5-1974

Interactive Hybrid Computer Program as an Aid for Teaching Hydrology

Arif Hikmet Atali

Utah State University

INTERACTIVE HYBRID COMPUTER PROGRAM AS AN AID FOR TEACHING HYDROLOGY

by

Arif Hikmet Atali

A report submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil Engineering

Plan B

UTAH STATE UNIVERSITY
Logan, Utah

1974

TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

INTRODUCTION

The science of water resource planning and management implies the utilization of available water supplies in order to meet specific goals and objectives (Hill and Riley, 1972). Essential to effective planning and management is the consideration and analysis of all possible alternatives. Past research at Utah State University has demonstrated that the hybrid computer simulation of hydrologic processes is a reliable planning technique which provides the capability to examine many possible alternatives in a short period of time (Hill et al., 1970; Riley, 1970; and Riley et al., 1967). This technique, because of its interactive characteristics, is valuable also in teaching some basic concepts of hydrology and water resource management.

Hill and Riley (1972) developed a basic simulation model to demonstrate storm-runoff relations. Past experience has proven that the exposure of undergraduate students to dynamic computer models would produce beneficial results such as an increased understanding of basic hydrologic concepts through personal involvement.

The author has taken this basic model and expanded it to include routing processes. Dynamic scaling and a question and answer type of interaction between student and computer (SUBROUTINE QUET) are added to the model to make it more realistic and attractive.

This report presents a brief explanation of basic concepts which are involved in the model, description and advantages of the hybrid computer, description of the model, and the beneficial results of the student-computer interaction.

BASIC CONCEPTS OF A HYDROLOGIC SYSTEM

Runoff

From the hydrologic point of view, the runoff from a drainage basin may be considered as a product in the hydrologic cycle, which is influenced by two major groups of factors: climatic factors and physiographic factors. Climatic factors include mainly the effects of various forms and types of precipitation, interception, evaporation, and transpiration, all of which exhibit seasonal variations in accordance with the climatic environment. Physiographic factors may be further classified into two kinds: basin characteristics and channel characteristics. Basin characteristics include such factors as size, shape, and slope of drainage area, permeability and capacity of groundwater formations, presence of lakes and swamps, and land use. Channel characteristics are related mostly to hydraulic properties of the channel which governs the movement of streamflows and determines channel storage capacity (Chow, 1964).

Infiltration

One of the basic concepts of hydrology is infiltration, which, in general terms, is that water which enters the earth. Infiltration affects many aspects of hydrology, such as surface runoff, the moisture content of the soil, transpiration by plants, and the evaporation of soil moisture. Infiltration reflects the soil characteristics and land-use patterns of the basin.

Evapotranspiration

Evapotranspiration is another term to be defined in the hydrologic cycle: it is the process by which water is evaporated from wet surfaces and transpired by plants.

Surface runoff from storms is a function of several things. Various watershed characteristics such as vegetative cover and soil properties influence the amount of water available for runoff. Storm time patterns of precipitation intensity and duration influence the relative amounts of rain which are abstracted by the processes of interception, depression, and infiltration. Channel outflow is influenced by the slope and size of the basin, which affect the rise time. The figure below serves to illustrate some of the basic relations of hydrologic processes.

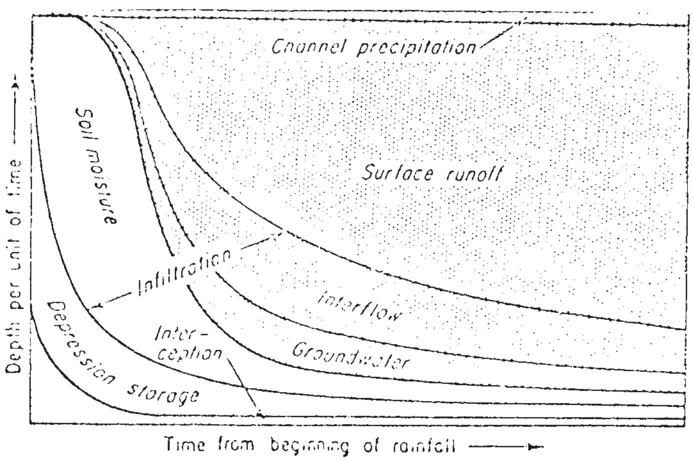


Figure 1. Schematic diagram of the disposition of storm rainfall (from Linsley et al., 1958).

DESCRIPTION AND ADVANTAGES OF HYBRID COMPUTERS

The hybrid computer is composed of two parts: digital and analog.

Digital Computer

Data input into the digital occurs through punched cards, magnetic tape, or from teletype. The digital computer is a sequential machine which does one thing at a time. The digital processes the data, stores the data, and transfers appropriate data to and from the analog.

Analog Computer

The analog computer is a parallel device in that all computations proceed simultaneously. Many of the processes which occur in nature are time dependent and as such are differential in form. The computations on the analog computer can be visualized as analogous to the processes occurring simultaneously in nature. It is in the solution of differential equations that the speed and parallel computation of the analog computer is particularly apparent because it can integrate the problem variables continuously instead of using numerical approximations. Visual response (graphical outputs) is obtained from the analog computer.

Hybrid computing systems gather the advantages of digital and analog computers. The hybrid computing system model provides the capability to examine many possible alternatives in a short period of time. The operator can visualize the results as being the actual

dynamic responses of the physical system under investigation. The interaction between the operator and the computer makes hybrid computer models attractive and useful from an educational viewpoint. Figure 2 shows the elements of hybrid computing system at the Utah Water Research Laboratory.

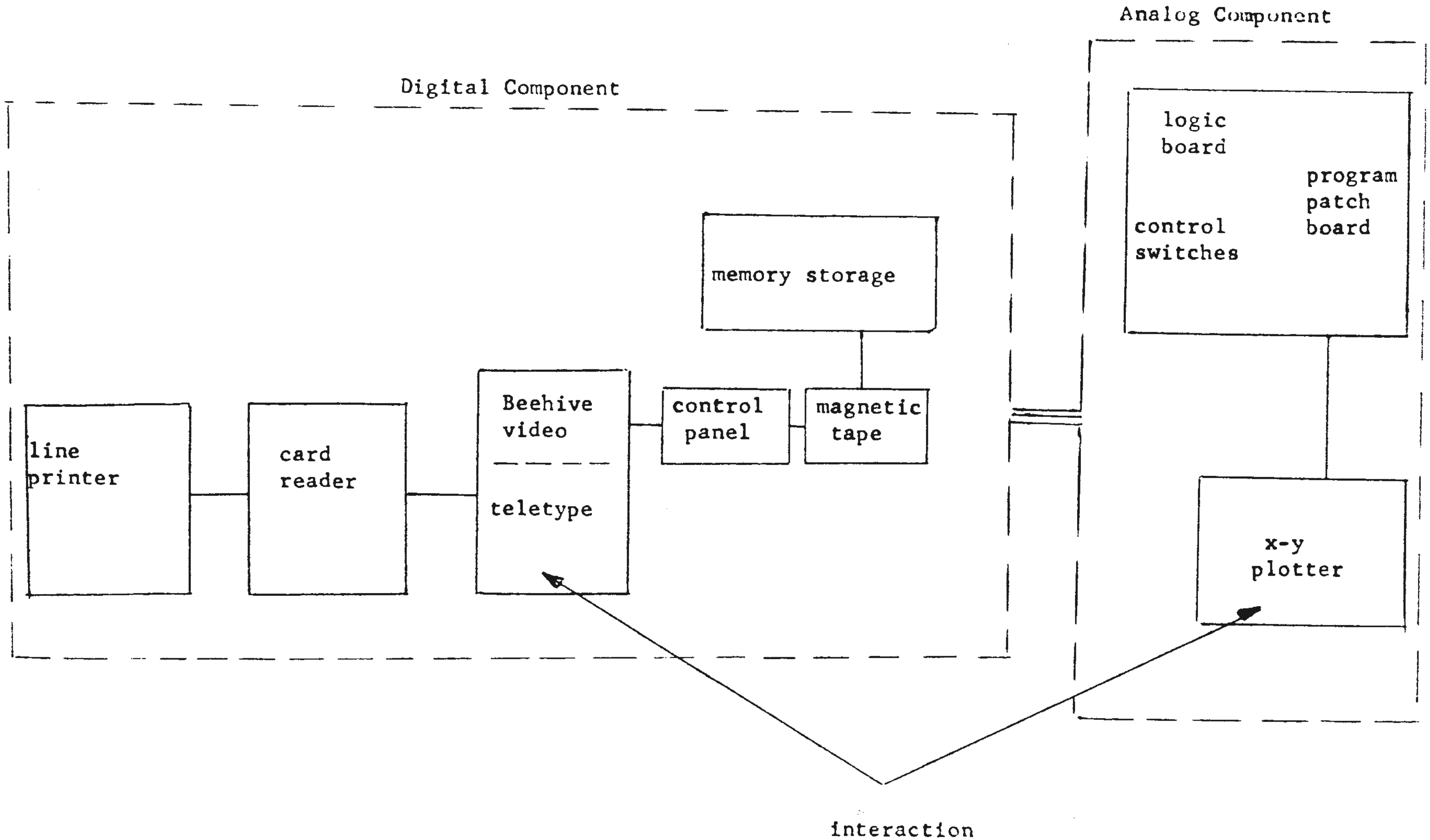


Figure 2. Hybrid computing system set-up at Utah Water Research Laboratory.

DESCRIPTION OF THE HYDROLOGIC MODEL

The basic concepts of the hydrological system were developed into a model which was programmed on a hybrid computer (see the listing and analog diagram in Appendix A for programming details). One result of developing hydrological system models on the computer is the identification of significant physical processes. System parameter changes relating to these processes can then be made easily and the effects rapidly determined.

For the sake of simplicity this model deals only with the upper portion (subsystem) of the system shown below (enclosed with dashed lines).

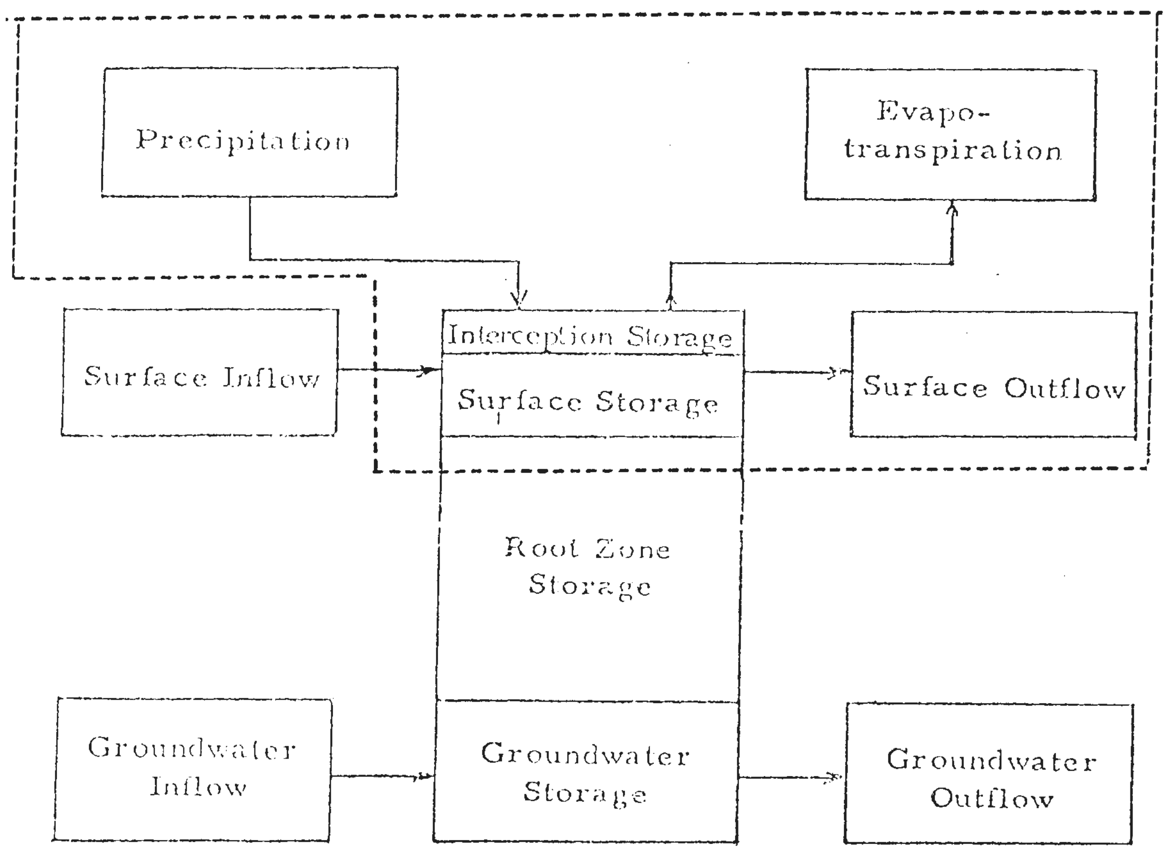


Figure 3. Block diagram of hydrologic processes.

A flow diagram of the various hydrologic processes which are represented by the model is shown in Figure 4.

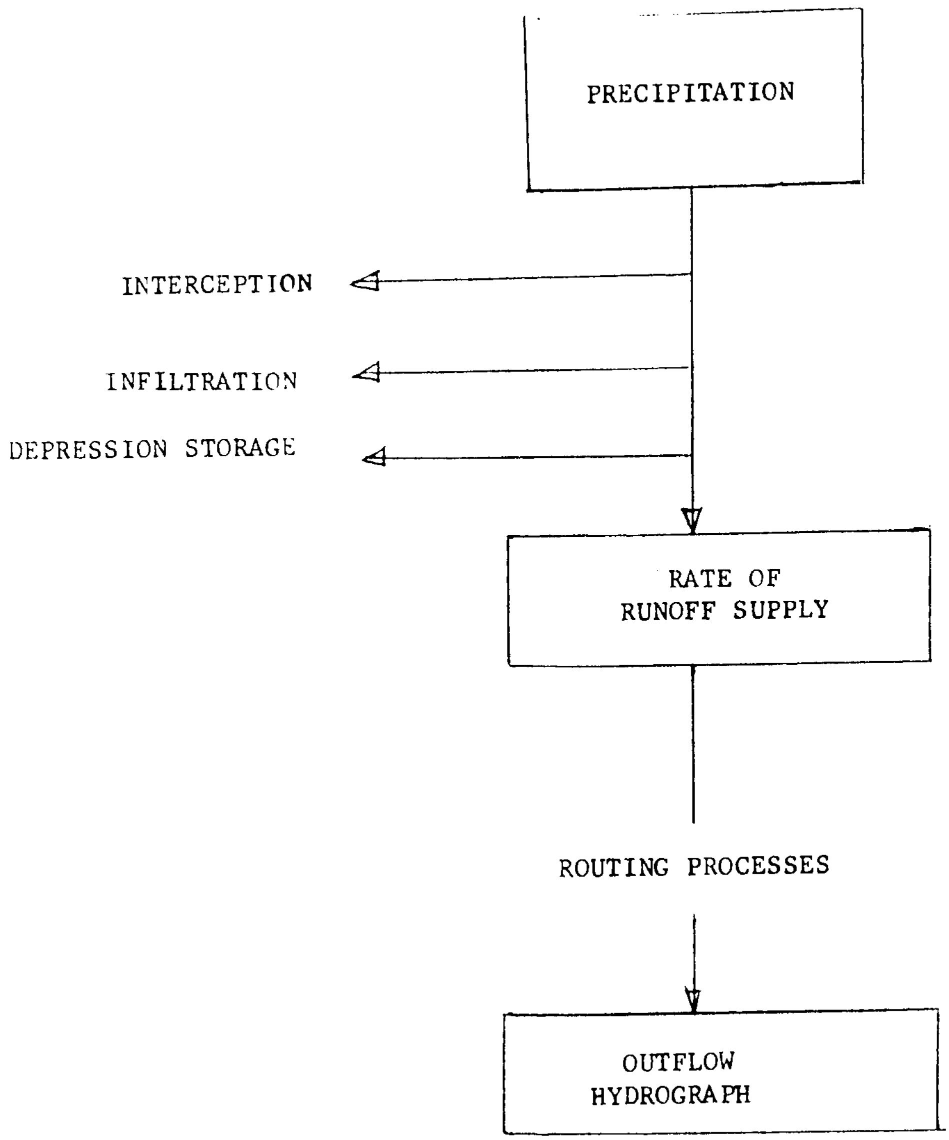


Figure 4. Schematic representation of watershed for hydrograph synthesis.

For the system represented by this model the supply minus the abstractions will determine the amount of runoff available. Figure 5 is a schematic representation of this simplified process.

Since both the interception and depression storage rates can be represented by similar mathematical expressions, in the model they are lumped together and called interception plus depression storage (IPD), or retention storage. The mathematical expression used to represent the combined processes is as follows:

$$\frac{d(IPD)}{dt} = -K(IPD) \qquad (1)$$

in which

IPD = interception plus depression storage capacity rates,

K = a constant, representing physical characteristics of the watershed foliage and ground surface.

Infiltration is considered to be a function of soil moisture and certain other soil characteristics. A linear approximation of the actual relationship (as shown in Figure 6) is used in the model.

The values of Io, Im, and Ic in (inches/hour) corresponding to dry, the wilting point (WP), and field capacity (FC) moisture contents come from data describing the particular soil used. The model was simplified by considering the soil as a single layer composed of the top few inches of the actual soil profile. The soil moisture level as a function of time is represented by the following equation:

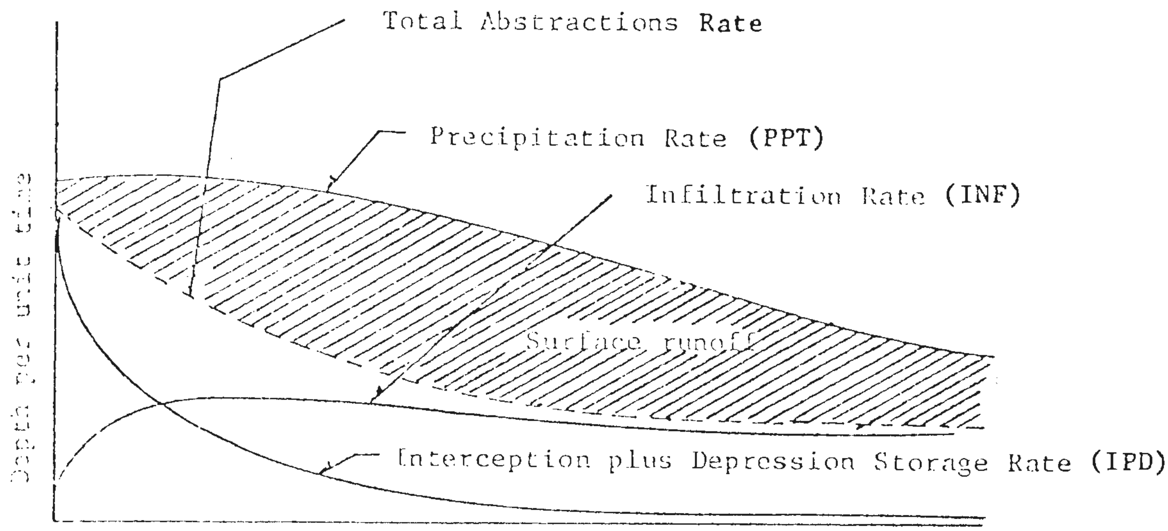


Figure 5. Storm supply and abstraction.

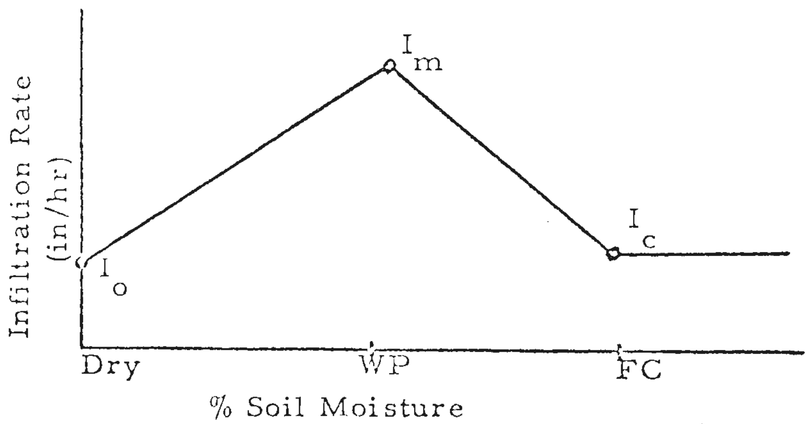


Figure 6. The linear approximation of infiltration function.

$$SM = SMI + \int (INF)\, dt \tag{2}$$

in which

SM = soil moisture level (inches of water),

SMI = initial soil moisture at beginning of storm (inches),

INF = actual rate of infiltration (inches/time).

A function generator is used on the analog computer to provide the necessary link between soil moisture and infiltration for use in the model.

Surface runoff, then, becomes the integral of the rainfall minus abstractions or:

$$RO = \int (PPT - IPD - INF)\, dt \tag{3}$$

in which

PPT = precipitation rate (inches/time) and the other variables are as previously defined.

The digital computer stores characteristic data for the storm and soil types encountered on the watershed. Equations 1, 2, and 3 are solved on the analog computer. In addition, the infiltration function is generated on this component. Whenever the rainfall rate is less than the potential total abstractions, the abstractions are decreased to match the supply, thus providing for proper mass balance in the system. The channel routing process is added to make the model more realistic and to compute the channel outflow for the whole basin.

What makes the model a teaching aid is the close interaction between the operator (the student) and the model, and its capability for sensitivity studies (which is explained in the next section).

The comments, consisting of a brief explanation of the model, are typed out on the screen in the beginning of the interaction; then there is a multiple-choice fun quiz. There are five questions with three possible answers for each question. After the question is typed out, the operator types his answer, and the computer types out whether the answer given by the operator is correct or not. It records two points for each correct answer and gives the final grade at the end of the quiz. (See Appendix C for sample outputs.)

SENSITIVITY STUDIES

Studies in which parameters are changed over a range of values are called sensitivity studies. Hybrid computer models become valuable aids in water resources planning studies which require the evaluation of many alternatives. For example, the model may take only five seconds to simulate events occurring during a real life period of several hours.

Two examples are given in Figures 7 and 8. Many other changes are possible (see the Instructions Manual in Appendix D for the parameters which can be changed and the procedure to be followed). In the first example, the operator has tried three different values for Initial Soil Moisture (ISM) and has observed the response (runoff). In the second example the operator has observed the effect of rise time on channel outflow. The channel outflow is delayed for greater rise time as was expected.

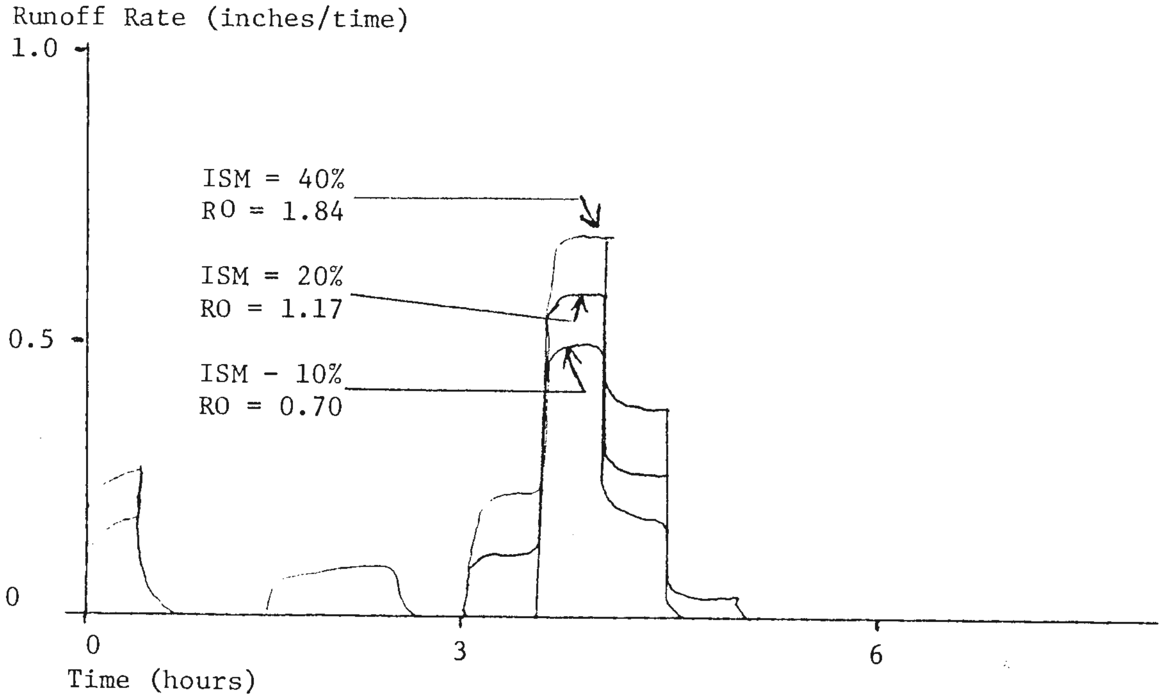


Figure 7. Example 1: Surface runoff as affected by changes of initial soil moisture.

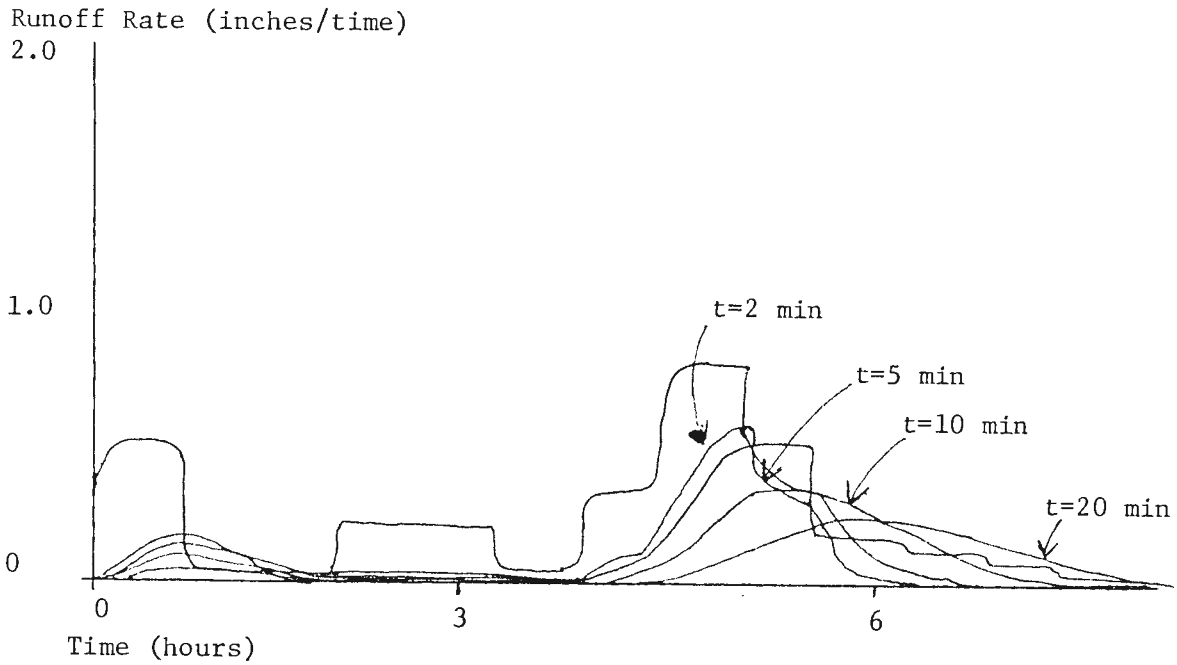


Figure 8. Example 2: Surface runoff as affected by changes of rise time.

OTHER INTERACTIVE PROGRAMS ALREADY DEVELOPED AT UTAH STATE UNIVERSITY

Other interactive programs have been developed in different subjects at Utah State University. Dr. W.O. Carter, Professor of Civil and Environmental Engineering, has developed a computer model for structural design. Dr. R. Hurst, Professor of Applied Statistics and Computer Science, has developed several interactive programs in the field of statistics. These interactive programs are being used as teaching aids as well as for professional uses.

All of these interactive computer programs have one common advantage: these programs eliminate the tedious work and enable the user to look into basic concepts more carefully. The user also has the opportunity to examine the possible alternatives in a very short time. This gives a better perspective of the problem and results in better solutions, and objective answers. Common sense and personal judgment, however, should always be used to check the answers against any manmade computer mistakes.

CONCLUSIONS

This simplified model is representative of more complex simulation models, and it reflects the capability of simulation models developed for water resources planning and management. It is, at the same time, an aid for teaching basic concepts of hydrology to undergraduate engineering students. In Winter Quarter of 1972-73 the undergraduate hydrology (CEE 443) students were exposed to the model, and the results indicated a significant increase in students' knowledge of basic concepts of hydrology. The students' comments about the model were positive. Some students (about 25 percent of the class) wanted to have more time on the computer to be able to exercise more sensitivity studies. Hopefully, this extra time will be given to the students in the future, for better performance.

This interactive model is also used for demonstrations at Utah Water Research Laboratory for casual visitors.

SELECTED REFERENCES

Chow, Ven Te. 1964. Handbook of Applied Hydrology. McGraw-Hill Book Company, Inc., New York. 1453 p.

Hill, Robert W. and J. Paul Riley. 1972. Interactive hybrid computer simulation for teaching hydrology and water resource management. ASEE, Annual Conference, June 19-22, 1972. Texas Tech. University, Lubbock, Texas. 20 p.

Hill, Robert W., Eugene K. Israelsen, A. Leon Huber, and J. Paul Riley. 1970. A hydrologic model of the Bear River basin. Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah. 85 p.

Linsley, Ray K., Jr., Max A. Kohler, and Joseph L.H. Paulhus. 1958. Hydrology for Engineers. McGraw-Hill Book Company, Inc. New York. 340 p.

Riley, J. Paul. 1970. Computer simulation of water resource systems at Utah State University. Occasional Papers, Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah. 20 p.

Riley, J. Paul, Duane G. Chadwick, and Eugene K. Israelsen. 1967. Application of an electronic analog computer for the simulation of hydrologic events on a southwest watershed. Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah. 53 p.

APPENDIXES

Appendix A:

1. Program Listing

2. Analog Diagram

```
PAGE  1     C      MAIN PROGRAM FOR INTERACTIVE HYBRID COMPUTER SIMULATION


C       OF STORM SURFACE RUNOFF
C       WRITTEN BY R. W. HILL  MARCH, 1972
C       DYNAMIC SCALING,SUBROUTINE QUET ,AND ROUTING ADDED BY  A.H. ATALI
        COMMON FR(12),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
       1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
       2QUEST(5,126),IQST(5),IANS(5)
C       SET UP ANALOG UNITS
        CALL QSHYIN(IE,580)
        CALL QSC(1,IE)
        DO 2 I=1,10
        A(I)=0.0
      2 B(I)=0.0
        CALL QWBDAR(A,0,8,IE)
        CALL QSTPA
        CALL QRBADR(A,0,10,IE)
        CALL QWLRB('00000,IE)
        CALL QRLRB(ISL,IE)
      1 READ(6,100) ITY,IFNT
        IPR=0
        IF(ITY)99,99,3
      3 GO TO (10,20,30,55,60,60),ITY
    100 FORMAT(4I5)
C       READ INITIAL DATA,COMMENTS FORTTY
C       IFNT=1 RD ONLY COMMENTS,IFNT=2 RD SOILS AND STORM DATA
     10 CALL DAT(ITY,IFNT)
        IF(IFNT-1)1,1,23
     20 CALL DAT(ITY,IFNT)
        IF(IFNT-1)1,1,23
     23 CALL SIML(0)
        J     .53
     30 CALL DAT(ITY,IFNT)
     55 CALL ROSM
        J     .1
C       INTERACTIVE PORTION
     60 WRITE(6,106)
    106 FORMAT(1H1)
        TYPE 62,(COM(M),M=1,28)
        WRITE(6,62)(COM(M),M=1,28)
     62 FORMAT(18A4)
     51 TYPE 109
    109 FORMAT(/9H          ?)
        ACCEPT 101,XNM(1),XNM(2)
    101 FORMAT(2A4)
        TYPE 64,(COM(M),M=29,31),XNM(1),XNM(2)
        WRITE(6,64)(COM(M),M=29,31),XNM(1),XNM(2)
     64 FORMAT(5A4)
        TYPE 62,(COM(M),M=32,53),XNM(1),XNM(2),(COM(L),L=54,64)
        WRITE(6,62)(COM(M),M=32,53),XNM(1),XNM(2),(COM(L),L=54,64)
        TYPE 62,(COM(M),M=65,252)
        WRITE(6,62)(COM(M),M=65,252)
        IF(ITY.EQ.6) CALL QUET
        PAUSE 0101
        TYPE 62,(COM(M),M=253,576)
        WRITE(6,62)(COM(M),M=253,576)
        WRITE(6,106)
     70 TYPE 103
```

```
PAGE  2      C      MAIN PROGRAM FOR INTERACTIVE HYBRID COMPUTER SIMULATION
      WRITE(6,103)
  103 FORMAT(/11H   PAR,   VAL/)
      ACCEPT104,IPR,VAL
      WRITE(6,104)IPR,VAL
  104 FORMAT(I5,F10.0)
      IF(IPR)74,90,75
   74 IF(IPR+2)70,60,73
   73 CALL DAT(2,2)
      CALL SIML(0)
      J    .70
   75 IF(IPR-11)76,78,76
   76 PR(IPR)=VAL
      CALL SIML(IPR)
      J    .70
   78 TYPE 105
      WRITE(6,105)
  105 FORMAT(/13H  INT, INCHES/)
      ACCEPT 104,INT,DEP
      WRITE(6,104)INT,DEP
      IF(INT)70,70,79
   79 PPT(INT)=DEP
      J    .78
C     PERFORM SIMULATION
   90 CALL ROSM
      J    .70
   99 STOP
      END
```

PAGE 1

```
      SUBROUTINE DAT(ICN,IRET)
      COMMON PR(10),WPI,FCI,SMT,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IFC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2QUEST(5,126),IQST(5),IANS(5)
      GO TO (10,20,30),ICN
   10 TYPE 53
   53 FORMAT( 9H  INITIAL/)
      READ(6,551)NPTS
  551 FORMAT(I5)
      READ(6,52)(PN(I),I=1,NPTS)
   52 FORMAT(20A4)
      READ(6,51)(COM(M),M=1,576)
   51 FORMAT(18A4)
      DO 43 K=1,5
   43 READ(6,13) (QUEST(K,I),I=1,126)
   13 FORMAT(18A4)
      IF(IRET.EQ.1)RETURN
   20 TYPE 54
   54 FORMAT(7H  SOILS/)
      READ(6,55) DRWT,(PR(I),I=1,8),PR(10)
   55 FORMAT(16F5.0)
      IF(IRET.EQ.1) GO TO 60
   30 TYPE 56
   56 FORMAT(7H  STORM/)
      READ(6,57)NPT,NIH,PR(9),(FMT(I),I=1,5)
   57 FORMAT(2I5,F5.0,5X,5A4)
      READ(6,FMT)(PPT(I),I=1,NPT)
      IF(NIH.LE.1) GO TO 33
      DT=PR(9)
      DO 32 I=1,NPT
   32 PPT(I)=PPT(I)*DT/60.0
   33 WRITE(6,59)
   59 FORMAT(//20X,15HPPT INPUT,IN/DT/)
      WRITE(6,58)(PPT(I),I=1,NPT)
   58 FORMAT(10F5.2)
C     DETERMINE SCL,SCF
   60 TDX=PR(9)/60.
      FCI=PR(5)*DRWT*12.0/6240.
      WPI=PR(4)*DRWT*12.0/6240.
      SCL1=PR(7)*TDX
      SCL2=FCI
      SCLA=SCL2
      IF(SCL1.GE.SCL2)SCLA=SCL1
      AXP=0.0
      DO 3 I=1,NPT
      IF(PPT(I).GE.AXP)AXP=PPT(I)
    3 CONTINUE
      SCL3=AXP
      SCL=SCL3*1.2
      IF(SCLA.GE.SCL3)SCL=SCLA*1.2
      SCF1=(PR(8)-PR(7))*TDX/(FCI-WPI)
      SCF2=(PR(7)-PR(6))*TDX/WPI
      SCF=SCF2*1.2
      IF(SCF1.GE.SCF2)SCF=SCF1*1.2
      IF(SCF.GT.10.)WRITE(6,1)SCF
    1 FORMAT(/10X,4HSCF=,F10.3/)
```

```
      IF(SCF.GT.10.0)SCF=10.0
      RETURN
      END


      SUBROUTINE QUET
      COMMON PR(10),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TOX,
     2QUEST(5,126),IOST(5),IANS(5)
      PAUSE 3101
      IGRD=3
C     CORRECT ANSWERS ARE AS FOLLOWS
      IANS(1)=3
      IANS(2)=2
      IANS(3)=1
      IANS(4)=3
      IANS(5)=1
C     SEVEN CARDS FOR EACH QUESTION,USE COLUMNS 2-72
      DO 13 N=1,5
      TYPE 10,(QUEST(N,I),I=1,126)
   10 FORMAT(// (18A4))
      WRITE(6,10) (QUEST(N,I),I=1,126)
      TYPE 500
  500 FORMAT(/3H  0)
      ACCEPT 20,IOST(N)
   20 FORMAT(I1)
      IF(IOST(N).EQ.IANS(N)) GO TO 55
      TYPE 30, IANS(N)
      WRITE(6,30) IANS(N)
   30 FORMAT(/,1X,17HNO, THE ANSWER IS,3X,I1)
      GO TO 13
   55 IGRD=IGRD+2
      TYPE 40, (XNM(J),J=1,2)
      WRITE(6,40) (XNM(J),J=1,2)
   40 FORMAT(/,1X,3HYES,2X,2A4,1H,,23HYOUR ANSWER IS CORRECT.)
   13 CONTINUE
      TYPE 50, (XNM(J),J=1,2),IGRD
      WRITE(6,50) (XNM(J),J=1,2),IGRD
   50 FORMAT(////,5X,2A4,1H,,14HYOUR GRADE IS,2X,I3)
      IF(IGRD.GT.7) GO TO 333
      TYPE 111
      WRITE(6,111)
  111 FORMAT(1X,23HNOT TOO GOOD, TRY AGAIN)
      GO TO 222
  333 TYPE 222
      WRITE(6,222)
  222 FORMAT(1X,9HVERY GOOD)
      RETURN
      END
```

PAGE 1

```
      SUBROUTINE SIML(IPR)
      COMMON PR(10),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2QUEST(5,125),INST(5),IANS(5)
      IF(IPR.LE.0) GO TO 50
      GO TO (5,10,15,20,25,30,35,40,45,48),IPR
    5 VAL=PR(1)*DRWT*12.0/(6240.0*SCL)
      P=PN(1)
      J    .46
   10 VAL=PR(2)*PR(9)/(60.0*SCL)
      P=PN(2)
      J    .46
   15 VAL=PR(9)*4.8/(PR(3)*10.0)
      P=PN(3)
      J    .46
   20 CALL DA1
      CALL DA2
      CALL DA6
      J    .47
   25 CALL DA1
      CALL DA5
      J    .47
   30 CALL DA2
      CALL DA4
      J    .47
   35 CALL DA1
      CALL DA2
      CALL DA3
      J    .47
   40 CALL DA1
      J    .47
   45 CALL DA1
      CALL DA2
      CALL DA3
      CALL DA4
      J    .47
   46 CALL OWPR(P,VAL,IE)
      RETURN
   47 CALL OWRDAR(A,01,05,IE)
      CALL SSTDA
      RETURN
C     SET ALL ANALOG VALUES
   48 VAL=PR(9)/(10.0*PR(10))
      P=PN(6)
      CALL OWPR(P,VAL,IE)
      P=PN(9)
      CALL OWPR(P,VAL,IE)
      P=PN(8)
      CALL OWPR(P,VAL,IE)
      P=PN(7)
      J    .46
   50 VAL=SCF/10.0
      P=PN(4)
      CALL OWPR(P,VAL,IE)
      P=PN(5)
      CALL OWPR(P,VAL,IE)
```

PAGE 2

```
      SMI=PR(1)*DRWT*12.0/6240.
      VAL=SMI/SCL
      P=PN(1)
      CALL GWPR(P,VAL,IE)
      VAL=PR(8)*PR(9)/(60.0*SCL)
      P=PN(2)
      CALL GWPR(P,VAL,IE)
      VAL=PR(9)*4.6/(PR(3)*10.0)
      P=PN(5)
      CALL GWPR(P,VAL,IE)
      VAL=1.0/PR(10)
      P=PN(6)
      CALL GWPR(P,VAL,IE)
      P=PN(7)
      CALL GWPR(P,VAL,IE)
      CALL DA1
      CALL DA2
      CALL DA3
      CALL DA4
      CALL DA5
      CALL DA6
      CALL GWEDAR(A,01,06,IE)
      CALL GSTDA
      WRITE(6,52)SMI,WPI,FCI,(PR(I),I=1,9),SCL,PR(10)
   52 FORMAT(//10X,11HSOIL VALUES/10X,3F7.2/10X,9F7.2/10X,2F7.2/)
      RETURN
      END
      SUBROUTINE DA1
      COMMON PR(10),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2QUEST(5,126),IQST(5),IANS(5)
      WPI=PR(4)*DRWT*12.0/6240.
      FCI=PR(5)*DRWT*12.0/6240.
      TDX=PR(9)/60.0
      A(1)=((PR(5)-PR(7))*TDX/(FCI-WPI))/SCF
      RETURN
      END


      SUBROUTINE DA2
      COMMON PR(10),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2QUEST(5,126),IQST(5),IANS(5)
      A(2)=((PR(7)-PR(6))*TDX/WPI)/SCF
      RETURN
      END
      SUBROUTINE DA3
      COMMON PR(10),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2QUEST(5,126),IQST(5),IANS(5)
      A(3)=-PR(7)*TDX/SCL
      RETURN
      END


      SUBROUTINE DA4
      COMMON PR(10),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2QUEST(5,126),IQST(5),IANS(5)
      A(4)=-PR(6)*TDX/SCL
      RETURN
      END
```

PAGE 1

```
      SUBROUTINE DA5
      COMMON FP(1Ø),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(1ØØ),PN(1Ø),XNM(4),
     1IFC(35),FMT(5),NPT,NIH,A(1Ø),B(1Ø),NL,COM(56Ø),XL,XPS,TPI,YPS,TOX,
     2QUEST(5,126),IQST(5),IANS(5)
      A(5)= FCI/SCL
      RETURN
      END

      SUBROUTINE DA6
      COMMON FP(1Ø),WPI,FCI,SMI,DRWT,SCL,SCF,PPT(1ØØ),PN(1Ø),XNM(4),
     1IEC(35),FMT(5),NPT,NIH,A(1Ø),B(1Ø),NL,COM(576),XL,XPS,TPI,YPS,TOX,
     2QUEST(5,126),IQST(5),IANS(5)
      A(6)= WPI/SCL
      RETURN
      END
```

```
      SUBROUTINE ROSM
      COMMON PR(10),HPI,FCI,SMI,DRWT,SCL,SCF,PPT(100),PN(10),XNM(4),
     1IFC(35),FMT(5),NPT,MIN,A(10),B(10),NL,COM(576),XL,XPS,TPI,YPS,TDX,
     2HOST(5,120),IOST(5),IANS(5)
C     PRINT PAGE HEADINGS
      WRITE(6,100)NPT,PR(9)
  100 FORMAT(1H1/34X,17HRUNOFF SIMULATION/34X,2HN=,I5,5H  T= ,F6.0,
     14H MIN//19X,1HI,5X,3HPPT,7X,3HIPD,7X,3HINF,8X,2HRO,8X,2HSM,7X,3HCH
     20//)
      CALL OSIC(IE)
C     LOWER PEN AND SET UP COUNTER
      CALL OWLBB('40000,IE)
C     INITIALIZE STORM TOTALS
      VRO=0.0
      VINF=0.0
      VIPD=0.0
      VPPT=0.0
      VCRD=0.0
      L=1
      CALL OSDLY(100)
C     DO FOR EACH INTERVAL
      DO 50 I=1,NPT
      LA  I
      S    NPT
      OCT 027407
      J    .33
   20 PT= PPT(L)/SCL
      LA  L
      S   /1
      OCT 027410
      J    .33
C     OPERATE ANALOG AFTER TRANSFER OF PT
   28 CALL OWDAR(PT,03,IE)
C     RESET CLOCK AND MONTHLY INTEGR. KEEP PEN DOWN
      CALL OWLBB('43000,IE)
      CALL OSDLY(5)
      CALL OSOP(IE)
      L=L+1
      LA  L
      S   /2
      OCT 027410
      J    .32
      J    .20
C     WAIT LOOP FOR B TRANSFER
   30 CALL ORLBB(ISL,IE)
      LA  ISL
      S   /'200
      OCT 027407
      J    .31
      CALL OSH(IE)
C     TRANSFER B FROM ANALOG
      CALL ORRADR(B,0,5,IE)
C     RESET INF. INTEGR. TO IC, KEEP PEN DOWN
      CALL OWLBB('50000,IE)
      CALL OSDLY(K)
      LA  I
```

PAGE 2

```
       5    NPT
       OCT 027410
       J    .23
C      WORK ON B - PRINT INTERVAL VALUES
    32 VPD= B(1)*SCL
       VNF= B(2)*SCL
       VR = B(3)*SCL
       SM =-B(4)*SCL
       VCR=B(5)*SCL
       VPT= PPT(I)
       VIPD=VIPD+VPD
       VINF=VINF+VNF
       VRO=VRO+VR
       VSM=SM
       VPPT=VPPT+VPT
       VCRO=VCRO+VCR
       WRITE(6,101) I,VPT,VPD,VNF,VR,SM,VCR
   101 FORMAT(13X,I5,6F10.2)
    90 CONTINUE
C      WRITE OUT TOTAL STORM SUMS
       WRITE(6,102)VPPT,VINF,VIPD,VRO,VCRO
   102 FORMAT(1H //20X,22HSTORM TOTALS  (INCHES)//20X,15HPRECIPITATION =,
      1F10.2/20X,15HINFILTRATION   =,F10.2/20X,15HINTER+DEPRESS =,F10.2/
      220X,15HRUNOFF DEPTH  =,F10.2////20X,17HCHANNEL OUTFLOW =,F10.2/)
C      LIFT UP PEN GO TO SET PDT MODE
       CALL GPLBB('10000,IE)
       CALL OSPLY(100)
       CALL GSSP(IE)
       RETURN
       END
```

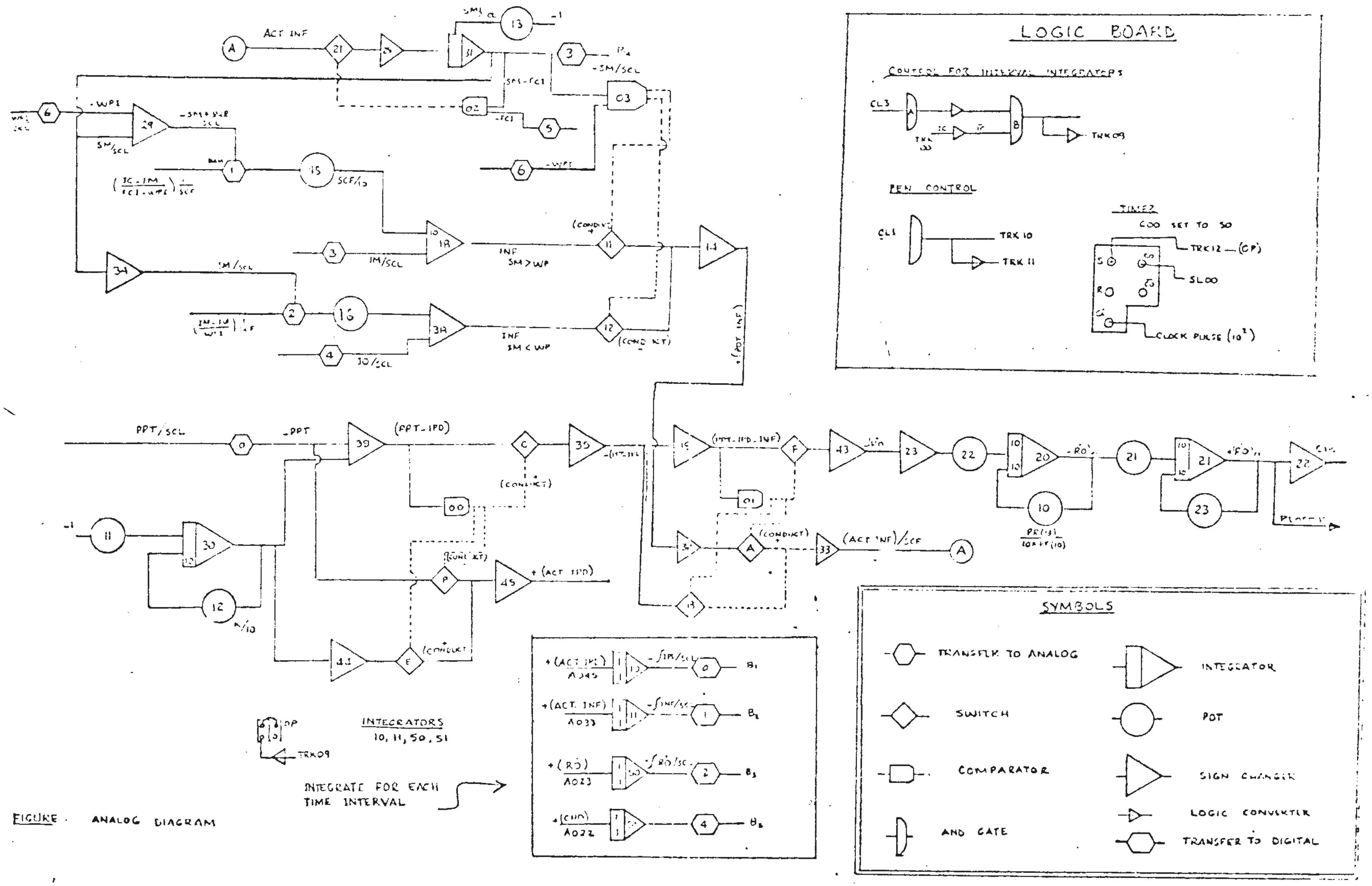


FIGURE . ANALOG DIAGRAM

Table B-1. Input data information

Card Type	Mnemonic	Format	Description		
			ITY	IFNT	
1	ITY, IFNT	(215)	1	1	Read initial - return
				2	Read all data - simulate
			2	1	Read soils - return
				2	Read soils and storm - simulate
			3	1	Read storm - return
				2	Read storm - simulate
			4		Simulate with present data
			5		Do the interaction part
			6		Do the interaction and quiz
2	NPTS	(15)	Number of pots		
3	PN(I), J=1, NPTS	(20A4)	Must read - PO Tentiometer names		
4	COM(I), J=1, 576	(18A4)	Comments to be typed out (32 cards required)		
5	QUEST(K, J) I=1, 126 K=1, 5	(18A4)	Quiz questions and possible answers. (5 questions, 3 answers for each question. 35 cards required.)		

Table B-1. Continued

Card Type	Mnemonic	Format	Description
6	DRWT, PR(I), I=1, 9	(16F5.0)	DRWT = Soil dry weight RR(I) = Parameters I 1 Initial soil moisture, % 2 Initial IPD rate (in/hr) 3 Time for IPD to decay to 1% 4 WP % moisture 5 FC % moisture 6 IO infiltration at dry soil 7 IM infiltration at WP 8 IC infiltration at FC 9 Rise time (minutes)
7	NPT, NIH, PR(9), FMT	(2I5, F5.0, 5X, 10A4)	NPT = No. of PPT intervals NIH=1, PPT inches per interval NIH=2, PPT inches per hour PR(9) = Time in minutes per interval FMT = Format PPT data are in
8	PPT(I), I=1, NPT	(FMT)	Precipitation, data values

2. Input Card Listing

1 1

9

```
P013P011P012P015P015P010P022P023P021

 *****   WELCOME TO THE UTAH WATER RESEARCH LABORATORY-HYBRID COMPUTING
 FACILITY.  PLEASE TYPE YOUR FIRST NAME. THANK YOU   TODAY WE WILL BE US
ING A COMPUTER MODEL WHICH DESCRIBES THE STORM  RUN- OFF PROCESSES. AS Y
OU ARE AWARE,RUNOFF CAN BE CONSIDERED AS A RESPONSE OF   A   WATERSHED (
OR A RESPONSE OF A HYDROLOGIC SYSTEM) TO A PARTICULAR  INPUT FUNCTION,WH
ICH IS PRECIPITATION.  THE  RESPONSE      FUNCTION , THEN IS CHANGED
IF ALTERATIONS OCCUR IN EITHER THE BASIC INPUT    FUNCTION   (PRECIPITAT
ION PATTERN) OR IN THE HYDROLOGIC SYSTEM ITSELF. WE WILL BE  USING A COM
PUTER  MODEL   OF A TYPICAL HYDROLOGIC   SYSTEM  TO  DEMONSTRATE  CHANGE
S IN THE RESPONSE OR THE OUTPUT FUNCTION THAT YOU WILL INDUCE BY  INTROD
UCING ALTERATIONS IN BOTH THE HYDROLOGIC SYSTEM AND THE PRECIPITATION PA
TTERNS.STUDIES OF THIS NATURE ARE TERMED SENSITIVITY STUDIES BECAUSE THE
Y PROVIDE CONSIDERABLE INSIGHT INTO THE  RELATIVE IMPORTANCE  OF THE VAR
IOUS PROCESSES IN HIGHLY COMPLEX AND     INTERACTING  SYSTEMS....
 PARAMETERS WHICH WE WILL BE USING TODAY ARE
    PAR   DESCRIPTION
     -2   RETYPE THESE COMMENTS
     -1   READ INITIAL DATA FROM CARDS
      1   INITIAL SOIL MOISTURE PERCENT
      2   INITIAL INTERCEPTION PLUS DEPRESSION RATE
      3   TIME FOR IPD DECAY
      4   SOIL WP PERCENT MOISTURE
      5   SOIL FC PERCENT MOISTURE
      6   IC,INFILTRATION AT DRY SOIL(IN/HR)
      7   IM,INFILTRATION AT WP(IN/HR)
      8   IC,INFILTRATION AT FC(IN/HR)
      9   TIME INTERVAL(MIN)
     10   RISE TIME(MIN)
     11   CHANGE STORM DEPTH
      0   NO MORE CHANGES
I WILL TYPE   PAR,VAL   THEN YOU MAY TYPE WHAT PARAMETER AND VALUE YOU
WANT ME TO CHANGE.   THANK  YOU.




        QUESTION-1   (2 POINTS)
---WHAT SORT OF RESPONSE WOULD YOU EXPECT TO SEE IN RUNOFF
IF YOU DOUBLE THE INITIAL SOIL MOISTURE
*****   ANSWERS   *****
   1-NO CHANGE IN RUNOFF
   2-DECREASE IN RUNOFF
   3-INCREASE IN RUNOFF
        QUESTION-2  (2 POINTS)
---A MILLION   GOLFERS WENT OUT TO THE FIELD AND GOLFED FOR EIGHT HOURS
WHICH OF THE FOLLOWING WOULD BE CORRECT
*****   ANSWERS   *****
   1-GOLFERS DID  NOT ALTER THE SOIL CONDITIONS
   2-BY COMPACTING THE SOIL,THEY INCREASED THE RUNOFF
   3-IT WAS TOO CROWDED,NO ONE COULD ENJOY HIMSELF.
```

```
        QUESTION-3  (2 POINTS)
---SAY WE CUT ALL THE TREES ,AND DESTROY ALL THE PLANTS.
THIS RUDE ACTION OF OURS WOULD CAUSE
*****    ANSWERS    *****
   1-DRASTIC INCREASE IN RUNOFF
   2-PLANTS AND TREES ARE GOOD ONLY FOR ESTHETICS
   3-NO CHANGE IN RUNOFF
        QUESTION-4  (2 POINTS)
---IN GENERAL,SURFACE RUNOFF WILL ONLY OCCUR
AT THAT INSTANT OF TIME  WHEN.......................
*****    ANSWERS    *****
   1-THE INFILTRATION RATE IS GREATER THAN THE INTERCEPTION RATE
   2-HOW  WOULD  I  KNOW..
   3-PRECIPITATION IS MORE THAN (INFILTRATION+INTERCEPTION+DEPRESSION)
        QUESTION-5  (2 POINTS)
---WHICH OF THE FOLLOWING  COMBINATIONS OF WORDS WOULD BE APPROPRIATE
TO USE IN THE DEFINITION OF   HYDROLOGIC  SYSTEM
*****    ANSWERS    *****
   1-PRECIPITATION-WATERSHED-RUNOFF
   2-GOLFERS-RAIN-GRASS
   3-NONE OF THE ABOVE


   2    2


  40   20   .5  120   25   42  .35  .45  .15  25.
  15    1   30       (16F5.2)
  56   33   03   25   25   05   38   91   57   20   15   10   05


   4


   5

   6
```

Appendix C

1. Output Symbols (Table C-1)

2. Sample Outputs

   a. Digital
      i. Comments and Quiz (Table C-2)
      ii. Numerical Results of Simulation (Table C-3)

   b. Analog
      i. Graphs of Initial Data (Figure C-1)
      ii. Graphs of Sensitivity Studies (Figure C-2) "Responses to parameter changes."

Table C-1. Output Symbols

Mnemonic	Description
N	Number of intervals (PPT)
T	Time in minutes per interval
I	Number of intervals (simulation process)
PPT	Precipitation, inches per interval
IPD	Interception, plus depression, inches per interval
INF	Infiltration, inches per interval
RO	Runoff, inches per interval
SM	Soil moisture, inches per interval
CHO	Routed channel outflow, inches per interval

Table C-2. Comments and quiz

```
*****   WELCOME TO THE UTAH WATER RESEARCH LABORATORY-HYFRID COMPUTING
FACILITY.  PLEASE TYPE YOUR FIRST NAME.
THANK YOU  ARIF
TODAY WE WILL BE USING A COMPUTER MODEL WHICH DESCRIBES THE STORM  RUN-
OFF PROCESSES. ARIF     AS YOU ARE AWARE,RUNOFF CAN BE CONSIDERED AS
A RESPONSE OF   A   WATERSHED (OR A RESPONSE OF A HYDROLOGIC SYSTEM) TO
A PARTICULAR  INPUT FUNCTION,WHICH IS PRECIPITATION.  THE  RESPONSE
FUNCTION , THEN IS CHANGED      IF ALTERATIONS OCCUR IN EITHER THE BASIC
INPUT    FUNCTION   (PRECIPITATION PATTERN) OR IN THE HYDROLOGIC SYSTEM
ITSELF. WE WILL BE  USING A COMPUTER  MODEL   OF A TYPICAL HYDROLOGIC
SYSTEM  TO  DEMONSTRATE  CHANGES IN THE RESPONSE OR THE OUTPUT FUNCTION
THAT YOU WILL INDUCE BY  INTRODUCING ALTERATIONS IN BOTH THE HYDROLOGIC
SYSTEM AND THE PRECIPITATION PATTERNS.STUDIES OF THIS NATURE ARE TERMED
SENSITIVITY STUDIES BECAUSE THEY PROVIDE CONSIDERABLE INSIGHT INTO THE
RELATIVE IMPORTANCE  OF THE VARIOUS PROCESSES IN HIGHLY COMPLEX AND
INTERACTING  SYSTEMS....


        QUESTION-1   (2 POINTS)
---WHAT SORT OF RESPONSE WOULD YOU EXPECT TO SEE IN RUNOFF
IF YOU DOUBLE THE INITIAL SOIL MOISTURE
*****    ANSWERS    *****
   1-NO CHANGE IN RUNOFF
   2-DECREASE IN RUNOFF
   3-INCREASE IN RUNOFF

YES  ARIF     ,YOUR ANSWER IS CORRECT.


        QUESTION-2  (2 POINTS)
---A MILLION   GOLFERS WENT OUT TO THE FIELD AND GOLFED FOR EIGHT HOURS
WHICH OF THE FOLLOWING WOULD BE CORRECT
*****    ANSWERS    *****
   1-GOLFERS DID  NOT ALTER THE SOIL CONDITIONS
   2-BY COMPACTING THE SOIL,THEY INCREASED THE RUNOFF
   3-IT WAS TOO CROWDED,NO ONE COULD ENJOY HIMSELF.

YES  ARIF     ,YOUR ANSWER IS CORRECT.


        QUESTION-3  (2 POINTS)
---SAY WE CUT ALL THE TREES ,AND DESTROY ALL THE PLANTS.
THIS RUDE ACTION OF OURS WOULD CAUSE
*****    ANSWERS    *****
   1-DRASTIC INCREASE IN RUNOFF
   2-PLANTS AND TREES ARE GOOD ONLY FOR ESTHETICS
   3-NO CHANGE IN RUNOFF

NO, THE ANSWER IS    1


        QUESTION-4  (2 POINTS)
---IN GENERAL,SURFACE RUNOFF WILL ONLY OCCUR
AT THAT INSTANT OF TIME  WHEN.........................
*****    ANSWERS    *****
   1-THE INFILTRATION RATE IS GREATER THAN THE INTERCEPTION RATE
   2-HOW WOULD  I  KNOW..
   3-PRECIPITATION IS MORE THAN (INFILTRATION+INTERCEPTION+DEPRESSION)

YES  ARIF     ,YOUR ANSWER IS CORRECT.
```

Table C-2. Continued

```
        QUESTION=5  (2 POINTS)
---WHICH OF THE FOLLOWING  COMBINATIONS OF WORDS WOULD BE APPROPRIATE
TO USE IN THE DEFINITION OF   HYDROLOGIC  SYSTEM
*****   \ 3STEPS    *****
   1-PRECIPITATION-WATERSHED-RUNOFF
   2-GOLFERS-RAIN-GRASS
   3-NONE OF THE ABOVE

YES  ARIF     ,YOUR ANSWER IS CORRECT.



    ARIF     ,YOUR GRADE IS,     8
VERY GOOD
PARAMETERS WHICH WE WILL BE USING TODAY ARE
   PAR   DESCRIPTION
    -2   RETYPE THESE COMMENTS
    -1   READ INITIAL DATA FROM CARDS
     1   INITIAL SOIL MOISTURE PERCENT
     2   INITIAL INTERCEPTION PLUS DEPRESSION RATE
     3   TIME FOR IPD DECAY
     4   SOIL WP PERCENT MOISTURE
     5   SOIL FC PERCENT MOISTURE
     6   IO,INFILTRATION AT DRY SOIL(IN/HR)
     7   IM,INFILTRATION AT WP(IN/HR)
     8   IC,INFILTRATION AT FC(IN/HR)
     9   TIME INTERVAL(MIN)
    10   RISE TIME(MIN)
    11   CHANGE STORM DEPTH
     0   NO MORE CHANGES
I WILL TYPE   PAR,VAL   THEN YOU MAY TYPE WHAT PARAMETER AND VALUE YOU
WANT ME TO CHANGE.   THANK  YOU.
```

Table C-3. RUNOFF SIMULATION
N= 23 T= 30. MIN

I	PPT	IPD	INF	RO	SM	CHO
1	.56	.18	.21	.14	1.64	.04
2	.03	.02	-.00	-.00	1.64	.08
3	.03	.02	-.00	-.00	1.64	.01
4	.25	.03	.20	-.00	1.75	-.00
5	.25	.01	.21	.00	1.86	-.00
6	.05	.01	.03	-.00	1.88	.00
7	.38	.01	.22	.14	1.99	.05
8	.91	-.00	.22	.66	2.10	.33
9	.57	-.00	.22	.33	2.21	.48
10	.20	-.00	.19	-.00	2.31	.23
11	.15	-.00	.14	-.00	2.38	.03
12	.10	-.00	.09	-.00	2.43	.00
13	.05	-.00	.04	-.00	2.45	-.00
14	.00	-.00	-.00	-.00	2.45	-.00
15	.00	-.00	-.00	-.00	2.45	-.00
16	.00	-.00	-.00	-.00	2.45	-.00
17	.00	-.00	-.00	-.00	2.45	-.00
18	.00	-.00	-.00	-.00	2.46	-.00
19	.00	-.00	-.00	-.00	2.45	-.00
20	.00	-.00	-.00	-.00	2.46	-.00
21	.00	-.00	-.00	-.00	2.46	-.00
22	.00	-.00	-.00	-.00	2.45	-.00
23	.00	-.00	-.00	-.00	2.45	-.00

STORM TOTALS (INCHES)

PRECIPITATION = 3.53
INFILTRATION = 1.79
INTER+DEPRESS = .28
RUNOFF DEPTH = 1.26

CHANNEL OUTFLOW = 1.26

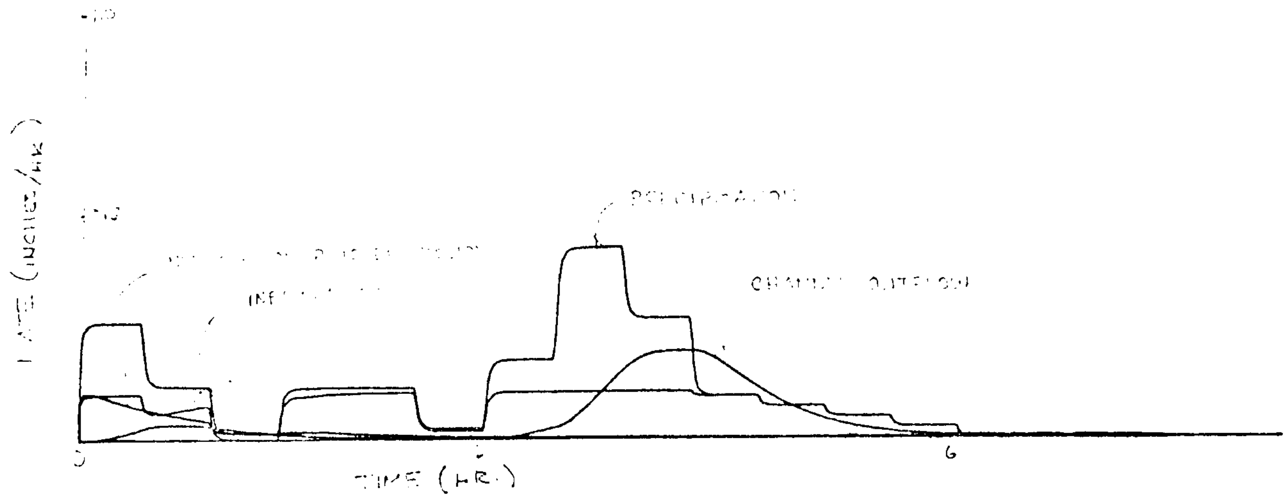


Figure C-1. Graphs of initial data.

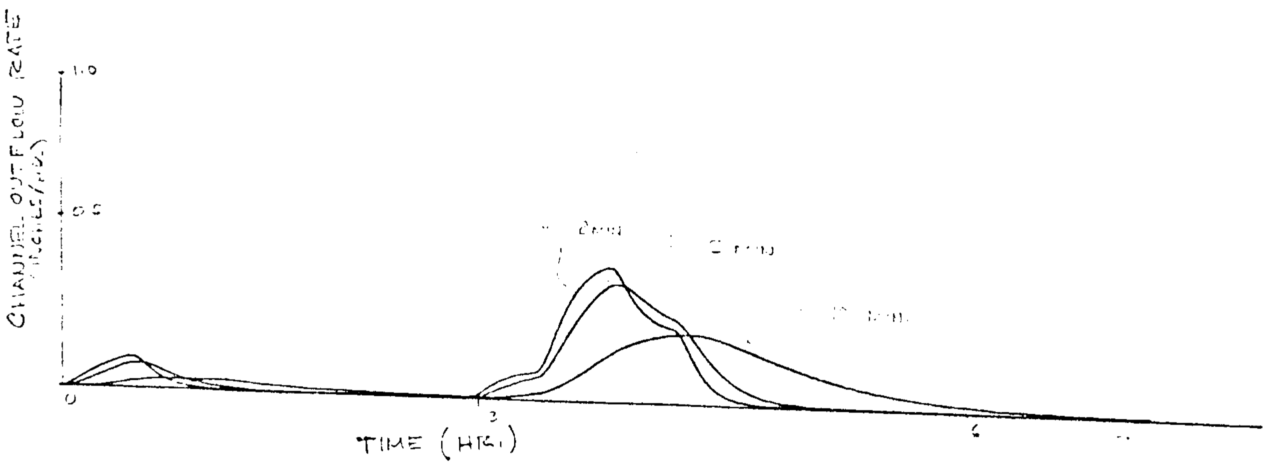


Figure C-2. Sample output for sensitivity studies (changes in channel outflow due to changes in rise time).

Appendix D

Instructions Manual Prepared for Undergraduate Hydrology Students

Utah State University
Civil and Environmental Engineering Department
CEE 443 - Hydrology

INTERACTIVE HYBRID COMPUTER MODEL OF STORM RUNOFF

By
R. W. Hill
A. H. Atali

PART I: BASIC CONCEPTS INVOLVED, AND GENERAL INFORMATION ABOUT THE MODEL

Surface runoff from storms is a function of many things. Various watershed characteristics such as vegetative cover and soil properties influence the amount of water available for runoff. Storm time patterns of precipitation intensity and duration influence the relative amounts of rain which are abstracted by the processes of interception, depression, and infiltration.

The figure below (from page 168 of L., K., and P.) serves to illustrate some of these basic needs.

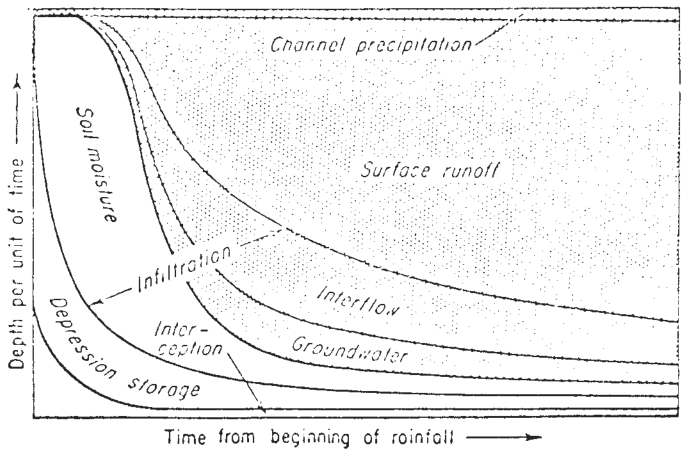


Fig. 1 - Schematic Diagram of the Disposition of Storm Rainfall

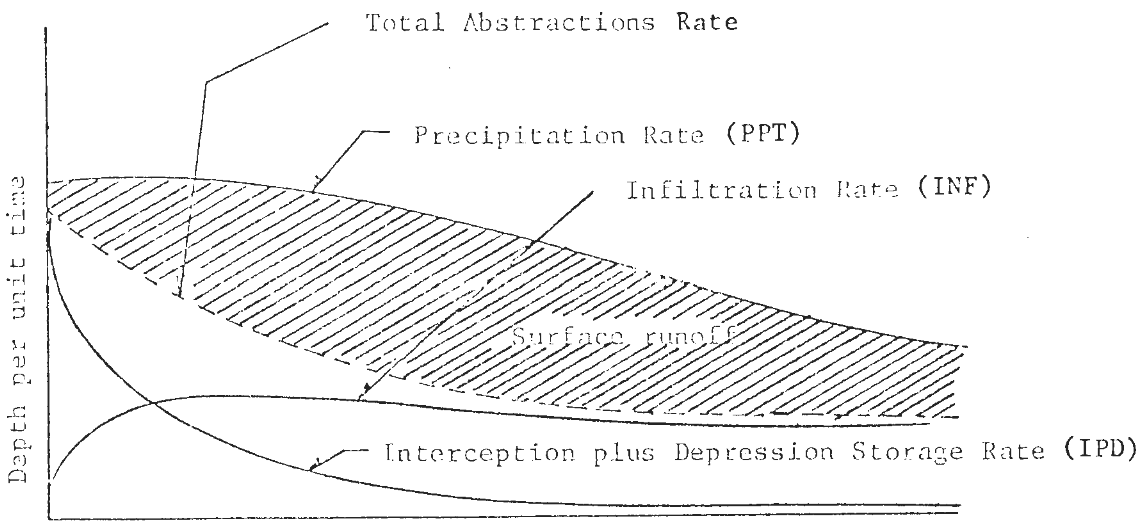


Fig. 2 - Storm Supply and Abstraction

The surface runoff depth becomes the integral of (supply - abstractions) or:

$$\boxed{RO = \int (PPT - IPD - INF)dt} \quad \text{. . . . . . Eq. 1.}$$

The shaded area in Figure 2 represents the surface runoff depth.

The precipitation values come from the particular storm data, interception and depression from estimated watershed conditions and infiltration rate from soil properties.

In this model the infiltration rate is considered to be a function of soil moisture as shown below.

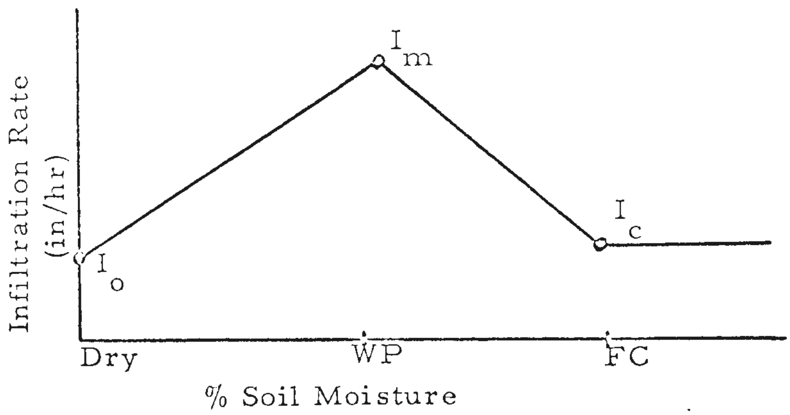


Fig. 3

This figure is a linear approximation of the actual relationship. The values of I_o, I_m, and I_c in (inches per hour) corresponding to dry, the wilting point (WP) and field capacity (FC) moisture contents come from data describing the particular soil used.

Computer Model

One result of developing hydrological system models on the computer is the identification of significant physical processes. System parameter changes relating to these processes can then be made easily and the effects rapidly determined.

For illustration purposes, in this model we shall deal only with the upper portion of the system shown below (enclosed with dashed lines).

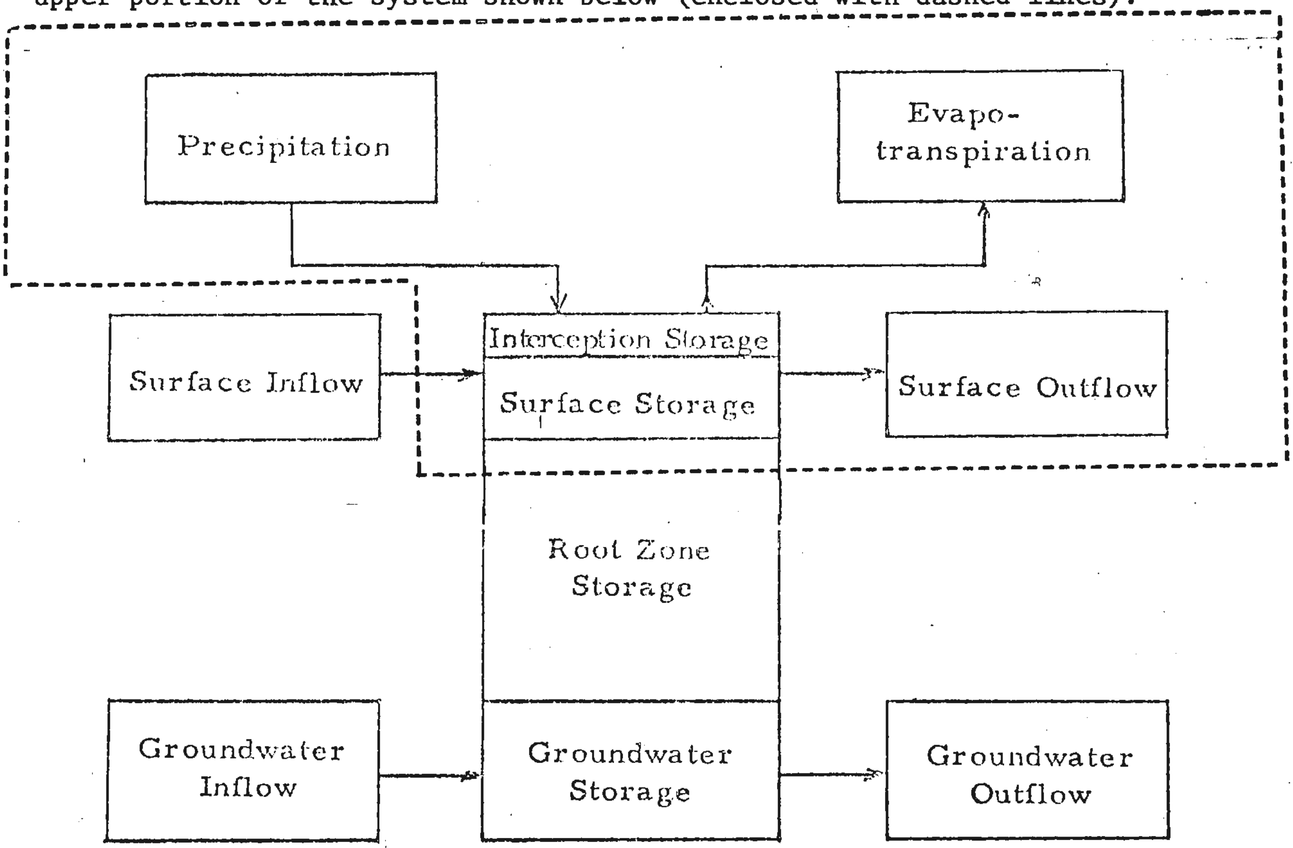


Fig. 4

The basic concepts of the hydrological system were developed into a model which was programmed on a hybrid computer. The hybrid computer is composed of two parts: A. Digital Computer: Data input into the digital occurs through punched cards, magnetic tape, or from teletype. The digital processes the data, stores the data, and transfers appropriate data to and from the analog. The digital computer is a sequential machine which does one thing at a time.

B. Analog Computer: Analog computer is a parallel device in that all computations proceed simultaneously.

Many of the processes which occur in nature are time dependent and as such are differential in form. It is in the solution of differential equations that the speed and parallel computation of the analog computer is particularly apparent because it can integrate the problem variables continuously instead of using numerical approximations. Visual output is obtained from the analog computer.

The Hybrid computer model provides the capability to examine many possible alternatives in a short period of time. The operator can vizualize results as being the actual dynamic responses of the physical system under investigation.

Studies in which parameters are changed over a range of values are called sensitivity studies. Hybrid computer models become valuable aids in water resources planning studies which require the evaluation of many alternatives. For example the model may take only five seconds to simulate events occuring during a real life period of four years.

Data Needed for the Model

A. Storm pattern with time

1. Time interval length
2. Total number of time intervals
3. Precipitation depth for each interval

B. Watershed and soil characteristics

1. Interception and depression characteristics (initial rates (in/hr) and time to satisfy total storage
2. Initial soil moisture
3. Infiltration characteristics

PART II: NECESSARY DATA INFORMATION FOR THE MODEL

Comments

In the Appendix you will find some information on watershed and soil characteristics (e.g. soil moisture levels at WP and at FC, . . etc.).

Note

Consider soil to be three inches thick for infiltration control. Dry unit weight of soils: Sand ≈ 125 pcf; silts ≈ 100 pcf (1 foot square surface area by 1 foot deep).

One set of data is required from each group. Punch your data on cards (use KP 026) with the given format as follows:

Data and Format to be Used

Card No.	Data	Format
1	Soil dryweight (lbs. per sq. ft. for the top 3" of soil) Initial soil moisture % Initial IPD rate, in/hr. Time for IPD decay (min.) WP % moisture FC % moisture IO, infiltration at dry soil IM, infiltration at WP IC, infiltration at FC	9F5.0 (punch the decimals)
2	Number of intervals in storm NHI Time in minutes per interval Format PPT data is in (FMAT)	I5 I5 F5.0, 5X 10A4
3 4 5	PPT values	According to above specified format (FMAT) e.g. (16F5.2)

Note

NHI = 1

PART III: INSTRUCTIONS MANUAL

I. Description of the Model

A flow diagram of the various hydrologic processes which are represented by the model is shown by Fig. 1.

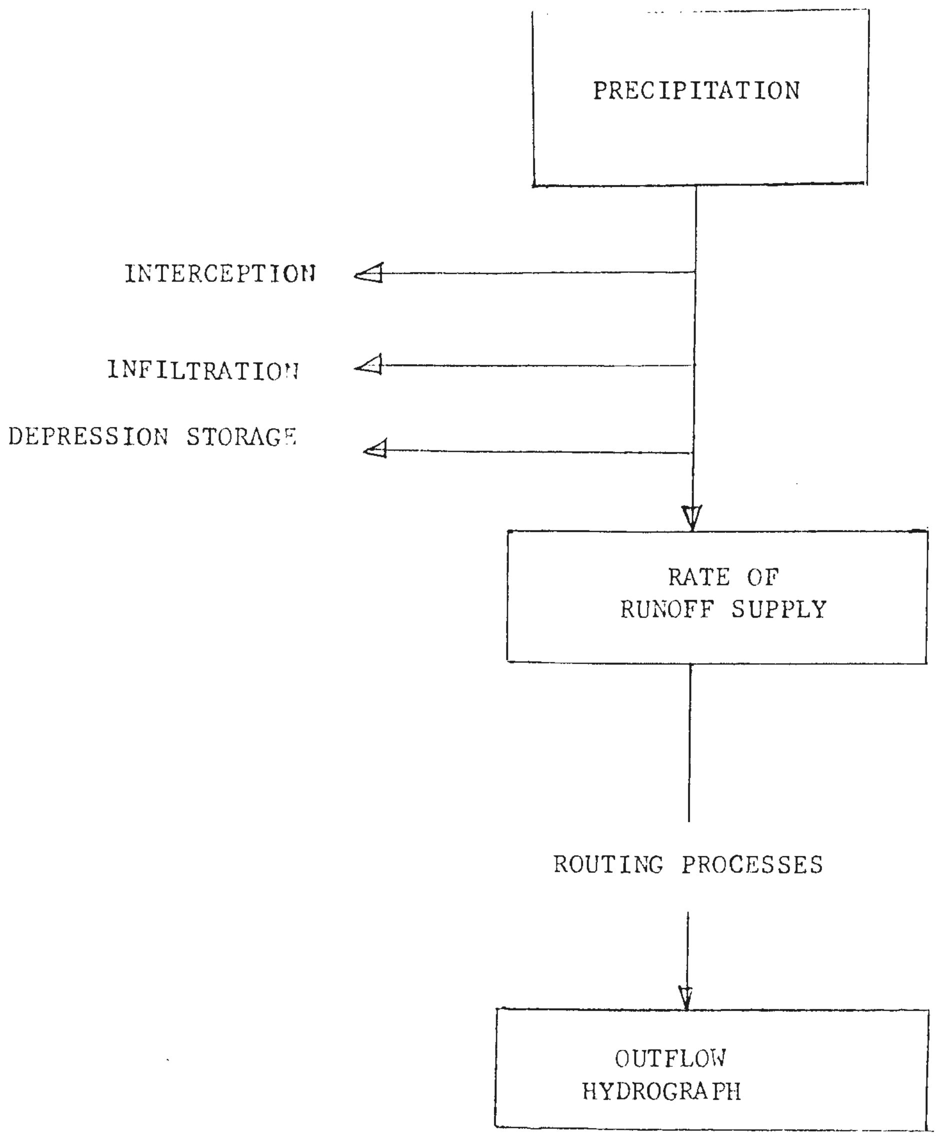


Fig. 1 = Schematic representation of watershed for hydrograph synthesis.

Since both the interception and depression storage rates can be represented by similar mathematical expressions, in the model they are lumped together and called interception plus depression storage (IPD), or retention storage. The mathematical expression used to represent the combined processes is as follows:

$$\frac{d(IPD)}{dt} = -K(IPD) \quad \ldots\ldots (1)$$

in which:

IPD = interception plus depression storage capacity rates

K = a constant, representing physical characteristics of the watershed foliage and ground surface.

Infiltration is considered to be a function of soil moisture and certain other soil characteristics. A linear approximation to this function was explained in the first part of this manual. The model was simplified by considering the soil as a single layer composed of the top few inches of the actual soil profile. The soil moisture level as a function of time is represented by the following equation:

$$SM = SMI + \int (INF)\, dt \quad \ldots\ldots (2)$$

in which:

SM = soil mositure level (inches of water)
SMI = initial soil moisture at beginning of storm (inches)
INF = capacity rate of infiltration (inches/time)

A function generator is used on the analog computer to provide the necessary link between soil moisture and infiltration for use in the model.

Surface runoff then, becomes the integral of the rainfall minus abstractions or:

$$RO = \int (PPT - IPD - INF)\, dt \quad \ldots\ldots (3)$$

in which:

PPT = precipitation rate (inches/time) and the other variables are as previously defined.

The digital computer stores characteristic data for the storm and soil types encountered on the watershed, and also stores the text of the interactive conversation between the computer and the student. Digital computer also transfers the precipitation rate for each time interval to the analog computer.

Equations 1, 2, and 3 are solved on the analog computer. In addition, the infiltration function is generated on this component. Whenever the rainfall rate is less than the ptotential total abstractions, this rate is decreased to match the rate of supply, thus, providing for proper mass balance in the system.

II. How to Operate the Model

On Fig. 2 the schematic representation of the hybrid computing system set-up at Utah Water Research Laboratory is given. Your instructor will load the program (from the tape) and check the system. You should then read in your initial data (storm, soil, etc.) through the card reader after the "welcome. . .etc." (see Fig. 4). Type your first name, and space till two small lines coincide; then hit RETURN. This will bring up the brief information about the model on the screen, and you will see code number and description for each parameter involved as follows:

Par	Description
1	Initial Soil Mositure %
2	Initial Interception Plus Depression Rate (Inches/Hr)
3	Time for IPD Decay (Min)
4	Soil WP % Moisture
5	Soil FC % Moisture
6	IO, Infiltration at Dry Soil (In/Hr)
7	IM, Infiltration at WP (In/Hr)
8	IC, Infiltration at FC (In/Hr)
9	Time Interval (Min)
10	Change Storm Depth
0	No More Changes

To start with you may want to plot PPT, IPD, INF, RO functions as is (with no changes). To do this, you need to type 0, then hit RETURN (after pushing corresponding relay function switch on the analog, e.g.: relay function 00 for PPT, 01 for INF, etc.).

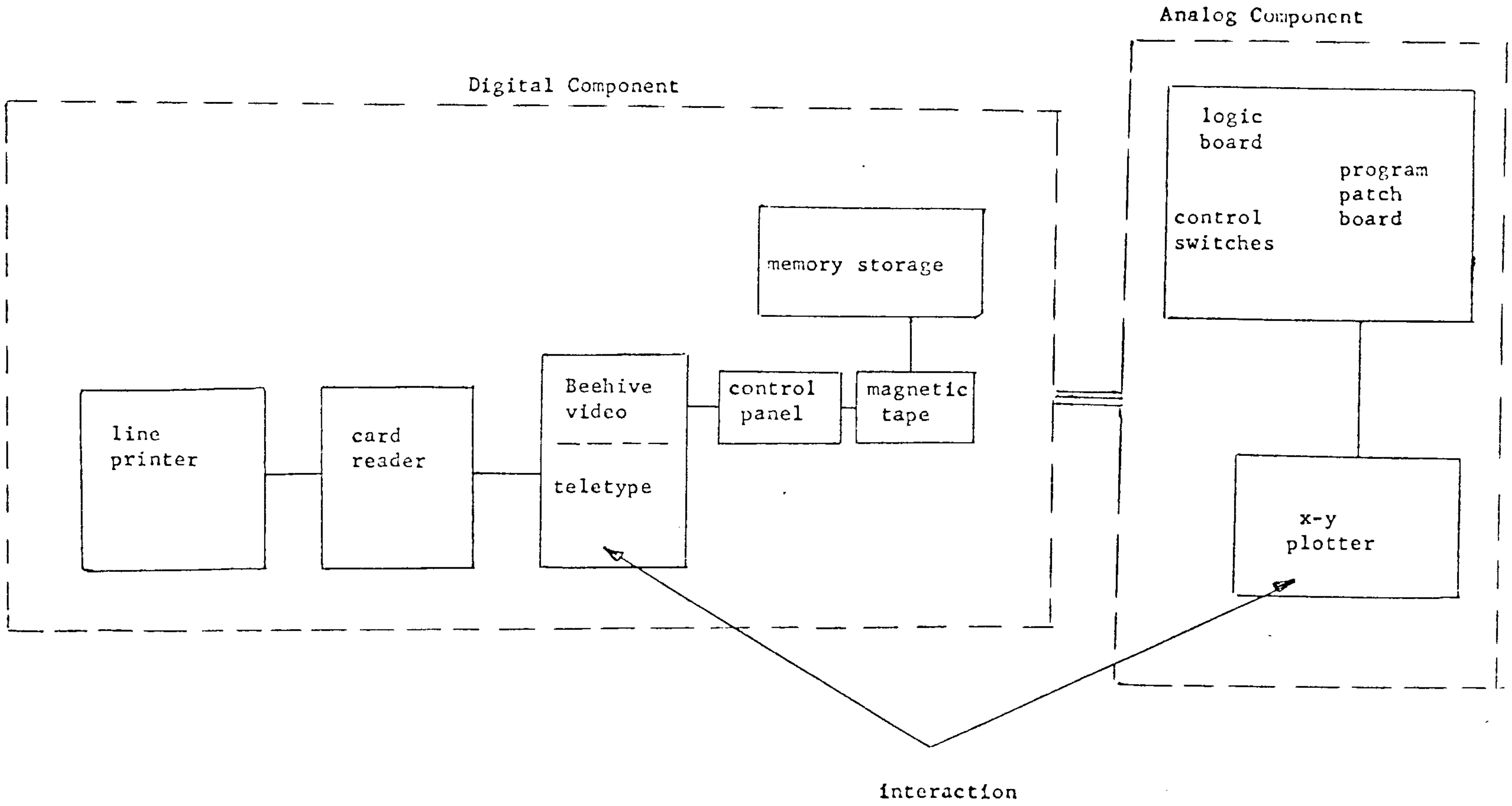
The main purpose here is to observe the system response (runoff) to parameter changes (e.g.: if we increase the initial soil moisture, what happens to runoff? How much effect does infiltration at WP, IM, have on runoff?).

To illustrate the procedure let us give you an example: Say the initial value for WP is 29. Plot RO as is (relay function - no lights on, type zero comma then hit RETURN). Immediately you will see the RO function plotted as is. Let's change WP to 35. - to do this you need to type 4, 35. and hit RETURN. (4 is the code number of WP, 35. is the new value of WP). As a result you will observe the response to the parameter change, graphically as shown on Fig. 3. This would be similar to changing soil types and observing the runoff change as a result. At the same time numeric values will be printed out by the digital component (see table 1).

Symbols and their descriptions used in digital output are as follows:

- I - Intervals
- PPT - Precipitation
- IPD - Interception Plus Depression
- INF - Infiltration
- RO - Runoff
- SM - Soil Moisture
- N - Number of Intervals
- T - Time Intervals (min)

Fig. 2: Hybrid Computing-System Set-up At Utah Water Research Laboratory



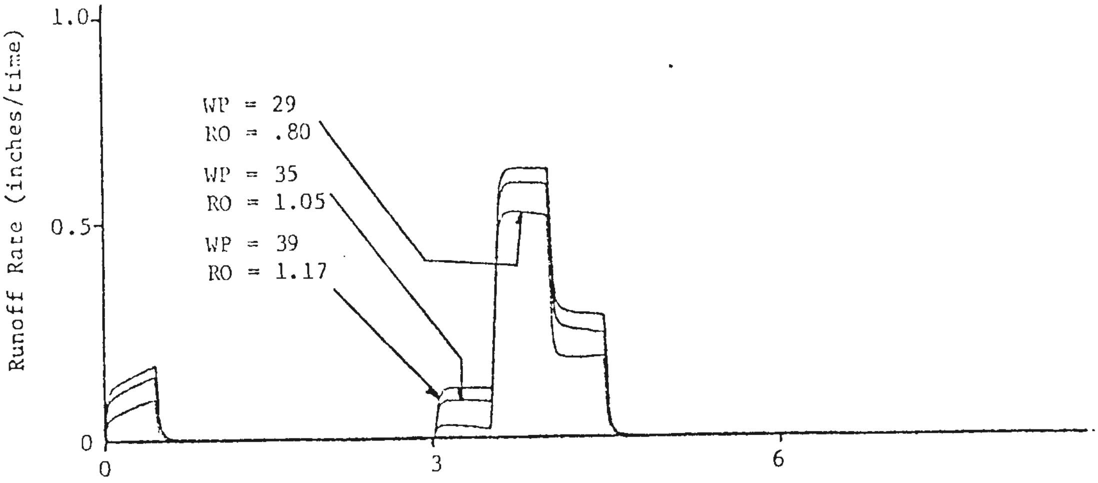


Fig. 3 Time (hours)

Surface runoff as affected by changes of soil wilting point moisture.

Table 1: Typical Digital Output

RUNOFF SIMULATION
N= 16 T= 30. MIN

I	PPT	IPD	INF	RO	SM
1	2.00	.75	1.21	-.00	1.58
2	3.40	.42	2.67	.23	2.92
3	5.50	.23	2.14	3.10	3.99
4	7.70	.13	1.60	5.95	4.14
5	4.00	.07	1.59	2.32	4.14
6	1.00	.04	.94	-.01	4.14
7	3.50	.02	1.59	1.87	4.14
8	3.50	.01	1.59	1.83	4.14
9	2.00	-.00	1.59	.39	4.14
10	.75	-.00	.73	-.00	4.14
11	.25	-.00	.24	-.01	4.14
12	2.00	-.00	1.59	.44	4.14
13	3.75	-.00	1.59	2.15	4.14
14	4.50	-.00	1.59	2.90	4.14
15	2.00	-.00	1.59	.43	4.14
16	.30	-.00	.29	-.00	4.14

STORM TOTALS (INCHES)

PRECIPITATION = 46.15
INFILTRATION = 22.64
INTER+DEPRESS = 1.68
RUNOFF DEPTH = 21.65

Fig. 4: Beehive Terminal Display

WELCOME TO THE UTAH WATER RESEARCH LABORATORY-HYBRID COMPUTING FACILITY.
PLEASE TYPE YOUR FIRST NAME

ROBERT ←
THANK YOU ROBERT
TODAY WE WILL BE USING A COMPUTER MODEL WHICH DESCRIBES THE STORM RUNOFF PROCESSES. ROBERT, AS YOU ARE AWARE, RUNOFF CAN BE CONSIDERED AS A RESP ONSE OF A WATERSHED (OR HYDROLOGIC SYSTEM) TO A PARTICULAR INPUT FUNCTIO N, WHICH IS PRECIPITATION. THE OUTPUT, OR RESPONSE FUNCTION, THEN IS CH ANGED IF ALTERATIONS OCCUR IN EITHER THE BASIC INPUT FUNCTION (PRECIPITA TION PATTERN) OR IN THE HYDROLOGIC SYSTEM ITSELF. WE WILL BE USING A CO MPUTER MODEL OF A TYPICAL HYDROLOGIC SYSTEM TO DEMONSTRATE CHANGES IN TH E RESPONSE OR OUTPUT FUNCTION THAT YOU WILL INDUCE BY INTRODUCING ALTERA TIONS IN BOTH THE PRECIPITATION PATTERNS AND THE HYDROLOGIC SYSTEM. STU DIES OF THIS NATURE ARE TERMED SENSITIVITY STUDIES BECAUSE THEY PROVIDE CONSIDERABLE INSIGHT INTO THE RELATIVE IMPORTANCE OF THE VARIOUS PROCESS ES IN HIGHLY COMPLEX AND INTERACTING SYSTEMS.

PARAMETERS WHICH WE WILL BE USING TODAY ARE

APPENDIX

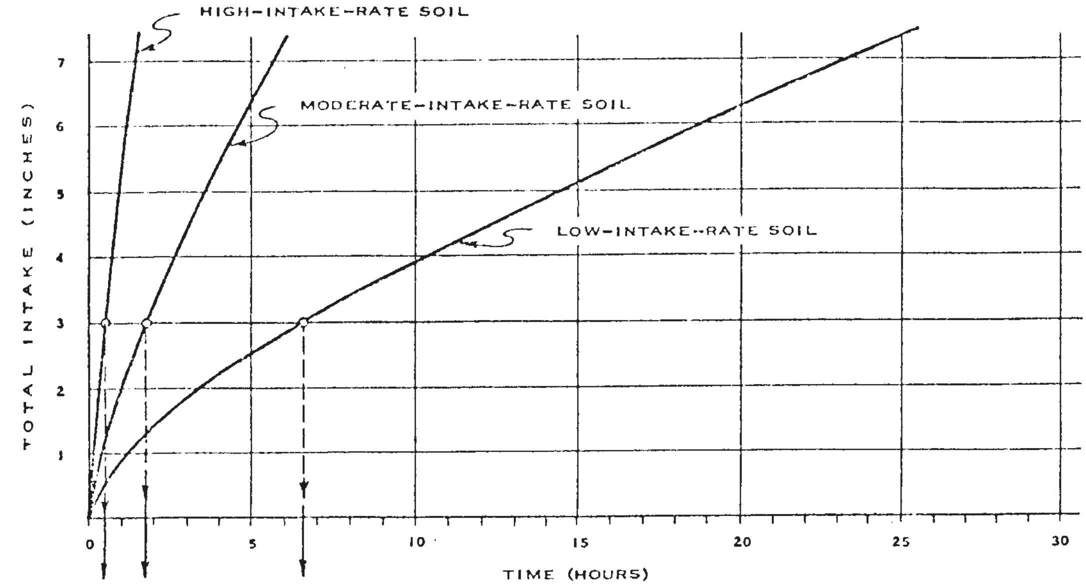


Figure 1-8.--Relation of total intake to time for three soils. A 3-inch application is absorbed by the high-intake-rate soil in one-third of an hour, by the moderate-intake-rate soil in 1-3/4 hours, and by the low-intake-rate soil in 6-1/2 hours.

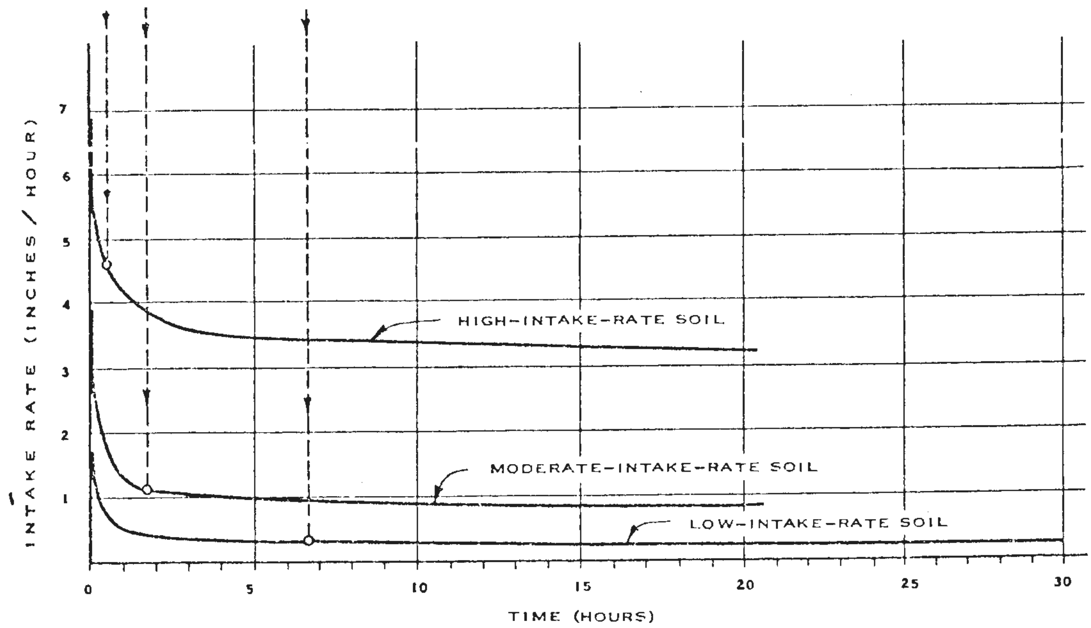


Figure 1-9.--Relation of intake rate to time for the three soils shown in figure 1-8. At end of the 3-inch application, the intake rate in the high-intake-rate soil has declined to 4.6 inches per hour, in the moderate-intake-rate soil to 1.2 inches per hour, and in the low-intake-rate soil to 0.3 inch per hour.

TABLE 7.4

REPRESENTATIVE PHYSICAL PROPERTIES OF SOILS

Soil Texture	Infiltration[1] and Permeability Inches/hour I_f	Total Pore Space % N	Apparent Specific Gravity A_s	Field Capacity % FC	Permanent Wilting % PW	Total Available Moisture[2] Dry Weight % $P_w = FC - PW$	Volume % $P_v = P_w A_s$	Inches per Foot $d = \frac{P_w}{100} A_s D$
Sandy	2 (1–10)	38 (32–42)	1.65 (1.55–1.80)	9 (6–12)	4 (2–6)	5 (4–6)	8 (6–10)	1.0 (0.8–1.2)
Sandy Loam	1 (0.5–3)	43 (40–47)	1.50 (1.40–1.60)	14 (10–18)	6 (4–8)	8 (6–10)	12 (9–15)	1.4 (1.1–1.8)
Loam	0.5 (0.3–0.8)	47 (43–49)	1.40 (1.35–1.50)	22 (18–26)	10 (8–12)	12 (10–14)	17 (14–20)	2.0 (1.7–2.3)
Clay Loam	0.3 (0.1–0.6)	49 (47–51)	1.35 (1.30–1.40)	27 (23–31)	13 (11–15)	14 (12–16)	19 (16–22)	2.3 (2.0–2.6)
Silty Clay	0.1 (0.01–0.2)	51 (49–53)	1.30 (1.25–1.35)	31 (27–35)	15 (13–17)	16 (14–18)	21 (18–23)	2.5 (2.2–2.8)
Clay	0.2 (0.05–0.4)	53 (51–55)	1.25 (1.20–1.30)	35 (31–39)	17 (15–19)	18 (16–20)	23 (20–25)	2.7 (2.4–3.0)

Note: Normal ranges are shown in parentheses.

[1] Intake rates vary greatly with soil structure and structural stability, even beyond the normal ranges shown above.

[2] Readily available moisture is approximately 75% of the total available moisture.

Table 11.—*Physical properties of watershed soils, H. J. Andrews Experimental Forest*

Soil series, horizon, and depth	Bulk density (per cc.)	Stones > 2 mm. (by volume)	Soil particles < 2 mm. Sand	Silt	Clay	Textural class	Percolation rate (per hour)	Soil moisture at tensions of — 1/3 atm.	1 atm.	5 atm.	15 atm.	Total pore space	Capillary porosity	Noncapillary porosity	Retention capacity[2]	Detention capacity[2]
	Grams	Percent	Percent dry weight				Inches	Percent dry weight				Percent	Percent	Percent	Inches of water	
McKenzie River:																
A1, 0-4 inches	0.87	....	23.9	41.7	34.4	shotty clay loam	149.0	29.42	31.70	23.82	17.80	69.7	22.3	47.4	0.76	1.63
A3, 4-9 inches	.91	....	22.5	41.2	36.3	clay loam	237.0	29.68	29.89	23.76	17.87	66.7	26.2	40.5	1.23	1.73
B1, 9-21 inches	1.18	10	16.9	39.7	43.4	clay	149.0	30.91	30.09	25.59	20.40	63.7	29.8	33.9	3.07	3.49
B2, 21-33 inches	1.14	15	12.9	39.7	47.4	clay	22.0	34.99	35.53	28.93	24.21	63.1	34.2	28.9	3.57	3.02
B3, 33-43+ inches	1.14	30	10.9	36.5	52.6	clay	(1)	37.92	43.91	33.06	28.12	63.1	37.1	26.0	2.75	1.93
Frissell:																
A, 0-5 inches	.57	25	19.9	50.6	29.5	clay loam	> 250.0	39.80	36.03	27.98	23.17	76.9	22.8	54.1	.66	1.96
AC, 5-22 inches	.82	25	19.7	45.1	35.2	clay loam	119.4	36.86	33.92	28.68	24.14	69.5	30.3	39.2	3.70	4.78
C, 22-31+ inches	1.06	75	25.1	42.8	32.1	clay loam	20.9	39.10	36.76	29.64	24.24	56.0	41.2	14.8	2.37	.85
Slipout:																
A, 0-2 inches	(1)	10	50.9	26.3	22.8	sandy clay loam	(1)	34.92	29.58	25.54	22.54	62.7	31.4	31.3	.56	.56
AC, 2-9 inches	1.01	10	43.5	30.0	26.5	loam	29.9	28.50	24.83	21.00	18.46	59.7	28.7	31.0	1.79	1.93
C1, 9-15 inches	1.13	15	51.9	25.0	23.1	sandy clay loam	4.8	24.10	20.22	16.20	12.55	57.5	27.1	30.4	1.41	1.57
C2, 15-21 inches	1.24	15	53.8	25.7	20.6	sandy clay loam	6.8	24.22	21.14	17.06	13.08	54.6	29.9	24.7	1.64	1.35
A1b, 21-27 inches	1.29	10	43.0	33.9	23.0	loam	1.0	27.14	23.12	17.95	13.36	52.0	35.1	16.9	1.88	.90
A3b, 27-33 inches	1.25	15	39.2	35.2	25.6	loam	.5	30.11	25.16	20.39	15.59	47.8	37.7	10.1	1.94	.52
B2b, 33-58 inches	1.19	5	31.9	31.6	36.5	clay loam	.1	37.15	33.09	27.30	23.60	52.4	44.2	8.2	10.36	1.92
B3b, 58-67+ inches	(1)	10	29.0	33.3	37.7	clay loam	(1)	35.11	32.21	26.50	22.72	51.6	42.1	9.5	3.43	.78
Budworm:																
A, 0-9 inches	.74	15	36.5	37.2	26.3	shotty loam	> 250.0	37.20	33.60	25.84	22.90	69.8	27.4	42.4	2.07	3.20
B1, 9-20 inches	.80	7	36.0	35.2	28.8	clay loam	60.3	36.29	33.62	25.05	21.65	67.5	28.9	38.6	2.87	3.83
B2, 20-34 inches	1.01	3	27.3	45.9	26.8	clay loam	2.0	40.71	36.23	30.55	25.58	62.1	41.0	21.1	5.35	2.75
B3, 34-54 inches	.96	15	27.5	47.3	25.3	clay loam	6.0	45.37	40.21	33.10	27.92	64.0	43.5	20.5	7.99	3.76
C, 54-72+ inches	(1)	80	27.8	48.8	23.3	clay loam	(1)	49.91	43.44	34.05	27.18	69.8	40.1	29.7	5.07	3.76

Table 11 (*continued*).

Soil series, horizon, and depth	Bulk density (per cc.)	Stones > 2 mm. (by volume)	Soil particles <2 mm. Sand	Silt	Clay	Textural class	Percolation rate (per hour)	Soil moisture at tensions of — 1/3 atm.	1 atm.	5 atm.	15 atm.	Total pore space	Capillary porosity	Noncapillary porosity	Retention capacity[2]	Detention capacity[2]
	Grams	Percent	Percent dry weight				Inches	Percent dry weight				Percent	Percent	Percent	Inches of water	
Limberlost:																
A1, 0-5 inches	.80	20	41.0	35.1	23.9	loam	55.3	39.19	32.46	26.22	23.96	67.7	31.5	36.2	1.24	1.42
AC1, 5-15 inches	.91	15	36.8	36.9	26.3	loam	23.7	35.10	31.38	27.68	22.54	65.3	32.0	33.3	2.56	2.66
AC2, 15-29 inches	.94	20	31.0	42.4	26.6	loam	9.0	38.19	33.78	28.39	23.04	64.8	35.7	29.1	3.91	3.18
C, 29-50+ inches	([1])	20	36.9	37.0	26.1	loam	([1])	36.52	31.99	27.93	23.08	62.3	36.5	25.8	6.13	4.34
Flunky:																
A, 0-4 inches	([1])	65	33.4	45.8	20.8	loam	([1])	26.78	20.00	18.76	14.18	72.2	17.9	54.3	.36	1.07
C, 4-23+ inches	([1])	50	53.9	29.8	16.3	sandy loam	([1])	26.96	20.92	13.64	11.73	66.7	21.6	45.1	2.00	4.18
Unnamed soil from mixed colluvium:																
A1, 0-7 inches	.58	15	36.4	36.4	27.2	shotty loam	27.2	35.24	30.86	23.07	20.91	77.0	20.3	56.7	1.09	3.05
A3, 7-12 inches	.75	8	23.5	44.3	32.2	clay loam	54.2	39.82	36.12	27.90	23.21	71.4	30.0	41.4	1.29	1.78
B2, 12-31 inches	.76	5	15.5	47.7	36.8	silty clay loam	4.3	42.62	38.20	32.38	27.59	67.3	32.4	34.9	6.16	6.63
B3, 31-54 inches	.82	6	21.9	42.0	36.1	clay loam	12.1	44.72	40.26	34.37	31.65	69.5	37.1	32.4	6.74	5.88
C, 54-70+ inches	([1])	15	25.2	43.3	31.5	clay loam	([1])	47.17	40.74	31.90	28.73	69.5	39.2	30.3	4.66	3.61
Unnamed soil from andesite colluvium:																
A, 0-6 inches	([1])	50	42.9	35.5	21.6	loam	([1])	39.43	33.03	24.24	19.84	73.7	26.3	47.4	.55	1.00
AC, 6-15 inches	([1])	40	45.2	34.8	20.0	loam	([1])	36.67	30.72	21.50	18.96	69.5	24.6	44.9	.81	1.48
C, 15-60+ inches	([1])	40	42.2	36.2	21.6	loam	([1])	35.76	30.07	23.68	19.82	65.0	32.2	32.8	4.96	5.05

[1]*Data unavailable.*

[2]*Corrected for stones.*