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A Program For Estimating Runoff From Indiana Watersheds, Part II: Assembly Of Hydrologic And Geomorphologic Data For Small Watersheds In Indiana

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A PROGRAM FOR ESTIMATING RUNOFF FROM INDIANA WATERSHEDS

Part II. Assembly of Hydrologic And Geomorphologic Data For Small Watersheds in Indiana

by

M. T. Lee
D. Blank
J. W. Delleur

MAY 1972

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
LAFAYETTE, INDIANA
School of Civil Engineering
Purdue University
Lafayette, Indiana 47907

A PROGRAM FOR ESTIMATING RUNOFF FROM INDIANA WATERSHEDS

Part II

ASSEMBLY OF HYDROLOGIC AND GEOMORPHOLOGIC DATA

FOR SMALL WATERSHEDS IN INDIANA

by

M. T. Lee
D. Blank
J. W. Delleur

Period of Investigation: July 1968 - May 1972
Partial Report for OWRR-B-008-IND
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Purdue University Water Resources Research Center
Technical Report No. 23
May 1972
PREFACE AND ACKNOWLEDGMENTS

This report presents an extension of previous work on surface water hydrology of Indiana small watersheds supported by the Department of the Interior under project OWRR-A-001-IND entitled "Estimation of Runoff from Small Watersheds in Indiana". The work presented herein was supported partly by the Office of Water Resources Research under projects OWRR-A-001-IND, and OWRR-B-008-IND (Assembly and Analysis of Hydrological and Geomorphic Data for Small Watersheds in Indiana), partly by Purdue Research Foundation under grant XR5869 and partly by Purdue University.

J. W. Delleur is the project director for the above mentioned projects, D. Blank and M. T. Lee served as Graduate Research Assistants on Projects OWRR-A-001-IND and OWRR-B-008-IND respectively. D. Blank was responsible for the acquisition of the hydrologic data and M. T. Lee for the acquisition of the geomorphologic data.

Parts of the material of sections 3-1 through 3-6 appeared in the completion report of project OWRR-A-001-IND (A Program for Estimating Runoff from Indiana Watersheds, Part I), reference (23), but are repeated here for completeness. A previous report on project OWRR-B-008-IND was Technical Report No. 20 entitled "The Instantaneous Unit Hydrograph: Its Calculation by the Transform Method and Noise Control by Digital Filtering" by R. A. Rao and J. W. Delleur, dated June 1971. The completion report on project OWRR-B-008 concerned with the analysis of the hydrologic and geomorphologic data for Indiana is expected to be issued as Technical Report No. 24 dated August 1972.

The authors wish to express their appreciation to Dr. Dan Wiersma, Director of the Water Resources Research Center at Purdue University and to Dr. J.
F. McLaughlin, Head of the School of Civil Engineering for their help in the administration of the project. The authors are grateful to Professor W. M. Melhorn, and to Mr. D. M. Coffman for their permission to use the W.A.T.E.R. computer programs (reference 20), and for their assistance in the use of these programs and in the interpretation of the results. The authors also wish to express their thanks to Mr. M. Hale, formerly District Chief of the U.S. Geological Survey Indianapolis Office, and to Mr. McCollam of the same office for their cooperation and assistance in assembling the hydrologic data.
ABSTRACT

This report presents banks of hydrologic and geomorphologic data for Indiana small watersheds and discusses some applications of these data. Four major types of data were collected. They are: the rainfall, and the runoff data which were collected for 55 watersheds, and the drainage networks and the topography data which were collected for 34 of these watersheds. The data were recorded on computer cards first. They were printed, plotted and checked. Then they were loaded on four different magnetic tapes. The first one contains the single storm rainfall excesses and the direct runoffs. The second one contains the single storm rainfalls and the runoff hydrographs. The third one contains the planform of the stream networks. The fourth one contains the elevation contours of the watersheds. These data banks are useful in hydrograph analysis, estimation of instantaneous hydrographs, identification and calibration of hydrologic models for runoff estimation. They have potential applications in drainage design, development and management of water resources in general.
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LIST OF SYMBOLS

A       Drainage Area, square miles
a       Parameter of Eq. (3)
AREA    Area of Watershed, square miles
b       Parameter of Eq. (3)
D       Drainage Area
DATE    Date of storm
DIRROF  Direct surface runoff, in inches
DP      Time increment, in hours
ELL     Elevation of contour
F1      Linear scale of map
F2      Areal scale of map
G(t)    Loss function
M       Number of sampling point in each read record
NEW     Number of contours in data set
NP      Number of points in input function (excess precipitation)
NQ      Number of points in the output function (direct runoff)
NTPS    Total number of sampling points in a watershed
NW      Watershed number
P_e     The total amount of excess precipitation
P_f     The accumulated precipitation at the end of surface runoff
P_s     The accumulated precipitation at the beginning of the surface runoff
P(I)    Input function, in in/hr
P(t)    Total accumulated precipitation distribution
Q       Discharge at time t
QBAV    Average base flow, in cfs
LIST OF SYMBOLS (continued)

\( Q_0 \)  
Discharge at time \( t_0 \)

\( Q_P \)  
Peak discharge before base flow separation

\( Q(I) \)  
Output function array, in cfs

\( R \)  
Recession constant

\( t_f \)  
The ending time of storm

\( PL \)  
Total stream length

\( PNM \)  
Total link number

\( t_s \)  
The starting time of storm

\( WN \)  
Watershed number

\( X \)  
Longitude coordinate of sampling point

\( X(t) \)  
Excess precipitation distribution

\( Y \)  
Latitude coordinate of sampling point
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1. INTRODUCTION

The study of the hydrologic cycle requires extensive data. Systems analysis of the rainfall-runoff process in particular needs a considerable data bank of good quality for model identification and verification. Among these models, the instantaneous unit hydrograph is of particular importance.

Hydrologic data are collected by many agencies and published in scattered reports. As a result the compilation of hydrologic data banks is both time consuming and expensive. This report presents a hydrologic and geomorphologic data bank for small Indiana watersheds.

In this Assembly of Hydrologic and Geomorphologic data the following information is stored for several Indiana watersheds:

1) Single storm rainfalls
2) Single storm rainfall excess
3) Single storm runoff hydrographs
4) Single storm direct runoff hydrographs
5) Planform of stream networks
6) Contour maps of watersheds

These data are particularly useful in hydrograph analysis, estimation of instantaneous unit hydrographs, identification and calibration of hydrologic models for runoff estimation etc. These techniques are particularly important for drainage design, development of small watersheds and development of water resources in general.

2. DATA ACQUISITION

In this report four major types of data were collected. They are: the rainfall, the runoff, the drainage network and the topography. The
rainfall data were obtained from the U.S. Department of Commerce, Environment Science Services Administration [2]. The stage hydrographs and the stage-discharge tables were obtained from the U.S. Geological Survey [1]. The drainage network was compiled from the Indiana county drainage atlas prepared by Purdue University [19]. The topographic data were digitized from U.S. Geological Survey 1/24,000 quadrangle and 1/125,000 topographic maps. All these sets of data were digitized and recorded on computer cards. The CALCOMP plotter was used to display the data for checking purposes. Then they were loaded on magnetic tapes. The outline of data collection procedures is shown in Figure 1. Detailed procedures of the data storage and retrieval system will be discussed in the following sections.

2.1 Selection of Watersheds

The selection of the watersheds was determined by: 1) the desire to cover most of the regions of the state of Indiana, and 2) the condition that man-made disturbances were not predominant factors controlling the behavior of the watershed. It should be realized, however, that with the increase in urbanization and with the ever increasing use of surface water in the state, most watersheds already are or will be subjected to some form of disturbance such as diversions for water supply, dams, or sewage disposal into the main stream. A total of 1059 hydrographs in 55 watersheds were selected. Table 1 gives a list of the watersheds selected, their area in square miles, the number of storms included, the assigned precipitation stations, and the availability of digitized topography and stream network. Figure 2 shows the location of the stream and rain gage stations considered.
<table>
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<tr>
<th>Watershed No.</th>
<th>Watershed Name and Location</th>
<th>Area (sq.mi.)</th>
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<th>Precipitation Stations</th>
<th>Topo-Map</th>
<th>Network</th>
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<td>Vernon Fork at Vernon</td>
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<td>49</td>
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<td>45,134</td>
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<td>50</td>
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<td>17</td>
<td>4,51</td>
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* There is no watershed with No. 25 or No. 55
2.2 Watershed Boundaries

The watershed divides were delineated on 7.5 min. (1:24,000 scale) topographic maps from which the areas were measured. The areas were then compared with the published values [1]. The discrepancy between the two (for the majority of the watersheds) was found to be less than 5%.

3. Effective Rainfall and Direct Runoff

This section describes the creation of a hydrologic library for watersheds in Indiana. The library, at this stage consists of 1059 hydrological events. Each event includes a direct runoff hydrograph and the corresponding excess precipitation, in addition several parameters pertaining to the storm are also included.

The procedure employed is presented in Figure 1 and is described below.

3.1 Acquisition of Hydrograph Data

Stage hydrographs of all Indiana watersheds under 300 sq. mi. in area for which the U.S.G.S. has records were examined. The watersheds having at least seven to ten well defined single peak hydrographs were selected for further considerations.

The stage hydrographs for the selected watersheds were traced from the original records of the U.S.G.S. office at Indianapolis. The corresponding rating tables (stage-discharge relation) were also obtained from the above mentioned agency. The stage hydrographs were digitized at 30 min. intervals corresponding to 0.05 in. on the recording chart. Fig. 3 shows a typical stage record. The stages were read to the nearest five hundredths of a foot. The peak discharges and their times of occurrence were always recorded. For the analysis a constant time interval was used. If the peak
could not be included using a 30 min. interval, a 15 min. time interval was used interpolating between the digitized reading. The rating tables were digitized using a 0.1 ft. stage increment, see Fig. 4b. On the average, 200 data points (time-stage) were recorded for each hydrograph, see Fig. 4c. The hydrologic raw data also include the following identification shown in Fig. 4a: 1) number of storms recorded for this watershed, 2) drainage area of watershed in square miles, 3) the watershed name, 4) the number of sampling points in the rating table, 5) the number of sampling points in the total runoff hydrograph, 6) an index, if equal to 1, the rating table must be read, otherwise the rating table is not read, 7) the watershed number, 8) the storm number, 9) the point number in rating table at which interpolation starts. These identifications are not necessary for the programs described in this report. They were used in conjunction with the program "Linear Hydrograph Analysis - Evaluation of the Kernel Function", listed in Appendix A, p. 134 of reference 21. The total discharge hydrographs were obtained from the stage hydrographs and the stage discharge table using an interpolation scheme. Plots of the total discharge hydrographs were obtained; they served as a check for errors and in determining that part of the hydrograph in which the ground water flow constitutes the predominant contributing source of the flow.

3.2 Precipitation Data

Precipitation records from over 150 recording stations in Indiana were assembled [2]. The stations were located on the topographic maps and assigned to the watersheds so as to reflect the average climatic environment of the watershed at the time of the storm. The density of precipitation
stations in the state of Indiana is rather low (about one station per 250 sq. mi.). For the majority of the watersheds, it was not possible to find several stations inside the watershed boundaries. In such cases, stations were selected in the close vicinity of the watershed boundaries. The arithmetic average of the records from those stations was taken to obtain the mass precipitation curve for the storm. It should be pointed out, however, that such an approach would have to be taken also for practical engineering design as the density of the data available at the present or the foreseeable future is not likely to change greatly. The average mass precipitation for a storm was recorded at one hour intervals. The readings were taken to the nearest hundredth of an inch.

3.3 Input and Output Functions

The determination of the kernel function or instantaneous unit hydrograph, h(t), requires having an excess precipitation function (input) and a direct surface runoff hydrograph (output function). As the basic hydrologic data consist of a total hydrograph and a total precipitation, a method is needed for obtaining the excess precipitation and the direct runoff hydrograph, respectively, from the total precipitation and the total hydrograph. This is usually accomplished by means of base flow separation and the use of a loss function.

3.4 Base Flow Separation

The total hydrograph is composed of two parts, the direct runoff and the base flow. Direct runoff is that part of the hydrograph which can be attributed directly to the storm event (overland flow, channel precipitation and prompt subsurface flow). The base flow, on the other hand, is sustained by ground water flow and delayed subsurface flow [3]. It is practically im-
possible to measure and identify the various flow components once they reach the channel network of the watershed and their sum is measured at the basin outlet. At present the analytical methods available for the determination of base flow are for idealized boundary conditions and for homogeneous geological formations [4,5]. The application of such methods to heterogeneous watershed formations and actual boundary conditions requires extensive hydrogeological data generally unavailable for the selected watersheds. Various empirical procedures have been employed by hydrologists for the purpose of base flow separation [6,7,8]. Experience has shown that the shape of and the volume under the direct runoff hydrograph are essentially unaffected by the method of base flow separation, but that the base time of the direct runoff may vary with the method used.

The method adopted in this study is as follows: from the initial point (point of rise) the recession slope of the total hydrograph of the previous storm is extended as a straight line to a point located below the peak of the discharge hydrograph. It is assumed that the resulting straight line constitutes the base flow from the starting point to the time of peak runoff. The direct runoff hydrograph is then obtained by subtracting the ordinates of the straight line from those of the total hydrograph.

The critical part in the base flow separation procedure is the determination of the end point, or the time at which the direct surface runoff ceases and the ground water (including delayed components) constitutes the sole source sustaining the flow. This point fixes the base time of the direct runoff hydrograph. The following procedure was employed to determine the end point. As the majority of Indiana streams are sustained by unconfined aquifers, the equation expressing the discharge from such an
aquifer was assumed to describe the ground water recession part of the hydrograph. The discharge from an unconfined aquifer under idealized conditions is given by \([9,10,11,12]\)

\[
\frac{1}{Q^{1/2}} = \frac{1}{Q_o^{1/2}} + R(t-t_o)
\]

(1)

where:

- \(R\) is the recession constant
- \(Q_o\) is the discharge at time \(t_o\) (\(t_o\) can be chosen arbitrarily on the recession), and
- \(Q\) is the discharge at time \(t\).

The recession constant, \(R\), was determined by fitting (by least squares method) a curve corresponding to the above equation to the ground water recession part of the hydrograph. The end point was then determined as that point where the fitted curve departed from the total hydrograph by about 5%. This point was then joined by a straight line to the point under the peak to complete the base flow separation (see Figure 5).

The following is suggested as a physical interpretation of the method. From the point of rise to the peak of the hydrograph the water level in the main stream increases, causing a decrease in the hydraulic head moving ground water into the stream. In addition, water will be stored in the banks of the channel. After the peak when the water level in the channel is receding, the effect is reversed.

3.5 Determination of Excess Precipitation

Average watershed precipitation is usually determined by either the Thiessen polygon or isohyetal method. [13] Due to the limited number of stations available, an arithmetic mean of the precipitation from the sta-
tions, thought to represent the climatic condition of the watershed at the
time of storm, was taken to obtain the total rainfall distribution. The ex-
cess precipitation distribution, \( x(t) \), can be obtained by solving the follow-
ing differential equation

\[
x(t) = \frac{dP(t)}{dt} - \frac{dG(t)}{dt}
\]

(2)

where:

- \( P(t) \) is the total precipitation distribution, and
- \( G(t) \) is a loss function, including interception, evapotranspiration,
depression and detention storages, and infiltration.

As \( G(t) \) is now known, various empirical methods are used to obtain ex-
cess precipitation distribution. A summary of these methods can be found
in Van De Leur. [14] The following semi-analytical approach was attempted.
Assuming that the loss function can be represented by a relationship of the
form of Philip's infiltration equation, [15]

\[
G(t) = at^{1/2} + bt
\]

(3)

the two parameters \( a \) and \( b \) can be determined for every storm from the two
boundary conditions that may be imposed on Equation (2). The first bound-
ary condition is that \( x(t) = 0 \) at the starting time, \( t_s \), at which time the
requirements of storage, of surface detention and of depression storage,
are just being satisfied. Thus, for this condition Equations (2) and (3)
yield

\[
\left. i_s = \frac{dP(t)}{dt} \right|_{t=t_s} = \frac{a}{2} t_s^{-1/2} + b
\]

(4)

The second boundary condition is obtained by integrating both sides
of Equation (1) for the duration of the storm:
\[ \int_{t_s}^{t_f} x(t) \, dt = \int_{t_s}^{t_f} \frac{dP(t)}{dt} \, dt - \int_{t_s}^{t_f} \frac{dG(t)}{dt} \, dt \]

where \( t_f \) is the time at the end of the storm. Now the total amount of excess precipitation \( P_e = \int_{t_s}^{t_f} x(t) \, dt \) can be evaluated after the base flow has been separated and is equal to the area under the direct runoff hydrograph so that

\[ P_e = P_f - P_s - a(t_f^{1/2} - t_s^{1/2}) - b(t_f - t_s) \]

where:

- \( P_f \) is the accumulated precipitation at the end of the surface runoff, and
- \( P_s \) is the accumulated precipitation at the beginning of the surface runoff.

From Equations (3) and (4)

\[ a = \frac{P_e + P_s + i_s(t_f - t_s) - P_f}{(t_f^{1/2} - t_s^{1/2})^2} \cdot 2t_s^{1/2} \]

and

\[ b = i_s - \frac{a}{2} t_s^{-1/2} \]

Difficulties arose in the use of Equation (2) as a result of the occurrence of periods during the storm when the supply rate was less than the calculated abstraction rate. As \( x(t) > 0 \), discontinuities resulted in the excess precipitation function. To avoid the latter problem the method used by Eagleson [16] and Prasad [17] was adopted. The excess precipitation was obtained by multiplying the ordinates of the total rainfall hyetograph by the ratio of the total amount of rainfall during the storm to the
total precipitation excess $P_e$, see Figure 3. The assumption underlying this method is that the sum of the interception, evapotranspiration, and depression storages is directly related to rainfall intensity. [18]

3.6 Tape Format, Read and Write

The data on the tape was written in the following way. Each storm is split into two binary records. The first record is of fixed length and includes the watershed number (corresponding to Table 1) and the storm number (212 format). The statement used to write the first binary record was: WRITE(4) K,L; where K is the watershed number, L is the storm number and 4 is the arbitrary magnetic tape unit assigned. (WRITE(4) implies: i) control card with at least TPL, ii) REQUEST(TAPE4, 594, MT, HI, WRITE), and iii) program card with TAPE4)

The second record which is of variable length, includes the following data.

- **WN** - watershed name, 50 words (one letter apiece)
- **AREA** - area of the watershed in sq. mi., 1 word
- **DATE** - date of storm, 2 words
- **DT** - time increment in hours, 1 word
- **QP** - peak discharge before base flow separation, in cfs, 1 word
- **DIRROF** - direct surface runoff, in inches, 1 word
- **PTOTAL** - total precipitation, in inches, 1 word
- **R** - recession constant (see Eq. 1), 1 word
- **A** - constant (see Eq. 3), 1 word
- **B** - constant (see Eq. 3), 1 word
- **QBAV** - average base flow, in cfs, 1 word
- **NP** - number of points in the input function (excess precipitation), 1 word
- **NQ** - number of points in the output function (direct runoff), 1 word
- **P(I)** - input array in in/hr, NP words
- **Q(I)** - output array in cfs, NQ words

The statement used to write the second binary record was:

```
WRITE(4)((WN(I),I=1,50),AREA,DATE,DT,QP,DIRROF,PTOTAL,R,A,B,QBAV,NP,NQ,
P(I),I=1,NP),(Q(I),I=1,NQ))
```
Usage

In every use of the data on the tape the following variables should be declared in a DIMENSION or TYPE statement:

the input array (floating point, length $\geq 100$),
the output array (floating point, length $\geq 330$),
watershed name array (floating point, length = 50), and
date array (integer array, length = 2)

For example:

```
DIMENSION WNAME(50),PREC(100),DISCBE(330)
INTEGER DATEST(2)
```
or;

```
REAL INPUT(100),OUTPUT(330),NAMEWS(50)
DIMENSION IDATE(2)
```

The following is an example using the tape to read the storms and to list for each watershed, its name, number area, and for each storm its number, date, number of points in the input and output arrays, the time interval and the direct surface runoff. The first 6 cards are the C.D.C. 6500 control cards as used at the Purdue Computer Science Center.

```
Name, Account number, TPL,L4000,T20,P20.
REQUEST(TAPE1,594,MT,HI,READ)
REWIND(TAPE1)
RUN(S)
LG0.
```

```
7-8-9
```

```
PROGRAM LIST(INPUT,OUTPUT,TAPE1,TAPE5=INPUT,TAPE6=OUTPUT)
DIMENSION PI(100),QG(330),WSNAME(50)
INTEGER DATEST(2)
KEY=0
9 READ(1) KK,LL
 IF(EOF,1) 10,11
11 READ(1) ((WSNAME(I),I=1,50),AREA,DATE,DT,GPTH,DRSRF,
1PTOTAL,REC,A,B,QTUP,NPI,NQ,(PI(I),I=1,NPI),
1(QG(I),I=1,NQ))
 IF((KK,EQ.KEY) GO TO 6
 WRITE(6,1) KK, (WSNAME(I),I=1,50)
 WRITE(6,2) AREA
 WRITE(6,3)
```
WRITE(6,4)
KEY=KK
6 WRITE(6,8) LL,DATE,NPI,NQ,DT,DRSRF
WRITE(6,35)
35 FORMAT(1H0,14X,3(*TIME*,5X,*RAINFALL*,5X,*DIRECT*,
*5X)/15X,3(*EXCESS*,7X,*RUNOFF*,5X)/15X,
*3(*HR*,5X,*INCH*,7X,*CPS*,6X))
WRITE(6,36)((T(I),PI(I),QG(I)),I=1,NQ)
36 FORMAT(14X,3(F6.2,4X,F8.4,3X,F8.2,4X))
GO TO 9
1 FORMAT(1H1,20X,17HWATERSHED NUMBER,I3,3X,50A1/1HO)
2 FORMAT(57X,7H AREA=,F9.2,3X,7HSQ.MI.)
3 FORMAT(1HO,14X,5HSTORM,15X,4HDATE,14X,16HNUMBER OF POINTS,
*14X,13HTIME INTERVAL, 14X,13HRUNOFF VOLUME)
4 FORMAT(53X,5HINPUT,3X,6HOUTPUT,19X,4H(HR),18X/1HO 22X,6H(INCH),18X/1HO)
8 FORMAT(16X,I2,14X,2A4,13X,I3,5X,I4,10X,F8.3,18X,El1.5)
10 STOP
END

6-7-8-9

Sample output of this program is shown in Fig. 6a

Tape Copying

The data is stored on two tapes (593,594), and were written at a density of 556 bpi(HI). In order to copy the tape to another one the following procedure should be employed:

1. Certify the tape to be copied on at the requested density,
2. Exchange the tape to be copied on with tape 593,
3. Submit the job to accomplish copying, and
4. Exchange 593, with the tape which now contains the data.

Two examples will be given, the first describes copying on a CDC tape, the second on an IBM 360 tape.

CDC Tape:

Name, Acc. #, CM10000, TP1, T20, P20.
REQUEST(TAPE, 594, MT, HI, READ)
REWIND(TAPE)
COPYBF(TAPE, TAPE1)
RETURN(TAPE, TAPE1=SAME)
REWIND(TAPE1)
REQUEST(TAPE2, 593, MT, H1, WRITE)
REWIND(TAPE2)
COPYBF(TAPE1, TAPE2)
RETURN(TAPE2)
6-7-8-9

**IBM 360 Tape**

The following is an example of conversion from CDC tape to an IBM tape. The tape, as previously mentioned, was written on the CDC 6500 computer, whose word length is 60 bits and seven channels for tape input and output. The IBM 360 computer has a word length of 32 bits. This program copies the tape in formated card image form (record length of 80) as opposed to binary CDC internal representation. This is not only true of the 360 but for any machine that is not CDC. The data will be slightly modified due to both base conversion (binary to decimal) and to rounding.

Name, Acc #, CM20000, TP1, TL90, P.
REQUEST(TAPE, 594, MT, H1, READ)
REWIND(TAPE)
COPYBF(TAPE, SCRRT)
RETURN(TAPE, TAPELIM=SAME)
REWIND(SCRRT)
REQUEST(TIBM, 593, MT, HY, C=80, WRITE)
REWIND(TIBM)
RUN(S)
LGO.
7-8-9

PROGRAM TCOPY(INPUT, OUTPUT, TIBM, SCRRT, TAPE5=INPUT,
*TAPE6=OUTPUT, TAPE7=SCRRT, TAPE8=TIBM)
DIMENSION P(100), Q(330), WN(50)
INTEGER D(2)
21 READ(7) K, L
IF(EOF, 7) 22, 3
3 READ(7) ((WN(I), I=1, 50), AR, D, DT, QP, DR, PT, R, A, B,
*NP, NQ, (P(I), I=1, NP), (Q(I), I=1, NQ))
IF(EOF, 7) 10, 5
5 WRITE(8, 6) K, L
6 FORMAT(2I6)
WRITE(8, 7) ((WN(I), I=1, 50), AR, D, DT, QP, DR, PT, R, A, B,
NP, NQ, (P(I), I=1, NP), (Q(I), I=1, NQ))
7 FORMAT(50A1, F11.5, 2A4, F10.4/3E13.6, E13.6, 2E14.6/
The output will contain the following parameters of the first six storms:

date, number of points in the input and output functions, the time interval
and the direct runoff volume.

4. RAINFALL AND RUNOFF DATA

Because of the somewhat arbitrary methods of estimating the rainfall
excess and the direct runoff, another data bank was prepared which includes
the raw data of total rainfall and total runoff. This second part of the
hydrologic libraries consists of 1059 hydrologic events. Each event in-
cludes rainfall and runoff. Runoff data obtained from the state-discharge
conversion were loaded on a magnetic tape. This is tape 2 shown in Fig. 1.
The rainfall data, hourly precipitation for each storm, were loaded on the
same tape.
4.1 Tape Format, Read and Write

The data on this tape are similar to those of the previous tape. Each storm has two binary records as in tape 1 in Fig. 1. The first record consists of the watershed number and the storm number. The second record includes the following information:

AREA - Area of watershed, sq. mi., 1 word
WSNAME - Name of the watershed, 50 words
IQ2 - Total number of runoff sampling points, 1 word
NP - Total number of rainfall sampling points, 1 word
DT - Time interval of sampling, hrs., 1 word
Q(I) - Runoff array, cfs, max 330
P(I) - Rainfall array, in/hr, max 100
Z - Conversion factor of rainfall and runoff in/hr/cfs

The statement used to write the second binary record was:

WRITE(8) AREA,WSNAME,IQ2,NP,DT,(Q(I),I=1,IQ2)

The following example shows how to retrieve data from this tape.

NAME,ACCT #,TP1,CM60000,L40000,T20,P5.
REQUEST (TAPE8,1647,MT,H1,READ)
REWIND (TAPE8)
RUN(S)
LGO.
7/8/9

PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8)
DIMENSION T(330),Q(330),QPP(5),HR(330),QPTH(30),WSNAME(50),NSW(30),XXX(100),P(100)
110 CONTINUE
READ(5,100)NW,NST
T(1)=0
100 FORMAT(2(I5))
  2 READ(8)KK,LL
  IF(EOF(8))19,1
  1 IF(NW.EQ.KK.AND.LL.EQ.NST)GO TO 11
  READ(8)
  GO TO 2
  11 READ(8) AREA,WSNAME,IQ2,NP,DT,(Q(I),I=1,IQ2)
900 FORMAT(30X,70A1)
  WRITE(905)WSNAME,AREA,IQ2,NP,DT,(Q(I),I=1,IQ2),(P(I),I=1,NP),Z
905 FORMAT(10X,50A1/
  $ 10X,*AREA*,F10.2/
  $ 10X,*NO. OF Q*,I10/
  $ 10X,*NO. OF P*,I10/
  $ 10X,*THIS IS THE LIST OF Q*./(8F10.3)/,
Column 1-10 watershed number, right adjusted

Column 11-20 storm number, right adjusted

Repeat this card for as many storms as desired. However, all the requested watersheds and storms number should be in increasing sequence in order to avoid rewinding the tape.

5. DRAINAGE NETWORK DATA

This is the third part of the data bank. It consists of 34 drainage networks as shown in Table 1. Data were digitized from Indiana county drainage maps compiled by Purdue University [19]. Figure 7 is an example of a drainage network in a watershed.

The procedures for a unique definition of a network were reported by earlier workers [25,26]. The detailed procedures were reported by Coffman et al. in WATER system [20].

5.1 Coding of Drainage Network Data

A drainage network could be defined by a sequence of three quantities: an X-Y coordinate pair which represents the longitude and latitude of the point and an identifying code. The coding numbers used for the identification of networks sampling points are listed in Table 2.
Table 2

<table>
<thead>
<tr>
<th>Code</th>
<th>Function of Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>source</td>
</tr>
<tr>
<td>2</td>
<td>mid point</td>
</tr>
<tr>
<td>3</td>
<td>junction</td>
</tr>
<tr>
<td>4</td>
<td>basin boundary</td>
</tr>
<tr>
<td>5</td>
<td>mouth of stream network</td>
</tr>
<tr>
<td>6</td>
<td>end of data set</td>
</tr>
<tr>
<td>7</td>
<td>mouth of sub-basin</td>
</tr>
<tr>
<td>8</td>
<td>end of sub-basin</td>
</tr>
<tr>
<td>9</td>
<td>sub-basin boundary</td>
</tr>
</tbody>
</table>

The simplified network, shown in Fig. 8, is used to illustrate the basic methodology. Small basins requiring less than 3000 sampling points, (usually smaller than 20 to 30 square miles) are treated as a single unit. The sampling makes use of code numbers 1 through 6. The data sampling sequence starts from the mouth of the basin. The sequence proceeds along one bank of the stream until it finds the source of the stream, then turns around and returns along the other bank as shown by arrows in Fig. 8. The junctions are digitized during the first pass. Each identical point in stream network is allowed to be sampled only once.

Watersheds requiring more than 3000 sampling points (usually larger than 20 to 30 square miles) are divided into sub-basins. This is because the drainage data in this system take a large computer memory space. In order to limit the memory requirements, the watersheds are divided into sub-basins. Within a sub-basin, the data can be checked and analyzed as an independent unit. Then the sub-basin results can be combined in order to obtain the results for the whole watershed. The sequence of data collection is as indicated before with the addition of more special function points with code numbers 7, 8 and 9 to divide the basin. Code 7 indicates the beginning of the sub-
basin and code 8 indicates the end of the current sub-basin. The sequences of codes 7 and 8 will indicate which section of the data pertains to a specific sub-basin. Fig. 9 illustrates the particular function of codes 7 and 8. Sub-basin 1 contains data section a-b and g-h. Similarly sub-basin 2 contains b-c, d-e and f-g, etc.

The data were recorded on computer cards. Sample data are shown in Fig. 10. The first line of this figure shows the watershed number, the second line has the following identifications: 1) the total number of sampling points of the whole basin, 2) the number of sub-basins, 3) an index, if equal to 9 this is the last basin data set for one computer run, otherwise other data sets follow, 4) watershed identification number. The CALCOMP plotter was used to display the networks for visual check. Fig. 11 shows watershed No. 35, Salamonie River at Portland, Indiana subdivided in eight sub-basins. Fig. 12-1 and Fig. 12-2 show the CALCOMP plots of the drainage networks of all the sub-basins in this watershed.

5.2 Tape Format, Read and Write

The data were loaded on magnetic tape on a watershed basis. For each watershed the data were divided into two parts. The first part contains the identification and summary information. The second part contains the drainage network data compiled as a sequence of X,Y coordinate pairs and a code number as shown in Fig. 10. Due to computer memory limitation, the drainage networks were divided into small units. Each unit is written in one record. In the present case, each record contains 999 points, except the last one which contains the residual data points.
The first part contains one record which has the following information:

- **WN** - Watershed name, 50 words
- **NSPT** - Total number of sampling points, 1 word
- **NSUBA** - Number of sub-basins in whole basin, 1 word
- **KOR** - An index used to show the last basin of each magnetic tape loading which contains several basins (it will not be used for future analysis), 1 word
- **NW** - Watershed number, 1 word

The write statement of first record was:

```
WRITE(8) (WN(I),I=1,50),NSPT,NSUBA,KOR,NW
```

The second part contains several records. It depends on the size of data. Each set of 999 points forms a record. It contains:

- **X** = longitude coordinate of sampling point
- **Y** = latitude coordinate of sampling point
- **KD** = code number of sampling point

The write statement was:

```
WRITE(8)((X(I),Y(I),KD(I)),I=1,M)
```

where M = 999, not last unit

M = residual data point for last unit

It is important to mention that the code numbers 7, 8, 9 are only for temporary assignment for the large basin for future retrieval of the sub-basin unit. Data could be retrieved based on the sub-basin unit. Each sub-basin unit only contains the coding numbers from 1 to 6 which are the same as those used in WATER system. In such case, the data structure matches the input data requirement in WATER system. The program shown in Appendix A illustrates the data retrieval from magnetic tape or computer cards based on the sub-basin unit for each watershed.
6. TOPOGRAPHIC DATA

This is the fourth part of this data bank. It contains 38 watersheds with contours and watershed boundaries as listed in Table 1. The data were digitized from USGS topographic maps, 31 of them at the 1/24,000 scale and 7 of them at the 1/125,000 scale.

6.1 Coding of Topographic Data

The digitization procedure was designed as follows: first locate the gaging station and draw the watershed boundary on the topographic map. Secondly, choose the contours to be digitized. The coordinates of the boundary points were digitized first, followed by the coordinates of the contours. The data format of the computer cards was designed as shown in Fig. 13. The first four columns represent the order number of the first of a set of five points whose coordinates were digitized and typed on one card. It is followed by two digits, column 5-6, indicating the watershed number. The four digits in column 7-10 represent the contour elevation except for the boundary points which were assigned elevation 0000. Column 11 to 69 contained five pairs of X-Y coordinates along a contour with the elevation given in column 7 to 10 on the same card. If the last card of a contour does not contain exactly five points, the last point was repeated to fill up that data card. This treatment does not affect the data accuracy to describe basin topography. CALCOMP plots were used to display the data, as shown in Fig. 14 for checking purposes. The data were then loaded on the magnetic tape.
6.2 Tape Format, Read and Write

The data records were split into two parts. The first part contains
the watershed name, the scales, the elevations and other summary infor-
mation. The statement for writing the first record was:

WRITE(8) (TITLE(I),I=1,8),F1,F2,NTPS,NW,(ELL(I),I=1,NEV)

where:

- TITLE - watershed name, 8 words
- F1  - linear scale, 1 word
- F2  - areal scale, 1 word
- NTPS - total number of sampling points, 1 word
- NW  - watershed number, 1 word
- NEV - number of contours in data set, 1 word
- ELL - elevation of contour, NEV word, maximum 20 words

The second part contained the sampling data points. Due to the limi-
tation of the computer memory size, the data were divided into small units as
for the drainage network data. In the present case, 3000 points constitute
the unit size. Then each unit was loaded as a record except the last unit
which only contained the residual data. The statement for writing the se-
cond part of the data was:

WRITE(8) ((X(I),Y(I),Z(I)),I=1,M)

where M is 3000 except the last unit M is the residual number of data points.

The following example shows how to retrieve the topographic data from
the magnetic tape.

NAME,ACCT#,TPL,CM77000,T30,P5.
FUN(8)
REQUEST(TAPE8,1439,MT,HI,READ)
LGO.
7/8/9

PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
1TAPE8,PLOT)
DIMENSION X(3000),Y(3000),ELL(30),TITLE(30),Z(3000)
1,XR(3000),YR(3000),ZR(3000)
KNOWN=56
517 CONTINUE
45 IF(ZOF,5)40,45
10 IF(ZOF,8)1000,520
520 READ(8)(TITLE(I),I=1,8),F1,F2,NTPS,NEV,NW,(EL(I),I=1,NEV)
MC=NTPS/3000+1
KEY=NTPS-3000*(MC-1)
IF(NK.EQ.NW) GO TO 20
DO 25 I=1,MC
25 READ(8)
GO TO 520
20 WRITE(6,50)(TITLE(I),I=1,8),F1,F2,NTPS,NEV,NW,
1(EL(I),I=1,NEV)
50 FORMAT(I*8A10/,1X,2F10.1/,1X,3I10,/(1X,8F10.1))
M=3000
DO 55 J=1,MC
55 IF(J.EQ.MC)M=KEY
READ(8)((X(I),Y(I),Z(I)),I=1,M)
WRITE(6,65)((X(I),Y(I),Z(I)),I=1,M)
65 FORMAT(5X,21F6.0)
55 CONTINUE
WRITE(6,222)
222 FORMAT(1H1)
IF(NK.EQ.KNOWN)GO TO 1000
GO TO 517
40 CONTINUE
1000 STOP
END
7/8/9

Input data have the following format.

Column 1-5: watershed number requested, right adjusted.

(If more watershed data are requested, the same format should be repeated.

One restriction is that the watershed number should be in increasing sequence in order to avoid rewinding the data tape.)

6/7/8/9

7. HYDROLOGIC APPLICATIONS

The principal hydrologic applications of the data bank are the estimation of instantaneous unit hydrographs, unit hydrographs and runoff hydrographs. These applications have been treated in detail in separate reports and will not be repeated here.
Blank and Delleur [21] in Purdue University Water Resources Research Center Technical Report No. 4 have discussed in detail the calculations associated with the hydrograph estimation using the data bank and have given several examples and the associated computer programs. The mathematical and computational techniques used in the estimation of the instantaneous unit hydrograph by the transform method have been reported in detail by Rao and Delleur [22] in Technical Report No. 20. These reports have been summarized in three papers published in the open literature and are listed under references [23,24,27].

8. GEOMORPHOLOGIC APPLICATIONS

Recent developments in quantitative fluvial geomorphology are closely related with the classification of stream network. The study of stream networks requires a considerable amount of data to support its fundamental principles. The availability of this data bank makes such studies possible. Such an improvement leads to a possible way to handle the complex stream network by computer. This report also makes it possible to bring the study of hydrology and geomorphology together to investigate the quantitative geomorphologic relationships governing the hydrologic behavior of watersheds. The stream network has its own systematic and persistent characteristics. Before studying the hydrologic behavior, an understanding of the geomorphology is useful in the modeling of the hydrologic system for runoff estimation or prediction.

There are two phases of runoff estimation in Indiana small watersheds which are currently in progress at the Water Resources Research Center at Purdue University. They are: 1) the utilization of WATER system [20] for stream network analysis; 2) the application of geomorphic data for hydrologic modeling. The results of these applications will be reported in the third part of the runoff estimation program of small Indiana watersheds.
REFERENCES


FIG. 1 DATA ACQUISITION PROCEDURE
### Figure 4: Sample of Hydrologic Raw Data

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#### (b) Stage-Discharge Table

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<th>Disc. Stage (cfs)</th>
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#### (d) Hourly Precipitation (in)

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WS 35
WS 355721
Figure 5. Base flow separation and determination of excess precipitation.
<table>
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**FIGURE 6a. SUMMARY TABLE FOR STORMS OF WATERSHED NO. 10**

**BIG BLUE RIVER AT CARTHAGE, INDIANA**
### Figure 6.b. Direct Runoff and Rainfall Excess Data Sample

**Watershed Number 10**  
**Big Blue River at Carthage**

<table>
<thead>
<tr>
<th>Storm</th>
<th>Date</th>
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<th>Runoff Volume (INCH)</th>
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<th>Time (HR)</th>
<th>Rainfall (INCH)</th>
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FIGURE 7 DRAINAGE MAP - WATERSHED NO. 35 SALAMONIE RIVER AT PORTLAND
FIG. 8  SIMPLIFIED NETWORK

DATA COLLECTION SEQUENCE
FIG. 9 SUBDIVISION OF WATERSHED INTO SUB-BASINS
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*INCOMPLETE DATA SHOWN*

| FIGURE 10 | NETWORK DATA SAMPLE |
FIGURE 12-2 CALCOMP PLOTS OF DRAINAGE NETWORKS, SUB-BASINS OF WATERSHED NO. 35
SALAMONIE RIVER AT PORTLAND, INDIANA
Figure 14 Calcomp Plot of Topographic Map with 20 ft Contour Interval Watershed No. 35, Salamonie River
APPENDIX A

PROGRAM MAIN(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT,TAPE8,PLOT, WTRD 10
$PUNCH,TAPE4)  WTRD 11

******************************************************************************
*THIS IS THE PROGRAM TO SORT SUB-BASIN DATA.                          *
******************************************************************************

THERE ARE TWO OPTIONS IN THIS PROGRAM.
THE INPUT DATA MAY BE ON THE CARDS OR MAGNETIC TAPE.
IF NTP=1 THE DATA ARE RETRIEVED FROM MAGNETIC TAPE, OTHERWISE
DATA ARE RETRIEVED FROM COMPUTER CARDS.

I. PURPOSE--
THIS PROGRAM WAS DESIGNED TO HAVE THE FOLLOWING FUNCTIONS.
1). TO SPLIT DATA INTO SUB-BASIN UNITS.
2). TO CHECK NO. OF CODE 1 AND CODE 3 FOR EACH SUB-BASIN UNIT.
3). TO PLOT THE DATA FOR EACH SUB-BASIN.
4). TO PUNCH DECK FOR EACH SUB-BASIN WHICH CONTAINS CODES 1 TO 6
MEETING THE INPUT REQUIREMENT OF M.A.T.E.R. SYSTEM.

II. INPUT FORMAT--
INPUT DATA OF THIS PROGRAM IS SPLIT INTO TWO CATEGORIES.
(a). DATA RETRIEVED FROM MAGNETIC TAPE.
  *1ST INPUT CARD--
  COL 1-4  BLANK
  COL 5   1
  COL 6-8  BLANK
  COL 9-10 WATERSHED NUMBER REQUESTED
  COL 11-19 BLANK
  COL 20  9 FOR LAST WATERSHED REQUESTED, OTHERWISE USE ANY NUM-
           BER Except 9.
  THIS CARD CAN BE REPEATED AS MANY TIMES AS USER WISHES.
(b). DATA RETRIEVED FROM COMPUTER CARDS.
  *1ST INPUT CARD--
  COL 1-4  BLANK
  COL 5   0
  COL 6-80 BLANK
  *2ND INPUT CARD--
  COL 1-50 WATERSHED NAME OR IDENTIFICATION.
  *3RD INPUT CARD--
  COL 1-5 NO. OF TOTAL SAMPLING POINTS.
  COL 6-10 NO. OF SUB-BASINS.
  COL 11-14 BLANK
  COL 15  9 FOR LAST DRAINAGE NETWORK DATA SET, OTHERWISE USE
           ANY NUMBER Except 9.
  * DRAINAGE NETWORK DATA SET NOT INCLUDE FIRST FOUR IDENTIFICATION
   CARDS (SEE REF. 20).
   DIMENSION X(3000), Y(3000), KD(3000), XR(3000), YR(3000), WN(50),
   * KR(3000), KCTR(40)
   DIMENSION XCR(20), YCR(20), JKE=0(20), XNEW(1000), YNEW(1000)
   COMMON XR, YR, KR, X, Y, KD
   CALL PLOTS

3939 CONTINUE
READ(5,113)NTP,K,KL, KOR
IF(NTP,LQ, 1) GO TO 321
113 FORMAT(4I5)
WRITE(6,496)
496 FORMAT(1H1, 10X,*THIS IS THE INFORMATION FOR PRIMARY CHECK*,// WTRD 22
KNT5=0  WTRD 23
KNT6=0  WTRD 24
KNT7=0  WTRD 25
KNT8=0  WTRD 26

******************************************************************************
*THIS IS THE PRIMARY CHECK INFORMATION

******************************************************************************
C

****************************************************************************
MC=0
READ(5,10)(WN(I),I=1,50)
10 FORMAT(50A1)
WRITE(5,10)(WN(I),I=1,50)
READ(5,11)NSPT,NSUBA,KOR
11 FORMAT(15,15,15)

****************************************************************************

*READ ON SCRATCH TAPE
****************************************************************************

N=NSPT
16 CONTINUE
IF(N.GT.999) GO TO 18
M=N
M=999
KKK=1
GO TO 19
18 M=999
19 DO 21 I=1,M,3
READ(5,22)((X(I+J-1),Y(I+J-1),KD(I+J-1)),J=1,3)
IF(EQV,F) 975,21
21 CONTINUE
975 CONTINUE
IF(KKK,NE. 1) GO TO 980
M=I+2
980 CONTINUE
22 FORMAT(10X,3(2F7.0,I2))
DO 495 I=1,M
IF(KD(I).EQ. 5) KNT5=KNT5+1
IF(KD(I).EQ. 5) GO TO 494
IF(KD(I).EQ. 6) KNT6=KNT6+1
IF(KD(I).EQ. 6) GO TO 494
IF(KD(I).EQ. 7) KNT7=KNT7+1
IF(KD(I).EQ. 7) GO TO 494
IF(KD(I).EQ. 8) KNT8=KNT8+1
IF(KD(I).EQ. 8) GO TO 495
IF(KD(I).LE. 4) GO TO 495
494 WRITE(6,497)(X(I),Y(I),KD(I))
495 CONTINUE
497 FORMAT(10X,2H1X,10X,F10.0,2H1X,10X,F10.0,2H1X,I5,/) WRITE(6)((X(I),Y(I),KD(I)),I=1,M)
MC=MC+1
IF(KKK,GT.0) GO TO 23
N=N-999
GO TO 16
23 CONTINUE
END FILE 8
REWIND 8
WRITE(6,499)KNT5,KNT6,KNT7,KNT8
499 FORMAT(1H1,10X,*NO. OF CODE 5*,I5/ 
* 10X,*NO. OF CODE 6*,I5/ 
* 10X,*NO. OF CODE 7*,I5/ 
*10X,*NO. OF CODE 8*, I5)
IF(KNT5,NE. 1 ) GOTO 501
IF(KNT7,NE. KNT8 ) GO TO 502
NSUBA=KNT7+1
IF(KNT7,NE. NSUBA-1 ) GO TO 503
WRITE(6,504)
504 FORMAT(1H1,10X,*PRIMARY CHECK IS O. K. PLEASE KEEP GOING ON CALL
*CALCOMP PLOT* //

* NOW THE DATA ARE ON THE SCRATCH TAPE *

* THE FUNCTION OF GET SUBROUTINE IS TO GET DATA FROM MAGNETIC TAPE *

* AND TO STORE ON SCRATCH TAPE *

321 CONTINUE
IF(NTP,EQ.,1)CALL GET(KK,WN,NSTP,NSUBA,KOR,MC, M)
CALL SYMBOL(0,0,0,0,0,2,11M L5115517,90,0,11)
CALL PLOT(2,0,0,0,-3)
WRITE(6,184)NSUBA

484 FORMAT(10X,*NUMBER OF SUB-BAII4*,I5)
NSUB=NSUBA
DO 149 NSJJ=1,NSUB
REWIND 8
JJK=1
K=1
WRITE(6,183)NSJJ

184 FORMAT(//,10X,*THIS IS THE SUB-BAII4N OF NO.4*I5)
DO 145 JJJ=1,MC
IF(JJJ,EQ,MC)GO TO 150
LEAD(JJJ)((X(JJJ),Y(JJJ),KD(JJJ)),J=1,999)
GO TO 151

150 READ(8)((X(JJJ),Y(JJJ),KD(JJJ)),J=1,M)

151 CONTINUE

IF(JJJ,EQ,MC)KM=M
DO 146 L=1,KM
IF(KD(L),EQ,5.OR.KD(L),EQ,7)GO TO 509
IF(KD(L),EQ,6)GO TO 201
GO TO 203

503 IF(KD(L),EQ,7)NWOLD=JK

200 IF(KCTR(JK),EQ,1.OR.KCTR(JK),EQ,-1)JK=JK+1
IF(KCTR(JK),EQ,-1)GO TO 206
KCTR(JK)=1
GO TO 203

201 KCTR(JK)=KCTR(JK)*(-1)

205 JK=JK-1
IF(JK,EQ,0)GO TO 190
IF(KCTR(JK),EQ,-1)GO TO 205
GO TO 148

"TO SORT THE DATA WHICH WE WANT."

203 IF(NSJJ,EQ,NWOLD)GO TO 915
NWOLD=0
IF(NSJJ,EQ,JK)GO TO 915
GO TO 148

915 XK(K)=X(L)
YK(K)=Y(L)
KK(K)=KD(L)
K=K+1
NWULD=0

143 CONTINUE
K=1
5
K(M)=6
KMNL=K
XK(K)=XR(1)
YK(K)=YR(1)
GO 478 NG=1,40
KCTP(NG) = 0
DO 2189 I = 1, K
X(I) = 0,
Y(I) = 0,
2189 CONTINUE
DO 487 I = 1, K
IF (K(I) EQ 3) KR(I) = 4
487 CONTINUE
CALL NUMBER(10, 0, 9, 0, 0, 2, NSJJ, 0, 2, 2H12)
CALL SYMBOL(9, 0, 9, 0, 0, 2, 4Harness, 0, 1, 4)
CALL SPLOT(NSJJ, KOUNT, XR, YYR, JSEND, YNEW, JJMAX)
170 FORMAT(1X, 6(5X, F6.0, F6.0, I3))
171 FORMAT(6(F6.0, F6.0, I3))
453 CONTINUE
WRITE(6, 170) ((XR(I), YR(I), KR(I)), I = 1, K)
DO 552 I = 1, K
552 FORMAT(1X, I3, 4X, 9X, (XR(I+J-1), YR(I+J-1), KR(I+J-1)), J = 1, 3)
556 FORMAT(I4, I2, 4X, 3(2F6.0, I2))
563 CONTINUE
K = 1
REWIND 8
149 CONTINUE
GO TO 951
561 WRITE (6, 507)
507 FORMAT(10X, *ERROR MESSAGES DUE TO CODE 5 AND CODE 6 ARE NOT UNIQUE*,
*/ **,//)
GO TO 951
502 WRITE (6, 508)
508 FORMAT(10X, *ERROR MESSAGES DUE TO CODE 7 AND CODE 8 ARE NOT EQUALEQUAL*,
*/ **, //)
GO TO 951
503 WRITE (6, 509)
509 FORMAT(10X, *ERROR MESSAGES DUE TO CODE 7 AND CODE 5 DO NOT MATCH WITH NO. OF SUBAREA. PLEASE CHECK ORIGINAL DRAINAGE MAP*,
*/ **, //)
951 CONTINUE
K = 0
DO 1210 I = 1; JMAX, 5
K = K + 1
X(K) = FLOAT(K) *.25
Y(K) = YNEW(I) + YNEW(I+1) + YNEW(I+2) + YNEW(I+3) + YNEW(I+4)
Y(K) = Y(K) *.2
1210 CONTINUE
KMAX = K
PUNCH1143, ((X(I), Y(I)), I = 1, KMAX)
WRITE (6, 1143) ((X(I), Y(I)), I = 1, KMAX)
1143 FORMAT(1X, *THIS IS THE LINK DISTRIBUTION*, /(1X, 3(2F10.2)))
CALL SETPLT(1, X, Y, KMAX, 1HX, 10, 10, N0, OF SEG)
XLENG = FLOAT(KMAX) *.25
WRITE (6, 1943) XLENG
REWIND 8
IF (KOR.EQ.0) GO TO 3999
GO TO 856
139 WRITE (6, 419)
419 FORMAT(1H1, // /* THERE ARE SOME ERRORS IN INDEX JK*, //)
856 CALL PLOT(0, 0, 399)
STOP
END

SUBROUTINE SBPLOT(NSJJ,KOUNT,XX,YR,JJEND,YNEW,JMAX)

*******************************************************************************
* THIS IS THE PROGRAM TO PLOT DRAINAGE MAP IN WATER RESOURCE DATA ANALYSIS *
*******************************************************************************

NSJJ=SUB-BASIN SEQUENCE NUMBER
KOUNT=INDEX TO COUNT THE MAXIMUM NUMBER OF SUB-BASINS.
XARR=ARRAY OF ALL CODES 7 IN SUB-BASIN NUMBER SEQUENCE.
YARR=ARRAY OF ALL CODES 7 IN SUB-BASIN NUMBER SEQUENCE.
JJEND=AN RUNNING INDEX OF ALL CODES 7 TO BASIN MOUTH.
YNEW=LINK DISTRIBUTION ARRAY OF EACH SUB-BASIN.
JMAX=NUMBER OF SAMPLING POINTS IN LINK DISTRIBUTION CURVE.

*******************************************************************************

DIMENSION YQ(1000)
DIMENSION XARR(200), YARR(200), JJEND(200), XNEW(1000), YNEW(1000)
DIMENSION X(3000), Y(3000), KD(3000), XR(3000), YR(3000), WN(50),
* KR(3000), KCTR(40)

DIMENSION NR(200), LR(200), KK(200)
DIMENSION LN(3000)

COMMON X, Y, KD, XR, YR, KR
DO 1253 I=1,3000
XR(I)=0
LN(I)=0
KR(I)=0

1253 YR(I)=0.
DO 1256 I=1,200
LN(I)=0
KR(I)=0

1256 NR(I)=0
MT=0
JEND=0
JMAX=0
JJ=6
M=0
K=0
N=0
KNT1=0
KNT3=0

17 N=N+1
K=K+1
IF(KD(N).EQ.1 .OR. KD(N).EQ.7) KNT1=KNT1+1
IF(KD(N).EQ.3) KNT3=KNT3+1
IF(KD(N).EQ.4) GO TO 14
IF(KD(N).EQ.1 .OR. KD(N).EQ.7) GO TO 15
M=M+1
NB(N)=N
L(M)=0
KK(M)=KD(N)
IF(KK(M).EQ.6) GO TO 16

14 XR(K)=X(N)
YR(K)=Y(N)
KR(K)=KD(N)
IF(KR(K).EQ.4 .OR. KR(K).EQ.5) GO TO 1152
NJ=NSTEP(XR(K),YR(K),XR(K-1),YR(K-1),5.,)
JJ=J+1
JFND=MT+NJ
MT=JEND
IF(JMAX.LT.JEND) JMAX=JEND
RETURN
END

SUBROUTINE GET(KK,WN,NSPT,NSUBA,KOR,NJC,KEY)
******************************************************************************
* THIS IS THE PROGRAM TO GET DATA FROM MAGNETIC TAPE *
******************************************************************************
KK=WATERSHED IDENTIFICATION NUMBER
WN=WATERSHED NAME
NSUBA=NUMBER OF SUB-BASINS IN A WATERSHED
KOR=AN INDEX, 9 FOR THE LAST WATERSHED PROCESSED, OTHERWISE
     INDICATE ANOTHER WATERSHED FOLLOW TO BE PROCESSED.
NJC=SUB-BASIN SEQUENCE NUMBER.
KEY=THE RESIDUAL NUMBER IN LAST READ RECORD ON MAGNETIC TAPE
******************************************************************************
DIMENSION XXR(20),YYR(20),JENC(20),XNEW(1000),YNEW(1000)
DIMENSION X(3000),Y(3000),KD(3000),XR(3000),YR(3000),WN(50),
     * KR(3000),KCTR(40)
COMMON XR,YYR,XR,FR,KD
CALL TAPELMT(1)
CALL FILERET(5LTAPE4,4L1400,1WHAT WIREAD ,0)
REWIN 4
70 CONTINUE
    M=999
11 FORMAT(215)
30 IF(EOF,4)330,320
320 READ(4)(WN(I),I=1,50),NSPT,NSUBA,KOR,NW
     NF=NSPT/999+1
     KEY=NSPT-(NJC-1)*999
     IF(WN.EQ.KK)GO TO 20
     DO 25 I=1,NJC
     IF(EOF,4)330,25
25 READ(4)
     IF(EOF,4)330,70
20 WRITE(6,35)(WN(I),I=1,50),NSPT,NSUBA,KOR,NW
35 FORMAT(1H1,1X,50A1,1X,4I10)
     DO 60 I=1,NJC
     IF(I.EQ.NJC)M=KEY
     READ(4)((X(J),Y(J),KD(J)),J=1,M)
     WRITE(6,55)((X(K),Y(K),KD(K)),K=1,M)
     WRITE(6) ((X(K),Y(K),KD(K)),K=1,M)
55 FORMAT(1X,9(2F6.0,I2))
60 CONTINUE
REWIN 6
CALL FILERET(5LTAPE4,6LREDUCE)
RETURN
330 STOP
END
******************************************************************************
THIS IS THE FUNCTION TO CALCULATE THE DISTANCE BETWEEN TWO
POINTS AND BE SAMPLED AT DISCRETE POINT.
******************************************************************************
A=X COORDINATE OF 1ST POINT
B=Y COORDINATE OF 1ST POINT
C=X COORDINATE OF 2ND POINT
D=Y COORDINATE OF 2ND POINT
UNIT=SAMPLING INTERVAL
******************************************************************************
FUNCTION NSTEP(A,B,C,D,UNIT)
    DIST=SQRT((A-C)*(A-C)+(B-D)*(B-D))
    TOTAL=(DIST+UNIT/2.)/UNIT
RETURN
******************************************************************************
21 FORMAT(10X, 'THIS IS THE LIST OF RE-ARRANGEMENT OF FUNDAMENTAL
       * DATA' // (1X, 3(2X, F6.0, 2X, F6.0)))
WRITE(6, 944) KNT1, KNT3
944 FORMAT(1H1, ' ', 10X, ' THESE ARE THE MESSAGES OF NO. OF CODE 1 AND 5',//
       *E 3*, ' ', 10X, ' NO. OF CODE 1*, I5',//
       * 10X, ' NO. OF CODE 3*, I5)
WRITE(6, 945)
XMAX=XR(1)
YMAX= YR(1)
XMIN=XR(1)
YMIN=YR(1)
DO 158 I=1, KMAX
IF(NSJ, .NE. 1) GO TO 558
IF(KR(I).NE. 4) GO TO 558
XR(I)=XR(I)
YR(I)=YR(I)
553 CONTINUE
IF(XR(I).LE. XMIN) XMIN=XR(I)
IF(YR(I).LE. YMIN) YMIN=YR(I)
IF(XR(I).GE. XMAX) XMAX=XR(I)
IF(YR(I).GE. YMAX) YMAX=YR(I)
158 CONTINUE
157 CONTINUE
KMAX1=KMAX+1
KMAX2=KMAX+2
XR(KMAX1)=XMIN
XR(KMAX2)=(XMAX-XMIN)/2.
YR(KMAX1)=YMIN
YR(KMAX2)=(YMAX-YMIN)/2.
IF(XR(KMAX2).GT. YR(KMAX2)) GO TO 24
XR(KMAX2)=YR(KMAX2)
GO TO 25
24 YR(KMAX2)=XR(KMAX2)
25 CALL AXIS(0, 0, 0, 6HX AXIS, 6, 6, 0, 0, 0, 0, XR(KMAX1), XR(KMAX2), -0)
CALL AXIS(0, 0, 0, 6HY AXIS, 0, 0, 0, 0, 0, YR(KMAX1), YR(KMAX2), -1)
CALL LINE(XR, YR, KMAX1, 1, 1)
CALL PLOT(12.0, 0.0, -3)
UNIT=5.
DY=2.
DO 1135 I=1, JMAX
1135 YQ(I)=LN(I)/DY
WRITE(6, 1143) ((I, YQ(I)), I=1, JMAX)
1143 FORMAT(1X, *LENGTH FREQUENCY*, /(1X, 6(I10, F10.2)))
1148 FORMAT(4(2F10.3))
WRITE(6, 1144)
1144 FORMAT(1H1)
1144 IF(NSJ, .EQ. 1) JBEG=0
1144 IF(NSJ, .EQ. 1) GO TO 2510
DO 2200 KSR=1, 20
2200 CONTINUE
IF(KR(I).EQ. XRXR(KSR), AND, YR(I).EQ. YR(KSR)) GO TO 2310
2200 CONTINUE
WRITE(6, 2410)
2410 FORMAT(1X, *THERE ARE SOME ERRORS IN CODE 7 STORAGE*)
STOP
2310 JBEG=JEND(KSR)
2310 CONTINUE
DO 2320 I=1, JMAX
2320 YNEW(I+JBEG)=YQ(I)+YNEW(I+JBEG)
IF((JMAX+JBEG).GE. JMAX) JMAX=JMAX+JBEG
NSSTEP=TOTAL
RETURN
END