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OPSET Program for Computerized Selection of Watershed Parameter Values for the Stanford Watershed Model

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Research Report No. 34

OPSET
PROGRAM FOR COMPUTERIZED SELECTION OF WATERSHED PARAMETER VALUES FOR THE STANFORD WATERSHED MODEL

Earnest Yuan-Shang Liou

Part 1 of a completion report describing work supported in part by the Office of Water Resources Research, Department of the Interior, under provisions of Public Law 88-379, as Project Number C-1282 under Title II Research Grant No. 14-01-0001-1964.

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Lexington, Kentucky
1970

INTRODUCTION

Land use control in the tributary watershed as well as in the flood plain has been receiving increased attention as a method for reducing flood damage. One of the most complex technical questions which has to be resolved in structuring the appropriate use of this alternative is how downstream flood hazard varies with tributary watershed conditions. The approach to this problem in this research sponsored through the University of Kentucky Research Foundation and supported in part by funds provided by the United States Department of the Interior as authorized under Title II of the Water Resources Research Act of 1964, Public Law 88-379, revolved around using the Stanford Watershed Model as a tool for correlating runoff patterns with land use through model parameters as intermediate variables. The completion report for the project is in three parts.

1. Liou, Earnest Y. OPSET: Program for Computerized Selection of Watershed Parameter Values for the Stanford Watershed Model. Lexington: University of Kentucky Water Resources Institute, Research Report No. 34, 1970.

2. Ross, Glendon A. The Stanford Watershed Model: The Correlation of Parameter Values Selected by a Computerized Procedure with Measurable Physical Characteristics of the Watershed. Lexington: University of Kentucky Water Resources Institute, Research Report No. 35, 1970.

3. James, L. Douglas. An Evaluation of Relationships Between Streamflow Patterns and Watershed Characteristics Through Use of OPSET: A Self-Calibrating Version of the Stanford Watershed Model Lexington: University of Kentucky Water Resources Institute, Research Report No. 36, 1970.

The first of the reports describes the development of OPSET, a version of the Stanford Watershed Model programmed to estimate best-fit values of watershed parameters directly from climatological and streamflow data, and contains a program listing. The second report describes the application of OPSET to 17 rural watersheds and correlations derived between model parameters and watershed characteristics. It also describes and examines the significance of changes noted in parameter values with urbanization in three other watersheds. The third report applies the findings of the first two to flood control management problems. The results on all three levels have been highly encouraging. The three reports need to be read together for a complete understanding of the research approach.

The study is indebted to many besides the sponsors. Considerable use was made of the facilities of the Water Resources Institute and of the Computing Center at the University of Kentucky. Much of the data was obtained through A. B. Elam, Jr., Kentucky State Climatologist and the Louisville Office of the U.S. Geological Survey. Miss Nancy Crewe and Miss Patricia Miller prepared the reports.

ABSTRACT

The advent of high-speed electronic computer made it possible to model complex hydrologic processes by mathematical expressions and thereby simulate streamflows from climatological data. The most widely used program is the Stanford Watershed Model, a digital parametric model of the land phase of the hydrologic cycle based on moisture accounting processes. It can be used to simulate annual or longer flow sequences at hourly time intervals. Due to its capability of simulating historical streamflows from recorded climatological data, it has a great potential in the planning and design of water resources systems. However, widespread use of the Stanford Watershed Model has been deterred by difficulties in understanding and finding a computer sufficiently large to run the bulky program. More important, the estimation of values for key parameters was both time-consuming and subjective as it had to be done by trial and error.

The objective of this study is to develop a computerized parameter optimization procedure, a self-calibrating watershed model, based on the FORTRAN version of the Stanford Watershed Model known as the Kentucky Watershed Model. This computerized procedure is named OPSET because its objective is to determine an <u>op</u>timum <u>set</u> of parameter values. The basic approach of OPSET is to match synthesized flows with recorded flows. The first step is by sensitivity studies to determine which key watershed parameters are sensitive in the simulation of flows and are difficult to measure or estimate directly. The second step is to devise a scheme for adjusting numerical estimates of the selected key parameters systematically improving flow simulation until the best possible matching is achieved

and to program this scheme into a streamlined Kentucky Watershed Model. Independent adjustment schemes are used for parameters associated with simulating runoff volumes, recession flows and flood hydrograph. The third step is to empirically test and improve this self-calibrating watershed model by applying it to a number of watersheds in Kentucky. OPSET estimates selected watershed parameters on a one water year basis, and the values of parameters best describing the watershed characteristics should be averaged from several OPSET-selected one-year-based values.

In applying OPSET to over 20 Kentucky watersheds which represent quite a wide range of topographic and soil conditions, this model was found to be rather successful. It is able to simulate streamflows and find more consistently estimated parameter values than the trial-and-error approach. The time spent on calibrating the watershed parameters is greatly reduced. The user does not have to spend so much time familiarizing himself with the program before he can properly use the Model. The program uses standardized criteria which reduce the subjectivity of estimating parameter values.

The recommendation is made that OPSET should be applied to areas where the climatological setting and geographical conditions differ from Kentucky in order to refine and modify it for a wider range of applicability. Also, the Model itself needs periodic updating in order to take advantage of subsequent empirical relationships or moisture accounting procedures.

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CHAPTER I

HYDROLOGIC MODELING

THE MODELING CONCEPT

The high-speed electronic computer is revolutionizing hydrology. The capacity of the computer to store large volumes of data and to perform repetitious calculations has made hydrologic modeling a viable tool for the quantitative estimation of runoff. Chow (5*, pp. 29-1 to 29-2) points out

> "that hydrologic analysis and design necessitate processing a large amount of quantitative data which has been accumulating at a rapid rate, and that theoretical approaches have been gainfully introduced into modern quantitative hydrology and such approaches involve complicated mathematical procedures and models which can be solved practically only by high-speed computers."

A hydrologic model uses some analogous system to estimate the outcome of hydrologic processes. A model may represent only an individual hydrologic phenomenon (e.g., ground-water movement), or it may attempt to capture all the interacting processes determining catchment behavior. Some model builders have used a reduced scale laboratory replica of the natural system or an arrangement of analog components. Others have used mathematical expressions in digital computer programs. Each type of model seeks to simulate the physical response of a natural system to stimulation by climatological events and to study variation in the response as man changes the system.

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*This number refers to the list of references at the end of this report.

In 1964, Amorocho and Hart (1) classified the methodologies used in hydrologic research into two broad categories. One is devoted to scientific research into physical hydrology in an attempt to better understand the mechanisms and interactions within each component of the hydrologic cycle. The other has been motivated by the pressing need to solve practical problems and has therefore concentrated on establishing quantitative relationships between precipitation and streamflow from data describing the functioning of the runoff system as a whole.

The distinction is found in the two aspects of modeling: the overall model and the component model. The overall model lumps the combined effects of component hydrologic processes occurring at rates varying with time and over an area into a single analogy. If the entire runoff cycle is lumped together, the generation of streamflow from runoff is modeled by one transform which makes no pretense of representing physical processes. Overall models are largely empirically derived from observed patterns of inputs and outputs from the lumped system.

On the other hand, the component model attempts to portray the overall reaction of a system by summing the functioning of its component physical processes. The modeling is shifted from the system as a whole to a series of individual processes and becomes less empirical and more theoretical. As fewer processes are lumped in a given equation, the representation becomes more complex and computationally more time-consuming. The component processes used in any model can conceptually be further subdivided into a group of lesser processes, but experience with the overall results is needed to judge which lines of additional refinement are most productive.

THE STANFORD WATERSHED MODEL

The Stanford Watershed Model developed by Crawford and Linsley (10) is the pioneering effort modeling the runoff cycle from precipitation to streamflow by dividing overall watershed response into individual components each representing a known hydrologic process by an empirical expression. Each transform lumps the outcome of a process occurring at varying rates over a watershed segment and over a 15-minute period into a single estimate. Without lumping, even the most rapid computer could not simulate streamflow. With process-oriented lumping, a model makes the best use of information on process functioning.

The digital computer program models the whole of the land phase of the hydrologic cycle. The model utilizes a moisture accounting process to synthesize continuous streamflow from climatological data, measurable physical watershed characteristics, and a set of numerical values estimated for selected critical watershed parameters which govern key components of the runoff cycle (25, p. 15).

The Stanford Watershed Model has made a marked contribution to hydrologic research and water resources planning. The major obstacle to even wider use is the difficulty new users experience in estimating the numerous watershed parameter values required as input data. Some can be measured or approximated from raw data sources (25, pp. 40-47). A trial-and-error process has been used to estimate the other parameter values by adjusting them until achieving an acceptable matching between synthesized and recorded streamflows (10, 14). The calibration process is time-consuming, and each adjustment is subjective. Different investigators may end up with substantially different sets of parameter values for the same data.

In addition to these practical problems, use of a large number of parameters creates a conceptual difficulty. While a large number of parameters are required to index the large number of component hydrologic processes active between precipitation and runoff, one has to be cautious because any increase in the number of parameters increases the power of a model to match recorded flows irrespective of whether or not the parameters have any physical significance. Even though the model is designed on the basis of a conceptual representation of hydrologic processes, once one decides to estimate hydrologic-process oriented parameters by an essentially numerical test of best matching between recorded and simulated flows, he cannot be sure that the value resulting for a specific parameter retains its meaning in terms of the process as originally conceived. Carried to an extreme, one has no concrete assurance that the model actually represents real hydrologic processes; perhaps any complicated series of equations with a large number of variable parameters could do as well.

These two difficulties suggest two needs. The practical difficulty suggests the need for a computerized process for estimating parameter values in a consistent and an objective manner. The conceptual difficulty suggests the need to examine relationships between paired parameter estimates and the measured watershed characteristics known to relate to the relevant hydrologic process.

THE PHYSICAL SIGNIFICANCE OF PARAMETERS

The potential contribution of the Stanford Watershed Model to hydrologic teaching and research and to water resources engineering design, planning, and management can only be fully realized as the practical and theoretical difficulties associated with having a large number of parameters are overcome. Let us look more closely at what these parameters represent. Hydrologic processes are continually going on at rates varying in time and by location over a real watershed. The movement of moisture at any point is in response to acting forces (principally gravity) counteracted by the resistance to moisture movement along a given flow path and the resultant moisture queueing in low resistance zones because of high resistance areas ahead. Moisture movement would ideally be estimated from the physical factors known to govern saturated and unsaturated flow processes (including the size and shape of the particles; the porosity, orientation, and moisture content of the media; and the viscosity and surface tension of the water) and information on how these factors vary over the surface of the watershed and how the spatial patterns change with time.

Practically, the model builder must use lumped estimation. The parameters indexing the physical factors must reflect the attributes of a large area of watershed surface. In the Stanford Watershed Model (SWM), the user has the option of using the whole watershed of subdividing it into a limited number of segments, Area lumping does not require the factors to be taken as uniform over the area. The SWM uses assumed distributions between extreme values without specifying relative locations of different values on the watershed. The estimates must also be lumped over a finite interval of time (15 minutes in the SWM). They also often can be lumped to represent a group of related hydrologic processes (interception storage is added to depression storage in the SWM). Base flow recession constants represent the cumulative effect of moisture movement along a large number of routes.

Lumped estimates imply that watershed parameters somehow aggregate the effects over space, time, and process of spot parameters. Pragmatically, the best values are those that best model the flow. However, the set of parameter values best matching simulated to recorded flows will vary for a watershed among data covering different time periods with data measurement errors, spatial patterns of major storm sequences over the watershed, size of the area and length of time represented, etc. Furthermore, the best estimate of a parameter for use in modeling with 15-minute time increments is not necessarily the best estimate for use with 60-minute increments. The art of hydrologic modeling comes in being able to choose combinations for lumping which closely approximate known events with an acceptable computational effort. Two tactics come to mind for making the SWM parameters more closely match measurable watershed characteristics. One is to use a finer grid in space and time and a more thorough separation of hydrologic processes. Such an approach is limited by the cost of program execution and by our understanding of the processes. The other tactic is to make estimation of values for the lumped parameters as objective as possible in the hope that the resulting values will correlate with measurable watershed parameters and hypothesized hydrologic process divisions in a meaningful way. This is the goal of the study.

COMPUTERIZED OPTIMIZATION OF PARAMETER VALUES

Given the Stanford Watershed Model as a computational scheme operating on precipitation and evaporation data under the control of the values assigned for a set of lumped parameters, the estimation problem is to find the best set of values for these parameters. Mathematically, the problem can be visualized as a search in an n-dimensional vector space for the best set of values for the n parameters. The search requires an explicit definition of "best" and an ordered procedure for considering various points.

The mathematics of the search is complicated by the impossibility of analytically taking the partial derivative of any objective function with respect to each parameter and by physical limitations to acceptable parameter values. Dawdy and O'Donnell (12) adapted a computerized technique developed by Rosenbrock (24) to find best fit values for a set of nine parameters in a hydrologic simulation model using a coarser process grid than the SWM. They tested their optimization technique by simulating a sequence of flows, changing the parameter values to something else, and determining whether their optimization approach would return to the original set of values. Their major conclusion was that "the greater the sensitivity of the model response to a parameter, the closer and sooner will that parameter be optimized" (12, p. 133). They did not at that time report how their model or the optimization worked in the context of measured data for real watersheds. No other self-calibrating model could be found in the literature.

Thus the effort to program a computerized procedure for selecting the optimum set of parameter values for the Stanford Watershed Model began from a minimum contribution from the experience of others. The research turned into a long process of gradually expanding the program to work in a wider variety of situations.

STUDY OUTLINE

The Stanford Watershed Model was originally written in a digital computer language (BALGOL) used by the Stanford Computing Center. James translated it into FORTRAN IV and called his translated, revised, and expanded version the Kentucky Watershed Model (KWM). The objective of this study is to develop a self-calibrating watershed model based on the KWM. This model is named as OPSET because its objective is to determine the optimum set of parameter values in the watershed model.

The processes used to develop the self-calibrating model are given in Chapter II. Chapter III describes the structure of OPSET and the principles contained in its subroutine programs. Recommended procedures for use in applying the program are presented in Chapter IV.

Chapter V reviews the results and recommends further research.

Listings of the most recent version of the Kentucky Watershed Model, OPSET, and a dictionary defining and giving units for all parameters and all the other variables used in either program are provided in Appendices A, B, and C respectively. The reader should consult Appendix C for information defining all mnemonics used in the subsequent text.

Two companion reports supplement this study and provide background information which this report will reference rather than repeat. Ross (25) describes the details of collecting input data and discusses how OPSET-estimated parameter values vary with watershed characteristics such as soil depth and permeability and with urban change. James (16) reviews the accomplishments of the overall research project and makes specific applications to flood control hydrology.

CHAPTER II

THE DEVELOPMENT OF OPSET

THE BASIC MODEL

The Stanford Watershed Model has not been and in fact no regularly used large computer program can be a single fixed entity. It is continually changing. At Stanford, Crawford and Linsley designated five versions by number, and Crawford has continued updating the Model in his work at Hydrocomp International (14). Other users have made their own changes (6, 19). A number of different people are simultaneously using a number of different versions, each adapted to meet their own modeling requirements (2, 4, 15).

Some choice had to be made on a specific version to use in the development of OPSET. The version selected was the Fortran version of the Kentucky Watershed Model (KWM) which had previously been used to model runoff from several Kentucky watersheds (8, 13, 22). Each parameter was taken as defined by the programming in this version. Any change in the simulation programming which changes the flows simulated from a given deck of input data changes the relationship between the simulation parameters and physical watershed characteristics. A program estimating optimum parameter values would make compensating adjustments in the estimates to match a fixed set of measured flows.

Minor reprogramming to increase computational efficiency, to introduce some new options, and to revise output format were made to the KWM during the development of OPSET. The final KWM version (dated June 6, 1970) is listed in Appendix A. Ross (25) lists typical input data for the KWM in his Appendix A and outlines the moisture accounting process used in the Model and the role of each parameter in that accounting. The reader unfamiliar with the Model and the parameters should read his Chapter II before continuing through this report.

STARTING ISSUES

The use of the above version of the KWM as a basis for developing OPSET required certain decisions which need to be brought out for discussion. Three major differences exist between the Kentucky Watershed Model and the current Hydrologic Simulation Program (14) used by Crawford. Each is discussed in the following paragraphs.

Seasonal Parameters: Two parameters have been retained from Stanford Watershed Model III to control seasonal variation in infiltration (SIAC) and in upper zone storage capacity (SUZC). Physical factors supporting seasonal variation in infiltration include differences in soil temperature and hence viscosity of infiltrating water, changes in vegetation and tillage and organic content of the soil surface, and a tendency for fine grained soils to shrink and crack during warm dry periods (23). All of these factors favor higher infiltration rates in the summer than in the winters. Upper zone storage capacity would logically increase with the growth of vegetation and summer cultivation.

The decision to keep these two parameters turned out to be wise in light of the results obtained when OPSET was developed and applied. OPSET was free to pick zero values for these parameters if it could not use positive values to better match recorded flows. In fact, it selected positive values in virtually every case (25, Table 11). For two watersheds (Cave Creek near Lexington, Kentucky, and the Clemson University Experimental Watershed near Clemson, South Carolina), OPSET was also run to determine the best set of values for all the other parameters with the two seasonal parameters arbitrarily forced to zero. The modeling, as demonstrated by the summary of the results on Table 1, was significantly worse (more so for Cave Creek than the Clemson Watershed). Even though it is dangerous to generalize from one comparison, the tabulated figures suggest a physically reasonable trend toward greater seasonal variation as one goes from South Carolina to the more northerly and continental climate of Kentucky.

Table 1 also illustrates how the values of other parameters change in an attempt to take up the slack as certain parameters are removed from the modeling. Strictly speaking, such variables as LZC and BMIR have become different entities. It is not correct to take a value for LZC as estimated by OPSET and use it literally in any other version of the Stanford Watershed Model other than that listed in Appendix A. Those wishing to use another version should adjust OPSET accordingly.

Channel Routing: The modified Muskingum routing approach used in Stanford Watershed Model IV (10) was retained instead of being replaced by the kinematic wave approach used in the HSP (14). Several factors influenced this decision. The programming from Model IV is less complex and hence consumes less computer time in execution. In the cycling which was anticipated to be necessary for estimating parameter values in OPSET, time would be an essential factor determining computational feasibility. More important, the greatest need for OPSET is to better estimate and interpret values of the parameter associated with the land phase of the runoff cycle. A program which used much time in routing computations would not be appropriate.

In practice, parameters controlling the fraction of precipitation becoming runoff are relatively independent of parameters controlling

TABLE 1

EFFECTS OF ELIMINATING SEASONAL VARIATION IN MODELING UPPER ZONE STORAGE CAPACITY AND INFILTRATION

Selected Values for Parameter	Cave Creek 1964 Seasonal Variation Yes	 No	Clemson Watershed 1966 Seasonal Variation Yes	 No
LZC*	1.26	1.65	10.12	5.55
BMIR	10.77	3.71	7.40	4.64
SUZC	1.21	0.00	0.46	0.00
ETLF	0.04	0.50	0.14	0.19
BUZC	0.59	3.38	0.81	0.35
SIAC	0.66	0.00	0.74	0.00
Minimum SSQM	0.186	1.047	0.099	0.329

Comparison of Monthly Flow Totals

	Cave Creek 1964 Recorded	Simulated		Clemson Watershed 1966 Recorded	Simulated	
October	0.9	0.4	0.3	37.1	49.9	48.7
November	2.6	0.2	0.0	24.8	22.9	22.6
December	1.8	2.8	0.0	18.1	15.9	13.4
January	59.5	70.0	43.9	34.9	26.8	23.2
February	117.4	88.3	75.9	82.3	77.2	67.6
March	536.0	634.9	606.4	67.4	79.0	80.8
April	30.4	34.5	59.8	25.8	29.1	43.5
May	14.1	13.7	21.0	28.8	27.3	34.5
June	7.6	6.4	0.8	17.4	19.1	21.2
July	5.5	0.7	0.1	12.1	12.4	14.9
August	1.2	0.4	0.0	16.0	10.2	15.3
September	10.6	10.8	24.1	10.5	10.0	10.2

*All mnemonics with units are defined in Appendix C. Parameters are defined on Table 2.

routing. The land phase parameters can be estimated first and applied with either routing scheme. OPSET continues by fitting the parameters associated with the Muskingum approach to guide those wishing to use them and to make the modeling complete.

The emphasis of OPSET is on land surface rather than channel routing processes because this is where the greater modeling problem lies. Routing parameters based on the kinematic wave approach can already be directly estimated from measurable channel characteristics without resorting to trial and error (14).

Watershed Segmentation: The KWM does not provide the option of subdividing a watershed into segments and modeling runoff as the sum of segment totals. Even the older SWM versions provide this option, but it is not included in the KWM principally because none of the watersheds used were of such nature that modeling by segment was appropriate and hence no data were collected that were suitable for debugging a translation into Fortran of this feature. The two main advantages of segmenting are the greater ability to handle spatial variation in precipitation and the greater ability to handle spatial variation in watershed characteristics.

Spatial variation in precipitation can be either associated with consistent, usually orographical, rainfall patterns or with random differences from storm to storm. Orographic segments could be assigned individual precipitation multipliers (RGPMB) to precipitation at a single gage. Segmenting to better cope with random precipitation patterns requires several rain gages. For the small Kentucky watersheds to which OPSET was applied (25, Table 9) rain gage spacing was too large with respect to basin size to permit segmenting to reflect random precipitation patterns and orographic patterns were minor.

Segmenting to handle spatial variation in watershed characteristics is not practical for a self-calibrating model seeking parameters giving the best fit. One must work with recorded flows undifferentiated by watershed source area. The parameters cannot be subdivided on a finer grid than the data. Ross minimized this problem by working with normally more homogeneous small watersheds. If they revealed a pattern between parameter values and watershed characteristics, derived correlations could be used to estimate parameter values from the characteristics of segments of larger watersheds; and the KWM could be revised to simulate flows by segment and accumulate the results. Some revision in the structure of OPSET may be necessary to improve results for watersheds for highly orographic rainfall patterns.

THE BASIC STRATEGY

The Kentucky Watershed Model simulates a sequence of streamflows from input climatological data through a defined computational procedure based on equations containing parameters. The goal is to estimate for the parameters the set of values which simulates the streamflows most closely matching gaged values. The general strategy is to define the difference between simulated and recorded flows as a scalar quantity and vary parameter values to minimize this objective. Direct analysis making use of the partial differential of the objective function with respect to each parameter is infeasible because of the complexity of the simulation algorithm and the large number of conditional routes through it. Some systematic pattern of selecting trial sets of values and making appropriate adjustments must be substituted.

One issue which had to be resolved early was which parameters to estimate by use of OPSET. Parameters were ruled out if they were amenable to direct measurement (drainage area) or if the simulated streamflows proved to be insensitive to large fluctuations in parameter magnitude. Estimating through matching disintegrates when the simulated flow variation associated with parameter value changes is less than that associated with model inadequacies and data difficulties. As Dawdy and O'Donnell discovered (12, p. 133), the process is already becoming imprecise and time consuming when the sensitivity range is slightly greater than the difficulty range. Parameters passing both tests are listed on Table 2. Ross (25) recommends means for estimating the other parameters.

The next issue was whether the parameter values should be estimated individually, simultaneously, or simultaneously by groups. Individual estimation requires independent parameters. In OPSET, some defined characteristic of the total flow pattern must correlate closely with that parameter and be relatively independent of all the others. Interdependent parameter groups must be estimated simultaneously because a change in the value of any one changes the values of the others. Cyclic single parameter optimization sometimes converges, but more than one cycle is always needed.

The 13 parameters listed on Table 2 fall into three groups. The first six land phase parameters form a subgroup called runoff volume parameters because they control the volume and distribution over the year of simulated runoff. The recession constants can be estimated directly from recorded flows. The parameters within each of the other two groups were found through sensitivity studies to be so interdependent that simultaneous parameter adjustment by group would be required. The two groups as a whole were sufficiently independent for adjusting the first after estimating the second to be unnecessary. Each cycle requires (1) a simulation unit to synthesize flows for comparison with recorded flows for a given set of parameter values, (2) establishment of adjustment rules for selecting a new set of

TABLE 2

PARAMETERS ESTIMATED BY OPSET

Recession Constants

IFRC - interflow recession constant
BFRC - base flow recession constant

Land Phase Parameters

Runoff Volume Parameters

LZC - lower zone storage capacity
BMIR - basic maximum infiltration rate within watershed
SUZC - seasonal upper zone storage capacity factor
ETLF - evapotranspiration loss factor
BUZC - basic upper zone storage capacity factor
SIAC - seasonal infiltration adjustment constant

Interflow Volume Parameter

BIVF - basic interflow volume factor

Channel Routing Parameters

NCTRI - number of current time routing increments
CSRX - channel storage routing index
FSRX - flood plain storage routing index
CHCAP - channel capacity - indexed to basin outlet

parameter values, and (3) a scalar objective function for judging goodness of matching.

The optimization procedure used in each cycle is shown schematically in Figure 1. The simulation unit for the first cycle (TRIP 1) is a streamlined version of the portions of the inner loop of the KWM which simulate surface runoff. The simulation unit for TRIP 2 is a streamlined version of the portions of the inner loop of pertaining to channel routing. Whenever a new set of flows is simulated, the parameters are saved if the matching is better than any found previously but the adjustment continues until hope of finding a still better matching is lost. Various sensitivity studies were made and were used to guide the adjustment rules.

REARRANGEMENT OF THE MODEL

The first step in the development of OPSET was to rearrange the programming from the order efficient for proceeding directly from given input data to a single simulated flow sequence as found in the KWM to an order efficient for executing the optimization strategy of Figure 1. Because of the large number of times it would have to be called, all programming preforming computations identical for all simulation runs was pulled out of the simulation unit and placed earlier in the program. All climatological data were placed in fixed arrays so they could be held constant for each parameter set. Constants representing combinations of parameters not included in the 13 were developed so they would not have to be formed within the inner loop. Programming to provide supplementary output was dropped.

The KWM contains a hierarchy of daily, hourly, and period loops. The inner-most or 15-minute loop simulates rapid hydrologic processes such as interception, infiltration, upper and lower zone moisture storages, overland flow, interflow, etc. Slower processes are

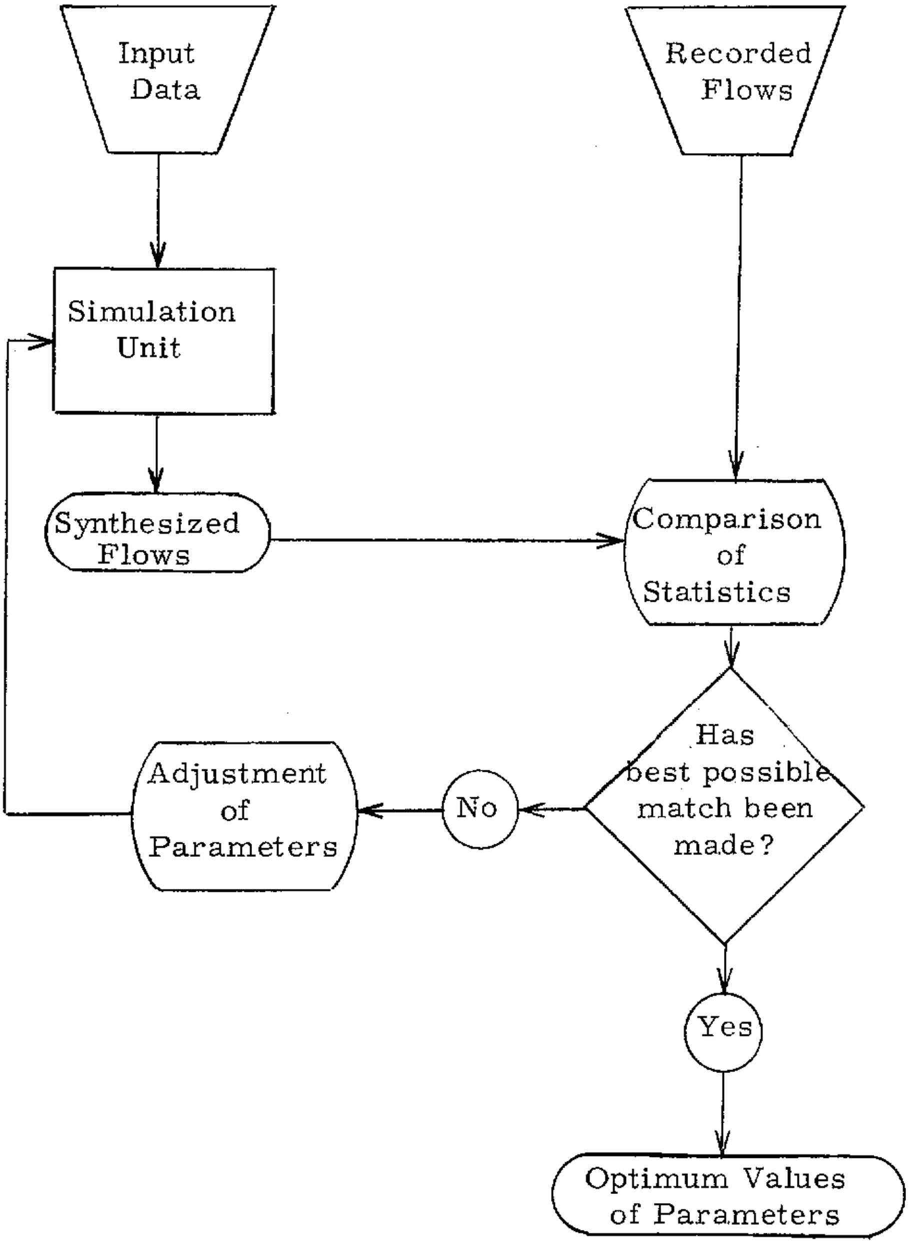

FIG. 1. Schematic Diagram of Parameter Optimization Procedure.

simulated hourly (for example, stream evaporation and base flow). The outer or day loop orders the calculations and sums the flows in daily totals.

THE OBJECTIVE FUNCTION

The true flow in a stream varies continuously throughout the year. Flows are simulated by the KWM by discrete 15-minute periods. Recorded flows can be estimated from recorder charts or punched tape on a comparable time base, but published flows represent calendar day average values. The logical objective function would minimize some measure of the difference between recorded and simulated flows taken at some appropriate time interval and summed over the year. With parameters placed in three groups, an appropriate objective function had to be found for each one.

The objective used to estimate the two recession constants was to minimize the sum of the squares of the differences between recorded and simulated average daily flows during selected recession sequences. The objective used to estimate the first six land phase parameters was to minimize the sum of the squares of normalized ratios relating simulated to recorded monthly flow totals. The objective used to estimate BIVF was to minimize the difference between total simulated and total recorded interflow summed over selected three-day periods. The objective used to estimate the channel routing parameters minimized the difference between recorded and simulated flow peaks within specified timing constraints.

The monthly time grid used for the objective function for estimating the runoff volume parameters reduced interdependence between the land phase and channel routing parameter groups. The channel routing parameters, for small watersheds, may significantly change the distribution of flows among days. Months are long enough for the channel routing of direct runoff to have minimal effect on the month it reaches the gage and short enough to reflect seasonal runoff patterns. Monthly totals are published and are units with which most hydrologists are familiar (see Subroutine DAYSUM). The use of time periods divided at low flows between storms was considered but rejected because of added programming complexity and problems associated with different seasons being represented by different numbers of periods.

More precise definitions of each objective are given in the descriptions of Subroutines SET2RC, SETFDI, SETFVP, and SETHRP.*

EVALUATION OF TWO RECESSION CONSTANTS

Both a base flow recession constant and an interflow recession constant are needed in the Model. Traditional graphical techniques for estimating appropriate values take too much time, often require flows subdivided by a finer time grid than a day, and are somewhat subjective; therefore, a computer procedure was sought to make data preparation easier for the user and minimize any effect caused by subjectively estimated values on subsequent parameter estimation.

The first approach tried to evaluate the base flow recession constant (BFRC) by averaging flow ratios for successive days on which neither direct runoff nor interflow were synthesized, and to estimate the interflow recession constant (IFRC) from the ratio of the sum of interflows (total recorded flow minus simulated base flow) of the second to the first day after the major recorded streamflow rises. The approach was later abandoned in favor of the least squares method to estimate the two recession constants developed by James and Thompson (18). This approach uses selected recorded daily

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*Each Subroutine is presented individually in Chapter III.

streamflow data and assumes that each sequence contains two linear recession flow components. Much more consistent and reasonable results were obtained. The approach as adopted in OPSET is presented in greater detail in the discussions of Subroutines RECESS, SET2RC, and SET1RC.

EVALUATION OF SIX RUNOFF VOLUME PARAMETERS

The task most critical to the success of OPSET was development of a workable algorithm for estimating the six runoff volume parameters (LZC, BMIR, SUZC, ETLF, BUZC, and SIAC).[1] A least squares approach to simultaneously estimate these six parameter values was tried first. The approach postulates a model

$$\begin{pmatrix} q_1 \\ q_2 \\ \vdots \\ q_{12} \end{pmatrix} = \underset{12 \times 1}{\underline{q}} = \underset{12 \times 7}{\Gamma^*} \underset{7 \times 1}{\begin{pmatrix} 1 \\ x_1 \\ x_2 \\ \vdots \\ x_6 \end{pmatrix}} \qquad (1)$$

where $q_1, q_2, \ldots, q_{12}$ are the simulated monthly flows with six parameter values $x_1, x_2, \ldots, x_6$, and Γ^* is a 12 x 7 matrix of constants. Assuming the model is correct and there are no data or modeling difficulties, a unique set of parameter values, say $\tilde{x}_i$, would synthesize a set of monthly flows which exactly match the recorded monthly flows $\eta_1, \eta_2, \ldots, \eta_{12}$. If the matrix Γ^* can be estimated, then the approach would obtain the best set of x's by some sort of inverse relationship by substituting $\underline{\eta}$ for $\underline{q}$.

However, Γ^* is unknown and furthermore it is not square. To formulate the model so that an inverse of the matrix of constants can be obtained, seven functions of the simulated annual hydrograph, say

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[1] For discussion on the grouping of parameters see 16, pp. 27-32.

$f_1, f_2, \ldots, f_7$, were chosen. The model is then

$$\begin{pmatrix} f_1(\underline{q}) \\ f_2(\underline{q}) \\ \vdots \\ f_7(\underline{q}) \end{pmatrix} = \underset{7 \times 1}{\underline{f}} = \underset{7 \times 7}{\Gamma} \underset{7 \times 1}{\begin{pmatrix} 1 \\ x_1 \\ x_2 \\ \vdots \\ x_6 \end{pmatrix}} \tag{2}$$

By redefining the model as Equation 2, Γ is square; and if it is non-singular, its inverse can be used to estimate the parameter values $\tilde{x}_i$.

The seven functions of the q's chosen for this purpose were the annual runoff volume, the peak monthly volume, the minimum monthly volume, the total volume in selected summer months, the total volumes in selected winter months, the total volume in selected low flow months, and the sum of squares of monthly flow deviations. After the seven functions $\{f_i(\underline{q})\}$ were defined, eight sets of parameter values $\{\underline{x}_i\}$ which were systematically arranged by high and low combinations were used to establish the relationships in the following equations:

$$\begin{matrix} \underline{f}_1 = \Gamma\, \underline{x}_1 & & \underline{f}_1' = \underline{x}_1'\Gamma' & & \\ \underline{f}_2 = \Gamma\, \underline{x}_2 & \Rightarrow & \underline{f}_2' = \underline{x}_2'\Gamma' & \Rightarrow & F = X\Gamma' \\ \vdots & & \vdots & & \\ \underline{f}_8 = \Gamma\, \underline{x}_8 & & \underline{f}_8' = \underline{x}_8'\Gamma' & & \end{matrix} \tag{3}$$

where $\underline{f}_i$ and $\underline{x}_i$ were 7 x 1 vectors as defined in Equation 2. The least squares estimate of Γ is

$$\hat{\Gamma} = (X'X)^{-1}X'F \tag{4}$$

With the estimated Γ, Equation 2 was used to obtain the estimated parameter values $\{\tilde{x}_i\}$ by substituting the recorded monthly flows $\underline{\eta}$ for $\underline{q}$; that is

$$\begin{pmatrix} 1 \\ \hat{\tilde{x}}_1 \\ \vdots \\ \hat{\tilde{x}}_6 \end{pmatrix} = \hat{\Gamma}^{-1} \begin{pmatrix} f_1(\underline{\eta}) \\ f_2(\underline{\eta}) \\ \vdots \\ f_7(\underline{\eta}) \end{pmatrix} \qquad (5)$$

This approach did not prove successful. The parameter values did not converge well and were inconsistent from run to run. This failure may have been caused by the variance of $\hat{\Gamma}$ being too large or the linear approximation being too gross. The approach was finally abandoned and was later replaced by another approach which produced better results.

The second and more successful method adjusted the estimate of each parameter according to rules based on the deviations between recorded and simulated flows which were known to be most sensitive to that parameter. The sensitivity was determined by varying each of the six parameters one at a time with a selected set of climatological data (see Subroutine SETFVP) as checked by what seemed reasonable from qualitative knowledge of the hydrologic cycle.

The method was refined as it was applied to 69 station-years on 20 Kentucky watersheds. Through detailed analysis of synthesized flows and comparison of parameter estimates among runs for different years, the method was continually modified to improve the correlation between synthesized and recorded flows closer and closer, to estimate computer selected parameter values within the physically reasonable range, and to improve the consistency of the parameter values from year to year. Safeguards were built in to keep the program from becoming severely upset by faulty precipitation data. Highlights of the adjustment process include

1. Some adjustment rules not only examine monthly total flows, but also component flows. Some parameters affect one component

flow, say overland flow, in a quite different pattern than other components of the total flow.

2. Alternative adjustment rules are set up for use when the initial adjustment rules do not work well.

3. Upper and lower limits on parameter values were established by reviewing the experience others have had with the model, and attempts to adjust values outside this range are taken to suggest that an alternate adjustment procedure should be tried.

4. Limitations on the size of a given adjustment are made to prevent estimates for one parameter from being kept from convergence by rapid fluctuation in the values of other parameters.

The estimation of the runoff volume parameters starts with an initial set of trial values which are judged to be near the median encountered in modeling watersheds. A year of flows are simulated, and the parameters are adjusted according to the established rules. The value, SSQM, of the objective function for these parameter values is estimated. Using the adjusted parameter values, a new year of flows is simulated, and SSQM is again calculated. The set of parameter values with the smaller SSQM is judged as the better set, and both the value of SSQM and the parameter value are saved to compare with the next run. The process is continued until the number of trials since the last improvement suggests that the best possible set has been found.

In order to save computer time, channel routing is by-passed while estimating runoff volume parameters. This means that synthesized land phase runoff is taken as the simultaneous outflow at the mouth of the watershed. Unless the watershed is large or an unusually large storm occurs on the last day of the month, the above assumption will not materially affect the distribution of monthly flow volumes. A second strategy to save computer time is to increase the time period represented by the inner loop. Table 3 shows the effect of changing the length of this time period on synthesized monthly flows. A 15-minute loop (i. e., the number of loops equals 4) is used as a base, and the entries of Table 3 are the volume ratios. Inspection of Table 3 reveals that hourly looping gives only a coarse underestimation of the 15-minute looping flows while 20-minute looping provides a much closer approximation. Table 4 shows the effect of the number of loops within an hour on the number of adjustments required to converge on a best set of parameter values, and the monthly flow deviations. Use of a shorter inner loop period increases the computer time required to simulate a year of flows and increases the number of times a year flows must be simulated to estimate a set of parameters.

Significant computer time can be saved by first adjusting runoff volume parameter values by hourly looping to bring the estimates in range. Then, 20-minute looping can be used to refine the best estimates obtained in hour looping. Use of 20 rather than 15 minutes saves lots of time at a small sacrifice in accuracy. The first stage of adjustment which uses hour looping to simulate streamflows is called the "Rough" adjustment cycle, and the 20-minute looping is called the "Fine" adjustment cycle. The best set of parameters obtained by the fine adjustment cycle is taken as the optimal set of parameter values. Detailed description of the two adjustment cycles is presented in Chapter III.

EVALUATION OF ONE INTERFLOW VOLUME PARAMETER

Crawford and Linsley recommend that the interflow volume parameter be adjusted by matching the simulated hydrograph shape to the recorded shape (10, p.69). If recorded flows were readily available on hourly intervals, a possible objective would be to minimize hourly

TABLE 3

EFFECT OF INTERVAL USED IN INNER LOOP ON SIMULATED MONTHLY FLOW VOLUMES: ELKHORN CREEK NEAR FRANKFORT, KENTUCKY 1964 CLIMATOLOGICAL DATA

	Number of Loops within an Hour					
	1	2	3	4	5	6
Oct.	0.990	0.995	1.000	1.000	1.000	1.005
Nov.	0.976	0.976	1.000	1.000	0.976	0.976
Dec.	0.628	0.868	0.953	1.000	1.010	1.028
Jan.	0.931	0.977	0.992	1.000	0.997	0.999
Feb.	0.902	0.972	0.992	1.000	0.989	0.988
Mar.	0.997	1.000	1.000	1.000	1.001	1.000
Apr.	1.021	0.991	0.996	1.000	1.002	0.997
May	0.930	0.963	0.988	1.000	1.012	1.022
June	0.642	0.845	0.942	1.000	1.045	1.078
July	0.795	0.934	0.979	1.000	1.024	1.047
Aug.	0.839	0.950	0.994	1.000	1.025	1.037
Sep.	0.915	0.969	0.992	1.000	1.004	1.007

Note: All volumes are expressed as ratios to volumes with 4 loops. See right hand column of Table 11 for absolute units.

TABLE 4

EFFECT OF INTERVAL USED IN INNER LOOP ON NUMBER OF ADJUSTMENTS TO CONVERGENCE, OPTIMAL PARAMETER VALUES AND THE MONTHLY FLOW DEVIATIONS: ELKHORN CREEK NEAR FRANKFORT, KENTUCKY 1964 DATA

No. of loops within an hour	1	2	3
Cycles to convergence	8	13	15*
Optimal parameter values			
LZC	4.89	4.74	4.72
BMIR	4.00	4.00	3.47
SUZC	1.96	1.92	1.81
ETLF	0.10	0.10	0.12
BUZC	1.16	1.23	1.10
SIAC	0.75	1.51	2.53
Monthly flow deviations			
Oct.	-1.847	-1.046	-1.065
Nov.	-1.097	-0.828	-0.804
Dec.	-0.146	0.022	-0.314
Jan.	-0.375	-0.489	-1.060
Feb.	-0.109	-0.127	-0.255
Mar.	-0.049	-0.059	-0.073
Apr.	-0.018	0.040	0.063
May	-1.923	-1.314	-1.040
June	-0.338	-0.043	0.005
July	-0.600	-0.282	0.300
Aug.	0.071	0.244	0.207
Sep.	0.738	0.713	0.549
SSQM**	9.513	4.416	4.594

*Optimization procedure still improving flows.

**Index defined in presentation of Subroutine SETFDI (pp. 40-43).

differences. The required data, however, is not published by the USGS and may be difficult to obtain. Rather than let this become an obstacle discouraging use of OPSET, a criterion based on daily flow totals was substituted. The daily flow totals most sensitive to interflow are those immediately following major peaks. The first method was tried to adjust BIVF by multiplying the parameter value by the ratio of the sum of the estimated recorded interflows to the sum of the synthesized interflow volumes. The estimated recorded interflow is obtained by subtracting the simulated base flow from the recorded daily total flow. The results were not stable.

Later, the method was improved by using interflow in the first three days after a peak flow. The recorded interflows were estimated by the method used in estimating the recession constants (see Subroutine SETRBF), and instead of using a ratio of sums, the average of the daily ratios was used for adjusting the parameter value. The new method proved to be more consistent, and the values were more reasonable. A more detailed description is given under Subroutine SETBIV. The adjustment of BIVF occurs in the Fine adjustment cycle for the six runoff volume parameters.

EVALUATION OF FOUR CHANNEL ROUTING PARAMETERS

The estimation process for the channel routing parameters like that for the runoff volume parameters follows the optimization scheme shown in Figure 1. The simulation unit in optimizing runoff volume parameters is the inner loop. In optimizing hydrograph parameters, it is the channel routing unit. By using different sets of trial parameter values, the routed hydrographs are compared with the recorded hydrographs in the timing and magnitudes of the peaks. The set of parameter values which gives the best match is accepted.

The channel routing parameters are estimated after values for the other nine parameters have been determined. The nine estimated values are used in simulating an annual hydrograph with 15-minute looping. Synthesized land phase runoffs during the periods contributing to read recorded hydrograph peaks (the beginning and ending hours of the runoff periods estimated as contributing to the recorded hydrograph are estimated by Subroutine STRHRS) are saved. In order to overcome the bias caused by using different volumes in estimating hydrograph routing parameters, the synthesized runoff volumes are adjusted to match the recorded volumes (See Subroutine ADJHYD). The adjusted land phase hydrograph is used as the input data shown in Figure 1. Two channel routing subroutines (Subroutine TIMERT performs channel time routing, and Subroutine STORRT performs channel storage routine) serve as a simulation unit. Trial parameter values are used to route the adjusted inflow hydrographs, and the routed outflow hydrographs are compared with the recorded hydrographs in flow peaks and in times. The parameters are adjusted until the best set of parameter values are found.

Early in the development of the optimization procedure for the hydrograph parameters, the number of time routing increments (NCTRI) was found to be the primary parameter governing the flood peak timing, and the storage routing index (SRX) was found relatively more influential in controlling the magnitude of hydrograph peak. First, they were adjusted separately, but a later and better procedure combined the two adjustment procedures into Subroutine SETHRP.

ADJUSTMENTS OF CLIMATOLOGICAL DATA

The simulation takes input precipitation and evaporation data, operates on it in a manner dictated by a set of parameter values, and produces a synthesized annual hydrograph. OPSET estimates the set of parameter values which operate on given climatological data to most closely match given streamflow data. In order for the estimates to truly represent the watershed and correlate well with physical watershed characteristics, the climatological data must truly reflect watershed experience and the streamflow data must truly measure actual flows. Otherwise, the estimated parameters will contain components which are nothing more than mathematical attempts to compensate for faulty data.

Precipitation falls in a pattern which varies continuously with time and at a given time varies in rate over the area of the watershed. A precipitation gage network samples this variation in time and space by measuring rainfalls at selected spots. Some error is associated with incorrect measurement of spot rainfall. A larger problem is subdividing measured totals over time. Storage gages are read daily at times which vary from gage to gage. Recording gages provide a record of accumulated totals from which clock hour totals are published. A great deal of work is involved in going to the original records to obtain totals on a finer time grid. A still larger problem is estimating precipitation over larger areas from spot values. Where orographic influences are minimal, one normally assumes that spot precipitation represents areal precipitation on a probability if not on an historical basis.

Streamflow varies continuously with time. A stream gage measures this flow by indicating a water surface elevation and converting it to flow through a stage-discharge curve. Some error is caused by inadequacies in the stage-discharge curve, particularly where the relationship changes with calendar time or flows must be estimated for stages significantly higher than that for the largest measured discharge. The largest errors are normally associated with very high or very low flows. Continuous stage measurements are integrated to daily flow totals in the published record. Very large flood peaks are also given. A great deal of work is required to obtain flows on a finer time grid.

OPSET had to be designed to handle constant errors, random errors, and grid errors. Constant errors can be handled by a rainfall multiplier (RGPMB) and an additive streamflow (DIV). Random errors can only be handled by using a long enough record for positive and negative effects on parameter estimates to cancel. The larger these errors are the longer the record has to be. Therefore, an effort to filter records for obvious precipitation-streamflow anomalies can significantly reduce required computer time.

The selected strategy for dealing with hydrologic data was to design OPSET to use published data sources rather than require the user to analyze original records to subdivide totals over a finer time grid. A finer time grid has some merit for better estimating the channel routing parameters and better matching recorded flood peaks but it is not much help with respect to the primary research goal of estimating the land phase parameters. Better estimation of runoff volume from precipitation is lagging research on better channel routing.

The input data thus consists of hourly precipitation totals, daily evaporation totals, and daily streamflow totals.* Procedures used by the Stanford Watershed Model for doing such things as allocating daily evaporation totals by hour, taking watershed rainfall as a weighted average of amounts gaged at two points, and providing for streamflow diversions are retained and are described by Ross. Several new features were added for OPSET:

1. The adjustment of precipitation data where there are precipitation-streamflow anomalies. A subroutine was made to check

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*For more detailed information see Ross (<u>25</u>, pp. 25-35, 56).

for anomalies and to adjust the recorded precipitation where necessary (see Subroutine PRECHK).

2. Provision for non-uniform distribution of rainfall within the hour for small watersheds where the time of concentration is comparatively short to better match flood peaks. A subroutine was developed to divide the hourly rainfall totals among 15-minute periods using an average distribution (see Subroutine PREPRD). Hydrocomp International (14) has an option for directly reading 15-minute precipitation, and the same option could be readily added to OPSET.

3. Provision for handling situations where changes in precipitation gage location or storage gage reading time occurs during the year.

4. Addition of provision for an approximate approach to estimate the daily evaporation data from estimated total annual evapotranspiration. A subroutine was developed to distribute an annual total among the days of the year (see Subroutine EVPDAY).

INITIAL PARAMETER VALUES

The parameter estimation scheme shown on Figure 1 begins with some initial set of parameter values. The initial set of values can only be chosen arbitrarily if the procedure will converge on the same final set from any beginning. Because the cost of computer time is an important factor in trial-and-error estimation, the initial trial values should be reasonably close to the final ones most often encountered.

A study was made to see how much difference variation in the initial set made on the final estimated set of parameter values. The approach used low, middle, and high starting values and three years of data for Cave Creek near Lexington, Kentucky. Table 5 shows the results and reveals that the parameter values have a tendency to converge toward common values but exhibit certain degree of variation.

TABLE 5

STUDIES ON SENSITIVITY TO STARTING PARAMETER VALUES: CAVE CREEK NEAR LEXINGTON, KENTUCKY

	Starting Values			OPSET Estimates[1]								
				1955			1958			1965		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
Parameter												
LZC	2.0	12.0	30.0	8.00	9.22	10.23	2.62	2.00	2.00	1.86	1.66	1.56
BMIR	0.2	1.20	4.0	2.02	3.59	9.79	8.24	12.46	16.60	3.95	19.27	25.44
SUZC	0.3	1.30	4.0	0.72	1.10	0.80	0.30	0.30	0.30	0.60	0.39	1.46
ETLF	0.05	0.25	0.6	0.13	0.36	0.31	0.21	0.22	0.15	0.09	0.12	0.29
BUZC	0.2	1.50	5.0	0.72	1.62	5.41	0.50	1.13	4.55	0.27	0.70	1.35
SIAC	0.3	0.90	4.0	0.03	0.64	1.29	0.03	0.49	0.03	0.15	0.77	0.87
Statistics												
Number of Rough Cycles				3	2	3	9	7	10	2	3	4
Number of Fine Cycles				2	3	3	2	2	2	5	9	4
Final SSQM				0.685	0.671	0.338	1.310	1.549	1.781	0.293	0.313	0.328
Annual Total												
Recorded					1051			1442			1032	
Simulated				1079	988	984	1398	1415	1419	953	962	916
Max. Peak												
Recorded					117			87			40	
Simulated				163	160	105	90	83	94	79	83	101

[1] A preliminary version of OPSET was used for this study.

In later versions of OPSET this amount was reduced by increasing adjustment jumps for such sluggish parameters as BUZC. Comparing the results from the three sets of starting values shows the speed of convergence (numbers of Rough and Fine cycles) and the matching of synthesized to recorded flows (SSQM, annual totals, and maximum flood peaks) to be quite close to each other. For the consistent estimate of reasonable parameter values the medium starting values work best because they have the best chance of being close to the final estimate and less chance to produce out-of-range adjusted values which may cause the program to stop before the optimum point is reached. The value to be gained by rerunning the computations for Table 5 with the final version of OPSET did not seem worthwhile and thus the results shown are only a tool for program improvement and are not indicative of the sensitivity of the final program to initial values.

TIME PERIOD COVERED BY CALIBRATION RUN

The ordering of computations in the KWM is to read and store values which remain fixed for a given watershed, read values of initial moisture storage by storage category, read and store climatological data for a water year, simulate a year of flows, take the ending moisture storages as the initial moisture storages for the next year, read and store climatological data for the next year, and continue this cycle for as many years of simulated flows as are desired. In designing OPSET, one question was how long a period of flows should be used in a run to estimate parameter values. Selection of a long enough period to dampen out parameter estimating errors caused by random data measurement problems did not prove practical because too many years would be required. Storage requirements to simultaneously hold all the data for such a long period are excessive.

Computer time requirements to simulate so many flows per trial set of parameter values are also excessive. The decision was to design OPSET to estimate parameters from one year of record. Chapter IV discusses means for estimating appropriate values for a watershed from a group of OPSET estimates for different water years.

With only one year of flows to be used, it was necessary to estimate appropriate initial moisture storages. The best estimate of these values would come from the ending moisture storages from a simulation run for the previous year using the optimum set of parameter values. However, the optimum set of values would not be known in advance, and it was impractical in light of storage and computing time constraints to simulate blocks of flow longer than one year. The decision was to make the best possible estimate of each initial storage as of October 1, base that estimate on the context of the corresponding set of parameter estimates, but leave October matching out of the least squares criterion to minimize bias caused by initialization error (pp. 40-43, 102).

One advantage of designing OPSET to estimate parameters from one year of flows is that it permits one to select the years of record which by inspection seem to be relatively free of data problems capable of upsetting the estimating process.* More important, it permits selection of years with diverse flow patterns so that OPSET can be tried under as diverse a range of conditions as possible.

In selecting years to use, years with certain types of initial conditions should be avoided. A year following a large storm late enough in September for surface runoff and significant upper zone storage to continue into the next water year is undesirable. So is

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*These problems are discussed in more detail on p. 155.

a year with very low October and November rainfalls. The effects of initial conditions dampen more quickly in wet months.

SUMMARY

OPSET is built around a streamlined inner loop of the KWM. Watershed parameters are estimated simultaneously by group and three separate trip sequences are devised. Since the two recession constants can be estimated from the recorded streamflows by a least squares method, they are evaluated before the first trip begins. In the first trip (TRIP 1), the six runoff volume parameters are approximated in Rough adjustment cycles with hourly looping, and then the six estimates are refined and the one interflow volume parameter is estimated in Fine adjustment cycles with 20-minute looping. The optimization of the six volume parameters is based on matching synthesized to recorded monthly totals, and the adjustment of the one interflow volume parameter is based on matching the interflow volumes for the first three days after the major floods. In TRIP 1, channel routing is by-passed to save computer time.

The second trip (TRIP 2) uses 15-minute looping to synthesize land phase runoff hydrographs based on the values for the first nine parameters as estimated in TRIP 1. These hydrographs are then used in trial-and-error estimation of the four channel routing parameters.

Using all 13 parameter values as estimated, a final trip (TRIP 3) is made to simulate a year of streamflows with 15-minute looping so that the effectiveness of the whole optimization process can be observed and evaluated.

CHAPTER III

PROGRAM DESCRIPTION

OPSET is composed of one master program (MAIN) and 22 subroutine programs. MAIN controls operations as directed by coded control options by reading the required input data, setting up the parameter estimating processes, controlling the streamflow simulation and calling subroutine programs. Subroutine programs calculate statistics used in the adjustment of parameters, adjust the parameters according to established rules, check and if necessary adjust input data, read the coded data in a free format, and print the requested output.

This chapter describes the programming in detail. Because of the length of the program, statement-by-statement analysis is not practical; however, it is hoped that the reader will find the discussion herein sufficient for him to comprehend, understand the reasoning behind, and properly use the program.

MAIN Program

MAIN has three major parts. The first part (MAIN0005-0238)* initiates the computer run. The second part (MAIN0239-0746) is basically the streamlined inner loop of KWM and is used to simulate streamflows. The third part (MAIN0747-0834) sequences the calling of the subroutines used in parameter estimation.

In the first part, MAIN reads the control options and data required

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*This designation locates the referenced statements within the program listings of Appendix B.

for a computer run, calculates other values which will remain constant no matter what parameter values are chosen later. Control options include the number of station-years included in a given computer run (NSYT), three input data control options (CONOPT), and three operational control options (MNRC, NFTR, NLTR). All will be discussed in detail in Chapter IV. The data required for a computer run include a time-area histogram, values for the parameters estimated by the user, evaporation data, recorded daily streamflows storm hydrographs, and precipitation data. Sample data are listed in Appendix B of the report by Ross (25). He also described methods of collecting data and for estimating fixed parameters. The two recession constants (BFRC and IFRC) are estimated. Precipitation data are checked for anamolies and adjusted as necessary. Climatological data are converted from the form in which it is read into the arrays needed for flow simulation. A title read from alphanumeric input, the recorded daily streamflows, and the recorded storm hydrographs are printed out for visual comparison.

The second part contains the essence of the streamflow synthesis of KWM. It performs the moisture accounting process to synthesize flows. Depending on the particular run, it can simulate a year of continuous streamflows with 15-minute, 20-minute, or hourly looping. No detailed description of this part of the program will be given in this report. It is amply covered in the description of the Stanford Watershed Model by Crawford and Linsley (10) the HSP Manual by Hydrocomp International (14), and the report of an evaluation study of the Model based on KWM by Ligon et al. (19).

The third part with all its associated subroutine programs is the essence of OPSET. Except for the two recession constants which are evaluated in the first part of MAIN, the remaining eleven of the 13 selected critical parameters are estimated here.

TRIP 1

The trip number denotes the conditions pertaining when the program passes through the streamflow simulation process in MAIN. During TRIP 1, streamflow routing is bypassed. The procedure starts with the initial middle set of assigned parameter values and simulates a year of continuous streamflows using hourly looping (Rough Cycle). Then Subroutine SETFVP is called to adjust LZC, SUZC, ETLF, BUZC, and SIAC and Subroutine SETBMI is called to adjust BMIR. Using adjusted parameters, another year of streamflow is simulated. SSQM is computed in Subroutine SETFDI and compared with that found previously. The set of parameter values associated with the smaller SSQM is considered as the better one, and its values are saved. The Rough adjustment cycle continues, each time using the last simulation to adjust parameter values for the next simulation cycle until the value of SSQM is less than 0.15 (MAIN0801), or the number of the Rough adjustment cycles exceeds the preassigned minimum number of Rough adjustment cycles (MNRC) and the SSQM values are found to have consecutively worsened at least twice (MAIN0788). In other words, the process continues as long as simulated flows continue to improve. The "twice" enters because sometimes the flows get worse and then start to improve again with the next adjustment. The minimum number of adjustment cycles is necessary because estimates often jump around a lot at first before they settle into a groove converging on a best value.

The optimization procedure then shifts to the Fine adjustment cycle which uses a 20-minute looping interval, and starts with the saved best set of parameter values from the Rough adjustment cycle. The optimization process of the Fine adjustment cycle is essentially the same as that of the Rough adjustment cycle except for the termination of the adjustment procedure. In the Fine adjustment cycle, the only criterion for termination is for a new set of adjusted parameters to have a larger SSQM than the previous set. The six volume parameter values from the run in the Fine adjustment cycle with the smallest SSQM are taken as the optimal values. A numerical example is given in the description of Subroutine SETFVP (Table 9).

In the Fine adjustment phase, the interflow volume parameter (BIVF) is adjusted if the program finds that the interflow recession constant (IFRC) exceeds 0.30 (MAIN0222-0226, 0769). The adjustment of BIVF is based on matching the first three days of interflow volumes after major streamflow rises, and the best value of BIVF is taken as the adjusted value of the last run instead of the best run of the Fine adjustment cycle (See Subroutine SETBIV). If the value of IFRC is less than 0.3, the interpretation is that a division between base flow and direct runoff is sufficient for that station-year data, and the value of BIVF is set as 0.0 (MAIN0222-0226) without calling Subroutine SETBIV.

INITIAL MOISTURE CONDITIONS

OPSET estimates a set of values for the parameters for a particular watershed from one year of data (p. 35). The year starts with some amount of water stored on the land surface, stored in the upper zone, stored in the soil, stored below the water table, etc. (25, p. 24). An appropriate procedure had to be devised for estimating each initial moisture storage within the basin at the start of the water year because computer storage and time restraints made it impractical to simulate several months at the end of the previous water year for the sole purpose of establishing initial conditions. The drier the late summer weather, the further back it would be necessary to go, and the more trouble this approach would cause.

Fortunately, in fact purposefully, the water year begins at a time (October 1) when moisture storages on an average annual basis are near minimum levels because of the long summer of evaporation excess. Since the user of OPSET can exercise discretion in selecting which years to use, he can avoid years known to immediately follow a large storm in late September. The overland flow unrouted storage (OFUS), the overland flow unrouted storage on impervious surfaces (OFUSIS), the unrouted direct runoff in the channel (URHF), the upper zone storage (UZS), and the interflow storage (IFS) are set to be zero (MAIN0255-0272).

The groundwater storage (GWS) is estimated by substituting estimated October 1 baseflow (OCT1BF) and the base flow recession constant into the simulation equation (MAIN0289). One twentieth of the total recorded October flow is taken as a first estimate of the October 1 base flow. If less than one twentieth of the total recorded October flow occurs on October 1, it is assumed that there was minimal direct runoff that day, and the flow recorded on October 1 is taken as the October 1 base flow. OCT1BF may still exceed the true base flow value. For example, the October 1 flow may contain appreciable direct runoff or interflow but be less than five percent of the total runoff during a wet October. Much of this moisture will have run off two days later. If the recorded October 3 daily flow is less than the calculated third day base flow, OCT1BF is taken as the October 3 recorded flow brought forward in time by twice dividing by BFRC (MAIN0286-0288). After OCT1BF is estimated, the initial groundwater storage (GWS) is estimated by solving the groundwater simulation equation (MAIN0519):

$$\mathrm{GWS} = \frac{(\mathrm{OCT1BF}/\mathrm{BFRC}^{0.5})}{\mathrm{WCFS} * \mathrm{BFRL}} \qquad (6)^{*}$$

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*The asterisk (*) is used in all equations of this report as denoting multiplication in the convention of Fortran IV.

where the numerator is the base flow at the beginning of October 1 (adjusted by one half day from the daily average value), BFRL is the logarithm of the hourly base flow recession constant, and WCFS is a factor to convert cfs into watershed inches.

The lower zone storage (LZS) at the beginning of the year is most difficult moisture storage to initialize. Its value depends on the lower zone capacity (LZC). Since in TRIP 1, LZC is adjusted from cycle to cycle, the value of LZS (unlike the value of all the other initial moisture storage values) needs to be kept in harmony with the value of LZC.

LZS is taken as 6.00 for the first adjustment cycle to be commensurate with the starting trial value for LZC of 12.0. The initial values of LZS for all subsequent adjustment cycles are adjusted by the following rules gradually evolved through trial-and-error experience.

1. LZS is estimated as the end-of-year LZS of previous cycle multiplied by the ratio of the adjusted LZC to the previous cycle multiplied by the ratio of the adjusted LZC to the previous value of LZC. LZS increases with LZC, and this ratio assumes direct proportionality. If the end-of-September value of LZS is greater than the end-of-August value, then the end-of-August value is taken as the end-of-year value of LZS (MAIN0278-0279) under the assumption that an abnormally wet September has raised the value of LZS above a best estimate.

2. In the case when LZC is adjusted by annual runoff (See SETFVP), the initial LZS is estimated by subtracting from the adjusted LZC an amount which is the product of the difference between the adjusted LZC and the previous end-of-year value of LZS and the ratio used to adjust LZC (MAIN0280 and 0781). Subtraction eliminated the possibility of LZS exceeding LZC in the case when the two were of nearly equal value.

3. If after five Rough adjustment cycles the synthesized monthly flows for November and December are way too high or too low, it is taken as a sign that the starting value of LZS may be bad. The "fall trouble index" (FTX) is used to indicate these cases and to adjust LZS as well. When the sum of the two monthly deviation indices is greater than 2.0* (synthesized flow too high), FTX is set to be 0.90; and when the sum is less than -2.0* (synthesized flow too low), FTX is set to be 1.10 (STFV0009-0010). The adjustment of starting value of LZS is (MAIN0282)

$$\mathrm{LZS} = \mathrm{FTX} * \mathrm{BBYLZS} * \left(\frac{\mathrm{LZC}}{\mathrm{BLZC}}\right) \qquad (7)$$

where BBYLZS = initial value of LZS used in the previous adjustment cycle which had the smallest value of SSQM (MAIN0799),

BLZC = saved value of LZC used in the previous best adjustment cycle (MAIN0792).

Equation 7 is particularly helpful when LZS is getting out of line from the first adjustment rule because the previous year ended with significantly different moisture storage than the current one.

The saved best starting value (BBYLZS) of the best Rough adjustment cycle is used (MAIN0284) when the program enters fine adjustment or later trips. When the computer run starts from TRIP 2 or TRIP 3, the starting value of LZS is needed as input data (See Chapter IV).

TRIP 2

The purpose of TRIP 2 is to estimate the four channel routing parameters CHCAP, CSRX, FSRX, and NCTRI to best match the time and peak flow of synthesized to recorded hydrographs. CHCAP

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*These numbers are defined in Subroutine SETFDI.

and NCTRI are first read as input data while both CSRX and FSRX are initially taken to be 0.98. Up to five recorded hydrograph peaks and times of peak are read as input data. Within TRIP 2, a year of streamflows is synthesized using the other nine parameter values, the preliminary estimates for these four values, and a 15-minute looping interval. During the periods contributing to the recorded hydrographs, synthesized land surface runoffs are saved. Then Subroutine ADJHYD adjusts the total runoff volume to match the recorded volume. The adjusted synthesized runoff provides the inflow hydrograph to be routed through the channel system and compared with the corresponding recorded hydrograph. The estimation procedure calls Subroutine SETHRP to find the best pair of NCTRI and SRX values to match each recorded hydrograph. The optimum value of NCTRI is determined in Subroutine SETHRP, while the SRX values are regressed on the magnitudes of hydrograph peaks to determine how much they really vary with flow by calling Subroutine SETSRP.

When the watershed is small (time of concentration is less than 1.5 hours) and the streamflow routing is done every 15 minutes (CONOPT 92) = 0), Subroutine PREPRD is called at the beginning of TRIP 2 to distribute the hourly rainfalls into the four periods according to a typical unequal distribution so as to better match hydrograph peak MAIN0377). Peak intensities for periods shorter than one hour are needed to simulate flood peaks from small watersheds. When called, this same unequal distribution is also carried into TRIP 3.

TRIP 3

Within TRIP 3, the final set of estimated parameter values and 15-minute inner looping are used to simulate a year of streamflows for comparison of "best" synthesized and recorded streamflows. The purpose is simply to provide information needed to observe the effectiveness of the optimization procedure.

ARRANGEMENT OF SUBROUTINE PROGRAMS

There are 22 subroutine programs used in OPSET. Each subroutine performs its own function as an independent unit; however, some subroutines are closely related to one another in program execution. Such subroutines are grouped together in the presentation in order to make the report more readable and minimize confusion. The subroutines are put into four groups and presented within the group in an order designed to help the reader follow the programed approach. Table 6 gives the arrangement of the 22 subroutine programs in the following sections. It should be noticed, however, that the subroutines are listed alphabetically in Appendices A and B for the convenience of the reader.

Subroutine READ

(First Accounting Subroutine)

CONTEXT

Large amounts of climatological data are required in streamflow simulation. OPSET, as does the KWM, uses a specially developed Subroutine READ to read unformatted data and thereby make data preparation easier. With this subroutine, it is not necessary to check to make sure the data is punched in specific columns, one can use data obtained from others but punched in a different format without repunching, and one has greater freedom to punch explanatory notes directly on the cards as a means of remembering or conveying certain points to others. This subroutine is written in computer machine language and is available on the University of Kentucky Computer Center's IBM system 360/65. A listing is presented by Cline (9, pp. 249-253). The subroutine cannot read alphanumeric data· therefore all alphanumeric data is formatted as usual. An alphanumeric data card

TABLE 6

SUMMARY OF SUBROUTINE PROGRAMS SHOWING MNEMONIC DEFINITIONS, PROGRAM LISTING LOCATIONS, AND ABBREVIATED NAMES

Subroutine Name	Mnemonic Definition	Program Listing Location	Abbreviated Name
A. Accounting Subroutines			
READ	Reads numerical input data	Cline (9, pp. 249-253)	---
DAYNXT	Determines next day of the yr.	Appendix A	DYNX
DAYSUM	Sums daily values to get monthly and annual totals	Appendix B	DYSM
DAYOUT	Prints out daily values in tabular form	Appendix A	DYOT
EVPDAY	Determines dated pan evaporation totals	Appendix A	EVDY
PRECHK	Checks precipitation-streamflow anomalies and adjusts precipitation where necessary	Appendix B	PRCK
PREPRD	Divides hourly precipitation totals among periods for small basins	Appendix A	PREP
B. Recession Constant Subroutines			
RECESS	Establishes recession sequences	Appendix B	RCSS
SET2RC	Sets 2 recession constants	Appendix B	ST2R
SET1RC	Sets 1 recession constant	Appendix B	ST1R
C. Land Phase Parameter Subroutines			
SETFVP	Sets new values of flow volume parameters	Appendix B	STFV
SETFDI	Sets values of flow deviation indices	Appendix B	STFD
SETBMI	Sets new value of basic maximum infiltration rate within watershed	Appendix B	STBM
SETRBF	Sets values of interflow and base flow at recession beginning	Appendix B	STRB
SETBIV	Sets new value of basic interflow volume factor	Appendix B	STBV

TABLE 6 (cont'd.)

	Subroutine Name	Mnemonic Definition	Program Listing Location	Abbreviated Name
D.	Channel Routing Parameter Subroutines			
	STRHRS	Sets beginning and end hours of runoff entering recorded hydrographs	Appendix B	SHRS
	ADJHYD	Adjusts synthesized hydrograph volumes	Appendix B	ADJH
	SETHRP	Sets best values of hydrograph routing parameters	Appendix B	STHP
	FIXTRI	Fixes values of time routing increments	Appendix B	FXTI
	TIMERT	Performs channel time routing	Appendix B	TMRT
	STORRT	Performs channel storage routing	Appendix B	SRRT
	SETSRP	Sets best values of storage routing parameters	Appendix B	STSP

must follow a card containing numerical data; it cannot follow a card containing only a comment.

PURPOSE

Subroutine READ is employed to read numerical input data (real or integer) from the punched data cards. The input data can be coded and punched onto computer cards without format and with explanatory messages.

PROCEDURE

The following two examples illustrate the use of Subroutine READ. One may want to read the values of real variables ALPHA and BETA and integer variable IOTA from one or more punched cards without worrying about the specific locations of these values on the cards. The instruction CALL READ (ALPHA, BETA, IOTA) would cause the data cards to be scanned consecutively from left to right with the first value found being stored as ALPHA, the second as BETA, and the third as IOTA, regardless of the spacing of the values on the card or how many blank cards are passed before the data is found. However, it is necessary that there be at least one blank column between any two values. As a second example, the instruction CALL READ (DATA (I), I = 1, 27) will cause the first 27 values encountered to be stored in array DATA (27). The 27 values may be placed on a single card or may be spread over any desired number of cards.

Variable values should be punched on the cards in the calling order of the corresponding variable names, and the type of values (real or integer) should agree with the specification of the variable names. An integer number read for a real variable will usually cause floating point underflow in program execution. A floating point number read for an integer variable will usually disrupt program execution by misdirecting program control.

When an asterisk (*) is encountered in scanning a card, READ skips on to the next card, ignoring all notes punched on columns to the right of the asterisk. This feature makes it very convenient to place identifying data labels, which may be several cards long, throughout the data list. Many examples of such labeling can be found in Appendices A and B in the report by Ross (25).

Subroutine DAYNXT

(Second Accounting Subroutine)

CONTEXT

Frequently within the program, it is necessary to begin at the first day of the water year and loop through the subsequent days in chronological order. The numbers assigned the days of the year within the program go from 274 for October 1 to 365 for December 31, from 1 for January 1 to 59 for February 28, 366 for February 29 in leap years, and from 60 for March 1 to 273 for September 30.

PURPOSE

Because the required order of days cannot conveniently be prescribed by a Fortran DO loop, Subroutine DAYNXT is used to determine the number of the next day of the year with the number of the current day given.

PROCEDURE

The number of the next day of the year is the number of current day of the year plus 1, unless:

(1) the current day is February 28 in a leap year, then the number of the next day is set equal to 366, and the following day is set equal to 60.

(2) the current day is December 31, then the number of the next day is set equal to 1.

Subroutine DAYSUM

(Third Accounting Subroutine)

CONTEXT

The estimation of the runoff volume parameters is based on an objective function matching synthesized to recorded flow volumes on a monthly time grid (pp. 19-20). By comparing the twelve recorded and synthesized monthly flows, one can observe patterns in seasonal variance and make adjustments in search of a better set of parameter values.

PURPOSE

Subroutine DAYSUM sums monthly and annual flow volumes from daily values. The monthly and annual totals are used in the printed tabulations and in the process estimating five runoff volume parameters.

PROCEDURE

DAYSUM first sums daily values to get cumulative flows through the end of each month in the calendar year. The annual runoff is the amount accumulated through December. Monthly flows are then calculated from the excess of the cumulative flows at the end of each month over that at the end of the previous month. Finally, the monthly flows are converted to a water year order. Both recorded and synthesized daily streamflows are summed to obtain the annual and monthly flow volumes. (MAIN0127, 0686).

DISCUSSION

The real issue associated with Subroutine DAYSUM is deeper than the need to sum daily values to get long-term totals. OPSET is seeking to estimate the set of watershed parameter values minimizing the deviation between recorded and synthesized flow totals. The issue is how many flow periods should be used (p. 19). Too few will not properly test the distribution of synthesized flows over the year. Too many will require routing to simulate runoff at the watershed mouth during the right period. The quick simulation of flow volumes for trial sets of parameter values requires that the routing be bypassed. Therefore, the flow periods must be long enough so that the shift of runoff volumes from a later to an earlier period by ignoring channel routing delay will have a relatively small effect on total period volumes. Monthly periods provide a convenient compromise between the effects of rainfall in one period producing runoff in the next period and the need to consider the seasonal distribution of runoff. The OPSET user needs to be wary, however, of selecting years of data in which major storms occur the last day of any month, particularly when both that month and the following month otherwise have low flows because severe cases can badly upset the estimating procedure. If OPSET is to be applied to larger watersheds, it may be advisable to add an automatic delay feature moving the precipitation timing later by a number of hours indexed to watershed size to reduce the boundary problem without taking time to route.

Subroutine DAYOUT

(Fourth Accounting Subroutine)

CONTEXT

It is desirable to be able to print out a complete listing of daily values of various items in a neatly labelled table. As this requires about 40 lines of programming, it is convenient to have a single subroutine for this purpose.

PURPOSE

Subroutine DAYOUT prints a table of daily values given the magnitude of each desired value, the day of the year of the last day of each month, and the number of days in the year.

PROCEDURE

The tabulation process converts values arranged by calendar-year day (VDCY) into values arranged by month day (VDMD) and then prints the daily values arranged by month in the water-year month order--as shown on Table 7. Provision is made for leap year and the irregular number of days per month.

Subroutine EVPDAY

(Fifth Accounting Subroutine)

CONTEXT

One of the aspects of data collection for the Stanford Watershed Model which has been most troublesome to users has been the development of suitable evaporation data. Evaporation pans are much fewer and more scattered than either precipitation or stream gages, and their operation is often discontinued during periods of subfreezing weather.

According to the quality of the data he has available, the user of OPSET can choose from among three approaches to reading the necessary information. These in order of decreasing refinement and as specified by control option 1 (25, pp. 29-35) are:

0. Individual values for every day of the year. These should be taken directly from a nearby record and reflect the weather conditions on that day.

1. Average values over 10-day periods. Where actual recorded values are available for the same days for which flows are to be synthesized, it is both more work and less accurate to average the numbers by 10-day periods. The primary purpose of this approach is to serve other situations. A user may have to estimate evaporation

TABLE 7

TABLE PRINTED BY SUBROUTINE DAYOUT
1967-68 WATER YEAR STREAMFLOWS: POND CREEK, LOUISVILLE, KY.

	Recorded Flows											
Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	8.5	104.0	106.0	28.0	155.0	18.0	314.0	18.0	160.0	14.0	20.0	6.2
2	8.5	72.0	499.0	28.0	684.0	18.0	145.0	17.0	370.0	19.0	15.0	7.4
3	8.5	37.0	294.0	29.0	184.0	17.0	169.0	15.0	198.0	26.0	42.0	8.8
4	8.5	56.0	94.0	28.0	119.0	17.0	2840.0	14.0	134.0	24.0	24.0	9.0
5	8.5	28.0	63.0	27.0	91.0	22.0	493.0	12.0	104.0	22.0	11.0	17.0
6	23.0	18.0	51.0	24.0	74.0	25.0	246.0	10.0	87.0	20.0	12.0	15.0
7	11.0	16.0	46.0	21.0	66.0	24.0	166.0	12.0	71.0	18.0	17.0	15.0
8	29.0	12.0	31.0	19.0	57.0	24.0	131.0	12.0	57.0	14.0	30.0	15.0
9	31.0	10.0	23.0	17.0	51.0	31.0	93.0	16.0	48.0	18.0	32.0	14.0
10	11.0	7.6	30.0	18.0	36.0	63.0	69.0	60.0	39.0	27.0	298.0	14.0
11	11.0	64.0	102.0	20.0	32.0	98.0	56.0	138.0	30.0	33.0	310.0	14.0
12	10.0	50.0	80.0	22.0	30.0	566.0	41.0	68.0	21.0	18.0	290.0	13.0
13	24.0	19.0	49.0	23.0	26.0	174.0	27.0	46.0	20.0	14.0	240.0	13.0
14	94.0	18.0	89.0	25.0	24.0	113.0	297.0	42.0	20.0	15.0	190.0	14.0
15	16.0	16.0	125.0	24.0	24.0	93.0	340.0	38.0	20.0	31.0	160.0	12.0
16	12.0	12.0	69.0	22.0	24.0	251.0	128.0	34.0	102.0	39.0	135.0	10.0
17	59.0	11.0	164.0	23.0	21.0	166.0	115.0	30.0	68.0	19.0	110.0	7.3
18	28.0	9.0	221.0	27.0	19.0	116.0	119.0	31.0	40.0	16.0	90.0	12.0
19	13.0	7.6	101.0	43.0	20.0	96.0	88.0	15.0	24.0	27.0	76.0	16.0
20	13.0	6.7	84.0	70.0	28.0	134.0	177.0	9.1	15.0	18.0	62.0	13.0
21	12.0	5.8	285.0	169.0	31.0	1180.0	88.0	8.0	14.0	12.0	50.0	13.0
22	12.0	5.8	615.0	207.0	28.0	991.0	60.0	8.0	13.0	13.0	41.0	12.0
23	12.0	7.5	120.0	204.0	21.0	488.0	65.0	101.0	15.0	20.0	34.0	6.8
24	55.0	16.0	79.0	120.0	16.0	499.0	51.0	160.0	15.0	16.0	29.0	8.1
25	120.0	13.0	68.0	77.0	15.0	497.0	36.0	85.0	20.0	32.0	44.0	13.0

TABLE 7 (cont'd.)

						Recorded Flows						
Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
26	20.0	10.0	57.0	55.0	16.0	324.0	31.0	1190.0	18.0	44.0	33.0	10.0
27	16.0	8.2	42.0	50.0	16.0	191.0	29.0	674.0	20.0	74.0	25.0	11.0
28	15.0	6.4	37.0	56.0	16.0	146.0	25.0	246.0	18.0	87.0	17.0	8.2
29	13.0	30.0	32.0	64.0	17.0	126.0	22.0	160.0	15.0	24.0	13.0	6.1
30	11.0	460.0	29.0	406.0		112.0	20.0	116.0	13.0	18.0	6.7	5.9
31	12.0		28.0	207.0		207.0		81.0		22.0	5.8	

from other climatological data because no, or an incomplete, pan record is available and evaporations must be estimated from other climatological data (21, pp. 99-108). A lot of time can be saved by only going to the charts for one day out of ten. In other cases, the user may want to synthesize many years of record but have to rely on a few years of pan data. He can take 10-day period averages for the recent years as reasonable estimates for corresponding 10-day periods in earlier years.

2. Total average annual lake evapotranspiration (EPAET) and the average annual number of days of measurable rain recorded per year (MNRD). Where one desires to synthesize a large number of flow records in the same general area and has only fragmentary evaporation data, it is convenient to be able to use the model without having to work up an entire data set for each location. Subroutine EVPDAY uses regional data to distribute a total annual evaporation over the days of the year. Rainy days enter into the distribution because more evaporation usually occurs on clear than on rainy days. The distribution programmed in OPSET was developed from Kentucky data in the manner described by Ross (25, p. 35), but a check against California data showed that it did not work badly there either. The distribution seems fairly good for central United States but should be slightly more summer peaked for northern latitudes or higher elevations and slightly flatter for areas further south.

PURPOSE

Subroutine EVPDAY distributes the estimated annual evapotranspiration at a particular location among the days in the water year based on the Kentucky distribution of daily fractions of the average annual total.

PROCEDURE

The sequence of computations required to estimate daily potential evapotranspiration totals from EPAET using Subroutine EVPDAY is relatively straightforward. First, the annual potential evapotranspiration (EMAET) which would occur during the year if no rain were recorded is estimated by using the equation (MAIN0109):

$$\text{EMAET} = \text{EPAET}\left(\frac{365 + \text{MNRD}}{404}\right) \qquad (8)$$

where EPAET and MNRD are the estimated potential annual evapotranspiration and the mean annual number of rainy days respectively and are read as input data (25, pp. 31-33). If rain were equally likely to occur any day of the year, Equation 8 would have 365 + 0.5*MNRD in the denominator to offset the reduction of evaporation by one half on rainy days (MAIN0186). The value of 404 worked a little better for Kentucky where rainy days are slightly more likely to occur during times of the year when evaporation is low.

Within Subroutine EVPDAY, EMAET is multiplied by each of the 366 daily evaporation fractions derived in the method described by Ross (25, p. 35). Later each value is multiplied, by one half if rain is recorded during the day (MAIN0186, 0358).

DISCUSSION

The concept behind Subroutine EVPDAY is very helpful for use in locations where evaporation data is sparse; however, one of the other two approaches to input data should be used when more extensive data is available. The precise numbers used in apportioning the total annual evaporation among the days should be adjusted if Subroutine EVPDAY is to be used in a climatic setting much different than that of Kentucky.

Subroutine PRECHK

(Sixth Accounting Subroutine)

CONTEXT

In streamflow simulation and particularly where one must rely on precipitation gages located at a distance from the watershed, one must continually cope with the problem of the gaged record inaccurately representing average precipitation over the basin. For years containing major storms when the input data deviates significantly from precipitation actually experienced within the basin, OPSET will adjust the watershed parameters in an attempt to compensate. For example, data specifying far too little rainfall for a given runoff volume will suggest parameter values which greatly understate the ability of the watershed to store moisture. Such distorted parameter estimates can cause wildly fluctuating estimates of parameter values and greatly increase the number of years whose results must be averaged to get a good set of values (pp. 173-176).

Early in the development of OPSET, no check was made for major precipitation anomalies; and a great deal of difficulty was experienced with fluctuating parameter estimates. Therefore, it became necessary to develop a subroutine to filter out the worst storms, mostly spotty summer thunder showers. As examples, storms with runoff volumes exceeding recorded rainfall volumes or with no recorded runoff from very large rainfalls simply do not make hydrologic sense.

PURPOSE

Subroutine PRECHK is used to check for precipitation-streamflow anomalies and adjust precipitation where necessary.

PROCEDURE

In a study on the effect of rainfall variability on streamflow simulation, Dawdy and Bergmann (11) discussed errors caused in estimation of parameter values by errors in measurement of storm volume and intensity over the basin. In the application of OPSET, cases were found when recorded rainfall was simply not commensurate with recorded streamflow. Improper estimation of parameter values is inevitable if there are data errors in either the recorded flow or the recorded precipitation. The most severe problem is caused by the raingage being too far from the watershed or by trying to represent too large a watershed with too few gages.

In order to balance the effects of positive and negative errors, one may use many years of data on the same watershed. However, it was found that the same goal can be achieved by checking the data for precipitation-streamflow anomalies and adjusting the rainfall data at a significant savings in the time and cost of data compilation and computer execution. As a result, the required number of data years are much fewer.

Rainfall adjustments were made in cases where the recorded streamflow rises significantly exceed the volume of recorded rainfalls, or where very large rainfall but small or no streamflow rises are recorded. For most station-years in the OPSET trial runs of Kentucky watersheds, only two or three summer thunderstorm rainfalls are adjusted. Table 8 summarizes the number of adjustments made by watershed.

Two items were used to check for discrepancies between recorded streamflows and recorded rainfalls. One was daily recorded flow rise (RFRISE), and the other was the recorded watershed rainfall on the corresponding day (RWRAIN). RFRISE is the net increase in flow volume during the current day over the previous day in inches. RWRAIN is the rainfall recorded for that day as estimated from the accumulated recorded hourly rainfalls in inches. Inspection of the results when Subroutine PRECHK was not used showed the primary difficulty to occur during the summer months. Therefore, the checking and adjusting processes were made from the end of March through the end of September (i.e., days of the year 90 through 273).

If on any day, RFRISE exceeds 0.1 inch and RWRAIN is less than 0.05 inch, an indication that there was a significant streamflow rise but very little (if any) rainfall was recorded, the adjustment is made by adding an amount of rainfall which was set after comparing the results of a series of runs with OPSET to make the total be 1.0

TABLE 8

NUMBER OF ADJUSTMENTS MADE FOR RAINFALL ANAMOLIES FOR TESTED WATERSHEDS

Name	Area mi.^{2}	Distance from Gage to Watershed Centroid		Anamolies		Smallest SSQM
		Recording Gage	Storage Gage	+/yr	-/yr	
Bear Branch	2.21	14.86	14.00	1.67	0.67	0.654
Cane Creek	0.67	10.75	6.60	0.00	0.33	0.194
Cave Creek	2.53	2.00		0.33	1.00	0.788
Elkhorn Creek	473.0	10.00	4.00	0.00	0.00	4.003
Flat Creek	5.63	7.50	7.10	0.67	0.00	7.660
Green River	22.4	16.00	16.00	0.00	0.67	4.208
Helton Branch	0.85	10.94	6.70	0.33	0.67	0.226
McDougal Creek	5.34	3.00		1.00	0.33	1.544
McGills Creek	2.14	15.00	5.50	0.67	1.00	1.613
M. Fork Beargrass Creek	18.9	11.20		0.13	0.13	1.584
Perry Creek	1.72	19.00		0.33	0.33	0.695
Pond Creek	64.83	3.50		0.17	0.00	3.431
Rock Lick Creek	20.1	13.00		0.67	0.67	9.001
Rose Creek	2.10	9.00		0.67	2.00	0.656
S. Elkhorn Creek	24.00	0.50	5.50	0.00	1.33	10.656
S. Fork Beargrass Creek	17.2	5.00		0.33	0.17	4.062
S. Fork Little Barren River	18.3	4.00		0.33	1.33	10.246
Stillwater Creek	24.00	23.00		0.67	2.00	2.545
West Bays Fork	7.47	15.50	3.00	0.00	0.00	3.905
Wood Creek	3.89	2.00		0.33	0.67	3.630

inch plus twice the streamflow rise (PRCK0026). If RFRISE exceeds 0.1 inch, and RWRAIN is less than RFRISE yet greater than 0.05 inch, an indication that there was a significant streamflow rise which exceeded a significant recorded rainfall, the recorded rainfalls are multiplied by twice the ratio of RFRISE to RWRAIN (PRCK0031,0039).

In the situation of a large recorded rainfall but little recorded streamflow rise, the precipitation is reduced by multiplication by ten times of the ratio of RFRISE to RWRAIN, if 1) RWRAIN exceeds a preassigned maximum value of rainfall without runoff (RMWR) and RFRISE is less than two percent of RWRAIN, or 2) RWRAIN exceeds three inches and RFRISE is less than five percent of RWRAIN (PRCK 0022, 0023, 0033). The value of RMWR varies with watershed size and soil surface conditions. One would expect RMWR to be largest for a larger watershed following dry weather conditions. A value of 1.25 inches is used in late spring and early summer, while 2.00 inches is used in later summer (day of the year greater than 200) when the expected soil moisture is less. For watersheds with areas over 28 square miles, a value of 2.00 for RMWR is always used since more rainfall is required to produce a significant streamflow rise from larger watersheds.

DISCUSSION

As OPSET had previously been run for a number of watersheds without checking for rainfall-runoff anamolies, the process used to establish the adjustment rules for Subroutine PRECHK began by inspecting the output to find storms causing difficulty. Recorded rainfalls, runoffs, and dates for these storms were tabulated as were like statistics for the storms OPSET was able to handle without undue distortion of parameter estimates. While the decision on what is or is not undue distortion is subjective, a distinct boundary could be seen between the two types of events as tabulated; and this boundary provided the basis for the dates and volumes programmed into PRECHK to separate out storms requiring rainfall adjustment. The goal of PRECHK is to reduce the number of years of record required to estimate a set of parameter values, and one can argue that the quality of the adjustment rules used affects the standard deviation of estimates among years more than the mean of estimates from many years of record. Furthermore, the subroutine will seldom select any storms for adjustment in a well instrumented watershed.

The multipliers or additive rainfalls used for adjusting the selected storm rainfalls were selected by trial and error for representative years. Trial results were compared to minimize SSQM and provide estimates of parameter values commensurate with those estimated from other years of record for the same watershed. Those using OPSET in climatic settings where thunderstorms or other highly localized precipitation events frequently occur outside the months from April through September or where prevailing soil moisture conditions vary radically from those in Eastern United States may be able to improve their results by adjusting some of the empirical constants used in PRECHK.

Subroutine PREPRD

(Seventh Accounting Subroutine)

CONTEXT

The Kentucky Watershed Model employs hourly precipitation data, but moisture movement is simulated by 15-minute periods. While 15-minute rainfalls could just as well be read from the point of view of the Model (this may be done optionally by the HSP Model, 14), this information may be difficult to obtain without time-consuming analysis of the original records. Hours are the shortest time periods for which precipitation data are available on a continuous basis in published sources. Hourly totals are used in the Model, and 15-minute values are simply taken as one quarter of the hour totals.

The assumption of precipitation uniformly distributed over the hour is not correct, but it does not make much difference for watersheds having routing lags over two or three hours. Precipitation never falls at a constant rate for periods anywhere near an hour; however, the flows at the mouth of a larger watershed so blend rain falling at different times that hourly precipitation can be evenly distributed for streamflow simulation.

The problem comes with smaller watersheds. Fifteen-minute rainfall data would be desirable; but since it may not be readily available, the question is whether the results could be improved by using some pattern of unequal rather than equal distribution of hourly totals among 15-minute periods. The problem is most significant in connection with underestimation of flood peaks from short intense rainstorms on small watersheds.

PURPOSE

Two basic approaches to unequal distribution of hourly rainfalls among 15-minute periods are possible. One would be to employ a stochastic process randomly selecting from observed hourly rainfall patterns according to their observed frequency of occurrence. This approach was not used because it is complicated to program, expensive in terms of computer time to execute, and requires extensive data collection and analysis to construct. Furthermore, the difference in distributions which happen to be randomly selected for the various hours in the storms used to estimate the channel routing parameters, may well have an adverse influence on parameter estimation.

Randomly selected distributions are likely to differ sharply from a particular historical experience and introduce a new source of parameter estimation error.

The second approach is to utilize an average distribution. The largest 15-minute precipitation would be the portion of the hourly rainfall occurring on the average during the wettest of the first, second, third, and fourth quarter hours. The second largest would be the portion during the second wettest, etc. Subroutine PREPRD divides hourly precipitation among the 15-minute periods using the average distribution approach.

PROCEDURE

The average distribution curve used is shown in Figure 2 and taken from a similar curve (26, p. 32) developed by U. S. Bureau of Reclamation for the area in the United States east of 105° meridan. This cumulative distribution curve of rainfall within an hour gives four incremental fractions for successive 15-minute periods: namely 0.46, 0.28, 0.16, 0.10. Because of the lack of data and likelihood of a negligible effect, the difference between peak consecutive 15 minutes and peak clock 15 minutes was neglected.

The next issue was how to arrange these fractions in an order that gives a reasonable approximation of patterns of hourly precipitation. For example, the rainfall distribution within an hour when the precipitation total exceeds both the previous and the succeeding hour may be quite different from that within an hour when the total is less than either the previous or the succeeding hour.

PREPRD uses four patterns of hourly precipitation rainfall fractions and selects from among them by comparing current hourly precipitation with that during previous and succeeding hours. They are:

1. If the current hourly precipitation exceeds both the previous

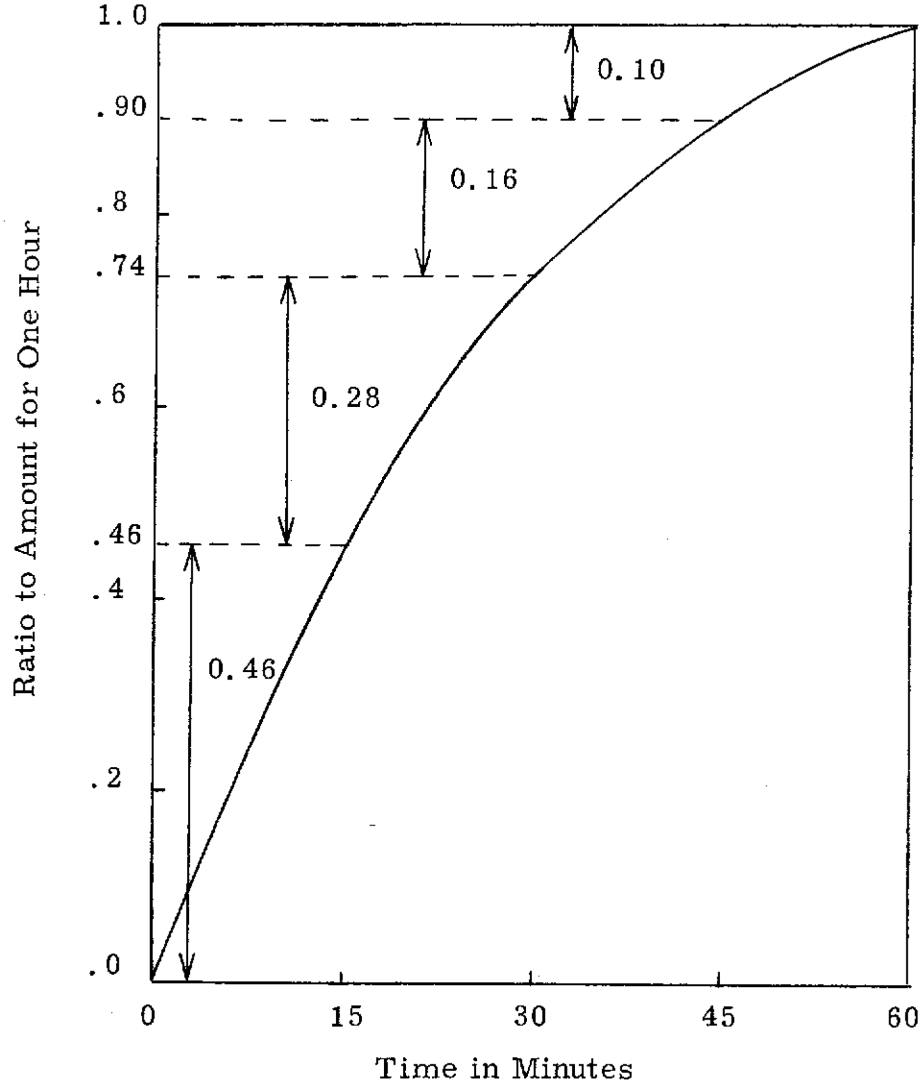

FIG. 2. Distribution of 1-hour Rainfall for Area East of 105° Meridian.

and the next hour, the four 15-minute period precipitations are taken as 0.10, 0.28, 0.46, and 0.16 of the hourly total.

2. If the current hourly precipitation is less than both the previous and the next hour, the order is 0.28, 0.10, 0.16, and 0.46.

3. If the current hourly precipitation exceeds the previous hour but is less than the next hour, the order is 0.10, 0.28, 0.16, and 0.46.

4. If the current hourly precipitation is less than the previous hour but exceeds the next hour, the order is 0.46, 0.16, 0.28, and 0.10.

PREPRD is called only during TRIPS 2 and 3 and only then when stream routing is being done on a 15-minute basis and the initial estimate of the time of concentration is less than 90 minutes (MAIN 0047, 0377).

DISCUSSION

While consistent use of the average distribtuion of hourly precipitation among 15-minute periods and the arbitrary selection of order for the four periods within the hour does not duplicate actual historical storm patterns, it does simulate higher peaks from small watersheds. The approach thus reduces the systematic simulating bias toward low flow peaks from small watersheds, and this is the primary justification for its use.

Subroutine RECESS

(First Recession Constant Subroutine)

CONTEXT

The Stanford Watershed Model required base flow and interflow recession constants as input data. Crawford and Linsley (10, p. 68) recommend the graphical approach suggested by Barnes (3) to estimate these two values. It requires plotting the logarithm of recession flow against time and measuring the slopes of two straight lines on the plot. More recently, James and Thompson (18) developed a least squares method to estimate these two recession constants from daily flow totals in an attempt to avoid the human randomness of graphical curve fitting and the time spent in obtaining and plotting complete hydrographs.

Subroutine RECESS selects recession flow sequences from recorded daily streamflows and then calls Subroutines SET2RC and/or SET1RC to evaluate the recession constants from each selected sequence. It estimates average values of the two recession constants by weighting sequence values proportional to sequence length because longer sequences were found to give more reliable results.

For sequences with both baseflow and interflow, the first day values of these two flow components are estimated by a least squares method for use in estimating the basic maximum infiltration rate (BMIR) and basic interflow volume factor (BIVF). Subroutine SETRBF is called from RECESS (RCSS0110) to make these estimates.

PURPOSE

Subroutine RECESS is used to examine daily flows throughout the year to pick out recession sequences for determining the two recession constants (BFRC and IFRC) and to establish volumes of base flow and interflow as a first step in estimating BMIR and BIVF.

PROCEDURE

The sequence selection procedure described by James and Thompson (18) is programed in RECESS. For each station-year, up to 20 flow sequences are selected, and the length of each sequence has the maximum limit of 50 days.

The minimum number of days required for an estimate of a single recession constant is two. For two constants, the minimum is four days. However, longer sequences provide better estimates from both models as the estimating procedure goes from a forced solution to an estimate minimizing random observation error by statistical methods. An analysis of the consistency of results among estimates from sequences of different lengths showed sequences at least 8 days long to be desirable. As the first or peak runoff day should not be included in the data because it usually contains a large percentage of direct runoff, the first pass through the daily flows has a minimum acceptable number of recession sequence days (MRSL) equal to 9. If three or fewer such sequences are found, MRSL is reduced to 6; and a second pass is made. Thus recession sequences as short as 5 days are used where longer sequences do not exist. If the data do not contain a single recession sequence as long as 6 days in the 365 daily values, OPSET will be halted; but this situation was never encountered in any real data.

As recessions from very small flow peaks seldom give good results (possibly because measurement errors in flow differences from day to day tend to be relatively larger with low flows) a criterion that the second-day flow should be either greater than 10 cfs or greater than 0. 4*AREA (where AREA is the watershed area in square miles) is used. Here, the second day is defined as the day after the peak or the first day whose flow is actually used in estimating the recession constants. The AREA criterion is used to increase the number of accepted sequences from small watersheds. The recession sequence is terminated by a flow rise exceeding 0. 1*SQRT(AREA) cfs. A small positive value is used to avoid ending the sequence at very small rises stemming from channel precipitation or non-hydrologic causes. The magnitude of these effects also tend to vary with the size of the watershed (RCSS0011).

After the recession sequences are established and printed, Subroutine SET2RC and SET1RC are used to estimate IFRC and BFRC. Subroutine SET2RC is always called first to try to estimate values for both recession constants (RCSS0076) from each recession sequence unless the sequence is found to begin with a relatively low flow and flat recession. In this case, the low probability of significant interflow being present made it advisable to assume only base flow was present from the beginning and use Subroutine SET1RC. If Subroutine SET2RC cannot produce two estimates in the range preselected as being reasonable (See Subroutine SET2RC), the data sequence is next used in Subroutine SET1RC to estimate a single recession constant (BFRC). If Subroutine SET1RC does not come up with a value of BFRC between 0.6 and 1.2, the sequence is entirely discarded.

The sequence estimates for BFRC and IFRC are then used to obtain average values by weighting each sequence value proportional to the length of the sequence. In the weighting, the base flow days include the length of all accepted sequences while the interflow days count only days in those sequences with acceptable IFRC values. Also, a maximum of 20 days is used in the interflow weighting. Interflow estimation is not significantly improved from longer sequences (also 95 percent of sequences with interflow are shorter than 20 days).

The annual average values are then inspected for reasonableness. If BFRC is greater than 0.99, it is set equal to 0.99; and if BFRC is less than 0.70, it is set equal to 0.70. (RCSS0105, 0106). If IFRC is less than 0.30, it is assumed that the watershed can be satisfactorily modeled by using only direct runoff and base flow. Interflow is either minimal or so rapid it can just as well be classified with direct runoff. IFRC is nominally set equal to 0.10, and this value is subsequently used throughout the program as a test to exclude interflow from the flow simulation (MAIN0222, 0225).

Finally, given the weighted average values of BFRC and IFRC, the sequences with interflow and base flow are used to estimate values of interflow and base flow at the beginning of each recession sequence by calling Subroutine SETRBF (RCSS0110).

Subroutine SET2RC

(Second Recession Constant Subroutine)

CONTEXT

Subroutine RECESS selects from the complete water year tabulation of recorded daily flows those sequences sufficiently long to provide an adequate basis for estimating recession constants. Separation of subsurface flow into interflow and base flow requires two recession constants; however, a given recession sequence may contain only one of the two flow types. The approach was to try to estimate both constants if possible but revert to the estimation of only one where that is all the data allows.

PURPOSE

Subroutine SET2RC is used to estimate two recession constants (BFRC and IFRC) for each recession sequence. It returns to Subroutine RECESS either with both values or the message that data at hand does not yield two real solutions.

PROCEDURE

The subroutine follows the approach of James and Thompson (18) of fitting the recession sequence $q_0, q_1, q_2 \ldots q_n$ into the model

$$q_t = K_b Q_{b,t-1} + K_i Q_{i,t-1} + \epsilon_t \quad (t = 1, 2, \ldots n) \tag{9}$$

where q_t = the recorded daily flow on t^{th} day of the sequence under consideration;

$Q_{b,t-1}$ = the base flow on the $t-1^{th}$ day;

$Q_{i,t-1}$ = the interflow on the $t-1^{th}$ day;

K_b = base flow recession constant, BFRC;

K_i = interflow recession constant, IFRC;

ϵ_t = a random error on the t^{th} day.

By assuming that both base flow and interflow follow a linear model, they derived the expression:

$$q_t = (K_b + K_i)\, q_{t-1} - K_b K_i\, q_{t-2} + \eta_t \tag{10}$$

where

$$\eta_t = \epsilon_t - (K_b + K_i)\, \epsilon_{t-1} + K_b K_i\, \epsilon_{t-2} \tag{11}$$

For convenience, let

$$\alpha = K_b + K_i \tag{12}$$

and $$\beta = -K_b K_i \tag{13}$$

then the model (Equation 10) became

$$q_t = \alpha\, q_{t-1} + \beta\, q_{t-2} + \eta_t \tag{14}$$

The least squares estimates of α and β ($\hat{\alpha}$ and $\hat{\beta}$) were found by solving the "normal equations"

$$\begin{bmatrix} \sum_{t=1}^{n-1} q_t^2 & \sum_{t=0}^{n-2} q_t q_{t+1} \\ \sum_{t=0}^{n-2} q_t q_{t+1} & \sum_{t=0}^{n-2} q_t^2 \end{bmatrix} \begin{bmatrix} \hat{\alpha} \\ \hat{\beta} \end{bmatrix} = \begin{bmatrix} \sum_{t=1}^{n-1} q_t q_{t+1} \\ \sum_{t=0}^{n-2} q_t q_{t+2} \end{bmatrix} \tag{15}$$

Combining equations 12, 13, and 14, and bearing in mind that K_b is always greater than K_i because the base flow receeds slower, the estimated K_b and K_i were shown to be

$$\hat{K}_b = \frac{\hat{\alpha} + \sqrt{\hat{\alpha}^2 + 4\hat{\beta}}}{2} \qquad (16)$$

$$\hat{K}_i = \frac{\hat{\alpha} - \sqrt{\hat{\alpha}^2 + 4\hat{\beta}}}{2} \qquad (17)$$

if the discriminant $\hat{\alpha}^2 + 4\hat{\beta}$ is non-negative. If the discriminant is negative (Equation 13 shows β to be negative), the complex estimates of K_b and K_i have no physical meaning. There also has to be at least four q's for the matrix of coefficients in Equation 15 to be non-singular.

DISCUSSION

If the recession sequence data can be represented by two distinct flow categories, each with a fixed linear recession constant, Subroutine SET2RC will provide a least squares estimate of two constants and designate the larger BFRC and the smaller IFRC. However, observed recession data will deviate from the model because of non-linear recession of subsurface runoff, the presence of small quantities of direct runoff from storms too small to cause a flow rise, flow measurement errors, or other reasons (18). If Subroutine SET2RC is applied to a recession sequence which is best modeled by a single recession constant, it will estimate a value for that constant. The estimate for the other constant will be based on error term residuals and have no physical meaning. When either K_b or K_i falls outside the reasonable range or can only be estimated as a complex number, the results with Subroutine SET2RC are discarded, and Subroutine RECESS shifts to Subroutine SET1RC to try to estimate a single value. The single constant is assumed to represent base flow as it is difficult to picture a prolonged period of time when all flow is interflow.

The reasonable ranges were taken as 0.6 to 1.2 for K_b and -0.4 for 0.8 for K_i. These ranges are broadly defined in order to include sequences producing estimates with positive and negative random estimating error. As many sequences are averaged in Subroutine RECESS to get an overall estimate, the positive and negative estimating errors tend to cancel. The range of acceptable estimates of BFRC and IFRC becomes much narrower (p. 68). Use of such a limited range at this point would bias the averaged estimate.

Subroutine SET1RC

(Third Recession Constant Subroutine)

CONTEXT

The recession sequences selected by Subroutine RECESS potentially have two flow components. When attempts were made to estimate two constants with SET2RC from flow sequences with a small beginning flow and slow recession, the results were usually bad because base flow usually predominated. As a cutoff which gave the best results, the sequences with a first flow less than 0.4*AREA and a second flow greater than 80 percent of the first flow were filtered out and were fitted into a model to evaluate a single recession constant (RCSS0073, 0074).

Some other flow sequences yielded physically unreasonable values for either one or both of the two recession constants. These also were considered to be base flow sequences. In both cases, the need was for an estimating procedure to evaluate a single recession constant (RCSS 0076-0078).

PURPOSE

Subroutine SET1RC is used to estimate the base flow recession from sequences of daily flow totals determined to be essentially base flow.

PROCEDURE

Given a sequence of base flows $q_0, q_1, \ldots q_n$ following the linear model

$$q_t = K_b q_{t-1} + \epsilon_t \qquad (t = 1, 2, \ldots n) \tag{18}$$

the least squares estimator for the coefficient K_b (BFRC) as developed by James and Thompson (18) can be expressed as

$$K_b = \frac{\sum_{t=0}^{n-1} q_t q_{t+1}}{\sum_{t=0}^{n-1} q_t^2} \tag{19}$$

Equation 19 was programed into Subroutine SET1RC (STIR 0006-0010) and used to estimate BFRC for each base flow sequence. The values of BFRC for all the flow sequences (including those estimated by SET2RC for sequences with interflow) were then used in RECESS to estimate an average BFRC for that station-year.

DISCUSSION

The value of BFRC estimated by OPSET proved to be consistent among sequences and among years. Close inspection of the results, however, revealed a trend toward larger estimates of BFRC from sequences of relatively lower flows than from sequences beginning with higher flows. This trend is the very reason for use of a second base flow recession parameter (BFNLR) in the Kentucky Watershed Model to make the base flow recession relatively more rapid during periods of high groundwater storage and then progressively less rapid as the sequence continues (10, pp. 68-69). Recommendations for estimating BFNLR are presented on pp. 170-173.

Subroutine SETFVP

(First Land Phase Parameter Subroutine)

CONTEXT

The most important single function of OPSET is to estimate an optimum set of values for the six parameters which the sensitivity studies revealed to govern the month by month distribution of flow volume synthesized from a precipitation record. In order of decreasing sensitivity, these are

1. LZC - An index of the moisture storage capacity of the lower zone or soil,
2. BMIR - An index of infiltration rate,
3. SUZC - An index of the degree to which the moisture storage capacity of the upper zone or watershed surface and soil cover increases into the summer season because of vegetation changes, cultivation practices, and other factors,
4. ETLF - An index to the rate of moisture loss through evapotranspiration from the soil,
5. BUZC - An index of the degree to which the upper zone moisture storage capacity decreases with increasing lower zone moisture content because of the development of better surface drainage during wetter conditions,
6. SIAC - An index of the degree to which the infiltration rate increases into the summer.

Each parameter is described in more detail by Ross (25, pp. 47-55) and was originally developed under different names for the Model by Crawford and Linsley (10).

In order to see how and to what degree each parameter affects runoff (annual total as well as distribution over the year), a sensitivity study was made with the data for Elkhorn Creek near Frankfort, Kentucky, for the 1964 water year. First, a best set of parameter values was selected by trial-and-error. Then for each of the six parameters, two more computer runs were made by varying that parameter while all the other parameters were held constant. Each parameter was found to have its own effect on the simulated volumes, and this effect varies by type of flow and with the time of the year. This sensitivity study helps translate each parameter from a variable in an equation to a term with hydrologic meaning and thereby provides very useful guidelines for establishing rules for adjusting each parameter value in a fashion likely to lead to the synthesis of better matching flows.

The adjustment rules for five of these six volume parameters are based on observing differences between synthesized and recorded flows during the months when the synthesized monthly flows are most sensitive to variation in that variable. These five are grouped in Subroutine SETFVP. Better adjustment for BMIR was found to be indexed to matching the recorded and the synthesized base flows during the first three days of selected recession sequences (See Subroutine SETBMI). However, in the process of estimating the flow volume parameters, these two subroutines function as a unit to adjust the six parameters simultaneously between trial flow simulations.

The optimization process begins by simulating a year of streamflows with a set of initial trial values for the six parameters. Then each parameter is adjusted by its adjustment rule. The new set of six values is used to simulate another year of streamflows, and the process continues until the adjustments no longer are able to achieve simulated flows which have a smaller value of SSQM as computed by Subroutine SETFDI.

If estimation of the six volume parameters functioned in an ideal manner, each adjustment would improve the match between recorded and simulated flows until the final adjustment achieved exact duplication. Of course, an exact match is impossible with real data and a model which cannot reflect the full complexity of the runoff process. Somewhere, the adjustment will have to be stopped because it can no longer improve the matching.

Perfect matching is prevented by data difficulties and by modeling difficulties. Better data will yield better matching and increase the relative difficulty with the model. No matter which difficulty predominates for a given run with OPSET, it is certain to be monthly asymmetrical. For example, measured precipitation will depart from true watershed precipitation in some months more than in others. If a parameter is indexed on a month with data difficulty, repeated adjustment will overcorrect. Synthesized flows for the other months will worsen. A worsening for many months will overshadow an improvement for an index month, and a larger SSQM will halt the process. If the data difficulty in the index months is large, the worsening may begin early in the adjustment process; and OPSET will be prevented from making a good estimate. For this reason, an alternate adjusting index is developed for each parameter. If overcorrection is leading a parameter into wild values and resulting in poor matching, the index suggested by the sensitivity studies is abandoned, and the alternate adjustment is tried.

A number of specific observations about this process are useful.

1. The smaller the largest data difficulty, the better will be the final matching.

2. If all the data were accurate and the only difficulty lay with the model, OPSET would adjust the parameters in an attempt to compensate for model imperfections and cause the process to halt as matching worsened in months where the model worked better.

3. Data difficulties in months used to index adjustments to the parameters to which the flows as a whole are the most sensitive are the most likely to quickly terminate the process and produce poor estimates for all six parameters. This suggests indexing these parameters on larger groups of months to minimize susceptibility to this difficulty.

4. These more "sensitive" parameters are estimated by OPSET with greater precision because faulty estimates are more likely to upset the entire annual pattern of simulated flows.

5. Data difficulties in months used to index adjustments to the parameters to which the flows as a whole are least sensitive will more slowly terminate the process. If the index is leading this parameter to bad values but the other parameters are improving, the matching as a whole will likely improve too.

6. These less "sensitive" parameters are estimated by OPSET with less precision. This may in part explain the greater difficulty Ross had in correlating the values estimated for these parameters with his measured watershed characteristics (25, pp. 103-118).

7. Simultaneous adjustment of six parameter values leads to interactions as faulty estimates for one parameter upsets the adjust-

ment index for and hence the selected value of another parameter. The sensitivity tables show flows in some months to be more sensitive to the value of a given parameter than are the flows in other months, but flows in all months are to some degree sensitive to all parameters.

8. Months more likely to have data difficulties provide less desirable adjustment indices. October is a poor month for indexing because of the difficulty in estimating initial contitions. Summer months are worse than winter months because the greatest data problems are associated with convective precipitation.

PURPOSE

Subroutine SETFVP adjusts the values of five flow volume parameters LZC, SUZC, ETLF, BUZC, and SIAC during the process of estimating the best set of values for the six flow volume parameters.

PROCEDURE

The values of the five flow volume parameters are adjusted in Subroutine SETFVP by examining the monthly flow indices determined in Subroutine SETFDI. The specific indices examined were based for a given parameter on months with flows known from the Elkhorn sensitivity studies to be particularly sensitive to that parameter and adjusted as experience was gained with OPSET.

A numerical example of the estimation process is shown on Table 9 based on South Fork Beargrass Creek near Louisville, Kentucky, for 1947 water year. Table 10 provides supplemental information illustrating how overland flow and base flow months were defined in the adjustment of LZC. The information on these tables will be gradually explained as the parameter adjustments are individually presented.

TABLE 9

ADJUSTMENT OF FLOW VOLUME PARAMETERS: SOUTH FORK BEARGRASS CREEK, LOUISVILLE, KENTUCKY, 1947

		PARAMETER VALUES*					
Cycle		LZC	BMIR	SUZC	ETLF	BUZC	SIAC
1	(ROUGH)	12.00	1.20	1.30	0.25	1.50	0.90
2		10.16	4.35	0.74	0.19	2.14	0.45
3		8.63	4.37	0.49	0.18	2.72	0.22
4		7.90	3.29	0.47	0.21	4.61	0.11
5		7.53	2.73	0.42	0.24	6.54	0.06
6		7.13	2.83	0.37	0.26	5.42	0.03
7		7.06	3.19	0.33	0.27	4.60	0.02
8		6.56	3.55	0.31	0.27	4.45	0.01
9		6.02	3.73	0.31	0.28	4.59	0.01
10		5.37	3.94	0.31	0.29	4.49	0.01
11		4.67	4.19	0.31	0.29	4.31	0.01
12		3.97	4.49	0.32	0.29	4.05	0.01
13		3.36	4.79	0.32	0.28	3.74	0.01
1	(FINE)	4.67	4.19	0.31	0.29	4.31	0.01
2		4.45	4.64	0.36	0.31	4.37	0.01
3		3.90	5.43	0.44	0.31	4.37	0.02
4		3.37	6.14	0.52	0.30	3.99	0.02

*For this station-year, the basic interflow volume factor (BIVF) is 0.0 because no interflow was encountered in Subroutine RECESS. For station-years where interflow is appreciable, BIVF in the Rough cycles is set at 0.90, and its value is adjusted in the Fine cycles by Subroutine SETBIV.

TABLE 9 (cont'd.)

MONTHLY FLOW DEVIATIONS

Cycle		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1	(ROUGH)	-0.12	0.98	0.19	-0.09	-3.58	-0.22	-0.16
2		-0.07	0.45	0.27	-0.20	-1.00	-0.35	-0.16
3		0.05	1.02	0.74	-0.11	-0.73	-0.18	-0.08
4		-0.03	0.92	0.73	-0.06	-0.78	-0.17	-0.04
5		-0.09	0.50	0.48	-0.08	-0.88	-0.17	-0.04
6		-0.11	0.18	0.28	-0.11	-0.84	-0.18	-0.04
7		-0.12	0.04	0.14	-0.17	-0.76	-0.20	-0.05
8		-0.12	0.11	0.17	-0.16	-0.69	-0.18	-0.04
9		-0.12	-0.05	0.18	-0.15	-0.65	-0.15	-0.02
10		-0.13	-0.11	0.22	-0.12	-0.61	-0.12	-0.00
11		-0.13	-0.15	0.32	-0.08	-0.56	-0.08	0.02
12		-0.13	-0.17	0.49	-0.04	-0.51	-0.03	0.05
13		-0.13	-0.09	0.72	-0.01	-0.47	0.01	0.07
1	(FINE)	-0.05	-0.09	0.34	-0.08	-0.53	-0.08	0.04
2		-0.05	-0.23	0.24	-0.08	-0.47	-0.08	0.03
3		-0.05	-0.23	0.37	-0.06	-0.37	-0.06	0.04
4		-0.05	-0.15	0.58	-0.02	-0.31	-0.02	0.05

Cycle		May	Jun.	Jul.	Aug.	Sep.	SSQM
1	(ROUGH)	-0.61	-1.09	-0.70	-0.76	-0.11	16.49
2		-0.17	-0.42	-0.21	-0.18	-0.05	1.72
3		0.03	-0.30	0.73	-0.01	-0.01	2.78
4		0.06	-0.35	0.65	-0.13	-0.06	2.59
5		0.09	-0.39	0.65	-0.19	-0.09	1.91
6		0.11	-0.36	0.68	-0.19	-0.09	1.51
7		0.13	-0.29	0.72	-0.15	-0.09	1.31
8		0.15	-0.22	0.71	-0.12	-0.10	1.16
9		0.16	-0.19	0.63	-0.13	-0.10	0.99
10		0.18	0.18	0.52	-0.16	-0.11	0.83
11		0.19	-0.16	0.39	-0.20	-0.11	0.71
12		0.21	-0.15	0.24	-0.26	-0.12	0.73
13		0.23	-0.13	0.10	-0.31	-0.12	0.94
1	(FINE)	0.23	-0.09	0.45	-0.13	0.03	0.70
2		0.19	-0.11	0.28	-0.16	0.03	0.50
3		0.16	-0.14	0.11	-0.21	0.02	0.44
4		0.13	-0.14	-0.01	-0.28	0.02	0.58

TABLE 10

DIVISION OF SIMULATED FLOWS: S. FK. BEARGRASS CREEK, LOUISVILLE, KY. 1947

	Recorded Monthly Totals	Recorded Rainfalls	Estimated Evapotranspiration	Synthesized Flows							
				Cycle 1 (initial)				Cycle 2			
				Overland flow	Interflow	Baseflow	Total flow[*]	Overland flow	Interflow	Base flow	Total flow[*]
	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)
Oct.	0.099	2.16	3.03	0.079[a]	0.000	0.011	0.084	0.079[a]	0.000	0.019	0.090
Nov.	0.279	4.33	1.48	0.306[a]	0.228	0.068	0.597	0.178	0.084	0.170	0.426
Dec.	0.695	2.92	0.85	0.258	0.265	0.306	0.825	0.119	0.126	0.645[b]	0.886
Jan.	3.540	5.30	0.64	2.217[a]	0.563	0.487	3.264	0.633	1.042	1.289	2.960
Feb.	1.042	0.40	0.71	0.000	0.018	0.181[b]	0.199	0.000	0.043	0.464[b]	0.504
Mar.	0.636	2.19	0.96	0.167	0.226	0.127	0.516	0.071	0.112	0.282[b]	0.461
Apr.	3.660	6.26	2.05	1.911[a]	0.731	0.533	3.165	0.458	1.248	1.473	3.168
May	2.110	6.04	4.03	0.500	0.446	0.380	1.306	0.292	0.615	0.922[b]	1.809
Jun.	1.390	4.03	5.76	0.205	0.131	0.337[b]	0.646	0.149	0.138	0.711[b]	0.972
Jul.	0.472	4.22	6.08	0.142[a]	0.034	0.111	0.260	0.149	0.120	0.338[b]	0.578
Aug.	0.158	1.75	6.88	0.054[a]	0.000	0.033	0.071	0.054	0.000	0.103[b]	0.128
Sep.	0.108	2.86	4.74	0.089[a]	0.000	0.010	0.094	0.089[a]	0.000	0.025	0.102

[*] Total flow is the sum of overland flow, interflow, and base flow less stream evaporation.

a. Overland-flow month

b. Base-flow month

Subroutine SETFVP calls Subroutine SETFDI to calculate the monthly flow deviation indices (STFV0008) and then adjusts the five parameters one by one according to the rules which follow.

LZC: LZC is an index of soil-moisture storage capacity. The bigger its value, the more water can be stored in soil. It directly or indirectly controls the simulated rates of infiltration, evapotranspiration, and percolation to groundwater.

The response of different flow components to the variation of LZC can be seen in the results of the Elkhorn Creek sensitivity studies (Tables 11 and 12). Increasing LZC reduces overland flows with the greatest decrease coming toward the end of the wet months when precipitation is less apt to saturate the available storage capacity. The overland flows decrease sharply in those wet months right after long dry season because more water infiltrates into the soil and is stored.

Increasing LZC decreases interflows and base flows in wet winter months but increases them in dry summer months. When the soil storage capacity is increased, more water is stored in the soil during the wet season so that less is available to contribute to interflows and base flows, but the greater soil moisture contributes to base flow in dry months and contributes indirectly to interflow because the soil is wetter during storm periods (Equation 35).

The consistency with which overland flows decrease when LZC increases suggests that the adjustment of LZC be tied to overland flow. Recorded overland flow cannot be readily estimated on a monthly basis, so direct matching is not possible. The next best approach was to use total flow in months where overland flow is known to predominate. An "overland-flow month" is defined as a month in which more than half of the simulated total flow is overland flow. Such months are selected in MAIN0732 to 0746 and tagged by

TABLE 11

SENSITIVITY STUDIES: ELKHORN CREEK WATERSHED (1964) with LZC = 3.50, BMIR = 0.65, SUZC = 0.10, ETLF = 0.20, BUZC = 0.75, SIAC = 3.0

	Precipitation (in)	Potential Evapo-transpiration (in)	Overland flow less stream evaporation (in)	Interflow (in)	Baseflow (in)	Total Flow (in)
Oct.	0.46	4.68	0.028	0.000	0.015	0.043
Nov.	1.71	2.42	0.039	0.000	0.001	0.040
Dec.	1.14	0.22	0.034	0.067	0.022	0.123
Jan.	2.75	0.45	0.438	0.809	0.176	1.423
Feb.	2.68	0.32	0.244	0.979	0.279	1.502
Mar.	11.22	0.61	7.031	2.509	0.680	10.220
Apr.	3.32	1.60	0.365	0.570	0.307	1.242
May	1.49	4.12	0.062	0.070	0.153	0.295
June	3.19	5.77	0.063	0.061	0.059	0.183
July	4.03	5.27	0.070	0.015	0.039	0.124
Aug.	2.66	6.50	0.052	0.001	0.010	0.063
Sept.	4.53	5.52	0.068	0.053	0.015	0.136

TABLE 12

ELKHORN CREEK WATERSHED SENSITIVITY STUDIES: MONTHLY SYNTHESIZED FLOW VOLUMES AS A FRACTION OF VOLUMES WITH LZC = 3.50

	Overland Flow		Interflow		Base Flow		Total Flow	
	LZC= 7.0	LZC= 24.0	LZC= 7.0	LZC= 24.0	LZC= 7.0	LZC= 24.0	LZC= 7.0	LZC= 24.0
Nov.*	1.00	0.97	1.00	1.00	1.00	2.00	1.00	1.02
Dec.	1.03	1.03	0.48	1.45	0.50	1.41	0.63	1.32
Jan.	0.64	0.60	0.78	0.78	0.49	0.56	0.70	0.70
Feb.	0.52	0.41	0.82	0.68	0.52	0.39	0.72	0.58
Mar.*	0.95	0.86	0.99	0.98	0.61	0.37	0.93	0.85
Apr.	0.87	0.79	0.85	0.68	0.65	0.36	0.81	0.60
May	0.94	0.87	0.93	0.67	0.72	0.39	0.82	0.56
Jun.	1.00	0.97	1.03	0.79	0.92	0.54	0.98	0.77
Jul.*	0.99	0.99	1.33	1.20	1.31	1.03	1.13	1.03
Aug.*	1.00	0.98	3.00	4.00	1.80	1.80	1.15	1.16
Sep.*	0.93	0.87	1.32	1.72	1.53	2.00	1.15	1.32

*Overland flow month in which synthesized overland flow is more than one-half of total flow (See Table 11).

setting XMPFT for that month equal to 2.0. If there are at least three overland-flow months during the water year, the following steps are used to adjust the value of LZC:

1) Sum the monthly flow deviation indices into SOFMD for the FNOFM overland flow months.

2) Calculate the adjustment factor (FLZC) for LZC as

$$\text{FLZC} = \frac{\text{SOFMD}}{0.75*\text{FNOFM}} \tag{20}$$

3) If FLZC is positive (the synthesized flow averages greater than the recorded flow in the overland-flow months), increase LZC by multiplying by (1+FLZC) so that the synthesized flow may be decreased. If FLZC is negative, decrease the value of LZC by dividing by the factor (1-FLZC) to make the flows bigger.

The constant 0.75 in Equation 20 (STFV0041) was established in conjunction with values for a set of like constants, one per parameter. The other values are 1.0 for SUZC (STFV0089), 1.2 for ETLF (STFV0134), 0.4 for BUZC (STFV0147), and 1.5 for SIAC (STFV0177). The overall and relative magnitude of these constants were established by trial-and-error. The overall magnitude was adjusted downward as needed to prevent the trial estimates from varying so much that they never stabilized to a good match. It was adjusted upward as needed to prevent excessive computer time from being used. The relative magnitude of the constant for a given parameter was increased as needed to make that parameter arrive at its optimum value about the same time the others did. If a constant was too small, the parameter would not reach an equilibrium value before the process was halted. A single parameter being adjusted in increments too large would upset the estimation process by changing flows faster than changes in the other parameters could bring them in line.

Sometimes, the value of FLZC may be quite large (positive or negative) because of data difficulties in some months or because of the initial trial set of values being far from optimal. If so, the adjusted value would be either so big (when FLZC is positive) or so small (when FLZC is negative) as to upset the whole optimizing process from the very beginning. In order to prevent this, FLZC is limited to the range between -1.0 and 1.0. When the calculated FLZC exceeds 1.0, it is set equal to 1.0; and when FLZC is less than -1.0, it is set equal to -1.0. This limitation confines the adjusted LZC to between one-half and twice the previous value.

Even with the limitation on FLZC, the adjusted value of LZC may eventually become too big or too small if there are data difficulties which cause overcorrection. For example, if an overland-flow month happens to have recorded streamflows too small to be commensurate with the recorded rainfalls, the program would increase the value of LZC time after time in an attempt to decrease the synthesized flows until an unreasonably large value of LZC resulted. As a control, LZC is restricted to values between 30.0 and 2.0 inches.

For a year with many overland-flow months, the above method works well. When there are only one or two, the process may be severely upset by data difficulties in these months. The danger is particularly great when a low flow summer month is an overland-flow month because of overland flow from one summer thunderstorm. When there are no overland flow months, the process breaks down completely. For these reasons, when there are less than three overland-flow months, the average of the monthly flow deviation indices of the two largest runoff months is taken as the adjustment factor FLZC. The two largest total flow months are sensitive to LZC and are less likely than low flow months to be associated with rainfall measurement problems.

For the example of Tables 9 and 10, the first adjustment of LZC is based on seven overland-flow months (October, November, January, April, July, August, and September) and changes LZC from 12.0 to 10.16 by using Equation 20. The second adjustment is based on the two largest runoff months (April and January) instead of the two overland-flow months (October and September), changes LZC from 10.16 to 8.63 instead of 9.41, and thereby speeds convergence on a final value of 3.90.

The alternate procedure for adjusting LZC is invoked when after six adjustments during the Rough phase LZC exceeds 29.0 (MAIN0777). A value this large hints that something else should be tried. An alternate procedure is not adopted sooner than this because wild values may occur before the program has a chance to recover from initial parameter values which may be quite poor for the watershed at hand. Adjustments by the alternate procedure are handled in MAIN by setting the logical variable LLZC to be TRUE, and the Subroutine SETFVP adjustment is skipped (STFV0030).

The alternate procedure adjusts LZC based on the total annual runoff volume according to the equation (MAIN0781):

$$\mathrm{LZC} = \mathrm{PLZC}\left(\frac{\mathrm{SATFV}}{\mathrm{RATFV}}\right) \tag{21}$$

where PLZC = previous trial value of LZC;

SATFV = synthesized annual total flow volume;

RATFV = recorded annual total flow volume.

One special case in adjusting LZC comes when there is "Fall trouble" (See Subroutine SETBMI) caused by difficulty in establishing initial soil moisture conditions. If the adjustment is in Rough adjustment cycle and the adjusted value of LZC is less than the associated estimate of initial soil moisture (LZS) plus 2.0, the value of LZC is set to be LZS + 2.0 (MAIN0283). This step was found to eliminate wild adjustment patterns caused by starting the water year with a saturated watershed.

In the Fine adjustment cycle, the limitation on extreme values (30.0 and 2.0) is removed because a reasonable set of values is estimated during the Rough cycle. If adjustment outside this range can now improve the overall matching, the adjusted value should be accepted for LZC. If during the Rough adjustment, annual runoff volume has been invoked to adjust LZC, then Equation 21 is retained for the Fine adjustment.

SUZC: This parameter is used in the Model to account for the growing season increase in upper zone storage capacity (25, pp. 47-48). The sensitivity studies (Tables 11 and 13) show increases in SUZC to 1) reduce total runoff during summer months, particularly those with significant shower activity, and 2) reduce base flow by an amount which becomes progressively larger through the summer. Each trend makes hydrologic sense. If the watershed surface is able to hold more moisture, summer storms are likely to be adsorbed on the surface (thus reducing runoff from larger rains and eliminating it from smaller rains), and the water will stay near the surface until it evaporates. Summer infiltration will decrease, and groundwater will gradually drain. If little or no rain occurs in August and September, flows in these months will be quite low.

The adjustment of SUZC is based on the monthly flow deviation indices during the two months between April and November inclusive with the greatest recorded rainfall plus indices for August and September when more than half of the flow synthesized for the months during the last trial was base flow. The adjustment is executed in the following steps:

TABLE 13

ELKHORN CREEK WATERSHED SENSITIVITY STUDIES: MONTHLY SYNTHESIZED FLOW VOLUMES AS A FRACTION OF VOLUMES WITH SUZC = 1.0

	Overland Flow		Interflow		Base Flow		Total Flow	
	SUZC= 0.5	SUZC= 2.0	SUZC= 0.5	SUZC= 2.0	SUZC= 0.5	SUZC= 2.0	SUZC= 0.5	SUZC= 2.0
Nov.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dec.	1.00	0.97	1.22	0.75	1.09	0.82	1.13	0.82
Jan.	0.99	0.95	1.00	0.96	0.99	1.03	0.99	0.97
Feb.	0.96	0.76	1.00	0.96	1.00	1.14	1.00	0.97
Mar.	1.00	0.98	1.00	1.00	1.00	1.04	1.00	0.99
Apr.	1.47	0.49	1.24	0.76	1.04	0.99	1.26	0.74
May*	1.13	0.92	2.39	0.63	1.10	0.95	1.42	0.87
Jun.	1.60	0.94	4.49	0.15	1.39	0.71	2.50	0.60
Jul.	1.01	0.99	7.27	0.13	2.10	0.49	2.12	0.73
Aug.	1.00	1.00	1.70	0.00	3.00	0.30	1.56	0.87
Sep.	0.63	1.19	3.42	0.11	3.07	0.00	1.98	0.64

*Base-flow month in which synthesized base flow is more than one-half of total flow (See Table 11).

1. Determine the two months in the period of April through November with the greatest recorded precipitation (STFV0071-0083). For the example given in Table 10, April and May are the two wettest.

2. Check the synthesized flows for August and September to determine whether base flow is over one-half of the total. The example in Table 10 shows August in Cycle 2 to be a base flow month.

3. Sum the monthly flow deviation indices of the two wettest summer months (STFV0084) plus those for Augusts and Septembers which are base flow months (STFR0086, 0089) to get FSUZC.

4. If FSUZC exceeds 1.0, set it equal to 1.0; if it is less than -1.0 set it equal to -1.0.

5. If FSUZC is positive, increase SUZC by multiplying by (1 + FSUZC) to decrease the index month flows. If FSUZC is negative, decrease SUZC by dividing by a factor (1 - FSUZC) to increase index month flows.

The extreme accepted values of SUZC are 0.3 and 3.0 during Rough adjustment cycle. However, the limitation is again removed for the Fine adjustment cycle. The ust of both wet and dry summer months in the adjustment as described made it unnecessary to develop a secondary adjustment such as those used for the other volume parameters. No further trouble with SUZC was noted once the base flow months were brought in to check unwise adjustments caused by rainy month data difficulties.

<u>ETLF:</u> This parameter is used in estimating the volume of evapotranspiration from the lower zone. Since the Model assumes lower zone evapotranspiration only occurs after the upper zone has dried out and this usually does not occur during winter periods of low evaporation, larger values of ETLF are primarily associated with more thorough drying of the soil during the summer. A larger value of ETLF should reduce runoff from summer rain by an amount which

progressively increases through the season and continues on through the fall period of soil moisture replenishment. The sensitivity studies (Tables 11 and 14) show that when ETLF increases, flows decrease throughout the year, but the most drastic decreases are experienced in summer month flows. The decrease becomes progressively severe until the first major winter storm and is least noticeable during months where most of the flow is from moisture previously stored within the watershed.

The adjustment of ETLF is based on matching the flows in summer months when the rainfall exceeds an aribtrary two inches. When necessary, ETLF is increased to prevent moisture buildup at the end of the water year. The summer months are defined as the months ending with the month beginning the wet season (MBWS) and beginning with the month beginning the dry season (MBDS). MBWS is the first of the months of November and afterwards when the precipitation total exceeds the potential evapotranspiration. MBDS is the month following the first month when the potential evapotranspiration exceeds precipitation (STFV0052-0064). Skipping to the second month allows a month for the upper zone moisture to dry. For the example given in Table 10, MBWS is November, and MBDS is March. Actually, July would probably have been a better choice for this example, but a provision to prevent triggering of the dry season by an extremely dry winter month was not worked into OPSET. The effect on the final estimate of ETLF was minimized by preventing use of an MBDS earlier than June (STFV0111).

If at least one month in the period beginning with MBDS and ending with MBWS has over two inches of recorded precipitation, ETLF is adjusted as follows.

1. Sum the monthly flow deviation indices of WSM wet summer months to get SWSMD. In the example in Table 10, the months are October, November, June, July, and September.

TABLE 14

ELKHORN CREEK WATERSHED SENSITIVITY STUDIES: MONTHLY SYNTHESIZED FLOW VOLUMES AS A FRACTION OF VOLUMES WITH ETLF = 0.2

	Overland Flow		Interflow		Base Flow		Total Flow	
	ETLF= 0.1	ETLF= 0.4	ETLF= 0.1	ETLF= 0.4	ETLF= 0.1	ETLF= 0.4	ETLF= 0.1	ETLF= 0.4
Nov.	1.00	0.97	1.00	1.00	1.00	1.00	1.01	0.99
Dec.	1.00	0.91	1.96	0.43	1.91	0.45	1.68	0.57
Jan.	1.09	0.92	1.05	0.95	1.31	0.77	1.10	0.91
Feb.	1.05	0.86	1.02	0.98	1.15	0.88	1.06	0.95
Mar.	1.00	1.00	1.01	0.99	1.05	0.95	1.01	0.99
Apr.	1.01	0.99	1.01	0.99	1.03	0.97	1.02	0.99
May	0.98	1.00	1.16	0.89	1.05	0.97	1.06	0.96
Jun.	1.02	0.97	1.52	0.54	1.68	0.64	1.40	0.72
Jul.	1.00	0.99	2.13	0.33	2.64	0.33	1.66	0.71
Aug.	0.98	1.04	6.00	0.00	4.30	0.00	1.58	0.84
Sep.	0.72	1.12	2.53	0.45	3.87	0.20	1.77	0.76

2. Calculate the ETLF adjustment factor, FETLF, by the equation

$$\mathrm{FETLF} = 1.2 \left(\frac{\mathrm{SWSMD}}{\mathrm{WSM}}\right) \qquad (22)$$

3. If FETLF exceeds 1.0, set it equal to 1.0; if it is less than -1.0, set it equal to -1.0.

4. If FETLF is positive, which means the synthesized flows in the index months are too high, increase ETLF by the factor (1 + FETLF). If FETLF is negative, decrease the value of ETLF by dividing the factor (1 - FETLF) in order to increase flows in wet summer months.

Since summers may be so dry that no month has more than two inches of precipitation, an alternate adjustment procedure is provided for this case using the deviation index for the month with the largest runoff volume to adjust ETLF. The following relationship replaces Equation 22:

$$\mathrm{FETLF} = 5.0 * \mathrm{MFDP(M1R)} \qquad (23)$$

where MFDP(M1R) is the deviation index for the month with the largest runoff volume. The relatively high constant of 5.0 is dictated by a low sensitivity.

In the Rough adjustment cycle, the adjusted value of ETLF is bounded by the minimum and maximum values of 0.05 and 0.60. If after six cycles the adjusted ETLF exceeds 0.59, an indication that one wet summer month may have a large positive deviation caused by a precipitation data problem which forces the adjustment to choose a still higher value of ETLF, the largest positive deviation month is thereafter excluded in evaluation of the adjustment factor (STFV0123-0134) for both the remaining Rough cycles and the Fine adjustment cycles.

At the other extreme, circumstances adjusting ETLF to a very low value may cause the soil moisture to build up through the water year. In order to prevent such moisture buildup, the value of ETLF is doubled whenever the end-of-month soil moistures (EMLZC) of both August and September exceed the value of LZC, and annual precipitation is less than 1.5 times annual potential evapotranspiration (STFV0101-0102). Usually this will bring the trial estimates back into line.

BUZC: The basic upper zone storage capacity factor (BUZC) indexes the capacity of the soil surface to hold moisture as interception or depression storage. Sensitivity studies (Tables 11 and 15) show that by increasing BUZC: 1) simulated flows in the spring months slightly increase, and 2) flows in the summer and fall become much smaller with the most severe decrease coming in September through December when these months have significant rainfall. The hydrologic explanation is much the same as it is for SUZC with the added factor of increased late winter or spring runoff caused by a wetter soil surface during this period of low evaporation.

The adjustment of BUZC proceeds as follows.

1. Calculate the adjustment factor (FBUZC) as the product of 0.4 and the sum of monthly flow deviation indices for September, November, and December. The constant 0.4 was found to provide the best adjustment step size. October is omitted to minimize problems caused by poor estimates of initial soil moisture conditions.

2. If FBUZC exceeds 1.0, set it equal to 1.0; if it is less than -1.0, set it equal to -1.0.

3. Adjust BUZC by multiplying the factor (1 + FBUZC), if FBUZC is positive. If FBUZC is negative, divide the value of BUZC by the factor (1 - FBUZC).

In the Rough adjustment, the value of BUZC is limited to the

TABLE 15

ELKHORN CREEK WATERSHED SENSITIVITY STUDIES: MONTHLY SYNTHESIZED FLOW VOLUMES AS A FRACTION OF VOLUMES WITH BUZC = 0.75

	Overland Flow		Interflow		Base Flow		Total Flow	
	BUZC= 0.25	BUZC= 4.0	BUZC= 0.25	BUZC= 4.0	BUZC= 0.25	BUZC= 4.0	BUZC= 0.25	BUZC= 4.0
Nov.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dec.	1.00	0.94	1.48	0.00	1.18	0.05	1.29	0.27
Jan.	0.99	0.62	0.99	0.62	0.97	0.82	0.99	0.64
Feb.	0.96	1.20	1.00	1.03	0.99	1.38	1.00	1.13
Mar.	1.00	1.00	1.00	1.01	1.00	1.16	1.00	1.01
Apr.	1.06	0.93	1.03	1.01	1.00	1.10	1.03	1.01
May	0.98	1.00	1.07	0.81	1.01	1.05	1.02	0.98
Jun.	1.00	0.95	1.18	0.43	1.03	0.88	1.07	0.76
Jul.	1.00	1.00	1.27	0.27	1.10	0.67	1.07	0.81
Aug.	1.00	1.02	3.00	0.00	1.20	0.40	1.05	0.89
Sep.	0.94	1.18	1.38	0.09	1.27	0.00	1.15	0.63

range between 0.2 and 4.0. If after six Rough cycles the value exceeds 3.9, it is taken to mean that the three months (September, November, and December) do not provide a suitable adjustment index. Three other months (June, July, and August) are substituted in Step 1 for the remaining Rough cycles and all the Fine cycles.

SIAC: The seasonal infiltration adjustment constant (SIAC) relates infiltration rates to antecedent evaporation to account for more rapid infiltration during warmer periods. A zero value implies a seasonally constant infiltration rate. As the value is made larger, infiltration rates are reduced in the winter and increased in the summer. The sensitivity studies (Tables 11 and 16) show that when SIAC increases, the flows in winter months increase and the flows in summer months decrease.

The adjustment of SIAC uses both summer and winter monthly flow deviation indices. If the previous SIAC value exceeds 1.0, the adjustment is based only on summer months. Table 16 shows winter flows to be almost completely insensitive to changes of SIAC in this range. The particular summer months used are the first three months of the year when rainfall is less than potential evapotranspiration. The procedure is as follows.

1. Average the monthly deviation indices of these three months to get the summer flow deviation index (SFDX).
2. Calculate the adjustment factor FSIAC as 1.5 times SFDX.
3. Confine the value of FSIAC between -1.0 and 1.0.
4. If FSIAC is positive, increase SIAC by multiplying by (1 + FSIAC) to decrease the synthesized flows in these months. If FSIAC is negative, decrease SIAC by dividing by (1 - FSIAC).

When the value of SIAC is less than one, winter flows as well as summer flows are sensitive to value changes and the adjustment

TABLE 16

ELKHORN CREEK WATERSHED SENSITIVITY STUDIES: MONTHLY SYNTHESIZED FLOW VOLUMES AS A FRACTION OF VOLUMES WITH SIAC = 3.0

	Overland Flow		Interflow		Base Flow		Total Flow	
	SIAC= 0.1	SIAC= 1.0	SIAC= 0.1	SIAC= 1.0	SIAC= 0.1	SIAC= 1.0	SIAC= 0.1	SIAC= 1.0
Nov.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dec.*	1.00	1.00	0.31	0.91	1.09	1.00	0.64	0.95
Jan.	0.30	1.00	0.79	1.00	1.64	1.00	0.75	1.00
Feb.	0.24	0.96	0.74	1.00	1.91	1.00	0.88	1.00
Mar.	0.63	1.00	1.59	1.00	2.10	1.00	0.97	1.00
Apr.	0.37	0.99	1.02	1.00	2.05	1.00	1.08	1.00
May	0.90	1.00	0.77	0.90	2.04	1.02	1.48	0.99
Jun.**	1.00	0.98	1.48	1.11	1.76	1.02	1.41	1.04
Jul.	0.99	1.00	3.67	2.07	1.38	0.95	1.44	1.11
Aug.	0.98	1.00	8.00	4.00	1.50	1.00	1.16	1.04
Sep.	0.60	0.76	3.68	2.34	0.87	0.87	1.83	1.39

*December is the month beginning wet season (MBWS)

**June is the month beginning dry season (MBDS) rule is modified to include winter months. First, the winter flow deviation index (WFDX) is taken as the average deviation index of the first three months in which rainfall exceeds potential evapotranspiration. The value of WFDX is further modified by multiplying the factor (1.0 - SIAC)/0.4, if the value of SIAC is between 0.6 and 1.0. This factor provides a smooth transition gradually increasing the weight placed on winter deviations as winter flows become more sensitive to differences in SIAC. Because changing the value of SIAC changes simulated flows in the opposite direction in winter from what it does in summer, the adjustment factor FSIAC is calculated as

$$\mathrm{FSIAC} = 1.5(\mathrm{SFDX} - \mathrm{WFDX}). \tag{24}$$

The example given in Table 10 is of this case, and the adjustment is based on the months of November, December, January, February, March, and April.

In the Rough adjustment cycle, if SIAC is adjusted to less than 0.02, it is taken as 0.00; if the adjusted SIAC is greater than 4.0, it is set equal to 4.0. The implication is that if SIAC is less than 0.02, infiltration does not vary by season; however, the value is again set back to 0.02 before each subsequent adjustment to make it possible for the adjusting multipliers to increase the value if the flows so indicate.

DISCUSSION

The purely empirical approach used to adjust the values of the flow volume parameters in the trial-and-error search for the best match between record and synthesized monthly flow volumes was necessitated by a breakdown in the more formal search procedures tried earlier in the development of OPSET (pp. 21-23). The scheme of indexing the adjustment of each parameter to particular types of deviations preselected by examining sensitivity studies was used in OPSET because of a better overall performance. The scheme has the following advantages.

1. It stabilizes on a reasonable set of parameter estimates within far less computer time than any other method tried.

2. Single factor variation from the chosen point did not improve the results by changing the values of any of the parameters in either direction.

3. The finally selected set of parameter estimates are relatively independent of the initial set of estimates (p. 33).

4. The method has remarkable recuperative powers when started from or led into bad values by data problems. The other types of adjustment were often not able to recover from such circumstances.

5. Adjusting parameter values based on rules derived from their hydrologic meaning proved far superior to any other method which did not directly use this knowledge.

The chief limitation to Subroutine SETFVP is that it was developed and tested only on 20 Kentucky watersheds. Other watersheds may have flow sequences which the trial-and-error procedure can not handle or handles inefficiently. The user will find many opportunities for programing improvement.

Subroutine SETFDI

(Second Land Phase Parameter Subroutine)

CONTEXT

The adjustment of the flow volume parameters seeks to improve the seasonal distribution as well as the total magnitude of simulated runoff volume over the water year. Monthly flow totals are obtained by summing the synthesized and recorded daily values. Their comparison has two aspects. Indices of differences between recorded and synthesized monthly runoff volumes are used to determine how much each parameter needs to be adjusted. Where its flows are found to be sensitive to a particular parameter and the comparison reveals poor matching to occur that month, that parameter is adjusted in Subroutine SETFVP. The second aspect is the need to incorporate all monthly differences in a scalar value to use as an objective function in comparing the relative merit of alternative parameter sets.

PURPOSE

Given recorded and synthesized monthly flow totals, Subroutine SETFDI is used to index the twelve monthly flow differences for adjusting the flow volume parameters and to establish a single statistic used to evaluate alternative parameter sets.

PROCEDURE

The monthly flow deviation index (MFDP) was defined as

$$\mathrm{MFDP} = \frac{\mathrm{TMSTF} + 20}{\mathrm{TMRTF} + 20} - 1 \qquad (\mathrm{TMSTF} > \mathrm{TMRTF}) \quad (25)$$

or

$$\mathrm{MFDP} = 1 - \frac{\mathrm{TMRTF} + 20}{\mathrm{TMSTF} + 20} \qquad (\mathrm{TMSTF} < \mathrm{TMRTF}) \quad (26)$$

where TMSTF is the synthesized monthly total flow volume and TMRTF is the recorded monthly total flow volume, both in second-foot-days. When the synthesized monthly flow volume exceeds the recorded, Equation 25 is used, and the index is positive. When the synthesized monthly total is smaller, Equation 26 is used, and the index is negative. When the recorded and the synthesized flows are identical, both equations are made to indicate zero deviation by using the factor 1.

The simple difference between recorded and the synthesized monthly totals is not used as the monthly flow deviation index because it is too biased toward achieving closeness for a high flow month at the expense of low flow months (6, p. 96). For example, if the recorded monthly flows had a low of 120 sfd and a high of 13200 sfd and the synthesized flows were 20 and 13000 sfd respectively, the differences would be 100 sfd for the low flow month, and 200 sfd for the high flow month. The adjustment would stress further improvement for the high flow month even though that month was really already much better than the low flow month. The above equations attempt to minimize this difficulty by dividing to look at a ratio.

When a ratio index is used, another problem exists when the monthly flow is comparatively small. For example, if the recorded low flow month is 40 sfd, the high flow month is 2000 sfd, and the synthesized low and high flow months are 10 and 500 sfd respectively, the ratios are the same (i. e., 4); but the synthesized high flow is much poorer than the low flow. In order to dampen this effect and prevent an undefined ratio when either flow is zero, an arbitrary 20 is added to the recorded and synthesized monthly totals before taking the ratios. In the example, this makes the low flow monthly deviation index much smaller (changed from 3 to 1) while the high flow index remains high (changed from 3 to 2.88).

The reason for using two rather than a single equation stems from a third effect. If simple ratios are used and the synthesized flow was twice the recorded flow, the ratio would be 2.00. If the synthesized flow was half the recorded flow, the ratio would be 0.50. The deviations from a perfect match of 1.00 would be +1.00 and -0.50; however, in both cases, the appropriate parameter adjustment would be one which changes the flows by a factor of 2. As deviations for several months are usually averaged in making parameter adjustments, the average is biased toward increasing the flows. Equations 25 and 26 attempt to restore symmetry to the deviations and thereby speed convergence on optimal parameter sets. Indices which exceed 8 or are less than -8 are set to be 8 and -8 respectively to prevent months with severe data problems from completely upsetting the estimation process.

Monthly flow deviation indices are calculated from Equation 25 or 26, and the minimum sum of the squares of the deviations for 11 months, SSQM, is used to indicate which set of volume parameter values gives the best synthesis of flow volume. October is excluded because flows in the first month of the water year are too dependent on unknown initial conditions (moisture storages entering the water year). To include it will cause the adjustment of parameters when the adjustment of initial moisture storage is really needed.

Subroutine SETFDI is called from Subroutine SETFVP (STFV0008) which uses the monthly flow deviation indices to adjust five flow volume parameters.

DISCUSSION

The formulation of Equations 25 and 26 was essentially a trial-and-error process in program development seeking the most rapid convergence toward consistant estimates of flow volume parameter sets.

Subroutine SETBMI

(Third Land Phase Parameter Subroutine)

CONTEXT

The basic maximum infiltration rate (BMIR) is the parameter used within the Model to control the rate of infiltration of moisture from the watershed surface into the soil. The parameter represents a concept which is a maximum in two senses. It is a maximum (or capacity) rate which could occur, considering current soil conditions, if moisture supply were no limitation. It is also a maximum in that it represents a rate at the most pervious point in the watershed. More specifically, infiltration over the total watershed is modeled by assuming a linear variation of point infiltration capacity with fraction of the basin area from zero to this maximum value (25, p. 54). The maximum value is adjusted with season of the year and current soil moisture storage (MAIN0418). As the basic index of watershed infiltration, BMIR governs the volume of runoff synthesized during storms by controlling basin recharge and governs the volume of base flow by controlling percolation to groundwater.

In order to determine how to adjust BMIR to bring simulated flows more in line with the corresponding recorded flows, it is necessary to develop some feel for the changes in simulated flows caused by a given change in BMIR. For this purpose, three computer runs were made with data for Elkhorn Creek near Frankfort, Kentucky, for the 1964 water year. All parameters were held constant at a trial-and-error (not an OPSET selected) best fit value except BMIR which was varied from 0.2 to 2.5 in three runs. By inspecting the results, certain synthesized flows were found to vary significantly with changes in BMIR while others were more insensitive. The approach to adjusting BMIR was to single out several of the more sensitive flow categories (specified by time of the year and flow type) and use the differences between their recorded and simulated values as an index for setting the next trial value of BMIR. Several rather than single categories were used to dampen bad estimates caused by poor data particularly affecting a single category.

The degree to which BMIR affects simulated overland flow, interflow, and base flow volumes is illustrated in the summary from the Elkhorn Creek sensitivity studies on Table 17. Increasing the value of BMIR was seen to sharply reduce overland flow during winter low flow months by converting direct runoff to basin recharge, to more moderately reduce overland flow from major flow months because a fixed amount of infiltration is a smaller portion of the precipitation total, and to increase synthesized overland flow from storms following prolonged dry periods by increasing soil moisture storage. Increasing BMIR reduced interflow in low flow months by pushing the interflow triangle (25, p. 54) to the left so that less of its area was below the residual precipitation line and increased interflow in high flow months where higher residual precipitation lines produced opposite results. Increasing BMIR increased base flow by an amount which was largest immediately after major recharge periods and then progressively reduced through low flow months.

The process used in estimating BMIR is basically the same as that used for and is performed simultaneously with the estimation of the other five volume parameters. An initial trial estimate is made for each of the six variables (1.2 for BMIR, MAIN0210). A year of flows is simulated. Each parameter is adjusted by looking at preselected index differences of simulated from recorded flows. A new year of flows is simulated and the process continues until a set of parameter values is accepted. Subroutine SETBMI looks at the index differences for and then adjusts BMIR. Subroutine SETFVP looks at the index differences and then adjusts LZC, SUZC, ETLF, BUZC, and SIAC. BMIR adjustments are performed in a separate subroutine because the adjustment is indexed to a different sort of flow information.

TABLE 17

ELKHORN CREEK WATERSHED SENSITIVITY STUDIES: MONTHLY SYNTHESIZED FLOW VOLUME AS A FRACTION OF VOLUMES WITH BMIR = 0.65

	Overland Flow			Interflow			Base Flow			Total Flow		
	BMIR=			BMIR=			BMIR=			BMIR=		
	0.2 Ratio	0.65 Inch	2.5 Ratio	0.2 Ratio	0.65 Inch	2.5 Ratio	0.2 Ratio	0.65 Inch	2.5 Ratio	0.2 Ratio	0.65 Inch	2.5 Ratio
Dec.	1.38	0.034	0.91	2.76	0.067	0.19	0.50	0.022	1.41	1.97	0.123	0.61
Jan.	2.36	0.438	0.15	0.93	0.809	0.57	0.42	0.176	2.07	1.31	1.423	0.63
Feb.	3.68	0.244	0.21	0.69	0.979	0.47	0.35	0.279	2.56	1.12	1.502	0.82
Mar.	1.31	7.031	0.40	0.41	2.509	1.88	0.31	0.680	3.06	1.02	10.220	0.94
Apr.	1.90	0.365	0.21	0.68	0.570	0.96	0.34	0.307	2.78	0.95	1.242	1.19
May	0.87	0.062	0.90	1.07	0.070	0.61	0.37	0.153	2.56	0.65	0.295	1.72
Jun.	1.13	0.063	0.97	1.82	0.061	0.34	0.32	0.059	2.53	1.10	0.183	1.26
Jul.	1.00	0.070	1.00	2.47	0.015	0.33	0.41	0.039	2.18	1.00	0.124	1.29
Aug.	1.02	0.052	0.98	4.00	0.001	0.00	0.30	0.010	2.40	0.95	0.063	1.19
Sep.	0.65	0.068	1.10	3.26	0.053	0.28	0.47	0.015	1.80	1.65	0.136	0.86

Adjustment of BMIR indexed on total monthly flows was considered first. Table 17 suggests that a reasonable rule might be to increase BMIR if total synthesized flows in mid-winter were too high and total synthesized flows in mid-summer were too low; however, the results were not good. The close tie of BMIR to base flows suggested shifting to adjusting BMIR to better match recorded base flows. Subroutine SETBMI is based on this concept.

PURPOSE

Subroutine SETBMI adjusts the value of the parameter controlling infiltration rate (BMIR) by inspecting the match between synthesized and recorded base flows during the search for the best set of six values for the flow volume parameters.

PROCEDURE

The distinctive feature of the adjustment of BMIR is that it is indexed on base as contrasted with total flows. Since base flows are not distinguished within the total flows in the raw data, some technique for hydrograph separation is necessary. The technique employed calls on Subroutine SETRBF to estimate a least squares base flow recession line and thereby provide daily base flow totals. The base flows estimated are for the first three days following a flow peak in each recession sequence selected by Subroutine RECESS. The use of every sequence provides the broadest available data base. Three days are enough to minimize the effects on the adjustment of data peculiarities for individual days. More days could be used, but computational time is increased and the index begins to be weighted according to the recession sequence length.

Actually, only the first of each series of three "recorded" base flows needs to be saved in RSBBF because each later value in the linear recession is BFRC times the previous value. The synthesized base flow totals for each of the same set of days are saved in SBFRS at MAIN0595. The overall relationship between recorded and synthesized base flows is found by dividing each synthesized by the corresponding recorded base flow (STBM0010) checking the ratio for a maximum of 3.0 to dampen the harm caused by sequences with data problems, and averaging the results (STBM0019). An average greater than one indicates BMIR needs to be reduced to decrease synthesized base flows. An average less than one suggests an increase in BMIR.

The data in Table 17 also provide some idea as to the amount of adjustment of BMIR required to achieve a given change in synthesized base flow. The increase of BMIR by a factor of 3.25 from 0.2 to 0.65 increased the average of the ten monthly base flows by a factor of 2.64 (1/0.379). The increase by a further factor of 3.85 to 2.5 increased the average base flow by a factor of 2.34. If the relationship between the two ratios is assumed to be of the form

$$\frac{BMIR_2}{BMIR_1} = \left(\frac{BF_2}{BF_1}\right)^n \qquad (27)$$

the two estimates of n from the tabulated data would be 1.22 and 1.59 respectively. From the viewpoint of quickly converging on a best estimate of BMIR in the context of all the watersheds tested, 1.3 gave the best results.

One of the major problems encountered in OPSET was the development of a satisfactory method for handling estimates of initial (October 1) moisture conditions (pp. 40-43). Despite the rather elaborate procedure developed for adjusting the initial LZS to match LZC (MAIN0274-0285) in the context of the values being used for the six other parameters, difficulty was still occasionally encountered. The estimates of initial LZS were close enough so that the problem would be minor after the first major storm; but in some situations, the synthesis of the first storm and subsequent recession would be so poor as to corrupt the adjustment of BMIR.

An index called FTX was established to handle this situation. Its value is set to be 1.0 when no problem was encountered. During the first five rough adjustments, the program is left free to try to bring the synthesized flow volumes in line. If the sum of the second and the third (November and December) monthly flow deviation indices exceeds 2.0 or is less than -2.0 after this (p. 43) the first recession sequence is skipped (STBM0018) by changing the value of IFT from 1 to 2 (MAIN 0075).

Some cases were encountered where the method outlined above for adjusting BMIR using an index estimated from base flows just did not work properly. For example, one may encounter a year with only a few well-defined recession sequences and when each of these happens to be associated with a storm where the recorded rainfall is significantly less than what actually fell. The simulated base flow may then well be less than the recorded values until one makes BMIR so big that all simulated flow is base flow and the true storm hydrograph disappears. The programing is handled by developing a second or alternate adjustment rule to be used whenever the first rule is not working properly.

The shift to the alternate rule for adjusting BMIR comes when BMIR exceeds 20.0 after the fifth rough adjustment (MAIN0785). As 20.0 is an unreasonably large value, the alternate adjustment is to reduce BMIR in a sequence of ten-percent reductions (MAIN0773). The overall synthesis is usually much better during this reduction period than it was during the initial increase of BMIR from 1.2 to over 20.0 because the other parameters have had time to adjust to better values and the increments are smaller. No problem was encountered with faulty data causing an unmanageably small BMIR during operation of the first adjustment rule because the programing in Subroutine RECESS prevents acceptance of recession sequences with very low base flow.

DISCUSSION

The adjustment of BMIR based on an index keyed to differences between recorded and synthesized base flows supplemented by an alternate adjustment scheme of retreating from very large values when necessary (actually programed in MAIN rather than Subroutine SETBMI) proved to work well and produce reasonable and consistent (from year to year) results. The user, however, does need to beware of the possibility of encountering data which the programed rules cannot handle. The programing in OPSET was developed and refined until it worked for the over 20 tested watersheds, but this does not mean that further refinement will not be necessary.

Subroutine SETRBF

(Fourth Land Phase Parameter Subroutine)

CONTEXT

The volume of simulated interflow is controlled by the basic interflow volume factor (BIVF). The basic maximum infiltration rate (BMIR) controls infiltration and thereby the volume of base flow by limiting the amount of moisture entering the ground. Consequently, the adjustment of BIVF in Subroutine SETBIV is designed to improve the match between recorded and simulated interflow volumes. The adjustment of the BMIR in Subroutine SETBMI is designed to improve the match between recorded and simulated base flow volumes. Since recorded flows are not tagged by category, a technique for separating the recorded flows is required.

Recession sequences are selected from the recorded daily streamflows. After the sequences are used to estimate the two recession constants (See Subroutines RECESS, SET2RC, and SET1RC), the volumes of interflow and base flow on the second day of the recession (first or peak days are omitted because they normally include too much direct runoff) can be estimated from the average recession constants and the individual sequences. A least squares method was developed based on assumptions that the two flow components follow linear recession models and the two recession constants are known.

For cases when no interflow is found, an abbreviated least squares method was developed for estimating base flow on the second day. The estimate slightly differs from the recorded total on that day because observed values will not fall exactly on a linear recession line.

PURPOSE

Subroutine SETRBF is used to estimate volumes of interflow and base flow during the first day after direct runoff becomes minimal, given the two recession constants and a sequence of recorded recession daily flow volumes beginning with a volume for the day for which an estimate is desired.

PROCEDURE

Subroutine RECESS provides a sequence of recession flows $q_1, q_2, \ldots q_n$ which are assumed to follow the two-component non-linear model

$$q_t = q_{b,o} K_b^{\,t} + q_{i,o} K_i^{\,t} + \epsilon_t \qquad (t=1, 2, \ldots n) \qquad (28)$$

where $q_{b,o}$ and $q_{i,o}$ are the base flow and interflow components one day before the day for which volumes are to be estimated. K_b and K_i are base flow and interflow daily recession constants, and ϵ_t is the random error of the t^{th} day. If K_b and K_i are known, an approximate solution for $q_{b,o}$ and $q_{i,o}$ can be obtained by a least squares method. After rewriting the model of Equation 28 in matrix form as

$$\begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{bmatrix} = \begin{bmatrix} K_{b_2} & K_{i_2} \\ K_b & K_i \\ \vdots & \vdots \\ K_b^n & K_i^n \end{bmatrix} \begin{bmatrix} q_{b,o} \\ q_{i,o} \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_n \end{bmatrix} \tag{29}$$

then the least squares estimates of $q_{b,o}$ and $q_{i,o}$ ($\hat{q}_{b,o}$ and $\hat{q}_{i,o}$) are the solutions of the "normal equations"

$$\begin{bmatrix} \hat{q}_{b,o} \\ \hat{q}_{i,o} \end{bmatrix} = \begin{bmatrix} \sum_{t=1}^{n} K_b^t \; q_t \\ \sum_{t=1}^{n} K_i^t \; q_t \end{bmatrix} \tag{30}$$

Application of Equation 30 requires at least two flows in any sequence. The maximum number of flows used is preassigned to be 12 to avoid extensive calculations which have little effect on the results.

With $\hat{q}_{b,o}$ and $\hat{q}_{i,o}$ estimated, the base flow and interflow at the recession beginning day ($\hat{q}_{b,1}$ and $\hat{q}_{i,1}$) can be readily obtained as

$$\hat{q}_{b,1} = \hat{q}_{b,o} \cdot K_b \tag{31}$$

$$\hat{q}_{i,1} = \hat{q}_{i,o} \cdot K_i \tag{32}$$

When a recession sequence has an interflow recession constant less than 0.3, which was taken (Subroutine RECESS) as meaning that the interflow in that sequence is negligible, a one-component (base flow only) model is used to estimate the first day base flow, and the first day interflow is set equal to zero. The one-component model can be written as

$$q_t = q_{b,o} K_b^t + \epsilon_t \qquad (t=1, 2, \ldots n) \qquad (33)$$

The least squares estimate of $q_{b,o}$, denoted as $\hat{q}_{b,o}$, is

$$\hat{q}_{b,o} = \frac{\sum_{t=1}^{n} K_b^t \cdot q_t}{\sum_{t=1}^{n} K_b^{2t}} \qquad (34)$$

The base flow on the recession sequence beginning day is obtained by using Equation 31.

DISCUSSION

The results revealed flow sequences with an interflow recession constant greater than 0.3 to yield estimates of interflow and base flow which total very close to the recorded flow. Estimates for sequences with interflow recession constants less than 0.3 indicate slightly less base flow than the recorded total flow. This might be expected because the interflow is neglected.

Subroutine SETBIV

(Fifth Land Phase Parameter Subroutine)

CONTEXT

The basic interflow volume factor (BIVF) controls the division of moisture not infiltrating into the soil between interflow and direct runoff and thus indirectly governs the time distribution of storm hydrographs. Crawford and Linsley (10, p. 69) defined BIVF (their name was CC) "as an index to the ratio of the increment added to interflow detention to the increment added to surface runoff detention". They recommended trial-and-error adjustment of its value in an effort to better match recorded with simulated hydrograph shape. A larger value of BIVF reduces the hydrograph peak and increases later flows to net a flatter crested hydrograph.

In exploring for a means of estimating BIVF within OPSET, several factors had to be considered. Hydrograph shape is not a very viable criterion for mathematical testing and relates to direct runoff routing as well as to interflow delay. If some other means could be found for estimating BIVF, information on hydrograph peaks and volumes could be reserved for estimating the streamflow routing parameters.

A review of the procedure used in estimating the interflow and base-flow recession constants suggested an independent method. Subroutine SETRBF was developed to estimate the volume of interflow the first day after the peak preceding each recession sequence. These estimates from the recorded flows could then be compared with synthesized interflow volumes, and BIVF could be adjusted to bring the simulated total in line.

Another factor to be considered was the proper timing within OPSET of the adjustment of BIVF. The program first sets six parameters based on matching the recorded distribution of total runoff among the months of the year and then sets four parameters based on achieving the recorded hydrograph peaks and times. BIVF is an intermediate parameter between the six volume parameters and the four channel routing parameters. It cannot be estimated during the initial adjustment of the six flow volume parameters because simulated interflow volume also depends on these other parameters and their values are being adjusted in increments too large for BIVF to stabilize on a reasonable estimate. BIVF could be estimated in a special TRIP between that for setting the flow volume parameters and that for setting the routing parameters; however, this approach would add significantly to the required computer time.

The compromise was to combine the estimation of BIVF with the final fine adjustment phase of the six flow volume parameters. In the early rough adjustment of the volume parameters, BIVF is taken as 0.90 (MAIN0215). During fine adjustment, the flow volume parameters are not changing in large enough increments from one trial to the next to create major problems in estimating BIVF. Neither do changes in BIVF change the simulated flows from one month to another enough to upset the criterion used to estimate the other parameters. In fact, the small movement of simulated flow among months which does occur is probably beneficial in terms of estimating a better set of all seven parameters taken together.

The fine adjustment of the flow volume parameters is terminated by criteria devised to indicate that the search cannot find a better fit of recorded monthly flow volumes (pp. 39-40). Even though BIVF is being estimated simultaneously, the procedure is seeking the best match of simulated to recorded interflow volumes on selected days. Each adjustment gives a better match, and the number of fine adjustments required to determine whether the best possible set of volume parameters has been estimated is enough for the adjustment of BIVF to converge on an acceptable value. Therefore, the estimate of BIVF is taken as the final one and not that associated with the minimum value of SSQM.

When the analysis of flow recession data does not detect any appreciable interflow, BIVF is set to 0.00 (MAIN0226) and Subroutine SETBIV is skipped (MAIN0769).

PURPOSE

Subroutine SETBIV adjusts the value of the parameter controlling the portion of the moisture which does not infiltrate into the soil that does go into interflow (BIVF) in order to achieve a better match between synthesized and recorded interflow volumes. This match is used as the sole criterion of the adjustment as BIVF does not alter the distribution of simulated flows among months to a degree which warrants basing goodness of fit on SSQM.

PROCEDURE

The adjustment of BIVF is based on matching simulated to recorded interflows during the first three days of each recession sequence selected by Subroutine RECESS. It is assumed that interflow and base flow comprise the total flow beginning on the second day of the recession (See Subroutine SET2RC), and the interflow phases out more quickly than baseflow. By using the first three days, the effects of data difficulties on individual days are damped to give a reasonable estimate of the volume ratio between the recorded and the synthesized interflows while largely avoiding the problem of getting a good ratio between two very small values later in the sequence.

The recorded interflow at the recession beginning is determined by Subroutine SETRBF, and the second and third day interflows are determined by multiplying the first day interflow by the estimated interflow recession constant (IFRC) once and twice respectively. The synthesized interflows are saved on the first three days during the simulation process (MAIN0325-0328, 0593-0594) by keeping track of the recession beginning date (RCSS0025, 0120-0122).

A timing differential must be handled before synthesized are compared with recorded interflows. Flows are recorded at the mouth of the watershed while interflows are simulated for points all over the watershed and not separately (from direct runoff) routed to the mouth. In order to compensate for the simulated interflows within the watershed reaching the mouth of the watershed at a later time, the synthesized interflows are adjusted backward in time by the duration estimated for flow to travel from the centroid to the mouth of watershed (STBV0010).

The ratio of the adjusted synthesized interflow to the recorded interflow is calculated for each of the first three days, and an averaged ratio is used to adjust BIVF. Because too small an estimate of recorded interflow will cause the adjustment factor to be unreasonably large, the ratio for each day is limited to a maximum of 3.0 in computing the average.

BIVF enters the streamflow simulation through the equation (MAIN0411, 0419):

$$\mathrm{CIVM} = \mathrm{BIVF} * 2^{(\mathrm{LZS}/\mathrm{LZC})} \qquad (35)$$

In order to prevent simulation of negative interflows, CIVM must be held to a minimum of 1.0 (<u>25</u>, p. 54). No interflow is simulated except when CIVM exceeds unity. Equation 35 thus shows how with BIVF and LZC held constant, interflow will not be simulated during periods when the watershed is very dry (LZS is small). The smaller the value of BIVF, the larger LZS has to be for interflow to commence. However, other simulation controls prevent LZS from becoming much larger than LZC (actual soil moisture storage cannot pass some upper limit). The upper limit on the multiplier of BIVF in Equation 35 is about 2.5. Therefore no interflow will be simulated when BIVF is less than 0.40.

The adjustment of BIVF assumes synthesized interflow to be proportional to (BIVF - 0.40). For example, if the old value of BIVF is 0.90, and the averaged ratio is 0.25 (synthesized interflow volume is one-fourth of recorded interflow), then (by STBV 0023) the new BIVF is

$$0.40 + \frac{(0.90 - 0.40)}{0.25} = 2.40$$

DISCUSSION

Generally speaking, flow recession becomes more complex as the size of the watershed increases. Two distinct recession constants could be developed from the data for the larger watersheds, but the best modeling for the smaller watersheds came by dividing all flows between direct runoff and baseflow. Consequently, Subroutine SETBIV was not called for most of the small watersheds used to test and develop OPSET because BIVF had already been set equal to zero. Thus, this subroutine, probably more than any other in the program, needs further testing and refinement using additional data.

Subroutine STRHRS

(First Channel Routing Subroutine)

CONTEXT

The channel routing parameters are estimated by comparing recorded with simulated times and peaks of selected flood hydrographs. As no more than five points on the total annual hydrograph are compared, it would be very inefficient to route all flows throughout the year to try to match so few points. A great deal of computer time is saved by going through the entire annual hydrograph in TRIP 2, storing all channel inflows contributing to the specified peaks, and then performing the repetitive routing on these selected inflows.

In order to use this approach, it is necessary to determine when to start and stop saving channel inflows for each hydrograph peak. The saved inflows should include all runoff contributing to the peak as well as to the rapid rise just before the peak. The saved inflows should continue long enough to make sure that the flows are receding toward base values with no chance of a subsequent rise from the same runoff event producing a new and higher peak for any combination of trial routing parameters.

PURPOSE

The purpose of STRHRS is to set the beginning and ending times of channel inflows anywhere in the basin contributing to selected flood peaks so that simulated inflows between these two times may be saved for the trial routings necessary for selecting an optimal set of channel routing parameters.

PROCEDURE

The day of the year (RHPD) and the hour of the day (RHPH) for each selected hydrograph peak are specified in the input data. The interval for saving inflows extends both ways from this point in time. Typical hydrograph shapes have recession limbs about three times as long as rising limbs. (21, pp. 197-206). The length of the interval is based on the value of the read parameter INHPT. The flexibility provided by reading this value gives the user an opportunity to adjust the length of this period for any reason. INHPT also represents the number of hours between points printed on the simulated outflow hydrograph. Normally, prescribed values should increase with the size of the watershed.

The method of specifying the total storm period is shown in Figure 3 and takes the following steps.

1. Specify the number of hours from beginning of saved runoff to recorded hydrograph peak (IBTPR) and the number of hours from recorded peak to the end of saved runoff (IPTE). IBTPR is taken as the maximum number of hours (MXTRH) used by OPSET in any time routing (twice the estimated number of time routing hours MAIN0203) plus five times INHPT, and IPTE is taken as 15 times INHPT. MXTRH is included in determining the beginning hour to take into account the time lag from the far end of the watershed. Use of a maximum value ensures that enough inflows will be saved to include flows from the far end of the watershed with the maximum value of NCTRI the program is allowed to use. (SHRS0009, 0010).

2. Convert the points in time IBTPR hours before the peak and IPTE hours after the peak into dates and hours by counting backward and foreward respectively from the recorded peak day and peak hour for each recorded hydrograph (SHRS0012-0042).

3. Check the calculated dates and hours of all recorded hydrographs for two types of overlapping. First, flows

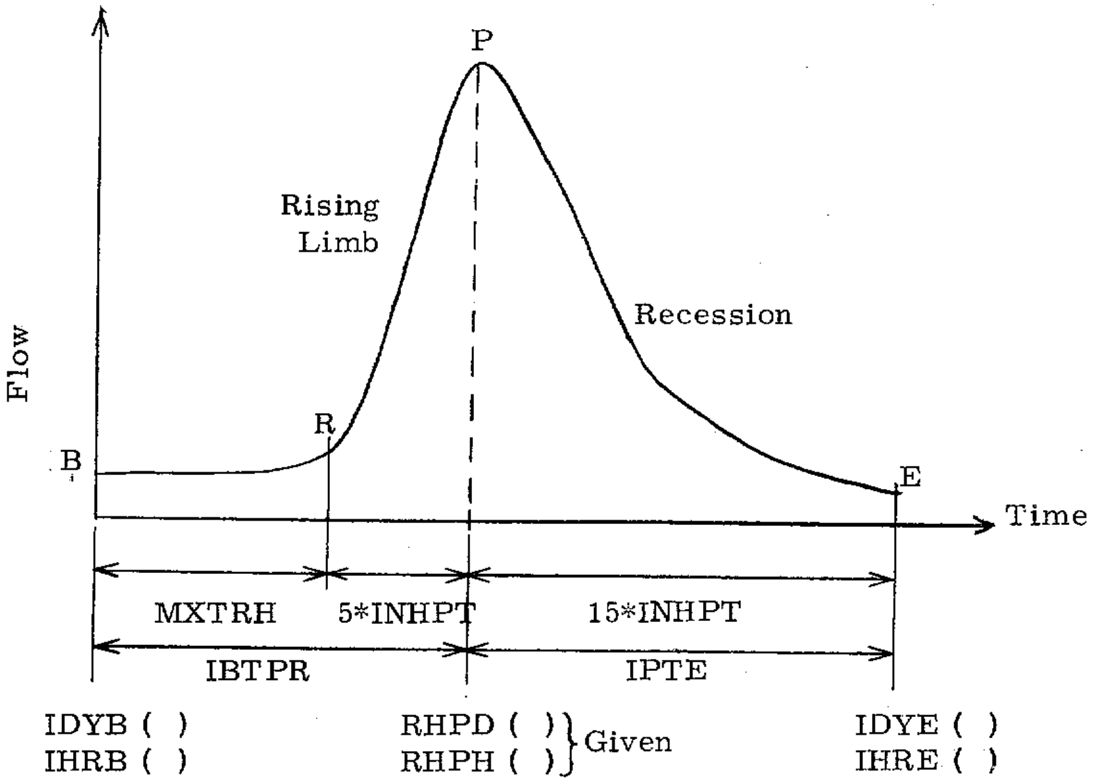

FIG. 3. Determination of Beginning and Ending Times of a Recorded Hydrograph.

contributing to the first recorded flood peak may begin before the start of the water year, or the last recorded hydrograph may extend into the following water year. These cases are handled by confining the beginning and ending to the current water year (SHRS0055-0065). These situations are illustrated in Figures 4(a) and 4(b). Actually, because of the problem of establishing initial conditions, the user should avoid using early October storms unless they represent extraordinarily large events. Second, the ending time of one hydrograph may overlap the beginning time of the next (Figure 4(c)). In this case, the cutoff point of the first hydrograph is shortened to the beginning time of the second (SHRS0051, 0052). A recession limb is arrested by the subsequent rise.

DISCUSSION

In choosing INHPT, one should inspect the published daily streamflow data to obtain a general idea of the time base for a typical hydrograph for the watershed. Too large a value of INHPT adds to the computer time, and too small a value may cause the program to drop part of the synthesized inflow which contributes to the peak. If this occurs, the simulated peak will be too low, and OPSET will be biased toward selecting smaller values of NCTRI and SRX in an attempt to compensate by producing a sharper peak.

Subroutine ADJHYD

(Second Channel Routing Subroutine)

CONTEXT

The criteria for selecting the best set of channel routing parameters seek to minimize differences between recorded and synthesized hydrograph peaks. Differences between recorded

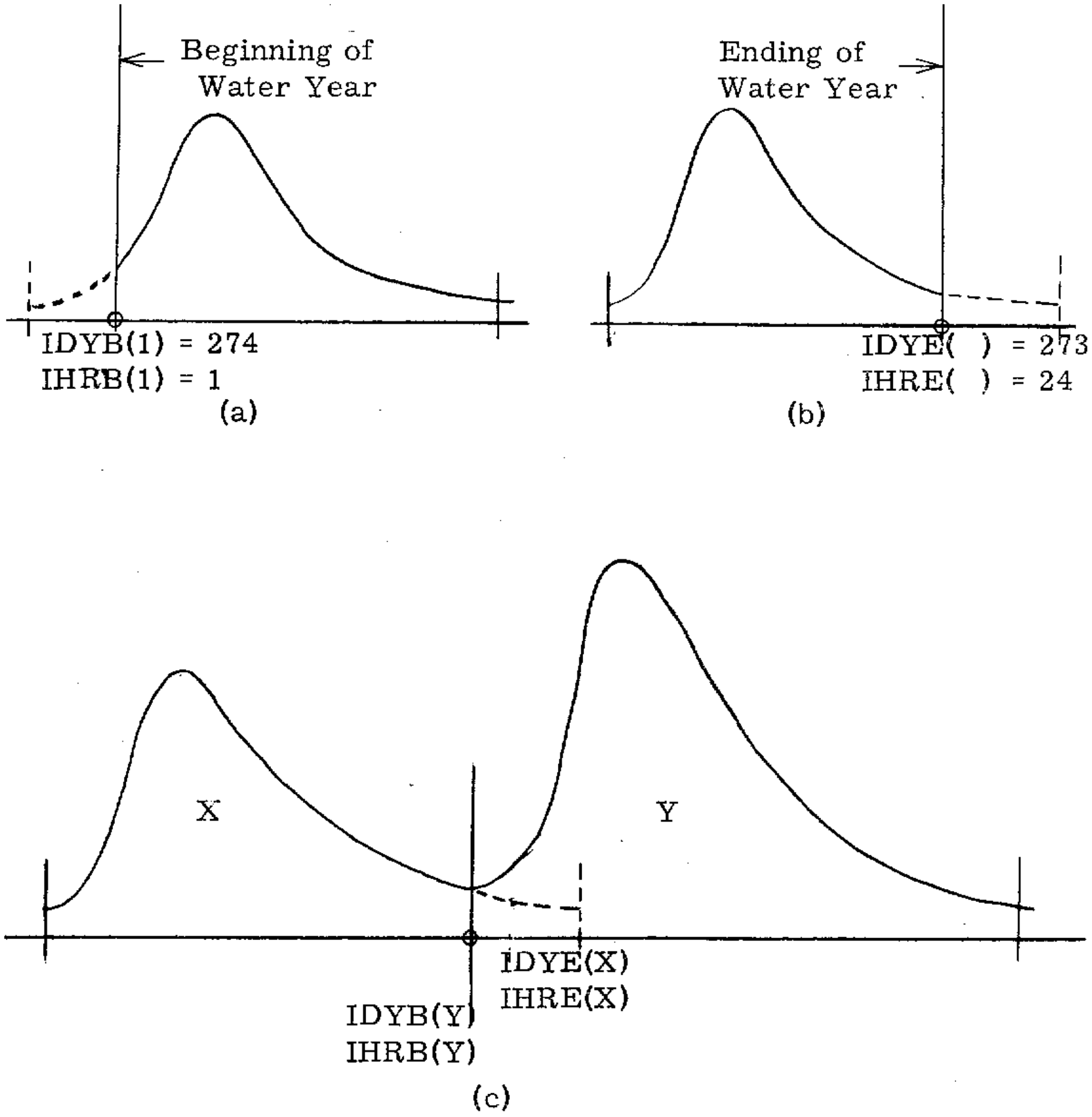

FIG. 4. Elimination of Recorded Hydrograph Overlapping.

peaks and peaks synthesized with the best set of land phase parameters selected in TRIP 1 stem from two causes. First, the set of values for the land phase parameters selected on the basis of providing the best overall estimate of the magnitude and monthly distribution of the annual runoff volume may simulate a volume that is either too high or too low for a given flood. Second, the set of routing parameters may not produce the proper hydrograph shape.

The objective of Subroutine ADJHYD is to adjust each simulated channel inflow hydrograph by a constant multiplier to make the simulated equal the recorded hydrograph volume in order to eliminate differences caused by using an incorrect volume. The goal of TRIP 2 is to select parameters which will do the best job of channel routing, and the results will be distorted if the routing parameters are forced to take on inappropriate values to match a recorded peak having some different total volume. For example, if the peaks selected for fixing the routing parameters happen to be associated with volumes which are too small, the routing parameters selected would produce too sharp a flood hydrograph in an attempt to match the specified peaks.

PURPOSE

Subroutine ADJHYD adjusts flow volumes of synthesized channel inflow hydrographs to match the flow volumes of recorded hydrographs in order to overcome bias caused by using different volumes in estimating the two channel routing parameters NCTRI and SRX.

PROCEDURE

The flow volume adjustment is accomplished by multiplying each synthesized runoff during the storm period (excluding base flow which is not modeled by use of channel routing) by a factor equalling the ratio of the recorded to the synthesized storm period runoff volume. This procedure takes three steps:

1. Calculate the recorded and the synthesized direct runoff including interflow) volumes during the specified storm duration (See Subroutine STRHRS). Hydrograph average base flows are subtracted from daily total flow volumes, and the difference is multiplied by the fraction of the day included within the storm period. Results are summed over all days within the total period, but zero values are added for days with negative differences (i. e. having daily average total flow less than the storm average base flow).

2. Calculate a synthesized hydrograph multiplier (SHM) equal to the ratio of total recorded hydrograph volume (TRHV) to total synthesized hydrograph volume (TSHV).

3. If SHM is less than 8 and greater than 1/8, then adjust each value of synthesized storm runoff (SSR) by multiplying by SHM. If SHM is greater than 8 or less than 1/8, the hydrograph is discarded for use in estimating routing parameters by setting the logical variable LSHA true. The cutoff of 8 is arbitrary, but some value was needed to avoid estimating erroneous routing parameters caused by storms where the direct runoff volume was simulated very poorly, usually because of watershed precipitation measurement problems.

Subroutine SETHRP

(Third Channel Routing Subroutine)

CONTEXT

The channel routing process incorporated into the earlier versions of the Stanford Watershed Model (10) employs a time-delay histogram to account for the time required for runoff originating throughout the watershed to reach the mouth and then uses storage routing through a theoretical reservoir to account for the effect of channel storage on the hydrograph (21, p. 304). The time lag routing is based on NCTRI fractions in array CTRI. The storage routing uses the equation

$$O_2 = \bar{I} - SRX\,(\bar{I} - O_1) \qquad (36)$$

where O_2 = routed outflow at the end of the time interval;
$\bar{I}$ = average inflow during the time interval;
O_1 = outflow at the beginning of the time interval;
SRX = a storage routing index less than unity in which smaller values imply less storage dampening.

Conceptually, both NCTRI and SRX should vary during the course of a flood hydrograph. NCTRI decreases with increasing flow because the associated faster flow velocities reduce travel time. SRX increases by more closely approaching unity with increasing flow because of greater hydrograph dampening as more water is stored in the channel system, an increase becoming most rapid when large volumes of water begin to spill into the flood plain.

The experience gained by applying the Model to a number of watersheds has shown the variation in SRX to be more pronounced than that in NCTRI. In traditional hydrologic terms, the storage routing coefficients vary more than does the time base of the unit hydrograph. Even though the KWM provides the option of varying NCTRI (25, pp. 23-24), OPSET only considers variation in SRX. The analysis attempts to distinguish a value of SRX for low flows (CSRX) from another one for flood flows (FSRX). The strategy is to estimate one at a time the values of NCTRI and SRX (taken as independent of flow in the first pass) best matching the times and peak flows of up to five specified hydrograph peaks.

PURPOSE

Subroutine SETHRP estimates single best values for NCTRI and SRX for each of the up to five hydrographs specified in the input data. It then averages the hydrograph values of NCTRI to make a single overall best estimate. It calls on Subroutine SETSRP with the hydrograph values of SRX to regress on hydrograph peaks to determine whether the data at hand substantiate the expected tendency for higher values to be associated with higher peaks.

PROGRAM DEVELOPMENT

For each station-year, and for up to five flood hydrographs, the flood peak day of the year, the flood peak hour of the day, and flood peak magnitude are read. Subroutine STRHRS is used to determine the beginning and ending hour of runoff contributing to the recorded flood hydrograph, and all synthesized channel inflows between these two times are saved in the pass of TRIP 2 through MAIN. In order to prevent the estimates of NCTRI and SRX from being biased by any difference between recorded and synthesized flood volumes, Subroutine ADJHYD is used to adjust the magnitude of each synthesized flow entering the channel to make the synthesized flow volume equal the recorded volume. Subroutine SETHRP is then called to estimate the two hydrograph routing parameters for <u>each</u> flood hydrograph.

The first step in developing a procedure for this purpose was to study how the magnitude and timing of the synthesized flood peak change with these two variables. Figure 5 shows how NCTRI and SRX affect a simulated flood hydrograph. Two values are shown. The upper one is the synthesized hydrograph peak flow (SHPF), and lower one is the number of time intervals from the recorded to the synthesized

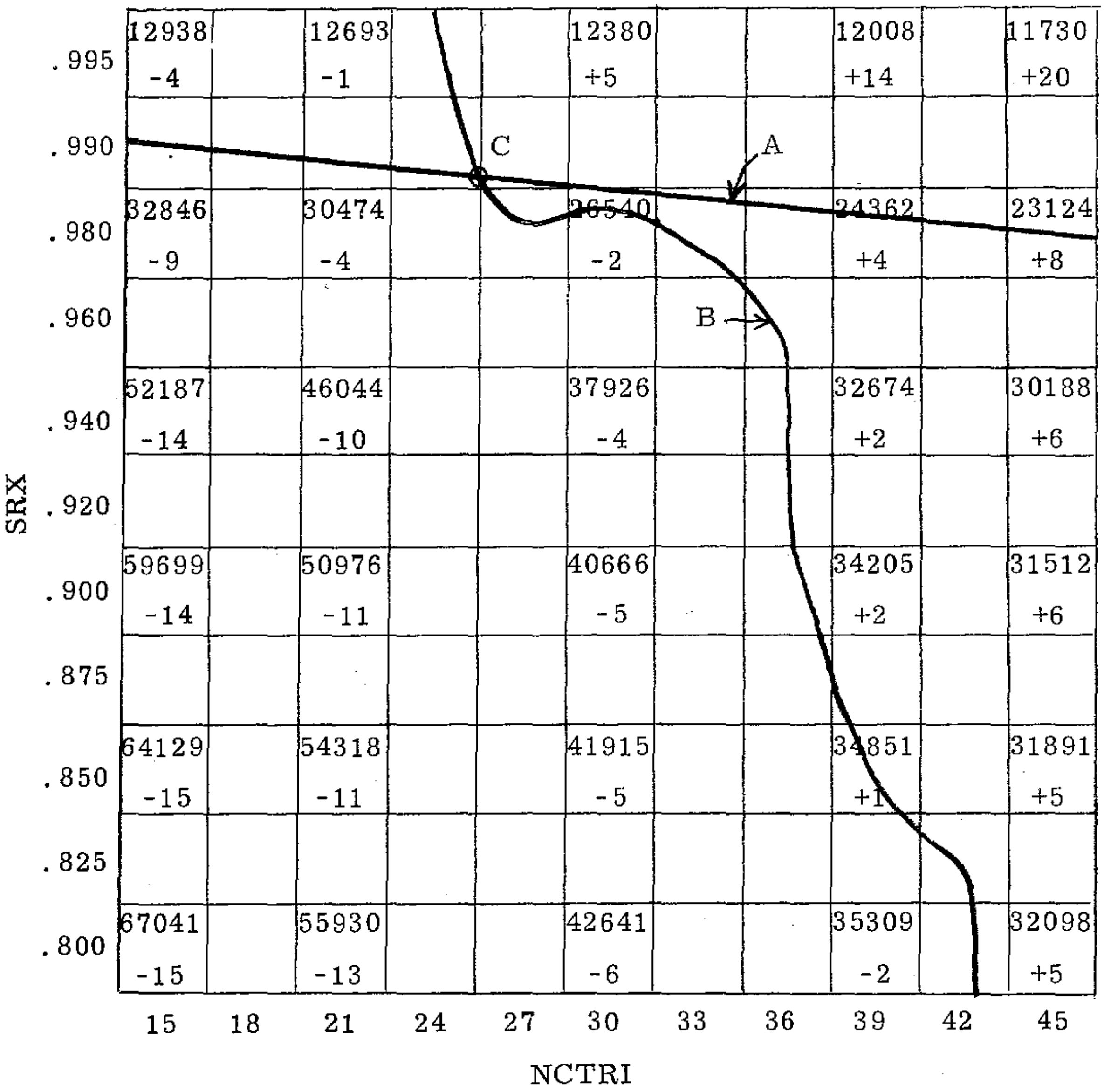

FIG. 5. Response of a Given Flood Hydrograph (Elkhorn Creek, March, 1964) to Changing the Two Hydrograph Routing Parameters NCTRI and SRX. (RHPF = 23200 cfs, upper number is SHPF, lower number is NIRTS).

peak (NIRTS). A negative NIRTS means the synthesized hydrograph peak comes sooner than the recorded; a positive value means it comes later.

Figure 5 reveals what Equation 36 and the time-area routing procedure already imply, namely that 1) with constant NCTRI, SHPF increases and NIRTS decreases as SRX decreases because a smaller storage effect produces a quicker and higher peak, and 2) with constant SRX, SHPF decreases and NIRTS increases as NCTRI increases because longer flow times produce a later and lower peak.

Line A represents the combinations of values of NCTRI and SRX for which the synthesized hydrograph peak (SHPF) equals the recorded hydrograph peak (RHPF). Above line A, SHPF is smaller than RHPF; below line A, SHPF is larger than RHPF. Line B represents the combinations for which the synthesized hydrograph peak hour is identical to recorded hydrograph peak hour, i. e., NIRTS is equal to zero. To the left of line B, NIRTS is negative; and to the right, NIRTS is positive. Point C, at the intersection of lines A and B, indicates the values of NCTRI and SRX for which the synthesized hydrograph would have its time and magnitude equal to the recorded time and magnitude. The consistency with which both lines slope from the upper left to the lower right because of the two rules stated above suggests use of a search procedure for Point C following this same basic pattern. Once it has been established that a better match lies to the right, no further need exists to search to the left. Once it has been established that a better match lies below, no further need exists to search above.

Subroutine SETHRP seeks the combination of values for NCTRI and SRX which produces a synthesized hydrograph with a flood peak most closely matching the recorded peak in magnitude and time. If gaged rainfall closely represents watershed rainfall in amounts and timing and synchronizes with streamflow measurements and if land surface runoff is adequately simulated, one would expect to always find the solution point (C on Figure 5). Unfortunately, poor quality data may produce lines which do not cross or a solution point outside reasonable limits.

The major difficulty experienced was caused by a difference in timing between the watershed and gaged rainfall. If a storm was slowly moving from the watershed toward the gage and the runoff peak were recorded soon after the gaged rain began, point C might indicate a time of concentration of 15 minutes (NCTRI=1) for a large watershed. With the storm moving the other way, a very long time might be indicated for a small watershed. The consistency of the error depends on the prevailing storm movement pattern.

Subroutine SETHRP is programmed to find the solution point if one exists within the range of reasonable values for NCTRI and SRX. While one might take all solution points, whether or not they are individually reasonable, and average them over many flood peaks to cancel errors in scattered directions and get a reasonable overall best estimate, too few distinct hydrographs normally occur in any given year. More consistent estimates can be found in fewer runs by discarding unacceptable solutions than by saving them and hoping they average out. Thus, Subroutine SETHRP looks for solution points or approximate solution points in a predetermined "reasonable" range and rejects the data when it cannot find one.

Two rules and four boundary limits are used in Subroutine SETHRP. Figure 6 shows the area bounded by the four limits for a typical flood hydrograph. Definitions of lines A and B and Point C are the same as those in Figure 5. Arrows indicate the directions and circled numbers indicate the rule numbers used in converging on Point C.

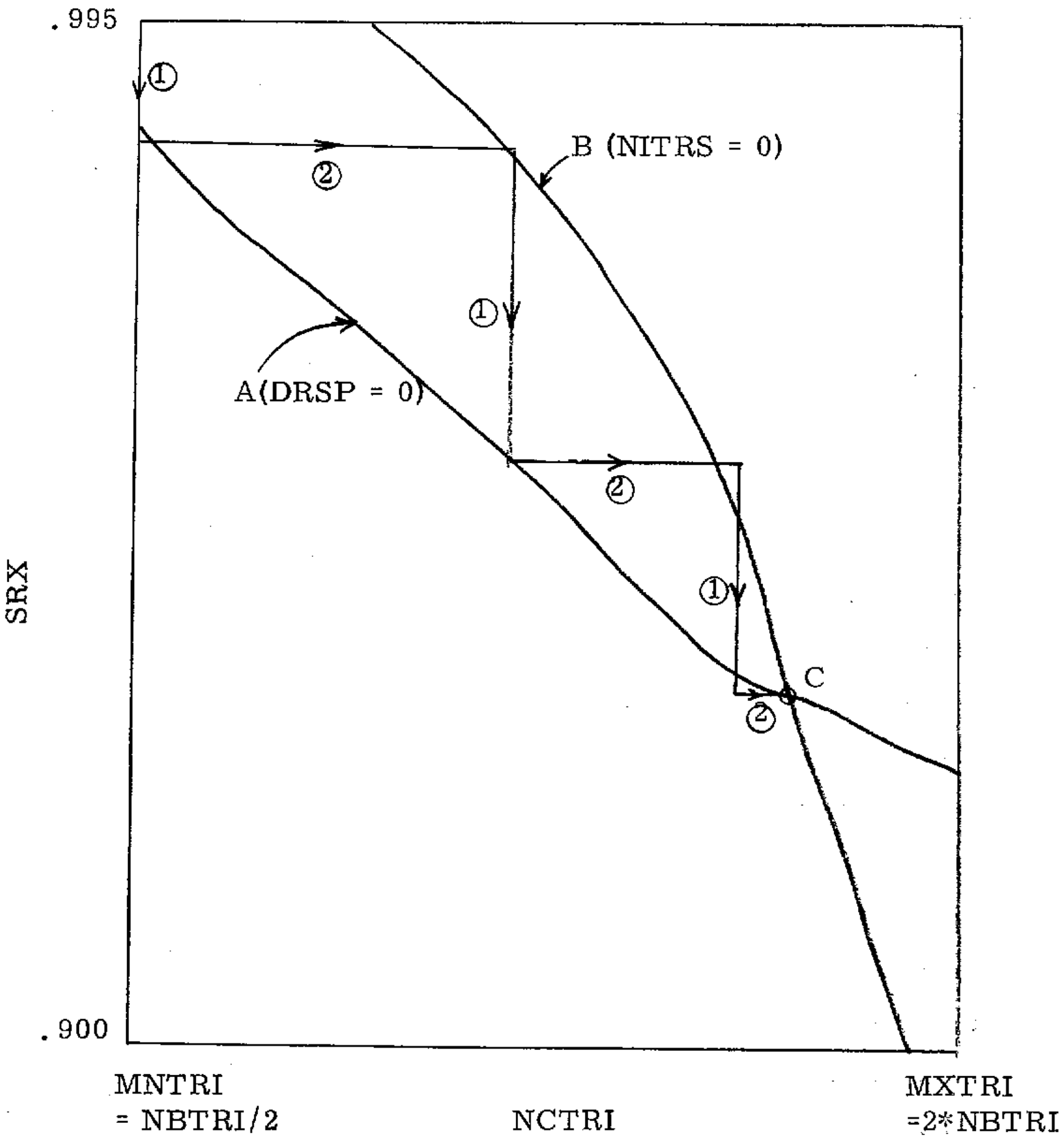

FIG. 6. Rules Used to Find Optimal Set of NCTRI and SRX for Each Flood Hydrograph.

The maximum acceptable value of NCTRI (MXTRI) is twice the number of basic time routing increments (NBTRI) and the minimum value of NCTRI (MNTRI) is one-half NBTRI. The assumption is that the user should be able to estimate the time of concentration (NBTRI) of a basin from topographic information within a factor of two, one way or the other.

The upper limit of SRX is set to 0.995, slightly less than the theoretical upper limit of unity. This is the maximum value which could be used and still avoid computer rounding which increases the volume of the storm during routing unless one resorts to double precision computations. Sensitivity studies show that the effectiveness of SRX in damping the flood peak becomes rapidly more pronounced the closer the value gets to unity. When SRX is decreased to 0.900 or lower, changes in SRX cause rather small changes in simulated flood peak magnitude and time. Therefore, the increments of change in SRX are made smaller for higher values but larger for lower values, and 0.900 is the lower limit of SRX.

The scatter of solution points among storms on a given watershed caused by differences in data quality also suggests that little can be gained by seeking the exact mathematical solution for each of the recorded hydrograph peaks. Computationally, it is much quicker to search among discrete points for the combination of NCTRI and SRX providing a synthesized peak closest to the recorded peak. Six values were chosen for SRX (0.995, 0.99, 0.98, 0.96, 0.93, and 0.90). One is already confined to searching among integer values for NCTRI by the way the variable is defined in the program.

OPTIMIZATION RULES AND PROCEDURE

As shown in Figure 6,the estimation procedure starts in upper left hand corner and moves down looking for Line A. After Line A is found, it moves to the right to find Line B and then moves down to find Line A again. The pattern is repeated until Point C is found.

Examining the process in more detail by using the hydrographs illustrated in Table 18 as numerical examples, it starts with values of NCTRI equal to MNTRI and SRX equal to 0.995. Subroutine FIXTRI is called to establish values of the fractional individual time routing increments (CTRI) to match MNTRI. Then Subroutines TIMERT and STORRT are called to execute channel time routing and channel storage routing of the saved channel inflows. The synthesized flood hydrograph peak (SHPF) and the flood peak time(ITBTS) are used to calculate 1) NIRTS--the number of time routing intervals from the recorded to the synthesized peak and 2) DRSP--the difference in cfs between the recorded and synthesized hydrograph peaks.

The search procedure then chooses between two rules in selecting the discrete point in the field of acceptable points to try next. One rule moves downward by reducing SRX; the other moves to the right by increasing NCTRI. SRX is reduced when it is desirable to increase the synthesized peak flow to more closely match the recorded. NCTRI is increased when it is desirable to more closely match the recorded peak timing.

Rule 1: Hold NCTRI constant and decrease SRX through the series of discrete points until

1. SHPF exceeds RHPF/1.2. If the synthesized flood peak is more than 20 percent too low, a reduction in SRX to improve the matching by increasing the peak flow is preferred over an increase in NCTRI to improve the timing since that can only further reduce the peak. If NIRTS is negative, the adjustment shifts to Rule 2 in an attempt to improve the timing (See trial 6 for the storm of December 22 on Table 18). If NIRTS is zero or positive, the search ends; and SRX

TABLE 18

ESTIMATION OF NCTRI AND SRX FOR POND CREEK, KY. 1968, STORM HYDROGRAPHS

Trial No.	Trial Values NCTRI	SRX	NIRTS	DRSP	Make Next Estimate by Rule
Storm of December 2			Recorded Peak = 1330.0 cfs		
1	2	0.995	-1	1112.0	1
2	2	0.990	-1	1029.6	1
3	2	0.985	-2	957.6	1
4	2	0.980	-2	891.1	1
5	2	0.960	-3	687.3	1
6	2	0.930	-4	427.8	1
7	2	0.900	-4	221.8	
Storm of December 22			Recorded Peak = 1550.0 cfs		
1	2	0.995	-3	1275.4	1
2	2	0.990	-3	1126.4	1
3	2	0.985	-3	993.2	1
4	2	0.980	-3	872.7	1
5	2	0.960	-4	428.8	1
6	2	0.930	-4	78.4[a]	2
7	6	0.930	-2	304.7	1
8	6	0.900	-2	109.9[a]	2
9	8	0.900	-1	295.6	
Storm of March 21			Recorded Peak = 3320.0 cfs		
1	2	0.995	-12	2615.4	1
2	2	0.990	-12	2056.9	1
3	2	0.985	-13	1547.3	1
4	2	0.980	-13	1065.6	1
5	2	0.960	-13	531.5[b]	2&1
6	8	0.930	-10	505.3[b]	1
7	8	0.900	-11	1016.6[b]	
Storm of April 4			Recorded Peak = 4320.0 cfs		
1	2	0.995	-1	3002.6	1
2	2	0.990	-2	2026.4	1
3	2	0.985	-2	1155.2	1
4	2	0.980	-2	384.5[a]	2
5	4	0.980	-1	480.2[a]	2
6	5	0.980	-1	562.2	1
7	5	0.960	-1	1672.3[a, b]	2
8	6	0.960	-1	1462.6[b]	

TABLE 18 (cont'd.)

Trial No.	Trial Values		NIRTS	DRSP	Make Next Estimate by Rule
	NCTRI	SRX			
Storm of May 26			Recorded Peak = 1820.0 cfs		
1	2	0.995	-2	1380.5	1
2	2	0.990	-2	1162.4	1
3	2	0.985	-3	1008.8	1
4	2	0.980	-20	877.0	1
5	2	0.960	-20	203.2	2&1
6	8	0.930	-17	249.8	

a. DRSP not saved in Rule 2 because the rule seeks smaller NIRTS.

b. Synthesized peak is greater than recorded peak. (In all other cases, the synthesized is less than the recorded peak.)

and NCTRI are taken as their trial values.

2. SRX reaches the lower limit of 0.90 with a value of SHPF which is still too small even though increasing (See the storm of December 2, in Table 18). For such a storm event, SRX is taken as 0.90, and NCTRI is taken as the last value selected for this parameter (MNTRI if Rule 2 was never applied during the search). While SRX could be reduced to lower values, this did not prove wise because a low sensitivity makes a large reduction in SRX required to significantly raise the synthesized peak and averaging the low value (usually caused by a data inconsistency anyway) with those from other storms did not yield a good overall parameter estimate for the watershed.

Rule 2: Hold the value of SRX and adjust NCTRI by subtracting NIRTS. As NIRTS is usually negative (Table 18), the subtraction will lengthen the time base to produce the desired later peak. After each change of NCTRI, Subroutine FIXTRI is called to fix the time routing increments. Then Subroutines TIMERT and STORRT are used to simulate another hydrograph peak, and new values of NIRTS and DRSP are calculated. The adjustment of NCTRI is repeated until

1. NIRTS is reduced to zero or as close to zero as is possible with integer variation of NCTRI. The test for this latter case is whether NIBRS, the absolute value of NCTRI, is decreasing.

2. NCTRI is increased past the maximum acceptable value.

3. NCTRI is increased to the point where the synthesized flood peak is too low to make a larger NCTRI and hence a further reduction in SHFP wise.

Each case needs to be described in further detail.

1. Here, the search has arrived at the best possible estimate of NCTRI associated with the held value of SRX. One of two things is done next: 1) if DRSP is greater than it was for the previously

held value of SRX, the search is interpretted as having passed the solution point. NCTRI and SRX are taken as their trial values for the best point using the previous value of SRX. An example occurs as the program returns from trial 8 to 6 during the tabulated storm for April 4; 2) if DRSP is less than what it was for the previously held value of SRX, return to Rule 1 in an attempt to find a still better value. An example occurs as the program goes from trial 6 to 7 during the April 4 storm.

2. Here, the search is prevented from trying a value of NCTRI outside the acceptable range. The search uses the same criteria as in Case 1 to decide whether to return to Rule 1 and further reduce SRX with NCTRI equal to MXTRI or take a solution from a previous trial value. The tabulated storm of March 21 truncated NCTRI from 15 to 8 and continued the search with trials 6 and 7. In this case to save computer time, the search goes to Rule 2 and back to Rule 1 without performing a routing under Rule 2 (March 21, trial 5).

3. Here, the search returns immediately to Rule 1 to increase the peak (See trial 7 for the storm of December 22).

Close inspection of these rules reveals that they produce an approximate solution point without specifying an explicit criteria for weighting the relative importance attached to peak and time. Operationally, the rules stress peak flow rate when synthesized flows miss by over 20 percent and the time of peak when they do not. Thus, for December 22, trial 9 is preferred over trials 6 or 8. Admittedly, such a search procedure is coarse, but most data do not permit greater precision.

If the highest hydrograph peak synthesized for a given storm is less than one-half of the recorded peak, the set of values of NCTRI and SRX are rejected and that storm is excluded in estimating the parameters.

The average value of NCTRI for a given station-year is taken as the mean of the storm weighted by recorded hydrograph peak flow because a larger flood hydrograph gives a better estimate of NCTRI. The subroutine then calls Subroutine SETSRP to estimate CSRX and FSRX.

DISCUSSION

Subroutine SETHRP uses a coarse search procedure to estimate a pair of values which simply cannot be estimated with any precision with the quality of data normally encountered by the model. The procedure relies on the mean of a series of estimates to dampen a large random estimating error likely to be encountered in a particular hydrograph. Fifteen estimates may be available in the three years of record recommended in Chapter IV.

Subroutine FIXTRI

(Fourth Channel Routing Subroutine)

CONTEXT

OPSET is supplied input data describing the shape of the watershed in the form of a time-area histogram. Read are a specified number (NBTRI) of time-area elements (BTRI) and a specification in Control Option 2 as to whether the elements are estimated on a 15-minute or on an hourly basis. However, during the channel routing parameter optimization, it is necessary to perform routings with a value of NCTRI different from NBTRI; therefore, the values of the individual elements must also be adjusted.

For example while data is being collected, a basin may be estimated to have a time of concentration of three hours, and the fractions of the basin from which runoff reaches the mouth of the basin during the first, second, and third hours respectively as estimated from topographic maps provide the numerical values of the three elements. When a routing is to be done using 2 hours for the time of concentration (NCTRI), a numerical procedure is needed for estimating appropriate values for two elements from the values of three elements.

PURPOSE

Subroutine FIXTRI is used to fix values of the individual time routing elements to match the required total number of values. FIXTRI is called whenever there is a change of NCTRI since the last channel time routing.

PROCEDURE

For a given watershed, a base number of time routing increments (NBTRI) and the values of increments (BTRI) are read as input data and represent a histogram derived from a topographic map of the watershed. (10, pp. 21-26; 25, pp. 36-39). For purposes of explaining the procedure used in Subroutine FIXTRI, consider a hypothetical basin having three read time-area elements of 0.42, 0.32, and 0.26 and where a two-element array is needed. The following procedure is used.

1. Divide each of the base time routing increments (BTRI) by the number of current time routing increments (NCTRI); thus there will be (NBTRI) x (NCTRI) elements. For the given example, NBTRI is 3, NCTRI is 2; therefore, the resulting six elements will be 0.21, 0.21, 0.16, 0.16, 0.13, and 0.13.

2. In the order of time intervals in time-area histogram, place the elements into NCTRI groups with NBTRI elements in each group. In the example, the six elements are grouped into two groups as (0.21, 0.21, 0.16) and (0.16, 0.13, 0.13).

3. Sum the values of elements in each group, and the values of group sums are assigned to be the values of the current time routing increments. In the example, the resulting two elements are 0.58 and 0.42.

DISCUSSION

The above procedure will produce the required NCTRI increments. However, the results are approximate because it is assumed that the sub-areas in the base time-area histogram are uniformly distributed in each time interval. In the example, the second original increment of 0.32 was assumed to divide equally between its first and second half hours when in fact a larger share of the basin might be in one of the two. For watersheds with a large NBTRI, this assumption gives better results.

Subroutine TIMERT

(Fifth Channel Routing Subroutine)

CONTEXT

Two groups of equations are used within the Model to simulate the process whereby the stream channel system translates patterns of runoff from the land surface to an outflow hydrograph. The MAIN program accounts for the time lag from the time runoff enters the channel to when it reaches the mouth by use of a time area histogram (MAIN0484-0498). It then follows with programing to account for the effect of channel storage on hydrograph attenuation (MAIN0500-0504).

During the process wherein OPSET estimates the length of the time-area histogram (NCTRI) and the storage routing index (SRX), a large number of routings with trial values are required. Because the trial routings differ from those in MAIN in that they must save the channel inflow hydrographs for later trials, require some adjustment in terminology, and are repetitious, special subroutines were developed for both procedures. Subroutine TIMERT is an adaptation of the time routing programing in MAIN for use by Subroutines SETHRP (STHP0035) and SETSRP (STSP0076). Subroutine STORRT is an adaptation of the storage routing programing in MAIN called in Subroutines SETHRP (STHP0038) and SETSRP (STSP0077).

PURPOSE

Subroutine TIMERT is used to perform the repetitious trial routing required in the search for the channel routing parameter values which best account for the time lag it takes runoff to pass through the channel system.

PROCEDURE

The channel time routing technique originally used by Crawford and Linsley (10, p. 44) can be expressed as

$$I_t = \sum_{x=0}^{x=z-1} R_{t-x} C_{x+1} \qquad (37)$$

where I_t = storm runoff in period t routed to the mouth of the channel (SRR);

R_{t-x} = unrouted synthesized overland flow plus interflow runoff (SSR) x time periods ago;

C_{x+1} = the x+1 time routing increment value (CTRI), expressed as a fraction of the watershed area;

z = number of time routing increments in the time-area histogram (NCTRI).

For example, given a series of unrouted synthesized runoffs and a time routing histogram, the routed runoff at the end of the third time interval will be the sum of 1) channel inflow in the first (closest to the gage) time routing incremental area during the most recent time interval, 2) channel inflow in the second time routing incremental area during the previous time interval, and 3) channel inflow in the third time routing incremental area during the second previous time interval.

DISCUSSION

In their reports describing the adaption of the method developed by Clark (7) to simulate channel time routing, Crawford and Linsley suggested using a modified time-delay histogram (10, pp. 24-27) rather than the time-area histogram derived in the method described by Ross (25, pp. 36-39) and used in developing the input data for testing OPSET. The time-delay histogram is a time-area histogram slightly delayed to account for the finite time required for flows to traverse the width of the histogram band. The difference between the two histograms decreases as one deals with watersheds divided into an increasingly large number of bands.

The modified or time-delay histogram was not used in gathering the test data for OPSET because it is more difficult to construct. More importantly, it is doubtful that the time-area bands can be plotted sufficiently accurately to justify the refinement as really adding to the precision of the results. Even more importantly, OPSET adjusts the length of the originally read histogram to best match simulated with recorded hydrographs. If a delayed hydrograph produces a better fit, OPSET will automatically provide one by calling Subroutine FIXTRI with a larger optimum value of NCTRI.

Subroutine STORRT
(Sixth Channel Routing Subroutine)

PURPOSE

Subroutine STORRT serves as a companion to Subroutine TIMERT and is used to perform the repetitious trial routing required in the search for the routing parameter values which best account for observed storage attentuation effects as runoff moves through the channel system.

PROCEDURE

The time-routed synthesized storm runoff (SRR) from Subroutine TIMERT is taken as the inflow to a hypothetical "reservoir." The storage routing is based on Equation 36 and starts at the beginning of the saved synthesized runoff and continues throughout the Subroutine STRHRS selected hydrograph duration. When CONOP2 is specified in the input data as zero, 15-minute routing is used; when CONOP2 = 1, a 60-minute period is used. Base flow is not routed (MAIN0468, 0481-0482); however, a fixed uniform base flow is estimated for each storm hydrograph (MAIN0521, 0664) and added to each routed runoff to determine total flow (SRRT0027). The time (IBTPS) from the beginning of saved runoff to the synthesized hydrograph peak (SHPF) is recorded. SHPF and IBTPS are used in Subroutine SETHRP in the selection of optimum values for NCTRI and SRX.

When Subroutine STORRT is called from Subroutine SETHRP, a single value of SRX is used throughout the entire routing (i.e., FSRX = CSRX) in an attempt to find a value which produces the best estimate of the recorded hydrograph peak flows. However, when it is called from Subroutine SETSRP, SRX is varied as a function of the synthesized total flows in the manner shown on Figure 5 (SRRT0021-0024).

In order to provide information on the shapes of the synthesized storm hydrographs, 21 points from the channel-routed hydrograph (5 points before the time of the recorded hydrograph peak, and 15 points after that time) are tabulated. The interval of printing points (INHPT) is chosen to make the total time base long enough to cover the storm hydrograph (See Subroutine STRHRS). The 21 values are for visual inspection only, and those other than the peak do not enter into parameter estimation. While the recorded hydrographs are set up to all peak at the sixth point, the synthesized peak will not necessarily fall at this time and in fact may not fall at any of the preselected time points. The synthesized peak value is printed below the hydrograph.

Subroutine SETSRP

(Seventh Channel Routing Subroutine)

CONTEXT

The first pass at estimating a watershed value for SRX begins as presented in Subroutine SETHRP. For each of up to five flow peaks specified in the input data, a value of SRX is found which when used throughout the entire routing produces the best estimate of the recorded flow peak values. The remaining issue is whether the watershed SRX should be taken as the mean of the storm values or whether two values should be used, CSRX when flows are confined to the channel and FSRX when flow enters the flood plain.

Resolution of this issue requires a test. The one used was to regress storm values of SRX against storm flow peaks. If the regression shows SRX to increase with flood peak, the trend to be expected from qualitative analysis of the physical problem, the data is further evaluated to see if separate values of CSRX and FSRX can be estimated. If the regression shows no (or a reverse) trend, the storm values of SRX can be averaged for a single overall watershed value; CSRX equals FSRX.

PURPOSE

Subroutine SETSRP estimates two channel routing parameters. CSRX is the confined flow channel storage routing index and FSRX is the flood flow channel storage routing index.

DISCUSSION OF STORAGE ROUTING

In their earlier versions of the Stanford Watershed Model (10, p. 46), Crawford and Linsley used a single value for SRX[*] in Equation 36 for all routing through the theoretical reservoir used to account for the effect of channel storage on streamflow. More recently they have used a more sophisticated but computationally more complicated kinematic wave routing in a program capable of simultaneously simulating flows at a large number of points within a given watershed. In developing OPSET, emphasis was placed on estimating the parameters which control the volume and seasonal distribution runoff rather than flood hydrograph shape. The strategy of retaining the theoretical storage reservoir concept provides good results for simulating runoff at the mouth of a single small watershed. Anyone desiring more comprehensive storage routing can readily combine estimates for the other parameters made by OPSET with the routing features of the more recent versions.

While the theoretical reservoir concept was retained, the single parameter approach was modified. Streamflow is often better modeled by varying SRX with stream flow rate in order to incorporate the effectiveness of flood plain storage in dampening flood hydrographs

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[*] SRX is equivalent to KS1 as used by Crawford and Linsley.

to a greater degree than can storage in the channel alone. Therefore, the Kentucky Watershed Model selects the value for SRX it uses at any given time according to the magnitude of the streamflow synthesized for the previous routing period (Figure 7). CHCAP is used to index the flow rate at which flood plain, as contrasted with natural channel storage, becomes the predominate influence on storage routing.

When the synthesized streamflow is less than one-half of CHCAP, CSRX is used for routing. If the synthesized flow exceeds twice CHCAP, FSRX is used. When the synthesized flow is between these values, SRX is interpolated from the cubic curve expressed mathematically by the equation

$$SRX = CSRX + (FSRX - CSRX) \times \left(\frac{Q - 0.5CHCAP}{1.5CHCAP}\right)^3 \qquad (38)$$

where Q is the synthesized streamflow.

PROCEDURE

In order to determine whether the hydrographs used in a given run of OPSET exhibit a trend toward higher values of SRX for larger flows, the values of SRX selected by Subroutine SETHRP (which estimates one value of SRX for use in routing the entire hydrograph) were regressed on the corresponding recorded hydrograph peak flows. An increase of SRX with peak flow suggests flood plain damping. In other words, for smaller hydrographs, flows are confined to the main channel, the damping of the hydrograph is limited, and the result is a low SRX. On the contrary, large floods overflow the channel bank. The much greater flood plain storage damps the flood peaks more drastically, and the value of SRX is higher.

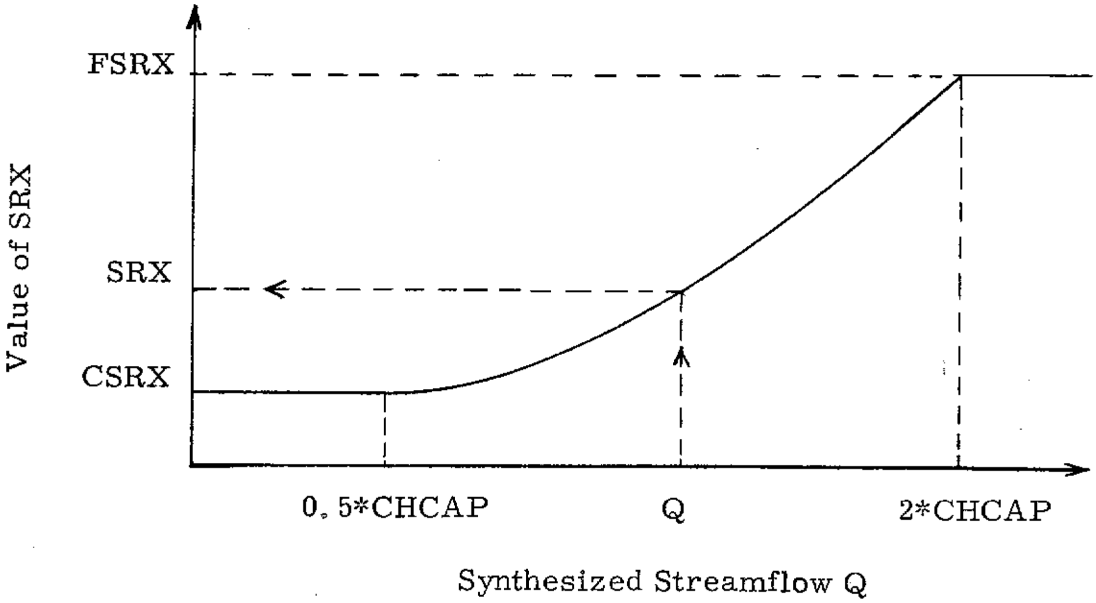

FIG. 7. Relationship Between SRX and Synthesized Streamflow.

If the coefficient from the regression of the estimates of SRX on the corresponding recorded hydrograph peaks is positive, the first step is to estimate CSRX (Figure 7) as

$$\text{CSRX} = a + b(\text{CHCAP}/2) \tag{39}$$

where the coefficients a and b are the least squares estimates of α and β in the linear model

$$\text{SRX} = \alpha + \beta \cdot \text{RHPF} + \epsilon \tag{40}$$

If CSRX turns out less than 0.8, CSRX is set equal to 0.8 to prevent the selection of physically unreasonable values caused by hydrographs with nearly equal peak flows having comparatively large differences in estimated SRX.

For floods peaking at a flow less than one-half of CHCAP, CSRX is used for all storage routing throughout the hydrograph. For larger storms, SRX is varied with flow in the manner depicted in Figure 7. FSRX cannot be estimated by substituting twice CHCAP for CHCAP/2 in Equation 39 because the data were derived by routing the entire hydrograph with a fixed SRX. The value of FSRX is instead estimated by trial-and-error adjustment between the values of CSRX and 0.99 used as the upper limit to minimize the effect of rounding errors on flood volume.

Figure 8 illustrates the scheme used to estimate FSRX based on the criterion of minimizing SQPKD, the sum of the squares of the differences between recorded and synthesized hydrograph peaks. The adjustment uses two sizes of increments for FSRX. The big increment (BISRX) is used to rapidly locate the low region in the U-shaped curve whose minimum point indicates the optimal value of FSRX, and the small increment (SISRX) is used to backtrack once

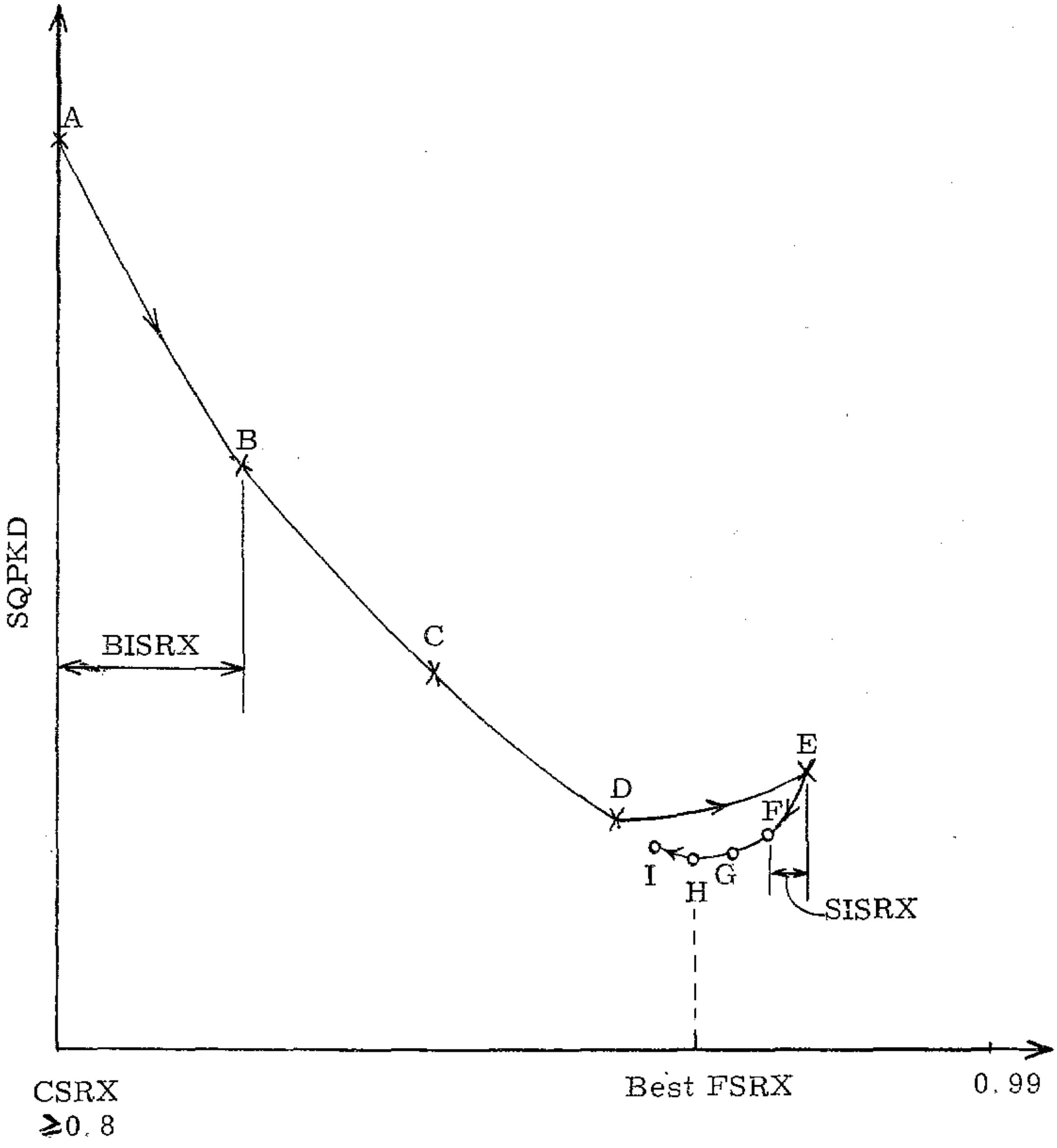

FIG. 8. Determination of FSRX by Trial and Error Method.

the minimum is passed to more closely estimate FSRX. BISRX is taken as one-fifth of the difference between 0.99 and CSRX. SISRX is one-fifth of BISRX.

The iterative procedure starts with FSRX=CSRX to route the selected flood hydrographs. The optimized NCTRI (calculated in Subroutine SETHRP) is used for channel time routing and the trial values of CSRX and FSRX are used for channel storage routing. Then the difference between each pair of recorded and synthesized hydrograph peaks (DRSP), the accumulated sum of DRSP (ADRSP), and the sum of the squares of DRSP (SQPKD) are calculated by the following equations:

$$\mathrm{DRSP}_i = \mathrm{SHPF}_i - \mathrm{RHPF}_i \qquad (i=1,2,\ldots \mathrm{NRHP}) \tag{41}$$

$$\mathrm{ADRSP} = \sum_{i=1}^{\mathrm{NRHP}} \mathrm{DRSP}_i \tag{42}$$

$$\mathrm{SQPKD} = \sum_{i=1}^{\mathrm{NRHP}} (\mathrm{SHPF}_i - \mathrm{RHPF}_i)^2 \tag{43}$$

where SHPF and RHPF are the synthesized and recorded hydrograph peaks respectively.

When SQPKD is plotted against the first trial value of FSRX (Point A in Fig. 8), the point usually has a rather high value of SQPKD. The next point (Point B in Fig. 8) is obtained as the trial value of FSRX is set equal to the previous value plus BISRX. If SQPKD becomes smaller, the new values of SQPKD and FSRX are saved before going on to try a larger FSRX. The process continues until 1) the new value of SQPKD exceeds the previous one (Point E in Fig. 8), or 2) the minimum value of SQPKD is found at the maximum value for FSRX of 0.99.

The first case indicates that the minimum point of SQPKD has been passed. The direction of search is reversed by determining the next value of FSRX by subtracting the small incremental SRX (SISRX) from the last value. The reverse adjustment of FSRX continues until a new value of SQPKD exceeds the last value, then the last value of FSRX is selected as its best estimate (Point H in Fig. 8).

The case where the smallest SQPKD is for an FSRX of 0.99 may be associated with an ADRSP either larger or smaller than zero. If ADRSP is negative, the search backtracks within the last big increment to find a minimum point in the manner described above. If ADRSP is positive, the synthesized flood peaks are too big but further reduction by increasing FSRX is not practical. In order to make the synthesized peaks smaller, the curve in Fig. 8 is moved to the left by reducing CHCAP to 80 percent of its previous value. Smaller peaks are simulated because a higher value of SRX will now be used for any given flow. The estimate provided in the data is assumed to be in error. With the new values of CSRX (estimated by substituting the new CHCAP in Equation 39) and CHCAP, the procedure of Fig. 8 is again used to estimate FSRX. However, to prevent the program from hanging in a loop, the number of adjustments to CHCAP is limited to four. At this point, OPSET sets the values of both CSRX and FSRX to their upper limit of 0.99 to reduce synthesized flood peaks in a situation where a better estimate is taking too much computer time. A review of the estimated CHCAP as an index of the flow at which flooding begins is recommended. The user may wish to rerun the program starting with a lower estimate.

The two cases in which the above method cannot be applied must be considered separately. They are:

1. Less than two hydrographs may be accepted by Subroutine SETHRP. Subroutine SETSRP is not called and OPSET terminates if no hydrographs are accepted. The user should try another run with better data. Since a slope cannot be estimated from one point, both CSRX and FSRX are set equal to SRX when just one hydrograph is accepted.

2. The estimate of b in Equation 40 may be negative. Since such a value does not make physical sense, a single estimate is made for both parameters. A mean weighted by the recorded hydrograph peaks is used because the arithmetic mean may be too biased by SRX values arising from a hydrograph with a small magnitude. Small hydrograph peaks are more subject to anomalies between recorded flood peaks and recorded precipitation.

CONCLUSION

A great many arbitrary sounding empirical rules have been presented in this chapter. Few can be quantitatively verified theoretically. Their merit can best be judged by the results they produce. Space does not permit extensive analysis of results in this report. Ross (25) discusses the results with respect to estimating parameter values by watershed. James (16, pp. 34-36) tabulates the success of estimated parameters values when used in the Model in matching simulated to recorded stream flow. The tables in the following chapter also provide information which can be used in evaluating the results.

CHAPTER IV

OPERATION AND APPLICATIONS

The use of OPSET to estimate a set of parameter values for a given watershed is enhanced by a well-planned strategy. Water years of record need to be selected to give the best results. A technique is needed for obtaining the best overall estimate from estimates from individual years. Options are provided in the program to meet the needs of individual users. These topics are discussed in this chapter.

OPERATION OF THE OPSET PROGRAM

Even though parameter estimation by OPSET is on a station-year basis, many station years can be handled in a single computer run. The variable NSYT specifies the number of station years included in a given computer run. Since each station year is an independent operational unit, the total number of station years will not affect the result for any station year.

For each station year, a title card for identification and the following six data and operation options are read as input data:

1. CONOPT(1) -- evapotranspiration data option. This is identical to CONOPT(3) in the KWM control options (25, p. 29). When read as 0, daily evaporation data (DPET) and monthly evaporation pan coefficient data (EPCM) are used and read in MAIN0098 and MAIN0103. When read as 1, then 10-day average evaporation data as well as the monthly evaporation pan coefficient data are used. When read as 2, then estimated potential annual evapotranspiration (EPAET) and mean annual number of days with more than

0.01 inch of rain (MNRD) are read and Subroutine EVPDAY is called to estimate daily evapotranspiration values (MAIN0108-0110). The user should choose his option according to the availability of evaporation data. More detailed descriptions are given by Ross (25, pp. 29-35) and in the discussion of Subroutine EVPDAY.

2. CONOPT(2) -- channel routing option. This is identical to CONOPT(12) in the KWM control options (25, p. 23). For larger watersheds, the channel routing in optimizing the hydrograph routing parameters is done hourly so as to save computer time. CONOPT(2) is read as 1, and the input time-area histogram is constructed on an hourly basis. For small watersheds, fifteen-minute routing periods are used in OPSET by setting Option 2 equal to 0, and the input time-area histogram is constructed in 15-minute time intervals.

3. CONOPT(3) -- rain gage moving option. This is identical to CONOPT(8) in the KWM control options. The option specifies whether some event occurred during the water year which would alter the procedure used in combining recording and storage gage amounts to estimate hourly rainfalls on the basin. If it has, CONOPT(3) should be read as 1, and the new storage gage weighting factor (WSG2), the new storage gage reading time (SGRT2), and the day of the change (SGMD) should be read (MAIN0153). If no such event occurred in that station-year, CONOPT(3) should be read as 0, and the other data are not needed. A more detailed description is given by Ross (25, pp. 25-29).

4. MNRC -- minimum number of Rough cycles. In the Rough adjustment of the six volume parameters in TRIP 1, a minimum number of cycles is preassigned to provide the user flexibility to make a more thorough search of parameter value combinations for use in cases where the estimating procedure is experiencing difficulty

in finding a path toward a reasonable solution. Unless the process first finds a set of parameters for which SSQM is less than 0.15 (rough looping cannot be more precise), the estimation requires at least MNRC times of Rough adjustment. Although the last few cycles sometimes get consistently worse, experience has shown that the process may reverse. The opportunity to increase MNRC provides the power to find the best possible combination of the six parameter values without being halted by difficulties in the initial trials which may start from a bad set of values. Smaller values of MNRC will save computer time where the estimation is quicker. A value of 12 was used in most of the studies reported by Ross (25, p. 87).

5. NFTR -- number of the first TRIP to be run for a given station-year of data. If NFTR is 1, the input data is as shown by Ross (25, Appendix B). Sometimes, the user may not want to start with TRIP 1. For example, if the parameter values estimated in TRIP 1 have been established in a previous computer run, and it is desired to repeat the optimization procedure for the channel routing parameters because the hydrograph data was punched incorrectly the first time, the program can be started with TRIP 2 by setting NFTR equal to 2 and adding eight parameter values on punched cards right after the end of hourly precipitation data (MAIN0227):

For the example of the best run of the Fine adjustment cycle for the 1956 Wood Creek data (25, pp. 82-87), the cards would be:

11.14 * LZC, lower zone storage capacity
4.23 * BMIR, basic maximum infiltration rate within watershed
0.65 * SUZC, seasonal upper zone storage capacity factor
0.15 * ETLF, evapotranspiration loss factor
1.04 * BUZC, basic upper zone storage capacity factor
0.45 * SIAC, seasonal infiltration adjustment constant

0.00 * BIVF, basic interflow volume factor

8.58 * LZS, current lower zone storage.

If it is desired to run the program with the final trip alone, the value of NFTR should be set equal to 3 and six more parameter values should be placed right after the eight parameter values on punched cards as follows:

0.935 * CSRX, channel storage routing index

0.935 * FSRX, flood plain storage routing index

3 * NCTRI, number of current time routing increments

100.0 * CHCAP, channel capacity - indexed to basin outlet

0.100 * IFRC, interflow recession constant

0.895 * BFRC, base flow recession constant

6. NLTR -- number of the last trip to be run for a given station year. This value can be 1, 2, or 3 but must equal or exceed NFTR. The complete run of OPSET will have NFTR equal to 1 and NLTR equal to 3.

SELECTION OF WATER YEARS

Data from 20 watersheds in Kentucky were used in developing OPSET. Ross (25, pp. 58-78) describes the criteria followed in selecting the watersheds and gives detailed information on those watersheds selected. Seventeen of the 20 watersheds were classified as rural in that physical change within the watershed was judged not extensive enough to change the value of the parameters with time. The other three were classified as urbanizing as urban development has been changing the face of the watershed. From the published record for each rural watershed, three water years were chosen to represent a wide range of flow patterns. They were (1) the year with largest winter (December-May) flood, (2) the year with the largest summer (June-November) flood, and (3) the year with the least summer runoff. For each urbanizing watershed, the first four and the last four years of record were obtained to represent both ends of the urbanizing experience.

AVERAGING METHOD STUDIES

OPSET estimates parameters from the data for a given water year. If the hydrologic simulation model were perfect, the parameters estimated directly from watershed characteristics were measured correctly, and the climatological data represented watershed experience, OPSET would estimate the same set of parameter values from any year of data (p. 76). The exception would be estimates for parameters which relate to processes that do not occur in a year of record. For example, the parameter for routing major floods cannot be estimated from data years when the flow does not leave the banks of the channel, and the parameters best estimated from their effect on summer flows are difficult to estimate from years with very little summer rainfall.

Because parameter estimates do vary from year to year, a suitable method for averaging the results is needed. The issues considered were:

1. Should one use an arithmetic or a geometric mean?
2. Should years with certain extreme flow characteristics be excluded from the averaging?
3. Should parameter estimates obtained from years when simulated flows closely match recorded flows be weighted more heavily than estimates from years when the matching is not so good?
4. How much is the estimate improved by including more years in the averaging?

These issues were resolved through a series of studies. It was recognized ahead of time that the best averaging procedure would probably vary by parameter. It was also recognized that the available computer time would not permit exhaustive analysis. The studies would have to be exploratory and the conclusions tentative.

Questions 1 and 2: The first study used the Cave Creek watershed where a recording rain gage is located quite close to a small watershed. OPSET was applied to the data for each water year to estimate three sets of parameter values. From these estimates, four different mean values were calculated for each parameter (Table 19). Because of the parameters more sensitive to summer storms, if any year were to be excluded, a year with a dry summer seemed to be the most logical. In all, there were four different means, namely, the arithmetic mean of all three years (A_m), the geometric mean of all three years (A_g), the arithmetic mean of two wet years (A_{mw}), and the geometric mean of two wet years (A_{gw}).

In order to examine how parameter estimates based on one water year work on data for another water year, a series of runs were made. For each water year, the set of parameter values obtained from each OPSET run and the four sets of mean values were used to simulate an annual hydrograph (TRIP 3 only). The results of these three computer runs are shown on Tables 20, 21, and 22.

Inspection of the three tables reveals the following features which lend insight useful in choosing the best possible means of averaging parameter values:

1. The best set of parameter values (smallest SSQM) for a given water year is the one obtained from the OPSET run based on that water year. The estimating procedure is doing its job.

2. Averaged parameter values give better simulation results than a set of values based on any other water year (Table 21).

3. The averaged mean values based on all three years are superior to those based on two of the three years. Table 20 shows

TABLE 19

PARAMETER VALUES USED FOR STUDYING AVERAGING METHODS: CAVE CREEK NEAR FORT SPRING, KY.

	1955 (W^*)	1958 (S^*)	1965 (D^*)	$\overset{*}{\text{Am}}$	$\overset{*}{\text{Ag}}$	$\overset{*}{\text{Amw}}$	$\overset{*}{\text{Agw}}$
LZC	5.77	1.86	1.37	3.00	2.45	3.81	3.27
BMIR	3.92	4.66	6.06	4.88	4.80	4.29	4.27
SUZC	0.77	0.25	0.94	0.65	0.57	0.51	0.44
ETLF	0.21	0.25	0.17	0.21	0.21	0.23	0.23
BUZC	3.02	1.46	0.65	1.71	1.42	2.24	2.10
SIAC	0.26	0.09	0.40	0.25	0.21	0.18	0.15
BIVF	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BFRC	0.877	0.836	0.877	0.863	0.863	0.857	0.856
IFRC	0.100	0.255	0.128	0.161	0.148	0.178	0.160
CSRX	0.970	0.970	0.984	0.975	0.975	0.970	0.970
FSRX	0.977	0.994	0.984	0.985	0.985	0.986	0.985
NCTRI	2	3	6	4	3	3	2
LZS	3.33	0.95	0.04	1.44	0.50	2.14	1.78

*W = Winter flood year values

S = Summer flood year values

D = Driest year values

Am = $(W + S + D)/3$

Ag = $(W \cdot S \cdot D)^{1/3}$

Amw = $(W + S)/2$

Agw = $(W \cdot S)^{1/2}$

TABLE 20

AVERAGING METHOD STUDIES: CAVE CREEK 1955
THE WINTER FLOOD YEAR (W)

	Recorded Flows (sfd)	Synthesized Flows (monthly deviation indices)						
		W	S	D	Am	Ag	Amw	Agw
Monthly flows (sfd)								
Nov.	3.1	-0.127	-0.090	-0.095	-0.127	-0.138	-0.121	-0.127
Dec.	20.9	-0.033	1.076	1.355	0.406	0.499	0.244	0.389
Jan.	50.7	-0.063	0.420	0.562	0.255	0.293	0.149	0.202
Feb.	320.9	-0.198	0.089	0.101	-0.021	0.016	-0.075	-0.033
Mar.	401.5	0.076	0.176	0.177	0.145	0.156	1.128	1.140
Apr.	40.6	-0.170	-0.015	-0.287	-0.152	-0.098	-0.092	-0.034
May	136.6	0.148	0.625	-0.003	0.246	0.326	0.411	0.471
Jun.	37.9	0.178	0.465	0.159	0.306	0.358	0.383	0.421
Jul.	16.3	0.033	0.113	-0.418	-0.093	-0.103	0.061	0.058
Aug.	19.4	-0.190	0.376	-0.589	-0.271	-0.235	-0.139	-0.091
Sep.	1.7	-0.043	-0.059	-0.074	-0.069	-0.069	-0.059	-0.059
SSQM		0.187	2.146	2.837	0.531	0.692	1.724	1.924
Annual total (sfd)	1051	1037	1369	1222	1172	1214	1176	1220
Flood peaks (cfs)								
Feb. 5	46.0	39.7	50.9	43.7	43.2	44.9	42.3	45.8
Mar. 21	60.0	118.9	102.2	98.4	106.6	107.7	109.0	111.0
May 13	117.0	197.1	138.3	106.5	163.4	170.5	181.7	190.7
May 21	52.0	26.1	71.0	-*	20.7	28.1	40.7	49.9

*Synthesized flow less than the preassigned minimum value (MINH) which is 10 cfs for this station year.

TABLE 21

AVERAGING METHOD STUDIES: CAVE CREEK 1958 THE SUMMER FLOOD YEAR (S)

	Recorded Flows (sfd)	Synthesized Flows (monthly deviation indices)						
		W	S	D	Am	Ag	Amw	Agw
Monthly flows (sfd)								
Nov.	72.0	-0.064	0.932	0.712	0.358	0.389	0.287	0.418
Dec.	293.9	-0.366	-0.107	-0.025	-0.187	-0.169	-0.254	-0.226
Jan.	136.1	-0.130	0.001	0.015	-0.066	-0.049	-0.102	-0.082
Feb.	150.5	-0.464	-0.306	-0.258	-0.327	-0.306	-0.377	-0.351
Mar.	79.8	-0.672	-0.363	-0.465	-0.446	-0.420	-0.483	-0.455
Apr.	160.0	-0.326	-0.036	-0.250	-0.180	-0.121	-0.141	-0.108
May	160.8	0.341	0.569	0.380	0.433	0.467	0.462	0.488
Jun.	12.6	-0.342	-0.523	-0.462	-0.424	-0.455	-0.387	-0.399
Jul.	250.7	-0.813	-0.238	-1.286	-0.859	-0.759	-0.644	-0.587
Aug.	115.4	-1.163	-0.643	-0.948	-1.106	-1.021	-1.096	-0.991
Sep.	7.9	-0.177	-0.208	-0.280	-0.229	-0.224	-0.203	-0.203
SSQM		3.206	2.217	3.842	2.886	2.570	2.573	2.339
Annual total (sfd)	1442	1051	1411	1233	1183	1219	1183	1225
Flood peaks (cfs)								
Nov. 18	44.0	47.2	73.3	65.3	65.7	70.5	72.6	82.4
Dec. 7	53.0	50.6	58.2	46.3	51.3	52.3	56.0	57.1
Dec. 26	43.0	95.7	70.1	70.3	85.5	86.8	92.3	94.0
Jul. 24	87.0	128.3	89.0	64.2	106.6	111.9	121.2	127.1

TABLE 22

AVERAGING METHOD STUDIES: CAVE CREEK 1965
THE DRIEST YEAR (D)

	Recorded Flows (sfd)	Synthesized Flows (monthly deviation indices)						
		W	S	D	Am	Ag	Amw	Agw
Monthly flows (sfd)								
Nov.	4.8	-0.210	-0.143	-0.122	-0.204	-0.204	-0.210	-0.210
Dec.	236.1	-0.781	0.093	0.166	-0.196	-0.095	-0.350	-0.234
Jan.	187.5	-0.601	-0.334	-0.244	-0.409	-0.363	-0.501	-0.451
Feb.	156.4	-0.595	-0.288	-0.251	-0.387	-0.348	-0.453	-0.409
Mar.	305.7	-0.241	-0.081	-0.096	-0.127	-0.109	-0.150	-0.131
Apr.	99.1	0.008	0.188	0.022	0.081	0.128	0.113	0.149
May	21.4	-0.266	-0.251	-0.310	-0.314	-0.310	-0.318	-0.298
Jun.	5.2	-0.235	-0.254	-0.248	-0.241	-0.248	-0.241	-0.241
Jul.	3.2	-0.069	-0.126	-0.149	-0.126	-0.132	-0.105	-0.110
Aug.	0.6	-0.025	-0.030	-0.030	-0.030	-0.030	-0.030	-0.030
Sep.	1.3	-0.060	-0.060	-0.065	-0.065	-0.065	-0.060	-0.065
SSQM		1.562	0.413	0.359	0.597	0.512	0.833	0.673
Annual total (sfd)	1032	701	945	958	836	874	794	830
Flood peaks (cfs)								
Dec. 4	18.0	13.0	96.4	66.6	39.1	56.6	29.1	42.6
Dec. 12	33.5	19.6	46.5	38.5	31.8	36.4	30.8	35.6
Dec. 26	16.5	14.8	20.3	22.4	17.8	18.7	16.9	18.0
Mar. 17	14.0	81.1	80.4	52.9	71.6	72.5	81.3	82.2
Mar. 26	40.0	94.6	92.3	74.9	88.1	88.6	93.2	93.8

how bringing the dry year into the average even improves the simulation for the wet years.

4. The results do not give much grounds for choosing the geometric mean.

Two conclusions came from this study. The first was to prefer the arithmetic mean over the geometric mean because it gives equally good results with less computational effort. The exception was for SIAC where use of the geometric mean seemed intuitively more reasonable because that parameter is an exponent in the modeling equations (MAIN0308, 0551). The second was to include years in the averaging regardless of their flow patterns.

Question 3: The second study examined the merit of weighting the averaged flow volume parameters on SSQM based on the hypothesis that the ability to better match recorded flows is an index of a better estimate. Three types of weighting were tried. Type A takes the arithmetic mean of the parameter values obtained from the various years. That is

$$\bar{X}_A = \frac{\sum_{i=1}^{n} X_i}{n} \tag{44}$$

where the X_i are the parameter values obtained from n single year OPSET runs. Type B weights the parameter values on the reciprocal of SSQM. The mathematical expression is

$$\bar{X}_B = \frac{\sum_{i=1}^{n} \left(\frac{1}{SSQM_i}\right) X_i}{\sum_{i=1}^{n} \left(\frac{1}{SSQM_i}\right)} \tag{45}$$

where $SSQM_i$ is the value of SSQM for the year. Type C weights the parameter values on the portion of the grand total SSQM not pertaining to the year. The expression is

$$\overline{X}_C = \frac{\sum_{i=1}^{n} \left[\left(\sum_{i=1}^{n} SSQM_i \right) - SSQM_i \right] X_i}{(n-1) \sum_{i=1}^{n} SSQM_i} \qquad (46)$$

In all three averaging methods, the logarithms of SIAC were used in keeping with the decision to use its geometric mean. For this study, the parameters other than the land phase parameters were averaged in manners independently developed from reviews of the estimating procedures and presented later.

To test the three types of weighting, three watersheds whose values of SSQM differed substantially from one year to another were selected. Weighting would have no effect if all values of SSQM were equal. The values based on individual years and the averages according to each of the three equations are tabulated in Table 23.

For each of the nine station years, the three types of averaged parameter values were used to run TRIP 3 of OPSET. The monthly flow deviations for each station year are summarized on Table 24. The evidence is not very conclusive for selecting a type of averaging. Type B averaging did the relatively best job for the most months, but it also did the relatively worst job most often. Type A averaging also ranged from one extreme to the other. Type C averaging usually produced a result that was not the best matching or the worst either. The verdict was to recommend unweighted averaging on the grounds that it gave equally good results from much less effort.

TABLE 23

PARAMETER VALUES WITH DIFFERENT TYPES OF AVERAGING

	Water Year			Type of Averaging		
West Bays Fork near Scottsville, Kentucky						
	1956	1957	1961	A	B	C
LZC	8.88	9.96	17.13	11.99	15.69	13.01
BMIR	7.75	5.28	4.96	6.00	5.32	5.96
SUZC	0.40	0.83	0.30	0.51	0.34	0.43
ETLF	0.18	0.14	0.28	0.20	0.26	0.22
BUZC	1.09	0.20	0.79	0.69	0.79	0.78
SIAC	0.00	0.00	0.85	0.07	0.42	0.12
BIVF	0.40	0.40	0.80	0.439	0.727	0.590
BFRC	0.870	0.888	0.939	0.905	0.905	0.905
IFRC	0.234	0.117	0.516	0.332	0.332	0.332
NCTRI	4	4	4	4	4	4
CSRX	0.900	0.880	0.900	0.893	0.893	0.893
FSRX	0.900	0.990	0.900	0.930	0.930	0.930
CHCAP	750	750	750	750	750	750
LZS	5.05	3.51	10.90	--	--	--
SSQM	3.783	7.362	0.560			
McDougal Creek near Hodgenville, Kentucky						
	1954	1958	1966	A	B	C
LZC	9.16	2.18	2.55	4.63	7.67	5.53
BMIR	8.03	2.59	4.20	4.94	6.97	5.14
SUZC	0.20	0.19	0.65	0.35	0.23	0.29
ETLF	0.21	0.16	0.10	0.16	0.19	0.17
BUZC	0.27	0.93	0.23	0.48	0.36	0.48
SIAC	0.02	0.57	0.61	0.19	0.04	0.12
BIVF	0.00	0.00	0.00	0.00	0.00	0.00
BFRC	0.882	0.901	0.923	0.908	0.908	0.908
IFRC	0.100	0.100	0.100	0.100	0.100	0.100
NCTRI	5	5	5	5	5	5
CSRX	0.930	0.925	0.914	0.920	0.920	0.920
FSRX	0.930	0.925	0.914	0.921	0.921	0.921
CHCAP	440	440	440	440	440	440
LZS	4.76	1.77	1.98	--	--	--
SSQM	0.277	1.544	2.802			

TABLE 23 (cont'd.)

Elkhorn Creek near Frankfort, Kentucky						
	1948	1960	1964	A	B	C
LZC	2.64	2.00	1.46	2.03	2.32	2.17
BMIR	10.63	12.24	20.00	14.29	12.28	13.15
SUZC	0.92	0.30	1.30	0.84	0.81	0.78
ETLF	0.10	0.60	0.34	0.35	0.26	0.33
BUZC	2.50	0.20	0.78	1.16	1.75	1.33
SIAC	0.02	4.00	1.29	0.10	0.12	0.31
BIVF	6.48	2.66	1.03	3.39	4.76	3.99
BFRC	0.880	0.864	0.894	0.877	0.877	0.877
IFRC	0.430	0.336	0.442	0.403	0.403	0.403
NCTRI	19	15	17	17	17	17
CSRX	0.874	0.941	0.983	0.927	0.927	0.927
FSRX	0.874	0.941	0.983	0.927	0.927	0.927
CHCAP	1000	1000	1000	1000	1000	1000
LZS	0.97	0.54	0.33	--	--	--
SSQM	1.479	3.407	6.878			

TABLE 24(a)

DEVIATIONS OF MONTHLY SIMULATED FLOWS WITH DIFFERENT TYPES OF AVERAGING

Watershed	West Bays Fork at Scottsville, Kentucky								
Water Year	1956			1957			1961		
Type	A	B	C	A	B	C	A	B	C
Nov.	0.03	0.22	0.09	-0.27	-0.16	-0.21	-0.40	-0.60	-0.80
Dec.	0.25	0.33	0.27	-0.18	0.11	-0.14	-0.12	0.02	-0.54
Jan.	-0.92	0.04	-0.73	-0.85	-0.57	-0.78	-0.21	0.29	-0.59
Feb.	-0.22	-0.23	0.21	0.26	0.13	0.24	-0.88	-0.50	-1.22
Mar.	0.02	-0.11	0.01	0.27	0.13	0.23	-0.07	0.12	-0.16
Apr.	0.06	0.01	0.05	0.14	0.04	0.12	-0.01	0.06	-0.04
May	-0.08	-0.01	0.03	0.34	0.40	0.40	-0.04	0.10	0.01
Jun.	-1.31	-1.06	-1.16	0.17	0.13	0.15	0.21	0.24	0.22
Jul.	0.84	1.08	1.03	-1.79	-1.58	-1.70	0.14	0.18	0.16
Aug.	0.09	0.20	0.15	0.79	-0.76	-0.78	-0.33	-0.36	-0.36
Sep.	-0.25	-0.20	0.21	0.73	0.61	0.67	-0.69	0.69	-0.69
Watershed	McDougal Creek near Hodgenville, Kentucky								
Water Year	1954			1958			1966		
Nov.	-0.27	-0.03	-0.15	-0.10	-0.27	-0.13	-0.82	-0.65	-0.74
Dec.	0.31	0.35	0.35	-0.19	-0.31	-0.24	-0.57	-0.43	-0.53
Jan.	0.57	0.07	0.41	-0.30	-0.54	-0.37	-0.21	-0.43	-0.28
Feb.	0.75	0.33	0.63	-0.26	-0.20	-0.25	-0.54	-0.81	-0.64
Mar.	0.28	0.29	0.29	-0.42	-0.52	-0.47	-0.20	-0.32	-0.22
Apr.	0.11	-0.09	0.05	-0.86	-1.02	-0.89	-0.08	-0.32	-0.13
May	0.19	0.20	0.28	-0.17	-0.18	-0.16	-0.09	-0.05	-0.06
Jun.	-0.16	0.03	-0.05	0.77	0.93	0.87	-0.22	-0.00	-0.14
Jul.	-0.10	-0.06	-0.09	0.27	0.32	0.29	-0.21	-0.03	-0.09
Aug.	-0.62	-0.26	-0.51	-0.94	-0.64	-0.80	1.04	1.08	1.08
Sep.	-0.11	0.10	-0.02	0.38	0.67	0.51	0.40	0.60	0.41

TABLE 24(a) (cont'd.)

Watershed	Elkhorn Creek near Frankfort, Kentucky								
Water Year	1948			1960			1964		
Type	A	B	C	A	B	C	A	B	C
Nov.	0.44	0.32	0.41	-0.06	-0.08	-0.06	-0.67	-0.68	-0.68
Dec.	0.02	-0.03	-0.00	0.00	-0.02	-0.01	-1.63	-2.16	-1.85
Jan.	-0.07	-0.10	-0.08	-0.21	-0.22	-0.21	-0.95	-1.38	-1.12
Feb.	-0.85	-0.86	-0.81	-0.16	-0.17	-0.16	-0.14	-0.20	-0.18
Mar.	0.06	0.06	0.07	-0.95	-0.98	-1.00	-0.10	-0.12	-0.10
Apr.	-0.19	-0.19	-0.19	-2.64	-2.59	-2.46	0.50	0.48	0.49
May	0.05	0.05	0.06	0.21	0.41	0.34	-0.04	-0.05	-0.06
Jun.	-1.28	-1.20	-1.28	-0.19	-0.08	-0.14	-0.68	-0.24	-0.55
Jul.	-2.18	-2.08	-2.16	-0.03	-0.04	-0.03	-1.39	-1.14	-1.31
Aug.	0.13	-0.12	-0.13	-1.39	-0.85	-1.12	-0.17	-0.17	-0.17
Sep.	0.42	-0.42	-0.42	-1.16	-0.84	-1.00	1.24	0.95	1.20

TABLE 24(b)

SUMMARY STATISTICS

No. Type of of monthly Average Flow simulations	A	B	C
Best	41	44	14
Second Best	16	12	71
Worst	42	43	14

AVERAGING RECOMMENDATIONS BY PARAMETER

From the previously described studies and examination of the OPSET estimating programing by parameter, the following procedures are recommended for averaging parameter estimates obtained year by year from OPSET.

1. LZC: Take the arithmetic mean of the annual estimates.
2. BMIR: Take the arithmetic mean of the annual estimates.
3. SUZC: Take the arithmetic mean of the annual estimates.
4. ETLF: Take the arithmetic mean of the annual estimates.
5. BUZC: Take the arithmetic mean of the annual estimates.
6. SIAC: Take the geometric mean of the annual estimates.

In taking the mean, use a value of 0.02 for years where a smaller value was estimated. This rule prevents one zero estimate from causing a zero geometric mean and follows the rules used in estimating SIAC within the program (STFV0185).

7. BIVF: Hinge the estimate on the estimated value of IFRC. If the estimate of IFRC is less than 0.3, take BIVF as 0.0. This is the rule used by OPSET in making as estimate for an individual year. If the estimate exceeds 0.3, take the arithmetic mean of the annual estimates; however, use 0.40 as the annual estimate for years when the OPSET estimate is less than that value (p.116).

8. BFRC: Weight the mean of the annual estimates on the number of days OPSET used within the year to make an estimate. The number of days (ABFSL) is printed out by the program. The weighting formula

$$\overline{\mathrm{BFRC}} = \frac{\sum_{i=1}^{n} (\mathrm{BFRC}_i \cdot \mathrm{ABFSL}_i)}{\sum_{i=1}^{n} \mathrm{ABFSL}_i}. \qquad (47)$$

extends the type of weighting used within the year to weight estimates from the various recession sequences to a multiyear context.

9. IFRC: Take the mean of the annual estimates weighted by the same procedure used for BFRC with the difference that the weighting factor is AIFSL, also printed in the OPSET output. The two weighting factors vary because the program may not detect interflow in some recession sequences and uses a cutoff to exclude tails of very long sequences in the interflow weighting (pp. 68-69). The raw estimate of IFRC should be used for each year. This value is printed before noting a change to a value of 0.1 where the raw value was smaller than 0.3. If $\overline{\text{IFRC}}$ is less than 0.3, it should be taken as 0.1.

10. NCTRI: Take the mean of the annual estimates weighted on the number of read historical hydrograph peaks accepted by Subroutine SETHRP and round to the nearest integer. The number can be counted from the output data. This procedure is another extension of the method used by OPSET for averaging within the year. Once an estimate of NCTRI has been accepted, it is also necessary to fill the array of time-area increments with the specified number of values. The user has his initial array, and OPSET prints an array corresponding to the best estimate of NCTRI for each year. Usually, one of these arrays will have a correct number of elements. If none do, the user can return to his watershed map and form a new array.

11. CSRX: Take the mean of the annual estimates weighted on the number of read historical hydrograph peaks accepted by Subroutine SETHRP.

12. CHCAP: Take the <u>median</u> of the annual estimates. This prevents extreme estimates caused by timing discrepancies between recorded precipitation and recorded streamflow from causing problems.

13. FSRX: Take the mean of the annual estimates weighted on the number of read historical hydrograph peaks accepted by Subroutine SETHRP and whose simulated peak exceeds CHCAP as estimated above. This eliminates the impact of smaller events on a parameter which does not pertain to them.

A CLOSER LOOK AT MODELING BASE FLOW RECESSION

In the KWM as in the Stanford Watershed Model, base flow is modeled by two parameters, BFRC and BFNLR. In OPSET, only BFRC is used, and only BFRC is estimated. The second parameter, BFNLR, provides a recession rate which is more rapid at first and gradually becomes slower as flows diminish. The question to be considered here is the value of OPSET in estimating BFNLR.

One way to test whether a watershed has nonlinear baseflow recession is to plot the least squares estimate of sequence recession rate against the initial base flow in the sequence. These values are printed in the output from OPSET. Values for the Helton Branch watershed, for which the OPSET estimate of BFRC was 0.915, are plotted on Figure 9. If the points are randomly scattered around a horizontal line estimated by the method recommended above, BFRC should be taken as estimated and BFNLR should be taken as 1.00. If a distinct trend toward lower points is noted as one moves toward the right on the plot, BFRC should be increased and BFNLR should be reduced. While Figure 9 exhibits some downward trend, it is not strong enough to warrant this modification.

The same type plot for McDougal Creek follows on Figure 10. Here, the trend is distinctly downward to the right. A closer inspection showed the scatter to be reasonably homogeneous around the best estimate for flows less than about 10 cfs but for values of BFRC to be significantly smaller for recessions beginning with

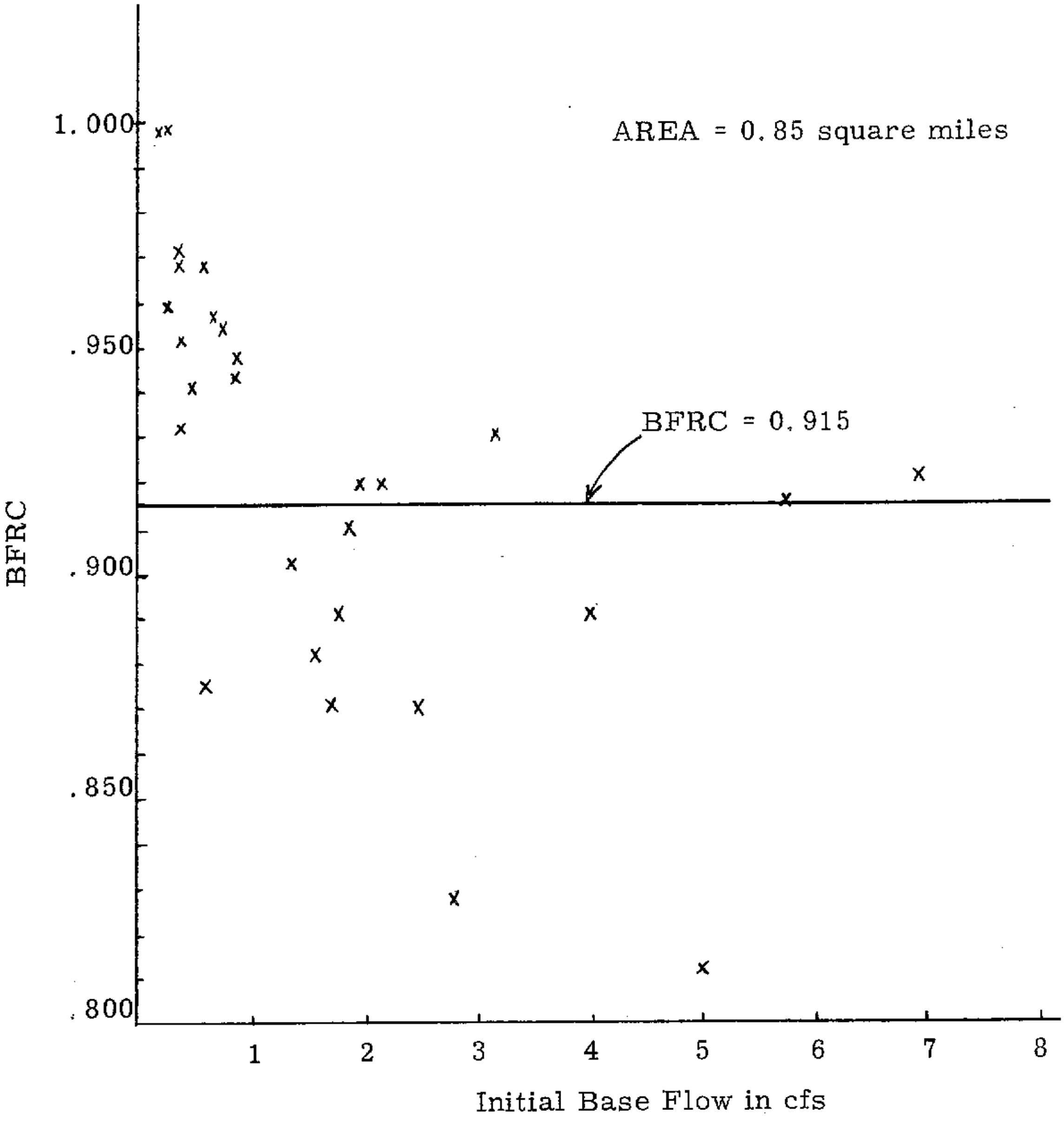

FIG. 9. Relationship Between BFRC and Initial Base Flow, Helton Branch Watershed.

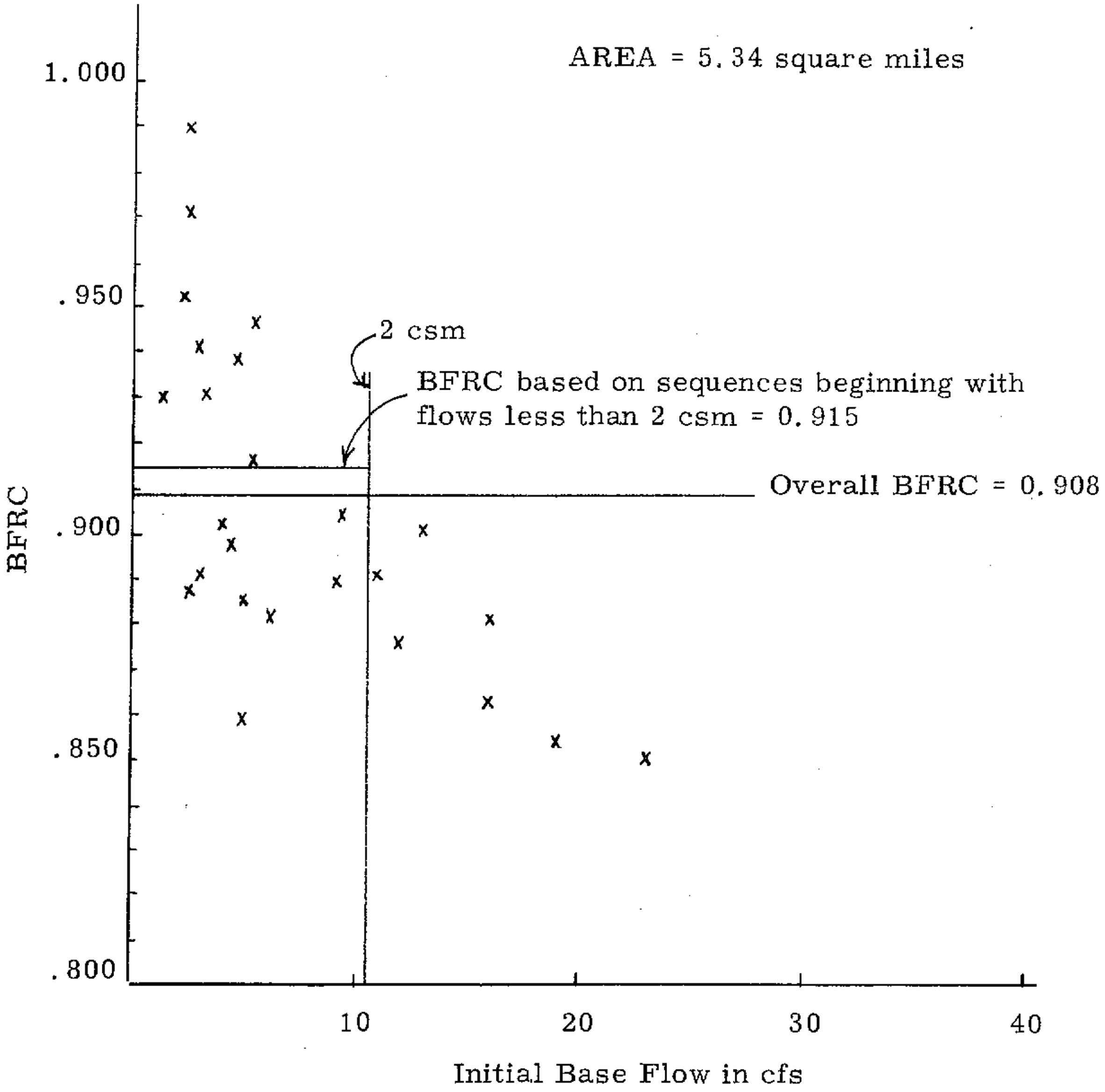

FIG. 10. Relationship Between BFRC and Initial Base Flow, McDougal Creek Watershed.

larger base flows. Using a division line at 10.68 cfs (2.0 csm), BFRC from points to the left is estimated as 0.915 by applying Equation 47 to all the relevant recession sequences. In cases like this, it is recommended that a dividing line be selected and BFRC be estimated in this manner. A good first estimate for BFNLR is 0.97. The value may be varied by trial-and-error as desired, but the modeling is not too sensitive.

NUMBER OF WATER YEARS TO USE IN AVERAGING

Intuitively, one would expect the estimates of parameter values to improve as more years are used. However, the computer cost is directly proportional to the number of years. The purpose of this section is to use the Cave Creek example as a case study for developing some feel for how much the results improve as more years are used.

First, nine water-year-based parameter values were estimated by running TRIP 1 for each of six water years. Then, the arithmetic mean for each parameter and LZS was calculated for three-year, four-year, five-year, and six-year periods. The calculated mean parameter values are shown in Table 25. The channel routing parameters were held at the three-year means since the other three years were run on TRIP 1 alone.

Using the 14 values shown on Table 25, the six water years were run on TRIP 3 of OPSET alone, and Table 26 shows the results. This table shows the degree to which the use of more water years yields better estimates of the annual volume as well as the seasonal distribution (SSQM was used as an index). On the other hand, the highest flood peak seemed to be getting worse. This is probably caused by using the M3 values of the four hydrograph routing parameters for M4, M5, and M6.

TABLE 25

PARAMETER VALUES WITH DIFFERENT NUMBERS OF YEARS AVERAGED: CAVE CREEK WATERSHED

	Water Year						Averaged Values			
	1955	1958	1965	1964	1967	1968	M3*	M4*	M5*	M6*
LZC	6.73	2.24	1.89	1.08	3.67	1.91	3.62	2.99	3.12	2.92
BMIR	5.87	13.88	20.86	7.70	18.05	10.71	13.54	12.08	13.27	12.85
SUZC	0.90	0.20	0.49	1.09	0.63	0.21	0.53	0.67	0.66	0.59
ETLF	0.23	0.21	0.14	0.05	0.14	0.15	0.19	0.16	0.15	0.15
BUZC	2.18	1.88	0.38	0.68	0.31	0.59	1.48	1.28	1.09	1.00
SIAC	0.54	0.08	0.77	0.62	2.30	0.09	0.32	0.38	0.54	0.40
BIVF	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00
BFRC	0.877	0.836	0.877	0.895	0.876	0.890	0.863	0.871	0.872	0.875
IFRC	0.100	0.100	0.100	0.100	0.100	0.413	0.100	0.100	0.100	0.100
NCTRI	2	4	5	--	--	--	4	4	4	4
CSRX	0.97	0.94	0.98	--	--	--	0.96	0.96	0.96	0.96
FSRX	0.98	0.99	0.98	--	--	--	0.98	0.98	0.98	0.98
CHCAP	50	16	50	--	--	--	39	39	39	39
LZS	4.64	1.46	0.27	0.25	3.12	0.96	2.12	1.66	1.95	1.78

*M3 = (1955 + 1958 + 1965)/3

M4 = (1955 + 1958 + 1965 + 1964)/4

M5 = (1955 + 1958 + 1965 + 1964 + 1967)/5

M6 = (1955 + 1958 + 1965 + 1964 + 1967 + 1968)/6

TABLE 26

SUMMARY OF RESULTS WITH DIFFERENT NUMBERS OF YEARS AVERAGED: CAVE CREEK WATERSHED

Water Year	Recorded Flows	Synthesized Flows				
		OPSET	M3	M4	M5	M6
1955 (F)						
Annual (sfd)	1051	1010	1204	1215	1229	1257
SSQM		0.192	0.940	0.803	0.951	1.221
Largest Peak (cfs)	117	164	182	182	180	183
1958 (W)						
Annual (sfd)	1442	1415	1195	1213	1225	1253
SSQM		1.008	1.804	1.950	1.906	1.673
Largest Peak (cfs)	87	82	133	137	135	136
1965 (D)						
Annual (sfd)	1032	960	802	847	849	862
SSQM		0.237	0.894	0.581	0.553	0.555
Largest Peak (cfs)	40	80	74	87	90	87
1964						
Annual (sfd)	788	863	684	719	725	739
SSQM		0.186	2.112	1.322	1.184	1.179
Largest Peak (cfs)	132	152	152	170	174	169
1967						
Annual (sfd)	1226	1173	1008	1027	1038	1060
SSQM		1.447	2.859	2.274	1.952	2.026
Largest Peak (cfs)	135	174	141	140	139	143
1968						
Annual (sfd)	1105	1156	927	946	957	978
SSQM		1.661	5.757	4.176	5.464	3.295
Largest Peak (cfs)	49	63	75	82	89	83
Summary						
Annual Σ (Rec.-Sim.)			824	677	621	495
Σ SSQM			14.106	11.106	12.010	9.949
Flood Peaks Σ (Rec.-Sim.)			-177	-238	-247	-251

More years give better estimates of parameter values, but economy should be taken into consideration. The cost of collecting additional years of data plus the computer time might not make it worthwhile to increase the number of water years. The study verified that the three years of record selected by Ross (25, p. 62) should give fair estimates, although the user might want to use more water years to obtain a closer estimate. Ross found this greater precision helped in studying the effects of urban change on parameter estimates.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Digital hydrologic simulation as exemplified by the Stanford Watershed Model has great potential. Its success at simulating historical stream flows from historical climatological records makes it possible for the planning and design of water resources systems to proceed from a much broader data base. The same ability can be applied to estimate flows for reservoir operation decisions during the time lag between rainfall and runoff. Model success at simulating stream flows with empirical equations representing hydrologic processes provides a challenge and a framework for new research to develop better equations. The ability to simulate changes in flow patterns from changes in parameter values is a powerful tool contributing to a better understanding of the interactions within the runoff process to the student and practitioner of hydrology alike.

Despite this great potential, a number of factors have deterred widespread use of the Stanford Watershed Model. Those most frequently mentioned include:

1. Programing in a little used computer language (6, p. 46).

2. Difficulty in obtaining access to a computer with enough core storage to make modeling feasible and to be able to handle the program without time-consuming adjustments.

3. Difficulty in understanding the program as complicated by its bulk and an unfamiliarity of many hydrologists with digital modeling processes.

4. Disagreements over the appropriateness of specific modeling equations.

5. The inability to directly relate key model parameter values with physical watershed characteristics (6, p. 46).

6. The time and acquired skill required to estimate values for these key parameters by trial and error, the lack of an explicit test for deciding on a best flow matching, and doubts about the Model as a whole caused by difficulties in matching certain flows.

This research has been directly addressed to these factors. A Fortran listing of the Model is provided. The subjective trial-and-error parameter estimating process is standardized. The ability to relate key model parameter values to physical watershed characteristics is improved. The gains are achieved at some sacrifice. The program is bigger and bulkier and hence more imposing to the uninitiated who try to follow its logic. The modeling equations are submerged more deeply into the inner workings of the program and are hence more difficult to change.

In applying OPSET to over 20 Kentucky watersheds which represent a wide range of topographic and soil conditions, it was found to do as good a job of simulating flows and a more consistent job of estimating parameter values than the past trial-and-error approach. Except for summer thunderstorm flood peaks, the simulation was even quite good for watersheds located at a distance from the nearest precipitation gage. The time spent calibrating watershed parameters is greatly reduced. The user does not have to spend so much time familiarizing himself with the program before he can properly use the Model. The program uses standardized criteria to test adequacy of matching and systematic optimization procedures which not only eliminate much of the subjectivity of choosing which parameters to adjust and determining how large an adjustment to make but also obtain consistent convergence on reasonable parameter values.

The adjustment rules have been thoroughly tested on small watersheds in the climatological setting of Kentucky. However, the extent of the testing done in this research should not be taken as an excuse not to apply OPSET to larger watersheds or locations in another climatological setting. On the contrary, OPSET should be tested in those areas in order to refine and modify it for a wider range of applicability. Likewise, the Model itself needs periodic updating in order to take advantage of better empirical relationships or moisture accounting procedures. Significant changes to the Model will require changes to OPSET to better estimate parameter values in the revised context. The rules used in OPSET to estimate parameter values are not to be taken as the last word and should be modified whenever it would be helpful.

Changes to which special attention is needed include:

1. Expansion of OPSET to estimate parameter values for watersheds where appreciable runoff comes from snowmelt.
2. Checking and adjustment of OPSET to better handle climatological patterns remote from Kentucky.
3. Consideration of alternate equations or combination of equations within the Model and derivation of an objective approach for selecting among these.
4. Refinement of procedures for estimating BFNLR, GWETF, OFSL, and several other parameters which are still not handled by OPSET.
5. Adjustments for simulating flows from climatological data estimated on a different time grid and with a different level of precision.

6. Expansion of the Kentucky Watershed Model to incorporate the power of the Stanford Watershed Model to simulate runoff from watersheds divided into parts and adjustment of OPSET to handle cases where orographic rainfall patterns require simulation by parts.

APPENDIX

APPENDIX A

LISTING OF KWM

```
C  KENTUCKY WATERSHED MODEL (VERSION OF JUNE 6, 1970)                   MAIN0001
C    BASED ON STANFORD WATERSHED MODELS III & IV                        MAIN0002
      DIMENSION BTRI(99), CONOPT(15), CRFMI(22), CTRI(99), DDIW(366),   MAIN0003
     1  DMNT(366), DMXT(366), DPSE(366), DRGPM(366), DRHP(366,24),      MAIN0004
     2  DRSGP(366), DPET(366), DRSF(366), DSSF(366), EDLZS(366),        MAIN0005
     3  EMBFNX(12), EMGWS(12), EMIFS(12), EMLZS(12), EMSIAM(12),        MAIN0006
     4  EMUZC(12), EMUZS(12), EPCM(12), FIRR(15), MEDCY(12), MEDWY(12), MAIN0007
     5  RICY(37), SATRI(99), SERA(22), SERR(22), SESF(22), SQER(22),    MAIN0008
     6  THSF(24), TITLE(20), TMBF(12), TMFSIL(12), TMIF(12), TMNET(12), MAIN0009
     7  TMOF(12), TMPET(12), TMPREC(12), TMRPM(12), TMRTF(12), TMSE(12),MAIN0010
     8  TMSNE(12), TMSTF(12), TMSTFI(12), T20OFH(21), T20PRH(21),       MAIN0011
     9  UHFA(99), YTITLE(20)                                            MAIN0012
      LOGICAL  LSHFT                                                    MAIN0013
      INTEGER  CDSDR,CN,CONOPT,DATE,DAY,DPY,EHSGD,HOUR,HRF,HRL,PDAY,    MAIN0014
     1  PRD,RHPD,RHPH,RSBD,SGMD,SGRT,SGRT2,YEAR,YR1,YR2                 MAIN0015
      REAL  IFPRC,IFRC,IFRL,IFS,LZC,LZRX,LZS,LZSR,MHSM,MNRD,MRNSM,NHPT  MAIN0016
      DATA  MEDCY/  0,        31,59,90,120,151,181,212,243,273,304,334/ MAIN0017
      DATA  MEDWY/304,334,365,31,59,90,120,151,181,212,243,273        / MAIN0018
  100 CONTINUE                                                          MAIN0019
      DO 101 KRD = 1,14                                                 MAIN0020
  101 CALL READ(CONOPT(KRD))                                            MAIN0021
      DO 102 KIA = 1,99                                                 MAIN0022
      SATRI(KIA) = 0.0                                                  MAIN0023
      CTRI(KIA) = 0.0                                                   MAIN0024
      BTRI(KIA) = 0.0                                                   MAIN0025
  102 UHFA(KIA) = 0.0                                                   MAIN0026
      CALL READ(NCTRI)                                                  MAIN0027
      DO 103 KRD = 1, NCTRI                                             MAIN0028
  103 CALL READ(CTRI(KRD))                                              MAIN0029
```

```
      IF(CONOPT(7) .NE. 1) GO TO 110                                    MAIN0030
      DO 104 KRD = 1,15                                                 MAIN0031
  104 CALL READ(FIRR(KRD))                                              MAIN0032
      DO 105 KRD = 1, 37                                                MAIN0033
  105 CALL READ(RICY(KRD))                                              MAIN0034
      DO 106 KRD = 274,360,10                                           MAIN0035
  106 CALL READ(DPSE(KRD))                                              MAIN0036
      DO 107 KRD = 1,273,10                                             MAIN0037
  107 CALL READ(DPSE(KRD))                                              MAIN0038
      DO 109 IDAY2 = 1, 9                                               MAIN0039
      DO 108 IDAY1 = 274,360,10                                         MAIN0040
      DAY = IDAY1 + IDAY2                                               MAIN0041
  108 DPSE(DAY) = DPSE(IDAY1)                                           MAIN0042
      DO 109 IDAY1 = 1,273,10                                           MAIN0043
      DAY = IDAY1 + IDAY2                                               MAIN0044
      IF(DAY .GT. 273) GO TO 109                                        MAIN0045
      DPSE(DAY) = DPSE(IDAY1)                                           MAIN0046
  109 CONTINUE                                                          MAIN0047
      DPSE(366) = DPSE(59)                                              MAIN0048
      DPSE(365) = DPSE(363)                                             MAIN0049
      DPSE(364) = DPSE(363)                                             MAIN0050
      CALL READ(BDDFSM,SPBFLW,SPTWCC,SPM,ELDIF,XONFS,FFOR,FFSI,MRNSM,   MAIN0051
     1  DSMGH,PXCSA)                                                    MAIN0052
  110 CALL READ(RMPF)                                                   MAIN0053
      CALL READ (RGPMB,AREA,FIMP,FWTR)                                  MAIN0054
      CALL READ (VINTMR,BUZC,SUZC,LZC,ETLF,SUBWF,GWETF,SIAC,BMIR,BIVF)  MAIN0055
      CALL READ (OFSS,OFSL,OFMN,OFMNIS,IFRC)                            MAIN0056
      CALL READ (CSRX,FSRX,CHCAP,EXQPV,BFNLR,BFRC)                      MAIN0057
      BFHRC = BFRC**(1.0/24.0)                                          MAIN0058
      BFRL = -ALOG(BFHRC)                                               MAIN0059
      BFNRL = 0.0                                                       MAIN0060
      IF(BFNLR .LT. 0.00001 .OR. BFNLR .GT. 0.9999) GO TO 111           MAIN0061
      BFNHR = BFNLR**(1.0/24.0)                                         MAIN0062
      BFNRL = -ALOG(BFNHR)                                              MAIN0063
  111 IFPRC = IFRC**(1.0/96.0)                                          MAIN0064
      IFRL = -ALOG(IFPRC)                                               MAIN0065
```

```
      CALL READ (GWS,UZS,LZS,BFNX,IFS)                                  MAIN0066
      LSHFT = .FALSE.                                                   MAIN0067
      IF(CONOPT(13) .NE. 1) GO TO 113                                   MAIN0068
      NBTRI = NCTRI                                                     MAIN0069
      FNTRI = NCTRI                                                     MAIN0070
      MXTRI = (10.0**EXQPV)*FNTRI + 0.5                                 MAIN0071
      IF(MXTRI .GE. 98) WRITE(6,1)                                      MAIN0072
    1 FORMAT(29HWARNING: EXQPV ARRAY OVER RUN)                          MAIN0073
      NCSTRI = 99                                                       MAIN0074
      DO 112 KIA = 1, NBTRI                                             MAIN0075
  112 BTRI(KIA) = CTRI(KIA)                                             MAIN0076
      TFCFS = 1.0                                                       MAIN0077
      CALL RTVARY (CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCSTRI,EXQPV,LSHFT,MAIN0078
     1 TFCFS)                                                           MAIN0079
  113 EPAET = 0.0                                                       MAIN0080
      FPER = 1.0 - FIMP - FWTR                                          MAIN0081
      IF(FPER .GT. 0.01) GO TO 114                                      MAIN0082
      TPLR = 100.0                                                      MAIN0083
      FPER = 0.01                                                       MAIN0084
      GO TO 115                                                         MAIN0085
  114 TPLR = (1.0 - FWTR)/FPER                                          MAIN0086
  115 VINTCR = 0.25*VINTMR                                              MAIN0087
      HSE = 0.0                                                         MAIN0088
      NRTRI = 0                                                         MAIN0089
      PEAI = 0.0                                                        MAIN0090
      SPIF = 0.0                                                        MAIN0091
      CBF = GWS*BFRL*(1.0 + BFNRL*BFNX)                                 MAIN0092
      SPDR = 0.0                                                        MAIN0093
      OFUS = 0.0                                                        MAIN0094
      OFUSIS = 0.0                                                      MAIN0095
      OFR = 0.0                                                         MAIN0096
      OFRIS = 0.0                                                       MAIN0097
      PEIS = 0.0                                                        MAIN0098
      RHFO = 0.0                                                        MAIN0099
      URHF = 0.0                                                        MAIN0100
      AMIF = 0.0                                                        MAIN0101
```

```
      AMNET = 0.0                                     MAIN0102
      AMPET = 0.0                                     MAIN0103
      AMSNE = 0.0                                     MAIN0104
      AMFSIL = 0.0                                    MAIN0105
      SASFX = 0.0                                     MAIN0106
      SARAX = 0.0                                     MAIN0107
      SRX = CSRX                                      MAIN0108
      VWIN = 26.8888*AREA                             MAIN0109
      WCFS = 24.0*VWIN                                MAIN0110
      RHFMC = 0.025/WCFS                              MAIN0111
      TFCFS = CBF*WCFS                                MAIN0112
      SSRT = SQRT(OFSS)                               MAIN0113
      OFRF = 1020.0*SSRT/(OFMN*OFSL)                  MAIN0114
      OFRFIS = 1020.0*SSRT/(OFMNIS*OFSL)              MAIN0115
      EQDF = 0.00982*((OFMN*OFSL/SSRT)**0.6)          MAIN0116
      EQDFIS = 0.00982*((OFMNIS*OFSL/SSRT)**0.6)      MAIN0117
      SOFRF = OFRF                                    MAIN0118
      SOFRFI = OFRFIS                                 MAIN0119
      SDEPTH = 0.0                                    MAIN0120
      ASM = 0.0                                       MAIN0121
      IF(CONOPT(7) .EQ. 0) GO TO 116                  MAIN0122
      WT4AM = 60.0                                    MAIN0123
      WT4PM = 60.0                                    MAIN0124
      SAX = 15.0                                      MAIN0125
      TANSM = 0.0                                     MAIN0126
      SPTW = 0.0                                      MAIN0127
      STMD = 0.7                                      MAIN0128
      SFMD = 0.7                                      MAIN0129
      ASMRG = 0.0                                     MAIN0130
  116 READ(5,2) TITLE                                 MAIN0131
    2 FORMAT(20A4)                                    MAIN0132
C  BEGIN NEW YEAR                                     MAIN0133
  117 BYLZS = LZS                                     MAIN0134
      BYUZS = UZS                                     MAIN0135
      BYGWS = GWS                                     MAIN0136
      BYIFS = IFS                                     MAIN0137
```

```
      DO 118 KIA = 1,22                                                 MAIN0138
      CRFMI(KIA) = 0.0                                                  MAIN0139
      SESF(KIA) = 0.0                                                   MAIN0140
      SERR(KIA) = 0.0                                                   MAIN0141
      SERA(KIA) = 0.0                                                   MAIN0142
  118 SQER(KIA) = 0.0                                                   MAIN0143
      RGPM = RGPMB                                                      MAIN0144
      DO 119 KIA = 1,21                                                 MAIN0145
      T20DFH(KIA) = 0.0                                                 MAIN0146
  119 T20PRH(KIA) = 0.0                                                 MAIN0147
      DO 120 KIA = 1,12                                                 MAIN0148
  120 EPCM(KIA) = 1.0                                                   MAIN0149
      RDPT = 0.0                                                        MAIN0150
      PDAY = 274                                                        MAIN0151
      CALL READ (YR1,YR2)                                               MAIN0152
      READ (5,2)YTITLE                                                  MAIN0153
      DPY = 365                                                         MAIN0154
      IF(MOD(YR2,4) .EQ. 0) DPY = 366                                   MAIN0155
      IF(CONOPT(1) .EQ. 1) CALL READ(CDSDR,NDSDR)                       MAIN0156
      NDSDP = 0                                                         MAIN0157
      MEDWY(5) = 59                                                     MAIN0158
      IF(DPY .EQ. 366) MEDWY(5) = 366                                   MAIN0159
C   READ EVAPORATION DATA                                               MAIN0160
      IF(CONOPT( 3) .NE. 1) GO TO 125                                   MAIN0161
      DO 121 KRD = 274,360,10                                           MAIN0162
  121 CALL READ(DPET(KRD))                                              MAIN0163
      DO 122 KRD = 1,273,10                                             MAIN0164
  122 CALL READ(DPET(KRD))                                              MAIN0165
      DO 124 IDAY2 = 1,9                                                MAIN0166
      DO 123 IDAY1 = 274,360,10                                         MAIN0167
      DAY = IDAY1 + IDAY2                                               MAIN0168
  123 DPET(DAY) = DPET(IDAY1)                                           MAIN0169
      DO 124 IDAY1 = 1,273,10                                           MAIN0170
      DAY = IDAY1 + IDAY2                                               MAIN0171
      IF(DAY .GT. 273) GO TO 124                                        MAIN0172
      DPET(DAY) = DPET(IDAY1)                                           MAIN0173
```

```
  124 CONTINUE                                                          MAIN0174
      DPET(366) = DPET(59)                                              MAIN0175
      DPET(365) = DPET(363)                                             MAIN0176
      DPET(364) = DPET(363)                                             MAIN0177
      GO TO 127                                                         MAIN0178
  125 IF(CONOPT( 3) .EQ. 2) GO TO 130                                   MAIN0179
      DAY = 274                                                         MAIN0180
  126 CALL READ (DPET(DAY))                                             MAIN0181
      IF(DAY .EQ. 273) GO TO 127                                        MAIN0182
      CALL DAYNXT(DAY, DPY)                                             MAIN0183
      GO TO 126                                                         MAIN0184
  127 DO 128 MONTH = 1,12                                               MAIN0185
  128 CALL READ(EPCM(MONTH))                                            MAIN0186
      IF(EPAET .NE. 0.0) GO TO 133                                      MAIN0187
      DO 129 DAY = 1,DPY                                                MAIN0188
  129 EPAET = EPAET + DPET(DAY)                                         MAIN0189
      IF(EPCM(6) .NE. 1.0) EPAET = 0.7*EPAET                            MAIN0190
      GO TO 131                                                         MAIN0191
  130 CALL READ(EPAET,MNRD)                                             MAIN0192
      EMAET = EPAET*(365.0 + MNRD)/404.0                                MAIN0193
      CALL EVPDAY(DPET,EMAET)                                           MAIN0194
  131 AETX = 24.0*EPAET/365.0                                           MAIN0195
      AEX96 = 1.2*AETX                                                  MAIN0196
      AEX90 = 0.3*AETX                                                  MAIN0197
      SIAM = 1.2**SIAC                                                  MAIN0198
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)                         MAIN0199
      IF(UZC .LT. 0.25) UZC = 0.25                                      MAIN0200
      SGRT = 0                                                          MAIN0201
      DO 132 DAY = 1,366                                                MAIN0202
      DDIW(DAY) = 0.0                                                   MAIN0203
      DRSF(DAY) = 0.0                                                   MAIN0204
      DRGPM(DAY) = RGPMB                                                MAIN0205
      DRSGP(DAY) = 0.0                                                  MAIN0206
      DO 132 HOUR = 1,24                                                MAIN0207
  132 DRHP(DAY,HOUR) = 0.0                                              MAIN0208
  133 IF(CONOPT(9) .NE. 1) GO TO 135                                    MAIN0209
```

```
      DAY = 274                                                         MAIN0210
      DRSF(366) = 0.0                                                   MAIN0211
  134 CALL READ(DRSF(DAY))                                              MAIN0212
      CALL DAYNXT(DAY, DPY)                                             MAIN0213
      IF(DAY .NE. 274) GO TO 134                                        MAIN0214
  135 IF(CONOPT(11) .NE. 1) GO TO 137                                   MAIN0215
      DAY = 274                                                         MAIN0216
      DDIW(366) = 0.0                                                   MAIN0217
  136 CALL READ(DDIW(DAY))                                              MAIN0218
      CALL DAYNXT(DAY, DPY)                                             MAIN0219
      IF(DAY .NE. 274) GO TO 136                                        MAIN0220
  137 IF(CONOPT(7) .EQ. 0) GO TO 139                                    MAIN0221
      DAY = 274                                                         MAIN0222
  138 CALL READ(DMXT(DAY), DMNT(DAY))                                   MAIN0223
      CALL DAYNXT(DAY, DPY)                                             MAIN0224
      IF(DAY .NE. 274) GO TO 138                                        MAIN0225
  139 CALL READ(NSGRD)                                                  MAIN0226
      IF(NSGRD .EQ. 0) GO TO 141                                        MAIN0227
      CALL READ(WSG,SGRT)                                               MAIN0228
      IF(CONOPT( 8) .EQ. 1) CALL READ(WSG2,SGRT2,SGMD)                  MAIN0229
      DO 140 KRD = 1,NSGRD                                              MAIN0230
      CALL READ(ISGRD)                                                  MAIN0231
  140 CALL READ(DRSGP(ISGRD))                                           MAIN0232
C  READ RECORDING RAIN GAGE HOURLY TOTALS                               MAIN0233
  141 CALL READ(IWBG,YEAR,MONTH,DATE,CN)                                MAIN0234
C  PUNCH NO NUMBER AFTER CN ON YEAR .EQ. 98 CARD                        MAIN0235
      IF(YEAR .GE. 98) GO TO 144                                        MAIN0236
      HRF = 12*(CN - 1) + 1                                             MAIN0237
      HRL = 12*(CN - 1) + 12                                            MAIN0238
      DAY = MEDCY(MONTH) + DATE                                         MAIN0239
      DO 142 HOUR = HRF, HRL                                            MAIN0240
  142 CALL READ(DRHP(DAY,HOUR))                                         MAIN0241
      IF(DPY .NE. 366 .OR. MONTH .NE. 2 .OR. DATE .NE. 29) GO TO 141    MAIN0242
      DO 143 HOUR = HRF, HRL                                            MAIN0243
      DRHP(366,HOUR) = DRHP(60,HOUR)                                    MAIN0244
  143 DRHP(60,HOUR) = 0.0                                               MAIN0245
```

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      GO TO 141
C  CALCULATE PRECIPITATION WEIGHTING FACTORS
  144 DAY = 274
      IF(NSGRD .EQ. 0) GO TO 151
      PDAY = 274
      RDPT = 0.0
  145 EHSGD = SGRT
      IF(SGRT .EQ. 0) EHSGD = 24
      EHSGDF = EHSGD
  146 CONTINUE
      DO 150 HOUR = 1,24
      RDPT = RDPT + DRHP(DAY,HOUR)
      IF(HOUR .NE. EHSGD) GO TO 150
      IF(RDPT .LE. 0.0) GO TO 147
      IF(SGRT .EQ. 0) PDAY = DAY
      DRGPM (PDAY) = (DRSGP(DAY)*WSG + RDPT*(1.0 - WSG))/RDPT
      IF(CONOPT(3) .NE. 0) DPET(PDAY) = 0.5*DPET(PDAY)
      IF(SGRT .NE. 0) PDAY = DAY
      RDPT = 0.0
      GO TO 150
  147 IF(DRSGP(DAY) .LE. 0.0) GO TO 149
      DO 148 KHOUR = 1,EHSGD
  148 DRHP(DAY,KHOUR) = (WSG*DRSGP(DAY))/EHSGDF
  149 IF(SGRT .NE. 0) PDAY = DAY
  150 CONTINUE
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 151
      IF(CONOPT(8) .EQ. 0) GO TO 146
      IF(DAY .NE. SGMD) GO TO 146
      WSG = WSG2
      SGRT = SGRT2
      GO TO 145
  151 MONTH = 1
      MDAY = 273
      AMRPM = 0.0
      AMPREC = 0.0
```

```
      AMBF = 0.0                                                        MAIN0282
      AMSE = 0.0                                                        MAIN0283
      AMSTF = 0.0                                                       MAIN0284
      AMRTF = 0.0                                                       MAIN0285
      WRITE(6,3) (TITLE(KTA), KTA = 1,20)                               MAIN0286
    3 FORMAT(1H1,10X,20A4)                                              MAIN0287
      WRITE(6,4) (YTITLE(KTA), KTA = 1,20),YR1,YR2                      MAIN0288
    4 FORMAT(1H0,20A4,2X,13HWATER YEAR 19,I2,1H-,I2)                    MAIN0289
      WRITE(6,5)                                                        MAIN0290
    5 FORMAT(8H OCTOBER)                                                MAIN0291
C   BEGIN DAY LOOP                                                      MAIN0292
  152 TDSF = 0.0                                                        MAIN0293
      PET = EPCM(MONTH)*DPET(DAY)                                       MAIN0294
      PETU = PET                                                        MAIN0295
      TFMAX = 0.0                                                       MAIN0296
C   EVAPOTRANSPIRATION ADJUSTMENTS                                      MAIN0297
      IF(CONOPT(7) .NE. 1) GO TO 153                                    MAIN0298
      IF(DMXT(DAY) - 4.0*ELDIF .LT. 40.0) PET = 0.0                     MAIN0299
      IF(SPTW .GT. SPTWCC) PET = FFOR*PET                               MAIN0300
C   CALCULATION OF SNOW EVAPORATION                                     MAIN0301
      IF(DMNT(DAY) .GT. 32.0 .OR. SPTW .LE. DPSE(DAY)) GO TO 153        MAIN0302
      SE = DPSE(DAY)                                                    MAIN0303
      AMSNE = AMSNE + SE                                                MAIN0304
      SPTW = SPTW - SE                                                  MAIN0305
      IF(SFMD .GT. 0.0) SDEPTH = SDEPTH - SE/SFMD                       MAIN0306
  153 DO 202 HOUR = 1,24                                                MAIN0307
      IF((NSGRD .EQ. 0) .AND. (DRHP(DAY,HOUR) .NE. 0.0)  .AND. (PET .EQ.MAIN0308
     1 PETU) .AND. (CONOPT(3) .EQ. 1)) PET = 0.5*PET                    MAIN0309
  154 IF(HOUR .EQ. SGRT + 1) RGPM = DRGPM(DAY)                          MAIN0310
      IF(HOUR .EQ. 9) HSE = (FWTR*PET)/12.0                             MAIN0311
      IF(HOUR .EQ.21) HSE = 0.0                                         MAIN0312
      PRH = RGPM*DRHP(DAY,HOUR)                                         MAIN0313
      AMPREC = AMPREC  + PRH                                            MAIN0314
C   ENTER SNOWMELT SUBROUTINE                                           MAIN0315
      IF(CONOPT(7) .EQ. 1) CALL SNOMEL(BDDFSM,SPTWCC,SPM,ELDIF,DAY,     MAIN0316
     1  SPBFLW, XDNFS,FFOR,FFSI,MRNSM,DSMGH,SDEPTH,STMD, PXCSA,HOUR,    MAIN0317
```

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     2 SAX,SOFRF,OFRFIS,SOFRFI,AMFSIL,PRH,SPTW,TANSM,SPLW,SFMD,OFRF,
     3 WT4AM,WT4PM,ASM,ASMRG,SASFX,SARAX,DMXT,DMNT,RICY,FIRR)
  155 AMRPM = AMRPM + PRH
  156 TOFR = 0.0
      ARHF = 0.0
C  15 MINUTE ACCOUNTING AND ROUTING LOOP
      DO 187 PRD = 1,4
      PEBI = 0.0
      PPI = 0.0
      OFR = 0.0
      OFRIS = 0.0
      WI = 0.0
      WEIFS = 0.0
      PMEUZS = 0.0
      PMELZS = 0.0
      PMEIFS = 0.0
      PMEOFS = 0.0
      PEP = 0.25*PRH
      IF(CONOPT(2) .EQ. 1) CALL PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,
     1  PRH)
      IF(PEP .GT. 0.0) GO TO 157
      IF(OFUS .GT. 0.0) GO TO 159
      IF(IFS .GT. 0.0) GO TO 170
      IF(NRTRI .GT. 0) GO TO 172
      TRHF = 0.0
      IF(RHFO .GT. 0.0) GO TO 181
      GO TO 184
C  RAINFALL UPPER ZONE INTERACTION
  157 IF(PEP .GE. VINTCR) GO TO 158
      UZS = UZS + PEP*TPLR
      VINTCR = VINTCR - PEP
      PPI = 0.0
      PEBI = 0.0
      PMEUZS = PEP
      IF(OFUS .GT. 0.0) GO TO 159
      GO TO 170
```

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  158 PPI = PEP - VINTCR                                                MAIN0354
      UZS = UZS + VINTCR*TPLR                                           MAIN0355
      VINTCR = 0.0                                                      MAIN0356
      LZSR = LZS/LZC                                                    MAIN0357
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZSR)                            MAIN0358
      IF(UZC .LT. 0.25) UZC = 0.25                                      MAIN0359
      UZRX = 2.0*ABS(UZS/UZC - 1.0) + 1.0                               MAIN0360
      FMR = (1.0/(1.0 + UZRX))**UZRX                                    MAIN0361
      IF(UZS .GT. UZC) FMR = 1.0 - FMR                                  MAIN0362
      PEBI = PPI*FMR                                                    MAIN0363
      PMEUZS = PEP - PEBI                                               MAIN0364
      UZS = UZS + PPI - PEBI                                            MAIN0365
C  LOWER ZONE AND GROUNDWATER INFILTRATION                              MAIN0366
  159 LZSR = LZS/LZC                                                    MAIN0367
      EID = 4.0*LZSR                                                    MAIN0368
      IF(LZSR .LE. 1.0) GO TO 160                                       MAIN0369
      EID = 4.0 + 2.0*(LZSR - 1.0)                                      MAIN0370
      IF(LZSR .LE. 2.0) GO TO 160                                       MAIN0371
      EID = 6.0                                                         MAIN0372
  160 PEBI = PEBI + OFUS                                                MAIN0373
      CMIR = 0.25*SIAM*BMIR/(2.0**EID)                                  MAIN0374
      CIVM = BIVF*2.0**LZSR                                             MAIN0375
      IF(CIVM .LT. 1.0) CIVM = 1.0                                      MAIN0376
      PEAI = PEBI*PEBI/(2.0*CMIR*CIVM)                                  MAIN0377
      WI = PEBI*PEBI/(2.0*CMIR)                                         MAIN0378
      IF(PEBI .GE. CMIR) WI = PEBI - 0.5*CMIR                           MAIN0379
      IF(PEBI .GE. CMIR*CIVM) PEAI = PEBI - 0.5*CMIR*CIVM               MAIN0380
      WEIFS = WI - PEAI                                                 MAIN0381
      IF(PEBI .LE. OFUS) GO TO 161                                      MAIN0382
      PMELZS = (PEBI - WI)*((PEBI - OFUS)/PEBI)                         MAIN0383
      PMEIFS = WEIFS*((PEBI - OFUS)/PEBI)                               MAIN0384
      PMEOFS = PEAI*((PEBI - OFUS)/PEBI)                                MAIN0385
  161 CONTINUE                                                          MAIN0386
      IF((PEAI - OFUS) .GT. 0.0) GO TO 162                              MAIN0387
      EQD = (OFUS + PEAI)/2.0                                           MAIN0388
      GO TO 163                                                         MAIN0389
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  162 EQD = EQDF*((PEAI - OFUS)**0.6)
  163 IF((OFUS + PEAI) .GT. (2.0*EQD)) EQD = 0.5*(OFUS + PEAI)
      IF((OFUS + PEAI) .LE. 0.001) GO TO 164
      OFR = 0.25*OFRF*(((OFUS + PEAI)*0.5)**1.67)*((1.0 + 0.6*((OFUS +
     1 PEAI)/(2.0*EQD))**3.0)**1.67)
      IF(OFR .GT. (0.75*PEAI)) OFR = 0.75*PEAI
  164 IF(FIMP .EQ. 0.0) GO TO 168
  165 PEIS = PPI + OFUSIS
      IF((PEIS - OFUSIS) .GT. 0.0) GO TO 166
      EQDIS = (OFUSIS + PEIS)/2.0
      GO TO 167
  166 EQDIS = EQDFIS*((PEIS - OFUSIS)**0.6)
  167 IF((OFUSIS + PEIS) .GT. (2.0*EQDIS)) EQDIS = 0.5*(OFUSIS + PEIS)
      IF((OFUSIS + PEIS) .LE. 0.01) GO TO 168
      OFRIS = 0.25*OFRFIS*(((OFUSIS + PEIS)*0.5)**1.67)*((1.0 + 0.6*((
     1 OFUSIS + PEIS)/(2.0*EQDFIS))**3.0)**1.67)
      IF(OFRIS .GT. PEIS) OFRIS = PEIS
  168 TOFR = TOFR + FPER*OFR + FIMP*OFRIS + PPI*FWTR
      OFUSIS = PEIS - OFRIS
      OFUS = PEAI - OFR
      IF(OFUS .GE. 0.001) GO TO 169
      LZS = LZS + OFUS
      OFUS = 0.0
      OFRIS = OFRIS + OFUSIS
      OFUSIS = 0.0
  169 LZRX = 1.5*ABS(LZS/LZC - 1.0) + 1.0
      FMR = (1.0/(1.0 + LZRX))**LZRX
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*(LZS/LZC)
      PLZS = FMR*(PEBI - WI)
      PGW = (1.0 -FMR)*(PEBI - WI)*(1.0 - SUBWF)*FPER
      GWS = GWS + PGW
      BFNX = BFNX + PGW
      LZS = LZS + PLZS
      IFS = IFS + WEIFS*FPER
  170 SPIF = IFRL*IFS
      AMIF = AMIF + SPIF
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      IFS = IFS - SPIF                                                  MAIN0426
      IF(IFS .GE. 0.0001) GO TO 171                                     MAIN0427
      LZS = LZS + IFS                                                   MAIN0428
      IFS = 0.0                                                         MAIN0429
  171 UHFA(1) = FPER*OFR + PPI*FWTR + FIMP*OFRIS + SPIF                 MAIN0430
      SPDR = UHFA(1)                                                    MAIN0431
C  ROUTING                                                              MAIN0432
  172 IF(CONOPT(12) .NE. 1) GO TO 173                                   MAIN0433
      URHF = URHF + 0.25*UHFA(1)                                        MAIN0434
      IF(PRD .NE. 4) GO TO 181                                          MAIN0435
      UHFA(1) = URHF                                                    MAIN0436
  173 TRHF = 0.0                                                        MAIN0437
      KTRI = NCTRI                                                      MAIN0438
      IF(CONOPT(13) .EQ. 1) KTRI = NCSTRI                               MAIN0439
  174 URHF = UHFA(KTRI)                                                 MAIN0440
      IF(URHF .LE. 0.0) GO TO 176                                       MAIN0441
  175 TRHF = TRHF + URHF*CTRI(KTRI)                                     MAIN0442
      IF(CONOPT(13) .EQ. 1 .AND. LSHFT .AND. KTRI .GE. 2) TRHF = TRHF + MAIN0443
     1  URHF*SATRI(KTRI - 1)                                            MAIN0444
      UHFA(KTRI + 1) = URHF                                             MAIN0445
      GO TO 177                                                         MAIN0446
  176 UHFA(KTRI+ 1) = 0.0                                               MAIN0447
  177 KTRI = KTRI - 1                                                   MAIN0448
      IF(KTRI .GE. 1) GO TO 174                                         MAIN0449
  178 IF(URHF .LE. 0.0) GO TO 179                                       MAIN0450
      NRTRI = NCTRI                                                     MAIN0451
      IF(CONOPT(13) .EQ. 1) NRTRI = MXTRI                               MAIN0452
  179 NRTRI = NRTRI - 1                                                 MAIN0453
      UHFA(1) = 0.0                                                     MAIN0454
      IF(CONOPT(13) .NE. 1) GO TO 180                                   MAIN0455
      NNSTRI = NCSTRI + 1                                               MAIN0456
      UHFA(NNSTRI) = 0.0                                                MAIN0457
  180 URHF = 0.0                                                        MAIN0458
  181 IF(SRX .LE. CSRX) SRX = CSRX                                      MAIN0459
      RHF1 = TRHF - SRX*(TRHF - RHFO)                                   MAIN0460
      RHFO = RHF1                                                       MAIN0461
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      IF(RHFO .LT. RHFMC) RHFO = 0.0                                    MAIN0462
      TFCFS = (4.0*RHF1 + CBF - HSE)*WCFS                               MAIN0463
      IF(CONOPT(13) .NE. 1) GO TO 182                                   MAIN0464
      IF(CONOPT(12) .EQ. 1 .AND. PRD .NE. 4) GO TO 182                  MAIN0465
      CALL RTVARY (CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCSTRI,EXQPV,LSHFT,MAIN0466
     1 TFCFS)                                                           MAIN0467
      DATE = MOD(DAY,MDAY)                                              MAIN0468
      IF(LSHFT) WRITE(6,6) DATE,HOUR,PRD,NCSTRI                         MAIN0469
    6 FORMAT(2X,I2,2X,I2,2X,I2,2X,20HHISTOGRAM CHANGES TO,1X,I2,1X,     MAIN0470
     1 8HELEMENTS)                                                      MAIN0471
  182 CONTINUE                                                          MAIN0472
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX                               MAIN0473
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX = CSRXMAIN0474
     1  +(FSRX - CSRX)*(((TFCFS - 0.5*CHCAP)/(1.5*CHCAP))**3            MAIN0475
      IF(TFCFS .GT. 2.0*CHCAP) SRX = FSRX                               MAIN0476
      IF(TFCFS .LE. TFMAX) GO TO 183                                    MAIN0477
      PRDF = PRD                                                        MAIN0478
      TDFP24 = HOUR                                                     MAIN0479
      IF(PRD .LE. 3) TDFP24 = (TDFP24 - 1.0) + 0.15*PRDF                MAIN0480
      TFMAX = TFCFS                                                     MAIN0481
  183 ARHF = ARHF + RHF1                                                MAIN0482
C  STORM OUTPUT REQUESTED BY CONOPT(1)                                  MAIN0483
  184 IF(CONOPT(1) .NE. 1) GO TO 186                                    MAIN0484
      IF(DAY .NE. CDSDR) GO TO 186                                      MAIN0485
      IF(HOUR .EQ. 1 .AND. PRD .EQ. 1) WRITE(6,7)                       MAIN0486
    7 FORMAT(1H//,21X,19HRAINFALL DEPOSITION,12X,16HMOISTURE STORAGE,   MAIN0487
     1 14X,17HSTREAMFLOW ORIGIN,6X,14HSTREAM OUTFLOW/2X,116HDY HR PD RAMAIN0488
     2IN   EUZS   ELZS   EIFS   EOFS      UZS    LZS    IFS    OFS     SMAIN0489
     3POF   SPIF   SPBF   SPTF  INCHES    CFS)                          MAIN0490
      DATE = MOD(DAY,MDAY)                                              MAIN0491
      OFS = OFUS*FPER + OFUSIS*FIMP                                     MAIN0492
      SPOF = OFR*FPER + OFRIS*FIMP + PPI*FWTR                           MAIN0493
      SPBF = 0.25*(CBF-HSE)                                             MAIN0494
      SPTF = SPDR + SPBF                                                MAIN0495
      SPDR = 0.0                                                        MAIN0496
      IF(RHFO .LE. 0.0) TFCFS = (CBF - HSE)*WCFS                        MAIN0497
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      RSPTF = 0.25*TFCFS/WCFS                                           MAIN0498
      WRITE(6,8) DATE,HOUR,PRD,PEP,PMEUZS,PMELZS,PMEIFS,PMEOFS,UZS,LZS  MAIN0499
     1,IFS,OFS,SPOF,SPIF,SPBF,SPTF,RSPTF,TFCFS                          MAIN0500
    8 FORMAT(2X,I2,1X,I2,1X,I1,5(1X,F6.4),2X,4(F7.4),2X,5(1X,F6.4),1X,  MAIN0501
     1  F7.1)                                                           MAIN0502
      IF(HOUR .EQ. 24 .AND. PRD .EQ. 4) GO TO 185                       MAIN0503
      GO TO 186                                                         MAIN0504
  185 NDSDP = NDSDP + 1                                                 MAIN0505
      IF(NDSDR .EQ. NDSDP) GO TO 186                                    MAIN0506
      CALL DAYNXT(CDSDR,DPY)                                            MAIN0507
  186 CONTINUE                                                          MAIN0508
      IF(VINTCR .LT. 0.25*VINTMR) VINTCR = VINTCR + DPET(DAY)/96.0      MAIN0509
  187 CONTINUE                                                          MAIN0510
C  END OF 15 MINUTE LOOP                                                MAIN0511
      IF(CONOPT(5) .NE. 1) GO TO 197                                    MAIN0512
C  HOURLY OVERLAND FLOW AND RAINFALL SORTING                            MAIN0513
      IF(TOFR .LE. 0.0) GO TO 193                                       MAIN0514
      KT20 = 20                                                         MAIN0515
  188 IF(KT20 .LT. 1) GO TO 192                                         MAIN0516
      IF(TOFR .GT. T20OFH(KT20)) GO TO 189                              MAIN0517
      GO TO 190                                                         MAIN0518
  189 T20OFH(KT20+1) = T20OFH(KT20)                                     MAIN0519
      GO TO 191                                                         MAIN0520
  190 T20OFH(KT20+1) = TOFR                                             MAIN0521
      GO TO 193                                                         MAIN0522
  191 KT20 = KT20 - 1                                                   MAIN0523
      GO TO 188                                                         MAIN0524
  192 T20OFH(1) = TOFR                                                  MAIN0525
  193 IF(PRH .LE. 0.0) GO TO 197                                        MAIN0526
      KT20 = 20                                                         MAIN0527
  194 IF(KT20 .LT. 1) GO TO 196                                         MAIN0528
      IF(PRH .GT. T20PRH(KT20)) GO TO 195                               MAIN0529
      T20PRH(KT20 + 1) = PRH                                            MAIN0530
      GO TO 197                                                         MAIN0531
  195 T20PRH(KT20+1) = T20PRH(KT20)                                     MAIN0532
      KT20 = KT20 - 1                                                   MAIN0533
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      GO TO 194                                                         MAIN0534
  196 T20PRH(1) = PRH                                                   MAIN0535
C  ADDING GROUNDWATER FLOW                                              MAIN0536
  197 CBF = GWS*BFRL*(1.0 + BFNRL*BFNX)                                 MAIN0537
      GWS = GWS - CBF                                                   MAIN0538
      AMBF = AMBF + CBF                                                 MAIN0539
      THGR = ARHF + CBF                                                 MAIN0540
      IF(HSE .GT. THGR) HSE = THGR                                      MAIN0541
      AMSE = AMSE + HSE                                                 MAIN0542
      THSF(HOUR) = (THGR - HSE)*WCFS                                    MAIN0543
      TDSF = TDSF + THSF(HOUR)                                          MAIN0544
C  DRAINING OF UPPER ZONE STORAGE                                       MAIN0545
      UZINFX = (UZS/UZC) - (LZS/LZC)                                    MAIN0546
      IF(UZINFX .LE. 0.0) GO TO 198                                     MAIN0547
      LZSR = LZS/LZC                                                    MAIN0548
      UZINLZ = 0.003*BMIR*UZC*UZINFX**3.0                               MAIN0549
      IF(UZINLZ .GT. UZS) UZINLZ = UZS                                  MAIN0550
      UZS = UZS - UZINLZ                                                MAIN0551
      LZRX = 1.5*ABS(LZSR - 1.0) + 1.0                                  MAIN0552
      FMR = (1.0/(1.0 + LZRX))**LZRX                                    MAIN0553
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*LZSR                             MAIN0554
      PGW = (1.0-FMR)*UZINLZ*(1.0 - SUBWF)*FPER                         MAIN0555
      PLZS = FMR*UZINLZ                                                 MAIN0556
      LZS = LZS + PLZS                                                  MAIN0557
      GWS = GWS + PGW                                                   MAIN0558
      BFNX = BFNX + PGW                                                 MAIN0559
C  4 PM ADJUSTMENTS OF VARIOUS VALUES                                   MAIN0560
  198 IF(HOUR .NE. 16) GO TO 202                                        MAIN0561
      AEX90 = 0.9*(AEX90 + PET)                                         MAIN0562
      AEX96 = 0.96*(AEX96 + PET)                                        MAIN0563
C  INFILTRATION CORRECTION                                              MAIN0564
      SIAM = (AEX96/AETX)**SIAC                                         MAIN0565
      IF(SIAM .LT. 0.33) SIAM = 0.33                                    MAIN0566
      BFNX = 0.97*BFNX                                                  MAIN0567
      IF(PET .EQ. 0.0) GO TO 202                                        MAIN0568
C  EVAP-TRANS LOSS FROM GROUNDWATER                                     MAIN0569
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      GWET = GWS*GWETF*PET*FPER                                         MAIN0570
      GWS = GWS - GWET                                                  MAIN0571
      BFNX = BFNX - GWET                                                MAIN0572
      IF(BFNX .LT. 0.0) BFNX = 0.0                                      MAIN0573
      AMPET = AMPET + PET                                               MAIN0574
      IF(PET .GE. UZS) GO TO 199                                        MAIN0575
      UZS = UZS - PET                                                   MAIN0576
      AMNET = AMNET + PET                                               MAIN0577
      GO TO 202                                                         MAIN0578
  199 PET = PET - UZS                                                   MAIN0579
      AMNET = AMNET + UZS                                               MAIN0580
      UZS = 0.0                                                         MAIN0581
      LZSR = LZS/LZC                                                    MAIN0582
      IF(PET .GE. ETLF*LZSR) GO TO 200                                  MAIN0583
      SET = PET*(1.0 - PET/(2.0*ETLF*LZSR))                             MAIN0584
      GO TO 201                                                         MAIN0585
  200 SET = 0.5*ETLF*LZSR                                               MAIN0586
  201 LZS = LZS - SET                                                   MAIN0587
      AMNET = AMNET + SET                                               MAIN0588
  202 CONTINUE                                                          MAIN0589
C  END OF HOUR LOOP                                                     MAIN0590
      DSSF(DAY) = TDSF/24.0                                             MAIN0591
      IF(CONOPT(11) .EQ. 1) DSSF(DAY) = DSSF(DAY) + DDIW(DAY)           MAIN0592
  203 AMRTF = AMRTF + DRSF(DAY)                                         MAIN0593
      AMSTF = AMSTF + DSSF(DAY)                                         MAIN0594
      IF(CONOPT(6) .EQ. 1) EDLZS(DAY) = LZS                             MAIN0595
C  STORE ERRORS AND FLOW DURATION                                       MAIN0596
      IF(CONOPT(4) .NE. 1) GO TO 204                                    MAIN0597
      ERR = DSSF(DAY) - DRSF(DAY)                                       MAIN0598
      IF(DRSF(DAY) .LT. 1.0) KRFMI = 1.0                                MAIN0599
      IF(DRSF(DAY) .GT. 1.0) KRFMI= 2.0*ALOG(DRSF(DAY)) + 2.0           MAIN0600
      CRFMI(KRFMI) = CRFMI(KRFMI) + 1.0                                 MAIN0601
      SERR(KRFMI) = SERR(KRFMI) + ERR                                   MAIN0602
      SERA(KRFMI) = SERA(KRFMI) + ABS(ERR)                              MAIN0603
      SQER(KRFMI) = SQER(KRFMI) + ERR*ERR                               MAIN0604
      SESF(KRFMI) = 0.0                                                 MAIN0605
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```
      IF(CRFMI(KRFMI) .GT. 1.0) SESF(KRFMI) = SQRT(ABS((SQER(KRFMI) -   MAIN0606
     1 SERR(KRFMI)**2/CRFMI(KRFMI))/(CRFMI(KRFMI) - 1.0)))              MAIN0607
  204 IF(DAY .EQ. 366) MDAY = 337                                       MAIN0608
      DATE = MOD(DAY,MDAY)                                              MAIN0609
      IF(TFMAX .LE. RMPF) GO TO 206                                     MAIN0610
      WRITE(6,9) DATE, (THSF(HOUR),HOUR=1,12)                           MAIN0611
    9 FORMAT(1H/,1X/,1X,I4,2X,2HAM,1X,6F8.1,3X,6F8.1)                   MAIN0612
      WRITE(6,10) (THSF(HOUR),HOUR=13,24), DSSF(DAY)                    MAIN0613
   10 FORMAT(1HJ,6X,2HPM,1X,6F8.1,3X,7F8.1)                             MAIN0614
      IF(TDFP24 .LT. 12.0) GO TO 205                                    MAIN0615
      TDFP12 = TDFP24 - 12.0                                            MAIN0616
      WRITE(6,11) TFMAX, TDFP12                                         MAIN0617
   11 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,  MAIN0618
     1 4HP.M.)                                                          MAIN0619
      GO TO 206                                                         MAIN0620
  205 WRITE(6,12) TFMAX,TDFP24                                          MAIN0621
   12 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,  MAIN0622
     1 4HA.M.)                                                          MAIN0623
  206 IF(CONOPT(7) .EQ. 1 .AND. SDEPTH .GT. 0.0) WRITE(6,13)DATE,       MAIN0624
     1SDEPTH,STMD,SAX,TANSM,SPLW                                        MAIN0625
   13 FORMAT(3X,I4,2X,7HSDEPTH=,F8.2,2X,5HSTMD=,F6.2,2X,4HSAX=,F6.2,    MAIN0626
     1 2X,6HTANSM=,F6.2,2X,5HSPLW=,F6.2)                                MAIN0627
C  MONTHLY SUMMARY STORAGE                                              MAIN0628
      IF(DAY .NE. MEDWY(MONTH)) GO TO 220                               MAIN0629
      TMSTF(MONTH) = AMSTF                                              MAIN0630
      AMSTF = 0.0                                                       MAIN0631
      TMRTF(MONTH) = AMRTF                                              MAIN0632
      AMRTF = 0.0                                                       MAIN0633
      EMBFNX(MONTH) = BFNX                                              MAIN0634
      TMPREC(MONTH) = AMPREC                                            MAIN0635
      AMPREC = 0.0                                                      MAIN0636
      TMRPM(MONTH) = AMRPM                                              MAIN0637
      AMRPM = 0.0                                                       MAIN0638
      TMBF(MONTH) = AMBF                                                MAIN0639
      AMBF = 0.0                                                        MAIN0640
      TMIF(MONTH) = AMIF                                                MAIN0641
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```
      AMIF = 0.0
      TMSE(MONTH) = AMSE
      AMSE = 0.0
      TMPET(MONTH) = AMPET
      AMPET = 0.0
      TMNET(MONTH) = AMNET
      AMNET = 0.0
      TMSNE(MONTH) = AMSNE
      AMSNE = 0.0
      TMFSIL(MONTH) = AMFSIL
      AMFSIL = 0.0
      EMGWS(MONTH) = GWS
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)
      IF(UZC .LT. 0.25) UZC = 0.25
      EMUZC(MONTH) = UZC
      EMUZS(MONTH) = UZS
      EMSIAM(MONTH) = SIAM
      EMLZS(MONTH) = LZS
      EMIFS(MONTH) = IFS
      IF(MONTH .EQ. 5) MEDWY(5) = 59
      MDAY = MEDWY(MONTH)
  207 IF(MONTH .NE. 0) GO TO (208,209,210,211,212,213,214,215,216,217,
     1  218,219),MONTH
  208 WRITE(6,14)
   14 FORMAT(1H/,8HNOVEMBER)
      GO TO 219
  209 WRITE(6,15)
   15 FORMAT(1H/,8HDECEMBER)
      GO TO 219
  210 WRITE(6,16)
   16 FORMAT(1H/,7HJANUARY)
      GO TO 219
  211 WRITE(6,17)
   17 FORMAT(1H/,8HFEBRUARY)
      GO TO 219
  212 WRITE(6,18)
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   18 FORMAT(1H/,5HMARCH)                                                MAIN0678
      GO TO 219                                                          MAIN0679
  213 WRITE(6,19)                                                        MAIN0680
   19 FORMAT(1H/,5HAPRIL)                                                MAIN0681
      GO TO 219                                                          MAIN0682
  214 WRITE(6,20)                                                        MAIN0683
   20 FORMAT(1H/,3HMAY)                                                  MAIN0684
      GO TO 219                                                          MAIN0685
  215 WRITE(6,21)                                                        MAIN0686
   21 FORMAT(1H/,4HJUNE)                                                 MAIN0687
      GO TO 219                                                          MAIN0688
  2160 WRITE(6,22)                                                       MAIN0689
   22 FORMAT(1H/,4HJULY)                                                 MAIN0690
      GO TO 219                                                          MAIN0691
  217 WRITE(6,23)                                                        MAIN0692
   23 FORMAT(1H/,6HAUGUST)                                               MAIN0693
      GO TO 219                                                          MAIN0694
  218 WRITE(6,24)                                                        MAIN0695
   24 FORMAT(1H/,9HSEPTEMBER)                                            MAIN0696
  219 MONTH = MONTH + 1                                                  MAIN0697
  220 CALL DAYNXT(DAY,DPY)                                               MAIN0698
      IF(DAY .NE. 274) GO TO 152                                         MAIN0699
C   END OF DAY LOOP                                                      MAIN0700
  221 CONTINUE                                                           MAIN0701
  222 WRITE(6,25) (TITLE(KTA), KTA=1,20,1)                               MAIN0702
   25 FORMAT(1H1,10X,20A4)                                               MAIN0703
      WRITE(6,26) (YTITLE(KTA),KTA=1,15,1),YR1,YR2                       MAIN0704
   26 FORMAT(1H/,15A4,3X,14HWATER YEAR  19,I2,1H-,I2,7X,                 MAIN0705
     1  29H KENTUCKY WATERSHED MODEL     )                               MAIN0706
C   ANNUAL SUMMARY                                                       MAIN0707
      SATFV = 0.0                                                        MAIN0708
      RATFV = 0.0                                                        MAIN0709
      APREC = 0.0                                                        MAIN0710
      ABFV = 0.0                                                         MAIN0711
      ARPM = 0.0                                                         MAIN0712
      ASEV = 0.0                                                         MAIN0713
```

```
      ANET = 0.0
      APET = 0.0
      AIFV = 0.0
      ASE = 0.0
      AFSIL = 0.0
      DO 223 MONTH = 1,12
      SATFV = SATFV + TMSTF(MONTH)
      RATFV = RATFV + TMRTF(MONTH)
      APREC = APREC + TMPREC(MONTH)
      ABFV = ABFV + TMBF(MONTH)
      ARPM = ARPM + TMRPM(MONTH)
      ASEV = ASEV + TMSE(MONTH)
      ANET = ANET + TMNET(MONTH)
      APET = APET + TMPET(MONTH)
      AIFV = AIFV + TMIF(MONTH)
      ASE = ASE + TMSNE(MONTH)
  223 AFSIL = AFSIL + TMFSIL(MONTH)
      IF(CONOPT(14) .NE. 1) GO TO 224
      WRITE(6,27)
   27 FORMAT(1H///44X,20HRECORDED        FLOWS)
      CALL DAYOUT(DRSF,MEDWY,DPY)
      WRITE(6,28)
   28 FORMAT(1H///44X,23HSYNTHESIZED       FLOWS)
  224 CALL DAY OUT(DSSF, MEDWY, DPY)
      WRITE(6,29) (TMSTF(KWD), KWD=1,12), SATFV
   29 FORMAT(1X, 9HSYNTHETIC,3X,12F8.1,2X,F10.1,2X,3HSFD)
      DO 225 MONTH = 1,12
  225 TMSTFI(MONTH) = (TMSTF(MONTH))/VWIN
      SATFVI = SATFV/VWIN
      WRITE(6,30) (TMSTFI(KWD), KWD=1,12),SATFVI
   30 FORMAT(1X,5HTOTAL,8X,12F8.3,4X,F7.3,2X,6HINCHES)
      DO 226 MONTH = 1,12
      TMOF(MONTH) = TMSTFI(MONTH)- TMIF(MONTH) - TMBF(MONTH) +
     1  TMSE(MONTH)
  226 IF(TMOF(MONTH) .LT. 0.0) TMOF(MONTH) = 0.0
      AOFV = SATFVI - AIFV - ABFV + ASEV
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      IF(AOFV .LT. 0.0) AOFV = 0.0
      WRITE(6,31) (TMOF(KWD), KWD=1,12), AOFV
   31 FORMAT(1X,8HOVERLAND ,5X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,32) (TMIF(KWD), KWD=1,12),AIFV
   32 FORMAT(1X,9HINTERFLOW,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,33) (TMBF(KWD), KWD=1,12),ABFV
   33 FORMAT(1X,4HBASE,9X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,34) (TMSE(KWD), KWD=1,12), ASEV
   34 FORMAT(1X,9HSTRM EVAP,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      IF(CONOPT(9) .EQ. 0) GO TO 227
      WRITE(6,35) (TMRTF(KWD), KWD=1,12),RATFV
   35 FORMAT(1X,8HRECORDED,4X,12F8.1,2X,F10.1,2X,3HSFD)
      RATFVI = RATFV/VWIN
      WRITE(6,36) RATFVI
   36 FORMAT(112X,F9.2,2X,6HINCHES)
  227 WRITE(6,37) (TMPREC(KWD), KWD=1,12),APREC
   37 FORMAT( 1X,6HPRECIP,7X,12F8.2,3X,F8.2,2X,6HINCHES)
      IF(CONOPT(7) .EQ.1) WRITE(6,38) (TMRPM(KWD), KWD=1,12),ARPM
   38 FORMAT(1X,9HRAIN+MELT,4X,12F8.2,3X,F8.2,2X,6HINCHES)
      IF(CONOPT(7) .EQ.1) WRITE(6,39) (TMSNE(KWD), KWD=1,12),ASE
   39 FORMAT( 1X,11HSURSNOWEVAP,3X,12F8.3,3X,F7.3,2X,6HINCHES)
      IF(CONOPT(7) .EQ.1) WRITE(6,40) (TMFSIL(KWD), KWD=1,12),AFSIL
   40 FORMAT(1X,11HINTSNOWLOSS,3X,12F8.3,3X,F7.3,2X,6HINCHES)
      WRITE(6,41) (TMNET(KWD), KWD=1,12),ANET
   41 FORMAT(1X,12HEVP/TRAN-NET,2X,12F8.3,3X,F7.3,2X,6HINCHES)
      WRITE(6,42) (TMPET(KWD), KWD=1,12),APET
   42 FORMAT(3X,10H-POTENTIAL,2X,12F8.3,3X,F7.3,2X,6HINCHES)
      WRITE(6,43) (EMUZS(KWD), KWD=1,12)
   43 FORMAT( 1X,12HSTORAGES-UZS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,44) (EMLZS(KWD), KWD=1,12)
   44 FORMAT(10X,3HLZS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,45) (EMIFS(KWD), KWD=1,12)
   45 FORMAT(10X,3HIFS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,46) (EMGWS(KWD), KWD=1,12)
   46 FORMAT(10X,3HGWS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,47) (EMUZC(KWD), KWD=1,12)
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   47 FORMAT(1X,12HINDICES- UZC,2X,12F8.3)                              MAIN0786
      WRITE(6,48) (EMBFNX(KWD), KWD=1,12)                               MAIN0787
   48 FORMAT(9X,4HBFNX,2X,12F8.3)                                       MAIN0788
      WRITE(6,49) (EMSIAM(KWD), KWD=1,12)                               MAIN0789
   49 FORMAT(9X,4HSIAM,2X,12F8.3)                                       MAIN0790
      IF(CONOPT(7) .NE. 1) SPM = 1.0                                    MAIN0791
      AMBER = (LZS - BYLZS + IFS - BYIFS)*FPER + (UZS - BYUZS + GWS -   MAIN0792
     1 BYGWS)*(1.0 - FWTR) + SATFV/VWIN + ANET*FPER + ASEV - APREC      MAIN0793
     2 + ASE + AFSIL - ((SPM - 1.0)/SPM)*ASM                            MAIN0794
      WRITE(6,50) AMBER                                                 MAIN0795
   50 FORMAT(1H/7HBALANCE,5X,F10.4,2X,6HINCHES)                         MAIN0796
      IF(CONOPT(7) .NE. 1) GO TO 228                                    MAIN0797
      WRITE(6,51) ASM, ASMRG                                            MAIN0798
   51 FORMAT(1H/,13HCHECK ON SNOW,5X,F10.4,5X,F10.4)                    MAIN0799
      ASM = 0.0                                                         MAIN0800
      ASMRG = 0.0                                                       MAIN0801
  228 CONTINUE                                                          MAIN0802
      IF(CONOPT(4) .NE. 1) GO TO 232                                    MAIN0803
      WRITE(6,52)                                                       MAIN0804
   52 FORMAT(1H1,10X,35HDAILY FLOW DURATION AND ERROR TABLE)            MAIN0805
      WRITE(6,53)                                                       MAIN0806
   53 FORMAT(1H/,10X,13HFLOW INTERVAL,5X,5HCASES,3X,8HAV.ERROR,3X,      MAIN0807
     1 16H AVR. ABS. ERROR,3X,14HSTANDARD ERROR)                        MAIN0808
      SSESF = 0.0                                                       MAIN0809
      SSERA = 0.0                                                       MAIN0810
      SSERR = 0.0                                                       MAIN0811
      ACRFMI = 0.0                                                      MAIN0812
      DO 230 KRFMI = 1,22                                               MAIN0813
      IF(KRFMI .EQ. 1) ETIBF = 0.0                                      MAIN0814
      IF(KRFMI .EQ. 2) ETIBF = 1.0                                      MAIN0815
      FKRFMI = KRFMI                                                    MAIN0816
      IF(KRFMI .GT. 2) ETIBF = EXP((FKRFMI/2.0) - 1.0)                  MAIN0817
      CCRFMI = CRFMI(KRFMI)                                             MAIN0818
      IF(CCRFMI .EQ. 0.0) WRITE(6,54) ETIBF, CCRFMI                     MAIN0819
   54 FORMAT(1X,13X,F8.1,1H-,F9.1,F12.1,5X,F8.2,5X,F8.2)                MAIN0820
      IF(CCRFMI .EQ. 0.0) GO TO 229                                     MAIN0821
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      SERAV = SERA(KRFMI)/CCRFMI                                        MAIN0822
      SERRV = SERR(KRFMI)/CCRFMI                                        MAIN0823
      IF(CCRFMI .EQ. 1) WRITE(6,54) ETIBF,CCRFMI,SERRV,SERAV            MAIN0824
      IF(CCRFMI .NE. 1) WRITE(6,54) ETIBF,CCRFMI,SERRV,SERAV,           MAIN0825
     1SESF(KRFMI)                                                       MAIN0826
  229 ACRFMI = ACRFMI + CRFMI(KRFMI)                                    MAIN0827
      IF(ACRFMI .EQ. 0.0) GO TO 230                                     MAIN0828
      SSERR= SSERR + SERR(KRFMI)                                        MAIN0829
      SSERRV= SSERR/ACRFMI                                              MAIN0830
      SSERA = SSERA + SERA(KRFMI)                                       MAIN0831
      SSERAV = SSERA/ACRFMI                                             MAIN0832
  230 SSESF = SSESF + SESF(KRFMI)                                       MAIN0833
      WRITE(6,55) ACRFMI,SSERRV,SSERAV,SSESF                            MAIN0834
   55 FORMAT(1H/,22X,F9.1,F12.1,5X,F8.2,5X,F8.2)                        MAIN0835
      FDPY = DPY                                                        MAIN0836
      SADF = SATFV/FDPY                                                 MAIN0837
      RADF = RATFV/FDPY                                                 MAIN0838
      RA1 = 0.0                                                         MAIN0839
      RA2 = 0.0                                                         MAIN0840
      RA3 = 0.0                                                         MAIN0841
      DO 231 DAY = 1,DPY                                                MAIN0842
      DRAF = DRSF(DAY) - RADF                                           MAIN0843
      DSAF = DSSF(DAY) - SADF                                           MAIN0844
      RA1 = RA1 + DRAF*DRAF                                             MAIN0845
      RA2 = RA2 + DSAF*DSAF                                             MAIN0846
  231 RA3 = RA3 + DRAF*DSAF                                             MAIN0847
      DFCC= RA3/SQRT(RA1*RA2)                                           MAIN0848
      WRITE(6,56) DFCC                                                  MAIN0849
   56 FORMAT(1H/,10X,31HCORRELATION COEFFICIENT (DAILY),3X,F10.4)       MAIN0850
  232 CONTINUE                                                          MAIN0851
      IF(CONOPT(5) .NE. 1) GO TO 233                                    MAIN0852
C     OUTPUT MAXIMUM RUNOFF, PRECIPITATION AT END OF YEARS              MAIN0853
      WRITE(6,57)                                                       MAIN0854
   57 FORMAT(1H/,10X,58HTWENTY HIGHEST CLOCKHOUR RAINFALL EVENTS IN THE MAIN0855
     1WATER YEAR)                                                       MAIN0856
      WRITE(6,58) (T20PRH(KT20), KT20=1,20)                             MAIN0857
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   58 FORMAT(1H/,5X,20F6.3)                                             MAIN0858
      WRITE(6,59)                                                       MAIN0859
   59 FORMAT(1H/,10X,70HTWENTY HIGHEST CLOCKHOUR OVERLAND FLOW RUNOFF EVMAIN0860
     1ENTS IN THE WATER YEAR)                                           MAIN0861
      WRITE(6,58) (T20OFH(KT20), KT20=1,20)                             MAIN0862
  233 CONTINUE                                                          MAIN0863
      IF(CONOPT(6) .EQ. 0) GO TO 234                                    MAIN0864
      WRITE(6,60)                                                       MAIN0865
   60 FORMAT(1H1,30X,27HDAILY SOIL MOISTURE OUTPUT )                    MAIN0866
      CALL DAYOUT(EDLZS,MEDWY,DPY)                                      MAIN0867
  234 CONTINUE                                                          MAIN0868
      IF(CONOPT(10) .EQ. 1) GO TO 100                                   MAIN0869
      GO TO 117                                                         MAIN0870
      END                                                               MAIN0871
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      SUBROUTINE DAYNXT(DAY,DPY)                                        DYNX0001
C  DETERMINES NUMBER OF NEXT DAY OF THE YEAR                            DYNX0002
      INTEGER  DAY,DPY                                                  DYNX0003
      DAY = DAY + 1                                                     DYNX0004
      IF(DAY .EQ. 366) DAY = 1                                          DYNX0005
      IF(DAY .EQ. 60 .AND. DPY .EQ. 366) DAY = 366                      DYNX0006
      IF(DAY .EQ. 367) DAY = 60                                         DYNX0007
      RETURN                                                            DYNX0008
      END                                                               DYNX0009
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      SUBROUTINE DAYOUT(VDCY,MEDWY,DPY)                                 DYOT0001
C  PRINTS TABLE OF DAILY VALUES                                         DYOT0002
      DIMENSION  MEDWY(12),VDCY(366),VDMD(12)                           DYOT0003
      INTEGER  DATE,DAY,DPY                                             DYOT0004
  100 WRITE(6,1)                                                        DYOT0005
```

```
    1 FORMAT(7X,3HDAY,7X,3HOCT,5X,3HNOV,5X,3HDEC,5X,3HJAN,5X,3HFEB,5X,      DYOT0006
     1 3HMAR,5X,3HAPR,5X,3HMAY,5X,3HJUN,5X,3HJUL,5X,3HAUG,5X,4HSEPT)        DYOT0007
      MEDWY(3) = 0                                                          DYOT0008
      DO 104 DATE = 1,28,1                                                  DYOT0009
      IF(MOD(DATE,5) .NE. 1) GO TO 102                                      DYOT0010
      DO 101 KMO = 1,12                                                     DYOT0011
      DAY = MEDWY(KMO) + DATE                                               DYOT0012
  101 VDMD(KMO) = VDCY(DAY)                                                 DYOT0013
      WRITE(6,2) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)                        DYOT0014
    2 FORMAT(1H0,3X,I6,3X,12F8.1)                                           DYOT0015
      GO TO 104                                                             DYOT0016
  102 DO 103 KMO = 1,12                                                     DYOT0017
      DAY = MEDWY(KMO) + DATE                                               DYOT0018
  103 VDMD(KMO) = VDCY(DAY)                                                 DYOT0019
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD = 1,11)                      DYOT0020
    3 FORMAT(1X,3X,I6,3X,12F8.1)                                            DYOT0021
  104 CONTINUE                                                              DYOT0022
      IF(DPY .NE. 366) GO TO 106                                            DYOT0023
      DATE = 29                                                             DYOT0024
      VDCY(60) = VDCY(366)                                                  DYOT0025
      DO 105 KMO = 1,12                                                     DYOT0026
      DAY = MEDWY(KMO) + DATE                                               DYOT0027
  105 VDMD(KMO) = VDCY(DAY)                                                 DYOT0028
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)                        DYOT0029
      GO TO 107                                                             DYOT0030
  106 CONTINUE                                                              DYOT0031
      WRITE(6,4) VDCY(302),VDCY(333),VDCY(363),VDCY(29),VDCY(88),           DYOT0032
     1VDCY(119),VDCY(149),VDCY(180),VDCY(210),VDCY(241),VDCY(272)           DYOT0033
    4 FORMAT(1X,7X,2H29,3X,4F8.1,8X,7F8.1)                                  DYOT0034
  107 CONTINUE                                                              DYOT0035
  108 WRITE(6,5) VDCY(303),VDCY(334),VDCY(364),VDCY(30),VDCY(89),           DYOT0036
     1VDCY(120),VDCY(150),VDCY(181),VDCY(211),VDCY(242),VDCY(273)           DYOT0037
    5 FORMAT(1X,7X,2H30,3X,4F8.1,8X,7F8.1)                                  DYOT0038
      WRITE(6,6) VDCY(304),VDCY(365),VDCY(31),VDCY(90),VDCY(151),           DYOT0039
     1VDCY(212),VDCY(243)                                                   DYOT0040
    6 FORMAT(1H/,7X,2H31,3X,F8.1,8X,2F8.1,8X,F8.1,8X,F8.1,8X,2F8.1)         DYOT0041
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      MEDWY(3) = 365                                                    DYOT0042
      RETURN                                                            DYOT0043
      END                                                               DYOT0044


      SUBROUTINE EVPDAY(DPET, EMAET)                                    EVDY0001
C   DETERMINES DATED PAN EVAPORATION TOTALS                             EVDY0002
      DIMENSION  DPET(366)                                              EVDY0003
      INTEGER DAY                                                       EVDY0004
      DO 100  DAY = 1,5                                                 EVDY0005
  100 DPET(DAY) = 0.00060*EMAET                                         EVDY0006
      DPET(  6) = 0.00059*EMAET                                         EVDY0007
      DPET(  7) = DPET(  6)                                             EVDY0008
      DO 101 DAY = 8,10                                                 EVDY0009
  101 DPET(DAY) = 0.00058*EMAET                                         EVDY0010
      DO 102 DAY = 11,16                                                EVDY0011
  102 DPET(DAY) = 0.00057*EMAET                                         EVDY0012
      DPET( 17) = DPET(  8)                                             EVDY0013
      DO 103 DAY = 18,20                                                EVDY0014
  103 DPET(DAY) = DPET(  6)                                             EVDY0015
      DO 104 DAY = 21,32                                                EVDY0016
  104 DPET(DAY) = DPET(  1)                                             EVDY0017
      DPET( 33) = 0.00061*EMAET                                         EVDY0018
      DO 105 DAY = 34,38                                                EVDY0019
  105 DPET(DAY) = 0.00062*EMAET                                         EVDY0020
      DPET( 39) = 0.00063*EMAET                                         EVDY0021
      DPET( 40) = DPET( 39)                                             EVDY0022
      DPET( 41) = 0.00064*EMAET                                         EVDY0023
      DPET( 42) = 0.00065*EMAET                                         EVDY0024
      DPET( 43) = 0.00066*EMAET                                         EVDY0025
      DO 106 DAY = 44,50                                                EVDY0026
  106 DPET(DAY) = 0.00067*EMAET                                         EVDY0027
      DO 107 DAY = 51,55                                                EVDY0028
  107 DPET(DAY) = 0.00068*EMAET                                         EVDY0029
      DPET( 56) = 0.00069*EMAET                                         EVDY0030
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      DO 108 DAY = 57,61                                                EVDY0031
  108 DPET(DAY) = 0.00070*EMAET                                         EVDY0032
      DPET( 62) = 0.00071*EMAET                                         EVDY0033
      DPET( 63) = 0.00072*EMAET                                         EVDY0034
      DPET( 64) = DPET( 63)                                             EVDY0035
      DPET( 65) = 0.00073*EMAET                                         EVDY0036
      DPET( 66) = 0.00074*EMAET                                         EVDY0037
      DPET( 67) = 0.00075*EMAET                                         EVDY0038
      DPET( 68) = 0.00076*EMAET                                         EVDY0039
      DPET( 69) = 0.00077*EMAET                                         EVDY0040
      DPET( 70) = DPET( 69)                                             EVDY0041
      DPET( 71) = 0.00078*EMAET                                         EVDY0042
      DPET( 72) = DPET( 71)                                             EVDY0043
      DPET( 73) = 0.00079*EMAET                                         EVDY0044
      DPET( 74) = DPET( 73)                                             EVDY0045
      DPET( 75) = 0.00080*EMAET                                         EVDY0046
      DPET( 76) = 0.00081*EMAET                                         EVDY0047
      DPET( 77) = 0.00082*EMAET                                         EVDY0048
      DPET( 78) = 0.00084*EMAET                                         EVDY0049
      DPET( 79) = 0.00086*EMAET                                         EVDY0050
      DPET( 80) = 0.00088*EMAET                                         EVDY0051
      DPET( 81) = 0.00090*EMAET                                         EVDY0052
      DPET( 82) = 0.00092*EMAET                                         EVDY0053
      DPET( 83) = 0.00094*EMAET                                         EVDY0054
      DPET( 84) = 0.00097*EMAET                                         EVDY0055
      DPET( 85) = 0.00099*EMAET                                         EVDY0056
      DPET( 86) = 0.00102*EMAET                                         EVDY0057
      DPET( 87) = 0.00106*EMAET                                         EVDY0058
      DPET( 88) = 0.00109*EMAET                                         EVDY0059
      DPET( 89) = 0.00113*EMAET                                         EVDY0060
      DPET( 90) = 0.00118*EMAET                                         EVDY0061
      DPET( 91) = 0.00122*EMAET                                         EVDY0062
      DPET( 92) = 0.00128*EMAET                                         EVDY0063
      DPET( 93) = 0.00132*EMAET                                         EVDY0064
      DPET( 94) = 0.00137*EMAET                                         EVDY0065
      DPET( 95) = 0.00142*EMAET                                         EVDY0066
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      DPET( 96) = 0.00147*EMAET                                         EVDY0067
      DPET( 97) = 0.00151*EMAET                                         EVDY0068
      DPET( 98) = 0.00157*EMAET                                         EVDY0069
      DPET( 99) = 0.00163*EMAET                                         EVDY0070
      DPET(100) = 0.00168*EMAET                                         EVDY0071
      DPET(101) = 0.00173*EMAET                                         EVDY0072
      DPET(102) = 0.00178*EMAET                                         EVDY0073
      DPET(103) = 0.00185*EMAET                                         EVDY0074
      DPET(104) = 0.00193*EMAET                                         EVDY0075
      DPET(105) = 0.00201*EMAET                                         EVDY0076
      DPET(106) = 0.00208*EMAET                                         EVDY0077
      DPET(107) = 0.00214*EMAET                                         EVDY0078
      DPET(108) = 0.00221*EMAET                                         EVDY0079
      DPET(109) = 0.00227*EMAET                                         EVDY0080
      DPET(110) = 0.00234*EMAET                                         EVDY0081
      DPET(111) = 0.00241*EMAET                                         EVDY0082
      DPET(112) = 0.00249*EMAET                                         EVDY0083
      DPET(113) = 0.00256*EMAET                                         EVDY0084
      DPET(114) = 0.00262*EMAET                                         EVDY0085
      DPET(115) = 0.00268*EMAET                                         EVDY0086
      DPET(116) = 0.00276*EMAET                                         EVDY0087
      DPET(117) = 0.00281*EMAET                                         EVDY0088
      DPET(118) = 0.00287*EMAET                                         EVDY0089
      DPET(119) = 0.00293*EMAET                                         EVDY0090
      DPET(120) = 0.00299*EMAET                                         EVDY0091
      DPET(121) = 0.00305*EMAET                                         EVDY0092
      DPET(122) = 0.00310*EMAET                                         EVDY0093
      DPET(123) = 0.00317*EMAET                                         EVDY0094
      DPET(124) = 0.00322*EMAET                                         EVDY0095
      DPET(125) = 0.00328*EMAET                                         EVDY0096
      DPET(126) = 0.00333*EMAET                                         EVDY0097
      DPET(127) = 0.00338*EMAET                                         EVDY0098
      DPET(128) = 0.00344*EMAET                                         EVDY0099
      DPET(129) = 0.00348*EMAET                                         EVDY0100
      DPET(130) = 0.00354*EMAET                                         EVDY0101
      DPET(131) = 0.00359*EMAET                                         EVDY0102
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      DPET(132) = 0.00365*EMAET                                         EVDY0103
      DPET(133) = 0.00370*EMAET                                         EVDY0104
      DPET(134) = 0.00374*EMAET                                         EVDY0105
      DPET(135) = 0.00378*EMAET                                         EVDY0106
      DPET(136) = 0.00382*EMAET                                         EVDY0107
      DPET(137) = 0.00387*EMAET                                         EVDY0108
      DPET(138) = 0.00391*EMAET                                         EVDY0109
      DPET(139) = 0.00394*EMAET                                         EVDY0110
      DPET(140) = 0.00399*EMAET                                         EVDY0111
      DPET(141) = 0.00402*EMAET                                         EVDY0112
      DPET(142) = 0.00407*EMAET                                         EVDY0113
      DPET(143) = 0.00411*EMAET                                         EVDY0114
      DPET(144) = 0.00417*EMAET                                         EVDY0115
      DPET(145) = 0.00420*EMAET                                         EVDY0116
      DPET(146) = 0.00426*EMAET                                         EVDY0117
      DPET(147) = 0.00430*EMAET                                         EVDY0118
      DPET(148) = 0.00436*EMAET                                         EVDY0119
      DPET(149) = 0.00440*EMAET                                         EVDY0120
      DPET(150) = 0.00446*EMAET                                         EVDY0121
      DPET(151) = 0.00450*EMAET                                         EVDY0122
      DPET(152) = 0.00455*EMAET                                         EVDY0123
      DPET(153) = 0.00460*EMAET                                         EVDY0124
      DPET(154) = 0.00466*EMAET                                         EVDY0125
      DPET(155) = 0.00470*EMAET                                         EVDY0126
      DPET(156) = 0.00473*EMAET                                         EVDY0127
      DPET(157) = 0.00478*EMAET                                         EVDY0128
      DPET(158) = 0.00482*EMAET                                         EVDY0129
      DPET(159) = 0.00487*EMAET                                         EVDY0130
      DPET(160) = 0.00491*EMAET                                         EVDY0131
      DPET(161) = 0.00495*EMAET                                         EVDY0132
      DPET(162) = 0.00500*EMAET                                         EVDY0133
      DPET(163) = 0.00504*EMAET                                         EVDY0134
      DPET(164) = 0.00508*EMAET                                         EVDY0135
      DPET(165) = 0.00510*EMAET                                         EVDY0136
      DPET(166) = 0.00512*EMAET                                         EVDY0137
      DPET(167) = 0.00514*EMAET                                         EVDY0138
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      DPET(168) = 0.00515*EMAET                                         EVDY0139
      DPET(169) = 0.00517*EMAET                                         EVDY0140
      DPET(170) = 0.00519*EMAET                                         EVDY0141
      DPET(171) = 0.00520*EMAET                                         EVDY0142
      DPET(172) = 0.00521*EMAET                                         EVDY0143
      DPET(173) = DPET(172)                                             EVDY0144
      DPET(174) = DPET(172)                                             EVDY0145
      DPET(175) = 0.00522*EMAET                                         EVDY0146
      DPET(176) = 0.00523*EMAET                                         EVDY0147
      DPET(177) = 0.00524*EMAET                                         EVDY0148
      DPET(178) = 0.00525*EMAET                                         EVDY0149
      DPET(179) = 0.00527*EMAET                                         EVDY0150
      DPET(180) = 0.00528*EMAET                                         EVDY0151
      DPET(181) = DPET(180)                                             EVDY0152
      DPET(182) = 0.00529*EMAET                                         EVDY0153
      DPET(183) = 0.00530*EMAET                                         EVDY0154
      DPET(184) = DPET(183)                                             EVDY0155
      DPET(185) = 0.00531*EMAET                                         EVDY0156
      DPET(186) = 0.00532*EMAET                                         EVDY0157
      DPET(187) = 0.00533*EMAET                                         EVDY0158
      DPET(188) = 0.00534*EMAET                                         EVDY0159
      DPET(189) = DPET(188)                                             EVDY0160
      DPET(190) = 0.00535*EMAET                                         EVDY0161
      DPET(191) = 0.00536*EMAET                                         EVDY0162
      DPET(192) = 0.00537*EMAET                                         EVDY0163
      DPET(193) = 0.00538*EMAET                                         EVDY0164
      DPET(194) = DPET(193)                                             EVDY0165
      DPET(195) = 0.00539*EMAET                                         EVDY0166
      DPET(196) = 0.00540*EMAET                                         EVDY0167
      DPET(197) = DPET(196)                                             EVDY0168
      DPET(198) = 0.00541*EMAET                                         EVDY0169
      DPET(199) = 0.00542*EMAET                                         EVDY0170
      DPET(200) = 0.00543*EMAET                                         EVDY0171
      DPET(201) = 0.00545*EMAET                                         EVDY0172
      DPET(202) = 0.00546*EMAET                                         EVDY0173
      DPET(203) = 0.00547*EMAET                                         EVDY0174
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      DPET(204) = 0.00548*EMAET                                         EVDY0175
      DPET(205) = 0.00549*EMAET                                         EVDY0176
      DPET(206) = 0.00550*EMAET                                         EVDY0177
      DPET(207) = 0.00551*EMAET                                         EVDY0178
      DPET(208) = 0.00552*EMAET                                         EVDY0179
      DPET(209) = 0.00553*EMAET                                         EVDY0180
      DPET(210) = 0.00555*EMAET                                         EVDY0181
      DPET(211) = 0.00557*EMAET                                         EVDY0182
      DPET(212) = 0.00558*EMAET                                         EVDY0183
      DPET(213) = 0.00560*EMAET                                         EVDY0184
      DPET(214) = DPET(213)                                             EVDY0185
      DPET(215) = 0.00561*EMAET                                         EVDY0186
      DPET(216) = 0.00562*EMAET                                         EVDY0187
      DPET(217) = 0.00563*EMAET                                         EVDY0188
      DPET(218) = 0.00565*EMAET                                         EVDY0189
      DPET(219) = 0.00567*EMAET                                         EVDY0190
      DPET(220) = DPET(219)                                             EVDY0191
      DO 109 DAY = 221,226                                              EVDY0192
  109 DPET(DAY) = 0.00568*EMAET                                         EVDY0193
      DO 110 DAY = 227,229                                              EVDY0194
  110 DPET(DAY) = DPET(219)                                             EVDY0195
      DPET(230) = 0.00566*EMAET                                         EVDY0196
      DPET(231) = 0.00564*EMAET                                         EVDY0197
      DPET(232) = DPET(217)                                             EVDY0198
      DPET(233) = DPET(216)                                             EVDY0199
      DPET(234) = DPET(213)                                             EVDY0200
      DPET(235) = 0.00559*EMAET                                         EVDY0201
      DPET(236) = DPET(211)                                             EVDY0202
      DPET(237) = DPET(210)                                             EVDY0203
      DPET(238) = DPET(209)                                             EVDY0204
      DPET(239) = DPET(206)                                             EVDY0205
      DPET(240) = DPET(203)                                             EVDY0206
      DPET(241) = DPET(199)                                             EVDY0207
      DPET(242) = DPET(193)                                             EVDY0208
      DPET(243) = DPET(190)                                             EVDY0209
      DPET(244) = DPET(185)                                             EVDY0210
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      DPET(245) = DPET(179)                                             EVDY0211
      DPET(246) = DPET(175)                                             EVDY0212
      DPET(247) = DPET(169)                                             EVDY0213
      DPET(248) = 0.00511*EMAET                                         EVDY0214
      DPET(249) = DPET(163)                                             EVDY0215
      DPET(250) = 0.00497*EMAET                                         EVDY0216
      DPET(251) = 0.00490*EMAET                                         EVDY0217
      DPET(252) = DPET(158)                                             EVDY0218
      DPET(253) = 0.00476*EMAET                                         EVDY0219
      DPET(254) = 0.00468*EMAET                                         EVDY0220
      DPET(255) = 0.00461*EMAET                                         EVDY0221
      DPET(256) = 0.00454*EMAET                                         EVDY0222
      DPET(257) = DPET(150)                                             EVDY0223
      DPET(258) = 0.00437*EMAET                                         EVDY0224
      DPET(259) = 0.00427*EMAET                                         EVDY0225
      DPET(260) = 0.00418*EMAET                                         EVDY0226
      DPET(261) = DPET(142)                                             EVDY0227
      DPET(262) = 0.00397*EMAET                                         EVDY0228
      DPET(263) = DPET(137)                                             EVDY0229
      DPET(264) = 0.00377*EMAET                                         EVDY0230
      DPET(265) = 0.00367*EMAET                                         EVDY0231
      DPET(266) = 0.00356*EMAET                                         EVDY0232
      DPET(267) = 0.00347*EMAET                                         EVDY0233
      DPET(268) = 0.00337*EMAET                                         EVDY0234
      DPET(269) = 0.00329*EMAET                                         EVDY0235
      DPET(270) = DPET(124)                                             EVDY0236
      DPET(271) = 0.00315*EMAET                                         EVDY0237
      DPET(272) = 0.00308*EMAET                                         EVDY0238
      DPET(273) = 0.00303*EMAET                                         EVDY0239
      DPET(274) = 0.00300*EMAET                                         EVDY0240
      DPET(275) = 0.00298*EMAET                                         EVDY0241
      DPET(276) = 0.00294*EMAET                                         EVDY0242
      DPET(277) = 0.00290*EMAET                                         EVDY0243
      DPET(278) = 0.00286*EMAET                                         EVDY0244
      DPET(279) = 0.00283*EMAET                                         EVDY0245
      DPET(280) = 0.00279*EMAET                                         EVDY0246
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      DPET(281) = DPET(116)                                             EVDY0247
      DPET(282) = 0.00271*EMAET                                         EVDY0248
      DPET(283) = DPET(115)                                             EVDY0249
      DPET(284) = DPET(114)                                             EVDY0250
      DPET(285) = 0.00259*EMAET                                         EVDY0251
      DPET(286) = 0.00254*EMAET                                         EVDY0252
      DPET(287) = 0.00252*EMAET                                         EVDY0253
      DPET(288) = 0.00247*EMAET                                         EVDY0254
      DPET(289) = 0.00244*EMAET                                         EVDY0255
      DPET(290) = 0.00239*EMAET                                         EVDY0256
      DPET(291) = DPET(110)                                             EVDY0257
      DPET(292) = 0.00230*EMAET                                         EVDY0258
      DPET(293) = 0.00225*EMAET                                         EVDY0259
      DPET(294) = 0.00222*EMAET                                         EVDY0260
      DPET(295) = 0.00217*EMAET                                         EVDY0261
      DPET(296) = 0.00213*EMAET                                         EVDY0262
      DPET(297) = 0.00210*EMAET                                         EVDY0263
      DPET(298) = 0.00206*EMAET                                         EVDY0264
      DPET(299) = 0.00200*EMAET                                         EVDY0265
      DPET(300) = 0.00197*EMAET                                         EVDY0266
      DPET(301) = 0.00194*EMAET                                         EVDY0267
      DPET(302) = 0.00189*EMAET                                         EVDY0268
      DPET(303) = 0.00186*EMAET                                         EVDY0269
      DPET(304) = 0.00183*EMAET                                         EVDY0270
      DPET(305) = 0.00180*EMAET                                         EVDY0271
      DPET(306) = 0.00177*EMAET                                         EVDY0272
      DPET(307) = 0.00174*EMAET                                         EVDY0273
      DPET(308) = 0.00172*EMAET                                         EVDY0274
      DPET(309) = DPET(100)                                             EVDY0275
      DPET(310) = DPET( 99)                                             EVDY0276
      DPET(311) = 0.00160*EMAET                                         EVDY0277
      DPET(312) = 0.00156*EMAET                                         EVDY0278
      DPET(313) = 0.00152*EMAET                                         EVDY0279
      DPET(314) = 0.00149*EMAET                                         EVDY0280
      DPET(315) = 0.00146*EMAET                                         EVDY0281
      DPET(316) = DPET( 95)                                             EVDY0282
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      DPET(317) = 0.00138*EMAET                                         EVDY0283
      DPET(318) = 0.00135*EMAET                                         EVDY0284
      DPET(319) = 0.00131*EMAET                                         EVDY0285
      DPET(320) = 0.00127*EMAET                                         EVDY0286
      DPET(321) = 0.00124*EMAET                                         EVDY0287
      DPET(322) = 0.00120*EMAET                                         EVDY0288
      DPET(323) = DPET( 90)                                             EVDY0289
      DPET(324) = 0.00116*EMAET                                         EVDY0290
      DPET(325) = DPET( 89)                                             EVDY0291
      DPET(326) = 0.00110*EMAET                                         EVDY0292
      DPET(327) = 0.00107*EMAET                                         EVDY0293
      DPET(328) = 0.00104*EMAET                                         EVDY0294
      DPET(329) = DPET( 86)                                             EVDY0295
      DPET(330) = 0.00100*EMAET                                         EVDY0296
      DPET(331) = 0.00098*EMAET                                         EVDY0297
      DPET(332) = 0.00097*EMAET                                         EVDY0298
      DPET(333) = 0.00095*EMAET                                         EVDY0299
      DPET(334) = 0.00093*EMAET                                         EVDY0300
      DPET(335) = DPET( 81)                                             EVDY0301
      DPET(336) = DPET( 80)                                             EVDY0302
      DPET(337) = 0.00087*EMAET                                         EVDY0303
      DPET(338) = DPET( 79)                                             EVDY0304
      DPET(339) = DPET( 78)                                             EVDY0305
      DPET(340) = DPET( 77)                                             EVDY0306
      DPET(341) = DPET( 75)                                             EVDY0307
      DPET(342) = DPET( 73)                                             EVDY0308
      DPET(343) = DPET( 71)                                             EVDY0309
      DPET(344) = DPET( 71)                                             EVDY0310
      DPET(345) = DPET( 69)                                             EVDY0311
      DPET(346) = DPET( 68)                                             EVDY0312
      DPET(347) = DPET( 66)                                             EVDY0313
      DPET(348) = DPET( 63)                                             EVDY0314
      DPET(349) = DPET( 62)                                             EVDY0315
      DPET(350) = DPET( 57)                                             EVDY0316
      DPET(351) = DPET( 57)                                             EVDY0317
      DPET(352) = DPET( 56)                                             EVDY0318
```

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      DO 111 DAY = 353,355                                              EVDY0319
  111 DPET(DAY) = DPET( 51)                                             EVDY0320
      DPET(356) = DPET( 44)                                             EVDY0321
      DPET(357) = DPET( 44)                                             EVDY0322
      DPET(358) = DPET( 42)                                             EVDY0323
      DPET(359) = DPET( 41)                                             EVDY0324
      DPET(360) = DPET( 39)                                             EVDY0325
      DPET(361) = DPET( 34)                                             EVDY0326
      DPET(362) = DPET( 33)                                             EVDY0327
      DO 112 DAY = 363,365                                              EVDY0328
  112 DPET(DAY) = DPET(  1)                                             EVDY0329
      DPET(366) = DPET( 57)                                             EVDY0330
      RETURN                                                            EVDY0331
      END                                                               EVDY0332


      SUBROUTINE PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,PRH)             PREP0001
C   DIVIDES HOURLY PRECIPITATION TOTALS AMONG PERIODS FOR SMALL BASINS  PREP0002
      DIMENSION DRHP(366,24), PE4P(4)                                   PREP0003
      INTEGER DAY,DPY,HOUR,PRD                                          PREP0004
      PEP = 0.0                                                         PREP0005
      IF(PRH .EQ. 0.0) RETURN                                           PREP0006
      IF(PRD .EQ. 1) GO TO 100                                          PREP0007
      PEP = PE4P(PRD)                                                   PREP0008
      RETURN                                                            PREP0009
  100 LHOUR = HOUR - 1                                                  PREP0010
      LDAY = DAY                                                        PREP0011
      IF(LHOUR .GE. 1) GO TO 101                                        PREP0012
      LHOUR = 24                                                        PREP0013
      LDAY = DAY - 1                                                    PREP0014
      IF(LDAY .EQ. 0) LDAY = 365                                        PREP0015
      IF(LDAY .EQ. 365) LDAY = 59                                       PREP0016
      IF(LDAY .EQ. 59 .AND. DPY .EQ. 366) LDAY = 366                    PREP0017
  101 PRLH = RGPM*DRHP(LDAY,LHOUR)                                      PREP0018
      NHOUR = HOUR + 1                                                  PREP0019
```

```
      NDAY = DAY
      IF(NHOUR .LE. 24) GO TO 102
      NHOUR = 1
      CALL DAYNXT(NDAY,DPY)
  102 PRNH = RGPM*DRHP(NDAY,NHOUR)
      IF(PRH .GT. PRLH .AND. PRH .GT. PRNH) GO TO 103
      GO TO 104
  103 PE4P(1) = 0.10
      PE4P(2) = 0.28
      PE4P(3) = 0.46
      PE4P(4) = 0.16
      GO TO 108
  104 IF(PRH .LT. PRLH .AND. PRH .LT. PRNH) GO TO 105
      GO TO 106
  105 PE4P(1) = 0.28
      PE4P(2) = 0.10
      PE4P(3) = 0.16
      PE4P(4) = 0.46
      GO TO 108
  106 IF(PRNH .GE. PRLH) GO TO 107
      PE4P(1) = 0.46
      PE4P(2) = 0.16
      PE4P(3) = 0.28
      PE4P(4) = 0.10
      GO TO 108
  107 PE4P(1) = 0.10
      PE4P(2) = 0.28
      PE4P(3) = 0.16
      PE4P(4) = 0.46
  108 DO 109 KPRD = 1,4
  109 PE4P(KPRD) = PE4P(KPRD)*PRH
      PEP = PE4P(1)
      RETURN
      END
```

```
      SUBROUTINE RTVARY(CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCTRI,EXQPV,  RTVY0001
     1 LSHFT,TFCFS)                                                     RTVY0002
      DIMENSION  AWSBIT(99),BTRI(99),CTRI(99),SATRI(99)                 RTVY0003
      LOGICAL LSHFT                                                     RTVY0004
      DO 100 KIA = 1,MXTRI                                              RTVY0005
      SATRI(KIA) = 0.0                                                  RTVY0006
  100 AWSBIT(KIA) = 0.0                                                 RTVY0007
      LSHFT = .FALSE.                                                   RTVY0008
      FMXTRI = MXTRI                                                    RTVY0009
      FNBTRI = NBTRI                                                    RTVY0010
      FNPTRI = NCTRI                                                    RTVY0011
      TFX = TFCFS                                                       RTVY0012
      TFMRT = 0.1*CHCAP                                                 RTVY0013
      IF(TFX .LT. TFMRT) TFX = TFMRT                                    RTVY0014
      IF(FNPTRI .EQ. FMXTRI .AND. TFX .EQ. TFMRT) RETURN                RTVY0015
      FNTRI = FNBTRI*(CHCAP/TFX)**EXQPV + 0.5                           RTVY0016
      IF(FNTRI .LT. 1.0) FNTRI = 1.01                                   RTVY0017
      NCTRI = FNTRI                                                     RTVY0018
      FNSTRI = NCTRI                                                    RTVY0019
      IF(FNSTRI .NE. FNPTRI) LSHFT = .TRUE.                             RTVY0020
      IF(.NOT. LSHFT) RETURN                                            RTVY0021
      IF(FNPTRI .GT. 98.5) GO TO 101                                    RTVY0022
      FCNTRI = ABS(FNSTRI - FNPTRI)                                     RTVY0023
      IF(FCNTRI .LE. 1.1) GO TO 101                                     RTVY0024
      IF(FNSTRI .GT. FNPTRI) FNSTRI = FNPTRI + 1.0                      RTVY0025
      IF(FNSTRI .LT. FNPTRI) FNSTRI = FNPTRI - 1.0                      RTVY0026
      NCTRI = FNSTRI                                                    RTVY0027
  101 KB1 = 0                                                           RTVY0028
      KB2 = 1                                                           RTVY0029
      KB3 = 0                                                           RTVY0030
  102 KB1 = KB1 + 1                                                     RTVY0031
      IF(KB1 .GT. NBTRI) GO TO 105                                      RTVY0032
      KB4 = 0                                                           RTVY0033
      WSBIT = BTRI(KB1)/FNSTRI                                          RTVY0034
  103 KB4 = KB4 + 1                                                     RTVY0035
```

```
      IF(KB4 .GT. NCTRI) GO TO 102                                      RTVY0036
      AWSBIT(KB2) = AWSBIT(KB2) + WSBIT                                 RTVY0037
      KB3 = KB3 + 1                                                     RTVY0038
      IF(KB3 .LT. NBTRI) GO TO 104                                      RTVY0039
      KB3 = 0                                                           RTVY0040
      KB2 = KB2 + 1                                                     RTVY0041
  104 GO TO 103                                                         RTVY0042
  105 IF(FNPTRI .GT. 98.5) GO TO 108                                    RTVY0043
      DO 107 KB6 = 1,NCTRI                                              RTVY0044
      DO 106 KB7 = 1,KB6                                                RTVY0045
  106 SATRI(KB6) = SATRI(KB6) + AWSBIT(KB7) - CTRI(KB7)                 RTVY0046
  107 CONTINUE                                                          RTVY0047
  108 DO 109 KB5 = 1,MXTRI                                              RTVY0048
  109 CTRI(KB5) = AWSBIT(KB5)                                           RTVY0049
      RETURN                                                            RTVY0050
      END                                                               RTVY0051


      SUBROUTINE SNOMEL(BDDFSM,SPTWCC,SPM,ELDIF,DAY,SPBFLW,XDNFS,FFOR,  SNOW0001
     1  FFSI,MRNSM,DSMGH,SDEPTH,STMD,PXCSA,HOUR,SAX,SOFRF,OFRFIS,SOFRFI,SNOW0002
     2  AMFSIL,PRH,SPTW,TANSM,SPLW,SFMD,OFRF,WT4AM,WT4PM,ASM,ASMRG,      SNOW0003
     3  SASFX,SARAX,DMXT,DMNT,RICY,FIRR)                                SNOW0004
C   SNOWMELT COMPUTATION                                                SNOW0005
      DIMENSION  DMNT(366),DMXT(366),FIRR(15),RICY(37)                  SNOW0006
      INTEGER  DAY,HOUR                                                 SNOW0007
      REAL  MHSM,MRNSM                                                  SNOW0008
      IF((DAY .NE. 274) .OR. (HOUR .NE. 1)) GO TO 100                   SNOW0009
      SPLW = 0.0                                                        SNOW0010
      XELR = 0.0                                                        SNOW0011
      SDSC = 0.0278                                                     SNOW0012
      FDSC = 0.0                                                        SNOW0013
      FTA = 0.0                                                         SNOW0014
      RICD = 0.0                                                        SNOW0015
      KRIA = 0                                                          SNOW0016
  100 CONTINUE                                                          SNOW0017
```

```
C  CALCULATION OF HOURLY AIR TEMPERATURE                                 SNOW0018
C     DMXT CURRENT DAY, DMNT NEXT DAY                                    SNOW0019
      IF(HOUR .NE. 4) GO TO 101                                          SNOW0020
      FDSC = 0.0                                                         SNOW0021
      FTA = FDSC                                                         SNOW0022
      WT4PM = DMXT(DAY) - 4.0*ELDIF + (XELR/4.0)*0.7*ELDIF               SNOW0023
  101 IF(HOUR .EQ. 10) SDSC = -0.0278                                    SNOW0024
      IF(HOUR .EQ. 22) SDSC = 0.0278                                     SNOW0025
      IF(HOUR .NE. 16) GO TO 102                                         SNOW0026
      NDAY = DAY + 1                                                     SNOW0027
      IF(NDAY .EQ. 366) NDAY = 1                                         SNOW0028
      IF(NDAY .EQ. 60 .AND. DMXT(366) .NE. 0.0) NDAY = 366               SNOW0029
      IF(NDAY .EQ. 367) NDAY = 60                                        SNOW0030
      WT4AM = DMNT(NDAY) - (XELR/4.0)*3.3*ELDIF                          SNOW0031
  102 IF(PRH .LE. 0.0 .OR. XELR .GE. 4.0) GO TO 103                      SNOW0032
      WT4AM = WT4AM - 0.825*ELDIF                                        SNOW0033
      WT4PM = WT4PM + 0.175*ELDIF                                        SNOW0034
      XELR = XELR + 1.0                                                  SNOW0035
  103 IF(PRH .NE. 0.0 .OR. XELR .LE. 0.0) GO TO 104                      SNOW0036
      WT4AM = WT4AM + 0.825*ELDIF                                        SNOW0037
      WT4PM = WT4PM - 0.175*ELDIF                                        SNOW0038
      XELR = XELR - 1.0                                                  SNOW0039
  104 TEH = WT4AM + FTA*(WT4PM - WT4AM)                                  SNOW0040
      FDSC = FDSC + SDSC                                                 SNOW0041
      FTA = FTA + FDSC                                                   SNOW0042
      IF(PRH+SPTW .EQ. 0.0) GO TO 128                                    SNOW0043
      IF(HOUR .NE. 24) GO TO 105                                         SNOW0044
C  CALCULATION OF TIME AGING OF THE SNOWPACK                             SNOW0045
      SAX = SAX + 1.0                                                    SNOW0046
      IF(SAX .GT. 15.0) SAX = 15.0                                       SNOW0047
  105 IF(TEH .GT. 32.0) GO TO 110                                        SNOW0048
C  PRECIPITATION IN FORM OF SNOW - CALCULATE INTERCEPTION DENSITY OF NEWSNOW0049
C     SNOW COMPACTION, AND SETTLING SNOW PACK AND THE EFFECT ON ALBEDO   SNOW0050
      IF(PRH .LE. 0.0) GO TO 110                                         SNOW0051
      PRH = SPM*PRH                                                      SNOW0052
      HSF = PRH                                                          SNOW0053
```

```
      ASM = ASM + HSF
      PRH = (1.0 - (FFSI*FFOR))*PRH
      HSFRG = PRH
      ASMRG = ASMRG + HSFRG
      FSIL = FFSI*FFOR*HSF
      AMFSIL = AMFSIL + FSIL
      IF(TEH .LE. 0.0) GO TO 106
      DNFS = XDNFS + ((0.01*TEH)**2)
      GO TO 107
  106 DNFS = XDNFS
  107 IF(SPTW .GT. 0.0 .AND. SDEPTH .GT. SPTW) SDEPTH = SDEPTH - ((PRH*
     1  SDEPTH/SPTW)*((0.10*SDEPTH)**0.25))
      SPTW = SPTW + PRH
      SDEPTH = SDEPTH + (PRH/DNFS)
      SASFX = SASFX + PRH
      IF(SASFX .GE. PXCSA) GO TO 108
      GO TO 109
  108 SAX = SAX - 1.0
      IF(SAX .LT. 0.0) SAX = 0.0
      SASFX = SASFX - PXCSA
  109 PRH = 0.0
  110 CONTINUE
      IF(SPTW .LE. 0.0) GO TO 127
C   SEASONAL MELT FACTOR ADJUSTMENT
      FDAY = DAY
      KAAO = KRIA
      KRIA = 1.0 + (FDAY/10.0)
      IF(KAAO .NE. KRIA) RICD = RICY(KRIA)
      IF(TEH .LE. 32.0) GO TO 111
      GO TO 114
C   CALCULATION OF NEGATIVE MELT
  111 IF(TANSM .LE. 11.5*MRNSM) GO TO 112
      IF(TANSM .LT. 1.0) TANSM = TANSM + ((5.0*MRNSM)**(1.3 + 2.0*
     1  TANSM))
      GO TO 113
  112 TANSM = TANSM + MRNSM
```

```
  113 IF(TANSM .GT. 0.08*SPTW) TANSM = 0.08*SPTW                         SNOW0090
      GO TO 127                                                         SNOW0091
C  EFFECT OF RAIN ON ALBEDO                                             SNOW0092
  114 SARAX = SARAX + PRH                                               SNOW0093
      IF(SARAX .LT. PXCSA/2.0) GO TO 115                                SNOW0094
      SAX = SAX + 1.0                                                   SNOW0095
      IF(SAX .GT. 15.0) SAX = 15.0                                      SNOW0096
      SASFX = 0.0                                                       SNOW0097
      SARAX = SARAX - (PXCSA/2.0)                                       SNOW0098
  115 IF(TEH .GT. 32.0) HSM = (TEH -32.0)*BDDFSM                        SNOW0099
      IF(TEH .LT. 32.0) HSM = 0.0                                       SNOW0100
      HSM = HSM*RICD                                                    SNOW0101
      KAA = 1.0 + SAX                                                   SNOW0102
      IF(SAX .LT. 15.0) HSM = HSM*(1.0 - ((1.0 - FFOR)*FIRR(KAA)))      SNOW0103
      IF(SAX .EQ. 15.0) HSM = HSM*(1.0 - ((1.0 - FFOR)*FIRR(15)))       SNOW0104
      IF(PRH .GT. 0.0) HSM = HSM + ((TEH - 32.0)*(PRH/144.0))           SNOW0105
      IF(STMD .GT. 0.3 .AND. SPTW .LT. SPTWCC) GO TO 116                SNOW0106
      GO TO 117                                                         SNOW0107
  116 MHSM = HSM                                                        SNOW0108
      HSM = (SPTW/SPTWCC)*HSM                                           SNOW0109
      IF(HSM .LT. 0.1*MHSM) HSM = 0.1*MHSM                              SNOW0110
  117 IF(HSM .LT. SPTW) GO TO 118                                       SNOW0111
      HSM = SPTW                                                        SNOW0112
      SDEPTH = 0.0                                                      SNOW0113
      SPTW = 0.0                                                        SNOW0114
      SPLW = 0.0                                                        SNOW0115
      RICD = 0.0                                                        SNOW0116
      TANSM = 0.0                                                       SNOW0117
      SAX = 15.0                                                        SNOW0118
      OFRF = SOFRF                                                      SNOW0119
      OFRFIS = SOFRFI                                                   SNOW0120
      GO TO 122                                                         SNOW0121
  118 SPTW = SPTW - HSM                                                 SNOW0122
      IF(SFMD .LE. 0.0) GO TO 122                                       SNOW0123
      IF(SAX .GE. 15.0) GO TO 121                                       SNOW0124
      IF(SAX .GE. 6.0) GO TO 119                                        SNOW0125
```

```
      SDEPTH = SDEPTH - (HSM/(0.5*SFMD))
      GO TO 122
  119 IF(SAX .LE. 10.0) GO TO 120
      SDEPTH = SDEPTH - (HSM/(0.9*SFMD))
      GO TO 122
  120 SDEPTH = SDEPTH - (HSM/(0.7*SFMD))
      GO TO 122
  121 SDEPTH = SDEPTH - (HSM/SFMD)
  122 CONTINUE
      IF(SPTW .LT. 0.00001) SPTW = 0.0
C  CALCULATION OF LIQUID-WATER-HOLDING CAPACITY
      SPLWC = SPBFLW*SPTW
      IF(SFMD .GT. 0.6) SPLWC = SPBFLW*(3.0 - 3.33*SFMD)*SPTW
      IF(SPLWC .LT. 0.0) SPLWC = 0.0
C  ACCOUNTING OF MELT WATER AND RAIN
      IF((SPLW + HSM + PRH) .GT. (SPLWC + TANSM)) GO TO 123
      GO TO 124
  123 PRH = HSM + PRH + SPLW - SPLWC - TANSM
      SPLW = SPLWC
      SPTW = SPTW + TANSM
      TANSM = 0.0
      GO TO 127
  124 IF((HSM + PRH) .LE. TANSM) GO TO 126
  125 SPTW = SPTW + TANSM
      SPLW = SPLW + HSM + PRH - TANSM
      PRH = 0.0
      TANSM = 0.0
      GO TO 127
  126 TANSM = TANSM - HSM - PRH
      SPTW = SPTW + HSM + PRH
      PRH = 0.0
  127 CONTINUE
      HSM = 0.0
C  CALCULATION OF DENSITY AND ADJUSTMENT OF OVERLAND FLOW TIME
      IF(SDEPTH .LE. 0.0 .OR. SPTW .GE. SDEPTH) GO TO 128
      STMD = (SPTW + SPLW)/SDEPTH
```

```
      SFMD = SPTW/SDEPTH                                                SNOW0162
      OFRF = 0.33*SOFRF                                                 SNOW0163
      IF(SPTW .LE. SPTWCC) OFRF = (1.0 - (SPTW/SPTWCC)*0.67)*SOFRF      SNOW0164
  128 IF(SDEPTH .LE. 0.0) OFRF = SOFRF                                  SNOW0165
      OFRFIS = SOFRFI*OFRF/SOFRF                                        SNOW0166
C  CALCULATION OF GROUNDMELT                                            SNOW0167
      IF( HOUR .NE. 12 .OR. SPTW .LE. 0.0) RETURN                       SNOW0168
      IF(SPTW .LE. DSMGH) GO TO 129                                     SNOW0169
      PRH = PRH + DSMGH                                                 SNOW0170
      SPTW = SPTW - DSMGH                                               SNOW0171
      IF(STMD .LT. 0.50 .AND. SDEPTH .GT. 2.0*DSMGH) SDEPTH = SDEPTH -  SNOW0172
     1  2.0*DSMGH                                                       SNOW0173
      RETURN                                                            SNOW0174
  129 PRH = SPTW + PRH + SPLW                                           SNOW0175
      TANSM = 0.0                                                       SNOW0176
      RIGD = 0.0                                                        SNOW0177
      SPLW = 0.0                                                        SNOW0178
      SDEPTH = 0.0                                                      SNOW0179
      SPTW = 0.0                                                        SNOW0180
      SAX = 15.0                                                        SNOW0181
      OFRF = SOFRF                                                      SNOW0182
      OFRFIS = SOFRFI                                                   SNOW0183
      RETURN                                                            SNOW0184
      END                                                               SNOW0185
```

APPENDIX B

LISTING OF OPSET

```
C  OPSET                                                                MAIN0001
C    A SELF-CALIBRATING VERSION OF THE STANFORD WATERSHED MODEL         MAIN0002
C  BASIC LOGIC OF INNER LOOP BASED ON STANFORD WATERSHED MODELS III & IVMAIN0003
C    VERSION OF NOVEMBER 12,1970                                        MAIN0004
      DIMENSION BTRI(99), CONOPT(5), CTRI(99), DRGPM(366), DRHP(366,24),MAIN0005
     1  DRSGP(366), DPET(366), DRSF(366), DSSF(366), EMGWS(12),         MAIN0006
     2  EMIFS(12), EMLZS(12), EMSIAM(12), EMUZC(12), EMUZS(12),         MAIN0007
     3  EPCM(12), HBF(5), IDYB(5), IDYE(5), IHRB(5), IHRE(5), KPSH(5),  MAIN0008
     4  LSHA(5), MEDCY(12), MEDWY(12), RHPD(5), RHPF(5), RHPH(5),       MAIN0009
     5  RSBBF(20),RSBD(20),RSBIF(20),SBFRS(3,20),SIFRS(3,20),SSR(5,170),MAIN0010
     6  THSF(24), TITLE(20), TMBF(12), TMIF(12), TMNET(12), TMOF(12),   MAIN0011
     7  TMPET(12), TMPREC(12), TMRTF(12), TMSE(12), TMSTF(12),          MAIN0012
     8  TMSTFI(12), UHFA(99), XMPFT(12)                                 MAIN0013
      LOGICAL LBMIR, LBUZC, LETLF, LLZC, LNPR, LRC, LSHA, LSHP          MAIN0014
      INTEGER CN, CONOPT, DATE, DAY, DPY, EHSGD, HOUR, HRF, HRL, PDAY,  MAIN0015
     1  PRD, RHPD, RHPH, RSBD, SGMD, SGRT, SGRT2, TRIP, YEAR, YR1,      MAIN0016
     2  YR2                                                             MAIN0017
      REAL IFPRC, IFRC, IFRL, IFS, LZC, LZRX, LZS, LZSR, MNRD, NHPT     MAIN0018
      DATA  MEDCY/  0,        31,59,90,120,151,181,212,243,273,304,334/ MAIN0019
      DATA  MEDWY/304,334,365,31,59,90,120,151,181,212,243,273         / MAIN0020
C  SPECIFY NUMBER OF STATION-YEARS INCLUDED IN COMPUTER RUN             MAIN0021
      NSYC = 0                                                          MAIN0022
      CALL READ(NSYT)                                                   MAIN0023
  100 NSYC = NSYC + 1                                                   MAIN0024
C  READ TITLE TO COMPUTER RUN                                           MAIN0025
      READ (5,1) TITLE                                                  MAIN0026
    1 FORMAT(20A4)                                                      MAIN0027
C  READ CONTROL OPTIONS                                                 MAIN0028
      DO 101 KRD = 1,3                                                  MAIN0029
```

```
 101 CALL READ(CONOPT(KRD))                                             MAIN0030
     CALL READ(MNRC,NFTR,NLTR)                                          MAIN0031
C  READ BASIC TIME-AREA HISTOGRAM                                       MAIN0032
     DO 102 KIA = 1,99                                                  MAIN0033
     BTRI(KIA) = 0.0                                                    MAIN0034
 102 UHFA(KIA) = 0.0                                                    MAIN0035
     CALL READ(NBTRI)                                                   MAIN0036
     DO 103 KRD = 1,NBTRI                                               MAIN0037
 103 CALL READ(BTRI(KRD))                                               MAIN0038
C  SET INITIAL CONDITIONS                                               MAIN0039
     IFT = 1                                                            MAIN0040
     LRC = .TRUE.                                                       MAIN0041
     LLZC = .FALSE.                                                     MAIN0042
     LBUZC = .FALSE.                                                    MAIN0043
     LBMIR = .FALSE.                                                    MAIN0044
     LETLF = .FALSE.                                                    MAIN0045
     LNPR = .FALSE.                                                     MAIN0046
     IF(CONOPT(2) .EQ. 0 .AND. NBTRI .LE. 6) LNPR = .TRUE.              MAIN0047
     KRC = 1                                                            MAIN0048
     KBRC = 0                                                           MAIN0049
     KFFC = 0                                                           MAIN0050
     SSSQM = 950.0                                                      MAIN0051
     SGRT = 0                                                           MAIN0052
C  READ FIXED PARAMETERS                                                MAIN0053
 104 CALL READ(RMPF,CHCAP)                                              MAIN0054
     CALL READ(RGPMB,AREA,FIMP,FWTR)                                    MAIN0055
     CALL READ(VINTMR,SUBWF,GWETF,OFSS,OFMN,OFMNIS,OFSL,DIV)            MAIN0056
C  CALCULATE CONSTANTS SET BY FIXED PARAMETERS                          MAIN0057
     FPER = 1.0 - FIMP - FWTR                                           MAIN0058
     IF(FPER .GT. 0.01) GO TO 105                                       MAIN0059
     TPLR = 100.0                                                       MAIN0060
     FPER = 0.01                                                        MAIN0061
     GO TO 106                                                          MAIN0062
 105 TPLR = (1.0 - FWTR)/FPER                                           MAIN0063
 106 VWIN = 26.8888*AREA                                                MAIN0064
     WCFS = 24.0*VWIN                                                   MAIN0065
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```
      RHFMC = 0.025/WCFS
      SSRT = SQRT(OFSS)
      OFRF = 1020.0*SSRT/(OFMN*OFSL)
      OFRFIS = 1020.0*SSRT/(OFMNIS*OFSL)
      EQDF = 0.00982*((OFMN*OFSL/SSRT)**0.6)
      EQDFIS = 0.00982*((OFMNIS*OFSL/SSRT)**0.6)
      RGPM = RGPMB
C   READ WATER YEAR
      CALL READ(YR1,YR2)
      DPY = 365
      IF(MOD(YR2,4) .EQ. 0) DPY = 366
C   READ EVAPORATION DATA
      IF(CONOPT( 1) .NE. 1) GO TO 111
      DO 107 KRD = 274,360,10
  107 CALL READ(DPET(KRD))
      DO 108 KRD = 1,273,10
  108 CALL READ(DPET(KRD))
      DO 110 IDAY2 = 1,9
      DO 109 IDAY1 = 274,360,10
      DAY = IDAY1 + IDAY2
  109 DPET(DAY) = DPET(IDAY1)
      DO 110 IDAY1 = 1,273,10
      DAY = IDAY1 + IDAY2
      IF(DAY .GT. 273) GO TO 110
      DPET(DAY) = DPET(IDAY1)
  110 CONTINUE
      DPET(366) = DPET(59)
      DPET(365) = DPET(363)
      DPET(364) = DPET(363)
      GO TO 113
  111 IF(CONOPT( 1) .EQ. 2) GO TO 116
      DAY = 274
  112 CALL READ (DPET(DAY))
      IF(DAY .EQ. 273) GO TO 113
      CALL DAYNXT(DAY, DPY)
      GO TO 112
```

```
  113 DO 114 MONTH = 1,12                                                 MAIN0102
  114 CALL READ(EPCM(MONTH))                                              MAIN0103
      DO 115 DAY = 1,DPY                                                  MAIN0104
  115 EPAET = EPAET + DPET(DAY)                                           MAIN0105
      IF(EPCM(6) .NE. 1.0) EPAET = 0.7*EPAET                              MAIN0106
      GO TO 117                                                           MAIN0107
  116 CALL READ(EPAET,MNRD)                                               MAIN0108
      EMAET = EPAET*(365.0 + MNRD)/404.0                                  MAIN0109
      CALL EVPDAY(DPET,EMAET)                                             MAIN0110
C  READ DAILY FLOW DATA                                                   MAIN0111
  117 DRSF(366) = 0.0                                                     MAIN0112
  118 DAY = 274                                                           MAIN0113
  119 CALL READ(DRSF(DAY))                                                MAIN0114
      CALL DAYNXT(DAY,DPY)                                                MAIN0115
      IF(DAY .NE. 274) GO TO 119                                          MAIN0116
      IF(DIV .EQ. 0.0) GO TO 122                                          MAIN0117
      DO 121 DAY = 1,DPY                                                  MAIN0118
      IF(DRSF(DAY) .GT. DIV) GO TO 120                                    MAIN0119
      DRSF(DAY) = 0.0                                                     MAIN0120
      GO TO 121                                                           MAIN0121
  120 DRSF(DAY) = DRSF(DAY) - DIV                                         MAIN0122
  121 CONTINUE                                                            MAIN0123
  122 WRITE(6,2) (TITLE(KTA), KTA = 1,20)                                 MAIN0124
    2 FORMAT(1H1,25X,20A4)                                                MAIN0125
C  WRITE DAILY FLOWS                                                      MAIN0126
      CALL DAYSUM(DRSF,MEDCY,DPY,RATFV,TMRTF)                             MAIN0127
      WRITE(6,3)                                                          MAIN0128
    3 FORMAT(1H0,42X,'RECORDED        FLOWS')                             MAIN0129
      CALL DAYOUT(DRSF,MEDWY,DPY)                                         MAIN0130
      WRITE(6,4) (TMRTF(KWD), KWD = 1,12),RATFV                           MAIN0131
    4 FORMAT(6X,'TOTAL',2X,12F8.1,2X,F10.1,2X,3HSFD)                      MAIN0132
C  READ STORM HYDROGRAPH DATA                                             MAIN0133
      CALL READ(NRHP,NHPT)                                                MAIN0134
      IF(NRHP .EQ. 0) GO TO 124                                           MAIN0135
      DO 123 KRD = 1,NRHP                                                 MAIN0136
      CALL READ(RHPD(KRD),RHPH(KRD),RHPF(KRD))                            MAIN0137
```

```
  123 WRITE(6,5) KRD,NHPT,RHPD(KRD),RHPH(KRD),RHPF(KRD)                 MAIN0138
    5 FORMAT(//5X,'RECORDED HYDROGRAPH',I3/10X,'HYDROGRAPH INTERVAL =', MAIN0139
     1F5.2,1X,5HHOURS/10X,'CALENDAR DAY OF PEAK =',I5,5X,'HOUR OF DAY ='MAIN0140
     2,I4,5X,'PEAK FLOW =',F8.1,1X,3HCFS)                               MAIN0141
C  INITIALIZE PRECIPITION DATA ARRAYS                                   MAIN0142
  124 DO 125 DAY = 1,366                                                MAIN0143
      DRGPM(DAY) = RGPMB                                                MAIN0144
      DSSF(DAY) = 0.0                                                   MAIN0145
      DRSGP(DAY) = 0.0                                                  MAIN0146
      DO 125 HOUR = 1,24                                                MAIN0147
  125 DRHP(DAY,HOUR) = 0.0                                              MAIN0148
C  READ AUXILIARY RAIN GAGE DAILY TOTALS                                MAIN0149
      CALL READ(NSGRD)                                                  MAIN0150
      IF(NSGRD .EQ. 0) GO TO 127                                        MAIN0151
      CALL READ(WSG,SGRT)                                               MAIN0152
      IF(CONOPT(3) .EQ. 1) CALL READ(WSG2,SGRT2,SGMD)                   MAIN0153
      DO 126 KRD = 1,NSGRD                                              MAIN0154
      CALL READ(ISGRD)                                                  MAIN0155
  126 CALL READ(DRSGP(ISGRD))                                           MAIN0156
C  READ RECORDING RAIN GAGE HOURLY TOTALS                               MAIN0157
  127 CALL READ(IWBG,YEAR,MONTH,DATE,CN)                                MAIN0158
C  PUNCH NO NUMBERS AFTER CN ON YEAR .EQ. 98 CARD                       MAIN0159
      IF(YEAR .GE. 98) GO TO 130                                        MAIN0160
      HRF = 12*(CN-1) + 1                                               MAIN0161
      HRL = 12*(CN-1) + 12                                              MAIN0162
      DAY = MEDCY(MONTH) + DATE                                         MAIN0163
      DO 128 HOUR = HRF,HRL                                             MAIN0164
  128 CALL READ(DRHP(DAY,HOUR))                                         MAIN0165
      IF(DPY .NE. 366 .OR. MONTH .NE. 2 .OR. DATE .NE. 29) GO TO 127    MAIN0166
      DO 129 HOUR = HRF,HRL                                             MAIN0167
      DRHP(366,HOUR) = DRHP(60,HOUR)                                    MAIN0168
  129 DRHP(60,HOUR) = 0.0                                               MAIN0169
      GO TO 127                                                         MAIN0170
C  CALCULATE PRECIPITATION WEGHTING FACTORS                             MAIN0171
  130 IF(NSGRD .EQ. 0) GO TO 137                                        MAIN0172
      PDAY = 274                                                        MAIN0173
```

```
      RDPT = 0.0
      DAY = 274
  131 EHSGD = SGRT
      IF(SGRT .EQ. 0) EHSGD = 24
      EHSGDF = EHSGD
  132 CONTINUE
      DO 136 HOUR = 1,24
      RDPT = RDPT + DRHP(DAY,HOUR)
      IF(HOUR .NE. EHSGD) GO TO 136
      IF(RDPT .LE. 0.0) GO TO 133
      IF(SGRT .EQ. 0) PDAY = DAY
      DRGPM (PDAY) = (DRSGP(DAY)*WSG + RDPT*(1.0 - WSG))/RDPT
      IF(CONOPT(1) .NE. 0) DPET(PDAY) = 0.5*DPET(PDAY)
      IF(SGRT .NE. 0) PDAY = DAY
      RDPT = 0.0
      GO TO 136
  133 IF(DRSGP(DAY) .LE. 0.0) GO TO 135
      DO 134 KHOUR = 1,EHSGD
  134 DRHP(DAY,KHOUR) = (WSG*DRSGP(DAY))/EHSGDF
  135 IF(SGRT .NE. 0) PDAY = DAY
  136 CONTINUE
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 137
      IF(CONOPT(3) .EQ. 0) GO TO 132
      IF(DAY .NE. SGMD) GO TO 132
      WSG = WSG2
      SGRT = SGRT2
      GO TO 131
C  ADJUST RAINFALL ANOMALIES
  137 MXTRH = 2*NBTRI
      IF(CONOPT(2) .EQ. 0) MXTRH = (2*NBTRI - 1)/4 + 1
      NATRH = MXTRH/2
      IF(NFTR .GE. 2) GO TO 138
      IF(NATRH .LT. 12) CALL PRECHK(DRGPM,DRHP,DRSF,VWIN,SGRT,NATRH)
C  SET INITIAL VALUES OF VARIABLE PARAMETERS TO BE OPTIMIZED
      LZC = 12.0
```

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      BMIR = 1.2                                                        MAIN0210
      SUZC = 1.3                                                        MAIN0211
      ETLF = 0.25                                                       MAIN0212
      BUZC = 1.50                                                       MAIN0213
      SIAC = 0.90                                                       MAIN0214
      BIVF = 0.90                                                       MAIN0215
  138 IF(NFTR .EQ. 3) GO TO 139                                         MAIN0216
      SRX = 0.98                                                        MAIN0217
      NCTRI = NBTRI                                                     MAIN0218
      CSRX = SRX                                                        MAIN0219
      FSRX = SRX                                                        MAIN0220
      CALL RECESS(DRSF,DPY,BFRC,IFRC,AREA,RSBD,RSBIF,NRS,RSBBF)         MAIN0221
      IF(IFRC .GE. 0.3) GO TO 139                                       MAIN0222
      WRITE(6,6) IFRC                                                   MAIN0223
    6 FORMAT(/10X,'REJECTED IFRC =',F8.4)                               MAIN0224
      IFRC = 0.1                                                        MAIN0225
      BIVF = 0.0                                                        MAIN0226
  139 IF(NFTR .GE. 2) CALL READ(LZC,BMIR,SUZC,ETLF,BUZC,SIAC,BIVF,LZS)  MAIN0227
      IF(NFTR .EQ. 3) CALL READ(CSRX,FSRX,NCTRI,CHCAP,IFRC,BFRC)        MAIN0228
  140 BFHRC = BFRC**(1.0/24.0)                                          MAIN0229
      BFRL = -ALOG(BFHRC)                                               MAIN0230
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                                MAIN0231
      TRIP = NFTR                                                       MAIN0232
      SRX = CSRX                                                        MAIN0233
      KHYD = 1                                                          MAIN0234
      LSHP = .FALSE.                                                    MAIN0235
      DO 141 KIA = 1,5                                                  MAIN0236
      KPSH(KIA) = 0                                                     MAIN0237
  141 HBF(KIA) = 0.0                                                    MAIN0238
C   POINT OF RETURN FOR NEW TRIP                                        MAIN0239
  142 IF(KRC .LE. 5) FTX = 1.0                                          MAIN0240
      IF(DPY .EQ. 366) MEDWY(5) = 366                                   MAIN0241
      PPH = 1.0                                                         MAIN0242
      IF(.NOT. LRC) PPH = 3.0                                           MAIN0243
      IF(TRIP .NE. 1) PPH = 4.0                                         MAIN0244
      IPPH = PPH                                                        MAIN0245
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      FHPP = 1.0/PPH                                                    MAIN0246
      IFPRC = IFRC**(FHPP/24.0)                                         MAIN0247
      IFRL = -ALOG(IFPRC)                                               MAIN0248
      VINTCR = FHPP*VINTMR                                              MAIN0249
      NCTRH = NCTRI                                                     MAIN0250
      IF(CONOPT(2) .EQ. 0) NCTRH = (NCTRI - 1)/4 + 1                    MAIN0251
C  DETERMINE STORM HOURS FOR ADJUSTING HYDROGRAPH SHAPE VARIABLES       MAIN0252
      IF(NRHP .NE. 0 .AND. TRIP .EQ. 2) CALL STRHRS(RHPD,RHPH,IDYB,     MAIN0253
     1  IDYE,IHRB,IHRE,NHPT,MXTRH,DPY,NRHP,IBTPR)                       MAIN0254
      HSE = 0.0                                                         MAIN0255
      NRTRI = 0                                                         MAIN0256
      PEAI = 0.0                                                        MAIN0257
      SPIF = 0.0                                                        MAIN0258
      OFUS = 0.0                                                        MAIN0259
      OFUSIS = 0.0                                                      MAIN0260
      RHFO = 0.0                                                        MAIN0261
      URHF = 0.0                                                        MAIN0262
      AMIF = 0.0                                                        MAIN0263
      AMNET = 0.0                                                       MAIN0264
      AMPET = 0.0                                                       MAIN0265
      AMPREC = 0.0                                                      MAIN0266
      AMBF = 0.0                                                        MAIN0267
      AMSE = 0.0                                                        MAIN0268
      KRS = 1                                                           MAIN0269
      KDRS = 400                                                        MAIN0270
      UZS = 0.0                                                         MAIN0271
      IFS = 0.0                                                         MAIN0272
      IF(NFTR  .GE. 2) GO TO 145                                        MAIN0273
      IF(KRC .NE. 1) GO TO 143                                          MAIN0274
      BYLZS = 6.00                                                      MAIN0275
      LZS = BYLZS                                                       MAIN0276
      GO TO 145                                                         MAIN0277
  143 IF(EMLZS(11) .LT. LZS) LZS = EMLZS(11)                            MAIN0278
      LZS = LZS*LZC/PLZC                                                MAIN0279
      IF(LLZC) LZS = LZC - (LZC-LZS)*(SATFV/RATFV)                      MAIN0280
      IF(ABS(FTX - 1.0) .LT. 0.02) GO TO 144                            MAIN0281
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      LZS = FTX*BBYLZS*LZC/BLZC                                         MAIN0282
      IF(LRC .AND. LZC-LZS .LT. 2.0) LZC = LZS + 2.0                    MAIN0283
  144 IF(TRIP .EQ. 3 .OR. KFFC .EQ. 1) LZS = BBYLZS                     MAIN0284
      KFFC = 0                                                          MAIN0285
  145 OCT1BF = 0.05*TMRTF(1)                                            MAIN0286
      IF(DRSF(274) .LT. 0.05*TMRTF(1)) OCT1BF = DRSF(274)               MAIN0287
      IF(DRSF(276) .LT. OCT1BF*BFRC**2) OCT1BF = DRSF(276)/BFRC**2      MAIN0288
      BYGWS = OCT1BF/(WCFS*BFRL*SQRT(BFRC))                             MAIN0289
      GWS = BYGWS                                                       MAIN0290
      BYLZS = LZS                                                       MAIN0291
      BFNX = GWS*BFRL                                                   MAIN0292
      TFCFS = BFNX*WCFS                                                 MAIN0293
      WRITE(6,7) TRIP,LZC,BMIR,SUZC,ETLF,BUZC,SIAC,BIVF,BFRC,IFRC,      MAIN0294
     1CSRX,FSRX,NCTRI,CHCAP                                             MAIN0295
    7 FORMAT(1H1,3X,'TRIAL RUN NUMBER',I3/5X,'PARAMETER VALUES'/10X,    MAIN0296
     1  5HLZC =,3X,F8.4,2X,6HBMIR =,2X,F8.4,2X,6HSUZC =,2X,F8.4,2X,     MAIN0297
     2  6HETLF =,2X,F8.4,2X,6HBUZC =,2X,F8.4,2X,6HSIAC =,2X,F8.4/10X,   MAIN0298
     3  6HBIVF =,2X,F8.4,2X,6HBFRC =,2X,F8.4,2X,6HIFRC =,2X,F8.4,2X,    MAIN0299
     4  6HCSRX =,2X,F8.4,2X,6HFSRX =,2X,F8.4,2X,7HNCTRI =,1X,I8/10X,    MAIN0300
     5  7HCHCAP =,1X,F8.0)                                              MAIN0301
      WRITE(6,8) LZS,GWS                                                MAIN0302
    8 FORMAT(/5X,'INITIAL MOISTURE STORAGES,  LZS =',F9.4,5X,'GWS =',   MAIN0303
     1  F9.4)                                                           MAIN0304
      AETX = 24.0*EPAET/365.0                                           MAIN0305
      AEX96 = 1.2*AETX                                                  MAIN0306
      AEX90 = 0.3*AETX                                                  MAIN0307
      SIAM = 1.2**SIAC                                                  MAIN0308
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)                         MAIN0309
      IF(UZC .LT. 0.25) UZC = 0.25                                      MAIN0310
      MONTH = 1                                                         MAIN0311
      MDAY = 273                                                        MAIN0312
      IF(TRIP .EQ. 1) GO TO 147                                         MAIN0313
  146 WRITE(6,9) (TITLE(KTA), KTA=1,20)                                 MAIN0314
    9 FORMAT(25X,20A4)                                                  MAIN0315
      WRITE(6,10) YR1,YR2                                               MAIN0316
   10 FORMAT(03X,61HOPTIMIZATION OF MODEL INPUT PARAMETERS BASED ON WATEMAIN0317
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     1R YEAR 19,I2,1H-,I2)
      WRITE(6,11)
   11 FORMAT(8H OCTOBER)
C  BEGIN DAY LOOP
  147 DAY = 274
  148 CONTINUE
      IF(TRIP .NE. 1) GO TO 149
      KDRS = KDRS + 1
      IF(RSBD(KRS) .NE. DAY) GO TO 149
      KDRS = 1
      KRS = KRS + 1
  149 CONTINUE
      ADIF = 0.0
      ADBF = 0.0
      TDSF = 0.0
      PET = DPET(DAY)
      IF(CONOPT(1) .NE. 2) PET = PET*EPCM(MONTH)
      PETU = PET
      TFMAX = 0.0
      DO 190 HOUR = 1,24
      IF(TRIP .NE. 2) GO TO 152
C  LOGICAL VARIABLE 'LSHP' SET TRUE DURING DURATION OF RECORDED HYDRO-
C  GRAPH SO SYNTHESIZED DATA MAY BE SAVED DURING CORRESPONDING PERIOD
      IF(KHYD .GT. NRHP) GO TO 152
      IF(IDYB(KHYD) .EQ. DAY .AND. IHRB(KHYD) .EQ. HOUR) LSHP = .TRUE.
      IF(KHYD .GE. NRHP) GO TO 150
      IF(IDYB(KHYD+1) .EQ.  DAY .AND. IHRB(KHYD+1) .EQ. HOUR) KHYD =
     1  KHYD + 1
  150 IF(IDYE(KHYD) .NE. DAY .OR. IHRE(KHYD) .NE. HOUR) GO TO 151
      KHYD = KHYD + 1
      LSHP = .FALSE.
  151 IF(.NOT. LSHP) GO TO 152
      KPSH(KHYD) = KPSH(KHYD) + 1
      IF(KPSH(KHYD) .LT. 171) GO TO 152
      WRITE(6,12)
   12 FORMAT(5X,'FLOOD HYDROGRAPH ARRAY EXCEEDED, SHORTEN NHPT OR SHIFT
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     1TO HOURLY ROUTING')
      GO TO 228
  152 CONTINUE
      IF((NSGRD .EQ. 0) .AND. (DRHP(DAY,HOUR) .NE. 0.0) .AND. (PET .EQ.
     1  PETU) .AND. (CONOPT(1) .NE. 0)) PET = 0.5*PET
  153 IF(HOUR .EQ. SGRT+1) RGPM = DRGPM(DAY)
      IF(HOUR .EQ. 9) HSE = (FWTR*PET)/12.0
      IF(HOUR .EQ. 21) HSE = 0.0
      PRH = RGPM*DRHP(DAY,HOUR)
      AMPREC = AMPREC + PRH
      ARHF = 0.0
C   15 MIN ACCOUNTING AND ROUTING LOOP (60 MINUTES USED FOR ROUGH
C     ADJUSTMENT, AND 20 MINUTES FOR FINE ADJUSTMENT IN TRIP 1)
      DO 182 PRD = 1,IPPH
      IF(LSHP .AND. CONOPT(2) .EQ. 0 .AND. PRD .NE. 1) KPSH(KHYD) =
     1  KPSH(KHYD) + 1
      PEBI = 0.0
      PPI = 0.0
      OFR = 0.0
      OFRIS = 0.0
      WI = 0.0
      WEIFS = 0.0
      PEP = FHPP*PRH
      IF(TRIP .GE. 2 .AND. LNPR) CALL PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,
     1  PEP,PRH)
      IF(PEP .GT. 0.0) GO TO 155
      IF(OFUS .GT. 0.0) GO TO 157
      IF(IFS .GT. 0.0) GO TO 167
      IF(TRIP .EQ. 1) GO TO 181
      IF(NRTRI .GT. 0) GO TO 169
      TRHF = 0.0
      IF(.NOT. LSHP) GO TO 154
      KHPT = KPSH(KHYD)
      SSR(KHYD,KHPT) = 0.0
  154 CONTINUE
      IF(RHFO .GT. 0.0) GO TO 178
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      GO TO 181                                                         MAIN0390
C  RAINFALL UPPER ZONE INTERACTION                                      MAIN0391
  155 IF(PEP .GE. VINTCR) GO TO 156                                     MAIN0392
      UZS = UZS + PEP*TPLR                                              MAIN0393
      VINTCR = VINTCR - PEP                                             MAIN0394
      PPI = 0.0                                                         MAIN0395
      PEBI = 0.0                                                        MAIN0396
      IF(OFUS .GT. 0.0) GO TO 157                                       MAIN0397
      GO TO 167                                                         MAIN0398
  156 PPI = PEP - VINTCR                                                MAIN0399
      UZS = UZS + VINTCR*TPLR                                           MAIN0400
      VINTCR = 0.0                                                      MAIN0401
      LZSR = LZS/LZC                                                    MAIN0402
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZSR)                            MAIN0403
      IF(UZC .LT. 0.25) UZC = 0.25                                      MAIN0404
      UZRX = 2.0*ABS(UZS/UZC - 1.0) + 1.0                               MAIN0405
      FMR = (1.0/(1.0 + UZRX))**UZRX                                    MAIN0406
      IF(UZS .GT. UZC) FMR = 1.0 - FMR                                  MAIN0407
      PEBI = PPI*FMR                                                    MAIN0408
      UZS = UZS + PPI - PEBI                                            MAIN0409
C  LOWER ZONE AND GROUNDWATER INFILTRATION                              MAIN0410
  157 LZSR = LZS/LZC                                                    MAIN0411
      EID = 4.0*LZSR                                                    MAIN0412
      IF(LZSR .LE. 1.0) GO TO 158                                       MAIN0413
      EID = 4.0 + 2.0*(LZSR - 1.0)                                      MAIN0414
      IF(LZSR .LE. 2.0) GO TO 158                                       MAIN0415
      EID = 6.0                                                         MAIN0416
  158 PEBI = PEBI + OFUS                                                MAIN0417
      CMIR = FHPP*SIAM*BMIR/(2.0**EID)                                  MAIN0418
      CIVM = BIVF*2.0**LZSR                                             MAIN0419
      IF(CIVM .LT. 1.0) CIVM = 1.0                                      MAIN0420
      PEAI = PEBI*PEBI/(2.0*CMIR*CIVM)                                  MAIN0421
      WI = PEBI*PEBI/(2.0*CMIR)                                         MAIN0422
      IF(PEBI .GE. CMIR) WI = PEBI - 0.5*CMIR                           MAIN0423
      IF(PEBI .GE. CMIR*CIVM) PEAI = PEBI - 0.5*CMIR*CIVM               MAIN0424
      WEIFS = WI - PEAI                                                 MAIN0425
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      IF((PEAI - OFUS) .GT. 0.0) GO TO 159                              MAIN0426
      EQD = (OFUS + PEAI)/2.0                                           MAIN0427
      GO TO 160                                                         MAIN0428
  159 EQD = EQDF*((PEAI - OFUS)**0.6)                                   MAIN0429
  160 IF((OFUS + PEAI) .GT. (2.0*EQD)) EQD = 0.5*(OFUS + PEAI)          MAIN0430
      IF((OFUS + PEAI) .LE. 0.001) GO TO 161                            MAIN0431
      OFR = FHPP*OFRF*(((OFUS + PEAI)*0.5)**1.67)*((1.0 + 0.6*((OFUS +  MAIN0432
     1  PEAI)/(2.0*EQD))**3.0)**1.67)                                   MAIN0433
      IF(OFR .GT. (0.75*PEAI)) OFR = 0.75*PEAI                          MAIN0434
  161 IF(FIMP .EQ. 0.0) GO TO 165                                       MAIN0435
  162 PEIS = PPI + OFUSIS                                               MAIN0436
      IF((PEIS - OFUSIS) .GT. 0.0) GO TO 163                            MAIN0437
      EQDIS = (OFUSIS + PEIS)/2.0                                       MAIN0438
      GO TO 164                                                         MAIN0439
  163 EQDIS = EQDFIS*((PEIS - OFUSIS)**0.6)                             MAIN0440
  164 IF((OFUSIS + PEIS) .GT. (2.0*EQDIS)) EQDIS = 0.5*(OFUSIS + PEIS)  MAIN0441
      IF((OFUSIS + PEIS) .LE. 0.01) GO TO 165                           MAIN0442
      OFRIS = FHPP*OFRFIS*(((OFUSIS + PEIS)*0.5)**1.67)*((1.0 + 0.6*((  MAIN0443
     1  OFUSIS + PEIS)/(2.0*EQDFIS))**3.0)**1.67)                       MAIN0444
      IF(OFRIS .GT. PEIS) OFRIS = PEIS                                  MAIN0445
  165 OFUSIS = PEIS - OFRIS                                             MAIN0446
      OFUS = PEAI - OFR                                                 MAIN0447
      IF(OFUS .GE. 0.001) GO TO 166                                     MAIN0448
      LZS = LZS + OFUS                                                  MAIN0449
      OFUS = 0.0                                                        MAIN0450
      OFRIS = OFRIS + OFUSIS                                            MAIN0451
      OFUSIS = 0.0                                                      MAIN0452
  166 LZRX = 1.5*ABS(LZS/LZC - 1.0) + 1.0                               MAIN0453
      FMR = (1.0/(1.0 + LZRX))**LZRX                                    MAIN0454
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*(LZS/LZC)                        MAIN0455
      PLZS = FMR*(PEBI - WI)                                            MAIN0456
      PGW = (1.0 -FMR)*(PEBI - WI)*(1.0 - SUBWF)*FPER                   MAIN0457
      GWS = GWS + PGW                                                   MAIN0458
      LZS = LZS + PLZS                                                  MAIN0459
      IFS = IFS + WEIFS*FPER                                            MAIN0460
  167 SPIF = IFRL*IFS                                                   MAIN0461
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      AMIF = AMIF + SPIF                                                MAIN0462
      ADIF = ADIF + SPIF                                                MAIN0463
      IFS = IFS - SPIF                                                  MAIN0464
      IF(IFS .GE. 0.0001) GO TO 168                                     MAIN0465
      LZS = LZS + IFS                                                   MAIN0466
      IFS = 0.0                                                         MAIN0467
  168 UHFA(1) = FPER*OFR + PPI*FWTR + FIMP*OFRIS + SPIF                 MAIN0468
      IF(TRIP .NE. 1) GO TO 169                                         MAIN0469
      ARHF = ARHF + UHFA(1)                                             MAIN0470
      GO TO 181                                                         MAIN0471
C  ROUTING                                                              MAIN0472
  169 IF(CONOPT( 2) .NE. 1) GO TO 170                                   MAIN0473
      URHF = URHF + 0.25*UHFA(1)                                        MAIN0474
      IF(PRD .NE. 4) GO TO 178                                          MAIN0475
      UHFA(1) = URHF                                                    MAIN0476
C  SAVE SYNTHESIZED DIRECT RUNOFF AND INTERFLOW ENTERING STREAM DURING  MAIN0477
C    DURATION OF RECORDED HYDROGRAPH                                    MAIN0478
  170 IF(.NOT. LSHP) GO TO 171                                          MAIN0479
      KHPT = KPSH(KHYD)                                                 MAIN0480
      IF(CONOPT(2) .EQ. 1) SSR(KHYD,KHPT) = 4.0*URHF*WCFS               MAIN0481
      IF(CONOPT(2) .EQ. 0) SSR(KHYD,KHPT) = 4.0*UHFA(1)*WCFS            MAIN0482
  171 CONTINUE                                                          MAIN0483
      TRHF = 0.0                                                        MAIN0484
      KTRI = NCTRI                                                      MAIN0485
  172 URHF = UHFA(KTRI)                                                 MAIN0486
      IF(URHF .LE. 0.0) GO TO 174                                       MAIN0487
  173 TRHF = TRHF + URHF*CTRI(KTRI)                                     MAIN0488
      UHFA(KTRI + 1) = URHF                                             MAIN0489
      GO TO 175                                                         MAIN0490
  174 UHFA(KTRI+ 1) = 0.0                                               MAIN0491
  175 KTRI = KTRI - 1                                                   MAIN0492
      IF(KTRI .GE. 1) GO TO 172                                         MAIN0493
  176 IF(URHF .LE. 0.0) GO TO 177                                       MAIN0494
      NRTRI = NCTRI                                                     MAIN0495
  177 NRTRI = NRTRI - 1                                                 MAIN0496
      UHFA(1) = 0.0                                                     MAIN0497
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      URHF = 0.0                                                        MAIN0498
  178 IF(TRIP .LE. 2) GO TO 179                                         MAIN0499
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX                               MAIN0500
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX = CSRXMAIN0501
     1 +(FSRX - CSRX)*((TFCFS - 0.5*CHCAP)/(1.5*CHCAP))**3              MAIN0502
      IF(TFCFS .GT. 2.0*CHCAP) SRX = FSRX                               MAIN0503
  179 RHF1 = TRHF - SRX*(TRHF - RHF0)                                   MAIN0504
      RHF0 = RHF1                                                       MAIN0505
      IF(RHF0 .LT. RHFMC) RHF0 = 0.0                                    MAIN0506
      TFCFS = (4.0*RHF1 + CBF - HSE)*WCFS                               MAIN0507
      IF(TFCFS .LE. TFMAX) GO TO 180                                    MAIN0508
      PRDF = PRD                                                        MAIN0509
      TDFP24 = HOUR                                                     MAIN0510
      IF(PRD .LE. 3) TDFP24 = (TDFP24 - 1.0) + 0.15*PRDF                MAIN0511
      TFMAX = TFCFS                                                     MAIN0512
  180 ARHF = ARHF + RHF1                                                MAIN0513
  181 IF(VINTCR .LT. FHPP*VINTMR) VINTCR = VINTCR + DPET(DAY)/(24.0/    MAIN0514
     1 FHPP)                                                            MAIN0515
  182 CONTINUE                                                          MAIN0516
C  END OF 15 MINUTE LOOP                                                MAIN0517
C  ADDING GROUNDWATER FLOW                                              MAIN0518
  183 CBF = GWS*BFRL                                                    MAIN0519
      IF(KHYD .GT. NRHP) GO TO 184                                      MAIN0520
      IF(LSHP .AND. (HBF(KHYD) .EQ. 0.0)) HBF(KHYD) = CBF*WCFS          MAIN0521
  184 GWS = GWS - CBF                                                   MAIN0522
      AMBF = AMBF + CBF                                                 MAIN0523
      THGR = ARHF + CBF                                                 MAIN0524
C  EVAPORATION FROM STREAM SURFACE                                      MAIN0525
  185 IF(HSE .GT. THGR) HSE = THGR                                      MAIN0526
      IF(CBF .GT. HSE) ADBF = ADBF + CBF - HSE                          MAIN0527
      AMSE = AMSE + HSE                                                 MAIN0528
      THSF(HOUR) = (THGR - HSE)*WCFS                                    MAIN0529
      IF(TFMAX .LE. 0.0) TFMAX = THSF(HOUR)                             MAIN0530
      TDSF = TDSF + THSF(HOUR)                                          MAIN0531
C  DRAINING OF UPPER ZONE STORAGE                                       MAIN0532
      UZINFX = (UZS/UZC) - (LZS/LZC)                                    MAIN0533
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      IF(UZINFX .LE. 0.0) GO TO 186                                     MAIN0534
      LZSR = LZS/LZC                                                    MAIN0535
      UZINLZ = 0.003*BMIR*UZC*UZINFX**3.0                               MAIN0536
      IF(UZINLZ .GT. UZS) UZINLZ = UZS                                  MAIN0537
      UZS = UZS - UZINLZ                                                MAIN0538
      LZRX = 1.5*ABS(LZSR - 1.0) + 1.0                                  MAIN0539
      FMR = (1.0/(1.0 + LZRX))**LZRX                                    MAIN0540
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*LZSR                             MAIN0541
      PGW = (1.0-FMR)*UZINLZ*(1.0 - SUBWF)*FPER                         MAIN0542
      PLZS = FMR*UZINLZ                                                 MAIN0543
      LZS = LZS + PLZS                                                  MAIN0544
      GWS = GWS + PGW                                                   MAIN0545
C   4 PM ADJUSTMENTS OF VARIOUS VALUES                                  MAIN0546
  186 IF(HOUR .NE. 16) GO TO 190                                        MAIN0547
      AEX90 = 0.9*(AEX90 + PET)                                         MAIN0548
      AEX96 = 0.96*(AEX96 + PET)                                        MAIN0549
C   INFILTRATION CORRECTION                                             MAIN0550
      SIAM = (AEX96/AETX)**SIAC                                         MAIN0551
      IF(SIAM .LT. 0.33) SIAM = 0.33                                    MAIN0552
      IF(PET .EQ. 0.0) GO TO 190                                        MAIN0553
C   EVAP-TRANS LOSS FROM GROUNDWATER                                    MAIN0554
      GWET = GWS*GWETF*PET*FPER                                         MAIN0555
      GWS = GWS - GWET                                                  MAIN0556
      AMPET = AMPET + PET                                               MAIN0557
      IF(PET .GE. UZS) GO TO 187                                        MAIN0558
      UZS = UZS - PET                                                   MAIN0559
      AMNET = AMNET + PET                                               MAIN0560
      GO TO 190                                                         MAIN0561
  187 PET = PET - UZS                                                   MAIN0562
      AMNET = AMNET + UZS                                               MAIN0563
      UZS = 0.0                                                         MAIN0564
      LZSR = LZS/LZC                                                    MAIN0565
      IF(PET .GE. ETLF*LZSR) GO TO 188                                  MAIN0566
      SET = PET*(1.0 - PET/(2.0*ETLF*LZSR))                             MAIN0567
      GO TO 189                                                         MAIN0568
  188 SET = 0.5*ETLF*LZSR                                               MAIN0569
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  189 LZS = LZS - SET                                                   MAIN0570
      AMNET = AMNET + SET                                               MAIN0571
  190 CONTINUE                                                          MAIN0572
C  END OF HOUR LOOP                                                     MAIN0573
      DSSF(DAY) = TDSF/24.0                                             MAIN0574
      IF(TRIP .EQ. 1) GO TO 192                                         MAIN0575
      IF(TFMAX .LE. RMPF) GO TO 192                                     MAIN0576
      IF(DAY .EQ. 366) MDAY = 337                                       MAIN0577
      DATE = MOD(DAY,MDAY)                                              MAIN0578
      WRITE(6,13) DATE, (THSF(HOUR),HOUR=1,12)                          MAIN0579
   13 FORMAT(1H/,1X/,1X,I4,2X,2HAM,1X,6F8.1,3X,6F8.1)                   MAIN0580
      WRITE(6,14) (THSF(HOUR),HOUR=13,24), DSSF(DAY)                    MAIN0581
   14 FORMAT(1HJ,6X,2HPM,1X,6F8.1,3X,7F8.1)                             MAIN0582
      IF(TDFP24 .LT. 12.0) GO TO 191                                    MAIN0583
      TDFP12 = TDFP24 - 12.0                                            MAIN0584
      WRITE(6,15) TFMAX, TDFP12                                         MAIN0585
   15 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,  MAIN0586
     1  4HP.M.)                                                         MAIN0587
      GO TO 192                                                         MAIN0588
  191 WRITE(6,16) TFMAX,TDFP24                                          MAIN0589
   16 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,  MAIN0590
     1  4HA.M.)                                                         MAIN0591
  192 CONTINUE                                                          MAIN0592
      IF(TRIP .EQ. 1 .AND. .NOT. LRC .AND. KDRS .LE. 3 .AND. IFRC .GT.  MAIN0593
     1  0.1) SIFRS(KDRS,KRS-1) = ADIF*VWIN                              MAIN0594
      IF(TRIP .EQ. 1 .AND. KDRS .LE. 3) SBFRS(KDRS,KRS-1) = ADBF*VWIN   MAIN0595
C  MONTHLY SUMMARY STORAGE                                              MAIN0596
      IF(DAY .NE. MEDWY(MONTH)) GO TO 206                               MAIN0597
      TMPREC(MONTH) = AMPREC                                            MAIN0598
      AMPREC = 0.0                                                      MAIN0599
      TMBF(MONTH) = AMBF                                                MAIN0600
      AMBF = 0.0                                                        MAIN0601
      TMIF(MONTH) = AMIF                                                MAIN0602
      AMIF = 0.0                                                        MAIN0603
      TMSE(MONTH) = AMSE                                                MAIN0604
      AMSE = 0.0                                                        MAIN0605
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      TMPET(MONTH) = AMPET                                              MAIN0606
      AMPET = 0.0                                                       MAIN0607
      TMNET(MONTH) = AMNET                                              MAIN0608
      AMNET = 0.0                                                       MAIN0609
      EMGWS(MONTH) = GWS                                                MAIN0610
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)                         MAIN0611
      IF(UZC .LT. 0.25) UZC = 0.25                                      MAIN0612
      EMUZC(MONTH) = UZC                                                MAIN0613
      EMUZS(MONTH) = UZS                                                MAIN0614
      EMSIAM(MONTH) = SIAM                                              MAIN0615
      EMLZS(MONTH) = LZS                                                MAIN0616
      EMIFS(MONTH) = IFS                                                MAIN0617
      IF(MONTH .EQ. 5) MEDWY(5) = 59                                    MAIN0618
      MDAY = MEDWY(MONTH)                                               MAIN0619
      IF(TRIP .EQ. 1) GO TO 205                                         MAIN0620
  193 GO TO (194,195,196,197,198,199,200,201,202,203,204,               MAIN0621
     1    205),MONTH                                                    MAIN0622
  194 WRITE(6,17)                                                       MAIN0623
   17 FORMAT(1H/,8HNOVEMBER)                                            MAIN0624
      GO TO 205                                                         MAIN0625
  195 WRITE(6,18)                                                       MAIN0626
   18 FORMAT(1H/,8HDECEMBER)                                            MAIN0627
      GO TO 205                                                         MAIN0628
  196 WRITE(6,19)                                                       MAIN0629
   19 FORMAT(1H/,7HJANUARY)                                             MAIN0630
      GO TO 205                                                         MAIN0631
  197 WRITE(6,20)                                                       MAIN0632
   20 FORMAT(1H/,8HFEBRUARY)                                            MAIN0633
      GO TO 205                                                         MAIN0634
  198 WRITE(6,21)                                                       MAIN0635
   21 FORMAT(1H/,5HMARCH)                                               MAIN0636
      GO TO 205                                                         MAIN0637
  199 WRITE(6,22)                                                       MAIN0638
   22 FORMAT(1H/,5HAPRIL)                                               MAIN0639
      GO TO 205                                                         MAIN0640
  200 WRITE(6,23)                                                       MAIN0641
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   23 FORMAT(1H/,3HMAY)                                                 MAIN0642
      GO TO 205                                                         MAIN0643
  201 WRITE(6,24)                                                       MAIN0644
   24 FORMAT(1H/,4HJUNE)                                                MAIN0645
      GO TO 205                                                         MAIN0646
  2020 WRITE(6,25)                                                      MAIN0647
   25 FORMAT(1H/,4HJULY)                                                MAIN0648
      GO TO 205                                                         MAIN0649
  203 WRITE(6,26)                                                       MAIN0650
   26 FORMAT(1H/,6HAUGUST)                                              MAIN0651
      GO TO 205                                                         MAIN0652
  204 WRITE(6,27)                                                       MAIN0653
   27 FORMAT(1H/,9HSEPTEMBER)                                           MAIN0654
  205 MONTH = MONTH + 1                                                 MAIN0655
C  END OF DAY LOOP                                                      MAIN0656
  206 CALL DAYNXT(DAY,DPY)                                              MAIN0657
      IF(DAY .NE. 274) GO TO 148                                        MAIN0658
      IF(TRIP .NE. 2) GO TO 208                                         MAIN0659
C  ADJUST BASE FLOW FOR AVERAGE VALUE DURING STORM                      MAIN0660
      DO 207 KHYD = 1,NRHP                                              MAIN0661
      DAY = IDYB(KHYD)                                                  MAIN0662
      IF(DSSF(DAY) .GT. HBF(KHYD)) GO TO 207                            MAIN0663
      HBF(KHYD) = (HBF(KHYD) + DSSF(DAY))/2.0                           MAIN0664
  207 CONTINUE                                                          MAIN0665
  208 IF(TRIP .NE. 1) WRITE(6,28) (TITLE(KTA), KTA=1,20,1)              MAIN0666
   28 FORMAT(1H1,25X,20A4)                                              MAIN0667
C  ANNUAL SUMMARY                                                       MAIN0668
      APREC = 0.0                                                       MAIN0669
      ABFV = 0.0                                                        MAIN0670
      ASEV = 0.0                                                        MAIN0671
      ANET = 0.0                                                        MAIN0672
      APET = 0.0                                                        MAIN0673
      AIFV = 0.0                                                        MAIN0674
      DO 209 MONTH = 1,12                                               MAIN0675
      APREC = APREC + TMPREC(MONTH)                                     MAIN0676
      ABFV = ABFV + TMBF(MONTH)                                         MAIN0677
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      ASEV = ASEV + TMSE(MONTH)                                         MAIN0678
      ANET = ANET + TMNET(MONTH)                                        MAIN0679
      APET = APET + TMPET(MONTH)                                        MAIN0680
  209 AIFV = AIFV + TMIF(MONTH)                                         MAIN0681
      WRITE(6,29)                                                       MAIN0682
   29 FORMAT(1H///44X,23HSYNTHESIZED       FLOWS)                       MAIN0683
  210 IF(TRIP .EQ. 1) WRITE(6,30)                                       MAIN0684
   30 FORMAT(//5X,'SUMMARY WHILE OPTIMIZING VOLUME VARIABLES')          MAIN0685
  211 CALL DAYSUM(DSSF,MEDCY,DPY,SATFV,TMSTF)                           MAIN0686
      IF(TRIP .EQ. 1) GO TO 212                                         MAIN0687
      CALL DAYOUT(DSSF,MEDWY,DPY)                                       MAIN0688
  212 WRITE(6,31) (TMSTF(KWD), KWD=1,12),SATFV                          MAIN0689
      DO 213 MONTH = 1,12                                               MAIN0691
   31 FORMAT(1X, 9HSYNTHETIC,3X,12F8.1,2X,F10.1,2X,3HSFD)               MAIN0690
  213 TMSTFI(MONTH) = TMSTF(MONTH)/VWIN                                 MAIN0692
      SATFVI = SATFV/VWIN                                               MAIN0693
      WRITE(6,32) (TMSTFI(KWD),KWD=1,12),SATFVI                         MAIN0694
   32 FORMAT(1X,5HTOTAL,8X,12F8.3,4X,F7.3,2X,6HINCHES)                  MAIN0695
      DO 214 MONTH = 1,12                                               MAIN0696
      TMOF(MONTH) = TMSTFI(MONTH)- TMIF(MONTH) - TMBF(MONTH) +          MAIN0697
     1  TMSE(MONTH)                                                     MAIN0698
  214 IF(TMOF(MONTH) .LT. 0.0) TMOF(MONTH) = 0.0                        MAIN0699
      AOFV = SATFVI - AIFV - ABFV + ASEV                                MAIN0700
      IF(AOFV .LT.0.0) AOFV = 0.0                                       MAIN0701
      WRITE(6,33) (TMOF(KWD), KWD=1,12), AOFV                           MAIN0702
   33 FORMAT(1X,8HOVERLAND ,5X,12F8.3,4X,F7.3,2X,6HINCHES)              MAIN0703
      WRITE(6,34) (TMIF(KWD), KWD=1,12),AIFV                            MAIN0704
   34 FORMAT(1X,9HINTERFLOW,4X,12F8.3,4X,F7.3,2X,6HINCHES)              MAIN0705
      WRITE(6,35) (TMBF(KWD), KWD=1,12),ABFV                            MAIN0706
   35 FORMAT(1X,4HBASE,9X,12F8.3,4X,F7.3,2X,6HINCHES)                   MAIN0707
      WRITE(6,36) (TMSE(KWD), KWD=1,12), ASEV                           MAIN0708
   36 FORMAT(1X,9HSTRM EVAP,4X,12F8.3,4X,F7.3,2X,6HINCHES)              MAIN0709
      WRITE(6,37) (TMPREC(KWD), KWD=1,12),APREC                         MAIN0710
   37 FORMAT( 1X,6HPRECIP,7X,12F8.2,3X,F8.2,2X,6HINCHES)                MAIN0711
      WRITE(6,38) (TMNET(KWD), KWD=1,12),ANET                           MAIN0712
   38 FORMAT(1X,12HEVP/TRAN-NET,2X,12F8.3,3X,F7.3,2X,6HINCHES)          MAIN0713
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      WRITE(6,39) (TMPET(KWD), KWD=1,12),APET                           MAIN0714
   39 FORMAT(3X,10H-POTENTIAL,2X,12F8.3,3X,F7.3,2X,6HINCHES)            MAIN0715
      WRITE(6,40) (EMUZS(KWD), KWD=1,12)                                MAIN0716
   40 FORMAT(1X,12HSTORAGES-UZS,2X,12F8.3,12X,6HINCHES)                 MAIN0717
      WRITE(6,41) (EMLZS(KWD), KWD=1,12)                                MAIN0718
   41 FORMAT(10X,3HLZS,2X,12F8.3,12X,6HINCHES)                          MAIN0719
      WRITE(6,42) (EMIFS(KWD), KWD=1,12)                                MAIN0720
   42 FORMAT(10X,3HIFS,2X,12F8.3,12X,6HINCHES)                          MAIN0721
      WRITE(6,43) (EMGWS(KWD), KWD=1,12)                                MAIN0722
   43 FORMAT(10X,3HGWS,2X,12F8.3,12X,6HINCHES)                          MAIN0723
      WRITE(6,44) (EMUZC(KWD), KWD=1,12)                                MAIN0724
   44 FORMAT(1X,12HINDICES- UZC,2X,12F8.3)                              MAIN0725
      WRITE(6,45) (EMSIAM(KWD), KWD=1,12)                               MAIN0726
   45 FORMAT(9X,4HSIAM,2X,12F8.3)                                       MAIN0727
      AMBER = (LZS - BYLZS)*FPER + (UZS + IFS + GWS - BYGWS)*(1.0 - FWTRMAIN0728
     1  ) + SATFVI + ANET*FPER + ASEV - APREC                           MAIN0729
      WRITE(6,46) AMBER                                                 MAIN0730
   46 FORMAT(1H/7HBALANCE,5X,F10.4,2X,6HINCHES)                         MAIN0731
C  ESTABLISH WHETHER MONTH IS PREDOMINATELY BASE FLOW OR DIRECT RUNOFF  MAIN0732
      NOFM = 0                                                          MAIN0733
      MONTH1 = 1                                                        MAIN0734
      IF(FTX .LT. 0.95) MONTH1 = 4                                      MAIN0735
      DO 216 MONTH = 1,12                                               MAIN0736
      XMPFT(MONTH) = 0.0                                                MAIN0737
      IF(MONTH .LT. MONTH1) GO TO 216                                   MAIN0738
      IF(TMSTFI(MONTH) .GT. 0.001) GO TO 215                            MAIN0739
      XMPFT(MONTH) = 1.0                                                MAIN0740
      GO TO 216                                                         MAIN0741
  215 IF(TMBF(MONTH)/TMSTFI(MONTH) .GT. 0.5) XMPFT(MONTH) = 1.0         MAIN0742
      IF(TMOF(MONTH)/TMSTFI(MONTH) .LT. 0.5) GO TO 216                  MAIN0743
      NOFM = NOFM + 1                                                   MAIN0744
      XMPFT(MONTH) = 2.0                                                MAIN0745
  216 CONTINUE                                                          MAIN0746
C  NATURE OF TRIPS                                                      MAIN0747
C     TRIP 1  OPTIMIZE VOLUME VARIABLES WHILE BYPASSING ROUTING         MAIN0748
C     TRIP 2  SET FLOOD HYDROGRAPH VARIABLES: CSRX,FSRX,NCTRI,CHCAP     MAIN0749
```

```
C     TRIP 3  FINAL RUN WITH OPTIMIZED VALUES
  217 IF(TRIP .EQ. 1) GO TO 218
      KRC = MNRC + 1
      IF(TRIP .EQ. 2) GO TO 226
      GO TO 228
C SYSTEMATIC ADJUSTMENT OF VOLUME VARIABLES CONVERGING ON OPTIMUM VALUES
  218 KRC = KRC + 1
      KBRC = KBRC + 1
      PLZC = LZC
      PBMIR = BMIR
      PSUZC = SUZC
      PETLF = ETLF
      PBUZC = BUZC
      PSIAC = SIAC
C  ADJUST FIVE VOLUME VARIABLES: LZC,SUZC,ETLF,BUZC,SIAC
      CALL SETFVP(LZC,SUZC,ETLF,BUZC,SIAC,TMSTF,TMRTF,TMPREC,TMPET,
     1  EMLZS,SSQM,LRC,XMPFT,FTX,NOFM,LBUZC,LETLF,LLZC,APREC,APET)
C  ADJUST INTERFLOW VOLUME CONSTANT DURING FINE ADJUSTMENT PHASE
      FNCTRH = NCTRH
      IF(.NOT. LRC .AND. IFRC .GT. 0.1) CALL SETBIV(BIVF,NRS,IFRC,RSBIF,
     1  SIFRS,FNCTRH)
C  ADJUST INFILTRATION RATE CONSTANT: BMIR
      IF(.NOT. LBMIR) GO TO 219
      BMIR = 0.9*BMIR
      GO TO 220
  219 IF(ABS(FTX-1.0) .GT. 0.02 .AND. KRC .GT. 5) IFT = 2
      CALL SETBMI(BMIR,NRS,BFRC,RSBBF,SBFRS,FNCTRH,IFT)
  220 IF((KRC .GT. 6) .AND. (LZC .GT. 29.0)) LLZC = .TRUE.
      IF((KRC .GT. 6) .AND. (ETLF .GT. 0.59)) LETLF = .TRUE.
      IF((KRC .GT. 6) .AND. (BUZC .GT. 3.9)) LBUZC = .TRUE.
      IF(.NOT. LLZC) GO TO 221
      LZC = PLZC*SATFV/RATFV
      WRITE(6,47) LZC
   47 FORMAT(/2X,'LZC WAS CHANGED TO',F6.2,' BASED ON ANNUAL RUNOFF VOLU
     1ME')
  221 IF(KRC .LT. 6 .OR. BMIR .LT. 20.0) GO TO 222
```

```
      LBMIR = .TRUE.                                                    MAIN0786
      BMIR = 20.0                                                       MAIN0787
  222 IF(SSSQM .LE. SSQM .AND. ((KRC .GE. MNRC .AND. KBRC .GE. 2) .OR.  MAIN0788
     1  (.NOT. LRC))) GO TO 224                                         MAIN0789
      IF(SSSQM .LE. SSQM) GO TO 142                                     MAIN0790
      IF(KRC .GE. MNRC) KRC = KRC - 1                                   MAIN0791
      BLZC = PLZC                                                       MAIN0792
      BBMIR = PBMIR                                                     MAIN0793
      BSUZC = PSUZC                                                     MAIN0794
      BETLF = PETLF                                                     MAIN0795
      BBUZC = PBUZC                                                     MAIN0796
      BSIAC = PSIAC                                                     MAIN0797
      SSSQM = SSQM                                                      MAIN0798
      BBYLZS = BYLZS                                                    MAIN0799
      KBRC = 0                                                          MAIN0800
      IF(SSQM .LT. 0.15 .AND. LRC) GO TO 223                            MAIN0801
      GO TO 142                                                         MAIN0802
  223 LRC = .FALSE.                                                     MAIN0803
      WRITE(6,48)                                                       MAIN0804
   48 FORMAT(/5X,'SHIFT TO FINE ADJUSTMENT BEGINNING AT BEST ROUGH ADJUSMAIN0805
     1TMENT POINT')                                                     MAIN0806
      SSSQM = 1000.0                                                    MAIN0807
      GO TO 225                                                         MAIN0808
  224 CONTINUE                                                          MAIN0809
      IF(LRC) GO TO 223                                                 MAIN0810
      IF(TRIP .GE. NLTR) GO TO 228                                      MAIN0811
      TRIP = TRIP + 1                                                   MAIN0812
  225 LZC = BLZC                                                        MAIN0813
      BMIR = BBMIR                                                      MAIN0814
      SUZC = BSUZC                                                      MAIN0815
      ETLF = BETLF                                                      MAIN0816
      BUZC = BBUZC                                                      MAIN0817
      SIAC = BSIAC                                                      MAIN0818
      KFFC = 1                                                          MAIN0819
      GO TO 142                                                         MAIN0820
  226 IF(NRHP .EQ. 0) GO TO 227                                         MAIN0821
```

```
C  CORRECT SYNTHESIZED RUNOFF TO RECORDED VOLUMES
      CALL ADJHYD(IDYB,IDYE,IHRB,IHRE,KPSH,DPY,HBF,NRHP,DSSF,DRSF,SSR,
     1  LSHA)
C  ESTABLISH STORM AND OVERALL OPTIMUM VALUES FOR SRX AND NCTRI
      CALL SETHRP(CTRI,BTRI,WCFS,CONOPT(2),HBF,LSHA,SSR,NHPT,KPSH,
     1  IBTPR,SRX,CSRX,FSRX,CHCAP,NRHP,RHPF,NCTRI,NBTRI)
      IF(NCTRI .EQ. 0) GO TO 228
  227 IF(TRIP .GE. NLTR) GO TO 228
      TRIP = TRIP + 1
      GO TO 142
  228 CONTINUE
      IF(NSYC .LT. NSYT) GO TO 100
      END
```

```
      SUBROUTINE ADJHYD(IDYB,IDYE,IHRB,IHRE,KPSH,DPY,HBF,NRHP,DSSF,
     1  DRSF,SSR,LSHA)
C  ADJUSTS SYNTHESIZED FLOW VOLUME TO MATCH RECORDED VOLUME FOR SETTING
C    HYDROGRAPH ROUTING PARAMETERS
      DIMENSION  IDYB(5),IDYE(5),IHRB(5),IHRE(5),KPSH(5),SSR(5,170),
     1  DSSF(366),DRSF(366),HBF(5),LSHA(5)
      LOGICAL  LSHA,LSHP
      INTEGER  DAY,DPY
      LSHP = .FALSE.
      KRHP = 1
      DAY = 274
  100 CONTINUE
      IF(LSHP) GO TO 102
      IF(IDYB(KRHP) .NE. DAY) GO TO 107
  101 HTH = IHRB(KRHP)
      HBFM = 1.0
      IF(DSSF(DAY) .LT. HBF(KRHP)) HBFM = 0.0
      TSHV = (24.0 - HTH)*(DSSF(DAY) - HBF(KRHP))*HBFM/24.0
```

```
      HBFM = 1.0                                                        ADJH0019
      IF(DRSF(DAY) .LT. HBF(KRHP)) HBFM = 0.0                           ADJH0020
      TRHV = (24.0 - HTH)*(DRSF(DAY) - HBF(KRHP))*HBFM/24.0             ADJH0021
      IF(IDYE(KRHP) .EQ. DAY) GO TO 104                                 ADJH0022
      LSHP = .TRUE.                                                     ADJH0023
      GO TO 107                                                         ADJH0024
  102 IF(DSSF(DAY) .LT. HBF(KRHP)) GO TO 103                            ADJH0025
      TSHV = TSHV + DSSF(DAY) - HBF(KRHP)                               ADJH0026
  103 IF(DRSF(DAY) .LT. HBF(KRHP)) GO TO 104                            ADJH0027
      TRHV = TRHV + DRSF(DAY) - HBF(KRHP)                               ADJH0028
  104 CONTINUE                                                          ADJH0029
      IF(IDYE(KRHP) .NE. DAY) GO TO 107                                 ADJH0030
      HTH = IHRE(KRHP)                                                  ADJH0031
      TSHV = TSHV - (24.0 - HTH)*(DSSF(DAY) - HBF(KRHP))/24.0           ADJH0032
      TRHV = TRHV - (24.0 - HTH)*(DRSF(DAY) - HBF(KRHP))/24.0           ADJH0033
      LSHP = .FALSE.                                                    ADJH0034
      SHM = TRHV/TSHV                                                   ADJH0035
      LSHA(KRHP) = .TRUE.                                               ADJH0036
      IF(SHM .GT. 8.0 .OR. SHM .LT. 0.125) LSHA(KRHP) = .FALSE.         ADJH0037
      IF(.NOT. LSHA(KRHP)) GO TO 106                                    ADJH0038
      KPCH = KPSH(KRHP)                                                 ADJH0039
      DO 105 KHPT = 1,KPCH                                              ADJH0040
  105 SSR(KRHP,KHPT) = SHM*SSR(KRHP,KHPT)                               ADJH0041
  106 WRITE(6,1) KRHP,SHM                                               ADJH0042
    1 FORMAT(//10X,'VOLUME ADJUSTMENT FACTOR  FOR HYDROGRAPH',I2,       ADJH0043
     1   ' EQUALS',F10.4)                                               ADJH0044
      KRHP = KRHP + 1                                                   ADJH0045
      IF(KRHP .GT. NRHP) RETURN                                         ADJH0046
      IF(IDYB(KRHP) .EQ. IDYE(KRHP-1)) GO TO 101                        ADJH0047
  107 CALL DAYNXT(DAY,DPY)                                              ADJH0048
      IF(DAY .NE. 274) GO TO 100                                        ADJH0049
      RETURN                                                            ADJH0050
      END                                                               ADJH0051
```

```
      SUBROUTINE DAYSUM(DRSF,MEDCY,DPY,ATFV,TMTFWY)                     DYSM0001
C   SUMS DAILY VALUES TO GET MONTHLY AND ANNUAL TOTALS                  DYSM0002
      DIMENSION  DRSF(366),EMATF(13),MEDCY(12),TMTFCY(12),TMTFWY(12)    DYSM0003
      INTEGER  DAY,DPY                                                  DYSM0004
C   SUM ANNUAL AND CUMULATIVE MONTHLY FLOWS                             DYSM0005
      EMATF(1) = 0.0                                                    DYSM0006
      ATF = 0.0                                                         DYSM0007
      DO 101 DAY = 1,365                                                DYSM0008
      ATF = ATF + DRSF(DAY)                                             DYSM0009
      DO 100 KMO = 2,12                                                 DYSM0010
  100 IF(DAY .EQ. MEDCY(KMO)) EMATF(KMO) = ATF                          DYSM0011
  101 CONTINUE                                                          DYSM0012
      EMATF(13) = ATF                                                   DYSM0013
      ATFV = ATF + DRSF(366)                                            DYSM0014
C   CALCULATE MONTHLY FLOWS                                             DYSM0015
      DO 102 KMO = 1,12                                                 DYSM0016
  102 TMTFCY(KMO) = EMATF(KMO + 1) - EMATF(KMO)                         DYSM0017
      TMTFCY(2) = TMTFCY(2) + DRSF(366)                                 DYSM0018
C   CONVERT MONTHLY FLOWS TO A WATER YEAR ORDER                         DYSM0019
      DO 103 KMO = 1,9                                                  DYSM0020
  103 TMTFWY(KMO+3) = TMTFCY(KMO)                                       DYSM0021
      DO 104 KMO = 10,12                                                DYSM0022
  104 TMTFWY(KMO-9) = TMTFCY(KMO)                                       DYSM0023
      RETURN                                                            DYSM0024
      END                                                               DYSM0025
```

```
      SUBROUTINE FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                          FXTI0001
C   FIX VALUES OF THE TIME ROUTING INCREMENTS TO MATCH REQUIRED TOTAL    FXTI0002
C     NUMBER OF VALUES                                                  FXTI0003
      DIMENSION  AWSBIT(99),BTRI(99),CTRI(99)                           FXTI0004
      IF(NCTRI .GT. 99) GO TO 101                                       FXTI0005
      IF(NBTRI .NE. NCTRI) GO TO 102                                    FXTI0006
      DO 100 KRD = 1,99                                                 FXTI0007
  100 CTRI(KRD) = BTRI(KRD)                                             FXTI0008
```

```
      RETURN
  101 WRITE(6,1) NCTRI                                                  FXTI0009
    1 FORMAT(5X,'NCTRI OF',I5,1X,'EXCEEDS MAXIMUM VALUE OF 99, 99 USED')FXTI0010
      NCTRI = 99                                                        FXTI0011
  102 DO 103 KIA = 1,99                                                 FXTI0012
  103 AWSBIT(KIA) = 0.0                                                 FXTI0013
      FNTRI = NCTRI                                                     FXTI0014
      KB1 = 0                                                           FXTI0015
      KB2 = 1                                                           FXTI0016
      KB3 = 0                                                           FXTI0017
  104 KB1 = KB1 + 1                                                     FXTI0018
      IF(KB1 .GT. NBTRI) GO TO 107                                      FXTI0019
      KB4 = 0                                                           FXTI0020
      WSBIT = BTRI(KB1)/FNTRI                                           FXTI0021
  105 KB4 = KB4 + 1                                                     FXTI0022
      IF(KB4 .GT. NCTRI) GO TO 104                                      FXTI0023
      AWSBIT(KB2) = AWSBIT(KB2) + WSBIT                                 FXTI0024
      KB3 = KB3 + 1                                                     FXTI0025
      IF(KB3 .LT. NBTRI) GO TO 106                                      FXTI0026
      KB3 = 0                                                           FXTI0027
      KB2  = KB2 + 1                                                    FXTI0028
  106 GO TO 105                                                         FXTI0029
  107 DO 108 KB5 = 1,99                                                 FXTI0030
  108 CTRI(KB5) = AWSBIT(KB5)                                           FXTI0031
      RETURN                                                            FXTI0032
      END                                                               FXTI0033
                                                                        FXTI0034


      SUBROUTINE PRECHK(DRGPM,DRHP,DRSF,VWIN,SGRT,NATRH)                PRCK0001
C   CHECKS PRECIPITATION-STREAMFLOW ANOMALIES AND ADJUSTS PRECIPITATION PRCK0002
C     WHERE NECESSARY                                                   PRCK0003
      DIMENSION  DRGPM(366),DRHP(366,24),DRSF(366)                      PRCK0004
      INTEGER  DAY,HOUR,SGRT                                            PRCK0005
      AHP = 0.0                                                         PRCK0006
      NRHA = 24 - NATRH                                                 PRCK0007
```

```
      RGPM = DRGPM(90)                                                  PRCK0008
      DAY = 90                                                          PRCK0009
      RMWR = 1.25                                                       PRCK0010
  100 DAY = DAY + 1                                                     PRCK0011
      IF(DAY .GT. 200 .OR. VWIN .GT. 750.0) RMWR = 2.00                 PRCK0012
      RFRISE = (DRSF(DAY) - DRSF(DAY-1))/VWIN                           PRCK0013
      DO 101 HOUR = 1,24                                                PRCK0014
      IF(HOUR .EQ. SGRT+1) RGPM = DRGPM(DAY)                            PRCK0015
      AHP = AHP + DRHP(DAY,HOUR)*RGPM                                   PRCK0016
      IF(HOUR .NE. NRHA) GO TO 101                                      PRCK0017
      RWRAIN = AHP                                                      PRCK0018
      AHP = 0.0                                                         PRCK0019
  101 CONTINUE                                                          PRCK0020
      IF(RFRISE .GT. RWRAIN .AND. RFRISE .GT. 0.1) GO TO 102            PRCK0021
      IF((RWRAIN .GT. RMWR .AND. RFRISE .LT. 0.02*RWRAIN) .OR. (RWRAIN  PRCK0022
     1 .GT. 3.00 .AND. RFRISE .LT. 0.05*RWRAIN)) GO TO 104              PRCK0023
      GO TO 108                                                         PRCK0024
  102 IF(RWRAIN .GT. 0.05) GO TO 103                                    PRCK0025
      RAA = RFRISE*2.0 - RWRAIN + 1.0                                   PRCK0026
      DRHP(DAY,13) = RAA                                                PRCK0027
      WRITE(6,1) DAY, RAA                                               PRCK0028
    1 FORMAT(/10X,'FOR DAY',I4,1X,'RAIN ADDED OF',F7.2)                 PRCK0029
      GO TO 108                                                         PRCK0030
  103 RAM = 2.0*RFRISE/RWRAIN                                           PRCK0031
      GO TO 105                                                         PRCK0032
  104 RAM = 10.0*RFRISE/RWRAIN                                          PRCK0033
  105 IF(RAM .LT. 0.0) GO TO 108                                        PRCK0034
      WRITE(6,2) DAY,RAM,RWRAIN                                         PRCK0035
    2 FORMAT(/5X,'FOR DAY',I4,1X,'RAIN ADJUSTMENT MULTIPLIER IS',F8.4,  PRCK0036
     1 1X,'RECORDED RAIN IS',F7.2)                                      PRCK0037
      DO 106 HOUR = 1,NRHA                                              PRCK0038
  106 DRHP(DAY,HOUR) = DRHP(DAY,HOUR)*RAM                               PRCK0039
      IF(NATRH .EQ. 0) GO TO 108                                        PRCK0040
      NFRHA = NRHA + 1                                                  PRCK0041
      DO 107 HOUR = NFRHA,24                                            PRCK0042
  107 DRHP(DAY-1,HOUR) = DRHP(DAY-1,HOUR)*RAM                           PRCK0043
```

```
  108 IF(DAY .NE. 273) GO TO 100                                        PRCK0044
      RETURN                                                            PRCK0045
      END                                                               PRCK0046


      SUBROUTINE RECESS(DRSF,DPY,BFRC,IFRC,AREA,RSBD,RSBIF,NRS,RSBBF)   RCSS0001
C  ESTABLISHES RECESSION SEQUENCES                                      RCSS0002
      DIMENSION  DRSF(366),LBFO(20),NDRS(20),RSBBF(20),RSBD(20),        RCSS0003
     1  RSBFRC(20),RSBIF(20),RSIFRC(20),RSTF(50,20)                     RCSS0004
      LOGICAL  LBFO                                                     RCSS0005
      INTEGER  DAY,DPY,RSBD,RSL                                         RCSS0006
      REAL  IFRC                                                        RCSS0007
      MRSL = 9                                                          RCSS0008
      BFRC = 0.9                                                        RCSS0009
      IFRC = 0.05                                                       RCSS0010
      FRERS = 0.1*SQRT(AREA)                                            RCSS0011
  100 DO 101 KSD = 1,50                                                 RCSS0012
      DO 101 KRS = 1,20                                                 RCSS0013
  101 RSTF(KSD,KRS) = 0.0                                               RCSS0014
      KRS = 0                                                           RCSS0015
      DAY = 274                                                         RCSS0016
C  BEGIN NEW SEQUENCE                                                   RCSS0017
  102 IF(KRS .GE. 20) GO TO 109                                         RCSS0018
      KRS = KRS + 1                                                     RCSS0019
      KSD = 1                                                           RCSS0020
      RSF1 = DRSF(DAY)                                                  RCSS0021
      CALL DAYNXT(DAY,DPY)                                              RCSS0022
      IF(DAY .EQ. 274) GO TO 107                                        RCSS0023
      RSF2 = DRSF(DAY)                                                  RCSS0024
      RSBD(KRS) = DAY                                                   RCSS0025
      IF(RSF2 .LT. RSF1+FRERS .AND. (RSF2 .GT. 0.4*AREA .OR. RSF2 .GT.  RCSS0026
     1  10.0)) GO TO 103                                                RCSS0027
      KRS = KRS - 1                                                     RCSS0028
      GO TO 102                                                         RCSS0029
  103 RSTF(1,KRS) = RSF2                                                RCSS0030
```

```
      RSFM = RSF2
  104 KSD = KSD + 1
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 107
      RSFN = DRSF(DAY)
      IF(RSFN .LT. (RSFM + FRERS) .AND. RSFN .GT. 0.0) GO TO 106
      IF(KSD .GE. MRSL) GO TO 102
      NDRS(KRS) = 0
      DO 105 KSD = 1,MRSL
  105 RSTF(KSD,KRS) = 0.0
      KRS = KRS - 1
      GO TO 102
  106 IF(RSFN .LT. RSFM) RSFM = RSFN
      RSTF(KSD,KRS) = RSFN
      NDRS(KRS) = KSD
      IF(KSD .GE. 50) GO TO 102
      GO TO 104
  107 IF(KSD .GE. MRSL) GO TO 109
      NTRS = KRS - 1
      DO 108 KSD = 1,MRSL
  108 RSTF(KSD,KRS) = 0.0
      GO TO 110
  109 NTRS = KRS
  110 CONTINUE
      IF(NTRS .GE. 3) GO TO 111
      IF(MRSL .LT. 7) RETURN
      MRSL = 6
      GO TO 100
C  WRITE OUT ESTABLISHED ARRAY OF FLOW SEQUENCES
  111 WRITE(6,1)
    1 FORMAT(/5X,'FLOW SEQUENCES USED TO ESTIMATE RECESSION CONSTANTS')
      DO 113 KRS = 1,NTRS
      NDRSC = NDRS(KRS)
      DO 112 KSD = 2,NDRSC
  112 RSTF(KSD-1,KRS) = RSTF(KSD,KRS)
      NDRS(KRS) = NDRS(KRS) - 1
```

```
      NDRSC = NDRSC - 1
      WRITE(6,2) KRS,(RSTF(KSD,KRS),KSD=1,NDRSC)
    2 FORMAT(/10X,I2,5(10F8.1/12X))
  113 CONTINUE
C  DETERMINE RECESSION CONSTANTS FROM EACH SEQUENCE
  114 DO 116 KRS = 1,NTRS
      IF((RSTF(1,KRS) .LT. 0.4*AREA) .AND. (RSTF(2,KRS) .GT. 0.8*
     1  (RSTF(1,KRS)))) GO TO 115
      LBFO(KRS) = .FALSE.
      CALL SET2RC(RSTF,KRS,NDRS(KRS),RSIFRC(KRS),RSBFRC(KRS),LBFO(KRS))
      IF(LBFO(KRS) .OR. RSBFRC(KRS) .GT. 1.2 .OR. RSBFRC(KRS) .LT. 0.6
     1  .OR. RSIFRC(KRS) .GT. 0.8 .OR. RSIFRC(KRS) .LT. -0.4) GO TO 115
      GO TO 116
  115 LBFO(KRS) = .TRUE.
      CALL SET1RC(RSTF,KRS,NDRS(KRS),RSBFRC(KRS))
  116 CONTINUE
C  CALCULATE WEIGHTED AVERAGE RECESSION CONSTANTS
      BFRC = 0.0
      IFRC = 0.0
      ABFSL = 0.0
      AIFSL = 0.0
      DO 118 KRS = 1,NTRS
      IF(RSBFRC(KRS) .GT. 1.2 .OR. RSBFRC(KRS) .LT. 0.6) GO TO 117
      RSL = NDRS(KRS)
      BFRC = BFRC + RSBFRC(KRS)*RSL
      ABFSL = ABFSL + RSL
      IF(LBFO(KRS)) GO TO 118
      IF(RSL .GE. 20.0) RSL = 20.0
      IFRC = IFRC + RSIFRC(KRS)*RSL
      AIFSL = AIFSL + RSL
      GO TO 118
  117 WRITE(6,3) KRS
    3 FORMAT(10X,'SEQUENCE',I3,1X,'OMITTED IN AVERAGING')
  118 CONTINUE
      WRITE(6,4) ABFSL,AIFSL
    4 FORMAT(10X,'BASE FLOW DAYS =',F5.0,2X,'INTERFLOW DAYS =',F5.0)
```

```
      BFRC = BFRC/ABFSL                                                 RCSS0103
      IFRC = IFRC/AIFSL                                                 RCSS0104
      IF(BFRC .GT. 0.99) BFRC = 0.99                                    RCSS0105
      IF(BFRC .LT. 0.70) BFRC = 0.70                                    RCSS0106
      KSQ = 0                                                           RCSS0107
      DO 119 KRS = 1,NTRS                                               RCSS0108
      IF(LBFO(KRS)) GO TO 119                                           RCSS0109
      CALL SETRBF(RSTF,NDRS,KRS,BFRC,IFRC,CRSBIF,CRSBBF)                RCSS0110
      IF(CRSBIF .GT. 95000.0 .OR. CRSBBF .LT. 0.0) GO TO 119            RCSS0111
      IF(CRSBIF .LT. 0.0) CRSBIF = 0.0                                  RCSS0112
      KSQ  = KSQ + 1                                                    RCSS0113
      RSBD(KSQ) = RSBD(KRS)                                             RCSS0114
      RSBIF(KSQ) = CRSBIF                                               RCSS0115
      RSBBF(KSQ) = CRSBBF                                               RCSS0116
  119 CONTINUE                                                          RCSS0117
      NRS = KSQ                                                         RCSS0118
      DO 120 KSQ = 1,NRS                                                RCSS0119
      DAY = RSBD(KSQ)                                                   RCSS0120
      CALL DAYNXT(DAY,DPY)                                              RCSS0121
  120 RSBD(KSQ) = DAY                                                   RCSS0122
      DO 121 KSQ = 1,NRS                                                RCSS0123
      CRSBTF = RSBIF(KSQ) + RSBBF(KSQ)                                  RCSS0124
  121 WRITE(6,5) KSQ,RSBD(KSQ),RSBIF(KSQ),RSBBF(KSQ),CRSBTF             RCSS0125
    5 FORMAT(/10X,'REVISED FLOW SEQUENCE',I3,1X,1X,'BEGINS ON DAY',I4,  RCSS0126
     1  1X,'AT INTERFLOW =',F7.2,1X,'CFS,   BASE FLOW =',F7.2,1X,'CFS,  RCSS0127
     1  TOTAL =',F7.2,1X,'CFS')                                         RCSS0128
      RETURN                                                            RCSS0129
      END                                                               RCSS0130


      SUBROUTINE SETBIV(BIVF,NRS,IFRC,RSBIF,SIFRS,FNCTRH)               STBV0001
C   SETS BEST VALUE OF BASIC INTERFLOW VOLUME FACTOR                    STBV0002
      DIMENSION  RSBIF(20),SIFRS(3,20)                                  STBV0003
      REAL  IFRC                                                        STBV0004
      ARSTR = 0.0                                                       STBV0005
```

```
      DO 101 KRS = 1,NRS                                                STBV0006
      RIF = RSBIF(KRS)/IFRC                                             STBV0007
      DO 100 KDY = 1,3                                                  STBV0008
      RIF = RIF*IFRC                                                    STBV0009
      SIF = SIFRS(KDY,KRS)/IFRC**(FNCTRH/48.0)                          STBV0010
      RSTR = 0.0                                                        STBV0011
      IF(RIF .GT. 0.0) RSTR = SIF/RIF                                   STBV0012
      IF(RSTR .GT. 3.0 .OR. (SIF .GT. 0.0 .AND. RIF .EQ. 0.0))RSTR=3.0  STBV0013
      ARSTR = ARSTR + RSTR                                              STBV0014
      WRITE(6,1) KRS,KDY,SIF,RIF                                        STBV0015
    1 FORMAT(10X,'KRS =',I3,2X,'KDY =',I2,2X,'SIF =',F7.1,5X,'RIF =',   STBV0016
     1  F7.1)                                                           STBV0017
  100 CONTINUE                                                          STBV0018
  101 CONTINUE                                                          STBV0019
      TIRD = NRS*3                                                      STBV0020
      PBIVF = BIVF                                                      STBV0021
      BIVF = 0.40                                                       STBV0022
      IF(ARSTR .GT. 0.0) BIVF = ((PBIVF - 0.40)*TIRD)/ARSTR + 0.40      STBV0023
      WRITE(6,2) PBIVF,BIVF                                             STBV0024
    2 FORMAT(5X,'BIVF CHANGED FROM',F6.2,2X,'TO',F6.2//)                STBV0025
      RETURN                                                            STBV0026
      END                                                               STBV0027
```

```
      SUBROUTINE SETBMI(BMIR,NRS,BFRC,RSBBF,SBFRS,FNCTRH,IFT)           STBM0001
C  SETS BEST VALUE OF BASIC MAXIMUM INFILTRATION RATE WITHIN WATERSHED  STBM0002
      DIMENSION  RSBBF(20),SBFRS(3,20)                                  STBM0003
      ARSTR = 0.0                                                       STBM0004
      DO 101 KRS = IFT,NRS                                              STBM0005
      RBF = RSBBF(KRS)/BFRC                                             STBM0006
      DO 100 KDY = 1,3                                                  STBM0007
      RBF = RBF*BFRC                                                    STBM0008
      SBF = SBFRS(KDY,KRS)/BFRC**(FNCTRH/48.0)                          STBM0009
      RSTR = SBF/RBF                                                    STBM0010
      IF(RSTR .GT. 3.0) RSTR = 3.0                                      STBM0011
```

```
      ARSTR = ARSTR + RSTR                                              STBM0012
      WRITE(6,1) KRS,KDY,SBF,RBF                                        STBM0013
    1 FORMAT(10X,'KRS =',I3,2X,'KDY =',I2,2X,'SBF =',F7.1,5X,'RBF =',   STBM0014
     1  F7.1)                                                           STBM0015
  100 CONTINUE                                                          STBM0016
  101 CONTINUE                                                          STBM0017
      TBRD = (NRS + 1 - IFT)*3                                          STBM0018
      ARSTR = ARSTR/TBRD                                                STBM0019
      ARSTR = ARSTR**1.3                                                STBM0020
      PBMIR = BMIR                                                      STBM0021
      BMIR = PBMIR/ARSTR                                                STBM0022
      WRITE(6,2) PBMIR,BMIR                                             STBM0023
    2 FORMAT(5X,'BMIR CHANGED FROM',F6.2,2X,'TO',F6.2//)                STBM0024
      RETURN                                                            STBM0025
      END                                                               STBM0026


      SUBROUTINE SETFDI(MFDP,TMSTF,TMRTF,SSQM)                          STFD0001
C  SETS VALUES OF FLOW DEVIATION INDICES                                STFD0002
      DIMENSION MFDP(12),TMRTF(12),TMSTF(12)                            STFD0003
      REAL  MFDP                                                        STFD0004
      DO 101 MONTH = 1,12                                               STFD0005
      IF(MONTH .LE. 2) SSQM = 0.0                                       STFD0006
      SMFX = TMSTF(MONTH) + 20.0                                        STFD0007
      RMFX = TMRTF(MONTH) + 20.0                                        STFD0008
      MFDP(MONTH) = SMFX/RMFX - 1.0                                     STFD0009
      IF(MFDP(MONTH) .GT. 8.0) MFDP(MONTH) = 8.0                        STFD0010
      IF(MFDP(MONTH) .LT. 0.0) MFDP(MONTH) = 1.0 - RMFX/SMFX            STFD0011
      IF(MFDP(MONTH) .LT. -8.0) MFDP(MONTH) = -8.0                      STFD0012
  100 SSQM = SSQM + MFDP(MONTH)*MFDP(MONTH)                             STFD0013
  101 CONTINUE                                                          STFD0014
      WRITE(6,1) (MFDP(MONTH), MONTH=1,12), SSQM                        STFD0015
    1 FORMAT(//2X,'MONTHLY DEVIATIONS',/16X,12(F7.3,1X),'SSQM =',F7.3)  STFD0016
      RETURN                                                            STFD0017
      END                                                               STFD0018
```

```
      SUBROUTINE SETFVP(LZC,SUZC,ETLF,BUZC,SIAC,TMSTF,TMRTF,TMPREC,     STFV0001
     1 TMPET,EMLZS,SSQM,LRC,XMPFT,FTX,NOFM,LBUZC,LETLF,LLZC,APREC,APET) STFV0002
C   SETS BEST VALUES OF FLOW VOLUME PARAMETERS                          STFV0003
      DIMENSION  EMLZS(12),MFDP(12),MXA(12),TMPET(12),TMPREC(12),       STFV0004
     1  TMRTF(12),TMSTF(12),XMPFT(12)                                   STFV0005
      LOGICAL  LBUZC,LETLF,LLZC,LRC                                     STFV0006
      REAL  LZC,MFDP                                                    STFV0007
      CALL SETFDI(MFDP,TMSTF,TMRTF,SSQM)                                STFV0008
      IF((MFDP(2) + MFDP(3)) .GT. 2.0 .AND. FTX .LT. 1.05) FTX = 0.9    STFV0009
      IF((MFDP(2) + MFDP(3)) .LT. -2.0 .AND. FTX .GT. 0.95) FTX = 1.1   STFV0010
C   ADJUSTMENT OF LZC BASED ON MONTHS WHERE OVER HALF OF TOTAL          STFV0011
C     SYNTHESIZED RUNOFF IS OVERLAND FLOW, MINIMUM OF TWO MONTHS        STFV0012
C     WITH GREATEST RUNOFF USED                                         STFV0013
      PLZC = LZC                                                        STFV0014
      FNOFM = NOFM                                                      STFV0015
      IF(NOFM .GT. 2) GO TO 103                                         STFV0016
      M1R = 2                                                           STFV0017
      M2R = 1                                                           STFV0018
      IF(TMRTF(2) .GT. TMRTF(1)) GO TO 100                              STFV0019
      M1R = 1                                                           STFV0020
      M2R = 2                                                           STFV0021
  100 DO 102 MONTH = 3,12                                               STFV0022
      IF(TMRTF(MONTH) .LT. TMRTF(M2R)) GO TO 102                        STFV0023
      IF(TMRTF(MONTH) .GT. TMRTF(M1R)) GO TO 101                        STFV0024
      M2R = MONTH                                                       STFV0025
      GO TO 102                                                         STFV0026
  101 M2R = M1R                                                         STFV0027
      M1R = MONTH                                                       STFV0028
  102 CONTINUE                                                          STFV0029
      IF(LLZC) GO TO 106                                                STFV0030
      FLZC = (MFDP(M1R) + MFDP(M2R))/2.0                                STFV0031
      GO TO 105                                                         STFV0032
  103 SOFMD = 0.0                                                       STFV0033
```

```
      KM1 = 0
      DO 104 MONTH = 1,12
      IF(XMPFT(MONTH) .LT. 1.5) GO TO 104
      SOFMD = SOFMD + MFDP(MONTH)
      KM1 = KM1 + 1
      MXA(KM1) = MONTH
  104 CONTINUE
      FLZC = SOFMD/(FNOFM*0.75)
  105 IF(FLZC .GT. 1.0) FLZC = 1.0
      IF(FLZC .LT. -1.0) FLZC = -1.0
      IF(FLZC .GT. 0.0) LZC = (FLZC + 1.0)*LZC
      IF(FLZC .LE. 0.0) LZC = LZC/(1.0 - FLZC)
      IF(NOFM .LE. 2) WRITE(6,1) LZC,M1R,M2R
    1 FORMAT(/5X,'LZC WAS CHANGED TO',F6.2,' BASED ON MONTHS',2I3)
      IF(NOFM .GT. 2) WRITE(6,2) LZC,(MXA(KWD), KWD = 1,NOFM)
    2 FORMAT(/5X,'LZC WAS CHANGED TO',F6.2,' BASED ON MONTHS',12I3)
      IF(LZC .LT. 2.0 .AND. LRC) LZC = 2.0
      IF(LZC .GT. 30.0 .AND. LRC) LZC = 30.0
C  SELECTION OF MONTHS BEGINNING WET AND BEGINNING DRY SEASONS
  106 MBWS = 0
      MBDS = 0
      DO 109 MONTH = 2,10
      IF(TMPET(MONTH) .GT. TMPREC(MONTH)) GO TO 108
      IF(MBWS .NE. 0) GO TO 107
      MBWS = MONTH
      GO TO 109
  107 MBDS = MONTH + 1
      GO TO 109
  108 IF(MBDS .NE. 0) GO TO 110
  109 CONTINUE
  110 MBDS = MBDS + 1
C  ADJUSTMENT OF SUZC BASED ON TWO WETTEST SUMMER MONTHS AND LAST TWO
C     BASE FLOW MONTHS
      M11 = 0
      M12 = 0
      PRM1 = 0.0
```

```
      M1SP = 0
      DO 112 MNX = 7,14
      MONTH = MNX
      IF(MNX .GT. 12) MONTH = MNX - 12
      IF(TMPREC(MONTH) .LE. PRM1) GO TO 111
      M2SP = M1SP
      PRM2 = PRM1
      M1SP = MONTH
      PRM1 = TMPREC(MONTH)
      GO TO 112
  111 IF(TMPREC(MONTH) .LE. PRM2) GO TO 112
      M2SP = MONTH
      PRM2 = TMPREC(MONTH)
  112 CONTINUE
      FSUZC = MFDP(M1SP) + MFDP(M2SP)
      IF(ABS(XMPFT(12) - 1.0) .GT. 0.2) GO TO 113
      FSUZC = FSUZC + MFDP(12)
      M12 = 12
  113 IF(ABS(XMPFT(11) - 1.0) .GT. 0.2) GO TO 114
      FSUZC = FSUZC + MFDP(11)
      M11 = 11
  114 IF(FSUZC .GT. 1.0) FSUZC = 1.0
      IF(FSUZC .LT. -1.0) FSUZC = -1.0
      IF(FSUZC .GT. 0.0) SUZC = (FSUZC + 1.0)*SUZC
      IF(FSUZC .LE. 0.0) SUZC = SUZC/(1.0 - FSUZC)
      WRITE(6,3) SUZC,M1SP,M2SP,M11,M12
    3 FORMAT(4X,'SUZC WAS CHANGED TO',F6.2,' BASED ON MONTHS',4I3)
      IF(SUZC .LT. 0.3 .AND. LRC) SUZC = 0.3
      IF(SUZC .GT. 3.0 .AND. LRC) SUZC = 3.0
C  ADJUSTMENT OF ETLF BASED ON SUMMER MONTHS OF RAINFALL EXCEEDING TWO
C    INCHES OR NEED TO PREVENT MOISTURE BUILDUP
      IF(EMLZS(12) .LT. PLZC .OR. EMLZS(11) .LT. PLZC .OR. APREC .GT.
     1 1.5*APET) GO TO 115
      FETLF = 1.0
      MXA(1) = 13
      KWSM = 1
```

```
      GO TO 120                                                         STFV0106
  115 SWSMD = 0.0                                                       STFV0107
      KWSM = 0                                                          STFV0108
      DO 116 MONTH = 1,12                                               STFV0109
      IF((MONTH .GT. MBWS .OR. MONTH .GT. 2) .AND. (MONTH .LT. MBDS     STFV0110
     1  .AND. MONTH .LT. 9)) GO TO 116                                  STFV0111
      IF(TMPREC(MONTH) .LT. 2.0) GO TO 116                              STFV0112
      SWSMD = SWSMD + MFDP(MONTH)                                       STFV0113
      KWSM = KWSM + 1                                                   STFV0114
      MXA(KWSM) = MONTH                                                 STFV0115
  116 CONTINUE                                                          STFV0116
      IF(KWSM .GE. 1) GO TO 117                                         STFV0117
      MXA(1) = M1R                                                      STFV0118
      KWSM = 1                                                          STFV0119
      FETLF = 5.0*MFDP(M1R)                                             STFV0120
      GO TO 120                                                         STFV0121
  117 WSM = KWSM                                                        STFV0122
      IF(.NOT. LETLF .OR. KWSM .EQ. 1) GO TO 119                        STFV0123
      EMFDP = 0.0                                                       STFV0124
      DO 118 MONTH = 1,KWSM                                             STFV0125
      KM1 = MXA(MONTH)                                                  STFV0126
      IF(MFDP(KM1) .LT. EMFDP) GO TO 118                                STFV0127
      EMFDP= MFDP(KM1)                                                  STFV0128
      KM2 = MONTH                                                       STFV0129
  118 CONTINUE                                                          STFV0130
      MXA(KM2) = 0                                                      STFV0131
      SWSMD = SWSMD - EMFDP                                             STFV0132
      WSM = WSM - 1.0                                                   STFV0133
  119 FETLF = 1.2*SWSMD/WSM                                             STFV0134
  120 IF(FETLF .GT. 1.0) FETLF = 1.0                                    STFV0135
      IF(FETLF .LT. -1.0) FETLF = -1.0                                  STFV0136
      IF(FETLF .GT. 0.0) ETLF = (FETLF + 1.0)*ETLF                      STFV0137
      IF(FETLF .LT. 0.0) ETLF = ETLF/(1.0 - FETLF)                      STFV0138
      WRITE(6,4) ETLF,(MXA(KWD), KWD = 1,KWSM)                          STFV0139
    4 FORMAT(4X,'ETLF WAS CHANGED TO',F6.2,' BASED ON MONTHS',12I3)     STFV0140
      IF(ETLF .LT. 0.05 .AND. LRC) ETLF = 0.05                          STFV0141
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      IF(ETLF .GT. 0.6 .AND. LRC) ETLF = 0.6                            STFV0142
C  ADJUSTMENT OF BUZC BASED ON SEPTEMBER, NOVEMBER, AND DECEMBER        STFV0143
      KM1 = 12                                                          STFV0144
      KM2 = 2                                                           STFV0145
      KM3 = 3                                                           STFV0146
      FBUZC = 0.4*(MFDP(12) + MFDP(2) + MFDP(3))                        STFV0147
      IF(.NOT. LBUZC) GO TO 121                                         STFV0148
      FBUZC = 0.4*(MFDP(9) + MFDP(10) + MFDP(11))                       STFV0149
      KM1 = 9                                                           STFV0150
      KM2 = 10                                                          STFV0151
      KM3 = 11                                                          STFV0152
  121 IF(FBUZC .GT. 1.0) FBUZC = 1.0                                    STFV0153
      IF(FBUZC .LT. -1.0) FBUZC = -1.0                                  STFV0154
      IF(FBUZC .GT. 0.0) BUZC = (FBUZC + 1.0)*BUZC                      STFV0155
      IF(FBUZC .LE. 0.0) BUZC = BUZC/(1.0 - FBUZC)                      STFV0156
      WRITE(6,5) BUZC,KM1,KM2,KM3                                       STFV0157
    5 FORMAT(4X,'BUZC WAS CHANGED TO',F6.2,' BASED ON MONTHS',3I3)      STFV0158
      IF(BUZC .LT. 0.2 .AND. LRC) BUZC = 0.2                            STFV0159
      IF(BUZC .GT. 4.0 .AND. LRC) BUZC = 4.0                            STFV0160
C  ADJUSTMENT OF SIAC BASED ON THREE FIRST MOISTURE EXCESS AND THREE    STFV0161
C    FIRST MOISTURE DEFICIENT MONTHS                                    STFV0162
      KM1 = MBDS                                                        STFV0163
      KM2 = MBDS + 1                                                    STFV0164
      KM3 = MBDS - 1                                                    STFV0165
      KM4 = 0                                                           STFV0166
      KM5 = 0                                                           STFV0167
      KM6 = 0                                                           STFV0168
      WFDX = 0.0                                                        STFV0169
      IF(SIAC .GT. 1.0) GO TO 122                                       STFV0170
      WFDX = (MFDP(MBWS) + MFDP(MBWS+1) + MFDP(MBWS+2))/3.0             STFV0171
      IF(SIAC .GT. 0.6) WFDX = WFDX*(1.0 - SIAC)/0.4                    STFV0172
      KM4 = MBWS                                                        STFV0173
      KM5 = MBWS + 1                                                    STFV0174
      KM6 = MBWS + 2                                                    STFV0175
  122 SFDX = (MFDP(MBDS) + MFDP(MBDS+1) + MFDP(MBDS-1))/3.0             STFV0176
      FSIAC = 1.5*(SFDX - WFDX)                                         STFV0177
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```
      IF(FSIAC .GT. 1.0) FSIAC = 1.0                                    STFV0178
      IF(FSIAC .LE. -1.0) FSIAC = -1.0                                  STFV0179
      IF(SIAC .LT. 0.02) SIAC = 0.02                                    STFV0180
      IF(FSIAC .GT. 0.0) SIAC = (FSIAC + 1.0)*SIAC                      STFV0181
      IF(FSIAC .LE. 0.0) SIAC = SIAC/(1.0 - FSIAC)                      STFV0182
      WRITE(6,6) SIAC,KM4,KM5,KM6,KM3,KM1,KM2                           STFV0183
    6 FORMAT(4X,'SIAC WAS CHANGED TO',F6.2,' BASED ON MONTHS',6I3)      STFV0184
      IF(SIAC .LT. 0.02 .AND. LRC) SIAC = 0.00                          STFV0185
      IF(SIAC .GT. 4.0 .AND. LRC) SIAC = 4.0                            STFV0186
      RETURN                                                            STFV0187
      END                                                               STFV0188
```

```
      SUBROUTINE SETHRP(CTRI,BTRI,WCFS,CONOP2,HBF,LSHA,SSR,NHPT,KPSH,   STHP0001
     1 IBTPR,SRX,CSRX,FSRX,CHCAP,NRHP,RHPF,NCTRI,NBTRI)                 STHP0002
C   SETS BEST VALUES OF HYDROGRAPH ROUTING PARAMETERS                   STHP0003
      DIMENSION  BTRI(99),CTRI(99),HBF(5),HSRX(5),KPSH(5),LSHA(5),      STHP0004
     1 HNTRI(5),RHPF(5),SRR(5,170),SSR(5,170),TSRX(7)                   STHP0005
      LOGICAL  LSHA                                                     STHP0006
      INTEGER  CONOP2,HNTRI,SNTRI                                       STHP0007
      REAL  NHPT                                                        STHP0008
      MHTP = 1                                                          STHP0009
      IF(CONOP2 .EQ. 0) MHTP = 4                                        STHP0010
      MXTRI = 2*NBTRI                                                   STHP0011
      MNTRI = NBTRI/2                                                   STHP0012
      TSRX(1) = 0.995                                                   STHP0013
      TSRX(2) = 0.99                                                    STHP0014
      TSRX(3) = 0.985                                                   STHP0015
      TSRX(4) = 0.98                                                    STHP0016
      TSRX(5) = 0.96                                                    STHP0017
      TSRX(6) = 0.93                                                    STHP0018
      TSRX(7) = 0.90                                                    STHP0019
      LNIBRS = 0                                                        STHP0020
      DO 112 KHYD = 1,NRHP                                              STHP0021
      IF(.NOT. LSHA(KHYD)) GO TO 112                                    STHP0022
```

```
      KPCH = KPSH(KHYD)                                                 STHP0023
      NCTRI = MNTRI                                                     STHP0024
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                                STHP0025
      KH1 = 1                                                           STHP0026
      KH2 = 1                                                           STHP0027
      KH3 = 1                                                           STHP0028
      SDRSP = 80.0*CHCAP                                                STHP0029
      SNTRI = MXTRI                                                     STHP0030
  100 SRX = TSRX(KH1)                                                   STHP0031
      IF(KH2 .EQ. 2) LNIBRS = NIBRS                                     STHP0032
      WRITE(6,1) NCTRI,SRX                                              STHP0033
    1 FORMAT(//15X,'TRIAL VALUE OF NCTRI =',I3,',   SRX =',F6.3)        STHP0034
      CALL TIMERT(SSR,SRR,CTRI,NCTRI,KHYD,KPCH)                         STHP0035
      CSRX = SRX                                                        STHP0036
      FSRX = SRX                                                        STHP0037
      CALL STORRT(SRR,CSRX,FSRX,CHCAP,CONOP2,IBTPS,SHPF,KHYD,HBF(KHYD), STHP0038
     1  NHPT,KPCH,IBTPR)                                                STHP0039
      LNTRI = NCTRI                                                     STHP0040
      NIRTS = IBTPS - IBTPR*MHTP                                        STHP0041
      NIBRS = IABS(NIRTS)                                               STHP0042
      DRSP = ABS(SHPF - RHPF(KHYD))                                     STHP0043
      IF(NIRTS .EQ. 0 .OR. (KH2 .EQ. 2 .AND. NIBRS .GE. LNIBRS) .OR.    STHP0044
     1  RHPF(KHYD) .GT. 1.2*SHPF) GO TO 103                             STHP0045
      IF(NIRTS .GE. 1) GO TO 109                                        STHP0046
  101 NCTRI = NCTRI - NIRTS                                             STHP0047
      IF(NCTRI .LT. MNTRI) NCTRI = MNTRI                                STHP0048
      IF(NCTRI .GT. MXTRI) GO TO 106                                    STHP0049
  102 CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                                STHP0050
      KH2 = 2                                                           STHP0051
      GO TO 100                                                         STHP0052
  103 IF(DRSP .GT. SDRSP) GO TO 108                                     STHP0053
      SNTRI = LNTRI                                                     STHP0054
      SDRSP = DRSP                                                      STHP0055
      KH3 = 2                                                           STHP0056
  104 KH1 = KH1 + 1                                                     STHP0057
      IF(KH1 .EQ. 8) GO TO 105                                          STHP0058
```

```
      KH2 = 1
      GO TO 100
  105 HNTRI(KHYD) = LNTRI
      HSRX(KHYD) = SRX
      GO TO 111
  106 IF(KH1 .GE. 2 .AND. KH3 .EQ. 2 .AND. DRSP .GE. SDRSP) GO TO 108
      NCTRI = MXTRI
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)
      IF(KH2 .EQ. 2 .AND. KH1 .EQ. 1 .AND. SHPF .GT. RHPF(KHYD)) GO
     1 TO 107
      IF(KH2 .EQ. 2 .OR. KH1 .GE. 2) GO TO 109
      GO TO 102
  107 HNTRI(KHYD) = MXTRI
      HSRX(KHYD) = 0.995
      GO TO 111
  108 HSRX(KHYD) = TSRX(KH1-1)
      HNTRI(KHYD) = SNTRI
      GO TO 111
  109 IF(NCTRI .GT. MNTRI .AND. NCTRI .LT. MXTRI) GO TO 101
      IF(DRSP .GT. SDRSP) GO TO 110
      SDRSP = DRSP
      SNTRI = LNTRI
      GO TO 104
  110 HNTRI(KHYD) = NCTRI
      HSRX(KHYD) = 0.995
      IF(KH1 .GE. 2) HSRX(KHYD) = TSRX(KH1 - 1)
  111 IF(HSRX(KHYD) .LT. 0.91 .AND. SHPF .LT. 0.5*RHPF(KHYD)) LSHA(KHYD)
     1 = .FALSE.
      IF(.NOT. LSHA(KHYD)) GO TO 112
      WRITE(6,2) KHYD,HNTRI(KHYD),HSRX(KHYD)
    2 FORMAT(10X,'FOR STORM ',I2,' NCTRI =',I3,' SRX =',F6.3)
  112 CONTINUE
      KPA = 1
  113 ARHPF = 0.0
      APPKP = 0.0
      DO 114 KHYD = 1,NRHP
```

```
      IF(.NOT. LSHA(KHYD)) GO TO 114                                    STHP0095
      CHPV = HNTRI(KHYD)                                                STHP0096
      IF(KPA .EQ. 2) CHPV = HSRX(KHYD)                                  STHP0097
      APPKP = APPKP + CHPV*RHPF(KHYD)                                   STHP0098
      ARHPF = ARHPF + RHPF(KHYD)                                        STHP0099
  114 CONTINUE                                                          STHP0100
      WAPV = APPKP/ARHPF                                                STHP0101
      IF(KPA .EQ. 2) GO TO 115                                          STHP0102
      NCTRI = WAPV + 0.5                                                STHP0103
      WRITE(6,3) NCTRI                                                  STHP0104
    3 FORMAT(//10X,'OPTIMUM NCTRI =',I3)                                STHP0105
      IF(NCTRI .EQ. 0) RETURN                                           STHP0106
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                                STHP0107
      WRITE(6,4) (CTRI(KTRI), KTRI = 1,NCTRI)                           STHP0108
    4 FORMAT(18X,'CTRI ARE'/9(16X,11F8.4/))                             STHP0109
      WRITE(6,5)                                                        STHP0110
    5 FORMAT(18X,'WARNING: THE USER MAY HAVE TO ADJUST THESE VALUES TO  STHP0111
     1MAKE THEM ADD TO ONE TO COMPENSATE FOR ROUNDING.')                STHP0112
      KPA = 2                                                           STHP0113
      GO TO 113                                                         STHP0114
  115 SRX = WAPV                                                        STHP0115
      CSRX = SRX                                                        STHP0116
      FSRX = SRX                                                        STHP0117
      CALL SETSRP(CONOP2,NRHP,LSHA,RHPF,HSRX,CHCAP,SSR,SRR,CTRI,CSRX,   STHP0118
     1  FSRX,KHYD,IBTPS,SHPF,NCTRI,HBF,NHPT,KPSH,IBTPR)                 STHP0119
      SRX = CSRX                                                        STHP0120
      RETURN                                                            STHP0121
      END                                                               STHP0122


      SUBROUTINE SETRBF(RSTF,NDRS,KRS,BFRC,IFRC,CRSBIF,CRSBBF)          STRB0001
C   SETS VALUES OF INTERFLOW AND BASE FLOW AT RECESSION BEGINNING       STRB0002
      DIMENSION  RSTF(50,20),NDRS(20)                                   STRB0003
      REAL*8  RA1,RA2,RA3,RA4,RA5,RA6                                   STRB0004
      REAL  IFRC                                                        STRB0005
```

```
      RA1 = 0.0                                                         STRB0006
      RA2 = 0.0                                                         STRB0007
      RA3 = 0.0                                                         STRB0008
      RA4 = 0.0                                                         STRB0009
      RA5 = 0.0                                                         STRB0010
      MNDRS = 12                                                        STRB0011
      IF(NDRS(KRS) .LT. 12) MNDRS = NDRS(KRS)                           STRB0012
      IF(IFRC .GE. 0.3) GO TO 101                                       STRB0013
      CRSBIF = 0.0                                                      STRB0014
      DO 100 KSD = 1,MNDRS                                              STRB0015
      RA1 = RA1 + BFRC**(2*KSD)                                         STRB0016
  100 RA4 = RA4 + RSTF(KSD,KRS)*(BFRC**KSD)                             STRB0017
      CRSOBF = RA4/RA1                                                  STRB0018
      CRSBBF = CRSOBF*BFRC                                              STRB0019
      RETURN                                                            STRB0020
  101 CRSBIF = 100000.0                                                 STRB0021
      DO 102 KSD = 1,MNDRS                                              STRB0022
      RA1 = RA1 + BFRC**(2*KSD)                                         STRB0023
      RA2 = RA2 + IFRC**(2*KSD)                                         STRB0024
      RA3 = RA3 + (BFRC*IFRC)**KSD                                      STRB0025
      RA4 = RA4 + RSTF(KSD,KRS)*(BFRC**KSD)                             STRB0026
      RA5 = RA5 + RSTF(KSD,KRS)*(IFRC**KSD)                             STRB0027
  102 CONTINUE                                                          STRB0028
      RA6 = RA1*RA2 - RA3**2                                            STRB0029
      IF(RA6 .EQ. 0.0) RETURN                                           STRB0030
      CRSOIF = -(RA3/RA6)*RA4 + (RA1/RA6)*RA5                           STRB0031
      CRSBIF = CRSOIF*IFRC                                              STRB0032
      CRSOBF = (RA2/RA6)*RA4 - (RA3/RA6)*RA5                            STRB0033
      CRSBBF = CRSOBF*BFRC                                              STRB0034
      RETURN                                                            STRB0035
      END                                                               STRB0036


      SUBROUTINE SETSRP(CONOP2,NRHP,LSHA,RHPF,HSRX,CHCAP,SSR,SRR,CTRI,  STSP0001
     1  CSRX,FSRX,KHYD,IBTPS,SHPF,NCTRI,HBF,NHPT,KPSH,IBTPR)            STSP0002
```

```
C  SETS BEST VALUES OF STORAGE ROUTING PARAMETERS
      DIMENSION  CTRI(99),HBF(5),HSRX(5),KPSH(5),LSHA(5),RHPF(5),
     1  SRR(5,170),SSR(5,170)
      LOGICAL  LSHA
      INTEGER  CONOP2
      REAL  NHPT
      KLCCA = 1
      SRX = CSRX
      EPS = 0.000001
      NORHP = NRHP
      DO 100 KHYD = 1,NORHP
      IF(.NOT. LSHA(KHYD)) NRHP = NRHP - 1
  100 CONTINUE
      IF(NRHP .LE. 2) GO TO 103
C  FIND REGRESSION LINE FOR DETERMINING CSRX, WHEN NRHP EXCEEDS 3
      RA1 = 0.0
      RA2 = 0.0
      RA3 = 0.0
      RA4 = 0.0
C     FNRHP = NRHP
      DO 101 KHYD = 1,NORHP
      IF(.NOT. LSHA(KHYD)) GO TO 101
      RA1 = RA1 + RHPF(KHYD)
      RA2 = RA2 + HSRX(KHYD)
      RA3 = RA3 + RHPF(KHYD)*HSRX(KHYD)
      RA4 = RA4 + RHPF(KHYD)**2
  101 CONTINUE
      AVRHPF = RA1/FNRHP
      ASRX = RA2/FNRHP
      RSLP = (RA3 - RA1*ASRX)/(RA4 - RA1**2/FNRHP)
      IF(RSLP .LE. EPS) GO TO 106
      RINT = ASRS - RSLP*AVRHPF
  102 CSRX = RINT + RSLP*(0.5*CHCAP)
      IF(CSRX .GE. 0.99) RETURN
      IF(CSRX .LE. 0.8) CSRX = 0.8
      GO TO 107
```

```
  103 K1AH = 0                                                          STSP0039
      DO 104 KHYD = 1,NORHP                                             STSP0040
      IF(.NOT. LSHA(KHYD)) GO TO 104                                    STSP0041
      IF(K1AH .EQ. 0) K1AH = KHYD                                       STSP0042
      IF(K1AH .GT. 0) K2AH = KHYD                                       STSP0043
  104 CONTINUE                                                          STSP0044
      IF(NRHP .EQ. 1) GO TO 105                                         STSP0045
C   FIT THE STRAIGHT LINE WHEN NRHP = 2                                 STSP0046
      RSLP = (HSRX(K1AH) -HSRX(K2AH))/(RHPF(K1AH) - RHPF(K2AH))         STSP0047
      IF(RSLP .LE. EPS) GO TO 106                                       STSP0048
      RINT = HSRX(K1AH) - RSLP*RHPF(K1AH)                               STSP0049
      GO TO 102                                                         STSP0050
  105 CONTINUE                                                          STSP0051
      CSRX = HSRX(K1AH)                                                 STSP0052
      FSRX = CSRX                                                       STSP0053
      GO TO 115                                                         STSP0054
  106 CONTINUE                                                          STSP0055
      CSRX = SRX                                                        STSP0056
      FSRX = CSRX                                                       STSP0057
      WRITE(6,1)                                                        STSP0058
    1 FORMAT(//10X,'REGRESSION LINE HAS NEGATIVE SLOPE')                STSP0059
      GO TO 115                                                         STSP0060
  107 CONTINUE                                                          STSP0061
      BISRX = 0.2*(0.99 - CSRX)                                         STSP0062
      SISRX = 0.04*(0.99 - CSRX)                                        STSP0063
      TFSRX = CSRX                                                      STSP0064
      KISRX = 0                                                         STSP0065
  108 KISRX = KISRX + 1                                                 STSP0066
      FSRX = TFSRX                                                      STSP0067
      WRITE(6,2) KISRX,CSRX,FSRX,CHCAP                                  STSP0068
    2 FORMAT(//15X,'TRIAL',I3,',   CSRX =',F8.5,',   FSRX =',F8.5,      STSP0069
     1  ',   CHCAP =',F10.0)                                            STSP0070
      SQPKD = 0.0                                                       STSP0071
      ADRSP = 0.0                                                       STSP0072
      DO 109 KHYD = 1,NORHP                                             STSP0073
      IF(.NOT. LSHA(KHYD)) GO TO 109                                    STSP0074
```

```
      KPCH = KPSH(KHYD)                                                 STSP0075
      CALL TIMERT(SSR,SRR,CTRI,NCTRI,KHYD,KPCH)                         STSP0076
      CALL STORRT(SRR,CSRX,FSRX,CHCAP,CONOP2,IBTPS,SHPF,KHYD,HBF(KHYD), STSP0077
     1 NHPT,KPCH,IBTPR)                                                 STSP0078
      DRSP = SHPF - RHPF(KHYD)                                          STSP0079
      SQPKD = SQPKD + DRSP**2                                           STSP0080
      ADRSP = ADRSP + DRSP                                              STSP0081
  109 CONTINUE                                                          STSP0082
      WRITE(6,3) SQPKD                                                  STSP0083
    3 FORMAT(/25X,'SQPKD =',F14.0)                                      STSP0084
      IF(KISRX .NE. 1) GO TO 110                                        STSP0085
      TFSRX = CSRX + BISRX                                              STSP0086
      SSQPKD = SQPKD                                                    STSP0087
      BFSRX = FSRX                                                      STSP0088
      GO TO 108                                                         STSP0089
  110 IF(SQPKD .GT. SSQPKD) GO TO 113                                   STSP0090
      IF(KISRX .EQ. 6 .AND. ADRSP .GT. 0.0) GO TO 111                   STSP0091
      SSQPKD = SQPKD                                                    STSP0092
      BFSRX = FSRX                                                      STSP0093
      IF(KISRX .GE. 11) GO TO 114                                       STSP0094
      IF(KISRX .LE. 5) TFSRX = TFSRX + BISRX                            STSP0095
      IF(KISRX .GE. 6) TFSRX = TFSRX - SISRX                            STSP0096
      GO TO 108                                                         STSP0097
  111 KLCCA = KLCCA + 1                                                 STSP0098
      IF(KLCCA .GE. 5) GO TO 112                                        STSP0099
      CHCAP = 0.8*CHCAP                                                 STSP0100
      CSRX = RINT + RSLP*(0.5*CHCAP)                                    STSP0101
      GO TO 107                                                         STSP0102
  112 CSRX = 0.990                                                      STSP0103
      FSRX = 0.990                                                      STSP0104
      GO TO 115                                                         STSP0105
  113 IF(KISRX .GT. 6) GO TO 114                                        STSP0106
      KISRX = 6                                                         STSP0107
      SSQPKD = SQPKD                                                    STSP0108
      BFSRX = FSRX                                                      STSP0109
      TFSRX = TFSRX - SISRX                                             STSP0110
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```
      GO TO 108                                                         STSP0111
  114 FSRX = BFSRX                                                      STSP0112
      WRITE(6,4) CSRX,FSRX,SSQPKD                                       STSP0113
    4 FORMAT(//10X,'CSRX =',F7.4,10X,'FSRX =',F7.4,10X,'SQPKD =',F15.2) STSP0114
      RETURN                                                            STSP0115
  115 WRITE(6,5) CSRX,FSRX                                              STSP0116
    5 FORMAT(//10X,'CSRX =',F7.4,10X,'FSRX =',F7.4)                     STSP0117
      RETURN                                                            STSP0118
      END                                                               STSP0119


      SUBROUTINE SET1RC(RSTF,KRS,NDRSC,BFRC)                            ST1R0001
C   SETS BEST VALUE FOR ONE RECESSION CONSTANT                          ST1R0002
      DIMENSION  RSTF(50,20)                                            ST1R0003
      RA1 = 0.0                                                         ST1R0004
      RA2 = 0.0                                                         ST1R0005
      NDRSC1 = NDRSC - 1                                                ST1R0006
      DO 100 KSD = 1,NDRSC1                                             ST1R0007
      RA1 = RA1 + RSTF(KSD,KRS)**2                                      ST1R0008
  100 RA2 = RA2 + RSTF(KSD,KRS)*RSTF(KSD+1,KRS)                         ST1R0009
      BFRC = RA2/RA1                                                    ST1R0010
      WRITE(6,1) KRS,BFRC                                               ST1R0011
    1 FORMAT(15X,'KRS =',I3,5X,'BFRC =',F8.4)                           ST1R0012
      RETURN                                                            ST1R0013
      END                                                               ST1R0014


      SUBROUTINE SET2RC(RSTF,KRS,NDRSC,IFRC,BFRC,LBFO)                  ST2R0001
C   SETS BEST VALUES FOR TWO RECESSION CONSTANTS                        ST2R0002
      DIMENSION  RSTF(50,20)                                            ST2R0003
      LOGICAL  LBFO                                                     ST2R0004
      REAL   IFRC                                                       ST2R0005
      REAL*8  RA1,RA2,RA3,RA4,RA5,CRSTF(50),RA6,DBFRC,DIFRC,RA,RB,RD    ST2R0006
      DO 100 KSD = 1,NDRSC                                              ST2R0007
```

```
  100 CRSTF(KSD) = RSTF(KSD,KRS)                                         ST2R0008
      NDRSC2 = NDRSC - 2                                                ST2R0009
      RA1 = 0.0                                                         ST2R0010
      RA2 = 0.0                                                         ST2R0011
      RA3 = 0.0                                                         ST2R0012
      DO 101 KSD = 1,NDRSC2                                             ST2R0013
      RA1 = RA1 + CRSTF(KSD)**2                                         ST2R0014
      RA2 = RA2 + CRSTF(KSD)*CRSTF(KSD+1)                               ST2R0015
  101 RA3 = RA3 + CRSTF(KSD)*CRSTF(KSD+2)                               ST2R0016
      RA4 = RA1 + CRSTF(NDRSC-1)**2 - CRSTF(1)**2                       ST2R0017
      RA5 = RA2 + CRSTF(NDRSC-1)*CRSTF(NDRSC) - CRSTF(1)*CRSTF(2)       ST2R0018
      RA6 = RA4*RA1 - RA2**2                                            ST2R0019
      IF(RA6 .EQ. 0.0) GO TO 102                                        ST2R0020
      RA5 = RA5/RA6                                                     ST2R0021
      RA3 = RA3/RA6                                                     ST2R0022
      RA = RA1*RA5 - RA2*RA3                                            ST2R0023
      RB = RA4*RA3 - RA2*RA5                                            ST2R0024
      RD = RA**2 + 4.0*RB                                               ST2R0025
      IF(RD .LT. 0.0) GO TO 102                                         ST2R0026
      DBFRC = (RA + RD**0.5)/2.0                                        ST2R0027
      DIFRC = RA - DBFRC                                                ST2R0028
      BFRC = DBFRC                                                      ST2R0029
      IFRC = DIFRC                                                      ST2R0030
      WRITE(6,1) KRS,BFRC,IFRC                                          ST2R0031
    1 FORMAT(15X,'KRS =',I3,5X,'BFRC =',F8.4,5X,'IFRC =',F8.4)          ST2R0032
      GO TO 103                                                         ST2R0033
  102 LBFO = .TRUE.                                                     ST2R0034
      WRITE(6,2) KRS                                                    ST2R0035
    2 FORMAT(/15X,'IMAGINARY VALUES ENCOUNTERED IN SET2RC, SEQUENCE =', ST2R0036
     1  I3)                                                             ST2R0037
  103 RETURN                                                            ST2R0038
      END                                                               ST2R0039


      SUBROUTINE STORRT(SRR,CSRX,FSRX,CHCAP,CONOP2,IBTPS,SHPF,KHYD,     SRRT0001
```

```
     1  CHBF,NHPT,KPCH,IBTPR)                                           SRRT0002
C  PERFORMS CHANNEL STORAGE ROUTING                                     SRRT0003
      DIMENSION  ASRR(5,21),SRR(5,170)                                  SRRT0004
      INTEGER  CONOP2,PRD                                               SRRT0005
      REAL  NHPT                                                        SRRT0006
      WRITE(6,1) CHBF                                                   SRRT0007
    1 FORMAT(/25X,'BASE FLOW =',F7.1,' CFS')                            SRRT0008
      TFCFS = CHBF                                                      SRRT0009
      INHPT = NHPT                                                      SRRT0010
      MHTP = 1                                                          SRRT0011
      IF(CONOP2 .EQ. 0) MHTP = 4                                        SRRT0012
      INHPT = MHTP*INHPT                                                SRRT0013
      SHPF = 0.0                                                        SRRT0014
      RHFO = 0.9*SRR(KHYD,1)                                            SRRT0015
      KAFH = 0                                                          SRRT0016
      DO 102 KHPT = 1,KPCH                                              SRRT0017
      PRD = 0                                                           SRRT0018
  100 PRD = PRD + 1                                                     SRRT0019
      TRHF = SRR(KHYD,KHPT)                                             SRRT0020
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX                               SRRT0021
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX =     SRRT0022
     1  CSRX + (FSRX -CSRX)*((TFCFS - 0.5*CHCAP)/(1.5*CHCAP))**3        SRRT0023
      IF(TFCFS .GE. 2.0*CHCAP) SRX = FSRX                               SRRT0024
      RHF1 = TRHF - SRX*(TRHF - RHFO)                                   SRRT0025
      RHFO = RHF1                                                       SRRT0026
      TFCFS = RHF1 + CHBF                                               SRRT0027
      IF(TFCFS .LT. SHPF) GO TO 101                                     SRRT0028
      SHPF = TFCFS                                                      SRRT0029
      IBTPS = KHPT                                                      SRRT0030
  101 IF(PRD .LE. 3 .AND. CONOP2 .EQ. 1) GO TO 100                      SRRT0031
      KAHP = KHPT - IBTPR*MHTP + 5*INHPT                                SRRT0032
      IF(KAHP .LT. 0) GO TO 102                                         SRRT0033
      IF(MOD(KAHP,INHPT) .NE. 0) GO TO 102                              SRRT0034
      KAFH = KAFH + 1                                                   SRRT0035
      ASRR(KHYD,KAFH) = TFCFS                                           SRRT0036
  102 CONTINUE                                                          SRRT0037
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      IF(KAFH .EQ. 21) GO TO 104                                        SRRT0038
      KAFH = KAFH + 1                                                   SRRT0039
      DO 103 KIA = KAFH,21                                              SRRT0040
  103 ASRR(KHYD,KIA) = 0.0                                              SRRT0041
  104 WRITE(6,2) KHYD,NHPT,(ASRR(KHYD,KWD), KWD = 1,21)                 SRRT0042
    2 FORMAT(/25X,'SYNTHESIZED HYDROGRAPH',I3,' INTERVAL =',F5.2,       SRRT0043
     1  ' HOURS'/3(22X,7F10.1/))                                        SRRT0044
      WRITE(6,3) SHPF                                                   SRRT0045
    3 FORMAT(25X,'FLOOD PEAK =',F10.1,' CFS')                           SRRT0046
      RETURN                                                            SRRT0047
      END                                                               SRRT0048


      SUBROUTINE STRHRS(RHPD,RHPH,IDYB,IDYE,IHRB,IHRE,NHPT,MXTRH,DPY,   SHRS0001
     1  NRHP,IBTPR)                                                     SHRS0002
C  SETS BEGINNING AND END TIMES OF RUNOFF ENTERING RECORDED HYDROGRAPHS SHRS0003
      DIMENSION  RHPD(5),RHPH(5),IDYB(5),IDYE(5),IHRB(5),IHRE(5)        SHRS0004
      INTEGER  DAY,DPY,RHPD,RHPH                                        SHRS0005
      REAL  NHPT                                                        SHRS0006
C  ESTIMATE HOURS EACH WAY FROM PEAK                                    SHRS0007
      INHPT = NHPT                                                      SHRS0008
      IBTPR = 5*INHPT + MXTRH                                           SHRS0009
      IPTE = 15*INHPT                                                   SHRS0010
C  DETERMINE TIME OF BEGINNING AND ENDING FOR EACH STORM                SHRS0011
      DO 106 KRHP = 1,NRHP                                              SHRS0012
      KHBCK = IBTPR - RHPH(KRHP)                                        SHRS0013
      IF(KHBCK .LT. 0) GO TO 101                                        SHRS0014
      KDBCK = KHBCK/24 + 1                                              SHRS0015
      IHRB(KRHP) = 24*KDBCK - KHBCK                                     SHRS0016
      DAY = RHPD(KRHP)                                                  SHRS0017
  100 DAY = DAY - 1                                                     SHRS0018
      IF(DAY .EQ. 59 .AND. DPY .EQ. 366) DAY = 366                      SHRS0019
      IF(DAY .EQ. 365) DAY = 59                                         SHRS0020
      IF(DAY .EQ. 0) DAY = 365                                          SHRS0021
      KDBCK = KDBCK - 1                                                 SHRS0022
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      IF(KDBCK .GT. 0) GO TO 100                                        SHRS0023
      IDYB(KRHP) = DAY                                                  SHRS0024
      GO TO 102                                                         SHRS0025
  101 IDYB(KRHP) = RHPD(KRHP)                                           SHRS0026
      IHRB(KRHP) = RHPH(KRHP) - IBTPR                                   SHRS0027
  102 KHFOR = IPTE + RHPH(KRHP)                                         SHRS0028
      IF(KHFOR .LE. 24) GO TO 105                                       SHRS0029
      KDFOR = KHFOR/24                                                  SHRS0030
      IHRE(KRHP) = KHFOR - 24*KDFOR                                     SHRS0031
      IF(IHRE(KRHP) .NE. 0) GO TO 103                                   SHRS0032
      KDFOR = KDFOR - 1                                                 SHRS0033
  103 DAY = RHPD(KRHP)                                                  SHRS0034
  104 CALL DAYNXT(DAY,DPY)                                              SHRS0035
      KDFOR = KDFOR - 1                                                 SHRS0036
      IF(KDFOR .GT. 0) GO TO 104                                        SHRS0037
      IDYE(KRHP) = DAY                                                  SHRS0038
      GO TO 106                                                         SHRS0039
  105 IDYE(KRHP) = RHPD(KRHP)                                           SHRS0040
      IHRE(KRHP) = RHPH(KRHP) + IPTE                                    SHRS0041
  106 CONTINUE                                                          SHRS0042
C  ELIMINATE HYDROGRAPH OVERLAPPING                                     SHRS0043
      NRHP1 = NRHP - 1                                                  SHRS0044
      IF(NRHP1 .EQ. 0) GO TO 109                                        SHRS0045
      DO 108 KRHP = 1,NRHP1                                             SHRS0046
      IF((IDYE(KRHP) .GT. IDYB(KRHP+1) .AND. (.NOT. ((IDYE(KRHP) .GE.   SHRS0047
     1  274 .AND. IDYB(KRHP+1) .LE. 273) .OR. IDYE(KRHP) .EQ.366))) .OR.SHRS0048
     2  (IDYE(KRHP) .EQ. IDYB(KRHP+1) .AND. IHRE(KRHP) .GT. IHRB(KRHP+1)SHRS0049
     3  )) GO TO 107                                                    SHRS0050
      GO TO 108                                                         SHRS0051
  107 IDYE(KRHP) = IDYB(KRHP+1)                                         SHRS0052
      IHRE(KRHP) = IHRB(KRHP+1)                                         SHRS0053
  108 CONTINUE                                                          SHRS0054
  109 IF(IDYB(1) .LE. 273 .AND. RHPD(1) .GE. 274 .AND. RHPD(1) .NE. 366)SHRS0055
     1  GO TO 110                                                       SHRS0056
      GO TO 111                                                         SHRS0057
  110 IDYB(1) = 274                                                     SHRS0058
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      IHRB(1) = 1                                                       SHRS0059
  111 IF(IDYE(NRHP) .GE. 274 .AND. RHPD(NRHP) .LE. 273 .AND. IDYE(NRHP) SHRS0060
     1 .NE. 366) GO TO 112                                              SHRS0061
      GO TO 113                                                         SHRS0062
  112 IDYE(NRHP) = 273                                                  SHRS0063
      IHRE(NRHP) = 24                                                   SHRS0064
  113 CONTINUE                                                          SHRS0065
      DO 114 KRHP = 1,NRHP                                              SHRS0066
      WRITE(6,1) KRHP,IDYB(KRHP),IHRB(KRHP),IDYE(KRHP),IHRE(KRHP)       SHRS0067
    1 FORMAT(5X,'RUNOFF CONTRIBUTING TO RECORDED HYDROGRAPH',I2/10X,    SHRS0068
     1  'BEGINS ON DAY',I4,' AT HOUR',I3/10X,'AND ENDS ON DAY',I4,      SHRS0069
     2  ' AT HOUR',I3)                                                  SHRS0070
  114 CONTINUE                                                          SHRS0071
      RETURN                                                            SHRS0072
      END                                                               SHRS0073


      SUBROUTINE TIMERT(SSR,SRR,CTRI,NCTRI,KRHP,KPCH)                   TMRT0001
C  PERFORMS CHANNEL TIME ROUTING                                        TMRT0002
      DIMENSION  SSR(5,170),SRR(5,170),CTRI(99)                         TMRT0003
      DO 100 KHPT = 1,KPCH                                              TMRT0004
  100 SRR(KRHP,KHPT) = 0.0                                              TMRT0005
      KTRI = 1                                                          TMRT0006
  101 CONTINUE                                                          TMRT0007
      DO 102 KHPT = KTRI,KPCH                                           TMRT0008
      NRTRI = KHPT - KTRI + 1                                           TMRT0009
  102 SRR(KRHP,KHPT) = CTRI(KTRI)*SSR(KRHP,NRTRI) + SRR(KRHP,KHPT)      TMRT0010
      KTRI = KTRI + 1                                                   TMRT0011
      IF(KTRI .LE. NCTRI) GO TO 101                                     TMRT0012
      RETURN                                                            TMRT0013
      END                                                               TMRT0014
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APPENDIX C

DICTIONARY OF VARIABLES USED IN THE KENTUCKY WATERSHED MODEL AND OPSET

ITEM 1 - VARIABLE NAME

ITEM 2 - WHETHER VARIABLE IS REAL, INTEGER, OR LOGICAL

ITEM 3 - VARIBLE DIMENSIONS

ITEM 4 - UNITS

ITEM 5 - DEFINITION OF THE VARIABLE

1	2	3	4	5
ABFSL	R	1	DAY	ACCUMULATED BASE FLOW SEQUENCE LENGTH
ABFV	R	1	IN	ANNUAL BASE FLOW VOLUME
ACRFMI	R	1	-	ACCUMULATED CASES IN ALL RECORDED FLOOD MAGNITUDE INTERVALS
ADBF	R	1	IN	ACCUMULATED DAILY BASE FLOW
ADIF	R	1	IN	ACCUMULATED DAILY INTERFLOW
ADRSP	R	1	CFS	ACCUMULATED SUM OF DRSP
AETX	R	1	IN	ANNUAL EVAPOTRANSPIRATION INDEX
AEX90	R	1	IN	ANTECEDENT EVAPORATION INDEX, DECAY RATE = 0.9
AEX96	R	1	IN	ANTECEDENT EVAPORATION INDEX, DECAY RATE = 0.96
AFSIL	R	1	IN	ANNUAL FOREST SNOW INTERCEPTION LOSS
AHP	R	1	IN	ACCUMULATED HOURLY PRECIPITATION

AIFSL	R	1	DAY	ACCUMULATED INTERFLOW SEQUENCE LENGTH
AIFV	R	1	IN	ANNUAL INTERFLOW VOLUME
AMBER	R	1	IN	ANNUAL MOISTURE BALANCE ERROR
AMBF	R	1	IN	ACCUMULATED MONTHLY BASE FLOW
AMFSIL	R	1	IN	ACCUMULATED MONTHLY FOREST SNOW INTERCEPTION LOSS
AMIF	R	1	IN	ACCUMULATED MONTHLY INTERFLOW
AMNET	R	1	IN	ACCUMULATED MONTHLY NET EVAPOTRANSPIRATION
AMPET	R	1	IN	ACCUMULATED MONTHLY POTENTIAL EVAPOTRANSPIRATION
AMPREC	R	1	IN	ACCUMULATED MONTHLY PRECIPITATION
AMRPM	R	1	IN	ACCUMULATED MONTHLY RAIN PLUS MELT
AMRTF	R	1	CFS	ACCUMULATED MONTHLY RECORDED TOTAL FLOW
AMSE	R	1	IN	ACCUMULATED MONTHLY STREAM EVAPORATION
AMSNE	R	1	IN	ACCUMULATED MONTHLY SNOW EVAPORATION
AMSTF	R	1	CFS	ACCUMULATED MONTHLY SYNTHESIZED TOTAL FLOW
ANET	R	1	IN	ANNUAL NET EVAPOTRANSPIRATION
AOFV	R	1	IN	ANNUAL OVERLAND FLOW VOLUME
APET	R	1	IN	ANNUAL POTENTIAL EVAPOTRANSPIRATION
APPKP	R	1	-	ACCUMULATED PARAMETER PEAK PRODUCTS
APREC	R	1	IN	ANNUAL PRECIPITATION
AREA	R	1	SQ MI	AREA OF WATERSHED
ARHF	R	1	IN	ACCUMULATED ROUTED HYDROGRAPH FLOW
ARHPF	R	1	CFS	ACCUMULATED RECORDED HYDROGRAPH PEAK FLOWS
ARPM	R	1	IN	ANNUAL RAIN PLUS MELT
ARSTR	R	1	-	ACCUMULATED RATIO OF SYNTHESIZED TO RECORDED FLOWS
ASE	R	1	IN	ANNUAL SNOW EVAPORATION
ASEV	R	1	IN	ANNUAL STREAM EVAPORATION VOLUME
ASM	R	1	IN	ANNUAL SNOWFALL MOISTURE
ASMRG	R	1	IN	ANNUAL SNOWFALL MOISTURE REACHING GROUND
ASRR	R	5,21	CFS	ABSTRACTED SYNTHESIZED ROUTED RUNOFFS
ASRX	R	1	-	AVERAGE VALUE OF SRX
ATF	R	1	SFD	ACCUMULATED TOTAL FLOW
ATFV	R	1	SFD	ANNUAL TOTAL FLOW VOLUME
AVRHPF	R	1	CFS	AVERAGE VALUE OF RHPF
AWSBIT	R	99	-	ACCUMULATOR FOR WATERSHED BITS
BBMIR	R	1	IN/HR	CURRENT BEST ESTIMATE OF BASIC MAXIMUM INFILTRATION RATE
BBUZC	R	1	-	CURRENT BEST ESTIMATE OF BASIC UPPER ZONE STORAGE

				CAPACITY FACTOR
BBYLZS	R	1	IN	CURRENT BEST ESTIMATE OF BEGINNING OF YEAR LOWER ZONE STORAGE
BDDFSM	R	1	IN/HR	BASIC DEGREE DAY FACTOR FOR SNOW MELT
BETLF	R	1	-	CURRENT BEST ESTIMATE OF EVAPOTRANSPIRATION LOSS FACTOR
BFHRC	R	1	-	BASE FLOW HOURLY RECESSION CONSTANT
BFNHR	R	1	-	BASE FLOW HOURLY NONLINEAR RECESSION ADJUSTMENT FACTOR
BFNLR	R	1	-	BASE FLOW NONLINEAR RECESSION ADJUSTMENT FACTOR
BFNRL	R	1	-	BASE FLOW NONLINEAR RECESSION LOGARITHM
BFNX	R	1	IN	CURRENT VALUE OF BASE FLOW NONLINEAR RECESSION INDEX
BFRC	R	1	-	BASE FLOW RECESSION CONSTANT
BFRL	R	1	-	BASE FLOW RECESSION LOGARITHM
BFSRX	R	1	-	CURRENT BEST ESTIMATE OF FSRX
BISRX	R	1	-	BIG INCREMENTAL STORAGE ROUTING INDEX
BIVF	R	1	-	BASIC INTERFLOW VOLUME FACTOR
BLZC	R	1	IN	CURRENT BEST ESTIMATE OF LOWER ZONE STORAGE CAPACITY
BMIR	R	1	IN/HR	BASIC MAXIMUM INFILTRATION RATE WITHIN WATERSHED
BSIAC	R	1	-	CURRENT BEST ESTIMATE OF SEASONAL INFILTRATION ADJUSTMENT FACTOR
BSUZC	R	1	-	CURRENT BEST ESTIMATE OF SEASONAL UPPER ZONE STORAGE CAPACITY FACTOR
BTRI	R	99	-	BASE TIME ROUTING INCREMENTS
BUZC	R	1	-	BASIC UPPER ZONE STORAGE CAPACITY FACTOR
BYGWS	R	1	IN	BEGINNING OF YEAR GROUNDWATER STORAGE
BYIFS	R	1	IN	BEGINNING OF YEAR INTERFLOW STORAGE
BYLZS	R	1	IN	BEGINNING OF YEAR LOWER ZONE STORAGE
BYUZS	R	1	IN	BEGINNING OF YEAR UPPER ZONE STORAGE
CBF	R	1	IN/HR	CURRENT BASE FLOW
CCRFMI	R	1	-	CASES IN CURRENT RECORDED FLOW MAGNITUDE INTERVAL
CDSDR	I	1	-	CURRENT DAY FOR WHICH STORM DETAILS REQUESTED
CHBF	R	1	CFS	CURRENT HYDROGRAPH BASE FLOW
CHCAP	R	1	CFS	CHANNEL CAPACITY - INDEXED TO BASIN OUTLET
CHPV	R	1	-	CURRENT HYDROGRAPH PARAMETER VALUE
CIVM	R	1	-	CURRENT INTERFLOW VOLUME MULTIPLIER
CMIR	R	1	IN	CURRENT MAXIMUM INFILTRATION RATE DURING PERIOD
CN	I	1	-	1 = A. M., 2 = P. M.

CONOPT	I	15	-	CONTROL OPTION
CONOP2	I	1	-	SECOND CONTROL OPTION
CRFMI	R	22	-	CASES RECORDED IN FLOW MAGNITUDE INTERVAL
CRSBBF	R	1	CFS	CURRENT RECESSION SEQUENCE BEGINNING BASE FLOW
CRSBIF	R	1	CFS	CURRENT RECESSION SEQUENCE BEGINNING INTERFLOW
CRSBTF	R	1	CFS	CURRENT RECESSION SEQUENCE BEGINNING TOTAL FLOW
CRSTF	R	50	CFS	CURRENT RECESSION SEQUENCE TOTAL FLOWS
CRSOBF	R	1	CFS	CURRENT RECESSION SEQUENCE BASE FLOW ON DAY ZERO
CRSOIF	R	1	CFS	CURRENT RECESSION SEQUENCE INTERFLOW ON DAY ZERO
CSRX	R	1	-	CHANNEL STORAGE ROUTING INDEX
CTRI	R	99	-	CURRENT TIME ROUTING INCREMENTS
DATE	I	1	-	CURRENT DAY OF THE MONTH
DAY	I	1	-	CURRENT DAY OF THE YEAR
DBFRC	R	1	-	DOUBLE PRECISION BFRC
DDIW	R	366	CFS	DATED DIVERSIONS INTO WATERSHED
DFCC	R	1	-	DAILY FLOW CORRELATION COEFFICIENT
DIFRC	R	1	-	DOUBLE PRECISION IFRC
DIV	R	1	CFS	DIVERSION INTO BASIN, MEAN DAILY FLOW
DMNT	R	366	DEGF	DATED MINIMUM TEMPERATURE
DMXT	R	366	DEGF	DATED MAXIMUM TEMPERATURE
DNFS	R	1	-	DENSITY OF NEW FALLEN SNOW
DPET	R	366	IN	DATED POTENTIAL EVAPOTRANSPIRATION
DPSE	R	366	IN	DATED POTENTIAL SNOW EVAPORATION
DPY	I	1	-	DAYS PER YEAR
DRAF	R	1	CFS	DIFFERENCE BETWEEN RECORDED AND AVERAGE FLOW
DRGPM	R	366	-	DATED RECORDING GAGE PRECIPITATION MULTIPLIER
DRHP	R	366,24	IN	DATED RECORDED HOURLY PRECIPITATION
DRSF	R	366	CFS	DATED RECORDED STREAMFLOW
DRSGP	R	366	IN	DATED RECORDED STORAGE GAGE PRECIPITATION
DRSP	R	1	CFS	DIFFERENCE BETWEEN RECORDED AND SYNTHESIZED HYDROGRAPH PEAKS
DSAF	R	1	CFS	DIFFERENCE BETWEEN SYNTHESIZED AND AVERAGE FLOW
DSMGH	R	1	IN	RATE OF DAILY SNOWMELT FROM GROUND HEAT
DSSF	R	366	CFS	DATED SYNTHESIZED STREAMFLOW
EDLZS	R	366	IN	END OF DAY VALUES OF LZS
EHSGD	I	1	-	ENDING HOUR OF STORAGE GAGE DAY

EHSGDF	R	1	-	ENDING HOUR OF STORAGE GAGE DAY - FLOATING POINT
EID	R	1	-	EXPONENT OF INFILTRATION RATE DECAY WITH INCREASED SOIL MOISTURE CONTENT
ELDIF	R	1	1000FT	ELEVATION DIFFERENCE BETWEEN BASE THERMOMETER AND BASIN MEAN ELEVATION
EMAET	R	1	IN	ESTIMATED MAXIMUM ANNUAL EVAPOTRANSPIRATION
EMATF	R	13	SFD	END OF MONTH ACCUMULATED TOTAL FLOWS
EMBFNX	R	12	IN	END OF MONTH BASE FLOW NONLINEAR RECESSION INDEX
EMFDP	R	1	-	EXTREME MONTHLY FLOW DEVIATION PARAMETER
EMGWS	R	12	IN	END OF MONTH GROUNDWATER STORAGE
EMIFS	R	12	IN	END OF MONTH INTERFLOW STORAGE
EMLZS	R	12	IN	END OF MONTH LOWER ZONE STORAGE
EMSIAM	R	12	-	END OF MONTH SEASONAL INFILTRATION ADJUSTMENT MULTIPLIER
EMUZC	R	12	IN	END OF MONTH UPPER ZONE STORAGE CAPACITY
EMUZS	R	12	IN	END OF MONTH UPPER ZONE STORAGE
EPAET	R	1	IN	ESTIMATED POTENTIAL ANNUAL EVAPOTRANSPIRATION
EPCM	R	12	-	EVAPORATION PAN COEFFICIENT FOR MONTH
EPS	R	1	-	MAXIMUM REQUIRED ESTIMATING TOLERANCE
EQD	R	1	IN	EQUILIBRIUM DEPTH OF OVERLAND FLOW
EQDF	R	1	-	EQUILIBRIUM DEPTH FACTOR FOR OVERLAND FLOW
EQDFIS	R	1	-	EQUILIBRIUM DEPTH FACTOR FOR OVERLAND FLOW,IMPERVIOUS SURFACES
EQDIS	R	1	IN	EQUILIBRIUM DEPTH OF OVERLAND FLOW IMPERVIOUS SURFACES
ERR	R	1	CFS	DIFFERENCE BETWEEN RECORDED AND SYNTHESIZED DATED STREAMFLOW
ETIBF	R	1	CFS	ERROR TABLE INTERVAL BOUNDARY FLOODS
ETLF	R	1	-	EVAPOTRANSPIRATION LOSS FACTOR
EXQPV	R	1	-	EXPONENT OF FLOW PROPORTIONAL TO VELOCITY
FBUZC	R	1	-	ADJUSTMENT FACTOR FOR BUZC
FCNTRI	R	1	-	FLOATING POINT CHANGE IN NUMBER OF TIME ROUTING INCREMENTS
FDAY	R	1	-	FLOATING POINT CURRENT DAY OF THE YEAR
FDPY	R	1	-	FLOATING POINT DAYS PER YEAR
FDSC	R	1	-	FIRST DIFFERENTIAL OF SINE CURVE MAGNITUDE
FETLF	R	1	-	ADJUSTMENT FACTOR FOR ETLF
FFOR	R	1	-	FRACTION OF THE WATERSHED BEING FOREST

FFSI	R	1	-	FRACTION OF SNOW ON FOREST INTERCEPTED
FHPP	R	1	-	FRACTIONAL HOUR PER PERIOD
FIMP	R	1	-	FRACTION OF THE WATERSHED BEING IMPERVIOUS
FIRR	R	15	-	FRACTION OF INCOMING RADIATION REFLECTED BY SNOW SURFACE AS A FUNCTION OF AGE
FKRFMI	R	1	-	FLOATING POINT VALUE OF KRFMI
FLZC	R	1	-	ADJUSTMENT FACTOR FOR LZC
FMR	R	1	-	FRACTION OF MOISTURE RETENTION
FMXTRI	R	1	-	FLOATING POINT MAXIMUM NUMBER OF TIME ROUTING INCREMENTS
FNBTRI	R	1	-	FLOATING POINT NUMBER OF BASIC TIME ROUTING INCREMENTS
FNCTRH	R	1	-	FLOATING POINT NUMBER OF CURRENT TIME ROUTING HOURS
FNOFM	R	1	-	FLOATING POINT NUMBER OF OVERLAND FLOW MONTHS
FNPTRI	R	1	-	FLOATING POINT NUMBER OF PREVOIUS TIME ROUTING INCREMENTS
FNRHP	R	1	-	FLOATING POINT NUMBER OF RECORDED HYDROGRAPH PEAKS
FNSTRI	R	1	-	FLOATING POINT NUMBER OF SUBSEQUENT TIME ROUTING INCREMENTS
FNTRI	R	1	-	FLOATING POINT NUMBER OF TIME ROUTING INCREMENTS
FPER	R	1	-	FRACTION OF THE WATERSHED BEING PERVIOUS
FRERS	R	1	CFS	FLOW RISE ENDING RECESSION SEQUENCE
FSIAC	R	1	-	ADJUSTMENT FACTOR FOR SIAC
FSIL	R	1	IN	HOURLY FOREST SNOW INTERCEPTION LOSS
FSRX	R	1	-	FLOOD PLAIN STORAGE ROUTING INDEX
FSUZC	R	1	-	ADJUSTMENT FACTOR FOR SUZC
FTA	R	1	-	FACTOR FOR ESTIMATING DIURNAL TEMPERATURE VARIATION BASED ON SINE CURVE
FTX	R	1	-	FALL TROUBLE INDEX
FWTR	R	1	-	FRACTION OF THE WATERSHED BEING WATER
GWET	R	1	IN	CURRENT HOURLY GROUNDWATER EVAPOTRANSPIRATION
GWETF	R	1	-	GROUNDWATER EVAPOTRANSPIRATION FACTOR
GWS	R	1	IN	CURRENT GROUNDWATER STORAGE
HBF	R	5	CFS	HYDROGRAPH BASE FLOW
HBFM	R	1	-	HYDROGRAPH BASE FLOW MULTIPLIER
HNTRI	I	5	-	HYDROGRAPH NUMBER OF TIME ROUTING INCREMENTS
HOUR	I	1	-	CURRENT HOUR OF THE DAY
HOURF	R	1	HR	CURRENT HOUR OF THE DAY, FLOATING POINT
HRF	I	1	-	FIRST HOUR OF LOOP

HRL	I	1	-	LAST HOUR OF LOOP
HSE	R	1	IN	CURRENT HOURLY STREAM EVAPORATION
HSF	R	1	IN	HOURLY SNOWFALL
HSFRG	R	1	IN	HOURLY SNOWFALL REACHING GROUND
HSM	R	1	IN	HOURLY SNOWMELT RATE
HSRX	R	5	-	HYDROGRAPH STORAGE ROUTING INDEX
HTH	R	1	-	HOURS INTO DAY WHEN HYDROGRAPH STOPS OR STARTS
IBTPR	I	1	HR	TIME FROM BEGINNING OF SAVED RUNOFF TO RECORDED HYDROGRAPH PEAK
IBTPS	I	1	-	TIME FROM BEGINNING OF SAVED RUNOFF TO SYNTHESIZED HYDROGRAPH PEAK
IDAY1	I	1	-	INDEX TO 10-DAY PERIOD
IDAY2	I	1	-	INDEX WITHIN 10-DAY PERIOD
IDYB	I	5	-	DAY OF ROUTING HYDROGRAPH BEGINNING
IDYE	I	5	-	DAY OF ROUTING HYDROGRAPH ENDING
IFPRC	R	1	-	INTERFLOW PERIOD RECESSION CONSTANT
IFRC	R	1	-	INTERFLOW RECESSION CONSTANT
IFRL	R	1	-	INTERFLOW RECESSION LOGARITHM
IFS	R	1	IN	INTERFLOW STORAGE
IFT	I	1	-	INDICATOR OF FALL TROUBLE (SKIP FIRST RECESSION IN EVALUATION OF BMIR)
IHRB	I	5	-	HOUR OF DAY OF ROUTING HYDROGRAPH BEGINNING
IHRE	I	5	-	HOUR OF DAY OF ROUTING HYDROGRAPH ENDING
INHPT	I	1	HR	INTEGER NUMBER OF HOURS BETWEEN HYDROGRAPH PRINTING POINTS
IPPH	I	1	-	INTEGER PERIODS PER HOUR
IPTE	I	1	HR	TIME FROM PEAK OF RECORDED HYDROGRAPH TO END OF SAVED RUNOFF
ISGRD	I	1	-	CURRENT STORAGE GAGE RAINFALL DAY
IWBG	I	1	-	INDEX NUMBER OF WEATHER BUREAU PRECIPITATION GAGE
KAA	I	1	-	COUNTER OF APPROPRIATE ELEMENT FROM ALBEDO ARRAY
KAAO	I	1	-	PRECEDING VALUE OF KAA
KAFH	I	1	-	COUNTER FOR ABSTRACTED FLOW HYDROGRAPH
KAHP	I	1	-	COUNTER FOR ABSTRACTING HYDROGRAPH POINTS
KBRC	I	1	-	COUNTER OF ROUGH CYCLES SINCE BEST ONE
KB1-7	I	1	-	COUNTERS FOR COMBINING WATERSHED BITS

KDBCK	I	1 -	BACKWARD DAY COUNTER
KDFOR	I	1 -	FORWARD DAY COUNTER
KDRS	I	1 -	COUNTER OF CURRENT DAY IN RECESSION SEQUENCE
KDY	I	1 -	COUNTER FOR DAY
KFFC	I	1 -	COUNTER EQUALLING ONE ON FIRST FINE ADJUSTMENT CYCLE
KHBCK	I	1 -	BACKWARD HOUR COUNTER
KHFOR	I	1 -	FORWARD HOUR COUNTER
KHOUR	I	1 -	COUNTER FOR HOUR OF DAY
KHPT	I	1 -	COUNTER OF CURRENT HYDROGRAPH POINT
KHYD	I	1 -	COUNTER SPECIFYING CURRENT HYDROGRAPH
KH1-3	I	1 -	COUNTERS FOR FIXING HYDROGRAPH ROUTING PARAMETERS
KIA	I	1 -	COUNTER FOR INITIALIZING ARRAYS
KISRX	I	1 -	COUNTER FOR INCREMENTING STORAGE ROUTING INDEX
KLCCA	I	1 -	COUNTER FOR LIMITING NUMBER OF CHANNEL CAPACITY ADJUSTMENTS
KMO	I	1 -	COUNTER INDEXING MONTH OF THE YEAR
KM1-6	I	1 -	MONTH COUNTERS
KPA	I	1 -	COUNTER DESIGNATING PARAMETER TO BE AVERAGED
KPCH	I	1 -	COUNTED POINTS IN CURRENT HYDROGRAPH
KPRD	I	1 -	COUNTER FOR PERIOD
KPSH	I	5 -	COUNTER POINTS IN SUBSCRIPTED HYDROGRAPH
KRC	I	1 -	COUNTER OF CURRENT ROUGH CYCLE
KRD	I	1 -	COUNTER FOR READING DATA ARRAYS
KRFMI	I	1 -	COUNTER FOR RECORDED FLOW MAGNITUDE INTERVAL
KRHP	I	1 -	COUNTER FOR RECORDED HYDROGRAPH PEAKS
KRIA	I	1 -	COUNTER OF APPROPRIATE ELEMENT FROM RADIATION INCIDENCE ARRAY
KRS	I	1 -	COUNTER FOR RECESSION SEQUENCE NUMBER
KSD	I	1 -	COUNTER FOR RECESSION SEQUENCE DAYS
KSQ	I	1 -	COUNTER FOR REVISED SEQUENCES
KTA	I	1 -	COUNTER FOR TITLE ARRAY
KTRI	I	1 -	COUNTER FOR TIME ROUTING INCREMENTS
KT20	I	1 -	COUNTER FOR TOP 20 VALUES
KWD	I	1 -	COUNTER FOR WRITING DATA ARRAYS
KWSM	I	1 -	COUNTER OF WET SUMMER MONTHS
K1AH	I	1 -	COUNTER FOR FIRST ACCEPTED HYDROGRAPH

K2AH	I	1	-	COUNTER FOR SECOND ACCEPTED HYDROGRAPH
LBFO	L	20	-	LOGICAL VARIABLE SET TRUE WHERE BASE FLOW ONLY ENCOUNTERED
LBMIR	L	1	-	LOGICAL VARIABLE SET TRUE WHEN EXERCIZING SUBSTITUTE APPROACH FOR EVALUATING BMIR
LBUZC	L	1	-	LOGICAL VARIABLE SET TRUE WHEN EXERCIZING SUBSTITUTE APPROACH FOR EVALUATING BUZC
LDAY	I	1	-	LAST DAY OF YEAR
LETLF	L	1	-	LOGICAL VARIABLE SET TRUE WHEN EXERCIZING SUBSTITUTE APPROACH FOR EVALUATING ETLF
LHOUR	I	1	-	LAST HOUR OF DAY
LLZC	L	1	-	LOGICAL VARIABLE SET TRUE WHEN EXERCIZING SUBSTITUTE APPROACH FOR EVALUATING LZC
LNIBRS	I	1	-	LAST VALUE OF NIBRS
LNPR	L	1	-	LOGICAL VARIABLE SET TRUE FOR NONEQUAL PERIOD RAINFALL
LNTRI	I	1	-	LAST NUMBER OF TIME ROUTING INCREMENTS
LRC	L	1	-	LOGICAL VARIABLE SET TRUE DURING ROUGH ADJUSTMENT CYCLES
LSHA	L	5	-	LOGICAL VARIABLE KEPT TRUE WHILE SYNTHESIZED HYDROGRAPH IS ACCEPTED FOR COMPARISION WITH RECORDED HYDROGRAPH
LSHFT	L	1	-	LOGICAL VARIABLE SET TRUE WHILE SHIFTING THE NUMBER OF TIME ROUTING INCREMENTS
LSHP	L	1	-	LOGICAL VARIABLE SET TRUE DURING STORM HYDROGRAPH PERIODS
LZC	R	1	IN	LOWER ZONE STORAGE CAPACITY
LZRX	R	1	-	LOWER ZONE MOISTURE RETENTION INDEX
LZS	R	1	IN	CURRENT LOWER ZONE STORAGE
LZSR	R	1	-	CURRENT LOWER ZONE STORAGE RATIO (LZS/LZC)
MBDS	I	1	-	MONTH BEGINNING DRY SEASON
MBWS	I	1	-	MONTH BEGINNING WET SEASON
MDAY	I	1	-	DAY OF YEAR OF LAST DAY OF PREVIOUS MONTH
MEDCY	I	12	-	MONTH END DATES - CALENDAR YEAR
MEDWY	I	12	-	MONTH END DATES - WATER YEAR
MFDP	R	12	-	MONTHLY FLOW DEVIATION PARAMETER
MHSM	R	1	IN	MINIMUM HOURLY SNOWMELT RATE
MHTP	I	1	-	MULTIPLIER CONVERTING FROM HOURS TO PERIODS
MNDRS	I	1	-	MAXIMUM NUMBER OF DAYS IN RECESSION SEQUENCE
MNRC	I	1	-	MINIMUM NUMBER OF ROUGH CYCLES

MNRD	R	1	-	MEAN ANNUAL NUMBER OF RAINY DAYS
MNTRI	I	1	-	MINIMUM NUMBER OF TIME ROUTING INCREMENTS
MNX	I	1	-	MONTH INDEX
MONTH	I	1	-	CURRENT MONTH OF THE YEAR
MONTH1	I	1	-	COUNTER FOR BEGINNING MONTH
MRNSM	R	1	IN	MAXIMUM RATE OF NEGATIVE SNOWMELT (SNOW CHILLING)
MRSL	I	1	DAY	MINIMUM RECESSION SEQUENCE LENGTH
MXA	I	12	-	MONTH INDEX ARRAY (SPECIFYING MONTHS USED IN PARAMETER ADJUSTMENT)
MXTRH	I	1	-	MAXIMUM NUMBER OF TIME ROUTING HOURS
MXTRI	I	1	-	MAXIMUM NUMBER OF TIME ROUTING INCREMENTS
M1R	I	1	-	MONTH WITH MOST RUNOFF
M1SP	I	1	-	MONTH WITH MOST SUMMER PRECIPITATION
M11	I	1	-	SET AT 11 IF AUGUST IS A BASE FLOW MONTH
M12	I	1	-	SET AT 12 IF SEPTEMBER IS A BASE FLOW MONTH
M2R	I	1	-	MONTH WITH SECOND MOST RUNOFF
M2SP	I	1	-	MONTH WITH SECOND MOST SUMMER PRECIPITATION
NATRH	I	1	-	NUMBER OF ANTICIPATED TIME ROUTING HOURS
NBTRI	I	1	-	NUMBER OF BASE TIME ROUTING INCREMENTS
NCSTRI	I	1	-	NUMBER OF CURRENT TIME ROUTING INCREMENTS DURING SHIFTING
NCTRH	I	1	-	NUMBER OF CURRENT TIME ROUTING HOURS
NCTRI	I	1	-	NUMBER OF CURRENT TIME ROUTING INCREMENTS
NDAY	I	1	-	NEXT DAY OF YEAR
NDRS	I	20	DAY	NUMBER OF DAYS IN RECESSION SEQUENCE
NDRSC	I	1	DAY	NUMBER OF DAYS IN CURRENT RECESSION SEQUENCE
NDRSC1	I	1	DAY	NUMBER OF DAYS IN CURRENT RECESSION SEQUENCE LESS 1
NDRSC2	I	1	DAY	NUMBER OF DAYS IN CURRENT RECESSION SEQUENCE LESS 2
NDSDP	I	1	DAY	NUMBER OF DAYS FOR WHICH STORM DETAILS HAVE ALREADY BEEN PRINTED
NDSDR	I	1	DAY	NUMBER OF DAYS FOR WHICH STORM DETAILS REQUESTED
NFRHA	I	1	-	NUMBER OF FIRST RAINFALL HOUR ADJUSTED, PREVIOUS DAY
NFTR	I	1	-	NUMBER OF FIRST TRIP TO BE RUN FOR A GIVEN STATION YEAR
NHOUR	I	1	-	NEXT HOUR OF DAY
NHPT	R	1	HR	NUMBER OF HOURS BETWEEN HYDROGRAPH PRINTING POINTS
NIBRS	I	1	-	NUMBER OF TIME ROUTING INTERVALS BETWEEN RECORDED AND SYNTHESIZED PEAKS

NIRTS	I	1	-	NUMBER OF TIME ROUTING INTERVALS FROM RECORDED TO SYNTHESIZED PEAK
NLTR	I	1	-	NUMBER OF LAST TRIP TO BE RUN FOR A GIVEN STATION YEAR
NNSTRI	I	1	-	NUMBER OF NEXT TIME ROUTING INCREMENT DURING SHIFTING
NOFM	I	1	-	NUMBER OF OVERLAND FLOW MONTHS
NORHP	I	1	-	NUMBER OF ORIGINAL RECORDED HYDROGRAPH PEAKS
NRHA	I	1	-	NUMBER OF RAINFALL HOURS ADJUSTED, CURRENT DAY
NRHP	I	1	-	NUMBER OF RECORDED HYDROGRAPH PEAKS
NRHP1	I	1	-	NUMBER OF RECORDED HYDROGRAPH PEAKS LESS ONE
NRS	I	1	-	NUMBER OF RECESSION SEQUENCES
NRTRI	I	1	-	NUMBER OF TIME ROUTING INCREMENTS REMAINING TO BE ROUTED
NSGRD	I	1	-	NUMBER OF STORAGE GAGE RAINFALL DAYS
NSYC	I	1	-	NUMBER OF STATION YEAR, CURRENT ONE BEING RUN
NSYT	I	1	-	NUMBER OF STATION YEARS, TOTAL INCLUDED IN A GIVEN JOB
NTRS	I	1	-	NUMBER OF TENTATIVE RECESSION SEQUENCES
OCT1BF	R	1	-	OCTOBER FIRST BASE FLOW
OFMN	R	1	-	OVERLAND FLOW MANNING'S N
OFMNIS	R	1	-	OVERLAND FLOW MANNING'S N , IMPERVIOUS SURFACES
OFR	R	1	IN	CURRENT OVERLAND FLOW RUNOFF
OFRF	R	1	-	OVERLAND FLOW ROUTING FACTOR
OFRFIS	R	1	-	OVERLAND FLOW ROUTING FACTOR, IMPERVIOUS SURFACES
OFRIS	R	1	IN	CURRENT OVERLAND FLOW RUNOFF, IMPERVIOUS SURFACES
OFS	R	1	IN	OVERLAND FLOW STORAGE
OFSL	R	1	FT	OVERLAND FLOW SURFACE LENGTH
OFSS	R	1	-	OVERLAND FLOW SURFACE SLOPE
OFUS	R	1	IN	CURRENT OVERLAND FLOW UNROUTED STORAGE
OFUSIS	R	1	IN	CURRENT OVERLAND FLOW UNROUTED STORAGE, IMPERVIOUS SURFACES
PBIVF	R	1	-	PREVIOUS VALUE OF BIVF
PBMIR	R	1	IN/HR	PREVIOUS VALUE OF BMIR
PBUZC	R	1	-	PREVIOUS ESTIMATE OF BASIC UPPER ZONE STORAGE CAPACITY FACTOR
PDAY	I	1	-	PREVIOUS DAY OF THE YEAR
PEAI	R	1	IN	PRECIPITION EXCESS AFTER INFILTRATION
PEBI	R	1	IN	PRECIPITATION EXCESS, BEFORE INFILTRATION
PEIS	R	1	IN	PRECIPITATION EXCESS ON IMPERVIOUS SURFACES

PEP	R	1	IN	PRECIPITATION ESTIMATED FOR PERIOD
PET	R	1	IN	CURRENT DAILY POTENTIAL EVAPOTRANSPIRATION
PETLF	R	1	-	PREVIOUS ESTIMATE OF EVAPOTRANSPIRATION LOSS FACTOR
PETU	R	1	IN	UNADJUSTED CURRENT DAILY POTENTIAL EVAPOTRANSPIRATION
PE4P	R	4	IN	PRECEPITATION ESTIMATES FOR 4 PERIODS
PGW	R	1	IN	PERCOLATION TO GROUND WATER
PLZC	R	1	IN	PREVIOUS ESTIMATE OF LZC
PLZS	R	1	IN	PERCOLATION TO LOWER ZONE STORAGE
PMEIFS	R	1	IN	PERIOD MOISTURE ENTERING INTERFLOW STORAGE
PMELZS	R	1	IN	PERIOD MOISTURE ENTERING LOWER ZONE STORAGE
PMEOFS	R	1	IN	PERIOD MOISTURE ENTERING OVERLAND FLOW STORAGE
PMEUZS	R	1	IN	PERIOD MOISTURE ENTERING UPPER ZONE STORAGE
PPH	R	1	-	PERIODS PER HOUR
PPI	R	1	IN	PRECIPITATION PASSING INTERCEPTION
PRD	I	1	-	CURRENT PERIOD OF THE HOUR
PRDF	R	1	-	CURRENT PERIOD OF THE HOUR-FLOATING POINT
PRH	R	1	IN	PRECIPITATION RECORDED FOR HOUR
PRLH	R	1	IN	PRECIPITATION RECORDED FOR LAST HOUR
PRM1	R	1	IN	PRECIPITATION DURING WETTEST MONTH
PRM2	R	1	IN	PRECIPITATION DURING SECOND WETTEST MONTH
PRNH	R	1	IN	PRECEPITATION RECORDED FOR NEXT HOUR
PSIAC	R	1	-	PREVIOUS ESTIMATE OF SEASONAL INFILTRATION ADJUSTMENT
PSUZC	R	1	-	PREVIOUS ESTIMAED OF SEASONAL UPPER ZONE STORAGE CAPACITY FACTOR
PXCSA	R	1	IN	PRECIPITATION INDEX FOR CHANGING SNOW ALBEDO
RA	R	1	-	RECESSION ALPHA
RAA	R	1	IN	RAINFALL ADJUSTMENT ADDITION
RADF	R	1	CFS	RECORDED AVERAGE DAILY FLOW
RAM	R	1	-	RAINFALL ADJUSTMENT MULTIPLIER
RATFV	R	1	SFD	RECORDED ANNUAL TOTAL FLOW VOLUME
RA1-6	R	1	-	REGRESSION ACCUMULATORS
RB	R	1	-	RECESSION BETA
RBF	R	1	CFS	RECORDED BASE FLOW
RD	R	1	-	RECESSION DISCRIMINANT
RDPT	R	1	IN	RECORDED DAILY PRECIPITATION TOTAL
RFRISE	R	1	IN	RECORDED FLOW RISE

RGPM	R	1	-	RECORDING GAGE PRECIPITATION MULTIPLIER
RGPMB	R	1	-	RECORDING GAGE PRECIPITATION MULTIPLIER - BASIC
RHFMC	R	1	IN	ROUTED HYDROGRAPH FLOW AT MINIMUM CUTOFF
RHFO	R	1	IN	PRECEDING ROUTED HYDROGRAPH FLOW
RHF1	R	1	IN	CURRENT ROUTED HYDROGRAPH FLOW (EXCLUDING BASE FLOW)
RHPD	I	5	-	RECORDED HYDROGRAPH PEAK DAY
RHPF	R	5	CFS	RECORDED HYDROGRAPH PEAK FLOW
RHPH	I	5	-	RECORDED HYDROGRAPH PEAK HOUR
RICD	R	1	-	RADIATION INCIDENCE FOR THE CURRENT DAY
RICY	R	37	-	RADIATION INCIDENCE OVER THE CALENDAR YEAR
RIF	R	1	CFS	RECORDED INTERFLOW
RINT	R	1	-	REGRESSION INTERCEPT
RMFX	R	1	-	RECORDED MONTHLY FLOW INDEX
RMPF	R	1	CFS	REQUESTED MINIMUM DAILY PEAK FLOW TO BE PRINTED
RMWR	R	1	IN	RAINFALL MAXIMUM WITHOUT RUNOFF
RSBBF	R	20	CFS	ESTIMATED BASE FLOW AT BEGINNING OF RECESSION SEQUENCE
RSBD	I	20	-	RECESSION SEQUENCE BEGINNING DAY
RSBFRC	R	20	-	RECESSION SEQUENCE BASE FLOW RECESSION CONSTANT
RSBIF	R	20	CFS	ESTIMATED INTERFLOW AT BEGINNING OF RECESSION SEQUENCE
RSFM	R	1	CFS	RECESSION SEQUENCE FLOW MINIMUM
RSFN	R	1	CFS	RECORDED STREAMFLOW ON NEW DAY
RSF1	R	1	CFS	RECORDED STREAMFLOW ON DAY 1
RSF2	R	1	CFS	RECORDED STREAMFLOW ON DAY 2
RSIFRC	R	20	-	RECESSION SEQUENCE INTERFLOW RECESSION CONSTANT
RSL	I	1	DAY	CURRENT RECESSION SEQUENCE LENGTH
RSLP	R	1	-	REGRESSION SLOPE
RSPTF	R	1	IN	ROUTED SYNTHESIZED PERIOD TOTAL FLOW
RSTF	R	50,20	CFS	RECESSION SEQUENCE TOTAL FLOWS
RSTR	R	1	-	RATIO OF SYNTHESIZED TO RECORDED FLOW
RWRAIN	R	1	IN	RECORDED WATERSHED RAINFALL
SADF	R	1	CFS	SYNTHESIZED AVERAGE DAILY FLOW
SARAX	R	1	IN	SNOW ALBEDO RAINFALL AGING INDEX
SASFX	R	1	IN	SNOW ALBEDO SNOWFALL FRESHENING INDEX
SATFV	R	1	SFD	SYNTHESIZED ANNUAL TOTAL FLOW VOLUME
SATFVI	R	1	IN	SYNTHESIZED ANNUAL TOTAL FLOW VOLUME IN INCHES
SATRI	R	99	-	SHIFT ADJUSTMENTS FOR TIME ROUTING INCREMENTS

SAX	R	1	-	SNOW ALBEDO INDEX
SBF	R	1	CFS	SYNTHESIZED BASE FLOW
SBFRS	R	3,20	CFS	SYNTHESIZED BASE FLOW DURING THE FIRST THREE DAYS OF EACH RECESSION SEQUENCE
SDEPTH	R	1	IN	AVERAGE DEPTH OF SNOW ON GROUND
SDRSP	R	1	-	SMALLEST VALUE OF DRSP
SDSC	R	1	-	SECOND DIFFERENTIAL OF SINE CURVE MAGNITUDE
SE	R	1	IN	CURRENT DAILY SNOW EVAPORATION
SERA	R	22	CFS	ACCUMULATED ABSOLUTE DIFFERENCES BETWEEN RECORDED AND SYNTHESIZED DAILY STREAMFLOWS FOR INTERVAL
SERAV	R	1	CFS	AVERAGE INTERVAL ABSOLUTE DIFFERENCE BETWEEN RECORDED AND SYNTHESIZED DAILY STREAMFLOWS
SERR	R	22	CFS	ACCUMULATED DIFFERENCES BETWEEN RECORDED AND SYNTHESIZED DAILY STREAMFLOWS FOR INTERVAL
SERRV	R	1	CFS	AVERAGE INTERVAL DIFFERENCE BETWEEN RECORDED AND SYNTHESIZED DAILY STREAMFLOWS
SESF	R	22	CFS	STANDARD ERROR OF SYNTHESIZED FLOWS BY MAGNITUDE INTERVAL
SET	R	1	IN	CURRENT HOURLY SOIL EVAPOTRANSPIRATION
SFDX	R	1	-	SUMMER FLOW DEVIATION INDEX
SFMD	R	1	-	SNOW FROZEN MOISTURE DENSITY
SGMD	I	1	-	STORAGE GAGE MOVING DAY (WHEN IT IS MOVED DURING WATER YEAR)
SGRT	I	1	-	STORAGE GAGE READING TIME
SGRT2	I	1	-	SECOND STORAGE GAGE READING TIME
SHM	R	1	-	SYNTHESIZED HYDROGRAPH MULTIPLIER
SHPF	R	1	CFS	SYNTHESIZED HYDROGRAPH PEAK FLOW
SIAC	R	1	-	SEASONAL INFILTRATION ADJUSTMENT CONSTANT
SIAM	R	1	-	SEASONAL INFILTRATION ADJUSTMENT MULTIPLIER
SIF	R	1	CFS	SYNTHESIZED INTERFLOW
SIFRS	R	3,20	CFS	SYNTHESIZED INTERFLOW DURING THE FIRST THREE DAYS OF EACH RECESSION SEQUENCE
SISRX	R	1	-	SMALL INCREMENTAL STORAGE ROUTING INDEX
SMFX	R	1	-	SYNTHESIZED MONTHLY FLOW INDEX
SNTRI	I	1	-	SAVED NUMBER OF TIME ROUTING INCREMENTS
SOFMD	R	1	-	SUM OF OVERLAND FLOW MONTH DEVIATIONS
SOFRF	R	1	-	SNOW OVERLAND FLOW ROUTING FACTOR

SOFRFI	R	1	-	SNOW OVERLAND FLOW ROUTING FACTOR IMPERVIOUS SURFACES
SPBF	R	1	IN	SYNTHESIZED PERIOD BASE FLOW
SPBFLW	R	1	-	SNOW PACK BASIC MAXIMUM FRACTION IN LIQUID WATER
SPDR	R	1	IN	SYNTHESIZED PERIOD DIRECT RUNOFF
SPIF	R	1	IN	SYNTHESIZED PERIOD INTERFLOW
SPLW	R	1	IN	SNOW PACK LIQUID WATER CONTENT
SPLWC	R	1	IN	SNOWPACK LIQUID WATER HOLDING CAPACITY
SPM	R	1	-	SNOW PRECIPITATION MULTIPLIER
SPOF	R	1	CFS	SYNTHESIZED PERIOD OVERLAND FLOW (INCLUDING CHANNEL PRECIPITATION)
SPTF	R	1	IN	SYNTHESIZED PERIOD TOTAL FLOW
SPTW	R	1	IN	SNOW PACK TOTAL WATER CONTENT
SPTWCC	R	1	IN	SNOWPACK MINIMUM TOTAL WATER FOR COMPLETE BASIN COVERAGE
SQER	R	22	CFS	ACCUMULATED SQUARES OF DIFFERENCES BETWEEN RECORDED AND SYNTHESIZED DAILY STREAMFLOWS
SQPKD	R	1	-	SUM OF SQUARED PEAK DIFFERENCES
SRR	R	5,170	CFS	STORM RUNOFF ROUTED DOWN CHANNELS
SRX	R	1	-	CURRENT STORAGE ROUTING INDEX
SSERA	R	1	CFS	ACCUMULATED ABSOLUTE DIFFERENCES BETWEEN RECORDED AND SYNTHESIZED FLOWS OVER INTERVALS
SSERAV	R	1	CFS	OVERALL AVERAGE ABSOLUTE DIFFERENCE BETWEEN RECORDED AND SYNTHESIZED FLOWS
SSERR	R	1	CFS	ACCUMULATED DIFFERENCES BETWEEN RECORDED AND SYNTHESIZED FLOWS OVER INTERVALS
SSERRV	R	1	CFS	OVERALL AVERAGE DIFFERENCE BETWEEN RECORDED AND SYNTHESIZED FLOWS
SSESF	R	1	CFS	ACCUMULATED STANDARD ERROR OF SYNTHESIZED FLOW OVER INTERVALS
SSQM	R	1	-	SUM OF THE SQUARES OF THE MONTHLY FLOW DEVIATIONS
SSQPKD	R	1	-	SMALLEST VALUE OF SQPKD
SSR	R	5,170	CFS	SYNTHESIZED STORM RUNOFF (NOT CHANNEL ROUTED)
SSRT	R	1	-	SQUARE ROOT OF OVERLAND FLOW SURFACE SLOPE
SSSQM	R	1	-	CURRENT SMALLEST ESTIMATE OF SSQM
STMD	R	1	-	SNOW TOTAL MOISTURE DENSITY
SUBWF	R	1	-	SUBSURFACE WATER FLOW OUT OF THE BASIN
SUZC	R	1	-	SEASONAL UPPER ZONE STORAGE CAPACITY FACTOR

SWSMD	R	1	-	SUM OF WET SUMMER MONTH DEVIATIONS
TANSM	R	1	IN	TOTAL ACCUMULATED NEGATIVE SNOWMELT (SNOW CHILLING)
TBRD	R	1	-	TOTAL BASE FLOW RECESSION DAYS
TDFP12	R	1	-	TIME OF DAILY FLOOD PEAK, 12-HOUR CLOCK
TDFP24	R	1	-	TIME OF DAILY FLOOD PEAK, 24-HOUR CLOCK
TDSF	R	1	CFS	TOTAL DAILY STREAMFLOW
TEH	R	1	DEGF	TEMPERATURE ESTIMATED FOR HOUR
TFCFS	R	1	CFS	CURRENT TOTAL FLOW
TFMAX	R	1	CFS	MAXIMUM TOTAL FLOW DURING CURRENT DAY
TFMRT	R	1	CFS	TOTAL STREAMFLOW AT MAXIMUM STREAM ROUTING TIME
TFSRX	R	1	-	TRIAL VALUE OF FSRX
TFX	R	1	CFS	TOTAL STREAMFLOW INDEX
THGR	R	1	IN/HR	TOTAL HOURLY GROSS RUNOFF
THSF	R	24	CFS	TOTAL HOURLY STREAMFLOW
TIRD	R	1	-	TOTAL INTERFLOW RECESSION DAYS
TITLE	A	20	-	TITLE OF CURRENT STATION YEAR (STREAMGAGE LOCATION AND DATE)
TMBF	R	12	IN	TOTALS OF MONTHLY BASE FLOW
TMFSIL	R	12	IN	TOTALS OF MONTHLY FOREST SNOW INTERCEPTION LOSS
TMIF	R	12	IN	TOTALS OF MONTHLY INTERFLOW
TMNET	R	12	IN	TOTALS OF MONTHLY NET EVAPOTRANSPIRATION
TMOF	R	12	IN	TOTALS OF MONTHLY OVERLAND FLOW
TMPET	R	12	IN	TOTALS OF MONTHLY POTENTIAL EVAPOTRANSPORATION
TMPREC	R	12	IN	TOTALS OF MONTHLY PRECIPITATION
TMRPM	R	12	IN	TOTALS OF MONTHLY RAIN PLUS MELT
TMRTF	R	12	SFD	TOTALS OF MONTHLY RECORDED TOTAL FLOW
TMSE	R	12	IN	TOTALS OF MONTHLY STREAM EVAPORATION
TMSNE	R	12	IN	TOTALS OF MONTHLY SNOW EVAPORATION
TMSTF	R	12	SFD	TOTALS OF MONTHLY SYNTHESIZED TOTAL FLOW
TMSTFI	R	12	IN	TOTALS OF MONTHLY SYNTHESIZED TOTAL FLOW IN INCHES
TMTFCY	R	12	SFD	TOTALS OF MONTHLY TOTAL FLOW BY CALENDAR YEAR
TMTFWY	R	12	SFD	TOTALS OF MONTHLY TOTAL FLOW BY WATER YEAR
TOFR	R	1	IN	CURRENT TOTAL OVERLAND FLOW RUNOFF
TPLR	R	1	-	TOTAL TO PERVIOUS LAND RATIO
TRHF	R	1	IN/HR	CURRENT TIME ROUTED HYDROGRAPH FLOW
TRHV	R	1	-	TOTAL RECORDED HYDROGRAPH VOLUME

TRIP	I	1	-	COUNTER SPECIFYING PROGRAM PORTIONS
TSHV	R	1	-	TOTAL SYNTHESIZED HYDROGRAPH VOLUME
TSRX	R	7	-	ARRAY OF TRIAL STORAGE ROUTING INDICES
T20OFH	R	21	IN	TOP 20 VALUES DURING THE YEAR OF HOURLY OVERLAND FLOW
T20PRH	R	21	IN	TOP 20 VALUES DURING THE YEAR OF HOURLY PRECIPITATION
UHFA	R	99	IN	UNROUTED HYDROGRAPH FLOW ARRAY
URHF	R	1	IN	CURRENT UNROUTED HYDROGRAPH FLOW
UZC	R	1	IN	UPPER ZONE STORAGE CAPACITY
UZINFX	R	1	-	UPPER ZONE INFILTRATION INDEX
UZINLZ	R	1	IN/HR	CURRENT UPPER ZONE INFILTRATION TO LOWER ZONE
UZRX	R	1	-	UPPER ZONE MOISTURE RETENTION INDEX
UZS	R	1	IN	CURRENT UPPER ZONE STORAGE
VDCY	R	366	-	VALUE DATED BY CALENDAR DAY
VDMD	R	12	-	VALUE DATED BY MONTH DAY
VINTCR	R	1	IN	VEGETATIVE INTERCEPTION - CURRENT RATE PER PERIOD
VINTMR	R	1	IN/HR	VEGETATIVE INTERCEPTION - MAXIMUM RATE
VWIN	R	1	SFD	VOLUME OF AN INCH OF RUNOFF FROM WATERSHED
WAPV	R	1	-	WEIGHTED AVERAGE PARAMETER VALUE
WCFS	R	1	CFS	WATERSHED CFS EQUALLING ONE INCH PER HOUR
WEIFS	R	1	IN	WATER ENTERING INTERFLOW STORAGE
WFDX	R	1	-	WINTER FLOW DEVIATION INDEX
WI	R	1	IN	WATER INFILTRATION
WSBIT	R	1	-	WATERSHED BIT FOR RESTRUCTURING TIME-AREA HISTOGRAM
WSG	R	1	-	WEIGHTING FACTOR FOR STORAGE RAIN GAGE
WSG2	R	1	-	SECOND WEIGHTING FACTOR FOR STORAGE RAIN GAGE
WSM	R	1	-	NUMBER OF WET SUMMER MONTHS
WT4AM	R	1	DEGF	AVERAGE 4 A.M. TEMPERATURE OVER WATERSHED
WT4PM	R	1	DEGF	AVERAGE 4 P.M. TEMPERATURE OVER WATERSHED
XDNFS	R	1	-	INDEX DENSITY OF NEW-FALLEN SNOW
XELR	R	1	-	RAIN INDEX FOR ESTIMATING LAPSE RATE 0.0 = DRY, 4.0 = RAIN
XMPFT	R	12	-	INDEX OF MONTHLY PREDOMINATE FLOW TYPE
YEAR	I	1	-	LAST TWO DIGITS OF CURRENT YEAR
YR1	I	1	-	LAST TWO DIGITS OF FIRST CALENDAR YEAR IN WATER YEAR
YR2	I	1	-	LAST TWO DIGITS OF SECOND CALENDAR YEAR IN WATER YEAR
YTITLE	A	20	-	YEAR TITLE

BIBLIOGRAPHY

1. Amorocho, J. and Hart, W.E. "A Critique of Current Methods in Hydrologic Systems Investigations," Transactions: American Geophysical Union. Vol. 45, (June, 1964), pp. 307-321.

2. Balk, Everett L. "Application of the Stanford Watershed Model to the Coshocton Hydrologic Station Data," Unpublished Master's Thesis, Department of Civil Engineering, The Ohio State University, 1968.

3. Barnes, B.S. "Discussion of Analysis of Runoff Characteristics," Transaction A.S.C.E., Vol. 105, 1940, p. 106.

4. Briggs, Dana L. "Application of the Stanford Streamflow Simulation Model to Small Agricultural Watersheds at Coshocton, Ohio," Unpublished Master's Thesis, Department of Civil Engineering, The Ohio State University, 1969.

5. Chow, Ven Te. "Application of Electronic Computers in Hydrology," Handbook of Applied Hydrology. Ven Te Chow (ed.), New York: McGraw-Hill Book Co., 1964, pp. 29-1 to 29-2.

6. Claborn, B.J., and Moore, Walter L. Numerical Simulation of Watershed Hydrology. Austin: University of Texas, Department of Civil Engineering, Technical Report HYD 14-7001, August, 1970.

7. Clark, C.O. "Storage and the Unit Hydrograph," Transaction A.S.C.E., Vol. 110, 1945, pp. 1419-1488.

8. Clarke, K.D. Application of Stanford Watershed Model Concepts to Predict Flood Peaks for Small Drainage Areas. Lexington, Kentucky: Kentucky Department of Highways, Division of Research, HPR-1(3): KYHPR-64-23, 1968.

9. Cline, James N. Planning Flood Control Measures by Digital Computer. Lexington: University of Kentucky, Water Resources Institute Research Report No. 11, 1968, pp. 249-253.

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

11. Dawdy, David R. and Bergmann, J.M. "Effect of Rainfall Variability on Streamflow Simulation," *Water Resources Research,* Vol. 5, No. 5, October, 1969, pp. 958-966.

12. Dawdy, David R. and O'Donnell, T. "Mathematical Models of Catchment Behavior," *Proceedings of the A.S.C.E.*, Vol. 91, No. HY4, July, 1965, pp. 123-137.

13. Dempsey, Clyde R. *The Effects of Geographical and Climatic Setting on the Economic Advantages of Alternative Flood Control Measures.* Lexington: University of Kentucky, Water Resources Institute, Research Report No. 10, 1968.

14. Hydrocomp International. "HSP Operations Manual," Palo Alto, California, 1969.

15. Hydrocomp International. "Simulation of Continuous Discharge and Stage Hydrographs in the North Branch of the Chicago River," Palo Alto, California, 1970.

16. James, L. Douglas. *An Evaluation of Relationships Between Streamflow Patterns and Watershed Characteristics through the Use of OPSET: A Self-Calibrating Version of the Stanford Watershed Model*, Lexington: University of Kentucky, Water Resources Institute, Research Report No. 36, 1970.

17. James, L. Douglas. "Using a Digital Computer to Estimate the Effects of Urban Development on Flood Peaks," *Water Resources Research,* Vol. 1, (Second Quarter, 1965), pp. 223-233.

18. James, L. Douglas and Thompson, William O. "Least Squares Estimation of Constants in a Linear Recession Model," *Water Resources Research,* Vol. 6, (August, 1970), pp. 1062-1069.

19. Ligon, James R., Law, Albert G., and Higgins, Donald H. *Evaluation and Application of a Digital Hydrologic Simulation Model.* Clemson, South Carolina: Clemson University, Water Resources Research Institute, Report No. 12, November, 1969.

20. Linsley, Ray K. discussion on "Urban Runoff by Road Research Laboratory Method" by Terstriep and Stall, *Proceedings of the A.S.C.E.*, Vol. 96, HY4, April, 1970, pp. 1100-1102.

21. Linsley, Ray K., Kohler, Max A., and Paulhus, Joseph L. H., Hydrology for Engineers. New York: McGraw-Hill Book Co., 1958.

22. Miller, Carlos F. Evaluation of Runoff Coefficients from Small Natural Drainage Areas. Lexington: University of Kentucky, Water Resources Institute, Research Report No. 14, 1968.

23. Musgrave, G.W. "How Much of the Rain Enters the Soil?" Water: The Yearbook of Agriculture, 1955. Washington: U.S. Government Printing Office, 1955, pp. 151-159.

24. Rosenbrock, H.H. "An Automatic Method of Finding the Greatest or Least Value of a Function." The Computer Journal, Vol. 3, 1960, p. 175.

25. Ross, Glendon A. The Stanford Watershed Model: The Correlation of Parameter Values Selected by a Computerized Procedure with Measurable Physical Characteristics of the Watershed. Lexington: University of Kentucky, Water Resources Institute, Research Report No. 35, 1970.

26. U.S. Bureau of Reclamation, Design of Small Dams. Washington: USGPO, 1960.