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BROOK: A HYDROLOGIC SIMULATION MODEL FOR EASTERN FORESTS

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Research Report Number 19

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November 2, 1983

Dear Brook User:

The attached package includes a modification of the BROOK model. BROOK is being used at many universities in the northeastern U.S. and at several institutions in Europe. Continued demand has led me to provide a version that is easier to use.

The new model is called BROOK2. It differs from the original BROOK only in its Fortran coding and its input order. BROOK2 gives the same output that BROOK did from the same set of data, with the exception of one slight bug that has been fixed in snowmelt. The main reasons for recoding the model were to make input organization easier, to use disk files instead of cards, and to make the program easier to follow and thus to alter. Structured programming using the IF-THEN-ELSE statement of Fortran 77 clarifies the model flow.

Input requirements have changed slightly while retaining the basic structure of the parameter and data inputs. Variable names within the program have not been changed. Output format has changed only slightly. Multiple parameter sets can no longer be included in one run. There is no limit on the number of consecutive years that can be run as data is read in one year at a time.

Two problems mentioned on p. 45 have been fixed. New LAI and SAI functions and new EZDEP and UZDEP values can now be supplied at any day. However some caution is still needed because the LAI, SAI functions are still given on a calendar year, not a water year basis. A revised page 45-46 is included.

Chapter 8 is totally rewritten. Chapter 9 is omitted as variables are defined in the program listing.

BROOK2 has been tested enough so that I do not believe there are any problems. However, many combinations of input-output options have not been tried. Please inform me of any bugs you may find.

BROOK2 will not be available on cards, but if you send a magnetic tape and your specifications for writing on it, I will put the program and the test input and output data on the tape. ~~However, I will be out of the country from January to December of 1984 and unable to provide this service.~~

I urge anyone now using BROOK to convert to BROOK2 if they are considering any program modification, and to send a tape as soon as possible to obtain the model.

Sincerely yours,

C. ANTHONY FEDERER
Principal Soil Scientist

Enclosure

BROOK: A HYDROLOGIC SIMULATION MODEL FOR EASTERN FORESTS

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ABSTRACT

A hydrologic model called BROOK simulates water budgets for forest land in the eastern United States. BROOK is a water-yield model for small areas; it was not designed to simulate flood peaks or watersheds with multiple aspects. It operates with a daily time interval, and requires daily precipitation and daily mean temperature as input variables. BROOK can simulate hardwood, conifer, mixed, cleared, and regrowing vegetation types, but these types must be uniform over the watershed. Partial cuts cannot be simulated. Evapotranspiration is divided into five components and streamflow into three components. The model was calibrated and verified using experimental watersheds at the Hubbard Brook Experimental Forest in New Hampshire and the Coweeta Hydrologic Laboratory in North Carolina.

BROOK was designed to study the response of streamflow on different slopes and aspects to cover changes caused by harvesting and regrowth or by conversion from hardwoods to conifers. It has also been used to examine streamflow response to different hardwood transpiration characteristics, to estimate soil-water deficits prior to floods, to estimate soil water available for tree growth, as a base for nutrient concentration modeling, and as a teaching tool.

ACKNOWLEDGMENTS

We especially thank Martha Jean Erickson of Dartmouth College and John Aber of the University of Virginia for the struggle incumbent upon being the first to try BROOK on other computers. Their experience has improved the model. Lloyd W. Swift, Jr. graciously provided us with Coweeta data. This project was supported partly by a grant from the Northeastern Forest Experiment Station, U. S. Department of Agriculture, Forest Service, to the New Hampshire Water Resources Research Center, and partly by funds provided by the United States Department of Interior, Office of Water Research and Technology, as authorized under the Water Resource Research Act of 1964 (Public Law 88-379). This report is a contribution from the Hubbard Brook Ecosystem Project.

NOTES

H2 - Hubbard Brook Watershed 2

H3 - Hubbard Brook Watershed 3

C13 - Coweeta Watershed 13

C14 - Coweeta Watershed 14

* indicates multiplication and ** indicates exponentiation. We also use nested parentheses instead of various shapes of brackets, and EXX for 10^{xx}.

CHAPTER 1. INTRODUCTION

Hydrologic simulation aims at answering quantitative questions about the behavior of water in a watershed. Such questions might be: How does changing plant cover affect streamflow? What peak flow will occur from a given amount of rain? Does the soil dry enough to limit plant growth?

For any time interval, the input of water to a watershed minus the output of water from the watershed must equal the change of storage of water within the watershed. Water is neither created nor destroyed within the system because any net difference between photosynthesis and respiration is negligible. This conservation of mass of water is the basis for hydrologic simulation.

A simulation model is a set of equations that represent the behavior over time of significant flow and storage processes within a system. The equations are usually combined in a digital computer program, together with necessary input and output control. A simulation is run by applying a set of input data to the program to obtain a set of output. For a hydrologic simulation, the input includes precipitation, weather data, and watershed characteristics; and the output is simulated streamflow, and perhaps various storages such as snow and soil-water content.

Hydrologic simulation was developed in the 1960's. The principles for building models are now well established, though some processes are still not understood in detail. Many similar models are available and their similarities and differences have been described (Fleming 1975).

The Stanford Watershed Model (Crawford and Linsley 1966) was the first complicated, general-purpose model. The National Weather Service has adapted the Stanford model for flood forecasting (National Weather Service 1972). Huff and others (1977) greatly modified the Stanford model for studying water movement as a component of terrestrial ecosystems. A general model primarily for agricultural watersheds is also available (Holtan and others 1975). These are complex models requiring many input parameters and, usually, detailed precipitation and weather data.

At the other extreme are models that include only the simplest representation of evapotranspiration and soil-water storage (Diskin and others 1973; Haan 1972). These models are based on simple soil-water budgeting first proposed by Thornthwaite (1948) and are useful for monthly periods, whereas the complex models often work with fractions of a day.

Many models fall between the two extremes (Bergström and Forsman 1973; Knapp and others 1975). Such models usually work with daily time intervals, and are developed for more specific purposes than the general models. BROOK is such a model.

This paper describes the BROOK model, its purposes, development, programing, use, and problems. We have tried to be complete, leaving no questions unanswered. The user who wants to run the model as soon as possible need read only Chapters 4 and 8. The reader who is most interested in how well BROOK works can look first at Chapter 5.

In BROOK we have tried to include each important hydrologic process, to use physically realistic equations for these processes, and to define parameters as physically measurable properties of a watershed. In some processes we have succeeded and in others we have not. The proliferation of hydrologic models implies that there is still no standard way to describe many hydrologic processes. Most readers will feel that they would do something differently. After several years of struggling with this model our standard response to suggested improvement is, "Go ahead and try it yourself."

CHAPTER 2. WHY ANOTHER HYDROLOGIC MODEL?

With such a surfeit of models already in the literature it is very reasonable to ask: "Why present another one?" The answer is that we believe ours is more useful for certain kinds of problems and certain kinds of users than any other we know of.

BROOK was designed primarily for one purpose: to study changes in streamflow from eastern forests that are likely to occur because of changes in cover type caused by forest management. A secondary purpose is the simulation of soil-water content for flood, drought, and nutrient studies. Some studies that have already been done are described in Chapter 6.

BROOK is a lumped parameter model--all parts of the watershed are assumed to behave similarly so there is no spatial variation. Consequently, it is designed only for small watersheds, up to several hundred hectares. It is also designed as a water yield model and cannot be used to study peak flows.

BROOK may also be used as a learning tool because it includes all of the important hydrologic processes. The mathematical part of the model requires only about 100 FORTRAN statements, so it is not difficult to comprehend. As with all simulation models, the greatest learning occurs in the scientists who developed it. BROOK has indicated areas in which hydrologic knowledge is inadequate, so more theoretical and experimental work is needed. These areas are described in Chapters 4 and 7.

Modelers can be divided into two schools of thought. Some believe that general-purpose models can be developed to answer any questions that anyone might want to ask. Other modelers believe that a new model should be developed to answer each specific question because no general-purpose model can be as good as a special-purpose one. BROOK lies somewhere between these extremes. It can be used to study several kinds of hydrologic questions, but only on small forested watersheds in the eastern United States.

General use of more complex models is often precluded because of the required input variables. Hourly precipitation, daily solar radiation, and atmospheric humidity are not available for many locations. So we used only daily precipitation and mean daily temperature as input variables.

A final reason for developing our own model is that we could use new kinds of equations for some processes. In BROOK, interception is based on available energy rather than on storm size. The variable source area concept is included. Evaporation components are separated and made to depend on leaf area index and stem area index. Water movement in the soil is calculated from estimates of the hydraulic conductivity of the soil.

BROOK is far from a perfect model, but we hope it will be useful.

CHAPTER 3. HUBBARD BROOK AND COWEETA WATERSHEDS

Every hydrologic model requires data from one or more watersheds for its development. We chose Watersheds 2 and 3 on the Hubbard Brook Experimental Forest in central New Hampshire and Watersheds 13 and 14 at the Coweeta Hydrologic Laboratory in western North Carolina.

Hubbard Brook Watershed 3 (H3) is 42 ha and its elevation ranges from 525 to 730 m. It is completely covered by beech-birch-maple forest about 60 years old and 20 m tall. The watershed lid, a plane fitted to the perimeter of the watershed, has a slope of 12.1° at an aspect of S23.2°W. Average rooting depth (EZDEP in the model) is about 635 mm.

Hubbard Brook Watershed 2 (H2) is adjacent to H3. It is 16 ha and has nearly the same range of elevation. Its watershed lid slopes 18.5° at an aspect of S30.9°E. Before 1965, its forest cover was similar to H3. In December of 1965 it was deforested, and all slash was left in place (Hornbeck and others 1970). In the summers of 1966, 1967, and 1968, herbicides were applied to prevent regrowth. Since 1968 there has been regrowth.

Coweeta Watershed 14 (C14) is 61 ha, and its elevation ranges from 710 to 1010 m; it has a slope of 18° facing N50°W. Mature Appalachian hardwoods, primarily oak, hickory, and yellow poplar, cover the watershed. Average rooting depth (EZDEP) is about 900 mm (Lloyd Swift, personal communication 1975).

Coweeta Watershed 13 (C13) contains 16 ha, an elevation ranging from 740 to 910 m, and a slope of 17° at N60°E. In 1940, the forest was cut without removal of products. The hardwood forest was allowed to regrow until 1962 when the vegetation was again all cut and left in place. Since then there has been natural regrowth.

At Hubbard Brook, a generally thin layer of glacial till is deposited over and is totally discontinuous with an impermeable, unweathered, schistose bedrock. At Coweeta, the residual soil is deep and grades continuously into a tight, but locally fractured, gneiss. The different geologies produce a marked difference in streamflow response between the two areas.

At Coweeta it seldom snows; and any snow melts rapidly. At Hubbard Brook there is snowpack from December into April; the snowpack often stores more than 250 mm of water. This contrast causes further difference in streamflow behavior between the areas. Because of this contrast, a model that works at both watersheds is likely to work elsewhere in the eastern United States.

Daily precipitation for each watershed at Hubbard Brook was calculated by the Thiessen polygon method from several standard gages in or near the watershed. Daily precipitation at each standard gage is obtained by prorating weekly catches in a nearby recording gage (Station 1.) Daily mean temperature for H2 and H3 was obtained from the average of daily maximum and minimum temperatures from a thermograph near the foot of both watersheds (Station 1).

Precipitation data for the Coweeta watersheds was obtained from a single recording rain gage located near the foot of both watersheds (Recording gage 6). Daily mean temperature was calculated as the average of daily maximum and minimum temperatures from a thermograph at the same location.

CHAPTER 4. EQUATIONS AND PARAMETERS OF THE MODEL

Levels and rates

The model has five internal storage compartments: intercepted snow (INTSNO) snow on the ground (SNOW); water in the root zone (EZONE); water in unsaturated soil below the root zone (UZONE); and groundwater (GWZONE). Storage is expressed as depth of water in mm. The root zone includes a subcompartment that represents water that can evaporate from the soil surface (EVW). Flow of water can occur between pairs of these compartments, as well as from precipitation (PRECIP) and to evapotranspiration (EVAP), deep seepage (SEEP), and streamflow (STRFLO) (Fig. 4-1). The flow rates are expressed in mm/day.

In any dynamic model, storages or levels must be carefully differentiated from flows or rates. When all movement stops, all rates become zero, while all storages may have some non-zero value. Flow rates and their time-integrated totals must also be distinguished. This confusion occurs frequently in hydrology when daily streamflow is given units of mm/day, when the daily total flow in mm is meant.

BROOK is a finite difference model. This means that rates are assumed to be constant over some time interval (DT). The rates may depend on the storages at the beginning of the interval. At the end of each interval, time integration is determined by the continuity equation

new storage = old storage + (input rates - output rates) * DT

The length of DT is an important and early decision that must be made in developing a hydrologic model. Choice of DT depends on the purpose of the model. For prediction of flood peaks, DT's as small as 15 minutes have been used. For water yield models such as BROOK, a DT of 1 day is convenient because the detailed timing of streamflow is not important. In BROOK, DT is an explicit variable though its value is always 1 day. This helps to differentiate between levels and rates and keeps the equations dimensionally consistent. BROOK also uses a shorter time interval for the part of the model that includes water movement into and through the soil. The length of this interval varies with the amount of water involved. This is described in the section on flow iterations.

Input variables

Another important decision involves the meteorological variables that will be used to drive the model. The rates of input as rain or snow and those of output as evapotranspiration must be determined partly or wholly from the input variables. Snowmelt rates also may be determined by these meteorologic variables.

For precipitation, the choice is straightforward. For a DT of 1 day, daily precipitation is the logical input. Daily precipitation is readily available and is measured at all weather stations. We must then assume that the precipitation occurs at a constant rate (PRECIP) through 1 day; PRECIP is the daily precipitation/DT. In Chapter 8 we describe how subroutine SMOOTH reduces some of the error from the lack of uniformity in

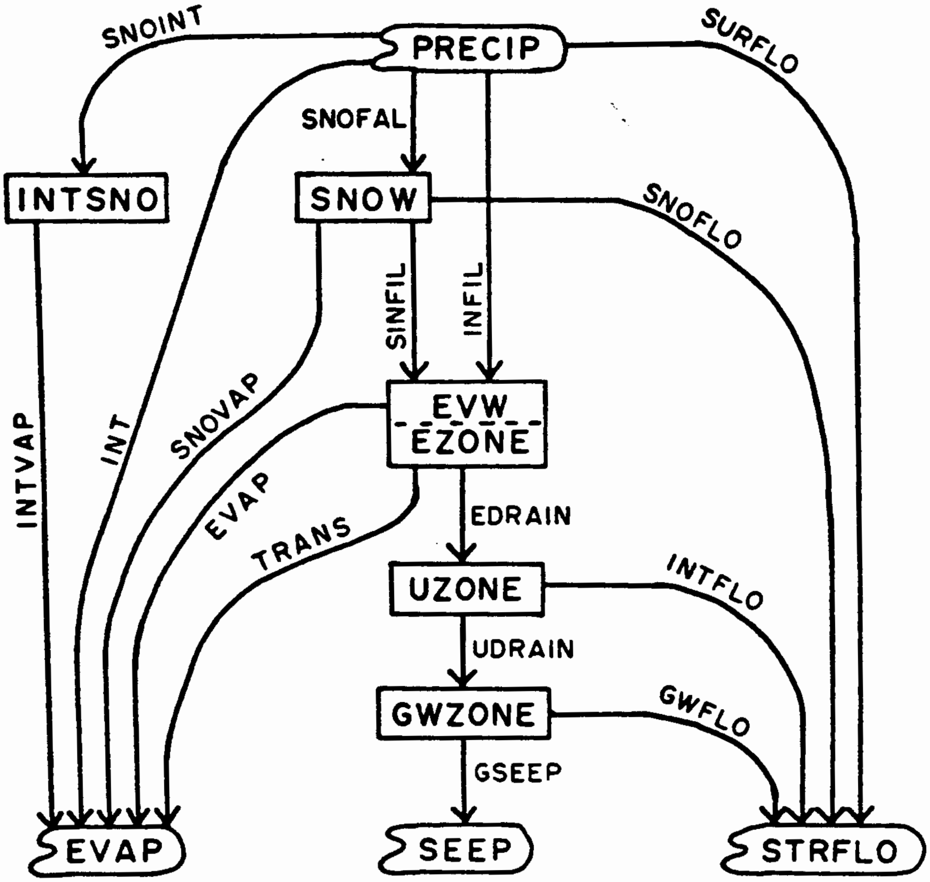

Figure 4-1. Block diagram of the BROOK model.

precipitation through the day. There is no provision in BROOK for combining precipitation measured at several locations, nor for correcting for differences in elevation between the gage and the watershed.

Meteorological variables that affect evapotranspiration and snowmelt include, in order of decreasing importance, solar radiation, atmospheric humidity, atmospheric temperature, longwave radiation, and wind speed. Unfortunately, solar radiation is measured routinely at only a few locations in the United States, longwave radiation is measured hardly anywhere, and humidity and wind are measured only at first order weather stations. Solar and longwave radiation can be estimated from sky cover or percent sunshine, but these also are only available from first order stations.

First order stations usually are separated by 100 or more miles. In northern New England there are stations only at Burlington, Vt., Concord, N. H., and Portland and Caribou, Maine. None is representative of the mountains where Hubbard Brook is located. On the other hand, atmospheric temperature, or at least its daily mean, is measured routinely wherever precipitation is measured. An interesting debate is whether to extrapolate first order data over long distances, or to use only the temperature data from local weather stations. For BROOK to be as widely useful as possible, the mean daily temperature (TEMP) is the only required atmospheric variable besides precipitation.

Temperature varies with elevation and aspect. If the elevation of the station where temperature is measured differs considerably from the mean elevation of the watershed, a correction should be made. The temperature can be assumed to decrease 0.65°C/100 m increase in elevation. North-facing slopes usually are cooler than south-facing slopes. However if temperature is measured at a valley weather station, this difference is not considered by the BROOK model. This is the case for our Coweeta simulations. On the other hand, Hubbard Brook simulations use temperatures measured on the same aspect as the watersheds.

Potential evapotranspiration

Potential evapotranspiration (PE) has been defined in several ways, and can be calculated in even more ways. For the BROOK model we can use a very loose definition that considers PE as an index to the demand of the atmosphere for water. Therefore PE equals the actual evapotranspiration when there is no intercepted water on the canopy and when soil water does not limit evapotranspiration. This definition applies at all times of year.

If all of the atmospheric variables mentioned in the preceding section are available, PE can be rigorously defined and calculated from the physically based "combination" or Penman-type equation (Thom and Oliver 1977). But if daily mean temperature is the only data available, an estimate of PE must be made by an empirical method.

The Thornthwaite (1948) method is widely used, but it gives zero PE when mean temperature is less than 0°C, so there can be no soil or snow evaporation in winter.

Hamon (1963) developed a simple equation that does not go to zero in winter but provides essentially the same annual total as that of Thornthwaite. We use the Hamon equation in BROOK. In mm/day

$$PE = 0.1651 * DAYL * RHOSAT$$

where DAYL is time from sunrise to sunset in multiples of 12 hours, and RHOSAT is the saturated vapor density in g/m^3 at the daily mean temperature (TEMP).

$$RHOSAT = 216.7 * ESAT / (TEMP + 273.3)$$

$$ESAT = 6.108 * EXP (17.26939 * TEMP / (TEMP + 237.3))$$

where ESAT is the saturated vapor pressure in mb at the given TEMP. The ESAT equation is from Murray (1967), and is also used here for temperatures below 0°C. DAYL is obtained from date, latitude, slope, and aspect of the watershed by Swift's (1976) procedure.

In Chapter 6 we describe how the Hamon calculation gives values that are too low for Coweeta. As a simple correction in the model we arbitrarily allow the Hamon PE to be multiplied by a constant called PEC. For Coweeta we needed a PEC of 1.2, but for Hubbard Brook PEC = 1.0. For lack of any other data, users at other locations may assume this is an effect of latitude and interpolate appropriately.

Slope-aspect correction

South-facing slopes are often drier than north-facing slopes. Their greater exposure to sunlight produces higher evapotranspiration. The difference is greatest at the winter solstice (December 22) and least, in fact almost nonexistent, on moderate slopes at the summer solstice (June 21). Potential insolation is defined as the solar radiation flux density that would reach the earth's surface if there were no atmospheric absorption, reflection, or scattering. We define a ratio (RS) of the potential insolation on a given slope to the potential insolation on a horizontal surface for the same date and latitude. Swift (1976) suggests that RS can be used as an index to the relative energy available to adjacent slopes. We used Swift's (1976) algorithm to calculate RS. Table 4-1 shows how RS varies with date for C14 and H3.

Radiation does not affect all evaporation processes equally. Evaporation of intercepted rain and snow often occurs shortly after a storm when skies are still cloudy. At such times more energy is supplied from the air, which may be warmer and drier than the surface, than from radiation. Evaporation from the snowpack is affected most by the humidity of the air, which is related more to temperature than to radiation. So we do not use RS in equations for interception or snow evaporation.

LAI and SAI

Seasonal variation in plant cover is important in most hydrologic models. We used two variables to describe cover, leaf area index (LAI) and stem area index (SAI). LAI has also been used by Swift and others (1975) for Coweeta.

Table 4-1. The ratio, RS, between potential insolation on a slope and on a horizontal surface for C14 and H3

Date	C14[a]	H3[b]
Feb 15	0.67	1.32
Apr 15	0.87	1.08
June 15	0.96	0.99
Aug 15	0.90	1.05
Oct 15	0.71	1.26
Dec 15	0.51	1.54

[a] Slope: 18°; aspect: 310°(NW).

[b] Slope: 12.1°; aspect: 203°(S).

LAI and SAI affect rain and snow interception, snow and soil evaporation, transpiration, and snowmelt. But these effects have not yet been quantified for forests. Still, there is enough quantitative and intuitive knowledge to hypothesize the form of the relations and this is what we have done.

LAI for broadleaved plants is defined as the total area of one side of the leaves above a unit ground area; it is 5 to 7 for mature hardwood forests. For needle-leaved plants LAI is defined as the total needle surface area above unit ground area; it is usually 10 or more. This value must be divided by 2 to get a number comparable to the broadleaved definition of one-sided leaf area. In BROOK we also use the one-sided definition for conifers. We assume that additional leaf area above an LAI of 4 has no additional effect on evapotranspiration and snowmelt processes. Any input values of LAI greater than 4 are reduced to 4 by the program.

SAI is the total surface area of stem, branches, and twigs above a unit ground area. BROOK requires SAI particularly to distinguish between leafless hardwoods and cleared areas during snowmelt. SAI is close to 2 for mature deciduous forests (Whittaker and Woodwell 1967) and has been estimated as 2.0 to 2.7 for the mature forest at Hubbard Brook (Whittaker and others 1974). Input values greater than 2 are reduced to 2 by the program.

For H3 we used LAI = 4 in summer and 0 in winter; for C14 we used LAI = 4 in summer and 0.5 in winter to represent an evergreen understory (Swift and others 1975). We assumed that transitions between dormant and growing conditions required 1 month in both spring and fall, with leafout occurring 1 month earlier and leaffall 1 month later at Coweeta than at Hubbard Brook (Fig. 4-2). SAI for mature hardwoods is 2 all year.

For cleared watersheds we reduced both LAI and SAI to 0. To simulate regrowth, LAI and SAI were gradually increased. For mature conifer-covered watersheds, LAI was 4 and SAI was 2 all year. We ignored seasonal variations in conifer LAI. For mixed forests, LAI in winter can be made directly proportional to the fraction of the watershed cover that is conifers.

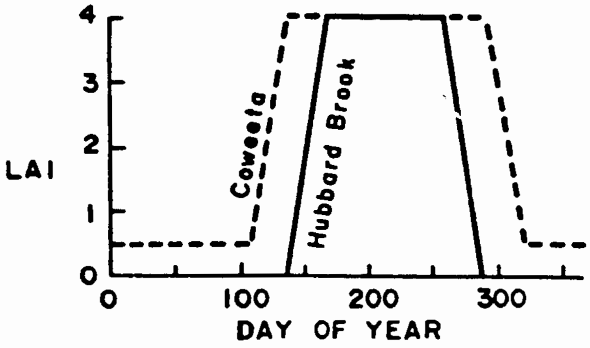

Figure 4-2. Seasonal variation of LAI assumed for Hubbard Brook and Coweeta.

Rain-snow separation

An important decision that must be made at the beginning of a day's simulation is whether precipitation for the day occurred as rain or snow. If a large storm at Hubbard Brook in December is called snow when it was really rain, then the storm peak will be missing from the hydrograph, the snowpack will be consistently overestimated through the winter, and streamflow from snowmelt runoff in April will be overestimated. In no other part of the model can an incorrect decision produce such large simulation errors.

In BROOK, only mean daily temperature is available for the decision. One of the best studies of snow as a function of temperature indicated roughly a linear transition from all rain at 4.5°C to all snow at 1.0°C (Auer 1974). Initially we tried this relation for Hubbard Brook, allowing mixed rain and snow at the intermediate temperatures. However this often produced no streamflow from winter storms in which streamflow was measured. By trial and error we finally decided to use a single transition temperature (RSF) of -2.8°C for Hubbard Brook. Snow that melts soon after it hits the ground may account for the low value of this temperature. For Coweeta we used a temperature criterion (RSF) of 0°C.

Rain interception

Most studies of rain interception have produced regressions of throughfall and stemflow on precipitation. These studies imply that interception increases linearly with the size of the storm, which ignores the fact that energy supply rather than water supply may limit interception. Recent models of the interception process (for example, Rutter and others 1972) are too complex to use in a hydrologic model like BROOK.

Because PE is our index of energy supply, we assumed that rain interception was proportional to PE. However, if rain was less than PE, rain rather than PE limited interception.

The dependence of interception on LAI and SAI was assumed to be linear, with an LAI of 4 contributing twice as much as an SAI of 2 (Fig. 4-3). Thus in leafless mature hardwoods, interception was one-third of that when the trees were fully leaved. This differs from Helvey and Patric (1965) and Leonard (1961) who found more than two-thirds as much interception in leafless as in fully leaved trees. But we don't see how leafless interception can be that much. For conifers, the high LAI year round increases the annual interception of rain; this was clearly demonstrated by Helvey (1967).

Therefore, the rain interception equation is

$$\mathrm{INT} = \mathrm{ISC} * (0.67 * \mathrm{LAI}/4 + 0.33 * \mathrm{SAI}/2)\ \mathrm{MIN}\ (\mathrm{PE}, \mathrm{RAIN})$$

For the proportionality constant ISC we used 0.75. This gave an annual rain interception of about 90 mm for H3 and 180 mm for C14. Leonard (1961) reported interception of about 12% of rainfall for Hubbard Brook or about 110 mm of rain interception a year. Helvey and Patric (1965) estimated about 13% of rainfall or 250 mm for Coweeta, but this includes litter interception of 50 mm. In BROOK, litter interception is considered as soil evaporation rather than as interception.

Recent studies show that interception from forests can exceed transpiration and PE (Federer 1975), though the subject is controversial (McNaughton 1976; Stewart 1977). In BROOK, interception of rain does not "use up" PE, and total evaporation for a day may be up to (1 + ISC) * PE for a mature, fully leaved forest.

Snow interception

Snow interception is a complicated process (Federer and others 1973). Hydrologically we need only be concerned about net interception--the snow that evaporates directly from the canopy. Temporary interception that later reaches the snowpack on the ground by blowing, sliding, or dripping off is not considered interception by BROOK. Snow interception is included in BROOK only because it may be significant for conifer forests. Annual snow interception for hardwoods turns out to be negligible.

A storage compartment for intercepted snow (INTSNO) is used because snow can remain on the canopy for a number of days. INTSNO has a maximum value that depends on LAI and SAI

$$\text{maximum INTSNO} = 0.833 * (\mathrm{LAI} + \mathrm{SAI}/2)$$

SAI/2 is used because SAI is less effective than LAI in creating storage. The origin of the 0.833 coefficient has been lost in the antiquity of BROOK. It gives a maximum INTSNO of 4.165 mm for mature conifer forest, which is a strange value. It is somewhat lower than the 5 and 7.5 mm that Leaf and Brink (1973) used for lodgepole pine and spruce-fir, but we assume that all of this will evaporate while they do not.

The rate at which snow is intercepted (SNOINT) is proportional to the snowfall rate (SNO) and to the intercepting surface which also is defined as LAI + SAI/2,

$$\text{SNOINT} = \text{ISCSNO} * (\text{LAI} + \text{SAI}/2) * \text{SNO}$$

The proportionality constant ISCSNO was given a value of 0.045. Snow interception in conifers, then, is 22.5%, which agrees with studies summarized by Federer and others (1973).

The rate at which intercepted snow evaporates is assumed to equal PE for as long as there is intercepted snow. Leaf and Brink (1973) modified this rate by dividing by the cover density (our LAI + SAI/2), which in retrospect might be more reasonable. BROOK assumes that all of the energy represented by PE goes to evaporating intercepted snow if it is present, even if the canopy is not dense. However a different assumption would probably not change simulated streamflow by much.

Evaporation from the snowpack

The flux of water vapor toward or away from a snow surface can occur as sublimation from frozen snow, evaporation from melting snow, condensation on melting snow, or the formation of hoar frost on frozen snow. Which of these four processes occurs at any time depends on complicated interactions of temperature and humidity of the air and the energy balance of the snow surface (Hofmann 1963). BROOK obviously cannot handle these processes in detail, particularly because mean daily temperature is the only available atmospheric variable.

When air temperature is below 0°C, we can assume the snow surface temperature is close to the air temperature and that the vapor pressure gradient decreases as temperature decreases. The Hamon PE, which follows the saturated vapor pressure in its dependence on temperature, is appropriate as an estimate of evaporation from a frozen snowpack (Leaf and Brink 1973).

When air temperature is greater than 0°C, the snow may be melting; if so, its vapor pressure is fixed at 6.1 mbar. Higher temperatures usually correspond to higher vapor pressure in the air, and, often, condensation rather than evaporation. In BROOK, we assumed that evaporation and condensation at mean daily temperatures above 0°C are equal and cancel each other.

A forest canopy reduces evaporation from the snowpack by shading and by reducing wind speed. When forest cover is complete as under winter conifers (LAI = 4), the differences in humidity and temperature between air and snow tend to approach zero, so evaporation is negligible. We used a nonlinear relation between evaporation and LAI for reasons described in the section on transpiration and soil evaporation (Fig. 4-3). We assumed the effect of SAI to be small but linear, with snow evaporation in hardwoods 75% of that in the open. Because slope does not affect atmospheric humidity, we did not use RS to modify snow evaporation for slope and aspect; this decision is debatable.

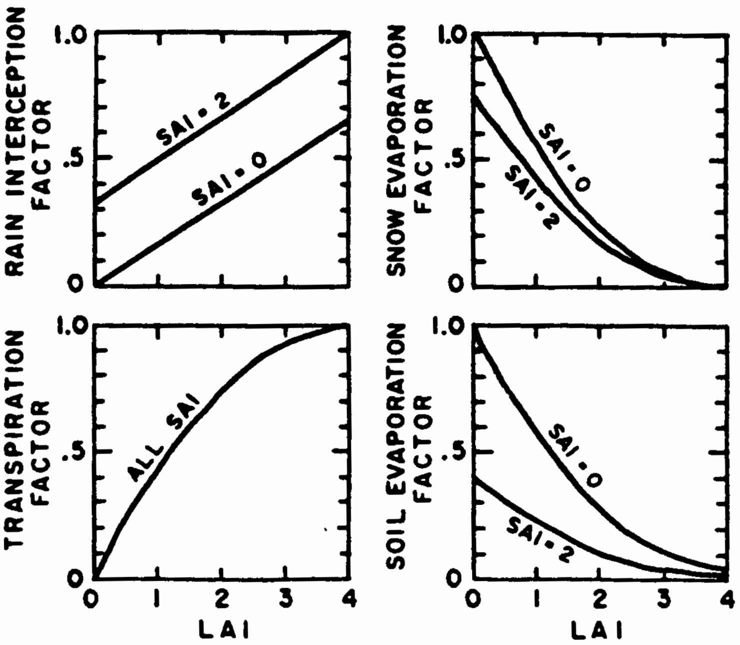

Figure 4-3. Assumed effects of LAI and SAI on rain interception, evaporation from the snowpack, transpiration, and soil evaporation.

The BROOK equation for evaporation from the snowpack is

$$\text{SNOVAP} = (\text{LAI}/4 - 1)^2 \, (1 - \text{SAI}/8) * \text{PE}/2 \qquad \text{TEMP} < 0$$

$$\text{SNOVAP} = 0 \qquad \text{TEMP} > 0$$

The divisor of 2 is a fudge factor. Without this factor BROOK simulated 10 mm a month of evaporation in spring for cleared H2, agreeing with values for open areas quoted by Williams (1958). But the annual snowpack evaporation of 40 mm, which is 20% of the annual total evaporation from H2, seemed too high to us so we reduced it by half. Obviously, the magnitude of snowpack evaporation is only crudely simulated by BROOK.

Snowmelt

Snowmelt simulation is a complex subject (U.S. Army Corps Eng. 1956; Anderson and Crawford 1964; Anderson 1976). If radiation, humidity, and wind data are not available, melt is usually assumed proportional to the excess of mean daily temperature above some threshold near 0°C. In BROOK, we modified this approach by considering groundmelt, cold content of the snowpack, refreezing rain, seasonal effects, and effect of canopy cover, slope, and aspect. This part of the model does not have to be very accurate because it affects only the timing and not the total amount of streamflow.

Groundmelt (GRDMLT) occurs at the bottom of the snowpack whenever the soil beneath is unfrozen. It averages about 0.35 mm a day in Hubbard Brook forests (Federer 1965), and we have used this value in all simulations. In BROOK, we neglected the possibility of frozen soil and allowed groundmelt whenever there was snowpack.

In the sense used in BROOK, snowmelt (SNOMLT) only occurs when water drains from the bottom of the snowpack. This requires that the snow be ripe, that is, it is isothermal at 0°C and is saturated--the liquid water content is 5% by weight. The cold content of a snowpack (CLDCON) is the amount of energy that must be supplied to make the pack ripe; it can be expressed in negative depth of water as a negative amount of melt.

When temperature is less than 0°C, BROOK multiplies the temperature by a factor (CCFUN) to obtain the negative contribution to cold content for that day. Following Anderson (1973), CCFUN varies linearly from 0.2 mm $°C^{-1}$ day^{-1} on January 1 to 0.4 on June 23 and then to 0.2 on December 31. These values were obtained by trial and error for 3 years of data from H3. We limited cold content to the negative of a constant (CCMAX) times the snowpack water equivalent (SNOW). CCMAX was chosen as 0.4 mm of cold content per mm of snow, which is the cold content of a snowpack at -28°C.

However, in early simulations, cold content still became too negative, though it did not reach the limit. Consequently, snowmelt was later than it should have been. To avoid this bias we calculated accumulated cold content only over the previous MT days, where MT was taken arbitrarily as 10.

In BROOK, when temperature is greater than 0°C, energy is assumed to be added to the snowpack. The equivalent melt from this energy is

MELT = COVFUN * MELFUN * RS * TEMP.

This melt is added to CLDCON; a sum greater than zero represents water draining from the snowpack (SNOMLT). In the northeastern United States, solar radiation is the most important energy source for snowmelt, so the slope-aspect factor (RS) is included. COVFUN varies with canopy cover, which we defined as (LAI/4 + SAI/2). COVFUN was made 3.0 in the open, 1.75 in hardwoods, and 1.0 in conifers (Fig. 4-4) (Federer and others 1973). MELFUN is the degree day melt factor for conifers and it varies seasonally (Anderson 1976). We used MELFUN equal to 0.7 mm day^{-1} $°C^{-1}$ on January 1 and December 31 and 2.2 on June 21, with linear interpolation between (Fig. 4-4). The product of MELFUN and COVFUN for open areas on April 15 is 4.8 mm day^{-1} $°C^{-1}$. This is in the lower end of the range given by Federer and others (1973) and is close to the value of 4.2 mm day^{-1} $°C^{-1}$ used by Anderson (1976).

Rain on a cold snowpack refreezes, thus adding to the snowpack and releasing latent heat, which reduces the cold content of the pack by warming it. Each millimeter of rain that falls on an unripe pack makes the cold content 1 millimeter less negative. In BROOK, the minor amount of heat contributed by rain warmer than 0°C is neglected. Once the pack is ripe, further rain passes directly through it.

Streamflow from source areas

Rates of rainfall and snowmelt on forest land do not exceed the infiltration capacity of the soil except in parts of the watershed where the

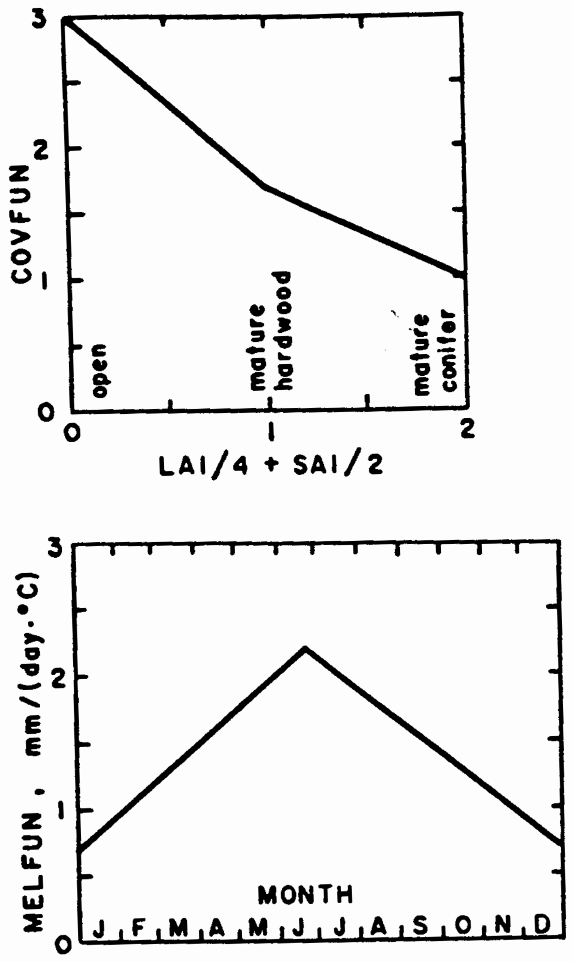

Figure 4-4. Assumed effects of LAI and SAI on COVFUN used in snowmelt, and seasonal variation of MELFUN used in snowmelt.

soil at the surface is saturated. Surface runoff occurs only on these saturated source areas. The source areas vary in size, growing smaller in dry periods and larger during storms or snowmelt (Hewlett 1974; Freeze 1974). Dunne and others (1975) have pioneered in mapping source areas and their changes, but quantitative relations of size of source area to soil water are not yet available.

For BROOK we assumed the fraction of the watershed acting as a source area (PRT) is an exponential function of the soil-water content in the root zone

PRT = IMPERV + PC * exp (PAC * EZONE / EZDEP)

where IMPERV is the fraction of the watershed area that is impervious even when soil is dry, EZONE is the water content of the root zone, and EZDEP is the depth of the root zone. Values for EZDEP of 635 mm for H3 and 900 mm for C14 were determined by knowledge of the watersheds and were not changed throughout the simulations. PC and PAC were fitted to 6 years of H3 and 6 years of C14, including the assumption that PRT at field capacity is around 5 to 10% of the watershed. (See next section for definition of field capacity.) We used IMPERV = 0.01 for both watersheds, and then obtained PC = 4.1E-6 and PAC = 40 for Hubbard Brook and PC = 7.4E-5 and PAC = 25 for Coweeta (Fig. 4-5). These values represent soil characteristics that should not change with timber harvest unless road construction and soil compaction are significant.

Rain and snowmelt on the source area become streamflow immediately as SURFLO and SNOFLO, respectively. No internal storages are needed because these processes are rapid with respect to a DT of 1 day. Rain and snowmelt on the remaining area infiltrate the soil and are added to EZONE.

Soil water in the root zone

Movement of water in the root zone has been a fundamental concern of soil physics for many years. It is best handled by dividing the zone into a number of thin layers, but this procedure is too complex for a model like BROOK. For the lumped root zone of BROOK we assumed a homogeneous soil through the root zone, and we ignored hysteresis, the penetration of a wetting front, nonuniform withdrawal by evapotranspiration, and the effects of a water table. But we did not need or want to be as unrealistic as many hydrologic models that use a "field capacity" below which no water drains from the soil and above which all water drains immediately.

When the soil is homogeneous and well above a water table, Darcy's equation for the rate of drainage of water from the soil reduces to

$$Q = K$$

where Q is the drainage rate and K is the hydraulic conductivity at the mean water content of the soil (Baver and others 1972, p. 383). This occurs because the gravitational potential gradient rather than the matric potential gradient controls the flow rate. Davidson and others (1969) and Black and others (1970) have shown that this equation holds in field situations. Black and others (1970) further show the use of this equation in a soil-water budget and state: "Although this approach has many limitations, it should find application in hydrological and climatological calculations." This is the equation we use in BROOK.

The hydraulic conductivity of the soil is defined as the rate at which water moves through the soil with a unit gradient of soil-water potential. If the potential gradient is expressed in pressure units of mm of water, then the conductivity can have units of mm/day.

Hydraulic conductivity varies rapidly as a function of water content. This function is seldom available for forest soils, but must be measured or estimated somehow. For BROOK we have used a method described by Campbell (1974), which is similar to methods of Rogowski (1972) and Mualem (1976). The relation of soil-water content, θ, to soil-water potential, ψ, known as the soil-water release curve, must be either measured or obtained from the literature on that soil. If the measurements are made on core samples,

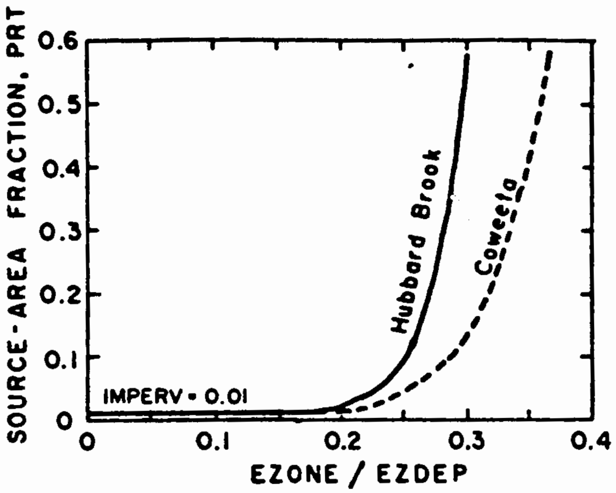

Figure 4-5. Source area fraction (PRT) as a function of EZONE/EZDEP for Coweeta and Hubbard Brook.

proper correction should be made for the large stones in the field that are not included in the core samples. Sieved samples should not be used. A curve of the form

$$\psi = c\ \theta^{b}$$

must then be fitted to the points to determine b. Points near saturation should be ignored as soil in the forest does not become saturated except in the source areas. Campbell (1974) then showed that

$$K = d\ \theta^{(-2b+3)}$$

The constant d must then be found by knowing the value of K at some value of θ. Measurement on a core sample is not ideal because it excludes stones and cracks from the measurement. Field measurement is best, but spatial sampling is necessary. We have used a crude, but effective, indirect method involving the concept of field capacity. Baver and others (1972) proposed that field capacity should be defined as the water content at a hydraulic conductivity of 2 mm/day. We think this useful definition should be widely adopted. If soil-water potential is routinely measured in a forest outside of source areas, the potential will nearly always have a certain value after thoroughly wetting storms. At Hubbard Brook this potential is -6 kPa. We obtained the constant d for Hubbard Brook simply by equating a K of 2 mm/day with the water content at -6 kPa from the soil-water release curve.

In BROOK, then, drainage from the root zone (EDRAIN) is calculated as

EDRAIN = KEINT * (EZONE / EZDEP) ** KESLP

where KEINT is d, EZONE/EZDEP is θ, and KESLP is $-2b + 3$. For Hubbard Brook we obtained KEINT = 2.04E7 mm/day and KESLP = 12.56; for Coweeta we calculated KESLP = 11.74 from a release curve, but KEINT = 1.05E7 mm/day was obtained from measured values of K (Fig. 4-6).

Water below the root zone

In BROOK, water draining from the root zone (EDRAIN) is all routed to an unsaturated zone below the root zone. This unsaturated zone has thickness (UZDEP) and water content (UZONE). The bottom of this zone may be a permanent groundwater surface or impermeable bedrock. BROOK has no provision other than the variable source area for a water table within the root zone. BROOK also has no provision for varying depth to the water table. UZDEP remains constant though groundwater storage varies.

At Coweeta, the unsaturated zone below the root zone is very thick. Lloyd Swift (personal communication 1975) provided a value of UZDEP = 4200 mm for Coweeta. We used this value for all Coweeta simulations. At Hubbard Brook, streamflow response is very rapid so we chose UZDEP = 40 mm as the smallest value that does not require an unreasonable number of iterations as described in the next section.

Drainage from UZONE (UZOUT) is assumed to follow the same theory as drainage from EZONE

UZOUT = KUINT * (UZONE / UZDEP) ** KUSLP

We assumed KUINT = KEINT and KUSLP = KESLP for both Hubbard Brook and Coweeta, though BROOK does allow them to be different.

The drainage UZOUT can go directly to streamflow as interflow (INTFLO) or to groundwater (UDRAIN). We used the simplest way of separating UZOUT into these two parts, assuming that a fixed fraction (DRNC) goes to groundwater and the remainder becomes interflow. For Hubbard Brook we have always used DRNC = 0 so that there is no groundwater at all (Federer 1973). For Coweeta we used trial and error to obtain a value of DRNC = 0.40.

For the behavior of groundwater we again used simple assumptions, that the flow from groundwater is directly proportional to the groundwater storage, and that a fixed proportion of the flow goes to seepage loss (GSEEP) and the remainder to streamflow (GWFLOW).

GSEEP = GWZONE * GSC * GSP

GWFLOW = GWZONE * GSC * (1 - GSP)

where GSC is the total loss fraction and GSP is the fraction that is lost from the watershed as unmeasurable deep seepage. For C13 and C14 we assumed GSP = 0 and obtained GSC = 0.005 by trial and error. With this algorithm the value of GWZONE may not represent the total water stored above some impermeable bottom of the watershed, but only represents an amount of groundwater that might become streamflow. This handling of UZONE and GWZONE is particularly crude.

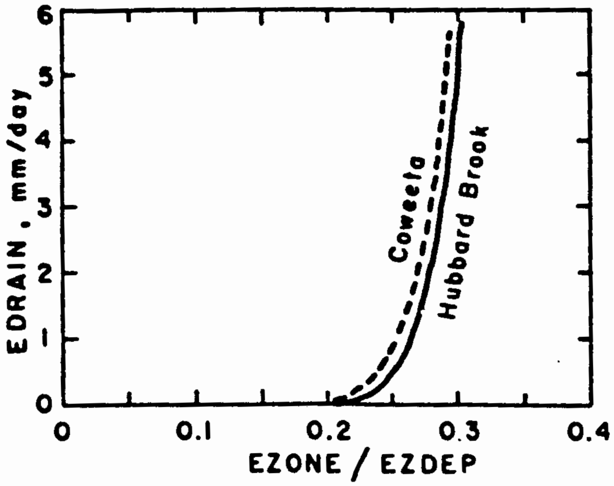

Figure 4-6. Hydraulic conductivity as a function of relative soil-water content and, therefore, EDRAIN as a function of EZONE/EZDEP.

Although complex theories for unsaturated and saturated flow are available (Freeze 1974), the soil and aquifer parameters needed to use them are not. This is especially true for small, hilly, forest watersheds, even for such a well-studied area as Coweeta. Further, such detailed analysis of water movement below the root zone greatly increases the complexity of a hydrologic model and the computer time required to run it. Intermediate levels of complexity are needed.

<u>Flow iterations</u>

These equations for water movement through the soil can blow up if the integration time interval (DT) is too long. For the finite difference approximation to work, DT must be small enough that the input to and output from a storage in one DT are small compared with the storage itself. With a DT of one day, this condition may not exist when rainfall or snowmelt rates are large, or when EZDEP or UZDEP are small.

In BROOK, we divided the day into a number of equal periods (NIT) for the parts of the model involved in calculating flow through the soil. This part of BROOK forms a subroutine called FLOW.

To save computer time, we made NIT only as large as was needed to maintain reasonable behavior. For each day four estimates of NIT are made; the largest estimate is then used for the actual calculations for the day. However, NIT is not allowed to be less than 2. Our four estimates of NIT are the number of intervals required in the day so that neither an estimated input to nor an estimated output from EZONE or UZONE in one interval exceeds 5% of the amount of water in the zone at field capacity. Field capacity, defined as the water content at a hydraulic conductivity of 2 mm/day, is used because it is a rough upper limit. The soil can't become much wetter because of the rapid rise in hydraulic conductivity. If the soil is drier, NIT is conservatively large. When the estimated drainage from both zones is less than 0.15 mm/day, NIT is always set equal to 2.

The four flow rates are estimated as follows: (1) The estimated rate of input to the root zone (EZIN) is the sum of net rain (NETRAN) and snowmelt (SNOMLT). Any output from the root zone as evapotranspiration is ignored, which keeps NIT larger than it might need to be. (2) The estimated rate of output from the root zone is the hydraulic conductivity at the water content EZONE. (3) The estimated rate of output from the unsaturated zone below the root zone is the hydraulic conductivity at the water content UZONE. (4) The input to the unsaturated zone below the root zone (UZIN) is estimated from EZIN and EZONE (Fig. 4-7). The first approximation to UZIN is the drainage from EZONE when EZIN is added to EZONE (KEMAX). But when EZIN is large, KEMAX is too large an estimate for UZIN so we take enough intervals so that UZIN is equal to EZIN. As a transition from one estimate to the other we use the point (K1) at which the two estimates have the same slope as a function of EZIN, namely unity (Fig. 4-7). This point is found by solving dKEMAX / dEZIN = 1 for K1 = KEMAX giving

K1 = (EZONE + EZIN * DT) / (KESLP * DT)

Transpiration and soil evaporation

The transpiration component dominates evaporation from green forested watersheds. Factors that influence transpiration include radiation fluxes, air temperature and humidity, wind, canopy structure, stomatal behavior, water potentials, and resistances to water movement in soil and plants. Literature on these effects fills volumes, but consensus has not been reached on how to consider them all for estimating transpiration for hydrologic purposes.

One widely used approach estimates transpiration first by estimating potential evapotranspiration (PE), which is the evapotranspiration that would occur if the plants were well supplied with water, and then by reducing the estimate if the soil is too dry to keep the plants well supplied. The calculation of PE by the Hamon method is described in the section on potential evapotranspiration.

Although the literature contains a variety of empirical relations of transpiration to PE and soil water (Baier 1969), we like the theoretical result of Cowan (1965) best. By considering a theory of water movement to plant roots and internal and stomatal resistance in the plant, Cowan (1965) and Molz and others (1968) concluded that actual transpiration (TRANS) was equal to the lesser of PE and a soil-water supply function. Boughton (1966) used this conclusion with a linear soil-water supply function in a hydrologic model. Mathematically, Boughton's relation is

TRANS = PE for EZA > CT * PE

TRANS = EZA / CT for EZA < CT * PE

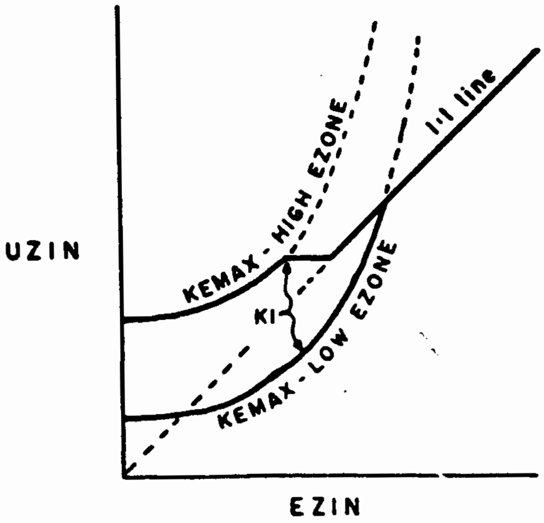

Figure 4-7. Estimation of maximum drainage rate (KEMAX) from estimated input rate (EZIN) and initial water content (EZONE).

where EZA is the available water in the root zone, and CT is a soil constant, which is the reciprocal of the slope of the soil-water supply function (Fig. 4-8).

Use of available water in the root zone rather than total water gives a zero intercept to the soil-water supply function. We calculated available water as

EZA = EZONE / EZDEP - EZ15

where EZ15 is the relative water content at -15 bar soil-water potential. This input to the model can be obtained from the water release curve for the soil, which is described in the section on soil water in the root zone. EZ15 was 0.09 for both Hubbard Brook and Coweeta.

In BROOK, interception of rain does not reduce the energy represented by PE, while snow interception and snow evaporation do. The remaining PE is used to calculate first soil evaporation and then transpiration. For both transpiration and soil evaporation, this remaining PE is multiplied by the slope-aspect factor RS to account for greater amounts of energy available on slopes with higher potential insolation. However when soil water is limiting transpiration and soil evaporation, these are not multiplied by RS because energy supply then is not affecting them.

Canopy cover also affects transpiration, but probably nonlinearly. A unit increment in LAI should increase transpiration more at low LAI than at high LAI, so we used a simple quadratic function (Fig. 4-3). The exact

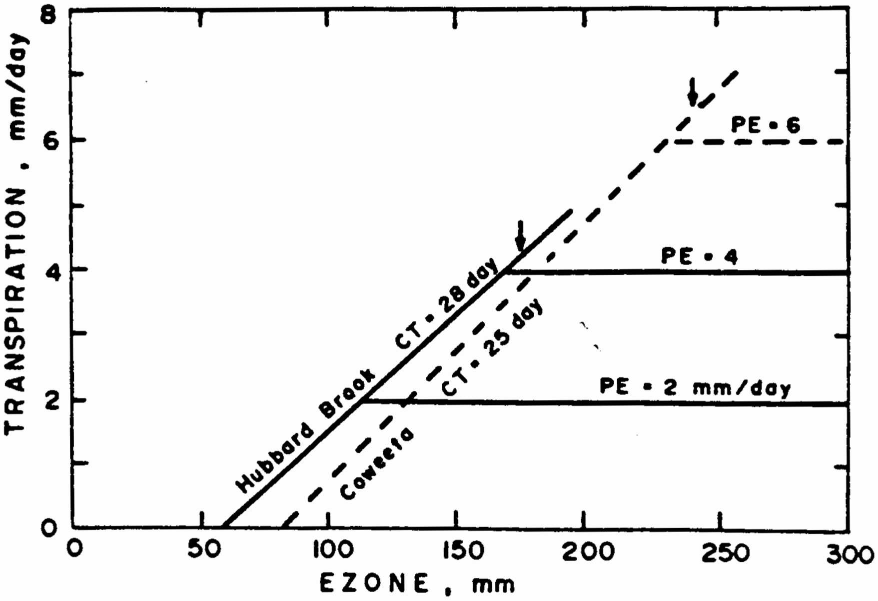

Figure 4-8. Transpiration as a function of soil-water storage (EZONE) and available PE for Hubbard Brook and Coweeta, with LAI = 4 and RS = 1.

form of this function has not been studied for forest vegetation. Stem area index (SAI) does not affect transpiration.

Soil evaporation is controlled by water content near the soil surface rather than by total water in the root zone (EZONE). We added a surface storage compartment (EVW) as a subcompartment of EZONE to represent soil water that could evaporate. This compartment has a fixed soil depth (EVDEP), which we always set at 50 mm. Rain and snowmelt are added to EVW (as well as to EZONE) to bring it up to field capacity, which is defined as the water content that gives a hydraulic conductivity of 2 mm/day.

Soil evaporation (SEVAP) was assumed to work similarly to transpiration, being limited by PE or by a linear soil-water supply function. The supply function represented the rate that water can move to the soil surface (Fig. 4-9); the reciprocal of its slope was assumed to be a constant (CE) for the soil.

In BROOK, soil evaporation includes evaporation from the litter layer, which some hydrologists call litter interception and consider a part of interception (Helvey and Patric 1965).

LAI and SAI limit soil evaporation because they reduce the available energy at the soil surface (Fig. 4-3). We assumed a linear reduction of soil evaporation to 40% as much with an SAI of 2 as with an SAI of 0. This gave a reasonable distinction between leafless hardwood forest and

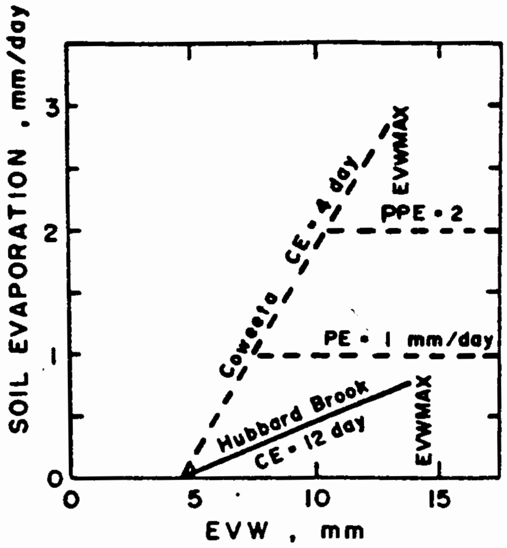

Figure 4-9. Soil evaporation as a function of soil-water in the evaporation zone (EVW) and available PE for Hubbard Brook and Coweeta, with LAI = 0, SAI = 0, and RS = 1.

open areas. For LAI we used the inverse of the dependence of transpiration on LAI, with a minor correction to allow evaporation with LAI = 4 to be 5% of that in the open.

Soil evaporation in BROOK contains a conceptual mistake. In the current programming transpiration is never removed from the surface storage, EVW. The consequent error is largest at intermediate LAI, because at high LAI soil evaporation is small anyway, while at low LAI transpiration is low. In the future, BROOK should be changed so that EVW is reduced for transpiration at least by TRANS * EVDEP/EZDEP. This is still an underestimate because the densest roots are found in the surface layer, so EVW is dried more rapidly by transpiration than is EZONE as a whole.

Values of CE and CT were obtained by empirical fitting. A CE of 12 d was need to give the correct measured streamflow for 3 years of H2 in its devegetated condition. For Coweeta three regrowing years of C13 required a CE of 3 d. We do not know why the Hubbard Brook and Coweeta values differ so much when the soils are similar.

The transpiration parameter CT was the last to be fitted, and was chosen to give the correct total streamflow over 6 years for H3 and C14. Values of 28 d for Hubbard Brook and 25 d for Coweeta are supported by independent analysis with Federer's (1979) model of the transpiration process. Further work with such models should produce methods for estimating CT from measured soil and plant properties.

Initial storage

As with every simulation model, BROOK requires initial values of storages to start a simulation run. In this case, EZONE, UZONE, GWZONE, and SNOW are required.

Water years are used in hydrology rather than calendar years so that the values of these storages change as little as possible from the beginning of one water year to the beginning of the next. This usually means the water year begins when there is no snow and when soil is close to "field capacity." Hubbard Brook scientists use a June 1 water year; Coweeta scientists use a May 1 water year.

To start BROOK, SNOW would usually be zero and EZONE and UZONE would be set to the value that provides a hydraulic conductivity of 2 mm/day, which is our definition of field capacity. To initialize GWZONE for Coweeta we chose a value that gave about the right streamflow for the first few days of the first month. Groundwater is neglected for Hubbard Brook. For mature forest conditions:

	H3	C14
initial EZONE, mm	176	241
initial UZONE, mm	11	1124
initial GWZONE, mm	0	220

These are only estimates of the initial storage, but storage is not always the same at the beginning of each water year. Our simulated total storage (sum of EZONE, UZONE, and GWZONE) for forested watersheds at the end of the water year range from 154 to 203 mm for 16 years of H3, and from 1571 to 1654 for 5 years of C14. So we always run several water years in sequence and use the simulated storage at the end of one water year as the initial storage for the next year. All results reported here are from runs in which storage was carried over rather than reinitialized at the beginning of each water year.

CHAPTER 5. TESTING THE MODEL

Those of you who want to see how well the BROOK model works have now come to the right place.

Our calibration or parameter selection process went about as follows. We used 6 years of H3 to do the major work of development. Then we made changes required for using 6 years of C14. To choose parameters for a completely cleared area, we used 3 water years of H2; for regrowing vegetation we used 6 years of C13. Our initial plan to use only 3 years of each watershed for calibration did not work. Three years is not long enough to establish good values of parameters.

For validation or testing of the model we were left with 11 years of H3, several years of regrowth on H2, and no data for Coweeta. We leave it up to others to validate BROOK for Coweeta or elsewhere. We will, however, also show how BROOK works for north-facing Watershed 7 at Hubbard Brook and for a very large watershed, the Pemigewasset River in New Hampshire.

Test criteria and optimization

By looking at simulated and measured hydrographs you can decide "That looks pretty good" or "That's terrible" (Fig. 5-1). But your "good" might be someone else's terrible. A variety of criteria for comparing simulated and measured hydrographs has been suggested (Dawdy and Bergmann 1969; Aitken 1973; Fleming 1975), but no single criterion has gained widespread acceptance. Different criteria test different aspects of the hydrograph.

In many models, the parameter selection process is done mathematically to optimize the value of a test criterion (Ibbitt and O'Donnell 1971; James 1972). But lacking the extravagant amount of computer time necessary for such optimization, we used trial and error and intuition to choose parameters that gave satisfactory results. Our parameters, therefore, are not optimized in the sense that any change in them will produce worse results.

Our first criterion was agreement of annual simulated and measured streamflow. A plot of measured vs. simulated annual streamflow provides a picture of this criterion, with improvement shown by points moving closer to the 1:1 line. Our second criterion compared measured and simulated monthly streamflow, again by plotting and examining closeness to the 1:1 line.

The Pearson correlation coefficient between the simulated and measured daily streamflow quantifies agreement of the daily hydrographs. McCuen and Snyder (1975) pointed out that this correlation coefficient considers neither bias in the total simulated flow over the period nor differences in dispersion of the simulated and measured flows. They suggested a modified correlation coefficient. BROOK calculates both the Pearson and McCuen-Snyder correlation coefficients for monthly and annual periods.

In the real world, peak streamflow may occur on the same day as precipitation or on the following day, depending on whether the precipitation

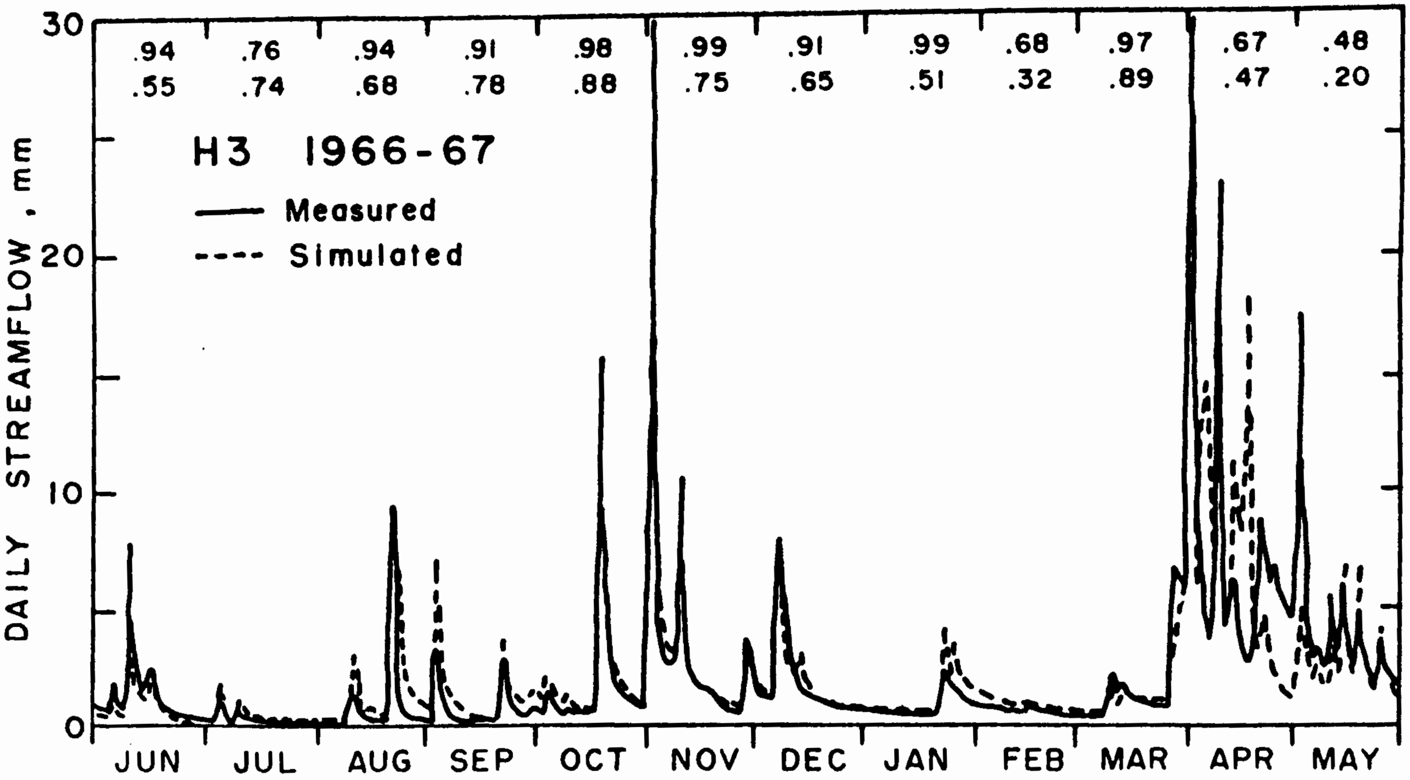

Figure 5-1. Measured and simulated daily streamflow for H3 in 1966-67. The first line of data is monthly Pearson correlation coefficients, the second line is monthly McCuen-Snyder correlation coefficients. Simulated annual flow was 770 mm, measured flow was 772 mm. Annual Pearson and McCuen-Snyder correlation coefficients were 0.86 and 0.69.

occurred early or late in the day. But BROOK does not use precipitation timing and the contribution of SURFLO is always on the same day. The peaks of simulated and measured hydrographs may, therefore, differ by a day. However, for a water yield model, we don't want to consider this as an error. So we used running 3-day means for smoothing streamflow before calculating correlation coefficients.

Mature hardwood forest

For 17 years, simulated and measured annual flows on H3 agreed well (Fig. 5-2). But this is not a very sensitive test; annual precipitation minus 500 mm agreed even better with measured streamflow (Fig. 5-3). This simply showed that storage changes over a water year were small and that annual evapotranspiration was close to 500 mm every year.

A curious and puzzling shift occurred in the relation of simulated to measured annual flow in 1966. Prior to this year, simulated flow consistently overestimated measured flow by about 60 mm; but after 1966, there was no difference or a slight underestimate (Fig. 5-2). The simulation model did not change over the 17 years, so there had been either a shift of bias in data or a physical change on the watershed. The shift also existed, though it was not as great, in the ratio of precipitation minus 500 mm to measured flow (Fig. 5-3). One possible explanation is that H2 was cleared in December of 1965. H2 and H3 share a boundary for about one-fourth of the perimeter of H3. Advection of warm dry air from H2 into H3 should increase evapotranspiration from H3. But this would result in a decrease in streamflow, which is the opposite direction of the observed shift. The shift remains unexplained.

Annual Pearson correlation coefficients for H3 ranged from 0.35 to 0.96 and averaged 0.81, but the second lowest value was 0.67. The one low coefficient occurred in water-year 1968 when snowmelt was very badly simulated. Much of the problem occurred because a storm of 100 mm in late February fell at a mean daily temperature of -2.2°C and was called rain by BROOK--we used -2.8°C as the separation value, RSF. Obviously it was actually snow. This illustrates the major dependence of the model on correct rain-snow separation where snowpacks persist.

The McCuen-Snyder correlation coefficient ranged from 0.25 to 0.94 and averaged 0.74 for the 17 years of H3. The low value was for 1968 and the second lowest value was 0.59. The mean McCuen-Snyder coefficient for the 6 calibration years was 0.83, and for 10 validation years (omitting 1968) was 0.73. As expected, the model generally works better for years in which the parameters have been tinkered with than for additional validation years.

Perhaps the best single exhibit of how a water yield model such as BROOK works is a plot of simulated vs. measured monthly streamflow. For H3, most points were reasonably close to the 1:1 line; but in certain individual months, there were large disagreements (Fig. 5-4). These disagreements were usually caused by problems with rain-snow separation and the timing of snowmelt. Sometimes errors in timing of only a few days shifted large amounts of water from March to April or vice versa. Validation years had more scatter than calibration years did.

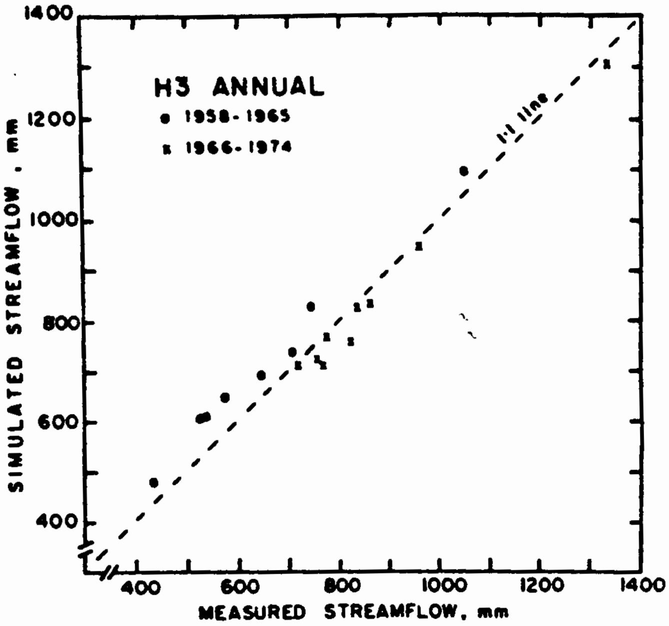

Figure 5-2. Simulated versus measured annual streamflow for 17 years of H3.

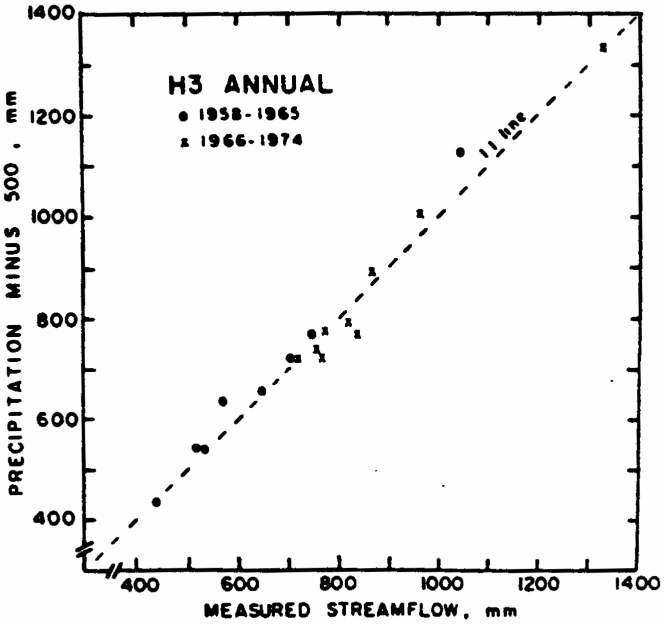

Figure 5-3. Precipitation minus 500 mm versus measured streamflow for 17 years of H3.

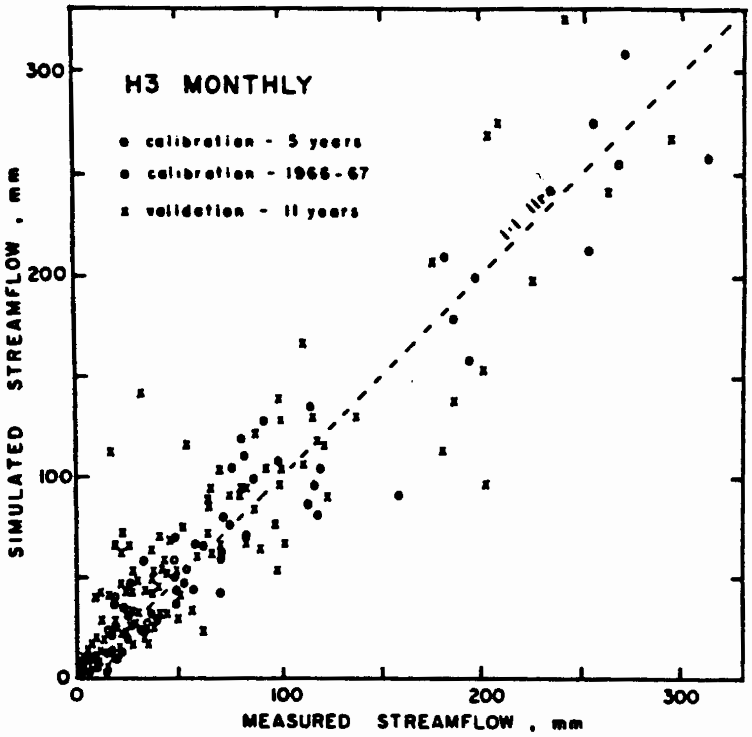

Figure 5-4. Simulated versus measured monthly streamflow for 17 years of H3.

The poorest monthly correlation coefficients occurred in the extreme cases of low flow in summer and high flow in spring. Correlations were as low as 0.1 in summer when flow as so small that relative errors were large. Correlations of 0.1 were also caused in spring by miscalling the form of precipitation in a large storm. In neither case does it pay to tinker with parameters to try to raise the correlation substantially.

Monthly streamflow is much easier to simulate at Coweeta than at Hubbard Brook (Fig. 5-5). Monthly flows of less than 30 mm were common in summer at Hubbard Brook, but there were none in 1965-1970 at Coweeta because of its large and relatively constant storage contribution from below the root zone. Further, Coweeta has little snow and so there are no large snowmelt runoffs to simulate.

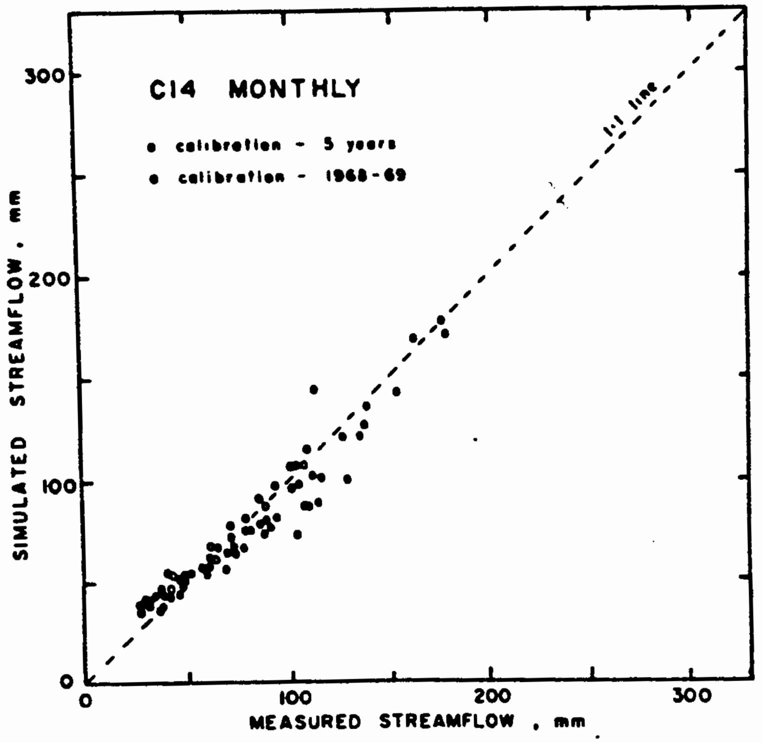

Figure 5-5. Simulated versus measured monthly streamflow for 6 years of C14.

For C14, the annual simulated flow was within 11% of the measured flow for 5 years. Two months of missing measured streamflow prevented annual comparisons for the sixth year. Annual correlation coefficients were somewhat higher than at Hubbard Brook, averaging 0.91 for the Pearson coefficient and 0.80 for the McCuen-Snyder.

The biggest problem in simulation at Coweeta was moving water through and out of storage below the root zone. Biases tended to persist over several months with measured flow consistently overestimated or underestimated (Fig. 5-6). The crude nature of the interflow-groundwater algorithms are responsible for this. But it is difficult to see how to fix it except by empirical fiddling for each specific watershed.

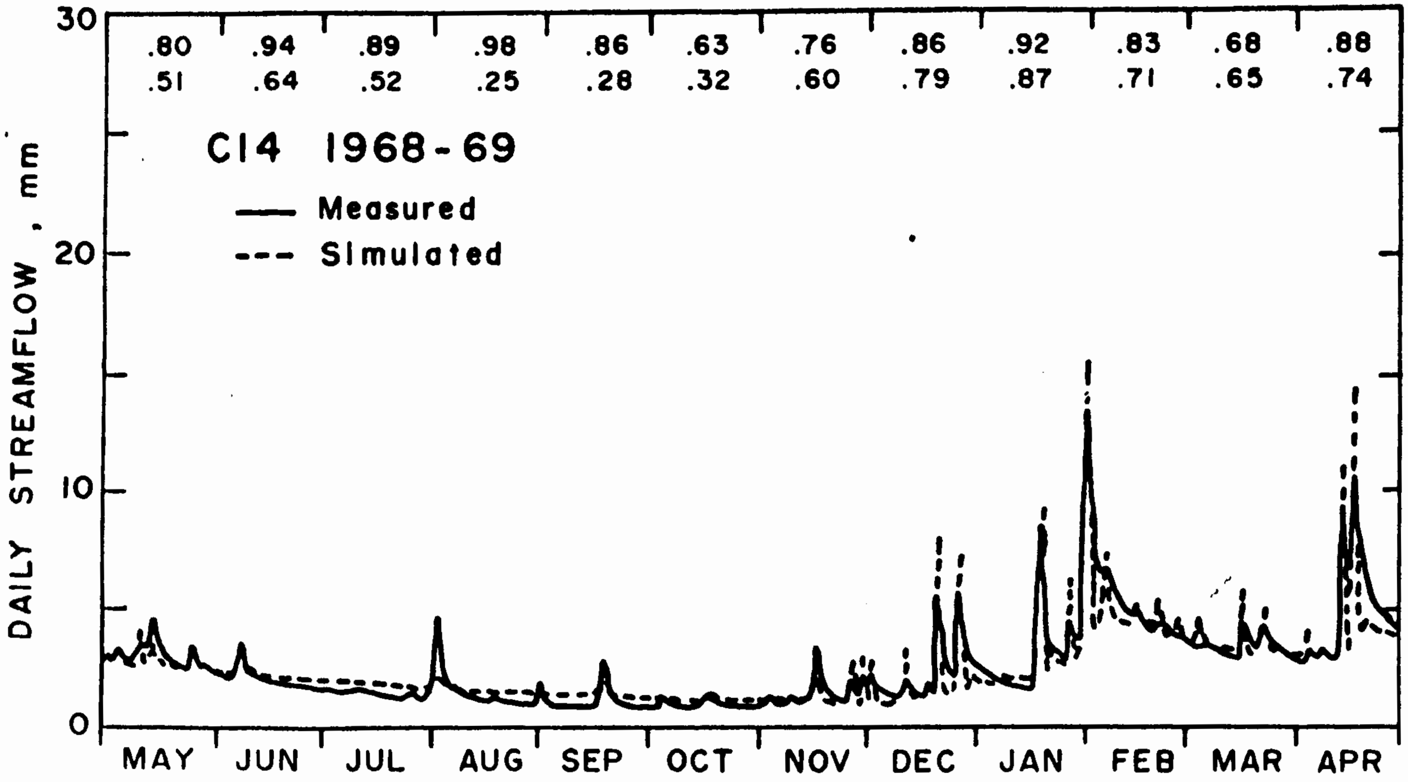

Figure 5-6. Measured and simulated daily streamflow for C14 in 1968-69. The first line of data is monthly Pearson correlation coefficients, the second line is monthly McCuen-Snyder correlation coefficients. Simulated annual flow was 897 mm, measured annual flow was 879 mm. Annual Pearson and McCuen-Snyder correlation coefficients were 0.95 and 0.84.

Watershed 7 at Hubbard Brook is similar to H3 except that it faces north instead of south and is at a somewhat higher elevation. Consequently, snowmelt on Watershed 7 lags about 3 weeks behind that on H3. We used a winter leaf area index (LAI) of 0.7 to represent the presence of some conifers, with the spring transition 5 days later and the autumn 5 days earlier than H3. Mean daily temperature was taken from a station in the middle of the watershed and was slightly lower than the temperature used for H3. The only other difference from H3 was in slope and aspect. The later snowmelt on Watershed 7 was adequately simulated in 2 of the 3 years run (Fig. 5-7). Simulation for months without snowmelt was acceptable. In winter months with no snowmelt, groundmelt is the only source of streamflow. These months were often biased because groundmelt is a constant in BROOK but slowly variable in reality.

Cleared and regrowing forest

C13 was cleared in November and December of 1962 without wood removal and then allowed to regrow (Hibbert 1965). BROOK simulates such clearing and regrowth by changing leaf area index (LAI), stem area index (SAI), and root zone depth (EZDEP). For C13, we set the root zone depth to 150, 250, 350, and 450 mm for the 4 years following clearcutting. We also arbitrarily set SAI equal to 0, 0, 0.1, and 0.2 in the 4 years. We then varied the soil-water availability constant for evaporation (CE) and LAI until annual measured streamflow was reasonably simulated, while maintaining a smoothly increasing LAI. The final maximum values of LAI for the four summers of regrowth were 1.0, 2,0, 3.0, and 3.5. Simulated flow was too large in the second and third years of regrowth, implying that larger LAI's or larger EZDEP could have been used in these years (Table 5-1).

BROOK produced the expected changes in transpiration, soil evaporation, and interception that occur following clearing (Table 5-1). The actual values of these amounts can be questioned, but they can be changed considerably by tinkering with seasonal variation in LAI. Better simulation of regrowth cannot be expected until much more is known about the relation of LAI to the several evaporation components, and unless the changes of LAI in regrowth are measured.

H2 was cleared in December 1965 without product removal. Regrowth was prevented in 1966, 1967, and 1968 by herbiciding with bromacil and 2,4,5-T (Hornbeck and others 1970). The watershed has been regrowing since 1969. For 1967 through 1972, LAI was estimated visually from photographs taken at 10 fixed locations roughly each month through the summer. These values were not changed thereafter. EZDEP and SAI were also estimated and fixed before simulation (Table 5-2). The evaporation parameter CE was adjusted to match the simulated and measured flows in the first 3 years after clearing. The low correlation coefficients for water year 1968 were caused by terrible snowmelt simulation, just as also occurred in H3.

The 5 regrowth years, 1969-1973, were run only once, so they are validation years. Simulated flow tended to exceed measured flow in these years (Table 5-2), as it did at Coweeta. About one-third of this difference could be eliminated by increasing EZDEP by 100 mm. Evidently, total evapotranspiration at intermediate LAI and EZDEP values is too low, but it is

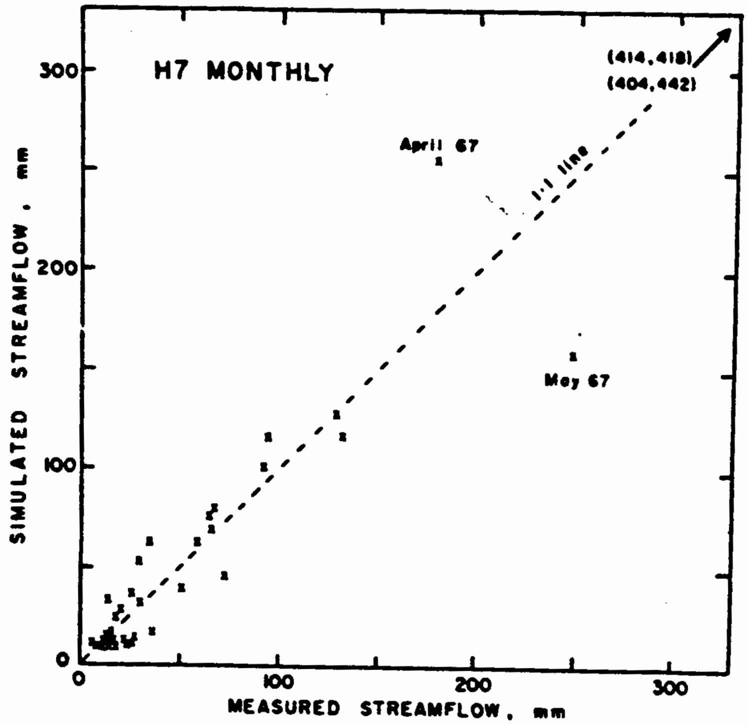

Figure 5-7. Simulated versus measured monthly streamflow for 3 years of Hubbard Brook Watershed 7.

not clear whether the LAI effect should be changed in transpiration, soil evaporation, interception, or all three. There are no measurements of the relative amounts of these fluxes for regenerating forests.

We adjusted measured streamflow of H2 by a factor of 0.91 to make it comparable to H3 (Hornbeck and others 1970). The necessity for this has been attributed to possible error in establishing the boundary of H2. Parameter selection and algorithm improvement cannot make a model better than the quality of the input data allows.

Table 5-1. Results from simulation of cutting and regrowth for C13

	Water year					
	1961	1962	1963	1964	1965	1966
LAI summer	4.0	4.0	0-1.0	1.5-2.0	2.0-3.0	2.5-3.5
LAI winter	0.5	0.0	0	0	0.1	0.2
SAI	1.5	1.5-0.0	0	0-0.1	0.1-0.3	0.3-0.5
EZDEP	900	900	150	250	350	450
Precipitation	2154	1546	1848	1838	1667	1637
Measured flow	1381	698	1322	1306	843	990
Simulated flow	1122	798	1328	1418	1035	1031
SURFLOW	210	105	314	346	224	154
SNOWFLOW	0	1	4	12	1	0
INTERFLOW	627	361	659	632	457	528
GROUNDFLOW	285	329	350	429	354	348
Evaporation	891	792	408	511	630	680
TRANS.	609	502	30	146	293	387
SOIL EVAP.	103	151	363	322	260	193
SNOW EVAP.	1	3	6	5	3	0
RAIN INT.	178	136	9	37	73	100
SNOW INT.	0	0	0	0	0	0
r^2	.907	.911	.752	.823	.884	.804
McCuen-Snyder r^2	.825	.823	.752	.505	.784	.768

Table 5-2. Results from simulation of cutting and regrowth for H2, by water year

	Forest		Cleared			Regrowing				
	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
LAI summer	4.0	4.0	0.0-0.3	0.0-0.3	0.0-0.6	0.3-0.5	0.5-1.5	1.6-2.2	2.8-3.3	3.3-3.5
LAI winter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SAI	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
EZDEP	635	635	100	100	150	150	250	350	400	450
Precipitation	952	1216	1300	1387	1239	1267	1217	1215	1516	1848
Measured flow x 0.91	454	724	1089	1122	1054	1005	897	756	975	1383
Simulated flow	486	734	1095	1177	1064	1059	961	854	1062	1395
SURFLOW	102	203	497	553	415	441	282	251	362	513
SNOFLOW	98	63	137	129	99	130	204	137	145	202
INTERFLOW	286	468	461	496	551	489	475	466	554	679
Evaporation	481	478	191	188	200	206	252	367	435	463
TRANS.	314	312	3	7	13	22	71	171	240	275
SOIL EVAP.	52	53	168	156	163	154	146	143	122	105
SNOW EVAP.	14	19	19	23	21	24	24	24	20	23
RAIN INT.	90	86	1	4	4	7	11	29	52	60
SNOW INT.	10	7	0	0	0	0	0	1	1	2
r^2	.85	.83	.74	.86	.09	.63	.70	.71	.81	.81
McCuen-Snyder r^2	.70	.75	.72	.77	.06	.55	.58	.68	.68	.74

Large watersheds

BROOK was developed for small, forested watersheds, but the hydrologic principles in it also apply to a large watershed. As a severe test we simulated 2 years of streamflow from the Pemigewasset River at Plymouth, N. H., a watershed of 1600 km^2. Much of this watershed is mountainous hardwood forest--including Hubbard Brook--but the elevation ranges from 140 m in flat river valleys containing some agriculture on deep alluvial soils to 1600 m and shallow, tundra-like soils and vegetation.

The model is a lumped parameter model, so it cannot consider the variations in slope, aspect, elevation, soil depth, and conifer cover on such a large watershed. We set slope and aspect equal to zero, the unsaturated zone below the root zone (UZDEP) to 1000 mm, groundwater parameters DRNC = 0.2 and GSC = 0.0025 (the values we were using for Coweeta at the time of the run), winter LAI = 0.5, and all other parameters as for H3. Precipitation and temperature data were obtained from a weather station at Woodstock, N. H., centrally located but at an elevation of only 220 m.

The simulation is not good (Fig. 5-8), but most months are as close as for H3 (Fig. 5-3). In the hydrograph, problems are evident with base flow, which could be improved by fiddling with DRNC, GSC, and UZDEP, and in snowmelt timing. The snowmelt timing probably cannot be improved because the cause of the problem is the desynchronization caused by varying aspect and elevation. Annual simulated and measured flows were 703 and 660 mm in 1971-1972 and 845 and 940 mm in 1972-1973. Pearson and McCuen-Snyder coefficients were 0.71 and 0.53 in 1971-1972 and 0.47 and 0.37 in 1972-1973.

Conifers

We have not tried to systematically test the behavior of BROOK for conifer-covered watersheds in which LAI is set at 4.0 all year. But in early runs to choose interception coefficients and to test LAI functions, we did ensure that interception and transpiration from conifer-covered watersheds for Coweeta were similar to the totals provided by Swift and others (1975) for the pine-covered Coweeta Watershed 1. In general, both for hardwoods and conifers, BROOK gives somewhat lower interception and higher transpiration than does the model of Swift and others (1975). An increase in the interception constant INC and a corresponding reduction in the potential evapotranspiration available for transpiration would make BROOK more similar to theirs.

Sensitivity analysis

A sensitivity analysis determines how much the results of the model are affected by varying each parameter separately. The results of a sensitivity analysis vary depending on the parameter set being studied. For example, the constant controlling soil-water availability for evaporation (CE) will have little effect for a mature forest and great effect for a cleared area. Similarly, snow parameters have little effect if there is little snow. Here we show results of sensitivity analysis only for the hardwood-forested H3 and C14. Parameter sensitivity should be averaged over several years but this takes too much computer time. We used just

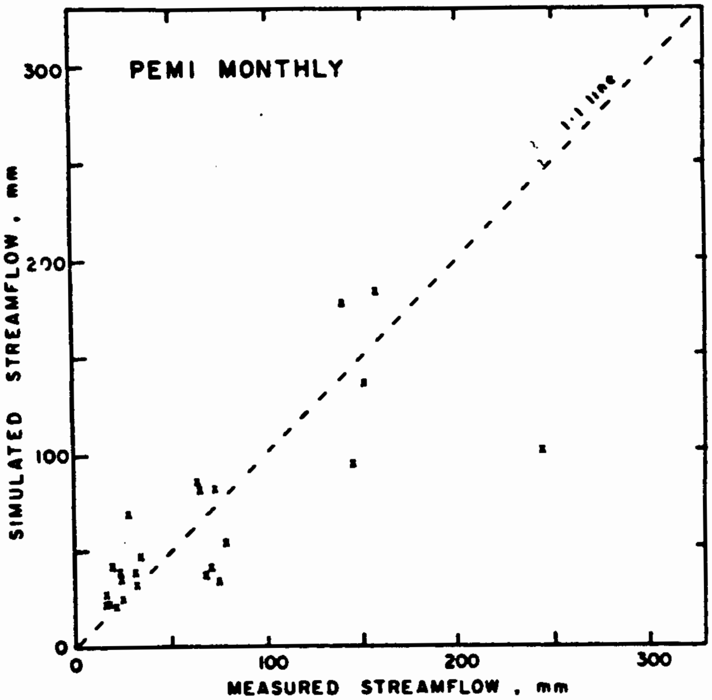

Figure 5-8. Simulated versus monthly streamflow for 2 years of the Pemigewasset River at Plymouth, N. H.

1 year for each watershed, but in each case the preceding year was also run to initialize storages. We made runs with each parameter decreased by 20% and increased by 20%, and report the resulting percentage change in annual simulated flow, and in annual Pearson and McCuen-Snyder correlation coefficients (Table 5-3).

The most sensitive parameter is the exponent of the hydraulic conductivity equation in the root zone (KESLP). For H3, a 20% decrease in KESLP caused an 11% increase in streamflow, while the response for Coweeta was only slightly less (Table 5-3). A 20% change in KESLP caused changes of 4 to 49% in the correlation coefficients. KESLP was not a fitted parameter.

Table 5-3. Percentage change in simulated flow, Pearson correlation coefficient, and McCuen-Snyder correlation coefficient caused by a 20% decrease and 20% increase in the given parameter for H3 in 1966-1967 and for C14 in 1968-1969

Parameter	Water-shed	Standard value	Simulated flow		Pearson correlation coefficient		McCuen-Snyder correlation coefficient	
			Dec.	Inc.	Dec.	Inc.	Dec.	Inc.
			% Change					
PE multiplier (PEC)	H3	1.0	9	-6	-2	1	0	-1
	C14	1.2	10	-8	0	0	4	-4
Interception constant (INC)	H3	0.75	2	2	0	0	0	0
	C14	0.75	2	2	0	0	1	-1
Root zone depth (EZDEP)	H3	635	4	-2	-1	0	4	-4
	C14	900	3	-3	0	-1	5	-5
Availability constant (CT)	H3	28	-2	2	0	-1	0	0
	C14	25	-1	1	0	0	-1	1
Evaporation availability constant (CE)	H3	12	0	0	0	0	0	0
	C14	3	0	0	0	0	0	0
Source area exponent (PAC)	H3	40	-1	1	-2	-4	-8	10
	C14	25	-1	2	-2	-12	-14	-25
Source area coefficient (PC)	H3	.00015	0	0	0	0	-1	1
	C14	.00070	0	0	1	-1	-4	4
Root zone conductivity exponent (KESLP)	H3	12.56	11	-2	-5	-6	-8	14
	C14	11.74	9	-2	-4	-22	-17	-49
Root zone conductivity coefficient (KEINT)	H3	.204E8	0	0	0	0	1	-1
	C14	.105E8	0	0	-1	0	3	-2
Unsaturated zone conductivity exponent (KUSLP)	H3	12.56	0	0	0	0	0	0
	C14	11.74	2	-2	0	0	4	-1
Unsaturated zone conductivity coefficient (KUINT)	H3	.204E8	0	0	0	0	0	0
	C14	.105E8	0	0	0	0	-1	0
Unsaturated zone depth (UZDEP)	H3	40	0	0	0	0	0	0
	C14	4200	0	0	1	-1	9	-8
Fraction to groundwater (DRNC)	C14	0.4	0	0	0	-1	8	-8
Groundwater flow constant (GSC)	C14	0.005	0	0	0	0	-1	1
Seasonal melt factor (MELFUN)	H3	.7,2.2,.7	0	0	-6	3	-8	7
Cold content accum. days (MT)	H3	10	0	0	2	-3	0	-2
Rain-snow separation temperature (RSF1)	H3	-2.8	0	0	1	0	0	0
Cold content factor (CCFUN)	H3	.2,.4,.2	0	0	1	-2	0	0

It was calculated from measured soil properties as described in Chapter 4. However it is near an optimal value for this year at least because both a 20% increase and a 20% decrease lower the Pearson correlation coefficient for both Coweeta and Hubbard Brook. For Hubbard Brook, KESLP is not near optimum by the McCuen-Snyder correlation coefficient, illustrating how different test criteria can indicate different optimum values for parameters.

The second most sensitive parameter in terms of the correlation coefficients is the exponent of the source area equation (PAC); but it had only a small effect on annual flow. For Hubbard Brook, the chosen PAC value is not optimum by the McCuen-Snyder coefficient for the 1 year tested here, but 6 years were used to select PAC. A parameter that is optimum over 6 years may not be optimum for any 1 of those years.

As expected, the multiplier of potential evapotranspiration (PEC) had a large effect on annual flows, a change of 20% changing the flows by 6 to 10%. The effect on the correlation coefficients, which evaluate the timing of the flows, was less.

Several other parameters were sensitive. Changes in root zone depth (EZDEP) changed annual flows and the McCuen-Snyder coefficient, but not the Pearson coefficient. For Coweeta, the depth of the unsaturated zone (UZDEP) and the fraction of flow to groundwater (DRNC) affected the timing of flow significantly but not the amount. For Hubbard Brook, the degree day factor (MELFUN) similarly affected the timing but not the annual flow.

All other parameters tested could be changed 20% without affecting total flow or correlation coefficients by more than 4%. They can be said to be insensitive.

The important parameters LAI and SAI were not tested. Summer values of these parameters for these watersheds must be 4.0 and 2.0, representing mature forest. The winter value of LAI for Hubbard Brook obviously should be zero. Only the winter LAI for Coweeta could have been fitted. The effect of changing the leafout and leaffall transition dates has been examined in a separate paper (Federer and Lash 1978).

CHAPTER 6. STUDIES WITH THE MODEL

Transpiration

Transpiration from mature hardwood trees may differ among species so forest management that selects for certain species can alter streamflow. In another paper (Federer and Lash 1978), we used BROOK to analyze differences in streamflow that could be caused by stands of species having extreme characteristics. Changing the transition dates for leaf area index (LAI) simulated differences in timing of leafout in spring and color change in autumn. Differences in stomatal resistance in trees that are not water-stressed were simulated by arbitrarily increasing and decreasing daily transpiration. Changes of the soil-water availability parameter (CT) simulated possible differences in root distribution with depth. Annual streamflow differed by as much as 120 mm because of these changes. For Hubbard Brook, with its fast response, the differences in streamflow occurred shortly after the differences in transpiration. For Coweeta, with its slow response, the streamflow differences were spread over the entire year.

Floods and droughts

Hornbeck (1973a) and Hornbeck and Federer (1974) used an early version of BROOK to evaluate soil-water deficits prior to midsummer stormflows. The frequency of agricultural drought, defined as the occurrence of low soil-water content, is now being studied with BROOK. Fifty years of weather records for several New Hampshire stations will be run through BROOK to estimate soil-water status in summer.

Nutrients

Concentrations of nutrients have been measured in streams flowing from regrowing forests in northern New Hampshire.[1/] BROOK provided estimates of monthly streamflow so that total amounts of nutrient loss could be calculated. Nutrient concentration in input precipitation and exchange of nutrients with water moving through the soil determine the nutrient content in streamflow. Ohba[2/] developed a simple nutrient mixing model from an early version of BROOK. The current BROOK model has been used similarly by Aber.[3/] The success of such models may be partly limited by lack of understanding of nutrient exchange, and also by the oversimplification of soil-water movement in models like BROOK.

[1/] Martin, C. Wayne, R. S. Pierce, and G. E. Likens. 1978. Commercial clearcutting affects nutrient cycles and stream chemistry in the White Mountains of New Hampshire. (Manuscript in preparation.)

[2/] Ohba, Takao. 1976. Hydrologic interpretation of stream water chemistry in W-6, Hubbard Brook Experimental Forest, N. H. (Unpublished M.S. thesis, University of New Hampshire.)

[3/] Aber, John. 1977. Personal communication.

Clearing of hardwoods

Hydrologists have long used paired watershed experiments to study the effect of forest alteration on streamflow. After several years of calibration, one watershed is treated and the other used as a control (Hornbeck 1973b). Langford and McGuinness (1976) recently concluded that a hydrologic model could replace the control watershed with little loss of sensitivity. However our experience with BROOK has not verified this. At Hubbard Brook, differences in measured streamflow among forested watersheds are much smaller than differences between simulated and measured streamflow from H3. Where there is excellent agreement between paired watersheds, a model cannot substitute for the control.

On the other hand, paired watershed experiments are subject to the vagaries of weather in the first year after treatment (Hornbeck 1973b). The "first-year increase" in streamflow following clearing of hardwoods may depend greatly on the precipitation pattern in that year. One way around this problem is to maintain the cleared condition of the watershed for several years by herbicides or cutting. This was done for 3 years on H2. But a hydrologic model like BROOK is required to examine the effect of any desired precipitation pattern on the first-year increase.

A second problem in paired watershed research is that only one slope and aspect can be studied in each experiment. Coweeta is the only place in the eastern United States where essentially similar experiments have been made on different aspects. The conclusion is that streamflow increases from clearing hardwood forests depend greatly upon aspect of the watershed (Douglass and Swank 1975).

With the two questions of differences in precipitation and aspect in mind, we made a number of simulations with BROOK. Rather than using real watersheds, we chose three slope-aspect combinations: 15° south-facing, horizontal surface, and 15° north-facing. All other parameters were the values for H3 or for C14. With the Coweeta parameters we used 6 water years of precipitation and temperature, 1962-1967. Annual precipitation ranged from 1538 to 2071 mm. We made another set of runs with that daily precipitation multiplied by 0.6 to produce a record representative of lower elevations in the southeastern United States; these runs are referred to as Coweeta x.6.

With Hubbard Brook parameters we constructed semi-artificial records for 4 of the 6 years we ran. (This is unfortunate because it is confusing, but we thought it was a good idea at the time.) From 18 years of available data we chose data for each month to give 2 years with somewhat low precipitation each month (annual totals 863 and 894 mm), one having large storms and the other smaller storms, and 2 years with somewhat high precipitation each month (annual totals 1214 and 1217 mm), again with one having larger and the other smaller storms. For the other 2 years, we used data for 1967, which was dry early in the summer and wet later, and for 1968, which was wet early in the summer and dry later (annual totals 1393 and 1270 mm).

Simulated streamflow increases caused by clearing hardwood forest varied from 230 to 325 mm for a 15° south-facing watershed at Hubbard

Brook (Table 6-1). The measured increases from H2 were successively 346, 273, and 240 mm (Hornbeck and Federer 1975). The agreement is not surprising because some parameters were chosen to fit H2 data.

For Coweeta, the mean simulated increase for all 6 years varied from 343 mm on a 15° north-facing slope to 381 mm on a 15° south-facing slope. The measured increase for the east-facing C13 was 361 mm in 1940 and 381 mm in 1962 (Douglass and Swank 1972). Again, agreement is not surprising because parameters were chosen to give it.

An equation by Douglass and Swank (1975), which is based on many paired watershed experiments in eastern forests, predicts much larger increases on north-facing than on south-facing slopes (Table 6-1). BROOK, on the other hand, predicts somewhat larger increases on south-facing slopes. The Douglass-Swank equation has two limitations. First, for a 15° north-facing slope at Hubbard Brook, the equation predicts a first-year increase of 514 mm (Table 6-1). This is larger than annual evapotranspiration on Hubbard Brook Watershed 7 and must be a considerable overestimate. Second, the Douglass and Swank equation does not consider variation in annual precipitation and gives the same prediction for Coweeta as for Coweeta with its precipitation reduced by 0.6. With the lower precipitation, BROOK predicts that soil-water supply sometimes limits transpiration, thus causing a 100-mm smaller increase in streamflow. The Douglass-Swank equation is based on measured results from gaged watersheds, mostly at Coweeta, whereas BROOK is a simulation that includes numerous assumptions. This question of effect of aspect on water yield increases following clearing needs more research.

Converting hardwoods to conifers

An experiment in streamflow changes from converting a hardwood forest to conifers has been carried out on Watershed 1 at Coweeta. Sixteen years after planting, the white pines on this watershed had a well-developed canopy and were probably similar to mature forest in terms of evapotranspiration. Streamflow was then 200 mm less than if the watershed had remained in hardwoods. BROOK simulates a mean of 195 mm for such a change on a 15° south-facing watershed similar to Watershed 1. On the basis of this agreement, a model like BROOK can study the range of variation with precipitation and aspect (Table 6-2) just as we did in the last section on clearing of hardwoods. The lower streamflow from conifers is caused both by greater interception and greater transpiration (Table 6-2) in months when the hardwoods are leafless.

Table 6-1. Simulated increase in annual streamflow (mm) by clearing hardwood forest, maximum, minimum, and mean of values for 6 different years. D-S values are predicted from Douglass and Swank's (1975) equation

Watershed		Max.	Min.	Mean	D-S
Hubbard Brook	15° S-facing	324	230	267	276
	horizontal	308	223	257	348
	15° N-facing	287	218	246	514
Coweeta	15° S-facing	452	319	381	249
	horizontal	427	300	362	297
	15° N-facing	396	295	343	402
Coweeta Precip x 0.6	15° S-facing	424	214	270	249
	horizontal	395	193	254	297
	15° N-facing	367	185	247	402

Table 6-2. Simulated decrease in streamflow (mm) by converting mature hardwood forest to mature conifers, maximum, minimum, and mean of values for 6 different years

Watershed		Maximum	Minimum	Mean
Hubbard Brook	15° S-facing	214	174	194
	horizontal	184	149	165
	15° N-facing	147	119	132
Coweeta	15° S-facing	229	143	195
	horizontal	194	126	164
	15° N-facing	146	105	126
Coweeta Precip x 0.6	15° S-facing	197	50	148
	horizontal	164	52	133
	15° N-facing	126	46	104

CHAPTER 7. PROBLEMS WITH THE MODEL

No simulation model is ever complete or perfect. BROOK has a number of problem areas that are not resolved to our satisfaction. Most of these areas are mentioned elsewhere but in this chapter we will list them all in one place. We leave it to future users to wrestle with them.

The determination of whether precipitation is rain or snow causes major errors in snow accumulation and timing of streamflow from snowmelt. If the form of precipitation were available, it could be added as an input variable, and would greatly improve simulation results. Tinkering with the critical temperature (RSF) might improve results for any specific location. Provision for mixed rain and snow at some temperatures did not help our simulations. An elevation correction for temperature could be added.

The relation of the components of evaporation to leaf area index (LAI) and stem area index (SAI) at intermediate values of these parmeters is hypothetical and could be modified. Part of the problem of simulating regrowth might be cured here, but only if good values of LAI and root zone depth (EZDEP) were known.

Water movement through the soil below the root zone controls streamflow timing. The model algorithms are crude and could be improved particularly when the soil is deep and there is groundwater. Timing is also affected by the source-area coefficients. But improvement of the source-area part of the model probably requires more field research.

With deep soils, the recession curves from a single storm are double-peaked, with the interflow peak occurring several days after the rain and, thus, the surface flow peak from source areas. Such double peaks are seldom observed, so the simulation result is an artifact of the artificial separation of flow sources. In reality, the watershed flow generation process is a continuum, but this is exceedingly hard to simulate (Freeze 1974).

The need to increase the Hamon potential evapotranspiration by 20% for Coweeta is frustrating, because it leaves unanswered the question of how to interpolate between Coweeta and Hubbard Brook. The only solution seems to be to use a PE method that requires more data, or to develop a new method.

BROOK has a conceptual difficulty with regard to the surface layer containing water that can become soil evaporation. At present, only soil evaporation and not transpiration removes water from this storage. Consequently, soil evaporation goes longer than it should before being limited by dry soil. This is not much of a problem for fully forested conditions when soil evaporation is low anyway, or in cleared conditions when transpiration is low. However in regrowing situations, soil evaporation will be larger than it should be in dry periods.

Another conceptual difficulty concerns the effect of slope and aspect. Although it is not obvious, this effect is accounted for in three ways: by the slope-aspect correction factor (RS), by daylength (DAYL), and by input temperature (TEMP). Daylength (DAYL), which is a multiplier in calculating PE, is calculated for the particular slope, not for a horizontal surface. Because RS is controlled partly by daylength, the RS and DAYL corrections are partly redundant. Perhaps DAYL for a horizontal surface should be used instead. If mean daily temperature is measured on the same aspect as the watershed, then it already includes some effect of aspect. It is not clear whether it is better to use a temperature measured on the slope, as we did for Hubbard Brook or in the valley floor, as we did for Coweeta.

Interception of rain by conifers is probably too low (Table 5-2). BROOK simulates about 200 mm for Coweeta, but Swift and others (1975) used 331 mm and Helvey (1967) estimated 530 mm for mature pine at Coweeta. Any attempt to increase interception by increasing the interception constant (INT) must be compensated somehow by a corresponding decrease in transpiration. Otherwise, the total evapotranspiration will be too high and the streamflow too low.

BROOK cannot handle partial cuts of a watershed reasonably, and neither, we believe, can any other model unless it is specifically fitted for a certain kind of cut. Sometimes the amount of watershed cut is specified by the fraction of basal area removed. But removing a large portion, say half, leaves much different configurations, depending on whether the cut was a selection cut, a strip cut, or a single block cut of half the watershed. The evporation components will differ drastically depending on the type of cut. The total evapotranspiration and resulting streamflow probably also differ. We tried to develop some kind of a relation to account for configuration based on exposure of individual remaining trees. But this failed primarily because there is virtually no data on which to base the relation.

Although the problem of predicting streamflow from partial cuts has been around for a long time and we are concerned with it, we must confess that BROOK makes no contribution to solving it. BROOK cannot be used for selection or shelterwood cuts. Only for block clearcuts where the blocks are sufficiently large, perhaps 5 hectare, is there a way out. Then BROOK must be run twice, once for the cleared blocks and once for the remaining forest, and the simulated streamflows weighted for the fraction of the watershed in each.

CHAPTER 8 (revised), USING THE MODEL

BROOK2 is written in ANSI Fortran-77 except for in-line definitions following /* in specification statements, and $INSERT to add COMMON to program blocks. Any other deviations from standard are unintentional.

The flow of the model is as follows, with subroutine names in capitals:

```
Interactive inputs
PARAMRD - reads parameters
Begin year loop
     DATARD - reads one year of data
     Begin month loop
          Begin day loop
               CHNGERD - if parameters are changed during run
               THEDAY - main day program
                    SOLAR - solar functions
                    POTET - potential evapotranspiration
                    RAINSNOW - rain-snow separation
                    SBINTER - rain interception
                    SBSNOINT - snow interception
                    SBINTVAP - evaporation of intercepted snow
                    SBSNOVAP - snow evaporation
                    SNOWMELT - snowmelt
                    FLOW - subsurface water movement
                    SBEVAP - soil evaporation
                    SBTRANS -transpiration
                    SBGSEEP - seepage loss
                    SBGWFLO - groundwater
               SUMARR - for daily output and monthly totals
          End of day loop
     End of month loop
     SMOOTH - running 3-day means of streamflow
     STAT - statistical comparison of simulated and measured
            streamflow
     SUMARR - for annual totals and output
     PLOT1 - plotted output
          PPLOT - one line of plotted output
End of year loop
```

In addition there is a general interpolation routine, INTERP, and an external common block COMM. Subroutine INTERP interpolates linearly between pairs of (X, Y) values when an intermediate value of X is given. This routine is used for LAIFUN, SAIFUN, MELFUN, and CCFUN for which X is the day number in the calendar year (COUNT), and for COVFUN, for which X depends on LAI and SAI. COMM is placed in several subroutines and the main program by the $INSERT statement. On systems where such an insert is not possible, COMM can be substituted wherever $INSERT COMM appears.

Output

Although it may seem illogical, things will be clearer if we describe the output first, then the inputs.

The model runs on a water year basis, but there is provision for running only a chosen number of months after the beginning of the water year. All output for one water year is printed before any output for the next year. Water years must begin on the first day of a month. Examples of output are shown in Chapter 12.

The first section of output echoes the values read in from a parameter file. All these parameters except for EZDEP, UZDEP, LAIFUN, and SAIFUN remain constant through the run. The parameters EZDEP, UZDEP, LAIFUN, and SAIFUN can be changed during a run as described in the Input section.

Yearly output begins with a 5 character label, ANAME, that describes the year's data set. The next line shows the initial storages in the EZONE, UZONE, GWZONE, and SNOW at the beginning of the water year. These values have been either provided as input for the first water year or carried over from the last day of the preceding water year if the sequence of water years is continuing.

Daily output is optional. If selected, it prints one line for each day in the year. The line contains precipitation, the four components of streamflow and their sum, seepage loss, the five components of evaporation and their sum, and the five storages at the end of the day.

The SMOOTH subroutine calculates 3-day running means of measured and simulated streamflow to use in statistical and graphed output. If the option is selected, a line "RUNNING MEAN OPTION" is printed.

Optional statistical output provides statistical comparisons of daily measured and simulated streamflow for each month and for the year. Obviously it is only useful when measured streamflow is provided as input. Values for each month and the water year are given on separate lines. Each line includes the measured and simulated daily flows, the mean difference between measured and simulated daily flows, the standard deviation of the differences, the sum of squares of the differences, the Pearson correlation coefficient, the McCuen and Snyder (1975) correlation coefficient (see Chapter 5), the total measured flow, and the total simulated flow. Running mean values are used for all this output if that option is in effect.

The next output section contains monthly summaries of flows and storages and is not optional. The first part contains the amount of water in each storage at the end of the month and the average values of EZONE and UZONE for each month. The second part provides the monthly and annual total flows for all flow paths in the model as well as measured flow, precipitation, PE, and mean monthly temperature. Running means are not used in this output as indicated by the labels "RAW".

Two graphs or plots are available as optional output. Each plot has one line for each day in the year. The flow plot shows daily precipitation (dots), measured streamflow (asterisks), and simulated streamflow (plus signs). Running 3-day means are plotted if that option was selected. The three columns of data are daily rainfall, daily snowfall, and daily mean temperature. An asterisk is shown when there is snow on the ground. The storage plot contains EZONE (plus signs), UZONE (dots), and SNOW (asterisks). The scale for UZONE should be multiplied by the scale factor given at the beginning of the graph. The data columns are identical to those in the first graph.

Input

BROOK2 is designed for interactive and disk oriented systems whereas the original BROOK was designed for batch processing of cards. The option in the original BROOK of running several sets of parameters at a time does not exist in BROOK2.

BROOK2 begins by asking for the filenames and Fortran unit numbers of a parameter file, a data file, and an output file. Specifying unit numbers allows the unit number for a terminal to be assigned if desired. The program then asks for the number of water years to be run. If the response is 1 then the program asks for a number of months to be run. Response must be 12 to run a full year but may be less to run part of a year. If more than one year is desired the run must be for a whole number of water years. The program will stop if the end of the data file is reached prematurely.

The program then asks about the optional output desired. Responses must be either T if the option is desired or F if the option is not wanted. The questions ask respectively about daily output, statistical output, running 3-day mean, flow plot, and storage plot. Futher operation of the program is automatic.

The parameter file in BROOK2 differs from the original BROOK in omitting the output options now specified interactively, and making COVFUN, MELFUN, and CCFUN input instead of BLOCK DATA. The file must be ordered as follows, with values on each line separated by a comma or blanks:

- Line 1 - LAT, SLOPE, ASPECT
    - LAT - latitude, degrees
    - SLOPE - watershed slope, degrees
    - ASPECT - watershed aspect, degrees from north through east
- Line 2 - INC, ISCSNO, MT, CCMAX, RSF, GRDMLT
    - INC - rain interception parameter
    - ISCSNO - snow interception parameter
    - MT - number of preceding days over which cold content of snow is accumulated
    - CCMAX - maximum cold content per mm of snow water content
    - RSF - rain-snow separation point, °C
    - GRDMLT - rate of groundmelt of snowpack, mm/day
- Line 3 - PAC, PC, IMPERV
    - PAC - source area coefficient
    - PC - source area exponent
    - IMPERV - impervious fraction of watershed
- Line 4 - CT, CE, PEC
    - CT - transpiration availability parameter
    - CE - soil evaporation availability parameter
    - PEC - multiplying factor for PE
- Line 5 - EZDEP, UZDEP, EVDEP, EZ15
    - EZDEP - thickness of root zone, mm
    - UZDEP - thickness of unsaturated zone below root zone, mm
    - EVDEP - thickness of zone of evaporation from soil surface, mm
    - EZ15 - fractional water content in EZONE at lower limit of available water, mm/mm
- Line 6 - KEINT, KESLP, KUINT, KUSLP
    - KEINT - coefficient for EZONE conductivity function, mm/day
    - KESLP - exponent for EZONE conductivity function
    - KUINT - coefficient for UZONE conductivity function, mm/day
    - KUSLP - exponent for UZONE conductivity function
- Line 7 - DRNC, GSC, GSP
    - DRNC - fraction of UZONE drainage to groundwater
    - GSC - fraction of GWZONE becoming seepage, day^{-1}
    - GSP - fraction of GWZONE becoming streamflow, day^{-1}
- Line 8 - COVFUN (3 pairs of values)
    - adjustment to degree day factor for LAI and SAI
- Line 9 - MELFUN (3 pairs of values)
    - degree day factor as function of date
- Line 10 - CCFUN (3 pairs of values)
    - cold content adjustment as function of date
- Line 11 - LAIFUN (9 pairs of values)
    - LAI as a function of day number of calendar year

Line 12 - SAIFUN (6 pairs of values)
SAI as a function of day number of calendar year

MELFUN, CCFUN, LAIFUN, and SAIFUN must have 1 as the day number of the first pair and 366 as the day number of a later pair. Day numbers must be in increasing order. Unneeded pairs must be put in as pairs of zeros. Linear interpolation is used between points.

Line 13 - YMIN1, YMAX1, YMIN2, YMAX2, DIV
YMIN1 - Minimum ordinate value for flow graph, mm
YMAX1 - Maximum ordinate value for flow graph, mm
YMIN2 - Minimum ordinate value for storage graph, mm
YMAX2 - Maximum ordinate value for storage graph, mm
DIV - Value by which UZONE is divided before graphing

Line 14 - EZONE, UZONE, GWZONE, SNOW, INTSNO
EZONE - Initial value of EZONE, mm
UZONE - Initial value of UZONE, mm
GWZONE - Initial value of GWZONE, mm
SNOW - Initial value of SNOW, mm
INTSNO - Initial value of INTSNO, mm

Lines 15 through 17 may be omitted if no parameters are to change through the run. Or they can be repeated as often as desired to make changes during the run.

Line 15 - CHWYR, CHCOUNT, CHEZDEP, CHUZDEP
CHWYR - The number of the water year in the run when the change is to be made, e.g. 1, 2, etc.
CHCOUNT - The day number of the calendar year on which the change is to be made.
CHEZDEP - New value of EZDEP
CHUZDEP - New value of UZDEP
To maintain water balance the sum of EZDEP and UZDEP must remain constant through the run.

Line 16 - CHLAIFUN - New LAIFUN (9 pairs of values).

Line 17 - CHSAIFUN - New SAIFUN (6 pairs of values).

The data file in BROOK2 requires the following lines as a minimum in order to run.

Line 1 - 'ANAME', N, MS, MBEG, YBEG
ANAME - 5 character label for the water year, in single quotes
N - number of days in the water year, 365 or 366
MS - T if measured streamflow data included, otherwise F
MBEG - number of month with which data begins, i.e. first month in water year. Must be the same for all years of data.
YBEG - year in which data begins, 4 digits

Lines 2-28 - PPT

PPT - daily precipitation in mm, 14 values per line, except on last line. Format (14F5.1).

Lines 29-55 - TMP

TMP - daily mean temperature in °C, 14 values per line, except on last line. Format (14F5.1).

Lines 56-82 - MSF

MSF - daily measured streamflow in mm, 14 values per line, except on last line. Format (14F5.1). If omitted, MS must be F.

The file may continue with as many additional years of data as desired. Line 1 must be the first line of each year's data.

The format of the data file can be modified easily by the user by changing the subroutine DATARD.

CHAPTER 9

Variable names are now defined in the program listing (Chapter 10). Variables in common are defined only in COMM. Variables used more locally are defined in the routine that first uses them.

CHAPTER 10. PROGRAM LISTING

```
C
C ***************
C
C     COMMON FILE
C        THIS FILE IS INSERTED AT COMPILE TIME INTO MOST SUBROUTINES AND MAIN.
C
      CHARACTER*5 ANAME          /* 5 CHARACTER LABEL FOR WATER YEAR DATA
      REAL        ASPECT         /* ASPECT OF WATERSHED FROM N THROUGH E, DEGREES
      CHARACTER*3 BMONTH (12)    /* NAMES OF MONTHS FOR CALENDAR YEAR
      REAL        CC (450)       /* COLD CONTENT
      REAL        CCFUN (6)      /* COLD CONTENT ADJUSTMENT BY DATE
      REAL        CCMAX          /* MAX. COLD CONTENT PER UNIT SNOW STORAGE
      REAL        CE             /* EVAPORATION AVAILABILITY PARAMETER
      LOGICAL     CHANGES        /* TRUE IF CHANGES TO BE MADE TO LAI,SAI,EZDEP,UZDEP
                                    DURING RUN
      CHARACTER*3 CMONTH (12)    /* NAMES OF MONTHS FOR WATER YEAR
      REAL        COUNT          /* NUMBER OF DAY FOR CALENDAR YEAR
      REAL        COVFUN (6)     /* ADJUSTMENT TO DEGREE DAY FACTOR FOR LAI AND SAI
      REAL        CT             /* TRANSPIRATION AVAILABILITY PARAMETER
      INTEGER     DAYCT (12)     /* NUMBER OF FIRST DAY OF MONTH FOR CALENDAR YEAR
      REAL        DIV            /* DIVISOR FOR DECREASING UZONE SCALING IN STORAGE PLOT
      REAL        DRNC           /* FRACTION OF UDRAIN GOING TO GWZONE
      REAL        EDRAIN         /* DRAINAGE FROM EZONE
      REAL        EVDEP          /* THICKNESS OF ZONE OF EVAPORATION FROM SOIL SURFACE
      REAL        EVW            /* TOTAL EVAPORABLE WATER
      REAL        EVWMAX         /* EVW AT HYDRAULIC CONDUCTIVITY OF 2 MM/DAY
      REAL        EZDEP          /* THICKNESS OF ROOT ZONE
      REAL        EZONE          /* WATER STORAGE IN ROOT ZONE
      REAL        EZONE1 (366)   /* EZONE AT END OF DAY BY DATE
      REAL        EZ15           /* LOWER LIMIT OF AVAILABLE WATER IN EZONE
      REAL        GRDMLT         /* RATE OF GROUNDMELT OF SNOWPACK
      REAL        GSC            /* FRACTION OF GWZONE GOING TO STREAMFLOW
      REAL        GSEEP          /* SEEPAGE LOSS FROM GROUNDWATER
      REAL        GSP            /* FRACTION OF GWZONE GOING TO SEEPAGE
      REAL        GWFLO          /* GROUNDWATER FLOW
      REAL        GWZONE         /* GROUNDWATER STORAGE
      INTEGER     IC             /* WATER YEAR COUNTER
      REAL        IMPERV         /* IMPERVIOUS FRACTION OF WATERSHED
      REAL        INC            /* RAIN INTERCEPTION PARAMETER
      REAL        INFIL          /* RAIN INFILTRATION
      REAL        INTER          /* RAIN INTERCEPTION
      REAL        INTFLO         /* INTERFLOW FROM UZONE
      REAL        INTSNO         /* INTERCEPTED SNOW STORAGE
      REAL        INTVAP         /* EVAPORATION OF INTERCEPTED SNOW
      LOGICAL     IOD            /* DAILY OUTPUT IF TRUE
      LOGICAL     IOS            /* STATISTICS OUTPUT IF TRUE
      LOGICAL     IOSM           /* RUNNING MEAN STATISTICS IF TRUE
      LOGICAL     IPF            /* TRUE IF FLOW PLOT WANTED
      LOGICAL     IPS            /* TRUE IF STORAGE PLOT WANTED
      REAL        ISCSNO         /* SNOW INTERCEPTION PARAMETER
      REAL        KEINT          /* COEFFICIENT FOR EZONE CONDUCTIVITY FUNCTION
```

```
REAL        KESLP          /* EXPONENT FOR EZONE CONDUCTIVITY FUNCTION
REAL        KUINT          /* COEFFICIENT FOR UZONE CONDUCTIVITY FUNCTION
REAL        KUSLP          /* EXPONENT FOR UZONE CONDUCTIVITY FUNCTION
REAL        LAI            /* LEAF AREA INDEX
REAL        LAIFUN (18)    /* LAI AS FUNCTION OF DATE
REAL        LAT            /* LATITUDE OF WATERSHED
INTEGER     MBEG           /* NUMBER OF FIRST MONTH IN WATER YEAR
INTEGER     ME             /* DAY COUNTER FOR WATER YEAR
REAL        MELFUN (6)     /* DEGREE DAY FACTOR AS FUNCTION OF DATE
REAL        MESFLO         /* MEASURED STREAMFLOW FOR DATE
LOGICAL     MS             /* TRUE IF MEASURED FLOW IS INPUT
REAL        MSF (366)      /* DAILY MEASURED FLOW
INTEGER     MT             /* NUMBER OF PRECEDING DAYS OVER WHICH COLD CONTENT
                              ACCUMULATED
INTEGER     N              /* NUMBER OF DAYS IN WATER YEAR
INTEGER     ND (12)        /* NUMBER OF DAYS IN MONTH FOR WATER YEAR
INTEGER     NDAY (12)      /* NUMBER OF DAYS IN MONTH FOR CALENDAR YEAR
REAL        NETRAN         /* NET RAINFALL
INTEGER     NM             /* DAY COUNTER FOR MONTH
INTEGER     NMO            /* 12 UNLESS NUMBER OF MONTHS TO BE RUN IS LESS
INTEGER     NN             /* MONTH COUNTER FOR WATER YEAR
REAL        NRAIN          /* REFREEZING RAIN IN SNOWPACK
INTEGER     NWYRS          /* NUMBER OF WATER YEARS
REAL        PAC            /* SOURCE AREA COEFFICIENT
REAL        PC             /* SOURCE AREA EXPONENT
REAL        PE             /* POTENTIAL EVAPORATION
REAL        PEC            /* MULTIPLYING FACTOR FOR PE
REAL        PPT (366)      /* DAILY PRECIPITATION
REAL        PRECIP         /* PRECIPITATION FOR THE DAY
REAL        PRT            /* SOURCE AREA FRACTION
REAL        RAIN           /* RAIN FOR THE DAY
REAL        RAIN1 (366)    /* RAIN BY DATE
REAL        RSF            /* RAIN-SNOW SEPARATION POINT
REAL        SAI            /* STEM AREA INDEX
REAL        SAIFUN (12)    /* SAI AS A FUNCTION OF DATE
REAL        SEVAP          /* EVAPORATION FROM SOIL SURFACE
REAL        SINFIL         /* SNOWMELT INFILTRATION
REAL        SLOPE          /* SLOPE OF WATERSHED
REAL        SNO            /* SNOWFALL FOR THE DAY
REAL        SNO1 (366)     /* SNOWFALL BY DATE
REAL        SNOFAL         /* NET SNOWFALL
REAL        SNOFLO         /* SNOWMELT RUNOFF FROM SOURCE AREA
REAL        SNOINT         /* SNOW INTERCEPTION RATE
REAL        SNOMLT         /* SNOWMELT RATE
REAL        SNOVAP         /* EVAPORATION FROM SNOWPACK
REAL        SNOW           /* SNOWPACK STORAGE
REAL        SNOW1 (366)    /* SNOW-WATER CONTENT BY DATE
REAL        STRFLO (366)   /* SIMULATED DAILY STREAMFLOW
REAL        SURFLO         /* RAIN RUNOFF FROM SOURCE AREA
REAL        TEMP           /* MEAN TEMPERATURE FOR THE DAY
REAL        TMP (366)      /* DAILY MEAN TEMPERATURE
REAL        TRANS          /* TRANSPIRATION
REAL        UDRAIN         /* DRAINAGE TO GWZONE
REAL        UZDEP          /* THICKNESS OF UNSATURATED ZONE BELOW
                              ROOT ZONE
```

```
      REAL        UZONE           /* UNSATURATED STORAGE BELOW ROOT ZONE
      REAL        UZONE1 (366)    /* UZONE AT END OF DAY BY DATE
      REAL        UZOUT           /* WATER MOVEMENT OUT OF UZONE
      INTEGER     YBEG            /* BEGINNING YEAR OF WATER YEAR
      REAL        YMAX1           /* MAXIMUM ORDINATE VALUE IN FLOW PLOT
      REAL        YMAX2           /* MAXIMUM ORDINATE VALUE IN STORAGE PLOT
      REAL        YMIN1           /* MINIMUM ORDINATE VALUE IN FLOW PLOT
      REAL        YMIN2           /* MINIMUM ORDINATE VALUE IN STORAGE PLOT
      COMMON PPT,TMP,MSF,STRFLO,
     *   SNOW1,SNO1,RAIN1,EZONE1,
     *   UZONE1,N,MBEG,ANAME,CC
      COMMON LAIFUN,MELFUN,CCFUN,COVFUN,SAIFUN
      COMMON BMONTH,NDAY,ND,CMONTH,DAYCT,
     *   ME,IC,NN,NM,NMO
      COMMON EZONE,PRT,COUNT,EDRAIN,SURFLO,SNOFLO,
     *   INTFLO,UDRAIN,UZOUT,INFIL,SINFIL,GWFLO,
     *   INTVAP,INTER,SNOVAP,TRANS,SEVAP,INTSNO,MESFLO,PRECIP,
     *   PE,SNOINT,SNOFAL,GSEEP,TEMP,SNO,RAIN,EZ15,IMPERV,EVW,
     *   EVWMAX,NWYRS,EVDEP
      COMMON ISCSNO,GRDMLT,PC,CT,
     *   EZDEP,UZDEP,DRNC,GSC,GSP,LAT,ASPECT,
     *   SLOPE,KEINT,KESLP,SNOMLT,NETRAN,KUINT,
     *   KUSLP,UZONE,SNOW,PAC,INC,CCMAX,RSF,MT,
     *   SAI,GWZONE,CE,PEC,IOD,IOS,IOSM,CHANGES,MS
      COMMON YMIN1,YMAX1,YMIN2,YMAX2,DIV,IPF,IPS
[redacted]

C
C ***************
C
      PROGRAM BROOK2
C THIS PROGRAM IS REWRITTEN IN ANSI STANDARD FORTRAN-77
C    FROM THE FORTRAN-66 VERSION IN UNH WRRC RES REP 19.
C    NON-STANDARD USAGE INCLUDES /* COMMENTS IN LINES.
C THE NEW PROGRAM PRODUCES THE SAME OUTPUT FROM THE SAME INPUT DATA,
C    BUT IT IS EASIER TO READ, EASIER TO MODIFY, AND HANDLES INPUT BETTER.
C THE NEW PROGRAM IS ALSO DESIGNED FOR TERMINAL AND DISK USE RATHER
C    THAN FOR BATCH CARD USE.
C
C REWRITTEN BY C.A.FEDERER IN SEPTEMBER,1983.
C
$INSERT COMM
      CHARACTER*12 DATNAME   /* FILE NAME OF INPUT DATA FILE
      CHARACTER*12 OUTNAME   /* FILE NAME OF OUTPUT FILE
      CHARACTER*12 PARNAME   /* FILE NAME OF PARAMETER FILE
      INTEGER      I        /* DO INDEX
      REAL         DT       /* TIME STEP, 1 DAY
      INTEGER      UD       /* UNIT NUMBER FOR INPUT DATA FILE
      INTEGER      UO       /* UNIT NUMBER FOR OUTPUT FILE
      INTEGER      UP       /* UNIT NUMBER FOR PARAMETER FILE
C
      INTRINSIC   REAL
      EXTERNAL DATARD,PARAMRD,CHNGERD,THEDAY,SMOOTH,
     *   SUMARR,STAT,PLOT1
```

```
      DATA BMONTH/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,3HAUG,
     *   3HSEP,3HOCT,3HNOV,3HDEC/
      DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA CC/450*0./
      DATA DAYCT/1,32,60,91,121,152,182,213,244,274,305,335/
C
C     OPEN DATA FILES
      PRINT*,'TYPE NAME OF INPUT DATA FILE IN QUOTES. MAX. OF 8 CHAR.',
     *   ' PLUS EXTENSION, THEN FORTRAN UNIT NUMBER'
      READ (1,*) DATNAME,UD
C          UNIT 1 IS EXPECTED TO BE A TERMINAL
      PRINT*,'TYPE NAME OF PARAMETER FILE IN QUOTES, THEN UNIT NUMBER'
      READ (1,*) PARNAME,UP
      PRINT*,'TYPE NAME OF OUTPUT FILE IN QUOTES, THEN UNIT NUMBER'
      READ (1,*) OUTNAME,UO
      OPEN (UD,FILE=DATNAME)
      OPEN (UO,FILE=OUTNAME)
      OPEN (UP,FILE=PARNAME)
C
C      INPUT RUN INFORMATION
      PRINT*,'NUMBER OF WATER YEARS TO BE RUN?'
      READ (1,*) NWYRS
      IF (NWYRS .EQ. 1) THEN
         PRINT*,'NUMBER OF MONTHS TO BE RUN?'
         READ (1,*) NMO
      ELSE
         NMO = 12
      ENDIF
      PRINT*,'DAILY OUTPUT WANTED? T OR F'
      READ (1,*) IOD
      PRINT*,'STATISTICAL OUTPUT WANTED? T OR F'
      READ (1,*) IOS
      PRINT*,'USE RUNNING THREE DAY MEAN? T OR F'
      READ (1,*) IOSM
      PRINT*,'FLOW PLOT WANTED? T OR F'
      READ (1,*) IPF
      PRINT*,'STORAGE PLOT WANTED? T OR F'
      READ (1,*) IPS
C
      DT=1.0
C        THERE IS NO PROVISION FOR DT NOT EQUAL TO ONE DAY
C
      CALL PARAMRD (UP,UO)
C        TO READ PARAMETERS
      CHANGES = .TRUE.
C        UNTIL NO MORE CHANGES CAN BE READ
      DO 5 IC = 1,NWYRS
C        BEGIN YEAR LOOP
         CALL DATARD (UP,UD,UO)
C           TO READ PRECIP, TEMP, AND MESFLO FOR THE YEAR
```

```
         DO 350 NN=1,NMO
C           BEGIN MONTH LOOP
            DO 340 NM=1,ND(NN)
C              BEGIN DAY LOOP
               ME=ME+1
               COUNT=COUNT+1.
               PRECIP=PPT(ME)/DT
               TEMP=TMP(ME)
               MESFLO=MSF(ME)
               IF (CHANGES) CALL CHNGERD(UP,UO)
               CALL THEDAY (DT)
               CALL SUMARR (UO,DT)
C              END OF DAY LOOP
  340       CONTINUE
            IF (COUNT-REAL(N).GE.-1.0)  COUNT=0.
C              FOR END OF CALENDAR YEAR
C           END OF MONTH LOOP
  350    CONTINUE
         NN=13
         IF (IOSM)  CALL SMOOTH (UO)
         IF (IOS)   CALL STAT (UO)
         CALL SUMARR (UO,DT)
         IF (IPF.OR.IPS)    CALL PLOT1 (UO)
         DO 355 I=1,MT+1
C           CARRY COLD CONTENT INTO NEXT YEAR
            CC(51-I) = CC(51-I+ME)
355      CONTINUE
C        END OF YEAR LOOP
5     CONTINUE
      END
C
C ******************
C
         SUBROUTINE PARAMRD (UP,UO)
C           TO READ A PARAMETER SET
C
$INSERT COMM
      INTEGER        I        /* DO INDEX
      INTEGER        UP       /* PARAMETER FILE UNIT
      INTEGER        UO       /* OUTPUT FILE UNIT
      INTRINSIC EXP,LOG
      READ (UP,*) LAT,SLOPE,ASPECT,
     *   INC,ISCSNO,MT,CCMAX,RSF,GRDMLT,
     *   PAC,PC,IMPERV,
     *   CT,CE,PEC,
     *   EZDEP,UZDEP,EVDEP,EZ15,
     *   KEINT,KESLP,KUINT,KUSLP,
     *   DRNC,GSC,GSP
      READ (UP,*) (COVFUN(I), I=1,6)
      READ (UP,*) (MELFUN(I), I=1,6)
      READ (UP,*) (CCFUN(I), I=1,6)
      READ (UP,*) (LAIFUN(I),I=1,18)
      READ (UP,*) (SAIFUN(I),I=1,12)
      READ (UP,*) YMIN1,YMAX1,YMIN2,YMAX2,DIV
      READ (UP,*) EZONE,UZONE,GWZONE,SNOW,INTSNO
```

```
      WRITE (UO,100) LAT,SLOPE,ASPECT,INC,ISCSNO,MT,CCMAX,RSF,GRDMLT,
     *   PAC,PC,IMPERV,CT,CE,PEC,EZDEP,UZDEP,EVDEP,EZ15,
     *   KEINT,KESLP,KUINT,KUSLP,DRNC,GSC,GSP
100   FORMAT (3X,/'LAT    ='F9.2,5X,'SLOPE ='F9.1,5X,'ASPECT=',F9.1//
     *   3X,'INC    ='F9.3,5X,'ISCSNO='F9.3,5X,'MT     ='I9  ,5X,
     *      'CCMAX ='F9.2,5X,'RSF   ='F9.2,5X,'GRDMLT='F9.2//
     *   3X,'PAC    ='F9.2,5X,'PC     ='E9.2,5X,'IMPERV='F9.3//
     *   3X,'CT     ='F9.2,5X,'CE     ='F9.2,5X,'PEC    ='F9.2//
     *   3X,'EZDEP ='F9.1,5X,'UZDEP ='F9.1,5X,'EVDEP ='F9.1,5X,
     *      'EZ15  ='F9.3//
     *   3X,'KEINT ='E9.3,5X,'KESLP ='F9.3,5X,'KUINT ='E9.3,5X,
     *      'KUSLP ='F9.3//
     *   3X,'DRNC  ='F9.3,5X,'GSC    ='F9.4,5X,'GSP    ='F9.4/)
      WRITE (UO,200) COVFUN,MELFUN,CCFUN,LAIFUN,SAIFUN
 200  FORMAT (3X,'COVFUN',5X,3(F6.1,F6.2)//
     *   3X,'MELFUN',5X,3(F6.0,F6.2)//
     *   3X,'CCFUN ',5X,3(F6.0,F6.2)//
     *   3X,'LAIFUN',5X,9(F6.0,F6.2)//
     *   3X,'SAIFUN',5X,6(F6.0,F6.2)//)
C
      EVWMAX=EVDEP*EXP(LOG(2./KEINT)/KESLP)
      EVW=EVWMAX
      RETURN
      END
C
C *******************
C
      SUBROUTINE DATARD (UP,UD,UO)
C        TO READ PRECIP, TEMP, AND MESFLO FOR ONE YEAR, AND TO INITIALIZE YEAR
C        THIS SUBROUTINE MAY BE MODIFIED TO READ DATA INTO PPT, TMP,
C        AND MSF ARRAYS FROM ANY FILE FORMATS.
C
$INSERT COMM
      INTEGER  J         /* DO INDEX
      LOGICAL  LEAP      /* T IF LEAP WATER YEAR
      INTEGER  STAT      /* 1 IF END OF FILE, -1 IF ERROR IN DATA
      INTEGER  UD        /* DATA FILE UNIT
      INTEGER  UO        /* OUTPUT FILE UNIT
      INTEGER  UP        /* PARAMETER FILE UNIT
      READ (UD,*,IOSTAT=STAT) ANAME,N,MS,MBEG,YBEG
      IF ((MOD(YBEG,4) .EQ. 0 .AND. MBEG .LE. 2) .OR.
     *   (MOD(YBEG,4) .EQ. 3 .AND. MBEG .GT. 2)) THEN
C        LEAP WATER YEAR
         LEAP = .TRUE.
      ELSE
         LEAP = .FALSE.
      ENDIF
      IF ((LEAP .AND. N .NE. 366) .OR.
     *   (.NOT.LEAP .AND. N .NE. 365)) STOP 'WRONG DAYS IN YEAR'
      IF (STAT .NE. 0) GO TO 50
      READ (UD,'(14F5.1)') (PPT(J),J=1,N)
      IF (STAT .NE. 0) GO TO 50
      READ (UD,'(14F5.1)') (TMP(J),J=1,N)
      IF (STAT .NE. 0) GO TO 50
```

```
      IF (MS) THEN
         READ (UD,'(14F5.1)') (MSF(J),J=1,N)
         IF (STAT .NE. 0) GO TO 50
      ELSE
         DO 40 J=1,N
            MSF(J) = 0.
40       CONTINUE
      ENDIF
50    IF (STAT .LT. 0) THEN
         CLOSE (UP)
         CLOSE (UO)
         CLOSE (UD)
         STOP 'END OF DATA FILE'
      ELSE IF (STAT .GT. 0) THEN
         CLOSE (UP)
         CLOSE (UO)
         CLOSE (UD)
         STOP 'ERROR IN DATA FILE'
      ENDIF
C
C     SET DAY COUNTERS, MONTH NAMES, AND DAYS IN MONTHS
      ME = 0
      COUNT=DAYCT(MBEG)-1
      IF (MBEG .GE. 3 .AND. MOD(YBEG,4) .EQ. 0) COUNT = COUNT + 1
      IF (LEAP) NDAY(2) = 29
      DO 80 NN=1,12
C        SETS MONTHS FOR WATER YEAR
         IF ((MBEG+NN-1) .LE. 12) THEN
            ND(NN) = NDAY(MBEG+NN-1)
            CMONTH(NN) = BMONTH(MBEG+NN-1)
         ELSE
            ND(NN) = NDAY(MBEG+NN-13)
            CMONTH(NN) = BMONTH(MBEG+NN-13)
         ENDIF
80    CONTINUE
C
C     WRITE INITIAL VALUES AND DAILY OUTPUT HEADER
      WRITE (UO,'(1H1,''DATA FILE''2X,A5/)') ANAME
      WRITE (UO,'(5X,''INITIAL STORAGE-'',A3,'' 1'',3X,''EZONE='',F8.1,
     *   3X,''UZONE='',F8.1,3X,''GWZONE='',F8.1,3X,''SNOW='',F8.1//)')
     *   BMONTH(MBEG),EZONE,UZONE,GWZONE,SNOW
      IF (IOD) WRITE (UO,'(6X'' PRECIP SURFLO SNOFLO INTFLO  GWFLO '',
     *   ''STRFLO  GSEEP INTVAP  INTER SNOVAP  SEVAP'',
     *   ''  TRANS   EVAP INTSNO   SNOW  EZONE  UZONE GWZONE'')')
      RETURN
      END
```

```
C
C ******************
C
      SUBROUTINE CHNGERD(UP,UO)
C        READ AND MAKE CHANGES TO LAIFUN,SAIFUN,EZDEP,UZDEP
C
$INSERT COMM
      REAL        CHEZDEP     /* NEW EZDEP
      REAL        CHLAIFUN(18)/* NEW LAIFUN
      REAL        CHSAIFUN(12)/* NEW SAIFUN
      INTEGER     CHWYR       /* YEAR NUMBER FOR NEXT CHANGES
      REAL        CHCOUNT     /* DAY NUMBER FOR NEXT CHANGES
      REAL        CHUZDEP     /* NEW UZDEP
      REAL        EZON1       /* NEW EZONE
      INTEGER     I           /* DO INDEX
      INTEGER     STAT        /* 1 IF NO MORE CHANGES
      INTEGER     UO          /* OUTPUT FILE UNIT
      INTEGER     UP          /* PARAMETER FILE UNIT
      REAL        UZON1       /* NEW UZONE
      SAVE
      IF (IC .EQ. 1 .AND. ME .EQ. 1) THEN
C        READ FIRST SET OF CHANGES
         READ (UP,*,IOSTAT=STAT) CHWYR,CHCOUNT,CHEZDEP,CHUZDEP
         IF (STAT .LT. 0) THEN
            CHANGES = .FALSE.
            CLOSE (UP)
            RETURN
         ELSE
            READ (UP,*) (CHLAIFUN(I),I=1,18)
            READ (UP,*) (CHSAIFUN(I),I=1,12)
            CHANGES = .TRUE.
         ENDIF
      ENDIF
C
      IF (IC .EQ. CHWYR .AND. COUNT .EQ. CHCOUNT) THEN
C        MAKE CHANGES
         IF (CHEZDEP.GT.EZDEP) THEN
C           INCREASING EZONE
            EZDEP=CHEZDEP
            UZON1=(UZONE/UZDEP)*CHUZDEP
            EZONE=EZONE+UZONE-UZON1
            UZONE=UZON1
            UZDEP=CHUZDEP
         ELSE
C           DECREASING EZONE
            UZDEP=CHUZDEP
            EZON1=(EZONE/EZDEP)*CHEZDEP
            UZONE=UZONE+EZONE-EZON1
            EZONE=EZON1
            EZDEP=CHEZDEP
         ENDIF
         DO 20 I = 1,18
            LAIFUN(I) = CHLAIFUN(I)
20       CONTINUE
```

```
         DO 25 I = 1,12
            SAIFUN(I) = CHSAIFUN(I)
25       CONTINUE
         WRITE (UO,'(''NEW VALUES AT YEAR'',I4,''  DAY'',F5.0/
     *      ''EZDEP ='',F7.2,''    UZDEP ='',F7.2,
     *      /3X,''LAIFUN'',5X,9(F6.0,F6.2)/
     *      3X,''SAIFUN'',5X,6(F6.0,F6.2)//)')
     *      IC,CHCOUNT,EZDEP,UZDEP,LAIFUN,SA1FUN
C        READ NEXT SET OF CHANGES
         READ (UP,*,IOSTAT=STAT) CHWYR,CHCOUNT,CHEZDEP,CHUZDEP
         IF (STAT .LT. 0) THEN
            CHANGES = .FALSE.
            CLOSE (UP)
            RETURN
         ELSE
            READ (UP,*) (CHLAIFUN(I),I=1,18)
            READ (UP,*) (CHSAIFUN(I),I=1,12)
            CHANGES = .TRUE.
         ENDIF
      ENDIF
      RETURN
      END
C
C **************
C
      SUBROUTINE THEDAY (DT)
C        CALCULATIONS FOR ONE DAY
$INSERT COMM
      REAL     DAYL           /* DAYLENGTH IN FRACTION OF 12 HOURS
      REAL     DT             /* TIME INTERVAL = 1 DAY
      REAL     EVWA           /* AVAILABLE EVAPORABLE WATER
      REAL     EZA            /* AVAILABLE WATER IN EZONE
      REAL     PEEV           /* POTENTIAL SOIL EVAPORATION
      REAL     PEIV           /* REMAINING POTENTIAL EVAP.
      REAL     RS             /* SLOPE-ASPECT CORRECTION FACTOR
      REAL     INTERP
      EXTERNAL    SOLAR,INTERP,POTET,RAINSNOW,SBINTER,SBSNOINT,
     *   SBINTVAP,SNOWMELT,FLOW,SBEVAP,SBTRANS,SBGSEEP,SBGWFLO,SBSNOVAP
      INTRINSIC MAX,MIN
C
      CALL SOLAR (SLOPE/57.2958,ASPECT/57.2958,LAT/57.2958,COUNT,RS,
     1      DAYL,ME)
      LAI = INTERP(COUNT,LAIFUN)
      LAI = MIN(LAI,4.)
      SAI = INTERP(COUNT,SAIFUN)
      SAI = MIN(SAI,2.)
C
      CALL POTET (DAYL,PE,PEC,TEMP)
C
      CALL RAINSNOW (PRECIP,RAIN,RSF,TEMP)
C        TO DETERMINE FRACTION OF PRECIP AS SNOW
C
      SNO = PRECIP-RAIN
```

```
C
      CALL SBINTER(INC,INTER,LAI,PE,RAIN,SAI)
C        TO CALCULATE RAIN INTERCEPTION
C
      NETRAN = RAIN-INTER
C
      CALL SBSNOINT (DT,INTSNO,ISCSNO,LAI,SAI,SNO,SNOINT)
C
      INTSNO = INTSNO + SNOINT*DT
      SNOFAL  =  SNO - SNOINT
      SNOW = SNOW + SNOFAL*DT
C
      CALL SBINTVAP(DT,INTSNO,PE,INTVAP)
C
      INTSNO = INTSNO-INTVAP*DT
      IF (INTSNO.LT.0.0001) INTSNO  =  0.
      PEIV = PE-INTVAP
C
      CALL SBSNOVAP (DT,LAI,PEIV,SAI,SNOVAP,SNOW,TEMP)
C
      SNOW = MAX(SNOW-SNOVAP*DT,0.)
      PEIV = (PEIV-SNOVAP)*RS
C
      CALL SNOWMELT (CC,CCFUN,CCMAX,COUNT,COVFUN,DT,GRDMLT,
     *   LAI,ME,MELFUN,MT,NETRAN,RS,SAI,SNOMLT,SNOW,TEMP)
C
      SNOW = MAX(SNOW-SNOMLT*DT,0.)
      IF (SNOW .LT. 0.0001) SNOW = 0.
C
      CALL FLOW (DT)
C        FOR SURFACE AND SUBSURFACE FLOWS
C
      EVW = MIN(EVW+SINFIL+INFIL, EVWMAX)
      EVWA = EVW-EZ15*EVDEP
C
      CALL SBEVAP (CE,DT,EVWA,LAI,PEEV,PEIV,SAI,SEVAP,SNOW)
C        FOR SOIL EVAPORATION
C
      EVW = EVW-SEVAP*DT
      PEIV = PEIV-SEVAP
      EZA = EZONE-EZ15*EZDEP
C
      CALL SBTRANS(CT,EZA,LAI,PEIV,TRANS)
C        FOR TRANSPIRATION
C
      EZONE = EZONE-(SEVAP+TRANS)*DT
C
      CALL SBGSEEP (GSC,GSEEP,GSP,GWZONE)
C        FOR SEEPAGE LOSS
C
      CALL SBGWFLO (GSC,GSP,GWFLO,GWZONE)
C        FOR GROUNDWATER FLOW
```

```
C
      GWZONE = GWZONE+UDRAIN-(GWFLO+GSEEP)*DT
      RETURN
      END
C
C *******************
C
        SUBROUTINE SOLAR (I,A,LO,DAY,F,DAYL,ME)
C
C    FROM SWIFT, L.W. 1976. ALGORITHM FOR SOLAR RASIATION ON MOUNTAIN
C    SLOPES. WATER RESOUR RES 12:108-112.
C    ALTERNATIVE ROUTINES FOR STEEP POLEWARD SLOPES ARE NOT INCLUDED.
C    ALL ANGLES IN RADIANS
        REAL L1,L2,I,LO
        REAL V,W,X,Y
        REAL A,DAY,F,DAYL
        REAL D,E,T,T0,T1,T2,T3,T6,T7,R3,R4
        REAL FUNC1,FUNC2,FUNC3
        INTEGER ME
        INTRINSIC COS,ACOS,SIN,ASIN,ATAN
        SAVE L1,L2
        FUNC1 (W,X,Y)=W-X*COS((DAY+Y)*0.986/57.2958)
        FUNC2 (Y)=ACOS(-(SIN(Y)/COS(Y))*(SIN(D)/COS(D)))
        FUNC3 (V,W,X,Y)=(SIN(D)*SIN(W)*(X-Y)*3.8197+COS(D)*COS(W)*
     *  (SIN(X+V)-SIN(Y+V))*12./3.14159)
C
         IF (ME .LE. 1) THEN
           L1=ASIN(COS(I)*SIN(LO)+SIN(I)*COS(LO)*COS(A))
           L2=ATAN((SIN(I)*SIN(A))/(COS(I)*COS(LO)-SIN(I)*
     *     SIN(LO)*COS(A)))
      ENDIF
        D=FUNC1 (.00698,.40666,10.0)
        E=FUNC1 (1.0,0.0167,-3.0)
        T=FUNC2 (L1)
        T7=T-L2
        T6=-T-L2
        T=FUNC2 (LO)
        T1=T
        T0=-T
        DAYL=T/1.5708
        T3=T7
        IF (T7.GT.T1) T3=T1
        T2=T6
        IF (T6.LT.T0) T2=T0
        R4=FUNC3 (L2,L1,T3,T2)
        R3=FUNC3 (0.,LO,T1,T0)
        F=R4/R3
        RETURN
        END
```

```
C
C ******************
C
      SUBROUTINE POTET (DAYL,PE,PEC,TEMP)
C        CALCULATES HAMON POTENTIAL EVAPOTRANSPIRATION
      REAL     ESAT    /* SATURATED VAPOR PRESSURE AT TEMP, KPA
      REAL     RHOSAT  /* SATURATED VAPOR DENSITY AT TEMP, G H2O/M3
      REAL     TEMP,PE,PEC,DAYL
      INTRINSIC EXP
C
      ESAT=6.108*EXP(17.26938 82*TEMP/(TEMP+237.3))
C                                          YES   237.3 IS CORRECT HERE
      RHOSAT=216.7*ESAT/(TEMP+273.3)
      PE=PEC*0.1651*DAYL*RHOSAT
      RETURN
      END
C
C ****************
C
      SUBROUTINE RAINSNOW (PRECIP,RAIN,RSF,TEMP)
C        SEPARATES RAIN FROM SNOW
      REAL      PRECIP,RAIN,RSF,TEMP
C
      IF (TEMP .GE. RSF) THEN
         RAIN = PRECIP
      ELSE
         RAIN = 0.
      ENDIF
      RETURN
      END
C
C ****************
C
      SUBROUTINE SBINTER (INC,INTER,LAI,PE,RAIN,SAI)
C        CALCULATES INTERCEPTION OF RAIN
      REAL INC,INTER,LAI,PE,RAIN,SAI
      INTRINSIC MIN
C
      INTER = (0.67*LAI/4. + 0.33*SAI/2.) * INC * MIN(PE,RAIN)
      RETURN
      END
C
C ****************
C
      SUBROUTINE SBSNOINT (DT,INTSNO,ISCSNO,LAI,SAI,SNO,SNOINT)
C        CALCULATES INTERCEPTION OF SNOW
      REAL DT,INTSNO,ISCSNO,LAI,SAI,SNO,SNOINT
      REAL   INTSN1       /* MAX. ALLOWABLE INTERCEPTED SNOW
      INTRINSIC MIN
C
      INTSN1 = (LAI+SAI/2.)*0.8333
      SNOINT = SNO * ISCSNO * (LAI+SAI/2.)
```

```
      IF ((INTSNO + SNOINT*DT) .GT. INTSN1) THEN
C        CAPACITY EXCEEDED
         SNOINT = SNOINT - (INTSNO + SNOINT*DT - INTSN1)/DT
      ENDIF
      RETURN
      END
C
C ********************
C
      SUBROUTINE SBINTVAP(DT,INTSNO,PE,INTVAP)
C        CALCULATES EVAPORATION OF INTERCEPTED SNOW
      REAL DT,INTSNO,PE,INTVAP
      INTRINSIC MIN
C
      INTVAP = MIN(INTSNO/DT,PE)
      RETURN
      END
C
C ****************
C
      SUBROUTINE SBSNOVAP (DT,LAI,PEIV,SAI,SNOVAP,SNOW,TEMP)
C        CALCULATES EVAPORATION FROM SNOWPACK
      REAL DT,LAI,PEIV,SAI,SNOVAP,SNOW,TEMP
      INTRINSIC MIN,ABS
C
      IF (TEMP .GT. 0.) THEN
         SNOVAP = 0.
      ELSE
         SNOVAP=MIN(SNOW/DT,PEIV/2.*ABS(LAI/4.-1.)**2*(1.-0.125*SAI))
      ENDIF
      RETURN
      END
C
C ****************
C
      SUBROUTINE SNOWMELT (CC,CCFUN,CCMAX,COUNT,COVFUN,DT,GRDMLT,
     *   LAI,ME,MELFUN,MT,NETRAN,RS,SAI,SNOMLT,SNOW,TEMP)
C        CALCULATES SNOW MELT
      REAL CCMAX,COUNT,DT,GRDMLT,LAI,NETRAN,RS,SAI,
     *   SNOMLT,SNOW,TEMP
      INTEGER ME,MT
      REAL CC(450),CCFUN(6),COVFUN(6),MELFUN(6)
      REAL    CLDCON  /* COLD CONTENT OF SNOWPACK, NORMALLY NEGATIVE
      INTEGER I       /* DO INDEX
      REAL    MELT    /* TEMPERATURE CONTRIBUTION TO SNOWMELT OR COLD CONTENT
      REAL    NRAIN   /* RAIN HELD IN SNOWPACK
      LOGICAL RIPE    /* TRUE IF SNOWPACK IS RIPE
      REAL    INTERP
      EXTERNAL INTERP
      INTRINSIC MIN,MAX
```

```
C
      IF (SNOW .LE. 0.) THEN
         SNOMLT = 0.
         CC(ME) = 0.
      ELSE
C        CALCULATE COLD CONTENT
         CLDCON = 0.
         DO 250 I=ME-MT+50,ME-1+50
            CLDCON = CLDCON + CC(I)
            IF (CLDCON .GT. 0.) CLDCON = 0.
  250    CONTINUE
C        TEMPERATURE CONTRIBUTION
         IF (TEMP .GT. 0.) THEN
            MELT = INTERP(LAI/4. + SAI/2., COVFUN)*
     *         INTERP(COUNT,MELFUN) * RS * TEMP
         ELSE
            MELT = INTERP(COUNT,CCFUN) * TEMP
         ENDIF
         CLDCON = MAX(CLDCON+MELT*DT,-CCMAX*SNOW)
         IF (CLDCON .GE. 0.) THEN
            RIPE = .TRUE.
            NRAIN = 0.
         ELSE IF (NETRAN .LE. 0.) THEN
            RIPE = .FALSE.
            NRAIN = 0.
         ELSE
C           RAIN ON UNRIPE SNOW
            NRAIN = MIN(NETRAN, -CLDCON/DT)
            NETRAN = NETRAN - NRAIN
            CLDCON = CLDCON + NRAIN*DT
            SNOW = SNOW + NRAIN*DT
            IF (CLDCON .GE. 0.) THEN
               RIPE = .TRUE.
            ELSE
               RIPE = .FALSE.
            ENDIF
         ENDIF
         IF (RIPE) THEN
            SNOMLT = MIN(SNOW/DT, GRDMLT + CLDCON/DT)
            CC(ME+50) = 999.
         ELSE
            SNOMLT = MIN(SNOW/DT, GRDMLT)
            CC(ME+50) = (MELT + NRAIN) * DT
         ENDIF
      ENDIF
      RETURN
      END
```

```
C
C *************
C
      SUBROUTINE SBEVAP (CE,DT,EVWA,LAI,PEEV,PEIV,SAI,SEVAP,SNOW)
C        CALCULATES SOIL EVAPORATION
      REAL CE,DT,EVWA,LAI,PEEV,PEIV,SAI,SEVAP,SNOW
      INTRINSIC ABS,MIN
C
      PEEV = PEIV*(ABS(LAI-4.)**2/16.84+.05)*(1.-0.3*SAI)
      IF (SNOW .GT. 0.) THEN
         SEVAP = 0.
      ELSE
         IF (CE*PEEV-EVWA .GT. 0.) THEN
            SEVAP = MIN(EVWA/DT,EVWA/CE)
         ELSE
            SEVAP = MIN(EVWA/DT,PEEV)
         ENDIF
      ENDIF
      RETURN
      END
C
C **************
C
      SUBROUTINE SBTRANS (CT,EZA,LAI,PEIV,TRANS)
C        CALCULATES ACTUAL FROM POTENTIAL TRANSPIRATION
      REAL CT,EZA,LAI,PEIV,TRANS
      REAL    LAIF    /* FUNCTION OF LAI
      INTRINSIC ABS
C
      LAIF = 1.-ABS(LAI/4.-1.)**2
      IF (CT*PEIV-EZA .GT. 0.) THEN
         TRANS = EZA*LAIF/CT
      ELSE
         TRANS = PEIV*LAIF
      ENDIF
      RETURN
      END
C
C ***************
C
      SUBROUTINE SBGSEEP (GSC,GSEEP,GSP,GWZONE)
C        CALCULATES SEEPAGE LOSS
      REAL GSC,GSEEP,GSP,GWZONE
C
      GSEEP=GWZONE*GSC*GSP
      RETURN
      END
```

```
C
C ****************
C
      SUBROUTINE SBGWFLO (GSC,GSP,GWFLO,GWZONE)
C        CALCULATES GROUNDWATER FLOW
      REAL      GSC,GSP,GWFLO,GWZONE
C
      GWFLO=GWZONE*(1.-GSP)*GSC
      RETURN
      END
C
C ***********************
C
      SUBROUTINE FLOW(DT)
C        WATER MOVEMENT THROUGH SOIL
C
$INSERT COMM
      REAL        DT          /* 1 DAY TIME STEP
      REAL        EF          /* FIELD CAPACITY OF EZONE, AT K = 2 MM/DAY
      REAL        EZ          /* DUMMY VARIABLE
      REAL        EZIN        /* ESTIMATE OF FLOW INTO EZONE
      REAL        F           /* RECIPROCAL OF ALLOWABLE CHANGE IN INTERVAL
      REAL        H           /* TIME STEP
      REAL        HEDRAIN     /* INTERVAL EDRAIN
      REAL        HINFIL      /* INTERVAL INFIL
      REAL        HINTFLO     /* INTERVAL INTFLO
      REAL        HSINFIL     /* INTERVAL SINFIL
      REAL        HSNOFLO     /* INTERVAL SNOFLO
      REAL        HSURFLO     /* INTERVAL SURFLO
      REAL        HUDRAIN     /* INTERVAL UDRAIN
      REAL        HUZOUT      /* INTERVAL UZOUT
      INTEGER     J           /* DO INDEX
      REAL        KE          /* ESTIMATED EZONE DRAINAGE
      REAL        KEMAX       /* MAXIMUM EXPECTED DRAINAGE FROM EZONE
      REAL        K1          /* KEMAX WHERE SLOPE = 1
      REAL        KU          /* ESTIMATED UZONE DRAINAGE
      INTEGER     NIT         /* NUMBER OF ITERATIONS
      REAL        UF          /* FIELD CAPACITY OF UZONE, AT K = 2 MM/DAY
      REAL        UZ          /* DUMMY VARIABLE
      REAL        UZIN        /* ESTIMATE OF FLOW INTO UZONE
C
      INTRINSIC   MIN,MAX,REAL,EXP
      PARAMETER   (F = 20.)   /* 1/5%
C     ARITHMETIC STATEMENT FUNCTIONS
      KE(EZ)=KEINT*(EZ/EZDEP)**KESLP
      KU(UZ)=KUINT*(UZ/UZDEP)**KUSLP
C
C  ESTIMATION OF NUMBER OF ITERATIONS NEEDED FOR DAY
C
      EF = EZDEP*(2.0/KEINT)**(1./KESLP)
      UF = UZDEP*(2.0/KUINT)**(1./KUSLP)
```

```
C     ESTIMATE OF EZIN
      EZIN = NETRAN+SNOMLT
C     ESTIMATE OF UZIN
      K1 = (EZONE+EZIN*DT)/(KESLP*DT)
      KEMAX = KE(EZONE+EZIN*DT)
      IF (KEMAX .LT. K1) THEN
         UZIN = KEMAX
      ELSE IF (KEMAX .LT. EZIN) THEN
         UZIN = KEMAX
      ELSE IF (K1 .GT. EZIN) THEN
         UZIN = K1
      ELSE
         UZIN = EZIN
      ENDIF
C     NUMBER OF ITERATIONS IN DAY
      IF (KEMAX .LT. 0.15 .AND. KU(UZONE+UZIN*DT) .LT. 0.15) THEN
         NIT = 2
      ELSE
         NIT = MAX (2.,
     *      F*EZIN/EF + 0.9,
     *      F*KE(EZONE)/EF + 0.9,
     *      F*UZIN/UF + 0.9,
     *      F*KU(UZONE)/UF + 0.9)
      ENDIF
C
      H = DT/REAL(NIT)
      EDRAIN = 0.
      UZOUT  = 0.
      INFIL  = 0.
      SINFIL = 0.
      SURFLO = 0.
      SNOFLO = 0.
      UDRAIN = 0.
      INTFLO = 0.
C
      DO 80 J=1,NIT
C
C        SOURCE AREA CONTRIBUTION
C
         PRT = PC*EXP(PAC*EZONE/EZDEP)+IMPERV
         PRT = MIN (PRT,1.)
         HSNOFLO = PRT*SNOMLT
         HSURFLO = PRT*NETRAN
         HSINFIL = SNOMLT -HSNOFLO
         HINFIL = NETRAN - HSURFLO
C
C        INTERFLOW
C
         EZONE = EZONE+(HSINFIL+HINFIL)*H
         HEDRAIN = KE(EZONE)
         HUZOUT = KU(UZONE)
         HUDRAIN = HUZOUT*DRNC
         HINTFLO = HUZOUT*(1.-DRNC)
```

```
C
C         NEW EZONE, UZONE
C
          EZONE = EZONE-HEDRAIN*H
          UZONE = UZONE+(HEDRAIN-HINTFLO-HUDRAIN)*H
C
C         SUMS FOR THE DAY
C
          EDRAIN = EDRAIN + HEDRAIN*H
          UZOUT = UZOUT + HUZOUT*H
          INFIL = INFIL + HINFIL*H
          SINFIL = SINFIL + HSINFIL*H
          SURFLO = SURFLO + HSURFLO*H
          SNOFLO = SNOFLO + HSNOFLO*H
          UDRAIN = UDRAIN + HUDRAIN*H
          INTFLO = INTFLO + HINTFLO*H
80    CONTINUE
      RETURN
      END
C
C ********************
C
      SUBROUTINE SUMARR (UO,DT)
C        DAILY OUTPUT AND MONTHLY AND ANNUAL SUMMARIES
C
$INSERT COMM
      INTEGER        I,J          /* DO INDEXES
      CHARACTER*10   LABEL(29)    /* ROW LABELS FOR MONTHLY OUTPUT, 29 LINES
      REAL           MSUM(12,29)  /* MONTHLY TOTALS, 12 MONTHS,29 LINES
      REAL           SUM(8:29)    /* ANNUAL TOTALS, LINES 8 TO 29
      REAL           DT           /* TIME STEP, 1 DAY
      REAL           EVAP         /* TOTAL EVAPORATION RATE
      INTEGER UO
      INTRINSIC REAL
      SAVE MSUM,LABEL,SUM
      DATA LABEL/'INTSNO,END','SNOW,END  ','EZONE,AV  ',
     * 'EZONE,END ','UZONE,AV  ','UZONE,END ','GWZONE,END',
     * 'MESFLO,RAW','SIMFLO,RAW','PRECIP    ','TRANSPIR. ',
     * 'SOIL EVAP.','SNOWVAP   ','RAIN INT. ','INTVAP    ',
     * 'TOT. EVAP.','PE        ','SNOWINT   ','SNOWFALL  ',
     * 'SNOWINFIL.','INFIL.    ','EDRAIN    ','INTERFLOW ',
     * 'UDRAIN    ','GRD. SEEP.','GRD. FLOW ','SURFLOW   ',
     * 'SNOWFLOW  ','AV. TEMP. '/
C
      IF (NN.LE.12) THEN
C        ACCUMULATION FOR MONTH
         IF (ME.EQ.1) THEN
C           INITIALIZE MSUM AND ANNUAL TEMPERATURE
            SUM(29) = 0.
            DO 3 I=1,29
            DO 3 J=1,12
               MSUM(J,I) = 0.
3           CONTINUE
         ENDIF
C
```

```
C     TOTAL EVAPORATION AND STREAMFLOW
C     DAILY VALUES INTO ARRAYS FOR YEAR
      EVAP = INTVAP + INTER + SNOVAP + TRANS + SEVAP
      STRFLO(ME) = (SURFLO + SNOFLO + INTFLO + GWFLO) * DT
      EZONE1(ME)=EZONE
      UZONE1(ME)=UZONE
      SNOW1(ME)=SNOW
      SNO1(ME)=SNO
      RAIN1(ME)=RAIN
C     SUM OVER MONTH
      MSUM(NN,1)=INTSNO
      MSUM(NN,2)=SNOW
      MSUM(NN,3)=MSUM(NN,3)+EZONE/REAL(ND(NN))
      MSUM(NN,4)=EZONE
      MSUM(NN,5)=MSUM(NN,5)+UZONE/REAL(ND(NN))
      MSUM(NN,6)=UZONE
      MSUM(NN,7)=GWZONE
      MSUM(NN,8)=MSUM(NN,8)+MESFLO
      MSUM(NN,9)=MSUM(NN,9)+STRFLO(ME)
      MSUM(NN,10)=MSUM(NN,10)+PRECIP
      MSUM(NN,11)=MSUM(NN,11)+TRANS*DT
      MSUM(NN,12)=MSUM(NN,12)+SEVAP*DT
      MSUM(NN,13)=MSUM(NN,13)+SNOVAP*DT
      MSUM(NN,14)=MSUM(NN,14)+INTER*DT
      MSUM(NN,15)=MSUM(NN,15)+INTVAP*DT
      MSUM(NN,16)=MSUM(NN,16)+EVAP*DT
      MSUM(NN,17)=MSUM(NN,17)+PE*DT
      MSUM(NN,18)=MSUM(NN,18)+SNOINT*DT
      MSUM(NN,19)=MSUM(NN,19)+SNOFAL*DT
      MSUM(NN,20)=MSUM(NN,20)+SINFIL
      MSUM(NN,21)=MSUM(NN,21)+INFIL
      MSUM(NN,22)=MSUM(NN,22)+EDRAIN
      MSUM(NN,23)=MSUM(NN,23)+INTFLO
      MSUM(NN,24)=MSUM(NN,24)+UDRAIN
      MSUM(NN,25)=MSUM(NN,25)+GSEEP*DT
      MSUM(NN,26)=MSUM(NN,26)+GWFLO*DT
      MSUM(NN,27)=MSUM(NN,27)+SURFLO
      MSUM(NN,28)=MSUM(NN,28)+SNOFLO
      MSUM(NN,29)=MSUM(NN,29)+TEMP/REAL(ND(NN))
      SUM(29)=SUM(29) + TEMP/REAL(N)
C
      IF (IOD) THEN
C        DAILY OUTPUT
         WRITE (UO,'(1X,A3,I2,18F7.2)') CMONTH(NN),NM,PRECIP,
     *   SURFLO,SNOFLO,INTFLO,GWFLO,STRFLO(ME),GSEEP,INTVAP,INTER,
     *   SNOVAP,SEVAP,TRANS,EVAP,INTSNO,SNOW,EZONE,UZONE,GWZONE
      ENDIF
      RETURN
```

```
      ELSE
C        ANNUAL SUMMARY
         DO 20 I=8,28
            SUM(I)=0.
            DO 10 J=1,12
               SUM(I)=SUM(I)+MSUM(J,I)
10          CONTINUE
20       CONTINUE
         WRITE (UO,'(''1'',17X,12(A3,5X),''TOTAL '')')
     *     (CMONTH(I),I=1,12)
         WRITE (UO,'(7(/,2X,A10,2X,12F8.2))') (LABEL(I),
     *      (MSUM(J,I),J=1,12),I=1,7)
         WRITE (UO,'(/,22(/,2X,A10,2X,12F8.2,F10.2))')
     1      (LABEL(I),(MSUM(J,I),J=1,12),SUM(I),I=8,29)
         RETURN
      ENDIF
      END
C
C ****************
C
      SUBROUTINE SMOOTH (UO)
C        FOR THREE DAY RUNNING MEAN
C
$INSERT COMM
      INTEGER     I,K             /* DO INDEXES
      INTEGER     UO              /* OUTPUT FILE UNIT
      REAL        SUM1,SUM2       /* TEMP ORARY SUMS
      REAL RMNMSF(366)            /* RUNNING MEAN MEASURED STREAMFLOW
      REAL RMNSTR(366)            /* RUNNING MEAN SIMULATED STREAMFLOW
C
      WRITE (UO,*) '     RUNNING MEAN OPTION'
      RMNMSF(1)=(MSF(1)+MSF(2))/2
      RMNMSF(2)=(MSF(1)+MSF(2)+MSF(3))/3
      RMNMSF(365)=(MSF(364)+MSF(365))/2
      RMNMSF(366)=(MSF(365)+MSF(366))/2
      RMNSTR(1)=(STRFLO(1)+STRFLO(2))/2
      RMNSTR(2)=(STRFLO(1)+STRFLO(2)+STRFLO(3))/3
      RMNSTR(365)=(STRFLO(364)+STRFLO(365))/2
      RMNSTR(366)=(STRFLO(365)+STRFLO(366))/2
C
      DO 20 I=2,N-2
         SUM1=0.
         SUM2=0.
         DO 10 K=I,I+2
           SUM1=SUM1+MSF(K)
           SUM2=SUM2+STRFLO(K)
 10      CONTINUE
         RMNMSF(I+1)=SUM1/3.
         RMNSTR(I+1)=SUM2/3.
 20   CONTINUE
```

```
      DO 30 I=1,N
         MSF(I)=RMNMSF(I)
         STRFLO(I)=RMNSTR(I)
30    CONTINUE
      RETURN
      END
C
C ******************
C
      SUBROUTINE STAT (UO)
C        STATISTICAL CALCULATIONS ON STREAMFLOW
C
$INSERT COMM
      REAL         AB           /* MCCUEN-SNYDER CORRECTION
      CHARACTER*3  AMONTH       /* NAME OF MONTH
      REAL         B            /* SUM OF CROSS PRODUCTS
      REAL         CORR         /* MCCUEN-SNYDER CORRELATION COEFFICIENT
      REAL         DIFF         /* MEAN DIFFERENCE
      REAL         F            /* SUM OF SQUARES OF DIFFERENCE
      REAL         FMDAY        /* REAL VALUE FOR DAYS IN MONTH
      INTEGER      I,M,MM       /* DO INDEXES
      INTEGER      MDAY         /* NUMBER OF DAYS IN MONTH OR YEAR
      INTEGER      N1           /* MONTH NUMBER
      REAL         R            /* PEARSON CORRELATION COEFFICIENT
      REAL         SDD          /* STANDARD DEVIATION OF DIFFERENCES
      INTEGER      UO           /* OUTPUT DEVICE NUMBER
      REAL         XBAR,YBAR    /* MEANS OF MEASURED AND SIMULATED FLOWS
      REAL         XSUM,YSUM    /* SUMS OF MEASURED AND SIMULATED FLOWS
      REAL         XSUM2,YSUM2  /* SQUARES OF SUMS
      REAL         X2SUM,Y2SUM  /* SUMS OF SQUARES
C
      INTRINSIC ABS,REAL,SQRT
C
      ME=0
      N1=NMO
      WRITE (UO,100)
 100  FORMAT (//' MONTH            MEASURED  SIMULATED   MEAN',
     * '     ST. DEV.  SM. SQ.   CORR.     MOD CORR  ',
     * 'TOTAL     TOTAL',/17X,'MEAN        MEAN          DIFF.   ',
     * 'OF DIFF.  OF DIFF.  COEF.      COEF.    MEAS FLOW',
     * '   SIM FLOW'/)
      DO 30 MM=1,2
C        MM=1 FOR INDIVIDUAL MONTHS, 2 FOR WHOLE YEAR
         DO 20 M=1,N1
            MDAY=ND(M)
            IF (MM.EQ.2) MDAY=N
            AMONTH=CMONTH(M)
            XSUM=0.
            YSUM=0.
            X2SUM=0.
            Y2SUM=0.
            B=0.
            F=0.
            FMDAY=REAL(MDAY)
```

```
            DO 10 I=1,MDAY
               ME=ME+1
               XSUM=XSUM+MSF(ME)
               YSUM=YSUM+STRFLO(ME)
               B=B+MSF(ME)*STRFLO(ME)
               F=F+ABS(MSF(ME)-STRFLO(ME))**2
               X2SUM=X2SUM+ABS(MSF(ME))**2
               Y2SUM=Y2SUM+ABS(STRFLO(ME))**2
10          CONTINUE
            XBAR=XSUM/FMDAY
            YBAR=YSUM/FMDAY
            DIFF=XBAR-YBAR
            SDD=(F-(ABS(XSUM-YSUM)**2)/FMDAY)/(FMDAY*(FMDAY-1))
            XSUM2=ABS(XSUM)**2
            YSUM2=ABS(YSUM)**2
            R=(FMDAY*B-XSUM*YSUM)/((FMDAY*X2SUM-XSUM2)**0.5*
     1         (FMDAY*Y2SUM-YSUM2)**0.5)
            AB=SQRT((X2SUM-XSUM2/FMDAY)/(Y2SUM-YSUM2/FMDAY))
            IF (AB.GT.1.)    AB=1/AB
            CORR=AB*R
            IF (MM.EQ.2)    GO TO 35
            WRITE (UO,'(2X,A3,8X,3F10.2,F10.3,F10.2,2F10.3,2F10.1)')
     1         AMONTH,XBAR,YBAR,DIFF,SDD,F,R,CORR,XSUM,YSUM
20       CONTINUE
         N1=1
         ME=0
30    CONTINUE
35    WRITE (UO,'(1X,''TOTAL      '',2X,3F10.2,F10.3,F10.2,
     1    2F10.3,2F10.1/)') XBAR,YBAR,DIFF,SDD,F,R,CORR,XSUM,YSUM
      RETURN
      END
C
C ********************
C
      SUBROUTINE PLOT1 (UO)
C        INITIATES PLOTTED OUTPUT
C
$INSERT COMM
      CHARACTER*3 AMONTH      /* NAME OF MONTH
      INTEGER     J2          /* DAY NUMBER
      INTEGER     J3          /* MONTH NUMBER
      INTEGER     MDAY        /* NUMBER OF DAYS IN MONTH
      INTEGER     NM,NN       /* DO INDEXES
      INTEGER     UO          /* OUTPUT FILE UNIT
C
      EXTERNAL PPLOT
C
      IF (IPF) THEN
C        FLOW PLOT
         ME=0
         WRITE (UO,'(1H1,''. PRECIP    * MESFLO    + SIMFLO'')')
```

```
         DO 20 J3=1,NMO
            AMONTH=CMONTH(J3)
            MDAY=ND(J3)
            DO 10 J2=1,MDAY
               ME=ME+1
               CALL PPLOT (MSF(ME),STRFLO(ME),PPT(ME),
     1            YMAX1,YMIN1,J2,AMONTH,J3,MDAY,UO)
10          CONTINUE
20       CONTINUE
      ENDIF
      IF (IPS) THEN
C        STORAGE PLOT
         IF (DIV.LE.0.0) DIV=1.0
         WRITE (UO,'(1H1,''. UZONE    * SNOW    + EZONE''/
     1      '' UZONE SCALE FACTOR =''F5.2)') DIV
         ME=0
         DO 40 J3=1,NMO
            AMONTH=CMONTH(J3)
            MDAY=ND(J3)
            DO 30 J2=1,MDAY
               ME=ME+1
               CALL PPLOT (SNOW1(ME),EZONE1(ME),UZONE1(ME)/DIV,
     1            YMAX2,YMIN2,J2,AMONTH,J3,MDAY,UO)
30          CONTINUE
40       CONTINUE
      ENDIF
      RETURN
      END
C
C ********************
C
      SUBROUTINE PPLOT(X1,X2,X3,XMAX,XMIN,J2,AMONTH,
     1   J3,MDAY,UO)
C        ONE LINE OF PLOTTED OUTPUT
C
$INSERT COMM
      CHARACTER*3    AMONTH   /* NAME OF MONTH
      INTEGER        J,NI     /* DO INDEXES
      INTEGER        J2       /* DAY NUMBER
      INTEGER        J3       /* MONTH NUMBER
      INTEGER        LIN      /* NUMBER OF POINT ON LINE
      CHARACTER*1    MAP(101) /* LINE OF PLOT SYMBOLS
      INTEGER        MDAY     /* NUMBER OF DAYS IN MONTH
      INTEGER        NSP      /* SCALED VALUE TO BE PLOTTED
      CHARACTER*1    SYMBOL(4)/* ARRAY OF PLOT SYMBOLS
      CHARACTER*1    SN       /* * IF SNOW
      INTEGER        UO       /* OUTPUT FILE UNIT
      REAL           XMAX,XMIN/* MAX. AND MIN. VALUES ON X AXIS
      REAL           XD       /* X AXIS RANGE
      REAL           X1,X2,X3 /* THREE VALUES TO BE PLOTTED ON LINE
      REAL           X(3)     /* ARRAY OF VALUES TO BE PLOTTED
      REAL           YS(11)   /* X AXIS SCALE VALUES
      DATA SYMBOL/'*','+','.','X'/
```

```
C
      X(1)=X1
      X(2)=X2
      X(3)=X3
      IF (ME.LE.1) THEN
C        BEGINNING OF PLOT, SCALE AND DRAW AXIS
         XD=100./(XMAX-XMIN)
         DO 50 J=1,11
            YS(J)=XMIN+10.0*(J-1)/XD
50       CONTINUE
         WRITE (UO,'('' '',26X,11(F6.2,4X))') YS
         DO 60 LIN=1,100
            MAP(LIN)='-'
60       CONTINUE
         DO 70 LIN=1,100,10
            MAP(LIN)='+'
70       CONTINUE
         MAP(101)='+'
         WRITE (UO,'('' '',28X,''I'',101A1)') MAP
      ENDIF
      DO 90 J=1,101
         MAP(J)=' '
 90   CONTINUE
      DO 130 NI=1,3
C        SCALE POINTS
         NSP=(X(NI)-XMIN)*XD+1.49999999
         IF (NSP.NE.0) THEN
            IF (NSP.GT.101)    NSP=101
            IF (NSP.LT.0)    NSP=1
            IF (MAP(NSP).EQ.' ') THEN
               MAP(NSP)=SYMBOL(NI)
            ELSE
               MAP(NSP)='2'
            ENDIF
         ENDIF
 130  CONTINUE
      SN=' '
      IF (SNOW1(ME).GT.0.)    SN='*'
      WRITE(UO,'('' '',A3,I3,I4,1X,2(F4.0,1X),F5.1,A1,1X,''I'',101A1)')
     *   AMONTH,J2,ME,RAIN1(ME),SNO1(ME),TMP(ME),SN,MAP
      IF (J3.NE.12.OR.J2.NE.MDAY) THEN
         RETURN
      ELSE
C        END OF YEAR
         DO 170 LIN=1,100
            MAP(LIN)='-'
 170     CONTINUE
```

```
          DO 180 LIN=1,100,10
             MAP(LIN)='+'
180       CONTINUE
          MAP(101)='+'
          WRITE (UO,'('' '',28X,''I'',101A1)') MAP
          WRITE (UO,'('' '',26X,11(F6.2,4X))') YS
          WRITE (UO,'(''1'')')
       ENDIF
       RETURN
       END
C
C ****************
C
       REAL FUNCTION INTERP (XE,FUNCT)
C         INTERPOLATES BETWEEN POINTS IN DATA FUNCTIONS
C
$INSERT COMM
       REAL         FUNCT(*)  /* ARRAY OF PAIRS OF VALUES
       INTEGER      I,J       /* DO INDEXES
       REAL         XE        /* X VALUE
       REAL         XX(20)    /* SERIES OF X VALUES OF FUNCT
       REAL         YY(20)    /* SERIES OF Y VALUES OF FUNCT
       I=0
       DO 10 J=1,19,2
          I=I+1
          XX(I)=FUNCT(J)
          YY(I)=FUNCT(J+1)
 10    CONTINUE
       DO 20 J=1,10
          IF (XE .EQ. XX(J)) THEN
             INTERP = YY(J)
             RETURN
          ELSE IF (XE .LT. XX(J)) THEN
             INTERP=YY(J-1)+(YY(J)-YY(J-1))/(XX(J)-XX(J-1))*(XE-XX(J-1))
             RETURN
          ELSE
          ENDIF
 20    CONTINUE
       END
```

CHAPTER 11. SAMPLE INPUT DATA SETS

Data file for Hubbard Brook Watershed 3 1966-67

```
'H66W3' 365 T 6 1966
   0.0  0.0  0.0  0.0 22.0  0.5  0.0  0.7  9.1 35.5  0.0  0.0  0.0  7.2
   2.9 13.7  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  5.8  3.4  0.0  0.0
   4.5  0.5  0.0  0.0  0.0  0.0  0.0 51.2  0.0  1.1  0.0 17.7  0.0  1.2
   2.4  0.0  0.0  0.0  0.0  3.5 10.4  1.0  1.1  0.0  0.0  0.0  0.0  0.0
   0.0  7.3  0.0  0.0  0.0  0.0 19.7  0.0  0.0  0.0  0.0  2.4  0.0  0.0
   0.3 54.2 24.9  0.7  0.0  1.2  2.4  1.5  0.0  0.0  0.0  0.0 54.4 16.1
   0.2  1.1  2.5  5.2  0.0  0.0  6.6  0.0  0.0  0.0  0.0 44.8  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  2.8  1.8  0.0  0.9  0.0  0.0  0.0
  17.6 31.3  4.3  2.1  0.9  0.0  0.0  0.0  5.2  5.4  6.5  0.0  0.0 10.1
   3.7  0.0  0.0  0.0  0.0  6.8  1.6  0.0  0.0  0.0  0.0  2.8  0.0  0.0
  25.0 24.4  1.5  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  23.3 49.2  0.0  2.8  3.4  0.0  2.8  2.1 11.0  9.3  0.0  0.0  0.0  0.0
   0.8  2.1  1.0  0.0  0.0  0.0  0.0  0.0  0.0  2.4  0.0  0.0  1.5 10.5
  12.0  2.0  3.6  0.0  0.0  1.1  0.0  9.3 15.8  0.0  0.0  2.2  0.0  0.8
   7.5  0.0  0.6  0.0  0.0  0.0  0.0  0.0  0.0  0.9  7.6 17.5  1.1  0.0
   0.0 28.2  1.2  0.0  5.5  1.0  2.1  3.4  3.7  0.8  6.0  0.5  0.0  0.0
   0.7  3.5  1.2  0.6  0.1  0.0  0.0  0.0  0.0  0.0  0.0  0.0 12.4  0.0
   0.6  0.3  3.7 10.5  0.6  0.0  0.0  2.9 18.3  0.0  7.2  2.0  0.0  3.7
   0.0  0.0  0.0  2.7  0.0  0.0  0.9  0.0  6.5  0.0  0.0  0.0  9.7  4.4
   0.0 32.0  2.3  0.0  0.0  1.2  5.3  0.2  0.9  3.6  0.3  8.5  1.5 12.9
   0.0  0.0  0.0  0.0  0.0  0.0  8.0  6.5  3.6  0.0  0.0  0.0  0.0  0.0
   0.0  1.0  0.0  0.0  0.0  1.5  4.4  0.0  0.0  0.0  0.0  4.2  6.8  0.0
   0.0 16.2 13.7  0.0  4.7 16.0  0.0  0.0  0.0  0.0  7.4 12.9 10.4 22.2
   4.5  0.0  0.0  7.0  6.3  0.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  8.5
  16.3  1.7  1.3  0.0  6.8  1.1  1.2  0.1 14.8  1.4  0.0  0.2 17.2  0.0
   0.0  1.1 16.6  1.5  0.0  1.5  0.0  0.1 12.9  4.0  0.0  0.0  0.0  0.0
   0.0
   8.9 12.8 15.6 18.9 21.1 22.8 20.0 18.3 15.0  7.8 10.0 14.4 12.8 22.2
  18.3 13.3 16.7 16.7 17.8 20.6 17.8 17.8 20.0 22.2 13.3 17.8 24.4 23.3
  21.7 18.9 20.0 23.3 26.7 21.1 20.0 16.7 22.2 19.4 18.9 20.0 20.6 21.1
  22.2 17.8 15.6 15.6 17.8 18.9 17.8 14.4 12.2 15.6 20.0 22.2 22.2 18.9
  15.6 14.4 18.3 17.8 18.3 20.0 19.4 14.4 17.8 20.0 19.4 22.2 22.8 21.1
  20.0 20.0 17.2 15.0 15.6 16.1 17.8 20.0 20.6 20.0 16.7 16.1 13.3 15.0
  14.4 16.1 15.6 17.2 14.4 16.7 21.1 20.0 18.3 20.0 12.2  9.4 16.1 15.6
  14.4 16.7 17.8 18.3 11.1 12.2 12.2 12.2 12.2  7.8 12.2 15.6 11.7  8.9
   6.7 11.1  7.8  6.7  6.7  5.6  6.7 10.6  9.4 10.0  5.0  7.2  7.8  8.9
   8.9  3.3 10.0 15.0 16.7  8.9  5.0  3.3  3.3  6.7  7.8  9.4  3.3  4.4
   5.6  3.9  4.4  8.9  9.4 10.0  7.2  4.4  6.7 11.1  5.6 -5.6 -3.3  6.7
  12.2  8.3  0.0 -0.6  1.1  2.8  3.3  7.2 11.7  9.4  4.4 -1.1 -2.2 -3.9
  -5.6  2.2  5.6 -1.1 -1.1  0.0 -0.6  3.3  6.7  5.6  7.8  6.7  8.3  5.6
   1.7  0.0 -6.7-12.2-10.0 -6.7 -2.8 -2.8  3.9 10.0 12.2  4.4 -4.4 -4.4
  -1.7 -6.7 -7.2 -1.1 -1.1-10.0-10.0 -6.7 -4.4-10.0-10.0 -8.9 -7.8 -8.9
 -10.0 -5.6 -8.9 -8.9 -6.7 -3.3 -3.9 -1.7 -3.3-11.7 -7.8 -3.3 -5.6 -5.6
  -5.6 -8.3  0.0 -3.3 -0.6 -8.9 -6.7-13.3-18.9-10.0 -3.3  2.2  4.4  6.7
  -0.6  2.2 -3.3 -4.4-11.1-12.2 -8.9 -1.7 -4.4-10.0 -9.4 -3.3-17.2-16.7
 -12.2 -8.9 -4.4 -7.8-22.8-15.6-11.1  2.2 -7.8-14.4-15.0-12.2-11.1 -7.2
  -7.8 -4.4-11.1-16.7-12.8 -8.3 -4.4-14.4-13.3 -0.6 -6.7 -8.9 -3.3 -6.1
  -6.7 -5.6  2.8  7.2 -4.4 -5.6  0.0 -3.3-12.2-17.2-18.9-12.2 -6.7 -6.7
  -5.6 -3.3 -1.1  0.0  3.3  1.7  3.3  2.8  2.8  2.8  8.3 10.0  4.4 -5.6
   5.0  0.0 -2.2  1.1  2.8  1.1 -7.8 -6.7  2.8  8.3  2.2 -2.2 -1.1 -0.6
```

```
  1.1   2.2   3.9   3.9   2.2   2.2   1.1   3.9   5.6   6.7   4.4   7.8  12.2   9.4
  6.1   5.0   3.9   3.9   2.8   2.8   4.4   3.3   5.0   4.4   5.0   7.2   5.6   5.6
  8.9   6.7  11.1  10.0   7.2   7.2   8.3   8.9   3.9   3.3   7.8  12.2  10.0   8.9
  8.9
  0.7   0.6   0.5   0.4   0.4   1.9   0.8   0.6   0.5   7.8   4.6   2.1   1.4   1.2
  1.3   2.1   2.6   1.2   0.8   0.6   0.4   0.3   0.2   0.2   0.2   0.3   0.2   0.1
  0.1   0.1   0.1   0.0   0.0   0.0   0.0   1.1   1.3   0.3   0.1   0.1   0.5   0.2
  0.1   0.1   0.1   0.0   0.0   0.0   0.1   0.1   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.1   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   1.0   1.5   0.9   0.2   0.1   0.1   0.1   0.1   0.1   0.0   0.0   2.2   9.4
  2.1   0.8   0.4   0.2   0.2   0.1   0.1   0.1   0.1   0.1   0.0   3.6   3.2   0.9
  0.4   0.2   0.2   0.1   0.1   0.1   0.1   0.1   0.1   0.1   0.1   0.1   0.1   0.1
  0.1   2.8   3.0   1.3   0.7   0.4   0.3   0.3   0.2   0.6   0.7   0.8   0.5   0.4
  1.6   1.0   0.7   0.5   0.4   0.5   0.7   0.5   0.4   0.4   0.4   0.5   0.5   0.5
  1.1  15.7   4.7   2.8   2.1   1.7   1.4   1.2   1.1   1.0   1.0   1.0   0.9   0.7
  1.9  43.1  10.6   4.6   3.3   2.8   2.7   2.8   3.1  10.5   4.8   3.1   2.4   2.0
  1.7   1.5   1.8   1.6   1.3   1.1   1.0   1.0   1.0   0.9   1.0   0.9   0.9   2.6
  3.7   2.4   1.9   1.4   1.1   1.1   1.0   1.0   7.0   8.0   4.2   3.4   2.5   2.0
  1.8   1.5   1.3   1.3   1.3   1.2   1.0   1.0   0.8   0.7   0.6   0.7   0.6   0.6
  0.6   0.6   0.6   0.6   0.5   0.5   0.5   0.5   0.6   0.5   0.5   0.5   0.5   0.5
  0.5   0.5   0.5   0.5   0.5   0.4   0.4   0.4   0.4   0.4   0.4   0.4   1.0   2.5
  2.0   1.6   1.4   1.2   1.1   0.9   0.8   0.8   0.7   0.7   0.6   0.6   0.6   0.6
  0.5   0.5   0.5   0.5   0.5   0.4   0.4   0.5   1.0   0.7   0.6   0.5   0.5   0.5
  0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4   0.4
  0.4   0.4   0.6   2.0   2.1   1.2   1.6   1.6   1.3   1.1   1.0   0.9   0.8   0.8
  0.7   0.7   0.7   0.7   0.9   1.2   3.3   6.6   5.9   5.5  14.3  35.2  51.4  11.7
  8.5   6.7   4.2   3.3   5.1  23.1   9.3   4.7   4.3   5.3   6.2   4.1   3.0   2.7
  2.4   3.7   5.4   8.6   8.3   5.9   6.1   6.9   6.1   5.4   5.2   4.6   4.5   4.5
 17.5   7.5   4.7   3.5   2.8   3.3   2.9   2.4   2.6   5.7   3.4   2.6   4.9   5.5
  3.4   2.8   4.4   4.7   3.3   2.6   2.2   1.9   2.1   3.6   2.7   2.2   1.8   1.6
  1.4
```

Parameter file for Hubbard Brook Watershed 3

```
43.95  12.1  203.2
0.75  0.045  10  0.4  -2.8  0.35
40.0  4.1E-6  0.01
28.0  12.0  1.0
635.  40.  50.  0.09
2.039E07  12.56  2.039E07  12.56
0  0  0
0 3.0   1 1.75   2 1.00
0 0.7   172 2.17   366 0.7
0 0.2   172 0.4   366 0.2
1 0   136 0 166 4   258 4   288 0   366 0   0 0   0 0   0 0
0 2   366 2   0 0   0 0   0 0   0 0
0 25 0 250 1
150.51 9.72 0 0 0
```

Data file for Coweeta Watershed 14 1968-69

```
'C68W4' 365 T  5 1968
  0.0  5.6  0.0  0.0 14.2  0.0  0.0  0.0  0.0  0.0 32.3  4.1  0.0 27.4
  0.5 13.2  4.1  0.5  0.0  0.0  0.0  0.0  0.0  0.0  0.0 28.7  1.3  3.8
 11.2  0.0  0.0  0.8  1.8  0.0  0.0  0.0  0.0 22.4 34.3  1.0  0.0  3.0
  3.0  0.0  0.0  0.0  0.0  7.6  1.3  4.8  0.0  0.0  0.0  0.0  0.5  0.0
  2.5  0.0  0.0  0.0  0.0  0.0  9.1  1.3  8.1  0.0  0.0  0.0  0.3  5.8
 16.3  0.0  2.5  7.9  0.0  0.0  0.0  0.0  1.3  5.8  0.0  0.0  0.0  0.0
  1.3  0.5 21.1  0.0  0.0 12.4  2.0 11.2  9.4 29.2 41.7  0.0  0.0  0.0
  0.0  0.0  0.0  1.3  0.0  0.0  1.0  0.0  3.0  3.6  0.0  0.0  8.1  0.8
  0.8  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0 19.1 22.4  0.0  0.8
  0.0  3.0  0.0  0.0  0.5  3.0  0.0  0.5  0.0  0.0  0.5  0.0  0.0 11.7
 44.5 25.9  0.8  0.0  0.0  0.0  0.0  0.0  6.1  0.0  0.0  0.0  0.0  0.0
  0.3  2.0  0.0  0.0 23.1  0.0  0.0  0.0  0.8  0.0  0.0 12.2  0.0  0.0
 16.3  8.1 13.2  6.1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  1.0 21.8  0.0  8.9  0.0  0.3  7.6 13.5  5.1  2.3
  0.0  4.6  0.0  0.0 23.1 18.5  0.0  0.0  0.0  0.0  0.0  2.0  0.0  0.0
  0.0 26.9  0.0  0.0 23.6  0.0 17.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0 27.7  0.0  0.0  0.0  0.0  0.0  9.4  0.0  9.1 53.6  0.0  0.0
  0.0  0.0  5.1 43.2  0.0  0.0 10.2  0.0  0.0  0.0  0.0  0.5  0.0  0.0
  0.0  3.8  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  6.9 51.3 39.1  0.0
  3.6  8.9  6.4  0.0  0.0  1.5 31.8  1.0  3.0  8.4 46.0 49.3  0.0  0.0
  0.0 24.6  0.0 22.9  0.0  0.0  0.0  0.0  0.0  0.0 21.1 10.4  0.8  1.0
  0.0  0.0  0.0 19.3  0.0  0.0  0.0  0.0  0.0 14.7  5.1  0.0  0.0  0.0
  0.0 17.3  0.8  3.0  1.5  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0 40.9
  0.0  0.3  0.0  0.0 11.4 22.4  0.0  0.0  0.0  0.0  2.3  0.0  0.0  0.0
  0.0  0.0  0.0 23.9  5.1  0.0  0.0  0.0 11.4  1.8  0.0  0.0 40.1 48.3
  0.0  8.1 56.6  0.5  0.0  0.0  4.8  0.0  0.0  0.0  0.0  0.0  4.1  0.0
  0.0
 14.7 15.8 16.4 14.7  9.7 10.0  9.7 15.0 13.6 15.6 16.9 20.0 18.3 18.9
 21.7 20.6 14.7 18.1 14.2 12.2 10.0 11.9 17.2 21.1 19.2 17.8 18.6 13.3
 12.8 13.3 14.7 16.4 20.0 20.6 18.3 19.4 17.2 16.4 20.0 22.2 22.8 21.9
 20.0 18.3 15.6 17.8 19.2 17.5 19.7 21.1 20.8 18.9 19.7 20.3 21.1 21.1
 23.1 18.1 14.4 18.6 21.1 22.2 22.5 20.6 19.7 19.2 22.8 21.4 21.9 19.4
 21.7 21.9 21.4 20.3 22.2 22.2 23.1 22.8 22.8 22.5 22.5 21.7 22.5 21.9
 21.1 23.1 23.9 24.2 24.2 21.4 21.9 23.1 23.6 23.9 22.8 23.3 24.4 24.7
 24.2 25.0 25.6 24.4 23.6 22.5 23.1 23.6 22.2 24.2 24.7 24.4 23.3 25.6
 26.1 25.3 24.4 24.2 23.3 21.9 16.9 16.4 15.3 15.8 14.2 17.5 19.7 18.1
 19.2 20.3 21.9 16.7 16.7 18.6 20.0 14.7 14.2 15.8 17.8 15.8 15.6 17.8
 15.6 16.7 18.9 18.3 18.1 16.4 17.5 17.5 15.8 18.6 17.2 17.2 16.1 16.1
 15.8 17.5  9.4  5.8  9.2 16.9 17.8 15.8 15.3 16.7 17.5 18.6 17.2 17.5
 14.7 17.8 18.6 18.3 12.8 12.2 11.9 12.8  8.6  5.8  6.7  7.2  6.4  5.0
  6.7 10.8 13.3 13.6 13.1 13.9 12.8 13.9 11.9  7.2  1.7  2.5  1.9 -0.3
  2.2  5.3  8.3 15.6 10.8 11.1  0.6  0.8  1.9  8.6  6.1  5.6  4.2  5.8
  7.2 15.0  7.5  7.2  6.9  9.2  7.2  1.7  5.0  3.3  4.7  0.0 -1.4 -2.8
  0.6-17.8  9.7 -2.8 -3.6 -1.9  0.0  5.8 11.7  7.2  3.3  5.3  1.1  0.0
 -1.1  1.1  3.9  8.1  3.9  1.4  5.8 -3.1 -3.1  1.7 -2.8 -6.7 -4.7  0.6
 -1.7  8.9 -3.3 -2.2 -3.3  1.1 -0.3  1.9  2.5  4.4 10.3 10.0  7.5  8.6
  8.3  7.2 10.6  0.8 -1.1 -1.1  2.5  8.3 12.5 13.3 12.8 12.8  5.3  1.9
  5.6  4.4  7.8  6.7  3.9  3.1  4.4  3.1 -1.1 -0.8 -2.2  3.1  1.9  2.8
  1.9  4.4  4.4  1.1  5.6  5.0  4.2  3.9  3.9  2.2  3.9  5.3  1.4  1.4
  3.1  2.2  3.6  4.7  4.4  0.6 -1.4 -1.7  3.1  4.7  5.6  8.1  7.8  8.9
 11.4 10.0 10.3  6.9  5.3 13.6 11.1  3.1  4.7  6.1  9.4 10.0  6.9  9.7
```

```
14.7 16.1 17.2 16.4 16.4 10.6 11.1 13.3 14.4 15.3 13.1 13.1 10.0 14.2
19.2 16.4 19.2 11.9 11.1 11.7 11.4  7.2 11.9 10.8 13.9 15.3 16.9 15.8
12.2
  2.8  3.1  2.8  3.1  2.8  2.7  2.6  2.6  2.6  2.5  3.6  3.4  2.9  4.6
  3.6  3.6  3.2  3.0  2.8  2.7  2.6  2.6  2.5  2.4  2.4  3.1  2.8  2.5
  2.6  2.5  2.3  2.2  2.2  2.2  2.1  2.0  2.0  2.4  3.8  2.7  2.3  2.3
  2.2  2.0  2.0  1.9  1.9  2.0  1.9  1.9  1.8  1.7  1.8  1.7  1.7  1.7
  1.7  1.6  1.5  1.5  1.5  1.5  1.8  1.6  1.7  1.5  1.5  1.4  1.4  1.6
  1.8  1.5  1.7  1.8  1.5  1.4  1.4  1.3  1.3  1.4  1.3  1.2  1.2  1.2
  1.2  1.1  1.6  1.2  1.1  1.3  1.2  1.4  1.4  3.1  4.6  2.2  1.7  1.5
  1.4  1.3  1.3  1.2  1.2  1.1  1.1  1.1  1.2  1.2  1.1  1.0  1.4  1.1
  1.0  1.0  1.0  0.9  1.0  0.9  0.9  0.9  0.8  0.8  1.2  2.0  1.0  0.9
  0.9  1.0  0.9  0.9  0.9  0.9  0.9  0.8  0.8  0.8  0.8  0.8  0.8  1.0
  2.2  2.9  1.3  1.0  1.0  0.9  0.9  0.9  1.0  0.9  0.9  0.8  0.8  0.8
  0.8  0.8  0.8  0.8  1.4  1.0  0.9  0.8  0.9  0.8  0.8  1.0  0.8  0.8
  1.0  1.3  1.4  1.5  1.0  1.0  0.9  0.9  0.9  0.9  0.8  0.8  0.8  0.8
  0.8  0.8  0.8  0.8  0.8  1.5  0.9  1.0  1.0  0.9  1.0  1.2  1.1  1.0
  0.9  0.9  1.0  1.1  1.5  3.2  1.7  1.4  1.3  1.2  1.1  1.1  1.0  1.0
  1.0  2.0  1.4  1.2  2.0  1.7  2.0  2.0  1.7  1.5  1.4  1.3  1.3  1.2
  1.2  1.2  2.1  1.7  1.4  1.4  1.3  1.3  1.5  1.3  1.3  5.2  4.0  2.7
  2.2  2.0  2.0  5.6  3.3  2.8  2.9  2.5  2.3  2.2  2.1  2.0  2.0  1.9
  1.9  1.9  1.8  1.8  1.7  1.7  1.7  1.7  1.6  1.6  1.7  3.7  8.9  4.2
  3.4  3.3  3.5  3.0  2.8  2.7  3.8  4.2  3.6  3.5  6.8 13.8 10.0  7.3
  6.3  6.9  6.3  6.8  6.4  5.7  5.4  5.1  4.8  4.6  4.7  5.0  4.6  4.3
  4.1  4.0  4.0  4.3  4.5  4.2  4.0  3.9  3.7  3.7  3.9  3.6  3.5  3.4
  3.3  3.5  3.4  3.4  3.6  3.3  3.2  3.1  3.0  2.9  2.9  2.9  2.8  4.5
  4.5  3.7  3.4  3.2  3.2  4.9  3.8  3.5  3.3  3.2  3.1  3.0  3.0  2.9
  2.9  2.8  2.8  3.4  3.1  2.9  2.8  2.8  3.2  2.9  2.8  2.7  3.8  9.3
  7.0  5.1 10.9  8.7  6.6  5.8  5.5  5.2  4.9  4.7  4.6  4.4  4.4  4.3
  4.1
```

Parameter file for Coweeta Watershed 14

```
35.05 18.0 310.0
25.0  7.4E-5  0.01
25.0  3.00  1.2
900.  4200.  50.  0.09
1.051E07  11.74  1.051E07  11.74
0.4  0.005  0.0
0 3.0   1 1.75   2 1.00
0 0.7   172 2.17   366 0.7
0 0.2   172 0.4   366 0.2
1 .5   106 .5   136 4.0   289 4.0   321 0.5   366 0.5   0 0   0 0   0 0
1 2.0   366 2.0   0 0   0 0   0 0   0 0
0 25 0 250 8.0
227.72 1160.75 244.09 0 0
```

```
DATA FILE  H66W3               TEST RUN

  LAT    =     43.98     SLOPE =      12.1     ASPECT=     203.2
  INC    =     0.750     ISCSNO=     0.048     NT    =        10     CCMAX =      0.40      RSF   =     -2.80      GPDMLT=      0.38
  PAC    =     40.00     PC    = 0.41E-05      IMPERV=     0.010
  CT     =     20.00     CE    =     12.00     PEC   =      1.00
  EZDEP  =     635.0     UZDEP =      40.0     EVDEP =      50.0     EZIS  =     0.090
  KEINT  = .204E+08      KESLP =    12.560     KUINT = .204E+00      KUSLP =    12.560
  DRNC   =     0.000     GSC   =    0.0000     GSP   =    0.0000
 (DAY,MELTFUN)-INTERPOLATION POINTS               (DAY,LAI)-INTERPOLATION POINTS
(  0.0, .7)(172.0,2.2)(366.0, .7) (   1., .00)(136., .00)(166.,4.00)(258.,4.00)(288., .00)(366., .00)(   0., .00)(   0., .00)(   0., .00
)

  (DAY,CCFUN)-INTERPOLATION POINTS               (DAY,SAI)-INTERPOLATION POINTS
(  0.0, .2)(172.0, .4)(366.0, .2)        (   0.,2.00)(366.,2.00)(   0., .00)(   0., .00)(   0., .00)(   0., .00)

    INITIAL STORAGE-JUN 1   EZONE=   150.8   UZONE=      9.7   GWZONE=      0.0   SNOW=      0.0

        PRECIP SURFLO SNOFLO INTFLO  GWFLO STRFLO  GSEEP INTVAP    INT SNOVAP  SEVAP  TRANS   EVAP INTSNO   SNOW  EZONE  UZONE GWZONE
JUN 1    0.00   0.00   0.00   0.38   0.00   0.38   0.00   0.00   0.00   0.00   0.19   1.27   1.46   0.00   0.00 148.77   9.63   0.00
JUN 2    0.00   0.00   0.00   0.34   0.00   0.34   0.00   0.00   0.00   0.00   0.21   1.71   1.92   0.00   0.00 146.60   9.54   0.00
JUN 3    0.00   0.00   0.00   0.30   0.00   0.30   0.00   0.00   0.00   0.00   0.22   2.13   2.35   0.00   0.00 144.05   9.44   0.00
JUN 4    0.00   0.00   0.00   0.26   0.00   0.26   0.00   0.00   0.00   0.00   0.24   2.60   2.92   0.00   0.00 140.96   9.34   0.00
JUN 5   22.00   1.10   0.00   0.24   0.00   1.34   0.00   0.00   2.24   0.00   0.24   3.18   5.66   0.00   0.00 155.81   9.49   0.00
JUN 6    0.50   0.02   0.00   0.31   0.00   0.32   0.00   0.00   0.30   0.00   0.23   3.20   3.73   0.00   0.00 152.12   9.63   0.00
JUN 7    0.00   0.00   0.00   0.35   0.00   0.35   0.00   0.00   0.00   0.00   0.17   3.14   3.31   0.00   0.00 148.49   9.61   0.00
JUN 8    0.70   0.01   0.00   0.33   0.00   0.34   0.00   0.00   0.44   0.00   0.13   2.94   3.52   0.00   0.00 145.41   9.52   0.00
JUN 9    9.10   0.39   0.00   0.30   0.00   0.69   0.00   0.00   1.75   0.00   0.09   2.47   4.31   0.00   0.00 149.52   9.52   0.00
JUN10   35.50   4.82   0.00   0.40   0.00   5.22   0.00   0.00   1.14   0.00   0.05   1.60   2.79   0.00   0.00 176.19  10.33   0.00
JUN11    0.00   0.00   0.00   1.33   0.00   1.33   0.00   0.00   0.00   0.00   0.05   1.87   1.92   0.00   0.00 172.31  10.97   0.00
JUN12    0.00   0.00   0.00   1.65   0.00   1.65   0.00   0.00   0.00   0.00   0.06   2.48   2.54   0.00   0.00 168.26  10.82   0.00
JUN13    0.00   0.00   0.00   1.35   0.00   1.35   0.00   0.00   0.00   0.00   0.05   2.27   2.32   0.00   0.00 164.02  10.60   0.00
JUN14    7.20   0.62   0.00   1.10   0.00   1.73   0.00   0.00   3.03   0.00   0.08   3.93   7.04   0.00   0.00 163.30  10.54   0.00
JUN15    2.90   0.09   0.00   1.01   0.00   1.10   0.00   0.00   2.18   0.00   0.07   3.19   5.43   0.00   0.00 159.86  10.35   0.00
JUN16   13.70   1.55   0.00   0.87   0.00   2.42   0.00   0.00   1.83   0.00   0.05   2.36   4.23   0.00   0.00 166.75  10.52   0.00
JUN17    0.00   0.00   0.00   1.05   0.00   1.05   0.00   0.00   0.00   0.00   0.06   2.90   2.96   0.00   0.00 162.78  10.49   0.00
JUN18    0.00   0.00   0.00   0.94   0.00   0.94   0.00   0.00   0.00   0.00   0.06   2.90   2.96   0.00   0.00 159.06  10.30   0.00
JUN19    0.00   0.00   0.00   0.75   0.00   0.75   0.00   0.00   0.00   0.00   0.06   3.10   3.16   0.00   0.00 155.34  10.11   0.00
JUN20    0.00   0.00   0.00   0.60   0.00   0.60   0.00   0.00   0.00   0.00   0.07   3.49   3.57   0.00   0.00 151.35   9.93   0.00
JUN21    0.00   0.00   0.00   0.48   0.00   0.48   0.00   0.00   0.00   0.00   0.06   3.10   3.16   0.00   0.00 147.88   9.75   0.00
JUN22    0.00   0.00   0.00   0.39   0.00   0.39   0.00   0.00   0.00   0.00   0.06   3.10   3.16   0.00   0.00 144.50   9.60   0.00
JUN23    0.00   0.00   0.00   0.32   0.00   0.32   0.00   0.00   0.00   0.00   0.07   3.11   3.19   0.00   0.00 141.14   9.45   0.00
JUN24    0.00   0.00   0.00   0.26   0.00   0.26   0.00   0.00   0.00   0.00   0.08   3.00   3.08   0.00   0.00 137.94   9.32   0.00
JUN25    5.80   0.14   0.00   0.22   0.00   0.36   0.00   0.00   1.83   0.00   0.05   2.36   4.23   0.00   0.00 139.24   9.22   0.00
JUN26    3.40   0.04   0.00   0.20   0.00   0.23   0.00   0.00   2.40   0.00   0.06   2.96   5.42   0.00   0.00 137.06   9.14   0.00
JUN27    0.00   0.00   0.00   0.17   0.00   0.17   0.00   0.00   0.00   0.00   0.09   2.85   2.94   0.00   0.00 134.03   9.05   0.00
JUN28    0.00   0.00   0.00   0.15   0.00   0.15   0.00   0.00   0.00   0.00   0.09   2.74   2.83   0.00   0.00 131.13   8.96   0.00
JUN29    4.50   0.04   0.00   0.14   0.00   0.18   0.00   0.00   3.01   0.00   0.08   2.69   5.78   0.00   0.00 129.75   8.88   0.00
JUN30    0.50   0.00   0.00   0.12   0.00   0.13   0.00   0.00   0.38   0.00   0.07   2.60   3.04   0.00   0.00 127.17   8.80   0.00
JUL 1    0.00   0.00   0.00   0.11   0.00   0.11   0.00   0.00   0.00   0.00   0.07   2.50   2.57   0.00   0.00 124.56   8.73   0.00
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JUN20	0.00	0.00	0.00	0.60	0.00	0.60	0.00	0.00	0.00	0.00	0.07	3.49	3.57	0.00	0.00	151.35	9.93	0.00
JUN21	0.00	0.00	0.00	0.48	0.00	0.48	0.00	0.00	0.00	0.00	0.06	3.10	3.16	0.00	0.00	147.88	9.75	0.00
JUN22	0.00	0.00	0.00	0.39	0.00	0.39	0.00	0.00	0.00	0.00	0.06	3.10	3.16	0.00	0.00	144.50	9.60	0.00
JUN23	0.00	0.00	0.00	0.32	0.00	0.32	0.00	0.00	0.00	0.00	0.07	3.11	3.19	0.00	0.00	141.14	9.45	0.00
JUN24	0.00	0.00	0.00	0.26	0.00	0.26	0.00	0.00	0.00	0.00	0.08	3.00	3.08	0.00	0.00	137.93	9.32	0.00
JUN25	5.80	0.14	0.00	0.22	0.00	0.36	0.00	0.00	1.83	0.00	0.05	2.36	4.23	0.00	0.00	139.24	9.22	0.00
JUN26	3.40	0.04	0.00	0.20	0.00	0.23	0.00	0.00	2.40	0.00	0.06	2.96	5.42	0.00	0.00	137.06	9.14	0.00
JUN27	0.00	0.00	0.00	0.17	0.00	0.17	0.00	0.00	0.00	0.00	0.09	2.85	2.94	0.00	0.00	134.03	9.05	0.00
JUN28	0.00	0.00	0.00	0.15	0.00	0.15	0.00	0.00	0.00	0.00	0.09	2.74	2.83	0.00	0.00	131.13	8.96	0.00
JUN29	4.50	0.04	0.00	0.14	0.00	0.18	0.00	0.00	3.01	0.00	0.08	2.69	5.78	0.00	0.00	129.75	8.88	0.00
JUN30	0.50	0.00	0.00	0.12	0.00	0.13	0.00	0.00	0.37	0.00	0.07	2.60	3.04	0.00	0.00	127.17	8.80	0.00
JUL 1	0.00	0.00	0.00	0.11	0.00	0.11	0.00	0.00	0.00	0.00	0.07	2.50	2.57	0.00	0.00	124.56	8.73	0.00
JUL 2	0.00	0.00	0.00	0.10	0.00	0.10	0.00	0.00	0.00	0.00	0.09	2.41	2.49	0.00	0.00	122.04	8.66	0.00
JUL 3	0.00	0.00	0.00	0.09	0.00	0.09	0.00	0.00	0.00	0.00	0.11	2.32	2.42	0.00	0.00	119.60	8.59	0.00
JUL 4	0.00	0.00	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.00	0.08	2.23	2.31	0.00	0.00	117.28	8.52	0.00
JUL 5	0.00	0.00	0.00	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.07	2.15	2.22	0.00	0.00	115.05	8.46	0.00
JUL 6	51.20	1.87	0.00	0.07	0.00	1.94	0.00	0.00	2.23	0.00	0.06	2.89	5.18	0.00	0.00	158.95	8.64	0.00
JUL 7	0.00	0.00	0.00	0.11	0.00	0.11	0.00	0.00	0.00	0.00	0.08	3.62	3.70	0.00	0.00	154.69	9.10	0.00
JUL 8	1.10	0.02	0.00	0.19	0.00	0.21	0.00	0.00	0.82	0.00	0.07	3.39	4.28	0.00	0.00	151.08	9.32	0.00
JUL 9	0.00	0.00	0.00	0.24	0.00	0.24	0.00	0.00	0.00	0.00	0.07	3.29	3.36	0.00	0.00	147.42	9.38	0.00
JUL10	17.70	0.99	0.00	0.26	0.00	1.26	0.00	0.00	2.70	0.00	0.07	3.51	6.28	0.00	0.00	157.31	9.66	0.00
JUL11	0.00	0.00	0.00	0.38	0.00	0.38	0.00	0.00	0.00	0.00	0.07	3.56	3.63	0.00	0.00	153.18	9.77	0.00
JUL12	1.20	0.02	0.00	0.41	0.00	0.43	0.00	0.00	0.90	0.00	0.08	3.43	4.40	0.00	0.00	149.60	9.72	0.00
JUL13	2.40	0.04	0.00	0.38	0.00	0.41	0.00	0.00	1.80	0.00	0.08	3.31	5.19	0.00	0.00	146.49	9.62	0.00
JUL14	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.06	3.07	3.14	0.00	0.00	143.16	9.49	0.00
JUL15	0.00	0.00	0.00	0.28	0.00	0.28	0.00	0.00	0.00	0.00	0.05	2.69	2.75	0.00	0.00	140.26	9.37	0.00
MAR15	6.50	0.00	0.06	1.16	0.00	1.23	0.00	0.29	0.00	0.12	0.00	0.00	0.41	0.00	156.05	167.85	10.61	0.00
MAR16	3.60	0.00	0.06	1.15	0.00	1.21	0.00	0.16	0.00	0.06	0.00	0.00	0.22	0.00	159.08	167.03	10.56	0.00
MAR17	0.00	0.00	0.06	1.10	0.00	1.16	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00	158.65	166.27	10.52	0.00
MAR18	0.00	0.00	0.05	1.04	0.00	1.10	0.00	0.00	0.00	0.07	0.00	0.00	0.07	0.00	158.23	165.57	10.48	0.00
MAR19	0.00	0.00	0.05	0.99	0.00	1.04	0.00	0.00	0.00	0.12	0.00	0.00	0.12	0.00	157.76	164.92	10.43	0.00
MAR20	0.00	0.00	0.05	0.94	0.00	0.99	0.00	0.00	0.00	0.19	0.00	0.00	0.19	0.00	157.22	164.32	10.39	0.00
MAR21	0.00	0.00	0.05	0.90	0.00	0.95	0.00	0.00	0.00	0.19	0.00	0.00	0.19	0.00	156.68	163.76	10.36	0.00
MAR22	0.00	0.00	0.05	0.86	0.00	0.91	0.00	0.00	0.00	0.20	0.00	0.00	0.20	0.00	156.13	163.23	10.32	0.00
MAR23	1.00	0.00	0.05	0.83	0.00	0.87	0.00	0.04	0.00	0.22	0.00	0.00	0.27	0.00	156.51	162.74	10.29	0.00
MAR24	0.00	0.00	0.04	0.80	0.00	0.84	0.00	0.00	0.00	0.28	0.00	0.00	0.28	0.00	155.88	162.78	10.26	0.00
MAR25	0.00	0.00	0.04	0.77	0.00	0.81	0.00	0.00	0.00	0.30	0.00	0.00	0.30	0.00	155.23	161.85	10.23	0.00
MAR26	0.00	0.00	0.04	0.74	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	154.88	161.44	10.21	0.00
MAR27	1.50	0.00	0.04	0.72	0.00	0.76	0.00	0.00	0.23	0.00	0.00	0.00	0.23	0.00	155.80	161.06	10.18	0.00
MAR28	4.40	0.61	1.42	0.79	0.00	2.82	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	146.21	171.59	10.56	0.00
MAR29	0.00	0.00	2.02	1.42	0.00	3.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	137.77	176.13	11.02	0.00
MAR30	0.00	0.00	2.61	2.18	0.00	4.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	129.31	179.54	11.29	0.00
MAR31	0.00	0.00	3.14	2.79	0.00	5.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	120.82	181.92	11.46	0.00
APR 1	0.00	0.00	12.81	3.86	0.00	16.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96.30	189.35	11.89	0.00
APR 2	4.20	2.74	21.32	5.71	0.00	29.77	0.00	0.00	0.40	0.00	0.00	0.00	0.40	0.00	66.74	192.68	12.13	0.00
APR 3	6.80	4.85	9.86	6.21	0.00	20.92	0.00	0.00	0.28	0.00	0.00	0.00	0.28	0.00	53.50	191.57	12.08	0.00
APR 4	0.00	0.00	0.22	5.35	0.00	5.57	0.00	0.00	0.00	0.21	0.00	0.00	0.21	0.00	52.93	186.62	11.81	0.00
APR 5	0.00	0.00	7.43	4.54	0.00	11.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.59	187.96	11.85	0.00
APR 6	16.20	9.71	0.21	4.92	0.00	14.84	0.00	0.00	0.21	0.32	0.00	0.00	0.53	0.00	38.92	189.36	11.93	0.00
APR 7	13.70	8.04	0.22	5.16	0.00	13.41	0.00	0.00	0.18	0.28	0.00	0.00	0.46	0.00	38.99	189.13	11.93	0.00
APR 8	0.00	0.00	2.05	4.77	0.00	6.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.37	186.09	11.77	0.00
APR 9	4.70	2.41	4.71	4.39	0.00	11.51	0.00	0.00	0.26	0.00	0.00	0.00	0.26	0.00	26.68	187.64	11.82	0.00
APR10	16.00	9.73	2.24	4.94	0.00	16.91	0.00	0.00	0.23	0.00	0.00	0.00	0.23	0.00	23.05	189.99	11.96	0.00
APR11	0.00	0.00	0.20	4.87	0.00	5.07	0.00	0.00	0.00	0.19	0.00	0.00	0.19	0.00	22.51	185.49	11.74	0.00

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APR12   0.00   0.00   0.16   3.78   0.00   3.94   0.00   0.00   0.80   0.20   0.00   0.00   0.20   0.00  21.96 182.11  11.53   0.00
APR13   0.00   0.00   1.65   3.20   0.00   4.86   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  17.79 181.48  11.46   0.00
APR14   0.00   0.00   8.35   3.55   0.00  11.91   0.00   0.00   0.00   0.00   0.66   0.00   0.66   0.00   0.00 186.42  11.75   0.00
APR15   7.40   3.68   0.00   4.21   0.00   7.89   0.00   0.00   0.25   0.00   0.44   0.00   0.70   0.00   0.00 185.26  11.72   0.00


MAY20   1.50   0.36   0.00   2.72   0.00   3.07   0.00   0.00   0.47   0.00   0.59   0.33   1.39   0.00   0.00 177.62  11.29   0.00
MAY21   0.00   0.00   0.00   2.34   0.00   2.34   0.00   0.00   0.00   0.00   0.46   0.35   0.81   0.00   0.00 174.66  11.11   0.00
MAY22   1.50   0.24   0.00   1.95   0.00   2.20   0.00   0.00   0.52   0.00   0.42   0.43   1.37   0.00   0.00 172.72  10.98   0.00
MAY23   0.00   0.00   0.00   1.69   0.00   1.69   0.00   0.00   0.00   0.00   0.42   0.54   0.96   0.00   0.00 170.21  10.84   0.00
MAY24   0.10   0.01   0.00   1.44   0.00   1.45   0.00   0.00   0.04   0.00   0.40   0.65   1.09   0.00   0.00 167.91  10.70   0.00
MAY25  12.90   2.62   0.00   1.42   0.00   4.04   0.00   0.00   0.52   0.00   0.27   0.53   1.31   0.00   0.00 175.18  10.98   0.00
MAY26   4.00   0.93   0.00   1.93   0.00   2.86   0.00   0.00   0.52   0.00   0.24   0.56   1.32   0.00   0.00 174.90  11.08   0.00
MAY27   0.00   0.00   0.00   1.92   0.00   1.92   0.00   0.00   0.00   0.00   0.29   0.83   1.12   0.00   0.00 171.98  10.96   0.00
MAY28   0.00   0.00   0.00   1.63   0.00   1.63   0.00   0.00   0.00   0.00   0.35   1.20   1.55   0.00   0.00 168.96  10.80   0.00
MAY29   0.00   0.00   0.00   1.35   0.00   1.35   0.00   0.00   0.00   0.00   0.28   1.13   1.41   0.00   0.00 166.37  10.63   0.00
MAY30   0.00   0.00   0.00   1.13   0.00   1.13   0.00   0.00   0.00   0.00   0.23   1.13   1.36   0.00   0.00 164.03  10.49   0.00
MAY31   0.00   0.00   0.00   0.97   0.00   0.97   0.00   0.00   0.00   0.00   0.21   1.20   1.41   0.00   0.00 161.79  10.35   0.00
     RUNNING MEAN OPTION

MONTH           MEASURED   SIMULATED   MEAN     ST. DEV.   SM. SQ.    CORR.     MOD CORR  TOTAL      TOTAL
                MEAN       MEAN        DIFF.    OF DIFF.   OF DIFF.   COEF.     COEF.     MEAS FLOW  SIM FLOW

 JUN              1.14       0.84       0.30     0.011      12.34     0.943     0.567      34.2       25.1
 JUL              0.14       0.27      -0.13     0.001       1.29     0.758     0.732       4.2        8.3
 AUG              0.64       1.34      -0.71     0.014      28.78     0.942     0.688      19.8       41.7
 SEP              0.65       1.21      -0.56     0.005      13.73     0.910     0.783      19.5       36.4
 OCT              1.50       1.91      -0.41     0.005       9.85     0.982     0.882      46.6       59.4
 NOV              4.00       3.48       0.53     0.060      60.15     0.987     0.759     120.0      104.3
 DEC              1.75       1.75       0.00     0.016      15.34     0.901     0.639      54.2       54.2
 JAN              0.74       1.10      -0.36     0.006       9.86     0.987     0.512      22.9       34.1
 FEB              0.54       0.84      -0.30     0.001       3.52     0.674     0.322      15.0       23.4
 MAR              1.54       1.42       0.12     0.008       7.42     0.968     0.879      47.7       44.0
 APR              8.96       8.49       0.47     1.178    1031.77     0.669     0.464     268.7      254.6
 MAY              3.84       2.64       1.21     0.111     148.38     0.474     0.194     119.1       81.7
TOTAL             2.12       2.10       0.01     0.010    1342.44     0.862     0.688     772.0      767.2

1                 JUN      JUL      AUG      SEP      OCT      NOV      DEC      JAN      FEB      MAR      APR      MAY      TOTAL

  INTSNO,END     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
  SNOW,END       0.00     0.00     0.00     0.00     0.00     0.00    50.98    57.19   140.54   120.82     0.00     0.00
  EZONE,AV     150.05   132.83   146.88   156.82   167.19   171.75   168.50   161.99   161.76   163.65   182.63   172.79
  EZONE,END    127.17   113.55   155.52   164.68   162.63   174.19   159.89   170.13   157.39   181.92   165.42   161.79
  UZONE,AV       9.76     8.92     9.54    10.05    10.59    10.86    10.66    10.21    10.23    10.31    11.55    10.95
  UZONE,END      8.80     8.30    10.12    10.44    10.32    10.82    10.11    10.76     9.94    11.46    10.51    10.35
  GWZONE,END     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
```

```
 MESFLO,RAW     34.20    4.20   19.80   19.50   46.70  120.40   53.80   22.90   15.00   44.80  271.70  119.00    772.00
 SIMFLO,RAW     25.13    8.29   41.73   36.22   59.52  104.66   53.75   34.16   23.36   40.45  258.26   81.62    767.14
 PRECIP        105.80   96.90  193.40  116.20   82.40  134.20   99.40   57.20   99.10   52.90  132.50  108.30   1278.30
 TRANSPIR.      81.30   83.91   81.75   58.97    7.60    0.00    0.00    0.00    0.00    0.00    0.00    9.35    322.88
 SOIL EVAP.      3.11    2.10    1.92    2.13   13.97   13.94    4.91    0.00    0.00    0.00    8.02   14.79     64.87
 SNOWVAP         0.00    0.00    0.00    0.00    0.00    0.15    1.61    3.43    2.09    3.68    1.20    0.00     12.15
 RAIN INT.      20.51   16.73   24.21    9.39    3.49    3.36    0.79    0.74    0.14    0.85    3.27    6.33     89.81
 INTVAP          0.00    0.00    0.00    0.00    0.00    0.04    2.37    1.76    3.72    1.59    0.00    0.00      9.49
 TOT. EVAP.    104.92  102.74  107.87   70.49   25.06   17.48    9.68    5.93    5.95    6.12   12.49   30.47    499.20
 PE             95.78  104.86   91.22   55.58   35.92   25.04   14.27   14.19   10.09   19.55   31.86   48.23    546.59
 SNOWINT         0.00    0.00    0.00    0.00    0.00    0.04    2.37    1.76    3.72    1.59    0.00    0.00      9.49
 SNOWFALL        0.00    0.00    0.00    0.00    0.00    0.76   60.23   37.44   92.48   33.81    0.00    0.00    224.71
 SNOWINFIL.      0.00    0.00    0.00    0.00    0.00    0.49    6.71   25.97    8.58   45.65   48.87    0.00    136.28
 INFIL.         76.45   76.85  148.45   93.26   59.93   81.52   25.84   11.28    0.00    7.72   54.78   76.26    712.34
 EDRAIN         15.38    4.46   22.81   22.99   40.41   56.51   41.93   27.01   21.32   28.84  112.12   55.76    449.54
 INTERFLOW      16.30    4.96   20.98   22.68   40.54   56.01   42.65   26.35   22.14   27.32  113.06   55.92    448.91
 UDRAIN          0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00      0.00
 GRD. SEEP.      0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00      0.00
 GRD. FLOW       0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00      0.00
 SURFLOW         8.84    3.32   20.75   13.55   18.98   48.52    9.36    1.45    0.00    1.40   73.76   25.71    225.63
 SNOWFLOW        0.00    0.00    0.00    0.00    0.00    0.13    1.75    6.35    1.22   11.72   71.44    0.00     92.61
 AV. TEMP.      17.37   18.89   17.94   11.87    6.55    3.48   -4.75   -5.06   -9.88   -4.39    2.16    6.77      5.16
1. PRECIP    * MESFLO    + SIMFLO
                               0.00      2.50      5.00      7.50     10.00     12.50     15.00     17.50     20.00     22.50     25.00
                               I+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
 JUN  1   1   0.    0.    8.9  I.+ *
 JUN  2   2   0.    0.   12.8  I.+*
 JUN  3   3   0.    0.   15.6  I.+*
 JUN  4   4   0.    0.   18.9  I. *+
 JUN  5   5  22.    0.   21.1  I   +*
 JUN  6   6   1.    0.   22.8  I  .+*
 JUN  7   7   0.    0.   20.0  I.+  *
 JUN  8   8   1.    0.   18.3  I  +2
 JUN  9   9   9.    0.   15.0  I        +   *
 JUN 10  10  36.    0.    7.8  I          +      *
 JUN 11  11   0.    0.   10.0  I.          +       *
 JUN 12  12   0.    0.   14.4  I.     +    *
 JUN 13  13   0.    0.   12.8  I.     2
 JUN 14  14   7.    0.   22.2  I     *+
 JUN 15  15   3.    0.   18.3  I      *+
 JUN 16  16  14.    0.   13.3  I      + *
 JUN 17  17   0.    0.   16.7  I.     + *
 JUN 18  18   0.    0.   16.7  I.   + *
 JUN 19  19   0.    0.   17.8  I.  2
 JUN 20  20   0.    0.   20.6  I. 2
 JUN 21  21   0.    0.   17.8  I. 2
 JUN 22  22   0.    0.   17.8  I.*+
 JUN 23  23   0.    0.   20.0  I.2
 JUN 24  24   0.    0.   22.2  I.2
 JUN 25  25   6.    0.   13.3  I 2
 JUN 26  26   3.    0.   17.8  I 2
 JUN 27  27   0.    0.   24.4  I.2
 JUN 28  28   0.    0.   23.3  I.2
 JUN 29  29   5.    0.   21.7  I*+
```

```
JUN 30  30   1.   0.  18.9  I.
JUL  1  31   0.   0.  20.0  I
JUL  2  32   0.   0.  23.3  I
JUL  3  33   0.   0.  26.7  I
JUL  4  34   0.   0.  21.1  I
JUL  5  35   0.   0.  20.0  I.
JUL  6  36  51.   0.  16.7  I
JUL  7  37   0.   0.  22.2  I.
JUL  8  38   1.   0.  19.4  I
JUL  9  39   0.   0.  18.9  I.
JUL 10  40  18.   0.  20.0  I
JUL 11  41   0.   0.  20.6  I.
JUL 12  42   1.   0.  21.1  I
JUL 13  43   2.   0.  22.2  I
JUL 14  44   0.   0.  17.8  I
JUL 15  45   0.   0.  15.6  I


MAR 15 288   0.   7.  -3.3* I
MAR 16 289   0.   4. -12.2* I
MAR 17 290   0.   0. -17.2* I.
MAR 18 291   0.   0. -18.9* I.
MAR 19 292   0.   0. -12.2* I.
MAR 20 293   0.   0.  -6.7* I.
MAR 21 294   0.   0.  -6.7* I.
MAR 22 295   0.   0.  -5.6* I.
MAR 23 296   0.   1.  -3.3* I
MAR 24 297   0.   0.  -1.1* I.
MAR 25 298   0.   0.   0.0* I.
MAR 26 299   0.   0.   3.3* I.
MAR 27 300   2.   0.   1.7* I
MAR 28 301   4.   0.   3.3* I
MAR 29 302   0.   0.   2.8* I.
MAR 30 303   0.   0.   2.8* I.
MAR 31 304   0.   0.   2.8* I.
APR  1 305   0.   0.   8.3* I.
APR  2 306   4.   0.  10.0* I
APR  3 307   7.   0.   4.4* I
APR  4 308   0.   0.  -5.6* I.
APR  5 309   0.   0.   5.0* I.
APR  6 310  16.   0.   0.0* I
APR  7 311  14.   0.  -2.2* I
APR  8 312   0.   0.   1.1* I.
APR  9 313   5.   0.   2.8* I
APR 10 314  16.   0.   1.1* I
APR 11 315   0.   0.  -7.8* I.
APR 12 316   0.   0.  -6.7* I.
APR 13 317   0.   0.   2.8* I.
APR 14 318   0.   0.   8.3  I.
APR 15 319   7.   0.   2.2  I
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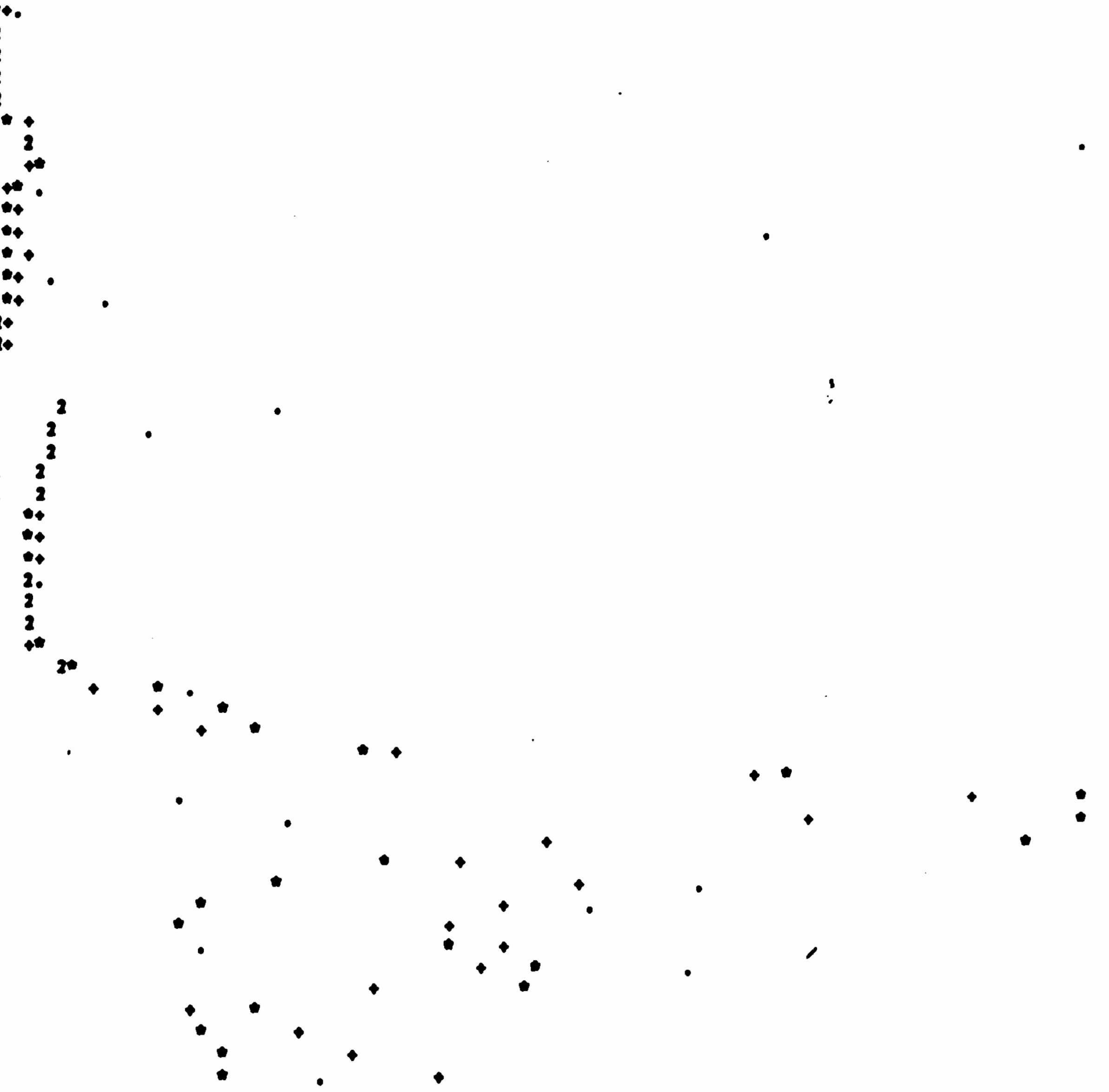

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MAY 20 354   2.   0.  10.0 I
MAY 21 355   0.   0.   7.2 I.
MAY 22 356   2.   0.   7.2 I
MAY 23 357   0.   0.   8.3 I.
MAY 24 358   0.   0.   8.9 I.
MAY 25 359  13.   0.   3.9 I
MAY 26 360   4.   0.   3.3 I
MAY 27 361   0.   0.   7.8 I.
MAY 28 362   0.   0.  12.2 I.
MAY 29 363   0.   0.  10.0 I.
MAY 30 364   0.   0.   8.9 I.
MAY 31 365   0.   0.   8.9 I.
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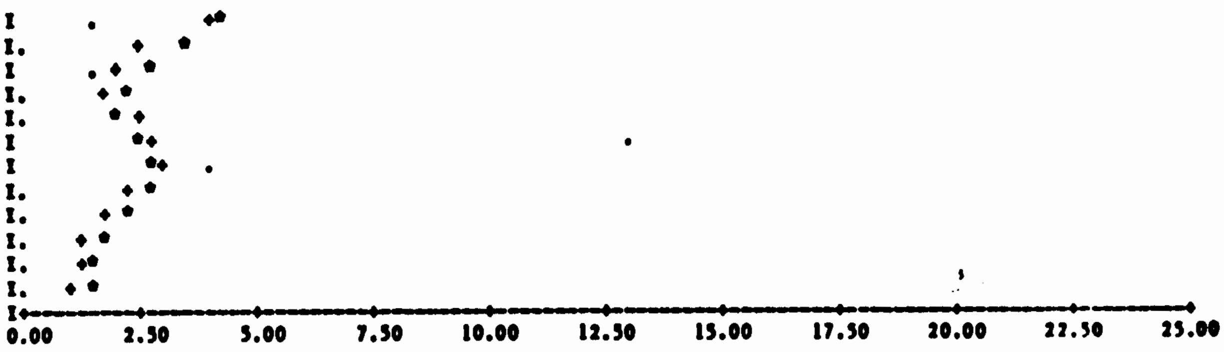

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1
1. UZONE    * SNOW    + EZONE
 UZONE SCALE FACTOR = 1.00
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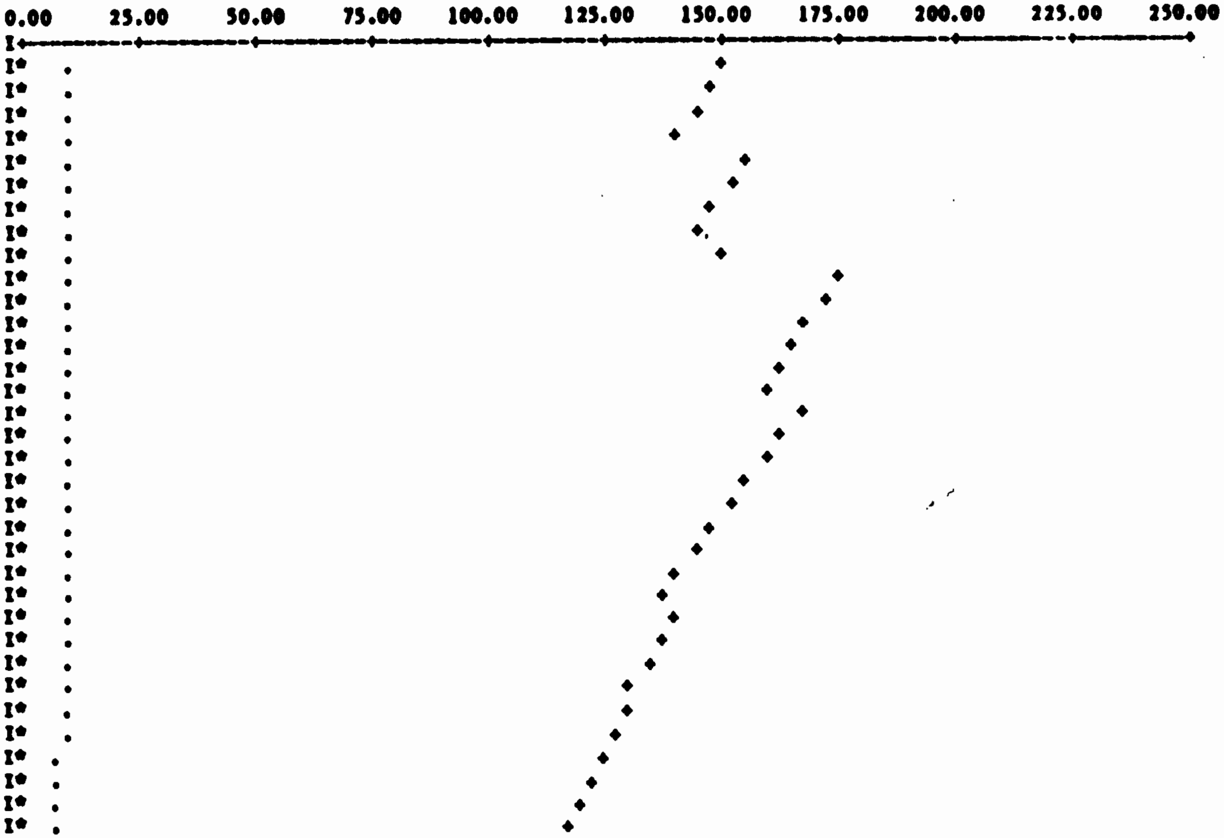
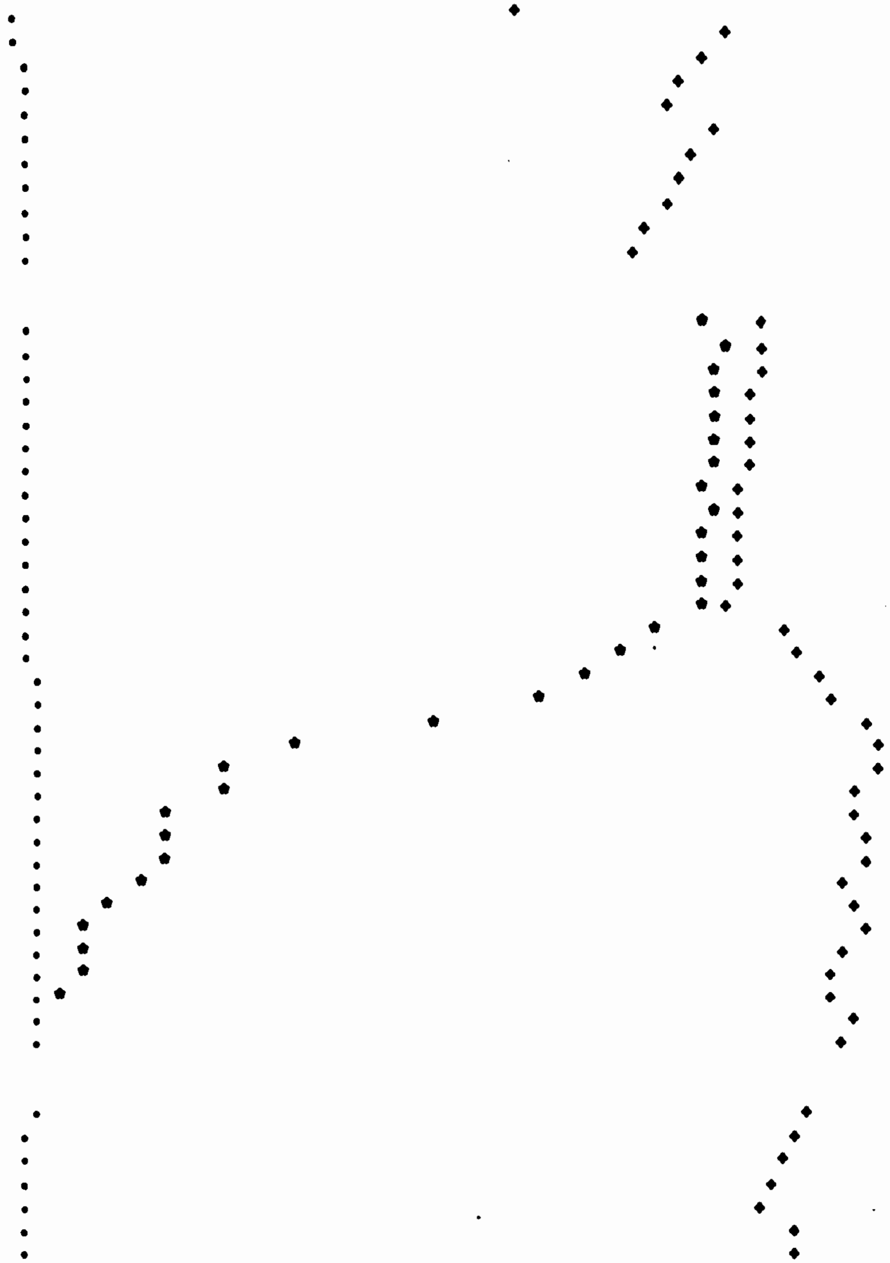


```
 JUN  1  1   0.   0.   8.9 I*
 JUN  2  2   0.   0.  12.8 I*
 JUN  3  3   0.   0.  15.6 I*
 JUN  4  4   0.   0.  18.9 I*
 JUN  5  5  22.   0.  21.1 I*
 JUN  6  6   1.   0.  22.8 I*
 JUN  7  7   0.   0.  20.0 I*
 JUN  8  8   1.   0.  18.3 I*
 JUN  9  9   9.   0.  15.0 I*
 JUN 10 10  36.   0.   7.8 I*
 JUN 11 11   0.   0.  10.0 I*
 JUN 12 12   0.   0.  14.4 I*
 JUN 13 13   0.   0.  12.8 I*
 JUN 14 14   7.   0.  22.2 I*
 JUN 15 15   3.   0.  18.3 I*
 JUN 16 16  14.   0.  13.3 I*
 JUN 17 17   0.   0.  16.7 I*
 JUN 18 18   0.   0.  16.7 I*
 JUN 19 19   0.   0.  17.8 I*
 JUN 20 20   0.   0.  20.6 I*
 JUN 21 21   0.   0.  17.8 I*
 JUN 22 22   0.   0.  17.8 I*
 JUN 23 23   0.   0.  20.0 I*
 JUN 24 24   0.   0.  22.2 I*
 JUN 25 25   6.   0.  13.3 I*
 JUN 26 26   3.   0.  17.8 I*
 JUN 27 27   0.   0.  24.4 I*
 JUN 28 28   0.   0.  23.3 I*
 JUN 29 29   5.   0.  21.7 I*
 JUN 30 30   1.   0.  18.9 I*
 JUL  1 31   0.   0.  20.0 I*
 JUL  2 32   0.   0.  23.3 I*
 JUL  3 33   0.   0.  26.7 I*
 JUL  4 34   0.   0.  21.1 I*
```

```
JUL  5  35   0.   0.  20.0  I*
JUL  6  36  51.   0.  16.7  I*
JUL  7  37   0.   0.  22.2  I*
JUL  8  38   1.   0.  19.4  I*
JUL  9  39   0.   0.  18.9  I*
JUL 10  40  18.   0.  20.0  I*
JUL 11  41   0.   0.  20.6  I*
JUL 12  42   1.   0.  21.1  I*
JUL 13  43   2.   0.  22.2  I*
JUL 14  44   0.   0.  17.8  I*
JUL 15  45   0.   0.  15.6  I*

MAR 15 288   0.   7.  -3.3* I
MAR 16 289   0.   4. -12.2* I
MAR 17 290   0.   0. -17.2* I
MAR 18 291   0.   0. -18.9* I
MAR 19 292   0.   0. -12.2* I
MAR 20 293   0.   0.  -6.7* I
MAR 21 294   0.   0.  -6.7* I
MAR 22 295   0.   0.  -5.6* I
MAR 23 296   0.   1.  -3.3* I
MAR 24 297   0.   0.  -1.1* I
MAR 25 298   0.   0.   0.0* I
MAR 26 299   0.   0.   3.3* I
MAR 27 300   2.   0.   1.7* I
MAR 28 301   4.   0.   3.3* I
MAR 29 302   0.   0.   2.8* I
MAR 30 303   0.   0.   2.8* I
MAR 31 304   0.   0.   2.8* I
APR  1 305   0.   0.   8.3* I
APR  2 306   4.   0.  10.0* I
APR  3 307   7.   0.   4.4* I
APR  4 308   0.   0.  -5.6* I
APR  5 309   0.   0.   5.0* I
APR  6 310  16.   0.   0.0* I
APR  7 311  14.   0.  -2.2* I
APR  8 312   0.   0.   1.1* I
APR  9 313   5.   0.   2.8* I
APR 10 314  16.   0.   1.1* I
APR 11 315   0.   0.  -7.8* I
APR 12 316   0.   0.  -6.7* I
APR 13 317   0.   0.   2.8* I
APR 14 318   0.   0.   8.3  I*
APR 15 319   7.   0.   2.2  I*

MAY 20 354   2.   0.  10.0  I*
MAY 21 355   0.   0.   7.2  I*
MAY 22 356   2.   0.   7.2  I*
MAY 23 357   0.   0.   8.3  I*
MAY 24 358   0.   0.   8.9  I*
MAY 25 359  13.   0.   3.9  I*
MAY 26 360   4.   0.   3.3  I*
```



```
MAY 27 361   0.   0.   7.8  I*   .                                                               +
MAY 28 362   0.   0.  12.2  I*   .                                                              +
MAY 29 363   0.   0.  10.0  I*   .                                                             +
MAY 30 364   0.   0.   8.9  I*   .                                                            +
MAY 31 365   0.   0.   8.9  I*   .                                                           +
                            I+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
                            0.00     25.00     50.00     75.00    100.00    125.00    150.00    175.00    200.00    225.00    250.00
1
```

```
                Coweeta Watershed 14  1968-69

LAT    =    35.05     SLOPE =      18.0     ASPECT=    310.0

INC    =    0.750     ISCSNO=     0.045     NT     =      10     CCMAX =      0.40     RSF   =      0.00     GRDMLT=      0.35

PAC    =    25.00     PC     = 0.74E-04     IMPERV=    0.010

CT     =    25.00     CE     =      3.00    PEC    =     1.20

RZDEP =     900.0     UZDEP =    4200.0     KVDEP =     50.0     RZ15   =    0.090

KRINT =0.105E+08      KRSLP =    11.740     KUINT =0.105E+08     KUSLP =   11.740

DRNC   =    0.400     GSC    =   0.0050     GSP    =   0.0000

COVFUN         0.0  3.00   1.0  1.75   2.0  1.00

MELFUN          0.  0.70  172.  2.17  366.  0.70

CCFUN           0.  0.20  172.  0.40  366.  0.20

LAIFUN          1.  0.50  106.  0.50  136.  4.00  289.  4.00  321.  0.50  366.  0.50    0.  0.00    0.  0.00    0.  0.00

SAIFUN          1.  2.00  366.  2.00    0.  0.00    0.  0.00    0.  0.00    0.  0.00

1DATA FILE  C68W4

    INITIAL STORAGE-MAY 1   RZONE=   227.7   UZONE=  1160.8   GWZONE=   244.1   SNOW=     0.0

     RUNNING MEAN OPTION

MONTH            MEASURED  SIMULATED    MEAN    ST. DEV.   SM. SQ.    CORR.     MOD CORR  TOTAL      TOTAL
                 MEAN      MEAN         DIFF.   OF DIFF.   OF DIFF.   COEF.     COEF.     MEAS FLOW  SIM FLOW

 MAY                2.88      2.83      0.05     0.002       1.95     0.793     0.500      89.3       87.6
 JUN                2.01      2.21     -0.20     0.001       1.97     0.944     0.637      60.2       66.2
 JUL                1.42      1.75     -0.33     0.000       3.57     0.894     0.512      44.1       54.2
 AUG                1.35      1.50     -0.14     0.007       7.21     0.977     0.251      41.9       46.4
 SEP                1.04      1.29     -0.25     0.002       3.80     0.864     0.287      31.3       38.8
 OCT                0.93      1.13     -0.20     0.001       1.76     0.630     0.318      28.8       35.1
 NOV                1.21      1.24     -0.03     0.002       1.37     0.784     0.602      36.3       37.1
 DEC                2.07      1.99      0.08     0.007       7.02     0.861     0.801      64.1       61.6
 JAN                2.77      2.93     -0.16     0.007       7.26     0.925     0.888      85.9       90.9
 FEB                5.51      5.11      0.40     0.036      31.70     0.834     0.712     154.2      143.0
 MAR                3.42      3.50     -0.08     0.003       2.87     0.673     0.638     105.9      108.5
 APR                4.58      4.27      0.31     0.021      21.63     0.901     0.733     137.4      128.0
TOTAL               2.41      2.46     -0.05     0.001      92.11     0.956     0.835     879.4      897.5
```

	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	TOTAL
INTSNO,END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SNOW,END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EZONE,AV	225.13	195.61	140.76	154.56	153.97	178.21	223.49	254.08	249.48	257.40	244.99	248.09	
EZONE,END	219.55	154.12	143.08	137.92	166.70	181.45	246.11	264.02	260.23	251.12	237.96	227.12	
UZONE,AV	1139.26	1103.71	1066.51	1038.79	1017.80	1002.04	1001.74	1071.66	1150.75	1225.24	1186.65	1189.20	
UZONE,END	1122.64	1084.97	1051.20	1027.58	1009.65	995.88	1022.05	1133.43	1187.24	1206.83	1177.23	1200.11	
GWZONE,END	236.17	221.42	202.09	182.18	163.73	146.16	131.53	126.15	138.63	178.19	196.36	213.36	
MESFLO,RAW	89.30	60.20	44.10	41.60	31.60	28.80	36.00	64.50	84.70	155.20	106.00	137.30	879.30
SIMFLO,RAW	87.61	66.25	54.21	46.33	38.85	35.09	36.41	62.63	88.52	145.29	108.31	127.94	897.46
PRECIP	146.90	83.00	106.90	118.00	119.70	82.10	135.60	198.90	166.20	210.10	105.00	204.70	1677.10
TRANSPIR.	86.47	110.38	77.31	93.82	69.35	48.61	9.93	3.02	3.38	3.85	5.88	20.91	532.92
SOIL EVAP.	2.66	2.32	2.70	2.57	1.54	1.49	6.64	5.83	6.36	6.21	11.32	17.41	67.06
SNOWVAP	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.32	0.00	0.00	0.00	0.45
RAIN INT.	24.33	21.90	36.80	23.97	17.54	13.50	6.07	3.49	4.98	3.46	4.07	9.37	169.47
INTVAP	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.13	1.25	0.00	0.00	1.59
TOT. EVAP.	113.47	134.60	116.81	120.36	88.43	63.60	22.98	12.34	15.17	14.76	21.27	47.70	771.50
PE	95.75	119.22	140.40	139.31	90.41	66.83	42.53	30.03	32.08	32.24	44.10	76.68	909.58
SNOWINT	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.13	1.25	0.00	0.00	1.59
SNOWFALL	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	1.86	19.85	0.00	0.00	23.81
SNOWINFIL.	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	1.40	18.14	0.00	0.00	21.41
INFIL.	116.48	58.78	69.14	92.39	100.57	67.25	121.00	174.13	140.28	156.95	92.87	168.76	1358.60
EDRAIN	35.51	11.51	0.16	1.16	0.90	2.40	41.64	147.37	135.72	174.14	88.83	141.27	780.60
INTERFLOW	44.17	29.50	20.36	14.87	11.29	9.70	9.28	21.59	49.14	92.73	71.05	71.03	444.69
UDRAIN	29.44	19.67	13.57	9.91	7.53	6.47	6.19	14.39	32.76	61.82	47.37	47.35	296.46
GRD. SEEP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRD. FLOW	37.36	34.42	32.90	29.82	25.97	24.04	20.81	19.77	20.28	22.26	29.20	30.35	327.18
SURFLOW	6.09	2.32	0.96	1.64	1.59	1.35	6.23	21.28	18.94	28.60	8.06	26.57	123.63
SNOWFLOW	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.15	1.72	0.00	0.00	1.96
AV. TEMP.	15.51	19.39	22.00	22.67	17.48	13.01	7.64	2.44	2.83	4.00	5.63	13.68	12.23

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