Computer Programs in Hydrology

by

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FOREWORD

This bulletin is published in furtherance of the purposes of the Water Resources Research Act of 1964. The purpose of the Act is to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of the scientists in the field of water and resources which affect water. The Act is promoting a more adequate national program of water resources research by furnishing financial assistance to non-federal research.

The Act provides for establishment of Water Resources Research Institutes or Centers at Universities through the Nation. On September 1, 1964, a Water Resources Research Center was established in the Graduate School as an interdisciplinary component of the University of Minnesota. The Center has the responsibility for stimulating University research with water resources programs of local, State and Federal agencies and private organizations throughout the State; and assisting in training additional scientists for work in the field of water resources through research.

This report is number 44 in a series of publications designed to present information bearing on water resources research in Minnesota and the results of some of the research sponsored by the Center. The study described in this Bulletin is concerned with the many computer programs in the field of hydrology. This report consists of four sections and ten appendices. Sections I and II include a discussion of the scope of the project and general comments on the sources of computer programs in hydrology. Section III contains information on specific computer programs. Most of the programs described in this section were run at the University of Minnesota Computer Center on a CDC 6600 digital computer. Section IV gives general conclusions, including suggestions to those who might make use of the types of computer programs included in this study. Appendix 2 is an annotated bibliography covering a variety of topics in hydrology for which computer programs or methods are of interest. The remaining appendices list the computer programs that have been developed by various organizations.

This Bulletin serves as the Research Project Technical Completion Report for the following Center project:

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Project Title: Evaluation of Selected Computer Programs in Hydrology

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Publication Abstract:

Many computer programs in the field of hydrology are developed each year and are playing an increasingly important part in both research and design activities in hydrology. Many of these programs are available for use by other agencies, organizations, and individuals. The study of which this report is a part was undertaken to review available programs in hydrology and to provide information on representative programs. Information ranging from the title only of the program to listings, source decks, and documentation was reviewed for about 200 programs. Of these, 25 were selected for operation on a CDC 6600 computer and/or preparation of an abstract. The report discusses problems associated with adapting programs to a given computer and with understanding the technical procedure on which the program was based.

Publication Descriptors: *Computer programs/ *Hydrology/ *Mathematical models/ Digital computers/ Surface water/ Groundwater/ Water data/ Hydrographs/ River forecast/ Watersheds

Publication Identifiers: *CDC 6600 Computer/ *Pearson Type III Method/ *Backwater programs

ACKNOWLEDGEMENTS

The study involved the procurement of reports, computer program listings, and in some instances program source decks from many individuals and organizations. Most of these are included in the annotated list of programs and associated reports in Appendix 1. The cooperation of all individuals and organizations supplying information for this study is sincerely appreciated. Among these are: Mr. Leo R. Beard, Director, U.S. Army Corps of Engineers Hydrologic Engineering Center; Mr. Charles Collier, Mr. David B. Anderson, Mr. J.O. Shearman, Mr. David Dawdy, and Mr. George F. Pinder of the U.S. Geological Survey; Mr. H.H. Holtan, Agricultural Research Service; Mr. Howard Midje and Mr. Robert E. Maclay, Soil Conservation Service; Mr. Joseph Strub, Jr. and Mr. Ray E. Johnson of the National Weather Service; Mr. Lester Herr, Federal Highway Administration; Mr. Stephen Poe, U.S. Bureau of Reclamation; Mr. David M. Rockwood, North Pacific Division, Corps of Engineers; Mr. Leonard Gloeb, St. Paul District, Corps of Engineers; Dr. L. Douglas James, Georgia Institute of Technology; Mr. Donald Newton and Mr. James Price, Tennessee Valley Authority; Mr. John B. Stall and Mr. Thomas Prickett, Illinois State Water Survey; Mr. Richard D. Dyrland, National Forest Service; and Mr. J.C. Dingwall, Texas Highway Department.

Mr. N. Pundarikanthan, Graduate Student at the University of Minnesota, assisted in the use and evaluation of the Log-Pearson Type III Program.

INTRODUCTION

The objective of this research study was the review of selected computer programs in the field of hydrology with the aim of assisting in the application of these programs by potential users. Research efforts in hydrology and hydraulic engineering have resulted in the development of many computer programs. Some of these are of primary interest to those in the research phase of hydrology. Others may be initially of interest to research people but will be used for design purposes as information on and confidence in the programs develop. Other programs are based on well known procedures and as a result have immediate application to design problems. The second and third types of programs are of primary interest in this report, but some programs of all three groups have been included because no sharp separation among them exists.

At a recent professional meeting in the field of hydrology, concern was expressed by design-oriented engineers over the problem of communication between research and design hydrologists. The designers are actively interested in mathematical modeling of hydrologic processes but are faced with a difficult choice as to which models to use. A solution to this problem may not be available at this time because new models are continuously being developed and these will require considerable testing and evaluation before they find general acceptance.

The reports by Isacson, Stoker and Troesch [C-14]* on Numerical Solution of Flood Prediction and River Regulation Problems for the U.S. Army Corps of Engineers represent an early and valuable effort in the application of the digital computer to unsteady flow or flood routing in rivers. Crawford and Linsley developed the well known "Stanford Model" of the overall runoff process. Other investigators have developed a variety of models, some of which are similar in principle to the Stanford Model while others are based on quite different assumptions.

Various Federal agencies have been very active in preparing computer programs in hydrology, including the Hydrologic Engineering Center (HEC) and other offices of the Corps of Engineers, the Soil Conservation Service, the U.S. Geological Survey, the Bureau of Reclamation, the Tennessee Valley Authority, and the U.S. Forest Service.

The initial objective of some of these agencies was the adaptation of existing methods to digital computer solution techniques. In the process, it was sometimes possible to introduce much more sophisticated procedures than were possible with desk top calculators while still retaining the basic principles associated with accepted design procedures.

The Hydrologic Engineering Center of the Corps of Engineers under the direction of Mr. Leo R. Beard has done an outstanding job in preparing a series of about 28 programs, well documented and available to cooperating agencies. Many of these are based on Corps of Engineers methods, such as unit hydrograph theory and various "hydrologic routing" proce-

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*Numbers in brackets refer to the annotated List of Programs and Associated Reports in Appendix 2.

dures. However, in some instances, HEC has incorporated features that were not feasible prior to the advent of the digital computer. For example, a loss-rate routine using four variables has been used in several programs for hydrograph analysis, in place of the Ø index. Another feature of some of these programs is an optimization process based on fitting of observed events to assist in an evaluation of variables in the program.

The HEC programs are well documented relative to the purpose of the program, identification of variables, and explanation of input and output procedures. However, they often presume a knowledge of Corps of Engineers design procedures and this can cause difficulty in the use of some programs.

The Soil Conservation Service has also prepared a series of programs that are well documented and of interest to the applied hydrologist. One of these (TR 20 PROGRAM Section H) concerns the computation, combining, and routing of hydrographs for a series of the sub-watersheds of a larger watershed. A second program is for the study of the effect of variations in the number and characteristics of proposed dams in the watershed upon flows. The SCS programs use some basic procedures associated with that agency while utilizing the computer to the best advantage.

The Bureau of Reclamation has a large number of programs covering a variety of hydrologic and hydraulic topics. These are listed in Abstracts of Electronic Computer Programs Developed by the Bureau of Reclamation; Electronic Computer Programs Abstract Issue No. 4, May 1966; and Abstract Issue No. 5, February 1969. Quite a few of these programs are described in the Annotated Bibliography of Appendix 2, and the titles of all hydrologic and hydraulic programs are listed in Appendix 7. Many of these are applicable to general hydrologic and hydraulic programs, while others apply to specific project studies. The only USBR program used in this study was the "Determination of Flood Flow Frequencies by the Log-Pearson Type III Method" (HY 173). This is a well-documented program.

The U.S. Geological Survey, Automatic Data Section, Water Resources Division, has a series of about 80 computer programs for processing water data. These are primarily for use by the U.S. Geological Survey. However, some of the programs, which are listed in Appendix 5, may be of interest to other organizations as well as Federal agencies. Only two programs were actually used as part of this study, and both were well documented.

The Tennessee Valley Authority has prepared a series of about 13 programs for hydrograph analysis, flood routing, and related subjects, as noted in Appendix 6. While all of these are of interest to the hydrologist, three are of special interest. The first is for the determination of unit graphs from complex floods [B-15], the second for natural and regulated flood determination (NARFE) [B-16], and the third (SOCH) [B-19] for the simulation of unsteady flow in natural open channels by solution of the continuity and momentum equations.

The National Weather Service has developed a number of computer programs of interest to the river hydrologist. Two of these, an API Model by W.T. Sittner, C.E. Schuss and J.C. Monroe E-21, and a "Generalized River Forecast Program" by R.H. Dickson of the Kansas City office, are reviewed herein. The National Weather Service and the Corps of Engineers collaborated on a computer program entitled: "Stream-Flow Synthesis Reservoir Regulation" or the "SSARR Model". D.M. Rockwood, J.A. Anderson, V.P. Schermerhorn and D.W. Kuehl have prepared several papers on this model, which has been quite successful on some large basins.

Some information has been received concerning a Forest Service program to assist in water and related land resource planning. Apparently this will involve quantity, quality, and cost of water and other resources. The program is still being developed.

Three programs developed or sponsored by the Environmental Protection Agency (or its predecessors FWPCA or FWQA) have been reviewed. One of them is for optimization of water quality and the other two relate to urban runoff. Doubtless, there are numerous other programs available, particularly concerning water quality.

The development of the Office of Water Resources Research and the creation of Water Resources Research Centers in each of the states has resulted in considerable research funded by the Federal and state governments. Other state and University research has been funded in part by the National Science Foundation, the Federal Highway Administration, and the Corps of Engineers. One item of special interest in some of the state and university efforts is the development of mathematical models of the hydrologic system and associated computer programs. The well-known Stanford Model [E-5] sponsored in part by NSF and Stanford University and developed by N.H. Crawford and R.K. Kinsley is a particularly noteworthy development involving University and Federal cooperation. The computer program associated with this model was initially written in a form of Algol. It has since been rewritten in Fortran by W.D. James at the University of Kentucky and referred to as the Kentucky Model or as the Kentucky-Stanford Model. It has also been rewritten in Fortran by the National Weather Service and W.L. Moore and associates at the University of Texas. A new model has been developed by B.J. Claborn and W.L. Moore [E-4] as a result of their work on the Stanford Model.

The work of G. Bugliarello at Carnegie Mellon University with the problem-oriented language HYDRO and of J.W. Delleur at Purdue University with FORTRAN-HYDRO is of special interest relative to University contributions. L.F. Huggins and E.J. Monke have prepared a program described in a report entitled "The Mathematical Simulation of the Hydrology of Small Watershed" [E-11]. R.E. Machmeier and C.L. Larson at the University of Minnesota [B-12] have developed a mathematical model of an idealized watershed and have prepared several interesting reports on hydrographs resulting from variation in the intensity and duration of rainfall excess. Two students of Dr. Larson, T.C. Wei and P. Golany, have worked with variations in a stream system pattern and rainfall pattern using a modified model.

V. Yevjevich and A.H. Barnes [C-21] at Colorado State University, supported in part by the Federal Highway Administration and the Public Health Service, have conducted a very interesting study of unsteady open channel flow in a circular conduit and developed a computer program for the analysis of this flow condition.

SELECTION OF PROGRAMS

A part of the original objective of this study was achieved by placing a group of about 22 programs in operation on the CDC 6600 computer at the University of Minnesota. These programs are described in Appendix 1 of the report. Because the large number of available programs, it was not possible to operate all programs on the computer.

Appendix 2 is an annotated list of computer programs and associated references in hydrology. This is supplemented by a list of programs prepared by each of 6 Federal agencies and the University of Minnesota in Appendices 3 through 10.

The programs and references in the annotated list of Appendix 1 are grouped under the following headings: A. Statistical; B. Runoff Analysis; C. Flow Routing Procedures; D. Steady Flow Water Surface Profile Programs; E. Comprehensive Basin Runoff Analysis; F. Urban Runoff Analysis; G. Peak Flow Rates (small watersheds); H. Groundwater; I. Water Resources Systems Analysis; and J. Miscellaneous.

COMMENTS ON SELECTED PROGRAMS

The following comments pertain primarily to programs that were used as part of this study, but comments on other programs of special interest are also included. The comments are intended to be helpful to potential users, but it should be noted that some very large and complex programs are involved, and the authors have not had the opportunity to become expert in the use of all of the programs. The comments, therefore, are of primary value as an indicator of documentation available and problems encountered by the new user.

As noted above, HEC has prepared a series of well documented programs that should be of interest to many Federal and state agencies and to consulting engineers. Six of these have been selected for use and for general discussion in this study. Two programs prepared by the Soil Conservation Service, two by TVA, one by the Bureau of Reclamation, and eleven from other sources were operated during the study.

Of primary interest were (1) those programs assisting in the computation of peak rates and volumes of runoff for specified design conditions, (2) programs concerned with the statistical analysis of floods by the log-Pearson Type III method, (3) mathematical models of watersheds, and (4) backwater or water-surface profile programs. While no attempt was made to review groundwater programs, a very interesting U.S. Geological Survey program on well drawdown was used, and a second by the Illinois Water Survey was reviewed.

Eichert of HEC has published an excellent paper comparing six flow profile programs for the computation of water surface profiles in natural channels. This paper eliminates the need for coverage of these programs under the present study. It is discussed in section M along with one additional water surface profile program by Steven P. Larson of the University of Minnesota. The latest version of Eichert's water surface profile program HEC-2 is discussed separately in Section B. In view of the extensive use of profile programs by many state agencies in the flood plain mapping program, it was considered desirable to include an abstract of Eichert's paper in this report.

Table I is a list of programs for which abstracts have been included in Appendix 1. They are grouped by agencies in three cases, with the rest listed as miscellaneous programs, many of which are already familiar to many hydrologists.

Table I

(Comments on Selected Programs)
(See Appendix 2)

Hydrologic Engineering Center

A. HEC 1 - Flood Hydrograph
B. HEC 2 - Water Surface Profiles
C. Unit Graph and Loss Rate Optimization
D. Streamflow Routing Optimization
E. Hydrograph Combining and Routing
F. Unit Graph and Hydrograph Computation
G. Flood Operation Forecast

Soil Conservation Service

H. TR 20 - Project Formulation Hydrology
I. Dams Program

Tennessee Valley Authority

J. Natural and Regulated Flood Estimation
K. Unit Graph Program (TVA UG 36)
L. Unsteady Flow Analysis (SOCH)

Miscellaneous

M. Backwater Programs - Summary (Eichert)
N. Log-Pearson Type III - Probability Distribution; Comparison
O. Statistical Programs - Summary
P. Problem Oriented Computer Language - HYDRO
Q. Problem Oriented Computer Language - FORTRAN-HYDRO
R. U.S. Geological Survey - Small Basin Rainfall - Runoff Simulation
S. USDAHL - 70 Model of Watershed Hydrology (Holtan and Lopez)
T. Kentucky-Stanford Model (and Stanford Model)
U. EPA (FWPCA) Model, River Basins Simulation Program
V. Streamflow Synthesis and Reservoir Regulation (SSARR)
W. Texas Model, Numerical Simulation of Watershed Hydrology
X. Flood Routing Through Storm Drains by Yevjevich and Barnes
Y. UROM 9, UROM 66 - University of Minnesota

SUMMARY AND RECOMMENDATIONS

Information was received on approximately 200 computer programs in hydrology. Most of these were prepared by Federal agencies to assist in the analysis and design of water resource projects. These have great potential value to other Federal agencies, state organizations and firms actively involved in the field of hydrology. Most of these programs are available from the developing agency. Obtaining source decks and listings may involve a fee to cover the cost of reproduction and mailing.

Sharing of programs should involve the saving of substantial sums of money, particularly in fields such as the flood plain program, since many of the states are actively involved with delineation of the flood plain of streams within their boundaries. Flow profile and frequency analysis programs will be required if such programs are not already in use.

Most of the programs are included in the annotated list of programs and supplementary reports of Appendix 2. The titles of most of the programs are also included by Federal or state agency in Appendices 3 through 10. Abstracts of 25 programs comprise Appendix 1 of the report.

A clearinghouse for available programs in the field of hydrology should be established, possibly by the Office of Water Resources Research. This clearinghouse could provide copies of the programs and information on modifications to them.

When using computer programs developed by other organizations, there are problems associated with documentation of the input requirements of programs and of the technical procedures incorporated in this program. The following recommendations may be of interest.

Recommendation for Program Originator

1. Source programs should include substantial internal documentation. The liberal use of comments within the source statements is of paramount importance if users outside the developing agency are to follow the program logic. Comments should be used to define all significant parameters; to indicate computations being performed by each section of the routine; to explain logic of decision statement; and to indicate all revisions made to the program.

2. Document all methods used. Proper documentation should include a description of the methods used, since these may not be familiar to engineers from other organizations. Such explanations will result in substantial savings to the user and may mean the difference between success and failure with the program.

3. Specify input format. The input data requirement should be explained and the format defined. This should include comments on the nature and purpose of each input parameter.

4. Include sample data sets. At least one and preferably two or more data sets should be provided with a program deck to verify the compilation and execution of the program on the user's equipment. An

exact listing of input data should be given along with the resulting program output.

5. Use standard FORTRAN statements. Whenever possible, use only USASI standard FORTRAN statements. While many FORTRAN compilers will accept non-standard statements, the use thereof greatly complicates adaptation of a program to other machines. The use of sense switches and other machine dependent options should be avoided where possible.

Recommendations for Program Users

1. Contact the program originator. If use will be made of a published program it is advisable to contact the program originator. Minor errors may have been detected after publication of the program. Revised copies of the program may save weeks or months of delay.

2. Become familiar with methods. The user of a program should become familiar with the hydrologic as well as computer methods employed. This is important if he is to understand limitations of the program and assumptions incorporated therein.

3. Test the program. The initial execution of a program on a different computer should be verified by testing it with a sample set of data provided by the program originator and comparing the results to those supplied by the program originator. In addition, the user should verify for himself that the program is accomplishing the desired computation. This might involve comparison with results obtained by other methods, such as by a desk calculator, for simple problems. While every effort is made by most programmers to check and debug routines, complex programs may contain errors not revealed by a given set of test problems. The user should assume the responsibility for final acceptance of the program results.

APPENDIX 1 - ABSTRACTS OF 25 PROGRAMS

Section A. HEC-1, FLOOD HYDROGRAPH PACKAGE

Source

Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California, Leo R. Beard.

Description

This program is the first in a series of package programs developed by HEC to incorporate all the basic flood hydrograph computations associated with a single recorded or hypothetical storm into a single unit. The objective was to eliminate some of the intermediate processing which was sometimes necessary to arrive at a final result using the several individual programs upon which this package program is based. HEC-1 is written in Fortran IV and is designed to be contained in 32000_{10} words of core storage on the CDC 6600 computer. At the University of Minnesota approximately 24600_{10} storage locations are necessary to load and execute the program.

The program is based on a number of computer programs (see Fig. A-1) which are discussed in Sections C through F. Although some capabilities of these individual programs were not included for the sake of economy, on the whole the package program can handle problems which previously required five individual programs. The program's most important feature is its ability to make a complete analysis of a problem in a single computer run. With a systems-analysis-type problem, for example, the program can generate runoff hydrographs and route and combine them in a single computer run, whereas previously it was necessary to generate the hydrographs with one program and then use the output as input for another program which would complete the analysis.

The capabilities of the composite program include

1. Hydrograph generation based on the unit hydrograph approach, including unit hydrographs computed from time-area curves.
2. Hydrograph combining and routing through channels and reservoirs via a number of alternate methods.
3. Rainfall, snowfall, snowpack, and snowmelt determinations.
4. Optimization of various runoff and loss rate parameters, snowmelt parameters, and routing parameters based on recorded data.
5. Designing flood computations for system design problems.
6. Computation of relative damages due to channel or reservoir development or flood magnitude.

7. Automatic plot routines to illustrate computational results.

Using these and other capabilities, the user is able to investigate many related water resources problems.

Methods

Standard U.S. Army Corps of Engineers design techniques are generally used in both the individual programs and the package program. As noted previously, most of the methods are described in detail in abstracts covering other HEC programs.

Basin total precipitation is determined from station precipitation based on normal precipitation amounts and station weighting factors. Thus

$$PRCPA = \frac{\Sigma(PRCPN \cdot WTN)}{\Sigma(ANAPN \cdot WTN)} \cdot ANAP \qquad (1)$$

where

PRCPA = Basin mean total precipitation
PRCPN = Station total precipitation
WTN = relative station weight
ANAPN = Station normal precipitation
ANAP = Basin-mean normal precipitation

If normal precipitation data are not available or not used, the basin mean total precipitation is given as input. Short period station-average precipitation is determined from

$$PRCP = \frac{\Sigma(PRCPR \cdot WTR)}{\Sigma WTR} \qquad (2)$$

where

PRCP = Station-average interval precipitation
PRCPR = Station interval precipitation
WTR = Station relative weight

The station average precipitation is pro-rated to give the basin mean total precipitation (PRCPA). The weighting factors and normal precipitation data are included in the input along with the station precipitation data.

Snowmelt is computed by one of three alternate equations depending on the availability of data and the current precipitation situation. Separate computations are made in each of up to ten elevation zones, the temperature in a zone being a function of the base temperature and a specified lapse rate. Also, the freezing temperature (FRZTP), which controls the point at which melt begins, can be specified on input.

The relations used to compute snowmelt are shown below. If only temperature data are available, Eq. (3) is used.

$$SNWMT = CØEF\ (TEMPR - FRZTP) \qquad (3)$$

SNWMT = CØEF(.09 + (.029 + .00504 WIND + .007 . PRCP)(TEMPR - FRZTP) (4)

SNWMT = CØEF(.002 SØL(1 - ALBDØ) + (.0011 . WIND + .0145)(TEMPR - FRZTP)
+ .039 WIND . (DEWPT - FRZTP) (5)

where

SNWMT = Melt in inches per day in a 1000-ft elevation zone
TEMPR = Air temperature in °F at the middle of the zone
FRZTP = Freezing temperature in °F
CØEF = Melt coefficient
PRCP = Rainfall in inches per day
SØL = Solar radiation in langleys per day
ALBDØ = Albedo of the snow ($.75/D^2$ but greater than .4)
WIND = Wind velocity in miles per hour 50 ft above the snow surface
D = Number of days since the last snowfall (age of surface snow)

Precipitation in a given zone is said to be snow if the zone temperature is less than the freezing excess temperature plus 2°. Rainfall patterns can be input to the program or computed from Corps of Engineer design criteria. Rainfall excess is computed according to one of two loss rate techniques. The total excess (rainfall and/or snowmelt) is then used to produce an outflow hydrograph using a unit hydrograph which can either be specified or be computed from a time-area curve by the Clark method. (This is completely outlined in Section F.) Various routing techniques are available for performing either reservoir routing or channel routing (Section E).

The program can derive the unit hydrograph and loss rate parameters and also the routing parameters and snowmelt parameters based on recorded data. The optimization of the various parameters is accomplished using a least-squares technique as in the individual optimization programs. The actual techniques are discussed in more detail in Section C, which deals with unit graph and loss rate optimization. This program has the same general capabilities as the individual optimization program, although it optimizes fewer parameters.

Balanced hydrographs can be computed based on a pattern hydrograph and specified durations of flood flow having the same recurrence interval. The program is also capable of accounting for decreased basin average precipitation due to increased basin size. This option is used in river system or storm drain system design. Many results of the various computations can be illustrated using an arithmetic plot subroutine.

Due to the many capabilities of the program, the input data required are somewhat complicated, although if users are familiar with conventional HEC input format, the requirements are more easily understood.

Discussion

This program has many desirable features, the most important being its ability to execute a variety of computational procedures in a single computer run, yet be contained within a reasonable amount of computer core storage. The relative compactness of the program is quite advantageous, since the amount of storage required is a significant factor in determining whether or not the program can be used for a particular purpose.

Although the computational procedures are geared toward Corps of Engineers techniques, the program can be very useful to others involved in rainfall-runoff investigations. Many of the computations are common to this type of analysis and have widespread applicability, while others can be used to provide a comparison with individual techniques. It is possible that the input requirements would be somewhat overwhelming to the occasional user. This program has significant potential for water resources planners and designers concerned with flood runoff analysis. Sections C through F, on individual HEC programs, describe in greater detail the methods used in this program.

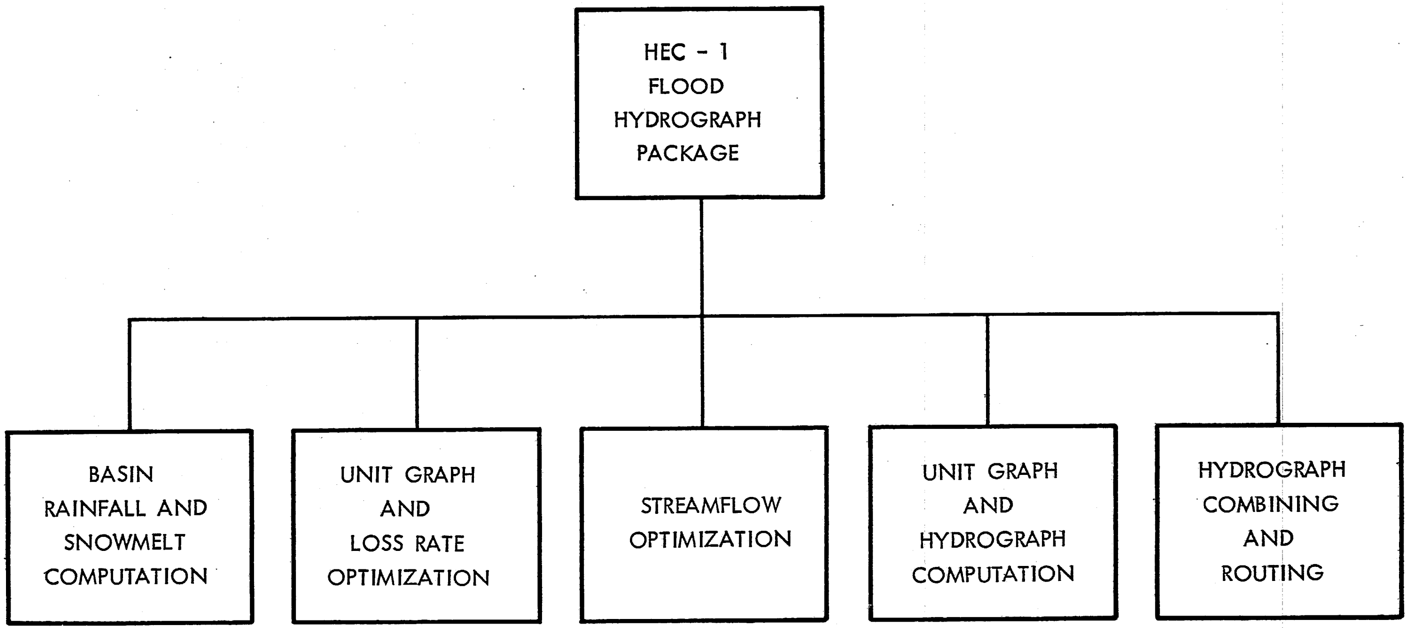


Figure A-1. Individual Tasks Combined in HEC-1, Flood Hydrograph Package.

Section B. HEC-2, WATER SURFACE PROFILES

Source

"HEC-2 - Water Surface Profiles," by Bill S. Eichert, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, 1969.

Description

The HEC-2 water surface profile program computes flow profiles for river channels of any cross section for either supercritical or subcritical flow conditions. Special consideration is given to bridges, culverts, weirs, embankments, and dams. The program allows variable roughness, islands, bends, levee overflow, river confluences, and waterfalls. Channel roughness can be established from known high water marks if desired.

The program, originally written for a CDC 6600, requires approximately 147000_8 locations on that machine. Most of the core storage is used only to retain the results of a series of flow profiles (up to 15) which are summarized for comparison at the end of all computations. If this option is not required, core storage can easily be reduced to about 40000_8 locations on the CDC 6600.

Methods

For all normal cross sections the standard step method is used to determine the depth at the next section. Subcritical computations proceed upstream and supercritical computations downstream. Three options are available for starting conditions: known depth, critical depth, and given energy slope. In addition to friction losses, expansion and contraction losses are evaluated at each cross section. Bridges and similar structures can be evaluated by either a normal or a special bridge routine. The normal bridge routine considers the bridge the same as any other cross section except that the area and wetted perimeter for the section are corrected due to the bridge structure. The special bridge routine evaluates losses for low flow, pressure flow, and weir flow or possible combinations of these. Common weir and pressure (orifice) flow relations are used, with applicable coefficients specified by the user. Figure B-1 shows a typical rating curve for a bridge culvert. Bridge computations involving critical or supercritican flow are analyzed according to the principle of conservation of momentum.

Special flow geometries involving levees are considered. The user can either allow or prevent the use of flow area behind a levee based on his knowledge of the flow conditions at the beginning or ending points of the levee, overtopping, breaks, etc. In addition, the effective area of a cross section may be reduced by encroachments, sediment scour, and deposition. These possible conditions are represented in Fig. B-2.

The entire river cross section is divided into three regions: left overbank, channel, and right overbank. The discharges in these regions are determined separately, and a discharge-weighted velocity head is calculated for the entire section.

If large changes in velocity occur from section to section, the user may allow the program to insert up to three interpolated cross sections between the actual cross sections. The interpolated sections are geometrically similar to the latest cross section used by the program, but shifted in elevation and proportioned in lateral stationing. The shift in elevation is based on minimum elevations in the respective past and present actual cross sections. The ratio applied to the lateral stationing is that of the area of the channel flow in the previous section to the area of the channel flow in the present section where the depth of flow is the same. The geometry determined is then used as the interpolated cross section to reduce the large velocity change that previously occurred. The user is cautioned not to compare various profiles determined with differing interpolated cross sections. Rather, when interpolated sections are inserted by the routine, the user should note this need for additional cross sections and rerun the profile, supplying additional ground cross sections as required to eliminate computer-inserted interpolated sections.

Discussion

A wide variety of flow conditions are allowable when water surface profiles are determined using the HEC-2 program. An important part of the analysis begins only after the computer has finished its initial solution.

The computations at each cross section should be checked by an engineer experienced in the practical aspects of water surface profile computations. Particular attention should be given to warning notes printed by the program, interpolated sections, bridge computations, and assumptions made by the program. It is impossible to program all conditions that may be encountered in backwater computations. In some cases an assumption is made which may or may not be valid in order that computations can be continued. In such a case a note is printed and the engineer must decide on the correct course of action.

A user of this program should be well versed in water surface profile computations. The preparation of input with a variety of options is an asset to the experienced user, but a hindrance to the beginner.

The program should be of considerable interest to those who are actively involved in flood plain delineation. It is a powerful tool in such studies, but it does require familiarity with the computational procedures employed. In this connection, training sessions are provided for Corps of Engineers employees and those of cooperating agencies.

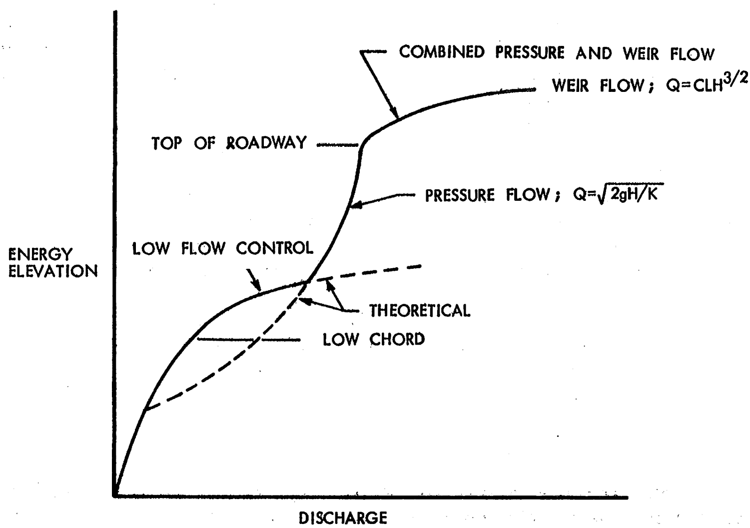
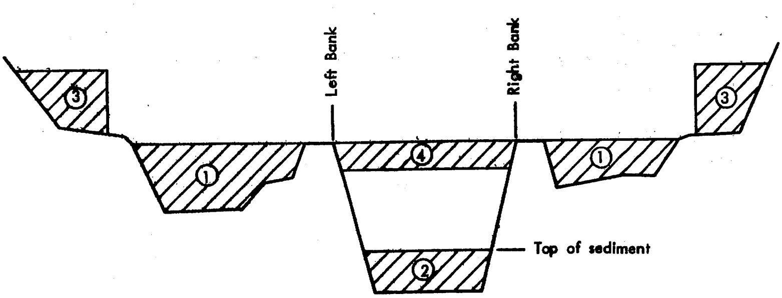


Figure B-1. Typical Discharge Rating Curve for Bridge [From Eichert, Ref. D-3].



Ineffective areas:

1. When flows are below bank elevations.
2. Caused by sediment deposition.
3. Caused by encroachment in flood plains.
4. Caused by bridge deck.

Figure B-2. Examples of Possible Reductions in Effective Cross-section Area. [From Eichert, Ref. D-3].

Section C. UNIT GRAPH AND LOSS RATE OPTIMIZATION

Source

"Unit Graph and Loss Rate Optimization," by Leo R. Beard, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, Aug. 1966.

Description

This program determines the best unit hydrograph and loss coefficients, within the limits of the mathematical model, to reproduce a number of flood hydrographs at a given location from specified rainfall amounts. A write-up supplied with the program includes a Fortran II source listing and a list of variables and their definitions. Comments within the program are sufficient to indicate what operations are being performed at various locations. All methods used are outlined briefly in the body of the write-up furnished with the program.

The data on each input card are listed and input parameters are defined. The documentation gives a very good description of the mechanics of input data preparation and organization. More detailed information on the significance of each input parameter would be desirable if the user had no previous familiarity with the program. The program contains some error checking of input data. Checks are made to assure that input data arrays will not exceed the maximum sizes allowed in the program. The program requires about 34000_8 words of core storage for execution on the CDC 6600.

Methods

The routine attempts to successively improve the fit between an observed and a computed runoff hydrograph. The fit is evaluated using a standard error calculated as a weighted sum of the squares of the differences between computed and observed flows. The higher discharges are weighted so that peak flows can be better reproduced. The invariate gradient method is used to obtain optimum parameter values. The effect of each parameter is determined by varying it in increments and evaluating the changes in the standard error. The variable is then changed in the direction and by the amount that should reduce the standard error the most.

Each variable is considered in turn, and those which improve the fit most are adjusted further. Optimization is declared when no variable can be adjusted to improve the standard error by one percent.

The variables under consideration are those describing the Clark unit hydrograph and the exponential loss rate function. A detailed discussion of each of these variables is given in Section F, Unit Graph and Hydrograph Computation. See Figs. F-1 and F-2.

The variables numbered 1 through 3 govern the unit hydrograph that is used, while variables 4 through 9 determine the rainfall excess.

Var (1) = Clark's TC, or time of concentration. As defined by Clark, time from end of runoff-producing rainfall to point on the hydrograph with most rapid relative decrease in runoff.

Var (2) = Ratio of Clark's R to TC. The R determines the routing coefficient, relating basin storage.

Var (3) = P, exponent of artificial time-area curve.

Var (4) = Ratio of impervious area to total drainage area.

Var (5) = RTIOL = slope of loss coefficient curve, ratio of K of straight-line portion of loss rate curve to K at 10 inches more accumulated loss.

Var (6) = Recovery index relating drying or drainage from soil, subtracted from accumulated loss each period.

Var (7) = E, exponent of rain rate.

Var (8) = Value of K on straight-line portion of loss rate curve when accumulated loss is 1/2 of storm loss. (Related to STARTK (BASEL) of Fig. F-2.)

Var (9) = High loss rate increment at beginning of event.

Discussion

Various runs were made to determine how effective the program is in accomplishing its objective. A total of nine variables describing the unit hydrograph and the loss rate are considered. The unit hydrograph is determined by three of the variables. Of the remaining six, describing the loss analysis, four apply to all storms (constant for basin) and two vary from storm to storm according to antecedent conditions.

In addition, two parameters governing the hydrograph recession must be set by the user. These two parameters are to be derived from the observed hydrograph. Variations of these parameters will also affect optimization results. The user may also temporarily weight specified flows on the observed hydrograph to force a better fit.

About 50 test runs were made to fit a single event for the Root River watershed above Lanesboro, Minnesota, on August 29, 1962. During these tests various parameters were changed to determine how the program would operate under different constraints. The results of selected runs are given in Table C-1.

Shown in Fig. C-1 are the results of two optimization runs to derive a unit hydrograph from the storm of August 29, 1962, on the Root River watershed near Lanesboro, Minnesota. The results obtained from run 7A give a unit graph with a peak flow of 11,000 cfs. This was obtained by allowing the program to assume its own estimates of initial values for all optimization parameters. In run 9A, which produced a unit graph with a peak of 22,000 cfs, the initial values of several parameters were set based on engineering judgment. The final optimum parameters for these two runs are shown on lines 1 and 4, respectively, of Table C-1.

While the derived unit graphs are very dissimilar, the computed flows obtained by applying the unit graph to the computed rainfall excess give peaks of 7000 cfs and 8200 cfs respectively (see Fig. C-2). This occurs because the computed runoff is determined by the optimal values of both the loss rate function and the optimal unit hydrograph. The loss function produced a longer period of excess to fit with the peaked unit graph in one case and a shorter period of excess to fit with the less peaked unit graph in the other case. The net effect was to produce reasonably similar computed flows from dissimilar unit hydrographs. This example illustrates the need to examine carefully the results of any program before final acceptance.

Table C-1 summarizes the results of several runs to obtain optimum parameters with variations in starting conditions and variables optimized.

This analysis indicates that substantially different optimal values of unit hydrograph and loss rate variables can combine to yield reasonably similar computed discharges. For this reason, care should be exercised if a unit hydrograph derived by the program is applied and a different loss analysis is utilized. That is, the derived unit hydrograph should not be considered independent of the loss analysis used in its derivation.

As indicated previously, line 1 of Table C-1 shows the results of an optimization run during which the program was allowed to assume its own initial value for each parameter. Line 2 shows the results of a run for which the optimum results given in line 1 were input as initial values for each variable. Similarly, line 3 shows the results of using line 2 values as initial parameters for further optimization. It may be noted that in each case the standard error (column 13) was decreased, indicating a better fit.

Using judgment, several parameters were given initial values. From several runs the overall best fit was obtained with the values given in line 4. These values were then used as the standards for further tests on individual variables. Line 5 shows the results when variable (2) was input at standard value and held fixed there (flagged). The other variables were all allowed to assume initial values and to be changed by optimization. No improvement in fit was obtained. Similar tests were made fixing each other variable at the standard value and allowing the others to be optimized, and in each case a poorer fit was obtained than with the standard values. Line 6 shows the results when variable (8) was handled in this manner. The large changes in several of the variables are compensated for by changes in other variables, giving a poorer, but still reasonable fit.

Another series of tests was made fixing all but certain specified variables at the standard values and allowing optimization of only a few variables. Line 7 shows the results of letting only variables (5), (8), and (9) be optimized further. In this case a very slight improvement resulted. Line 8 shows the results of letting only variables (2), (8), and (9) be optimized further. The "optimum" values here actually gave a much worse fit than had been obtained with the standard values.

Table C-1. RESULTS OF OPTIMIZATION

Line No.	Run No.	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6	Var 7	Var 8	Var 9	Unit peak	Stand. Error	Total Excess (in.)	STARTK (BASEL)	Peak Flow (cfs)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
															Actual Peak = 8700
1	7A	44.70	0.39	2.54	0.00	4.45	0.03	0.45	0.41	2.11	11152	876	0.66	0.53	7120
2	9B	51.84	0.29	4.79	0.00	4.22	0.03	0.44	0.40	2.35	14290	547	0.58	0.51	7719
3	12A	53.65	0.24	4.79	0.00	3.86	0.03	0.37	0.38	2.25	15258	523	0.56	0.48	7827
4	9A	62.10	0.11	6.38	0.05	4.43	0.01	0.09	0.38	0.28	21931	480	0.52	0.53	8146
5	13B	61.71	0.11	4.20	0.00	2.36	0.02	0.30	0.39	1.40	17795	476	0.51	0.45	8018
6	14D	42.25	0.46	3.11	0.00	20.32	0.05	0.46	0.36	2.22	11495	779	0.68	0.61	7302
7	22B	62.10	0.57	6.38	0.05	4.43	0.01	0.09	0.29	0.24	8164	1630	0.90	0.40	6546
8	23B	62.10	0.11	6.38	0.05	2.47	0.01	0.09	0.37	0.24	22300	464	0.52	0.48	8166
9	26A	62.10	0.11	6.89	0.04	4.69	0.01	0.06	0.38	0.24	22840	534	0.52	0.53	8376

Line 9 shows the use of an option to weight certain observed flows to force a better fit in a particular area of the hydrograph. In this run the peak flow was artificially given increased weight. The standard error increased slightly, but the peak discharge was reproduced better.

These tests show that often a marked improvement in fit can be obtained by further manipulating values, even though optimization has been declared in previous runs.

A maximum of six observed events can be used as the basis for deriving one unit hydrograph. This option was tested using six events from the Baptism River near Beaver Bay, Minnesota. These same events had previously been used individually to derive best-fit unit hydrographs. The results of the individually derived unit hydrographs and the combined best fit are shown in Fig. C-3.

The input data appear in the output listing, except for the input time-area curve where this option is used. The material in the output is presented in an easily understood format. The option of having the output hydrograph punched on cards for future use is available. A single-page graphical display of computed and observed results would be a desirable addition.

Figures C-4 and C-5 illustrate the use of the program for a storm which occurred on July 25 and 26, 1953, over a 1270 sq mile watershed in southeastern Minnesota.

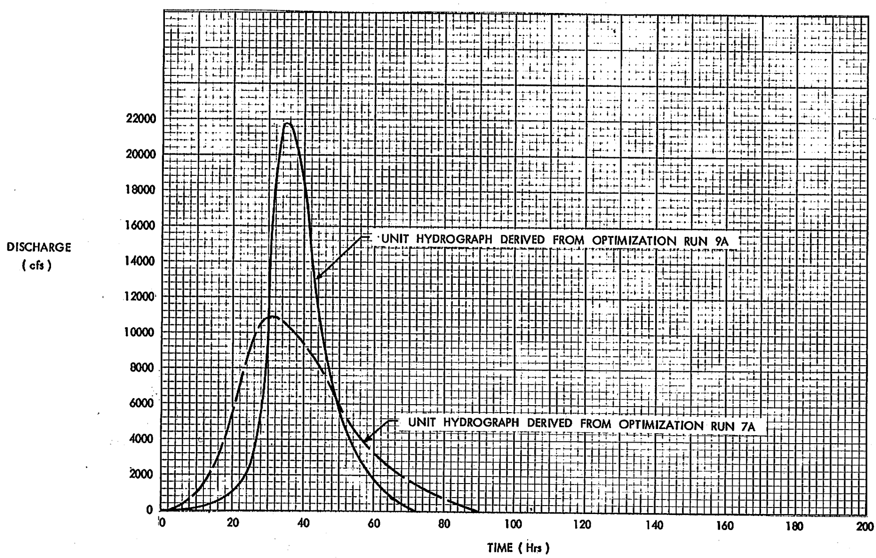


Figure C-1. Examples of Two Unit Hydrographs, Each Derived as Optimum in Separate Runs Using Data for Root River Near Lanesboro, August 29, 1962.

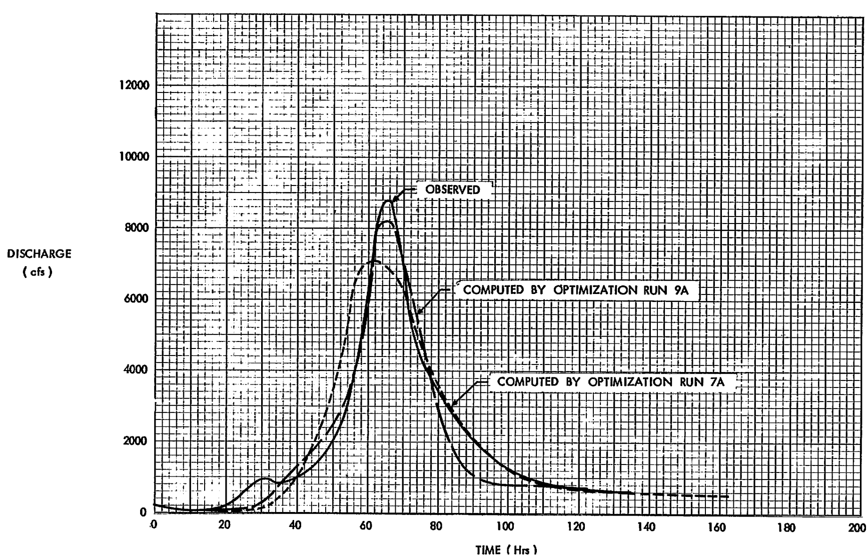


Figure C-2. Comparison of Observed and Two Computed Hydrographs for Root River Near Lanesboro, August 29, 1962.

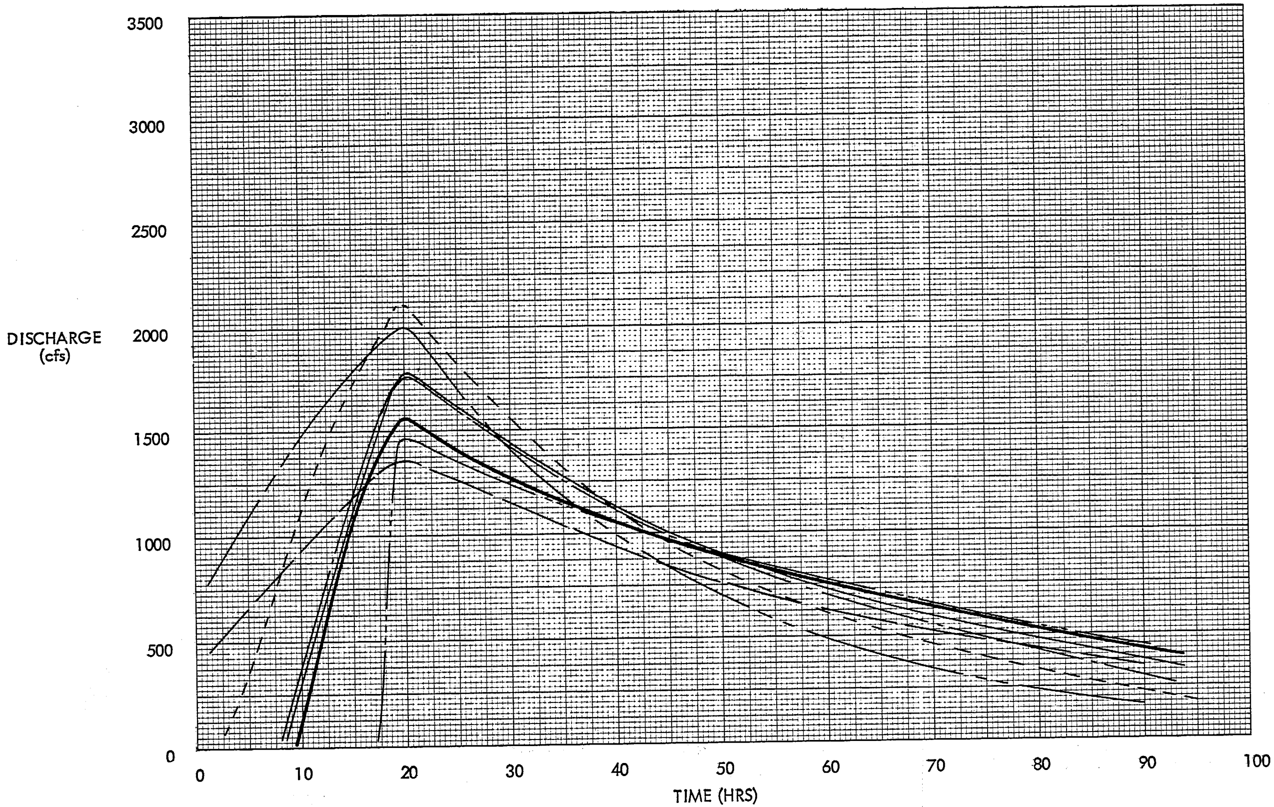


Fig -C-3 Optimum unit hydrographs from six individual events on the Baptism River, Minnesota. Heavy curve shows composite unit hydrograph obtained by optimizing all six events in one run.

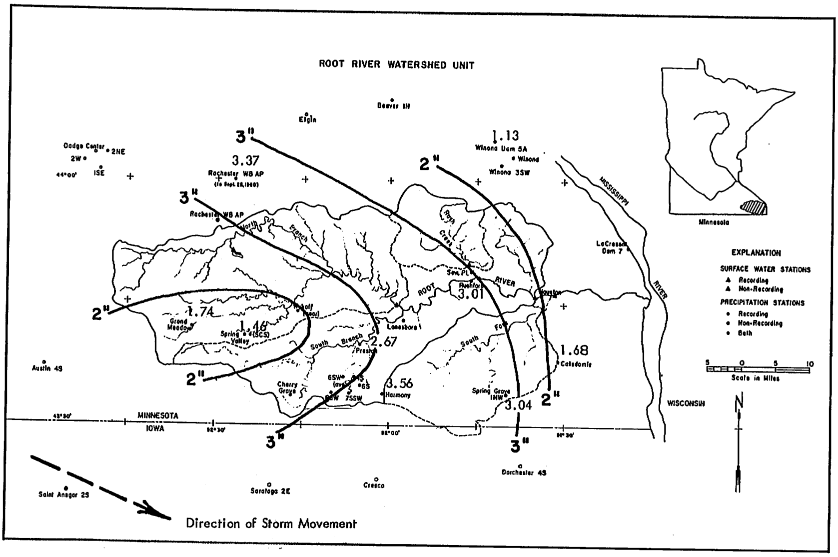


Fig. -C-4 Isohyetal map of Root River watershed storm of July 25-26, 1953.

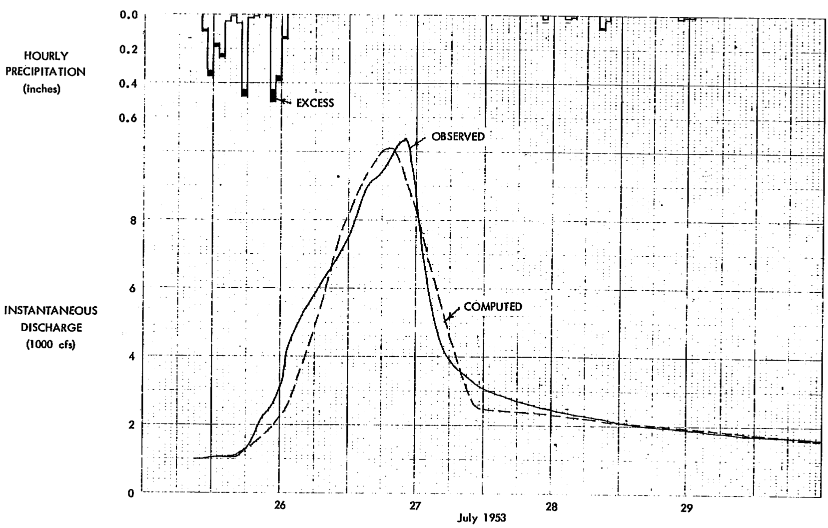


Fig. -C-5 Computed and observed discharge for Root River near Houston, event of July 25-26, 1953.

Section D. STREAMFLOW ROUTING OPTIMIZATION

Source

"Streamflow Routing Optimization," by Leo R. Beard, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, July 1966.

Description

This program uses successive approximations to optimize values for Muskingum routing coefficients K and X to best reproduce observed hydrographs. Several inflow hydrographs along the reach can be input. Additional local runoff can be computed as a ratio of a given hydrograph to make the volume of the computed downstream hydrograph equal to the observed hydrograph. The results are less reliable where local runoff is large compared to the observed flows.

This program consists of approximately 375 input statements and, when used on the CDC 6600 computer, requires approximately 57000_8 storage locations. The optimization takes less than three seconds of computer time for a single flood in one river reach. The program was originally prepared for an IBM 1620 computer having a 40,000 digit, variable word length memory with Fortran II capabilities.

Methods

The program first computes the number of subreaches that each specified routing reach will be divided into by finding the average travel time between the inflow and outflow hydrographs. The travel time is chosen to be the difference between the centers of mass of the total inflow hydrograph and the total outflow hydrograph. The number of subreaches is selected so that the travel time in each subreach is nearly equal to the chosen computation time interval. The value of the time interval is then used as an initial estimate of the value of the Muskingum K value. The Muskingum X value is initially set at 0.2. The inflow hydrograph is routed using the Muskingum technique.

Local inflow, if not provided, is determined as the difference in volume between the routed hydrograph and the observed hydrograph. The shape is determined by a specified hydrograph adjusting its ordinates to obtain this desired volume.

The sum of the squares of the differences between observed flows and routed flows plus local inflow is then computed as the standard error. The values of X and K are then adjusted in an attempt to minimize the standard error. Adjustments are made in such a way as to always reduce the standard error if possible. After six adjustments of all constants, optimization is declared and the results at this stage are printed out.

Discussion

The program provides an excellent means of computing Muskingum routing coefficients for stream reaches where inflow and outflow hydrographs are available. These estimates can then be used as a guide in selecting routing constants where observed hydrographs are not available. The literature on the program provides some explanation of methods used and definitions of important variables along with a complete list of input requirements with sample runs. In utilizing this program, an error was detected that led to slightly different coefficients if the number of subreaches was greater than one. This was called to the attention of HEC.

Figure D-1 shows a given upstream and downstream hydrograph. The upstream hydrograph that would best reproduce the downstream hydrograph, routed using the Muskingum method, is also shown. The optimum routing constants in this case were found to be 2 subreaches, K = 10.8 hrs, and x = 0.04. In this illustration the rising and falling limbs of the hydrograph are reproduced very well; however, the peak values are not. The program determines the best overall fit as indicated by the standard error.

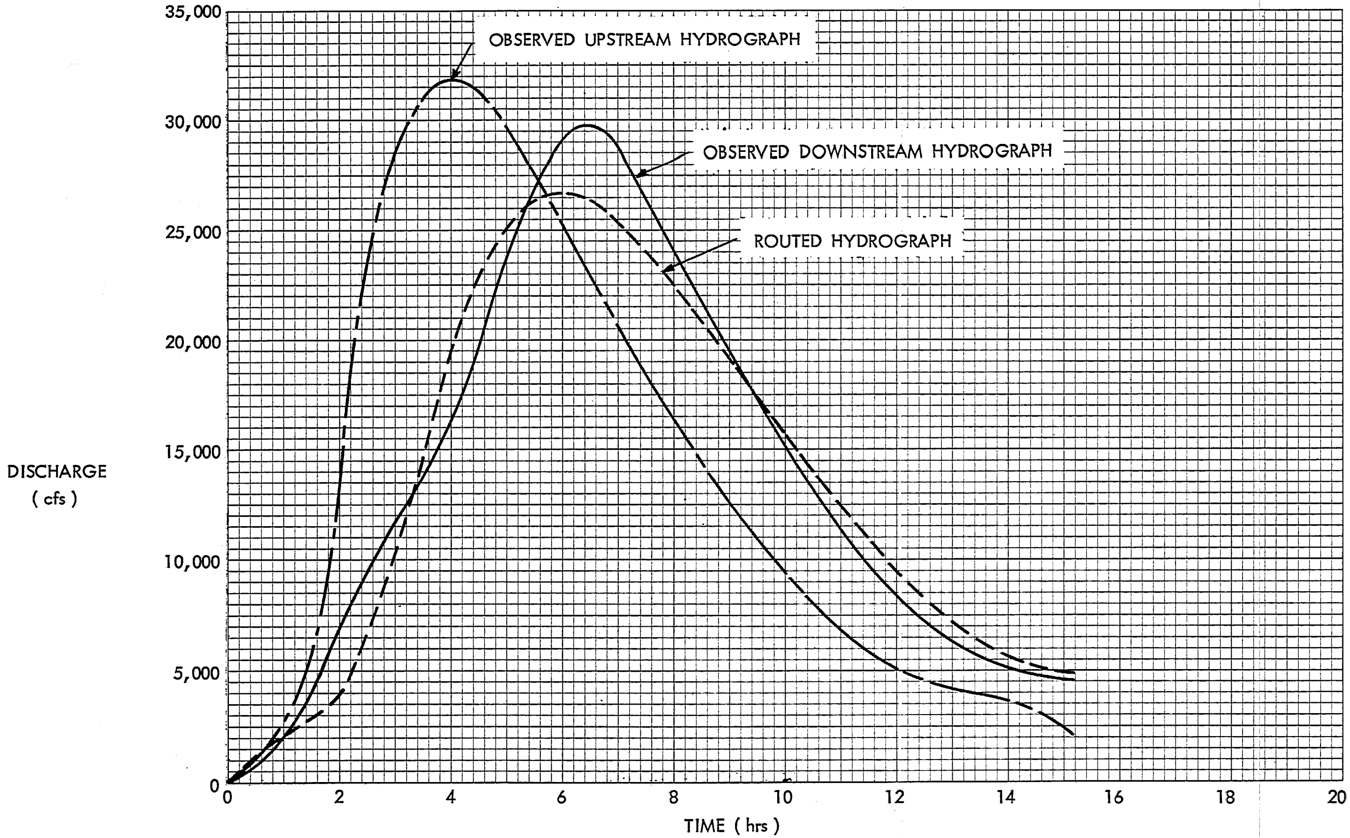


Fig -D-1 Observed upstream and downstream hydrograph, and optimum routed hydrograph by Muskingum method.

Section E. HYDROGRAPH COMBINING AND ROUTING

Source

"Hydrograph Combining and Routing," by Leo Beard, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, August 1966.

Description

The program is capable of any one of the following:

1. Given the holdout hydrograph for a reservoir and an observed hydrograph downstream, the unregulated hydrograph can be computed.

2. Given observed or unregulated hydrographs, local inflows can be computed.

3. A given hydrograph can be routed through a channel reach by any of four available methods and two or more hydrographs combined at junctions. The four available routing methods are

    a) Puls' method - both reservoir and channel routings; also Puls' lag method.

    b) Muskingum routing

    c) Tatum routing

    d) Straddle stagger routing

This program consists of approximately 340 input statements and requires 40000_8 storage locations when used on the CDC 6600 computer. The time required by the program is nominal (less than one second for a routing operation). The program was designed for use on an IBM 1620 computer with 40000 digit storage capacity and Fortran II capabilities.

Methods

1) Computation of Unregulated Hydrograph

This can be used to evaluate the operation of a control structure such as a reservoir, since it basically computes the hydrograph which would have appeared downstream had the control structure not been in use. As shown at the top of Fig. E-1, the computation of the unregulated hydrograph is made by first routing the holdout hydrograph from 1 to 2 and them combining it with the observed hydrograph. Using this technique, inflows along the reach do not have to be considered, as they would if the input hydrograph were merely routed to the end of the reach to determine the unregulated hydrograph.

2) Computing Local Inflows

Since a routed hydrograph does not include local inflows, the local inflow can be determined by subtracting the routed hydrograph from the observed downstream hydrograph (as shown at the bottom of Fig. E-1). When the variable LØCAL on the basin data card is positive, a command to combine two hydrographs will actually compute the local inflow by subtracting an observed hydrograph.

3) Routing of Hydrographs

a) Puls' Method

This method is most satisfactory for reservoir routing and is not well suited to channel routing. A storage versus outflow table is necessary from which the program can compute a storage indication table $(S + \frac{0}{2} \Delta t)$. Then, given the starting storage value and assuming $0_1 = I$, it uses the following equation to compute 0_2:

$$\frac{(I_1 + I_2)}{2} \Delta t + S_1 - \frac{0_1}{2} \Delta t = S_2 + \frac{0_2}{2} \Delta t \quad (1)$$

The left side of Eq. (1) is evaluated and the storage indication table is used to find 0_2.

b) Muskingum Method

The program does basic Muskingum routing given the values of K and X and the time interval.

K = storage constant (ratio of storage to discharge, has the dimension time)

X = relative effect of inflow and outflow in determining storage

The equation for 0_2 is

$$0_2 = C_0 I_2 + C_1 I_1 + C_2 0_1$$

where

$$C_0 = -\frac{Kx - 0.5t}{K - Kx + 0.5t}$$

$$C_1 = \frac{Kx + 0.5t}{K - Kx + 0.5t}$$

$$C_2 = \frac{K - Kx - 0.5t}{K - Kx + 0.5t}$$

c) Tatum Routing

This empirical method is also referred to as the successive average-lag method. Instantaneous flows a routing interval apart are averaged, resulting in the flow at the end of the interval. This procedure is repeated until the number of subreaches (NTATM) times the time interval is equal to twice the travel time for the reach. Thus

$$O_{n+1} = C_1 I_1 + C_2 I_2 + C_3 I_3 + \ldots C_{n+1} \; I_{n+1}$$

Where n is the number of subreaches and

$$C_1 + \frac{1}{2^n}$$

$$C_2 = \frac{n}{2^n}$$

$$C_n = \frac{n(n-1)(n-2) \ldots (2)}{2^n (n-1)!}$$

$$C_{n+1} = \frac{1}{2^n}$$

The number of subreaches needed is

$$\text{NTATM} = \frac{2 \text{ x travel time}}{\text{Routing interval}}$$

d) Straddle Stagger Routing

This empirical method is similar to the Tatum method. Two or more (NSTRL) inflows are averaged and this value is lagged by LAG number of intervals from the middle of the range over which the flows were averaged. If the number of points to be averaged is even, one-half a time interval is added to the specified value of the lag to keep the timing in order. The number of points to be averaged and the number of intervals to be lagged are determined by trial and error. The lag time is usually found to be from 3/4 to two times the travel time.

The program is also capable of allowing channel losses, either constant or as a ratio of the remaining outflow.

Discussion

This simple program provides an excellent means of performing several different operations separately. The literature on the program is reasonably well documented and includes references which give detailed explanations. A listing of the program is also given along with sample data sets and definitions of important variables used in the program. This program has been incorporated as part of HEC-1, "Flood Hydrograph Package" (see Section A).

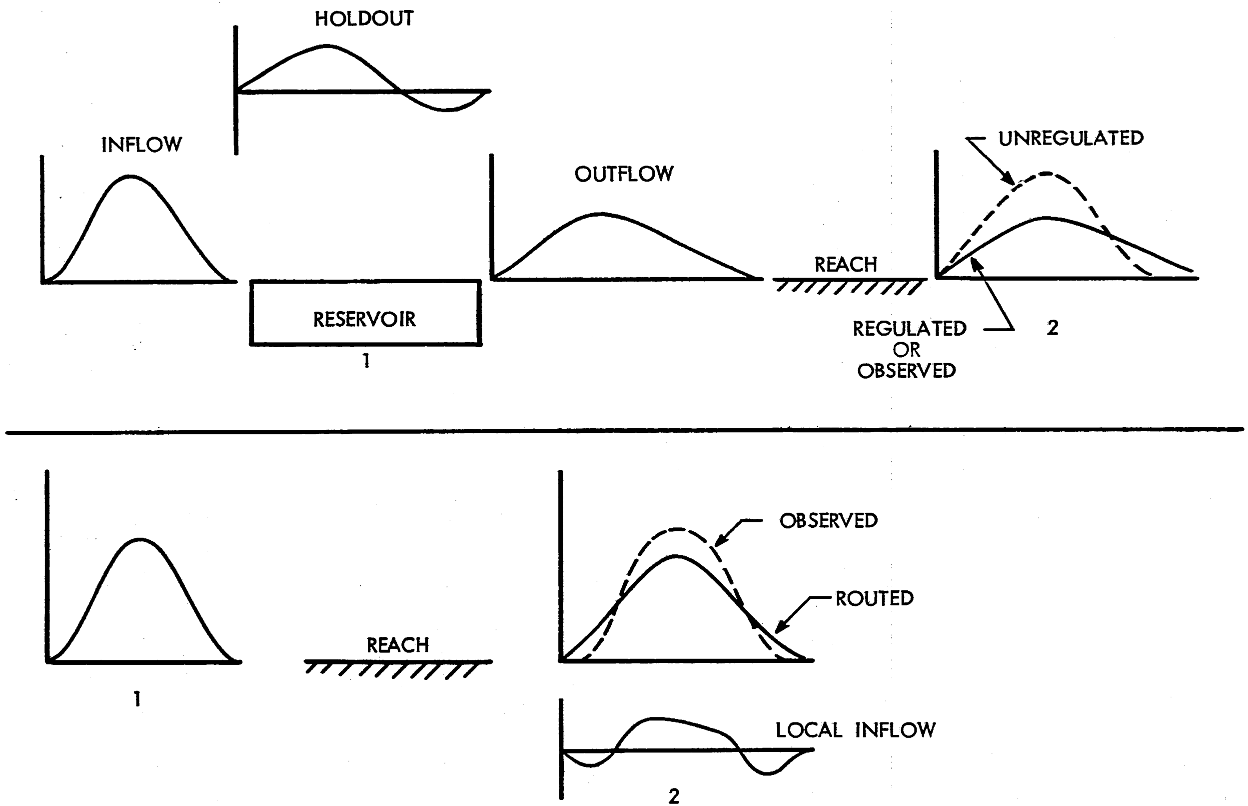


Figure E-1. Above, Use of Reservoir Holdout Hydrograph to Determine Unregulated Downstream Hydrograph.

Below, Local Inflow Determination From Routed and Observed Hydrographs.

Section F. UNIT GRAPH AND HYDROGRAPH GENERATION

Source

"Unit Graph and Hydrograph Generation," by Leo R. Beard, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California.

Description

This program deals with hydrograph generation based on the unit hydrograph technique. From a given rainfall distribution it will develop a rainfall excess distribution based on one of two available methods and apply the excess to a given or computed unit hydrograph to develop a runoff hydrograph. (See also Section A.)

The program consists of approximately 400 input statements and requires 16000_8 storage locations on the CDC 6600 computer. It can complete a run (i.e., compute a runoff hydrograph) in one or two seconds. The program was originally designed for use on an IBM 1620 computer with a 40000 digit capacity and Fortran II capabilities.

Methods

Two methods are available for computing the rainfall excess from a given rainfall distribution:

1) An initial loss followed by a uniform loss rate in which the excess is a fixed proportion of the rainfall.

2) Loss rate as a function of a power of rain intensity, decreasing exponentially with accumulated loss.

Using the notation in the program and Fig. F-1,

$$\text{ALOSS} = \text{AK}\ (\text{RAIN})^{E}$$

$$\text{AK} = \text{BASEL}(\text{RTIOL})^{\frac{-\text{ACUML}}{10}} + \text{TEMP}$$

and $$\text{TEMP} = 0.2\ \text{DLTAL}\ (1 - \frac{\text{ACUML}}{\text{DLTAL}})^{2}$$

where ALOSS is the loss rate (in./hr)
RAIN is the rainfall rate (in./hr)
E is an exponent between zero and one
BASEL is initial value of AK for dry soil conditions (often 0.1 < BASEL < 1.0)
RTIOL is slope of AK recession, ratio of AK on exponential recession curve to that at 10 inches more ACUML (Often 1.00 < RTIOL < 10.00)
ACUML is accumulated actual loss over basin
DLTAL is a constant allowing for large initial loss at beginning of event (often 0 < DLTAL < 2.0)

The range of values of the variables shown is based on experience with a limited number of streams in Minnesota.

This analysis determines the loss as a decreasing function of the moisture in the surface layers of the soil. In addition, the rate determined by the value of AK can be further modified to reflect the effects of rainfall intensity. If the exponent E is zero, the loss rate is independent of rainfall intensity for the period. If E is one, the loss rate is directly proportional to the rainfall intensity. In all, four parameters describe the basic loss function.

The unit hydrograph can be supplied to the program or computed using specified relationships. In the latter case, the unit hydrograph is computed from a time-area curve which also can be either supplied or computed. Using Clark's method, the time-area curve is used to compute a unit hydrograph of a given duration.

The time-area curve may either be provided by the user or calculated based on the following relationship:

$$A = kT^P \quad \text{for } (0 < T < 0.5)$$

$$1 - A = k(1 - T)^P \quad \text{for } (0.5 < T < 1.0)$$

where

$$A = \frac{\text{area contributing at time}}{\text{total basin area}}$$

$$T = \frac{\text{time}}{\text{total time of concentration, TC}}$$

P = specified power (often $1.0 < P < 3.0$, has been fixed at 1.5 in other HEC programs)

In either case the time-area curve is proportioned such that its base length is TC, the specified time of concentration, and its area represents one inch of excess over the given basin (see Fig. F-2). This curve is then routed through a simulated reservoir to reflect proportional storage in the watershed. The routing is done as specified by Clark.

$$Q_2 = C1(I_2) + C2(Q_1)$$

where

$$C1 = \frac{\Delta t}{R + 0.5\ \Delta t}$$

$$C2 = 1 - C1$$

Q = routed outflow

I = inflow

Δt = tabulation interval

R = Clark's routing coefficient

The resulting curve represents the instantaneous unit hydrograph for the basin. The unit hydrograph of duration Δt is found by averaging ordinates Δt apart.

It is important that the tabulation interval Δt, which is also the duration of the rainfall excess, be small compared to TC, the specified time of concentration, so that there will be an adequate number of points to define the time-area curve. This unit graph can be altered to conform to specified values of Snyder's T_p and C_p to within one percent.

The program can also compute standard project rain amounts from Corps of Engineers EB 52-8 criteria and probable maximum storm amounts from HMS 33 criteria. Rainfalls in inches or as percentages of a total storm amount can also be supplied. A shape factor is applied to the SPS and PMS amounts to reflect basin characteristics. This gives an artificial means of computing floods for a number of ratios of a given storm. In addition, the program can control the recession portion of the hydrograph after the rain has stopped and the flow has decreased to a point below a specified value.

Discussion

This program, which has also been incorporated into HEC-1, is a good routine for computing hydrographs. The user can provide the specific unit hydrograph and rainfall excess and the routine will simply determine the direct runoff hydrograph. If the options to allow the routine to develop its own unit hydrograph and rainfall excess are used, several parameters must be given. The determination of these parameters may require the use of past experience, companion programs, and a regional analysis. A companion program, Unit Hydrograph and Loss Rate Optimization (see Section C), will determine the set of parameters for the unit hydrograph and loss rate function that will best reproduce an observed runoff hydrograph.

An example taken from the description for program HEC-1 (see Section A) which uses a time-area curve and given unit hydrograph and loss rate parameters is shown in Figs. F-3 through F-8. Figure F-3 shows the computations needed to obtain the desired two-hour unit hydrograph given the time-area curve and Clark's constants. Figure F-4 shows the computations of the rainfall excess, direct runoff, base flow, and total flood hydrograph. Figure F-5 shows a map of the watershed which was used to determine the cumulative time-area curve. Figure F-6 shows the time-area curve plotted in order to determine interpolated values at two-hour increments; Fig. F-7 shows the final hydrograph and rainfall excess amounts for each time period; and Fig. F-8 shows how the loss coefficient K changes with accumulated loss for this watershed.

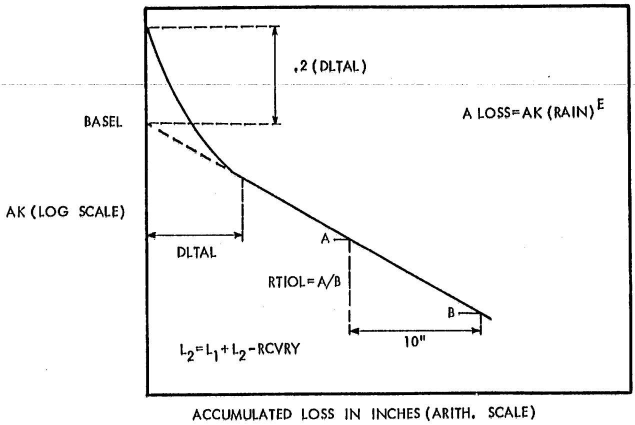


Figure F-1. Definition of Parameters in Loss Rate Function.

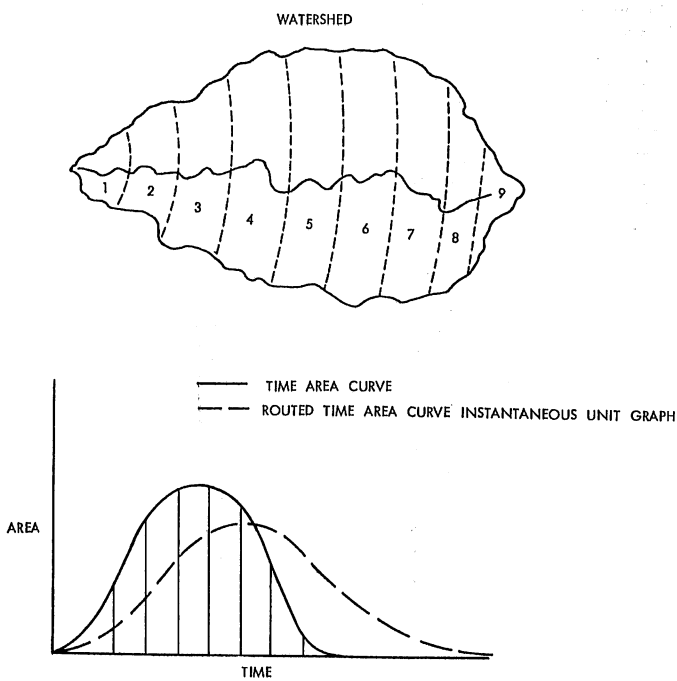


Figure F-2. Derivation of Instantaneous Unit Hydrograph From Basin Time-Area Curve.

Unit Graph Computation
Clark Method

THOMES CREEK AT PASKENTA, CALIFORNIA

DRAINAGE AREA = 190 SQUARE MILES
TIME OF CONCENTRATION (Tc) = 8.0 HOURS (See Plate 3)
ATTENUATION VALUE (R) = 5.5 HOURS (See Plate 3)
TIME INTERVAL (Δt) = 2.0 HOURS

EQUATIONS (Subscript i refers to current period)

$$X = \Delta t/(R + .5\Delta t) = 0.308$$

$$o_i = XI_i + (1-X)o_{i-1}$$

$$O_i = o_i 645/\Delta t$$

$$Q_i = .5(O_{i-1} + O_i)$$

TIME hr (1)	INFLOW (PLATE 2) I_i sq. mi.-in (2)	INSTANTANEOUS UNIT GRAPH o_i sq. mi.-in (3)	 O_i cfs (4)	2-HOUR UNIT GRAPH Q_i cfs (5)
0	0	0	0	0
2	14	4.32	1,393	700
4	44	16.54	5,334	3,360
6	53	27.78	8,959	7,150
8	79	43.54	14,042	11,500
10	0	30.13	9,717	11,880
12		20.85	6,724	8,220
14		14.43	4,654	5,690
16		9.99	3,222	3,940
18		6.91	2,228	2,720
20		4.78	1,542	1,890
22		3.31	1,067	1,300
24		2.29	739	900
26		1.58	510	630
28		1.09	352	430
30		0.75	242	300
32		0.52	168	200
34		0.36	116	140
36		0.25	81	100
38		0.17	55	70
40		0.12	39	50
42		0.08	26	30
44		0.06	19	20
46		0.04	13	20

Figure F-3. Computation of Unit Hydrograph (From Ref. E-9).

THOMES CREEK AT PASKENTA, CALIFORNIA
FLOOD HYDROGRAPH COMPUTATION
31 JANUARY - 2 FEBRUARY 1963

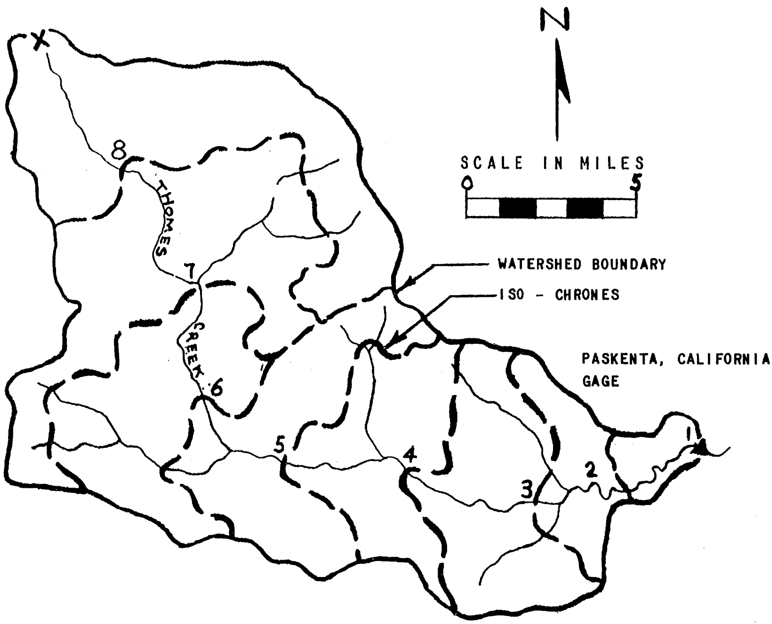
DRAINAGE AREA = 190 SQUARE MILES
RECESSION FLOW BELOW 4,000 cfs = 0.95(Q_{i-1})

DATE	TIME	PERIOD RAIN	RAIN RATE	K VALUE	LOSS RATE L=KP·7	PERIOD LOSS	ACCUMULATED LOSS	RAIN EXCESS Col 3–Col 7	UNIT GRAPH TABLE 1	RUNOFF	ANTECEDENT BASE FLOW 0.95(Q_{i-1})	FLOOD HYDROGRAPH Col 11 + Col 12
Day/Mo/Year	*hour*	*inches*	*in/hr*	*Plate 4*	*in/hr*	*inches*	*inches*	*inches*	*cfs*	*cfs*	*cfs*	*cfs*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
	INITIAL						.50				1,320	1,320
31 JAN 63	0600	.24	.12	.65	.12	.24	.74	0	0	0	1,250	1,250
	0800	.70	.35	.53	.25	.50	1.24	.20	700	140	1,190	1,330
	1000	1.68	.84	.41	.36	.72	1.96	.96	3,360	1,340	1,130	2,470
	1200	.78	.39	.36	.19	.38	2.34	.40	6,150	4,940	1,070	6,010
	1400	.06	.03	.34	.03	.06	2.40	0	11,500	10,510	1,020	11,530
	1600	.04	.02	.34	.02	.04	2.44	0	11,880	16,280	970	17,250
	1800	.82	.41	.34	.18	.36	2.80	.46	8,220	17,970	920	18,890
	2000	.58	.29	.33	.14	.28	3.08	.30	5,690	15,540	870	16,410
	2200	.24	.12	.32	.07	.14	3.22	.10	3,940	13,900	830	14,730
	2400	.02	.01	.31	.01	.02	3.24	0	2,720	14,370	790	15,160
1 FEB 63	0200	0	0	.31	0	0	3.24	0	1,890	14,200	750	14,950
	0400	0	0	.31	0	0	3.24	0	1,300	11,660	710	12,370
	0600	.26	.13	.31	.07	.14	3.38	.12	900	8,540	670	9,210
	0800	.24	.12	.30	.07	.14	3.52	.10	630	6,320	640	6,960
	1000	.36	.18	.30	.09	.18	3.70	.18	430	5,370	610	5,980
	1200	0	0						300	5,500	580	6,080
	1400	0	0						200	5,800	550	6,350
	1600	0	0						140	5,580	520	6,100
	1800	0	0						100	4,570	490	5,060
	2000	0	0						70	3,160	470	4,810*
	2200	0	0						50			4,570*
	2400	0	0						30			4,340*
2 FEB 63	0200	0	0						20			4,120*
	0400	0	0						20			

(0.95)(Q_{i-1})

*RUNOFF + ANTECEDENT BASE FLOW IS LESS THAN 4,000 cfs SO ANTECEDENT RECESSION FLOW IS COMPUTED FOR HYDROGRAPH.

Figure F-4. Application of Unit Hydrograph and Loss Rate Function (From Ref. E-9).



TRAVEL TIME FROM "X" TO GAGE IS 8.0 HOURS FOR THE 32 MILES

MAP AREA NUMBER	PLANIMETER VALUES FROM MAP INCREMENTAL units	ACCUMULATED units	ACCUMULATED AREA (sq.mi.) (Col 3) * (58.8)	TRAVEL TIME IN PERCENT [(1/8) * (100)]
1	*2*	*3*	*4*	*5*
1	0.08	0.08	5	12.5
2	0.15	0.23	14	25.0
3	0.40	0.63	37	37.5
4	0.36	0.99	58	50.0
5	0.45	1.44	85	62.5
6	0.45	1.89	111	75.0
7	0.66	2.55	150	87.5
8	0.68	3.23	190	100.0
TOTAL	3.23			

Sq.mi./Planimeter unit = 190/3.23 = 58.8

DRAINAGE AREA = 190 SQUARE MILES

THOMES CREEK AT PASKENTA, CALIFORNIA
WATERSHED MAP

COMPUTATION
OF
THE TIME-AREA RELATION

PREPARED BY: CEA DATE: 21 OCTOBER 1968

Figure F-5. Computation of Time-Area Curve (From Ref. E-9).

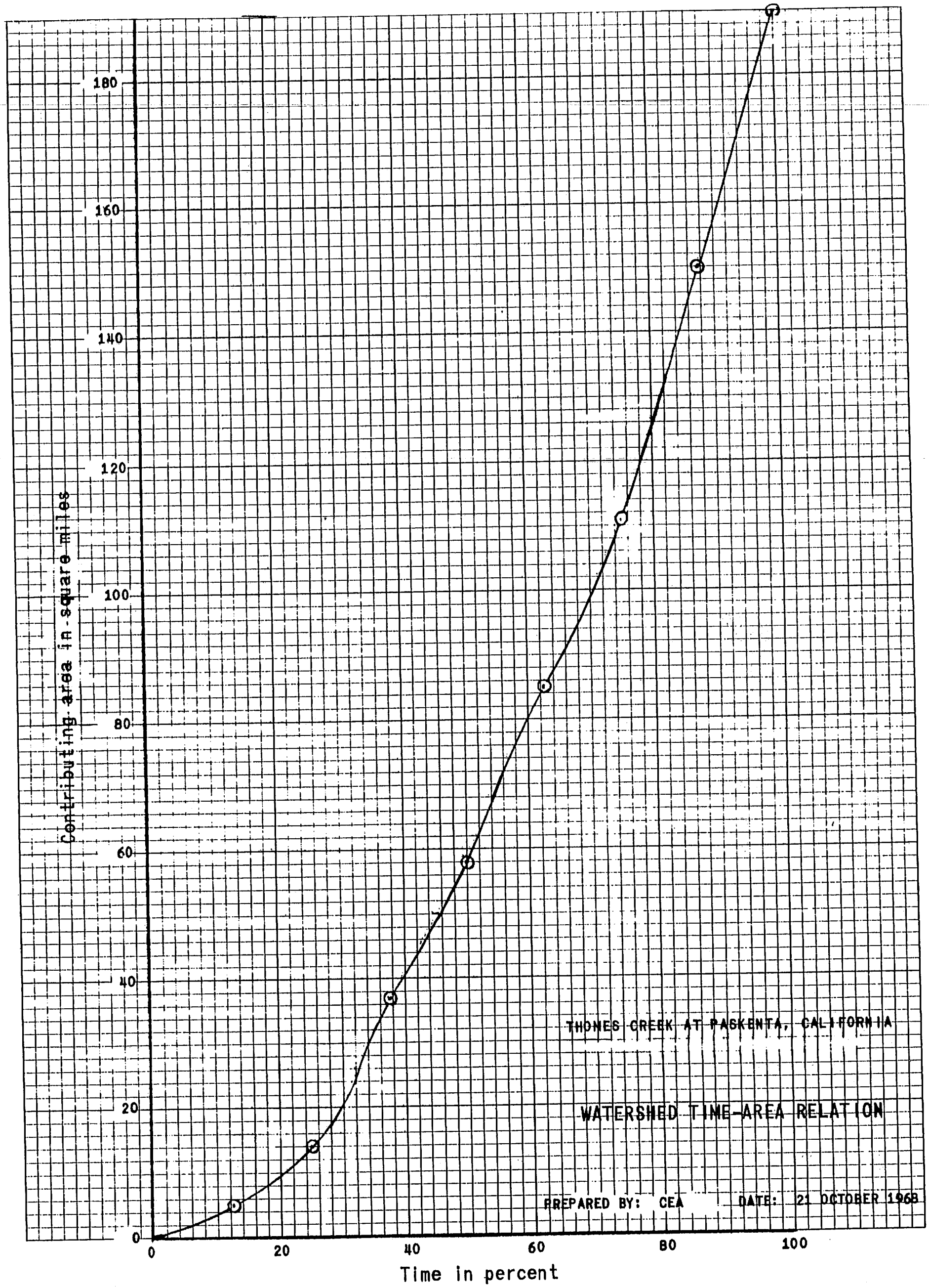


Fig -F-6 Cumulative time-area curve (from ref E-9)

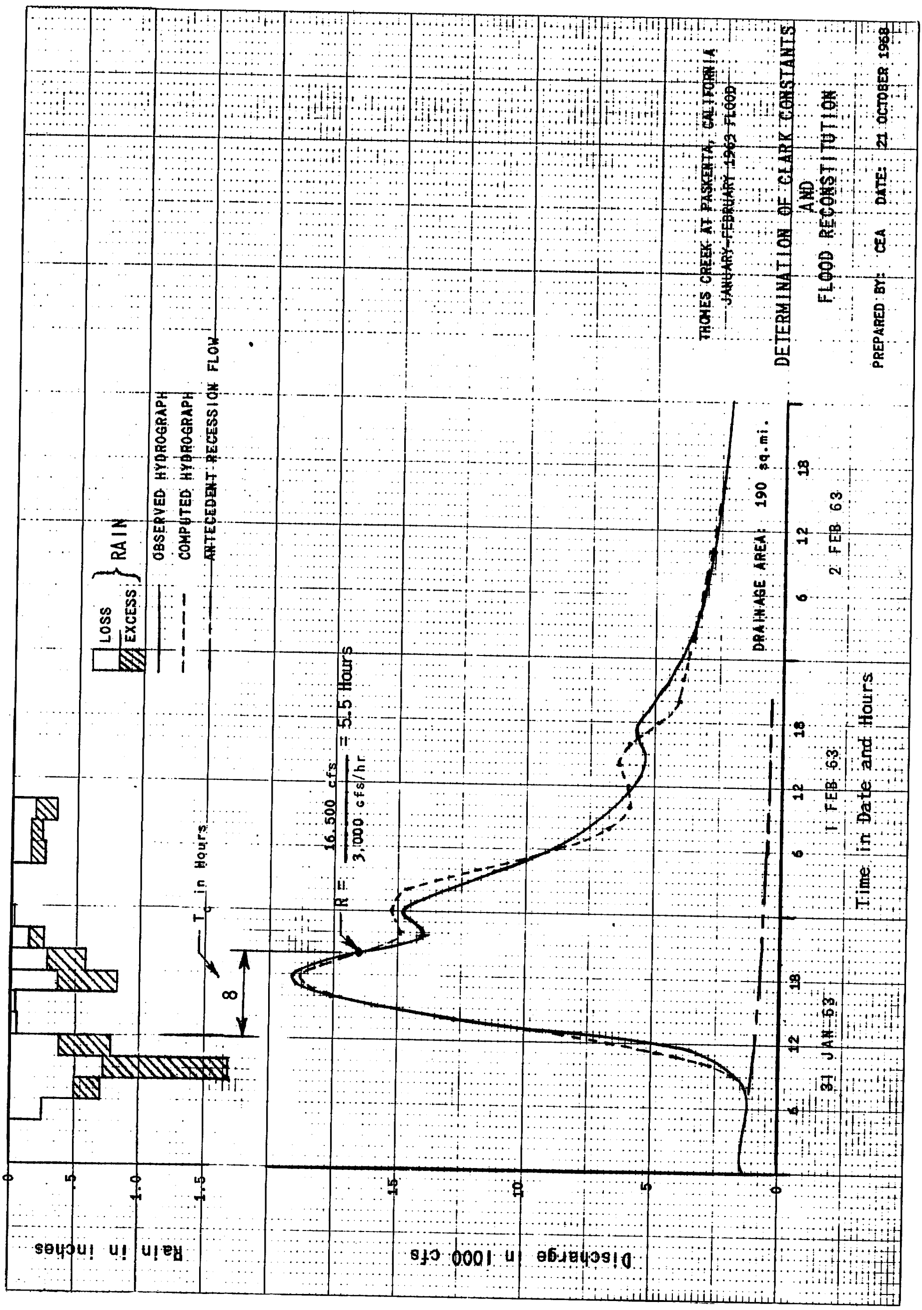
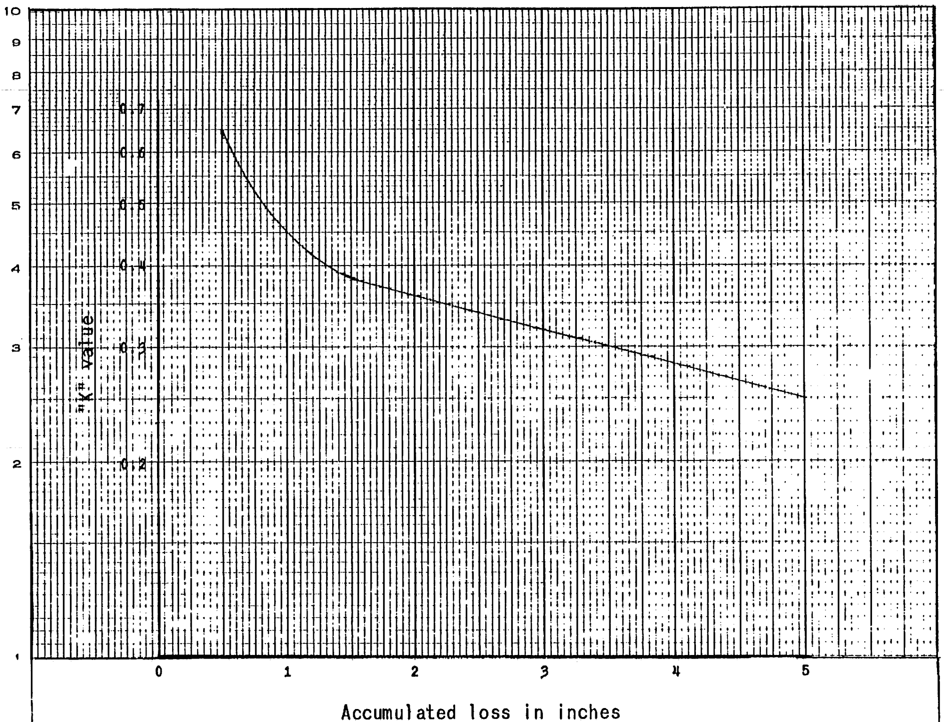


Fig -F-7 Computed and observed runoff hydrographs (from ref E-9)



LOSS RATE FUNCTION:

$L = KP^E$

WHERE:

L = LOSS RATE IN INCHES PER HOUR
K = VALUE FROM CURVE
P = RAINFALL IN INCHES PER HOUR
E = CONSTANT FOR WATERSHED AREA

THOMES CREEK AT PASKENTA, CALIFORNIA
WATERSHED LOSS CHARACTERISTIC

DETERMINATION
OF
"K" VALUES

PREPARED BY: CEA   DATE: 21 OCTOBER 1968

Fig, -F-8 Decreasing coefficient for loss rate function (from ref E-9)

Section G. FLOOD OPERATION FORECAST

Source

Hydrologic Engineering Center, Corps of Engineers, Sacramento, California.

Description

This program was written to aid in providing operational flood forecasts. Provision is made for determining snowmelt from up to ten elevation bands. A loss function evaluates losses to determine basin excess. A unit hydrograph is applied to the excess, and the resulting hydrograph can then be routed into reservoir storage if desired.

Observed precipitation and discharge can be entered in addition to the forecast of precipitation. The observed flows can be used as a basis for adjusting the loss function to best reproduce the observed discharge.

Methods

The mean basin precipitation can be determined by combining a weighting factor for the station and the mean annual precipitation for the station. Precipitation is considered rain or snow, depending on the temperature in the elevation zone in which it occurs. Temperatures are determined from a specified base value and a 3°F/1000 ft lapse rate. The loss rate used is similar to that described in the HEC program "Unit Graph and Hydrograph Computation" (see Section F). However, no initial high rate increment is used.

The program will adjust the specified value of STRTK (BASEL) in the loss function so that the computed flows will best reproduce a series of observed flows. The value of STRTK will then be fixed when the forecast is extended from the present to future times. In determining the best fit, the flows are weighted to better reproduce the most current observed flows.

The excess determined by the loss function is applied to a unit hydrograph given by the user. Reservoir storage for the resulting runoff can then be calculated given an initial value of storage and forecasted reservoir releases.

Source

Central Technical Unit, Soil Conservation Service, Department of Agriculture.

Description

This program computes surface runoff due to a given rainfall distribution, develops runoff hydrographs, and combines and routes these hydrographs in a specified manner in an attempt to simulate the rainfall-runoff process of a real watershed. The program can be used to design and analyze a watershed system using SCS techniques in the simulation of the rainfall-runoff process.

The program was originally designed for use on an IBM 7090/7094 computing system with Fortran II capabilities. The program consists of 2145 input cards and when run on the CDC 6600 computer requires 126000_8 storage locations.

Methods

The program can accept two types of rainfall data. A dimensionless time distribution and a given total rainfall can be specified or actual rainfall amounts for each period can be given. Examples of the dimensionless distribution that can be applied to a 24-hour storm are shown in Fig. H-1.

The SCS runoff computation technique was derived from studies of experimental plots which had various soil and vegetative conditions. It was originally developed to compute the excess from a 24-hour rainfall on a small watershed. The equation is

$$Q = \frac{(P - 0.25S)^2}{P + 0.8S}$$

where

Q = direct runoff in inches
P = rainfall in inches
S = potential maximum retention

The S values are transformed into curve numbers (CN) which are related to particular physical aspects of the watershed. S and CN are related by

$$CN = \frac{1000}{10 + S}$$

The family of curves representing the variety of curve numbers and relating rainfall to runoff is shown in Fig. H-2. Table H-1 relates physical characteristics of a watershed to an estimate of a curve number. In the program, curve numbers are adjusted based on antecedent moisture conditions.

TABLE H - 1

SCS Runoff Curve Numbers

(From Kent)

Land use and treatment or practice	Hydrologic condition	Hydrologic soil group			
		A	B	C	D
Fallow					
Straight row	----	77	86	91	94
Row crops					
Straight row	Poor	72	81	88	91
Straight row	Good	67	78	85	89
Contoured	Poor	70	79	84	88
Contoured	Good	65	75	82	86
Contoured and terraced ..	Poor	66	74	80	82
Contoured and terraced ..	Good	62	71	78	81
Small grain					
Straight row	Poor	65	76	84	88
Straight row	Good	63	75	83	87
Contoured	Poor	63	74	82	85
Contoured	Good	61	73	81	84
Contoured and terraced ..	Poor	61	72	79	82
Contoured and terraced ..	Good	59	70	78	81
Close-seeded legumes or rotation meadow					
Straight row	Poor	66	77	85	89
Straight row	Good	58	72	81	85
Contoured	Poor	64	75	83	85
Contoured	Good	55	69	78	83
Contoured and terraced ..	Poor	63	73	80	83
Contoured and terraced ..	Good	51	67	76	80
Pasture or range					
No mechanical treatment	Poor	68	79	86	89
No mechanical treatment	Fair	49	69	79	84
No mechanical treatment	Good	39	61	74	80
Contoured	Poor	47	67	81	88
Contoured	Fair	25	59	75	83
Contoured	Good	6	35	70	79
Meadow	Good	30	58	71	78
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	25	55	70	77
Farmsteads	----	59	74	82	86
Roads 1/					
Dirt	----	72	82	87	89
Hard surface	----	74	84	90	92

1/ Including rights-of-way.

Three antecedent conditions can be considered: dry, normal, or wet. The curve numbers which are a part of the input data are assumed to be at normal antecedent conditions. The adjustment made for wet or dry conditions is shown in Table H-2.

Table H-2: CURVE NUMBERS (CN) FOR WET (AMC III) AND DRY (AMC I) ANTECEDENT MOISTURE CONDITIONS CORRESPONDING TO AN AVERAGE ANTECEDENT MOISTURE CONDITION (AMC II)[1]

CN for	Corresponding CN's	
AMC II	AMC I	AMC III
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
45	26	65
40	22	60
35	18	55
30	15	50
25	12	43
20	9	37
15	6	30
10	4	22
5	2	13

(Table from SCS TP 149, Kent)

[1]AMC I. Lowest runoff potential. Soils in the watershed are dry enough for satisfactory plowing or cultivation.

AMC II. The average condition.

AMC III. Highest runoff potential. Soils in the watershed are practically saturated from antecedent rains.

Using the selected antecedent condition, the program computes rainfall excess using the required curve number. The incremental runoff for a time period $\Delta T = T_2 - T_1$ is computed by subtracting the total direct runoff due to the accumulated rainfall up to time T_1 from the total at time T_2.

The time interval which is used to compute the runoff hydrograph is selected by the program so as to guarantee at least four points on the rising side of the hydrograph. From SCS TP 149, $T_p = \frac{D}{2} + L$ where T_p is the time to peak, D is the rain duration, and L is the drainage area lag. It is necessary to determine an incremental rain duration ΔD which will give four points on the rising side of the hydrograph. Since $L = 0.6T_c$ and $T_p = 4\Delta D$, the incremental rain duration desired is defined by $4\Delta D = \frac{\Delta D}{2} + 0.6T_c$ where T_c is the estimated time of concentration of the area. T_p can then be computed from $T_p = \frac{\Delta D}{2} + 0.6T_c$.

For this incremental rain, an incremental hydrograph is produced. The peak flow is computed from

$$\Delta qp = \frac{484A(\Delta Q)}{T_p}$$

where

A = area in sq miles
ΔQ = incremental runoff determined by the rainfall and the curve number

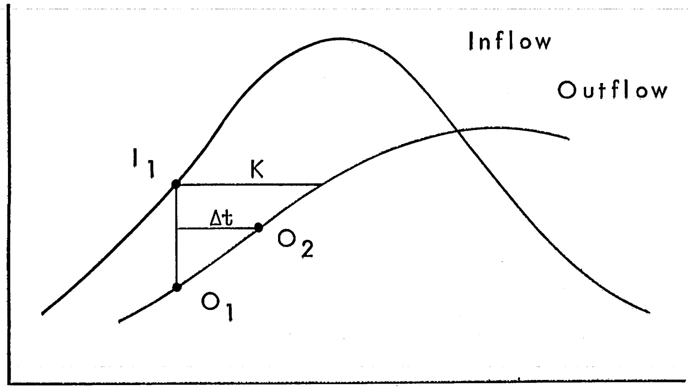
The program first computes a unit hydrograph of duration ΔD (i.e., ΔQ = 1.0) from a dimensionless hydrograph. The unit hydrograph so developed has a tabulation time increment of ΔD and a volume equal to one inch of excess. From this, incremental runoff hydrographs are calculated by applying the unit hydrograph to the amount of excess computed over the time period ΔD. Each succeeding incremental hydrograph is lagged by ΔD from the previous one, and the ordinates are summed to give the runoff hydrograph for the entire rainfall. Discharges at time intervals specified by the user are then interpolated from this runoff hydrograph.

Reservoir routing is done using conventional reservoir routing techniques.

$$I_1 + I_2 + (\frac{2S_1}{t} - O_1) = \frac{2S_2}{t} + O_2$$

Since the storage-outflow table is given for a particular site, the outflow hydrograph can easily be computed from the inflow hydrograph.

Channel routing is done using the convex routing method. This method is based on the theory of convex sets and wave motion. The necessary parameter for the method is the velocity of the flood wave in the channel.



Here K is the time required for steady flow discharge to travel the length of the reach = L/3600 V where V is the velocity and Δt is the time increment at which the flow reaches a value of 0_2 at the downstream section.

$$\text{If } I_1 \geq 0_1, \quad \text{then} \quad I_1 \geq 0_2 \geq 0_1$$

$$\text{If } I_1 \leq 0_1, \quad \text{then} \quad I_1 \leq 0_2 \leq 0_1$$

$$\frac{\Delta t}{K} = \frac{0_2 - 0_1}{I_1 - 0_1} = C \quad \text{where} \quad C = \frac{\Delta t}{K}$$

C is called the routing coefficient and is dependent on the velocity and a wave function; $C = \frac{V}{V + 1.7}$.

The velocity used is some average velocity in the stream or, if computed by the program, a weighted average of velocity in the upper half of the inflow hydrographs. Thus C and K are known and Δt can be computed. If the flows are desired for a different time increment, C is converted using the following equation:

$$C^* = 1 - (1 - C)\Delta t^*/\Delta t$$

where Δt* is the desired time increment. It is recommended that $\Delta t^* \leq T_p/5$.

Regarding the size and complexity of the problem to be handled, the program is limited only by storage availability. The following are some limitations which are imposed by storage availability:

1. 60 structures (unlimited variations of each structure)

2. 120 stream reaches (i.e., cross sections, with unlimited modifications for each reach)

3. 300 ordinates per hydrograph

4. Unlimited number of routings

5. 9 rainfall distributions (unlimited if depth and duration are applied to a dimensionless distribution)

6. 600 standard control instructions.

Discussion

A few problems were encountered in implementing the program on the CDC 6600 system. The different tape references had to be assigned to the proper input-output devices. The following assignments were made: TAPE 1 = input (cards), TAPE 6 = output (line printer), TAPE 15 = punch (card punch). TAPE 2 and TAPE 4 seem to be tape units to handle temporary storage of information and were both assigned as magnetic tapes (actually disk storage).

The size of the program, 126000_8 on the CDC 6600, required nearly all available core storage to be used in order to run and restricts use of the program to large computer installations. It required approximately 12 seconds to compile.

This program is a very valuable tool for persons interested in analyzing the rainfall-runoff relationship. Once the system to be analyzed has been set up, it is a simple task to investigate many alternative assumptions and to note their effect on the final result. Thus, with the solutions to many alternative ideas, one is able to make a better decision as to what course of action should be followed.

The documentation material furnished with the program describes only the preparation of input data cards. The methods used are generally discussed in standard SCS technical procedure documents. In some cases, minor assumptions necessary in programing the techniques remain undocumented. It is important that the user be aware of the specific techniques used in all parts of the runoff simulation.

A sample run was made using data from the Baptism River watershed in northern Minnesota, although available field data were not adequate for a real analysis. Figure H-3 is a map of the Baptism River watershed. Figure H-4 is a schematic diagram of the watershed along with the various parameters that were needed in the analysis. In this particular example, no cross section data were available, and so synthetic cross sections were used and an estimate of the velocity in the reaches was determined using routing coefficients. Figures H-5 through H-8 show the hydrograph at various points in the basin for this particular run.

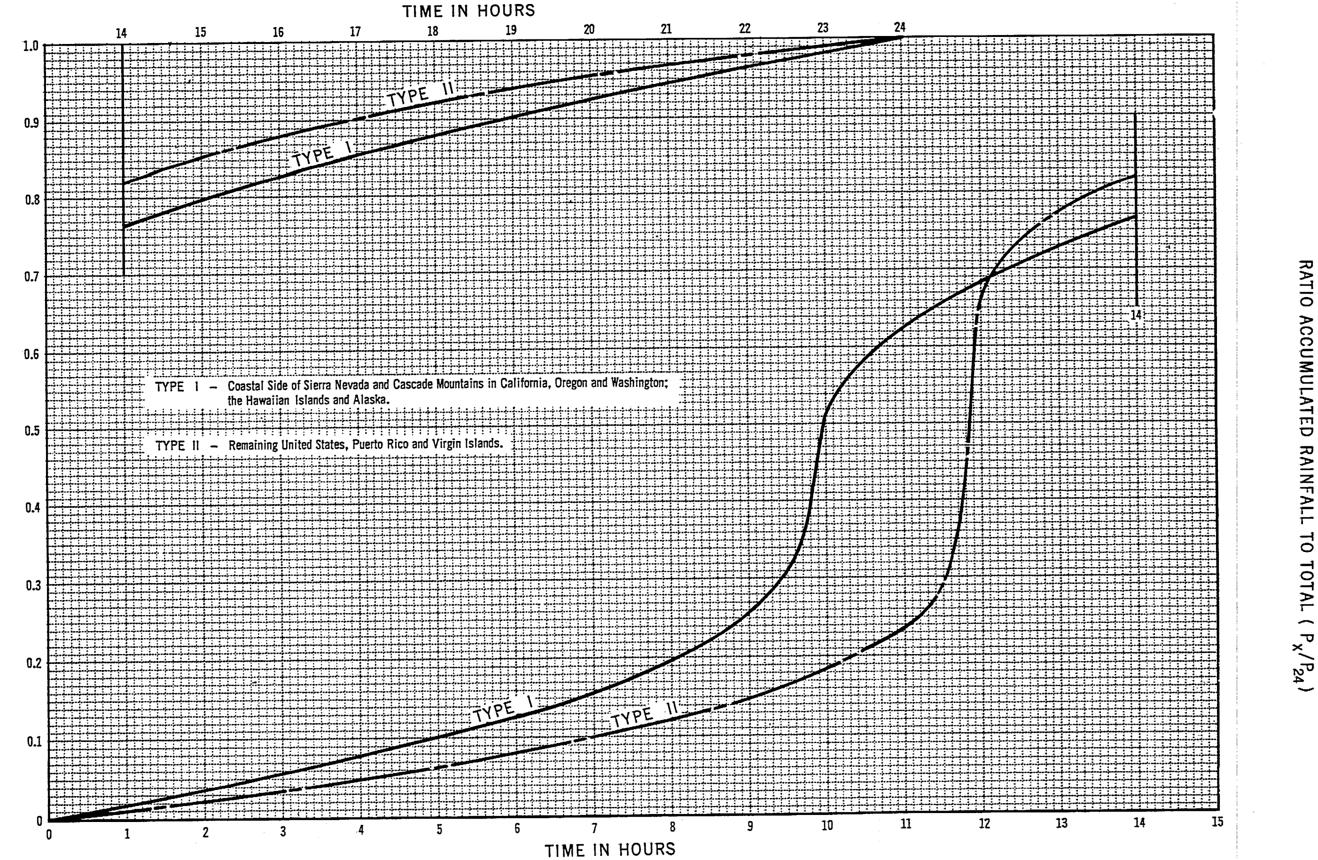


Fig -H-1 Distribution of rainfall for 24 hour totals (from SCS TP 149, Kent)

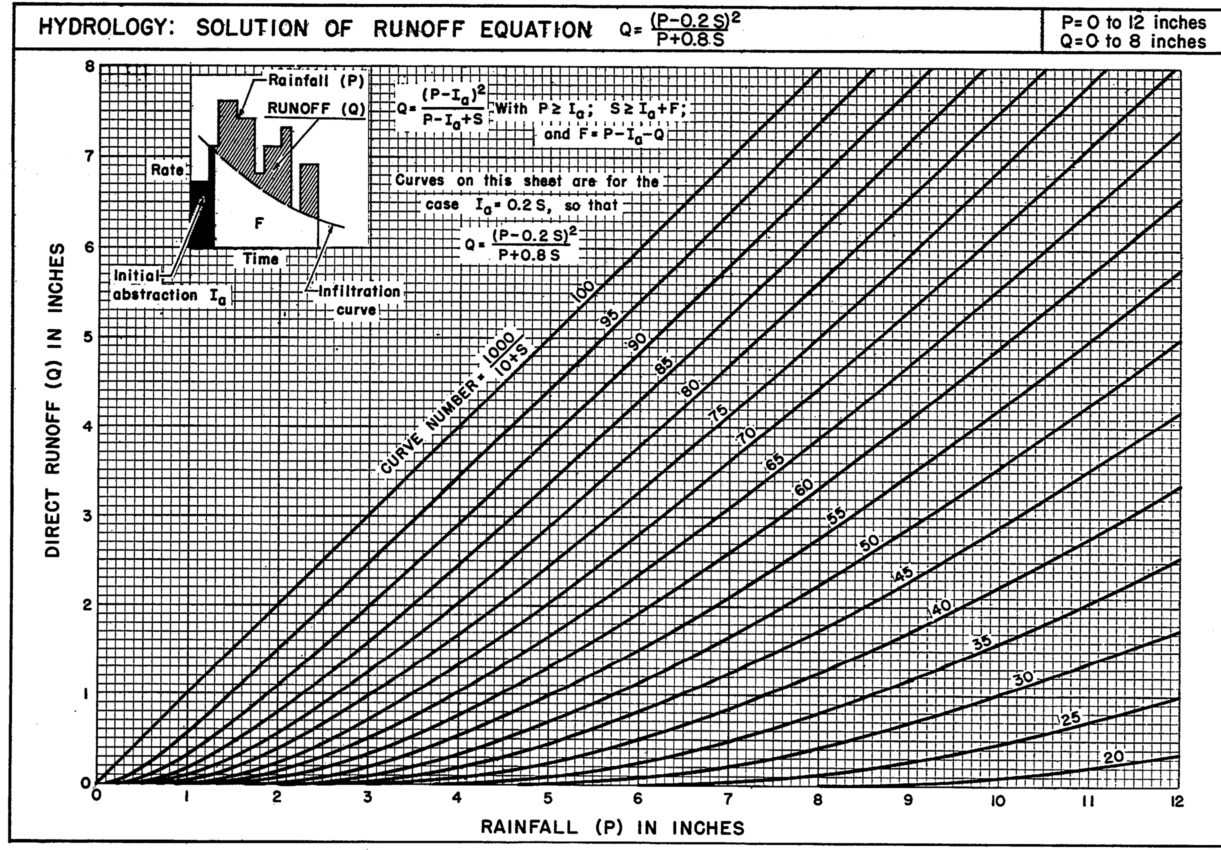


Fig -H-2 SCS rainfall-runoff relationship (from SCS TP 149, Kent)

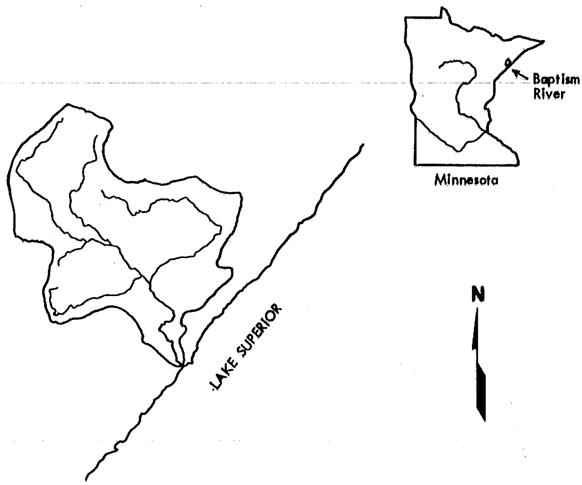


Figure H-3. Map of Baptism River Watershed.

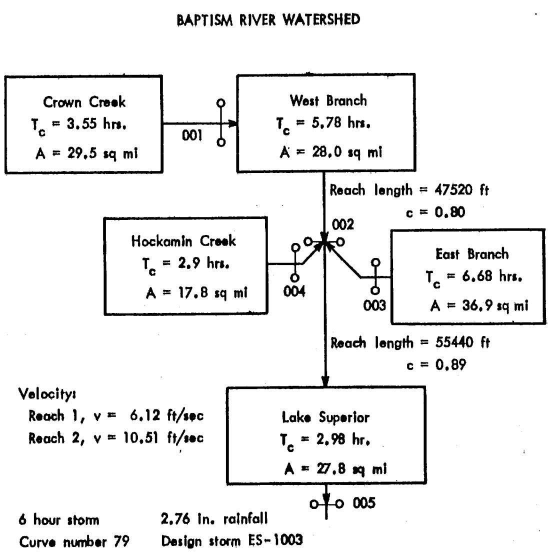


Figure H-4. Schematic of Baptism River Watershed Giving Characteristics of Sub Areas.

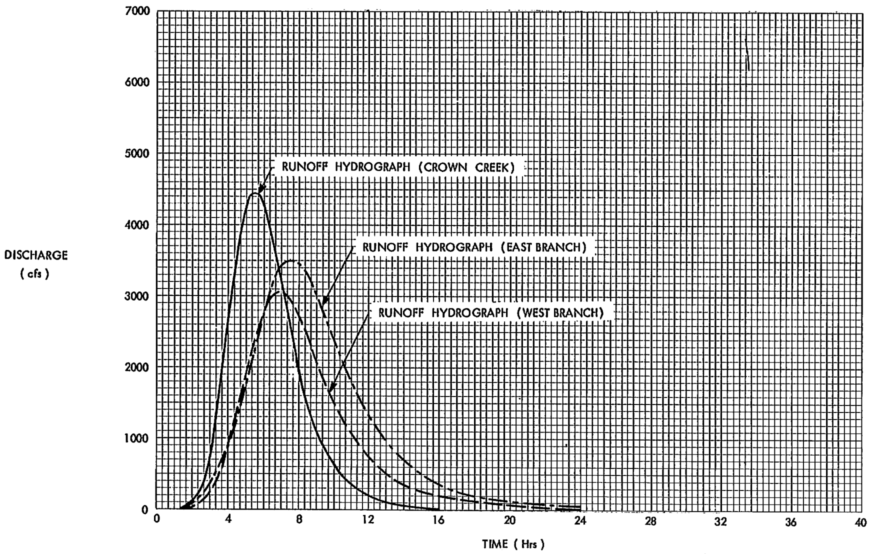


Figure H-5. Hydrographs for Three Tributary Areas of Baptism River.

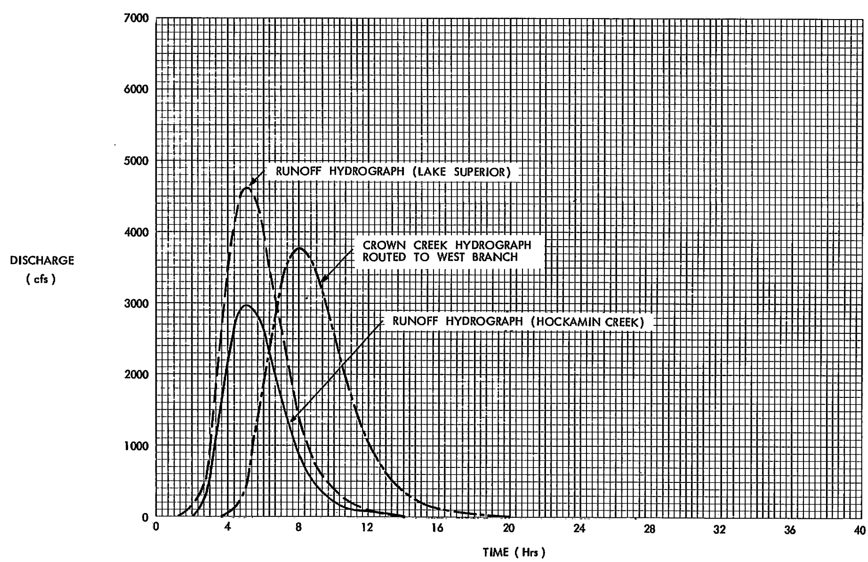


Figure H-6. Hydrographs for Additional Tributary Areas of Baptism River.

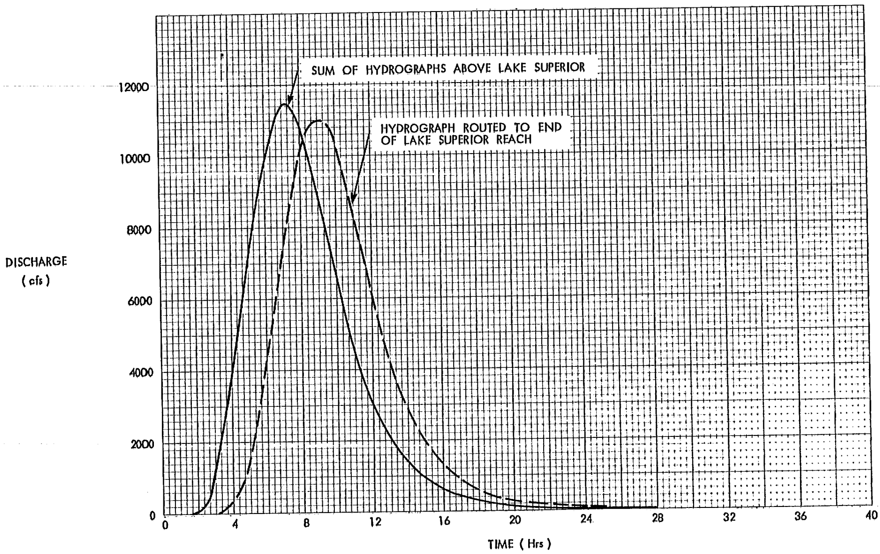


Figure H-7. Combined and Routed Hydrographs for all Watersheds Except Lake Superior Sub Area.

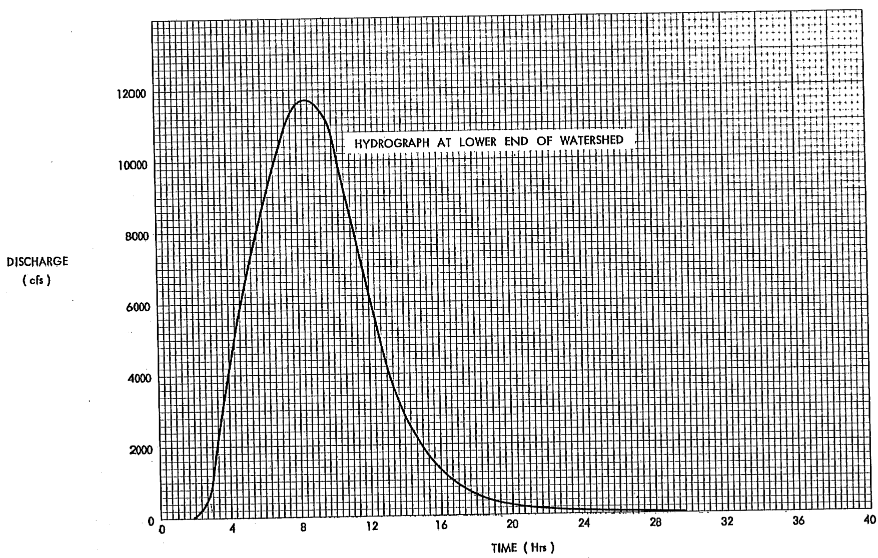


Figure H-8. Final Outflow Hydrograph for Baptism River Watershed.

Section I. DAMS - STRUCTURE SITE ANALYSIS

Source

Soil Conservation Service, Department of Agriculture

Description

This is a Fortran IV computer program used for the hydraulic and hydrologic analysis of flood water retarding structure sites*. Its basic purpose is to aid in the evaluation of a given reservoir by determining the effect of alternative reservoir designs on inflow hydrographs. Thus given a particular design alternative, the program computes a stage-discharge relationship which it then uses to route flows through the reservoir. It can either generate its own hydrographs from input rainfall amounts or read in specified hydrographs. It routes the inflow hydrographs through designated reservoirs using computed or input stage-discharge relationships. Embankment quantities can be computed and structures in series can be analyzed if other SCS programs are used in conjunction with this program.

Generally, the program is for design use within the SCS organization. The user is able to alter many of the controlling parameters, such as weir and orifice flow coefficients, emergency spillway profiles, and the number and shape of principal spillway conduits, thus permitting the investigation of many alternate reservoir designs. Complete simulation of an entire system would require the use of other SCS programs and would be somewhat cumbersome. The user is provided with enough input options to enable complete description of the particular reservoir under study and investigation of alternate designs or inflow events in a single computer run.

Methods

The program operating manual gives no description of the actual computations which are made, but it appears that standard SCS design criteria have been adhered to in the development of the program. Although no explicit computational schemes are given, the program summary contains brief descriptions of various user options from which the general scheme of computation can be inferred.

Reservoir storage is calculated from a given elevation-surface area relationship. Up to eight points can be used to extend the curve beyond the defined limits.

The discharge from the reservoir consists of principal and emergency spillway flows which are combined to determine the rating curve for the structure. The rating curve for either of the spillways can be input directly or calculated based on one of a number of alternate designs. For example, the principal spillway discharge can be calculated based on a covered drop inlet or a hooded inlet and the emergency spillway discharge

*SCS - Minnesota, "Input Manual for Automatic Data Processing," Soil Conservation Service, USDA, St. Paul, Minnesota.

computed based on water surface profile computations.

Design hydrographs for input into the reservoir are computed using SCS Engineering Memorandum 27 and Section 4 of the SCS National Engineering Handbook. This program uses unit hydrograph theory in its hydrograph development and differs somewhat from the dimensionless hydrograph used in NEH-4. The program is capable of developing a runoff hydrograph and routing the flow through a reservoir for a number of different reservoir designs. Total system simulation requires the use of additional SCS programs (e.g., TR 20--see Section H).

Discussion

This program is primarily design oriented and is directed mainly toward SCS design techniques. The input data requirements are fairly clear as presented in the input manual. The list of input options and requirements is quite extensive, and it appears that a very detailed analysis can be carried out using this program.

One feature that could be added to increase the program's applicability, especially in the area of system analysis, would be a combining and routing procedure. This would allow dams in series to be easily analyzed and would alleviate the necessity of using other programs to accomplish the combining and streamflow routing. Thus it appears that the program is very capable in the design and/or analysis of a single structure, but is somewhat limited in its usefulness for complete system simulation.

Section J. NATURAL AND REGULATED FLOOD ESTIMATION

Source

Water Control Planning, Flood Control, Tennessee Valley Authority (Attention: Bob Buehler, Chief, Flood Control Branch). Data Originator: Ramon G. Lee. Programmer: Rose Ann Hatcher.

Description

This program was written in Fortran IV and designed for use on IBM 360 computing equipment. It can perform any of six possible operations on a hydrograph and thus can be used to estimate natural and regulated discharge hydrographs throughout a watershed system. The six operations--(1) reading a hydrograph, (2) reservoir routing, (3) channel routing, (4) storage of a hydrograph, (5) hydrograph combining, and (6) printing the hydrograph--are selected by the user in the order necessary to simulate a system.

The program is not capable of hydrograph generation, although it is designed to input the results of a TVA hydrograph synthesis program if desired.

Methods

Reservoir routing is done using standard procedures based on a given storage-outflow relationship. Channel routing uses the Muskingum method, for which three coefficients are supplied by the user. Alternate system configurations can be analyzed in the same computer run through proper specification of the input data.

The program appears to have value mainly in system design and in system analysis when the input hydrographs are known or generated by some probabilistic technique. Its use in watershed modeling is severely limited by its inability to generate hydrographs within itself. In addition, its lack of alternate routing techniques limits its use as a design or analysis program.

If the system shown in Fig. J-1 were analyzed, the order of operations would appear as follows:

1. Read hydrograph (A)
2. Reservoir route (A)
3. Read hydrograph (C) and add to routed hydrograph (A)
4. Channel route the result (A + C)
5. Store this hydrograph for later use
6. Read hydrograph (B)

7. Reservoir route (B)

8. Channel route the result

9. Combine stored hydrograph (A + C) with this hydrograph (B) to form outflow hydrograph (D)

Various input variables are used to initiate the operations. Other data necessary for the operations, such as storage outflow relationships for the reservoirs, are presented in the order in which they are used by the operation commands. Other available options permit the analysis of alternate designs or alternate flood hydrographs. The other options are the most valuable feature of the program and were probably a primary consideration in its development.

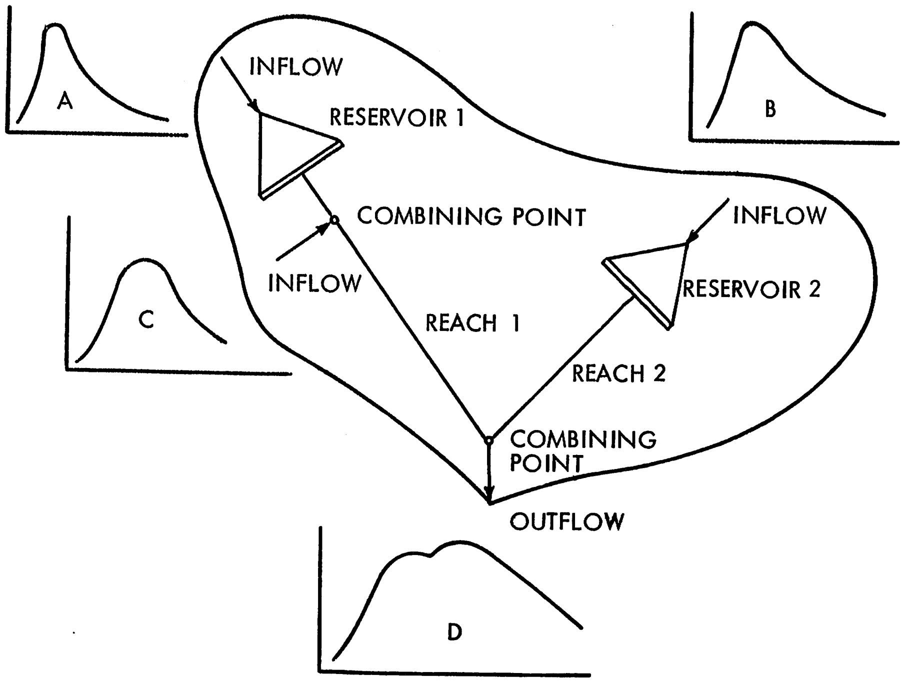


Figure J-1. Schematic of Typical Routing and Combining Operations in a Watershed System.

Section K. TVA - UNIT GRAPH (TVAUG36)

Source

Tennessee Valley Authority (Attention: Bob Buehler, Chief, Flood Control Branch). Programmers: Donald W. Newton, J.W. Vinyard.

Description

This program is used to derive the unit hydrograph that will best reproduce one or more observed direct runoff hydrographs. Up to ten observed events can be used in determining the best-fitting unit graph.

Methods

The solution for the unit hydrograph in this program is based on matrix algebra. The computed direct runoff hydrograph (vector Q) is expressed as the product of the unit hydrograph (matrix R) and the rainfall excess (vector U). It is assumed that both the direct runoff (vector Q) and the rainfall excess (vector U) are known. The unknown unit hydrograph (matrix R) is then solved for by matrix inversion. Since the rainfall excess is not actually known, a correction is made to the original amounts specified and a new unit graph is determined. At every iteration the least-squares error between computed and observed flows is determined and is used as a basis for either further iterations or acceptance of current results. When the error is reduced to a specified amount (e.g., 5 percent) or when a specified number of iterations have been made (e.g., 5), computations are halted.

The numerical solution does not always produce a smooth unit graph. An option is available to reduce the number of calculated ordinates on the recession limb of the unit graph, yielding a smooth recession curve. The corrections to the rainfall excess are made on the basis of the error between computed and observed flows. In applying the corrections, the volume of excess is preserved, but its distribution within the time periods may be changed. This will often lead to an improved fit with the observed runoff hydrographs. The resulting rainfall excess and unit graph should always be carefully checked before acceptance, as the numerical procedure does not constrain the hydrograph shape or the rainfall excess in any form. That is, even if it is known that the largest excess of a 6-hour rainfall occurred in the first hour, if a better fit is obtained with the largest excess in the last hour, the final solution will be the latter, the best numerical fit, although irrational hydrologically. An important consideration in such a case might be whether or not the assumptions of unit hydrograph theory are adequately met.

Discussion

The program is written in Fortran for an IBM 360 computer. No changes were necessary to adapt it for use on a CDC 6600. The program required 66000_8 for execution on a CDC 6600 and was compiled in 3.0 seconds. Figure K-1 shows the unit hydrograph derived by the TVA unit graph program along with the unit hydrograph derived by the Corps of Engineers, HEC, Unit Hydrograph and Loss Rate Optimization program (Section C). If the TVA unit graph is smoothed, the two hydrographs are quite similar. The initial rainfall excess provided to the TVA program in this case was based on the loss rate function used in the HEC program. These excess values were adjusted only slightly by the TVA program in obtaining the best fit. The routine was unable to reduce the error of fit below the specified 5 percent level, and computations were halted after five iterations. The average error indicated at the end of computations was 11 percent.

Figure K-2 shows the observed total runoff hydrograph and the runoff computed by both the TVA and the HEC programs. In this example both routines yielded results that agreed very closely with the observed flow. Shown above the hydrograph in Fig. K-2 are the hourly rainfall amounts and the optimal rainfall excess distributions as determined by each routine.

This example event was chosen for comparison at random. It does not imply that the TVA and HEC programs will always give such similar results. A large variety of hydrologic events would have to be analyzed before any valid conclusions could be drawn in this regard.

Data for the TVA unit graph program were easily prepared using the input description and data forms given in the program documentation.

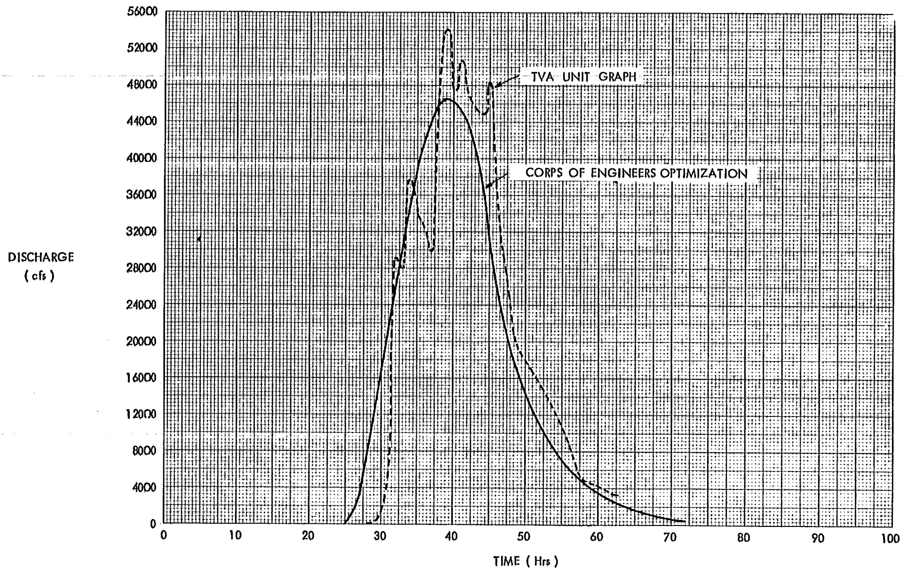


Figure K-1. Unit Hydrographs Derived by TVA Unit Graph Program and Corps of Engrs Unit Hydrograph and Loss Rate Optimization Program.

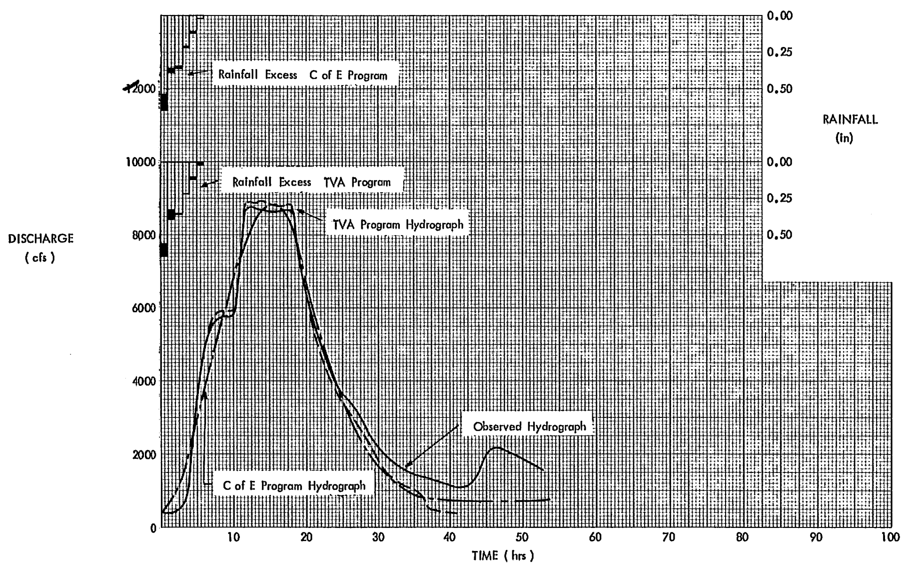


Figure K-2. Observed and Computed Runoff Hydrographs Determined by TVA and Corps of Engrs Programs.

Section L. SIMULATED OPEN CHANNEL HYDRAULICS (SOCH)

Source

Tennessee Valley Authority (Attention: Bob Buehler, Chief, Flood Control Branch). Programmers: James W. Vinyard and Inda M. Smith.

Description

This program uses the basic differential equations of continuity and momentum in a centered-differences finite-difference scheme to analyze unsteady flow in open channels and reservoirs. The geometry of the stream or reservoir is described at fixed intervals by tables of flow areas, (hydraulic radius)$^{2/3}$, and width, all versus elevation. The program is limited to 91 tables describing 91 cross sections.

The program, written in Fortran IV, yields computed values of stage, discharge, and velocity at the selected cross sections. Profiles of elevation, discharge, and velocity versus miles can also be plotted directly by the SOCH program at selected time intervals.

Reference C-18 describes unsteady flow studies in TVA rivers and reservoirs and the application of an unsteady flow simulation. A specific name was not applied to the program used, but it is presumed to be SOCH or an earlier version of it.

Very good agreement was obtained in the studies between observed and measured stages in the reservoirs studied. Waves in the system were usually induced by variations in powerhouse discharge.

Some limitations of the mathematical model were

1. Stability and convergence of the solution (now resolved).

2. Explicit scheme requires short time and distance steps when longer ones are desirable.

3. Flows in dry or nearly dry channels cannot be computed.

4. Supercritical flows cannot be calculated.

This program is of special interest because it provides a method of flood routing or unsteady flow analysis in natural channels through solution of the momentum and continuity equations. It was received too late in this study to permit operation and evaluation, but does appear to warrant further study.

Section M. SURVEY OF PROGRAMS FOR WATER SURFACE PROFILES

Source

"Survey of Programs for Water Surface Profiles," by Bill S. Eichert, Journal of Hydraulics Division, ASCE, Vol. 96, No. HY2, February 1970.

Discussion

This is an excellent paper in which the author compares in detail six flow profile programs developed by five federal agencies and one state (Iowa) agency. Before making this comparison, Eichert discusses the benefits and problems associated with the use of programs from other organizations. In connection with the comparison of programs, he comments on the overall analysis of flow profiles in natural channels, including types of flow, type and subdivision of natural channels, description of the cross section, critical depth computation, non-uniform velocity distribution, roughness description, and bridge losses.

This discussion provides an excellent overall view of gradually-varied profiles in natural channels regardless of the program to be used. For example, the comments concerning critical depth in natural channels indicate the desirability of an iterative process for determining the water surface elevation corresponding to the minimum specific energy as opposed to the critical depth equation normally used for prismatic channels.

Table M-1 has been reproduced from Eichert's paper and contains comparative data on six of the 11 programs he reviewed. The reader is referred to this original paper for more information on these programs.

It may be of interest to note that the Hydrologic Engineering Center program discussed in the paper is an earlier version of HEC-2, which is discussed in Section B above. HEC-2 is a very useful program and should be of interest to many organizations concerned with the flood plain program.

While not a part of Eichert's paper, a University of Minnesota program entitled "The Computation of Water Surface Profiles in Natural Channels" (Ref. D-7), by Steven P. Larson may be of interest. This program does not contain routines with which to compute losses through bridge waterways, and thus such losses must be computed separately. However, the simplicity of data input and the small size (14000_8 core locations) of such a program give it great simplicity for use on small machines for simple profiles. The program uses the following: (1) a standard step method of computation and (2) an iterative process to determine minimum energy and critical flow.

TABLE M - 1

(From Eichert)

Line		1	2	3	4	5	6
1	Developing Office	The Hydrologic Engineering Center US Army Corps of Engineers Sacramento, California	Bureau of Reclamation Chiefs Office, Denver	Little Rock District US Army Corps of Engineers	Iowa Natural Resources Co. and C.I.R.A.S.	Soil Conservation Service Hyattsville, Maryland	U.S. Geological Surv Washington, D. C.
1a	Reference Number	(19)	(22)	(20)	(18)	(21)	(14)
2	Authors and Telephone Numbers	Bill S. Eichert 961-449-2105	Eugene Cristofano 303-233-8037	W. A. Thomas 501-372-5394	James O. Shearman 608-622-2488 and Merwin D. Dougal 515-294-4244	Robert E. Maclay and others 202-388-7555, ext. 8655	Water Resources Divis for information call Harry Barnes 202-343-5018
3	Computer Used	CDC 6600 and others	CDC 6400 and others	GE 225	IBM 360 MOD 40	IBM 7090 or 360	IBM 360
4	Program Language	FORTRAN II or IV	FORTRAN IV	GE CARD FORTRAN	FORTRAN IV	FORTRAN IV	FORTRAN IV
5	Type of Flow	Gradually Varied Subcritical and Supercritical	Gradually Varied Subcritical and Supercritical	Gradually Varied Separate Programs for Subcritical and Supercritical	Gradually Varied Subcritical Only	Gradually Varied Subcritical Only	Gradually Varied Subcritical Only
6	Basic Method of Backwater	Standard Step ([illegible])	Standard Step	Standard Step	Standard Step	Standard Step	Standard Step
7	Are Tables of Hydraulic Elements Computed?	No	No	No	Separate Program	No	No
8	Type of Cross Section	Any	Any	Any	Any	Any	Any
9	Max. Number of Subdivisions of Cross Sections	100	9	7	25	3	6
10	Cross Section Description						
10a	Can Negative Stations Be Used?	Yes	Yes	No	No	Yes	Yes
10b	Max. Number Points	100	100	100	50	48	100
10c	Can Cross Section Be Repeated?	Yes	Yes	No	Yes	No	No
10d	Can Cross Section Be Skewed?	Yes	Yes	No	No	No	No
10e	Can Cross Sections be Interpolated Automatically?	Yes	No	No	No	No	No
10f	Can Effective Area Be Modified During Computation?	Yes	Yes	Yes	Yes	Not This Version	No
10g	Is Cross Section Extended Vertically?	Yes	Yes	Yes	Yes	Yes	Yes
11	Method of Computing Critical Depth	Min. Specific Energy	Min. Specific Energy	Min. Specific Energy	Modified Prismatic	Prismatic Channels	None
12	Assumption When Depth Crosses Critical	Critical Depth	Critical Depth	Critical Depth	Critical Depth Bridge Only	Critical Depth	Stops
13	Method for Cross Section Velocity Head	Weighted by Q	Weighted by Q	Weighted by Q	Weighted by Q	Weighted by Q	Weighted by Q
14	Friction Loss Computation						
14a	Formula	Manning					Manning
14b	Max. No. Subdivisions of Roughness	20	9	7	25	3	6
14c	Can Roughness Vary by Elevation?	Yes	Yes	Yes	No	No	Yes
14d	Can All Roughness Vary by Fixed Ratio?	Yes	Yes	No	No	No	No
15	Ability to Change Discharge						
15a	At Any Cross Section?	Yes	Yes	Yes	Yes	Not Directly	Yes
15b	At Any Cross Section, Diff. Each Prof.?	Yes	No	Yes	Yes	Not Directly	Yes
15c	Interpolate Q for Inserted Cross Section?	Yes	No	--	No	No	No
15d	Vary All Discharges by Fixed Ratio?	Yes	Yes	No	No	No	No

TABLE M - 1 (Continued)

Line		1	2	3	4	5	6
1	Developing Office	The Hydrologic Engineering Center	Bureau of Reclamation	Little Rock District	Iowa Natural Resources Co.	Soil Conservation Service	U.S. Geological Su
16	Starting Water Surface By:						
16a	Known Elevation	Yes	Yes	Yes	Yes	Yes	Yes
16b	Slope - Area	Yes	Yes	No	No	Not in this Version	No
16c	Critical Depth	Yes	Yes	Yes	No	No	No
17	Ability for Basin Backwater	No	No	No	No	Yes	No
18	Is Data Editing Program Available?	Yes	Yes - Symbolic Language	Yes	Under Development	Yes	No
19	Availability of Plotting Programs						
19a	For Cross Sections?	Yes	Separate Program	Yes	No	Separate Program	No
19b	For Profiles?	Yes	Separate Program	No	No	No	No
20	Can Metric Units Be Used?	Yes	Yes	No	No	No	No
21	Can Roughness Be Calculated Directly From Known High Water Marks?	Yes	Yes	Separate Program	No	No	Separate Program
22	Method of Loss Through Bridge	*				(Under Development)	
22a	Number of Bridges Per Cross Section	1	1	1	1		
22b	Method Low Flow - Subcritical Flow	Yarnell (12) and Carstanjen Trapazoidal Cross Section	Normal Backwater Bernoulli Formula	Kindsvater, Geological Survey Circular 284(3)	Normal Backwater Bernoulli Formula (1)		Bureau of Public Roa Criteria (17)
22c	Method Low Flow - Supercritical Flow	Carstanjen - Momentum (6)	Normal Backwater				
22d	Method of Pressure Flow	Orifice Formula (12)	Orifice Formula	Kindsvater, Geological Survey Circular 284(3)	Orifice Formula		None
22e	Method of Combination Pressure and Weir Flow	Trial and Error for Energy Gradient by Orifice and Weir Formulas (19)	Orifice (Bridge) and weir Flow (When Tailwater Below Road. Otherwise - Normal Backwater)	Considers either one but not both	Weir (2 and 15) and Normal Backwater or Weir and Orifice		None
22f	Method of Combination Low Flow and Weir Flow	Trial and Error for Energy Gradient by Yarnell and Weir Formulas	Normal Backwater	Considers either one but not both	Weir and Normal Backwater		None
22g	Method of Submergence on Weir	HDC 111-4 Based on Ratio Tailwater to Headwater (12)	Normal Backwater	By Master's Thesis of W. A. Thomas (7)	By Yarnell and Negler (16) and Master's Thesis of Sigundsson 1955 (6)		None
22h	Max. No. Subdivisions of Weir Flow	50	20	1	20		None
23	Reference Number	19	22	20	18	21	14

* A second bridge routine is available which uses the normal backwater with corrections for area and wetted perimeter for the bridge deck.

Section N. COMPARISON OF PROGRAMS FOR SOLUTION OF THE LOG-PEARSON TYPE III PROBABILITY DISTRIBUTION

Discussion

Based in part on the recommendation of the Water Resources Council in their Bulletin No. 15, "A Uniform Technique for Determining Flood Flow Frequencies," [A-21] a number of computer programs have been prepared for solution of the Log-Pearson Type III Probability Distribution.

Among these are programs prepared by (1) the Hydrologic Engineering Center of the Corps of Engineers [A-14], (2) the Soil Conservation Service, (3) the Geological Survey [A-18], (4) the Bureau of Reclamation [A-7], (5) the St. Paul District, U.S. Army Corps of Engineers [A-16], and (6) the University of Minnesota, St. Anthony Falls Hydraulic Laboratory [A-1].

The programs generally have similar functions to compute theoretical discharges for selected recurrence intervals or probabilities. Usually the intervals or probabilities correspond to the values in WRC Bulletin No. 15: recurrence intervals of 200, 100, 50, 25, 10, 5, 2, 1.25, 1.11, 1.05, and 1.01 years, or 0.5, 1 2, 4, 10, 20, 50, 80, 90, 95, and 99% probability of exceedence.

Table N-1 gives comparative data on six log-Pearson Type III programs. As noted therein, all programs are in FORTRAN II or IV or equivalent. The U.S. Geological Survey program is the only one with a line printer plot routine.

Several programs, including the University of Minnesota program, print the input data sorted in descending magnitude to assist in graphing the data. Of these, only the U.S.B.R. program retained the calendar year with each flood.

One feature of major interest concerns the computation of flood magnitudes for skewness values other than the one computed for the actual input data. Since the skewness may vary quite widely in short records, it is sometimes desirable to use a regional skewness coefficient. A similar effect is achieved with one very low annual flood in the record, which results in high negative skewness.

In the University of Minnesota program the theoretical flood values are computed for the actual skewness, zero skewness, and a regional skewness which is input with the original data. This permits a comparison of the effect of variation in skewness on the actual record.

Preliminary work by the authors indicates the need for a screening process for annual flood data to eliminate the low outliers which have a disproportionate effect at the high-discharge end as well as the low-discharge end of the theoretical curve. Apparently none of the programs were provided with such a process although checking for input errors, or data editing, is provided for in the St. Paul District Corps of Engineers Program and in the U.S. Geological Survey Program.

TABLE N-1

Summary of Program Capabilities for Flood Frequency Analysis - Pearson Type III Method

SOURCE	HEC	USBR	ST. PAUL C of E	U of M	SCS	USGS
COMPUTER	IBM 1620	HONEYWELL 800	IBM 1130 MODEL 2B	CDC 6600 IBM 1620	IBM 1130	IBM 360/65
LANGUAGE	FORTRAN II	AUTOMATH 1800	FORTRAN IV	FORTRAN IV	FORTRAN IV	FORTRAN IV
SORT AND COMPUTE PLOTTING POSITION	NO	YES HAZEN $P_C = \frac{100(2m-1)}{2N}$	YES BEARD $P_{LARGEST} = 1-(0.5)^{1/N}$ $P_{SMALLEST} = (0.5)^{1/N}$ IN BETWEEN INTERPOLATED	YES WEIBULL $R = \frac{N+1}{m}$	NO	YES $P = \frac{m}{N+1}$
FLOOD MAGNITUDE FOR SKEWNESS: A) COMPUTED	YES	YES	YES	YES	YES	YES
B) ZERO	NO	NO	YES	YES	NO	NO
C) REGIONAL	NO	NO	YES	YES	NO	NO
CHECK FOR ZERO OR NEGATIVE FLOODS	NOT APPLICABLE	YES DISCARDS VALUES	YES FLOW REPLACED BY 0.01	YES REJECTS DATA SET	YES FLOW REPLACED BY SMALL VALUE	YES REJECTS DATA SET
SPECIAL POINTS IN OUTPUT	1. EXCEEDANCE PROBABILITY AND THEORETICAL FLOODS	1. SORTED INPUT DATA 2. PLOTTING POSITION 3. EXCEEDANCE PROBABILITY AND THEORETICAL FLOODS	1. SORTED AND UNSORTED INPUT DATA 2. PLOTTING POSITION 3. EXCEEDANCE PROBABILITY AND THEORETICAL FLOODS	1. SORTED INPUT DATA 2. PLOTTING POSITION 3. EXCEEDANCE PROBABILITY AND THEORETICAL FLOODS	1. INPUT DATA 2. EXCEEDANCE PROBABILITY AND THEORETICAL FLOODS	1. INPUT DATA 2. EXCEEDANCE PROBABILITY AND THEORETICAL FLOODS 3. LINE PRINTER PLOT OF 1 AND 2
METHOD TO CALCULATE PEARSON III COORDINATES	USE SKEW COEFF. AND PROBABILITY TRANSFORMATION FROM BEARD	USE SKEW $= \frac{2.0}{G}\left(\frac{G}{6}\left(D - \frac{G}{6}\right) + 1.0\right)^3 - 1.0$ D = SKEW FACTOR	TABLES FROM WRC BULLETIN NO. 15	TABLES FROM WRC BULLETIN NO. 15	TABLES FROM WRC BULLETIN NO. 15	TABLES FROM LARGER SET BY H. LEON HARTER AND SCS
OPTIONS AVAILABLE	NONE	NONE	YES CHOOSE TO COMPUTE CURVES FROM A) DATA B) STATISTICS, LENGTHS OF RECORD, $\bar{X}$, S, G	NONE	NONE	NONE
INPUT DATA FORMAT	TITLE CARDS - S - $\bar{X}$ - BLANK CARDS	TITLE CARDS - YEAR AND FLOODS END DATA NEXT DATA SET	TABLES READIN TITLE FLOODS BLANK CARD STOP	TABLES READIN -DESCRIPTION -NO. OF FLOODS -REGIONAL SKEW FLOOD VALUES LAST SET	TABLES READIN -DESCRIPTION -DATA ENDDATA NEW DESCRIPTION OR END JOB	- A in I COL. - NAME, NO OF FLOODS, STATION FLOODS - FLOOD MAGNITUDES

The initial computation in the log-Pearson Type III methods involves transforming the data into logarithms of the floods. Any records with a zero annual flood cause problems because the log of zero is minus infinity. Some programs substitute the log of 0.01 and the computation continues (St. Paul Corps of Engineers). The U.S.B.R. program omits zero events from the log computation, but uses them in determining the plotting positions of the data. The U.S.G.S. program calls attention to the zero events and terminates the computation.

Some of the programs would benefit by printing out additional data, i.e., (1) discharges for other skewness values, (2) the mean and standard deviation of the floods as well as the log of the floods, and (3) the sum of the deviations squared and cubed.

Section O. GENERAL STATISTICAL AND UTILITY PROGRAMS

Discussion

Most computer applications in hydrology require the preparation of specific programs to perform specialized operations. In certain instances general programs, usually available in computer center libraries, or user program sharing organizations, may be utilized.

Examples of commonly available library programs of this type are routines for correlation and regression, numeric and alphabetic sorting, random number generation, roots of polynomials, calcomp and line printer plotting, and many others.

As an illustration of library routines, Appendix 10 lists those available at the University of Minnesota Computer Center. Shown in one list are subroutines and functions which may be included as part of any specially written program. That is, if in preparing a special program to generate synthetic runoff data a random number generator is needed instead of writing the routine, the user may simply incorporate the library subroutine to perform that function.

Another list (UMST) includes separate programs that perform the given statistical computation on a complete set of data. These are complete programs; no additional programming is required. Data must be provided in accordance with an established format.

In addition to basic frequency analysis of hydrologic data discussed in section N and general statistical routines, many programs are available for special applications in hydrology. The Bureau of Reclamation has prepared programs for streamflow duration analysis [A-3], and precipitation depth duration analysis [A-6]. Where runoff gaging stations in an area have unequal record lengths the station records may be correlated and the shorter record extended [A-4, A-10].

The Hydrologic Engineering Center has developed programs to simulate streamflow based on the statistical properties of a historical record [A-11, A-12].

Many routines have been prepared by the U.S.G.S. [Appendix 8] for tabulating, totaling, and other operations necessary in the preparation of reports on water resources data.

Section P. PROBLEM-ORIENTED COMPUTER PROGRAM-LANGUAGE HYDRO

Source

Bugliarello, G.; Gormley, J.T.; and McNally, W. An Informal Progress Report on HYDROL - A Content-Oriented Computer Language for Hydrology and Hydraulic Engineering. Carnegie Institute of Technology, Department of Civil Engineering, Pittsburgh, Pennsylvania, November 1963.

Bugliarello, G.; McNally, W.D.; Gormley, J.T.; and Onstott, J.T. A Pilot Problem-Oriented Computer Language for Hydrology and Hydraulic Engineering ("HYDRO"), Carnegie Institute of Technology, Pittsburch, Pennsylvania. Paper presented at the 47th AGU Meeting, Washington, D.C. April 1966.

Discussion

The philosophy, specifications, and operational characteristics of a problem-oriented computer language, HYDRO, for performing hydrological and hydraulic engineering analyses are presented in the above references.

The present version of HYDRO is intended as a pilot for further development of the concept of problem-oriented languages in the field of water resources. It encompasses the areas of precipitation analysis, hydrograph analysis, open channel hydraulics, flood routing, and frequency analysis.

From the user's viewpoint, the most significant characteristics of the language are the ease with which a person unskilled in computer programming can learn in a very short time to perform computer analysis in the areas covered by the language and the possibility of stringing long series of commands together.

HYDRO was written in ALGOL and later rewritten (in part) by Delleur and others at Purdue as FORTRAN-HYDRO (see Section Q).

Selected notes from the above (Previously mentioned) papers are as follows:

1. HYDRO should be much simpler to program than FORTRAN or ALGOL;

2. Commands and data should be oriented toward the field of water resources;

3. A broad area of water resources should be covered;

4. It should be flexible enough to handle different types of problems;

5. It should have a library organized systematically for stringing of programs;

6. There should be automatic data transfer between commands;

7. Inputs and outputs should be both by card and by teletype;

8. The language should be geared to the capabilities (i.e. memory capacities) of a broad range of computers;

9. The language, to be easily augmentable, should be designed in such a way as to facilitate the design of the procedures, the addition of new procedures to the library, and the removal and substitution of existing procedures.

A total of approximately 32,000 words of core memory capacity are needed for the implementation of the present HYDRO system. However, if necessary, the system can be broken into smaller segments and thus made suitable for smaller machines. The largest assembled program run to date (1966) consisted of 1,000 ALGOL card images, corresponding to 12,000 words of internal storage, to run.

Source

Delleur, J.W. and Toebes, G.H. "Fortran-Hydro," Journal of the Hydraulics Division, ASCE, Vol. 95, No. HY6, pp. 1933-2019, November 1969.

Discussion

Fortran-Hydro is a system of interlocking Fortran IV Subroutines for the solution of elementary problems encountered in hydrology, hydraulics, and water resources engineering.

Previous use of Fortran-Hydro (FH) was on the IBM 7094 system. FH is now available on the Purdue CDC 6500 computer system. It is stored on the 6638 disk unit in the form of a system permanent file and is also on a magnetic tape. The FH program can be loaded from any of the remote terminals on the Lafayette campus making use of the PROCSY system. "PROCSY", the Purdue remote on line system, is a remote terminal support system for the CDC 6500 located at the Purdue University Sciences Center. It allows remote creation, submission and retrieval of batch jobs which are executed at the central computer facility.

The terminal user can create, edit, and store data files; submit jobs for batch execution; and retrieve the resultant batch job output data.

Jobs submitted from remote terminals are indistinguishable from locally submitted jobs and therefore may utilize any and all features available to the local batch user, including the FORTRAN-HYDRO subroutine library.

File creation and editing is processed in an interactive mode, whereas job execution is processed in a batch or non-interactive mode. Job turnaround time will be a function of batch system loads and will vary from execution to execution.

Present and proposed programs are as follows:

FH 100-FH-199	reserved for hydrology subroutines
FH 200-FH-299	reserved for statistics and related subroutines
FH 300-FH 399	reserved for unsteady flow subroutines
FH 400-FH 499	reserved for free surface flow subroutines
FH 500-FH 599	reserved for network subroutines
FH 600-FH 699	reserved for ground water subroutines
FH 700-FH 799	reserved for water quality parameter subroutines

The subroutines that are operational and tested at Purdue as of March 1970 are:

FH 100	Arithmetic Average
FH 101	Local Rainfall Estimate Using Data from Surrounding Stations
FH 102	Normal Annual Precipitation

FH 103	Factor Average
FH 104	Missing Rainfall Data by Normal Ratio
FH 105	Computation and Plotting of Mass Curves
FH 106	Absolute Maximum Station Precipitation
FH 107	Computation of Depth-Area Data
FH 108	D-Hour Unit Hydrograph
FH 109	Computation of Unit Hydrographs from Complex Storm Data
FH 110	Triangular Unit Hydrograph
FH 112	Hydrographs from a Given Storm
FH 113	Double Mass Curve Break Check
FH 115	Reservoir Area Capacity
FH 116	Reservoir Routing
FH 200	Data Ordering
FH 201	Standard Deviation
FH 202	Frequency Analysis of Extreme Values by Gumbel's Method
FH 203	Interpolation by Spline Fit
FH 300	Flood Routing by the Method of Specified Intervals
FH 302	Kinematic Flood Routing
FH 303	Instantaneous Unit Hydrograph, Identification by Fourier Transform
FH 304	Numberical Evaluation of the Instantaneous Unit Hydrograph by Direct Solution of the Convolution Integral
FH 305	Numerical Convolution
FH 306	Moments
FH 400	Hydraulic Characteristics
FH 401	Normal and Critical Depths
FH 402	Alternate and Sequent Depths
FH 403	Specific Energy and Force Curves
FH 404	Water Surface Profiles by the Direct Step Method
FH 405	Profile Types
FH 406	M and N Exponents
FH 407	Varied Flow Function
FH 408	Water Surface Profile by the Direct Integration Method

Additions of subroutines on sediment transport, kinematic flood routing, and linear systems analysis are planned.

Section R. SMALL BASIN RAINFALL-RUNOFF SIMULATION

Source

Lichty, R.W., Dawdy, D.R., and Bergmann, J.M. "Rainfall-Runoff Model For Small Basin Flood Hydrograph Simulation," IASH Publication No. 80, The Use of Analog and Digital Computers in Hydrology, Volume II, Dec. 1968.

Description

This mathematical model is a simplified self-fitting flood hydrograph simulation model. It uses a soil moisture dependent function to determine infiltration rates during the rainfall period. This function is based on work by Philip:

> Philip, J.R. "An Infiltration Equation With Physical Significance, Soil Science, Vol. 77, No. 2, 1954, pp. 153-157.

The rainfall excess is distributed in time by the distance-area-curve yielding a hydrograph which is then routed through simulated basin storage to give the final outflow hydrograph.

Methods

This model uses the Philip infiltration equation to express potential infiltration as a function of soil moisture. The value of potential infiltration thus determined is taken as the maximum point infiltration in the basin. The basin wide infiltration is then determined assuming that the potential infiltration rate varies linearily from zero to the maximum point value. As long as the supply rate is in excess of the maximum potential infiltration rate this would yield a basin wide rate equal to one-half the maximum potential point value. With supply rates less than the maximum potential point value the assumption of linear variation in infiltration yields a value of basin wide infiltration somewhere between zero and one-half the maximum potential point value. This approach to variations in infiltration rates is taken from Crawford and Linsley [E-5].

Soil moisture in the basin is accounted for in a two-reservoir system. The first reservoir represents the saturated surface layer into which infiltration accumulates. This reservoir is depleted by drainage to the second reservoir and by evapotranspiration.

In all, 7 parameters are required to describe the infiltration and moisture function. The distance area diagram is derived from a map of the basin and is assumed fixed for all events. An eighth parameter is required to define the storage function for routing the hydrograph.

Discussion

This model is a useful tool for studying the runoff from a small watershed. Its use of an infiltration function dependent on soil moisture is an advantage over earlier functions based on time. The model will determine the best set of the model parameters that will fit a series of observed hydrographs. The program is written in PL-1.

Section S. MODEL OF WATERSHED HYDROLOGY: USDAHL-70

Source

USDAHL-70 Model of Watershed Hydrology, prepared by H.M. Holtan and N.C. Lopez. U.S. Department of Agriculture, Hydrograph Laboratory.

Description

This program was written in Level E Fortran for use on an IBM 360-30 computer. The model, in the words of the authors, is "the beginning of an effort to express watershed hydrology as a continuum". Its primary objective is to serve the needs of watershed engineering by providing detailed information on the runoff process to assist in the design of engineering structures. It is based on a series of empirical relationships.

Input consists of a continuous record of rainfall (average over the watershed). Snowfall is tabulated as water equivalent for the watersheds modeled. An example is given where the watersheds ranged in size from 3 to 98 square miles.

Methods

Infiltration is based on the Holtan equation:

$$f = a \cdot S_a^{1.4} + f_c$$

where f = infiltration capacity in in/hr.
a = infiltration capacity in inches per hour per inch of available storage (values given in report).
S_a = available storage in the surface layer in inches water equivalent (the A horizon in agricultural soils).
f_c = constant rate of infiltration after prolonged wetting in inches/hr.

Rainfall in excess of infiltration is routed across actual soil zones for the watershed to the channel using an empirical relationship by Musgrave and Holtan. Channel routing is by "simultaneous solution of the continuity equation and a storage function." The latter is obtained by integration of the flow recession curve for the test watershed.

Infiltrated water may be dissipated by evapotranspiration, downward seepage, or lateral return flow.

Discussion

Application of the model to 4 watersheds (Ohio, Texas, Nebraska, Florida) indicated good correlation between monthly observed and computed runoff. Continuous synthesis of mean daily flows at Upper Taylor Creek, Florida showed good agreement over a 5 year period. Standard output includes a daily printout and a monthly summary at the end of each year. The daily data includes day of year, inches of rainfall, inches of runoff, mean daily cfs, precipitation excess, etc.

The model was not tested as a part of the present study but appears worthy of study by interested agencies. The program is well documented.

Section T. THE KENTUCKY WATERSHED MODEL AND OPSET

Source

University of Kentucky Water Resources Institute, by L.D. James

Description

The Kentucky Watershed Model is basically a translation of the Stanford Watershed Model [E-5] into FORTRAN computer language. It is a very complex continuous synthesis, two phase watershed model, implying that the land phase and the channel phase are each modeled as separate entities. The program is fairly large, requiring over 70500_8 storage locations, and requires substantial computer time to operate. The input data requirements are quite lengthy but the bulk of it is easily accessible from published climatological data. Using this data, the most significant of which is rainfall, the program produces synthesized stream flow hydrographs and moisture storage values based on specified parameters which define the relationships representing the various processes involved in the hydrologic cycle. ØPSET is a companion program which uses optimization techniques to determine the values of 13 of the input parameters to the Kentucky Model such that the best approximation to observed results are produced. It uses a streamlined version of the Kentucky Model as a central core and by testing various values of the parameters, attempts to find the combination which gives the "best fit" with observed data. It is also a fairly large program, consisting of over 2400 source statements and requiring 100500_8 storage locations on the CDC 6600, and well over 100 seconds of central processing time to execute.

Methods

The actual model which is used is a two-phase model in which the land surface and channel system are treated separately. The actual equations which define the various relationships will not be included in this discussion and the reader is referred to Crawford and Linsley's report on the Stanford Watershed Model IV for a detailed discussion.

The land phase consists basically of interception, infiltration, overland flow, interflow, evapotranspiration, and depression storage. It also includes storage in various soil zones, groundwater storage, and groundwater flow. This phase accepts rainfall and other climatological data as input to produce inflow into the channel phase of the model. A moisture accounting procedure is used in which moisture movement is governed by the current moisture situation in the various areas and by constants which are intended to represent the physical properties of the watershed. Very detailed and complex relationships are used in an effort to simulate the real situation as closely as possible. Thus, basically, the land phase produces inflow to the channel system from impervious areas and overland flow, interflow, and groundwater flow.

The channel system of the model uses the output from the land phase to produce the outflow hydrograph for a watershed and does this basically in two steps. First, a time-area type of routing model is used, in which a channel time-delay histogram simulates the time-delay to the outlet, of flows entering the channel system. This flow is then routed through a conceptual reservoir to simulate the storage characteristics of the channel systems. Thus the outflow from the land phase is processed by these two techniques to simulate the channel system effect and produce the outflow hydrograph.

A snowmelt subroutine is also included as a part of the model. The particular snowmelt model used in the Kentucky Model is simplified in an effort to make its use feasible in areas where a limited amount of data necessary for this type of calculation is available. The main input is daily temperatures, with estimates of solar radiation and snow evaporation also necessary. A heat monitoring type of analysis is used where melt occurs when the heat content reaches some specified amount. Although the input data is limited, a thorough snow melt analysis is made, which in itself greatly enhances widespread applicability of the overall model.

ØPSET was developed to eliminate the subjective nature of trial and error type of fitting. Standard optimization techniques proved infeasible and other methods, which were based on the results of many sensitivity studies, were used. Basically, this program uses measurable watershed characteristics, climatological data and measured streamflow data to find the optimum set of values for thirteen of the constants which define the various flow and storage functions. The optimization is done in two phases, a rough phase which uses large time increments, and a fine adjustment phase which uses smaller time increments. Thus this program attempts to determine the optimum set of thirteen of the input parameters to the Kentucky Model.

Discussion

The watershed model used by these programs is very complex and complete, and has significant potential in both research and planning programs as well as design problems concerning water resources. However, because of its size and complexity, it is very important that users become thoroughly familiar with the model so that they can properly apply it to their individual problems. Only if the user is fully aware of all the techniques and assumptions incorporated in the program will the full benefit of the model be derived. The model is intended to be closely associated with physical watershed characteristics and if users are diligent and innovated in the use of the programs, they can be very valuable to water resources research, design, and planning.

Section U. RIVER BASIN SIMULATION PROGRAM

Source

"River Basin Simulation Program," by William C. Pisano, August 15, 1968. Environmental Protection Agency (EPA), Washington, D.C.

Description

As noted in the author's Preface, the set of programs and options included provides a new approach to river basin planning for water quality management. It models the behavior of a river basin with the primary intention of using Monte Carlo Sampling (simulation) to find the occurrence frequencies of: 1) various water quality indicators or pollutant fluxes, 2) water supply deficiencies, 3) seasonal flows and 4) reservoir contents. "The computations performed are designed for the users within FWPCA (now EPA). However, the underlying logic is sufficiently general to make the program useful to other organizations interested in water resources. For example, irrigation, flooding, and navigation can be studied."

"The user prepares a set of input cards for the program which serve two functions. The first function describes: 1) a natural hydrologic regime, 2) evaporation and seepage conditions, and 3) ambient water quality. The second function specified the plan which can be 1) water quality objectives (standards); 2) flow requirements and diversions; 3) waste loadings from towns, industries and irrigation districts; 4) various dams; and 5) (optionally) a table of the release schedules to be used at the dams."

Answers are obtained in the form of statistical information concerning the probable consequences of the implementation of proposals under study.

Discussion

The program was written in Fortran IV for the IBM 360/65 data processing system and contains in excess of 4000 input statements. There are 3 major options in the package. One option, "NMP" (Numerical Multisite Program), concerns the generation of operational hydrology. Another, "B" (Basin), concerns the detailed flow routing necessary to model a river basin. A third, called DEM, combines these two concepts in a one-dimensional inflow model.

The program deals in basic time units or seasons of 1, 2, 3, 4, 6, or 12 months. The entire routing of the basin, from headwater to the mouth, is accomplished during each time frame. The month is the length of time frame considered by the model and apparently restricts the selection of basins to those whose streams have an average travel time of a month or less.

The 4000 input statements noted above contain a liberal supply of comment statements which should assist the user.

The program tends to optimize water quality rather than cost. Thus, cost of dams, flood damages, and benefits from control are apparently not considered. It may be desirable to use the output in connection with some form of benefit/cost analysis.

An application example was given using the Red River of the North in North Dakota and Minnesota. The streamflow record for the area was augmented with synthetic data generated on the basis of the mean, standard deviation and a time correlation coefficient of the actual record.

Section V. STREAMFLOW SYNTHESIS AND RESERVOIR REGULATION "SSARR" PROGRAM

Source

North Pacific Division, Corps of Engineers, Portland, Oregon, and Portland River Forecast Center, Weather Bureau, ESSA.

Description

The SSARR model is used to simulate streamflow for planning, design, operation and forecasting purposes. The streamflow simulation model was originally developed from work in the Columbia River Basin in Northwestern United States. The model has also had significant use in simulations of the Lower Mekong River Basin in Southeast Asia. It may be applied to various size watersheds, in various climates. Routines to consider the snowmelt contribution to runoff for mountainous areas of Western U.S. are included. The model has also been applied as a streamflow forecasting tool by the U.S. Weather Bureau. The program containing about 8000 Fortran source cards was written for an IBM 360/50. It has been adapted for use on the CDC 6400. The program required multiple overlays of core storage and utilizes several disk or tape storage units. On the CDC 6600 it requires about 120000_8 core storage locations to run.

Methods

Water available for runoff on each of several sub-areas in the basin is determined from both rainfall and snowmelt where applicable. Rainfall data may be input at a number of stations in the basin. Snowmelt, and snow accumulation may be determined on the basis of precipitation, elevation, air temperature, dew point temperature, albedo, radiation, and wind speed. Snowmelt may be calculated using either the temperature index method or the energy budget method. The available water is then resolved into two components, that part retained in the basin and that part which will runoff. This division is determined as a function of the soil moisture in the basin. The part that will runoff is further divided into base flow, subsurface runoff, and surface runoff. The division is made based on a base flow index and the amount (intensity) of direct runoff. Each of these components of runoff is routed through a different amount of simulated reservoir storage and then combined to produce the final outflow hydrograph. A flow chart of this process is shown in Fig. V-1. The runoff from each sub-area of the watershed is routed through stream channels and reservoirs and combined with other sub-area hydrographs to yield the final simulated basin outflow.

When routing through actual reservoirs, provision is made for setting bounds on usable storage and allowable discharge. Channel routing is evaluated by use of the normal reservoir method assuming short stream reaches. Where necessary, provision is made to allow backwater to modify channel routing.

The routine is written so that a variable time increment may be used dependent on the magnitude of the runoff.

Discussion

The SSARR model is capable of simulating both large and small watersheds in climates where there may or may not be snow melt contributions. It would appear that the snow melt relations are those derived for the mountainous areas of the Northwestern U.S. These relations may not prove satisfactory for snow melt simulations in other areas such as the northern plains states.

The allowance for variable length time increments for flow computations is an important asset when simulating long flow records, particularly for small streams.

The large size of the program and its use of direct access disk storage may hamper its adaptation to other machines.

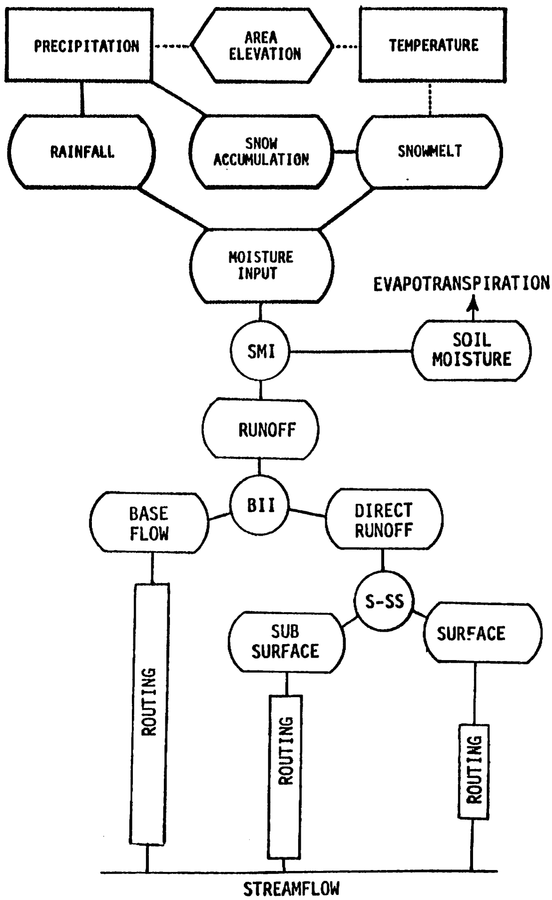


Figure V-1. Schematic of SSARR Watershed Model (From Ref. E-18).

Source

Claborn, B.J. and Moore, W.L. "Numerical Simulation of Watershed Hydrology." University of Texas, Civil Engineering Department, August 1970 (Univ. of Texas Model).

Description

This report includes a discussion of (1) the Runoff Phenomenon, (2) methods of estimating storm runoff, and (3) the Stanford Watershed Model IV, plus a listing, evaluation and discussion of a new mathematical model of the runoff process. As noted in the author's abstract, "The Stanford Model has been revised and used as a pattern for developing a new watershed simulation model."

The University of Texas Model is written in Fortran IV and has about 1,000 source statements.

Methods

Figure W-1 is an operational chart for the program. The program has been written to accommodate rainfall at irregular intervals as input, at intervals as short as one minute or as long as one day. The maximum length of the basic accounting cycle is 15 minutes. Provision has been made for variable interception and surface storage. Overland flow is handled by "a quasi-Turbulent form of Izzard's overland flow equation." Infiltration is based on flow through the upper soil zone using a form of Holtan's equation.

$$f = a(\text{UZ ST} - \text{UZS})^{n} + \text{SATPRM}$$

$$= \text{C1}(\text{US ST} - \text{UZS})^{\text{C2}} + \text{SATPRM}$$

where UZ ST is the total pore space in the upper zone (0 to 21'), porosity times thickness (in^3/in^2),

UZS is the current volume of water in the upper zone (in^3/in^2)
SATPRM is the saturated permeability of the upper zone (inches per hr.)
C1 and C2 are constants corresponding to Holtan's (a • k) and n.

It also provides for flow through the unsaturated zone using an equation based on the work of Ibrahim and Brutsaert, Gardner, and King.

Ibrahim, H.A. and Brutsaert, W. "Intermittent Infiltration into Soils with Hystereses," Jour. of Hydraulic Division, ASCE, Vol. 94, No. HY1, January 1968.

Gardner, W.R. "Solutions of the Flow Equation for the Drying of Soils and Other Porous Media," Soil Science Society of America, Proceedings, Vol. 28, p. 614-619, 1964.

King. "Description of Soil Characteristics for Partially Saturated Flow," Soil Science Society of America, Proceedings, Vol. 29, pp. 359-362, 1965.

Interflow is considered using the following equation for flow from the top level of the intermediate zone:

$$VINFL\emptyset = C_{16}\ (TIZS - C_{10} \cdot VINST)\ \Delta t$$

where VINFLO is the volume of flow added to the interflow process during time Δt,
TIZS is the volume of water stored in the top half of the intermediate zone,
VINST is the total volume of the intermediate zone, and
C_{10} and C_{16} are input parameters based on the permeability of differences between the two zones.

The interflow shape is determined by a lag function:

$$X = (C_{14} \cdot DELINF + C_{15})\ \Delta t$$

where X = volume discharged to stream from interflow storage in Δt,
DELINF is the volume in interflow storage.

The program makes provisions for groundwater to flow into the stream and also out of the basin.

Evaporation from soil surfaces is related to potential evaporation, volume in storage, maximum and minimum volumes in the upper zone, and a parameter based on the soils ability to transmit water to the surface.

A distribution graph technique similar to that of the Stanford Model is used for routing of the flow through the basin in order to produce the hydrograph of streamflow.

The program will simulate a watershed composed of subwatersheds. The model was applied to two watersheds with generally good results. The best agreement occurred for the larger of the storms analyzed.

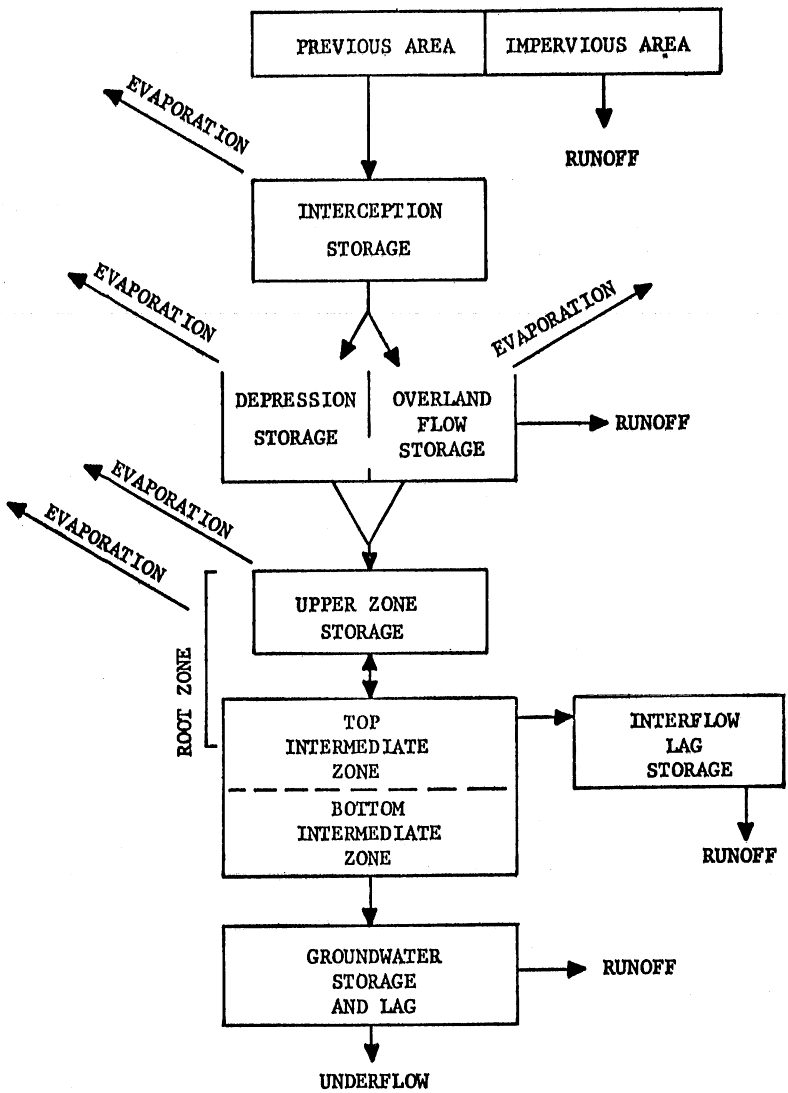


Figure W-1. Schematic of University of Texas Watershed Model (From Ref. E-4).

Section X. FLOOD ROUTING THROUGH STORM DRAINS

Source

Yevjevich, V. and Barnes, A.H. "Flood Routing Through Storm Drains," Parts I-IV. Hydrology Papers 43-46, Colorado State University, November 1970.

Description

This study and resulting computer programs deal with the computation of unsteady flow through circular conduits. Extensive experimental and numerical tests were conducted to evaluate the use of the equations of continuity and momentum for unsteady flow computations. These tests, sponsored by the U.S. Bureau of Public Roads, were made on a 3 ft diameter, 822 ft long circular conduit.

Methods

The experimental tests were conducted on a variable slope 3 ft diameter conduit. Metered discharge hydrographs were introduced at the upstream end of the conduit and the progress of the flood wave was recorded by a series of pressure transducers mounted at several points along the pipe. The depths observed were converted to digital values and punched on paper tape or cards.

This data was then used to evaluate various solutions to the equations of flow. Three numerical finite difference techniques were evaluated. Two explicit schemes, the diffusion scheme and the Lax-Wendroff scheme, were considered plus the solution by Method of Characteristics, with specified intervals.

Discussion

The experimental tests will undoubtedly be a source of data for many investigators studying the solution of unsteady flow. The numerical investigations showed the Lax-Wendroff scheme to be superior to the diffusion scheme with respect to stability and accuracy. The method of characteristics was found to give rapidly convergent and stable values. This latter method was considered the preferred technique by the authors and was used in subsequent computations of analytical waves. The computer programs for implementing each of the three computation schemes are included in Part III of the study reports.

Section Y. REAL-TIME COMPUTATION OF RUNOFF AND STORM FLOW IN THE MINNEAPOLIS-ST. PAUL INTERCEPTOR SEWERS

Source

Bowers, C.E.; Harris, G.S.; and Pabst, A.F. "The Real-Time Computation of Runoff and Storm Flow in the Minneapolis-St. Paul Interceptor Sewers," Memorandum M-118, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, December 1968.

Description

This computer program determines expected discharges at various points in an urban watershed. It has been applied to the Minneapolis-St. Paul area where it was necessary to compute, in real time, discharges at various locations. The routine developes inlet hydrographs at 15 locations, determines if excess flow must be discharged to the Mississippi River, and routes the remaining flow through the sewer system to the waste treatment plant.

Method

Precipitation is recorded at 9 locations around the area. Thiessen weighting factors are used to determine the average precipitation over each of the 15 sub-areas. A "loss" function determines the rainfall excess on the pervious and impervious parts of each sub-area.

A triangular unit hydrograph is used to represent the flow for each 5 minute period of excess precipitation. The resulting inlet hydrograph then represents the flow arriving at each of the major inlets to the interceptor sewer system. This inlet hydrograph may then divert into the interceptor system or release into the Mississippi River. The diversion is determined by the position of an inflatable dam and a hydraulically operated gate (at each of 15 locations), and the magnitude of discharge. The flow which enters the intercepter sewer system is combined with existing flow and routed to the waste treatment plant. The progressive average lag method is used to perform the routing with the necessary constants having been determined from comparison with similar routing using the Method of Characteristics.

Discussion

This program was written in two versions. One version was prepared for the CDC 6600. The second version was prepared for a PDP-9. This latter version requires several core loads to accomplish all necessary operations.

The model was tested using data obtained during 1969. Results showed that for most events the impervious area contributed most of the runoff volume, with pervious areas contributing only during short periods of high intensity precipitation.

APPENDIX 2 - ANNOTATED BIBLIOGRAPHY

A. STATISTICAL ANALYSIS OF DATA

A-1 Bowers, C.E.; Pabst, A.F.; and Larson, S.P.: COMPUTER PROGRAM FOR STATISTICAL ANALYSIS OF ANNUAL FLOOD DATA BY THE LOG-PEARSON TYPE III METHOD, Computer Program No. 1, St. Anthony Falls Hydraulic Laboratory, January 1971.

This computer program was initially developed as part of a beginning course in hydrology in the Department of Civil and Mineral Engineering of the University of Minnesota. It was subsequently modified and improved under a project sponsored by the Office of Water Resources Research, Department of the Interior, through the Water Resources Research Center, University of Minnesota.

The program sorts annual flood data and computes (1) empirical recurrence intervals and probabilities, (2) mean and standard deviation of the floods, (3) mean, standard deviation, and skewness of logarithms of the floods, and (4) theoretical flood values for specified probabilities and recurrence intervals in accordance with the log-Pearson Type III probability distribution.

In addition to the theoretical discharges for the skewness of the actual record, the program computes discharges for zero skewness and for a selected skewness (possibly a regional value) for comparison purposes. Nine graphs showing the theoretical curves and annual floods for selected streams in the United States have been included.

A-2 BuRec: HAZEN-TYPE FREQUENCY ANALYSIS, File No. HY-104A, p. 317, Abstracts of the Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

The program computes accumulative frequency curves of annual maximum peak discharge or volume based on recorded stream flows. It uses the computation method developed by Allen Hazen (Flood Flows, A Study of Frequencies and Magnitudes, by Allen Hazen, John Wiley and Sons, Inc., New York, 1930, 199 pp.). The program is limited to 100 years of record.

A-3 BuRec: FLOW DURATION ANALYSIS OF STREAM FLOW RECORDS, by J.V. Vredenburg, File No. HY-135, p. 350, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This routine performs flow duration analysis of stream flow records to determine flow duration curves.

Date: 2-1-65. Computer: HON 800. Language: Automath 1800. Storage req: 7000 words (decimal).

A-4 BuRec: EXTENDED RUNOFF RECORDS, by R.B. Brownrigg, File No. HY-125, p. 339, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program is used to extend runoff records after a satisfactory correlation has been found using the multiple correlation program. Constant correlation factors are assumed for the independent variables.

Date: 1-15-64. Computer: IBM 1620. Language: Fortran II. Storage req: 40,000 characters (decimal)

A-5 BuRec: DESIGN STORM DEPTH-DURATION VALUES, by D.G. Olson, File No. HY-108A, p. 322, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program extracts the highest value of a single precipitation increment of any two successive increments, any three successive increments, and so on for 4, 5, ... (N-1), N increments. These totals, multiplied by a constant, are called depth duration values. The maximum number of precipitation increments is 200.

Date: 6-1-64. Computer: HON 800. Language: Automath 1800. Storage req: 4000 words (decimal).

A-6 BuRec: DEPTH DURATION ANALYSIS, by J. Woerner and D. Olson, File No. HY-138, p. 353, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

Thiessen polygons are used to distribute the average depth of precipitation over a basin in time. The program can be used to weight observed rain at recording rain gage stations, to arrange increments in maximum depth-duration series, and to adjust increments to design depth over a basin. Number of distribution stations is not limited, but increments are limited to 500.

The methods of analysis are discussed in Manual for Depth-Area-Duration Analysis of Storm Precipitation, Cooperative Studies Technical Paper No. 1, U.S. Weather Bureau, September 1946.

Date: 6-1-65. Computer: HON 800. Language: Automath 1800. Storage req: 10,000 words (decimal).

A-7 BuRec: DETERMINATION OF FLOOD FLOW FREQUENCIES WITH THE USE OF THE LOG-PEARSON TYPE III METHOD, File No. HY-173, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This is a program for calculating flood frequencies using the log-Pearson Type III method.

A-8 Fed. Hwy. Admn.: ENGINEERING DESIGN HYDRAULICS, Prog. 1600, 1969.

HY-5 files gaging station flood records and produces a compilation of flood records, a frequency plot, and an index of the gaging stations.

A-9 HEC: BALANCED HYDROGRAPH, by Leo R. Beard, Program No. 23-237, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, November 1966.

A "balanced hydrograph" is defined as one that conforms to a specified set of volume-duration values. Given a specified set of durations and a pattern hydrograph whose duration equals or exceeds the longest specified duration, the program will compute any number of balanced hydrographs for specified sets of average flows corresponding to the set of durations.

Program specifications: Written in Fortran II. Methods: Successive approximations. Equipment details: IBM 1620 with 40 K memory. Input-output: Card input and printer output.

A-10 HEC: FREQUENCY STATISTICS, by Harold A. Keith and Denver L. Mills, Program No. 23-239, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, November 1966.

This program computes frequency statistics of annual peak flows and maximum or minimum flow volumes for several durations and extends these statistics from statistics of flows measured at a station having a longer record. Statistics for any number of volume durations up to six can be computed and extended in one run. The program also computes frequency statistics of annual maximum peak flows and extends these statistics by correlating peak flows and flow volumes (usually of one-day duration) measured at the same station and using the extended statistics computed for the flow volume.

Program specifications: Written in Fortran II. Methods: Based on Statistical Methods in Hydrology, by Leo R. Beard, January 1962. Equipment details: IBM 7090 class. Input-output: Card input and printer output.

A-11 HEC: MONTHLY STREAMFLOW SIMULATION, by Leo R. Beard and H.E. Kubik, Program No. 23-267, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, July 1967.

This program analyzes monthly stream flows at a number of interrelated stations to determine their statistical characteristics and generates a sequence of hypothetical stream flows of any desired length having those characteristics. It reconstitutes missing stream flows on the basis of concurrent flows observed at other locations and also uses the generalized simulation model for generating monthly stream flows at ungaged locations based on regional studies.

Program specifications: The program is dimensioned for a maximum of 10 stations and 100 years of monthly flows. Stations numbers should be 3 digits or less (can be 4 digits by changing input format) and generated values cannot exceed one million units. Methods: The mean, standard deviation, and skew coefficients of the logarithms are computed for each station and each month. Each flow is converted to a normalized standard deviate using an approximation of the Pearson Type III distribution. Missing and generated values are computed by a multiple regression equation which includes a random component whose influence is proportional to the unexplained error. The previous month is one of the independent variables, which serves to preserve the serial correlation.

Equipment details: This program requires a Fortran IV compiler and a fairly large computer. The program can be used on machines of the IBM 7094 class by reducing the number of stations. Input-output: Card input is tape 5 and printout is tape 6. Statistics and generated flows can be output on tape (tape 7), which in turn allows card output.

A-12 HEC: DAILY STREAMFLOW SIMULATION, by R.G. Willey, Program No. 24-235, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, April 1968.

This program analyzes historical daily stream flows at one station to determine their statistical characteristics and generates a sequence of hypothetical daily stream flows. The generated stream flows, which can be of any desired length and will have statistical characteristics similar to those of the historical daily stream flows, are based on given monthly flows. The sum of each month's generated daily flows is equal to the monthly flow previously generated by another program such as 23-C-L267. (See AP2)

Program specifications: The program is written in standard Fortran IV and is dimensioned for 300 years of synthetic data. Methods: The method is based on the second-order Markov chain using Beta coefficients for each month of the year to account for seasonal variations. The daily stream flow data are assumed to be log-normally distributed.

Equipment details: Required storage capacity is about 20,000 words (in the CDC 6600) and required library functions are the cosine and natural logarithm routines. Input-output: It is desirable, but not necessary, to use two input tapes and one output tape. An online printer is required. Card input is tape 5 and printer output is tape 6.

A-13 HEC: PARTIAL DURATION, INDEPENDENT EVENTS, Program No. 23-247, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, July 1966.

This program, written in Fortran II and IV, computes the data necessary to plot a partial duration curve depicting independent low flow events for a given period of monthly stream flows. Up to 20 durations can be specified in one computer run with partial duration plotting data being determined for each. Storage-yield relations can subsequently be determined from the output of this program.

A-14 HEC: REGIONAL FREQUENCY COMPUTATION, by Leo R. Beard and Harold E. Kubik, Program No. 23-268, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, July 1967.

The purpose of this program is to perform frequency computations of the annual maximum hydrologic events necessary to a regional frequency study. Frequency statistics are computed for recorded events at each station and for each duration. Missing events are computed so that complete sets of events are obtained for all years at all stations while preserving all intercorrelations.

Program specifications: The program is dimensioned for a maximum of 20 stations. The number of durations times the number of years cannot exceed 400, and the number of durations cannot exceed 8. Methods: The mean, standard deviation, and skew coefficients of the logarithms are computed for each station and each duration. An approximate Pearson Type III distribution is assumed. Missing events are computed by a regression equation which includes a random component whose influence is proportional to the unexplained error. The flows are then arranged in order of magnitude and tabulated with median plotting positions. Statistics are then adjusted regionally (regional skew may be specified) and frequency curves computed based on the expected-probability concept.

Equipment details: This program requires a Fortran IV compiler and a fairly large computer. The program can be used on machines of the IBM 7094 class by reducing the number of stations. Input-output: Card input is tape 5 and printout is tape 6.

A-15 SCS: LOG PEARSON TYPE III COMPUTER PROGRAM, U.S. Dept. of Agriculture, Soil Conservation Service, Midwest RTSC, Lincoln, Nebraska.

This computer program calculates the magnitude of annual maximum flood events based on fitting a log-Pearson Type III distribution to the observed annual maximum events.

A-16 St. Paul Dist., Corps of Engrs.: LOG-PEARSON FLOOD FREQUENCY ANALYSIS PROGRAM, St. Paul District, Corps of Engineers, St. Paul, Minnesota.

This is an unpublished computer program for the calculation of flood frequencies by the log-Pearson Type III method.

A-17 TVA: FACTOR ANALYSIS, Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

This program uses the multivariate statistical technique of factor analysis to reduce the dimensionality of a set of variables into a reduced set of orthogonal vectors that explain some preset precentage of the original variance.

A-18 USGS: LOG-PEARSON TYPE III DISTRIBUTION FLOOD FREQUENCY, Program No. 4014 from Computer Programs for Processing Water Data, Water Resources Division, U.S. Geological Survey, Washington, D.C., September 1968.

This program fits a Pearson Type III probability distribution to the logarithms of a set of sample observations on a variable. Based on the assumption that the sample is from a population conforming to a log-Pearson Type III distribution, the magnitudes of the variable are computed for selected probabilities of exceedance. A plot of variable magnitude versus exceedance probability can be obtained to compare visually the fit of the computed and observed values.

Input: Input is by punch cards prepared in a special format. Data sets may contain from 3 to 100 sample observations, and computations may be sequentially obtained on any number of data sets.

Output: Output consists of (1) a list of input data, (2) the mean, standard deviation, and coefficient of skewness in base 10 logarithms, (3) the standard error of the coefficient of skewness, and (4) the variable magnitude for 11 selected exceedance probabilities. The optional plot is formed by a line printer and has 3 inch log cycles along the ordinate and a normal probability scale covering 11 inches between exceedance probabilities of 0.995 and 0.005 along the abscissa.

A-19 BuRec:FLOOD FREQUENCY (CDC 6600) COMPUTER FLOOD FLOW FREQUENCIES USING THE LOG-PEARSON TYPE III FREQUENCY METHOD. File No. HY-183, Region 2, Computer: CDC 6600, Language: Fortran IV, Storage: 50,000 words (Dec.)

A-20 BuRec:FLOOD FREQUENCIES PLOT, File No. HY-191, Plot results of Flood Frequency Computations on Log-Probability Scales. Region 2; Language: Fortran IID, Storage: 35000 char. (Dec.), Computer: IBM 1620.

A-21 BuRec:129 DROUGHT ANALYSIS (CDC 6600) File No. HY-210. Performs drought analyses requiring many repetitive calculations, usually over one hundred thousand iterations. Region 2, Language: Fortran II D, Storage: 50,000 words (Dec.), Computer CDC 6600, Methods: Monte Carlo Analysis using random number generation.

A-22 BuRec:082 GRAPHICAL CORRELATION PLOT, File No. M-136, Performs graphical correlation between two variables and performs a double mass analysis in which the data are accumulater before plotting. Region 2, Language: Fortran II D, Storage: 8000 char. (Dec.), Computer: IBM 1620.

A-23 BuRec:088-MULTIPLE REGRESSION ANALYSIS, File No. M-137, Performs a multiple regression analysis for at most 20 variables, without the need for intermediate input and output. Region, Language: SPS, Storage: 40,000 Char. (Dec.), Computer: IBM 1620.

A-24 BuRec:090-MULTIPLE LINEAR CORRELATION, File No. M-138, Formulate a multiple regression analysis of up to 39 periods of record with a maximum of ten variable factors for each period. Analysis is then used in forecasting seasonal volume of runoff. Region 2, Language: SPS, Storage: 40,000 char. (Dec.), Computer: IBM 1620.

A-25 BuRec:091-POLYNOMIAL CURVE FITTING, File No. M-139. Program generates an approximating polynomial by the least squares technique and the derived polynomial is solved if specified by the user. The equation so derived contains as many terms as necessary to bring the standard error of the dependent variable within a specified range. Region, Language: Fortran IID, Storage: 22,000 char. (Dec.), Computer: IBM 1620, (Limitation: max. no. of observations in 150 and the polynomial to the 15th power).

A-26 BuRec:128 LOG-FLOW STATISTICS (CDC 6600), File No. M-140, Determines Mean, standard deviation and skew for log-normal frequency distributions. Region 2, Language: Fortran IID, Storage: 50,000 words I (Dec.), Computer CDC 6600.

Additional References

A-27 Beard, Leo R., Statistical Methods in Hydrology, Corps of Engineers, Hydrologic Engineering Center, Sacramento, California, January 1962.

A-28 Chow, Ven Te, "Statistical and Probability Analysis of Hydrologic Data," Section 8-I, Handbook of Applied Hydrology, McGraw-Hill, 1964.

A-29 A Uniform Technique for Determining Flood Flow Frequencies, Bulletin No. 15, Water Resources Council, Washington, D.C., December 1967.

B. RUNOFF ANALYSIS

B-1 Betson, Roger P.: ANALYTICALLY DERIVED UNIT GRAPH AND RUNOFF, Conference Preprint 564, ASCE National Meeting on Water Resources Engineering, New York, N.Y., October 16-20, 1967.

A technique has been programed to solve analytically for measures of precipitation excess and unit graph shape parameters. The procedure can be used to subdivide a watershed analytically and thus to resolve many of the conditions imposed upon the use of the conventional unit graph. With the optimization procedure being used, a high degree of adjustment to data can be achieved. Testing of the model on generated data capable of being fitted uniquely, however, indicates that parameter optimization is not being achieved. Inconsistent results are caused by high intercorrelations in the system and the approximations required to solve the nonlinear unit hydrograph function.

B-2 BuRec: FLOOD HYDROGRAPH BY UNITGRAPH PROCEDURE, by J.L. Woerner, File No. HY-131, p. 346, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Department of Interior, Bureau of Reclamation, February 1969.

The program will either derive a unitgraph from a dimensionless unitgraph or accept a unitgraph as input data, then apply the unitgraph to rainfall excess increments to derive a flood hydrograph.

The method of deriving a flood hydrograph from a unitgraph is discussed in Unitgraph Procedures, Hydrology Branch, Division of Project Planning, Denver, Colorado, November 1952.

Date: 10-1-64. Computer: HON 800. Language: Automath 1800. Storage req: 10,000 words (decimal). Unitgraph ordinates: 500.

B-3 BuRec: FLOOD HYDROGRAPH USING TRIANGULAR UNITGRAPH, by D.M. Hegarty, File No. HY-147, p. 362, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program can be used to determine a flood hydrograph from rainfall and basin data using the triangular unitgraph method. It is useful for canal cross-drainage solutions. Simple arithmetic operations are involved. Excesses are computed using initial loss and retention loss rate. The program is limited to 100 rainfall records.

Date: 1-2-66. Computer: HON 800. Language: Automath 1800. Storage req: 1513 words (decimal).

B-4 BuRec: FLOOD STUDY HYDROGRAPH COMPUTATION, by R. Buchanan and C. Schumate, File No. HY-136, p. 351, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program computes flood study hydrographs for a given location on a stream for feasibility and final design studies. It applies a unitgraph to excess precipitation to determine a hydrograph.

Date: 2-15-65. Computer: IBM 1620. Language: Fortran II. Storage req: 20,000 Characters (decimal).

B-5 BuRec: RAIN-ON-SNOW COMPUTATIONS, by D.M. Hegarty, File No. HY-148, p. 363, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

Rain-on-snow computations are performed according to the methods outlined in Engineering Monograph 35 using arithmetic operations.

Date: 1-4-66. Computer: HON 800. Language: Automath 1800. Storage req: 2707 words (decimal).

B-6 HEC: BASIN RAINFALL AND SNOWMELT, by Leo R. Beard, Program No. 23-266, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, July 1966.

This program is designed to compute basin input (rainfall plus snowmelt) values for a storm. It will (1) compute basin mean precipitation from station precipitation weighted in any designated proportion and, if desired, on the basis of normal seasonal precipitation; (2) determine, if desired, whether each period of precipitation is rain or snowfall in each of as many as ten 1000-foot elevation zones, subtracting snowfall from precipitation and adding to snowpack; and (3) determine, if desired, snowmelt during each period in each of as many as ten 1000-foot elevation zones, adding to basin input and subtracting from snowpack.

Program specifications: Written in Fortran II. Methods: Basin mean total precipitation is computed as a weighted average of station precipitation and is distributed in intervals in accordance with weighted patterns of recorder gages. Snowmelt is computed as a linear function of temperature. Equipment details: IBM 1620 with 40 K memory. Input-Output: Card input and output.

B-7 HEC. UNIT GRAPH AND HYDROGRAPH COMPUTATION, by Leo R. Beard, Program No. 23-228, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, July 1966.

This program will compute a unit graph, standard project rain amounts, probable maximum precipitation amounts, rain excess and flood runoff for any number of basins and for any number of storms for each basin.

Program specifications: Written in Fortran II. Methods: Criteria from EB 52-8 are used to compute standard project rain amounts and HMS 33 for probable maximum precipitation amounts. Equipment details: IBM 1620 with 40 K memory. Input-Output: Card input and output.

B-8 HEC: UNIT HYDROGRAPH AND LOSS RATE OPTIMIZATION, by Leo R. Beard, Program No. 23-211, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, August 1966.

This program will determine the best unit hydrograph and loss coefficients, within the limits of the mathematical model, to reproduce a number of flood hydrographs at a given location from specified rainfall amounts.

Program specifications: Written in Fortran II. Methods: Clark unit hydrograph technique is used to compute and Snyder unit hydrograph coefficients are derived. A highly flexible loss function based on rain intensity and accumulated loss is used. The gradient optimization method is employed. Equipment details: IBM 7090 class. Input-Output: Card input and printer output.

B-9 Jones, J.W. and Verma, B.P: A DIGITAL SIMULATION OF THE DYNAMIC SOIL MOISTURE STATUS, paper presented before ASAE meeting, Paper No. 70-234, Mississippi Agricultural Experiment Station Journal No. 1934, 1970.

A digital model of soil moisture status which includes rainfall, evaporation, and infiltration is developed to provide simulated soil moisture values under natural weather conditions for use in simulating a crop-production system.

B-10 Machmeier, R.E. and Larson, C.L., "Runoff Hydrographs for Mathematical Watershed Model," Journal of Hydraulics Division, ASCE, No. HY6, Paper No. 6248, November 1968, pp. 1453-1474.

Non-linear effects of supply rate and duration on the outflow hydrograph are investigated using a mathematical model of the channel drainage system of a basin. In a very interesting approach, a generalized geometry of sections is used and flow is routed by solution of the equations of continuity and momentum.

B-11 Maddaus, William O. and Eagleson, P.S.: A Distributed Linear Representation of Surface Runoff, Hydrodynamics Laboratory Report No. 115, Dept. of Civil Engineering, M.I.T., June 1969.

A distributed quasi-linear model of direct catchment runoff consisting of cascades of linear reservoirs connected by linear channels is developed. By fitting to the kinematic wave, the model parameters are expressed in terms of the physical characteristics of the catchment and the impulse-response function is constrained to be input-dependent.

Separate models of overland flow and streamflow are developed, facilitating consideration of spatially variable inputs. Investigation into the sensitivity of the catchment to distributed inputs shows that the kinematic wave method fails to provide realistic hydrograph dispersion when applied to the flood-routing problem.

B-12 Morgali, James R., Hydraulic Behavior of Small Drainage Basins, Technical Report No. 30, Civil Engineering Dept. Stanford University, October 1963.

This study presents a method for synthesizing overland and channel flow hydrographs for small drainage areas. A mathematical model is substituted for the actual flow situation. This model includes the continuity and momentum equations in finite difference form, boundary conditions, initial conditions, basin parameters, and flow parameters.

For the overland flow case, the parameters of slope, length, roughness, and rainfall excess are varied individually on a basin flow plane and a series of graphs showing the effect of the individual parameters is derived. The synthesized hydrographs compare quire favorably with experimental data. A single dimensionless hydrograph and a relationship defining the time to equilibrium in overland flow are presented.

The hydrograph from a natural drainage basin is synthesized using an overland flow hydrograph as the inflow into the channel system. The overland flow hydrograph is produced using a varied rainfall excess estimated from actual rainfall, an average length of overland flow for the basin, an average basin slope, and an average flow roughness (Manning n). Favorable results are obtained in comparisons on two small watersheds. The results of the synthesis for natural basins show that routing the overland flow hydrograph through the channel system has little effect on the outflow hydrograph.

B-13 Newton, D.W. and Vinyard, J.W., "Computer Determined Unit Hydrographs from Floods," Journal of Hydraulics Division, ASCE, No. HY5, September 1967. [See Ref. B-15.]

B-14 Pennsylvania Hwy Dept: SYNTHETIC HYDROGRAPH, 1967. FHWA 0010 Penn. BUR 5500/32K. Fortran.

B-15 TVA: COMPUTER PROGRAM FOR UNIT GRAPH DETERMINATIONS, Div. of Water Control Planning, Flood Control Branch, Flood Hydrology Section, Tennessee Valley Authority, Knoxville, Tennessee, September 1967.

A unit graph is computed from a single complex flood or a best-fit (composite) unit graph from several complex floods using matrix algebra to determine the best fit from statistical curve-fitting techniques. In addition, by an iterative fitting procedure, it will modify the given time distribution of precipitation excess, giving an improved estimate of the distribution. This program is described more completely in Ref. B-13.

B-16 TVA: FLOOD DISCHARGE (Q) PROGRAM, Div. of Water Control Planning, Flood Control Branch, Hydraulics Studies Section, Tennessee Valley Authority, Knoxville, Tennessee, 1967.

Natural and Regulated Flood Estimation (NARFE): This program estimates natural and regulated discharge hydrographs from watersheds

or at selected locations within a watershed. This is accomplished by dividing the total watershed into subwatershed units such that flows can be determined at each potential project and at each stream location at which project effects must be evaluated. Reservoir routings are carried out using standard procedures and any rule or relationship which can be expressed in terms of headwater elevation or storage. Channel routing is accomplished using the three-coefficients Muskingum method.

B-17 TVA: DIFCOR, Hydraulic Data Branch, Tennessee Valley Authority, Knoxville, Tennessee.

This program optimizes the parameters of nonlinear models using the method of differential corrections in conjunction with multivariate statistics.

B-18 TVA: PATSEAR, Hydraulic Data Branch, Tennessee Valley Authority, Knoxville, Tennessee.

The pattern search method is used for optimizing the parameters of a nonlinear model. The program has generally been found to work better than the DIFCOR approach. [B-17]

B-19 TVA: PROGRAM SOCH, SIMULATED OPEN CHANNEL HYDRAULICS, by James W. Vinyard and Inda M. Smith, 205 OPO-C, Ext. 2031, Flood Control Branch, Tennessee Valley Authority, Knoxville, Tennessee.

The program uses the basic differential equations of continuity and momentum which are solved by a centered finite-differences scheme. It computes the stage (elevation), discharge, and velocity at predetermined intervals of time and space throughout a reservoir or river channel.

The geometry of the stream or reservoir is described at fixed distance intervals (DX) by tables of flow area, (hydraulic radius)$^{2/3}$, and width, all versus elevation. The cross sections used to make up these tables are equidistant from each other and should represent fairly well the average cross section for a reach 2DX long. The program is limited to 91 tables describing the geometry of 91 cross sections. Each cross section is described in the table by a maximum of 21 entries of area, (hydraulic radius)$^{2/3}$, and width, all versus elevation. A maximum of three different elevation increments can be used in the 21 entry tables.

The program is written in Fortran IV and kept on a magnetic disk. It yields computed values, discharge, and velocity at DX intervals at each cross section described on tape 3.

The input data consist of the starting conditions at every cross section (elevation and discharge) and the local inflows, the roughness factor for each reach, and the description with time of the local inflows and boundary conditions. Each of these three sets (local upstream and downstream) has its own timing. The local inflows can be given as a table relating elevation and discharge (rating curve) or as a set of values of elevation or discharges related to time. The output data consist of a listing of the input edited for clarity and the computation results at intervals of time selected as multiples of DT and at mileages selected among the conditions used for tape 3.

The output can be obtained printed on regular 143 paper or saved on a 9-track magnetic tape (tape 8) to be plotted later with program ML 321-182. The tape 8 used must be specified on card 10 of JCL. Profiles of elevation, discharge, and velocity versus miles can also be plotted directly by the SOCH program at selected time intervals.

B-20 ARS: COMPUTER PROGRAM FOR THE REDUCTION AND PRELIMINARY ANALYSIS OF RUNOFF DATA, by D.A. Woolhiser and K.E. Saxton, U.S. Dept. of Agriculture, Agricultural Research Service, 41-109, October 1965.

This program is used to determine runoff discharge and statistics about the runoff from measured depth hydrographs at a gage given the rating curve for that site. Analysis can include effects of local ponding at gage site in determining the actual discharge hydrograph.

B-21 BuRec:120 and 120P FLOOD STUDY HYDROGRAPH, File No. HY-200, Computer and plots flood study hydrographs for a given location on a stream for feasibility and final design studies. Applies a unit graph to excess precipitation to determine a hydrograph (Limit 960 ordinates). Region 2, Language: Fortran II D, Storage: 40,000 char. (Dec.), Computer: IBM 1620.

B-22 BuRec:146 RESERVOIR INFLOW FORECASTING EQUATION, File No. HY-207. Program computes the dependent variable (Runoff) and the independent variable (snow-water content and precipitation) used to develop a multiple linear regression equation for forecasting reservoir inflow. Region 2, Language: Fortran II D, Storage: 39999 char. (Dec.), Computer IBM 1620, (Limitations: Program written for three variables, at four locations for up to 50 years data).

C. FLOW ROUTING

C-1 Amein, Michael and Fang, C.S., Streamflow Routing with Application to North Carolina Rivers, Report No. 17, Water Resources Research Institute, University of North Carolina, January 1969.

This paper gives the development and solution of the equations of unsteady flow. Three methods of solution are investigated: explicit, characteristics, and implicit. Solutions are obtained using prismatic and natural river cross sections.

C-2 USGS: COMPUTER SIMULATION OF UNSTEADY FLOWS IN RIVERS AND ESTUARIES, by Robert A. Baltzer and Chintu Lai, U.S. Geological Survey, Water Resources Division, Washington, D.C. Presented at ASCE Hydraulics Division conference, Madison, Wisconsin, August 1966.

This paper discusses the computation of unsteady flow by solving the equations of continuity and momentum. Three methods are considered: power series, method of characteristics, and implicit method.

C-3 ARS: STORAGE FLOOD ROUTING WITHOUT COEFFICIENTS, by D.L. Brakensiek, U.S. Dept. of Agriculture, Agricultural Research Service, ARS 41-122, June 1966.

This program implements kinematic routing by solving the continuity equation and a tabulated flow area versus discharge relationship. Several examples are given along with the program listing and the explanation of input data.

C-4 BuRec: COMPUTATION OF MANNING'S n, by J. Bergman and P.F. Enger, File No. H-115, p. 271, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

Manning's n is computed for circular conduits based on the average energy slope. The conduit may be partially full or under pressure. The average energy slope is determined by the least square fit of the total head at each station.

Date: 5-1-63. Computer: IBM 7090. Language: Fortran II. Storage req: 1000 words (decimal).

C-5 BuRec: RESERVOIR ROUTING BY MODIFIED PULS METHOD, by J.L. Woerner, File No. HY-130, p. 345, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program computes a storage-indicator curve from elevation-discharge-storage curves. An S-1 curve is used to route an inflow hydrograph through a reservoir or short reach of a stream. The procedure for reservoir routing is discussed in Ch. 6.10, "Flood

Hydrology," Vol. IV, Water Studies, Bureau of Reclamation manual. The inflow hydrograph is limited to 1000 ordinates.

Date: 10-1-64. Computer: HON 800. Language: Automath 1800. Storage req: 8000 words (decimal).

C-6 BuRec: WATER SURFACE PROFILES, by C.W. Corcoran, File No. HY-128A, p. 343, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

Water surface profiles, critical flow elevations, cross section characteristics, main channel roughness coefficients, starting elevation or discharge, and volumes between cross sections are determined. Method B in the guide is used for computing water surface profiles, sedimentation section report, PID, Reclamation.
The program is limited to 99 coordinates and eight overbank segments per station and to ten profiles per study.

Date: 5-5-64. Computer: HON 800. Language: Automath 1800. Storage req: 21,500 words (decimal).

C-7 BuRec: WATER SURFACE PROFILES BY STANDARD STEP METHOD, by D.L. King, File No. H-118, p. 274, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program combines previous programs for trapezoidal and circular channels and includes computations for transition sections. The standard trial step method of determining water surface profiles in open channels is used.

Date: 5-1-63. Computer: IBM 7090. Language: Fortran II. Storage req: 1000 words (decimal).

C-8 Dickson, R.H.: Generalized River Forecast Program - Manual of Operation, River Forecast Center, Kansas City, Missouri, revised, written May 1967.

The program is written for a CDC 3100-16K machine with 4 magnetic tape units, a card reader, and a line printer. It is written in Fortran as a single program containing no subroutines. The system for which it was written is user-controlled, utilizing many sense switches and cons-le commands, and in this respect the program is not suited to batch processing.

Data are stored on tape units. Apparently intermediate results are stored on tape. A large amount of carryover data for future forecasting runs is also stored on tape.

Input required by the program includes observed water surface elevation, estimated rainfall excess, and in some cases discharge rate. Also required are previous forecast carryover data, unitgraphs, rating curves, reservoir curves, routing coefficients, and other data. The output consists of the discharge and elevation of water surface at gaging stations or reservoirs. Predicted and observed flows are compared.

Apparently the program takes excess runoff, applies a unitgraph to get the runoff hydrograph, routes the flow through the reservoir or river reach, corrects (blends) predicted discharge with observed discharge and converts from discharge to stage. Three routing methods are mentioned: the K and L (Kohler and Linsley template) method, the Tatum layer method, and the Reservoir Routing (Goodrich) method. No references are given.

C-9 HEC: HYDROGRAPH COMBINING AND ROUTING, by Leo R. Beard, Program No. 23-232, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, August 1966.

This program will route hydrographs through river channels and reservoirs. For a river basin of any size or complexity, it will compute unregulated flows, local flows, or routed and combined hydrographs.

Program specifications: Written in Fortran II. Methods: Procedures for routing are described in EM 1110-2-1408, "Routing of Floods through River Channels," in ES-171 Technical Bulletin No. 22 (Multiple Storage) and in Handbook of Applied Hydrology, by Ven Te Chow. Equipment details: IBM 1620 with 40 K memory. Input-Output: Card input and output.

C-10 HEC: INTERIOR DRAINAGE FLOOD ROUTING, Program No. 23-279, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, April 1969.

This program is designed to route floods through interior drainage ponding areas to adjacent rivers. The program uses river discharge-elevation rating curve data and ponding area inflow from surface runoff, and can consider seepage through levees and pumping rates in performing the routing.

C-11 HEC: RESERVOIR YIELD, by Leo R. Beard, Program No. 23-245, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, August 1966.

This program performs a simulated operation study for a single reservoir with controls at the reservoir and one downstream control point. Operational considerations include water supply, power, water quantity, and water rights, with flood control and other storage restrictions at the reservoir, quantity and quality of inflow to the reservoir, evaporation, quantity and quality of local inflows downstream, channel and outlet capacities, and project requirements being taken into consideration. The operation interval can vary, but usually a month would be used. Translational and channel storage effects are ignored.

Program specifications: Written in Fortran II. Methods: Water quality routing assumes thorough mixing of the inflow and reservoir quantities and pure-water evaporation before releases are made. Power is computed as a function of average head, efficiency, outflow, and hydraulic losses. Equipment details: IBM 7090 class. Input-Output: Card input and printer output.

C-12 HEC: SPILLWAY RATING AND FLOOD ROUTING, by Bill S. Eichert, Program No. 22-210, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, October 1966.

The main purpose of this program is to compute a spillway rating curve for a concrete ogee spillway with vertical walls for an assumed design head, then make a flood routing of the spillway design flood to determine the maximum water surface. The rating can also be for a broad-crested weir and can include the discharge from a conduit or sluice. The routing can be for a gated or uncontrolled spillway.

Program specifications: Fortran II is used. Methods: Rating curves for spillway based on WES Hydraulic Design Criteria. Rating curves for conduits based on $Q = CA \sqrt{2gH/K}$. Reservoir routing for uncontrolled spillway by modified puls.. Reservoir routing for gated spillway by emergency release diagram discussed in EM 1110-2-3600.

Equipment details: IBM 1620 40 K version is available and requires two source decks. High-speed version requires a GE 225, 8 K or larger. Input-Output: Card input, card output for IBM 1620 version and on-line printer output for high-speed version.

Additional remarks: This program was developed from the Tulsa District Program 22-G1-G512 written in WIZ for the GE 225. Several additional features have been added since converting to Fortran II.

C-13 HEC: STREAMFLOW ROUTING OPTIMIZATION, by Leo R. Beard, Program No. 23-231, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, November 1966.

This program will solve by successive approximations for any number of cases and in turn for the optimum Muskingum routing coefficients, K and X, to reproduce observed outflow hydrographs for a number of floods.

Program specifications: Written in Fortran II. Methods: Gradient optimization method of successive approximations. Equipment details: IBM 1620 with 40 K memory. Input-Output: Card input and output.

Additional remarks: The program is not effective where local runoff is large in comparison to measured inflows or where one measured inflow is small in comparison to the outflow.

C-14 Isaacson, E., *et al.*: *Numerical Solution of Flood Prediction and River Regulation Problems*, Reports 2 and 3, Institute for Mathematics and mechanics, New York University, January 1954 and October 1956.

Report 3 is the last in a series concerning the basic theory of numerical analysis of flood wave problems in rivers and applications thereof prepared at the Institute of Mathematical Sciences of New York University under the sponsorship of the U.S. Army Corps of Engineers. The study investigated the use of high-speed computers to solve the basic differential equations for flow in open channels. Application of the results to severe floods of record on the Ohio River demonstrated very good agreement between a finite difference solution of the characteristic equations and the measured flood wave propagation through a 375-mile segment of the river.

C-15 Loucks, Daniel P.: COMPUTER MODELS FOR RESERVOIR REGULATION, Conference Preprint 534, ASCE National Meeting on Water Resources Engineering, New York, N.Y., October 16-20, 1967.

This paper describes computer and stochastic linear programing models developed to assist in defining alternative policies for regulating reservoirs with particular reference to the lake level and discharges for several of the Finger Lakes in New York State.

The models were programed for solution using the IBM 360 Mathematical Programing System. The program is included in an appendix.

C-16 Perkins, Frank E.: "Flood Plain Modeling," Water Resources Bulletin, Vol. 6, No. 3, May-June 1970, pp. 375-383.

This paper describes the application of kinematic wave theory to model overland flow and small-stream flow contributing to a river. River flood flow is modeled using the complete equations of continuity and momentum.

C-17 Rockwood, D.M.: "Columbia Basin Streamflow Routing by Computer," Journal of Waterways and Harbors Division, ASCE, Paper No. 1874, December 1958, pp. 1-15.

The IBM 650 is used for routing flows on the Columbia River. This paper covers one of the earliest applications of digital computers in hydrology. The formation and routing of hydrographs in the Columbia River Basin is described. The program is the predecessor of the SSARR models (see Refs. E-1 and E-19.)

C-18 TVA: OPEN CHANNEL TRANSIENT FLOW MATHEMATICAL MODEL, Flood Control Branch, Tennessee Valley Authority, Knoxville, Tennessee.

This model uses the basic differential equations of continuity and momentum which describe the unsteady, nonuniform behavior of open channel flow. The digital computer program provides the numerical solution to these equations. Engineering applications of this model are described in the following publications:

1. "Transient Flow Investigations for TVA's Browns Ferry Generating Station," by B.J. Buehler, J.T. Price, and J.M. Garrison, Proceedings, 7th Annual Sanitary and Water Resources Engineering Conference, Vanderbilt University, Nashville, Tenn., May 1968.

2. "Unsteady Flow Simulation in Rivers and Reservoirs," by J.M. Garrison, J.P. Granju, and J.T. Price, Journal of Hydraulics Division, ASCE, September 1969.

3. "Digital Computer Simulation of Transient Flows in the TVA System," by B.J. Buehler, J.H. Garrison, J.P. Granju, and J.T. Price, Proceedings, 13th Congress IAHR, Kyoto, Japan, August-Sept. 1969.

C-19 TVA: RESERVOIR ROUTING, Flood Control Branch, Tennessee Valley Authority, Knoxville, Tennessee.

This program makes all computations required to route floods through a reservoir using flat-pool storage and fixed outlets. The program has a plot option.

C-20 TVA: ROUGHNESS COEFFICIENTS (N) PROGRAM, Flood Control Branch, Tennessee Valley Authority, Knoxville, Tennessee, 1967.

This program, written in Fortran IV, is designed to compute the necessary roughness coefficients to be used in Manning's formula for open-channel flow.

C-21 Yevjevich, V. and Barnes, A.H.: FLOOD ROUTING THROUGH STORM DRAINS: Part 1 - Solution of Problems of Unsteady Free Surface Flow in Storm Drains, Hydrology Paper 43, Colorado State University, November 1970.

The first part of the series presents results of experimental studies in a 3 ft diameter, 822 ft long storm conduit and theoretical studies of the unsteady free-surface flow. The derivation of the two quasi-linear hyperbolic partial differential equations of gradually varied free-surface unsteady flow based on the principles of conservation of mass and momentum are given. The numerical integrations of differential equations by the specified interval scheme of the method of characteristics, the diffusing scheme, and the Lax-Wendroff scheme are discussed.

____________, Part II - Physical Facilities and Experiments, Hydrology Paper 44, Colorado State University, November 1970.

This second part relates exclusively to experimental research facilities and experiments. A large conduit, 3 ft in diameter and 822 ft long, was selected, designed, and contructed in the outdoor laboratory at Colorado State University's Engineering Research Center to accurately measure geometric and hydraulic characteristics as well as the propagation of flood hydrographs.

____________, Part III - Evaluation of Geometric and Hydraulic Parameters, Hydrology Paper 45, Colorado State University, November 1970.

The third part primarily presents results on the investigation (experimental and analytical) of the geometric and hydraulic parameters of the experimental conduit; these parameters in turn define the coefficients in the two quasi-linear hyperbolic partial differential equations of gradually varied free-surface unsteady flow.

__________, Part IV - Numerical Computer Methods of Solution, Hydrology Paper 46, Colorado State University, November 1970.

The fourth part presents computer-oriented numerical methods for solving the two quasi-linear hyperbolic partial differential equations known as the De Saint-Venant equations of gradually varied free-surface unsteady flow. Flow charts, computer programs, variable conversion tables, and sample inputs and outputs for the three numerical computer schemes, the diffusing scheme, the Lax-Wendroff scheme, and the specified intervals scheme of the method of characteristics used in the solution of the De Saint-Venant equations are given in appendices. Additional information from the authors' abstracts is included also.

The above series of reports summarizes the results of a ten-year study (1960-1970) of unsteady free-surface flow in storm drains sponsored by the U.S. Bureau of Public Roads, Federal Hyghway Administration, and the Public Health Service.

D. STEADY FLOW WATER SURFACE PROFILES

D-1 BuRec: WATER SURFACE PROFILES, by J.L. McCoy, File No. H-123, p. 280, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

The program computes water surface elevations and other pertinent information for successive stations of a river using a modification of USBR method B. The method is from Guide for Computing Water Surface Profiles, Sediment Section report, Hydrology Branch, Division of Project Investigations, USBR, Denver, Colorado, November 1957. The program has two phases.

Date: 8-24-61. Computer: CDC G-15. Storage req: 3800 words (decimal).

D-2 BuRec: WATER SURFACE PROFILE, by R.L. Buchanan, File No. HY-128, p. 342, Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, U.S. Dept. of Interior, Bureau of Reclamation, February 1969.

This program computes backwater surface profile, top width, surface area, and total volume for symmetrical prismatic channels with water depths greater than critical. Hydraulic elements are computed using Manning's formula and water surface elevation at successive upstream sections is computed according to Bernoulli's theorem.

Date: 7-15-64. Computer: IBM 1620. Language: Fortran II. Storage req: 40,000 characters (decimal).

D-3 Eichert, Bill S., "Survey of Programs for Water-Surface Profiles," Journal of Hydraulics Division, ASCE, Vol. 96, No. HY2, February 1970.

This paper discusses and compares six computer programs from various state and federal agencies for computation of water surface profiles. The various routines are compared with respect to specifying cross-section geometry and roughness, flexibility of changing discharge, bridge computations, and other salient features.

D-4 HEC: WATER SURFACE PROFILES, by Bill S. Eichert, Program No. 22-232, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, December 1968.

The program computes and plots the water surface profile for river channels of any cross section for flow profiles greater or less than critical depth. The effects of various hydraulic structures such as bridges, culverts, weirs, embankments, and dams can be considered in the computation. River conditions such as variable channel roughness, islands, bends, levee overflow, river confluences, and waterfalls can also be included. Investigating channel roughness from known high water marks is one of several special program applications. Input can be in either English or Metric units.

Program Specifications: Fortran II instructions are used except for tape units which are Fortran IV. Methods: Step method generally like Method 1, U.S. Army Corps of Engineers Engineering Manual EM 1110-2-1409, December 1959, Backwater Curves in River Channels. Critical depth is based on minimum energy.

Equipment details: The program was written for use in the CDC 6600 computer, but may be used with minor modifications on other high-speed computers having three or more magnetic tapes plus input and output units such as the IBM 360, IBM 7094, or GE 625. Various versions of the original program 22-J-L212 can be used on smaller computers such as the IBM 1620, GE 225, and IBM 1130. Memory requirements are approximately 32 K words on CDC 6600. Input-Output: Input by cards, tabular data and plotted profiles produced on printer. Plotted cross sections are listed on tape 7.

Additional remarks: This program replaces the high-speed version of Program 22-J2-L212. The input requirements are different and many new options are available in this program. A data conversion program (22-J2-L233) is available to convert old data to the new format.

D-5 HEC: CHANNEL IMPROVEMENT SECTIONS, by Bill S. Eichert, Program No. 23-234, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, November 1966.

The primary purpose of this program is to punch out new data cards from the natural cross section cards for the backwater program 22-J2-L212, which will describe the cross section resulting from a trapezoidal excavation.

Program specifications: Written in Fortran II. Methods: None. Equipment details: IBM 1620, 40 K digits storage. Input-Output: Card input and output.

Additional remarks: This program was developed from the Tulsa District Program 23-G1-G521, written in WIZ for the GE 225.

D-6 HEC: BACKWATER, ANY CROSS SECTION, by Bill S. Eichert, Program No. 22-212, Hydrologic Engineering Center, Corps of Engineers, Sacramento, California, June 1967.

Water surface profile resulting from backwater or fowline (supercritical) computations for a given discharge is computed. The program will start by using the slope area method, a known water surface elevation, or at critical depth. Critical depth is computed for each section if desired. Profiles through bridges are made for the following flow conditions: low-flow classes A, B, and C (supercritical), pressure flow, weir and pressure and weir and low-flow (class A). Cross section and profiles can be plotted if desired.

Program specifications: Written in PDQ Fortran II. Methods: The method is generally like Method 1, U.S. Army Corps of Engineers Engineering Manual EM 1110-2-1409, 7 December 1959, Backwater Curves in River Channels. Bridge losses based on energy and momentum principles and on weir and orifice formulas. Critical depth is based on minimum energy.

Equipment details: High-speed version has been executed on CDC 6600, 3300, IBM 7040, 7090, 7094, and 360. Versions are also available for IBM 1620, IBM 1130, and GE 225. Input-Output: Input by cards only; output by printer and on tape (high-speed version only).

D-7 Larson, Steven P.: THE COMPUTATION OF WATER SURFACE PROFILES IN NATURAL CHANNELS, Computer Program No. 3, St. Anthony Falls Hydraulic Laboratory, June 1971 (in preparation).

This program uses the "standard step" method to compute water surface profiles for subcritical flow in natural channels. The user can specify the number of subsections into which the cross section will be divided. Computation normally proceeds upstream from a known starting elevation. If necessary, the program will compute normal depth at a specified location as a starting elevation. Through an iteration process it also computes the water surface elevation of minimum energy, which is assumed to be at critical depth. The program requires $14{,}000_8$ storage locations.

D-8 New Jersey Hwy Dept: BACKWATER CURVE, FHWA 1520 NJ, IBM 1620 - 60 K, Fortran, 1966.

This program computes the water surface profile in an open channel.

D-9 Pennsylvania Hwy Dept: HYDRAULIC DESIGN - BRIDGE WATERWAY OPENINGS, INCLUDING BACKWATER CURVE, FHWA 0030 Penn, BUR 5500 - 32 K, Fortran, 1968.

D-10 Pennsylvania Hwy Dept: BACKWATER CURVE, FHWA 0020 Penn, BUR 5500 - 32 K, Fortran, 1967.

D-11 Shanholtz, V.O. and Holtan, H.M.: WATER SURFACE PROFILES FOR SPATIALLY VARIED FLOW IN NATURAL CHANNELS, Computer Program USHL No. 2, U.S. Hydrograph Laboratory, Beltsville, Maryland, June 1964.

The authors reviewed a number of existing hydraulic and hydrologic programs for IBM 1620 digital computers to see if any of them might be adapted to the watershed project formulation needs of the Soil Conservation Service and the hydrologic research needs in ARS watersheds. A program developed by the U.S. Army Corps of Engineers for computing water surface profiles by the step method, BACKWATER COMPUTATION FOR NATURAL CHANNELS WITH OVERBANK FLOW AND BRIDGE LOSS, by Ronald E. Becker, Program File Reference No. 22-J2-J203, U.S. Army Engineer District, Sacramento, California, August 1963, was selected and modified to vary flow spatially.

Spatial variations in flow and drastic differences in cross sections of the upland watershed streams used for trial runs caused the computed profiles to undulate unrealistically. A review of results indicated that undulations were greatest in reaches having steep slopes. As a result, the program was further modified to interpolate hydraulic elements for theoretical cross sections at predetermined vertical intervals. Spatial variation of flow was also graduated by interpolating flow between cross sections in the ratio of the accumulative interval to the total interval of elevation. By these means the water surface profiles were stabilized in close conformity with profiles computed by more sophisticated techniques such as are shown in Computation of Water Surface Profiles and Related Parameters by the IBM 650 Computer, by Paul D. Doubt, et al., Eng. Div. Tech. Release No. 14, Design Section, SCS, USDA, March 1, 1962.

This program is adapted for a 1620 computer, 40 K storage capacity with a card reader, a card punch, and an IBM 407 tabulating machine with an 80-80 control panel for listing punched output. This program is written in Fortran II.

The analytical procedure is basically an iterative solution of Bernoulli's energy theorem. Solutions are obtained to the nearest 0.1 ft. Friction losses are obtained from Manning's formula. Bridge losses, bend losses, and contraction-expansion losses are determined by the entry of coefficients at the appropriate cross sections.

Output from the program is a listing of water surface profile elevations for each csm assumed.

D-12 Shearman, J.O. and Dougal, M.D.: A COMPUTER PROGRAM FOR COMPUTING WATER SURFACE PROFILES, WSPPI, Center for Industrial Research and Service (CIRAS), Iowa State University, in cooperation with the Iowa Natural Resources Council, State House, Des Moines, Iowa, 1965.

This program, which has been developed to compute water surface profiles in natural channels, provides computer storage for the following:

1. 100 ground points in one valley cross section.
2. 25 subsections in any one cross section.
3. 50 elevations for determining the hydraulic characteristics at a cross section.
4. 99 cross sections in a specific reach under study.

The program was developed for cross sections aligned normal to the main channel or thread of the valley and uses the main channel length as the distance between sections. Skewed cross sections must be adjusted to a normal projection before the data are introduced into the program. Variations in distance between successive overbank sections compared to the main channel length can be adjusted hydraulically by varying the roughness values. These refinements may be added in future revisions of this program.

Additional reaches of a valley can be included in a study by using the results of the first reach as computer input for the second reach. For convenience, cross section data are placed on separate output to permit checking and reevaluation. The water surface profile computations are completed in a second operation for any particular reach of a river or for any particular discharge. At the conclusion of computer operation, all pertinent data are printed out in a summary. Intermediate results at each cross section are also printed out.

D-13 Shearman, J.O. and Dougal, M.D.: A COMPUTER PROGRAM FOR DETERMINING WATER SURFACE PROFILES IN FLOOD PLAIN ENCROACHMENT STUDIES, prepared for 16th Annual Conference of Hydraulics Division, ASCE, Cambridge, Massachusetts, August 21-23, 1968.

Authors' Summary and Conclusions: "A system of computer programs for the solution of water surface profiles has been discussed. This system is oriented towards flood plain encroachment studies but is equally applicable to most other water surface profile studies.

"The hydraulic methodology utilized is somewhat unique. The entire solution is based on the energy equations. Many simplifying assumptions have been made. However, use of these programs to data has indicated that this methodology can yield satisfactory results.

"The bridge backwater concepts adopted in this program are designed to be applicable to all bridges. In many instances this requires much personal judgment on the part of the user. However, one of the major shortcomings of the 'one-step' bridge backwater solutions which are available is the existence of bridges that are impossible to define for the 'one-step' solution.

"An ideal computer program for water surface profiles might include several of the methods which have been developed for the solution of bridge backwater. This would enable an engineer to evaluate a particular bridge using a specified method or various methods for comparative analysis."

D-14 TVA: NEW BACKWATER PROGRAM, Flood Control Branch, Tennessee Valley Authority, Knoxville, Tennessee, 1967.

This program, prepared by Rose Ann Hatcher, TVA Water Control Planning Division, Flood Control Branch, uses Fortran IV to compute the water surface profile for a given flow distribution.

D-15 TVA: SUBCRITICAL WATER SURFACE PROFILES, Flood Control Branch, Tennessee Valley Authority, Knoxville, Tennessee.

This program computes, using the step method, the water surface profile at selected locations along a stream based upon the Manning formula. A variation of the basic program will compute the discharge from known flow profiles and known or assumed friction coefficients. Also, friction factors can be computed from a known profile and discharges. (Bob Buehler)

D-16 Texas Hwy Dept: CALCULATES WATER SURFACE PROFILE THROUGH A BROKEN BACK CULVERT, FHWA 1040 Tex, IBM 360/50, FTN, 1969.

D-17 Texas Hwy Dept: COMPUTES STAGE DISCHARGE RELATIONSHIPS IN STREAM CHANNELS, FHWA 1010 Tex, IBM 360/50, FTN, 1969.

D-18 Virginia Hwy Dept: FLOW PROFILE COMPUTATIONS (DIRECT STEP), FHWA 1300 VA, IBM 360/40, Fortran IV, 1969.

This program, given increments in depth plus various constants for the channel, computes channel velocity, distances between the given depths, and a summation of these distances.

D-19 Virginia Hwy Dept: FLOW PROVILE COMPUTATIONS (STANDARD STEP), FHWA 1310 VA, IBM 360/40, Fortran IV, 1969.

Using cross sections data, discharges, and other controls, this program computes water surface profiles along natural stream channels.

D-20 Burec:WATER SURFACE PROFILE (072), File No. HY-178, Computer backwater surface-profile, top width, surface area and total volume for sub-critical flow in symmetrical prismatic channels. Region R-2, Computer IBM 1620, Language: Fortran II D, Storage: 40,000 char. (Dec.).

D-21 BuRec:133 WATER SURFACE PROFILE COMPUTATION (CDC 6600), File No. HY-204, Computes water surface profile of natural streams by utilizing Bernoullis' Theorem to obtain a balance of energy within successive stream reaches. Ref. USBR Guide for Computing Water Surface Profiles. Region 2, Language: Fortran IV, Storage: 200,000 words (Dec.), Computer: CDC 6600.

E. COMPREHENSIVE BASIN RUNOFF ANALYSIS

E-1 Anderson, James A.: Runoff Evaluation and Streamflow Simulation by Computer. U.S. Army Engineer Division, North Pacific, Portland, Oregon, December 1969.

In depth discussion of methodology of SSARR model. Example application of SSARR model to lower Mekong River as U.S. contribution to the International Hydrologic Decade. Also, there is an example application of SSARR to Willemette Basin Snow Laboratory data.

The SSARR model is a large comprehensive watershed simulation program of about 8000 statements. (See E-5, E-16, E-19, and section III-V)

E-2 Bugliarello, G.; Gormley, J.T.: and McNally, W.: An Informal Progress Report on Hydrol - A Content-Oriented Computer Language for Hydrology and Hydraulic Engineering. Carnegie Institute of Technology, Department of Civil Engineering, Pittsburgh, Pennsylvania, November 1963. (See E-3).

E-3 Bugliarello, G.; McNally, W.D.; Gormley, J.T.; and Onstott, J.T.: A Pilot Problem-Oriented Computer Language for Hydrology and Hydraulic Engineering ("HYDRO"). Carnegie Institute of Technology, Pittsburgh, Pennsylvania. Paper presented at the 47th AGU Meeting, Washington, D.C., April 1966.

The philosophy, specification and operational characteristics of a problem-oriented computer language, HYDRO, for performing hydrological and hydraulic engineering analyses are presented, as the result of a four year study. The present version of HYDRO is intended as a pilot for further development of the concept of problem-oriented languages in the field of water resources. It encompasses the areas of precipitation analysis, hydrograph analysis, open channel hydraulics, flood routing, and frequency analysis.

Reference is made to other problem oriented languages such as the M.I.T. Integrated Civil Engineering System (ICES) which is an assembly of

(1) different sublanguages for suveying (COGO),
(2) structural frame analyses (STRESS),
(3) soil stability analyses (SEPOC),
(4) etc.

HYDRO was initially written in ALGOL, and later rewritten (in part) by Delleur and others at Purdue as FORTRAN-HYDRO (Ref. E-8). Present (August 1966) HYDRO routines are included in the section on selected programs. (III-P, III-Q)

E-4 Claborn, B.J., and Moore, Walter L.: Numerical Simulation of Watershed Hydrology. By the Hydraulic Engineering Laboratory, Department of Civil Engineering, University of Texas at Austin. Submitted to the

Office of Water Resources Research, Department of the Interior, August 1970, Technical Report HYD 14-7001.

A detailed discussion is given of the methodology of the Stanford Watershed Model based on the Stanford Model. A new model written in FORTRAN was developed incorporating changes to input data and addition of new parameters describing infiltration, evaporation, and soil water movement. Examples are shown of application to two experimental watersheds; one in S.W. Illinois and the other in central Texas. A program listing is included.

E-5 Crawford, Norman H., and Linsley, Ray K.: Digital Simulation in Hydrology: Stanford Watershed Model IV. Technical Report No. 39, Department of Civil Engineering, Stanford University, July 1966.

This report describes the methodology of the Stanford Watershed Model. This model has evolved as one of the pioneering efforts of general watershed simulation. Many of the procedures used in other simulation models were first implemented in versions of the Standford Model.

The model simulates a watershed by representing mathematically each of the significant processes that effect runoff in a natural basin. Several storage reservoirs are used to represent the retention of water in the basin by interception, surface storage, soil moisture storage, and groundwater storage. The outflow from the basin then becomes a function of the rainfall, the current storage in each of the reservoirs and the routing characteristics of the basin.

The model requires many empirical coefficients that govern the transfer of water from reservoir to reservoir and routing in streams. These coefficients are best determined by fitting the model to several years of observed hydrometeorological data.

E-6 Dawdy, D.: Considerations Involved in Evaluating Mathematical Modeling of Urban Hydrologic Systems. U.S. Geological Survey, no date shown.

A general discussion is given of the mathematical modeling of watersheds, including interplay between objective function and simulation results, sensitivity analysis, mathematical tools, error analysis and effect of network density.

E-7 Dawdy, D.R., and O'Donnell, T.: Mathematical Models of Catchment Behavior. A contribution to the ASCE Hydraulic Division Conference, Vicksburg, Mississippi, August 18-21, 1964.

The authors discuss the trends in the modeling of hydrologi systems, recent studies, and the feasibility of automatic evaluation of catchment model parameters.

E-8 Delleur, J.W.: Fortran-Hydro User Manual. Department of Civil Engineering, Purdue University, no date shown.

This user manual describes the procedure used to solve problems in hydrology, hydraulics, water supply and pollution control by use of FORTRAN-HYDRO. FORTRAN-HYDRO is a library of prepared subroutines to perform various functions or tasks. The user, presently students at Purdue University, needs only an elementary knowledge of FORTRAN programming to utilize these subroutines. This level of programming ability could normally be attained with 4-6 hours of formal instruction and about one week of computer lab practice. (See section Q).

E-9 HEC: FLOOD HYDROGRAPH PACKAGE, by Leo R. Beard. Program No. 23-270, Hydrologic Engineering Center, Corps of Engineers, December 1968.

All ordinary flood hydrograph computations associated with a single recorded or hypothetical storm can be accomplished with this package. Routines include rainfall-snowfall-snowpack-snowmelt determinations, computations of basin precipitation, unit hydrographs, and of hydrographs, routing by reservoir, storage-lag, multiple-storage, straddle stagger, Tatum and Muskingum methods, and complete stream system hydrograph combining and routing. Best-fit unit hydrograph, loss-rate, snowmelt, base freezing temperatures and routing coefficients can be derived automatically. Automatic plot routines are also provided. (See Sec. A)

Methods: Unit hydrograph derivation is done by the instantaneous unit hydrograph method and Snyder coefficients are obtained. Snowmelt determinations are made by either the degreeday method or the energy budget method. Loss rates are computed using either an initial and uniform loss rate function or by a variable loss rate function. Derivation of unit hydrograph and loss rate coefficients or routing coefficients is accomplished by means of an optimization subroutine utilizing the Univariate Method. Program Specifications: Written in FORTRAN IV. Equipment Details: Program utilizes about 32,000 words of core. Input-Output: Card input and printer output. A-ditional Remarks: This program is a combination of a number of smaller programs for more efficient use, maximum flexibility and ease of operational control. Also, some routines have been developed which were not available in any of the other programs. Programs combined in this program are 23-J2-L211, 23-J2-L226, 23-J2-L228, 23-J3-L231, 23-J2-L232, and 23-J2-L237.

E-10 Holtan, H.M., and Lopez, N.C.: USDAHL-70 Model of Watershed Hydrology, Final Draft Copy, Agricultural Research Service, U.S. Dept. of Agriculture, no date shown.

Authors abstract: "The mathematical model of water hydrology under study in the USDA Hydrograph Laboratory is designed to serve the purposes of agricultural watershed engineering. We are not trying at this stage to refine the techniques used, because our primary emphasis now is on weparating out the details of what actually happens during the runoff process as a basis for planning the engineering structures and procedures that will control the times, routes, and amounts of water flow. In brief, we are trying to reduce the entire system of watershed hydrology to a predictable pattern of physical probabilities that will account for the dispersion of water and its subsequent concentration in channel systems."

The model is programmed in FORTRAN, and was written with two major objectives - clarity and versatility. It was developed on an IBM 360-30 computer in Level E FORTRAN, and can be obtained from the USDA Hydrograph Laboratory. (See also: Glymph, Louis M.; Holtan, H.M.; and England, Charles B: "Hydrologic Response of Watersheds to Land Use Management," Journal of Irrigation and Drainage Division, ASCE, Paper 8174, IR 2, June 1971.)

E-11 Huggins, L.F., and Monke, E.J.: The Mathematical Simulation of the Hydrology of Small Watersheds. Purdue University, Water Resources Research Center, Technical Report No. 1, August 1966.

Author's Summary: "The rapid development of large, high speed electronic computers has made feasible the development of mathematical models which integrate the relationships for the various hydrologic components of the runoff process at all points in the watershed to obtain the runoff hydrograph for the complete area. Such a model is proposed herein. Basically, the procedure consists of the development of relationships describing the runoff dynamics for very small elemental areas or points within the watershed. Quantitative relationships are suggested for five of the basic hydrologic components which describe the runoff processes: interception, infiltration, depression storage or surface retention, surface detention and surface runoff. A general purpose digital computer program, written in FORTRAN IV, is developed to evaluate the resulting mathematical watershed model.

The ability of the proposed watershed model to simulate observed runoff hydrographs from small (two acre) watersheds was investigated for several storm events. In general, with appropriate component relationships, the model is capable of simulating complex storm events very satisfactorily. A comparison between the runoff hydrograph predicted for each storm event by the synthetic hydrograph analysis and the proposed model was made.

The sensitivity of the predicted hydrographs of selected storm events to changes in the values of the assumed initial parameters is reported. Such results can be very useful as a guide in determining the critical components of the model which need further study." (See also: Huggins, L.F., and Monke, E.J., "Mathematical Simulation of Hydrologic Events of Ungaged Watersheds," Technical Report No. 14, Purdue University, Water Resources Research Center, March 1970).

E-12 LeFeuvre, Albert R., and Pogge, Ernest C.: A Dynamic Simulation of the Lower Kansas River Drainage System. Dept. of Civil Engr., U. of Kansas.

A digital computer was used to simulate the dynamic response of the Lower Kansas River Drainage System to unsteady hydrologic inputs. The model accounts for local inflow as well as upstream conditions. Boundary conditions for the model were the average daily flow hydrographs observed at 20 tributary stream gages.

The system hydrology thus simulated was incorporated into a Water Quality Model which simulated the distribution of both conservative and non-conservative pollutants throughout the drainage system. This paper discusses only the flow simulation.

The model was verified by comparing machine generated hydrographs for five mainstream gages with the corresponding observed hydrographs. Sic different time periods of approximately 40 days each are presented as verification of the model.

E-13 Lichty, R.W.; Dawdy, D.R.; and Bergmann, J.M.: "Rainfall-Runoff Model for Small Basin Flood Hydrograph Simulation," IASH Publication No. 80, The Use of Analog and Digital Computers in Hydrology, Vol. II, December 1968.

Abstract: A simplified, mathematical model of the surface-runoff component of streamflow response to storm rainfall was developed and programmed for digital-computer solution. The model uses an infiltration component based on an equation by Philip to determine rainfall excess, which is transformed by a linear basin-response function to simulate the flood hydrograph. An objective-fitting procedure that emphasizes the simulation of peak-discharge rate was used to identify optimum model parameters in a pilot study of a 5-square-mile drainage basin in North Carolina. Split-sample fitting and testing showed that predictive capability varied for three samples of flood events. Results of simulation for two test samples of pre-1948 flood events showed reasonable correspondence between simulated and observed flood peaks. The post-1948 test sample showed wide scatter between simulated and observed flood peaks. Sensitivity analysis of objective-function response to parameter incrementation showed that antecedent moisture accounting grossly controlled the results of optimization.

E-14 Ligon, J.T.; Law, A.G.; and Higgins, D.H.: The Stanford Model Applied to Piedmont Watersheds. Paper No. 70-730, presented before the 1970 Winter Meeting of the ASAE, Sherman House, Chicago, Illinois, December 8-11, 1970.

The Stanford Watershed Model as translated into FORTRAN by James, was applied to two watersheds in the South Carolina Piedmont with areas of 0.877 sq. mile and 44 sq. miles. The influence of the more important simulation parameters is discussed along with procedures for their determination. Annual and monthly streamflows were predicted quite well. Storm peak flow prediction was less satisfactory.

E-15 Prasad, Ramanand: "A Nonlinear Hydrologic System Response Model," from the Journal of the Hydraulics Division, ASCE, HY 4, Paper No. 5350, pp. 201-221, July 1967.

This is a paper based on the author's Ph.D. thesis at the University of Illinois. It is based on a conceptual non-linear storage reservoir with outlet control modified so as to include dynamic effects. This results in a second-order, non-linear, differential equation. The author suggests a solution based on an analog model as well as by numerical techniques.

E-16 Rockwood, Lt. Col. David M.: River Control by Computer. Reprint from the January-February 1970 issue of THE MILITARY ENGINEER.

"The computer program developed to produce the required stream-flow simulations for planning, design, and operational hydrologic studies is called the 'SSARR' model, as an abbreviation of Stream-flow Syntheses and Reservoir Regulation. This model is a general-purpose digital computer program, which has been revised twice since its original design in 1957, for use on the IBM 650 computer. The scope, techniques, and utility of the program for efficient use of present high-speed computers have increased manyfold since the model was originated.

The basic idea of the SSARR model is to create a mathematical hydrologic model of a river and reservoir system, whereby stream flows may be synthesized by evaluating the entire hydrologic process of snow-melt and rainfall-runoff for all significant points throughout the system. Drainage basins may be separated into homogeneous hydrologic units of a size and character which can be used as a logical delineation of a major drainage into its component subdrainages. Channel storage can be specified for channel reaches to represent the natural delay to runoff encountered in river systems."

E-17 Roos, Daniel: Ices System Design. M.I.T., Department of Civil Engineering, 1966.

This includes a discussion of basic design of Integrated Civil Engineering System (ICES) for solution of engineering problems. This programming language simplified the preparation of coding so that an engineer may more easily make use of the capabilities of large digital computers with little programming knowledge.

E-18 Schermerhorn, Vail, and Kuehl, D.W.: Application of the SSARR Model to a Basin Without Discharge Record. Prepared for presentation at the ASCE Specialty Conference, Minneapolis, Minnesota, August 19-21, 1970.

The discussion talks about the general concepts of SSARR Model with application to an area with limited discharge stations. (See E-1, E-19).

E-19 Schermerhorn, V.P., And Huehl, D.W.: "Operational Streamflow Forecasting With the SSARR Model." Extract of The Use of Analog and Digital Computers in Hydrology, Symposium of Tucson, December 1968, 12 pages.

Discussion is given of methodology of SSARR model with example application to McKenzie River, Oregon, for operational forecasting purposes.

"The SSARR model is a very general and flexible model designed originally to perform streamflow syntheses for planning study-type functions and the daily operational forecasting. For all of these functions the model in conjunction with the computer program must be able to reconstruct the historical streamflow events from hydro-climatic data with acceptable accuracy. However, in addition, the system must have the flexibility and provisions to solve the problems introduced by the considerations discussed above.

The application of the SSARR model and associated programs to historical data and planning type operations has been described by Lewis, Rockwood, and Nelson. Discussion and demonstration of the provisions which made the model usable for basin simulation in a forecast situation will follow a brief review of the makeup of the basin synthesis portion of the model.

The present SSARR model and associated computer programs is a third generation of the basic model designed in 1957 by Rockwood [C-17] and executed on the IBM model 650 computer. The second generation was adapted to the IBM model 1920 and was in use by the Cooperative Columbia River Forecast Unit[1] from 1962 through 1967.

In each revision the improvements which were evident from using the model were incorporated together with additional refinements which became possible because of the additional capability of the newer computing hardware. The latest major redesign as well as the subsequent refinements is a cooperative effort of the Corps of Engineers, North Pacific Division and River Forecast Center, ESSA Weather Bureau.

The current reprogramming was part of the Corps of Engineers cooperation with the Mekong Committee in connection with the training in system analysis [E-5]. Besides adding several powerful refinements to the basin rainfall-runoff, and channel backwater simulation, the program was reorganized to increase its flexibility in handling larger quantities of input data. Since the first application in early 1967, the model and the program have undergone continuous evolution. Because the model and the associated program were developed by the systems analysis approach, there is provision for maximum flexibility and ease in modification.

1. This unit was formed in 1962 by formal agreement between the Weather Bureau, ESSA, and the Corps of Engineers, U.S. Army, to make the best use of the streamflow forecasting capabilities of the Portland River Forecast Center of the Weather Bureau and the North Pacific Div. office of the Corps of Engineers. The unit prepares flood forecast and streamflow and reservoirs inflow forecast for the entire Columbia Basin, and the adjacent coastal areas in Washington and Oregon. The forecasts are used to satisfy the public service responsibilities of the Weather Bureau as well as the Corps of Engineers' requirements for forecasts for operation. Forecasts are supplied to agencies, both public and private, in United States and Canada which have river-related activities and responsibilities."

ACKNOWLEDGEMENTS

Earlier versions of the SSARR model were conceived and developed by David M. Rockwood. The revisions incorporated in the present version are the result of collaborations between the authors and Mr. Rockwood. Mr. Edward Davis, Corps of Engineers Programmer and Systems Analyst, must be recognized for converting the SSARR model into a computer program. His many suggestions have added materially to the flexibility and power of the SSARR program.

E-20 Sinha, L.K., and Lindahl, L.E.: An Operational Watershed Model: General Considerations, Purposes, and Progress. Paper No. 70-236, presented at the 1970 Annual Meeting of the ASAE, Leamington Hotel, Minneapolis, Minnesota, July 7-10, 1970.

The main considerations in development of this model were: (a) the determination of the potential and practicality of mathematical modeling for operational water management and (b) the selection of components of the operational watershed model.

The four principle components that would make up the operational watershed model are rainfall input model, physical system model, economic model for water allocation, and some constraints. The physical system model is further divided into two sub-components; one to simulate streamflow by utilizing information from rainfall input model and another to compute water surface elevations at control points by using simulated streamflow and set of gate operations as inputs. Using system states as one of the inputs to economic model, optimum allocation of water to different uses within the system may be made. Then the system states coupled with its economic consequences are to be evaluated. If the proposed long term general operating policy is accepted, it would then be used as a guide for short term policy execution. Otherwise, changes in the constraints have to be made accordingly.

It is very important to note that in developing long term operating policy the rainfall input to the system would be the values based upon historical records. However, in executing operational policy on short term (day to day) basis, it is quite likely that the rainfall input to the system would be the values based upon current occurrences of rainfall events.

E-21 Sittner, W.T.; Schauss, C.E.; and Monro, J.C.: "Continuous Hydrograph Synthesis with an API-Type Hydrologic Model," from Water Resources Research, Volume 5, No. 5, pp. 1007-1022, October 1969.

Abstract: "The U.S. ESSA Weather Bureau Hydrologic Research and Development Laboratory has developed a complete hydrologic model utilizing an antecedent precipitation index (API) type rainfall-runoff relation to compute surface runoff. With increasing demand for continuous river forecasts as well as flood forecasts, it is necessary to have a model that will predict all components of flow as functions of observable independent parameters on a continuous basis. To formulate the model, existing and proved techniques were used where possible and new techniques developed as necessary. The model consists of four basic parts: a relation for computing ground-water recession, a method of computing the ground-water flow hydrograph as a function of the direct runoff hydrograph, an API-type rainfall-runoff relation, and a unit hydrograph. The rainfall-runoff relation is of the incremental type, yielding a runoff computation for each 6-hour period rather than computing the total storm runoff. This has been accomplished through the inclusion of a new parameter, retention index. Two important features of the model are the ease of adjusting parameters to observed

flow and the sequential development of the four basic parts with a minimum of interaction."

E-22 TVA: NATURAL AND REGULATED FLOOD ESTIMATION (NARFE) PROGRAM. Tennessee Valley Authority, Division of Water Control Planning, Flood Control Branch, Flood Hydrology Section, Knoxville, Tennessee, October 1966.

This program estimates the natural and regulated discharge hydrographs from watersheds or at selected locations within a watershed. This is accomplished by dividing the total watershed into subwatershed units such that flows can be determined at each potential project and at each stream location where project effects must be evaluated. Reservoir routings are carried out using standard procedures and any rule or relationship which can be expressed in terms of headwater elevation or storage. Channel routing is accomplished using the three coefficient Muskingum method. (Bob Buehler).

E-23 Texas Highway Department, Division of Automation: Texas Hydraulic System "THYSYS". 1970.

This user manual describes the preparation of input data for various hydraulic engineering problems commonly encountered in highway work. Routines are described for establishing peak runoff discharges (choice of 4 methods), normal T.W. depths downstream of small structures, culverts or bridge hydraulic design, storm sewer design, and for pump station design. This system is developed so that an engineer with no understanding of computers may utilize machines for the above mentioned tasks. The engineer specifies methods to be used (where alternatives exist) and input. The overall effort objectives are good and the programs should be very helpful to the designer. A copy of the program was not received but is believed to be written for the Burroughts computer system.

F. URBAN RUNOFF ANALYSIS

F-1 Barr Engineering Company, Minneapolis, Minnesota: COMPUTER METHOD FOR DETERMINING PEAK RATES OF DISCHARGE AND VOLUME FOR URBAN STORM SEWER DESIGN.

The program takes into consideration land use, overland flow, ground slope, infiltration, depression storage, interception losses, and storm patterns. It converts storm and "loss" data into a design hyetograph, routes the hyetograph overland to develop unit area hydrographs for representative conditions of flow length and slope. By multiplying each of the unit area hydrographs by the area that it typifies, and routing the resulting hydrograph, the collector system hydrograph can be computed at any desired point.

A dimensionless synthetic hyetograph is developed, assuming a 1-inch rainfall and including any distribution of rainfall that the user desires. The amount and duration total rainfall in the selected design storm must be selected and applied to "design hyetograph". The program then deducts anticipated "losses" or retentions prior to overland routing of rainfall excess.

Infiltration loss is based on the Well known Horton equation:

$$f = f_c + (f_o - f_c)\, e^{-(k_s t)}$$

Depression loss, based on programmed land use and topograph is distributed over the hyetograph. After development of the hyetograph for turfed areas a similar one is developed for impermeable areas. The program converts the hyetographs to runoff hydrographs by overland flow routing based on the method outlined by W.W. Horner and S.W. Jens. The final step involves routing of the composite hydrographs through the collection system by means of a channel routing method outlined in ASCE Manual No. 28.

The program for routing through the collector system can be reused to combine and route all subwatersheds through the system. The program has not been documented sufficiently for distribution, but is being prepared for publication.

F-2 Bowers, C.E.; Harris, G.S.; and Pabst, A.F.: <u>The Real-Time Computation of Runoff and Storm Flow in the Minneapolis-St. Paul Interceptor Sewers</u>. Status Report, SAFHL Memorandum No. M-118, University of Minnesota, December 1968.

The studies reported in this report were at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota for the Minneapolis-St. Paul Sanitary District, as part of a demonstration grant from the Federal Water Pollution Control Administration. The objective of the grant was to show how modern techniques and methods of analysis can be applied to an existing combined sewer system to increase the effectiveness of the system in collecting sewage and to reduce the amount of pollution of the receiving water, which in this case is the Mississippi River. The analytical studies were concerned with the concepts involved in computing the amount of water from rainfall which enters the combined sewer system and in determining the way in which the consequent flood hydrographs travel through the system.

A mathematical model was prepared which operates on a PDP-9 computer on real time. Input consists of rainfall data from 9 raingages around the cities at selected intervals during the storm. Output may consist of a warning that design capacities will be exceeded or if desired complete hydrographs at various points in the system.

F-3 Brownlee, R.C.; Austin, T.A.; and Wells, Dan M.: Interim Report - Variation of Urban Runoff with Duration and Intensity of Storms. Water Resources Center, Texas Tech. University, September 1, 1970.

Surface runoff from rainstorms passing over the small residential watershed considered in this study contains pollutant concentrations which vary in average and extreme values from storm to storm. The average concentrations of total dissolved solids and nitrates as well as the average pH value for the samples tested are within the standards set by the U.S. Public Health Service (10) for drinking water. Solid concentrations and total alkalinity concentrations are in the range of those found in raw sewage influent. Average BOD concentrations of the smaples tested is approximately the same as that of secondary sewage treatment effluent. This study does not conclude that runoff from urban watersheds is an acceptable source for municipal water supply, nor does it preclude this possibility.

The results of regression and correlation analyses performed on the data obtained from this study indicate a definite reduction in constituent concentrations with duration of runoff. These results suggest that a relationship of the form,

$$\text{Log }(Y) = A + BX,$$

exists between constituent concentration (Y) and runoff duration (X) for storms considered. It is expected that rainfall intensities, antecedent moisture conditions, storm movements, and other parameters also influence this relationship.

F-4 Hicks, W.I.: "A Method of Computing Urban Runoff", from Transactions of the American Society of Cifil Engineers, Vol. 109, 1944.

This reference describes the Los Angeles Hydrograph method for designing urban storm runoff systems. This method has been programmed and is in use by the city of Los Angeles. The method considers infiltration, overland flow, gutter flow, and conduit storage in the development of the runoff hydrograph.

F-5 Horn, Dennis R., and Dee, Norbert: Syntheses of the Inlet Hydrograph from Small Pervious and Combination Pervious-Impervious Drainage Areas. Technical Report No. 7 of the Storm Drainage Research Project, The Johns Hopkins University, November 1967.

A method is presented for synthesizing the runoff hydrograph from the pervious and impervious portions of a drainage area. The method involves a computer solution of the equations of gradually varied unsteady flow in open channels, on which work had previously been done for paved areas only. The original work, described in Technical Report No. 3 of the Storm Drainage Research Project, is discussed in greater detail with a presentation of the computer program and instructions for use. The only input required is the geometry of the drainage area, the rainfall pattern, infiltration coefficients, and values of friction coefficients from the Manning and Darcy-Weisbach equations.

The alteration of the original program to the present model, which analyzes infiltration losses on pervious areas, is done by developing a method to calculate coefficients in Horton's infiltration equation from a gaged rainfall and runoff data. This involves using a simple linear storage reservoir model of the runoff process to determine effective precipitation and to find a best-fit solution for the infiltration coefficients based on the gaged infiltration losses. These coefficients are then applied to the computer program for all pervious portions of a drainage area.

Additional work is done on the friction coefficients, with a presentation of a sensitivity analysis of the hydrograph to variations in those coefficients for a variety of slopes and overland flow lengths. It is determined that for long reaches of overland flow on pervious areas, the friction coefficient is the single most important factor in obtaining the proper hydrograph shape.

The results of synthesizing hydrographs on several combination pervious-impervious drainage areas indicate very close agreement between observed and calculated runoff. Suggestions are given for future work in this area so that such an approach can be used more generally for solution of drainage problems.

F-6 Missouri Hwy Dept: BACKWATER, FHWA 001A MO, IBM 1620 - 60K, Fortran, 1965.

This program computes the amount of intercept and bypass for given opening lengths using gutter flow output.

F-7 Missouri Hwy Dept: GUTTER FLOW, FHWA 0010 MO, IBM 1620 - 60K, Fortran, 1965.

This program computes quantity of water and length of opening for given slopes and gutter sections.

F-8 Ringenoldus, J.C., and Bauer, K.W.: FLOOD SYNTHESIS IN URBANIZING AREAS. Harza Engineering Co., Chicago, and the Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin. No date shown.

Hydrologic Simulation: -Hydrologic simulation as used here is defined as the mathematical representation of the hydrologic and hydraulic behavior of the perennial stream channel system of the watershed. A mathematical model was constructed using available information on climate, topography, soils, land use, and hydraulics of the watershed combined by means of established hydrological relationships, primarily SCS procedures. The model was then calibrated to the watershed using data available on stream performance, particularly, recorded high water marks. After satisfactory calibration of the model, it became possible to explore the effects of changed land use and of streamflow regulation devices on the behavior of the stream system.

F-9 SEWRPC: A Comprehensive Plan for the Fox River Watershed, Southeastern Wisconsin Regional Planning Commission, Planning Report No. 12, Vol. 1, Waukesha, Wisconsin, April 1969.

This report describes the application of an urban runoff quality and quantity model to a rapidly developing area. The runoff simulation model is similar to that described in reference [F-8]. The model was used to predict the effect urbanization would have on future flows.

F-10 Terstriep, M.L., and Stall, John B.: "Urban Runoff by Road Research Laboratory Method," from The Journal of the Hydraulics Division, ASCE, Paper No. 6878, HY 6, pp. 1809-1834, November 1969.

This report describes a study of the British Road Research Laboratory Method for computation of urban runoff. Conclusions were:

1. The British Road Research Laboratory (RRL) hydrograph method is a highly useful tool for developing a physical understanding of storm runoff from urban basins.

2. The two major factors in the application of the RRL model to a basin are the time-area curve and the discharge-storage relation. These factors are hydraulic in nature and can currently be evaluated satisfactorily by the Manning, Izzard, and Hicks equations to provide for the workability of the overall RRL method. Because these factors are hydraulic in nature, they should be subject to further refinement in the future.

3. The RRL method considers the storm runo-f from an urban basin to be comprised of runoff from only the directly connected impervious areas of the basin. This unusual feature does not seem to limit the method, but is a major strength in that it simplifies the hydraulic processes which must be solved.

4. Storm peaks from the Boneyard Creek basin were computed for 28 storms to a mean error range of plus 8.5% to minus 11.7%. Mean errors for ten storms on the South Parking Lot No. 1 were plus 17.2 and minus 20.6%. The method provides complete storm hydrographs which are shown to reflect reasonably the duration of various storm discharges.

5. The method described can be applied to a basin prior to development. Mere plans for urbanization can provide the time-area diagram and the discharge-storage relationship. This is a major advantage which will allow for good design of a storm drainage system prior to its installation. This feature of the RRL method is one not available from the unit hydrograph method.

6. The method described can be used readily to show the hydraulic effects of a proposed change or alteration of urban features of a basin.

7. The use of pattern analysis for rainfall determination provides a much better input to the RRL method than any method of averaging rainfall data. These highly detailed data on the time and areal variability of storm rainfall contribute greatly to real understanding of the resulting physical runoff processes which are a part of this model.

8. The one-step routing procedure is a weakness in the model.

9. The computations required to apply the RRL method to a basin are such that the resulting computed outflow storm hydrograph can be compared with actual observed hydrographs, if available. Observed hydrographs can provide this comparison or calibration of the RRL model, even if the storm hydrographs are complex and contain multiple peaks. This is a further advantage of the RRL model over the use of a unit hydrograph which requires observed hydrographs of isolated, single-peak storms.

10. The value and utility of the RRL method for storm drainage design justify its further evaluation and use.

A computer program has been developed at the Illinois Water Survey, but apparently is not ready for release.

F-11 Tholin, A.L., and Keifer, C.J.: "The Hydrology of Urban Runoff," from the Transactions of the American Society of Civil Engineers, Vol. 125, 1960.

This method is used by the city of Chicago for the design of urban drainage systems. For a given design, storm losses are abstracted. The remaining excess is routed through overland flow and gutter flow. Routing through sewers is accomplished by a simple time offset method.

F-12 Washington Hwy Dept: STORM SEWER DESIGN, FHWA 0010 WASH, IBM: 1620 - 60K, Fortran, 1965.

Given contributing areas and impervious factors, this routine computes runoff into the Storm Sewer System. Given beginning pipe elevation, slope, distance, and Manning's N, the routine computes pipe sizes and invert elevations.

F-13 Lager, J.A.; Shubinski, R.P.; and Russell, L.W.: Triumvirate Model for Storm Water Management. Prepared for presentation at the 43rd Annual Conference of the Water Pollution Control Federation, October 4-9, 1970, Sheraton-Boston Hotel, Boston, Massachusetts.

The Triumvirate Model was developed under the sponsorship of the Federal Water Quality Administration to assist cities in planning, evaluation, and management of facilities used in the collection and treatment of combined sewer flows. It was written in FORTRAN IV and has about 10,000 input statements. It uses a digital computer to simulate real storm events on the basis of rainfall hydrograph inputs and system (catchment, conveyance, storage treatment, and receiving water) characteristics to predict outcomes in the form of quantity and quality values.

G. PEAK FLOW RATES

G-1 Eagleson, Peter S.: A Distributed Linear Model for Peak Catchment Discharge. Preprint from the International Hydrology Symposium, Fort Collins, Colorado, September 1967.

The kinematic wave solution for surface runoff is used to obtain the contribution to peak discharge from an impulse of rainfall excess located at distance x from the catchment outlet. This spatial impulse response is employed in a linearization of the catchment dynamics to obtain a simple, superposition relation for estimating the effect of areal variability in rainfall distribution upon the peak surface runoff.

G-2 Indiana Hwy Dept: DETERMINES PEAK DISCHARGE RATES OF RUNOFF BASED ON BPR HYD. Design 2 and HYD. Circular No. 4, 1968. FHWA 0070 IND, IBM 360/40, Fortran.

G-3 Larson, C.L., and Machmeier, R.E.: "Peak Flow and Critical Duration for Small Watersheds," from the Transactions of the ASAE, Vol. II, No. 2, 1968.

A two-phase approach is presented for estimating peak runoff from small watersheds. Results of a mathematical watershed model [Ref. B-10] are used to develop relationships giving peak discharge times and magnitudes.

G-4 Missouri Hwy Dept: PEAK DISCHARGE AT CULVERTS. FHWA 154 MO, IBM 360 - 256K, Fortran G, 1969.

This program calculates horizontal dimension of culvert to get a desired discharge.

G-5 Texas Hwy Dept: TEXAS HYDRAULIC SYSTEM - THYSYS. 1970.

Peak runoff rate may be determined by this package routine using anyone of four methods. The four methods include two methods locally applicable to the state of Texas, the rational method, and a Log-Pearson Type-III analysis of gaged streamflow data. This peak discharge valve may then be used for design purposes in other parts of the THYSYS package.

H. GROUNDWATER ANALYSIS

H-1 BuRec: GROUNDWATER FLOW BY RELAXATION METHODS. File No. H-134, p. 291, U.S. Dept. of the Interior, Bureau of Reclamation.

This program tracks movement of a saltwater interface with fresh water on which a surcharge has been placed. Two soil layers of different permeabilities are included in the study.

Relaxation - General numerical and algebraic methods are used to solve the Laplace equation. Limitations - Applies to a specific boundary condition. Author - P.F. Enger.

Status: Production Stage, Date: 1/1/64, Applc. Code: #701, Computer: HON 800, Type: Main Program, Mailing Code: D-1100.

H-2 BuRec: 108 COMPUTING DRAWDOWN IN A WELL FIELD, by Region 2. File No. HY 195, U.S. Dept. of the Interior, Bureau of Reclamation.

This program computes drawdown in an arbitrary well field at any point within or outside the well field.

Language: Fortran II D, Storage: 30,000 char. (Decimal), Computer: IBM 1620.

H-3 BuRec: 110 GROUNDWATER DATA CONTROL, by Region 2, File No. HY-196, U.S. Dept. of the Interior, Bureau of Reclamation.

This program derives groundwater elevation and change. It lists output on printer and punches output data on cards for plotting.

Language: SPS, Storage: 12,000 char. (Decimal), Computer: IBM 1620, Maximum number of wells: 4800.

H-4 Pinder, George F.: A Digital Model for Aquifer Evaluation, Book 7, Chapter C1, Techniques of Water-Resources Investigations of the U.S. Geological Survey, 1970.

This program simulates the response of a confined aquifer to pumping at a constant rate from one or more wells. The groundwater reservoir may be irregular in shape and non-homogeneous with infiltration from one or more lakes and streams. The program (Table 1) is written in FORTRAN IV for the IBM 360 system.

This program is designed to handle arrays which do not exceed 48x65. It requires 74K bytes of storage and approximately 3 minutes of computing time on the model 360-50 per log cycle of the pumping period. That is, it requires approximately 23 minutes to compute the drawdown for 7 years of pumping.

H-5 Prickett, T.A. and Lonnquist, C.G. "Selected Digital Computer Techniques for Groundwater Resource Evaluation," Illinois State Water Survey Bulletin 55 (in Press).

Prickett, Thomas A. "Selected Notes on Digital Computer Simulations in Groundwater Resource Evaluation, July 1971 (unpublished).

I. SYSTEMS ANALYSIS

I-1 BuRec: BUFFALO BILL RESERVOIR 26 YEAR OPERATION STUDY, by R.L. Berling. File No. HY - 134, p. 349, U.S. Dept. of the Interior, Bureau of Reclamation, February 1, 1965.

The program provides means to develop and test hydro-power operating criteria for Buffalo Bill Reservoir. Initial use was to create an operable subroutine for inclusion in the western division MRB annual operating plan program. Using current Hydro-power operating criteria and historic inflow data, the program determined monthly operation of Buffalo Bill Reservoir, Heart Mountain Canal, and ShoShone and Heart Mountain Powerplants.

Limitations: Requires historic or forecasted inflows and desired maintenance schedule, Language: Automath 1800, Storage Requirements: 7424 words (Decimal), Computer: HON 800.

I-2 BuRec: RESERVOIR OPERATION STUDY - MAXWELL PROJECT, by D.W. Webber and Blanchard. File No. HY - 107, p. 320, U.S. Dept. of the Interior, Bureau of Reclamation, November 1, 1962.

The study determined the most efficient operation of a series of reservoirs on the Salt and Verde rivers based on stream-flow data from historic years. The study results were used to determine the size of the proposed Maxwell Dam. Most mathematics used is of the bookkeeping type, however, some arithmetic formulae are necessary for unit conversion. Prediction equations up to second degree are used for determining tributary flow.

Language: FORTRAN II, Storage Requirements: 16,500 words (decimal), Computer: IBM 7090.

I-3 BuRec: WATER SUPPLY AND RESERVOIR OPERATION STUDIES, by C.A. Nelson. File No. HY - 116, p. 330, U.S. Dept. of the Interior, Bureau of Reclamation, March 1, 1963.

This program was to run reservoir operation studies for five existing reservoirs with provisions to include five additional reservoir sites in the Yakima River Basin.

Methods: Normal Arithmetic, Language: FORTRAM II, Storage Requirements: words (Decimal), Computer: IBM 7090.

I-4 BuRec: WESTERN DIVISION, MRB, ANNUAL OPERATING PLAN, by R.W. Nash. File No. HY - 117, p. 331, U.S. Dept. of the Interior, Bureau of Reclamation, October 1, 1962.

Computation of the Western Division Annual Operating plan for 22 storage and regulating reservoirs and 16 powerplants located in Colorado and Wyoming. Computation of water release schedules to meet irrigation demands and power loads within limiting storage and non-project requirements.

Language: FORTRAN II, Storage Requirements: 16,000 words (Decimal), Computer: IBM 7090.

I-5 BuRec: WESTERN DIVISION, MRB, ANNUAL OPERATING PLAN, by R.L. Berling. File No. HY - 117A, p. 332, U.S. Dept. of the Interior, Bureau of Reclamation, March 1, 1965.

The program determines monthly hydro-power operation of the western division system for a two year period under various water supply conditions. Developed from earlier version written for IBM 7090 in FORTRAN II. Using current operating criteria, forecasted inflows, forecasted system power load, and desired maintenance schedule, the program plans monthly operation of system to meet power load and all water requirements.

Language: Automath 1800, Storage Requirements: 29,169 words (Decimal), Computer: HON 800.

I-6 BuRec: WESTERN DIVISION - MRB 36 YEAR OPERATION STUDY, by R.L. Berling. File No. HY - 126, p. 340, U.S. Dept. of the Interior, Bureau of Reclamation, February 1, 1964.

The program is used to develop and test hydro-power operating criteria for the Western Division System. Initial application was the Kortes Fish Study as a forerunner of the proposed North Platte River Operation Study. Using current hydro-power operating criteria and historic inflow data, the program determines monthly operation of all features of the Western Division System for any desired period of time.

Limitations: Requires inflows, power load and desired maintenance schedules, Language: Automath 1800, Storage Requirements: 25,000 words (Decimal), Computer: HON 800.

I-7 BuRec: WESTERN DIVISION - BRM FEBRUARY-MARCH OP PLAN, by R.L. Berling. File No. HY - 141, p. 356, U.S. Dept. of the Interior, Bureau of Reclamation, June 28, 1965.

The program determines monthly hydro-power operating plan of the Western Division System for the February through September or March through September period under various water supply conditions as predicted by either the February 1 or March 1 forecast. Using hydro-power operating criteria, forecast inflows, forecast system power load and desired maintenance schedule, the program plans monthly operation of system to meet power load and water requirements.

Language: Automath 1800, Storage Requirements: 29,883 words (Decimal), Computer: HON 800.

I-8 BuRec: WESTERN DIVISION - MRB APRIL THROUGH MAY OPERATING PLAN, by R.L. Berling. File No. HY - 144, p. 359, U.S. Dept. of the Interior, Bureau of Reclamation, August 1, 1965.

This program determines monthly hydro-power operating plan of the Western Division System for the April through September or May through

September period under various water supply conditions as predicted by the April 1 or May 1 forecast. Using hydro-power operating criteria, forecast inflows, forecast system power load and desired maintenance schedule, program plans monthly operation of system to meet all power and water requirements.

Language: Automath 1800, Storage Requirements: 29,000 words (Decimal), Computer: HON 800.

I-9 BuRec: 077 - STOCHASTIC OPERATIONS STUDIES, File No. HY-180, Reservoir operation studies in which inflows are based on flow probabilities instead of historic events. Region 2; Language: Fortran II D, Storage: 40,000 char. (Dec.), Computer: IBM 1620.

I-10 BuRec: 144 RESERVOIR OPERATIONS STUDY COMPUTER ASSN PACK (CDC 6600), File No. HY-211. Objective of this program is to determine the most efficient operation of a multireservoir system. This is done by trial nad error process with an engineer making different selections of the controlling criteria. Language: Fortran IV, Storage: 364,000 words (Dec.), Computer: CDC 6600, Limitations: Input-Output 5 sig: digits - 100 reservoirs or other similar points.

I-11 Butsch, Richard J.: "Reservoir System Design Optimization," from the Journal of the Hydraulics Division, ASCE, Paper No. 7023, HY 1, pp. 125-130, January 1970.

Design for a reservoir system can be optimized by selective use of mathematical techniques. A simulation incorporated linear programming to optimize allocation of reservoir releases to various used for each time period and incorporates dynamic programming to optimize total benefits over the design life. Optimum seeking methods can be employed to determine optimum reservoir sizes and operating criteria and also the optimum number and locations of reservoirs, the measure of improvement being the total benefits determined by simulation. With larger and better data gathering systems, and the resulting improved predictions and development of statistical analysis and non-linear programming, the accuracy and validity of this design method will improve. Presently, the method give good qualitative answers. Mathematical programming produces an optimum operation design, and optimum seeking methods produce an optimum system design.

I-12 DeCicco, P.R., and Slutzah, R.: COMPUTER MODELING TECHNIQUES FOR ENVIRONMENTAL SYSTEMS, Center for Urban Environmental Studies, Polytechnique Institute of Brooklyn.

The objective of this study was the development of a computerized technique for the layout of waste water collection systems. It includes 32 routines including five major routines for defining the network. The program was written in FORTRAN IV (level G) for an IBM 360 Model 50 Computer. It includes a plotting routine.

I-13 Department of Environmental Sciences and Engineering: "Investigations of Water Quality in a River Basin Through Simulation," from ESE Notes, Vol. 6, No. 1, January 1969.

Reports on some development in water resources including generation of sequences of numbers that are representative of river flows. These were then routed through mathematical representations of various control and power generation units to study proposed facilities.

I-14 FWPCA: Fitting the Red River of the North Basin to the General River Basin Simulation Program. Federal Water Pollution Control Administration, Division of Technical Control, Comprehensive Planning and Programs, April, 1967.

A mathematical model of the Red River of the North Basin, Minnesota and North Dakota, can be used as a water quality planning management tool to stimulate time and spatial variations of flow and concentrations of total dissolved solids throughout the Basin. Other parameters of water quality can be included in the model with little effort. The model incorporates hydrologic and water quality data and the Fiering-Pisano mathematical model described in the report "River Basin Simulation Program" which was issued by the Office of Comprehensive Planning and Programs, March 1967.

Given 1) the River Basin Simulation Program, 2) the report, and 3) tape of operational hydrology, other investigators can study various combinations of water quality management schemes.

I-15 Pisano, William C.: River Basin Simulation Program. Federal Water Pollution Control Administration (FWPCA), Division of Technical Control, Dept. of the Interior, August 15, 1968.

A mathematical model has been developed for use as a water quality planning management tool to simulate time and spatial variations of flow and concentrations of total dissolved solids throughout the Basin. Other parameters of water quality can be included in the model with little effort. The model incorporates hydrologic and water quality data and the Fiering-Pisano mathematical model described in the report "River Rain Simulation Program", issued by the Office of Comprehensive Planning and Programs, March 1967.

Given 1) the River Basin Simulation Program, 2) the report, and 3) tape of operational hydrology, investigators can study various combinations of water quality management schemes. (See abstract in Sec. III of this report).

I-16 FWQA: Mathematical Programming for Regional Water Quality Management, University of California at Los Angeles, Graduate School of Business Administration, for the Federal Water Quality Administration. August 1970, Supt. of Documents, Washington, D.C. 20402.

This report covers the application of a non-linear programming algorithm to the problem of optimal water quality control in an estuary. The mathematical model that was developed gives the solution to the general mixed case of at-source treatment, regional treatment plants, and by pass piping. The non-linear algorithm is developed in considerable detail and a sample problem is worked out. Actual data from the Deleware Estuary is used to solve a large-scale problem, and the solution is given.

The results indicate that a regional treatment system for the Deleware Estuary is superior in terms of cost to other systems.

A computer program is not included as part of this report. On the basis of superficial study it is assumed that standard computer programs can be used to solve segments of the problem within which linear relationships can be used.

I-17 HEC: HEC-3, RESERVOIR SYSTEM ANALYSIS - CONSERVATION, No. 23-X6-L253, by Leo R. Beard, December 1968.

This program will perform a multipurpose, multi-reservoir routing of a reservoir system. All requirements are supplied from reservoirs so as to maintain a specified balance of storage in all reservoirs insofar as possible. Provision is included for shortage declaration which will reduce desired flows and diversions. Program will accept system power demands that override individual power plant requirements, but it does not provide for channel routings, percolation losses, or time translations. It can assign economic values to all outputs and summarize and allocate these in various ways.

Program Specifications: Written in FORTRAN IV. Methods: Power is computed as a function of average head, efficiency, outflow and hydraulic losses. Economic benefits are computed based on a fixed relationship between the hydrologic quantity for a specified calendar month and location, and associated economic benefit for that month.
Equipment Details: Program utilizes about 40,000 words of core.
Input-Output: Card input and printer output.

I-18 Villines, James Ray: Economic Analysis of Flood Detention Storage by Digital Computer, University of Kentucky, Water Resources Institute, Lexington, Kentucky. Research Report No. 9, 1968.

The objective of this study was to develop a digital computer procedure for preliminary analysis of the economic justification of reservoir detention storage for flood control and to present a sample study illustrating its application. A computer program called the "University of Kentucky Flood Control Planning Program III" was developed and tested on the flood plain of the South Fork of the Licking River in northeastern Kentucky.

Given a specified reservoir site and a downstream flood plain divided into planning units, Program III selects the economically efficient combination of reservoir detention storage and the associated combination of channel improvement, flood proofing, land-use management, and residual flooding for each downstream planning unit. The Program does not attempt final measure design but isolates those combinations of measures for which detailed data collection and analysis is warrented.

This study presents a description of the basic Program logic and the results of its application along the South Fork, Licking River, as well as a FORTRAN IV listing of the computer program and a listing of the input data used in the South Fork, Licking River Analysis.

J. MISCELLANEOUS

J-1 AASHO: Computer Program Index. American Association of State Highway Officials, November 10, 1969.

J-2 BuRec: Abstracts of Electronic Computer Programs Developed by Bureau of Reclamation, Electronic Program Abstracts Issue No. 5, U.S. Dept. of the Interior, Bureau of Reclamation, February 1969.

This report is a listing of USBR Programs with one page descriptions of the programs.

J-3 BuRec: CRITICAL DEPTH COMPUTATIONS FOR VENTURI FLUMES, by R. Dodge and P.F. Enger. File No. H-119, p. 276, U.S. Dept. of the Interior, Bureau of Reclamation, May 1, 1963.

This program computes critical depth for trapezoidal channel sections.

Language: Fortran II, Storage Requirements: 1,000 words (Decimal), Computer: IBM 7090, Methods: Bi-section and testing for Q**2/G = A**3/T.

J-4 BuRec: DATA REDUCTION FOR CANAL HYDRAULIC PARAMETERS, by J.V. Vredenburg. File No. H-154, p. 311, U.S. Dept. of the Interior, Bureau of Reclamation. March 1, 1965.

The purpose of this program is the reduction of canal survey data into the input format for the determination of hydraulic parameters program.

Language: Automath 1800, Storage Requirements: 1,927 words (Decimal), Computer: HON 800, Limitations: Limited to 50 stations per reach and 50 points per station.

J-5 BuRec: DETERMINATION OF HYDRAULIC PARAMETERS-CANALS, by J.V. Vredenburg. File No. H-150, p. 307, U.S. Dept. of the Interior, Bureau of Reclamation, December 10, 1964.

The purpose of this program is the determination of Manning's "N", friction factor "F", Reynolds' Number, Froude Number, and Chezy "C" from data collected under the canal capacity test program.

Language: Automath 1800, Storage Requirements: 1,827 words (Decimal), Computer: HON 800.

J-6 BuRec: EDIT RIVER X-SECTION DATA FOR PLOTTING, by J.M. Vredenburg. File No. HY-120, p. 344, U.S. Dept. of the Interior, Bureau of Reclamation, August 26, 1964.

The purpose of this program is to edit X-section data into a format suitable for plotting on the Benson-Lehner Model J electroplotter using the general purpose control board.

Language: Automath 1800, Storage Requirements: 10,000 words (decimal), Computer: HON 800.

J-7 BuRec: FRICTION LOSS TABLES FOR CONCRETE PIPE, by N.H. Wright. File No. H-138, p. 295, U.S. Dept. of the Interior, Bureau of Reclamation, March 13, 1964.

The program performs the repetitive calculations involved in producing tables of hydraulic properties of varying sizes of concrete pipe.

Language: Automath 1800, Storage Requirements: 2,000 words (Decimal), Computer: HON 800, Method: The basic calculation is based on the Scobey Formula.

J-8 BuRec: RESERVOIR AREA CAPACITY TABLE COMPUTATION, by R.B. Brownrigg. File No. HY-114, p. 328, U.S. Dept. of the Interior, Bureau of Reclamation, February 1, 1962.

This program computes area-capacity tables which are used in reservoir operations for determining daily inflow. These tables are also utilized during various phases of reservoir planning and development. Areas are computed at 1-ft intervals using a logarithmic curve between control elevations. Capacities are computed by double-end area method at 1-ft intervals with straight line interpolation for 0.1-ft. intervals.

Language: Fortran, Storage Requirements: 20,000 char. (Decimal), Computer: IBM 1620.

J-9 BuRec: SEEPAGE DISCHARGE FROM FLATBOTTOM PONDS, by P.F. Enger. File No. H-140, p. 297, U.S. Dept. of the Interior, Bureau of Reclamation, April 1, 1963.

This program computes seepage loss as a function of the pond water depth from data collected during ponding tests. The pond cross section must be well shaped and either trapezoidal or rectangular. General algebraic methods used to compute seepage from water volume change in pond during a certain time interval.

Language: Automath 1800, Storage Requirements: 500 words (Decimal), Computer: HON 800, Limitations: Limited to ponds with very small bottom slopes.

J-10 BuRec: SEEPAGE FROM PONDS WITH KNOWN VOLUMES AND SURFACE, by P.F. Enger. File No. H-141, p. 298, U.S. Dept. of the Interior, Bureau of Reclamation, May 1, 1963.

The program computes average seepage loss as a function of water depth from ponds on which curves of volume vs depth and wetted surface area vs depth are available. General algebraic methods are used to compute seepage from water volume change in pond during a given time interval.

Language: Automath 1800, Storage Requirements: 2,000 words

(Decimal), Computer: HON 800, Limitations: Limited to tests on ponds with known physical characteristics.

J-11 BuRec: SEEPAGE LOSS CALCULATIONS FOR GENERAL PONDS. File No. H-129, p. 286, U.S. Dept. of the Interior, Bureau of Reclamation.

The program computes average seepage loss as a function of water depth for a general ponding test. Cross sectional data and data from ponding tests are used as input. Volumes, wetted surface areas, and average seepage rates as a function of elevation are provided as output.

Forward and backward finite difference methods, general algebraic methods. Pond must be continuous with no undercut banks.

J-12 BuRec: SEEPAGE LOSS FROM SMALL CANALS AND LATERALS, by P.F. Enger. File No. H-110, p. 266, U.S. Dept. of the Interior, Bureau of Reclamation, April 1, 1963.

The program computes seepage loss from small canals and laterals when ponding tests are conducted and computes average seepage rates from maximum water surface elevation to low point of fill.

Language: Fortran II, Storage Requirements: 5,000 words (Decimal), Computer: IBM 7090, Methods: Integration by differences and general algebraic methods.

J-13 BuRec: SPILLWAY FLOW TABLE COMPUTATIONS, by J.O. Johnson. File No. H-130, p. 287, U.S. Dept. of the Interior, Bureau of Reclamation, May 15, 1963.

The program develops a discharge table of reasonable accuracy for the spillways and outlet works on various region 2 dams for which discharge curves are available. Simple equation arithmetic.

Language: Fortran II, Storage Requirements: 40,000 char. (Decimal), Computer: IBM 1620.

J-14 BuRec: TANK OPERATION STUDY, by N.H. Wright. File No. H-139, p. 296, U.S. Dept. of the Interior, Bureau of Reclamation, April 1, 1964.

This program was developed to assist in the design of a remote automatically controlled water supply system. The system consists of a supply reservoir, feeder lines, motor operated valves, and a water tank with float controls. The method of solution consists of a trial and adjustment procedure.

Language: Automath 1800, Storage Requirements: 2,000 words (Decimal), Computer: HON 800, Limitations: The output format is set up for three feeder lines.

J-15 BuRec: VOLUME AND WETTED SURFACE AREA CALCULATIONS, by P.F. Enger. File No. H-131, p. 288, U.S. Dept. of the Interior, Bureau of Reclamation, July 1, 1963.

The program computes volume and wetted surface areas of ponds on which cross-sectional data are available. Forward and backward finite difference methods and general algebraic methods are used.

Language: Fortran II, Storage Requirements: 2,000 words (Decimal), Computer: IBM 7090, Limitations: Ponds must be continuous with no undercut banks.

J-16 BuRec: VOLUME AND WETTED SURFACE AREAS FOR SMALL PONDS, by P.F. Enger. File No. H-107, p. 263, U.S. Dept. of the Interior, Bureau of Reclamation, April 1, 1963.

The program calculates volumes and wetted surface areas of laterals or canals from which it is desired to establish seepage rates. Cross-sections and lengths are integrated by divided difference methods.

Language: Fortran II, Storage Requirements: 1,000 words (decimal), Computer: IBM 7090, Limitations: At least three cross-sections are required.

J-17 California Dept. of Water Resources: Development of a Control System Model (including Appendices A, B, and C). Division of Operations, January 1965.

J-18 California Hwy Dept: Hydraulic Design of Culverts. FHWA 1041 CAL, IBM 360/50 512, FORTRAN E, 1968.

Converted from BPR HYD Engineering Circular No. 7. Calculates flow data.

J-19 HEC: Conduit Rating, Partial Gate Opening, by W.L. Sharp. No. 22-224, July 1966.

This program is designed to compute the discharge for reservoir outlet structures with partial (vertical lift) gate openings. By varying gate openings and/or water levels for a given invert elevation, computations are made resulting in a convenient tabulation of conduit ratings.

Program Specifications: This program is written in FORTRAN II. Methods: The program used the equation $Q = CGB\sqrt{2gH^1}$ as described in WES "Hydraulic Design Criteria - 320-1" to compute the discharge in cubic feet per second. Values of the discharge coefficient C may be furnished by the program user as desired or may be adopted from the above-mentioned criteria. Equipment Details: The program was prepared for use on the IBM 1620 computer with 40,000 digit variable work length memory, card input and output, and is usable in the GE-225 and RCA-301 computers having comparable memory, providing that any required input nad output statement changes are made.

J-20 HEC: Deposit of Suspended Sediment, by C.E. Abraham. No. 23-264, June 1967.

The program computes the estimated future distribution and location of sediments deposited in a reservoir. In addition, the sediment inflow, trap efficiency of the reservoir, and size distribution of passing sediments are computed. The program will accept various reservoir configurations such as tributary arms and will show deposition within the arms as well as the main body. Major simplifying assumptions are that there is no temperature stratification and all sediment remaining in suspension at the dam will pass the dam.

Program Specifications: The program is written in FORTRAN II and requires 40,000 digits memory on the IBM 1620 computer. Methods: Deposition of sediment is computed as a function of sediment size, reservoir temperature, variation of inflow, reservoir configuration, and type of reservoir operation. A table of corresponding duration, flow, and sediment values from a flow-duration relationship is used to describe variation in flow and suspended load. Equipment Details: IBM 1620, 40K memory. Input-Output: Card input-output.

J-21 HEC: Reservoir Area and Capacity Tables, by Warren L. Sharp. No. 23-233, July 1966.

This program will compute reservoir area-capacity tables for an elevation increment of 1.0, .1, or .01 foot.

Methods: The conic procedure employed is considered more suitable than the frequently used "average and area method" for determining reservoir capabilities. Language: Written in FORTRAN II. Equipment Details: IBM 1620 card input, 120 column printer.

J-22 HEC: Reservoir Delta Sedimentation, By C.E. Abraham. No. 23-269, July 1967.

The program computes an expected ultimate profile for sediment deposits forming the delta at head waters of the reservoir. The profile is determined from the given amount of sediment forming the delta and cross-sections of the reservoir arm.

Methods: The existing average thalweg slope is computed from minimum elevations given for cross-sections of the reservoir arm. Delta topset and forset slopes are based on specified ratios of the thalweg slope. The topset and forset slopes are used to compute a volume in the reservoir arm, which is recomputed with the volume of delta sediments. Program Specification: The program is written in FORTRAN II and requires 35,000 digits memory on the IBM 1620 computer. Equipment Details: IBM 1620, 40K memory. Input-Output: Card input-output.

J-23 HEC: Reservoir Temperature Stratification, by Leo R. Beard. No. 23-281, September 1969.

The reservoir temperature stratification model simulates temperature variation between horizontal strata within a reservoir on a monthly basis, given data on initial conditions and on inflow rates and temperatures, outflow rates and tolerable temperatures, evaporation, precipitation, radiation, air temperatures, specific outlet release requirements, if any, and the physical features of the dam and reservoir.

Methods: The procedure is based on the energy budget analysis. The analysis accounts for the energy in each horizontal layer and the energy and water transferred into and out of each layer of the reservoir. Program Specifications: The program is written in FORTRAN IV. Equipment Details: The program requires a computer of the IBM 7090 class. Input-Output: Card input is designated for tape 5 and printer output for tape 6. Tapes 2, 3, and 4 are used for temporary binary storage.

J-24 HEC: Spillway Gate Regulation Curve, by Bill S. Eichert. No. 23-236, February 1966.

This program will compute the gate regulation schedule curves for a reservoir utilizing the area capacity curves, the induced surcharge envelope curve, and a constant T_s which represents the slope of the recession leg of an inflow hydrograph. These curves are used to operate a gated spillway while the reservoir pool is rising under emergency conditions when communications have failed and in determining dam height for design purposes.

Methods: The method of computation is based on EM 1110-2-3600, "Reservoir Regulation." Program Specifications: FORTRAN II. Equipment Details: IBM 1620, 40K digits storage. Input-Output: Input and output by cards.

J-25 HEC: Spillway Rating, Partial Gate Opening, by Warren L. Sharp. No. 22-225, July 1966.

This program was developed to compute the discharge for ogee-type weirs with partial tainter gate openings. Precise ratings can be obtained in a convenient table form for use in reservoir regulation sections, or a limited volume of output can be obtained that is useful during the planning and design stages of a project. Partial gate opening ratings can be determined for any planned or existing ogee-spillway having radial-type gates.

Methods: In general, the computational procedure shown on WES "Hydraulic Design Charts 311-1 to 311-5" is followed with the primary difference being in the determination of G (effective gate opening). Program Specifications: Written in FORTRAN II and FORTRAN IV. Equipment Details: This program was prepared for use in the IBM 1620 (FORTRAN II) and IBM 7090 (FORTRAN IV) classes. Input-Output: Card input and output for FORTRAN II version. Card input-output for FORTRAN IV version.

Additional Remarks: Due to memory limitations of the IBM 1620 (40,000 digit, variable word length, card input and output), the convenient table form is only obtainable using the FORTRAN IV version.

J-26 HEC: Suspended Sediment Yield, by C.E. Abraham. No. 23-256, March 1968.

The program computes the annual suspended sediment load corresponding to observed daily water discharge measurements. The relation used in the computations is computed from a record of observed daily discharges and suspended sediment loads. Other options can be used, such as computing the weighted size distribution of particles, computing the relation of instantaneous sediment loads and flows, and computation of frequency statistics for the annual loads.

Methods: The relation for suspended sediment load is derived from regression analysis of the logarithms of load and discharge. In addition to the discharge, the daily relation depends on the sequence of daily discharges. The weighted size distribution of sediment particles is computed by weighing each sampled size analysis according to the load corresponding to the sample. Program Specifications: The program is written in FORTRAN II for the IBM 1620 computer with 40K memory. Execution time requires about 10 minutes per year of observed discharges.

J-27 Liu, Kannson T.H.: The Numerical Analysis of Water Supply Networks by Digital Computer. Massachusetts Inst. of Technology, no date shown.

Discussion of several methods of analysis relative to a pipe network including an implicit solution involving Newton's Method plus two forms of the Hardy-Cross Method. He concludes that the Hardy-Cross Method is usually faster in terms of computer time but sometimes has convergence problems.

J-28 Martin, C.S., and De Fazio, F.G.: A Contribution to Open-Channel Surge Simulation by Digital Computer. Georgia Inst. of Technology and Harza Engineering Company, Chicago. Presented at the Annual Conference of the Hydraulic Division, ASCE, Cambridge, Massachusetts, August 21-23, 1968.

The purpose of this paper is to demonstrate the use of the digital computer for simulation of prismatic open-channel wave problems. The equations of motion for gradually-varied flow are expressed in finite-difference form resulting in algebraic equations that are readily programmed for use on a digital computer. The question arises, however, as to the applicability of gradually-varied flow theory to problems involving surges or rapidly-varied wave forms.

Since the advent of the high-speed digital computer, there has been considerable effort in the use of numerical techniques for the solution to engineering problems. In the field of flood waves, Stoker pioneered the use of the finite-difference equations in his study of floods on the Ohio River.

J-29 Montana Hwy Dept: HYDRAULICS OF BRIDGE WATERWAYS (A Modified version of BPR Program HY-4). FHWA 2010 MONT, IBM 360/40/256, FORTRAN IV, 1968.

This program computes slope of channel, normal stage, and backwater for up to 99 Trial Constructions.

J-30 New Mexico Hwy Dept: BPR PROGRAM HY-1, HYDRAULIC ANALYSIS OF CIRCULAR CULVERTS. FHWA 0040 NM, IBM 1620, FORTRAN. Converted to Operating System, 1964.

J-31 New Mexico Hwy Dept: BPR PROGRAM HY-2, HYDRAULIC ANALYSIS OF PIPE-ARCH CULVERTS. FHWA 0050 NM, IBM 1620, FORTRAN. Converted to Operating System, 1964.

J-32 New Mexico Hwy Dept: BPR PROGRAM HY-3, HYDRAULIC ANALYSIS OF BOX CULVERTS. FHWA 0030 NM, IBM 1620, FORTRAN. Converted to Operating System, 1964.

J-33 New Mexico Hwy Dept: HYDRAULICS OF BRIDGE WATERWAYS, VERSION I-HY-4. FHWA 0010 NM, IBM 1620, FORTRAN. From Bureau of Public Roads. Card to Card. 1964.

J-34 New Mexico Hwy Dept: BPR PROGRAM HY-4, HYDRAULICS OF BRIDGE WATERWAYS, VERSION 2. FHWA 0020 NM, IBM 1620, FORTRAN. Converted to Operating System, 1964.

J-35 Ohio Hwy Dept: CULVERT ANALYSIS. FHWA 4410 OHIO, IBM 360/50, FORTRAN, 1967.

Generates for most economical type and size of culvert for a given set of hydrological conditions.

J-36 Ohio Hwy Dept: DITCH ANALYSIS. FHWA 4400 OHIO, IBM 360/50, FORTRAN, 1967.

Shows analysis of standard roadway ditches, special ditches, and Median Swales.

J-37 Okalahoma Hwy Dept: DESIGN AND ANALYSIS OF ROADWAY CULVERTS. FHWA 1210 OKLA, IBM 360/40 - 65K, FORTRAN E, 1968.

This is a combined program to handle box culverts, circular pipes, and pipe-arches in one execution. Adapted from BPR HY - series.

J-38 Oklahoma Hwy Dept: HYDRAULIC ANALYSIS OF ROADWAY CULVERTS. FHWA 1220 OKLA, IBM 360/40 - 65K, 1968.

Input size A and Tailwater. Output headwater velocity and wheter inlet or outlet control. Pipes and boxes.

J-39 Price, Bobby E., and Masch, Frank D.: Use of Digital Computers in Circular Culvert Design. Presented at the ASCE Hydraulics Division Specialty Conference, M.I.T., Cambridge, Massachusetts, August 21-23, 1968.

J-40 Rogers, A.E.: "An Introduction to Computer Simulation," in Educator's Demonstration Series, Statistics and Computer Science Department, University of Delaware, June 1967.

J-41 Shand, Michael J.: Final Report - The Hydraulic Filter Level Offset Method for the Feedback Control of Canal Checks. Hydraulic Engineering Laboratory, College of Engineering, University of California, Berkeley, June 1968.

Mathematical model to simulate unsteady flow in a trapezoidal canal with automatically controlled check gates. Used to evaluate design and performance of canal control system under simulated flow conditions.

J-42 Texas Hwy Dept: AN INTEGRATED SYSTEM OF PROGRAMS FOR HIGHWAY HYDRAULIC DESIGN AND ANALYSIS. FHWA 1080 TEX, IBM 360/50, FORTRAN, 1970.

J-43 Texas Hwy Dept: CARRIES THROUGH A HYDRAULIC DESIGN OF CULVERTS FROM DISCHARGE DETERMINATION THROUGH CULVERT DIMENSIONS. FHWA 1050 TEX, IBM 360/50, FORTRAN, 1969.

J-44 Texas Hwy Dept: DESCRIBES A METHOD WHEREBY ANNUAL MAXIMUM FLOOD RECORDS CAN BE STORED, RETRIVED, AND DISPLAYED FOR USE BY ENGINEERS INVOLVED IN THE DESIGN OF A STREAM CROSSING. FHWA 1030 TEX, IBM 360/50, FORTRAN, 1969.

J-45 TVA: MDQ2, by Paul C. Spoth. Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

This program computes the mean daily discharge and gage height and total monthly runoff from hand abstracts of time and gage height. The individual time-gate height-discharge values are tabulated.

J-46 TVA: DMDQ2, by Paul C. Spoth. Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

This program is similar to the Ref. J-45 except that input data are digitized using a Calma Model 302 digitizer.

J-47 TVA: DAILY SEDIMENT LOADS. Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

Daily and monthly total sediment loads in tons are computed from given time-discharge-concentration.

J-48 TVA: DIFCOR. Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

This program optimizes the parameters of non-linear models using the method of differential corrections in conjunction with multivariate statistics.

J-49 TVA: DIGSED. Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

This program is similar to J-51 except that the time-discharge-concentration data are digitized using the Calma digitizer.

J-50 TVA: PATSEAR. Tennessee Valley Authority, Hydraulic Data Branch, Knoxville, Tennessee.

This program uses the pattern search method for optimizing the parameters of a non-linear model. The program has generally been found to work better than the DIFCOR [Ref. J-48] approach.

J-51 U.S. Bureau of Public Roads, Engineering Design Hydraulics: PROGRAM 1200. FHWA 1200, IBM 360/40K, FORTRAN, 1969.

HY-1 used for hydraulic analysis of circular pipes. Given hydrological data and site conditions, produces number of pipes, sizes, headwater and outlet velocity, inlet and outlet conditions.

J-52 U.S. Bureau of Public Roads, Engineering Design Hydraulics: PROGRAM 1300. FHWA 1300, IBM 360/40K, FORTRAN, 1969.

Hy-2 used for hydraulic analysis of pipe-arches. Given hydrological data and site conditions, it selects size considering inlet and outlet control.

J-53 U.S. Bureau of Public Roads, Engineering Design Hydraulics: PROGRAM 1400. FHWA 1400, IBM 360/40K, FORTRAN, 1969.

HY-3 used for hydraulic analysis of boxes. Given hydrological data and site conditions, it determines size of culvert which satisfies data and site conditions for inlet and outlet conditions.

J-54 U.S. Bureau of Public Roads, Engineering Design Hydraulics: PROGRAM 1500. FHWA 1500, IBM 260/40K, FORTRAN, 1969.

HY-4 computes bridge backwater. Theory followed is in Hydraulics of Bridge Waterways, by J.M. Bradley, Bureau of Public Roads, 1965.

J-55 Virginia Hwy Dept: HYDRAULICS OF BRIDGE WATERWAYS (Modified BPR HY-4). FHWA 2180 VA, IBM 360/40, FORTRAN IV, 1969.

This program generally analyses the effect of a structure in a stream.

J-56 Wisconsin Hwy Dept: HYDRAULIC ANALYSIS FOR PIPE ARCH, BOX CULVERT, AND CIRCULAR CULVERT. FHWA 0010 WISC, IBM S/360 - 50, FORTRAN, 1968.

J-56 BuRec:095 - RESERVOIR TEMPERATURE PREDICTION, File No. HY-187.

Prediction of thermal energy distribution in streams and reservoirs. Prepared for California Department of Fish and Game by Water Resources Engineering, Inc. A mathematical model simulating thermal stratification for predicting reservoir and outlet temperatures. Language: Fortran IV, Storage: 100,000 words (Dec.), Computer: CDC 6600.

J-57 BuRec:101 - CROSS -DRAINAGE BY CALIFORNIA CULVERT METHOD, File No. HY-190.

Derives drainage from areas above road or canal by the California culvert method. Region 2, Language: Fortran II, Storage: 40,000 char. (Dec.), Computer: IBM 1620.

APPENDIX 3

THE HYDROLOGIC ENGINEERING CENTER

U.S. ARMY CORPS OF ENGINEERS

ACTIVE GENERALIZED COMPUTER PROGRAMS

Detailed descriptions of the following computer programs, which are written in FORTRAN, are available from the Hydrologic Engineering Center, Corps of Engineers, 650 Capitol Mall, Sacramento, California 95814. Up-to-date source decks are also available upon request. Such requests should specify computer facility on which the program is to be used.

There is a handling charge of $50, payable to the Treasurer of the United States, for source decks furnished to private organizations.

While the Government is not responsible for the results obtained when using these programs, assistance in resolving any malfunctioning of the programs will be furnished by The Hydrologic Engineering Center to the extent that time and funds are available.

Number	Name	Minimum Equipment	Latest Description
22-210	Spillway Rating & Flood Routing	GE 225	Oct 66
22-212	Backwater, Any Cross Section	GE 225	Jun 67
22-224	Conduit Rating, Partial Gate Opening	IBM 1620	Jul 66
22-225	Spillway Rating, Partial Gate Opening	IBM 1620	Jul 66
22-232	Water Surface Profiles (HEC-2)	IBM 7040	Aug 69
24-211	Unit Hydrograph & Loss Rate Optimization	IBM 7090	Aug 66
24-226	Basin Rainfall and Snowmelt	IBM 1620	Jul 66
23-228	Unit Graph and Hydrograph Computation	IBM 1620	Jul 66
23-231	Streamflow Routing Optimization	GE 225	Nov 66
23-232	Hydrograph Combining and Routing	IBM 1620	Aug 66
23-233	Reservoir Area and Capacity Tables	IBM 1620	Jul 66
23-234	Channel Improvement Sections	IBM 1620	Nov 66
23-236	Spillway Gate Regulation Curve	IBM 1620	Feb 66
23-237	Balanced Hydrograph	IBM 1620	Nov 66
23-239	Frequency Statistics	IBM 1620	Nov 66
23-245	Reservoir Yield	IBM 1620	Aug 66
23-247	Partial Duration, Independent Events	IBM 1620	Jul 66
23-253	Reservoir System Analysis, Conservation (HEC-3)	CDC 6600	Feb 71
23-256	Suspended Sediment Yield	IBM 1620	Mar 68
23-264	Deposit of Suspended Sediment	IBM 1620	Jun 67
23-267	Monthly Streamflow Simulation	CDC 6600	Feb 71
23-268	Regional Frequency Computation	IBM 7090	Jul 67
23-269	Reservoir Delta Sedimentation	IBM 1620	Jul 67
23-270	Flood Hydrograph Package (HEC-1)	CDC 6600	Oct 70
23-279	Interior Drainage Flood Routing	IBM 1620	Apr 69
23-281	Reservoir Temperature Stratification	IBM 7090	Sep 69
24-235	Daily Streamflow Simulation	CDC 6600	Apr 68

APPENDIX 4

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION

Partial List of Programs:

1) TR-20 Project Formulation Hydrology
2) Dams - Structure Site Analysis
3) Log Pearson Type III Frequency Analysis
4) Reservoir Operations Study
5) Water Surface Profiles (undergoing modification)

APPENDIX 5

U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Washington, D. C. 20242

ATTENTION: Mr. G.W. Whelstone, Chief
Reports and Data Processing

List of Programs

Program Number	Program Name
4014	Log Pearson Type III Distribution Flood Frequency
4104	Tide Gage Summary
4107	Digital Primary Computation (DISK)
4108	Primary Update (DISK)
4109	Daily Discharge Table, 9-211M (DISK)
4111	Digital Slope Computation (DISK)
4124	Phreatophyte Project
4150	Digital Monitor
4170	Digital Ground-water Levels
4200	Copy Historical Record - Tape to Tape
4203	Copy Historical Record (Consol) - Tape to Tape
4206	Edit Daily Discharges
4213	Statistical Summaries (360)
4217	Daily Q Table from BK File (9-211)
4250	Chemical Weighted Averages
4252	Sediment Load (SW Input Option)
4253	Particle Size Distribution (Oden)
4254	Daily Conductance
4255	Estuary Temperature Study
4258	Sediment Listing (Particle Size)
4259	Temperature Listing
4261	Chemical Statistics
4262	Frequency
4266	Chemical Multiple Tab
4267	Sediment File Maintenance
4268	Sediment-load Tabulation
4272	QW-SW Backfile Conversion, SW Analytical Data
4273	QW-SW Primary Processing
4274	QW-SW Primary Tabulation
4275	QW-SW Final Tabulation
4276	Store Individual Q's on Mag Tape -
4305	Ground Water Tape Write
4306	CKDATA (Kan. G.W.)
4307	STIFFU (Kan. G.W.)
4308	CVTVAL (Kan. G.W.)

Program Number	Program Name
4309	HYDROG (Kan. G.W.)
4310	IRCLSU (Kan. G.W.)
4311	KANS (Kan. G.W.)
4312	MIXU (Kan. G.W.)
4313	WELDAT (Kan. G.W.)
4314	MXMTU (Kan. G.W.)
4315	PIPERU (Kan. G.W.)
4316	WLTAB (Kan. G.W.)
4317	LT-LG (Kan. G.W.)
4318	COLINU (Kan. G.W.)
4319	RARU (Kan. G.W.)
4320	KTAB (Kan. G.W.)
4379	GW Well Data (Variable Heading)
4422	Flow Variability
M0035	ABCCHK - Checks Ground Water ABC Cards
M0039	Salary Budget
A130	River Basin Simulation
A131	Streamflow Analysis
A132	Streamflow Synthesis
A133	LINEAR - Free-formal linear equation solution
A139	Water Data System Simulation Model
A142	S-C 4020 Plotter Test Deck
A144	S-C 4020 Plotter Library Listing
A145	Cross Reference, FORTRAN
A149	General data plot of two variables for the S-C 4020 Plotter
A172	QW Modified Storet - Card to Print (360/20 Version)
A200	Digital Monitor List
A510	Diration Hydrograph
A549	Flood Hydrograph
A554	Rainfall Intensity
A593	Test Current Meter Ratings
A625	HIFLOW (Output of Statistical Summaries on Magnetic Tape)
A641	ANSTOR (Annual Storage)
A644	List Sediment Tables
A645	Update Sediment Backfile
A646	Sediment Data Retrieval Program
A647	Compute Average Daily Temp. from Max and Min
A648	Compute Max, Min, Av. Daily Temp. and Sediment Load
A670	Edit Cards of Daily Q
A675	Q-Backfile Cards to Disk
A720	Linear response analysis and Synthesis via Fourier Series
A890	LOGCVT - Log Pearson Type III Data-card Conversion
A891	CDCVT - STATPAC Data-card Conversion
A902	MON-DUR - Monthly duration table
A910	QPREP - Surface Water Record Preparation for STATPAC Processing
	A Digital Model for Aquifer Evaluation [H-4]

APPENDIX 6

TENNESSEE VALLEY AUTHORITY

FLOOD CONTROL BRANCH PROGRAMS

For additional information write:

Bob Buehler
Chief, Flood Control Branch
Tennessee Valley Authority
206 Evans Building
Knoxvi-le, Tennessee 37902

Unit Graph

Derivation of best fit unit hydrograph.

Reservoir Routing

Makes all computations required to route floods through a reservoir using flat-pool storage and fixed outlets. The program has a plot option.

Natural and Regulated Flood Estimation (NARFE)

Stream and reservoir routing and combining of specified runoff hydrographs.

Open Channel Transient Flow Mathematical Model (SOCH)

This model uses the basic differential equations of continuity and momentum which describe the unsteady, nonuniform behavior of open channel flow. The digital computer program provides the numerical solution to these equations.

Subcritical Water Surface Profiles

Computes using the step method the water surface profile at selected locations along a stream based upon the Manning formula.

TENNESSEE VALLEY AUTHORITY

HYDRAULIC DATA BRANCH PROGRAMS

For additional information write:

Paul C. Spath
Chief, Hydraulic Data Branch
Tennessee Valley Authority
350 Evans Building
Knoxville, Tennessee 37902

MDQ2

Computes the mean daily discharge and gage height and total monthly runoff from hand abstracts of time and gage height. The individual time-gage height-discharge values are tabulated.

DMDQ2

Similar to the above except that input data are digitized using a Calma model 302 digitizer.

Daily Sediment Loads

Daily and monthly total sediment loads in tons are computed from hand abstracts of time-discharge-concentration.

DIGSED

Similar to above except that the time-discharge-concentration data are digitized using the Calma digitizer.

DIFCOR

Optimizes the parameters of nonlinear models using the method of differential corrections in connunction with multivariate statistics.

PATSEAR

Uses the pattern search method for optimizing the parameters of a nonlinear model. The program has generally been found to work better than the DIFCOR approach.

Factor Analysis

Uses the multivariate statistical technique of factor analysis to reduce the dimensionality of a set of variables into a reduced set of orthogonal vectors that explain some preset percentage of the original variance.

GAFUUG

Fits a three-parameter gamma function to a unit hydrograph.

APPENDIX 7

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

Denver, Colorado 80225

Reference: Abstracts of Electronic Computer Programs, developed by the Bureau of Reclamation, Electronic Computer Program Abstracts Issue No. 5, February 1969.

This reference carries the notation: "For information concerning the programs, contact the originating organization. The organization and its mailing code are shown in each program abstract. Addresses for Reclamation Bureau Offices are shown below."

There may be a charge for listings and source decks. AUTOMATH 800 is the Honeywell version of FORTRAN II. AUTHMATH 1800 is the Honeywell version of FORTRAN IV.

Symbols for USBR Offices

OCE	Office of Chief Engineer, Bureau of Reclamation, Denver Federal Center, Denver, Colorado 80225
R1	Region 1 Office, Bureau of Reclamation, Post Office Box 937, Boise, Idaho 83701
R2	Region 2 Office, Bureau of Reclamation, 2800 Cottage Way, Sacramento, California 95825.
R3	Region 3 Office, Bureau of Reclamation, Post Office Box 427, Boulder City, Nevada 89005.
R4	Region 4 Office, Bureau of Reclamation, Post Office Box 11568, Salt Lake City, Utah 84111.
R5	Region 5 Office, Bureau of Reclamation, Post Office Box 1609, Amarillo, Texas 79105.
R6	Region 6 Office, Bureau of Reclamation, Post Office Box 2553, Billings, Montana 59103.
R7	Region 7 Office, Bureau of Reclamation, Building 20, Denver Federal Center, Denver, Colorado 80225.
SPRP	South Platte River Projects Office, Bureau of Reclamation, Post Office Box 449, Loveland, Colorado 80537.
KRP	Kansas River Projects Office, Bureau of Reclamation, Post Office Box 737, McCook, Nebraska 69001.

Symbols for USBR Offices (Continued)

SCDO Southern California Development Office - Region 3, Bureau of Reclamation, 528 Mountain View Avenue, San Bernardino, California 92402.

PROGRAMS

File No.	Descriptive Name of Program	Office
HY-100A	PSANDS - Total Sediment Load Computations	OCE
HY-104	Hazen-Type Frequency Analysis ($2.75)	OCE
HY-105	Computation of Area and Capacity Tables ($5.05)	OCE
HY-105C	Reservoir Area Capacity Tables	OCE
HY-107	Reservoir Operation Study--Maxwell Project	OCE
HY-110	Frequency Distribution	KRP
HY-111	Hazen-Type Frequency Computations	KRP
HY-114	Reservoir Area Capacity Table Computation	R2
HY-115	CVP Coordinated Water Operations Study	R2
HY-116	Water Supply and Reservoir Operation Studies	OCE
HY-117A	Western Division, MRB, Annual Operating Plan	SPRP
HY-121	East Side System Water Operations Study	R2
HY-122	Input Compiler for CVP Coord Water OP Study	SPS
HY-124	Fry-Ark Operation Study	R7
HY-125	Extended Runoff Records	R2
HY-126	Western Division - MRB 36 Year Operation Study	SPRP
HY-128	Water Surface Profile	R2
HY-129	Edit River X-Section Data for Plotting	OCE
HY-130	Reservoir Routing by Modified Puls Method	OCE
HY-131	Flood Hydrograph by Unitgraph Procedure	OCE
HY-132	Area-Capacity Tables	KRP
HY-133	Fry-Ark West Slope Collection System Sizing	R7
HY-134	Buffalo Bill Reservoir 26 Year Operation Study	SPRP
HY-135	Flow Duration Analyses of Stream Flow Records	OCE
HY-136	Flood Study Hydrograph Computation	R2
HY-138	Depth-Duration Analysis	OCE
HY-139	Irrigation Requirements	KRP
HY-140	Forecast of Water Supply and Requirements	R2
HY-141	Western Division-MRB February-March OP Plan	SPRP
HY-142	St. John River Operation Studies	SPRP
HY-144	Western Division - MRB April-May Operating Plan	OCE
HY-147	Flood Hydrograph Using Triangular Unitgraph	OCE
HY-148	Rain-on-Snow Computations	OCE
HY-148A	038-Rain-On-Snow Computation (6600)	OCE
HY-148B	023-Rain-On-Snow Computation--Phase I	R2
HY-148C	024-Rain-On-Snow Computation--Phase II	R2
HY-149	Passamaquoddy Tidal Power Plant Operation	R2
HY-150	Reservoir Operations	KRP
HY-151	Consumptive Use of Water	KRP
HY-152	002-Lahontan Reservoir Operation Study	R2

File No.	Descriptive Name of Program	Office
HY-153	015-Water Quality Analysis	R2
HY-154	020-Lake Evaporation Study	R2
HY-155	027-Ventura River Study	R2
HY-157	034-Groundwater Hydrograph Plot	R2
HY-158	036-Pre-Washoe Operations Study	R2
HY-159	Reservoir Operation Study--Vail	SCDO
HY-160	Reservoir Operation Study--Fallbrook and Deluz	SCDO
HY-161	Evapotranspiration and Irrigation Efficiencies	OCE
HY-163	Lower Colorado River Hourly Flow Predictions	OCE
HY-164	Lower Colorado River Daily Operations Studies	OCE
HY-165	Lower Colorado River Monthly Operations Studies	OCE
HY-166	Middle Colorado River Hourly Flow Predictions	OCE
HY-167	PSEUDO - Computation of Water Surface Profiles	OCE
HY-169	Reservoir Capacity and Filling Time	OCE
HY-170	Water Surface Profile for Canal Systems	OCE
HY-171	Area of Stream Cross-Section	SCDO
HY-172	037-Total Sediment Load Computation (6600)	R2
HY-174	N. Platte R. Storage Water Ownership Accounting	OCE
HY-175	065-Washoe Operations Study	R2
HY-176	066-Tehama-Colusa Canal Drainage Report	R2
HY-177	070-Tailwater Computations	R2
HY-178	072-Water Surface Profile	R2
HY-179	076-Automatic Downstream Gate Control (CDC-6600)	R2
HY-180	077-Stochastic Operation Studies	R2
HY-181	079-Watasheamu Operation Study	R2
HY-182	081-Canal Gradient Generator	R2
HY-183	084-Flood Frequency (CDC-6600)	R2
HY-184	085-Flood Freq. (CDC-6600 Corps of Engineers)	R2
HY-186	094-Input Generator for Program No. 95, (HY-187)	R2
HY-187	095-Reservoir Temperature Prediction (CDC-6600)	R2
HY-188	096-Weibull-Gumbel Flow Frequency Plot	R2
HY-190	101-Cross Drainage by California Culvert Method	R2
HY-191	102-Flood Flow Frequencies Plot	R2
HY-192	104-Gate Opening for Lake Tahoe Dam	R2
HY-193	105-Discharge Table for DMC Check No. 1.	R2
HY-194	107-Carson and Truckee Basin Operation Study	R2
HY-195	108-Computing Drawdown in a Well Field	R2
HY-196	110-Groundwater Data Control	R2
HY-197	115-San Luis Water Accounting (CDC-6600)	R2
HY-198	116-Flow Table Analysis	R2
HY-199	118-Accumulated Flow Program	R2
HY-200	120 & 120P-Flood Study Hydrograph	R2
HY-202	127-Reservoir Area-Capacity Tables (CDC-6600)	R2
HY-203	132-Discharge Table for Cachuma Dam	R2
HY-204	133-Water Surface Profile Computation (CDC-6600)	R2
HY-205	134-Lower Trinity Initial Filling	R2
HY-206	135-CVP-SWP Division of Uncontrolled Flows	R2
HY-207	146-Reservoir Inflow Forecasting Equation	R2
HY-208	202-Hydrograph Plot-Hydrology	R2
HY-209	117-California Framework Water Balance	R2
HY-210	129-Drought Analysis (CDC-6600)	R2
HY-211	144-Res. Op. Study Computer Ass'n Pack (CDC-6600)	R2

File No.	Descriptive Name of Program	Office
HY-212	707-Sacramento River Contracting Program	R2
H-107	Vol. and Wetted Surface Areas for Small Ponds	OCE
H-109	Statistical Analyses of Piezometer Data	OCE
H-110	Seepage Loss From Small Canals and Laterals	OCE
H-114	Computation of Venturi Meter Discharge Tables	OCE
H-117	Radioisotope Discharge Measurements	OCE
H-118	Water Surface Profiles by Standard Step Method	OCE
H-118A	Water Surface Profiles by Standard Step Method	OCE
H-119	Critical Depth Computations for Venturi Flumes	OCE
H-122	Irrigation Discharge Quantities	KRP
H-124	Orifice-in-Series Control for Automatic Gates	OCE
H-127	Flow Net for Abrubt Offsets in a Canal	OCE
H-128	Venturi Meter Calibration	OCE
H-129	Seepage Loss Calculations for General Ponds	OCE
H-130	Spillway Flow Table Computations	R2
H-131	Volume and Wetted Surface Area Calculations	OCE
H-132	Dynamic Pressures in Stilling Basins	OCE
H-133	Pitometer Velocity Data Analysis	OCE
H-134	Groundwater Flow by Relaxation Methods	OCE
H-135	Hydraulic Transients in Pump Discharge Lines	OCE
H-136	Cross Sectional Computations for Tractive Force	OCE
H-137	Velocity Distribution in Pumping Plant Intakes	OCE
H-140	Seepage Discharge from Flatbottom Ponds	OCE
H-141	Seepage from Ponds With Known Vols and Surface	OCE
H-142	Prototype Pressure Computations in Slide Gates	OCE
H-143	Rejection Surges in Trapezoidal Channels	OCE
H-144	Flow Index Calibration Curve Equation	OCE
H-145	Analysis of Waterhammer in Pipeline Systems	OCE
H-145A	Analysis of Waterhammer in Pipeline Systems	OCE
H-146	Attenuation of Surge by a Lateral Spillway	OCE
H-147	Hydraulic Transients in Closed Conduits	OCE
H-148	Air Chamber Analysis	OCE
H-149	Surge Tank Analysis	OCE
H-150	Determination of Hydraulic Parameters-Canals	OCE
H-151	Hyd. Transients in Variable-Pitch Pump-Turbines	OCE
H-152	Drawdown Curves with Curvilinear Flow	OCE
H-153	Seepage Meter Calculations	OCE
H-154	Data Reduction for Canal Hydraulic Parameters	OCE
H-155	Preston Boundary Shear Tube Calibration	OCE
H-157	35 Hydraulic Subroutines	OCE
H-158	Headworks Dimensions and Hydraulics	OCE
H-159	Pressure and Thrust at Pipe Bends	OCE
H-160	Hydraulic Prop. Flat Bottom Horseshoe Tunnel	OCE
H-161	Hydraulic Properties Unlined Horseshoe Tunnel	OCE
H-162	Pump Test Data Evaluation	OCE
H-163	USBR Powerplants with Pertinent Turbine Data	OCE
H-164	Empirical Equation for Ideal Specific Speed	OCE
H-165	Selection of Hydraulic Turbines	OCE
H-166	Hydraulic Turbine Efficiency Test	OCE
H-167	Turbine Runner Discharge Area Calibration	OCE

File No.	Descriptive Name of Program	Office
H-169	Backwater Curves in Circular Pipe	OCE
H-171	Hydraulic Properties of a Chute	OCE
H-172	Economic Design of Pumped Pipe Systems	OCE
H-173	Economic Design of Gravity Pipe Systems	OCE
H-174	Airflow Comp. Morrow Point Dam	OCE
H-178	Discharge Computation in Circular Pipes (CDC-6600)	OCE
M-110	Linear Regression Analysis	R1
M-113	Simple Correlation and Regression Analysis	R7
M-115	Multiple Correlation	R2
M-117	Least Square Fit of Arbitrary Function to Data	OCE
M-118	Least Squares Polynomial Fit	OCE
M-119	Solution of Quadratic Equation	OCE
M-120	Solution of General Cubic Equation	OCE
M-121	Cubic Solution for Incrementing Constant.	OCE
M-125	Curve Fitting of Y = YMAX (1-E**(-R(X-XO)))	OCE
M-126	Square Root - Floating Binary - Alfa Subroutine	OCE
M-127	ARC-SINE or ARC-COSINE-FLOATING Binary Alfa Sub	OCE
M-128	Complex Polynomial Evaluator-Float Bin Alfa Sub	OCE
M-129	Real Polynomical Evaluator-Floating Bin Alfa Sub	OCE
M-130	One-Way Analysis of Variance and "T" Test	OCE
M-131	Two-Way Analysis of Variance and "F" Test	OCE
M-132	General Curve Fit Program	OCE
M-133	Polynomial Solution - Bairstows Method	OCE
M-136	082-Graphical Correlation Plot	R2
M-137	088-Multiple Regression Analysis	R2
M-139	091-Polynomial Curve Fitting	R2
M-140	128-Log-Flow Statistics (CDC-6600)	R2

APPENDIX 8

FEDERAL HIGHWAY ADMINISTRATION

AND STATE HIGHWAY DEPARTMENTS

The following programs are taken from:

"AÀSHO Computer Program Index"
Subcommittee on Electronics, Nov. 10, 1969

Included are programs developed by the Federal Highway Administration as well as various state highway departments.

Program	Description
1200	HY-1 used for hydraulic analysis of circ. pipes. given hydrological data and site cond. produces no. pipes, sizes, headwater and outlet vel., inlet and outlet cond. available from FHWA
1300	HY-2 used for hydraulic analysis or pipe-arches given hydrological data and site cond. selects size considering inlet and outlet control.
1400	HY-3 used for hydraulic analysis of boxes given hydrological data and site cond. determines size of culvert which satisfies data and site cond. for inlet and outlet control. Available from FHWA.
1500	HY-4 computes bridge backwater. Theory followed is in hydraulics of bridge waterways by J.M. Bradley, Bureau of Public Roads, 1969. Available from FHWA.
1600	HY-5 files gaging station flood records. Produces a compilation of flood records, frequently plot and index of the gaging stations.
1041 CAL	Hydraulic design of culverts converted from BPR Hyd Engr Circular No. 7.
0070 IND	Determines peak discharge rates of runoff based on BPR hyd. design 2 and hyd. circular no. 4.
001A MO	Backwater. Computes amount of intercept and bypass for given opening lengths using gutter flow output. Lilley - Beatte AV-AB, LT.
0010 MO	Gutter flow. Computes quantity of water and length of opening for given slopes and gutter sections. Lilley - Beatte AV-AV, LT.
2010 MONT	Hydraulics of bridge waterways (a modified version of BPR program HY-4) This program computes slope of channel, normal stage, and backwater for up to 99 trial constrictions.

Program	Description
1520 NJ	Backwater curve Computes water surface profile in an open channel
0010 NM	Hydraulics of bridge waterways version 1 -HY-4 from Bureau of Public Roads. Card to card.
0020 NM	BPR Program HY-4. Hydraulics of bridge waterways version 2. Converted to operating system.
0030 NM	BPR Program HY-3. Hydraulic analysis of box culverts. Converted to operating system.
0040 NM	BPR Program HY-1. Hydraulic analysis of circular culverts. Converted to operating system.
0050 NM	BPR Program HY-2. Hydraulic analysis of pipe-arch culverts. Converted to operating system.
4400 OHIO	Ditch analysis-analyze standard roadway ditches, special ditches and median swales. 440.00
1210 OKLA	Design and analysis of roadway culverts. A combined program to handle box culverts, circular pipes, and pipe-arches in one execution. Adapted from BPR HY-series.
1220 OKLA	Hydraulic analysis of roadway culverts. Input size Q and tailwater. Output headwater velocity and whether inlet or outlet control. Pipes and boxes.
0010 PENN	Synthetic Hydrograph.
0020 PENN	Backwater curve.
0030 PENN	Hydraulic design - Bridge waterway openings including backwater curve.
1010 TEX	Computes stage discharge relationships in stream channels.
1030 TEX	Describes a method whereby annual maximum flood records can be stored, retrieved, and displayed for use by engineers involved in the design of a stream crossing.
1040 TEX	Calculates water surface profile through a broken back culvert.
1050 TEX	Carries through a hydraulic design of culverts from discharge determination through culvert dimensions.

Program	Description
1080 TEX	An integrated system of programs for highway hydraulic design and analysis. Avail. 1st QTR 70.
1300 VA	Flow profile computations (direct step). This program given increments in depth plus various constants for the channel computes channel velocity, distances between the given depths and a summation of these distances. Operational DDCUM. Inc.
1310 VA	Flow profile computations (standard step). Using cross-section data, discharges and other controls, this program computes water surface profiles along natural stream channels.
2180 VA	Hydraulics of bridge waterways (modified BPR HY-4). This program generally analyses the effect of a structure in a stream.
0010 WASH	Storm sewer design. Given areas, imperv. factors, computes runoff to storm sewer system. Given begin pipe elev., slope dist., Manning N., computes pipe sizes and invert elevations.
0010 WISC	Hydraulic analysis for pipe arch, box culvert, and circular culvert.

APPENDIX 9

UNIVERSITY OF MINNESOTA

ST. ANTHONY FALLS HYDRAULIC LABORATORY

AND CIVIL ENGINEERING DEPARTMENT:

1) Log Pearson TYPE III Frequency Analysis - SAFHL Computer Program No. 1, by C.E. Bowers, A.F. Pabst, and S.P. Larson.

2) Water Surface Profiles in Prismatic Channels - SAFHL Computer Program No. 2, by C.E. Bowers.

3) Water Surface Profiles in Natural Channels - SAFHL Computer Program No. 3, by S.P. Larson.

4) Hydraulic Network Analysis I and II.

5) UROM-66 (Urban Math Model).

6) VELO (Routing by Method of Characteristics).

7) MAIN (Characteristic Routing for Sewer Network)

(Reports are or will soon be available on items 1, 2, and 3).

Associated Routines

1) Normal Depth

2) Critical Depth

3) Critical Depth by Minimum Specific Energy

4) Merge-Sorting

5) Area and Perimeter from Coordinates

6) Interpolation routine for irregularly spaced data

APPENDIX 10

UNIVERSITY OF MINNESOTA

COMPUTER CENTER LIBRARY

SUBROUTINES AND STATISTICS PROGRAMS

These are included as an example of programs and subroutines available in many computer libraries

6600 Library Systems and Subroutines

Name	Description
MF501	Process display code for off-line microfilm facility
REMARK	Send comment to console and dayfile
TIME	Output current time in seconds and 1/1000 seconds
SECOND	Output time in seconds
DATE	Output current date typed in by operator at console
JDATE	Output - Julian - Date
CLOCK	Output current reading of system clock in hrs, min., secs
CTIME	Output central processor time use in seconds
ICPTIME	Output central processor time in milliseconds
PLOTPAC	Graphical plotting done on the CDC 165 CALCOMP plotter
PRNPLOT	Graphical plotting done on the printer
SCLPLT	Automatically scaled graphical plotting done on printer
LRSHFT	Left or right shift of 60-bit number
BUFF	Read and write long BCD or binary tape records
LOCORE	Read words from anywhere in central memory
ICOUNG	Count the number of bits in a central memory word
GREADS	Coded record input routine (Fortran extended, only)
*CONST	Important constants contained in labelled common blocks
*LEGAL	Tests for infinite, indefinite or un-normalized numbers
LOCF	Integer address of argument
XLOCF	Integer address of argument
LENGTH	Return numbers of words read on unit I after buffer in
*QLENGTH	Return users field length
*BLNKZRO	Converts blanks to 00 display codes
*ZROBLNK	Convert 00 display codes to blanks
*FLOT46	Convert CDC 1604 floating-poing numbers to 6600 floating-point
*CMPSDMP	Compass dump of binary words
READMS	Mass storage random file read routine
WRITEMS	Mass storage random file write routine
OPENMS	Mass storage random file open routine
STINDX	Mass storage random file store-index routine
*RESETFL	Reset field length routine

* Denotes write-up not available

Polynomials and Special Functions

RVAL	Evaluation of a real polynomial
DVAL	Evaluation of a double-precision polynomial
CVAL	Evaluation of a complex polynomial

Name	Description
PLROOT1	Complex roots of real polynomial
PLROOT2	Double precision roots of PLROOT1 and PLROOT3
PLROOT3	Complex roots of complex polynomial
ROOT1	Nonlinear function root finder
NLSYSTEM	Nonlinear system of equations root finder
BESJ	Bessel function of the first kind
CBIN	Real (floating point) binomial coefficient generator
IBIN	Integer binomial, coefficient generator
CDFN	Cumulative normal distribution function
CDFNI	Inverse of CDFN
ERFN	Error function
EI	Exponential integral
CAMMAF	Bamma and Beta functions, factorial power
CELIPFE	Complete elliptic integrals, first and second kinds
EILIPFE	Incomplete elliptic integrals, first and second kinds

Operations on functions and solutions of differential equations

SIMPSON	Integration of tabular data by Simpsons rule
ROM1F	Integral from A to B of F (X) DX
ROM2F	Integral from A to B of F (X) DX with error control
XINT	Gaussian multiple numerical integration
DXINT	Double-precision gaussian multiple numberical integration
CINTEG	Complex line integral (type complex variables)
RK	Differential equation solver with variable step and error control
RKGILL	Differential equation solver, tabular data (equally spaced points)

Interpolation and Approximations

AITKENF	Aitkens method interpolation
LINT	Lagrange polynomial interpolation
ORTHON	Least squares or regression with arbitrary functions
LSQORPY	Least squares with orthogonalized polynomials

Operations on Matrices, Vectors and Simultaneous Linear Equations

MXMOV	Move + or - Matrix A to B
MXCMBN	Matrix A + or - Matrix B to C
MXMPLY	Product of Matrices A and B to C (C may be A)
MXMPLY1	Produce of Matrices A and B to C (C may be B)
MXTRP	Transpose a retangular matrix.
MXTRP1	Transpose large rectangular matrices in place
MXTRIDI	Solve a tri-diagonal linear system
SYMINV	Symmetric matrix inverse, lin. equation and determinant solver
SYMSOLV	Solve a symmetric linear system
SYMSOLU	Solve a packed symmetric linear system
SYMPACK	Pack symmetric matrix for SYMINV, SYMSOLU
SYMUPK	Unpack symmetric matrix for SYMINV, SYMSOLU

Name	Description
MXLNEQ	Solve linear equations, determinant, and inverse
CMXLNEQ	Complex array matrix inverse, Lin. equation and determinant solver
QRSYM	Eigenvalues, Eigenvectors of real packed symmetric matrices
EIG3	Eigenvalues, eigenvectors of real non-symmetric matrices
QRCMPLX	Eigenvalues, eigenvectors of complex non-Hermitain matrices
RVECT	Real eigenvectors of real matrix when given the eigenvalue
CVECT	Complex eigenvectors of complex matrix when given the eigenvalue
RCVECT	Complex eigenvectors of real matrix when given the complex eigenvalue

Statistical Analysis and Probability

NRAN	Random integer generator in partially specified closed interval
IRAN	Random integer array generator in partially specified closed interval
PERMUTE	Random sampling without replacement (permutation)
RAN2F	Random real array generator, rectangular distribution (0,1)
RAN3F	Random real array generator, rectangular distribution (A,B)
NORMAL	Random real array generator, normal distribution (0,1)
RANBIN	Random array of bytes from 30 to 60 bits long
RANF	Random number of generator (CDC)
AMEAN	Mean of an array
MEANVAR	Mean and unbiased variance of an array
MXEXTRM	Maximum and minimum values of an array
CONVERT	Date conversion to uniform or given class intervals
FREQDSN	Frequency distribution of array S8 raw data
IVLFREQ	Frequency distribution for class intervals
CHSQ	Probability given CHI-Square and DF
CHSQI	CHI-Square given probability and DF
FVR	Probability given F and DF
TTEST	Probability given T and DT
TINV	T given probability and DT
BETAI	Incomplete Beta function distribution

Information Processing

CHECK	Missing data input conversion
MERGE2	Merge two sorted arrays
MERGE4	Merge two sorted arrays carrying two arrays
SORT1	Numeric sort of array
SORT2	Numeric sort of array carring corresponding elements of another
GENSORT	General sort of array
GENREAD	General card-reading routine

Miscellaneous

DESCRIB	Frequency domain analysis for control systems
LOCUS	Root LOCUS subroutine

Name	Description
ALGOL	ALGOL-60 Processor (see CDC manual)
ALMAP	Algebraic symbol manipulation system
BASIC	Dartmouth-G.E. basic interpreter
BMD	UCLA biomedical statistics programs (see UCLA manual)
COBOL	COBOL compiler (see CDC manual)
COMPASS	6400/6500/6600 assembly language (see CDC manual)
FUN	Fortran compiler (see CDC manual)
FTN	Fortran extended compiler (see CDC manual)
KWIC	Keyword-in-context program (see CDC manual)
LIST	Lisp 1.5.6 list-processing language interpreter
MIMIC	Analog computer simulator
MNF	Minnesota debugging, diagnostic, student-oriented Fortran compiler
MODIFY	Coded file update program
PERT	Pert/time analysis (see CDC manual)
RUN	Fortran compiler (see CDC manual)
SIMSCRIPT	Simscript simulation language compiler (see CDC manual)
SLIP	Symmetric list processing system
SNOBOL	IDA snobol - IV list-processing language interpreter
SORT-MERGE	CDC sort/merge program (see CDC manual)
TRANS	Translate ascent to compass (see CDC manual)
TRIAL	Information retreival for abstracts of literature
UPDATE	Coded file update program (see CDC scope 3.1 manual)

University of Minnesota Statistical Program (UMST)

UMST500 — CORRELATION AND MULTIPLE LINEAR REGRESSION
This program performs a correlation analysis followed by a multiple linear regression. This program does not handle missing data.

UMST510 — ANALYSIS OF VARIANCE, EQUAL FREQUENCIES
1) Analysis of variance for a complete factorial design (that is, sums of squares, mean squares, and degrees of freedom which appear in an analysis of variance table).

UMST520 — CHI-SQUARE
This program computes the chi-square criterion on two-way frequency tables.

UMST530 — MISSING DATA CORRELATION
This program computes:
1) Pearsonian correlation coefficients for all possible pairwise combinations of input variables (approximately 130 maximum for our 65K 6600).
2) Means, variances, convariances, and standard deviations.

UMST540 — NONPARAMETRIC (RANK ORDER) STATISTICS
This program computes:
1) Kruskal-Wallis One Way Analysis of Variance
2) Spearman Rank Correlation
3) Kendall Rank Correlation
4) Kendall Coefficients of Concordance

Name	Description
UMST550	CORRELATION AND ORTHOGONAL FACTOR ANALYSIS This program performs correlation analysis followed by orthogonal factor analysis.
UMST560	LEAST SQUARE CURVE FITTING USING ORTHOGONAL POLYNOMIALS Using a modified method of least squares, this program fits polynomials to pairs of input data vectors. It first calculates a polynomial of degree 1, then of degree 2, and so on up to the degree of the polynomial specified.
UMST570	MULTIVARIATE ANALYSIS OF VARIANCE This program performs multivariate analysis of variance and/or covariance on a vector of dependent variables.
UMST580	STEPWISE REGRESSION This program performs stepwise linear regression.
UMST590	CROSS TABULATION This program generates a cross-tabulation, i.e., a bivariate frequency distribution, for pairs of variable. As an option, a distribution may be formed for each value of a third variable or for each pair of values of a third and a fourth variable, i.e., using one or two control variables.
UMST600	DESCRIPTIVE STATISTICS This program computes and prints the following for each variable: 1) ΣX, ΣX^2 $\Sigma(X-\overline{X})^2$, mean, variance, standard deviation 2) ΣX^3, ΣX^4, $\Sigma(X-\overline{X})^3$, $\Sigma(X-\overline{X})^4$ (optional) 3) Maximum value, minimum value (optional) 4) X value (from largest to smallest), frequency, cumulative proportion, absolute proportion (optional).
UMST610	GENERAL LINEAR HYPOTHESIS FOR ANOVA, UNEQUAL FREQUENCIES This program analyzes the statistical significance of dependent variables for those experimental designs that can be formulated in terms of the General Linear Hypothesis model.
UMST620	CHI-SQUARE FROM RAW DATA This program computes and prints the following: 1) A frequency distribution of two variables based on intervals supplied to the program. 2) A check of all the frequencies as calculated above to determine if all are equal to or above the given frequency supplied to the program. If cell frequencies are below this value, they are printed out and the problem terminated. (optional)
UMST630	SINGLE AND SIMULTANEOUS (TSLS, LISE) EQUATION AND REGRESSION PACKAGE This is a multi-purpose program designed to estimate the coefficients of a multiple regression model or a simultaneous equation model. Three estimation techniques are available to the user: ordinary least squares (OLS); two stage least squares (TSLS); and limited information maximum likehood (LISE).

BMD

The Biomedical Computer (BMD) Programs are generalized "packaged" statistical programs for use in the analysis of large amounts of recorded data. The type of programs and their specific form have been guided by the demands arising in the UCLA Medical Center for statistical and mathematical procedures to assist with many different research problems.

The following is a list of the BMD programs by class:

Class D	Description and Tabulation
BMD01D	Simple Data Description
BMD02D	Correlation with Transgeneration
BMD03D	Correlation with Item Deletion
BMD04D	Alphanumeric Frequency Count
BMD05D	General Plot Including Histogram
BMD06D	Description of Strata
BMD07D	Description of Strata with Histogram
BMD08D	Cross-Tabulation with Variable Stacking
BMD09D	Cross-Tabulation, Incomplete Data
BMD10D	Data Patterns for Dichotomies
BMD11D	Data Patterns for Polychotomies

Class M	Multivariate Analysis
BMD01M	Principal Component Analysis
BMD02M	Regression on Principal Components
BMD03M	Factor Analysis
BMD04M	Discriminant Analysis for Two Groups
BMD05M	Discriminant Analysis for Several Groups
BMD06M	Canonical Analysis
BMD07M	Stepwise Discriminant Analysis

Class R	Regression Analysis
BMD01R	Simple Linear Regression
BMD02R	Stepwise Regression
BMD03R	Multiple Regression with Case Combinations
BMD04R	Periodic Regression and Harnomic Analysis
BMD05R	Polynomial Regression
BMD06R	Asymptotic Regression

Class S	Special Programs
BMD01S	Life Table and Survival Rate
BMD02S	Contingency Table Analysis
BMD03S	Biological Assay: Probit Analysis
BMD04S	Guttman Scale Prepocessor
BMD05S	Guttman Scale #1
*BMD06S	Guttman Scale #2, Part 1
*BMD07S	Guttman Scale #2, Part 2
*BMD08S	Guttman Scale #2, Part 3

* = Not implemented at the UCC.

BMD09S	Transgeneration
BMD10S	Transposition of Large Matrices
<u>Class T</u>	<u>The Series Analysis</u>
BMD01T	Amplitude and Phase Analysis
BMD02T	Autocovariance and Power Spectral Analysis
<u>Class V</u>	<u>Variance Analysis</u>
BMD01V	Analysis of Variance for One-Way Design
BMD02V	Analysis of Variance for Vactorial Design
BMD03V	Analysis of Covariance for Vactorial Design
BMD04V	Analysis of Covariance with Multiple Covariates
BMD05V	General Linear Hypothesis
BMD06V	General Linear Hypothesis with Contrasts
BMD07V	Multiple Range Tests
BMD08V	Analysis of Variance