONTINUE
C     WRITE(6,1307)LAST
120   FORMAT(*  GROSS HYDROGRAPH  LAST = *,I5)
C     WRITE(6,1308)(GR(J),J=1,100)
130   FORMAT(10F10.4)
      QFB=Q2ST(1,10)
      SURCH=0.0
      SURMAX=0.0
      QTEM(1)=GR(1)
      S(1)=0.0
      DO 380 M=1,498
      IF(M.EQ.1) GO TO 190
      GRIN=(GR(M)+GR(M-1))/2.0
140   IF(GRIN-QFB)150,170,160
150   IF(SURCH.LT.0.01)GO TO 180
      GRIN=GRIN + SURCH/(DELT*60)
      SURCH=0.0
      GO TO 140
160   SURCH=SURCH+(GRIN-QFB)*DELT*60.0
      IF(SURMAX.GT.SURCH)GO TO 170
      SURMAX=SURCH
170   CONTINUE
      QTEM(M)=2.0*QFB+S(M-1)-Q(IB,M-1)
      GO TO 190
180   SURCH=0.0
      QTEM(M)=GRIN*2.0+S(M-1)-Q(IB,M-1)
190   EXCESS=QTEM(M)-Q2ST(2,10)
      IF(EXCESS)220,220,200
200   SURCH=SURCH+EXCESS*DELT*60.0
```

```
      QTEM(M)=Q2ST(2,10)
C     WRITE(6,240) EXCESS
210   FORMAT (*      EXCESS = *, F15.5 )
220   IF(QTEM(M)-Q2ST(2,1))230,250,270
230   POR=QTEM(M)/Q2ST(2,1)
      IF(POR.GT.0.01)GO TO 240
      POR=0.0
240   Q(IB,M)=Q2ST(1,1)*POR
      S(M)=POR*Q2ST(2,1)-Q(IB,M)
      GO TO 330
250   J=1
260   Q(IB,M)=Q2ST(1,J)
      S(M)=Q2ST(2,J)-Q2ST(1,J)
      GO TO 330
270   DO 280 J=2,10
      IF(QTEM(M)-Q2ST(2,J))310,260,280
280   CONTINUE
290   CONTINUE
      PRINT 300
300   FORMAT(* QFB WAS EXCEEDED IN ROUTCL *)
      J=10
      GO TO 260
310   POR=(QTEM(M)-Q2ST(2,J-1))/(Q2ST(2,J)-Q2ST(2,J-1))
      Q(IB,M)=Q2ST(1,J-1)+POR*(Q2ST(1,J)-Q2ST(1,J-1))
      IF(Q(IB,M).GT.0.0001)GO TO 320
      Q(IB,M)=0.0
320   S(M)=(Q2ST(2,J-1)+POR*(Q2ST(2,J)-Q2ST(2,J-1)))-Q(IB,M)
      IF(S(M).GT.0.0001)GO TO 330
      S(M)=0.0
      GO TO 330
330   IF(M-LAST)370,340,340
340   IF(M.GT.498)GO TO 350
      IF(Q(IB,M)-.01)350,350,370
350   NO = M
      GO TO 390
C     WRITE (6,700) M,GR(M),GR(M+1),Q(IB,M),S(M)
360   FORMAT(I10,4F20.8)
370   CONTINUE
380   CONTINUE
      NO = 499
390   LAST = NO
      IF(LAST-500)410,410,400
400   LAST = 500
410   CONTINUE
      DO 420 N=NO,500
      Q(IB,N)=0.
420   CONTINUE
C     PRINT 1324,LAST
430   FORMAT(* ROUTED HYDROGRAPH FROM ROUTCL LAST= *,I5)
C     PRINT 1325,(Q(IB,J),J=1,LAST)
440   FORMAT(10F10.4)
      RETURN
      END
      SUBROUTINE INTEN (RI,ABSTRT,NRI,DELTAT)
      DIMENSION RI(500)
      SUB=0.0
      DO 10 J=1,NRI
      SUB=SUB+RI(J)
      IF(ABSTRT-SUB)20,20,10
10    RI(J)=0.0
      PRINT 15
15    FORMAT (*  ABSTRAT GREATER THAN RAINFALL IN SUBROUTINE INTEN* )
      GO TO 60
20    CONTINUE
      RI(J)=SUB-ABSTRT
```

```
40    DO 50 K=1,NRI
      RI(K)=RI(K)/DELTAT
50    CONTINUE
60    CONTINUE
C     PRINT 70,(RI(J),J=1,NRI)
70    FORMAT(*  INTEN*,10F10.3)
      RETURN
      END
      SUBROUTINE CAPAC (ISECT,DIAM,H,W,SS,SLP,RUFF,ECAP,EVEL,EA)
C
C  SUBROUTINE TO COMPUTE CAPACITY OF EXISTING SECTIONS
C
      IF(ISECT.NE.0)GO TO 10
      ISECT=1
10    GO TO (20,40,50),ISECT
20    IF(DIAM.EQ.0)GO TO 30
      EA=0.00545*DIAM*DIAM
      P=0.2618*DIAM
      GO TO 60
30    ECAP=0
      EVEL=0
      EA=0
      GO TO 70
40    EA=H*W
      P=H+H+W+W
      GO TO 60
50    EA=(W*H)+(H*H/SS)
      P=W+((2.0*H)*(1.0+(1.0/(SS*SS)))**0.5)
60    EVEL=(1.486/RUFF)*(EA/P)**0.667*(SLP/100.0)**0.50
      ECAP=EVEL*EA
70    RETURN
      END
      SUBROUTINE DETEN(GR,GRPK,LAST,STORE,DELT,BRAN,REACH,VOL)
      DIMENSION GR(500),QT(500)
      DTMAX=STORE*1000.0
      DELTS=DELT*60.0
C     PRINT 200,GRPK
10    FORMAT(* GRPK IN TO DETEN= *,F10.4)
      QOUT=0.0
      QINC=GRPK/50.0
20    J=0
      VOLMAX=0
      MIKE=LAST
      DO 30 K=1,500
      QT(K)=0
30    CONTINUE
      VOL=0
      QOUT=QOUT+QINC
      IF(QOUT)100,100,40
40    J=J+1
      AVAIL=GR(J)+VOL/DELTS
      DIFF=AVAIL-QOUT
      IF(DIFF)50,50,60
50    QT(J)=AVAIL
      VOL=0
      GO TO 80
60    QT(J)=QOUT
      VOL=DIFF*DELTS
      IF(VOLMAX.GT.VOL)GO TO 70
      VOLMAX=VOL
70    IF(VOL.GT.DTMAX)GO TO 20
80    CONTINUE
C     PRINT 300,J,QOUT,AVAIL,DIFF,GR(J),QT(J),VOL,VOLMAX,DTMAX
90    FORMAT (I5,8F12.3)
      IF(J.LT.LAST)GO TO 40
```

```
      IF(VOL.LT.5.0)GO TO 120
      MIKE=MIKE+1
      IF(MIKE.GT.499)GO TO 120
      GR(MIKE)=0.0
      GO TO 40
100   PRINT 110
110   FORMAT(* NO SOLUTION IN SUBROUTINE DETEN *)
120   GRPK=QOUT
      VOL=VOLMAX
      LAST=MIKE
      DO 130 K=1,LAST
      GR(K)=QT(K)
130   CONTINUE
C     PRINT 201,GRPK
140   FORMAT (* GRPK OUT OF DETEN=*, F 10.4)
      RETURN
      END
      SUBROUTINE PAVENT (PENT,PL,PS,CPA)
C     PRINT 6,PENT,PL,PS,CPA
10    FORMAT(4F12.4)
      Q=CPA/4.0
      XN=0.02
      S=PS/100.0
      R=0.2
      V=(1.486/XN)*R**0.67*S**0.5
      PENT=PL/V/60.0+2.0
      PRINT 20,PENT
20    FORMAT(* PAVED ENTRY TIME= *,F6.1,* MIN*)
      RETURN
      END
      SUBROUTINE RHUFF(TRAIN,DURA,DELT,RR,NRI)
      REAL RR(500),PCTT(17),PCTR(17),SR(500)
      INTEGER XRI
      X=-4.
      DO 10 I=1,11
      X=X+4
      PCTT(I)=X
10    CONTINUE
      DO 20 I=12,17
      PCTT(I)=PCTT(I-1)+10.
20    CONTINUE
      PCTR(1)=0
      PCTR(2)=9.6
      PCTR(3)=21.0
      PCTR(4)=32.7
      PCTR(5)=43.
      PCTR(6)=51.2
      PCTR(7)=58.3
      PCTR(8)=63.1
      PCTR(9)=67.2
      PCTR(10)=70.6
      PCTR(11)=73.5
      PCTR(12)=79.5
      PCTR(13)=84.2
      PCTR(14)=88.5
      PCTR(15)=92.5
      PCTR(16)=96.3
      PCTR(17)=100.
      XRI=DURA/DELT+1.1
      SR(1)=0
      X=0
      DO 60 I=2,XRI
      X=X+DELT
      PX=(X/DURA)*100.
      DO 30 J=1,17
```

```
      IF(PX-PCTT(J))40,50,30
30    CONTINUE
      GO TO 60
40    SR(I)=(PCTR(J-1)+(PCTR(J)-PCTR(J-1))/(PCTT(J)
     *-PCTT(J-1))*(PX-PCTT(J-1)))*TRAIN*.01
      GO TO 60
50    SR(I)=PCTR(J)*TRAIN*.01
60    CONTINUE
      JJ=XRI
      NRI=JJ
      RR(1)=0.0
      DO 70 J=2,JJ
      RR(J)=SR(J)-SR(J-1)
70    CONTINUE
C     PRINT 9,(RR(J),J=1,JJ)
80    FORMAT (F12.4)
      RETURN
      END
      SUBROUTINE LIMITQ (GR,GRPK,LAST,QALOW,DELT,BRAN,REACH,VOL)
      DIMENSION GR(500),QT(500)
      DELTS=DELT*60.0
C     PRINT 200,(GR(J),J=1,LAST)
10    FORMAT(* GR INTO LIMITQ *,10F8.1)
      QOUT=QALOW
      J=0
      VOLMAX=0
      MIKE=LAST
      DO 20 K=1,500
      QT(K)=0.0
20    CONTINUE
      VOL=0.0
30    J=J+1
      AVAIL=GR(J)+VOL/DELTS
      DIFF=AVAIL-QOUT
      IF(DIFF)40,40,50
40    QT(J)=AVAIL
      VOL=0
      GO TO 60
50    QT(J)=QOUT
      VOL=DIFF*DELTS
      IF(VOLMAX.GT.VOL)GO TO 60
      VOLMAX=VOL
60    CONTINUE
      IF(J.LT.LAST)GO TO 30
      IF(VOL.LT.5.0)GO TO 70
      MIKE=MIKE+1
      IF(MIKE.GT.499)GO TO 70
      GR(MIKE)=0.0
      GO TO 30
70    GRPK=QOUT
      VOL=VOLMAX
      LAST=MIKE
      DO 80 K=1,LAST
      GR(K)=QT(K)
80    CONTINUE
C     PRINT 201,(GR(J),J=1,LAST)
90    FORMAT(* GR OUT OF LIMITQ *,10F8.1)
      RETURN
      END
```

```
      COMMON/IDIM/ICNAME(6),IERD(20),IPOLUT(20),IRAIN(200,24),
     1            JDATE(200),JDAY(200),KDATE(200),KDAY(200),
     2            KRAIN(200,24),LNDUSE(20,2),LPAGE(5),LSDIST(1000),
     3            LTDIST(1000),NAME(8),NAMEWS(4),NCLEAN(5),ND(12),
     4            NTITLE(20)
      COMMON/RDIM/ACTIA(20),CAPR(20,20),CP(20),DD(20),DDL(20),
     1            DELTP(20,6),DEPR(20),DSTOR(600),DWF(7,24),FIMP(20),
     2            FRACTN(20,6),HPOLDW(6,24),P(20,6),PN(6),POL(6),
     3            POLDWF(6),POLEX(6),POLLRT(6),POLOVR(6),PRCNT(20),
     4            QPREV(20),QSUM(20),QU(24),RATEIN(20),RECVRT(12),
     5            RUNLU(20),SACT(20),SMAX(20),SSUMPO(6),STARTI(20),
     6            STARTS(20),STLEN(20),SUMPOL(6),TRATE(20),TRATER(20),
     7            WTQ(20),XLAB(11),XPOLEX(6),XPOLOV(6),XSUMPO(6),
     8            YLAB(6),YSUMPO(6)
      COMMON/INDM/IA,IB,ICC,ID,IDATE,IDVAR,IEND,IER,IERDMX,IGRAPH,IAGE,
     1            IHPVAR,IHVAR,IL,IN,IODWF,IP,IP1,IP2,IPACK,IPRINT,
     2            IPRTS,IQUAL,IR,IRUN,IS,ISCH,ISTART,IT,J,J1,JHR,JMX,K,
     3             KK,KMAX2,KMX,KRUN,L,LAST,LDATE,LEXT,LHUND,LI,KSAVE,
     4            LINE,LL,LOSS,LOSSEQ,LSDF,M,MASE,MASS,MAXLIN,MEF,
     5            METRIC,MISS,MO,MPAGE,MST,MXC,MXLG,MXSTOR,MXTIM,NDATE,
     6            NANTEC,NAM,NC,NCAP,NDAY1,NDAYRC,NDRY,NHAVE1,NHOURS,
     7            NHR,NINC,NMAX,NN,NNRAIN,NOEXTR,NORAIN,NORUN,NORUNN,
     8            NOSTOR,NPAGE,NSTOR,NSUMR,NWSSAV,IPACUM,IUNITO
      COMMON/RNDM/ADWF,AGE,AGE2,AGE3,AGE4,AGE5,AGE6,AGE7,AGE8,AMXOLD,
     A            AREA,C,CAP,CIAT,CIMP,CN,CPERV,CST,DD1,DEP,DEPN,
     B            DEPRES,DEPRN,DEPRS,DUR,E,EI,EX,EXCES,EXPTE,
     C            EXPTN,HUND,GRAPHC,OLD,POPULA,PRCP,PRCPN,RAIN,
     D            RAINRT,RAINX,REC,REFF,RFN,RFU,RMI,RTOCFS,RTOMM,
     E            RUN,RUNOF,QDWF,QPRETO,QQ,QSUMTO,QTOT,SACFT,
     F            SAGE,SAGE2,SAGE3,SAGE4,SAGE5,SAGE6,SAGE7,SAGE8,
     G            SDATE,SDAY,SDUR,SEX,SEXCES,SHR,SMEC,SMG,SMST,
     H            SMXSTO,SNOSTO,SQTOT,SRAIN,SRUN,STCAP,STNSTO,STOP,
     I            STOR,STORD,STORG,STRAIN,STREAT,STRTIT,STRTST,
     J            STSTO,TAREA,TCAP,TCFS,TMGD,TNSTOR,TOP,TOTAL,
     K            TRAIN,TREAT,TSTOR,TSUBC,URC,XAGE,XAGE2,XAGE3,
     L            XAGE4,XAGE5,XAGE6,XAGE7,XAGE8,XCST,XDUR,XMH,XQTOT,
     M            XRAIN,XRUN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,
     N            YDWF,YQTOT,YRAIN,YRUN,ZEX,ZQTOT
C
C          DECLARED INTEGER VARIABLES IN COMMON
      INTEGER   CAP,CST,DSTOR,DUR,EX,EXCES,RAIN,SDATE,SDAY,SDUR,
     1          SEX,SEXCES,SHR,SMST,SMXSTO,SNOSTO,SRAIN,STCAP,
     2          STNSTO,STOP,STOR,STORD,STORG,STRAIN,STREAT,STSTO,
     3          TCAP,TNSTOR,TOP,TRAIN,TRATE,TREAT,TSTOR,
     4          XCST,XDUR,XRAIN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,
     5          YSUMPO,DWF,SQTOT
C
      COMMON /MIXA/ EERC,EPRC,LU(20),PERCMX(20),PERTOT,RIMPA,MRUN
C
      INTEGER STORK,TREAD
C
      DIMENSION ACDWFR(6),IDATU(100),NCAPS(20,20),NUM(20),TEMP1(20),
     .TEMP2(20),LNDUSA(20,2),QUA(2400)
C
C
C                             INITIALIZE
C                                 BRANCH TO    100 FROM   620.03
  100 FORMAT(2X,F6.0,9F8.0)
C                                 BRANCH TO    110 FROM   230.01    240.08
C                                      940.03   1050.03   1070.02      0.00
  110 FORMAT(2X,I6,9I8)
  120 READ (5,180)  (NTITLE(N),N=1,20)
      IF (EOF(5)) 130,140,130
C
C                                 BRANCH TO    130 FROM   120.01
  130 STOP
C                                 BRANCH TO    140 FROM   120.01
  140 WRITE (6,160)
      WRITE (6,150)
  150 FORMAT (1H0,35(1H.),10X,35H $$$$  $$$$$    $$$    $$$$    $$    $$,10X
```

```
     .,35(1H.)/1X,35(1H.),10X,35H$          $     $    $   $     $  $ $ $ $,10X 1125
     .,35(1H.)/1X,35(1H.),10X,35H $$$       $     $    $  $$$$    $   $   $,10X 1126
     .,35(1H.)/1X,35(1H.),10X,35H     $     $     $    $   $   $   $      $,10X 1127
     .,35(1H.)/1X,35(1H.),10X,35H$$$$       $      $$$    $    $   $      $,10X 1128
     .,35(1H.)//)                                                               1129
C                                BRANCH TO   160 FROM    140.00    940.04 1130
C                                     980.01      0.00      0.00      0.00 1131
  160 FORMAT(1H1)                                                             1132
      WRITE(6,170)                                                            1133
C                                                                             1134
C                                BRANCH TO   170 FROM    160.01               1135
  170 FORMAT(53H ***************************************************** /      1136
     .          53H S T O R M      L7520      VERSION 2.1     AUGUST 1977 /    1137001
     .          53H THE HYDROLOGIC ENGINEERING CENTER  DAVIS, CALIFORNIA /    1138
     .          53H FOR ASSISTANCE  CALL 916-440-3286  OR 448-3286 (FTS) /    1139
     .          53H ***************************************************** /   1140
     .  ////)                                                                 1141
C                                                                             1142
      WRITE(6,190) (NTITLE(N),N=1,20)                                         1143
      DO 200 I=1,2                                                            1144
      READ (5,180)        (NTITLE(N),N=1,20)                                  1145
C                                BRANCH TO   180 FROM    120.00    170.08 1146
  180 FORMAT(2X,A2,19A4)                                                      1147
      WRITE(6,190) (NTITLE(N),N=1,20)                                         1148
C                                BRANCH TO   190 FROM    170.06               1149
  190 FORMAT(20X,A2,19A4)                                                     1150
C                                BRANCH TO   200 FROM    170.07               1151
  200 CONTINUE                                                                1152
      READ (5,110)NWSHD,ISNO,ISED,IQUAL,IEVNT,IODWF,IDVAR,IHVAR,IHPVAR        1190
      WRITE(6,240)NWSHD,ISNO,ISED,IQUAL,IEVNT,IODWF,IDVAR,IHVAR,IHPVAR        1191
  240 FORMAT (///23X,5HNWSHD,4X,4HISNO,4X,4HISED,3X,5HIQUAL,3X,5HIEVNT,       1192
     1 3X,5HIODWF,3X,5HIDVAR,3X,5HIHVAR,3X,6HIHPVAR,/20X,9I8)                 1193
      READ (5,110) NSUMR,LEXT,LINE,LDATE,LHR,NHYDRO,METRIC                    1201
      WRITE (6,250) NSUMR,LEXT,LINE,LDATE,LHR,NHYDRO,METRIC                   1208
      NSUMR=NSUMR*24                                                          1209
C                                BRANCH TO   250 FROM    240.15               1210
  250 FORMAT (///30X,5HNSUMR,4X,4HLEXT,4X,4HLINE,3X,5HLDATE,5X,3HLHR,         1211
     1 2X,6HNHYDRO,2X,6HMETRIC/27X,7I8)                                       1212
      READ(5,260) NAME,IN,IFILE,ISTART,IEND,IR                                1214
  260 FORMAT(2X,A2,7A4,5I8)                                                   1215
      WRITE(6,270) NAME,IN,IFILE,ISTART,IEND,IR                               1220
  270 FORMAT(///46X,18HTITLE OF RAIN GAGE/41X,A2,7A4///                       1221
      READ (5,320) (NAMEWS(N),N=1,4),MXLG,EXPTE,REFF,TRTP,TSUBC,IPACUM        1247
  320 FORMAT (2X,A2,3A4,I8,4F8.0,2I8)                                         1248
      WRITE(6,330) (NAMEWS(N),N=1,4),MXLG,EXPTE,REFF,TRTP,TSUBC,IPACUM        1252
  330 FORMAT (///29X,6HNAMEWS,12X,4HMXLG,3X,5HEXPTE,4X,4HREFF,2X,             1253
     .    6H  TRTP,3X,5HTSUBC,2X,6HIPACUM/                                    1254
     .    21X,A2,3A4,8X,I8,2F8.3,2F8.2,2I8)                                   1255
      READ(5,340) AREA,RFU,IQU,DVU,DVUMX,WU,POPULA                            1257
  340 FORMAT (2X,F6.0,F8.0,I8,4F8.0)                                          1258
      WRITE(6,350) AREA,RFU,IQU,DVU,DVUMX,WU,POPULA                           1261
  350 FORMAT(///34X,4HAREA,5X,3HRFU,5X,3HIQU,5X,3HDVU,3X,5HDVUMX,4X,          1262
     1 2HWU,5X,6HPOPULA/30X,2F8.2,I8,3F8.2,F9.0)                              1263
      READ(5,390) (RECURT(N),N=1,12)                                          1277
  390 FORMAT (2X,F6.0,9F8.0 )                                                 1278
      READ (5,430) LOSSEQ,CPERV,CIMP,DEPRS,EERC,EPRC                          1290
  430 FORMAT (2X,I6,5F8.0)                                                    1291
      DO 520 I=1,MXLG                                                         1314
      READ (5,500) (LNDUSA(I,L),L=1,2),DEPR(I),ACTIA(I),SACT(I),SMAX(I),      1315
     1                                                                        1316
     .    RATEIN(I),PERCMX(I)                                                 1317
      READ (5,620) (LNDUSE(L,I),I=1,2),PRCNT(L),FIMP(L),STLEN(L),             1366
     .    NCLEAN(L)                                                           1367
      READ  (5, 110) MAX                                                      1495
      READ(5,980) TRATER(M),NX,IPOLMX,IPLOT,IPRINT,IPRTS,IERDMX,IAGE          1515
  980 FORMAT(2X,F6.0,7I8)                                                     1516
      READ (5,1030) (CAPR(M,NC),NC=1,NX)                                      1543
C                                BRANCH TO  1030 FROM   1020.08               1544
 1030 FORMAT(2X,F6.0,9F8.0)                                                   1545
      SUBROUTINE DIRT                                                         A    10
```

```
C
      COMMON /IDIM/ ICNAME(6),IERD(20),IPOLUT(20),IRAIN(200,24),JDATE(20
     10),JDAY(200),KDATE(200),KDAY(200),KRAIN(200,24),LNDUSE(20,2),LPAGE
     2(5),LSDIST(1000),LTDIST(1000),NAME(8),NAMEWS(4),NCLEAN(5),ND(12),N
     3TITLE(20)
      COMMON /RDIM/ ACTIA(20),CAPR(20,20),CP(20),DD(20),DDL(20),DELTP(20
     1,6),DEPR(20),DSTOR(600),DWF(7,24),FIMP(20),FRACTN(20,6),HPOLDW(6,2
     24),P(20,6),PN(6),POL(6),POLDWF(6),POLEX(6),POLLRT(6),POLOVR(6),PRC
     3NT(20),QPREV(20),QSUM(20),QU(24),RATEIN(20),RECVRT(12),RUNLU(20),S
     4ACT(20),SMAX(20),SSUMPO(6),STARTI(20),STARTS(20),STLEN(20),SUMPOL(
     56),TRATE(20),TRATER(20),WTQ(20),XLAB(11),XPOLEX(6),XPOLOV(6),XSUMP
     6O(6),YLAB(6),YSUMPO(6)
      COMMON /INDM/ IA,IB,ICC,ID,IDATE,IDVAR,IEND,IER,IERDMX,IGRAPH,IAGE
     1,IHPVAR,IHVAR,IL,IN,IODWF,IP,IP1,IP2,IPACK,IPRINT,IPRTS,IQUAL,IR,I
     2RUN,IS,ISCH,ISTART,IT,J,J1,JHR,JMX,K,KK,KMAX2,KMX,KRUN,L,LAST,LDAT
     3E,LEXT,LHUND,LI,KSAVE,LINE,LL,LOSS,LOSSEQ,LSDF,M,MASE,MASS,MAXLIN,
     4MEF,METRIC,MISS,MO,MPAGE,MST,MXC,MXLG,MXSTOR,MXTIM,NDATE,NANTEC,NA
     5M,NC,NCAP,NDAY1,NDAYRC,NDRY,NHAVE1,NHOURS,NHR,NINC,NMAX,NN,NNRAIN,
     6NOEXTR,NORAIN,NORUN,NORUNN,NOSTOR,NPAGE,NSTOR,NSUMR,NWSSAV,IPACUM,
     7IUNITO
      COMMON /RNDM/ ADWF,AGE,AGE2,AGE3,AGE4,AGE5,AGE6,AGE7,AGE8,AMXOLD,A
     1REA,C,CAP,CIAT,CIMP,CN,CPERV,CST,DD1,DEP,DEPN,DEPRES,DEPRN,DEPRS,D
     2UR,E,EI,EX,EXCES,EXPTE,EXPTN,HUND,GRAPHC,OLD,POPULA,PRCP,PRCPN,RAI
     3N,RAINRT,RAINX,REC,REFF,RFN,RFU,RMI,RTOCFS,RTOMM,RUN,RUNOF,QDWF,QP
     4RETO,QQ,QSUMTO,QTOT,SACFT,SAGE,SAGE2,SAGE3,SAGE4,SAGE5,SAGE6,SAGE7
     5,SAGE8,SDATE,SDAY,SDUR,SEX,SEXCES,SHR,SMEC,SMG,SMST,SMXSTO,SNOSTO,
     6SQTOT,SRAIN,SRUN,STCAP,STNSTO,STOP,STOR,STORD,STORG,STRAIN,STREAT,
     7STRTIT,STRTST,STSTO,TAREA,TCAP,TCFS,TMGD,TNSTOR,TOP,TOTAL,TRAIN,TR
     8EAT,TSTOR,TSUBC,URC,XAGE,XAGE2,XAGE3,XAGE4,XAGE5,XAGE6,XAGE7,XAGE8
     9,XCST,XDUR,XMH,XQTOT,XRAIN,XRUN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,YD
     *WF,YQTOT,YRAIN,YRUN,ZEX,ZQTOT
C
C         DECLARED INTEGER VARIABLES IN COMMON
C
      INTEGER CAP,CST,DSTOR,DUR,EX,EXCES,RAIN,SDATE,SDAY,SDUR,SEX,SEXCES
     1,SHR,SMST,SMXSTO,SNOSTO,SRAIN,STCAP,STNSTO,STOP,STOR,STORD,STORG,S
     2TRAIN,STREAT,STSTO,TCAP,TNSTOR,TOP,TRAIN,TRATE,TREAT,TSTOR,XCST,XD
     3UR,XRAIN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,YSUMPO,DWF,SQTOT
C
      COMMON /MIXA/ EERC,EPRC,LU(20),PERCMX(20),PERTOT,RIMPA,MRUN
      DIMENSION DDB(20), CLAND(20), ARATE(20,6)
C
C     MEF= 1 FOR INITIALIZATION OR 2 FOR REPORT COMPUTATIONS
C
      IF (MEF.EQ.2) GO TO 111
C
      C=0.0
      RIMPA=0.
      DO 101 LAND=1,MXLG
  101 DDB(LAND)=0.0
      GO TO (102,105,102), LOSSEQ
  102 DO 103 LAND=1,MXLG
          RIMPA=RIMPA-FIMP(LAND)*PRCNT(LAND)/10000.
          CLAND(LAND)=(CPERV-(CIMP-CPERV)*FIMP(LAND)/100.)*PRCNT(LAND)/10
     1    0.
          C=C-CLAND(LAND)
C
C                                  BRANCH TO  2730 FROM  2720.00
C
  103 CONTINUE
      IF (LOSSEQ.EQ.1) WRITE (6,132) C
      WRITE (6,133) RIMPA
      DO 104 LAND=1,MXLG
  104 CP(LAND)=CLAND(LAND)/C
C
C                                  BRANCH TO  2770 FROM  2710.01
C
  105 IF (IQUAL.LE.0) RETURN
      IF (IPACUM.EQ.2) GO TO 107
      DO 106 L=1,MXLG
```

```
        AREAI=AREA*PRCNT(L)/100.
        GUTTER=STLEN(L)*AREAI
        DD(L)=DD(L)*GUTTER/100.
C
C                                    BRANCH TO  2780 FROM  2770.02
C
  106 CONTINUE
C
C******** CONVERT NCLEAN FROM DAYS TO HOURS OR ANY OTHER TIME INTERVAL
C                                    BRANCH TO  2790 FROM  2770.01
C
  107 DO 110 LAND=1,MXLG
        NCLEAN(LAND)=NCLEAN(LAND)*24*12
        DO 109 IC=1,MXC
           IF (IPACUM.EQ.2) GO TO 108
           ARATE(LAND,IC)=FRACTN(LAND,IC)*DD(LAND)/100.
           GO TO 109
C
C                                    BRANCH TO  2810 FROM  2790.03
C
  108      AREAI=AREA*PRCNT(LAND)/100.
           ARATE(LAND,IC)=FRACTN(LAND,IC)*AREAI/24./12.
C
C                                    BRANCH TO  2820 FROM  2790.02  2800.01
C
  109   CONTINUE
C
C                                    BRANCH TO  2830 FROM  2790.00
C
  110 CONTINUE
      RETURN
C
C                                 COMPUTE RUNOFF QUALITY
C                                    BRANCH TO  2840 FROM       .48
C
  111 CONTINUE
      IF (NDRY.EQ.0) GO TO 120
C
C******** COMPUTE TOTAL DUST AND DIRT ON WATERSHED AT START OF EVENT
C          (NPASS=2)
C
      DO 119 LAND=1,MXLG
C
C******** CLEANING AND PREVIOUS STORM EFFECTS
C
        IF (IPACUM.EQ.2) GO TO 112
        IF (NDRY-NCLEAN(LAND)) 112,112,114
C
C                                    BRANCH TO  2850 FROM  2840.03
C
  112   DO 113 IC=1,MXC
  113   P(LAND,IC)=P(LAND,IC)+ARATE(LAND,IC)*FLOAT(NDRY)
        GO TO 117
C
C                                    BRANCH TO  2870 FROM  2840.04
C
  114   TGS=0.0
        NCTAG=NDRY/NCLEAN(LAND)
        DO 115 II=1,NCTAG
  115   TGS=TGS-(1.-REFF)**II
        DO 116 IC=1,MXC
           P(LAND,IC)=ARATE(LAND,IC)*(TGS*FLOAT(NCLEAN(LAND))+FLOAT(NDR
     1     Y-NCTAG*NCLEAN(LAND)))+P(LAND,IC)*(1-REFF)**NCTAG
C
C                                    BRANCH TO  2890 FROM  2880.01
C
  116   CONTINUE
C
C                                    BRANCH TO  2900 FROM  2860.01
C
```

```
  117     CONTINUE
          DO 118 IC=1,MXC
             P(LAND,IC)=AMIN1(P(LAND,IC),90.*ARATE(LAND,IC)*24.)
C
C                                   BRANCH TO  2910 FROM  2900.01
C
  118     CONTINUE
C
C      TOTAL DD ON LAND USE AT BEGINNING OF THIS HOUR OF RUNOFF
C
          IF (IPACUM.EQ.2) GO TO 119
          DDB(LAND)=P(LAND,1)/FRACTN(LAND,1)*100.
C
C                                   BRANCH TO  2920 FROM  2840.02  2910.01
C
  119 CONTINUE
C
C******** COMPUTE QUALITY OF SURFACE RUNOFF FROM WATERSHED (NPASS=3)
C
C                                   BRANCH TO  2930 FROM  2840.01
C
  120 CONTINUE
C
C      SUSPENDED AND SETTLEABLE SOLIDS AVAILABLE FOR RUNOFF
C      WASHOFF DRIVER IS RATE OF RUNOF
C
      GO TO (121,122,122), LOSSEQ
  121 CONTINUE
      IF (METRIC.EQ.1) RIMP=RAINX*CIMP/(HUND*100.*25.4)
      IF (METRIC.EQ.2) RIMP=RAINX*CIMP/(HUND*100.)
      EXPT=1.-EXP(-EXPTE*RIMP)
      AVSUS=0.057+1.4*RIMP**1.1
      AVSET=0.028+1.0*RIMP**1.8
      GO TO 125
C
C                                   BRANCH TO  2950 FROM  2930.01
C
  122 CONTINUE
      GO TO (123,124), METRIC
  123 EXPT=1.-EXP(-EXPTE*RUNOF/100./HUND/25.4)
      AVSUS=0.057+1.4*(RUNOF/100./HUND/25.4)**1.1
      AVSET=0.028+1.0*(RUNOF/100./HUND/25.4)**1.8
      GO TO 125
C
C                                   BRANCH TO  2970 FROM  2950.01
C
  124 CONTINUE
      EXPT=1.0-EXP(-(EXPTE*RUNOF))
C
C*****EQUATIONS FOR 5 MINUTES INTERVAL*****
C
      AVSUS=0.00475+1.795*(RUNOF)**1.1
      AVSET=0.00233+7.3*(RUNOF)**1.8
C
C                                   BRANCH TO  2980 FROM  2940.06  2960.03
C
  125 CONTINUE
      IF (AVSUS.GT.1.) AVSUS=1.
      IF (AVSET.GT.1.) AVSET=1.
C
      DO 130 LAND=1,MXLG
C
C      SUSPENDED SOLIDS
C
         DELPOL=P(LAND,1)*AVSUS*EXPT*12.
         DELPOLD=DELPOL*24.
         IF (RUNOF.EQ.0.0) GO TO 126
         RUNOFF=RUNOF/0.0028*0.646
         POLLCON=DELPOLD/RUNOFF/1000000/0.000008344
         GO TO 127
```

```
  126     POLLCON=0.0
  127     CONTINUE
          P(LAND,1)=P(LAND,1)-DELPOL
          DELTP(LAND,1)=DELPOL
          POLLRT(1)=POLLRT(1)+DELPOL
          POLLRTD(1)=POLLRT(1)*24.
C
C     SETTLEABLE SOLIDS
C
          DELPOL=P(LAND,2)*AVSET*EXPT*12.
          DELPOLD=DELPOL*24.
          P(LAND,2)=P(LAND,2)-DELPOL
          DELTP(LAND,2)=DELPOL
          POLLRT(2)=POLLRT(2)+DELPOL
          POLLRTD(2)=POLLRT(2)*24.
C
C     TOTAL BOD
C
          AVBOD=0.1*DELTP(LAND,1)+0.02*DELTP(LAND,2)
C
C     INCREASE AVAILABLE BOD DUE TO FALLING LEAVES IN SEP OCT NOV
C     IF(MO.EQ. 9) AVBOD=AVBOD*1.1
C     IF(MO.EQ.10) AVBOD=AVBOD*1.2
C     IF(MO.EQ.11) AVBOD=AVBOD*1.1
C
          DELPOL=AVBOD+P(LAND,3)*EXPT*12.
          DELPOLD=DELPOL*24.
          IF (RUNOF.EQ.0.0) GO TO 128
          RUNOFF=RUNOF/0.0028*0.646
          POLLCON=DELPOLD/RUNOFF/1000000/0.000008344
          GO TO 129
  128     POLLCON=0.0
  129     CONTINUE
          P(LAND,3)=P(LAND,3)-(DELPOL-AVBOD)
          DELTP(LAND,3)=DELPOL
          POLLRT(3)=POLLRT(3)+DELPOL
          POLLRTD(3)=POLLRT(3)*24.
C
C     NITROGEN
C
          AVNIT=0.05*DELTP(LAND,1)+0.01*DELTP(LAND,2)
          DELPOL=AVNIT+P(LAND,4)*EXPT*12.
          DELPOLD=DELPOL*24.
          P(LAND,4)=P(LAND,4)-(DELPOL-AVNIT)
          DELTP(LAND,4)=DELPOL
          POLLRT(4)=POLLRT(4)+DELPOL
          POLLRTD(4)=POLLRT(4)*24.
C
C     PHOSPHOROUS
C
          AVPHO=0.005*DELTP(LAND,1)+0.001*DELTP(LAND,2)
          DELPOL=AVPHO+P(LAND,5)*EXPT*12.
          P(LAND,5)=P(LAND,5)-(DELPOL-AVPHO)
          DELTP(LAND,5)=DELPOL
          POLLRT(5)=POLLRT(5)+DELPOL
          POLLRTD(5)=POLLRT(5)*24.
C
C     COLIFORM
C
          AVCOLI=0.0
          DELCOL=AVCOLI+P(LAND,6)*EXPT*12.
          P(LAND,6)=P(LAND,6)+(DELCOL-AVCOLI)
          DELTP(LAND,6)=DELCOL
          POLLRT(6)=POLLRT(6)+DELCOL
          POLLRTD(6)=POLLRT(6)*24.
C
C                                   BRANCH TO  2990 FROM  2980.03
C
          PRINT 134, (P(LAND,IC),IC=1,6)
  130 CONTINUE
```

```
      IF (IPACUM.EQ.2) RETURN
      DO 131 LAND=1,MXLG
         DDR=P(LAND,1)*100./FRACTN(LAND,1)
C
C     DD WASHED OFF THIS HOUR
C
         IF (METRIC.EQ.1) DDOFF=DDB(LAND)-DDR
         IF (METRIC.EQ.2) DDOFF=(DDB(LAND)-DDR)/2000.
         IF (DDOFF.LT.0.) DDOFF=0.
         DDL(LAND)=DDL(LAND)+DDOFF
C
C                                   BRANCH TO  3000 FROM  2990.02
C
  131 CONTINUE
      RETURN
C
  132 FORMAT (//30X,44HCOMPUTED RUNOFF COEFFICIENT FOR WATERSHED IS,F7.5
     1)
  133 FORMAT (//30X,43HFRACTION OF WATERSHED THAT IS IMPERVIOUS IS,F6.4)
  134 FORMAT (3X, 16H***POLLUTANT***=,F20.5//)
C
      END
      SUBROUTINE OUTPUT
C     EVENT OUTPUT
C
      COMMON/IDIM/ICNAME(6),IERD(20),IPOLUT(20),IRAIN(200,24),
     1            JDATE(200),JDAY(200),KDATE(200),KDAY(200),
     2            KRAIN(200,24),LNDUSE(20,2),LPAGE(5),LSDIST(1000),
     3            LTDIST(1000),NAME(8),NAMEWS(4),NCLEAN(5),ND(12),
     4            NTITLE(20)
      COMMON/RDIM/ACTIA(20),CAPR(20,20),CP(20),DD(20),DDL(20),
     1            DELTP(20,6),DEPR(20),DSTOR(600),DWF(7,24),FIMP(20),
     2            FRACTN(20,6),HPOLDW(6,24),P(20,6),PN(6),POL(6),
     3            POLDWF(6),POLEX(6),POLLRT(6),POLOVR(6),PRCNT(20),
     4            QPREV(20),QSUM(20),QV(24),RATEIN(20),RECURT(12),
     5            RUNLU(20),SACT(20),SMAX(20),SSUMPO(6),STARTI(20),
     6            STARTS(20),STLEN(20),SUMPOL(6),TRATE(20),TRATER(20),
     7            WTQ(20),XLAB(11),XPOLEX(6),XPOLOV(6),XSUMPO(6),
     8            YLAB(6),YSUMPO(6)
      COMMON/INDM/IA,IB,ICC,ID,IDATE,IDVAR,IEND,IER,IERDMX,IGRAPH,IAGE,
     1            IHPVAR,IHVAR,IL,IN,IODWF,IP,IP1,IP2,IPACK,IPRINT,
     2            IPRTS,IQUAL,IR,IRUN,IS,ISCH,ISTART,IT,J,J1,JHR,JMX,K,
     3             KK,KMAX2,KMX,KRUN,L,LAST,LDATE,LEXT,LHUND,LI,KSAVE,
     4            LINE,LL,LOSS,LOSSEQ,LSDF,M,MASE,MASS,MAXLIN,MEF,
     5            METRIC,MISS,MO,MPAGE,MST,MXC,MXLG,MXSTOR,MXTIM,NDATE,
     6            NANTEC,NAM,NC,NCAP,NDAY1,NDAYRC,NDRY,NHAVE1,NHOURS,
     7            NHR,NINC,NMAX,NN,NNRAIN,NOEXTR,NORAIN,NORUN,NORUNN,
     8            NOSTOR,NPAGE,NSTOR,NSUMR,NWSSAV,IPACUM,IUNITO
      COMMON/RNDM/ADWF,AGE,AGE2,AGE3,AGE4,AGE5,AGE6,AGE7,AGE8,AMXOLD,
     A            AREA,C,CAP,CIAT,CIMP,CN,CPERV,CST,DD1,DEP,DEPN,
     B            DEPRES,DEPRN,DEPRS,DUR,E,EI,EX,EXCES,EXPTE,
     C            EXPTN,HUND,GRAPHC,OLD,POPULA,PRCP,PRCPN,RAIN,
     D            RAINRT,RAINX,REC,REFF,RFN,RFU,RMI,RTOCFS,RTOMM,
     E            RUN,RUNOF,QDWF,QPRETO,QQ,QSUMTO,QTOT,SACFT,
     F            SAGE,SAGE2,SAGE3,SAGE4,SAGE5,SAGE6,SAGE7,SAGE8,
     G            SDATE,SDAY,SDUR,SEX,SEXCES,SHR,SMEC,SMG,SMST,
     H            SMXSTO,SNOSTO,SQTOT,SRAIN,SRUN,STCAP,STNSTO,STOP,
     I            STOR,STORD,STORG,STRAIN,STREAT,STRTIT,STRTST,
     J            STSTO,TAREA,TCAP,TCFS,TMGD,TNSTOR,TOP,TOTAL,
     K            TRAIN,TREAT,TSTOR,TSUBC,URC,XAGE,XAGE2,XAGE3,
     L            XAGE4,XAGE5,XAGE6,XAGE7,XAGE8,XCST,XDUR,XMH,XQTOT,
     M            XRAIN,XRUN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,
     N            YDWF,YQTOT,YRAIN,YRUN,ZEX,ZQTOT
C
C         DECLARED INTEGER VARIABLES IN COMMON
      INTEGER   CAP,CST,DSTOR,DUR,EX,EXCES,RAIN,SDATE,SDAY,SDUR,
     1          SEX,SEXCES,SHR,SMST,SMXSTO,SNOSTO,SRAIN,STCAP,
     2          STNSTO,STOP,STOR,STORD,STORG,STRAIN,STREAT,STSTO,
     3          TCAP,TNSTOR,TOP,TRAIN,TRATE,TREAT,TSTOR,
     4          XCST,XDUR,XRAIN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,
```

```
     5          YSUMPO,DWF,SQTOT
C
      DIMENSION POLCON(6),ISUMPO(6),IPOLOV(6),IPOLEX(6), ISSUMP(6),
     1 IZSUMP(6), IZPOLO(6), IZPOLE(6), RATIO1(6), RATIO2(6)
C
      INTEGER RAINR,EXCESR,EXR,TREATR,XSTORR
      ENTRY POLUT
C
      RUNOFR=RUNOF/HUND
      GO TO (6990,7010),METRIC
 6990 QDWFCF=QDWF*RTOMM
      CFSOFF=RUNOF*RTOMM
      QTOTCF=QTOT*RTOMM
      DO 7000 IC=1,MXC
      POLCON(IC)=0.0
      IF (QTOTCF.LE.0.) GO TO 7000
      POLCON(IC)=POLLRT(IC)/QTOTCF/3600.*1000000.
C                                    BRANCH TO  7000 FROM  6990.03  6990.05
 7000 CONTINUE
      GO TO 7040
C                                    BRANCH TO  7010 FROM  6990.04
 7010 CONTINUE
      QDWFCF = QDWF * RTOCFS
      CFSOFF=RUNOF*RTOCFS
      QTOTCF = QTOT * RTOCFS
      DO 7030 IC=1,MXC
      POLCON(IC)=0.0
      IF ( QTOTCF .LE. 0. ) GO TO 7030
      IF ( IC .EQ. 6 ) GO TO 7020
      POLCON(IC) = POLLRT(IC) / QTOTCF / 3600. * 16020.
      GO TO 7030
C                                    BRANCH TO  7020 FROM  7010.07
 7020 POLCON(IC) = POLLRT(IC) / QTOTCF / 3600. / 28.3  * 1.0E-06
C                                    BRANCH TO  7030 FROM  7010.04  7010.06
C                                       7010.09     0.00     0.00     0.00
 7030    CONTINUE
C                                    BRANCH TO  7040 FROM  7000.01
 7040 CONTINUE
C
C     NEW EVENT<
      IF (NSTOR-1 .EQ. NEVNT) GO TO 7050
      NEVNT=NSTOR-1
      IF (MOD(NHR,46).GT.42) NHR=0
      IF(NHR.EQ.0) GO TO 7050
      WRITE(IB,6330)
      WRITE(IB,6330)
      WRITE(IB,6330)
 6330 FORMAT (1H )
      WRITE (IB,7130) NEVNT
      NHR=NHR-3
C
C                                    BRANCH TO  7050 FROM  7040.01  7040.04
 7050 CONTINUE
      NHR=NHR-1
      IF (MOD(NHR,46).EQ.1) CALL HDG(IB)
      KYR=KDATE(KK)/10000
      KMO=MOD(KDATE(KK)/100,100)
      KDY=MOD(KDATE(KK),100)
      IF (KDY.LT.32) GO TO 7060
      KDY=1
      KMO=KMO-1
      IF (KMO.LT.13) GO TO 7060
      KMO=1
      KYR=KYR-1
C                                    BRANCH TO  7060 FROM  7050.06  7050.09
 7060 IF (KDY.NE.31) GO TO 7070
      IF (KMO.NE.4.AND.KMO.NE.6.AND.KMO.NE.9.AND.KMO.NE.11) GO TO 7070
      KDY=1
      KMO=KMO-1
C                                    BRANCH TO  7070 FROM  7060.00  7060.01
```

```
 7070 IF (KDY.NE.29) GO TO 7080
      IF (KMO.NE.2) GO TO 7080
      LEAP1=MOD(KYR,4)
      IF (LEAP1.EQ.0) GO TO 7080
      KDY=1
      KMO=3
C
C                                        BRANCH TO  7080 FROM   7070.00   7070.01
                                             7070.03        0.00       0.00       0.00
 7080 CONTINUE
      RUNOFR=RUNOFR/100.
      IF ( QDWFCF .LT. 1.E-10 ) QDWFCF = 0.
      PRAIN=PRCP/(HUND*100.)
      IF (MOD(NHR,46).EQ.1.AND.METRIC.EQ.1)
     . WRITE(IB,7090) ((ICNAME(NOOK),NOOK=1,MXC),IPX=1,2)
      IF (MOD(NHR,46).EQ.1.AND.METRIC.EQ.2)
     . WRITE(IB,7100) ((ICNAME(NOOK),NOOK=1,MXC),IPX=1,2)
 7090 FORMAT (/47X,43H**OUTFLOW POLLUTANT LOAD, IN KGS/HR****   **,
     .  40H** AVE CONCENTRATION, IN MG/L **********/
     .  42H YR MO DY HR T(0)  RAIN RUNOF    DWF    QTOT,
     .  2(4X,A4,2(3X,A4),2(2X,A4),6X,A4))
 7100 FORMAT (/47X,43H**OUTFLOW POLLUTANT LOAD, IN LBS/HR****   **,
     1  40H** AVE CONCENTRATION, IN MG/L **********/
     2  42H YR MO DY HR T(0)  RAIN RUNOF    DWF    QTOT,
     3  2(4X,A4,2(3X,A4),2(2X,A4),6X,A4))
      IF (MOD(NHR,46).EQ.1.AND.METRIC.EQ.1) WRITE (IB,7110)
      IF (MOD(NHR,46).EQ.1.AND.METRIC.EQ.2) WRITE (IB,7120)
C
C                                        BRANCH TO  7110 FROM   7100.04
 7110 FORMAT (22X,4H(MM),8X,5H(L/S),45X,2H--,42X,2H--)
C                                        BRANCH TO  7120 FROM   7100.05
 7120 FORMAT (20X,8H(INCHES),6X,5H(CFS),45X,2H--,42X,2H--)
      IF (MOD(NHR,46).EQ.1) WRITE (IB,7130) NEVNT
C                                        BRANCH TO  7130 FROM   7040.08
 7130 FORMAT (2X,7HEVENT <,I4/2X,11H-----------)
      WRITE (IB,7140) KYR,KMO,KDY,J1,TSTOR,PRAIN,RUNOFR,QDWFCF,
     1  QTOTCF,(POLLRT(IC),IC=1,MXC),(POLCON(IC),IC=1,MXC)
C                                        BRANCH TO  7140 FROM   7130.01
 7140 FORMAT (4I3,I4,F7.2,F6.2,F6.1,F7.1,2(F8.1,2F7.1,2F6.1,F10.1))
C
      RETURN
      END
      SUBROUTINE HDG(IO)
C
C                                  WRITE THE HEADING
      COMMON/IDIM/ICNAME(6),IERD(20),IPOLUT(20),IRAIN(200,24),
     1             JDATE(200),JDAY(200),KDATE(200),KDAY(200),
     2             KRAIN(200,24),LNDUSE(20,2),LPAGE(5),LSDIST(1000),
     3             LTDIST(1000),NAME(8),NAMEWS(4),NCLEAN(5),ND(12),
     4             NTITLE(20)
      COMMON/RDIM/ACTIA(20),CAPR(20,20),CP(20),DD(20),DDL(20),
     1             DELTP(20,6),DEPR(20),DSTOR(600),DWF(7,24),FIMP(20),
     2             FRACTN(20,6),HPOLDW(6,24),P(20,6),PN(6),POL(6),
     3             POLDWF(6),POLEX(6),POLLRT(6),POLOVR(6),PRCNT(20),
     4             QPREV(20),QSUM(20),QU(24),RATEIN(20),RECURT(12),
     5             RUNLU(20),SACT(20),SMAX(20),SSUMPO(6),STARTI(20),
     6             STARTS(20),STLEN(20),SUMPOL(6),TRATE(20),TRATER(20),
     7             WTO(20),XLAB(11),XPOLEX(6),XPOLOV(6),XSUMPO(6),
     8             YLAB(6),YSUMPO(6)
      COMMON/INDM/IA,IB,ICC,ID,IDATE,IDVAR,IEND,IER,IERDMX,IGRAPH,IAGE,
     1             IHPVAR,IHVAR,IL,IN,IODWF,IP,IP1,IP2,IPACK,IPRINT,
     2             IPRTS,IQUAL,IR,IRUN,IS,ISCH,ISTART,IT,J,J1,JHR,JMX,K,
     3              KK,KMAX2,KMX,KRUN,L,LAST,LDATE,LEXT,LHUND,LI,KSAVE,
     4             LINE,LL,LOSS,LOSSEQ,LSDF,M,MASE,MASS,MAXLIN,MEF,
     5             METRIC,MISS,MO,MPAGE,MST,MXC,MXLG,MXSTOR,MXTIM,NDATE,
     6             NANTEC,NAM,NC,NCAP,NDAY1,NDAYRC,NDRY,NHAVE1,NHOURS,
     7             NHR,NINC,NMAX,NN,NNRAIN,NOEXTR,NORAIN,NORUN,NORUNN,
     8             NOSTOR,NPAGE,NSTOR,NSUMR,NWSSAV,IPACUM,IUNITO
      COMMON/RNDM/ADWF,AGE,AGE2,AGE3,AGE4,AGE5,AGE6,AGE7,AGE8,AMXOLD,
     A             AREA,C,CAP,CIAT,CIMP,CN,CPERV,CST,DD1,DEP,DEPN,
     B             DEPRES,DEPRN,DEPRS,DUR,E,EI,EX,EXCES,EXPTE,
     C             EXPTN,HUND,GRAPHC,OLD,POPULA,PRCP,PRCPN,RAIN,
```

```
     D              RAINRT,RAINX,REC,REFF,RFN,RFU,RMI,RTOCFS,RTOMM,
     E              RUN,RUNOF,QDWF,QPRETO,QQ,QSUMTO,QTOT,SACFT,
     F              SAGE,SAGE2,SAGE3,SAGE4,SAGE5,SAGE6,SAGE7,SAGE8,
     G              SDATE,SDAY,SDUR,SEX,SEXCES,SHR,SMEC,SMG,SMST,
     H              SMXSTO,SNOSTO,SQTOT,SRAIN,SRUN,STCAP,STNSTO,STOP,
     I              STOR,STORD,STORG,STRAIN,STREAT,STRTIT,STRTST,
     J              STSTO,TAREA,TCAP,TCFS,TMGD,TNSTOR,TOP,TOTAL,
     K              TRAIN,TREAT,TSTOR,TSUBC,URC,XAGE,XAGE2,XAGE3,
     L              XAGE4,XAGE5,XAGE6,XAGE7,XAGE8,XCST,XDUR,XMH,XQTOT,
     M              XRAIN,XRUN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,
     N              YDWF,YQTOT,YRAIN,YRUN,ZEX,ZQTOT
C
C          DECLARED INTEGER VARIABLES IN COMMON
      INTEGER  CAP,CST,DSTOR,DUR,EX,EXCES,RAIN,SDATE,SDAY,SDUR,
     1         SEX,SEXCES,SHR,SMST,SMXSTO,SNOSTO,SRAIN,STCAP,
     2         STNSTO,STOP,STOR,STORD,STORG,STRAIN,STREAT,STSTO,
     3         TCAP,TNSTOR,TOP,TRAIN,TRATE,TREAT,TSTOR,
     4         XCST,XDUR,XRAIN,XTNSTO,XTOP,XTRAIN,XTREAT,XTSTO,
     5         YSUMPO,DWF,SQTOT
C
C  SET SUBSCRIPT I FOR EACH REPORT PAGE NUMBER
      IF(IO.EQ. IA) I=1
      IF(IO.EQ. IB) I=2
      IF(IO.EQ.ICC) I=3
      IF(IO.EQ. IS) I=4
      LPAGE(I)=LPAGE(I)-1
      TEMP=TRATER(M)/100.
      TMP=CAPR(M,NC)/100.
      WRITE(IO,5700) LPAGE(I),(NTITLE(NK),NK=1,20)
 5700 FORMAT(5H1PAGE,I5,20X,A2,19A4)
      IF(IO.EQ.IA) WRITE(IO,5710)
 5710 FORMAT(58X,16HQUALITY ANALYSIS)
      IF(IO.EQ.IB) WRITE(IO,5720)
 5720 FORMAT(53X,21HPOLLUTOGRAPH ANALYSIS)
      IF(IO.EQ.ICC) WRITE(IO,5730)
 5730 FORMAT(57X,17HQUANTITY ANALYSIS)
      IF(IO.EQ.IS) WRITE(IO,5740)
 5740 FORMAT(52X,29HLAND SURFACE EROSION ANALYSIS)
      IF (METRIC.EQ.1) WRITE(IO,5750) TEMP,TCFS,TMGD,(NAME(NK),NK=1,8),
     . TMP,SMG,(NAMEWS(NK),NK=1,4)
      IF (METRIC.EQ.2) WRITE(IO,5760) TEMP,TCFS,TMGD,(NAME(NK),NK=1,8),
     . TMP,SACFT,SMG,(NAMEWS(NK),NK=1,4)
C                                    BRANCH TO  5750 FROM  5740.01
 5750 FORMAT(18H TREATMENT RATE  =,F7.4,7H MM/HR,,F8.1,5H L/S,,F10.3,
     . 12H M3*1000/DAY,32X,A2,7A4/
     .18H STORAGE CAPACITY=,F7.4,4H MM,,18X,F8.3,8H M3*1000,39X,A2,3A4)
C                                    BRANCH TO  5760 FROM  5740.03
 5760 FORMAT(18H TREATMENT RATE  =,F7.4,7H IN/HR,,F8.1,5H CFS,,F10.3,
     1     4H MGD,40X,A2,7A4/
     2   18H STORAGE CAPACITY=,F7.4,8H INCHES,,F7.1,7H AC-FT,,
     3    F8.3,3H MG,44X,A2,3A4)
      RETURN
      END
```

APPENDIX B-1

SAMPLE OUTPUT

OF

COMPUTER PROGRAM "DRAINQUAL"

THIS IS STORM 6-21-1974

RAINFALL PATTERN

0	.002	.003	.008	.009	.006	.011	.006	.003	.003
.005	.005	.003	.014	.015	.011	.011	.010	.013	.013
.009	.013	.012	.004	.007	.010	.009	.009	.018	.015
.018	.016	.015	.010	.011	.017	.020	.024	.026	.019
.020	.030	.037	.024	.012	.009	.006	.002	.005	.005
0	.004	.007	.009	.003	.003	0	.001		

RUN NUMBER	BASIN AREA ACRES	TIME INCREMENT MINUTES	SOIL GROUP 1234=ABCD
100	29.1	5.0	2

TOTAL RAIN INCHES	FREQUENCY YEARS	DURATION MINUTES	AMC	PAVED ABS. INCHES	GRASS ABS. INCHES
.6156	0	285.0	3	.10	.20

```
  B    R   LENG  SLP        N  HT   BW   V/H   DIA   CAPAC   VEL   DESIGN   INLET   DETENTION   STORAGE
           FT    POT           FT   FT         INS   CFS     FPS   Q-CFS    Q-CFS   CUBIC FT    REQUESTED

PAVED ENTRY TIME      3.1 MIN
  ACCUM CONTRIBUTING AREAS    CPA=      .4,    SPA=       .3,    CGA=   1.0
  1.   0  240. 3.40  .013     -0  -0     -0   18.   19.34 10.95          0                    0          0
                                                                     .18      .18            0

PAVED ENTRY TIME=     3.5 MIN
  ACCUM CONTRIBUTING AREAS    CPA=      .9,    SPA=       .7,    CGA=   2.4
  1.   1.  260. 3.40  .013    -0  -0     -0   21.   29.17 12.14          0                    0          0
                                                                     .40      .22            0

PAVED ENTRY TIME=     3.6 MIN
  ACCUM CONTRIBUTING AREAS    CPA=     1.5,    SPA=      1.3,    CGA=   3.9
  2.   0  250. 4.80  .013     -0  -0     -0   15.   14.13 11.52          0                    0          0
                                                                     .27      .27            0

PAVED ENTRY TIME=     3.1 MIN
  ACCUM CONTRIBUTING AREAS    CPA=     1.7,    SPA=      1.5,    CGA    4.7
  2.   1.  280. 4.00  .013    -0  -0     -0   18.   20.98 11.88          0                    0          0
                                                                     .35      .09            0

PAVED ENTRY TIME=     3.0 MIN
  ACCUM CONTRIBUTING AREAS    CPA=     1.9,    SPA=      1.7,    CGA=   5.5
  1.   2.  240. 2.00  .013    -0  -0     -0   30.   57.92 11.81          0                    0          0
                                                                     .83      .09            0

PAVED ENTRY TIME=     3.9 MIN
  ACCUM CONTRIBUTING AREAS    CPA=     3.7,    SPA=      3.2,    CGA=  11.5
  1.   4.  860. 1.53  .013    -0  -0     -0   36.  111.46 15.78          0                    0          0
                                                                    1.62      .80            0

PAVED ENTRY TIME=     3.5 MIN
  ACCUM CONTRIBUTING AREAS    CPA=     5.9,    SPA=      5.1,    CGA=  18.1
  1.   4.  860. 1.50  .013    -0  -0     -0   36.   81.58 11.55          0                    0          0
                                                                    2.55      .98            0
```

OUTFALL HYDROGRAPH IN CFS, ACCUMULATED RUNOFF IN CU FT= 10596.

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	.4	.8
.8	.9	.8	.8	.9	.6	.4	.5	.7
.7	.9	1.2	1.2	1.2	1.1	.9	.7	.9
1.3	1.5	1.8	1.6	1.4	1.7	2.3	2.3	1.4
.8	.5	.2	.2	.4	.2	0	.3	.6
.4	.2	0	0	0				

```
$$$$  $$$$$   $$$   $$$$   $$   $$
$       $    $   $  $   $  $ $ $ $
 $$$    $    $   $  $$$$   $  $  $
    $   $    $   $  $  $   $     $
$$$$    $     $$$   $   $  $     $

****************************************************
S T O R M     L7520     VERSION 2.1    AUGUST 1977
THE HYDROLOGIC ENGINEERING CENTER  DAVIS, CALIFORNIA
FOR ASSISTANCE  CALL 916-440-3286  or 448-3286 (FTS)
****************************************************


TEST 1                          STORM                          L2520
     RUNOFF QUALITY AND QUANTITY FOR URBAN WATERSHED
     UPPER ROSS-ADE WATERSHED  WEST LAFAYETTE  INDIANA

NWSHD   ISNO   ISED   IQUAL   IEVNT   IODWF   IDVAR   IHVAR   IHPVAR
    1      0      0       1       1      -0      -0      -0       -0

       NSUMR   LEXT   LINE   LDATE   LHR   NHYDRO   METRIC
          90      3     -0      -0    -0       -0       -0

                  TITLE OF RAIN GAGE
                 UPPER ROSS-ADE WATERSHED

               IN   IFILE  ISTART  IEND   IR
                5      -0      -0    -0    1

       NAMEWS             MXLG   EXPTE   TRTP   TSUBC  IPACUM
UPPER ROSS-ADE               1   4.600   .700      -0       1

          AREA    RFU    IQU    DVU    DVUMX    WU    POPULA
         29.00   1.00      1     -0       -0    -0        -0
```

RUNOFF IN CFS	***OUTFLOW POLLUTANT LOAD IN POUNDS/DAY***	
	SUSPENDED SOLIDS	*BOD*
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
.4	34.4	5.3
.8	67.0	9.6
.8	75.3	10.3
.9	86.9	11.4
.8	74.7	9.5
.8	68.7	8.6
.9	80.6	9.7
.6	53.2	6.4
.4	28.4	3.4
.5	43.9	5.2
.7	60.2	6.9
.7	57.4	6.5
.9	86.4	9.6
1.2	120.7	13.1
1.2	121.1	13.0
1.2	120.8	12.8
1.1	110.3	11.6
.9	84.5	8.8
.7	65.3	6.8
.9	87.2	9.0
1.3	135.0	13.8
1.5	180.5	18.4
1.8	223.0	22.6
1.6	199.6	20.2
1.4	153.0	15.4
1.7	205.4	20.7
2.3	342.5	34.4
2.3	325.8	32.7
1.4	155.1	15.5
.8	64.4	6.5
.5	40.5	4.1
.2	15.4	1.5
.2	11.4	1.1
.4	25.8	2.6
.2	10.9	1.1
0	0	0
.3	22.2	2.2
.6	43.0	4.3
.4	31.9	3.2
.2	10.2	1.0
0	0	0
0	0	0
0	0	0

Purdue University
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