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A WATER RESOURCE MANAGEMENT MODEL,
UPPER JORDAN RIVER DRAINAGE, UTAH

by

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Craig T. Jones
J. Paul Riley

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PRWG91-1

ABSTRACT

As demands upon available water supplies increase within a river basin, there is an accompanying increase in the need to assess the downstream consequences resulting from changes at specific locations within the hydrologic system. This problem is approached in this study by digital computer simulation of the hydrologic system. Modeling concepts are based upon basic relationships which describe the various hydrologic processes. Within a hydrologic system these relationships are linked by the continuity-of-mass principle which requires a mass balance at all points. Spatial resolution is achieved by considering the modeled area as a series of subbasins. The time increment adopted for the model is one month, so that time varying quantities are expressed in terms of mean monthly values. The model is general in nature and is applied to a particular hydrologic system through a programmed verification procedure whereby model coefficients are evaluated for the particular system.

In this study the model was applied to the Provo River basin of northern Utah, with emphases being placed upon water rights and operation of storage reservoirs within the system, including Utah Lake. The simulation model consists of three specific parts, namely: (1) parameter optimization; (2) river basin management; and (3) Utah Lake operation. The parameter optimization submodel identifies the model parameters for each subbasin through application of a parameter optimization technique. The river basin management submodel, using the optimized parameters, simulates the hydrologic response of the system to various water resources management alternatives. The Utah Lake operation submodel is linked with the river basin management submodel to comprise a combined Utah Lake operations model. Some comparisons between observed and computed outflow hydrographs at various points within the Provo River basin are shown. The utility of the model for predicting the effects of various possible water resource management alternatives is demonstrated.

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KEYWORDS–hydrologic models*/hydrologic simulation*/computer simulation*/simulation*/groundwater/watershed studies*/snowmelt/evapotranspiration/deep percolation/water yields/hydrologic relationships/hydrologic research*/hydrology/hydrologic data/evaporation*/water salinity management*/water resource planning and management*

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This publication represents the final report of a project which was supported primarily with funds provided by the U.S. Bureau of Reclamation of the United States Department of the Interior. The project involved a cooperative study between personnel from Utah State University and the U.S. Bureau of Reclamation, Central Utah Project Office, Provo, Utah, whereby a computer simulation model was developed for managing water resource systems. The model, although general in nature, is applied to the Provo River basin in Central Utah. The study involved rather detailed considerations of both surface and groundwater hydrology, and has required that other constraints be included, such as water rights and reservoir operating rules for multi-purpose development.

For this reason, counterpart teams of professionals were established at both the University and at the Provo District Office of the Bureau of Reclamation. Throughout the study there was a high degree of interchange through numerous meetings and discussions both at the University and at the Bureau offices in Provo. The teams from the University and the USBR have worked closely in developing and testing the model, and since then jointly have conducted several management studies involving water resource use and development in the Provo River basin, and the relationship of this resource use to the Central Utah Project being planned by the USBR. Personnel of the Bureau involved in the study are now thoroughly acquainted with the model and its development procedure, and are capable of applying it to various kinds of management studies in the future. This study has served to demonstrate that close cooperation between researchers and users, and the rapid "feedback" which this cooperation promotes, can lead to a highly effective application of research results.

The authors express gratitude to all who contributed to the success of this study. Particularly, special thanks are extended to Mr. Palmer DeLong, Project Manager, Central Utah Project, U.S. Bureau of Reclamation. The USBR supplied most of the financial support for this study, and in addition, Mr. DeLong and his staff provided valuable suggestions and direction throughout the entire project. In this respect, special acknowledgement is due to Mr. L. Gayle Moore, Chief of the Water Resources Branch, and to Mr. C. Roe Allman and Mr. Michael D. Staver, all of whom are engineers with the Central Utah Project Office, USBR, and who made substantial contributions during all phases of the study.

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CHAPTER I

INTRODUCTION

This project was initiated in June 1970 with the signing of a cooperative agreement between the United States Bureau of Reclamation and the Utah Water Research Laboratory at Utah State University to develop a hydrologic simulation model for the Upper Jordan River drainage. The main objective of the study, as outlined in the original agreement between the two agencies, was to develop and verify a hydrologic computer model for the study area which is capable of determining the following:

1. Various water yields and outflows of the system under different operation criteria.
2. The capacity of the proposed Jordanelle Reservoir under various operation rules.
3. The water quality of Utah Lake as affected by various methods of satisfying demands.
4. The influence of different water management alternatives on the groundwater flow in the Utah Valley. including the variation of piezometric pressure.

Due to the lack of data for sophisticated groundwater analysis and the recognition of the importance of water right constraints on the system, the original agreement was modified in April 1972 to delete the analysis of variation in groundwater piezometric elevation and to substitute a consideration of important water right constraints imposed on the system.

To accomplish the objectives, a hybrid computer model first was developed for the Provo River Basin. Under this initial step the capability of the proposed hydrologic simulation model was tested and improved. This model subsequently was programmed on a digital computer for use by the Bureau of Reclamation, and expanded to include the entire Upper Jordan River drainage, with emphasis being placed upon the operation of Utah Lake.

The simulation model discussed in this report consists of three specific parts, each of which was developed independently, and is capable of functioning as a separate entity. However, when combined into a single model, each of the three separate models becomes a component or submodel of the whole, and is referred to as such throughout this report. The three components, or submodels, perform the following specific functions or operations: (1) parameter optimization; (2) river basin management; and (3) Utah Lake operation. The parameter optimization submodel identifies the model parameters for each subbasin of interest through application of a parameter optimization technique. In this way, the simulation model is calibrated for each subbasin in the study area. The river basin management submodel, using the optimized parameters, simulates the hydrologic responses of the system to various water resources management alternatives. Represented by the model are rates of flow at different locations along the stream of interest, evapotranspiration and return flows from agricultural lands, soil moisture variations, reservoir storages, groundwater effluent flows, and other important processes in the hydrologic system. Through the operation of the model, reservoirs may be sized on the basis of different water management alternatives subject to various water right constraints.

The Utah Lake operation model was developed by the Central Utah Project Office of the Bureau of Reclamation to facilitate a study of the effects of the Central Utah Project on the hydrology of the lake, and particularly to evaluate the effects of diking within the boundaries of the present lake. When this model is linked with the river basin management model, the two become components or submodels of the so-called combined Utah Lake operations model. A water quality component was also incorporated into the combined model to enable the simulation of the variation of total dissolved solids in Utah Lake as a function of different water management schemes.

In this report, emphasis is placed upon the construction and application of the simulation model rather than upon the numerical values of the simulated results. Chapter II includes a brief description of the study area and the background behind the study, while Chapter III describes the mathematical equations used to describe the important hydrologic processes in the system. The computer version of the simulation model together with a discussion of the application of the model to the study area, are presented in Chapter IV. Chapter V discusses the results of the research and suggests the direction for further study.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Location

The Upper Jordan River drainage, covering an area of approximately 3,000 square miles, is located in the central part of the State of Utah, as shown in Figure 2.1. The area is part of the drainage system of the Great Salt Lake, which in turn is a part of the Great Basin.

Climate

The climate of the Upper Jordan River drainage may be described as temperate and semi-arid. Relatively low precipitation, low humidity, and high evaporation characterize the area. The summers are usually mild and the winters are cold, particularly in the higher elevations. The climatological characteristics of the area are summarized in Table 2.1 (Huntzinger, 1971).

Precipitation

Generally, the precipitation in the area decreases in a westerly direction from the Wasatch Mountains. In the lower valleys surrounding Utah Lake, the average annual precipitation varies from 12 to 16 inches. On the high peaks of the Wasatch Mountains, the average annual precipitation is more than 30 inches. The mountain valleys receive from 15 to 20 inches of precipitation annually.

Temperature

The mean annual temperatures on the valley floors surrounding Utah Lake range from 40 to 50 degrees Fahrenheit, while in the higher valleys of the Wasatch Mountains, corresponding temperatures are between 35 and 45 degrees Fahrenheit. A good summary of the temperature variation with respect to space and time within the study area is given in Hyatt et al. (1969). The locations of temperature and precipitation stations within and adjoining the Upper Jordan River drainage are shown in Figure 2.2, and the name of each station is listed in Table 2.2.

Land Use

Agriculture is the largest user of land within the Upper Jordan River drainage. There are approximately 220,000 acres of agricultural land in the area. Of this acreage, more than 160,000 acres are irrigated. Alfalfa, pasture, grain, corn, sugar beets, and orchards are representative irrigated crops, with the largest amount of irrigated land being used for alfalfa and pasture.

In addition, some land within the basin is occupied by settlements, with the largest of these being Provo. A list of population within each urban settlement is found in Huntzinger (1971).

Drainage System

The drainage system within the area includes Salt Creek, Santaquin Creek, Payson Creek, Spanish Fork River, Hobble Creek, Provo River, American Fork River, Dry Creek, and all tributaries between these streams as shown in Figure 2.2. Of these streams, the most important ones are the Provo River and the Spanish Fork River. The locations of important gaging stations for the streams within the area also are shown in Figure 2.2, with the name of each station listed in Table 2.2.

The Provo River, which drains an area of 680 square miles, originates at the western end of the Uinta Mountains, east of Kamas, Utah, and flows southwesterly about 60 miles past the south end of Kamas Valley, through Heber Valley, down Provo Canyon, and finally discharges into Utah Lake. The natural flow of the river averages about 260,000 acre-feet annually measured at Vivian Park below the confluence with South Fork.

The Spanish Fork River heads in the Wasatch Plateau west of Soldier Summit, flows across the southern part of Utah Valley, and also discharges into Utah Lake. The natural flow of the river averages about 150,000 acre-feet annually at Castilla, three miles downstream from Diamond Fork.

Reservoirs and Streamflow Regulations

Streamflow regulation has occurred along the Spanish Fork and Provo Rivers, but there is as yet little regulation on any other streams within the area. Fifteen small reservoirs have been developed at the headwaters of the Provo River, which contribute about 8,000 acre-feet of irrigation water annually. The Deer Creek Reservoir, located at the lower end of Heber Valley, releases nearly 97,000 acre-feet annually to the Provo River and provides

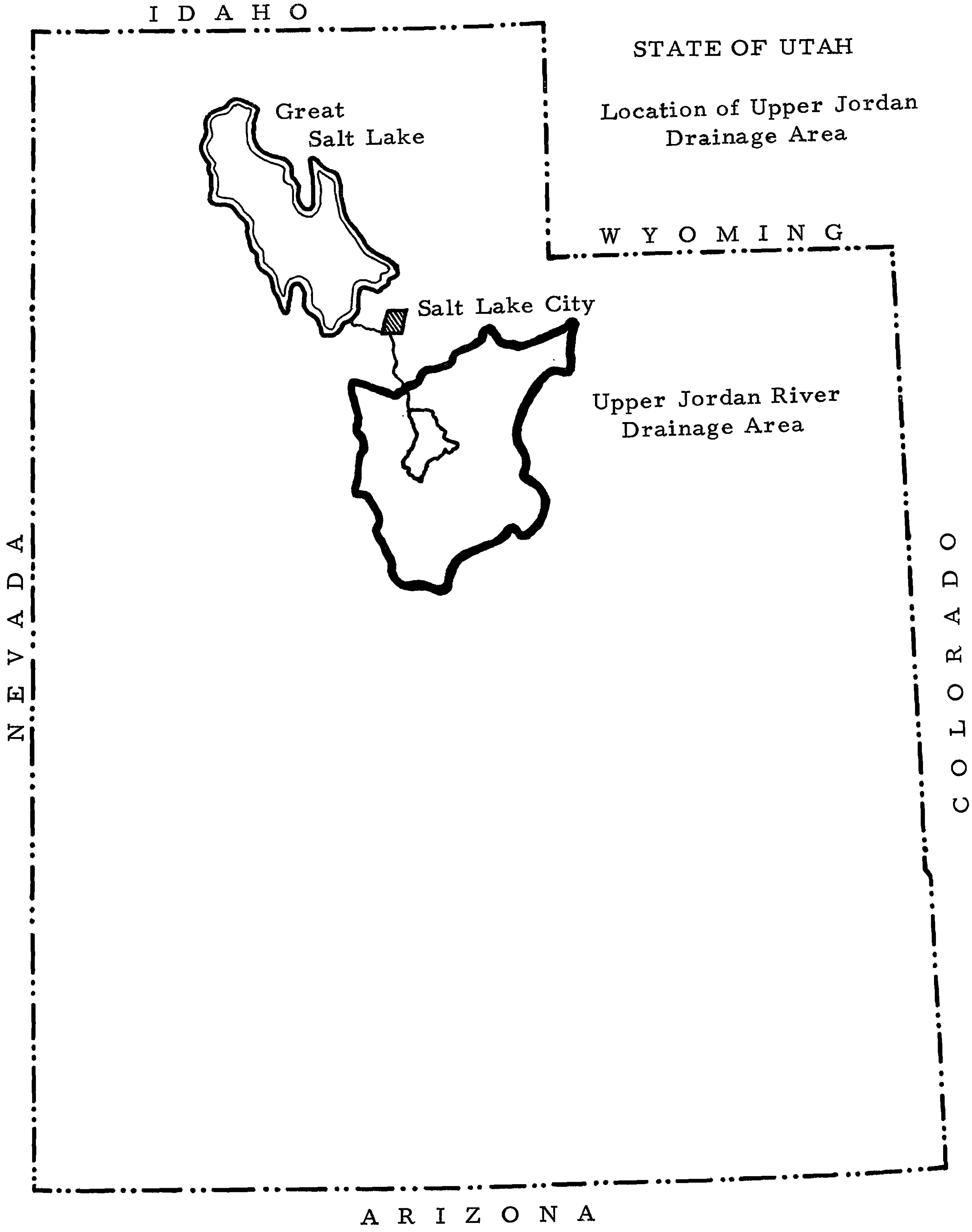


Figure 2.1. Location of the Upper Jordan Drainage area.

Table 2.1. Climatological characteristics of the Upper Jordan Drainage area (Huntzinger, 1971).

Station	Elevation ft.	Mean Annual Precip., In.	Mean Annual Temp., °F	Median frost free period[a]	
				Dates	Days
Utah Lake (Lehi)	4497	9.82	48.6	May 16 to Sep 24	132
Provo	4545	12.81	49.6	May 19 to Sep 22	127
Elberta	4690	10.22	50.6	May 14 to Oct 1	141
Spanish Fork PH	4711	16.79	52.0	May 1 to Oct 15	168
Lower American Fork PH	5044	16.45	52.2	Apr 30 to Oct 21	175
Heber	5593	15.05	44.5	Jun 19 to Sep 4	78
Snake Creek PH	5950	22.25	43.3	Jun 10 to Sep 4	87
Soldier Summit	7460	16.09	38.7	Jun 19 to Aug 13	56

[a] 50 percent probable chance that 32°F will occur after indicated dates.

Table 2.2. Hydrologic measuring stations in the Upper Jordan Drainage area.

Station No.	Station Name
	STREAM GAGING STATIONS
9-2820	Strawberry tunnel at west portal, near Thistle
10-1520	Spanish Fork near Lake Shore
10-1525	Hobble Creek near Springville
9-2725	Duchesne tunnel near Kamas
10-1535	Provo River near Kamas
10-1538	North Fork Provo River near Kamas
10-1540	Shingle Creek near Kamas
10-1545	Weber-Provo diversion canal near Woodland
10-1550	Provo River near Hailstone
10-1590	Dear Creek Reservoir near Charleston
10-1595	Provo River below Deer Creek Dam
10-1630	Provo River at Provo
10-1650	American Fork (River) near American Fork
10-1665	Utah Lake near Lehi
10-1670	Jordan River at narrows, near Lehi
	WEATHER STATIONS
2057	Dear Creek Dam
2418	Elberta
3183	Geneva Steel No. 2
3809	Heber
4467	Kamas
7068	Provo Radio KOVO
7846	Silver Lake
8973	Utah Lake (Lehi)

municipal and industrial water in Salt Lake County through the Salt Lake aqueduct. The Weber-Provo Diversion Canal diverts Weber River water to the Provo River basin, and excess water in the Duchesne River is diverted through Duchesne Tunnel to the Provo River. The Strawberry Reservoir, located in the Uintah Basin, also provides interbasin export through the Strawberry Tunnel into the Diamond Fork River, a tributary of the Spanish Fork River.

Mona Reservoir provides the only significant regulation of a minor stream in the drainage area. This reservoir is located on Currant Creek at the northern edge of Northern Juab Valley. It stores return flows from Northern Juab Valley and Currant Creek flows to supply the Elberta-Goshen irrigation district in the Southern Utah Valley.

Future Outlook

Operation studies in the Upper Jordan River drainage indicate that streamflows in the area need to be augmented and regulated in order to provide sufficient water for projected future requirements (U.S. Bureau of Reclamation, 1964). These requirements include: (1) the replacement storage required for stabilization of the 15 small reservoirs located at the headwaters of the Provo River; (2) additional irrigation water for the area; (3) water to maintain certain minimum streamflows for fish life; and (4) a supply of 70,000 acre-feet for municipal and industrial purposes in northern Utah County and Salt Lake County. These additional water requirements led to

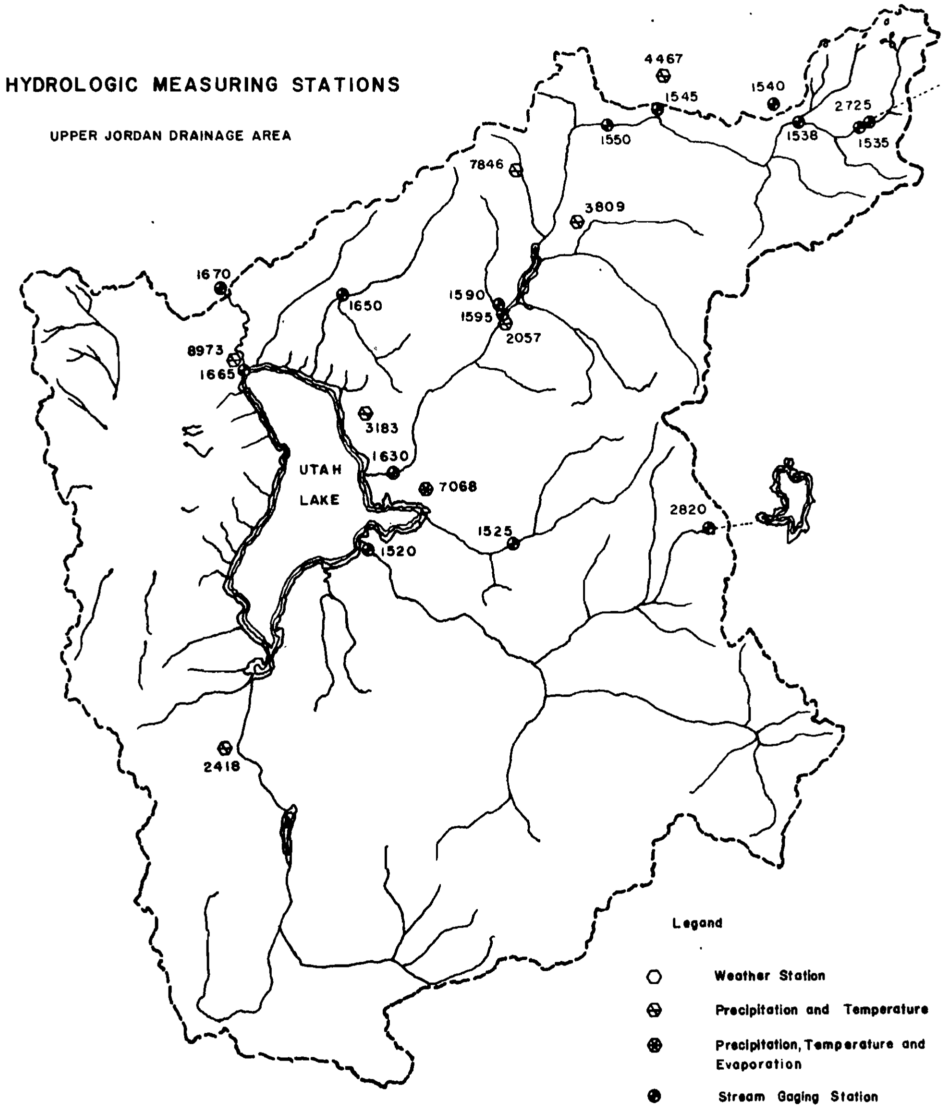


Figure 2.2. Hydrologic measuring stations in the Upper Jordan Drainage area.

the development of proposals which involve the Jordanelle Reservoir and the interbasin importations of water from Weber River, Duchesne River, and Strawberry Reservoir. The Bureau of Reclamation has attempted to evaluate these proposals and to select a proper plan for development. However, the problem is so complex and the possible alternatives so numerous, that additional study still is needed to better understand the behavior of the water distribution system, and to select a suitable plan for developing and managing the available water resources.

CHAPTER III

MATHEMATICAL MODELS

General Considerations

In essence, a simulation analysis is intended to reproduce the behavior or performance of particular variables and processes within the prototype system under study. The more closely the simulation model approximates the real world, the more useful is the prediction obtained from the model.

Simulation models are classified as being either physical or mathematical in nature, depending on the simulation technique. A physical model is a physical representation of the prototype system under the appropriate time and space scaling rules of similitude. Mathematical simulation is achieved by using arithmetic relationships to represent the various processes and functions of the prototype system, and by linking these equations into a systems model. A mathematical model is easily synthesized by means of modern electronic computers. Computer simulation has the following important advantages:

1. The system can be non-destructively tested.
2. Proposed modifications of existing systems can be tested.
3. Many proposals can be studied within a short time period.
4. Hypothetical system designs may be tested for feasibility or comparison with alternate systems.
5. Insight into the system being studied is increased. In particular, the relative importance of various system processes and input functions is suggested.

Model Development

In the development of a hydrologic simulation model, mathematical expressions for the important processes existing in the system are derived and linked by the equations of conservation of mass and/or momentum. For this study, advantage was taken of the simulation models already developed by Riley et al. (1966 and 1967). These models were modified to include water right constraints, and to provide for increased flexibility in using the model to examine various possible water management alternatives.

Time and Spatial Resolutions

The choice of time and spatial increments greatly influences the complexity of model design. When large increments are used, the effects of phenomena which change over small increments of time and space are ignored. As the time and space increments decrease, improved definition of the various processes within the system is required and the model becomes more complex.

Based upon the requirements of the study and the data available, the following spatial and time increments were employed:

1. The entire drainage was divided into seven subbasins, of which six subbasins are in the Provo River Basin.
2. A time increment of one month was used for the entire study.

Hydrologic Balance

Interrelations of the various components of a hydrologic system are achieved by the principles of continuity of mass and momentum. Due to the relatively low velocity of flows within a hydrologic system and the large time increment adopted for the model, the effects of momentum are neglected. Thus, the system is linked only by the continuity of mass concept, which is expressed as:

$$\text{Change in storage} = \text{inflow} - \text{outflow} \quad . \ . \ . \ (3.1)$$

Applying this equation to a hydrologic unit yields a hydrologic balance which is represented schematically in Figure 3.1. Development of the hydrologic model consists of representing, with mathematical expressions, the physical processes which influence the terms in Equation 3.1.

Model Boundaries

A subbasin consists of a hydrologic unit within the main drainage system under investigation. Thus, it is possible to divide a river basin into a series of subbasins with water flows cascading from one to the other in the downstream direction. In this study the modeled area within each subbasin includes only the valley bottom (see Figure 3.2). It is this area that is most subject to the management activities of man, and exclusion of the

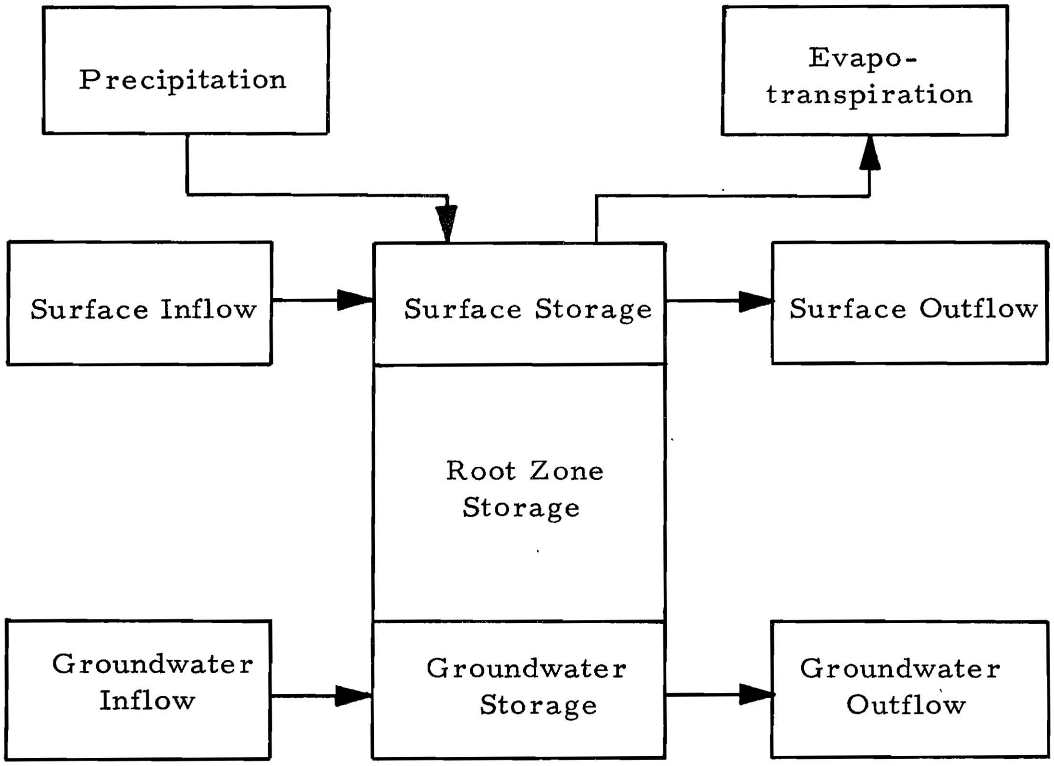


Figure 3.1. A simplified diagram of the hydrologic balance.

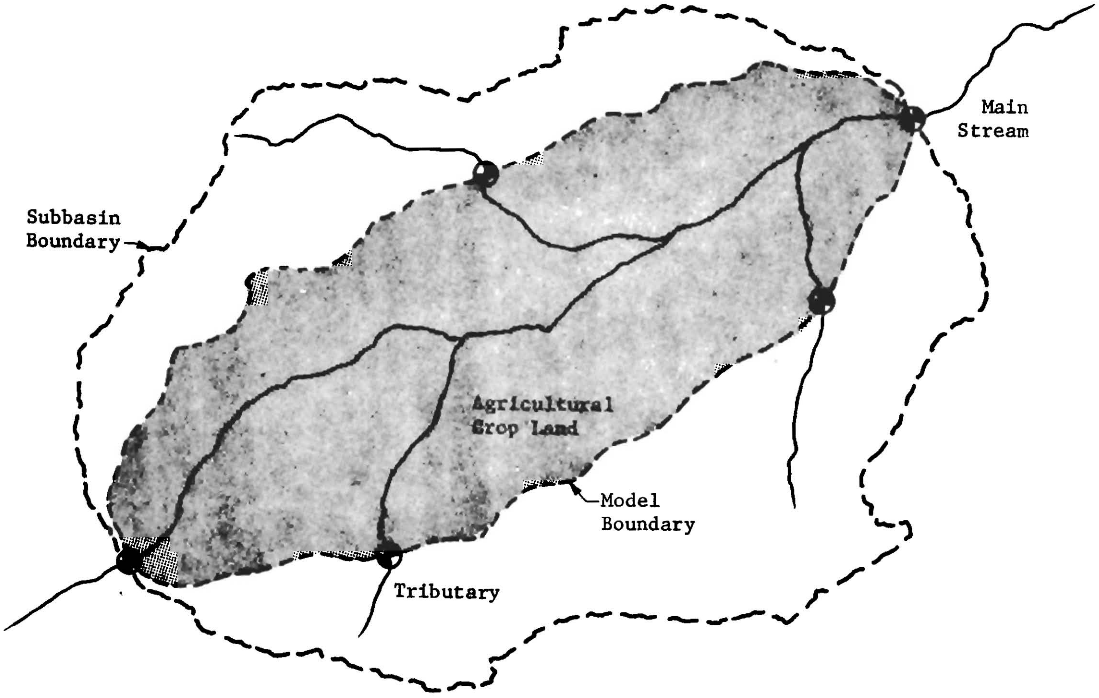


Figure 3.2. Modeled agricultural area within the subbasin.

surrounding watersheds reduces the size of the model. However, in modeling the valley bottom the surrounding watershed areas are considered from the standpoint of their surface and subsurface contributions to the valley floors.

Model Components

A mathematical model which simulates a complex system such as the hydrologic processes of a natural watershed consists of a number of model components, each of which describes a particular phenomenon. The following is a brief description of the important components of the model which are illustrated by Figure 3.1.

Precipitation

Precipitation is the original source of all inputs to a hydrologic unit. Measurements of precipitation are recorded and published by the U.S. Weather Bureau. Such records represent point measurements of precipitation and the use of such data in the model requires converting the data to an average over a specified area. The conversion techniques commonly used include the Thiessen and isohyetal methods. A modified isohyetal technique using the normal isohyetal map was used to estimate average precipitation for each subbasin.

Missing precipitation data are estimated by the normal-ratio method (Paulus and Kohler, 1952) which utilizes information from nearby stations as follows:

$$P_x = \frac{1}{3} \left[\frac{N_x}{N_a} P_a + \frac{N_x}{N_b} P_b + \frac{N_x}{N_c} P_c \right] \quad . . . \quad (3.2)$$

in which

x = the station with missing data
N = normal annual precipitation at each station indicated
P = precipitation at each station indicated over a desired period of time. Three nearby stations are used in this example.

In the present study, precipitation was assumed to occur in the form of rain or snow, and an air temperature criterion was used to indicate the form of precipitation. This index temperature was identified for each subbasin through the model calibration procedure.

Snowmelt

Numerous theoretical and rational formulas have been developed to calculate snowmelt based on various factors, but all necessitate extensive data, and thus their general use is restricted. For the large time increment used in the present model of this study, an empirical relationship presented by Riley et al. (1966) was considered appropriate.

In this relationship the rate of melt is stated as being proportional to an index of available energy and the quantity of water stored as snow. Expressed in mathematical form, the relationship is:

$$\frac{d\left[W_s(t)\right]}{dt} = -k_s\,(T_a - T_m)\,\frac{RI_s}{RI_h}\,W_s(t) \quad . . \quad (3.3)$$

in which

k_s = constant
RI_s = radiation index on a surface possessing a known slope and aspect
RI_h = radiation index for a horizontal surface at the same latitude as the particular watershed under study
T_a = surface air temperature in degrees Fahrenheit
T_m = assumed base temperature in degrees Fahrenheit at which melt begins
$W_s(t)$= snow storage at time t in terms of water equivalent

The ratio of the radiation indices in Equation 3.3 remains constant for a particular area. Thus, the two constant terms can be combined to yield the snowmelt coefficient:

$$K_s = k_s\,\frac{RI_a}{RI_r} \quad . . . . \quad (3.4)$$

Substituting Equation 3.4 into Equation 3.3 and solving the equation, the amount of snow storage at the end of a particular time period can be expressed as:

$$W_s(1) = W_s(0)\,\exp\left[-K_s\,(T_a - T_m)\right] \quad . . . . . . \quad (3.5)$$

in which $W_s(0)$ and $W_s(1)$ are the snow storage at the beginning and end of the time period, respectively.

Temperature

Air temperature, T_a, although not directly involved with water quantities, is an important element for hydrologic study. Air temperature is used as an indicator to determine the form of precipitation and as a basic parameter for calculating snowmelt and evapotranspiration rates.

Temperature measurements are recorded and published by the U.S. Weather Bureau. For the study area, most temperature stations are located in the valley floor.

Temperature in the higher elevations was, therefore, estimated by considering a lapse rate due to elevation difference as:

$$T'_a = T_a - L(El' - El_v) \quad \cdots\cdots \quad (3.6)$$

in which

T'_a = temperature in the higher elevations
T_a = temperature in the valley floor
L = lapse rate, °F/1000 feet
El_v = elevation of the valley floor in thousands of feet
El' = elevation of the higher land in thousands of feet

Gaged Surface Inflow

A portion of the precipitation which falls upon the land moves laterally both on the ground surface and through the soil root zone until it reaches small channels. When these channels reach a stream, they combine with other flow components to form total streamflow.

Stream outflows, both computed and gaged, from upstream subbasins, are treated as gaged inflows to adjacent downstream subbasins. Within a subbasin, the gaged streamflows that flow toward the modeled area also are treated as gaged surface inflows to the model. Many streams in the study area are gaged by the U.S. Geological Survey, and recorded data were used for direct input to the computer. The gaged surface inflow to a modeling area is designated as Q_{gi}.

Ungaged Surface Inflow

The remaining surface inflow consists of all ungaged surface runoff toward the modeling area. This ungaged inflow is estimated by a correlation procedure involving gaged streamflow, rates of rainfall and snowmelt, and a threshold rate for surface runoff. The relationship is expressed as:

$$Q_{ug} = K_1 Q_{cor} + K_2 (P_r + SM_r) + K_3 \quad \cdot\cdot \quad (3.7)$$

in which

Q_{ug} = estimated rate of ungaged surface inflow
Q_{cor} = measured rate of flow in a stream of similar flow pattern
P_r = gaged rainfall rate
SM_r = snowmelt rate which can be determined by taking the difference of $W_s(1)$ and $W_s(0)$ in Equation 3.5 for each time increment
K_1 = regression coefficient relating ungaged surface inflow to gaged streamflow
K_2 = regression coefficient relating ungaged surface inflow to rainfall and snowmelt rates
K_3 = minimum base flow for ungaged surface runoff

Q_{cor} in Equation 3.7 can be selected as the flow either in a tributary of the subbasin being studied or in a stream outside of the basin. The only criterion is that the watershed of the selected stream exhibits the same general runoff characteristics as the ungaged area being simulated. The third term, K_3, in the equation accounts for the integrated effect of rainfall interception, initial infiltration, and groundwater effluent to the ungaged streams.

The total surface inflow to the modeling area is the sum of the gaged and the ungaged components. Thus,

$$Q_{si} = Q_{gi} + Q_{ug} \quad \cdots\cdots\cdots\cdots \quad (3.8)$$

in which Q_{si} is the total surface inflow and the remaining terms are as previously defined.

Groundwater Inflow

This quantity accounts for the subsurface inflow from both the adjacent upstream subbasin and the watershed area within the subbasin being studied. The component from the watershed area within the subbasin is estimated as a residual quantity and the routing characteristics are established through the model calibration procedure. Outflows from the adjacent upstream subbasin already have been estimated. The total groundwater inflow rate is designated by Q_{gw}, which is an ungaged quantity.

Irrigation Diversions

During irrigation seasons, a large portion of the total streamflow is diverted to irrigate crop lands. In addition, water is often pumped from groundwater sources and imported from other basins or subbasins to provide sufficient irrigation water.

In the model, imports of water to the subbasin, both from other subbasins in the drainage and from outside the drainage basin, are treated as surface inflow quantities. In cases where all or a part of the imported water is applied to the land as irrigation, the imported quantity is added to the in-subbasin stream diversions for irrigation. Thus,

$$W_{sd} = W_{cd} + W_{ii} \quad \cdots\cdots\cdots\cdots \quad (3.9)$$

in which

W_{sd} = irrigation diversions from surface supplies within the subbasin for use within the area
W_{cd} = irrigation diversions from streams and reservoirs within the subbasin for use within the area
W_{ii} = irrigation water imported to the subbasin for use within the subbasin

Exports of water, W_x, from the subbasin, whether for irrigation or municipal and industrial use, are treated as separate surface outflow quantities.

The total water available for the irrigation of crop lands within the modeled area is given by the expression:

$$W_d = W_{cd} + W_{ii} + W_{pi}$$

$$= W_{sd} + W_{pi} \quad \ldots\ldots\ldots (3.10)$$

in which

W_d = total diversions of irrigation water for use within the subbasin

W_{pi} = pumped groundwater for irrigation within the subbasin, and the other terms are as previously defined

Municipal and Industrial Diversions

Total water used for municipal and industrial purposes in a subbasin is, like the irrigation water, the algebraic sum of diversions from streams, groundwater pumping, and water that is imported for this purpose. In mathematical form:

$$W_{mi} = W_{cmi} + W_{pmi} + W_{imi} \quad \ldots\ldots (3.11)$$

in which

W_{mi} = total diversions of water for municipal and industrial use within the subbasin

W_{cmi} = municipal and industrial diversions from streams and reservoirs within the subbasin for use within the area

W_{pmi} = groundwater pumped within the subbasin for municipal and industrial use within the area

W_{imi} = water imported to the subbasin for municipal and industrial use within the area

If the terms representing diversions from streams and reservoirs and from imports are combined into a single term which represents diversions from surface sources within the subbasin, W_{smi}, Equation 3.11 becomes:

$$W_{mi} = W_{smi} + W_{pmi} \cdot \ldots\ldots\ldots (3.12)$$

Surface Return Flows

Canal diversions affect the time and spatial distribution of water within an irrigated area. A portion of this diverted water is evaporated directly to the atmosphere, a second part enters the soil profile through canal seepage and infiltration on the irrigated lands, and the remainder returns to the source as overland flow. Some of the water which enters the soil profile is lost through plant consumptive use. The remainder either percolates downward to the groundwater basin or is intercepted by drainage systems. Irrigation practices, therefore, alter the distribution characteristics of a hydrologic system. The irrigation efficiency factor used in this study includes both the conveyance and application efficiencies. Thus, multiplying total diversions by this factor provides an estimate of that quantity of water which returns directly to the stream as overland flow and/or interflow. This composite irrigation efficiency factor is given by the following expression:

$$Eff = 100 \frac{W_i}{W_d} \quad \ldots\ldots\ldots\ldots (3.13)$$

in which

Eff = water conveyance and application efficiency in percent

W_i = rate at which diverted water enters the soil through seepage and infiltration

W_d = total diversion rate of irrigation water for use within the subbasin

As already indicated, a portion of the water diverted for irrigation returns to the streams as overland flow and interflow. Overland flow (often termed tailwater) is surface return flow or runoff from the end of the field resulting from the application of water to the irrigated land at rates exceeding the infiltration capacity of the soil. Interflow is defined as that part of the soil water which does not enter the groundwater basin, but rather which moves largely in a lateral direction through the upper and more porous portion of the soil profile until it enters a surface or subsurface drainage channel. Both the overland flow and the interflow return to the stream channels in short distances and time consisting of usually only a few days. The distribution of canal diversions within the hydrologic system now can be expressed as follows:

$$Q_{ri} = (1 - Eff/100)\, W_d + N_r \quad \ldots\ldots (3.14)$$

or

$$Q_{ri} = (W_d - W_i) + N_r \quad \ldots\ldots\ldots (3.15)$$

in which

Q_{ri} = surface return flow which is defined as being the total of overland flow (from irrigation applications at rates exceeding infiltration capacity rates) and interflow rates

N_r = interflow rate

All other quantities have been previously defined under Equation 3.13.

In model studies involving only the relatively flat lands in the valley bottoms, and further, when a large time increment, such as one month, is employed for the model, it is unnecessary to distinguish between the two components of surface runoff and interflow. Accordingly, in this study no interflow, N_r, is assumed to occur.

It is pointed out that evapotranspiration losses do not appear as such in Equations 3.14 and 3.15. These losses are, however, considered because they are abstracted from the infiltration quantity represented by W_i. The evapotranspiration process will be further discussed in a subsequent section.

Unlike agricultural water, much of the municipal and industrial water which is not consumed is returned to the streams by surface conveyance and does not enter the groundwater system. In equation form, municipal and industrial return flow can be expressed as:

$$Q_{rmi} = (1 - Eff_{mi}) W_{mi} \quad \cdots\cdots (3.16)$$

in which

Q_{rmi} = rate of municipal and industrial return flow

Eff_{mi} = municipal and industrial water use efficiency which also is identified through parameter optimization

W_{mi} is as defined in Equation 3.11.

The total surface return flow, Q_{rt}, thus, can be expressed as

$$Q_{rt} = Q_{ri} + Q_{rmi} \quad \cdots\cdots\cdots\cdots (3.17)$$

Available Soil Moisture

The usual definition of available soil moisture capacity is the difference between the field capacity and the wilting point of the soil. Water within this range is available for plant use, and is termed available soil moisture. The field capacity is defined as the soil moisture content after gravity drainage has occurred. Most of the gravity water drains rapidly from the soil thus affording plants little opportunity for its use. The wilting point represents the soil moisture content when plants are no longer able to abstract water in sufficient quantities to meet their needs, and permanent wilting occurs. Available soil moisture can be expressed in several units but in this report it carries the unit of depth in inches.

Sources of available water. Basically, moisture in the soil is derived from filtration, which is the passage of water through the soil surface into the soil profile. The water available for infiltration at the soil surface is derived from three sources, namely, effective precipitation in the form of rain, P_r, snowmelt, SM_r, and irrigation water, W_i. Because of the flat topography of the lands in the valley bottoms, it is assumed that all water from rainfall and melting snows on the land surface enter the soil mantle through the infiltration process. In the case of irrigated crops, the most important source of available soil moisture is water which is diverted to the agriculture lands. The rate at which water from this source enters the soil profile through canal seepage and infiltration has been designated as W_i. Thus, the total water available for infiltration into the soil, W_{it}, can be written as:

$$W_{it} = W_i + P_r + SM_r \quad \cdots\cdots\cdots (3.18)$$

in which all quantities are as previously defined.

Available soil moisture quantities. The maximum quantity of water in a soil available for use by plants is a function of the moisture holding capacity of the soil and the average rooting depth or extraction pattern of the plant.

The basic forces involved in the absorption of water by plants are osmotic, imbibitional, metabolic, and transpiration pull (Thorne and Peterson, 1954). These forces basically define the soil moisture tension or "pull" that must be exerted by the plant to remove water from the soil. Of these forces the principal one is the osmotic pressure created within plant root cells. Opposing these forces are those exerted on the moisture by the soil particles. The forces exerted by the plants vary with different plants, soils, and climates, but the average maximum force which plants can exert in obtaining sufficient water for growth is approximately 15 atmospheres of pressure. At field capacity where water is readily available for plant use, the average soil moisture tension is only about 0.1 atmosphere. However, the soil moisture tension or "pull" plants exert in their quest for water is in itself no indication of the amount of available water contained by the soil. The actual amount of water held by the soil at any given tension value is a function of the soil type.

Determination of the soil depth effectively utilized by a plant is based on the average rooting depth or the average moisture extraction pattern. The soil moisture available for extraction depends on the moisture holding capacity of the soil and the extraction pattern. The typical agriculture crop extracts 70 percent of its moisture from the upper 50 percent of the soil penetrated by the plant roots. Average or typical rooting depths for various plants are reported by McCullock et al. (1967). Illustrative depths include 4 to 6 feet for alfalfa, 4 feet for grains and corn, and 2 to 3 feet for pasture. The average available soil moisture capacity of the irrigated lands was estimated for each subbasin.

Under normal circumstances, additions to available soil moisture storage occur through the infiltration process, W_{it}. Abstractions or depletions from available soil moisture storage occur through evapotranspirational losses, ET_r, and deep percolation, DP_r. The assumption is made, however, that deep percolation does not occur until the soil moisture capacity is reached. Thus, the soil moisture storage existing at any time, t, can be stated:

$$M_s(t) = (W_{it} - ET_r - DP_r)\, dt \quad \cdots (3.19)$$

The processes of evapotranspiration and deep percolation are discussed in the following sections.

Evapotranspiration

Blaney and Criddle (1950) developed a simple formula for calculating evapotranspiration using temperature and daylight hours. This formula has been widely applied in the arid western states of the country. The equation is written as:

$$U = KF \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.20)$$

in which

U = monthly potential consumptive use

K = monthly coefficient which varies with type of crop

F = monthly consumptive use factor and is given by the following equation:

$$F = \frac{T_a P}{100} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.21)$$

in which

T_a = mean monthly air temperature in degrees Fahrenheit

P = monthly percentage of daylight hours of the year

Phelan (1962) modified the Blaney-Criddle formula by dividing the monthly coefficient, K, into a crop coefficient, K_c and a temperature coefficient, K_t. Expressed mathematically, it is:

$$K = K_c K_t \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.22)$$

The value of K_t is obtained from an empirical relationship depending on temperature and is expressed as:

$$K_t = (0.0173\, T_a - 0.314) \quad \ldots \ldots \quad (3.23)$$

Where T_a is the mean monthly temperature in degrees Fahrenheit. The crop coefficient, K_c, is a function of crop species and stage of growth. Values of K_c are obtained from crop growth stage coefficient curves such as the one shown in Figure 3.3 for dry beans. Similar K_c curves are available for many agricultural crops (Soil Conservation Service, 1964).

The modification by Phelan (1962) of the Blaney-Criddle equation for estimating potential evaporation rate, ET_{pr}, is expressed as:

$$ET_{pr} = \left[K_c K_t \frac{T_a P}{100}\right] \quad \ldots \ldots \ldots \ldots \quad (3.24)$$

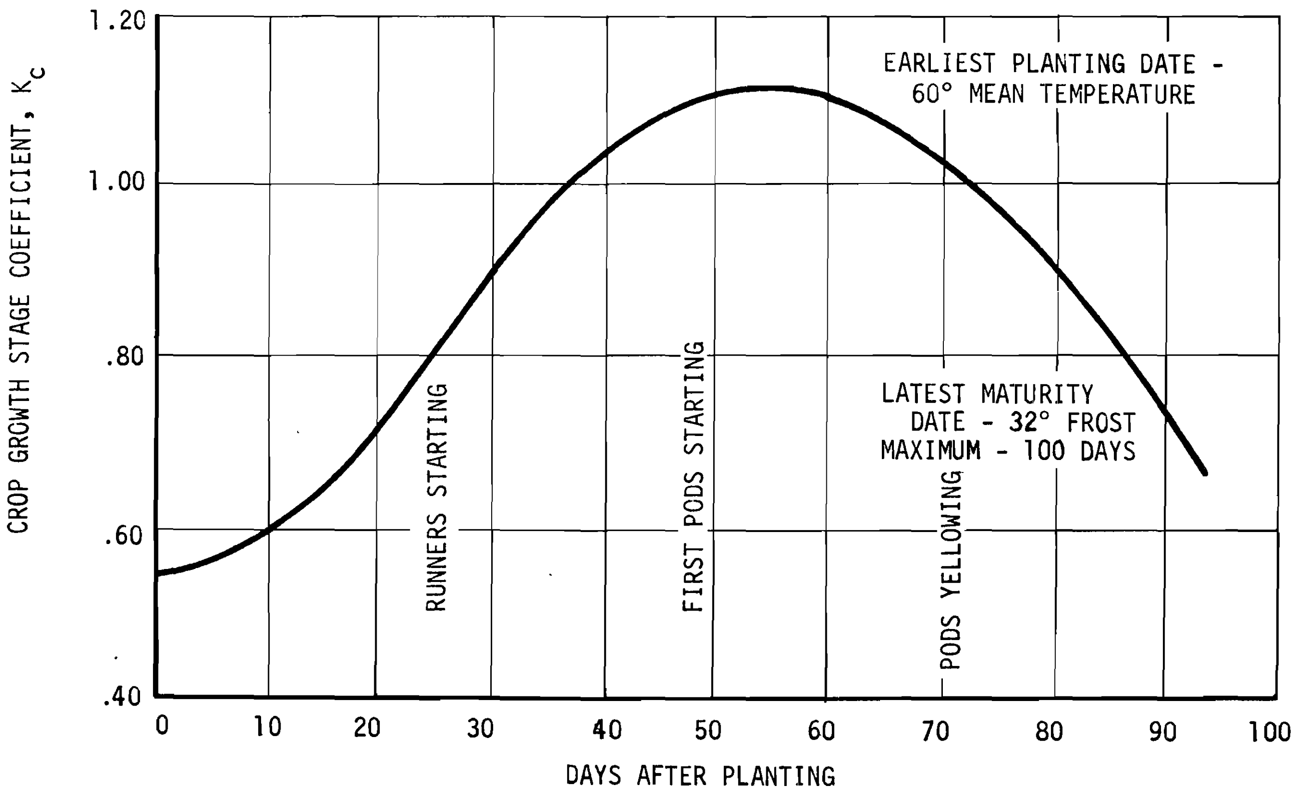


Figure 3.3. Crop growth stage coefficient curve for dry beans.

An additional coefficient, K_u, was introduced to account for the effect of elevation on evapotranspiration as suggested by Hargreaves (1973). Equation 3.24 then becomes:

$$ET_{pr} = K_u K_c K_t T_a P/100 \quad . . . . (3.25)$$

This equation was adopted for this study and was used to estimate monthly potential evapotranspiration rates.

The actual evapotranspiration depends in part on available moisture in the soil. Research at the U.S. Salinity Laboratory in California (Gardner and Ehlig, 1963) indicates that evapotranspiration occurs at the potential rate through approximately two-thirds of the range of available moisture in the root zone. When this point in the available moisture range is reached, soil moisture becomes a limiting factor, and thereafter, the actual evapotranspiration rate lags the potential rate with a virtually linear relationship between available soil moisture content and evapotranspiration rate.

Based on this finding, Riley, Chadwick, and Bagley (1966) expressed the actual evapotranspiration rate as:

$$ET_r = ET_{pr}, \text{ when } M_s(t) \geq M_{es} \quad . . (3.26)$$

and

$$ET_r = ET_{pr} \frac{M_s(t)}{M_{cs}}$$

$$\text{when } 0 \leq M_s(t) \leq M_{es} \quad . . . . . (3.27)$$

in which

ET_r = actual evapotranspiration rate
ET_{pr} = potential evapotranspiration rate
M_{es} = limiting soil moisture content (measured above wilting point) below which actual evapotranspiration rate is less than the potential evapotranspiration rate
M_{cs} = soil moisture holding capacity measured between the wilting point and the field capacity
$M_s(t)$ = soil moisture in the root zone at any time, t, measured above the wilting point, and is given by

$$M_s(t) = M_s(0) + (W_{it} - ET_r)\Delta t \quad . . . (3.28)$$

in which

$M_s(0)$ = initial soil moisture measured above the wilting point and the other terms are as defined previously

For phreatophytes which grow mostly along stream courses and on wet soils, the assumption was made that the potential evapotranspiration rate always occurs. Thus, evapotranspiration by phreatophytes is designated as ET_{ph}.

Deep Percolation

The final independent term, DP_r, of Equation 3.19 represents the rate of deep percolation. Percolation is simply the movement of water through the soil. Deep percolation is defined as water movement through the soil from the plant root zone to the underlying groundwater basin. The dominant potential forces causing water to percolate downward from the plant root zone are gravity and capillary. Water is removed quickly by gravity from a saturated soil under normal drainage conditions. Thus, the rate of deep percolation, DP_r, is most rapid immediately after irrigation when the gravity force dominates, and decreases constantly, continuing at slower rates through the unsaturated conditions. Because the capillary potential applies through all moisture regimes, deep percolation continues, though at low rates, even when the moisture content of the soil is less than field capacity (Willardson and Pope, 1963).

Because of lack of data in the study area regarding deep percolation rates in the unsaturated state, and in order to simplify the model, the assumption was made that deep percolation occurs only when the available soil moisture is at its capacity level. In most cases, this assumption causes only slight deviation from prototype conditions. Thus, for this model, the deep percolation rate is expressed as:

$$DP_r = 0, \text{ when } M_s(t) \leq M_{cs} \quad . . . . (3.29)$$

or

$$DP_r = (M_s(t) - M_{cs})/\Delta t,$$

$$\text{when } M_s(t) > M_{cs} \quad . . . (3.30)$$

in which $M_s(t)$ is as previously defined and other terms are

DP_r = rate of percolation
M_{cs} = as defined in Equation 3.27
Δt = time increment

Net Groundwater Recharge

As already indicated, inflows to the groundwater storage reservoir within a subbasin occur as percolation from the agricultural lands, and as ungaged subsurface inflows from both the watershed area within the subbasin and the adjacent upstream subbasin. Thus, inflow rate to the groundwater basin, Q_{gw}, is given as follows:

$$Q_{gw} = Q_{ss} + Q_{go} \quad . . . . (3.31)$$

in which

Q_{ss} = subsurface inflow rate to the modeled area from the watersheds within the subbasin

Q_{go} = subsurface inflow rate from the adjacent upstream subbasin

The quantity Q_{go} is further discussed in the next section under the heading "Groundwater Outflows." Subsurface inflows from the watershed areas within the subbasin, Q_{ss} , are estimated by assuming that a certain portion of the rainfall and snowmelt percolates into the ground and that this percolated water is routed through the subsurface soil according to a linear reservoir relationship before it enters the groundwater storage. In mathematical form, this recharge is expressed as:

$$Q_{ss} = I_r + (Q_{sg} - I_r) \text{ EXP } (-t/K_{ss}) \quad . \quad . \quad (3.32)$$

in which

Q_{sg} = initial recharge rate to the groundwater basin from the watershed areas

t = time

K_{ss} = storage coefficient for subsurface routing through the soil

I_r = rate of supply from percolation on the watershed areas

I_r is computed as follows:

$$I_r = C_i(P_r + SM_r) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.33)$$

in which

C_i = a constant coefficient identified through the parameter optimization procedure

and the other terms are as defined previously.

The net recharge to the groundwater storage, Q_{gf}, is thus expressed as:

$$Q_{gf} = Q_{gw} + DP_r - Q_{pi} - Q_{pmi} \quad . \quad . \quad . \quad (3.34)$$

in which all terms are as previously defined.

Groundwater Outflows

The rate of outflow from the groundwater reservoir is calculated by routing the net groundwater recharge, Q_{gf}, in Equation 3.34 through a linear reservoir. In equation form, this quantity is expressed as:

$$Q_{ga} = Q_{gf} + (Q_{gao} - Q_{gf}) \text{ EXP } (-t/K_g) \quad . \quad . \quad (3.35)$$

in which

Q_{ga} = total groundwater outflow including groundwater effluent as base flow and lateral groundwater outflow

Q_{gao} = initial total groundwater outflow

K_g = storage coefficient for the linear reservoir

t = time

and Q_{gf} is as previously defined by Equation 3.34.

Assuming that a certain portion of the total groundwater outflow joins the main stream as base flow, this quantity is expressed as:

$$Q_{bf} = K_{bf} Q_{ga} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.36)$$

in which

Q_{bf} = base flow

K_{bf} = base flow coefficient identified through the parameter optimization procedure.

The subsurface groundwater outflow component (usually to the adjacent downstream subbasin), Q_{go}, is, therefore, expressed as:

$$Q_{go} = Q_{ga} - Q_{bf} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.37)$$

Surface Outflow

The surface outflow from a subbasin is the flow remaining in the streams at the lower end of the subbasin. This quantity is composed of surface inflow to the subbasin which is not diverted, the return flow from municipal, industrial, and agricultural uses, and the base flow from groundwater. In equation form, the surface outflow, Q_{so} , is expressed as follows:

$$Q_{so} = Q_{si} + Q_{ri} + Q_{rmi} + Q_{bf} - W_{sd}$$

$$- W_{smi} + W_{ii} + W_{imi} - W_x + \Delta S \quad . \quad . \quad (3.38)$$

in which

Q_{so} = surface outflows from the subbasin

Q_{si} = surface inflows in streams

Q_{ri} = irrigation overland and interflow

Q_{rmi} = municipal and industrial return flows

Q_{bf} = base flow

W_{sd} = surface diversions for irrigation

W_{smi} = municipal and industrial diversions from surface supplies

W_{ii} = imports for irrigation

W_{imi} = municipal and industrial imports

W_x = exports

ΔS = change in surface storage within the basin, with increases in surface storage here being assigned a negative value

Total Outflow

If subbasins are selected such that there exists no flow of subsurface water past the gaged outflow point, the hydrograph of total outflow, Q_{to}, is given by Equation 3.38. This situation is assumed to exist at reservoir sites within the basin because of construction measures taken to eliminate subsurface flows under the dams which create the reservoir. For this reason, whenever possible, subbasins are terminated at the outfall of a reservoir. These sites thus enable a check to be made on groundwater inflow rates to the subbasin as predicted from verification studies involving models for one or more upstream subbasins.

Where possible, the termination or outlet point of subbasins is taken at a stream gaging station. However, it is possible that groundwater flow occurs in the streambed alluvium beneath the surface channel. For these basins, the total system outflow can be written as:

$$Q_{to} = Q_{so} + Q_{go} \quad \text{. . . . .} \quad (3.39)$$

in which

Q_{so} = rate of surface outflow from the subbasin (Equation 3.38)

Q_{go} = rate of subsurface or groundwater outflow from the subbasin (Equation 3.37)

CHAPTER IV

COMPUTER IMPLEMENTATION

Electronic computers can be classified into three main categories, analog, digital, and hybrid. The analog computer consists basically of high-gain amplifiers used in conjunction with simple resistor-capacitor circuits. In addition, special devices, such as function multipliers, function generators, diodes, and relays of various types are used as auxiliary elements for simulation of more complex systems. By connecting these devices through a program "patch panel" so that the circuit equations have the same mathematical form as the equations of the problem, the prototype is simulated. Simulation of a prototype system by using an analog computer has the advantage that the dependent variables are treated in continuous form, the computations are performed in parallel, nonlinear functions can be handled easily, and direct insight into the problem system can be gained by the engineer.

In contrast to the analog computer, the digital computer performs operations in a sequential manner, and this does not have some of the advantages of analog computer described above. However, the digital computer is capable of "memorizing" coded instructions and numerical data, and of performing logical operations and decisions.

The hybrid computer combines the memory and logic capabilities of the digital computer with the high speed and nonlinear solution capabilities of the analog computer. In addition, the high speed iterative solutions and graphical display which are characteristic of the hybrid computer provide close interaction between the hydrologist and the simulation model. These features make the hybrid computer a powerful tool in the development and verification of simulation models. In the present study, therefore, the EAI 590 hybrid computer system available at the Utah Water Research Laboratory was used to develop the initial model for the study area.

After the model had been wholly developed and verified, it was converted into digital form for operation on digital computers which are more generally available than hybrid computers. The converted model consists of three separate components, namely, a parameter optimization submodel, a river basin management model, and a component which represents the operation of Utah Lake. Each of these model components, or a combination thereof, is discussed in the following sections.

The Parameter Optimization Submodel

Any mathematical model that simulates the hydrology of a natural watershed contains a number of parameters which require identification through model calibration. An efficient approach to model calibration is to incorporate an appropriate optimization technique into the simulation model to determine the parameter vector that provides the best objective function. In this study, a direct search optimization method was incorporated into the model, and two objective functions were selected to provide the flexibility of calibrating the model by emphasizing either the high flows or the low flows as described in the following sections.

Basic Considerations

Optimization programs deal with the minimization or maximization of an objective function subject to a set of constraints. In general form, this operation is usually stated as:

$$\text{min. } f(X_1, X_2, \text{-----}, X_n) \quad . \; . \quad (4.1)$$

subject to a set of constraints, such as

$$G_i (X_1, X_2, \text{----}, X_n) \leq b_i,$$
$$i = 1, 2, \text{----}, m$$

and

$$X_1 \geq 0, X_2, \geq 0, \text{-----}, X_n \geq 0$$

However, the optimization procedure discussed here does not optimize the use of water, but rather it identifies those values of various model parameters which best reproduce the observed historical streamflow functions. The objective function for this optimization procedure is, therefore, to minimize the simulation error, with the constraints being the formulas used in the model for simulating the hydrology and the restrictions on the continuity of mass principles.

Objective Function

As mentioned previously, two objective functions were included in the computer program to provide the flexibility needed for calibrating the model by emphasizing either the high flows or the low flows. These two objective functions are described separately as follows:

1. Emphasizing high flows:

$$\min \frac{\sum_{S=1}^{n} \sum_{N=1}^{12} (Q_{so} - Q_{gag})^2}{\overline{Q}_{gag}} \quad . \ . \ . \ . \ (4.2)$$

in which

Q_{so} = simulated monthly surface outflow
Q_{gag} = gaged monthly surface outflow
$\overline{Q}_{gag}$ = mean gaged monthly surface outflow
n = number of years of simulation
N = number of months of simulation = 12 n

The objective function of Equation 4.2 emphasizes the high flows because the simulation error is measured by the square of deviation which, for high flows, may be small percentage-wise, but generally is large in magnitude when compared to that of the low flows.

2. Emphasizing low flows:

$$\min \frac{\sum_{S=1}^{n} \sum_{N=1}^{12} \left| (Q_{so} - Q_{gag})/Q_{gag} \right|}{N} \quad . \ . \ (4.3)$$

in which all terms are as previously defined.

This objective function emphasizes the low flows because a small deviation during low flow periods may constitute a large ratio for deviation versus gaged flow, while a large deviation in high flows may constitute only a small ratio.

Implementation

The parameters to be identified by the parameter optimization model include the following:

1. Snowfall temperature
2. Snowmelt temperature
3. Soil moisture holding capacity
4. Limiting soil moisture for evapotranspiration
5. Coefficient for correlation streams in estimating ungaged inflows
6. Subsurface storage coefficient
7. Groundwater storage coefficient
8. Snowmelt coefficient
9. Evapotranspiration coefficient
10. Irrigation efficiency
11. Municipal and industrial water use efficiency
12. Coefficient for rain and snowmelt in estimating ungaged inflow
13. Threshold for ungaged inflow correlation
14. Base flow coefficient, and
15. Infiltration coefficient

The procedures which are followed during the optimization procedure are as follows:

1. Determine the range of values and the number of increments for each parameter.
2. Arbitrarily select a set of initial values for the parameters, and use these values to simulate the hydrology. Select as the objective function either Equation 4.2 or Equation 4.3, and evaluate the objective function chosen on the basis of the initial parameter values selected. Tentatively store the value of the objective function thus obtained as being the "best" value.
3. Select the first parameter for examination.
4. Vary the value of the selected parameter over the entire range while holding the remaining parameters at their initial values. For each change of the parameter value, the hydrology is simulated and the objective function calculated. This objective function is compared with the best objective function stored in the memory. The better of the two is then stored in the memory together with its corresponding parameter value.
5. Reset the parameter that has just been examined to its initial value and select the next parameter as the new parameter for examination and repeat Step 4.
6. Steps 4 and 5 are repeated until all the parameters are examined and the best value for each parameter identified.
7. Use the best value identified for each parameter and operate the model to simulate the hydrology and compute the objective function. Compare this objective function with the best objective function in the storage and save the better one together with its corresponding parameter vector. This completes one phase of the optimization.
8. Set the parameters selected in Step 7 as the new initial parameters and repeat Steps 2 through 7 for second phase of the optimization. The number of phases can be arbitrarily preassigned but generally only two to three phases are required.
9. Arbitrarily select another set of parameters and repeat Steps 1 through 8. This procedure is repeated several times to ensure that the optimal parameter vector obtained is reasonably close to the global optimal.

Table 4.1 shows an example of one phase of optimization. The last column of the table indicates the gradient of the objective function with respect to the change in parameter value. This column is useful in analyzing the sensitivity of the model in terms of the influence of change in the model parameters on the response function.

Appendix A shows a complete list of the computer program for the parameter optimization submodel together with the necessary explanation for its application.

Table 4.1. Parameter optimization sample output.

Phase I

PAR	LVL	PAR. V.	OBJ	GRAD
1	1	30.00	.02421	
1	2	31.00	.02465	.00044243
1	3	32.00	.02469	.00004151
1	4	33.00	.02490	.00021237
1	5	34.00	.02521	.00030635
2	1	24.00	.02163	
2	2	25.00	.02283	.00122253
2	3	26.00	.02469	.00183722
2	4	27.00	.02549	.00080181
2	5	28.00	.02618	.00068536
3	1	8.00	.02528	
3	2	9.00	.02498	-.00030399
3	3	10.00	.02459	-.00028772
3	4	11.00	.02441	-.00027815
3	5	12.00	.02406	-.00035038
4	1	4.00	.02469	
4	2	5.00	.02487	.00017751
4	3	6.00	.02502	.00013689
5	1	.02	.01792	
5	2	.03	.01871	.07888676
5	3	.04	.02010	.13916715
5	4	.05	.02209	.19945058
5	5	.06	.02469	.25973135
5	6	.07	.02789	.32001215
5	7	.08	.03169	.38029408
5	8	.09	.03610	.44057673
5	9	.10	.04111	.50085937
6	1	.80	.02469	
6	2	.90	.02449	-.00201363
6	3	1.00	.02429	-.00194668
7	1	1.40	.02615	
7	2	1.60	.02469	-.00731933
7	3	1.80	.02345	-.00620297
7	4	2.00	.02240	-.00524893
8	1	.15	.02507	
8	2	.16	.02493	-.01356936
8	3	.17	.02481	-.01257136
8	4	.18	.02469	-.01164264
8	5	.19	.02456	-.01078173
8	6	.20	.02448	-.00998899

Calibration of the Model

The parameter optimization program is applied to a specific river basin by dividing it into subbasins, usually based on the locations of stream gaging stations. Figure 4.1 shows the Upper Jordan River drainage and the subdivision into which it was divided for this study. The relatively high resolution adopted for the Provo River basin was used because of the emphasis of this study on that basin. After calibration of the model, some of the subbasins in the Provo River basin were again divided into smaller units to correspond to selected points of interest along the river channel, as shown in Figure 4.2. The parameter values for each of these smaller units were assumed to be the same as those of the subbasin containing the unit. Table 4.2 shows the results of parameter optimization for each subbasin. The period of record used for the optimization procedure was 1964 through 1967.

In applying the parameter optimization program for model calibration, change in reservoir storage was treated as equivalent gaged streamflows. An increase in storage was treated as a negative inflow and a decrease as a positive inflow to the subbasin containing the reservoir. Precipitation and evaporation were treated as a positive and negative inflow, respectively, to the subbasin.

Testing of Calibration Results

After the model parameters were identified for each subbasin, the model was tested for the 20 year period 1950 to 1969. Land use conditions for 1965 were assumed to apply throughout the entire test period (Hyatt et al., 1968). Figures 4.3 through 4.5 represent some of the results of this test and show comparisons between simulated and observed hydrographs for the Provo River at different locations for the period 1950 to 1953. As indicated by these figures, generally good agreement was

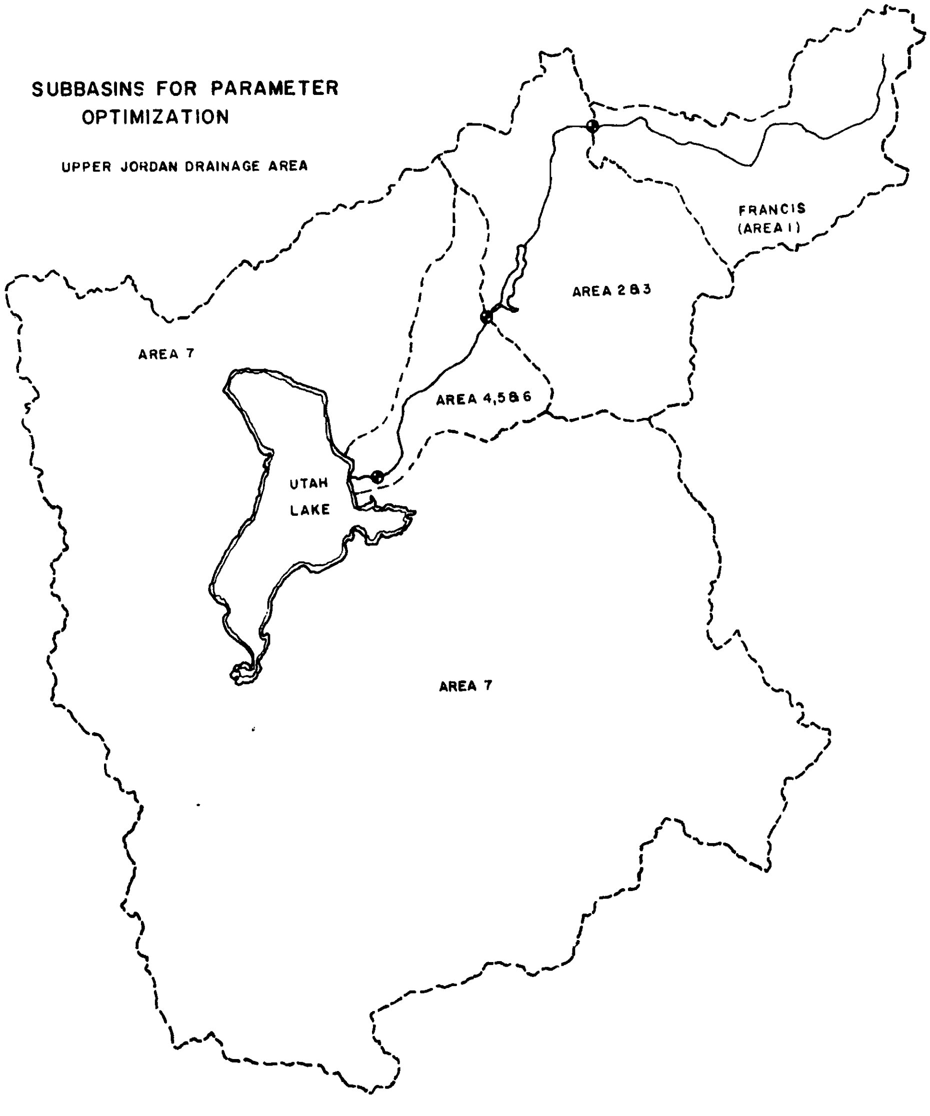


Figure 4.1. Division of the Upper Jordan River basin for parameter optimization.

achieved between observed and simulated flows. However, as shown by Figures 4.3 and 4.4, the model was not able to duplicate the exceptionally high recorded outflows at these stations for May 1952. These high runoff rates were generated by a short period of high temperatures accompanied by rain on a snowpack. The relatively short period of high temperature conditions was not reflected in the average monthly temperature used as input information to the model. For this reason, the response of the model was somewhat different from that of the real-world system. In this case, improved agreement between observed and simulated output functions at this particular point in time could be achieved by incorporating increased temporal resolution into the model.

The River Basin Management Submodel

The river basin management model, using the optimized parameters, simulates the hydrologic responses of the system being modeled to various water management alternatives. The model simulates, or generates, streamflow rates at different locations along the stream of interest. System processes incorporated into the model include evapotranspiration and return flow from agricultural land, soil moisture variations, reservoir storages, groundwater effluents, and other important phenomena in the hydrologic system. The model also is capable of sizing reservoirs on the basis of different water management patterns, subject to various water right constraints.

Basically, the model consists of the mathematical equations developed in Chapter III linked by the equation of continuity. In addition, necessary logic routines are included in the model to provide the flexibility of studying the effects of different water management alternatives subject to various constraints. Some important management principles included in the model are described in the following sections and a complete list of

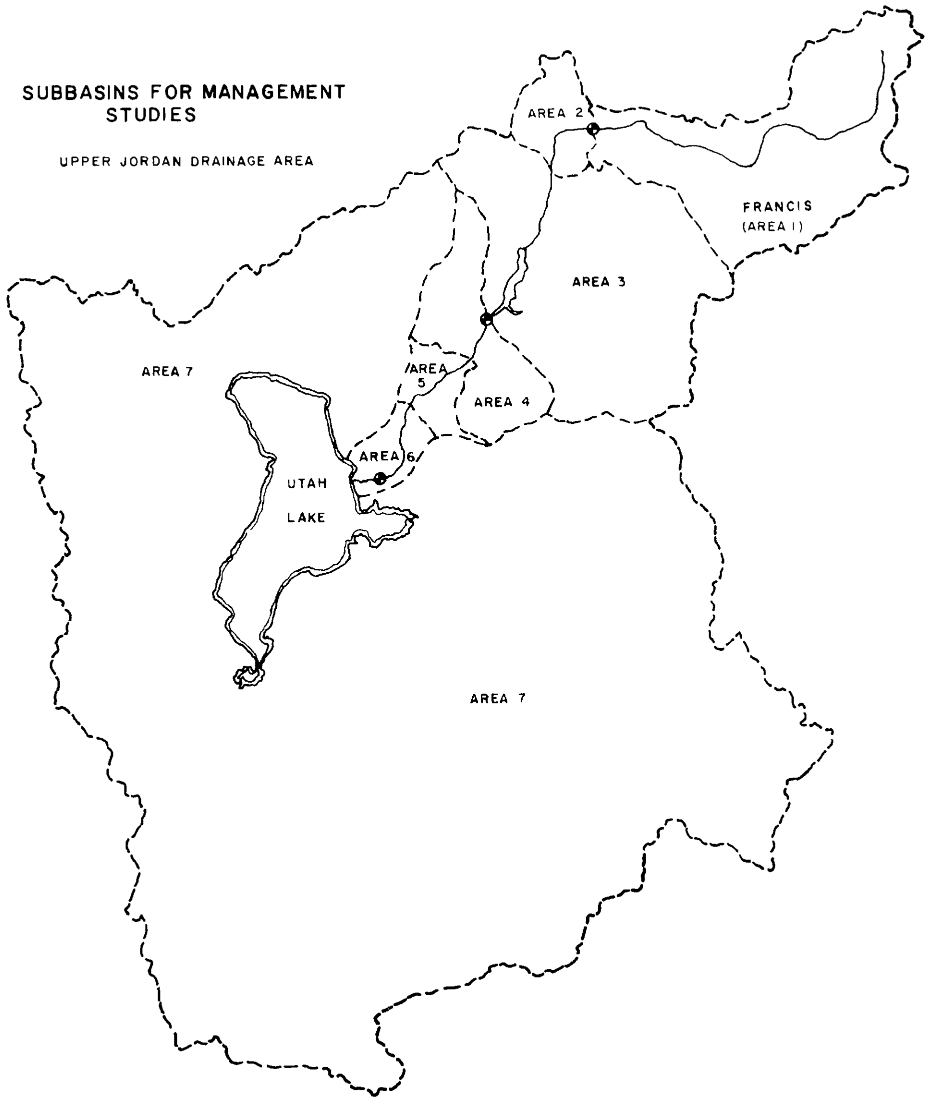


Figure 4.2. Division of the Upper Jordan River basin for management.

Table 4.2. Results of parameter optimization.

PARAMETER	Francis	Areas 2 & 3	Areas 4,5 & 6	Area 7
Snowfall Temperature	40.00	32.00	35.00	37.00
Snowmelt Temperature	30.00	26.00	25.00	33.00
Soil Moisture Holding Capacity	6.00	10.00	5.00	8.00
Critical Soil Moisture	4.00	4.00	3.00	6.00
Ungaged Stream Correlation Coefficient	.28	.06	.01	.84
Soil Storage Coefficient	.20	.80	1.00	1.00
Groundwater Storage Coefficient	.40	1.60	3.50	1.00
Snowmelt Coefficient	.12	.18	.18	.10
Consumptive Use Coefficient	1.00	1.10	1.24	1.20
Irrigation Efficiency	.30	.50	.60	.50
M & I Efficiency	.80	.80	.90	.80
Coefficient of Rain Plus Snowmelt for Ungaged Flow	.04	.02	.01	.01
Threshold for Ungaged Flow Correlation	.12	.20	.03	.02
Base Flow Coefficient	.40	.40	.32	.20
Infiltration Coefficient	.02	.05	.01	.01
Initial Soil Moisture	4.00	4.00	2.00	4.00
Initial Base and Groundwater Outflow	4.00	2.00	2.00	2.00
Initial Watershed Recharge	3.00	2.00	2.00	2.00

the computer program for the model is given in Appendices B and C, together with the necessary explanations for its application.

Important Management Principles

1. *Irrigation Diversions.* Better management of water within a river basin often can be accomplished through improved management techniques. The computer program provides two alternative ways of determining irrigation diversions for the modeled area.

The first alternative is to calculate irrigation diversions on the basis of available soil moisture and crop consumption in such a way that the soil moisture is maintained within the range between the critical soil moisture level, M_{es}, and the soil moisture holding capacity, M_{cs}. In equation form, this diversion is expressed as follows:

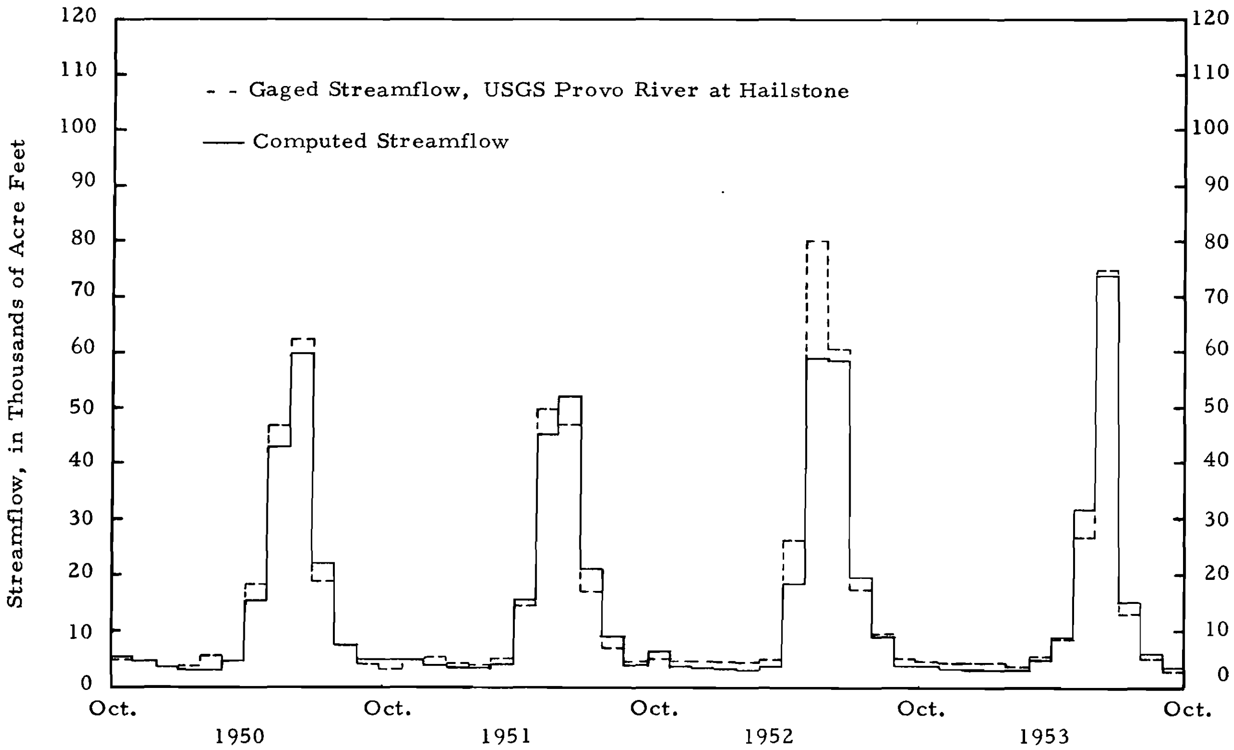


Figure 4.3. Computed and observed monthly streamflow from Francis Subbasin, 1950 - 1953.

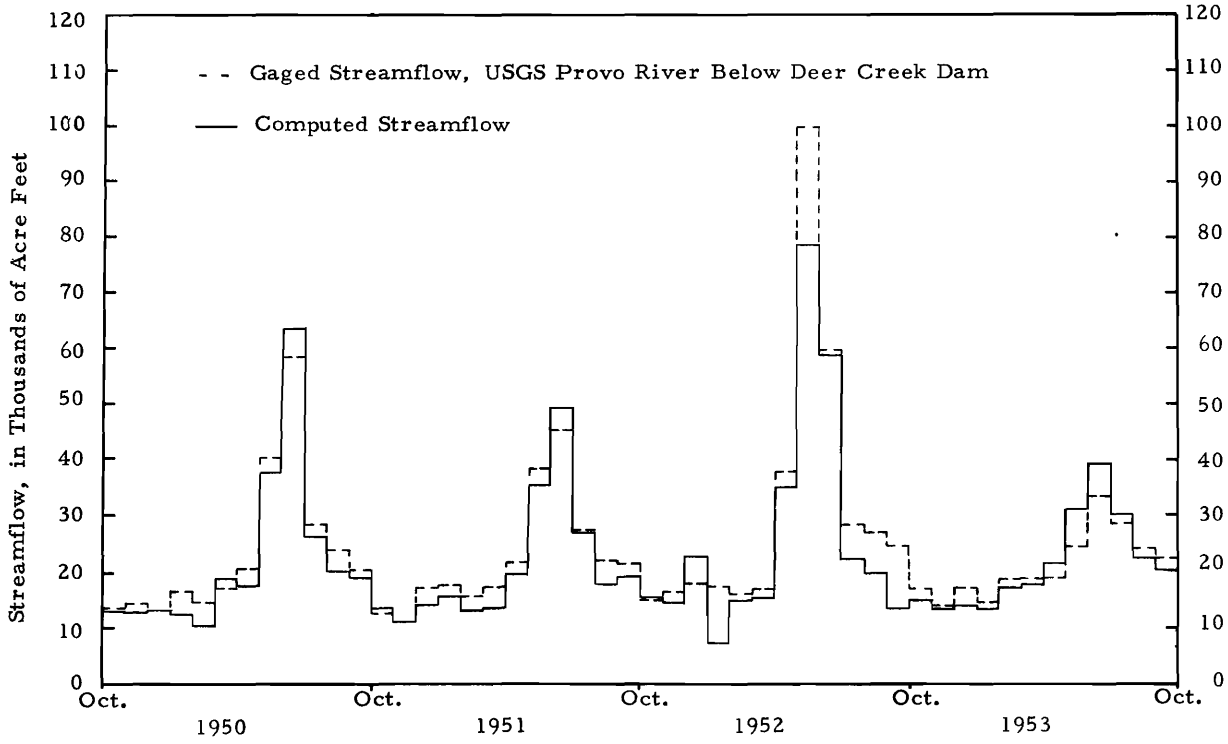


Figure 4.4. Computed and observed monthly streamflow from Area 2-3 Subbasin, 1950 - 1953.

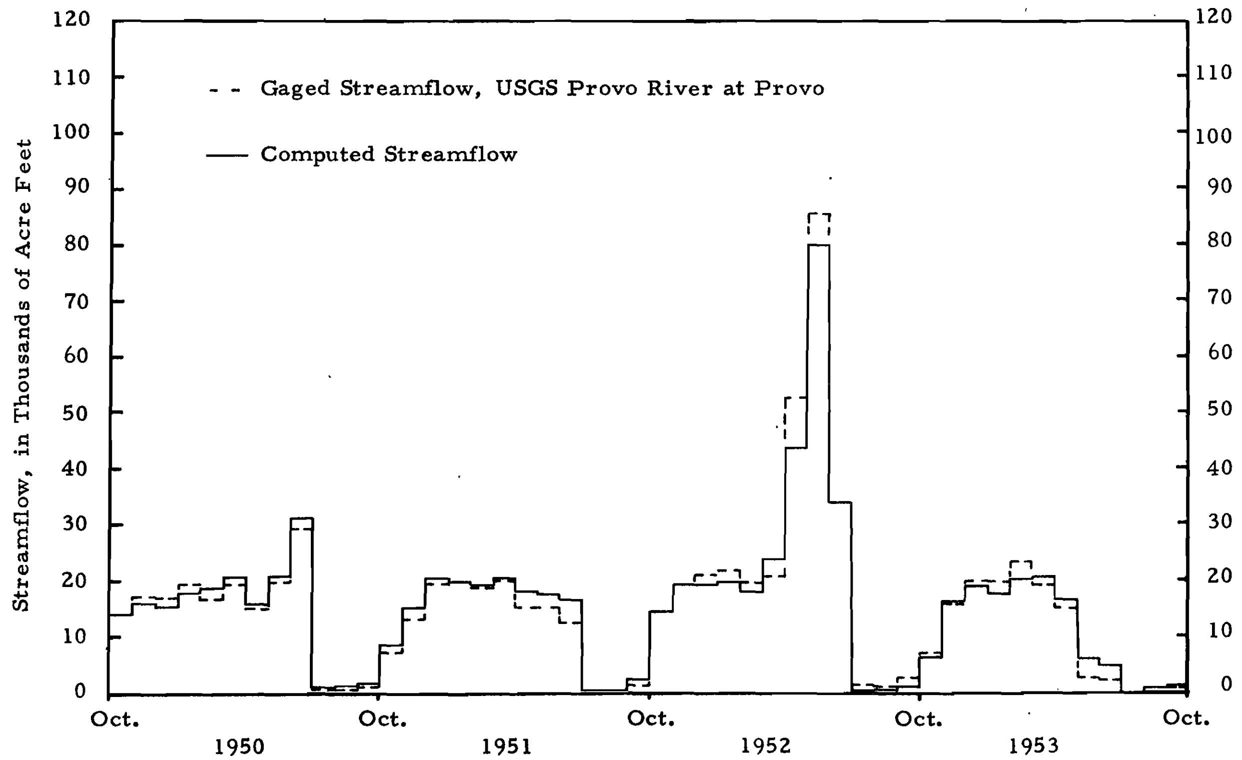


Figure 4.5. Computed and observed monthly streamflow from Area 4, 5, 6 Subbasin, 1950 - 1953.

$$ET_{pr} = P_r + SM_r + (W_d)\ Eff$$

or

$$W_d = \frac{ET_{pr}}{E_{ff}} - (P_r + SM_r) \quad \ldots\ldots \quad (4.4)$$

in which

W_d = total irrigation water for the subbasin
ET_{pr} = crop potential evapotranspiration
E_{ff} = irrigation efficiency
P_r = rainfall
SM_r = snowmelt

If Equation 3.10 is introduced into Equation 4.4, the expression becomes:

$$W_{cd} = \frac{ET_{pr}}{E_{ff}} - (P_r + SM_r + W_{pi} + W_{ii}) \quad \ldots\ldots \quad (4.5)$$

in which the additional terms are

W_{cd} = irrigation diversions from surface supplies within the subbasin
W_{ii} = irrigation imports

All of the above terms are previously defined in Chapter III. If export waters for irrigation use are diverted from surface supplies within the subbasin, this quantity, W_{xi}, must be added to W_{cd} to obtain the total irrigation diversions from surface supplies within the subbasin under consideration.

The second alternative is to calculate the irrigation diversion separately on the basis of irrigation requirement and water right constraints and input the resulting quantities to the model.

2. *Municipal and Industrial Diversions.* If municipal and industrial diversions and the corresponding efficiency of use factor are obtained, these values need to be input to the computer program. In simulating the responses associated with future water management priorities, the anticipated municipal and industrial diversions need to be estimated separately and input to the model.

3. *Reservoir Management.* Reservoirs are constructed for various purposes which include flood control, recreation, supplying water to new users, storing high flows for low-flow augmentation, and saving water which otherwise would be lost from the system during periods of high flow and low usage. The reservoir management routine incorporated into this program allows simulation of existing or proposed reservoir operations, including

releases for downstream water rights and storage of exchange waters imported from outside basins.

Inflows to a reservoir consist of the outflow from the subbasin immediately upstream from the reservoir and the precipitation which falls directly on the reservoir. Outflows from a reservoir consist of releases and spills to the downstream channel, diversions from the reservoir above the dam, and evaporation from the reservoir surface. In the reservoir operating routine of the model, the minimum reservoir release is specified for each month on the basis of downstream water rights. This amount is released from the reservoir and an examination is made to determine whether this release is sufficient to meet all downstream requirements. If a water deficiency is found, the release is adjusted upward to meet the requirement, providing sufficient water is available in the reservoir. In high flow seasons, inflows to the reservoir may be so large as to cause the reservoir storage to exceed the maximum capacity. In this case, additional water is released from the reservoir in order to bring the reservoir storage down to its specified maximum capacity.

Under conditions when the reservoir storage approaches the minimum level, it is possible that stored water quantities are not sufficient to meet both the downstream requirements and the allowable diversions above the dam. Under this situation, it is assumed that the available storage is used to meet prior rights to the extent possible.

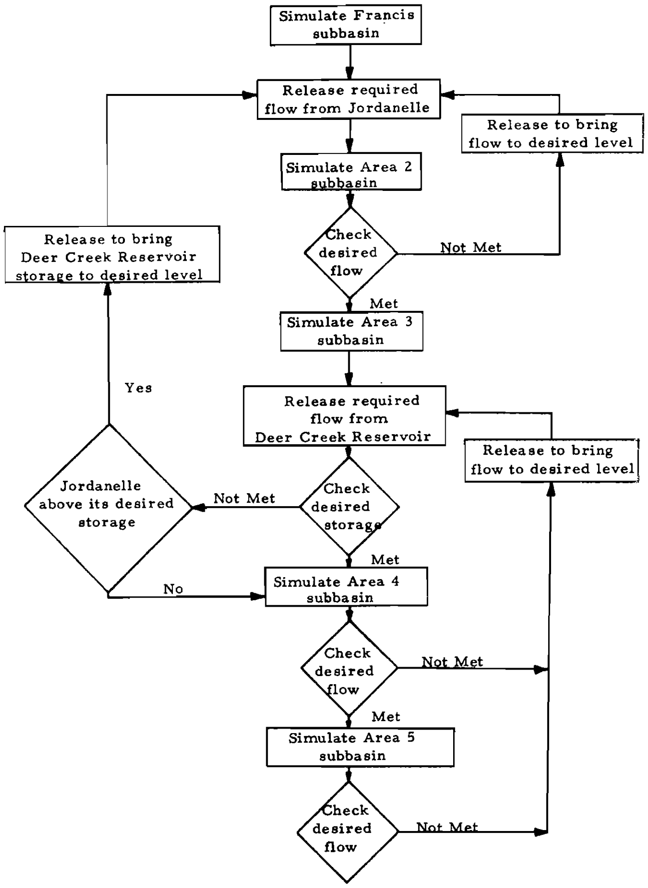


Figure 4.6. Illustration of a two reservoir system.

4. *Multiple Reservoir System.* When there are two or more reservoirs on a system, the management alternatives increase. In the program developed under this study, the operation of a sequence of reservoirs can be simulated over a wide range of management alternatives. As in the case of single reservoir, desirable flows at points below the reservoirs can be assigned and the reservoir releases adjusted to meet the requirement. In addition, a desirable storage for each reservoir can be specified for each month of the year, and the reservoir system operated in such a way that, within limits imposed by available water supplies, values in each reservoir are maintained at or above the desirable level. Maintaining a reservoir at or above a desirable storage enhances recreation opportunities and water quality.

Figure 4.6 illustrates the manner in which the desired storage and desired streamflow criteria are implemented for a two reservoir system. The system described is the Provo River basin with the proposed Jordanelle Reservoir in operation.

Under conditions when storage levels in downstream reservoirs are equal to or above minimum desired values, the system model holds excess water in the most upstream reservoir. When the storage in any reservoir drops below its desired level, water is released from the closest upstream reservoir to raise the storage to the desired level. If necessary, this process is continued in a sequential procedure through other reservoirs in the upstream direction. When all reservoirs drop below desired storage levels, available active storage is held at the highest reservoir possible on the stream system.

5. *Desired Streamflow.* Maintaining a minimum streamflow requires at least one reservoir on the system. The specified desired streamflow is designed to maintain streamflows below a reservoir above a specified level so that minimum fisheries, recreation, and other water requirements are satisfied.

In the model operation, the simulated outflow from a subbasin is compared with the specified desirable flow. When the simulated outflow is less than the desirable flow, additional necessary releases are made from one or more of the upstream reservoirs.

Application

The river basin management model is a powerful tool for studying both existing and proposed water development systems within a river basin. In the case of this study, the usefulness of the model was demonstrated by assuming various development alternatives for the Provo River basin, as shown in Table 4.3. Run 1 of this table was designed to provide information on the degree to which the present system of storages and diversions on the river meet the water demands under the conditions of full development of the Provo River Project. The results of this run provide an indication of the water shortages that might be experienced under these conditions, and the expected demands on the Central Utah Project are thus identified.

Runs 2 through 8 were designed to investigate the effect of the Central Utah Project on the Provo River system under different management alternatives. Among the important elements studied in these runs are the following:

1. The proper size of the proposed Jordanelle Reservoir as affected by various water management alternatives as indicated by Column 2.
2. The impacts of various project demands on the system, especially on the size of the Jordanelle Reservoir, as indicated by Columns 3, 4, and 6.
3. The influence of water right constraints as indicated by Column 7.
4. The feasibility of supplying a minimum flow for fishery and recreation as indicated by Column 8.
5. The effect of the proposed water right transfer from the Olmstead Power Plant to the Central Utah Project.

The input data used in these management runs consisted basically of historical temperature, precipitation, canal diversions, and gaged streamflows for the period from 1929 to 1969. Other inputs to the model included imported water quantities from the Weber and the Duchesne River basins, and the demands of various projects both within and outside of the Provo River basin. These data were obtained from a separate study made by the Bureau of Reclamation.

As was mentioned at the beginning of this report, the main objective of this study was to construct a generally applicable simulation model which is capable of predicting the responses of water resources development systems under a wide range of management alternatives, rather than to conduct an in-depth management study for a particular area. Available data, such as future project demands, used in the management runs discussed previously, are tentative and subject to changes. Therefore, the results of the computer runs set out by Table 4.3 are not included in this report. It is emphasized, however, that the simulation model applied well for each of these runs, and it is expected that the model will apply equally as well for a wide range of management studies in other river basins.

The Combined Utah Lake Operation Model

There are certain specific problems associated with the operation of Utah Lake in the system under investigation. These specific problems include:

1. The effects of the diking of the Provo and Goshen Bays on the operation of Utah Lake, including:
    a. Storage quantities in the proposed Jordanelle Reservoir. For example, diking will reduce the surface area of Utah Lake and thus presumably reduce evaporation losses from the lake. These evaporation savings might be exchanged for Provo River water which would be stored in the proposed Jordanelle Reservoir.
    b. The water quality of Utah Lake.
2. The constraints imposed on the system by the Utah Lake compromise level.

To provide a simulation model with sufficient flexibility to answer these kinds of questions, the river basin management model was combined with the Utah Lake operation model developed by the Central Utah

Table 4.3. Development alternatives for the Provo River Basin.

RUN	JORDANELLE RESERVOIR				DEER CREEK RESERVOIR			OTHER CONSTRAINTS	
	Storage (thousand acre-feet)	Utah County M&I	Salt Lake County M&I	Head of Provo River storage stabilized?	Storage (thousand acre-feet)	Salt Lake City M&I	Bypass Flow	Fishery	Olmstead Diversion
1	Initial: 0 Desirable: 0 Maximum: 0 Minimum: 0	0	0	no	Initial: 150.0 Desirable: Maximum: 150.0 Minimum: 2.8	61,700 acre-feet	Natural Flow Plus 38,300 acre-feet	none	up to 429 cfs
2	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet	Irrigation Season Natural Flow Plus 38,300 acre-feet ------------ Non-Irrigation Season Fishery Only	50 cfs Jordanelle Reservoir to Deer Creek Reservoir 60 cfs Deer Creek Reservoir to Murdock Canal	none
3	Initial: 350.0 Desirable: 170.0 Maximum: 1,000.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 120.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
4	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	10,000 af/yr	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
5	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
6	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	no	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
7	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Winter Demand	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
8	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	20,000 af/yr	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet		Above Plus 25 cfs Murdock to Utah Lake	none

Project Office of the Bureau of Reclamation to form the combined Utah Lake operation model.

In applying this combined model, the hydrology of the drainage just upstream from Utah Lake is simulated by the river basin management model, which is now a submodel of the combined model. The simulated results are carried over to the Utah Lake operation model, which is also a subroutine of the combined model, to simulate the operation of the lake. The river basin management model has been described previously in this report. The Utah Lake operation model was developed in a separate study by the Bureau's Central Utah Project Office and the documentation is available from that office. The detailed description of this model, therefore, will not be repeated here. However, a complete list of the computer program for the combined model is given in Appendix D, together with the necessary explanations for its application. In addition, some elements which are unique to the combined model are discussed in the following paragraphs.

Lake Evaporation

In the river basin management model, the modified Blaney-Criddle equation (Phelan, 1962) was used to estimate evaporation from reservoir surfaces. The adoption of this equation was considered appropriate on the basis of available data and the relative importance in the water budget of evaporation from upstream reservoirs, such as Deer Creek and Jordanelle Reservoirs. In the case of Utah Lake, however, the situation is different. The lake has an area of 96,000 acres with an average depth of only 9 feet at the compromise level. The inflow to the lake from all sources is rather moderate and is estimated at 600,000 acre-feet annually (USBR, 1964). Because of the moderate water yield of the basin and the large area of the lake, a small error in estimating the depth of evaporation will cause a large departure of the simulated hydrology from its actual magnitude. A more sophisticated and accurate method for estimating evaporation from the lake was, therefore, considered necessary and an effort was made to derive an evaporation equation based on the theories of mass transfer and energy budget as described in Appendix E. The resulting equation was applied to estimate the lake evaporation for the period of 1962 through 1969 in which the necessary data were available. A water budget analysis of the lake during that period indicated that the computed evaporation approximated well the actual evaporation. To extend the method to the period for which sufficient data, particularly solar radiation, are not available, the computed lake evaporation was correlated to the pan evaporation data available at the Lehi station near the lake. Figure 4.7 shows the resulting relationship and this relationship then was used to estimate lake evaporation in the simulation model.

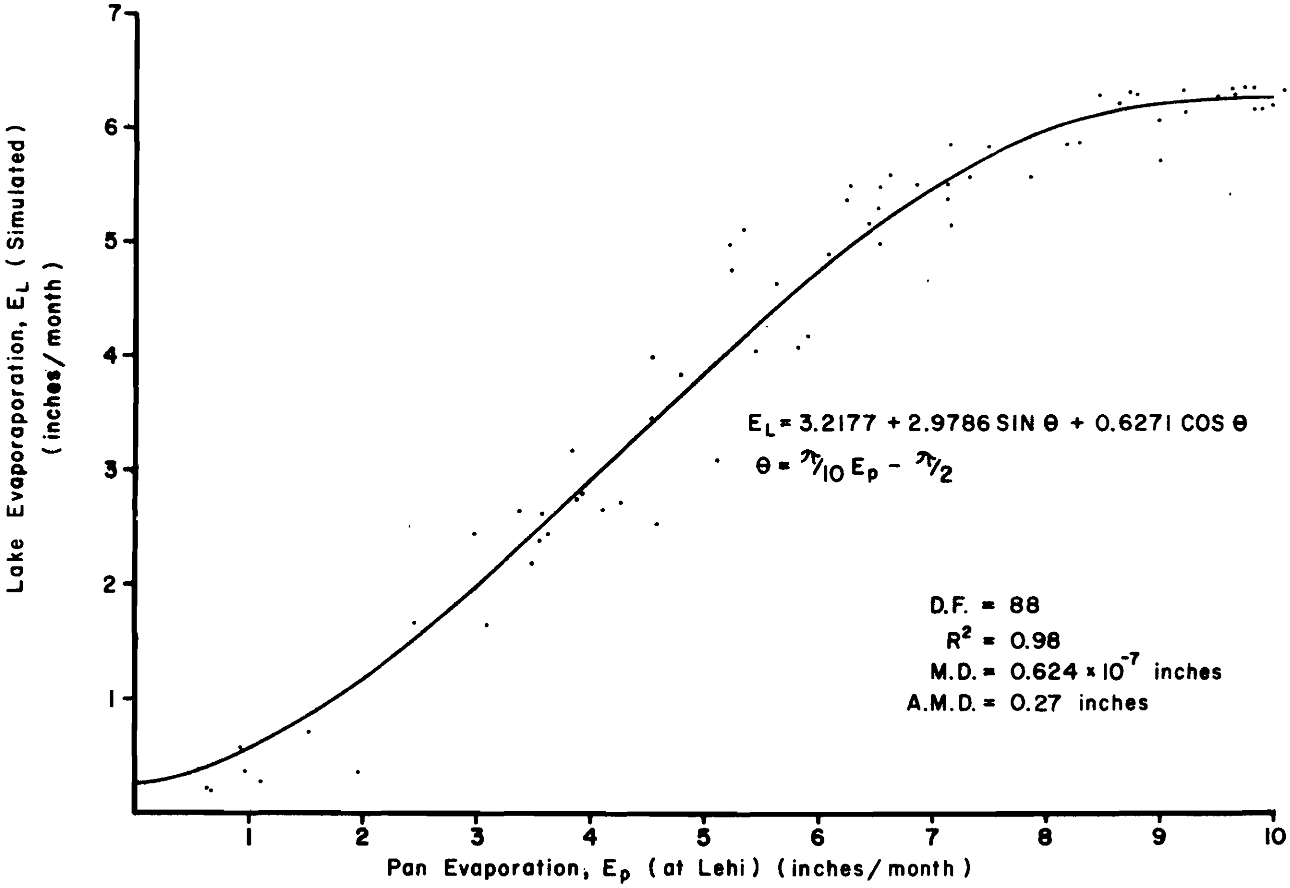


Figure 4.7. Lake and pan evaporation relationship, Utah Lake.

Water Quality

In studying the variation of water quality in Utah Lake, it was considered most important, at the present stage of study, to analyze the budget of total dissolved solids for the lake. To estimate the flow of dissolved solids to the lake, an attempt was made to correlate the total dissolved solids (t.d.s.) content to water flow rates on an individual stream basis. Unfortunately, the attempt was not successful because of the limited salinity data available. The number of data points were so limited and the plotting position of these points was so dispersed that no conclusive relationships could be established between the dissolved solids concentration and the flow rate. Therefore, in the management studies conducted to this point, the assumption was made that the total dissolved solids concentration in the streams does not change appreciably from year to year and for each stream an average concentration was calculated for each month of the year based on the available data. Table 4.4 shows the resulting values. These values were used in the preliminary management studies conducted under this project.

Table 4.4. Total dissolved solids content, in ppm, of the various inflows to Utah Lake.

<table>
<tr><th rowspan="2">Source</th><th colspan="12">Month</th></tr>
<tr><th>Oct.</th><th>Nov.</th><th>Dec.</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>June</th><th>July</th><th>Aug.</th><th>Sept.</th></tr>
<tr><td>Provo River Inflow</td><td>288.0</td><td colspan="4">281.0</td><td colspan="2">361.9</td><td>210.1</td><td>247.5</td><td>284.3</td><td>295.2</td><td>293.3</td></tr>
<tr><td>Other Surface Inflow</td><td colspan="7">795.3</td><td colspan="5">593.2</td></tr>
<tr><td>Groundwater Inflow</td><td></td><td></td><td></td><td></td><td></td><td>851.0</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

CHAPTER V

SUMMARY AND CONCLUSIONS

In this report, a generally applicable computer simulation model is proposed which simulates the hydrologic responses of a water resource system to various management alternatives. Under the study reported here the model was applied to the Upper Jordan River drainage. In total the model consists of three separate components, each of which is capable of functioning as a separate entity, or model, but which comprise submodels of the overall model proposed. These three components are: (1) the parameter optimization model; (2) the river basin management model; and (3) the Utah Lake operation model. The first two submodels are general in nature and can be applied directly to any river basin. The third submodel, the Utah Lake operation model, was developed specifically to simulate the operation of Utah Lake, but with minor modifications still can be applied to other locations.

In applying the model to the study area, the area was divided into several subbasins on the basis of available data and desired degree of spatial resolution. For each subbasin the model parameters were identified by applying the parameter optimization submodel. The identified parameter values were tested by simulating subbasin outflows for a 20 year period. As indicated by Figures 4.3 to 4.5, good agreement was achieved between observed and simulated outflows for the entire test period. The river basin management model was used to simulate the hydrology of the river basin for various water management alternatives. The major processes simulated by this model include streamflows at different locations along the stream of interest, evapotranspiration and return flows from agricultural land, soil moisture variations, reservoir storages and releases, and groundwater effluents. To simulate the operation of Utah Lake, the hydrology for the area above the lake was simulated by means of the river basin management model and the results were carried over to the Utah Lake operation model developed by the Bureau's Central Utah Project Office. The resulting so-called combined Utah Lake operation model thus has the river basin management model and the Bureau's Utah Lake operation model as its two component submodels. The combined model also is capable of simulating the variation of total dissolved solids in Utah Lake as affected by selected water resources management alternatives.

In general, the model developed under this project applied to the study area and produced meaningful predictions for the management alternatives used to test the model. It is expected that the model will function equally well over a wide range of management alternatives in any river basin to which it is applied. However, it is important to realize that any hydrologic simulation model, while providing much insight and understanding for the system under investigation, is also subject to certain limitations. For the particular model under discussion, the major limitations are:

1. A large time increment of one month was used for this model. This time increment generally is adequate for water supply studies, but is not suitable for analyses of phenomenon, such as flood flows, for which daily or even hourly variations are needed.
2. The model is deterministic in nature and the management studies made have been based on the historical records. The development of such a model was desirable because it is relatively easy to manipulate and it is capable of providing average information regarding the system. This kind of information is useful in investigating plans for the proper management for the system. However, it is necessary to realize that all hydrologic processes contain a strong stochastic element, and a historical record is no more than a particular realization of these processes over a limited time period.
3. The only water quality aspect considered in this model was the total dissolved solids content in the Utah Lake and its tributary inflows. Rather crude approximations of monthly salinity levels were developed for surface and groundwater flows. In order to improve and expand this aspect of the model, additional salinity data are needed so that predictive functions might be established for various water quality parameters.

REFERENCES CITED

Blaney, Harry F., and Wayne D. Criddle. 1950. Determining water requirements in irrigated areas from climatological and irrigation data. Technical Paper 96, Soil Conservation Service. U.S. Department of Agriculture. February. 48 p.

Dalton, J. 1802. Experimental essays on the constitution of mixed gases; on the force of steam or vapor from water and other liquids in different temperature, both in a Torricellian vacuum and air; on evaporation; and on the expansion of gases by heat. Manchester Lit. 1. Soc. Mem. Proc., 5:536-602.

Gardner, W. R., and C. F. Ehlig. 1963. The influence of soil water on transpiration by plants. Journal of Geophysical Research 68(20):5719-5724.

Harbeck, G. E., Jr., and others. 1954. Water-loss investigations, Vol. 1 Lake Hefner Studies. Technical Report, USGS Paper 269.

Harbeck, G. E., Jr., M. A. Kohler, G. E. Koberg, and others. 1958. Water-loss investigations, Lake Mead Studies. USGS Profess. Paper 298.

Harbeck, G. E., Jr. 1962. A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory, studies of evaporation. USGS Profess. Paper 272-E.

Hargreaves, George H. 1973. The estimation of potential and crop evapotranspiration. Utah State University, Logan, Utah. 11 p.

Huntzinger, Thomas L. 1971. Future water use model of Utah Valley. Colorado State University, Fort Collins, Colorado. 119 p.

Hyatt, M. L., G. V. Skogerboe, and F. W. Haws. 1968. Water related land use in the Utah Lake drainage area. Report WG40-1. Utah Water Research Laboratory, Utah State University, Logan, Utah. February.

Hyatt, M. L., G. V. Skogerboe, F. W. Haws and L. H. Austin. 1969. Hydrologic inventory of the Utah Lake drainage area. Report WG40-3. Utah Water Research Laboratory, Utah State University, Logan, Utah. November.

Jensen, M. E., and H. R. Haise. 1963. Estimating evaporation from solar radiation. Paper 3737, Proc. ASCE, J. Irrig. and Drain. Div., 89(IR4):15-41.

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

List, R. J. 1968. Smithsonian meteorological tables. Smithsonian Institution Press, City of Washington.

McCullock, Allan W., Jack Keller, Roger M. Sherman, and Robert C. Mueller. 1967. Ames irrigation handbook. W. R. Ames Company, Milipitas, California.

Meyer, A. F. 1915. Computing run-off from rainfall and other physical data. Trans. ASCE, 79:1056-1155.

Paulhus, Joseph L. H., and Max A. Kohler. 1952. Interpolation of missing precipitation records. Monthly Weather Rev., 80:129-133.

Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London, Ser. A. 193:120-145.

Phelan, John T. 1962. Estimating monthly "k" values for the Blaney-Criddle formula. Presented at the Agriculture Research Service–Soil Conservation Service Workshop on Consumptive Use, Phoenix, Arizona. March 6-8. 11 p.

Raphael, J. M. 1962. Prediction of temperature in rivers and reservoirs. Proc. ASCE, J. Power Div., 88:(PO2):157-181.

Riley, J. Paul, D. G. Chadwick, and J. M. Bagley. 1966. Application of electronic analog computer to solution of hydrologic and river-basin-planning problems: Utah Simulation Model II. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Riley, J. Paul, J. M. Bagley, D. G. Chadwick, and E. K. Israelsen. 1967. The development of an electronic analog device for hydrologic investigations and conservation planning in the Sevier River Basin: Utah Simulation Model I. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Riley, J. Paul, and D. G. Chadwick. 1967. Application of an electronic analog computer to the problems of river basin hydrology. Utah Water Research Laboratory, Utah State University, Logan, Utah. December.

Soil Conservation Service. Department of Agriculture. 1964. Irrigation water requirements. Technical Release No. 21, Washington, D.C. April. 61 p.

Thorne, D. W., and H. W. Peterson. 1954. Irrigated soils. McGraw-Hill Book Company, Inc., New York. 392 p.

U.S. Bureau of Reclamation. 1964. Central Utah Project initial phase. Bonneville unit. Definite plan report. Appendix B Water Supply. Vols. 1 and 2. Region 4, Salt Lake City, Utah. August.

Van Bavel, C. H. M. 1966. Potential evaporation, the combination concept and its experimental verification. Water Resources Research, 2(3):455-467.

Willardson, Lyman S., and Wendall L. Pope. 1963. Separation of evapotranspiration and deep percolation. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 89(IR3):77-88.

APPENDIX A

PARAMETER OPTIMIZATION MODEL

The Parameter Optimization Model was designed to be general in nature and not tied to a particular time sequence or specific units of input. The program presented is based on input and output for each month of the water year. The program is easily converted to a calendar year by changing the output titles and using data arranged on cards for the calendar year. The sample input is based on the water year so that the first month data on each card is for October.

The program was designed for use on the EAI 590 hybrid computer. The program presented is completely digital and contains logic statement peculiar to this computer. For example, the program makes use of sense switches which would have to be changed to "If" tests on many digital computers. The flow charts for this program indicate the intended logic of such controls.

A dummy scale area, ASCL, must be input when a subbasin does not contain agricultural area. The magnitude of ASCL must be chosen so the output will not overflow or underflow the output format. There must be at least one phreatophyte area within each subbasin.

Water which is imported to a subbasin can be treated as an import or a gaged inflow. When water is imported for direct application to agricultural or municipal and industrial use it should be handled as VAR(5) or VAR(6). Such water will be designated to those uses and will only enter the stream as return flow. Water which is imported to the stream should be treated as a gage inflow to the subbasin. Irrigation or municipal and industrial water is exported by diverting the water in VAR(7) and VAR(8), respectively, and then exporting the water under VAR(11) and VAR(12).

The program has the ability to optimize the parameters or simulate the hydrology for a set of fixed parameters. This option is designated to aid the operator in parameter selection. The program is limited to a four-year study only by the dimensions of DVAR.

Cards outlined in the input data layout under I and II are total river basin data, the remainder of the cards apply to particular subbasins within the river basin. The sample input is for the Francis subbasin of the Provo River. Extra cards have been added which refer to the order outlined in the input data layout and should not be confused with actual input. The sample data and sample output are for the parameter calibration option. Not all of the VAR(L) data are shown due to the amount of card input for this subbasin.

The output from the program is in inches of water over the agricultural area. The sense switches allow the additional output of the results in acre feet.

The program listing and flow charts should be referred to simultaneously when questions arise about the logic within the program.

INPUT DATA LAYOUT

I. Basic Data

	Col	Identifier	
Card 1	1-40	BSNM	The river basin name
	41-45	NVR	Number of variables; corresponds to number of VAR(L) in Table A-1
	46-50	NPR	Number of parameters; corresponds to number of PR(L) in Table A-1
	51-55	NYR	Number of year to be studied by the program
	56-60	INN	Input device indicator; i.e., tape or cards
	61-65	IOUT	Output device indicator; i.e., print or record on tape
	66-70	NITX	Maximum number of iterations in loop involving the calculation of soil moisture

Format (10A 4, 8I5)

II. Total Basin Data

Card 1	1-4	OTL(1)	Output title for VAR(1)
	5-8	OTL(2)	Output title for VAR(2)
	⋮		⋮
	45-48	OTL(12)	Output title for VAR(12)
	49-52	OTL(13)	Output title for SIM(1)
	53-56	OTL(14)	Output title for SIM(2)
	⋮		⋮
	77-80	OTL(20)	Output title for SIM(8)

Format (20 A4)

Card 2	1-4	OTL(21)	Output title for SIM(9)
	5-8	OTL(22)	Output title for SIM(10)
	⋮		⋮
	21-24	OTL(26)	Output title for SIM(14)
	25-28	OTL(27)	Output title for VAR(13)
	29-32	OTL(28)	Output title for SIM(15)

Format (20 A4)

The abbreviations used in the input and corresponding output refer to the definitions of the VAR(L)'s and SIM(L)'s given in Table A-1 and Table A-2, respectively. The plus and minus sign on the abbreviations indicate gains or losses to the system.

Card 3	1-5	DLH(1)	Fraction daylight hours for month 1
	6-10	DLH(2)	Fraction daylight hours for month 2
	⋮		⋮
	56-60	DLH(12)	Fraction daylight hours for month 12
	61-65	NCR	Number of crop evapotranspirations to be simulated, see Table A-2
	66-70	NPH	Number of phreatophyte evapotranspirations to be simulated, see Table A-2
	71-75	INPH	Indicates which objective function to use (0 or 1) 0 - will use Equation 4.3 and emphasize low flows 1 - will use Equation 4.2 and emphasize high flows

Format (12 F5.3, 4I5)

Card 4	1-10		Crop identification
	11-15	CCR(1, 1)	k_c for crop 1 month 1
	16-20	CCR(1, 2)	k_c for crop 1 month 2
	⋮		⋮
	66-70	CCR(1,12)	k_c for crop 1 month 12

Format (10X, 12F5.2)

This format is repeated for Crop 2, 3, ... NCR. (For k_c see Equation 3.18.)

Card 5	1-10		Phreatophyte identification
	11-15	CPH(1, 1)	k_c for phreatophyte 1 month 1
	16-20	CPH(1, 2)	k_c for phreatophyte 1 month 2
	⋮		⋮
	66-70	CPH(1, 12)	k_c for phreatophyte 1 month 2

Format (10X, 12F5.2)

This format is repeated for phreatophyte 2, 3, ... NPH.

III. Choose to Simulate the Hydrology or Optimize the Parameters

Card 1	4	IDOP	0 - Program will simulate the hydrology for a single set of parameters for NYR years 1 - Program will optimize the parameters based on NYR years of data

Format (20I4)

IV. Subbasin Data

Card 1	1-20	SBNM	Subbasin name
	21-30	AGAG	Gaged area of the subbasin in acres (does not include agricultural area)
	31-40	AUNG	Ungaged area of the subbasin in acres (does not include agricultural area)
	45	IDCR	0 - Indicates no crop land within subbasin 1 - Indicates crop land within subbasin
	46-50	ADMS	Tolerance desired in the calculation of soil moisture. ADMS is in inches of water
	51-60	ACOR	Drainage area of the stream used for ungaged flow correlation, in acres
	61-65	TMP1	Temperature adjustment in degrees Fahrenheit used in snowmelt calculation for the ungaged area; a positive number for decrease (see Equation 3.6)

Format (5A4, 2F10.0, I5, F5.3, F10.0, F5.1)

If IDCR = 0, Skip Card 2

Card 2	1-10	ACR(1)	Acres of crop 1
	11-20	ACR(2)	Acres of crop 2
	⋮		⋮
		ACR(NCR)	Acres of crop NCR
	10 col	TACR	Total crop acres (sum of ACR's)

Format (8F10.0)

Card 3	1-10	APH(1)	Acres of phreatophyte 1
	11-20	APH(2)	Acres of phreatophyte 2
	⋮		⋮
		APH(NPH)	Acres of phreatophyte NPH
	10 col	TAPH	Total phreatophyte acres (sum of APH's)
	10 col	ASCL	A dummy scaling area for subbasin with no crop area (necessary when IDCR = 0)

Format (8F10.0)

If IDOP = 0 input model parameter cards here (Card 2 of VI).

Card 4	1-4	NST(1)	Number of stations of VAR(1)
	5-8	NST(2)	Number of stations of VAR(2)
	⋮		⋮
		NST(NVR)	Number of stations of VAR(NVR)

Format (20I4)

VAR's given in Table A-1

Card 5	21-30	CONV(3)	Converstion factor for VAR(3)
	31-40	CONV(4)	Converstion factor for VAR(4)
	⋮		⋮
		CONV(NVR)	Conversion factor for VAR(NVR)
	10 col	CAF	Conversion of acre-feet to inches of water over the agricultural acres or scaling area

Format (8F10.6)

where:

CONV(L)	Converts the units of VAR(L) to inches of water over the agricultural area. If VAR(L) is in acre-feet, CONV(L) = CAF
CAF =	12/TACR if IDCR = 1
CAF =	12/ASCL if IDCR = 0

Card 6	1-5	CWT(1, 1)	Weight factor to apply to temperature station 1
	6-10	CWT(1, 2)	Weight factor to apply to temperature station 2
	⋮		⋮
		CWT(1, NST[1])	Weight factor to apply to temperature station NST(1)

Format (16F5.3)

Card 7	1-5	CWT(2, 1)	Weight factor to apply to precipitation station 1
	6-10	CWT(2, 2)	Weight factor to apply to precipitation station 2
	⋮		⋮
		CWT(2, NST[2])	Weight factor to apply to precipitation station NST(2)

Format (16F5. 3)

For this study CWT(2, N's) come from Equation 3. 2, but the program allows for any weighting factor to be input.

V. Observed Data

Card 1	1-5	LYRO	Starting year of data
	6-10	SNOW	Initial snow storage in inches of water

Format (I5, F5. 0)

Card 2	9-14	CORS(1, 1)	Correlation streamflow year 1 month 1
	15-20	CORS(1, 2)	Correlation streamflow year 1 month 2
	⋮		⋮
	75-80	CORS(1, 12)	Correlation streamflow year 1 month 12

Format (8X, -3P12F6. 1)

This format is repeated for year 2, 3, ... NYR. The input format is for CORS in thousands acre-feet.

Card 3	4	IFMT(1)	Read format indicator for VAR(1)
	8	IFMT(2)	Read format indicator for VAR(2)
	⋮		⋮
	4(NVR)	IFMT (NVR)	Read format indicator for VAR(NVR)

Format (20I4)

Input a 1 to 5 depending on which format on the next card, Card 4 is appropriate. (See flow chart for IPOD)

Card 4	1-16	FMT1	A specific input format
	17-32	FMT2	A specific input format
	⋮		⋮
	65-80	FMT5	A specific input format

Format (5[4A4])

Card 5

The VAR(L) of Table A-1 are input at this point, according to the formats specified on Cards 3 and 4. For example, with IFMT(2) = 3 the program will read all stations of VAR(2) according to FMT3. Card 4 of IV specifies the number of stations for each variable.

Each card must contain twelve monthly values and all stations of each VAR(L) must be punched with the same format and in the same units.

Starting with VAR(1) the data for year 1 to NYR are input in ascending yearly order for station 1. This is followed by NYR years of data for station 2, 3, ... NST(1). The ordering of the stations is not important because they are summed to form DVAR. Data for VAR(2), VAR(3), ..., VAR(NVR) are then input in the same manner.

The VAR(L) data are input by year, station, then variable. If any NST(L) = 0, that variable is skipped. The sample input should make the ordering clear.

If IDOP = 0, do not input remaining cards

VI. Parameter Input

Card 1	1-4	NPHS	Number of phases of the optimization to be run (generally 3 or 4)

Format (20I4)

Card 2	1-5	PRO(1)	Initial value of PR(1)
	6-10	PRO(2)	Initial value of PR(2)
	⋮		⋮
		PRO(NPR)	Initial value of PR(NPR)

Format (16F5. 2)

Card 3	1-4	NLV(1)	Number of increments for PR(1)
	5-8	NLV(2)	Number of increments for PR(2)
	⋮		⋮
		NLV(NPR)	Number of increments for PR(NPR)

Format (20I4)

If NLV(L) = 0 or 1, no Card 4 is to be input for that parameter and it is therefore not optimized.

Card 4 One card for each parameter with NLV(L) > 1, input in ascending order.

6-10	PRL(L)	Low level of PR(L)
7-15	PRH(L)	High level or PR(L)

Format (5X, 2F5. 2)

The step size for each parameter during optimization is calculated as:

$$\frac{PRH(L) - PRL(L)}{NLV(L)}$$

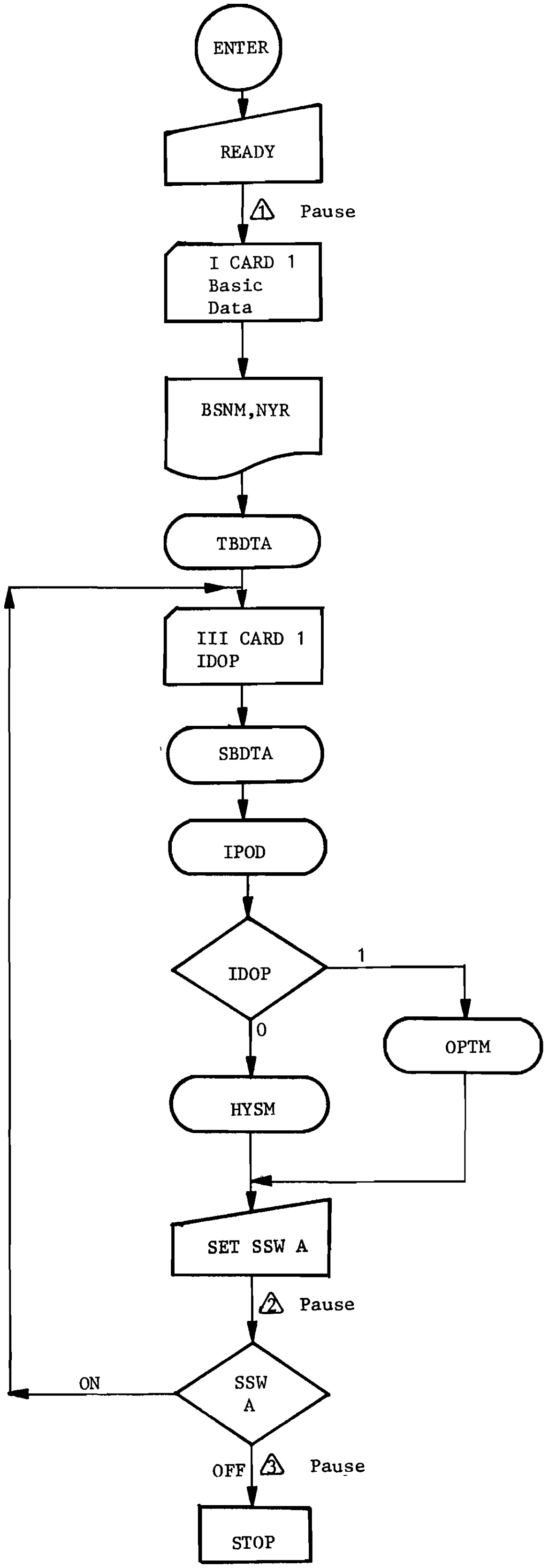
Table A1. Definition of variables and parameters.

L	Variables	Parameters	Equation
1	Mean monthly temperature	Snowfall temperature	Chapter 3 Precipitation Sect.
2	Total monthly precipitation	Snowmelt temperature	3.3 T_m
3	Gaged surface inflow	Soil moisture holding capacity	3.27 M_{cs}
4	Gaged or estimated groundwater inflow	Critical soil moisture	3.27 M_{es}
5	Irrigation Import	Ungaged stream correlation coefficient	3.7 K_1
6	M & I Import	Subsurface storage coefficient	3.33 K_{ss}
7	Irrigation surface flow diversions	Groundwater storage coefficient	3.35 K_g
8	M & I surface flow diversions	Snowmelt coefficient	3.4 K_s
9	Irrigation pumpage	Consumptive use coefficient	3.25 K_u
10	M & I pumpage	Irrigation efficiency	3.13 Eff
11	Irrigation Export	M & I efficiency	3.16 Eff_{mi}
12	M & I export	Coefficient of rain plus snowmelt for ungaged flow	3.7 K_2
13	Gaged surface outflow	Threshold for surface runoff	3.7 K_3
14	Minimum stream flow	Base flow coefficient	3.36 K_{bf}
15		Infiltration coefficient	3.33 C_i
16		Initial soil moisture	3.28 $M_s(0)$
17		Initial base and groundwater outflow	3.35 Q_{gao}
18		Initial watershed recharge	3.32 Q_{sg}

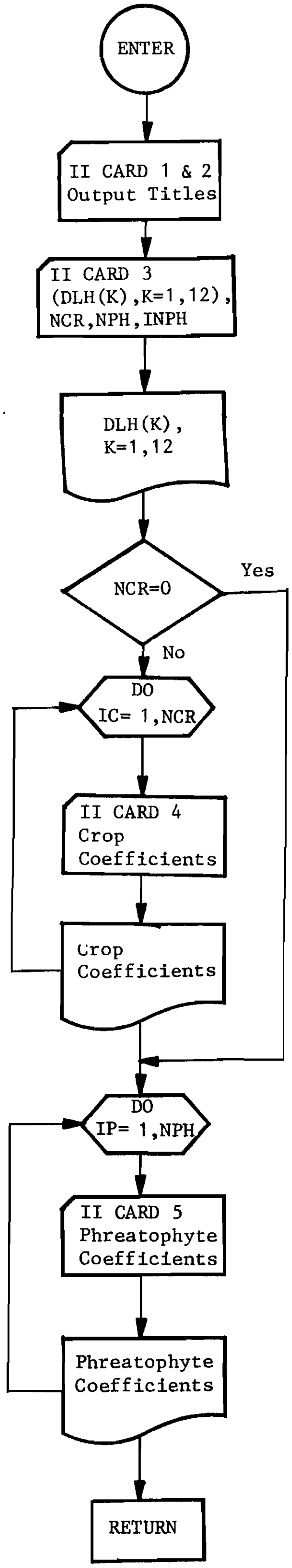
Table A2. Definition of variables and parameters.

L	Simulated Quantities	Equation
1	Not used	
2	Snow storage	3.5 $W_s(t)$
3	Snowmelt rate	3.5 $W_s(0) - W_s(1)$
4	Phreatophyte evapotranspiration	3.25 ET_{pr}
5	Crop evapotranspiration	3.26, 27 ET_r
6	Soil moisture	3.19 $M_s(t)$
7	Deep percolation	3.29, 30 DP_r
8	Ungaged surface inflow	3.7 Q_{ug}
9	Return flow	3.15, 16 $Q_{ri} + Q_{rmi}$
10	Base flow	3.36 Q_{bf}
11	Water deficit	SIM(14) - VAR(14)
12	Total outflow	3.39 Q_{to}
13	Groundwater outflow	3.37 Q_{go}
14	Surface outflow	3.38 Q_{so}
15	Deviation from observed surface outflow	VAR(13) - SIM(14)

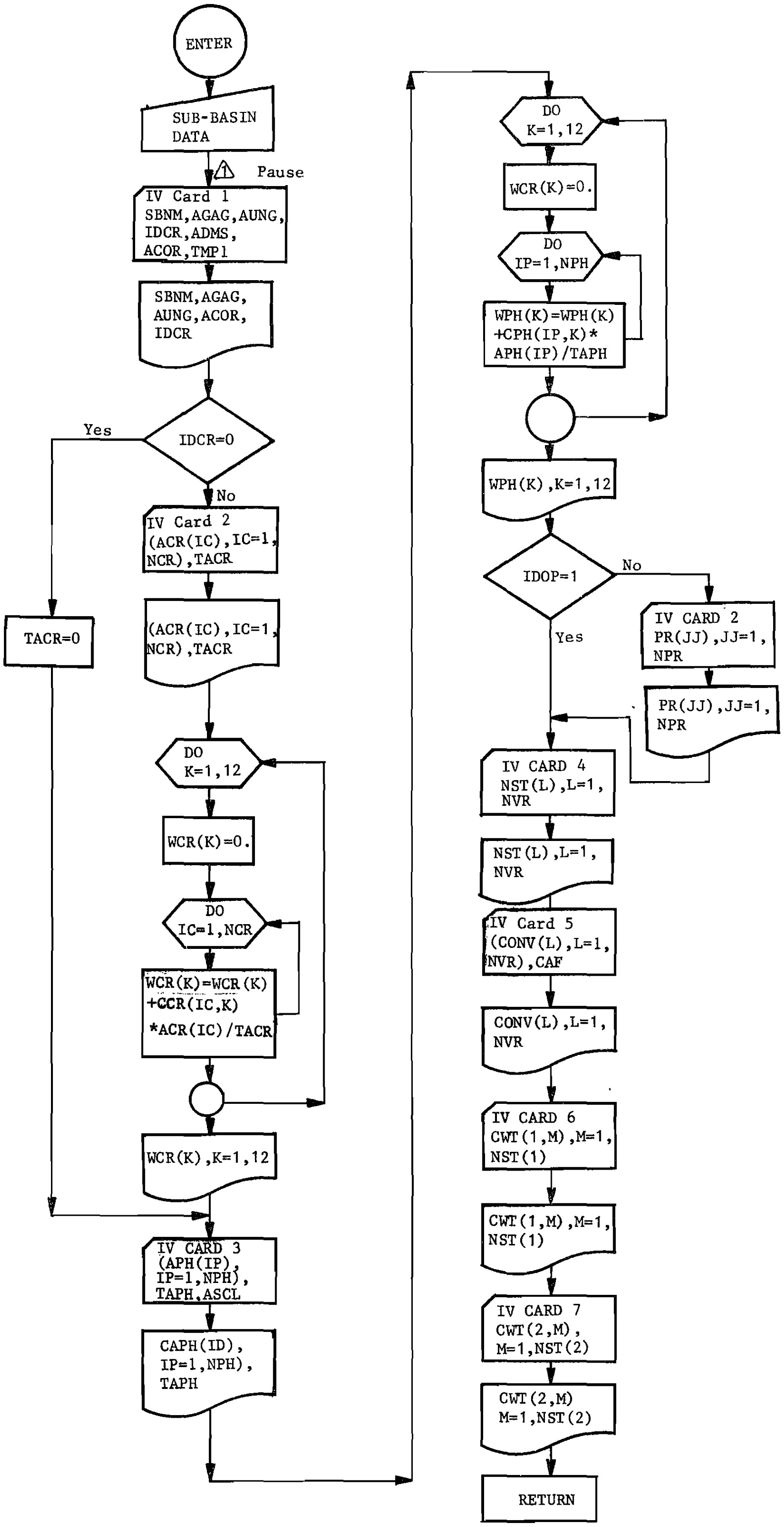
MAIN PROGRAM

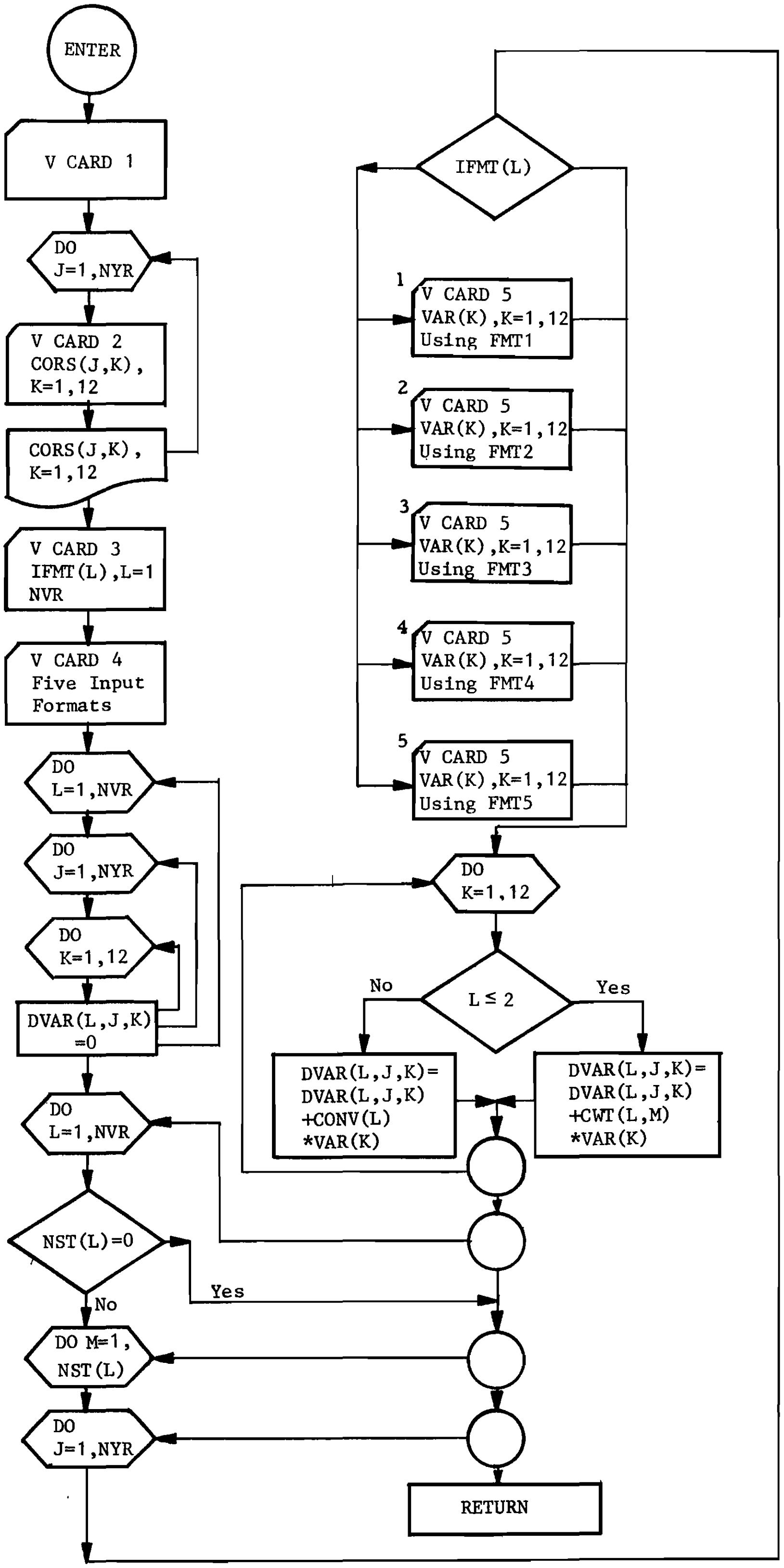


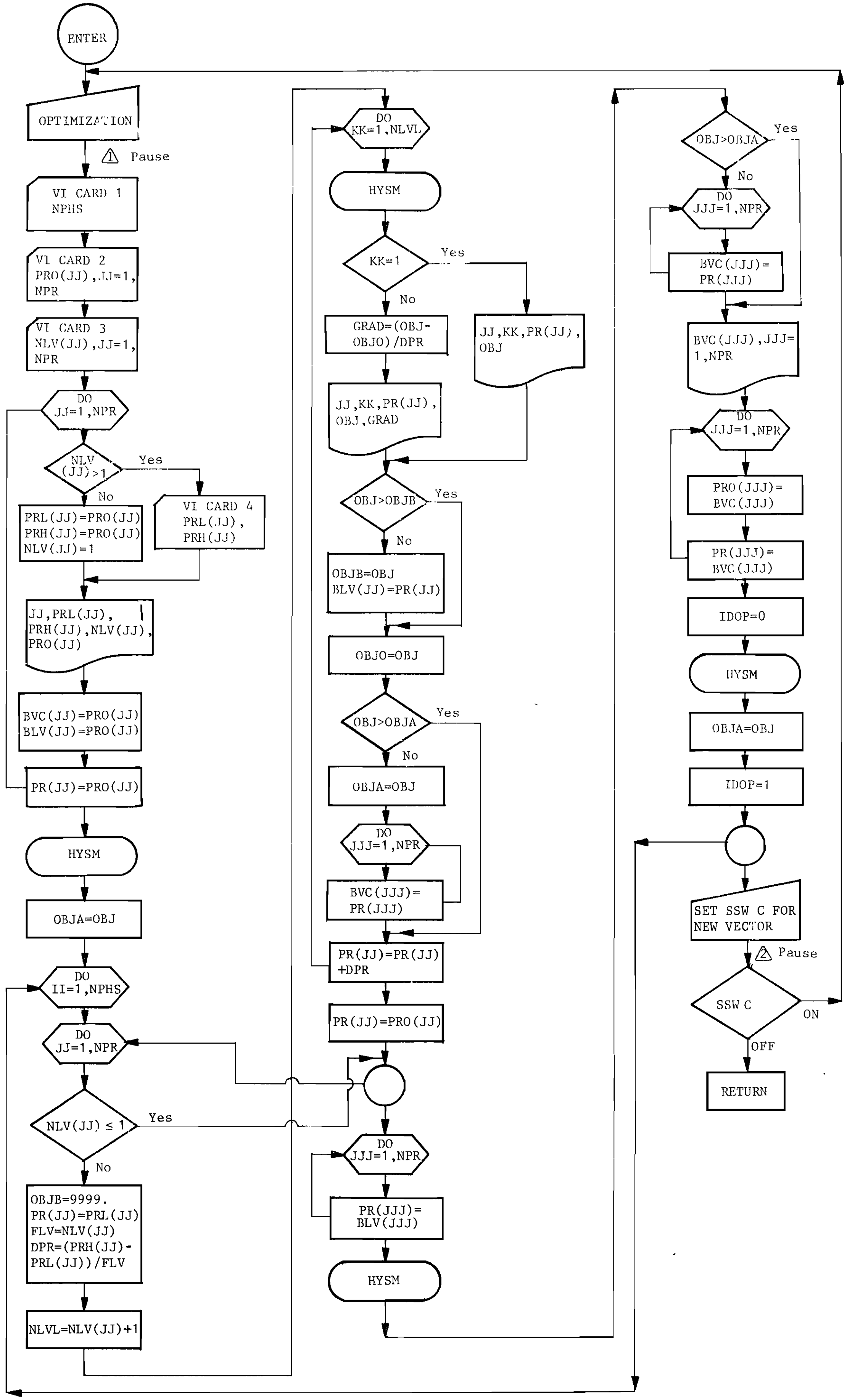
TBDTA

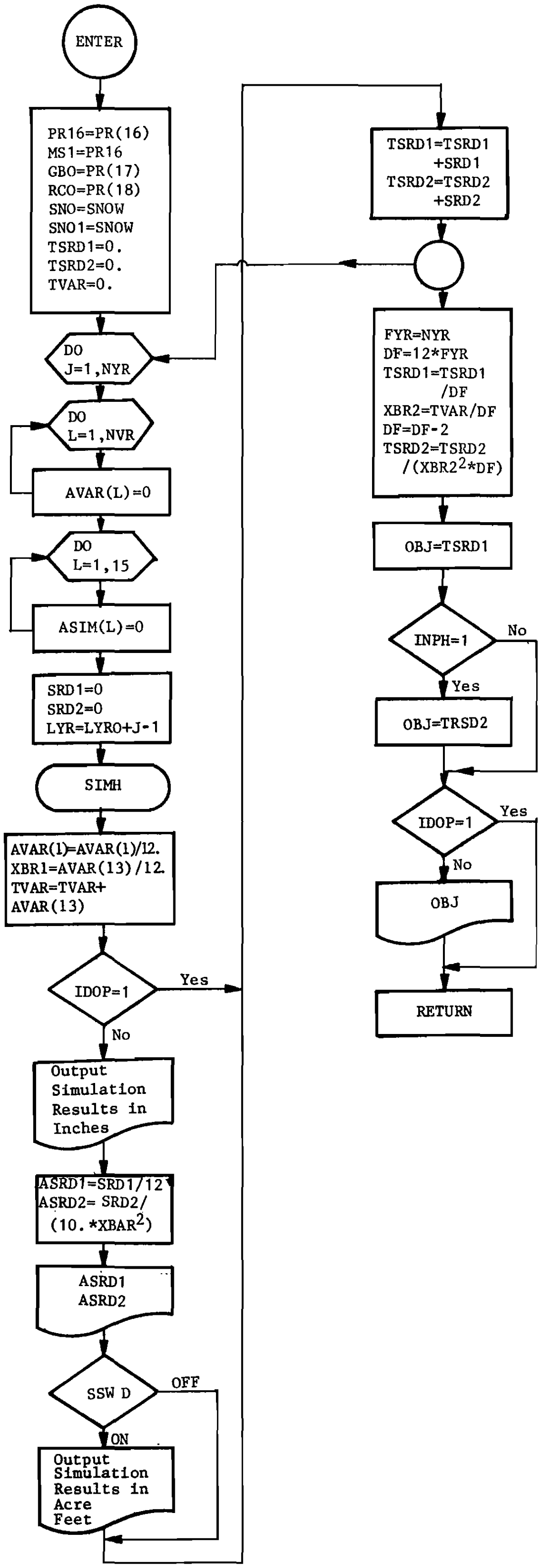


SBDTA

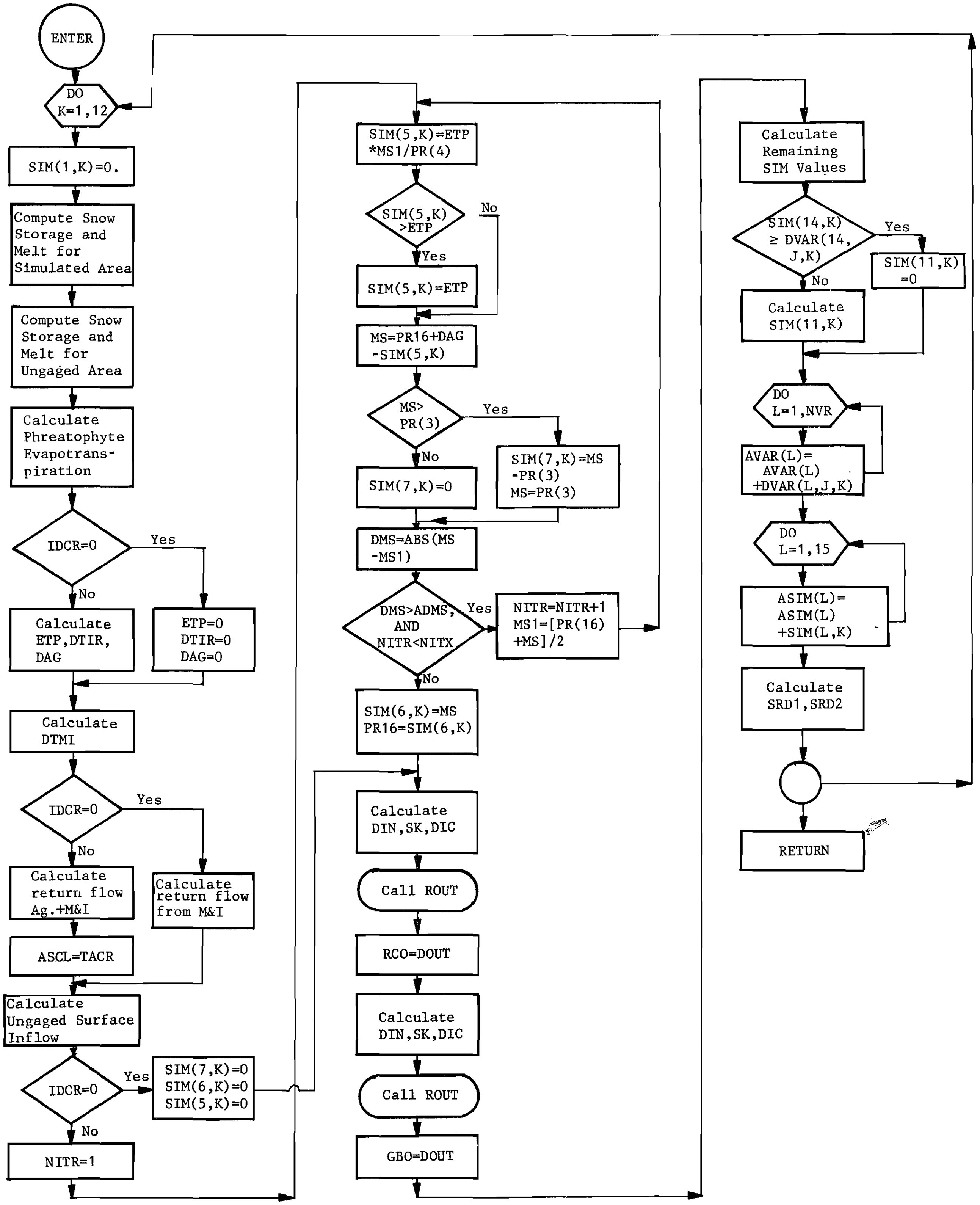

ENTER
SUB-BASIN DATA
Pause
IV Card 1 SBNM,AGAG,AUNG, IDCR,ADMS, ACOR,TMP1
SBNM,AGAG, AUNG,ACOR, IDCR
IDCR=0
Yes
No
TACR=0
IV Card 2 (ACR(IC),IC=1, NCR),TACR
(ACR(IC),IC=1, NCR),TACR
DO K=1,12
WCR(K)=0.
DO IC=1,NCR
WCR(K)=WCR(K) +CCR(IC,K) *ACR(IC)/TACR
WCR(K),K=1,12
IV CARD 3 (APH(IP), IP=1,NPH), TAPH,ASCL
CAPH(ID), IP=1,NPH), TAPH
DO K=1,12
WCR(K)=0.
DO IP=1,NPH
WPH(K)=WPH(K) +CPH(IP,K)* APH(IP)/TAPH
WPH(K),K=1,12
IDOP=1
No
Yes
IV CARD 2 PR(JJ),JJ=1, NPR
PR(JJ),JJ=1, NPR
IV CARD 4 NST(L),L=1, NVR
NST(L),L=1, NVR
IV Card 5 (CONV(L),L=1, NVR),CAF
CONV(L),L=1, NVR
IV CARD 6 CWT(1,M),M=1, NST(1)
CWT(1,M),M=1, NST(1)
IV CARD 7 CWT(2,M), M=1,NST(2)
CWT(2,M) M=1,NST(2)
RETURN


ENTER
V CARD 1
DO J=1,NYR
V CARD 2 CORS(J,K), K=1,12
CORS(J,K), K=1,12
V CARD 3 IFMT(L),L=1 NVR
V CARD 4 Five Input Formats
DO L=1,NVR
DO J=1,NYR
DO K=1,12
DVAR(L,J,K) =0
DO L=1,NVR
NST(L)=0
Yes
No
DO M=1, NST(L)
DO J=1,NYR
IFMT(L)
1
V CARD 5 VAR(K),K=1,12 Using FMT1
2
V CARD 5 VAR(K),K=1,12 Using FMT2
3
V CARD 5 VAR(K),K=1,12 Using FMT3
4
V CARD 5 VAR(K),K=1,12 Using FMT4
5
V CARD 5 VAR(K),K=1,12 Using FMT5
DO K=1,12
L ≤ 2
No
Yes
DVAR(L,J,K)= DVAR(L,J,K) +CONV(L) *VAR(K)
DVAR(L,J,K)= DVAR(L,J,K) +CWT(L,M) *VAR(K)
RETURN


ENTER
OPTIMIZATION
⚠1 Pause
VI CARD 1
NPHS
VI CARD 2
PRO(JJ),JJ=1,
NPR
VI CARD 3
NLV(JJ),JJ=1,
NPR
DO
JJ=1,NPR
NLV
(JJ)>1
Yes
No
PRL(JJ)=PRO(JJ)
PRH(JJ)=PRO(JJ)
NLV(JJ)=1
VI CARD 4
PRL(JJ),
PRH(JJ)
JJ,PRL(JJ),
PRH(JJ),NLV(JJ),
PRO(JJ)
BVC(JJ)=PRO(JJ)
BLV(JJ)=PRO(JJ)
PR(JJ)=PRO(JJ)
HYSM
OBJA=OBJ
DO
II=1,NPHS
DO
JJ=1,NPR
NLV(JJ) ≤ 1
Yes
No
OBJB=9999.
PR(JJ)=PRL(JJ)
FLV=NLV(JJ)
DPR=(PRH(JJ)-
PRL(JJ))/FLV
NLVL=NLV(JJ)+1
DO
KK=1,NLVL
HYSM
KK=1
Yes
No
GRAD=(OBJ-
OBJO)/DPR
JJ,KK,PR(JJ),
OBJ
JJ,KK,PR(JJ),
OBJ,GRAD
OBJ>OBJB
Yes
No
OBJB=OBJ
BLV(JJ)=PR(JJ)
OBJO=OBJ
OBJ>OBJA
Yes
No
OBJA=OBJ
DO
JJJ=1,NPR
BVC(JJJ)=
PR(JJJ)
PR(JJ)=PR(JJ)
+DPR
PR(JJ)=PRO(JJ)
DO
JJJ=1,NPR
PR(JJJ)=
BLV(JJJ)
HYSM
OBJ>OBJA
Yes
No
DO
JJJ=1,NPR
BVC(JJJ)=
PR(JJJ)
BVC(JJJ),JJJ=
1,NPR
DO
JJJ=1,NPR
PRO(JJJ)=
BVC(JJJ)
PR(JJJ)=
BVC(JJJ)
IDOP=0
HYSM
OBJA=OBJ
IDOP=1
SET SSW C FOR
NEW VECTOR
⚠2 Pause
SSW C
ON
OFF
RETURN


ENTER
PR16=PR(16)
MS1=PR16
GBO=PR(17)
RCO=PR(18)
SNO=SNOW
SNO1=SNOW
TSRD1=0.
TSRD2=0.
TVAR=0.
DO J=1,NYR
DO L=1,NVR
AVAR(L)=0
DO L=1,15
ASIM(L)=0
SRD1=0
SRD2=0
LYR=LYRO+J-1
SIMH
AVAR(1)=AVAR(1)/12.
XBR1=AVAR(13)/12.
TVAR=TVAR+
AVAR(13)
IDOP=1
Yes
No
Output Simulation Results in Inches
ASRD1=SRD1/12
ASRD2= SRD2/
(10.*XBAR2)
ASRD1
ASRD2
SSW D
OFF
ON
Output Simulation Results in Acre Feet
TSRD1=TSRD1
+SRD1
TSRD2=TSRD2
+SRD2
FYR=NYR
DF=12*FYR
TSRD1=TSRD1
/DF
XBR2=TVAR/DF
DF=DF-2
TSRD2=TSRD2
/(XBR22*DF)
OBJ=TSRD1
INPH=1
No
Yes
OBJ=TRSD2
IDOP=1
Yes
No
OBJ
RETURN

SIMH


ENTER
DO K=1,12
SIM(1,K)=0.
Compute Snow Storage and Melt for Simulated Area
Compute Snow Storage and Melt for Ungaged Area
Calculate Phreatophyte Evapotranspiration
IDCR=0
Yes
No
Calculate ETP,DTIR, DAG
ETP=0 DTIR=0 DAG=0
Calculate DTMI
IDCR=0
Yes
No
Calculate return flow Ag.+M&I
Calculate return flow from M&I
ASCL=TACR
Calculate Ungaged Surface Inflow
IDCR=0
Yes
No
SIM(7,K)=0 SIM(6,K)=0 SIM(5,K)=0
NITR=1
SIM(5,K)=ETP *MS1/PR(4)
SIM(5,K) >ETP
No
Yes
SIM(5,K)=ETP
MS=PR16+DAG -SIM(5,K)
MS> PR(3)
Yes
No
SIM(7,K)=0
SIM(7,K)=MS -PR(3) MS=PR(3)
DMS=ABS(MS -MS1)
DMS>ADMS, AND NITR<NITX
Yes
No
NITR=NITR+1 MS1=[PR(16) +MS]/2
SIM(6,K)=MS PR16=SIM(6,K)
Calculate DIN,SK,DIC
Call ROUT
RCO=DOUT
Calculate DIN,SK,DIC
Call ROUT
GBO=DOUT
Calculate Remaining SIM Values
SIM(14,K) ≥ DVAR(14, J,K)
Yes
No
SIM(11,K) =0
Calculate SIM(11,K)
DO L=1,NVR
AVAR(L)= AVAR(L) +DVAR(L,J,K)
DO L=1,15
ASIM(L)= ASIM(L) +SIM(L,K)
Calculate SRD1,SRD2
RETURN

PARAMETER OPTIMIZATION PROGRAM LISTING

```
C     PARAMETER OPTIMIZATION FOR HYDROLOGIC SIMULATION MODEL --MPOP
      COMMON/BLK1/          ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                                SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,      IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
      DIMENSION BSNM(10)
    1 TYPE 200
  200 FORMAT(5HREADY/)
      OCT 25000
C     INPUT BASIC DATA
      READ(6,300) (BSNM(I),I=1,10),NVR,NPR,NYR,INN,IOUT,NITX
  300 FORMAT(10A4,8I5)
      WRITE(IOUT,201) (BSNM(I),I=1,10),NYR
  201 FORMAT(1H1,10A4,5X,5HNYR =,I2//)
      CALL TBDTA
    2 READ(INN,301) IDOP
  301 FORMAT(20I4)
C     INPUT SUB-BASIN DATA
      CALL SBDTA
      CALL IPOD
      IF(IDOP.EQ.1) GO TO 3
      CALL HYSM(0)
      J   .4
    3 CALL OPTM
    4 TYPE 1202
 1202 FORMAT(10H SET SSW A/)
      OCT 25000
C     IF SSW A ON, REPEAT SUB-BASIN OPERATION
      OCT 023600
      J   .6
      J   .2
    6 OCT 25000
      STOP
      END
C     SUBROUTINE FOR TOTAL BASIN DATA
      SUBROUTINE TBDTA
      COMMON/BLK1/          ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                                SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,      IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
C     READ OUTPUT TITLES
      READ(INN,302) (OTL(II),II=1,28)
  302 FORMAT(20A4)
C     INPUT DAY-LIGHT HOURS AND NUMBER OF CROPS AND PHREATOPHYTES
      READ(INN,303) (DLH(K),K=1,12),NCR,NPH,INPH
  303 FORMAT(12F5.3,4I5)
      WRITE(IOUT,203) (DLH(K),K=1,12)
  203 FORMAT(25H FRACTION DAY-LIGHT HOURS/12F6.3//)
      IF(NCR.EQ.0) GO TO 9
C     INPUT CROP COEFFICIENTS
      WRITE(IOUT,204)
  204 FORMAT(18H CROP COEFFICIENTS)
      DO 8 IC=1,NCR
      READ(INN,304) (CCR(IC,K),K=1,12)
  304 FORMAT(10X,12F5.2)
    8 WRITE(IOUT,205) (CCR(IC,K),K=1,12)
  205 FORMAT(12F6.2)
C     INPUT PHREATOPHYTE COEFFICIENT
    9 WRITE(IOUT,206)
  206 FORMAT(//26H PHREATOPHYTE COEFFICIENTS)
      DO 10 IP=1,NPH
      READ(INN,304) (CPH(IP,K),K=1,12)
   10 WRITE(IOUT,205) (CPH(IP,K),K=1,12)
      RETURN
      END
C     SUBROUTINE FOR SUB-BASIN DATA
      SUBROUTINE SBDTA
      COMMON/BLK1/          ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                                SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,      IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
      DIMENSION ACR(14),APH(7)
      TYPE 207
  207 FORMAT(15H SUB-BASIN DATA/)
      OCT 25000
      READ(INN,305) (SBNM(IB),IB=1,5),AGAG,AUNG,IDCR,      ADMS,ACOR,TMP1
  305 FORMAT(5A4,2F10.0, I5,F5.3,F10.0,F5.1)
      WRITE(IOUT,208) (SBNM(IB),IB=1,5),AGAG,AUNG,ACOR,IDCR
  208 FORMAT(1H1,5A4/,2X6HAGAG =,F10.0,2X6HAUNG =,F10.0,2X6HACOR =,F10.0
     1,2X6HIDCR =,I2)
      IF(IDCR.EQ.0) GO TO 12
      READ(INN,306) (ACR(IC),IC=1,NCR),TACR
  306 FORMAT(8F10.0)
      WRITE(IOUT,209) (ACR(IC),IC=1,NCR),TACR
  209 FORMAT(11H CROP AREAS/(8F10.0))
C     COMPUTE WEIGHTED CROP COEFFICIENT
      DO 11 K=1,12
      WCR(K)=0.
      DO 11 IC=1,NCR
   11 WCR(K)=WCR(K)+CCR(IC,K)*ACR(IC)/TACR
      WRITE(IOUT,210) (WCR(K),K=1,12)
  210 FORMAT(//26H WEIGHTED CROP COEFFICIENT/12F6.2)
      J   .1013
   12 TACR=0.
 1013 READ(INN,306) (APH(IP),IP=1,NPH),TAPH,ASCL
      WRITE(IOUT,211) (APH(IP),IP=1,NPH),TAPH
  211 FORMAT(//19H PHREATOPHYTE AREAS/8F10.0)
C     COMPUTE WEIGHTED PHREATOPHYTE COEFFICIENT
      DO 13 K=1,12
      WPH(K)=0.
      DO 13 IP=1,NPH
   13 WPH(K)=WPH(K)+CPH(IP,K)*APH(IP)/TAPH
      WRITE(IOUT,212) (WPH(K),K=1,12)
  212 FORMAT(//34H WEIGHTED PHREATOPHYTE COEFFICIENT/12F6.2)
      IF(IDOP.EQ.1) GO TO 15
C     INPUT MODEL PARAMETERS
      READ(INN,1306) (PR(JJ),JJ=1,NPR)
 1306 FORMAT(16F5.2)
      WRITE(IOUT,213) (PR(JJ),JJ=1,NPR)
  213 FORMAT(//17H PARAMETER VALUES/(8F8.2))
   15 READ(INN,3306) (NST(L),L=1,NVR)
 3306 FORMAT(20I4)
      WRITE(IOUT,215) (NST(L),L=1,NVR)
  215 FORMAT(//37H NUMBER OF STATIONS FOR EACH VARIABLE/16I5)
      READ(INN,307) (CONV(L),L=1,NVR),CAF
  307 FORMAT(8F10.6)
      WRITE(IOUT,216) (CONV(L),L=1,NVR)
  216 FORMAT(//19H CONVERSION FACTORS/(8F10.6))
C     INPUT STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION
      NST1=NST(1)
      READ(INN,1307) (CWT(1,M),M=1,NST1)
 1307 FORMAT(16F5.3)
      WRITE(IOUT,217) (CWT(1,M),M=1,NST1)
  217 FORMAT(//32H STATION WEIGHTS FOR TEMPERATURE/1X,12F5.3)
      NST2=NST(2)
```

```
      READ(INN,1307) (CWT(2,M),M=1,NST2)
      WRITE(IOUT,218) (CWT(2,M),M=1,NST2)
  218 FORMAT(//34H STATION WEIGHTS FOR PRECIPITATION/1X,12F5.3)
      RETURN
      END
C     SUBROUTINE TO INPUT OBSERVED DATA
      SUBROUTINE IPOD
      COMMON/BLK1/         ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                            SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,     IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
      READ(INN,309) LYRO,SNOW
  309 FORMAT(I5,F5.0)
C
C     INPUT CORRELATION STREAMFLOW
      WRITE(IOUT,200)
  200 FORMAT(//17H CORR. STREAMFLOW)
      DO 31 J=1,NYR
      READ(INN,100) (CORS(J,K),K=1,12)
   31 WRITE(IOUT,201) (CORS(J,K),K=1,12)
  100 FORMAT(8X,-3P12F6.1)
  201 FORMAT(1X,-3P12F6.1)
C
C     INPUT DATA FORMAT INDICATOR AND FORMAT
      READ(INN,1309) (IFMT(L),L=1,NVR)
 1309 FORMAT(20I4)
      READ(INN,310) (FMT1(L1),L1=1,4),(FMT2(L2),L2=1,4),(FMT3(L3),L3=1,4
     1),(FMT4(L4),L4=1,4),(FMT5(L5),L5=1,4)
  310 FORMAT(5(4A4))
      DO 32 L=1,NVR
      DO 32 J=1,NYR
      DO 32 K=1,12
   32 DVAR(L,J,K)=0.
      DO 40 L=1,NVR
      NSTN=NST(L)
      IF(NSTN.EQ.0) GO TO 40
      LFMT=IFMT(L)
      DO 40 M=1,NSTN
      DO 40 J=1,NYR
      GO TO (33,34,35,36,37),LFMT
   33 READ(INN,FMT1) (VAR(K),K=1,12)
      J    .38
   34 READ(INN,FMT2) (VAR(K),K=1,12)
      J    .38
   35 READ(INN,FMT3) (VAR(K),K=1,12)
      J    .38
   36 READ(INN,FMT4) (VAR(K),K=1,12)
      J    .38
   37 READ(INN,FMT5) (VAR(K),K=1,12)
C     COMPUTE AVERAGE OR TOTAL MONTHLY DATA
   38 DO 40 K=1,12
      IF(L.LE.2) GO TO 39
      DVAR(L,J,K)=DVAR(L,J,K)+CONV(L)*VAR(K)
      J    .40
   39 DVAR(L,J,K)=DVAR(L,J,K)+CWT(L,M)*VAR(K)
   40 CONTINUE
      RETURN
      END
C     PARAMETER OPTIMIZATION SUBROUTINE
      SUBROUTINE OPTM
      COMMON/BLK1/         ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                            SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,     IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
      DIMENSION BLV(18),BVC(18),NLV(18),PRH(18),PRL(18)
   16 TYPE 219
  219 FORMAT(13H OPTIMIZATION/)
      OCT 25000
C     ASSIGN NO. OF PHASES
      READ(INN,2307) NPHS
C     INPUT INITIAL VECTOR
      READ(INN,1307) (PRO(JJ),JJ=1,NPR)
 1307 FORMAT(16F5.2)
      WRITE(IOUT,220) (SBNM(IB),IB=1,5)
  220 FORMAT(1H1,5A4//)
C     INPUT OPTIMIZATION INDICATOR
      READ(INN,2307) (NLV(JJ),JJ=1,NPR)
 2307 FORMAT(20I4)
      WRITE(IOUT,221)
  221 FORMAT(80H PARAMETER RANGE,NO. OF INCREMENTS AND INITIAL VECTOR'//
     13X2HJJ,5X3HPRL,5X3HPRH,3X3HNLV,6X3HPRO)
C     INPUT PARAMETER RANGE
      DO 19 JJ=1,NPR
      IF(NLV(JJ).GT.1) GO TO 17
      PRL(JJ)=PRO(JJ)
      PRH(JJ)=PRO(JJ)
      NLV(JJ)=1
      J    .18
   17 READ(INN,308) PRL(JJ),PRH(JJ)
  308 FORMAT(5X,2F5.2)
   18 WRITE(IOUT,222) JJ,PRL(JJ),PRH(JJ),NLV(JJ),PRO(JJ)
  222 FORMAT(I5,2F8.2,I5,F10.2)
C     INITIALIZE OPTIMAL VECTOR
      BVC(JJ)=PRO(JJ)
      BLV(JJ)=PRO(JJ)
C     SET PARAMETER TO INITIAL VALUE
   19 PR(JJ)=PRO(JJ)
C     INITIALIZE OBJECTIVE FUNCTION
      CALL HYSM(0)
      OBJA=OBJ
C     REPEAT OPTIMIZATION PROCEDURE FOR EACH PHASE
      DO 30 II=1,NPHS
      WRITE(IOUT,223) II
  223 FORMAT(1H1,5HPHASE,I3//10H  PAR  LVL,3X,7HPAR. V.,7X,3HOBJ,16X,4HG
     1RAD)
C     OPTIMIZE EACH PARAMETER
      DO 25 JJ=1,NPR
      IF(NLV(JJ).LE.1) GO TO 25
      OBJB=9999.
      PR(JJ)=PRL(JJ)
      FLV=NLV(JJ)
      DPR=(PRH(JJ)-PRL(JJ))/FLV
C     SEARCH FOR EVERY LEVEL
      NLVL=NLV(JJ)+1
      DO 24 KK=1,NLVL
      CALL HYSM (JJ)
      IF(KK.EQ.1) GO TO 20
      GRAD=(OBJ-OBJO)/DPR
      WRITE(IOUT,224) JJ,KK,PR(JJ),OBJ,GRAD
  224 FORMAT(2I5,F10.2,F10.5,5X,F15.8)
      J    .21
   20 WRITE(IOUT,224) JJ,KK,PR(JJ),OBJ
   21 IF(OBJ.GT.OBJB) GO TO 22
      OBJB=OBJ
      BLV(JJ)=PR(JJ)
   22 OBJO=OBJ
      IF(OBJ.GT.OBJA) GO TO 24
      OBJA=OBJ
      DO 23 JJJ=1,NPR
   23 BVC(JJJ)=PR(JJJ)
   24 PR(JJ)=PR(JJ)+DPR
      PR(JJ)=PRO(JJ)
   25 CONTINUE
      DO 26 JJJ=1,NPR
   26 PR(JJJ)=BLV(JJJ)
```

```
      CALL HYSM (0)
      IF(OBJ.GT.OBJA) GO TO 28
      DO 27 JJJ=1,NPR
   27 BVC(JJJ)=PR(JJJ)
   28 WRITE(IOUT,225) (BVC(JJJ),JJJ=1,NPR)
  225 FORMAT(1H1,34HTHE OPTIMAL FACTORS ARE AS FOLLOWS/(8F8.2))
      DO 29 JJJ=1,NPR
      PRO(JJJ)=BVC(JJJ)
   29 PR(JJJ)=BVC(JJJ)
C     SET IDOP TO 0 TO PRINT OUT SIMULATION RESULTS
      IDOP=0
      CALL HYSM (0)
      OBJA=OBJ
C     SET IDOP BACK TO 1 TO PROCEED FOR ANOTHER PHASE OF OPTIMIZATION
      IDOP=1
   30 CONTINUE
      TYPE 226
  226 FORMAT(25H SET SSW C FOR NEW VECTOR/)
      OCT 25000
      OCT 023400
      J   .31
      J   .16
   31 RETURN
      END
C     HYDROLOGIC SIMULATION SUBROUTINE
      SUBROUTINE HYSM (JJ)
      COMMON/BLK1/         ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                          SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADM8,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,     IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
      PR16=PR(16)
      MS1=PR16
      GB0=PR(17)
      RC0=PR(18)
      SNO=SNOW
      SNO1=SNOW
      TSRD1=0.
      TSRD2=0.
      TVAR=0.
C     REPEAT SIMULATION PROCEDURE FOR EACH YEAR
      DO 86 J=1,NYR
      DO 1068 L=1,NVR
 1068 AVAR(L)=0.
      DO 2068 L=1,15
 2068 ASIM(L)=0.
      SRD1=0.
      SRD2=0.
      LYR=LYRO+J-1
C     SIMULATE MONTHLY HYDROLOGY
      CALL SIMH(J)
      AVAR(1)=AVAR(1)/12.
C     ANNUAL STANDARD DEVIATION AND COEFFICIENT OF VARIATION
      XBR1=(AVAR(13)/12.)
      TVAR=TVAR+AVAR(13)
      IF(IDOP.EQ.1) GO TO 85
C     OUT-PUT SIMULATION RESULT
      WRITE(IOUT,228) (SBNM(IB),IB=1,5),LYR
  228 FORMAT(1H1,5A4,I5/)
      WRITE(IOUT,229)
  229 FORMAT(70H        VAR       OCT       NOV       DEC       JAN
     1 FEB       MAR)
      DO 69 L=1,12
   69 WRITE(IOUT,230) OTL(L),(DVAR(L,J,K),K=1,6)
  230 FORMAT(6X,A4,7F10.3)
      DO 70 L=2,14
      L1=L+12
   70 WRITE(IOUT,230) OTL(L1),(SIM(L,K),K=1,6)
      WRITE(IOUT,230) OTL(27),(DVAR(13,J,K),K=1,6)
      WRITE(IOUT,230) OTL(28),(SIM(15,K),K=1,6)
      WRITE(IOUT,231)
  231 FORMAT(/80H        VAR       APR       MAY       JUN       JUL
     1  AUG      SEPT       ANN)
      DO 71 L=1,12
   71 WRITE(IOUT,230) OTL(L),(DVAR(L,J,K),K=7,12),AVAR(L)
      DO 72 L=2,14
      L1=L+12
   72 WRITE(IOUT,230) OTL(L1),(SIM(L,K),K=7,12),ASIM(L)
      WRITE(IOUT,230) OTL(27),(DVAR(13,J,K),K=7,12),AVAR(13)
      WRITE(IOUT,230) OTL(28),(SIM(15,K),K=7,12),ASIM(15)
      ASRD1=SRD1/12.
      ASRD2=SRD2/(10.*XBR1*XBR1)
      WRITE(IOUT,1235) ASRD1,ASRD2
 1235 FORMAT(/8H ASRD1 =,F10.5,5X,8H ASRD2 =,F10.5)
C     IF SSW D ON, OUT-PUT ACRE-FEET
      OCT 023420
      J   .85
C     CONVERT QUANTITIES TO ACRE FEET
      DO 73 L=2,13
      AVAR(L)=AVAR(L)/CAF
      DO 73 K=1,12
   73 DVAR(L,J,K)=DVAR(L,J,K)/CAF
      DO 74 L=1,15
      ASIM(L)=ASIM(L)/CAF
      DO 74 K=1,12
   74 SIM(L,K)=SIM(L,K)/CAF
      WRITE(IOUT,233) (SBNM(IB),IB=1,5),LYR
  233 FORMAT(1H1,17HOUT-PUT ACRE-FEET,5X,5A4,I5)
      WRITE(IOUT,229)
      DO 75 L=1,12
   75 WRITE(IOUT,234) OTL(L),(DVAR(L,J,K),K=1,6)
  234 FORMAT(6X,A4,7F10.1)
      DO 76 L=2,14
      L1=L+12
   76 WRITE(IOUT,234) OTL(L1),(SIM(L,K),K=1,6)
      WRITE(IOUT,234) OTL(27),(DVAR(13,J,K),K=1,6)
      WRITE(IOUT,234) OTL(28),(SIM(15,K),K=1,6)
      WRITE(IOUT,231)
      DO 77 L=1,12
   77 WRITE(IOUT,234) OTL(L),(DVAR(L,J,K),K=7,12),AVAR(L)
      DO 78 L=2,14
      L1=L+12
   78 WRITE(IOUT,234) OTL(L1),(SIM(L,K),K=7,12),ASIM(L)
      WRITE(IOUT,234) OTL(27),(DVAR(13,J,K),K=7,12),AVAR(13)
      WRITE(IOUT,234) OTL(28),(SIM(15,K),K=7,12),ASIM(15)
      WRITE(IOUT,1235) ASRD1,ASRD2
C     CONVERT QUANTITIES BACK TO INCHES
      DO 10 L=2,13
      DO 10 K=1,12
   10 DVAR(L,J,K)=DVAR(L,J,K)*CAF
C     RESULTS OF RESERVOIR OPERATION
   85 TSRD1=TSRD1+SRD1
      TSRD2=TSRD2+SRD2
   86 CONTINUE
      FYR=NYR
      DF=12.*FYR
      TSRD1=TSRD1/DF
      XBR2=TVAR/DF
      DF=DF-2.
      TSRD2=TSRD2/(XBR2*XBR2*DF)
      OBJ=TSRD1
      IF(INPH.EQ.1) OBJ=TSRD2
      IF(IDOP.EQ.1) GO TO 87
      WRITE(IOUT,236) OBJ
  236 FORMAT(/6H OBJ =,F10.6)
   87 RETURN
      END
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C     SUBROUTINE TO SIMULATE MONTHLY HYDROLOGY
      SUBROUTINE SIMH(J)
      COMMON/BLK1/          ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                          SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,     IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,     NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1,MS
      DO 68 K=1,12
      SIM(1,K)=0.0
C
C     SNOW STORAGE AND SNOW MELT FOR SIMULATED AREA
      IF(DVAR(1,J,K).GT.PR(1).AND.DVAR(1,J,K).GT.PR(2)) GO TO 51
      IF(DVAR(1,J,K).LE.PR(1).AND.DVAR(1,J,K).GT.PR(2)) GO TO 50
      SIM(2,K)=SNO+DVAR(2,J,K)
      SIM(3,K)=0.
      RPMT=0.
      J    .52
   50 SIM(2,K)=SNO+DVAR(2,J,K)
      SIM(3,K)=SIM(2,K)*(1.-EXP(-PR(8)*(DVAR(1,J,K)-PR(2))))
      IF(SIM(3,K).GT.SIM(2,K)) SIM(3,K)=SIM(2,K)
      SIM(2,K)=SIM(2,K)-SIM(3,K)
      RPMT=SIM(3,K)
      J    .52
   51 SIM(3,K)=SNO*(1.-EXP(-PR(8)*(DVAR(1,J,K)-PR(2))))
      IF(SIM(3,K).GT.SNO) SIM(3,K)=SNO
      SIM(2,K)=SNO-SIM(3,K)
      RPMT=DVAR(2,J,K)+SIM(3,K)
   52 SNO=SIM(2,K)
C
C     SNOW STORAGE AND SNOW MELT FOR UNGAGED AREA
      TUNG=DVAR(1,J,K)-TMP1
      IF(TUNG.GT.PR(1).AND.TUNG.GT.PR(2)) GO TO 41
      IF(TUNG.LE.PR(1).AND.TUNG.GT.PR(2)) GO TO 40
      SNW1=SNO1+DVAR(2,J,K)
      RPMT1=0.
      J    .42
   40 SNW1=SNO1+DVAR(2,J,K)
      SNMT1=SNW1*(1.-EXP(-PR(8)*(TUNG-PR(2))))
      IF(SNMT1.GT.SNW1) SNMT1=SNW1
      SNW1=SNW1-SNMT1
      RPMT1=SNMT1
      J    .42
   41 SNMT1=SNO1*(1.-EXP(-PR(8)*(TUNG-PR(2))))
      IF(SNMT1.GT.SNO1) SNMT1=SNO1
      SNW1=SNO1-SNMT1
      RPMT1=DVAR(2,J,K)+SNMT1
   42 SNO1=SNW1
C
C     PHREATOPHYTE EVAPOTRANSPIRATION
      BCF=DVAR(1,J,K)*DLH(K)
      BCK=.0173*DVAR(1,J,K)-.314
      IF(BCK.LT..3) BCK=.3
      SIM(4,K)=PR(9)*WPH(K)*BCK*BCF
C     CROP POTENTIAL EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENT
      IF(IDCR.EQ.0) GO TO 54
      ETP=PR(9)*WCR(K)*BCK*BCF
      DTIR=DVAR(5,J,K)+DVAR(7,J,K)+DVAR(9,J,K)-DVAR(11,J,K)
      DAG=DTIR*PR(10)+RPMT
      J    .55
   54 ETP=0.
      DTIR=0.
      DAG=0.
   55 DTMI=DVAR(6,J,K)+DVAR(8,J,K)+DVAR(10,J,K)-DVAR(12,J,K)
C
C      RETURN FLOW
      IF(IDCR.EQ.0) GO TO 56
      SIM(9,K)=(1.-PR(10))*DTIR+(1.-PR(11))*DTMI
      ASCL=TACR
      J    .57
   56 SIM(9,K)=(1.-PR(11))*DTMI
C     UNGAGED SURFACE INFLOW
   57 CCC=12.*AUNG/(ACOR*ASCL)
      SIM(8,K)=PR(5)*CCC*CORS(J,K)+PR(12)*RPMT1*AUNG/ASCL+
C    1PR(13)*(AGAG+AUNG)/ASCL
C     EVAPOTRANSPIRATION,SOIL MOISTURE AND PERCOLATION
      IF(IDCR.EQ.0) GO TO 63
      NITR=1
   58 SIM(5,K)=ETP*MS1/PR(4)
      IF(SIM(5,K).GT.ETP) SIM(5,K)=ETP
      MS=PR16+DAG-SIM(5,K)
      IF(MS.GT.PR(3)) GO TO 59
      SIM(7,K)=0.
      J    .60
   59 SIM(7,K)=MS-PR(3)
      MS=PR(3)
   60 DMS=ABS(MS-MS1)
      IF(DMS.GT.ADMS.AND.NITR.LT.NITX) GO TO 61
      J    .62
   61 NITR=NITR+1
      MS1=(PR(16)+MS)/2.
      J    .58
   62 SIM(6,K)=MS
      PR16=SIM(6,K)
      J    .64
   63 SIM(7,K)=0.
      SIM(6,K)=0.
      SIM(5,K)=0.
C
C     GROUNDWATER RECHARGE AND OUTFLOW
   64 DIN=PR(15)*RPMT1*(AGAG+AUNG)/ASCL
      SK=PR(6)
      DIC=RC0
      CALL ROUT
      RC0=DOUT
      DIN=DVAR(4,J,K)+DOUT+SIM(7,K)-DVAR(9,J,K)-DVAR(10,J,K)
      SK=PR(7)
      DIC=GB0
      CALL ROUT
      GB0=DOUT
      SIM(10,K)=PR(14)*DOUT
      SIM(13,K)=DOUT-SIM(10,K)
      SIM(4,K)=SIM(4,K)*TAPH/ASCL
      SIM(14,K)=DVAR(3,J,K)-DVAR(7,J,K)-DVAR(8,J,K)-SIM(4,K)
     1+SIM(9,K)+SIM(10,K)+SIM(8,K)+RPMT*TAPH/ASCL
      SIM(12,K)=SIM(13,K)+SIM(14,K)
      SIM(15,K)=SIM(14,K)-DVAR(13,J,K)
C     CHECK AGAINST MINIMUM FLOW
      IF(SIM(14,K).GE.DVAR(14,J,K)) GO TO 1064
      SIM(11,K)=DVAR(14,J,K)-SIM(14,K)
      J    .65
 1064 SIM(11,K)=0.
C     CALCULATE ANNUAL SUMS
   65 DO 66 L=1,NVR
   66 AVAR(L)=AVAR(L)+DVAR(L,J,K)
C     CALCULATE ANNUAL SUMS
      DO 67 L=1,15
   67 ASIM(L)=ASIM(L)+SIM(L,K)
      SRD1=SRD1+ABS(SIM(15,K))/DVAR(13,J,K)
      SRD2=SRD2+SIM(15,K)**2
   68 CONTINUE
      RETURN
      END
C     SUBROUTINE FOR LINEAR RESERVOIR ROUTING
      SUBROUTINE ROUT
      COMMON/BLK1/          ASIM(15),AVAR(14),CCR(14,12),CONV(14),
     1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
     2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
     3PRO(18),                          SBNM(5),SIM(15,12),VAR(12),
     4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
     1IDCR,     IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,     NVR,NYR,
     2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2,    TACR,TAPH,TMP1,PR16
     3,INPH
      REAL MS1
      DOUT=DIN+(DIC-DIN)*EXP(-1./SK)
      RETURN
      END
```

SAMPLE INPUT

```
I. BASIC DATA  -
 CARD 1
PROVO                                       14   18    4    6    6   10

II. TOTAL BASIN DATA
 CARD 1
TEMP+PPTQRIVQGWI+IRI+MII+QIR+QMI+IRP+MIP-IRX-MIX     SNS+SMTETPH -ET  MS -DPQUNG
 CARD 2
-QRF QBFQDEF QTO QGO QSOQGAGDIFF
 CARD 3
 .077 .067 .065 .067 .067 .083 .089 .100 .101 .102 .096 .084   14    5    1
 CARD 4
A1   ALFA 1   90   79   65   63   74   86   99  112  119  110  105   99
A2   PAST 2   80   74   58   55   66   81   86  102   99   93   91   87
A3   AOHA 3   84   77   62   55   66   81   94  109  115  110  105   95
A4   SMGR 4   22   29   29   29   29   28   74  118  127   73   40   19
A5   CORN 5   99   29   29   29   29   28   22   60   73   93  106  109
A6   SUBT 6  102   29   29   29   29   28   22   58   95  106  120  111
A7   POTA 7   22   29   29   29   29   28   22   30   42   88  131  134
A8   ORCH 8   90   78   65   64   74   86   98  108  113  111  106   99
A9   PEAS 9
A10  TOMA10   40   29   29   29   29   28   45   50   75  101   97   83
A11  SMTR11   40   29   29   29   29   28   37   62   77   82   78   61
A12  IDLE12   35   30   25   25   25   30   33   38   39   39   39   39
A13  BEAN13   25   29   29   29   29   28   22   67  111   89   75   20
A14  BLAN14
 CARD 5
C1   HWMC 1  185  185  185  185  185  185  185  185  185  185  185  185
C2   HWGW 2  125  102   75   65   80  113  136  141  142  142  141  136
C3   MWGT 3   81   76   69   56   53   53   55   61   68   77   82   83
C4   LWGT 4   50   47   42   35   33   33   34   38   42   48   51   51
C5   OPWT 5  137  128  112  101  130  149  156  155  151  144  141  138

III. IDOP
 CARD 1
   1

IV. SUBBASIN DATA
 CARD 1
FRANCIS                      21376     109056     1    20     104320  5.2
 CARD 2
      1589        924         490        326          0          0          0          0
         0          0           0          0          0          0       3329
 CARD 3
         0          1         936         19          1        957       3329
 CARD 4
  1   3   5   0   0   0   8   0   0   0   2   0   1   0
 CARD 5
                        .003604686.003604686.003604686.003604686.003604686.003604686
.003604686.003604686.003604686.003604686.003604686.003604686.003604686.003604686
 CARD 6
.9393
 CARD 7
.5841.4963.2111

V. OBSERVED DATA
 CARD 1
 1964    0
 CARD 2
OAKL  64    3.7    3.4    3.0    2.6    2.0    2.3    4.6   44.1   56.5   19.2    7.3    4.7
```

```
OAKL  65    3.6    3.4    3.6    3.2    3.0    2.8    8.7   40.3   78.9   38.0   13.0    9.2
AAKL  66    6.6    5.2    4.6    4.1    3.3    4.7   14.9   48.2   24.9    8.4    5.0    4.1
OAKL  67     51     42     37     35     29     39     57    354    759    345     98     35
 CARD 3
  1   2   3   3   3   3   3   3   3   3   3   3   3   3
 CARD 4
(14X,12F5.1)    (14X,12F5.2)    (8X,-3P12F6.1)  (8X,12F6.1)     (8X,12F6.1)
 CARD 5
      VAR(1) STATION 1
HEBER 1964        527  374  233  168  175  244  417  510  574  681  651  558   426
HEBER 1965        503  309  264  258  263  316  447  489  568  660  621  511   434
HEBER 1966        492  391  296  194  198  350  431  541  597  683  655  586   451
HEBER 1967        459  385  206  229  243  379  409  493  565  681  668  585
      VAR(2) STATION 1
KAMAS PPT 1964  124  170   55  193  102  182  268  141  380   74   55   46
KAMAS PPT 1965   25  271  522  175   82   76  224  162  151  472  139  210
KAMAS PPT 1966   22  348  195  130  922  108   95  117   27   76  114  134
KAMAS PPT 1967  190  203  292  242   84  176  245  418  267   64   74  140
      VAR(2) STATION 2
HEBER 1964         77  174   43  207   25  126  168  202  355   57   44   29  1507
HEBER 1965         27  224  540  179   44   67  143   81  117   91  113  141  1767
HEBER 1966         14  331  210   60  190   46   65  154   66   20   72  169  1228
HEBER 1967        120  188  322  338   46  175  138  238  202   58   78   53
      VAR(2) STATION 3
SL        1964  232  374  141  673  153  736  655  416  447   99  101   60
SL        1965   45  789 1295  598  285  250  537  239  246  265  429  494
SL        1966   00  881  599  261  330  301  252  199   75  214  103  222
SL        1967  309  414  282  566  340  504  658  547  332   71  104  134
      .
      .
      .
      THE REMAINING VAR(L) DATA IS INPUT UNTIL, IN THIS EXAMPLE, VAR(13)
      STATION 1 DATA IS INPUT
      .
      .
      .
      VAR(13) STATION 1
19641550    3.6    5.1    4.9    4.9    4.6    5.1    9.6   79.9   88.1   22.8    6.9    3.9
19651550    3.4    4.7    6.3    6.3    5.1    5.5   19.5   81.2   93.8   52.7   16.1    7.4
19661550    6.2    4.7    4.2    3.8    3.6    6.6   25.3   76.3   23.0    5.2    2.5    3.1
19671550    5.2    5.9    7.8    6.9    6.0    9.4   14.2   69.4   86.3   37.9   10.1    5.8

VI. PARAMETER INPUT
 CARD 1
   2
 CARD 2
 4000 3000  600  400   34   20   40   12  100   30   80   04   12   40   02  400
  400  300
 CARD 3
   4   4   1   1   5   4   4   4   4   4   1   5   5   4   4
 CARD 4
1        3600 4000
2        2800 3200
5          28   38
6          10   50
7          20  100
8          10   14
9          80  120
10         20   60
12         00   10
13         10   20
14         20   60
15         01   05
```

SAMPLE OUTPUT

```
PROVO                                               NYR = 4


FRACTION DAY-LIGHT HOURS
 .077  .067  .065  .067  .067  .083  .089  .100  .101  .102  .096  .084


CROP COEFFICIENTS
   .90    .79    .65    .63    .74    .86    .99   1.12   1.19   1.10   1.05    .99
   .80    .74    .58    .55    .66    .81    .86   1.02    .99    .93    .91    .87
   .84    .77    .62    .55    .66    .81    .94   1.09   1.15   1.10   1.05    .95
   .22    .29    .29    .29    .29    .28    .74   1.10   1.27    .73    .40    .19
   .99    .29    .29    .29    .29    .28    .22    .60    .73    .93   1.06   1.09
  1.02    .29    .29    .29    .29    .28    .22    .58    .95   1.06   1.20   1.11
   .22    .29    .29    .29    .29    .28    .22    .30    .42    .88   1.31   1.34
   .90    .78    .65    .64    .74    .86    .98   1.08   1.13   1.11   1.06    .99
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
   .40    .29    .29    .29    .29    .28    .45    .50    .75   1.01    .97    .83
   .40    .29    .29    .29    .29    .28    .37    .62    .77    .82    .78    .61
   .35    .30    .25    .25    .25    .30    .33    .38    .39    .39    .39    .39
   .25    .29    .29    .29    .29    .28    .22    .67   1.11    .89    .75    .20
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00


PHREATOPHYTE COEFFICIENTS
  1.85   1.85   1.85   1.85   1.85   1.85   1.85   1.85   1.85   1.85   1.85   1.85
  1.25   1.02    .75    .65    .80   1.13   1.36   1.41   1.42   1.42   1.41   1.36
   .81    .76    .69    .56    .53    .53    .55    .61    .68    .77    .82    .83
   .50    .47    .42    .35    .33    .33    .34    .38    .42    .48    .51    .51
  1.37   1.28   1.12   1.01   1.30   1.49   1.56   1.55   1.51   1.44   1.41   1.38
FRANCIS
 AGAG =    21376.  AUNG =   109056.  ACOR =   104320.  IDCR = 1
CROP AREAS
    1589.       924.       490.       326.         0.         0.         0.         0.
       0.         0.         0.         0.         0.         0.      3329.


WEIGHTED CROP COEFFICIENT
  .79   .72   .59   .56   .66   .78   .92  1.09  1.13  1.01   .94   .87


PHREATOPHYTE AREAS
      0.         1.       936.        19.         1.       957.


WEIGHTED PHREATOPHYTE COEFFICIENT
  .80   .75   .68   .55   .52   .52   .54   .60   .67   .76   .81   .82


NUMBER OF STATIONS FOR EACH VARIABLE
   1    3    5    0    0    0    0    0    0    0    2    0    1    0


CONVERSION FACTORS
  .000000   .000000   .003604   .003604   .003604   .003604   .003604   .003604
  .003604   .003604   .003604   .003604   .003604   .003604


STATION WEIGHTS FOR TEMPERATURE
 .939


STATION WEIGHTS FOR PRECIPITATION
 .584 .496 .211


CORR. STREAMFLOW
   3.7   3.4   3.0   2.6   2.0   2.3   4.6  44.1  56.5  19.2   7.3   4.7
   3.6   3.4   3.6   3.2   3.0   2.8   8.7  40.3  78.9  38.0  13.0   9.2
   6.6   5.2   4.6   4.1   3.3   4.7  14.9  48.2  24.9   8.4   5.0   4.1
   5.1   4.2   3.7   3.5   2.9   3.9   5.7  35.4  75.9  34.5   9.8   3.5
```

```
FRANCIS


PARAMETER RANGE,NO. OF INCREMENTS AND INITIAL VECTOR

  JJ       PRL       PRH     NLV       PRO
   1     36.00     40.00      4      40.00
   2     28.00     32.00      4      30.00
   3      6.00      6.00      1       6.00
   4      4.00      4.00      1       4.00
   5       .28       .38      5        .34
   6       .10       .50      4        .20
   7       .20      1.00      4        .40
   8       .10       .14      4        .12
   9       .80      1.20      4       1.00
  10       .20       .60      4        .30
  11       .80       .80      1        .80
  12       .00       .10      5        .04
  13       .10       .20      5        .12
  14       .20       .60      4        .40
  15       .01       .05      4        .02
  16      4.00      4.00      1       4.00
  17      4.00      4.00      1       4.00
  18      3.00      3.00      1       3.00
 PHASE  1

  PAR   LVL    PAR. V.       OBJ                  GRAD
    1     1      36.00     .01424
    1     2      37.00     .01396             -.00027750
    1     3      38.00     .01402              .00006171
    1     4      39.00     .01409              .00006349
    1     5      40.00     .01408             -.00000811
    2     1      28.00     .01302
    2     2      29.00     .01336              .00033720
    2     3      30.00     .01408              .00072290
    2     4      31.00     .01514              .00105862
    2     5      32.00     .01646              .00131965
    5     1        .28     .00922
    5     2        .30     .00957              .01784991
    5     3        .32     .01119              .08103491
    5     4        .34     .01408              .14421972
    5     5        .36     .01823              .20740345
    5     6        .38     .02364              .27058863
    6     1        .10     .01408
    6     2        .20     .01408              .00000404
    6     3        .30     .01408              .00001708
    6     4        .40     .01408              .00002278
    6     5        .50     .01408              .00000965
    7     1        .20     .01408
    7     2        .40     .01408             -.00000238
    7     3        .60     .01409              .00005324
    7     4        .80     .01409              .00001974
    7     5       1.00     .01407             -.00009288
    8     1        .10     .01462
    8     2        .11     .01430             -.03181938
    8     3        .12     .01408             -.02280771
    8     4        .13     .01394             -.01398492
    8     5        .14     .01386             -.00746026
    9     1        .80     .01475
    9     2        .90     .01441             -.00345032
    9     3       1.00     .01408             -.00330105
    9     4       1.10     .01376             -.00322593
    9     5       1.20     .01347             -.00283002
   10     1        .20     .01542
   10     2        .30     .01408             -.01339750
   10     3        .40     .01294             -.01142414
   10     4        .50     .01191             -.01022503
   10     5        .60     .01099             -.00922393
   12     1        .00     .00918
   12     2        .02     .00996              .03880747
   12     3        .04     .01408              .20616793
   12     4        .06     .02155              .37352734
   12     5        .08     .03237              .54088854
   12     3        .10     .04653              .70824933
```

```
 13     1        .10     .01316
 13     2        .12     .01408               .04590582
 13     3        .14     .01524               .05796077
 13     4        .16     .01664               .07001441
 13     5       -.18     .01828               .08207131
 13     6        .20     .02016               .09412580
 14     1        .20     .01171
 14     2        .30     .01280               .01092022
 14     3        .40     .01408               .01277346
 14     4        .50     .01554               .01462640
 14     5        .60     .01719               .01647960
 15     1        .01     .01278
 15     2        .02     .01408               .12969934
 15     3        .03     .01556               .14771279
 15     4        .04     .01721               .16572588
 15     5        .05     .01905               .18373879
THE OPTIMAL FACTORS ARE AS FOLLOWS
  40.00   30.00     6.00     4.00       .34       .20       .40       .12
   1.00     .30      .80      .00       .12       .40       .02      4.00
   4.00    3.00

FRANCIS              1964

      VAR       OCT        NOV        DEC        JAN        FEB        MAR
     TEMP    49.501     35.129     21.885     15.780     16.437     22.918
     +PPT     1.596      2.646       .832      3.575      1.042      3.242
     QRIV     6.848     10.453      9.372      8.651      7.569     11.534
     QGWI      .000       .000       .000       .000       .000       .000
     +IRI      .000       .000       .000       .000       .000       .000
     +MII      .000       .000       .000       .000       .000       .000
     +QIR      .000       .000       .000       .000       .000       .000
     +QMI      .000       .000       .000       .000       .000       .000
     +IRP      .000       .000       .000       .000       .000       .000
     +MIP      .000       .000       .000       .000       .000       .000
     -IRX      .000       .000       .000       .000       .000       .000
     -MIX      .000       .000       .000       .000       .000       .000
      SNS      .000      1.429      2.262      5.837      6.880     10.122
     +SMT      .000      1.216       .000       .000       .000       .000
     ETPH      .478       .153       .084       .050       .050       .086
      -ET     1.636       .511       .252       .178       .218       .423
       MS     3.959      4.664      4.412      4.233      4.015      3.591
      -DP      .000       .000       .000       .000       .000       .000
     QUNG     9.442      9.057      8.545      8.032      7.264      7.648
     -QRF      .000       .000       .000       .000       .000       .000
      QBF      .594       .051       .004       .000       .000       .000
     QDEF      .000       .000       .000       .000       .000       .000
      QTO    17.758     19.837     17.844     16.634     14.783     19.096
      QGO      .892       .077       .006       .001       .000       .000
      QSO    16.866     19.759     17.837     16.633     14.783     19.096
     QGAG    12.976     18.383     17.662     17.662     16.581     18.383
     DIFF     3.889      1.375       .174     -1.029     -1.797       .713

      VAR       APR        MAY        JUN        JUL        AUG       SEPT        ANN
     TEMP    39.168     47.904     53.915     63.966     61.148     52.412     40.014
     +PPT     3.781      2.704      4.925       .924       .752       .539     26.562
     QRIV    14.058    211.955    251.607     71.733     23.790      8.290    635.866
     QGWI      .000       .000       .000       .000       .000       .000       .000
     +IRI      .000       .000       .000       .000       .000       .000       .000
     +MII      .000       .000       .000       .000       .000       .000       .000
     +QIR      .000      7.930     23.430     23.069     16.221      8.651     79.303
     +QMI      .000       .000       .000       .000       .000       .000       .000
     +IRP      .000       .000       .000       .000       .000       .000       .000
     +MIP      .000       .000       .000       .000       .000       .000       .000
     -IRX      .000      2.162      6.488      9.372      5.046      2.523     25.593
     -MIX      .000       .000       .000       .000       .000       .000       .000
      SNS     4.627       .539       .030       .001       .000       .000     31.729
     +SMT     9.277      4.087       .509       .030       .001       .000     15.120
     ETPH      .199       .430       .655      1.138      1.023       .618      4.968
      -ET     1.168      2.696      3.829      5.257      4.137      2.276     22.587
       MS     6.000      6.000      6.000      5.806      5.774      5.875     60.332
      -DP     5.699      5.824      6.687       .000       .000       .000     18.212
     QUNG    10.595     61.204     77.091     29.301     14.054     10.723    252.961
     -QRF      .000      4.037     11.859      9.588      7.822      4.289     37.596
```

```
      QBF     3.730      5.328      4.842       .734       .279       .178     15.744
     QDEF      .000       .000       .000       .000       .000       .000       .000
      QTO    36.445    284.109    330.140     88.525     29.339     14.635    889.150
      QGO     5.595      7.992      7.263      1.101       .419       .267     23.617
      QSO    30.850    276.116    322.876     87.423     28.919     14.367    865.533
     QGAG    34.604    288.014    317.572     82.186     24.872     14.058    862.961
     DIFF    -3.754    -11.897      5.303      5.236      4.047       .309      2.572

ASRD1 =     .08373      ASRD2 =     .00482

FRANCIS              1967

      VAR       OCT        NOV        DEC        JAN        FEB        MAR
     TEMP    43.113     36.163     19.349     21.509     22.824     35.599
     +PPT     2.357      2.992      3.898      4.285      1.436      2.960
     QRIV     7.930     10.093     14.418     13.337     10.814     16.221
     QGWI      .000       .000       .000       .000       .000       .000
     +IRI      .000       .000       .000       .000       .000       .000
     +MII      .000       .000       .000       .000       .000       .000
     +QIR      .000       .000       .000       .000       .000       .000
     +QMI      .000       .000       .000       .000       .000       .000
     +IRP      .000       .000       .000       .000       .000       .000
     +MIP      .000       .000       .000       .000       .000       .000
     -IRX      .000       .000       .000       .000       .000       .000
     -MIX      .000       .000       .000       .000       .000       .000
      SNS      .000      1.428      5.327      9.613     11.049      7.155
     +SMT      .000      1.564       .000       .000       .000      6.855
     ETPH      .331       .163       .074       .069       .069       .135
      -ET     1.142       .546       .222       .243       .303       .697
       MS     6.000      6.000      5.777      5.533      5.230      6.000
      -DP     1.054      1.017       .000       .000       .000      5.387
     QUNG    11.235     10.082      9.442      9.185      8.417      9.698
     -QRF      .000       .000       .000       .000       .000       .000
      QBF      .856       .568       .047       .003       .000      2.192
     QDEF      .000       .000       .000       .000       .000       .000
      QTO    21.652     21.882     23.905     22.463     19.162     33.237
      QGO     1.284       .852       .071       .005       .000      3.289
      QSO    20.368     21.030     23.834     22.458     19.162     29.947
     QGAG    18.744     21.267     28.116     24.872     21.628     33.884
     DIFF     1.624      -.237     -4.282     -2.414     -2.466     -3.936

      VAR       APR        MAY        JUN        JUL        AUG       SEPT        ANN
     TEMP    38.417     46.307     53.070     63.966     62.745     54.949     41.501
     +PPT     3.504      4.777      3.262       .811      1.038      1.363     32.691
     QRIV    29.918    191.048    224.932    118.954     29.918     14.779    682.366
     QGWI      .000       .000       .000       .000       .000       .000       .000
     +IRI      .000       .000       .000       .000       .000       .000       .000
     +MII      .000       .000       .000       .000       .000       .000       .000
     +QIR      .000     10.453     25.953     31.000     18.383     14.418    100.210
     +QMI      .000       .000       .000       .000       .000       .000       .000
     +IRP      .000       .000       .000       .000       .000       .000       .000
     +MIP      .000       .000       .000       .000       .000       .000       .000
     -IRX      .000      2.523      6.488     13.337      6.488      4.325     33.163
     -MIX      .000       .000       .000       .000       .000       .000       .000
      SNS     3.882       .548       .034       .001       .000       .000     39.040
     +SMT     6.777      3.333       .514       .033       .001       .000     19.079
     ETPH      .188       .393       .629      1.138      1.088       .696      4.979
      -ET     1.105      2.467      3.679      5.257      4.403      2.563     22.633
       MS     6.000      6.000      6.000      6.000      6.000      6.000     70.540
      -DP     5.672      8.023      5.936       .887       .205      1.827     30.011
     QUNG    12.004     50.057    101.947     48.904     17.257      9.185    297.419
     -QRF      .000      5.551     13.625     12.364      8.326      7.065     46.932
      QBF     3.986      7.340      4.593      1.056       .464      1.101     22.211
     QDEF      .000       .000       .000       .000       .000       .000       .000
      QTO    53.649    256.493    326.490    150.967     37.491     19.059    986.455
      QGO     5.979     11.011      6.889      1.584       .697      1.651     33.317
      QSO    47.669    245.482    319.600    149.383     36.794     17.408    953.138
     QGAG    51.186    250.165    311.084    136.617     36.407     20.907    954.880
     DIFF    -3.516     -4.683      8.516     12.765       .386     -3.499     -1.742

ASRD1 =     .08030      ASRD2 =     .00522

OBJ =    .009183
```

APPENDIX B

DATA PROGRAM

The data program and the river basin management model are designed to be operated in conjunction. The data program is used to prepare a data tape which is used as part of the input for the river basin management model.

The time sequence of the data program must be the same as the time sequence used in the river basin management model. All sample input and output are based on a water year but this program is not tied to any particular time sequence.

The data program inputs the observed data as outlined in the input data layout and illustrated in the sample input. The program sums the stations for each variable to form a single monthly quantity. The temperature and precipitation data are not summed but are averaged using input weighting factors. The resulting tape consists of one value for each of the subbasin and reservoir variables, VAR(C) and RVAR(C), respectively, for each month of the study.

The data for each variable, VAR(L), must be in the same units within each subbasin. This requires all stations of a particular variable to be input in the same units. This restriction does not affect input data for different subbasins. The reservoir variable, RVAR(L), data must be input in acre feet.

Water input as irrigation or municipal and industrial import will be designated to that use and will only enter the stream as return flow. Export of irrigation or municipal and industrial water is accomplished by diverting the water in VAR(7) and VAR(8), respectively, and then exporting the water under VAR(11) and VAR(12).

The values output on the tape are arranged by month for each year. Within each month the data are arranged according to subbasin. The subbasin data consist of the VAR(L) data followed, when appropriate, by the RVAR(L) data.

The program outputs a listing of the data which appears on the tape. The listing output by the data program differs from what appears on the corresponding tape only in the additional output of headings for year and month. These headings are output to aid in locating specific input and, therefore, do not appear on the tape.

The sample input and output is for a three subbasin case with a reservoir located in the second subbasin. The sample input is supplemented with cards referring to the location of cards in the input data layout. These cards should not be mistaken for actual input.

The data listing is divided so the individual subbasin data can be distinguished. The sample output corresponds to the three subbasin case used as sample input. The variable, VAR(L), data output consists of two lines for each subbasin. The reservoir data, RVAR(L), for the second subbasin follows on a separate line after the variable data for that subbasin. The VAR(L) and RVAR(L) are listing across the page in the same order they appear in Table C-1.

INPUT DATA LAYOUT

I. Basic Indicators

	Col	Identifier	
Card 1	1-6	NMDTA	Data tape name

Format (3A2)

	Col	Identifier	
Card 2	1-4	INN	Input device indicator
	5-8	IOT1	Output device indicator for print
	9-12	IOUT2	Output device indicator for tape
	13-16	NYR	Number of years of data
	17-20	NSB	Number of subbasins within the river basin
	21-24	NVR	Number of variables; corresponds to number of VAR(1) in Table C-1
	25-28	NRVR	Number of reservoir variables; corresponds to number of RVAR(L) in Table C-1
	29-32	LYRO	Beginning year of data

Format (20I4)

II. Input Formats and Format Indicators

	Col	Identifier	
Card 1	1-16	FMT1	A specific input format
	17-32	FMT2	A specific input format
	⋮		⋮
	65-80	FMT5	A specific input format

Format (5(4A4))

	Col	Identifier	
Card 2	4	IFMT(1, 1)	Read format indicator for Subbasin 1 VAR(1)
	8	IFMT(1, 2)	Read format indicator for Subbasin 1 VAR(2)
	⋮		⋮
		IFMT(1, NVR)	Read format indicator for Subbasin 1 VAR(NVR)

Format (20I4)

This input is repeated for Subbasins 2, 3, ..., NSB. The options for IFMT(I, L) are to input a 1 to 5 correspondence to which format, FMT1 to FMT5 respectively, is desired from Card 1 above.

III. Number of Stations

	Col	Identifier	
Card 1	1-4	NST(1, 1)	Number of stations for Subbasin 1 VAR(1)
	5-8	NST(1, 2)	Number of stations for Subbasin 1 VAR(2)
	⋮		⋮
		NST(1, NVR)	Number of stations for Subbasin 1 VAR(NVR)
		NRST(1, 1)	Number of stations for Subbasin 1 RVAR(1)
		NRST(1, 2)	Number of stations for Subbasin 1 RVAR(2)
	⋮		⋮
		NRST(1, NRVR)	Number of stations for Subbasin 1 RVAR(NRVR)

Format (20I4)

This input is repeated for Subbasins 2, 3, ..., NSB.

IV. Station Weight for Temperature and Precipitation

	Col	Identifier	
Card 1&2	1-5	CWT(1, 1, 1)	Weight factor to be applied to temperature Station 1 Subbasin 1
	6-10	CWT(1, 1, 2)	Weight factor to be applied to temperature Station 2 Subbasin 1
	⋮		⋮
		CWT[1, 1, NST (1, 1)]	Weight factor to be applied to temperature Station NST(1, 1) Subbasin 1

Format (16F5. 2)

The next card of this group contains the precipitation weight factor for Subbasin 1.

	Col	Identifier	
	1-5	CWT(1, 2, 1)	Weight factor to be applied to precipitation Station 1 Subbasin 1
	6-10	CWT(1, 2, 2)	Weight factor to be applied to precipitation Station 2 Subbasin 1

	.		.
	.		.
	.		.
		CWT[1, 2, NST (1, 2)]	Weight factor to be applied to precipitation Station NST(1, 2) Subbasin 1

Format (16F5. 2)

A similar set of cards is input for Subbasins 2, 3, . . . , NSB.

V. Reservoir Indicator

Card 1	4	IRS(1)	Reservoir indicator for Subbasin 1
	8	IRS(2)	Reservoir indicator for Subbasin 2
	.		.
	.		.
	.		.
		IRS(NSB)	Reservoir indicator for Subbasin NSB.

Format (20I4)

Where:

0 - indicates no reservoir at the outlet of the subbasin

1 - indicates a reservoir is at the outlet of the subbasin

VI. Observed Data

Card 1 The following ordering of cards, each containing twelve monthly values, is to be repeated for year 1, 2, 3, . . . , NYR.

Subbasin 1

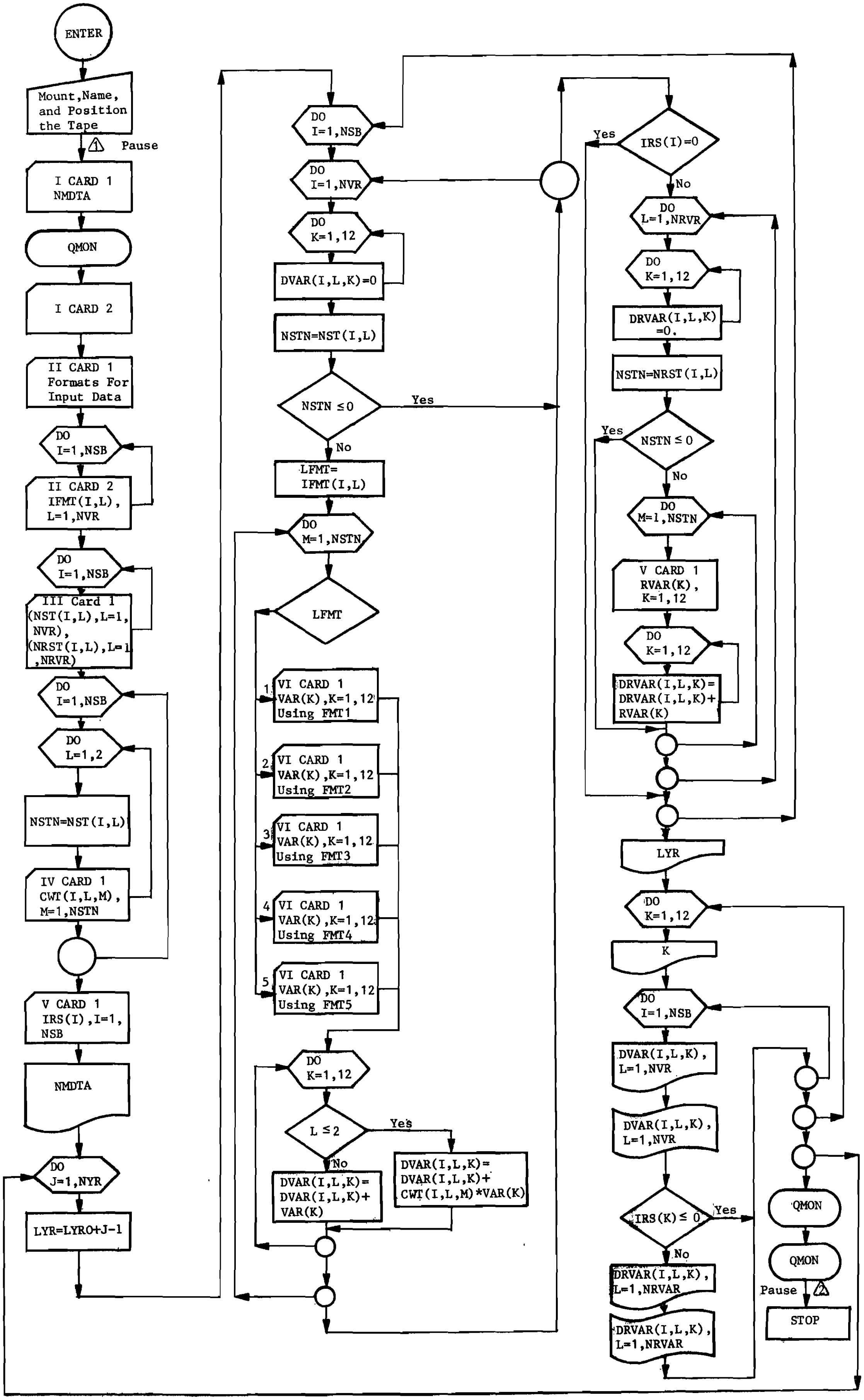
VAR(1)	Station 1, 2, . . . , NST(1, 1)
VAR(2)	Station 1, 2, . . . , NST(1, 2)
.	
.	
.	
VAR(NVR)	Station 1, 2, . . . , NST(1, NVR)

If IRS(1) = 0, skip RVAR(L) input

RVAR(1)	Station 1, 2, . . . , NRST(1, 1)
RVAR(2)	Station 1, 2, . . . , NRST(1, 2)
.	
.	
.	
RVAR(NRVR)	Station 1, 2, . . . , NRST(1, NRVR)

This arrangement of cards is repeated for Subbasins 2, 3, . . . , NSB before going to data for the next year. (See sample input.)

The VAR(L) data is input with one year of monthly data per card according to the format specified in cards 1 and 2 of II. As an example, if IFMT (3, 6) = 2 on card 2, VAR(6) data for Subbasin 3 is input according to FMT2 on card 1. When any NST(I, L) or NRST(I, L) is equal to zero, no cards are input for that VAR(L) or RVAR(L), respectively, of Subbasin I.


ENTER
Mount,Name, and Position the Tape
Pause
I CARD 1 NMDTA
QMON
I CARD 2
II CARD 1 Formats For Input Data
DO I=1,NSB
II CARD 2 IFMT(I,L), L=1,NVR
DO I=1,NSB
III Card 1 (NST(I,L),L=1, NVR), (NRST(I,L),L=1 ,NRVR)
DO I=1,NSB
DO L=1,2
NSTN=NST(I,L)
IV CARD 1 CWT(I,L,M), M=1,NSTN
V CARD 1 IRS(I),I=1, NSB
NMDTA
DO J=1,NYR
LYR=LYRO+J-1
DO I=1,NSB
DO I=1,NVR
DO K=1,12
DVAR(I,L,K)=0
NSTN=NST(I,L)
NSTN ≤0
Yes
No
LFMT= IFMT(I,L)
DO M=1,NSTN
LFMT
1
VI CARD 1 VAR(K),K=1,12 Using FMT1
2
VI CARD 1 VAR(K),K=1,12 Using FMT2
3
VI CARD 1 VAR(K),K=1,12 Using FMT3
4
VI CARD 1 VAR(K),K=1,12 Using FMT4
5
VI CARD 1 VAR(K),K=1,12 Using FMT5
DO K=1,12
L ≤2
Yes
No
DVAR(I,L,K)= DVAR(I,L,K)+ VAR(K)
DVAR(I,L,K)= DVAR(I,L,K)+ CWT(I,L,M)*VAR(K)
IRS(I)=0
Yes
No
DO L=1,NRVR
DO K=1,12
DRVAR(I,L,K) =0.
NSTN=NRST(I,L)
NSTN ≤ 0
Yes
No
DO M=1,NSTN
V CARD 1 RVAR(K), K=1,12
DO K=1,12
DRVAR(I,L,K)= DRVAR(I,L,K)+ RVAR(K)
LYR
DO K=1,12
K
DO I=1,NSB
DVAR(I,L,K), L=1,NVR
DVAR(I,L,K), L=1,NVR
IRS(K)≤ 0
Yes
No
DRVAR(I,L,K), L=1,NRVAR
DRVAR(I,L,K), L=1,NRVAR
QMON
QMON
Pause
STOP

DATA PROGRAM LISTING

```
C
C     PREPARE OBSERVED DATA IN PROPER FORMAT
      DIMENSION CWT(8,2,5),DVAR(8,14,12),DRVAR(8,2,12),FMT1(4),FMT2(4),
     1FMT3(4),FMT4(4),FMT5(4),IFMT(8,14),IRS(8),NST(8,14),NRST(8,2),
     2VAR(12),RVAR(12)
       DIMENSION NMDTA(3)
C
C     INPUT BASIC INDICATORS
      TYPE 199
  199 FORMAT(34H MOUNT  NAME AND POSITION THE TAPE/)
      OCT 25000
      READ(6,99) (NMDTA(I),I=1,3)
   99 FORMAT(3A2)
      CALL QMON(21,NMDTA(1),0,13)
      READ(6,100) INN,IOT1,IOT2,NYR,NSB,NVR,NRVR,LYR0
  100 FORMAT(20I4)
C
C     READ FORMAT FOR INPUT DATA
      READ(INN,101) (FMT1(L),L=1,4),(FMT2(L),L=1,4),(FMT3(L),L=1,4),
     1(FMT4(L),L=1,4),(FMT5(L),L=1,4)
  101 FORMAT(5(4A4))
C
C     INPUT FORMAT INDICATOR FOR INPUT DATA
      DO 2 I=1,NSB
    2 READ(INN,100) (IFMT(I,L),L=1,NVR)
C
C     INPUT NUMBER OF STATIONS FOR EACH VARIABLE AND RESERVOIR VARIABLE
      DO 3 I=1,NSB
    3 READ(INN,100) (NST(I,L),L=1,NVR),(NRST(I,L),L=1,NRVR)
C
C    INPUT STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION
      DO 4 I=1,NSB
      DO 4 L=1,2
      NSTN=NST(I,L)
    4 READ(INN,102) (CWT(I,L,M),M=1,NSTN)
  102 FORMAT(16F5.2)
C    INPUT RESERVOIR INDICATOR
C
      READ(INN,100) (IRS(I),I=1,NSB)
      WRITE(6,98) (NMDTA(L),L=1,3)
   98 FORMAT(1X,3A2)
C
C    INPUT AND REARRANGE OBSERVED DATA
      DO 19 J=1,NYR
      LYR=LYR0+J-1
      DO 17 I=1,NSB
      DO 20 L=1,NVR
      DO 5 K=1,12
    5 DVAR(I,L,K)=0.
      NSTN=NST(I,L)
      IF(NSTN.LE.0) GO TO 20
      LFMT=IFMT(I,L)
      DO 13 M=1,NSTN
      GO TO (6,7,8,9,10),LFMT
    6 READ(INN,FMT1) (VAR(K),K=1,12)
      J    .11
    7 READ(INN,FMT2) (VAR(K),K=1,12)
      J    .11
    8 READ(INN,FMT3) (VAR(K),K=1,12)
      J    .11
    9 READ(INN,FMT4) (VAR(K),K=1,12)
      J    .11
   10 READ(INN,FMT5) (VAR(K),K=1,12)
   11 DO 22 K=1,12
      IF(L.LE.2) GO TO 12
      DVAR(I,L,K)=DVAR(I,L,K)+VAR(K)
      J    .22
   12 DVAR(I,L,K)=DVAR(I,L,K)+CWT(I,L,M)*VAR(K)
   22 CONTINUE
   13 CONTINUE
   20 CONTINUE
      IF(IRS(I).EQ.0) GO TO 17
      DO 21 L=1,NRVR
      DO 14 K=1,12
   14 DRVAR(I,L,K)=0.
      NSTN=NRST(I,L)
      IF(NSTN.LE.0) GO TO 16
      DO 16 M=1,NSTN
      READ(INN,103) (RVAR(K),K=1,12)
      DO 15 K=1,12
   15 DRVAR(I,L,K)=DRVAR(I,L,K)+RVAR(K)
   16 CONTINUE
   21 CONTINUE
   17 CONTINUE
C
C     OUTPUT DATA FOR MANAGEMENT STUDY
      WRITE(IOT1,250) LYR
  250 FORMAT(//7H YEAR =,I4)
      DO 18 K=1,12
      WRITE(IOT1,251) K
  251 FORMAT(/4H K =,I2)
      DO 18 I=1,NSB
      WRITE(IOT1,200) (DVAR(I,L,K),L=1,NVR)
      WRITE(IOT2,200) (DVAR(I,L,K),L=1,NVR)
  200 FORMAT(2F8.3,5F8.0/10F8.0)
      IF(IRS(I).LE.0) GO TO 18
      WRITE(IOT1,201) (DRVAR(I,L,K),L=1,NRVR)
      WRITE(IOT2,201) (DRVAR(I,L,K),L=1,NRVR)
  201 FORMAT(10F8.0)
   18 CONTINUE
   19 CONTINUE
      CALL QMON(15)
      CALL QMON(15)
      OCT 25000
      STOP
      END
```

SAMPLE INPUT

```
I. BASIC INDICATORS
 CARD 1
OBDTA2
 CARD 2
   6  13   6  20   3  13   21950

II. INPUT FORMATS AND FORMAT INDICATORS
 CARD 1
(14X,12F5.1)    (14X,12F5.2)    (8X,-3P12F6.1)  (8X,12F6.1)     (8X,12F6.1)
 CARD 2
   1   2   3   3   3   3   3   3   3   3   3   3   3
   1   2   3   3   3   3   3   3   3   3   3   3   3
   1   2   3   3   3   3   3   3   3   3   3   3   3

III. NUMBER OF STATIONS
 CARD 1
   1   3   6   0   0   0   8   0   0   0   2   0   1   0   0
   1   3   3   0   0   0  12   0   0   0   0   0   1   1   1
   1   3   1   0   0   0  10   2   1   1   0   3   1   0   0

IV. STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION
 CARD 1 AND 2
.9393
.5841.4963.2111
1.000
.5004.1809.3518
1.000
.6488.2014.3918

V. RESERVOIR INDICATORS
 CARD 1
   0   1   0

VI. OBSERVED DATA
 CARD 1
     VAR(1) STATION 1,SUBBASIN 1,YEAR 1
          1950  436  402  223  177  256  348  438  477  567  649  625  562   430
     VAR(2) STATION 1,SUBBASIN 1,YEAR 1
          1950  205  169  296  315  111  148   74  176   30   45    6  115  1684
     VAR(2) STATION 2,SUBBASIN 1,YEAR 1
KAMAS PPT 1950  282  126  182  283  138  194   98  214   40   30   09  118
     VAR(2) STATION 3,SUBBASIN 1,YEAR 1
SL        1950  502  247  751  894  278  771  337  345   87   68   17  318

     THE REMAINING VAR(L) DATA IS INPUT TO SUBBASIN 1 FOR YEAR 1 UNTIL,
     IN THIS EXAMPLE, VAR(13) STATION 1 DATA IS INPUT

     VAR(13) STATION 1,SUBBASIN 1,YEAR 1
19501550  5.0   4.4   3.5   3.4   3.7   5.4  18.2  46.6  62.2  18.9   7.5   3.9

     THE INPUT OF VAR(L) AND RVAR(L) FOR THE SECOND AND THIRD SUBBASINS
     FOLLOW THIS INPUT

     SIMILAR DATA IS THEN INPUT FOR YEARS 2,3,...,20
```

SAMPLE OUTPUT

```
OBDTA2


YEAR =1950

K = 1
 40.953    3.656     800.        0.        0.        0.        0.
     0.       0.       0.        0.        0.     5000.
 43.599    3.232    3800.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    13600.
 13600.       0.
 47.500    4.150    -100.        0.        0.        0.        0.
  1600.       0.     500.        0.     2000.    13900.

K = 2
 37.759    2.133    1100.        0.        0.        0.        0.
     0.       0.       0.        0.        0.     4400.
 40.199    2.372    4600.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    14600.
 14600.       0.
 42.899    1.966     800.        0.        0.        0.        0.
     0.       0.     400.        0.      400.    16800.

K = 3
 20.946    4.217    1100.        0.        0.        0.        0.
     0.       0.       0.        0.        0.     3500.
 22.300    4.380    2700.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    13300.
 13300.       0.
 26.399    4.389    1600.        0.        0.        0.        0.
     0.       0.     400.        0.      300.    16600.

K = 4
 16.625    5.131    1100.        0.        0.        0.        0.
     0.       0.       0.        0.        0.     3400.
 17.699    4.678    6800.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    16700.
 16700.       0.
 24.199    4.816    1300.        0.        0.        0.        0.
     0.       0.     400.        0.      300.    18800.

K = 5
 24.046    1.920    1500.        0.        0.        0.        0.
     0.       0.       0.        0.        0.     3700.
 25.599    1.434    6700.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    14600.
 14600.       0.
 34.299    1.576   -2300.        0.        0.        0.        0.
     0.       0.     400.        0.      300.    16300.

K = 6
 32.687    3.454    2100.        0.        0.        0.        0.
     0.       0.       0.        0.        0.     5400.
 34.799    2.733    1200.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    17000.
 17000.       0.
 40.399    2.841   -1500.        0.        0.        0.        0.
     0.       0.     400.        0.      400.    19000.

K = 7
 41.141    1.590    6800.        0.        0.        0.        0.
     0.       0.       0.        0.        0.    18200.
 43.799    1.303    5900.        0.        0.        0.     2200.
     0.       0.       0.        0.        0.    20600.
 20600.       0.
 49.099    1.428    -700.        0.        0.        0.     7200.
  3500.    1800.     500.        0.     3900.    14700.
```

APPENDIX C

RIVER BASIN MANAGEMENT MODEL

The river basin management model was designed to be as general as possible in adaption to various time sequences and units of input. The program was designed for use on the EAI 590 hybrid computer. The program presented is completely digital and contains logic statement peculiar to this computer. The program, as presented, is operated for each month of the water year. Conversion to a different time sequence requires the input data and output headings which rely on monthly ordering to be rearranged.

The input to the program is outlined in the input data layout. The major portion of the input comes from the tape created by the data program. A dummy scaling area, ASCL, must be input for each subbasin which does not contain agricultural area. It is suggested that the magnitude of ASCL be the same as used in the Parameter Optimization Model. There must be at least one phreatophyte area within each subbasin.

The sample input and output is for the three subbasin case used to illustrate the use of the data program. A reservoir is located in the second subbasin in the sample case. The sample input is supplemented with cards referring to the location of cards in the input data layout. These cards should not be mistaken for actual input.

The output from the program is by month. The subbasin output is followed by the reservoir output within each month. The reservoir output is labeled according to which subbasin contains the reservoir.

INPUT DATA LAYOUT

I. Basic Data

	Col	Identifier	
Card 1	1-6	NMDTA	Name of data tape produced by data program

Format (3A2)

	Col	Identifier	
Card 2	1-16	BSNM	The river basin name
	17-19	NSB	Number of subbasins within the river basin
	20-22	NVR	Number of variables; corresponds to number of VAR(L) in Table C-1
	23-25	NPR	Number of parameters; corresponds to number of PR(L) in Table C-2
	26-28	NSM	Number of simulated quantities; corresponds to number of SIM(L) in Table C-3
	29-31	NRVR	Number of reservoir variables; corresponds to number of RVAR(L) in Table C-1
	32-34	NRPR	Number of reservoir parameters; corresponds to number of RPR(L) in Table C-2
	35-37	NRSM	Number of simulated reservoir quantities; corresponds to number of RSIM(L) in Table C-3
	38-40	NIND	Number of basic indicators; corresponds to number of IND(L) in Table C-4
	41-43	NARA	Number of areas; corresponds to number of AREA(L) in Table C-4
	44-46	NSIC	Number of initial conditions; corresponds to number of SYIC(L) in Table C-4

Format (4A4, 10I3)

	Col	Identifier	
Card 3	1-5	LYRO	Beginning year of study
	6-8	NYR	Number of years to be studied by the program
	9-11	IN1	Input device code for cards
	12-14	IN2	Input device code for tape
	15-17	IOUT	Output device code
	18-20	NITX	Maximum number of iterations in loop involving calculation of soil moisture
	21-25	AJSO	Tolerance in meeting downstream demands. If the total adjustment to the release from a reservoir is less than this amount, no adjustment to the release is made. AJSO is in acre feet
	26-30	ADMS	Tolerance desired in the calculation of soil moisture. ADMS is in inches of water
	31-35	CAJS	A multiplication factor which can be used to alter the adjustment to the reservoir release (See below)
	36-40	ITOP	Subbasin number of the most upstream subbasin containing a reservoir
	41-45	DAJS	An additive factor which can be used to alter the adjustment to the reservoir release (see below) DAJS in acre feet

Format (I5, 5I3, 3F5.2, I5, F5.0)

Where:

TAJS = CAJS*(SAJS + QAJS) + DAJS
TAJS = Total adjustment to previous reservoir release

With CAJS = 1.0 and DAJS = 0 the adjustment will consist of the exact downstream shortage to desired amounts. The release of additional water from an upstream reservoir effects many components of the downstream hydrology which can result in less than TAJS acre feet of water reaching the downstream check point. If the new calculated TAJS is greater than AJSO the program will iterate until the total release is sufficient to meet downstream requirements. The proper use of CAJS and DAJS can reduce the number of iterations.

Card 4	1-4	OTL(1)	SIM(1) Output title
	5-8	OTL(2)	SIM(2) Output title
	.		.
	.		.
	.		.
		OTL(L)	SIM(L) Output title

Format (20A4)

Table C-1. Definition of variable.

L	Variables VAR(L)	Reservoir Variables RVAR(L)
1	Mean monthly temperature	Minimum reservoir storage
2	Total monthly precipitation	Diversion from reservoir
3	Gaged surface inflow	
4	Gaged or estimated groundwater inflow	
5	Irrigation import	
6	M&I import	
7	Irrigation surface flow diversions	
8	M&I surface flow diversions	
9	Irrigation pumpage	
10	M&I pumpage	
11	Irrigation export	
12	M&I export	
13	Gaged surface outflow	

Table C-2. Definition of parameters.

L	Parameters PR(L)	Equation	Reservoir Parameters RPR(L)
1	Snowfall temperature	Chapter 3 precipitation section	Minimum reservoir storage
2	Snowmelt temperature	3.3 T_m	Lower break point for surface area equation
3	Soil moisture holding capacity	3.27 M_{cs}	High break point for surface area equation
4	Critical soil moisture	3.27 M_{es}	Maximum reservoir storage
5	Ungaged stream correlation coefficient	3.7 K_1	Low range coefficient, C_1
6	Subsurface storage coefficient	3.33 K_{ss}	Low range exponent, C_2
7	Groundwater storage coefficient	3.35 K_g	Intermediate range coefficient, C_1
8	Snowmelt coefficient	3.4 K_s	Intermediate range exponent, C_1
9	Consumptive use coefficient	3.25 K_u	High range coefficient, C_1
10	Irrigation efficiency	3.13 Eff	High range exponent, C_2
11	M&I efficiency	3.16 Eff_{mi}	
12	Coefficient of rain plus snowmelt for ungaged flow	3.7 K_2	
13	Threshold for surface runoff	3.7 K_3	
14	Base flow coefficient	3.36 K_{bf}	
15	Infiltration coefficient	3.33 C_i	

Table C-3. Definition of simulated quantities.

L	Simulated Quantities SIM(L)	Equation	Simulated Reservoir Quantities RSIM(L)
1	Snow storage	3.5 $W_s(t)$	Reservoir inflow
2	Ungaged surface inflow	3.7 Q_{ug}	Reservoir precipitation
3	Imported flow	VAR(5) + VAR(6)	Reservoir evaporation
4	Return flow	3.15, 16 $Q_{ri} + Q_{rmi}$	Reservoir storage diversion
5	Base flow	3.36 Q_{bf}	Reservoir spill flow
6	Pumped and artesian flow	VAR(9) + VAR(10)	Reservoir release
7	Deep percolation	3.29, 30 DP_r	Reservoir storage
8	Groundwater inflow	VAR(4) + QGRY(I-1)	
9	Flow to irrigation	4.4 or input data	
10	Flow to M&I	Input data	
11	Exported flow	VAR(11) + VAR(12)	
12	Flow shortage	QDSIR(I) - SIM(18)	
13	Phreatophyte evapotranspiration	3.25 ET_{pr}	
14	Crop evapotranspiration	3.26, 27 ET_r	
15	Soil moisture	3.19 $M_s(t)$	
16	Total outflow	3.39 Q_{to}	
17	Groundwater outflow	3.37 Q_{go}	
18	Surface outflow	3.38 Q_{so}	

Table C-4. Definition of model indicators.

L	Indicators IND(L)	Areas Area(L)	Initial conditions SYIC(L)
1	Number of cards	Gaged watershed area	Initial snow storage
2	Number of phreatophytes	Ungaged watershed area	Initial soil moisture, PR(16)[a]
3	Irrigation management indicator	Scaling area	NOT USED
4	Upstream reservoir indicator	Correlation stream drainage area	Initial watershed recharge, PR(18)[a]
5	Downstream reservoir indicator		Initial groundwater and base outflow, PR(17)[a]
6			Initial reservoir storage

[a] See Table A-1.

Card	Columns	Variable	Description
Card 5	1-4	ROTL(1)	RSIM(1) Output title
	5-8	ROTL(2)	RSIM(2) Output title
	⋮		⋮
		ROTL(L)	RSIM(L) Output title

Format (20A4)

Card	Columns	Variable	Description
Card 6	1-4	OTLV(1)	VAR(1) Output title (temperature)
	5-8	OTLV(2)	VAR(2) Output title (precipitation)
	9-12	OTLV(3)	VAR(3) Output title (gaged inflow)
	13-16	OTLV(4)	VAR(13) Output title (gaged outflow)

Format (20A4)

Card	Columns	Variable	Description
Card 7	1-5	DLH(1)	Fraction daylight hour for month 1
	6-10	DLH(2)	Fraction daylight hour for month 2
	⋮		⋮
	56-60	DLH(12)	Fraction daylight hour for month 12
	61-63	MSIR	First month of irrigation when using management option
	64-66	MEIR	Last month of irrigation when using management option

Format (12F5. 3, 2I3)

Card 8 This card inputs temperature adjustments in degrees fahrenheit used in snowmelt calculation for the ungaged area; a positive number for decrease (see Equation 3. 6).

Columns	Variable	Description
1-10		Identification
11-15	TMP1(1)	Temperature adjustment for Subbasin 1
16-20	TMP1(2)	Temperature adjustment for Subbasin 2
⋮		⋮
	TMP1(I)	Temperature adjustment for Subbasin I

Format (10X, 10F5. 2)

II. Model Indicators and Parameters for each Subbasin

Card	Columns	Variable	Description
Card 1	1-8	SBNM(1, L)	Name Subbasin 1 (L is only for the "A" format width)
	11-15	IND(1, 1)	Number of different crops in Subbasin 1
	16-20	IND(1, 2)	Number of different phreatophytes in Subbasin 1
	21-25	IND(1, 3)	Irrigation management indicator (0 or 1) 0 - will divert irrigation water in amount specified in input under VAR(7) 1 - will calculate diversion based on need (will ignore VAR(7) data if it is input)
	26-30	IND(1, 4)	Upstream reservoir indicator (0 or 1) 0 - indicates no reservoir in any upstream subbasin 1 - indicates a reservoir in a subbasin upstream from this subbasin Therefore IND(1, 4) is always 0 because it is the most upstream subbasin
	31-35	IND(1, 5)	Downstream reservoir indicator 0 - no reservoir at the outlet of this subbasin 1 - the subbasin contains a reservoir at its outlet
	36-45	AREA(1, 1)	Gaged area of Subbasin 1 in acres (does not include agricultural area)
	46-55	AREA(1, 2)	Ungaged area of Subbasin 1 in acres (does not include agricultural area)
	56-65	AREA(1, 3)	Scaling area in acres. Consists of total crop area for subbasins with crops. For subbasins with no crop area it is a dummy number

	66-75	AREA(1, 5)	Drainage area of the stream used for ungaged flow correlation, in acres

Format (2A4, 2X, 5I5, 4F10.0)

Card 2	1-5	PR(1, 1)	PR(1) value for Subbasin 1
	6-10	PR(1, 2)	PR(2) value for Subbasin 1
	.		.
	.		.
	.		.
		PR(1, L)	PR(L) value for Subbasin 1

Format (16F5.2)

The value of PR(I, L) comes from the parameter optimization of the subbasin as determined from the parameter optimization program. (See Table A-1 and Table C-2).

If IND(1, 5) = 0 skip card 3

Card 3	1-8	RPR(1, 1)	Minimum reservoir storage in acre feet for reservoir in Subbasin 1
	9-16	RPR(1, 2)	Lower break point for storage-surface area equation for reservoir in Subbasin 1
	17-24	RPR(1, 3)	High break point for storage-surface area equation for reservoir in Subbasin 1
	25-32	RPR(1, 4)	Maximum reservoir storage in acre feet for reservoir in Subbasin 1
	33-40	RPR(1, 5)	Low range coefficient, C_1, for reservoir in Subbasin 1
	41-48	RPR(1, 6)	Low range exponent, C_2, for reservoir in Subbasin 1
	49-56	RPR(1, 7)	Intermediate range coefficient, C_1, for reservoir in Subbasin 1
	57-64	RPR(1, 8)	Intermediate range exponent, C_2, for reservoir in Subbasin 1
	65-72	RPR(1, 9)	High range coefficient, C_1, for reservoir in Subbasin 1
	73-80	RPR(1, 10)	High range exponent, C_2, for reservoir in Subbasin 1

Format (4F8.0, 6F8.5)

The relationship, as outlined in the text (Eq. 3.36) gives:

Surface area = C_1 (storage capacity)

As an example, suppose Figure C-1 was for the reservoir in Subbasin 1. Then, from the graph:

RPR(1, 2) = 200 acre feet
RPR(1, 3) = 2500 acre feet
RPR(1, 5) = 37 (intercept)
RPR(1, 6) = .570 (slope)
RPR(1, 7) = 370
RPR(1, 8) = .121
RPR(1, 9) = 16
RPR(1, 10) = .531

Card 4	1-5	SYIC(1, 1)	Initial snow storage for Subbasin 1
	6-10	SYIC(1, 2)	Initial soil moisture for Subbasin 1 (PR(16) in Table A-1)
	11-15	SYIC(1, 3)	Open for use
	16-20	SYIC(1, 4)	Initial watershed recharge for Subbasin 1 (PR(18) in Table A-1)
	21-25	SYIC(1, 5)	Initial base and groundwater flow for Subbasin 1 (PR(17) in Table A-1)
	26-35	SYIC(1, 6)	Initial storage for reservoir in Subbasin 1

Format (5F5.2, F10.0)

SYIC(1, 2), SYIC(1, 4), and SYIC(1, 5) come from parameter optimization.

Card 5	1-10		Phreatophyte identification
	11-15	CPH(1)	k_c for this phreatophyte month 1
	16-20	CPH(2)	k_c for this phreatophyte month 2
	.		.
	.		.
	.		.
	66-70	CPH(12)	k_c for this phreatophyte month 12
	71-80	APH	Acres of this phreatophyte within the subbasin's agricultural area

Format (10X, 12F5.2, F10.0)

This format is repeated for the IND(1, 2) phreatophytes in the subbasin.

If IND(1, 1) = 0 skip card 6

Card 6	1-10		Crop Identification
	11-15	CCR(1)	k_c for this crop month 1
	16-20	CCR(2)	k_c for this crop month 2
	. . .		. . .
	66-70	CCR(12)	k_c for this crop month 12
	71-80	ACR	Acres of this crop within the subbasin's agricultural area

Format (10X, 12F5.2, F10.0)

This format is repeated for the IND(1, 1) crops in the subbasin.

Card 7	1-5	QDSIR(1, 1)	Desired streamflow at the outlet of Subbasin 1 in cfs for month 1
	6-10	QDSIR(1, 2)	Desired streamflow at the outlet of Subbasin 1 in cfs for month 2
	. . .		. . .
	56-60	QDSIR(1, 12)	Desired streamflow at the outlet of Subbasin 1 in cfs for month 12

Format (12F5.0)

If IND(1, 5) = 0 skip card 8

Card 8	1-6	SDSIR(1, 1)	Desired storage in acre feet for the reservoir in Subbasin 1 for month 1
	7-12	SDSIR(1, 2)	Desired storage in acre feet for the reservoir in Subbasin 1 for month 2
	. . .		. . .
	67-72	SDSIR(1, 12)	Desired storage in acre feet for the reservoir in Subbasin 1 for month 12

Format (12F6.0)

All of the cards under II are then repeated for Subbasins 2, 3, ..., NSB.

III. Input Conversion Factors

Card 1	1-8	CONV(1, 1)	Conversion factor for VAR(1) Subbasin 1
	9-16	CONV(1, 2)	Conversion factor for VAR(2) Subbasin 1
	. . .		. . .
		CONV(1, NVR)	Conversion factor for VAR(NVR) Subbasin 1

Format (10F8.5)

This format is repeated for Subbasins 2, 3, ..., NSB.

Where:

CONV(I, 1) Converts VAR(1), precipitation data, to inches of water

CONV(I, 2) Converts VAR(2), temperature data, to degrees fahrenheit

The remainder of the CONV(I, L)'s convert the input into inches of water over the agricultural area in acres. If VAR(L) is in acre feet

CONV(I, L) = 12/AREA(I, 3)

Card 2	1-6	CAF(1)	Conversion from inches of water over the agricultural area to acre feet for Subbasin 1
	7-12	CAF(2)	Conversion from inches of water over the agricultural area to acre feet for Subbasin 2
	. . .		. . .
		CAF(NSB)	Conversion from inches of water over the agricultural area to acre feet for Subbasin NSB

Format (12F6.0)

Where:

CAF(I) is calculated as:

CAF(I) = AREA(I, 3)/12.

IV. Consumptive Use for Open Water

Card 1	1-10		Card Identification
	11-15	CWS(1)	k_c for open water month 1
	16-20	CWS(2)	k_c for open water month 2
	. . .		. . .
	66-70	CWS(12)	k_c for open water month 12

Format (10X, 12F5.2, F10.0)

V. Output Formats

Card	Columns	Variable	Description
1	1-16	FMT1	Output format 1
	17-32	FMT2	Output format 2
	.		.
	.		.
	.		.
	49-64	FMT4	Output format 4

Format (16A4)

VI. Gaged Flow of the Correlation Streams (in Thousands of Acre Feet)

Card	Columns	Variable	Description
1	1-8		Identification
	9-14	QCOR(1, 1)	Correlation streamflow for Subbasin 1 month 1
	15-20	QCOR(1, 2)	Correlation streamflow for Subbasin 1 month 2
	.		.
	.		.
	.		.
	75-80	QCOR(1, 12)	Correlation streamflow for Subbasin 1 month 12

Format (8X, -3P12F6. 1)

This card is repeated for Subbasins 2, 3, . . . , NSB. This completes one year of correlation stream input. This set is followed by a similar set for year 2, 3, . . . , NYR.

VII. The VAR(I, L) and RVAR(I, L) data are read from the tape developed using the data program. Note that the input formats correspond to the formats used to create the tape.

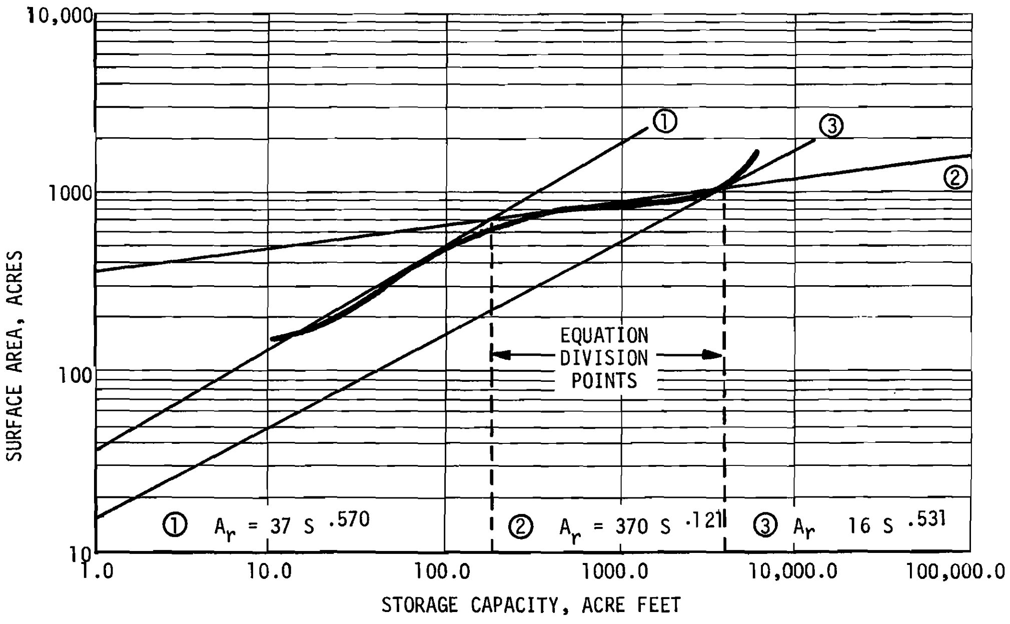
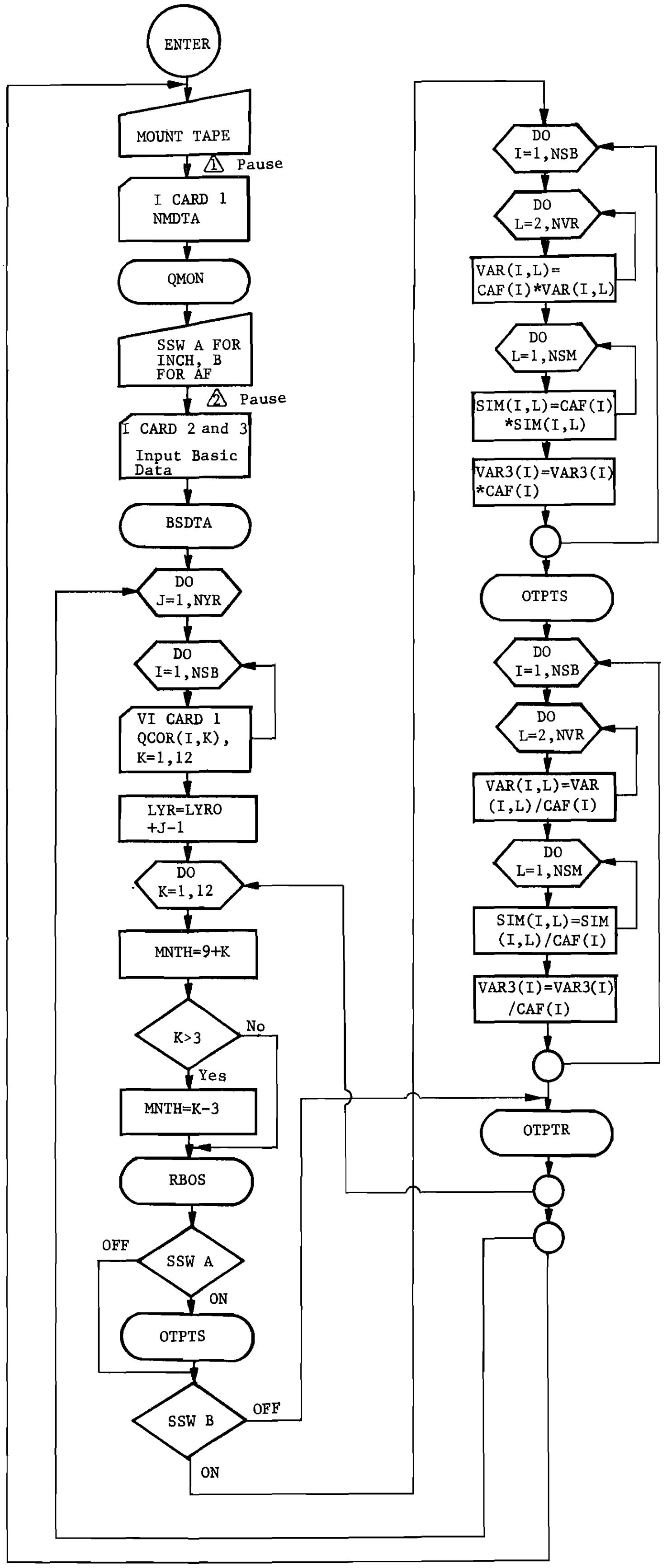
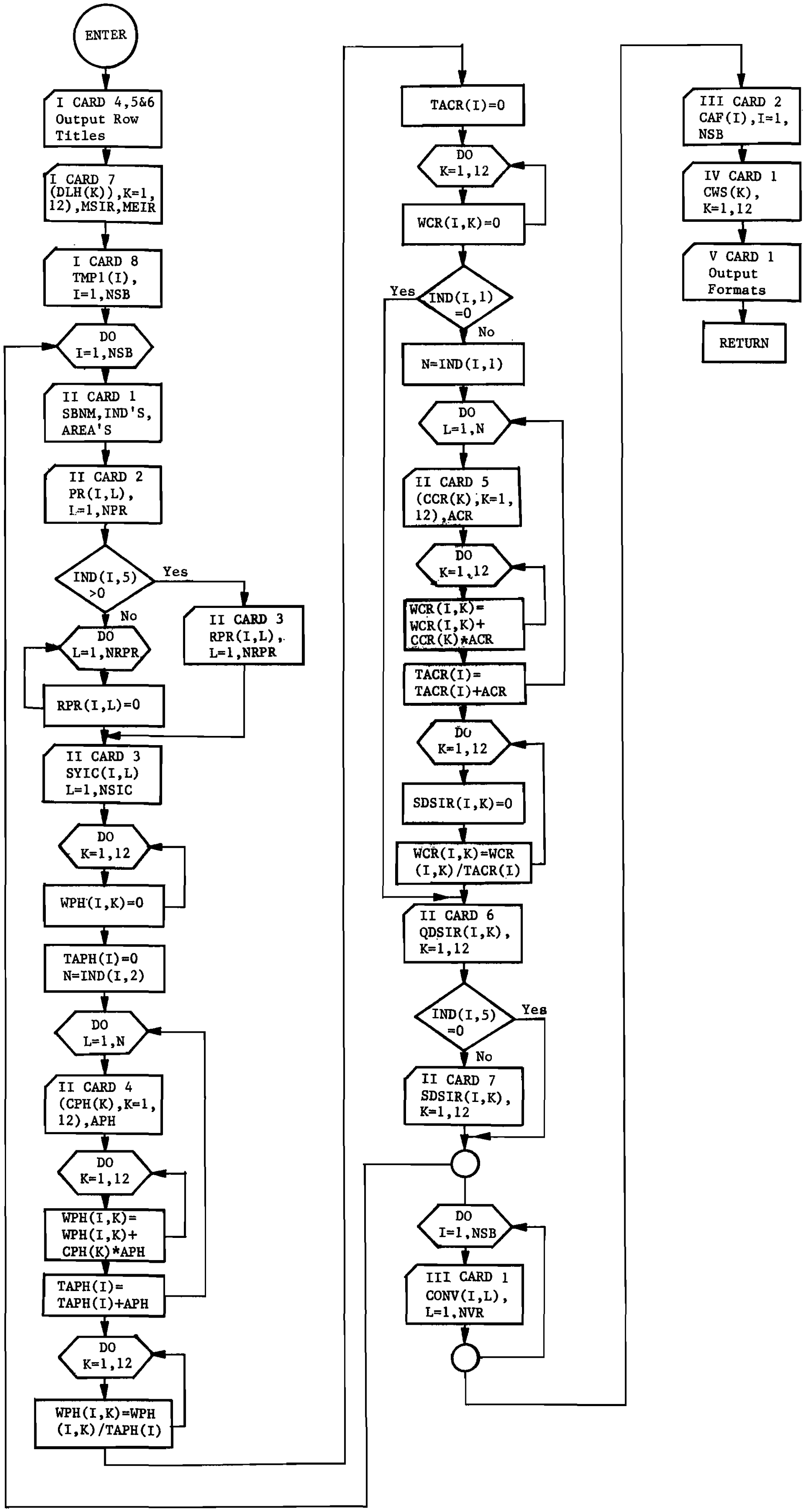


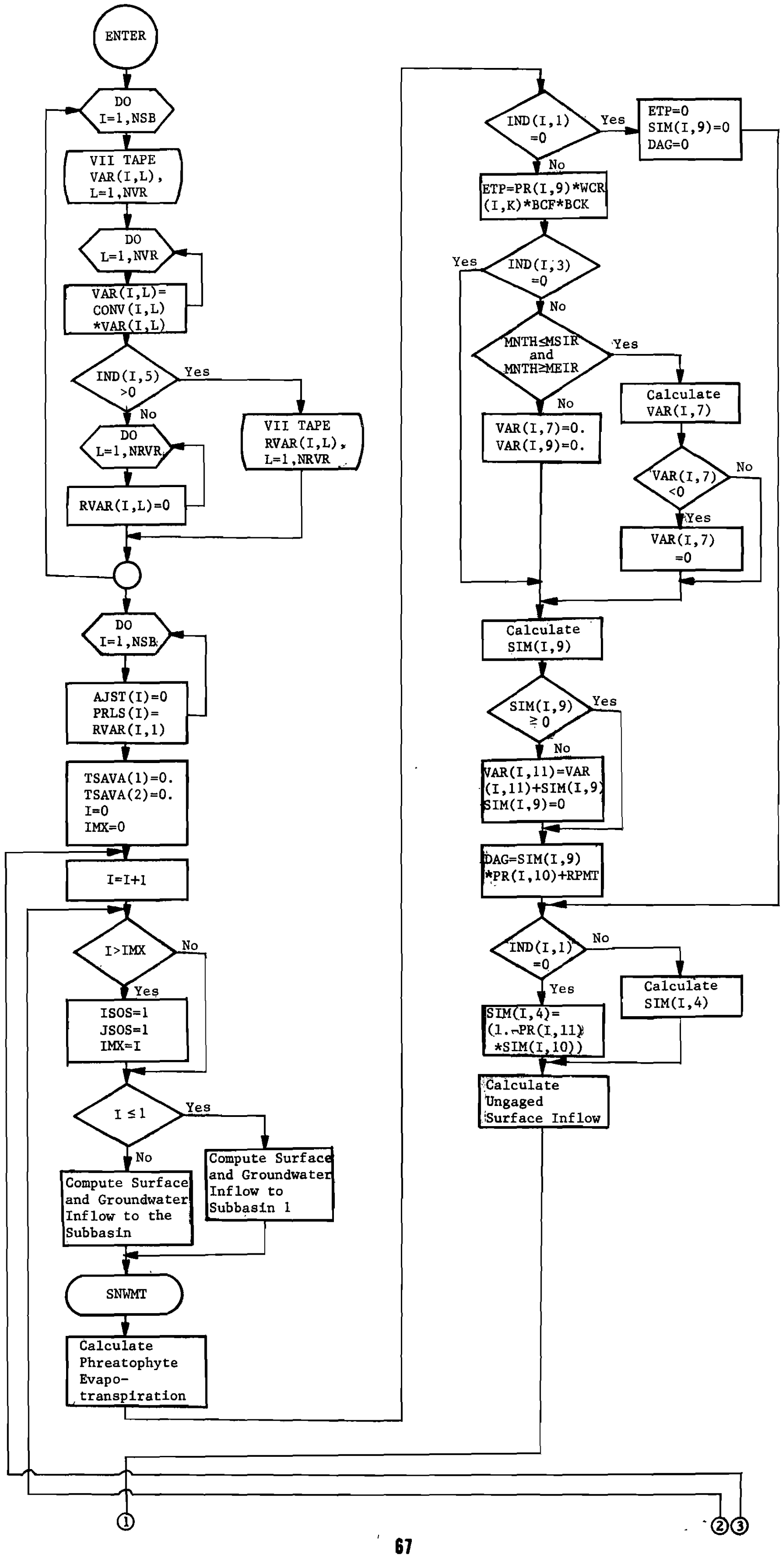
Figure C-1. Reservoir surface area-storage capacity relationship.

MAIN PROGRAM

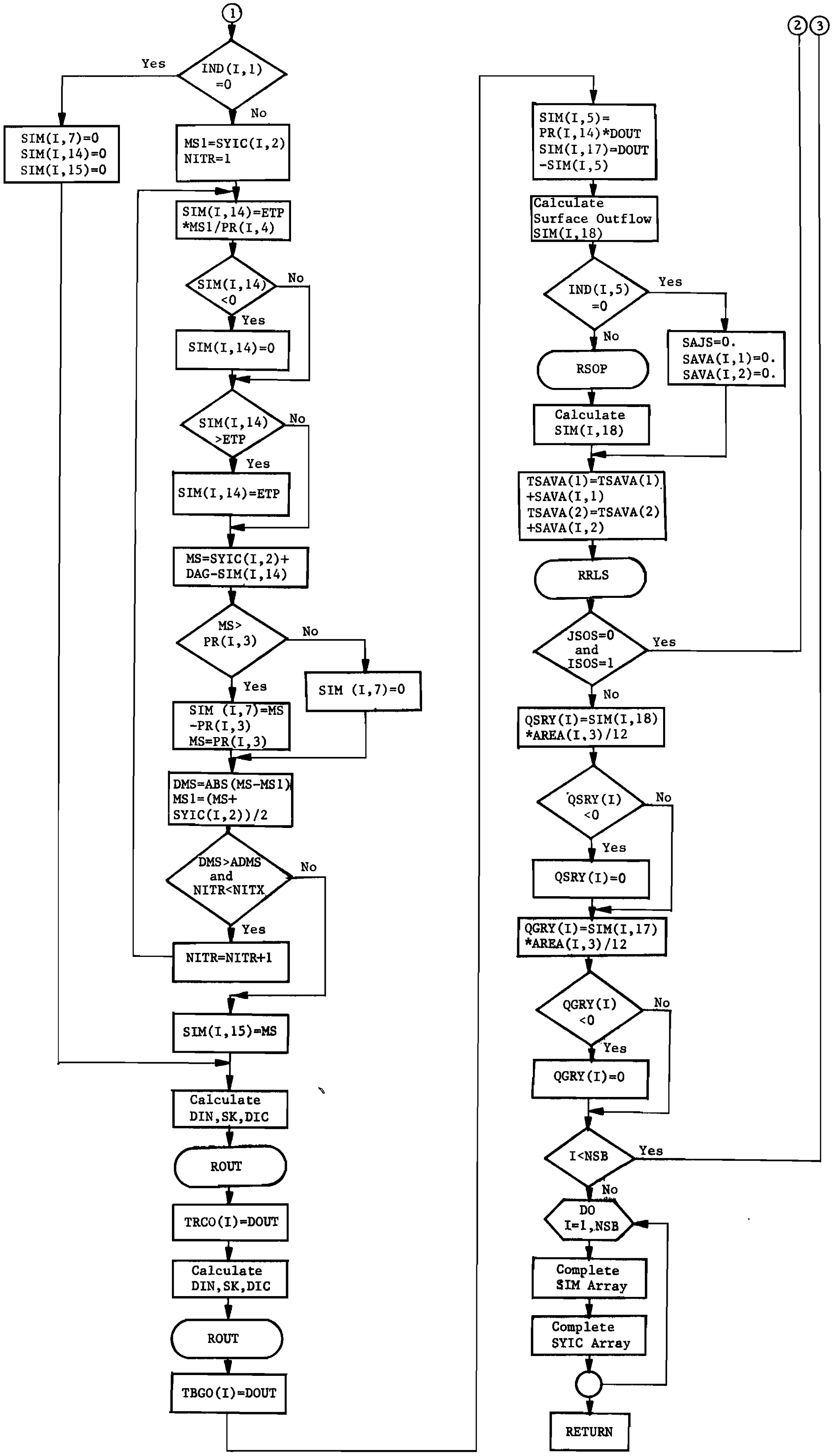


BSDTA

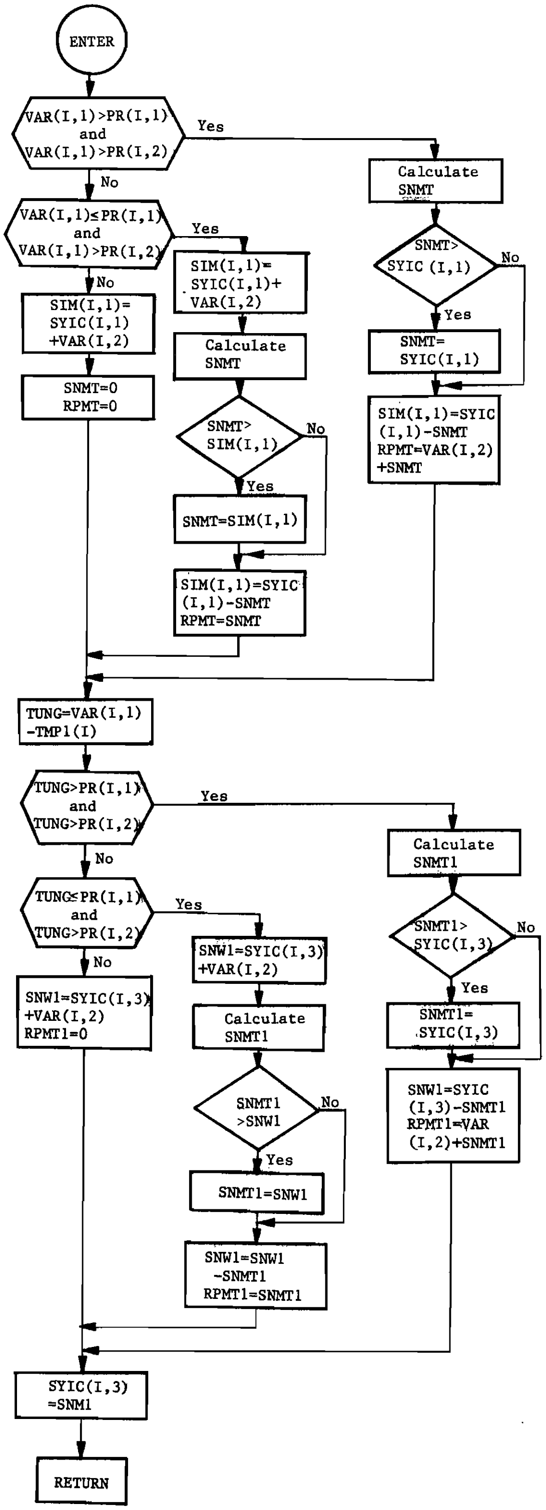

ENTER
I CARD 4,5&6 Output Row Titles
I CARD 7 (DLH(K)),K=1, 12),MSIR,MEIR
I CARD 8 TMP1(I), I=1,NSB
DO I=1,NSB
II CARD 1 SBNM,IND'S, AREA'S
II CARD 2 PR(I,L), L=1,NPR
IND(I,5) >0
Yes
No
II CARD 3 RPR(I,L), L=1,NRPR
DO L=1,NRPR
RPR(I,L)=0
II CARD 3 SYIC(I,L) L=1,NSIC
DO K=1,12
WPH(I,K)=0
TAPH(I)=0 N=IND(I,2)
DO L=1,N
II CARD 4 (CPH(K),K=1, 12),APH
DO K=1,12
WPH(I,K)= WPH(I,K)+ CPH(K)*APH
TAPH(I)= TAPH(I)+APH
DO K=1,12
WPH(I,K)=WPH (I,K)/TAPH(I)
TACR(I)=0
DO K=1,12
WCR(I,K)=0
Yes
IND(I,1) =0
No
N=IND(I,1)
DO L=1,N
II CARD 5 (CCR(K),K=1, 12),ACR
DO K=1,12
WCR(I,K)= WCR(I,K)+ CCR(K)*ACR
TACR(I)= TACR(I)+ACR
DO K=1,12
SDSIR(I,K)=0
WCR(I,K)=WCR (I,K)/TACR(I)
II CARD 6 QDSIR(I,K), K=1,12
IND(I,5) =0
Yes
No
II CARD 7 SDSIR(I,K), K=1,12
DO I=1,NSB
III CARD 1 CONV(I,L), L=1,NVR
III CARD 2 CAF(I),I=1, NSB
IV CARD 1 CWS(K), K=1,12
V CARD 1 Output Formats
RETURN


ENTER
DO I=1,NSB
VII TAPE VAR(I,L), L=1,NVR
DO L=1,NVR
VAR(I,L)= CONV(I,L) *VAR(I,L)
IND(I,5) >0
Yes
No
DO L=1,NRVR
RVAR(I,L)=0
VII TAPE RVAR(I,L), L=1,NRVR
DO I=1,NSB
AJST(I)=0 PRLS(I)= RVAR(I,1)
TSAVA(1)=0. TSAVA(2)=0. I=0 IMX=0
I=I+1
I>IMX
No
Yes
ISOS=1 JSOS=1 IMX=I
I ≤1
Yes
No
Compute Surface and Groundwater Inflow to the Subbasin
Compute Surface and Groundwater Inflow to Subbasin 1
SNWMT
Calculate Phreatophyte Evapo-transpiration
IND(I,1) =0
Yes
ETP=0 SIM(I,9)=0 DAG=0
No
ETP=PR(I,9)*WCR (I,K)*BCF*BCK
IND(I,3) =0
Yes
No
MNTH≤MSIR and MNTH≥MEIR
Yes
No
VAR(I,7)=0. VAR(I,9)=0.
Calculate VAR(I,7)
VAR(I,7) <0
No
Yes
VAR(I,7) =0
Calculate SIM(I,9)
SIM(I,9) ≥ 0
Yes
No
VAR(I,11)=VAR (I,11)+SIM(I,9) SIM(I,9)=0
DAG=SIM(I,9) *PR(I,10)+RPMT
IND(I,1) =0
No
Yes
Calculate SIM(I,4)
SIM(I,4)= (1.-PR(I,11)) *SIM(I,10))
Calculate Ungaged Surface Inflow
①
②
③

RBOS (Continued)

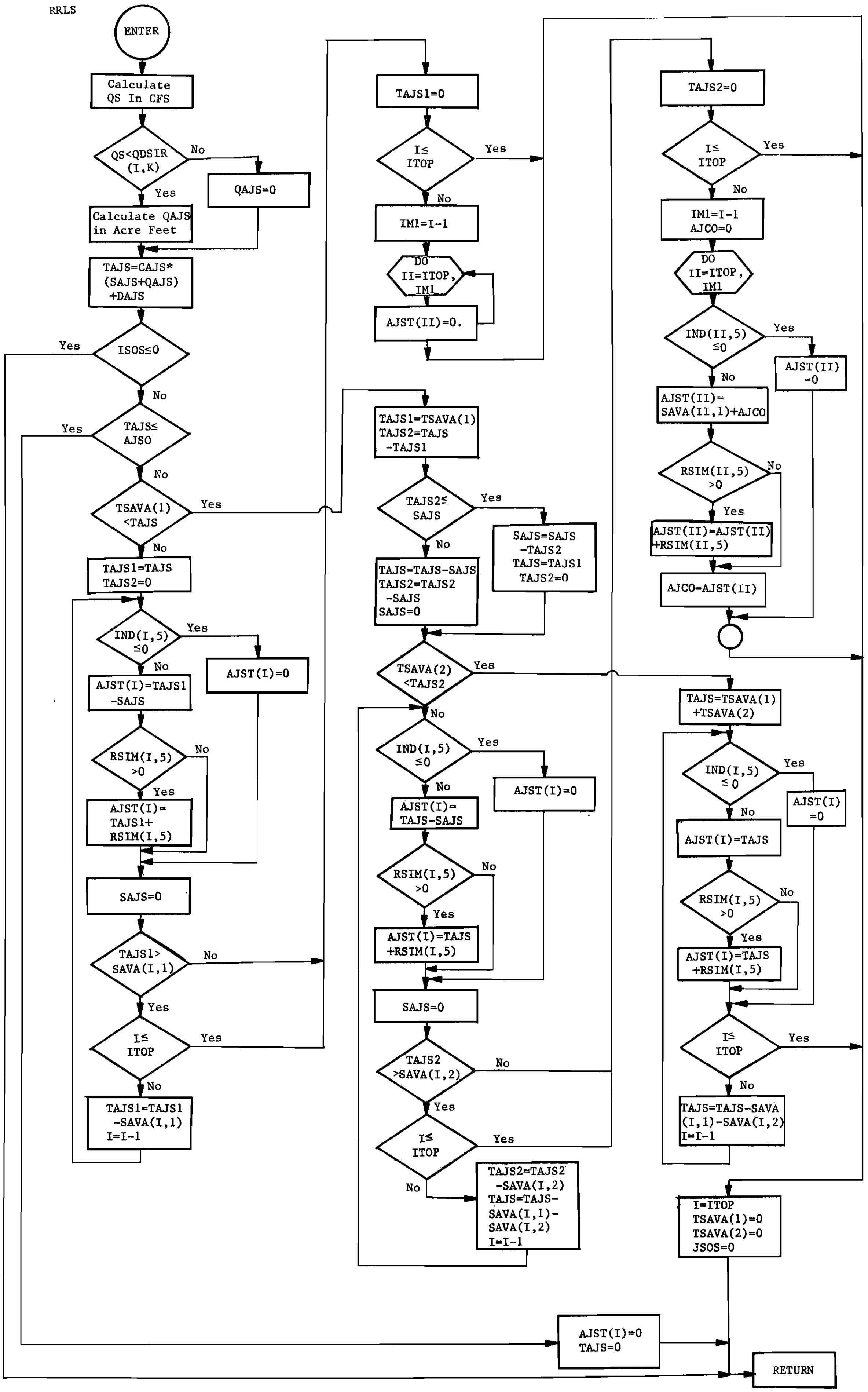


SNWMT



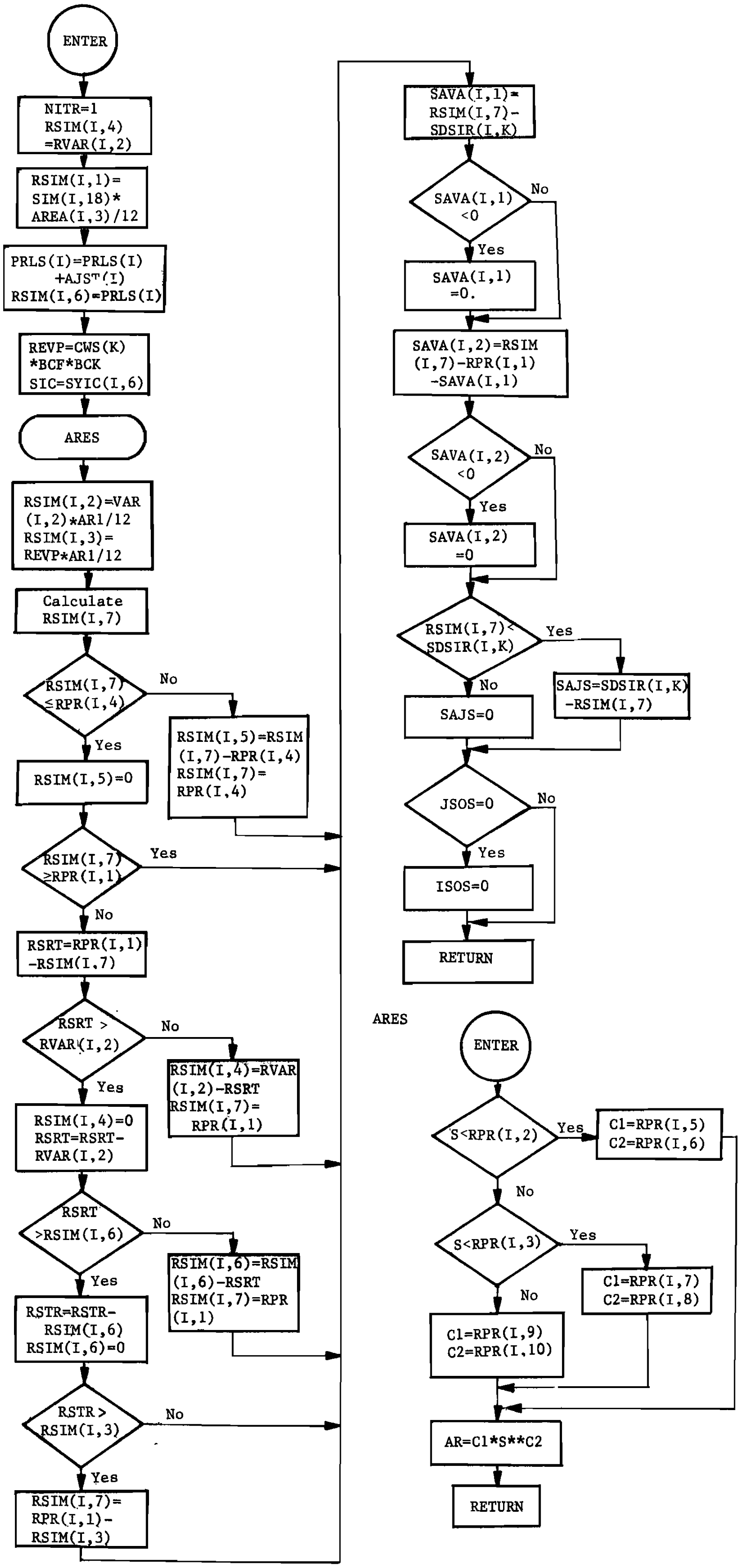
Snowmelt in the Simulated Area

Snowmelt in the Ungaged Area


RRLS
ENTER
Calculate QS In CFS
QS<QDSIR (I,K)
No
QAJS=0
Yes
Calculate QAJS in Acre Feet
TAJS=CAJS* (SAJS+QAJS) +DAJS
ISOS≤0
Yes
No
TAJS≤ AJSO
Yes
No
TSAVA(1) <TAJS
Yes
No
TAJS1=TAJS TAJS2=0
IND(I,5) ≤0
Yes
AJST(I)=0
No
AJST(I)=TAJS1 -SAJS
RSIM(I,5) >0
No
Yes
AJST(I)= TAJS1+ RSIM(I,5)
SAJS=0
TAJS1> SAVA(I,1)
No
Yes
I≤ ITOP
Yes
No
TAJS1=TAJS1 -SAVA(I,1) I=I-1
TAJS1=0
I≤ ITOP
Yes
No
IM1=I-1
DO II=ITOP, IM1
AJST(II)=0.
TAJS1=TSAVA(1) TAJS2=TAJS -TAJS1
TAJS2≤ SAJS
Yes
SAJS=SAJS -TAJS2 TAJS=TAJS1 TAJS2=0
No
TAJS=TAJS-SAJS TAJS2=TAJS2 -SAJS SAJS=0
TSAVA(2) <TAJS2
Yes
No
IND(I,5) ≤0
Yes
AJST(I)=0
No
AJST(I)= TAJS-SAJS
RSIM(I,5) >0
No
Yes
AJST(I)=TAJS +RSIM(I,5)
SAJS=0
TAJS2 >SAVA(I,2)
No
Yes
I≤ ITOP
Yes
No
TAJS2=TAJS2 -SAVA(I,2) TAJS=TAJS- SAVA(I,1)- SAVA(I,2) I=I-1
TAJS2=0
I≤ ITOP
Yes
No
IM1=I-1 AJCO=0
DO II=ITOP, IM1
IND(II,5) ≤0
Yes
AJST(II) =0
No
AJST(II)= SAVA(II,1)+AJCO
RSIM(II,5) >0
No
Yes
AJST(II)=AJST(II) +RSIM(II,5)
AJCO=AJST(II)
TAJS=TSAVA(1) +TSAVA(2)
IND(I,5) ≤ 0
Yes
AJST(I) =0
No
AJST(I)=TAJS
RSIM(I,5) >0
No
Yes
AJST(I)=TAJS +RSIM(I,5)
I≤ ITOP
Yes
No
TAJS=TAJS-SAVA (I,1)-SAVA(I,2) I=I-1
I=ITOP TSAVA(1)=0 TSAVA(2)=0 JSOS=0
AJST(I)=0 TAJS=0
RETURN

RSOP

ARES


ENTER
NITR=1
RSIM(I,4)
=RVAR(I,2)
RSIM(I,1)=
SIM(I,18)*
AREA(I,3)/12
PRLS(I)=PRLS(I)
+AJST(I)
RSIM(I,6)=PRLS(I)
REVP=CWS(K)
*BCF*BCK
SIC=SYIC(I,6)
ARES
RSIM(I,2)=VAR
(I,2)*AR1/12
RSIM(I,3)=
REVP*AR1/12
Calculate
RSIM(I,7)
RSIM(I,7)
≤RPR(I,4)
No
Yes
RSIM(I,5)=RSIM
(I,7)-RPR(I,4)
RSIM(I,7)=
RPR(I,4)
RSIM(I,5)=0
RSIM(I,7)
≥RPR(I,1)
Yes
No
RSRT=RPR(I,1)
-RSIM(I,7)
RSRT >
RVAR(I,2)
No
Yes
RSIM(I,4)=RVAR
(I,2)-RSRT
RSIM(I,7)=
RPR(I,1)
RSIM(I,4)=0
RSRT=RSRT-
RVAR(I,2)
RSRT
>RSIM(I,6)
No
Yes
RSIM(I,6)=RSIM
(I,6)-RSRT
RSIM(I,7)=RPR
(I,1)
RSTR=RSTR-
RSIM(I,6)
RSIM(I,6)=0
RSTR >
RSIM(I,3)
No
Yes
RSIM(I,7)=
RPR(I,1)-
RSIM(I,3)
SAVA(I,1)=
RSIM(I,7)-
SDSIR(I,K)
SAVA(I,1)
<0
No
Yes
SAVA(I,1)
=0.
SAVA(I,2)=RSIM
(I,7)-RPR(I,1)
-SAVA(I,1)
SAVA(I,2)
<0
No
Yes
SAVA(I,2)
=0
RSIM(I,7)<
SDSIR(I,K)
Yes
No
SAJS=0
SAJS=SDSIR(I,K)
-RSIM(I,7)
JSOS=0
No
Yes
ISOS=0
RETURN
ENTER
S<RPR(I,2)
Yes
C1=RPR(I,5)
C2=RPR(I,6)
No
S<RPR(I,3)
Yes
C1=RPR(I,7)
C2=RPR(I,8)
No
C1=RPR(I,9)
C2=RPR(I,10)
AR=C1*S**C2
RETURN

RIVER BASIN MANAGEMENT PROGRAM LISTING

```
C     RIVER BASIN OPERATION MODEL
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),    CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
      COMMON ACR,ADMS,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      DIMENSION BSNM(4),NMDTA(3)
    1 TYPE 199
  199 FORMAT(11H MOUNT TAPE/)
      OCT 25000
      READ(6,99) (NMDTA(I),I=1,3)
   99 FORMAT(3A2)
      CALL QMON(21,NMDTA(1),0,13)
C
      TYPE 202
  202 FORMAT(24HSSW A FOR INCH, B FOR AF/)
      OCT 25000
C     INPUT BASIC DATA
      READ(6,100) (BSNM(II),II=1,4),NSB,NVR,NPR,NSM,NRVR,NRPR,NRSM,NIND,
     1NARA,NSIC,LYRO,NYR,IN1,IN2,IOUT,NITX,AJSO,ADMS,CAJS,ITOP,DAJS
  100 FORMAT(4A4,10I3/I5,5I3,3F5.2,I5,F5.0)
      CALL BSDTA
C
C     REPEAT SIMULATION FOR EACH YEAR
      DO 26 J=1,NYR
      DO 2 I=1,NSB
    2 READ(IN1,101) (QCOR(I,K),K=1,12)
  101 FORMAT(8X,-3P12F6.1)
      LYR=LYRO+J-1
C
C     REPEAT SIMULATION FOR EACH MONTH
      DO 17 K=1,12
      MNTH=9+K
      IF(K.GT.3) MNTH=K-3
C
C     SIMULATION OPERATION
      CALL RBOS (K)
C
C     IF SSW A ON, OUTPUT MONTHLY HYDROLOGY IN INCHES
      OCT 023600
      J   .10
      CALL OTPTS(FMT1,FMT2,K)
C
C     IF SSW B ON, OUTPUT MONTHLY HYDROLOGY IN ACRE-FEET
   10 OCT 023500
      J   .16
C
C     OUTPUT MONTHLY HYDROLOGY IN ACRE-FEET
      DO 15 I=1,NSB
      DO 13 L=2,NVR
   13 VAR(I,L)=CAF(I)*VAR(I,L)
      DO 14 L=1,NSM
   14 SIM(I,L)=CAF(I)*SIM(I,L)
      VAR3(I)=CAF(I)*VAR3(I)
   15 CONTINUE
      CALL OTPTS(FMT3,FMT4,K)
      DO 52 I=1,NSB
      DO 50 L=2,NVR
   50 VAR(I,L)=VAR(I,L)/CAF(I)
      DO 51 L=1,NSM
   51 SIM(I,L)=SIM(I,L)/CAF(I)
      VAR3(I)=VAR3(I)/CAF(I)
   52 CONTINUE
C
C     OUTPUT MONTHLY RESERVOIR OPERATION IN ACRE-FEET
   16 CALL OTPTR (K)
   17 CONTINUE
   26 CONTINUE
      J   .1
      END
C
C     SUBROUTINE FOR BASIC DATA
      SUBROUTINE BSDTA
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),    CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
C
C     READ OUTPUT ROW TITLES
      READ(IN1,100) (OTL(L),L=1,NSM)
      READ(IN1,100) (ROTL(L),L=1,NRSM)
      READ(IN1,100) (OTLV(L),L=1,4)
  100 FORMAT(20A4)
C
C     READ AND CHECK FRACTION DAY-LIGHT HOURS
      READ(IN1,101) (DLH(K),K=1,12),MSIR,MEIR
  101 FORMAT(12F5.3,2I3)
C
C     INPUT UNGAGED WATERSHED TEMPERATURE ADJUSTMENT
      READ(IN1,120) (TMP1(I),I=1,NSB)
  120 FORMAT(10X,10F5.2)
C
C     INPUT MODEL INDICATORS AND PARAMETERS FOR EACH SUB-BASIN
    2 DO 12 I=1,NSB
      READ(IN1,102) (SBNM(I,L),L=1,2),(IND(I,L),L=1,NIND),(AREA(I,L),L=1
     1,NARA)
  102 FORMAT(2A4,2X,5I5,4F10.0)
      READ(IN1,103) (PR(I,L),L=1,NPR)
  103 FORMAT(16F5.2)
      IF(IND(I,5).GT.0) GO TO 41
      DO 40 L=1,NRPR
   40 RPR(I,L)=0.
      J   .42
   41 READ(IN1,104) (RPR(I,L),L=1,NRPR)
  104 FORMAT(4F8.0,6F8.5)
C
C     INPUT INITIAL CONDITIONS
   42 READ(IN1,105) (SYIC(I,L),L=1,NSIC)
  105 FORMAT(5F5.2,F10.0)
C
C     COMPUTE WEIGHTED PHREATOPHYTE AND CROP CONSUMATIVE USE COEFFICIENT
      DO 3 K=1,12
    3 WPH(I,K)=0.
      TAPH(I)=0.
      N=IND(I,2)
      DO 5 L=1,N
      READ(IN1,106) (CPH(K),K=1,12),APH
  106 FORMAT(10X,12F5.2,F10.0)
      DO 4 K=1,12
    4 WPH(I,K)=WPH(I,K)+CPH(K)*APH
    5 TAPH(I)=TAPH(I)+APH
      DO 6 K=1,12
    6 WPH(I,K)=WPH(I,K)/TAPH(I)
      TACR(I)=0.
      DO 7 K=1,12
    7 WCR(I,K)=0.
      IF(IND(I,1).EQ.0) GO TO 11
      N=IND(I,1)
      DO 9 L=1,N
      READ(IN1,106) (CCR(K),K=1,12),ACR
      DO 8 K=1,12
    8 WCR(I,K)=WCR(I,K)+CCR(K)*ACR
    9 TACR(I)=TACR(I)+ACR
```

```
      DO 10 K=1,12
      SDSIR(I,K)=0.
   10 WCR(I,K)=WCR(I,K)/TACR(I)
   11 READ(IN1,107) (QDSIR(I,K),K=1,12)
  107 FORMAT(12F5.0)
      IF(IND(I,5).EQ.0) GO TO 12
      READ(IN1,108) (SDSIR(I,K),K=1,12)
  108 FORMAT(12F6.0)
   12 CONTINUE
C
C     READ AND CHECK CONVERSION FACTORS
      DO 20 I=1,NSB
      READ(IN1,109) (CONV(I,L),L=1,NVR)
  109 FORMAT(10F8.5)
   20 CONTINUE
      READ(6,108)(CAF(I),I=1,NSB)
C
C     READ CONSUMPTIVE USE COEFFICIENT FO OPEN WATER
      READ(IN1,106) (CWS(K),K=1,12)
C
C     READ OUTPUT FORMAT
      READ(IN1,110) (FMT1(L),L=1,4),(FMT2(L),L=1,4),(FMT3(L),L=1,4),
     1(FMT4(L),L=1,4)
  110 FORMAT(16A4)
      RETURN
      END
C
C     SUBROUTINE FOR OPERATION STUDY
      SUBROUTINE RBOS (K)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,     AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      DIMENSION TRCO(7),TBGO(7)
      REAL MS1,MS
C     INPUT COMPILED OBSERVED DATA FOR EACH SUB-BASIN
      DO 3 I=1,NSB
      READ(IN2,100) (VAR(I,L),L=1,NVR)
  100 FORMAT(2F8.3,5F8.0/10F8.0)
      DO 2 L=1,NVR
    2 VAR(I,L)=CONV(I,L)*VAR(I,L)
      IF(IND(I,5).GT.0) GO TO 51
      DO 50 L=1,NRVR
   50 RVAR(I,L)=0.
      J    .3
   51 READ(IN2,101) (RVAR(I,L),L=1,NRVR)
  101 FORMAT(10F8.0)
    3 CONTINUE
      DO 47 I=1,NSB
      AJST(I)=0.
   47 PRLS(I)=RVAR(I,1)
      TSAVA(1)=0.
      TSAVA(2)=0.
      I=0
      IMX=0
    4 I=I+1
   44 IF(I.GT.IMX) GO TO 60
      J    .61
   60 ISOS=1
      JSOS=1
      IMX=I
   61 IF(I.LE.1) GO TO 49
      VAR3(I)=VAR(I,3)+QSRY(I-1)*12./AREA(I,3)
      VAR4(I)=VAR(I,4)+QGRY(I-1)*12./AREA(I,3)
      J    .52
   49 VAR3(I)=VAR(I,3)
      VAR4(I)=VAR(I,4)
```

```
C     SNOW STORAGE AND SNOWMELT
   52 CALL SNWMT (I,RPMT,RPMT1)
C
C     PHREATOPHYTE EVAPOTRANSPIRATION
      BCF=VAR(I,1)*DLH(K)
      BCK=.0173*VAR(I,1)-.314
      IF(BCK.LT..3) BCK=.3
      SIM(I,13)=PR(I,9)*WPH(I,K)*BCF*BCK*TAPH(I)/AREA(I,3)
C
C     CROP POTENTIAL EVAPOTRANSPIRATION AND WATER SUPPLIES
      IF(IND(I,1).EQ.0) GO TO 10
      ETP=PR(I,9)*WCR(I,K)*BCF*BCK
      IF(IND(I,3).EQ.0) GO TO 9
      IF(MNTH.GE.MSIR.AND.MNTH.LE.MEIR) GO TO 8
      VAR(I,7)=0.
      VAR(I,9)=0.
      J    .9
    8 VAR(I,7)=ETP/PR(I,10)-(RPMT+VAR(I,5)+VAR(I,9)-VAR(I,11))
      IF(VAR(I,7).LT.0.) VAR(I,7)=0.
    9 SIM(I,9)=VAR(I,5)+VAR(I,7)+VAR(I,9)-VAR(I,11)
      IF(SIM(I,9).GE.0.) GO TO 70
      VAR(I,11)=VAR(I,11)+SIM(I,9)
      SIM(I,9)=0.
   70 DAG=SIM(I,9)*PR(I,10)+RPMT
      J    .11
   10 ETP=0.
      SIM(I,9)=0.
      DAG=0.
   11 SIM(I,10)=VAR(I,6)+VAR(I,8)+VAR(I,10)-VAR(I,12)
C
C     RETURN FLOW
      IF(IND(I,1).EQ.0) GO TO 12
      SIM(I,4)=(1.-PR(I,10))*SIM(I,9)+(1.-PR(I,11))*SIM(I,10)
      J    .13
   12 SIM(I,4)=(1.-PR(I,11))*SIM(I,10)
C
C     UNGAGED SURFACE INFLOW
   13 SIM(I,2)=PR(I,5)*AREA(I,2)/AREA(I,4)*QCOR(I,K)*12./AREA(I,3)+
     1PR(I,12)*RPMT1*AREA(I,2)/AREA(I,3)+PR(I,13)*(AREA(I,1)+AREA(I,2))/
     2AREA(I,3)
C
C     EVAPOTRANSPIRATION, SOIL MOISTURE, AND PERCOLATION
      IF(IND(I,1).EQ.0) GO TO 19
      MS1=SYIC(I,2)
      NITR=1
   14 SIM(I,14)=ETP*MS1/PR(I,4)
      IF(SIM(I,14).LT.0.) SIM(I,14)=0.
      IF(SIM(I,14).GT.ETP) SIM(I,14)=ETP
      MS=SYIC(I,2)+DAG-SIM(I,14)
      IF(MS.GT.PR(I,3)) GO TO 15
      SIM(I,7)=0.
      J    .16
   15 SIM(I,7)=MS-PR(I,3)
      MS=PR(I,3)
   16 DMS=ABS(MS-MS1)
      MS1=(MS+SYIC(I,2))/2.
      IF(DMS.GT.ADMS.AND.NITR.LT.NITX) GO TO 17
      J    .18
   17 NITR=NITR+1
      J    .14
   18 SIM(I,15)=MS
      J    .20
   19 SIM(I,7)=0.
      SIM(I,14)=0.
      SIM(I,15)=0.
C
C     GROUNDWATER RECHARGE AND OUTFLOW
   20 DIN=PR(I,15)*RPMT*(AREA(I,1)+AREA(I,2))/AREA(I,3)
      SK=PR(I,6)
      DIC=SYIC(I,4)
      CALL ROUT
      TRCO(I)=DOUT
      DIN=VAR4(I)+DOUT+SIM(I,7)-VAR(I,9)-VAR(I,10)
```

```
      SK=PR(I,7)
      DIC=SYIC(I,5)
      CALL ROUT
      TBGO(I)=DOUT
      SIM(I,5)=PR(I,14)*DOUT
      SIM(I,17)=DOUT-SIM(I,5)
C
C     SURFACE OUTFLOW
   21 SIM(I,18)=VAR3(I) +SIM(I,2)+SIM(I,4)+SIM(I,5)-VAR(I,7)-VAR(I,8)-
     1SIM(I,13)+RPMT+TAPH(I)/AREA(I,3)
C
C     RESERVOIR OPERATION
      IF(IND(I,5).EQ.0) GO TO 22
      CALL RSOP (K,I,JSOS)
      SIM(I,18)=(RSIM(I,5)+RSIM(I,6))*12./AREA(I,3)
      J   .23
   22 SAJS=0.
      SAVA(I,1)=0.
      SAVA(I,2)=0.
   23 TSAVA(1)=TSAVA(1)+SAVA(I,1)
      TSAVA(2)=TSAVA(2)+SAVA(I,2)
      CALL RRLS(I,K,JSOS)
      IF(JSOS.EQ.0.AND.ISOS.EQ.1) GO TO 44
   40 QSRY(I)=SIM(I,18)*AREA(I,3)/12.
      IF(QSRY(I).LT.0.) QSRY(I)=0.
      QGRY(I)=SIM(I,17)*AREA(I,3)/12.
      IF(QGRY(I).LT.0.) QGRY(I)=0.
      IF(I.LT.NSB) GO TO 4
C
C     COMPLETE SIM ARRAY
      DO 39 I=1,NSB
      SIM(I,3)=VAR(I,5)+VAR(I,6)
      SIM(I,6)=VAR(I,9)+VAR(I,10)
      SIM(I,8)=VAR4(I)
      SIM(I,11)=VAR(I,11)+VAR(I,12)
      IF(IND(I,5).GE.1) SIM(I,11)=VAR(I,11)+VAR(I,12)+RSIM(I,4)*12./
     1AREA(I,3)
      SIM(I,12)=QDSIR(I,K)*1.98*30.*12./AREA(I,3)-SIM(I,18)
      IF(SIM(I,12).LT.0.) SIM(I,12)=0.
      SIM(I,16)=SIM(I,17)+SIM(I,18)
C
C     RESET INITIAL VALUES
      SYIC(I,1)=SIM(I,1)
      SYIC(I,2)=SIM(I,15)
      SYIC(I,4)=TRCO(I)
      SYIC(I,5)=TBGO(I)
      IF(IND(I,5).EQ.1) SYIC(I,6)=RSIM(I,7)
   39 CONTINUE
      RETURN
      END
C
C     SUBROUTINE FOR SNOW MELT
      SUBROUTINE SNWMT (I,RPMT,RPMT1)
       COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),    CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
       COMMON ACR,ADMS,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
   52 IF(VAR(I,1).GT.PR(I,1).AND.VAR(I,1).GT.PR(I,2)) GO TO 6
      IF(VAR(I,1).LE.PR(I,1).AND.VAR(I,1).GT.PR(I,2)) GO TO 5
      SIM(I,1)=SYIC(I,1)+VAR(I,2)
      SNMT=0.
      RPMT=0.
      J   .7
    5 SIM(I,1)=SYIC(I,1)+VAR(I,2)
      SNMT=SIM(I,1)*(1.-EXP(-PR(I,8)*(VAR(I,1)-PR(I,2))))
      IF(SNMT.GT.SIM(I,1)) SNMT=SIM(I,1)
      SIM(I,1)=SIM(I,1)-SNMT
      RPMT=SNMT
      J   .7
    6 SNMT=SYIC(I,1)*(1.-EXP(-PR(I,8)*(VAR(I,1)-PR(I,2))))
      IF(SNMT.GT.SYIC(I,1)) SNMT=SYIC(I,1)
      SIM(I,1)=SYIC(I,1)-SNMT
      RPMT=VAR(I,2)+SNMT
    7 TUNG=VAR(I,1)-TMP1(I)
      IF(TUNG.GT.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 41
      IF(TUNG.LE.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 90
      SNW1=SYIC(I,3)+VAR(I,2)
      RPMT1=0.
      J   .42
   90 SNW1=SYIC(I,3)+VAR(I,2)
      SNMT1=SNW1*(1.-EXP(-PR(I,8)*(TUNG-PR(I,2))))
      IF(SNMT1.GT.SNW1) SNMT1=SNW1
      SNW1=SNW1-SNMT1
      RPMT1=SNMT1
      J   .42
   41 SNMT1=SYIC(I,3)*(1.-EXP(-PR(I,8)*(TUNG-PR(I,2))))
      IF(SNMT1.GT.SYIC(I,3)) SNMT1=SYIC(I,3)
      SNW1=SYIC(I,3)-SNMT1
      RPMT1=VAR(I,2)+SNMT1
   42 SYIC(I,3)=SNW1
      RETURN
      END
C
C     SUBROUTINE FOR RESERVOIR RELEASE ADJUSTMENTS
      SUBROUTINE RRLS(I,K,JSOS)
       COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),    CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
       COMMON ACR,ADMS,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
C
C     CHECK FOR DESIRABLE FLOW AND ADJUST RESERVOIR RELEASE
      QS=SIM(I,18)*AREA(I,3)/(12.*30.*1.98)
      IF(QS.LT.QDSIR(I,K)) GO TO 24
      QAJS=0.
      J   .25
   24 QAJS=(QDSIR(I,K)-QS)*1.98*30.
   25 TAJS=CAJS*(SAJS+QAJS)+DAJS
      IF(ISOS.LE.0) GO TO 38
      IF(TAJS.LE.AJSO) GO TO 42
      IF(TSAVA(1).LT.TAJS) GO TO 30
C
C     SUFFICIENT WATER AVAILABLE IN RESERVOIRS
      TAJS1=TAJS
      TAJS2=0.
   40 IF(IND(I,5).LE.0) GO TO 41
      AJST(I)=TAJS1-SAJS
      IF(RSIM(I,5).GT.0.) AJST(I)=TAJS1+RSIM(I,5)
      J   .44
   41 AJST(I)=0.
   44 SAJS=0.
   45 IF(TAJS1.GT.SAVA(I,1)) GO TO 50
      J   .28
   50 IF(I.LE.ITOP) GO TO 28
      TAJS1=TAJS1-SAVA(I,1)
      I=I-1
      J   .40
   28 TAJS1=0.
      IF(I.LE.ITOP) GO TO 37
      IM1=I-1
      DO 29 II=ITOP,IM1
   29 AJST(II)=0.
      J   .37
C
C     STORAGE LESS THAN DESIRABLE IN SOME OR ALL RESERVOIRS
   30 TAJS1=TSAVA(1)
      TAJS2=TAJS-TAJS1
      IF(TAJS2.LE.SAJS) GO TO 90
      TAJS=TAJS-SAJS
```

```
      TAJS2=TAJS2-SAJS
      SAJS=0.
      J    .91
   90 SAJS=SAJS-TAJS2
      TAJS=TAJS1
      TAJS2=0.
   91 IF(TSAVA(2).LT.TAJS2) GO TO 35
   59 IF(IND(I,5).LE.0) GO TO 61
      AJST(I)=TAJS-SAJS
      IF(RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
      J    .65
   61 AJST(I)=0.
   65 SAJS=0.
   60 IF(TAJS2.GT.SAVA(I,2)) GO TO 51
      J    .33
   51 IF(I.LE.ITOP) GO TO 33
      TAJS2=TAJS2-SAVA(I,2)
      TAJS=TAJS-SAVA(I,1)-SAVA(I,2)
      I=I-1
      J    .59
   33 TAJS2=0.
      IF(I.LE.ITOP) GO TO 37
      IM1=I-1
      AJCO=0.
      DO 34 II=ITOP,IM1
      IF(IND(II,5).LE.0) GO TO 80
      AJST(II)=SAVA(II,1)+AJCO
      IF(RSIM(II,5).GT.0.) AJST(II)=AJST(II)+RSIM(II,5)
      AJCO=AJST(II)
      J    .34
   80 AJST(II)=0.
   34 CONTINUE
      J    .37
C
C     STORAGE LESS THAN MINIMUM IN SOME OR ALL RESERVOIRS
   35 TAJS=TSAVA(1)+TSAVA(2)
   70 IF(IND(I,5).LE.0) GO TO 71
      AJST(I)=TAJS
      IF(RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
      J    .72
   71 AJST(I)=0.
   72 IF(I.LE.ITOP) GO TO 37
      TAJS=TAJS-SAVA(I,1)-SAVA(I,2)
      I=I-1
      J    .70
   37 I=ITOP
      TSAVA(1)=0.
      TSAVA(2)=0.
      JSOS=0
      J    .38
   42 AJST(I)=0.
      TAJS=0.
   38 RETURN
      END
C
C     SUBROUTINE FOR LINEAR RESERVOIR ROUTING
      SUBROUTINE ROUT
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,     AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      DOUT=DIN+(DIC-DIN)*EXP(-1./SK)
      RETURN
      END
```

```
C     SUBROUTINE FOR RESERVOIR OPERATION
      SUBROUTINE RSOP (K,I,JSOS)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,     AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      NITR=1
      RSIM(I,4)=RVAR(I,2)
C
C     RESERVOIR INFLOW
      RSIM(I,1)=SIM(I,18)*AREA(I,3)/12.
C
C     RESERVOIR RELEASE
      PRLS(I)=PRLS(I)+AJST(I)
      RSIM(I,6)=PRLS(I)
C
C     RESERVOIR EVAPORATION
      REVP=CWS(K)*BCF*BCK
      SIC=SYIC(I,6)
      CALL ARES(SIC,AR1,I)
    1 RSIM(I,2)=VAR(I,2)*AR1/12.
      RSIM(I,3)=REVP*AR1/12.
C
C     RESERVOIR STORAGE
      RSIM(I,7)=SIC+RSIM(I,1)+RSIM(I,2)-RSIM(I,3)-RSIM(I,4)-RSIM(I,6)
C
C     SPILL FLOW
      IF(RSIM(I,7).LE.RPR(I,4)) GO TO 2
      RSIM(I,5)=RSIM(I,7)-RPR(I,4)
      RSIM(I,7)=RPR(I,4)
      J    .6
    2 RSIM(I,5)=0.
      IF(RSIM(I,7).GE.RPR(I,1)) GO TO 6
      RSRT=RPR(I,1)-RSIM(I,7)
      IF(RSRT.GT.RVAR(I,2)) GO TO 3
      RSIM(I,4)=RVAR(I,2)-RSRT
      RSIM(I,7)=RPR(I,1)
      J    .6
    3 RSIM(I,4)=0.
      RSRT=RSRT-RVAR(I,2)
      IF(RSRT.GT.RSIM(I,6)) GO TO 4
      RSIM(I,6)=RSIM(I,6)-RSRT
      RSIM(I,7)=RPR(I,1)
      J    .6
    4 RSRT=RSRT-RSIM(I,6)
      RSIM(I,6)=0.
      IF(RSRT.GT.RSIM(I,3)) GO TO 5
      RSIM(I,7)=RPR(I,1)-RSRT
      J    .6
    5 RSIM(I,7)=RPR(I,1)-RSIM(I,3)
C
C     CHECK FOR AVAILABLE AND DESIRABLE STORAGES
    6 SAVA(I,1)=RSIM(I,7)-SDSIR(I,K)
      IF(SAVA(I,1).LT.0.) SAVA(I,1)=0.
      SAVA(I,2)=RSIM(I,7)-RPR(I,1)-SAVA(I,1)
      IF(SAVA(I,2).LT.0.) SAVA(I,2)=0.
      IF(RSIM(I,7).LT.SDSIR(I,K)) GO TO 8
      SAJS=0.
      J    .9
    8 SAJS=SDSIR(I,K)-RSIM(I,7)
    9 IF(JSOS.EQ.0) ISOS=0
      RETURN
      END
C     SUBROUTINE FOR RESERVOIR WATER SURFACE AREA
      SUBROUTINE ARES(S,AR,I)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
```

```
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,     AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      IF(S.LT.RPR(I,2)) GO TO 2
      IF(S.LT.RPR(I,3)) GO TO 1
      C1=RPR(I,9)
      C2=RPR(I,10)
      J    .3
    1 C1=RPR(I,7)
      C2=RPR(I,8)
      J    .3
    2 C1=RPR(I,5)
      C2=RPR(I,6)
    3 AR=C1*S**C2
      RETURN
      END
C
C     SUBROUTINE FOR OUTPUT SIMULATED HYDROLOGY
      SUBROUTINE OTPTS(FMTA,FMTB,K)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,     AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      DIMENSION FMTA(4),FMTB(4)
      IF(MNTH.EQ.0) GO TO 1
      WRITE(IOUT,200) LYR,K
  200 FORMAT(//1X,3HL =,I5,5X,3HK =,I3)
      J    .2
    1 WRITE(IOUT,201) LYR
  201 FORMAT(//1X,3HL =,I5,2X,6HANNUAL)
    2 WRITE(IOUT,202) ((SBNM(I,L),L=1,2),I=1,NSB)
  202 FORMAT(/7H ITEM   ,9(1X,2A4))
      WRITE(IOUT,FMTA) OTLV(1),(VAR(I,1),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(2),(VAR(I,2),I=1,NSB)
      WRITE(IOUT,FMTB) OTL(1),(SIM(I,1),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(3),(VAR3(I),I=1,NSB)
      DO 4 L=2,NSM
    4 WRITE(IOUT,FMTB) OTL(L),(SIM(I,L),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(4),(VAR(I,13),I=1,NSB)
      RETURN
      END
C     SUBROUTINE FOR OUTPUT RESERVOIR OPERATION
      SUBROUTINE OTPTR (K)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
     1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
     2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
     3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
     4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS,     AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      NRS=0
      DO 1 I=1,NSB
    1 NRS=NRS+IND(I,5)
      IF(NRS.EQ.0) GO TO 4
      WRITE(IOUT,200)
  200 FORMAT(//1X,9HRESERVOIR)
      WRITE(IOUT,202) (ROTL(L),L=1,NRSM)
  202 FORMAT(/9H SUB BSN,7(5XA4),4X,4HAJST)
      DO 3 I=1,NSB
      IF(IND(I,5).EQ.0) GO TO 3
      WRITE(IOUT,203) (SBNM(I,L),L=1,2),(RSIM(I,L),L=1,NRSM),AJST(I)
  203 FORMAT(1X,2A4,7F9.0,F8.0)
    3 CONTINUE
    4 RETURN
      END
```

SAMPLE INPUT

```
I. BASIC DATA
 CARD 1
OBDTA2
 CARD 2
 PROVO R. BASIN   3 13 15 18  2 10  7  5  4  6
 CARD 3
 1950 20  6 13  6 20 2000   10  100    2    0
 CARD 4
SNOWQUNGQIMPQRTNQBSEQWELQPRCQGWIQIRRQMNIQEXPQSRTETPHETCRSLMSQTOTQGWOQSOTQDEV
 CARD 5
RQINRPPTREVPRDIVRSPLRRLSRSTR
 CARD 6
TEMPPRCPQGINQGOT
 CARD 7
 .077 .067 .065 .067 .067 .083 .089 .100 .101 .102 .096 .084  4 10
 CARD 8
TMP1          5.2  5.2  7.9

II. MODEL INDICATORS AND PARAMETERS FOR EACH SUBBASIN
 CARD 1
 FRANCIS      4    4    0    0    0     21376     109056      3329    104320
 CARD 2
 4000 3000  600  400   28   20   40   12  100   30   80   04   12   40   02
 CARD 3
  IND(1,5)=0 SKIP CARD 3 FOR THIS SUBBASIN
 CARD 4
   00  400  100  300  400
 CARD 5
C2  HWGW 2  125  102   75   65   80  113  136  141  142  142  141  136          1
C3  MWGT 3   81   76   69   56   53   53   55   61   68   77   82   83        936
C4  LWGT 4   50   47   42   35   33   33   34   38   42   48   51   51         19
C5  OPWT 5  137  128  112  101  130  149  156  155  151  144  141  138          1
 CARD 6
A1  ALFA 1   90   79   65   63   74   86   99  112  119  110  105   99       1389
A2  PAST 2   80   74   58   55   66   81   86  102   99   93   91   87        924
A3  AOHA 3   84   77   62   55   66   81   94  109  115  110  105   95        490
A4  SMGR 4   22   29   29   29   29   28   74  118  127   73   40   19        326
 CARD 7 (NOTE-THE FLOW IS SET NEGATIVE SO THAT ACTUAL SIMULATIONS ARE OUTPUT
   WITH NO ADJUSTMENT BY THE RESERVOIR.)
-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999
 CARD 8
  IND(1,5)=0 SKIP CARD 8 FOR THIS SUBBASIN

REPEAT CARDS UNDER II. FOR REMAINING SUBBASINS

   A 2,3      7    4    0    0    1     19200     190413     16531     104320
 3200 2600 1000  400   06   80  160   18  110   50   80   02   20   40   05
 -999999    9500  111000 9999999     1.85    .6249     4.58     .528     .187    .8016
   00  400  100  200  200
C2  HWGW 2  125  102   75   65   80  113  136  141  142  142  141  136        191
C3  MWGT 3   81   76   69   56   53   53   55   61   68   77   82   83        410
C4  LWGT 4   50   47   42   35   33   33   34   38   42   48   51   51       2133
C5  OPWT 5  137  128  112  101  130  149  156  155  151  144  141  138         49
A1  ALFA 1   90   79   65   63   74   86   99  112  119  110  105   99       6794
A2  PAST 2   80   74   58   55   66   81   86  102   99   93   91   87       5428
A3  AOHA 3   84   77   62   55   66   81   94  109  115  110  105   95       1970
A4  SMGR 4   22   29   29   29   29   28   74  118  127   73   40   19       1739
A5  CORN 5   99   29   29   29   29   28   22   60   73   93  106  109         30
A12 IDLE12   35   30   25   25   25   30   33   38   39   39   39   39        533
A13 BEAN13   25   29   29   29   29   28   22   67  111   89   75   20         37
-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999
 80000 80000 80000 80000 80000 80000 80000 80000 80000 80000 80000 80000
   A456      12    5    0    1    0          0     64487     18959     104320
 3500 2500  500  300   01  100  350   18  124   60   90   01   03   32   01
   00  200   50  200  200
C1  HWMC 1  185  185  185  185  185  185  185  185  185  185  185  185        811
C2  HWGW 2  125  102   75   65   80  113  136  141  142  142  141  136       1842
C3  MWGT 3   81   76   69   56   53   53   55   61   68   77   82   83       1038
C4  LWGT 4   50   47   42   35   33   33   34   38   42   48   51   51        459
C5  OPWT 5  137  128  112  101  130  149  156  155  151  144  141  138         17
```

```
A1  ALFA 1   90   79   65   63   74   86   99  112  119  110  105   99       4121
A2  PAST 2   80   74   58   55   66   81   86  102   99   93   91   87       4480
A3  AOHA 3   84   77   62   55   66   81   94  109  115  110  105   95       1537
A4  SMGR 4   22   29   29   29   29   28   74  118  127   73   40   19       3054
A5  CORN 5   99   29   29   29   29   28   22   60   73   93  106  109       2013
A6  SUBT 6  102   29   29   29   29   28   22   58   95  106  120  111        235
A7  POTA 7   22   29   29   29   29   28   22   30   42   88  131  134        136
A8  ORCH 8   90   78   65   64   74   86   98  108  113  111  106   99       2823
A10 TOMA10   40   29   29   29   29   28   45   50   75  101   97   83         44
A11 SMTR11   40   29   29   29   29   28   37   62   77   82   78   61        137
A12 IDLE12   35   30   25   25   25   30   33   38   39   39   39   39        367
A13 BEAN13   25   29   29   29   29   28   22   67  111   89   75   20         12
-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999

III. INPUT CONVERSION FACTORS
 CARD 1 REPEATED FOR THE SIX SUBBASINS
      1.        1..0036047.0036047.0036047.0036047.0036047.0036047.0036047.0036047
.0036047.0036047.0036047.0036047
      1.        1..0007259.0007259.0007259.0007259.0007259.0007259.0007259.0007259
.0007259.0007259.0007259.0007259
      1.        1..0006328.0006328.0006328.0006328.0006328.0006328.0006328.0006328
.0006328.0006328.0006328.0006328
 CARD 2
277.411377.51579.7

IV. CONSUMPTIVE USE FOR OPEN WATER
 CARD 1
C5  OPWT 5  137  128  112  101  130  149  156  155  151  144  141  138

V. OUTPUT FORMATS
 CARD 1
(1X,A4,2X,8F9.3)(1X,A4,2X,8F9.3)(1X,A4,2X,8F9.3)(1X,A4,2X,8F9.0)

VI. GAGED FLOW OF THE CORRELATION STREAMS
 CARD 1
 INPUT QCOR FOR YEAR ONE FOR THE THREE SUBBASINS(1950)
OAKL1950     51     44     39     36     33     37    136    460    776    236     83     65
OAKL1950     51     44     39     36     33     37    136    460    776    236     83     65
OAKL1950     51     44     39     36     33     37    136    460    776    236     83     65
 THIS SET OF CARDS FOR 1950 IS FOLLOWED BY SIMILAR INPUT FOR THE YEARS 1951-69
VII. THE VAR(I,L) AND RVAR(I,L) DATA ARE READ FROM THE DATA TAPE DEVELOPED
     USING THE DATA PROGRAM
```

SAMPLE OUTPUT

```
L = 1950     K =  1


L = 1950     K =  1

ITEM     FRANCIS     A 2,3     A4567
TEMP      40.952    43.598    47.500
PRCP       1014.     4452.     6555.
SNOW          0.        0.        0.
QGIN        799.     8848.    13498.
QUNG       3640.     5360.      440.
QIMP          0.        0.        0.
QRTN          0.        0.       10.
QBSE        396.     1221.      969.
QWEL          0.        0.      499.
QPRC        184.        0.        0.
QGWI          0.      594.     1831.
QIRR          0.        0.        0.
QMNI          0.        0.       99.
QEXP          0.        0.     1999.
QSRT          0.        0.        0.
ETPH         79.      230.      939.
ETCR        274.     1723.     2736.
SLMS       1664.     8238.     6978.
QTOT       5642.    15431.    15879.
QGWO        594.     1832.     2059.
QSOT       5048.    13599.    13820.
QGOT       4999.    13599.    13894.


RESERVOIR

SUB BSN,      RQIN       RPPT       REVP       RDIV       RSPL       RRLS       RSTR      AJST
   A 2,3    15949.       588.       369.         0.         0.    13600.   121369.        0.


L = 1950     K =  2


L = 1950     K =  2

ITEM     FRANCIS     A 2,3     A4567
TEMP      37.758    40.198    42.898
PRCP        591.     3267.     3105.
SNOW        233.        0.        0.
QGIN       1099.     8977.    15397.
QUNG       3021.     4755.      278.
QIMP          0.        0.        0.
QRTN          0.        0.        0.
QBSE        205.     1135.      930.
QWEL          0.        0.      399.
QPRC        186.        0.      698.
QGWI          0.      307.     1702.
QIRR          0.        0.        0.
QMNI          0.        0.        0.
QEXP          0.        0.      399.
QSRT          0.        0.        0.
ETPH         51.      148.      560.
ETCR        172.     1090.     1487.
SLMS       1664.    10415.     7898.
QTOT       4686.    16301.    18707.
QGWO        307.     1702.     1978.
QSOT       4378.    14599.    16729.
QGOT       4399.    14598.    16793.


RESERVOIR

SUB BSN,      RQIN       RPPT       REVP       RDIV       RSPL       RRLS       RSTR      AJST
   A 2,3    15270.       439.       243.         0.         0.    14600.   122236.        0.
```

APPENDIX D

COMBINED UTAH LAKE OPERATION MODEL

The combined model is composed of the Utah Lake operation model developed by the Central Utah Project Office of the Bureau of Reclamation and the previously described river basin management model. Slight alteration of both of the programs was necessary to combine the models but the basic logic of the programs was not affected. The combined program is tied more to operation on a water year than any of the previously described models.

The use of the data program was eliminated in the combined model by directly inputing all data to the combined model. The input of VAR and RVAR data was altered so that all NYR years of data for each station could be input as a group as outlined in the input data layout. This is the same procedure used to input VAR data to the parameter calibration model.

A set of indications was used to replace the use of sense switches with "If" statements and provide additional logic tests. These indicators are outlined in the data input.

The management portion of the program simulates the Provo River flow, ungaged streamflow and groundwater flow to Utah Lake. Additionally, this portion of the program tabulates the inflow to the lake from gaged surface sources. This becomes input to the Utah Lake operation portion of the combined model.

The original Utah Lake model was adapted to the combined model by redefining the basic variable, C(J,L,K). This allows certain variables to be transferred from the management portion of the program. The basic variables are listed in Table D-1. Calculation of precipitation on the lake and a total dissolved solids balance, as discussed in the text, were added to the Utah Lake operation portion of the study.

The output from the combined program is composed of two distinct portions. The management portion of the program outputs results of simulation for the NYR years followed by the output of the Utah Lake operation for the same time period. The output for the management portion of the combined program is the same as the output for the river basin management model. The output of the Utah Lake operation portion of the model is based on a water year and consists of monthly values for the C(J,L,K)'s.

INPUT DATA LAYOUT

I. Basic Data

Card 1 same as I Card 2 **Appendix** C
Card 2 same as I Card 3 Appendix C

II. Gaged Flow of the Correlation Streams (in Thousands of Acre Feet)

	Col	Identifier	
Card 1	1-8		Identification
	9-14	QCOR(1,1,1)	Correlation streamflow for Subbasin 1 month 1 year 1
	15-20	QCOR(1,1,2)	Correlation streamflow for Subbasin 1 month 2 year 1
	. . .		. . .
	75-80	QCOR(1,1,12)	Correlation streamflow for Subbasin 1 month 12 year 1

Format (8X,-3P12F6.1)

This card is repeated for year 2, 3, ..., NYR. This completes the correlation stream input data for Subbasin 1. This set is followed by a similar set of data for Subbasin 2, 3, ..., NSB.

III. Indicators

Card 1	4	INAF	= 1 output monthly hydrology of the Provo River in inches = 2 output monthly hydrology of the Provo River in acre feet = 3 output only reservoir operation
	8	NOUT	= 0 program outputs Provo River simulation = 1 program skips all output of the Provo River simulation (overrides INAF)
	9-12	IPR	Subbasin number of the most downstream subbasin in the Provo River system
	13-16	IUL	The subbasin number of the subbasin containing Utah Lake. (IUL = IPR+1) or = 0 program operates as river basin management model with no lake operation

Format (4I4)

IV. River Basin Data

Card 1 same as I	Card 4 Appendix C
Card 2 same as I	Card 5 Appendix C
Card 3 same as I	Card 6 Appendix C
Card 4 same as I	Card 7 Appendix C
Card 5 same as I	Card 8 Appendix C
Card 7 same as II	Card 1 Appendix C
Card 8 same as II	Card 2 Appendix C
Card 9 same as II	Card 3 Appendix C
Card 10 same as II	Card 4 Appendix C
Card 11 same as II	Card 5 Appendix C
Card 12 same as II	Card 6 Appendix C
Card 13 same as II	Card 7 Appendix C
Card 14 same as III	Card 1 Appendix C
Card 15 same as III	Card 2 Appendix C
Card 16 same as IV	Card 1 Appendix C
Card 17 same as V	Card 1 Appendix C

V. Input Variable Data Indications

Card 1 same as II Card 1 Appendix B

With Only Four Formats

Card 2 same as II	Card 2 Appendix B
Card 3 same as III	Card 1 Appendix B
Card 4 same as IV	Card 1 Appendix B

VI. Input VAR and RVAR Data

The VAR and RVAR data described in Table C-1 are input at this point. These variables are read in as DVAR and DRVAR in the program and then the stations for each variable are summed to form VAR and RVAR, respectively.

Each card must contain twelve monthly values and all stations of a specific variable must be in the same units and punched in the same format within a subbasin (refer to VI Card 1 Appendix B for use of input formats for the variables).

The following ending of the cards values, each containing twelve monthly values, is to be used:

Subbasin 1
VAR(1) Station 1 Year 1, 2, 3, ..., NYR
Station 2 Year 1, 2, 3, ..., NYR
.
.
.
Station NST(1,1) Year 1,2,3, ..., NYR
VAR(2) Station 1 Year 1, 2, 3, ..., NYR
Station 2 Year 1, 2, 3, ..., NYR
.
.
.
⋮
Station NST(1,2) Year 1,2,3, ..., NYR
VAR(NVR) Station 1 Year 1, 2,3, ..., NYR
Station 2 Year 1, 2,3, ..., NYR
.
.
.
Station NST(1,NVR) Year 1,2,3,...,NYR

If IRS(1) = 0, SKIP RVAR(L) input

RVAR(1)	Station 1	Year 1,2,3,. . . ,NYR
	Station 2	Year 1,2,3,. . . ,NYR
	.	
	.	
	.	
	Station NRST(1,1)	Year 1,2,3,. . . ,NYR
RVAR(2)	Station 1	Year 1,2,3,. . . ,NYR
	Station 2	Year 1,2,3,. . . ,NYR
	.	
	.	
	.	
.	Station NRST(1,2)	Year 1,2,3,. . . ,NYR
.		
.		
RVAR(NRVR)	Station 1	Year 1,2,3,. . . ,NYR
	Station 2	Year 1,2,3,. . . , NYR
	.	
	.	
	.	
	Station NRST(1,NRVR)	Year 1,2,3,...,NYR

This arrangement of cards is repeated for subbasin 2, 3, . . . , NSB. When any NST(I, L) or NRST(I, L) is equal to zero no cards are input for that VAR(L) or RVAR(L), respectively, of Subbasin I.

VII. Input Data for Utah Lake Operation

	Col	Identifier	
Card 1	1-12	TITLE	Title card which will appear at the top of each page put in the first 72 columns

Format (12A6)

Card 2	1-8	CTDS	Conversion of ppm to a desired unit
	9-13	GWSC	Groundwater salt content, ppm
	14-21	SDEAD	Dead storage of Utah Lake, acre feet
	22-26	NUMENT	The number of values to be in the area-capacity tables of Utah Lake expressed as an integer
	27-31	NUGNT	The number of values to be in the area-capacity tables of Goshen Bay expressed as an integer
	32-36	KPPT	Number of precipitation stations to be input for calculation of precipitation on Utah Lake
	37-41	DLS	A dummy lake storage used in calculating total dissolved solids when the lake content is zero

Format (F8. 5, F5. 0, F8. 2, 3I5, F5. 1)

Card 3	1-10	CPPT(1)	The weighting factor to be applied to lake precipitation station 1
	11-20	CPPT(2)	The weighting factor to be applied to lake precipitation station 2
		.	.
		.	.
		.	.
		CPPT(KPPT)	The weighting factor to be applied to lake precipitation station KPPT

Format (8F10. 0)

Card 4 The lake precipitation, BPPT(I, J) data is input at this point. NYR years of data are input for station 1 with one year of monthly data in inches of water per card. The cards are arranged in ascending yearly order. A similar set is input for station 2, 3, . . . , KPPT. This is the same technique used to input the VAR & RVAR data to this program.

Format (8X, 12F6. 2)

Card 5	1-6	C(14, 1, 1)	Initial value of C(14, L, K), thousands of acre feet
	7-12	C(13, 1, 1)	Initial value of C(13, L, K), thousands of acre feet
	13-18	C(21, 1, 1)	Initial value of C(21, L, K), thousands of acre feet
	19-24	C(20, 1, 1)	Initial value of C(20, L, K), thousands of acre feet
	25-34	C(29, 1, 1)	Initial value of C(29, L, K), in tons

Format (4F6. 1, F10. 0)

Card 6		AREAS(J)	Values of area of diked lake from area-capacity curve punched 10 numbers per card for NUMENT values as shown on Card 2

Format (10F8. 1)

Card 7		CAP(J)	Values of capacity of diked lake from area-capacity curve as explained in Card 6

Format (10F8. 1)

Card 8		AREASG(J)	Values of area from area-capacity curve for Goshen Bay as explained in Card 6

Format (10F8. 1)

Card 9		CAPG(J)	Values of capacity from area-capacity curve for Goshen Bay as explained in Card 6

Format (10F8. 1)

Card 10		SPILLS(J)	17 values of spill rates from Utah Lake into Jordan River based on the elevation of the lake

Format(10F8. 1)

Card 11		CH(J)	Values of differential change in water surface elevation between Goshen Bay and Utah Lake to be used in determining the value of flow rate from the lake to the bay

Format (12F6. 2)

Card 12		ELEV(J)	Values of elevation of water surface in Utah Lake to be used with Card 11

Format (12F6. 2)

Card 13		QQQ(M, N)	A table of discharge values from Utah Lake into Goshen Bay as related to the elevation of the lake and the differential head between the two bodies of water

Format (11I5)

The relationship between CH(J), ELEV(J), and QQQ(M, N) is given in Table D-1.

Card 14	9-14	DMND(1, 2)	The demand placed on Utah Lake from Jordan River month 1
	15-20	DMND(1, 3)	The demand placed on Utah Lake from Jordan River month 2
		.	.
		.	.
		.	.
	75-80	DMND(1, 13)	The demand placed on Utah Lake from Jordan River month 12

Format (8X, 12F6. 1)

Card 15	9-14	DMND(2, 2)	The demand placed on Utah Lake from the Mosida area month 1
	15-20	DMND(2, 3)	The demand placed on Utah Lake from the Mosida area month 2
		.	.
		.	.
		.	.
	75-80	DMND(2, 13)	The demand placed on Utah Lake from the Mosida area month 12

Format (8X, 12F6. 1)

Card 16	9-14	QRTN(2)	Return inflow to Goshen Bay from the Mosida area month 1
	15-20	QRTN(3)	Return inflow to Goshen Bay from the Mosida area month 2
		.	.
		.	.
		.	.
	75-80	QRTN(13)	Return inflow to Goshen Bay from the Mosida area month 12
Card 17		WEVP(I, J)	The rate of evaporation from Goshen Bay expressed in feet, with 12 months of record on each card, 1 card for each year of the study

Format (8X, 12F6. 2)

Card 18		HISA(I, J)	Historical average water surface area, with 12 months of record on each card, 1 card for each year of the study, in thousands of acres

Format (8X, 12F6. 1)

Card 19		C(16, I, J)	Values to reduce the lake inflow by withholding Goshen Bay inflow, with 12 months of record on each card, 1 card for each year of the study, in thousands of acre feet

Format (8X, 12F6. 1)

Elevation of Utah Lake

ELEV (N), N = 1, 11

Head difference between diked lake and Goshen Bay. CH(M), M = 1, 10

QQQ (1, 1)	QQQ (1, 2)	. . . . .	QQQ (1, 11)
QQQ (2, 1)	QQQ (2, 2)	. . . . .	QQQ (2, 11)
.	.		.
.	.		.
.	.		.
.	.		.
.	.		.
.	.		.
.	.		.
.	.		.
QQQ (10, 1)	QQQ (10, 2)	. . . . .	QQQ (10, 11)

QQQ (M, N) is a spillrate into Goshen Bay which depends on the elevation of the diked lake and head difference. The CH (M) and ELEV (N) are used to determine the position in the QQQ (M, N) Table. The spillrate in CFS into Goshen Bay is found by interpolation.

Table D 1. Determination of spillrate into Goshen Bay.

COMBINED UTAH LAKE OPERATION MODEL PROGRAM LISTING

```
C     RIVER BASIN OPERATION MODEL
      COMMON/JOBTIT/ TITLE(12),IPAGE
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)           ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),    CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,     LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      DIMENSION BSNM(4),NST(8,14),NRST(8,2),IFMT(8,14)
C     INPUT BASIC DATA
    1 READ(5,100,END=27) (BSNM(II),II=1,4),NSB,NVR,NPR,NSM,NRVR,NRPR,
     1NRSM,NIND,NARA,NSIC,LYRO,NYR,IN1,IN2,IOUT,NITX,AJSO,ADMS,CAJS,
     2ITOP,DAJS
  100 FORMAT(4A4,10I3/I5,5I3,3F5.2,I5,F5.0)
      DO 2 I=1,NSB
      DO 2 J=1,NYR
    2 READ(IN1,101) (QCOR(J,I,K),K=1,12)
  101 FORMAT(8X,-3P12F6.1)
C     INAF IS THE CONTROL ON TYPE OF OUTPUT FOR THE PROVO RIVER
C     SIMULATION
C     NOUT IS THE CONTROL TO OUTPUT THE PROVO RIVER SIMULATION . NOUT=0
C      WILL OUTPUT RESULTS. NOUT=1 WILL  RESULT IN NO OUTPUT OF THE
C     PROVO RIVER SIMULATION
C     IPR IS THE NUMBER OF THE LOWEST SUBBASIN IN THE PROVO RIVER SYSTEM
C     IUL IS THE NUMBER OF THE SUBBASIN CONTAINING UTAH LAKE
      READ(IN1,99) INAF,NOUT,IPR,IUL
   99 FORMAT(4I4)
      CALL BSDTA
      READ(IN1,102) (AFMT1(L),L=1,4),(AFMT2(L),L=1,4),(AFMT3(L),L=1,4),
     1(AFMT4(L),L=1,4)
  102 FORMAT(5(4A4))
C
C     INPUT FORMAT INDICATOR FOR INPUT DATA
      DO 3 I=1,NSB
    3 READ(IN1,104) (IFMT(I,L),L=1,NVR)
  104 FORMAT(20I4)
C
C     INPUT STATION NUMBER
      DO 4 I=1,NSB
    4 READ(IN1,104) (NST(I,L),L=1,NVR),(NRST(I,L),L=1,NRVR)
C
C    INPUT STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION
      DO 5 I=1,NSB
      DO 5 L=1,2
      NSTN=NST(I,L)
    5 READ(IN1,103) (CWT(I,L,M),M=1,NSTN)
  103 FORMAT(16F5.2)
C
      DO 19 J=1,NYR
      DO 19 K=1,12
      DO 19 I=1,NSB
      DO 18 LL=1,NRVR
   18 RVAR(J,K,I,LL)=0.0
      DO 19 L=1,NVR
   19 VAR(J,K,I,L)=0.0
      DO 25 I=1,NSB
      DO 20 L=1,NVR
      NSTN=NST(I,L)
      IF(NSTN.LE.0) GO TO 20
      DO 420 M=1,NSTN
      DO 320 J=1,NYR
      LFMT=IFMT(I,L)
      GO TO (6,7,8,9),LFMT
```

```
    6 READ(IN1,AFMT1) (DVAR(K),K=1,12)
      GO TO 11
    7 READ(IN1,AFMT2) (DVAR(K),K=1,12)
      GO TO 11
    8 READ(IN1,AFMT3) (DVAR(K),K=1,12)
      GO TO 11
    9 READ(IN1,AFMT4) (DVAR(K),K=1,12)
   11 DO 220 K=1,12
      IF(L.LE.2) GO TO 12
      VAR(J,K,I,L)=VAR(J,K,I,L)+DVAR(K)*CONV(I,L)
      GO TO 220
   12 VAR(J,K,I,L)=VAR(J,K,I,L)+DVAR(K)*CWT(I,L,M)
  220 CONTINUE
  320 CONTINUE
  420 CONTINUE
   20 CONTINUE
      IF(IND(I,5).EQ.0) GO TO 25
      DO 225 LL=1,NRVR
      NSTN=NRST(I,LL)
      IF(NSTN.LE.0) GO TO 225
      DO 325 MM=1,NSTN
      DO 425 JJ=1,NYR
      READ(IN1,110) (DRVAR(K),K=1,12)
  110 FORMAT(8X,-3P12F6.1)
      DO 525 K=1,12
      RVAR(JJ,K,I,LL)=RVAR(JJ,K,I,LL)+DRVAR(K)
  525 CONTINUE
  425 CONTINUE
  325 CONTINUE
  225 CONTINUE
   25 CONTINUE
C
C     REPEAT SIMULATION FOR EACH YEAR
      DO 26 J=1,NYR
      LYR=LYRO+J-1
C
C     REPEAT SIMULATION FOR EACH MONTH
      DO 17 K=1,12
      MNTH=9+K
      IF(K.GT.3) MNTH=K-3
C
C     SIMULATION OPERATION
      CALL RBOS (J,K)
      IF(NOUT.EQ.1) GO TO 17
      GO TO (30,31,16),INAF
C
C     IF INAF = 1, OUTPUT MONTHLY HYDROLOGY IN INCHES
   30 CALL OTPTS(FMT1,FMT2,K,J)
      GO TO 16
C
C     IF INAF = 2, OUTPUT MONTHLY HYDROLOGY IN ACRE-FEET
   31 DO 15 I=1,NSB
      DO 13 L=2,NVR
   13 VAR(J,K,I,L)=CAF(I)*VAR(J,K,I,L)
      DO 14 L=1,NSM
   14 SIM(I,L)=CAF(I)*SIM(I,L)
      VAR3(I)=CAF(I)*VAR3(I)
   15 CONTINUE
      CALL OTPTS(FMT3,FMT4,K,J)
      DO 52 I=1,NSB
      DO 50 L=2,NVR
   50 VAR(J,K,I,L)=VAR(J,K,I,L)/CAF(I)
      DO 51 L=1,NSM
   51 SIM(I,L)=SIM(I,L)/CAF(I)
      VAR3(I)=VAR3(I)/CAF(I)
   52 CONTINUE
C
C     OUTPUT MONTHLY RESERVOIR OPERATION IN ACRE-FEET
   16 CALL OTPTR (K)
   17 CONTINUE
   26 CONTINUE
      IF(IUL.GT.0) CALL LAKE
      GO TO 1
   27 STOP
      END
```

```
C       SUBROUTINE FOR BASIC DATA
        SUBROUTINE BSDTA
        COMMON/BLK1/AREA(7,4)
        COMMON AJST(7)           ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
       1ACOR(7),    CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
       2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
       3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
       4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
       5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
       6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
C
        COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
       1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
       2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
       $IPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
       1,NYR,INAF,
       7VAR(41,12,7,13)
C       READ OUTPUT ROW TITLES
        READ(IN1,100) (OTL(L),L=1,NSM)
        READ(IN1,100) (ROTL(L),L=1,NRSM)
        READ(IN1,100) (OTLV(L),L=1,4)
    100 FORMAT(20A4)
C
C       READ AND CHECK FRACTION DAY-LIGHT HOURS
        READ(IN1,101) (DLH(K),K=1,12),MSIR,MEIR
    101 FORMAT(12F5.3,2I3)
C
C       INPUT UNGAGED WATERSHED TEMPERATURE ADJUSTMENT
        READ(IN1,120) (TMP1(I),I=1,NSB)
    120 FORMAT(10X,10F5.2)
C
C       INPUT MODEL INDICATORS AND PARAMETERS FOR EACH SUB-BASIN
      2 DO 12 I=1,NSB
        READ(IN1,102) (SBNM(I,L),L=1,2),(IND(I,L),L=1,NIND),(AREA(I,L),L=1
       1,NARA)
    102 FORMAT(2A4,2X,5I5,4F10.0)
        READ(IN1,103) (PR(I,L),L=1,NPR)
    103 FORMAT(16F5.2)
        IF(IND(I,5).GT.0) GO TO 41
        DO 40 L=1,NRPR
     40 RPR(I,L)=0.
        GO TO 42
     41 READ(IN1,104) (RPR(I,L),L=1,NRPR)
    104 FORMAT(4F8.0,6F8.5)
C
C       INPUT INITIAL CONDITIONS
     42 READ(IN1,105) (SYIC(I,L),L=1,NSIC)
    105 FORMAT(5F5.2,F10.0)
C
C       COMPUTE WEIGHTED PHREATOPHYTE AND CROP CONSUMATIVE USE COEFFICIENT
        DO 3 K=1,12
      3 WPH(I,K)=0.
        TAPH(I)=0.
        N=IND(I,2)
        DO 5 L=1,N
        READ(IN1,106) (CPH(K),K=1,12),APH
    106 FORMAT(10X,12F5.2,F10.0)
        DO 4 K=1,12
      4 WPH(I,K)=WPH(I,K)+CPH(K)*APH
      5 TAPH(I)=TAPH(I)+APH
        DO 6 K=1,12
      6 WPH(I,K)=WPH(I,K)/TAPH(I)
        TACR(I)=0.
        DO 7 K=1,12
      7 WCR(I,K)=0.
        IF(IND(I,1).EQ.0) GO TO 11
        N=IND(I,1)
        DO 9 L=1,N
        READ(IN1,106) (CCR(K),K=1,12),ACR
        DO 8 K=1,12
      8 WCR(I,K)=WCR(I,K)+CCR(K)*ACR
      9 TACR(I)=TACR(I)+ACR
        DO 10 K=1,12
        SDSIR(I,K)=0.
```

```
     10 WCR(I,K)=WCR(I,K)/TACR(I)
     11 READ(IN1,107) (QDSIR(I,K),K=1,12)
    107 FORMAT(12F5.0)
        IF(IND(I,5).EQ.0) GO TO 12
        READ(IN1,108) (SDSIR(I,K),K=1,12)
    108 FORMAT(12F6.0)
     12 CONTINUE
C
C       READ AND CHECK CONVERSION FACTORS
        DO 20 I=1,NSB
        READ(IN1,109) (CONV(I,L),L=1,NVR)
    109 FORMAT(10F8.5)
     20 CONTINUE
        READ(IN1,108)(CAF(I),I=1,NSB)
C
C       READ CONSUMPTIVE USE COEFFICIENT FO OPEN WATER
        READ(IN1,106) (CWS(K),K=1,12)
C
C       READ OUTPUT FORMAT
        READ(IN1,110) (FMT1(L),L=1,4),(FMT2(L),L=1,4),(FMT3(L),L=1,4),
       1(FMT4(L),L=1,4)
    110 FORMAT(16A4)
        RETURN
        END
C       SUBROUTINE FOR OPERATION STUDY
        SUBROUTINE RBOS (J,K)
        COMMON/BLK1/AREA(7,4)
        COMMON AJST(7)           ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
       1ACOR(7),    CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
       2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
       3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
       4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
       5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
       6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
        COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
       1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
       2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
       $IPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
       1,NYR,INAF,
       7VAR(41,12,7,13)
        DIMENSION TRCO(7),TBGO(7)
        REAL MS1,MS
        L1=1
        L2=2
        L3=3
        L4=4
        L5=5
        L6=6
        L7=7
        L8=8
        L9=9
        L10=10
        L11=11
        L12=12
        DO 47 I=1,NSB
        AJST(I)=0.
     47 PRLS(I)=RVAR(J,K,I,1)
        TSAVA(1)=0.
        TSAVA(2)=0.
        I=0
        IMX=0
      4 I=I+1
     44 IF(I.GT.IMX) GO TO 60
        GO TO 61
     60 ISOS=1
        JSOS=1
        IMX=I
     61 IF(I.LE.1) GO TO 49
        VAR3(I)=VAR(J,K,I,L3)+QSRY(I-1)*12./AREA(I,3)
        VAR4(I)=VAR(J,K,I,L4)+QGRY(I-1)*12./AREA(I,3)
        GO TO 52
     49 VAR3(I)=VAR(J,K,I,L3)
        VAR4(I)=VAR(J,K,I,L4)
```

```
C     SNOW STORAGE AND SNOWMELT
   52 CALL SNWMT (I,RPMT,RPMT1,J,K)
C
C     PHREATOPHYTE EVAPOTRANSPIRATION
      BCF=VAR(J,K,I,L1)*DLH(K)
      BCK=.0173*VAR(J,K,I,L1)-.314
      IF(BCK.LT..3) BCK=.3
      SIM(I,13)=PR(I,9)*WPH(I,K)*BCF*BCK*TAPH(I)/AREA(I,3)
C
C     CROP POTENTIAL EVAPOTRANSPIRATION AND WATER SUPPLIES
      IF(IND(I,1).EQ.0) GO TO 10
      ETP=PR(I,9)*WCR(I,K)*BCF*BCK
      IF(IND(I,3).EQ.0) GO TO 9
      IF(MNTH.GE.MSIR.AND.MNTH.LE.MEIR) GO TO 8
      VAR(J,K,I,L7)=0.0
      VAR(J,K,I,L9)=0.0
      GO TO 9
    8 VAR(J,K,I,L7)=ETP/PR(I,10)-(RPMT+VAR(J,K,I,L5)+VAR(J,K,I,L9)
     1-VAR(J,K,I,L11))
      IF(VAR(J,K,I,L7).LT.0.) VAR(J,K,I,L7)=0.0
    9 SIM(I,9)=VAR(J,K,I,L5)+VAR(J,K,I,L7)+VAR(J,K,I,L9)-VAR(J,K,I,L11)
      IF(SIM(I,9).GE.0.) GO TO 70
      VAR(J,K,I,L11)=VAR(J,K,I,L11)+SIM(I,9)
      SIM(I,9)=0.
   70 DAG=SIM(I,9)*PR(I,10)+RPMT
      GO TO 11
   10 ETP=0.
      SIM(I,9)=0.
      DAG=0.
   11 SIM(I,10)=VAR(J,K,I,L6)+VAR(J,K,I,L8)+VAR(J,K,I,L10)
     1-VAR(J,K,I,L12)
C
C     RETURN FLOW
      IF(IND(I,1).EQ.0) GO TO 12
      SIM(I,4)=(1.-PR(I,10))*SIM(I,9)+(1.-PR(I,11))*SIM(I,10)
      GO TO 13
   12 SIM(I,4)=(1.-PR(I,11))*SIM(I,10)
C
C     UNGAGED SURFACE INFLOW
   13 SIM(I,2)=PR(I,5)*AREA(I,2)/AREA(I,4)*QCOR(J,I,K)*12./AREA(I,3)+
     1PR(I,12)*RPMT1*AREA(I,2)/AREA(I,3)+PR(I,13)*(AREA(I,1)+AREA(I,2))/
     2AREA(I,3)
C
C     EVAPOTRANSPIRATION, SOIL MOISTURE, AND PERCOLATION
      IF(IND(I,1).EQ.0) GO TO 19
      MS1=SYIC(I,2)
      NITR=1
   14 SIM(I,14)=ETP*MS1/PR(I,4)
      IF(SIM(I,14).LT.0.) SIM(I,14)=0.
      IF(SIM(I,14).GT.ETP) SIM(I,14)=ETP
      MS=SYIC(I,2)+DAG-SIM(I,14)
      IF(MS.GT.PR(I,3)) GO TO 15
      SIM(I,7)=0.
      GO TO 16
   15 SIM(I,7)=MS-PR(I,3)
      MS=PR(I,3)
   16 DMS=ABS(MS-MS1)
      MS1=(MS+SYIC(I,2))/2.
      IF(DMS.GT.ADMS.AND.NITR.LT.NITX) GO TO 17
      GO TO 18
   17 NITR=NITR+1
      GO TO 14
   18 SIM(I,15)=MS
      GO TO 20
   19 SIM(I,7)=0.
      SIM(I,14)=0.
      SIM(I,15)=0.
C
C     GROUNDWATER RECHARGE AND OUTFLOW
   20 DIN=PR(I,15)*RPMT*(AREA(I,1)+AREA(I,2))/AREA(I,3)
      SK=PR(I,6)
      DIC=SYIC(I,4)
      CALL ROUT
      TRCO(I)=DOUT
      DIN=VAR4(I)+DOUT+SIM(I,7)-VAR(J,K,I,L9)-VAR(J,K,I,L10)
      SK=PR(I,7)
      DIC=SYIC(I,5)
      CALL ROUT
      TBGO(I)=DOUT
      SIM(I,5)=PR(I,14)*DOUT
      SIM(I,17)=DOUT-SIM(I,5)
C
C     SURFACE OUTFLOW
   21 SIM(I,18)=VAR3(I) +SIM(I,2)+SIM(I,4)+SIM(I,5)-VAR(J,K,I,L7)
     1-VAR(J,K,I,L8)-SIM(I,13)*RPMT*TAPH(I)/AREA(I,3)
C
C     RESERVOIR OPERATION
      IF(IND(I,5).EQ.0) GO TO 22
      CALL RSOP (K,I,JSOS,J)
      SIM(I,18)=(RSIM(I,5)+RSIM(I,6))*12./AREA(I,3)
      GO TO 23
   22 SAJS=0.
      SAVA(I,1)=0.
      SAVA(I,2)=0.
   23 TSAVA(1)=TSAVA(1)+SAVA(I,1)
      TSAVA(2)=TSAVA(2)+SAVA(I,2)
      CALL RRLS(I,K,JSOS)
      IF(JSOS.EQ.0.AND.ISOS.EQ.1) GO TO 44
   40 QSRY(I)=SIM(I,18)*AREA(I,3)/12.
      IF(QSRY(I).LT.0.) QSRY(I)=0.
      QGRY(I)=SIM(I,17)*AREA(I,3)/12.
      IF(QGRY(I).LT.0.) QGRY(I)=0.
      IF(I.NE.IUL) GO TO 80
      IK=K+1
      C(1,IK,J)=SIM(IPR,18)*CAF(IPR)/1000.
      C(2,IK,J)=VAR(J,K,I,L3)*CAF(I)/1000.
      C(3,IK,J)=SIM(I,2)*CAF(I)/1000.
      C(4,IK,J)=SIM(I,17)*CAF(I)/1000.
   80 IF(I.LT.NSB) GO TO 4
C
C     COMPLETE SIM ARRAY
      DO 39 I=1,NSB
      SIM(I,3)=VAR(J,K,I,L5)+VAR(J,K,I,L6)
      SIM(I,6)=VAR(J,K,I,L9)+VAR(J,K,I,L10)
      SIM(I,8)=VAR4(I)
      SIM(I,11)=VAR(J,K,I,L11)+VAR(J,K,I,L12)
      IF(IND(I,5).GE.1) SIM(I,11)=VAR(J,K,I,L11)+VAR(J,K,I,L12)
     1+RSIM(I,4)*12./AREA(I,3)
      SIM(I,12)=QDSIR(I,K)*1.98*30.*12./AREA(I,3)-SIM(I,18)
      IF(SIM(I,12).LT.0.) SIM(I,12)=0.
      SIM(I,16)=SIM(I,17)+SIM(I,18)
C
C     RESET INITIAL VALUES
      SYIC(I,1)=SIM(I,1)
      SYIC(I,2)=SIM(I,15)
      SYIC(I,4)=TRCO(I)
      SYIC(I,5)=TBGO(I)
      IF(IND(I,5).EQ.1) SYIC(I,6)=RSIM(I,7)
   39 CONTINUE
      RETURN
      END
C     SUBROUTINE FOR SNOW MELT
      SUBROUTINE SNWMT (I,RPMT,RPMT1,J,K)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)          ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7.12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     SIPR,IUL,     LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      L1=1
```

```
      L2=2
   52 IF(VAR(J,K,I,L1).GT.PR(I,1).AND.VAR(J,K,I,L1).GT.PR(I,2)) GO TO 6
      IF(VAR(J,K,I,L1).LE.PR(I,1).AND.VAR(J,K,I,L1).GT.PR(I,2)) GO TO 5
      SIM(I,1)=SYIC(I,1)+VAR(J,K,I,L2)
      SNMT=0.
      RPMT=0.
      GO TO 7
    5 SIM(I,1)=SYIC(I,1)+VAR(J,K,I,L2)
      SNMT=SIM(I,1)*(1.-EXP(-PR(I,8)*(VAR(J,K,I,L1)-PR(I,2))))
      IF(SNMT.GT.SIM(I,1)) SNMT=SIM(I,1)
      SIM(I,1)=SIM(I,1)-SNMT
      RPMT=SNMT
      GO TO 7
    6 SNMT=SYIC(I,1)*(1.-EXP(-PR(I,8)*(VAR(J,K,I,L1)-PR(I,2))))
      IF(SNMT.GT.SYIC(I,1)) SNMT=SYIC(I,1)
      SIM(I,1)=SYIC(I,1)-SNMT
      RPMT=VAR(J,K,I,L2)+SNMT
    7 TUNG=VAR(J,K,I,L1)-TMP1(I)
      IF(TUNG.GT.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 41
      IF(TUNG.LE.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 90
      SNW1=SYIC(I,3)+VAR(J,K,I,L2)
      RPMT1=0.
      GO TO 42
   90 SNW1=SYIC(I,3)+VAR(J,K,I,L2)
      SNMT1=SNW1*(1.-EXP(-PR(I,8)*(TUNG-PR(I,2))))
      IF(SNMT1.GT.SNW1) SNMT1=SNW1
      SNW1=SNW1-SNMT1
      RPMT1=SNMT1
      GO TO 42
   41 SNMT1=SYIC(I,3)*(1.-EXP(-PR(I,8)*(TUNG-PR(I,2))))
      IF(SNMT1.GT.SYIC(I,3)) SNMT1=SYIC(I,3)
      SNW1=SYIC(I,3)-SNMT1
      RPMT1=VAR(J,K,I,L2)+SNMT1
   42 SYIC(I,3)=SNW1
      RETURN
      END
C     SUBROUTINE FOR RESERVOIR RELEASE ADJUSTMENTS
      SUBROUTINE RRLS(I,K,JSOS)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     SIPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
C
C     CHECK FOR DESIRABLE FLOW AND ADJUST RESERVOIR RELEASE
      QS=SIM(I,18)*AREA(I,3)/(12.*30.*1.98)
      IF(QS.LT.QDSIR(I,K)) GO TO 24
      QAJS=0.
      GO TO 25
   24 QAJS=(QDSIR(I,K)-QS)*1.98*30.
   25 TAJS=CAJS*(SAJS+QAJS)+DAJS
      IF(ISOS.LE.0) GO TO 38
      IF(TAJS.LE.AJSO) GO TO 42
      IF(TSAVA(1).LT.TAJS) GO TO 30
C
C     SUFFICIENT WATER AVAILABLE IN RESERVOIRS
      TAJS1=TAJS
      TAJS2=0.
   40 IF(IND(I,5).LE.0) GO TO 41
      AJST(I)=TAJS1-SAJS
      IF(RSIM(I,5).GT.0.) AJST(I)=TAJS1+RSIM(I,5)
      GO TO 44
   41 AJST(I)=0.
      44 SAJS=0.
      45 IF(TAJS1.GT.SAVA(I,1)) GO TO 50
      GO TO 28
   50 IF(I.LE.ITOP) GO TO 28
      TAJS1=TAJS1-SAVA(I,1)
      I=I-1
      GO TO 40
   28 TAJS1=0.
      IF(I.LE.ITOP) GO TO 37
      IM1=I-1
      DO 29 II=ITOP,IM1
   29 AJST(II)=0.
      GO TO 37
C
C     STORAGE LESS THAN DESIRABLE IN SOME OR ALL RESERVOIRS
   30 TAJS1=TSAVA(1)
      TAJS2=TAJS-TAJS1
      IF(TAJS2.LE.SAJS) GO TO 90
      TAJS=TAJS-SAJS
      TAJS2=TAJS2-SAJS
      SAJS=0.
      GO TO 91
   90 SAJS=SAJS-TAJS2
      TAJS=TAJS1
      TAJS2=0.
   91 IF(TSAVA(2).LT.TAJS2) GO TO 35
   59 IF(IND(I,5).LE.0) GO TO 61
      AJST(I)=TAJS-SAJS
      IF(RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
      GO TO 65
   61 AJST(I)=0.
   65 SAJS=0.
   60 IF(TAJS2.GT.SAVA(I,2)) GO TO 51
      GO TO 33
   51 IF(I.LE.ITOP) GO TO 33
      TAJS2=TAJS2-SAVA(I,2)
      TAJS=TAJS-SAVA(I,1)-SAVA(I,2)
      I=I-1
      GO TO 59
   33 TAJS2=0.
      IF(I.LE.ITOP) GO TO 37
      IM1=I-1
      AJCO=0.
      DO 34 II=ITOP,IM1
      IF(IND(II,5).LE.0) GO TO 80
      AJST(II)=SAVA(II,1)+AJCO
      IF(RSIM(II,5).GT.0.) AJST(II)=AJST(II)+RSIM(II,5)
      AJCO=AJST(II)
      GO TO 34
   80 AJST(II)=0.
   34 CONTINUE
      GO TO 37
C
C     STORAGE LESS THAN MINIMUM IN SOME OR ALL RESERVOIRS
   35 TAJS=TSAVA(1)+TSAVA(2)
   70 IF(IND(I,5).LE.0) GO TO 71
      AJST(I)=TAJS
      IF(RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
      GO TO 72
   71 AJST(I)=0.
   72 IF(I.LE.ITOP) GO TO 37
      TAJS=TAJS-SAVA(I,1)-SAVA(I,2)
      I=I-1
      GO TO 70
   37 I=ITOP
      TSAVA(1)=0.
      TSAVA(2)=0.
      JSOS=0
      GO TO 38
   42 AJST(I)=0.
      TAJS=0.
   38 RETURN
      END
```

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C     SUBROUTINE FOR LINEAR RESERVOIR ROUTING
      SUBROUTINE ROUT
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,     LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      DOUT=DIN+(DIC-DIN)*EXP(-1./SK)
      RETURN
      END
C     SUBROUTINE FOR RESERVOIR OPERATION
      SUBROUTINE RSOP (K,I,JSOS,J)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,     LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      L2=2
      NITR=1
      RSIM(I,4)=RVAR(J,K,I,2)
C
C     RESERVOIR INFLOW
      RSIM(I,1)=SIM(I,18)*AREA(I,3)/12.
C
C     RESERVOIR RELEASE
      PRLS(I)=PRLS(I)+AJST(I)
      RSIM(I,6)=PRLS(I)
C
C     RESERVOIR EVAPORATION
      REVP=CWS(K)*BCF*BCK
      SIC=SYIC(I,6)
      CALL ARES(SIC,AR1,I)
    1 RSIM(I,2)=VAR(J,K,I,L2)*AR1/12.
      RSIM(I,3)=REVP*AR1/12.
C
C     RESERVOIR STORAGE
      RSIM(I,7)=SIC+RSIM(I,1)+RSIM(I,2)-RSIM(I,3)-RSIM(I,4)-RSIM(I,6)
C
C     SPILL FLOW
      IF(RSIM(I,7).LE.RPR(I,4)) GO TO 2
      RSIM(I,5)=RSIM(I,7)-RPR(I,4)
      RSIM(I,7)=RPR(I,4)
      GO TO 6
    2 RSIM(I,5)=0.
      IF(RSIM(I,7).GE.RPR(I,1)) GO TO 6
      RSRT=RPR(I,1)-RSIM(I,7)
      IF(RSRT.GT.RVAR(J,K,I,2)) GO TO 3
      RSIM(I,4)=RVAR(J,K,I,2)-RSRT
      RSIM(I,7)=RPR(I,1)
      GO TO 6
    3 RSIM(I,4)=0.
      RSRT=RSRT-RVAR(J,K,I,2)
      IF(RSRT.GT.RSIM(I,6)) GO TO 4
      RSIM(I,6)=RSIM(I,6)-RSRT
      RSIM(I,7)=RPR(I,1)
      GO TO 6
    4 RSRT=RSRT-RSIM(I,6)
      RSIM(I,6)=0.
      IF(RSRT.GT.RSIM(I,3)) GO TO 5
      RSIM(I,7)=RPR(I,1)-RSRT
      GO TO 6
    5 RSIM(I,7)=RPR(I,1)-RSIM(I,3)
C
C     CHECK FOR AVAILABLE AND DESIRABLE STORAGES
    6 SAVA(I,1)=RSIM(I,7)-SDSIR(I,K)
      IF(SAVA(I,1).LT.0.) SAVA(I,1)=0.
      SAVA(I,2)=RSIM(I,7)-RPR(I,1)-SAVA(I,1)
      IF(SAVA(I,2).LT.0.) SAVA(I,2)=0.
      IF(RSIM(I,7).LT.SDSIR(I,K)) GO TO 8
      SAJS=0.
      GO TO 9
    8 SAJS=SDSIR(I,K)-RSIM(I,7)
    9 IF(JSOS.EQ.0) ISOS=0
      RETURN
      END
C     SUBROUTINE FOR RESERVOIR WATER SURFACE AREA
      SUBROUTINE ARES(S,AR,I)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,     LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      IF(S.LT.RPR(I,2)) GO TO 2
      IF(S.LT.RPR(I,3)) GO TO 1
      C1=RPR(I,9)
      C2=RPR(I,10)
      GO TO 3
    1 C1=RPR(I,7)
      C2=RPR(I,8)
      GO TO 3
    2 C1=RPR(I,5)
      C2=RPR(I,6)
    3 AR=C1*S**C2
      RETURN
      END
C     SUBROUTINE FOR OUTPUT SIMULATED HYDROLOGY
      SUBROUTINE OTPTS(FMTA,FMTB,K,J)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,     LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      DIMENSION FMTA(4),FMTB(4)
      IF(IUL.GT.0) NSB=NSB-1
      L1=1
      L2=2
      L13=13
      WRITE(IOUT,200) LYR,K
  200 FORMAT(//1X,3HL =,I5,5X,3HK =,I3)
    2 WRITE(IOUT,202) ((SBNM(I,L),L=1,2),I=1,NSB)
  202 FORMAT(/7H ITEM  ,9(1X,2A4))
      WRITE(IOUT,FMTA) OTLV(1),(VAR(J,K,I,L1),I=1,NSB)
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      WRITE(IOUT,FMTB) OTLV(2),(VAR(J,K,I,L2),I=1,NSB)
      WRITE(IOUT,FMTB) OTL(1),(SIM(I,1),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(3),(VAR3(I),I=1,NSB)
      DO 4 L=2,NSM
    4 WRITE(IOUT,FMTB) OTL(L),(SIM(I,L),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(4),(VAR(J,K,I,L13),I=1,NSB)
      IF(IUL.GT.0) NSB=NSB+1
      RETURN
      END
C     SUBROUTINE FOR OUTPUT RESERVOIR OPERATION
      SUBROUTINE OTPTR (K)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      IF(INAF.LT.3) GO TO 100
      WRITE(IOUT,101) LYR,K
  101 FORMAT(//1X,3HL =,I5,5X,3HK =,I3)
  100 NRS=0
      DO 1 I=1,NSB
    1 NRS=NRS+IND(I,5)
      IF(NRS.EQ.0) GO TO 4
      WRITE(IOUT,200)
  200 FORMAT(//1X,9HRESERVOIR)
      WRITE(IOUT,202) (ROTL(L),L=1,NRSM)
  202 FORMAT(/9H SUB BSN,7(5XA4),4X,4HAJST)
      DO 3 I=1,NSB
      IF(IND(I,5).EQ.0) GO TO 3
      WRITE(IOUT,203) (SBNM(I,L),L=1,2),(RSIM(I,L),L=1,NRSM),AJST(I)
  203 FORMAT(1X,2A4,7F9.0,F8.0)
    3 CONTINUE
    4 RETURN
      END
C      SUBROUTINE - MODEL OF UTAH LAKE
      SUBROUTINE LAKE
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS PROGRAM IS WRITTEN TO DUPLICATE THE PROJECT OPERATION STUDY
C *** FOR UTAH LAKE AS IT WAS DONE IN THE 1964 DEFINITE PLAN REPORT
C *** THE STUDY ASSUMES THAT BOTH PROVO AND GOSHEN BAY DIKES ARE
C *** CONSTRUCTED AND IN OPERATION AS PLANNED
C *** * * * * * * * * * * * * * * * * * * * * * *
      COMMON/JOBTIT/ TITLE(12),IPAGE
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),   CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,      AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      DIMENSION  MONTH(13) , TOTAL(33,41) , SUMTOT(33) , AVE(33) ,
     1AREAS(1810) , TOMD(2) , SPILLS(20) , AREASG(1780) , DMND(2,13) ,
     2ELEV(11) , QQQ(10,11) , CH(10) , TABLE(17) , KARD(14) , QRTN(13) ,
     3WEVP(13,41) , HISA(13,41) , APPT(13,41) , BPPT(13,41) , PPT(13,41)
     4,CPPT(4)
      DATA MONTH/3HSEP,3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,
     13HJUN,3HJUL,3HAUG,3HSEP/
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS DATA STATEMENT IS AN ARRAY OF DIFFERENCES IN ELEVATION
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C *** BETWEEN THE DIKED LAKE AND GOSHEN BAY
C *** * * * * * * * * * * * * * * * * * * * * * *
      DATA TABLE/4.,3.5,3.,2.5,2.,1.5,1.,0.5,0.,-0.5,-1.,-1.5,-2.,-2.5,
     1-3.,-3.5,-4./
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS TITLE APPEARS AT THE TOP OF EACH PAGE OF OUTPUT
C *** * * * * * * * * * * * * * * * * * * * * * *
      AREA=ELEGOS((C(22,L,K)),KKX)
      READ(5,10) TITLE
   10 FORMAT(12A6)
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** CTDS = CONVERSION OF PPM TO A DESIRED UNIT
C *** GWSC = GROUND WATER SALT CONTENT
C *** SDEAD = DEAD STORAGE IN UTAH LAKE , ACRE-FEET
C *** NUMENT = THE NUMBER OF VALUES IN THE DIKED LAKE AREA-CAPACITY
C *** TABLES
C *** NUGNT = THE NUMBER OF VALUES IN THE GOSHEN BAY AREA-CAPACITY
C *** TABLES
C *** KPPT= THE NUMBER OF STATIONS USED TO CALCULATED THE PRECIPITATION
C *** ON UTAH LAKE
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** DLS = A DUMMY LAKE STORAGE USED TO CALCULATE TDS WHEN THE LAKE
C *** CONTENT REACHES ZERO
       READ(5,979) CTDS,GWSC,SDEAD,NUMENT,NUGNT,KPPT,DLS
  979 FORMAT(F8.5,F5.0,F8.2, 3I5,F5.1)
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THE FOLLOWING PORTION OF THE PROGRAM READS AND CALCULATES THE
C *** WEIGHTED PRECIPITATION FOR THE DIKED LAKE IN FEET
C *** CPPT(M) = THE WEIGHTING FACTOR TO BE APPLIED TO EACH PRECIPITATION
C *** STATION
C *** * * * * * * * * * * * * * * * * * * * * * *
      DO 400 K=1,NYR
      DO 400 L=2,13
  400 APPT(L,K)=0.0
      READ(5,403) (CPPT(M),M=1,KPPT)
  403 FORMAT(8F10.0)
      DO 402 M=1,KPPT
      READ(5,401) ((BPPT(I,J),I=2,13),J=1,NYR)
  401 FORMAT (8X,12F6.2)
      DO 402 K=1,NYR
      DO 402 L=2,13
  402 APPT(L,K)=APPT(L,K)+BPPT(L,K)*CPPT(M)/12.
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS STATEMENT READS THE INITIAL CONDITIONS FOR COLUMNS 14 ,13,
C *** 21, 20, AND 29
C *** * * * * * * * * * * * * * * * * * * * * * *
      READ(5,12) C(14,1,1), C(13,1,1) , C(21,1,1) , C(20,1,1), C(29,1,1)
   12 FORMAT(4F6.1,F10.0)
   13 FORMAT(8X,12F6.1)
   37 FORMAT(8X,12F6.2)
      READ(5,14,ERR=1000) (AREAS(J), J=1,NUMENT)
      READ(5,14,ERR=1000) (CAP  (J), J=1,NUMENT)
      READ(5,14,ERR=1000) (AREASG(J),J=1,NUGNT)
      READ(5,14,ERR=1000) (CAPG (J), J=1,NUGNT)
      READ(5,14,ERR=1000) (SPILLS(J),J=1,17)
   14 FORMAT(10F8.1)
      READ(5,91,ERR=1000) (CH(J),J=1,10)
      READ(5,91,ERR=1000) (ELEV(J),J=1,11)
   91 FORMAT(12F6.2)
      DO 98 M=1,10
      READ(5,92,ERR=1000) (QQQ(M,N),N=1,11)
   92 FORMAT(11I5)
   98 CONTINUE
      DO 701 K=1,NYR
      DO 702 J=1,30
      TOTAL(J,K)=0.0
  702 CONTINUE
  701 CONTINUE
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** ALL CALCULATIONS WITHIN THE PROGRAM DEFINE VALUES IN THE FORMAT
C *** C(J,L,K) WHICH STANDS FOR A COLUMN NUMBER 'J', A MONTH 'L', AND
C *** YEAR 'K'
C ***    C(1,L,K) = PROVO RIVER INFLOW TO UTAH LAKE
C ***    C(2,L,K) = OTHER GAGED STREAM INFLOWS TO UTAH LAKE
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C ***     C(3,L,K) = OTHER UNGAGED STREAM INFLOWS TO UTAH LAKE
C ***     C(4,L,K) = GROUNDWATER INFLOW TO UTAH LAKE
C ***     C(5,L,K) = TOTAL INFLOW TO UTAH LAKE - COLUMNS 1 + 2 + 3 + 4
C ***     C(6,L,K) = THE AMOUNT OF JORDAN RIVER DEMAND THAT CAN BE
C ***                SUPPLIED
C ***     C(7,L,K) = THE SHORTAGE FOR JORDAN RIVER SUPPLY
C ***     C(8,L,K) = THE AMOUNT OF MOSIDA AREA DEMAND THAT CAN BE
C ***                SUPPLIED
C ***     C(9,L,K) = THE SHORTAGE FOR MOSIDA AREA SUPPLY
C ***    C(10,L,K) = EVAPORATION FROM THE DIKED LAKE
C ***    C(11,L,K) = INCREMENTAL CONSUMPTIVE USE - USED TO MODIFY THE
C ***                INFLOW TO REFLECT CURRENT OPERATION
C ***    C(12,L,K) = SPILLS TO JORDAN RIVER
C ***    C(13,L,K) = END OF MONTH ACTIVE CONTENT IN THE DIKED LAKE
C ***    C(14,L,K) = END OF MONTH WATER SURFACE AREA FOR THE DIKED LAKE
C ***    C(15,L,K) = WATER SURFACE ELEVATION IN THE DIKED LAKE AS IT
C ***                RELATES TO COMPROMISE ELEVATION
C ***    C(16,L,K) = GOSHEN BAY INFLOW WITHHELD FROM UTAH LAKE BY DIKING
C ***    C(17,L,K) = SPILLS INTO GOSHEN BAY FROM UTAH LAKE
C ***    C(18,L,K) = TOTAL INFLOW TO GOSHEN BAY
C ***    C(19,L,K) = EVAPORATION FROM GOSHEN BAY
C ***    C(20,L,K) = END OF MONTH CONTENT IN GOSHEN BAY
C ***    C(21,L,K) = END OF MONTH WATER SURFACE AREA FOR GOSHEN BAY
C ***    C(22,L,K) = WATER SURFACE ELEVATION IN GOSHEN BAY AS IT RELATES
C ***                TO COMPROMISE ELEVATION
C ***    C(23,L,K) = PROVO RIVER TDS INFLOW TO UTAH LAKE
C ***    C(24,L,K) = OTHER STREAM TDS INFLOW TO UTAH LAKE
C ***    C(25,L,K) = GROUNDWATER TDS INFLOW TO UTAH LAKE
C ***    C(26,L,K) = TOTAL TDS INFLOW TO UTAH LAKE
C ***    C(27,L,K) = TOTAL TDS OUTFLOW FROM UTAH LAKE
C ***    C(28,L,K) = END OF MONTH TDS PPM IN UTAH LAKE
C ***    C(29,L,K) = END OF MONTH TDS CONTENT IN UTAH LAKE
C ***    C(30,L,K) = CHANGE IN TDS CONTENT DURING THE MONTH
C *** * * * * * * * * * * * * * * * * * * * * * *
      WRITE(6,600)
  600 FORMAT(1H1,5X,'THE FOLLOWING DATA ARE CONSTANT FOR EACH YEAR')
      READ(5,13,ERR=1000) ((DMND(I,J),J=2,13),I=1,2)
      DO 500 I=1,2
      TDMD(I)=0.
      DO 500 J=2,13
  500 TDMD(I)=TDMD(I)+DMND(I,J)
      WRITE(6,601)
  601 FORMAT(///8X,'DEMAND FOR JORDON RIVER')
      WRITE(6,602)(MONTH(J),J=2,13)
  602 FORMAT(8X,12(5X,A3),4X,'ANNUAL')
      WRITE(6,603)(DMND(1,J),J=2,13),TDMD(1)
  603 FORMAT(8X,12F8.1,F10.1)
      WRITE(6,604)
  604 FORMAT(///8X,'DEMAND FOR MOSIDA AREA')
      WRITE(6,602)(MONTH(J),J=2,13)
      WRITE(6,603)(DMND(2,J),J=2,13),TDMD(2)
      READ(5,13,ERR=1000)(QRTN(J),J=2,13)
      TRTN=0.
      DO 501 J=2,13
  501 TRTN=TRTN+QRTN(J)
      WRITE(6,605)
  605 FORMAT(///8X,'RETURN FLOW FROM MOSIDA AREA')
      WRITE(6,602)(MONTH(J),J=2,13)
      WRITE(6,603)(QRTN(J),J=2,13),TRTN
      READ(5,37,ERR=1000)((WEVP(I,J),I=2,13),J=1,NYR)
      READ(5,13,ERR=1000)((HISA(I,J),I=2,13),J=1,NYR)
      READ(5,13,ERR=1000)((C(16,I,J),I=2,13),J=1,NYR)
      GO TO 978
 1000 READ(16,989) (KARD(L),L=1,14)
  989 FORMAT(13A6,A2)
      WRITE(6,998) (KARD(L),L=1,14)
  998 FORMAT('0','THE FOLLOWING CARD IS IN ERROR, PLEASE EXAMINE YOUR DA
     1TA',/,10X,13A6,A2 )
    9 STOP ERROR
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS STATEMENT BEGINS THE DO LOOP FOR EACH YEAR
C *** * * * * * * * * * * * * * * * * * * * * * *
  978 DO 900 K=1,NYR                    @ CYCLE FOR EACH YEAR
98765 FORMAT(   )
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS STATEMENT BEGINS THE DO LOOP FOR EACH MONTH
C *** * * * * * * * * * * * * * * * * * * * * * *
      DO 999 M=2,13                     @ CYCLE FOR EACH MONTH
      L=M
      LCNT=0
      C(14,L,K) = C(14,L-1,K)
    2 AVGA=(C(14,L,K)+C(14,L-1,K))/2.
      LCNT = LCNT+1
      C(10,L,K) = WEVP(L,K)*AVGA
      PPT(L,K)=APPT(L,K)*AVGA
      ADIF=AVGA-HISA(L,K)
      CDIF=0.35*WEVP(L,K)
      C(5,L,K) = C(1,L,K) + C(2,L,K) + C(3,L,K) + C(4,L,K)
      C(11,L,K) = ADIF+CDIF
      C(13,L,K) = C(13,L-1,K)+C(5,L,K)-DMND(1,L)-DMND(2,L)-C(10,L,K)+
     1C(11,L,K) + PPT(L,K)
   40 IF(C(13,L,K).GT.629.2) GO TO 800
      IF(C(13,L,K).LT.-12.5) GO TO 3
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THE FOLLOWING PORTION OF THE PROGRAM MAKES CALCULATIONS IF ACTIVE
C *** EOM CONTENT IS BETWEEN 629,200 ACRE FEET AND -12,500 ACRE FEET
C *** * * * * * * * * * * * * * * * * * * * * * *
      CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      IF(C(15,L,K).LE.-7.5) C(15,L,K) = C(15,L,K) + 0.5
      AREA=ELEUTL((C(15,L,K)),KXX)
      IF(LCNT.GE.5) C(14,L,K) = AREA
      IF(AREA.EQ.C(14,L.K)) GO TO 41
      C(14,L,K) = AREA
      GO TO 2
   41 LCNT=0
      IF(C(13,L,K).GE.0.0) GO TO 42
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THE FOLLOWING PORTION OF THE PROGRAM MAKES CALCULATIONS IF ACTIVE
C *** EOM CONTENT IS LESSER THAN 0 ACRE FEET
C *** * * * * * * * * * * * * * * * * * * * * * *
    3 AVGA=(C(14,L,K)+C(14,L-1,K))/2.
      C(10,L,K) = WEVP(L,K)*AVGA
      PPT(L,K)=APPT(L,K)*AVGA
      ADIF=AVGA-HISA(L,K)
      LCNT = LCNT + 1
      C(11,L,K) = ADIF*CDIF
      C(13,L,K) = C(13,L-1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
     1 + PPT(L,K)
      IF(C(13,L,K).LT.-12.5) GO TO 55
   51 CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      IF(C(15,L,K).LT.-7.5) C(15,L,K) = C(15,L,K) + 0.5
      AREA=ELEUTL((C(15,L,K)),KXX)
      IF(LCNT.GE.5) C(14,L,K) = AREA
      IF(AREA.EQ.C(14,L,K)) GO TO 52
      C(14,L,K) = AREA
      GO TO 3
   52 IF(C(13,L,K).LT.0.0) GO TO 53
      C(15,L,K) = -12.0
      C(14,L,K) = 33.0
      AVGA=(C(14,L,K)+C(14,L-1,K))/2.
      C(10,L,K) = WEVP(L,K)*AVGA
      PPT(L,K)=APPT(L,K)*AVGA
      ADIF=AVGA-HISA(L,K)
      C(11,L,K) = ADIF*CDIF
      C(13,L,K) = C(13,L-1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
     1 + PPT(L,K)
      GO TO 54
   55 C(15,L,K) = -13.3
      C(14,L,K) = 6.0
      AVGA=(C(14,L,K) + C(14,L-1,K))/2.
      C(10,L,K) = WEVP(L,K)*AVGA
      PPT(L,K)=APPT(L,K)*AVGA
      ADIF=AVGA-HISA(L,K)
      C(11,L,K) = ADIF*CDIF
      C(13,L,K) = C(13,L-1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
     1 + PPT(L,K)
```

```
      IF(C(13,L,K).LT.-12.5) GO TO 56
      GO TO 51
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THE FOLLOWING PORTION OF THE PROGRAM MAKES CALCULATIONS IF ACTIVE
C *** EOM CONTENT IS GREATER THAN 629,200 ACRE-FEET
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
  800 C(13,L,K) = C(13,L-1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
     1 + PPT(L,K)
      CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      AVERGE    = (C(15,L,K) + C(15,L-1,K)) /2.0
      C(12,L,K) = SPILL (AVERGE)
      DAYS      = DAYMON(L,K)
      IF(C(12,L,K).GT.1500.) GO TO 81
      C(12,L,K) = C(12,L,K) * 1.98 * DAYS * .001
      TOTDMD = DMND(1,L)+DMND(2,L)
      IF (C(12,L,K) .GE. TOTDMD) GO TO 82
      GO TO 31
   81 C(12,L,K) =(1500.0) * 1.98 * DAYS * .001
   82 C(13,L,K) = C(13,L,K) - C(12,L,K)
      C(12,L,K) = C(12,L,K) - DMND(1,L) - DMND(2,L)
      IF(C(13,L,K).GT.629.2) GO TO 84
      AREA = 61.0
      IF(LCNT.GE.5) C(14,L,K) = AREA
      IF(AREA.EQ.C(14,L,K)) GO TO 83
      C(14,L,K) = AREA
      GO TO 2
   84 CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      AREA=ELEUTL((C(15,L,K)),KXX)
      IF(LCNT.GE.5) C(14,L,K) = AREA
      IF(AREA.EQ.C(14,L,K)) GO TO 8555
      C(14,L,K) = AREA
      GO TO 2
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** AFTER CALCULATING VALUES FOR THE DIKED LAKE ABOVE, THE FOLLOWING
C *** PORTION OF THE PROGRAM MAKES CALCULATIONS PERTINENT TO GOSHEN BAY
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
   85 C(18,L,K) = C(16,L,K) + QRTN(L)
      C(21,L,K) = C(21,L-1,K)
 9999 AVGB=(C(21,L,K)+C(21,L-1,K))/2.
      C(19,L,K) = WEVP(L,K)*AVGB
      C(20,L,K) = C(18,L,K) - C(19,L,K) + C(20,L-1,K)
      IF(C(20,L,K).LT.0.0) C(20,L,K) = 0.01
      CALL CAPGOO((C(20,L,K)),CAPGOS,KKX)
      C(22,L,K)=CAPGOS
      AREA=ELEGOS((C(22,L,K)),KKX)
      LCNT = LCNT + 1
      IF(LCNT.GE.5) C(21,L,K) = AREA
      IF(AREA.EQ.C(21,L,K)) GO TO 9988
      C(21,L,K) = AREA
      GO TO 9999
 9988 TESTCH = C(15,L,K) - C(22,L,K)
      IF(TESTCH.GT.0.1.AND.C(13,L,K).GT.629.2) GO TO 997
      GO TO 899
  997 C(17,L,K) = EQL(TESTCH,C(15,L,K) )
      LCNT = 0
      C(17,L,K) = C(17,L,K) * 1.98 * DAYS * .001
      C(18,L,K) = C(16,L,K) + C(17,L,K) + QRTN(L)
      C(21,L,K) = C(21,L-1,K)
 8554 AVGB=(C(21,L,K)+C(21,L-1,K))/2.
      C(19,L,K) = WEVP(L,K)*AVGB
      C(20,L,K) = C(20,L-1,K) + C(18,L,K) - C(19,L,K)
      IF(C(20,L,K).LT.0.0) C(20,L,K) = 0.01
      CALL CAPGOO((C(20,L,K)),CAPGOS,KKX)
      C(22,L,K)=CAPGOS
      AREA=ELEGOS((C(22,L,K)),KKX)
      LCNT = LCNT + 1
      IF(LCNT.GE.5) C(21,L,K) = AREA
      IF(AREA.EQ.C(21,L,K)) GO TO 921
      C(21,L,K) = AREA
      GO TO 8554
  921 DIFEOM = C(13,L,K) - C(17,L,K)
      IF(DIFEOM.GE.629.2) GO TO 922
      C(13,L,K) = 629.2
      C(17,L,K) = C(13,L,K) - DIFEOM
      C(18,L,K) = C(16,L,K) + C(17,L,K) + QRTN(L)
      C(21,L,K) = C(21,L-1,K)
  920 AVGB=(C(21,L,K)+C(21,L-1,K))/2.
      C(19,L,K) = WEVP(L,K)*AVGB
      C(20,L,K) = C(20,L-1,K) + C(18,L,K) - C(19,L,K)
      IF(C(20,L,K).LT.0.0) C(20,L,K) = 0.01
      CALL CAPGOO((C(20,L,K)),CAPGOS,KKX)
      C(22,L,K)=CAPGOS
      LCNT = LCNT + 1
      IF(LCNT.GE.5) C(21,L,K) = AREA
      IF(AREA.EQ.C(21,L,K)) GO TO 923
      C(21,L,K) = AREA
      GO TO 920
  922 C(13,L,K) = DIFEOM
      C(6,L,K) = DMND(1,L.
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      LCNT = 0
      GO TO 899
  923 LCNT = 0
      C(6,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      GO TO 899
   83 C(15,L,K) = 629.2
      C(6,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      C(12,L,K) = C(13,L-1,K) + C(5,L,K) - DMND(1,L) - DMND(2,L) -
     1C(10,L,K) - C(13,L,K) + C(11,L,K) + PPT(L,K)
      C(15,L,K) = 0.0
      LCNT = 0
      GO TO 85
 8555 LCNT = 0
      C(6,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      GO TO 85
   42 C(6,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      GO TO 85
   53 C(6,L,K) = 0.0
      C(8,L,K) = 0.0
      C(7,L,K) = DMND(1,L)
      C(9,L,K) = DMND(2,L)
      C(12,L,K) = 0.0
      C(15,L,K) = C(15,L,K) - 0.5
      LCNT = 0
      GO TO 85
   54 C(6,L,K) = (DMND(1,L)/(DMND(1,L)+DMND(2,L)))*(C(13,L,K))
      C(8,L,K) = (DMND(2,L)/(DMND(1,L)+DMND(2,L)))*(C(13,L,K))
      C(7,L,K) = DMND(1,L) - C(6,L,K)
      C(9,L,K) = DMND(2,L) - C(8,L,K)
      C(13,L,K) = 0.0
      LCNT = 0
      GO TO 85
   56 C(10,L,K) = C(13,L-1,K) + C(5,L,K) +12.5 + CDIF + PPT(L,K)
      C(13,L,K) = -12.5
      C(6,L,K) = 0.0
      C(7,L,K) = DMND(1,L)
      C(8,L,K) = 0.0
      C(9,L,K) = DMND(2,L)
```

```
      C(13,L,K) = -12.5
      C(15,L,K) = 0.0
      LCNT = 8
      GO TO 85
   31 C(13,L,K) = C(13,L-1,K) + C(5,L,K) - DMND(1,L) - DMND(2,L) -
     1C(10,L,K) + C(11,L,K) + PPT(L,K)
      CALL CAPUTT((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K) = CAPUTL
      AVERGE = (C(15,L,K) + C(15,L-1,K))/2.0
      C(12,L,K) = SPILL(AVERGE)
      DAYS = DAYMON(L,K)
      IF(C(12,L,K).GT. 1500.0) GO TO 34
      C(12,L,K) = C(12,L,K)*1.98*DAYS*.001
      GO TO 35
   34 C(12,L,K) = (1500.0)*1.98*DAYS*.001
   35 DLEFT =C(13,L,K) - 629.2
      IF(DLEFT .GE. C(12,L,K)) GO TO 32
      C(12,L,K) = DLEFT
   32 C(13,L,K) = C(13,L,K) -C(12,L,K)
      C(6,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = DMND(1,L) - C(6,L,K)
      C(9,L,K) = DMND(2,L) - C(8,L,K)
      GO TO 85
  899 C(23,L,K) = TDS1(C(1,L,K),L)
      QOTHR=C(2,L,K)+C(3,L,K)
      C(24,L,K)=TDS2(QOTHR,L)
      C(25,L,K)=CTDS*GWSC*C(4,L,K)
      C(26,L,K)=C(23,L,K)+C(24,L,K)+C(25,L,K)
      TLS=C(13,L,K)+C(12,L,K)+C(6,L,K)+C(8,L,K)+C(17,L,K)+SDEAD
      IF(TLS.LE.0.0) TLS=DLS
      C(28,L,K) = ((C(26,L,K)+C(29,L-1,K))/TLS)/CTDS
      C(27,L,K)=CTDS*C(28,L,K)*(C(12,L,K)+C(6,L,K)+C(8,L,K)+C(17,L,K))
      STM=SDEAD + C(13,L,K)
      IF(STM.LE.0.0) STM=DLS
      C(29,L,K)=CTDS*C(28,L,K)*STM
      C(30,L,K)=C(29,L,K)-C(29,L-1,K)
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS IS THE END OF THE DO LOOP FOR EACH MONTH
C *** * * * * * * * * * * * * * * * * * * * * * *
  999 CONTINUE
  715 DO 901 L=2,13
      DO 902 J=1,30
      ROUND = 0.5
      IF(C(J,L,K).LT.0.0) ROUND = -0.5
      IF(J.EQ.10) GO TO 777
      IF(J.EQ.19) GO TO 777
      IF(J.EQ.15) GO TO 777
      IF(J.EQ.22) GO TO 777
      C(J,L,K) = FLOAT(INT(C(J,L,K)*10.0 + ROUND )) / 10.0
  777 TOTAL(J,K) = TOTAL(J,K) + C(J,L,K)
  902 CONTINUE
  901 CONTINUE
      DO 903 IL = 1,30
      C(IL,1,K+1) = C(IL,13,K)
  903 CONTINUE
      KK=K
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THIS IS THE END OF THE DO LOOP FOR EACH YEAR
C *** * * * * * * * * * * * * * * * * * * * * * *
  900 CONTINUE
C *** * * * * * * * * * * * * * * * * * * * * * *
C *** THE REMAINING PORTION OF THIS PROGRAM SUMS, AVERAGES, AND PRINTS
C *** THE VALUES IN TABULAR FORM
C *** * * * * * * * * * * * * * * * * * * * * * *
      DO 703 L=1,30
      SUMTOT(L) = 0.0
  703 CONTINUE
      DO 904 K=1,KK
      DO 905 L=1,30
      SUMTOT(L) = SUMTOT(L) + TOTAL(L,K)
  905 CONTINUE
  904 CONTINUE
      DO 906 I=1,30
```

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      AVE(I) = SUMTOT(I) / FLOAT(KK)
  906 CONTINUE
    4 DO 5 I=1,NYR
      CALL TITLES(1)
      WRITE(6,100)
      WRITE(6,101)
  100 FORMAT(38X,'MINIMUM DRAWDOWNLEVEL AT 12.0 FEET BELOW COMPROMISE',
     1/,53X,'(UNITS: 1,000 ACRE-FEET)')
  101 FORMAT(' ',130('-'),
     1/,11X,68('*'),'UTAH LAKE OPERATION WITH PROVO AND GOSHEN BAYS DIKE
     2D',10('*'),
     3//12X,'*',6('-'),'INFLOWS TO UTAH LAKE',6('-'),'*',2X,'*--JORDAN R
     4.--*',2X,'*--MOSIDA A.--*',2X,'*',12('-'),'THE DIKED UTAH LAKE',
     512('-'),'*',/,3X,'MONTH',90X,'SPILL',2X,'ACTIVE',3X,'EOM',
     6/,4X,'AND',5X,'PROVO',2X,'OTHER',2X,'OTHER',1X,'GROUND',3X,'TOTAL'
     7,5X,'SUPP-',2X,'SHOR-',5X,'SUPP-',2X,'SHOR-',5X,'W.S.',2X,'INCRM'
     8,3X,'TO',6X,'EOM',4X,'W.S.',4X,'W.S.',/,3X,'YEAR',4X,'RIVER',2X,
     9'GAGED',2X,'UNGAG',2X,'WATER',3X,'INFLO',6X,'LIED',3X,'TAGE',
     16X,'LIED',3X,'TAGE',5X,'EVP.',3X,'CONS',2X,'JORDN',3X,'CONT.',3X,
     2'AREA',4X,'ELEV',
     3/,127('-'),
     4/,14X,'1',6X,'2',6X,'3',6X,'4',7X,'5',9X,'6',6X,'7',9X,'8',6X,'9',
     58X,'10',5X,'11',5X,'12',6X,'13',5X,'14',5X,'15',
     6/,127('-'))
      DO 6 J=2,13
      IYR = LYRO + I
      IF(J.LE.4) IYR = IYR - 2
      IF(J.GT.4) IYR = IYR - 1
   99 WRITE(6,102) MONTH(J),IYR, (C(K,J,I),K=1,15)
  102 FORMAT(' ',A3,2X,I4,4F7.1,F8.1,3X,2F7.1,3X,2F7.1,2X,3F7.1,F8.1,
     1F7.1,F8.2)
    6 CONTINUE
      WRITE(6,207)
  207 FORMAT(' ',130('-'))
      WRITE(6,108) (TOTAL(K,I),K=1,12)
      WRITE(6,103)
  103 FORMAT(' ',//)
      WRITE(6,109)
  109 FORMAT(' ',130('-'),
     1/,11X,42('*'),
     2//,12X,'*',16('-'),'THE GOSHEN BAY',17('-'),'*',4X,'*',6('-'),
     3'TDS INFLOW AND OUTFLOW',7('-'),'*',3X,'*',3('-'),'UTAH LAKE TDS',
     43('-'),'*',/,3X,'MONTH',12X,'SPIL',25X,'EOM',37X,'TOTAL',3X,
     5'TOTAL',5X,'EOM',4X,'EOM',4X,'CHNGE',/,4X,'AND',5X,'GOS.B',3X,
     6'FROM',3X,'TOTAL',3X,'W.S.',3X,'EOM',4X,'W.S.',4X,'W.S.',6X,
     7'PROVO',2X,'OTHER',1X,'GROUND',4X,'IN-',3X,'R. OUT',5X,'TDS',4X,
     8'TDS',6X,'IN',/,3X,'YEAR',5X,'INFLO',3X,'U.L.',3X,'INFLO',3X,'EVP'
     9,3X,'CONS',3X,'AREA',4X,'ELEV',6X,'RIVER',2X,'STREM',2X,'WATER',
     14X,'FLOW',3X,'FLOW',6X,'PPM',3X,'CONT.',5X,'TDS',/,127('-'),
     2/,14X,'16',5X,'17',6X,'18',5X,'19',5X,'20',5X,'21',5X,'22',10X,
     3'23',5X,'24',5X,'25',6X,'26',6X,'27',6X,'28',6X,'29',6X,'30',
     4/,127('-'))
      DO 66 J=2,13
      IYR = LYRO + I
      IF(J.LE.4) IYR = IYR - 2
      IF(J.GT.4) IYR = IYR - 1
      WRITE(6,302) MONTH(J),IYR,(C(K,J,I),K=16,30)
  302 FORMAT(' ',A3,2X,I4,2F7.1,F8.1,3F7.1,F8.2,4X,3F7.0,5F8.0)
   66 CONTINUE
      WRITE(6,207)
      WRITE(6,308)  (TOTAL(K,I),K=16,19),(TOTAL(K,I),K=23,27),
     1(TOTAL(30,I))
  108 FORMAT(' ',1X,'WY TOTAL',4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
  308 FORMAT(' ',1X,'WY TOTAL',2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
    5 CONTINUE
      CALL TITLES(1)
      WRITE(6,100)
      WRITE(6,101)
      DO 88 I=1,NYR
      IYR = LYRO + I - 1
      WRITE(6,105) IYR, (TOTAL(J,I),J=1,12)
  105 FORMAT(' ',5X,I4,4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
   88 CONTINUE
      WRITE(6,207)
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      WRITE(6,106)  (SUMTOT(J),J=1,12)
  106 FORMAT(' ',4X,'TOTAL',4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
      WRITE(6,107)  (AVE(J),J=1,12)
  107 FORMAT(' ',2X,'AVERAGE',4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
      CALL TITLES(1)
      WRITE(6,100)
      WRITE(6,109)
      DO 888 I=1,NYR
      IYR = LYRO + I - 1
      WRITE(6,305) IYR, (TOTAL(J,I),J=16,19),(TOTAL(J,I),J=23,27),
     1(TOTAL(30,I))
  305 FORMAT(' ',5X,I4,2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
  888 CONTINUE
      WRITE(6,207)
      WRITE(6,306) ((SUMTOT(J),J=16,19),(SUMTOT(J  ),J=23,27),
     1(SUMTOT(30)))
  306 FORMAT(' ',4X,'TOTAL',2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
      WRITE(6,307) ((AVE(J),J=16,19),(AVE(J),J=23,27),(AVE(30)))
  307 FORMAT(' ',2X,'AVERAGE',2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
      WRITE(6,208)
  208 FORMAT(1H1)
      STOP
C******************************************************************
C *** THIS FUNCTION SUB-PROGRAM WILL RETURN THE TDS CONTENT OF THE
C.*** PROVO RIVER
C******************************************************************
      FUNCTION TDS1(Q1,L)
      GO TO (2,2,3,3,3,3,7,7,9,10,11,12,13),L
    2 TDS1=Q1*CTDS*288.0
      RETURN
    3 TDS1=Q1*CTDS*281.0
      RETURN
    7 TDS1=Q1*CTDS*361.9
      RETURN
    9 TDS1=Q1*CTDS*210.1
      RETURN
   10 TDS1=Q1*CTDS*247.5
      RETURN
   11 TDS1=Q1*CTDS*284.3
      RETURN
   12 TDS1=Q1*CTDS*295.2
      RETURN
   13 TDS1=Q1*CTDS*293.3
      RETURN
C******************************************************************
C *** THIS FUNCTION SUB-PROGRAM WILL RETURN THE TDS CONTENT OF THE
C *** UTAH LAKE DRAINAGE AREA LESS PROVO RIVER
C******************************************************************
      FUNCTION TDS2(Q2,L)
      GO TO(2,2,2,2,2,2,2,2,3,3,3,3,3),L
    2 TDS2=Q2*CTDS*795.3
      RETURN
    3 TDS2=Q2*CTDS*593.2
      RETURN
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUEMENTS ELVA AND KXX RETURNS AN
C *** AREA OF UTAH LAKE GIVEN AN ELEVATION 'ELVA' AND A STARTING POINT
C *** 'KXX'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      FUNCTION ELEUTL(ELVA,KXX)
      DO 7 J=KXX,NUMENT
      KM=J
        EL = -13.35 + (FLOAT(J))* .01
      IF(ELVA.LE.EL    ) GO TO 8
    7 CONTINUE
      KX=NUMENT
      KM=NUMENT
      GO TO 10
    8 KM=J
      KX=KM-1
   10 PKX=(ELVA-(-13.35+(FLOAT(KX))* .01))/ .01
      AREDIF = AREAS(KM) - AREAS(KX)
      ELEUTL = AREAS(KX) + (PKX * AREDIF)
      RETURN
```

```
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUEMENTS I AND J RETURNS THE
C *** NUMBER OF DAYS IN MONTH 'I' IN YEAR 'J'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      FUNCTION DAYMON(I,J)
      GO TO(1,2,1,2,2,3,2,1,2,1,2,2,1), I
    1 DAYMON = 30
      RETURN
    2 DAYMON = 31
      RETURN
    3 DAYMON = 28
      IF(FLOAT( (LYRO+K)/4 ).LT. 0.1 )  DAYMON = 29
      RETURN
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUEMENT AVERGE RETURNS THE SPILL
C *** RATE TO JORDAN RIVER BASED ON AVERAGE ELEVATION OF THE LAKE
C *** 'AVERGE'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      FUNCTION SPILL (AVERGE)
      DO 10 J=1,20
      IF(AVERGE.GE.TABLE(J)) GO TO 11
   10 CONTINUE
   11 IF(J.EQ.1) GO TO 12
      KL=J
      KX=KL-1
      GO TO 13
   12 KX=J
      KL=J
   13 PKX=(AVERGE - TABLE(KX)) / 0.5
      DIFF = SPILLS(KX) - SPILLS(KL)
      SPILL = SPILLS(KX) + PKX * DIFF
      RETURN
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUEMENTS ELVA AND KKX RETURNS
C *** AN AREA OF GOSHEN BAY GIVEN AN ELEVATION 'ELVA' AND A STARTING
C *** POINT 'KKX'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      FUNCTION ELEGOS(ELVA,KKX)
      DO 417 J=KKX,NUGNT
      KM=J
      ELG = -13.15 + (FLOAT(J)) * .01
      IF(ELVA.LE.ELG    ) GO TO 418
  417 CONTINUE
      KX=NUGNT
      KM=NUGNT
      GO TO 419
  418 IF(J.EQ.1) GO TO 4188
      KM = J
      KX = KM-1
      GO TO 419
 4188 KM=J
      KX = J
  419 PKX =(ELVA-(-13.15+(FLOAT(KX)) * .01)) /  .01
      AREDIF = AREASG(KM) - AREASG(KX)
      ELEGOS = AREASG(KX) + (PKX * AREDIF)
      RETURN
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS FUNCTION SUB-PROGRAM RETURNS THE SPILLS TO GOSHEN BAY BASED
C *** ON THE DIFFERENCE IN ELEVATION BETWEEN THE DIKED LAKE AND GOSHEN
C *** BAY 'TESTCH' AND THE ELEVATION OF UTAH LAKE 'ELELOR'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      FUNCTION EQL(TESTCH,ELELOR)
      C(15,L,K) = ELELOR
      DO 435 I=1,10
      M=I
      IF(TESTCH.GE.CH(I).AND.TESTCH.LE.CH(I+1) ) GO TO 436
  435 CONTINUE
  436 DO 437 J=1,11
      N=J
      PP = ELEV(J+1) - ELEV(J)
      IF(C(15,L,K).GE.ELEV(J).AND.C(15,L,K).LE.ELEV(J+1) ) GO TO 438
  437 CONTINUE
  438 X = (QQQ(M,N+1)-QQQ(M,N)/PP) * (C(15,L,K) - ELEV(J) ) + QQQ(M,N)
      Y = (QQQ(M+1,N+1)-QQQ(M+1,N)/PP)*(C(15,L,K)-ELEV(J))+QQQ(M+1,N)
```

```
      EQL = (Y-X) * (TESTCH - CH(M)) / (CH(M+1) - CH(M)) + X
      RETURN
      SUBROUTINE TITLES(NO)
C    ******************************************************************
C    *
C    *  THIS SUBROUTINE USED ALONG WITH SUBROUTINE DAY, GIVES 5 VERSIONS  *
C    *
C    * THAT MAY BE USED WITH ALL PROGRAMS TO IDENTIFY THE OUTPUT, AND     *
C    *                                                                  *
C    * ALSO IDENTIFY THE DATA CARDS.                                    *
C    *                                                                  *
C    *         VERSION 1. CALL TITLES(1)-WRITES THE TITLE,THE JOB NO.,  *
C    *                                   THE DATE PROCESSED,AND PAGE NO. *
C    *                                                                  *
C    *         VERSION 2. CALL TITLES(2)-WRITES THE TITLE,THE PAGE NO., *
C    *                                   SKIPS A LINE,THEN WRITES THE   *
C    *                                   JOB NO.,AND DATE PROCESSED.    *
C    *                                                                  *
C    *         VERSION 3. CALL TITLES(3)-WRITES THE TITLE,THE DATE      *
C    *                                   PROCESSED,AND PAGE NO.         *
C    *                                                                  *
C    *         VERSION 4. CALL TITLES(4)-WRITES ONLY THE TITLE,CENTERED *
C    *                                   ON THE PAGE,AS LONG AS THE TITLE *
C    *                                   IS CENTERED IN THE FIRST 60    *
C    *                                   COLUMNS ON THE CARD.           *
C    *                                                                  *
C    *         VERSION 5. CALL TITLES(5)-THIS VERSION IS USED FOR PUNCH *
C    *                                   CARD VERFICATION ONLY. IT WRITES *
C    *                                   NOTHING.                       *
C    *                                                                  *
C    ******************************************************************
      COMMON/JOBTIT/TITLE(12),IPAGE
      DIMENSION DATE(2)
      CALL DAY(DATE(1),DATE(2))
      IF(NO.GT.1)GO TO 20000
11111 WRITE(6,1010)TITLE,DATE,IPAGE
 1010 FORMAT(1H1,10X,10A6,8H JOB NO ,2A6,14H PROCESSED ON ,2A6,
     110H PAGE NO. ,I4)
      GO TO 10000
20000 IF(NO.GT.2)GO TO 30000
      WRITE(6,1020)(TITLE(I),I=1,10),IPAGE,(TITLE(I),I=11,12),DATE
 1020 FORMAT(1H1,5X,10A6,10H PAGE NO. ,I4/13X,9H (JOB NO ,2A6,
     114H PROCESSED ON ,2A6,2H) )
      GO TO 10000
30000 IF(NO.GT.3)GO TO 40000
      WRITE(6,1030)(TITLE(I),I=1,10),DATE,IPAGE
 1030 FORMAT(1H1,10X,10A6,20X,14H PROCESSED ON ,2A6,10H PAGE NO. ,I4)
      GO TO 10000
40000 IF(NO.GT.4)GO TO 50000
      WRITE(6,1040)(TITLE(I),I=1,10)
 1040 FORMAT(1H1,35X,10A6)
      GO TO 10000
50000 IF(NO.GT.5)GO TO 60000
      GO TO 10000
60000 GO TO 11111
10000 IPAGE=IPAGE+1
      RETURN
      END
@ASM,IN DAY,DAY
$(1)        AXRS
.           CALL DAY(A,B)
.           A IS A 2 WORD ARRAY
.           B IS IGNORED
DAY*        SSL         A3,36                   . THIS MAY HELP LATER
            ER          DATES                   . A0 IS MMDDYY
            LDSL        A0,2                    . REMOVE ZONE BITS
            LSSL        A1,36                   . CLEAR A1
            LDSC        A0,4                    . SHIFT FIRST TO A1
            MI,U        A1,10                   . SHIFT INTO A2 AND SIZE
            LDSL        A0,2                    . MORE ZONE
            LDSC        A0,4                    . MOVE THE GOOD PART
            AA          A2,A1                   . FORM THE SUM
            L           A1,M-1,A2               . LOAD THE ALPHA MONTH
            LSSC        A0,12                   . A0= YYXXDD   A1= '-MMM---'
```

```
            LDSC        A0,24                   . A0-1= DD-MMM--YY@@
            LSSL        A1,6                    . A0-1= DD-MMM-YY@@@
            LXM,U       A1,050505               . A0-A1=DD-MMM-YY---
            DS          A0,*0,X11               . GIVE IT TO THE USER
            J           3,X11                   . RETURN
$(0)
M           ' JAN  '
            ' FEB  '
            ' MAR  '
            ' APR  '
            ' MAY  '
            ' JUN  '
            ' JUL  '
            ' AUG  '
            ' SEP  '
            ' OCT  '
            ' NOV  '
            ' DEC  '
            END
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS SUBROUTINE WILL RETURN THE ELEVATION OF UTAH LAKE BASED UPON
C *** THE END OF MONTH CONTENT 'EOM'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      SUBROUTINE CAPUTT(EOM,CAPUTL,KX)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),    CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,       AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
      IEOM=1.91*EOM + 1.0
      DO 314 J=IEOM,NUMENT
      KY=J
      IF((EOM + 12.5) .LE. CAP(J) ) GO TO 315
  314 CONTINUE
      KX=NUMENT
      KY=NUMENT
      GO TO 316
  315 IF(J.EQ.1) GO TO 3155
      KY = J
      KX = KY - 1
      GO TO 316
 3155 KY = J
      KX=J
  316 PKX=(EOM + 12.5 - CAP(KX) ) / ( CAP(KY) - CAP(KX) )
      CAPUTL = -13.35 + ((FLOAT(KX)) + PKX) * .01
      RETURN
      END
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
C *** THIS SUBROUTINE WILL RETURN THE ELEVATION OF GOSHEN BAY BASED
C *** UPON THE END OF MONTH CONTENT OF 'EOM'
C *** *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      SUBROUTINE CAPGOO(EOM,CAPGOS,KKX)
      COMMON AJST(7)            ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
     1ACOR(7),    CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
     2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
     3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
     4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
     5FMT3(4),FMT4(4),QSRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
     6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON      ACR,       AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
     1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
     2    SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
     $IPR,IUL,      LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
     1,NYR,INAF,
     7VAR(41,12,7,13)
```

```
      IEOM=EOM*4.5 + 1.0
      DO 414 J=IEOM,NUGNT
      KY=J
      IF ( EOM .LE. CAPG(J) ) GO TO 415
  414 CONTINUE
      KX=NUGNT
      KY=NUGNT
      GO TO 416
  415 IF(J.EQ.1) GO TO 4155
      KY = J
      KX = KY-1
      GO TO 416
 4155 KY = J
      KX = J
  416 PKX = ( EOM - CAPG(KX) ) / (CAPG(KY) - CAPG(KX) )
      CAPGOS = -13.15 + ((FLOAT(KX)) + PKX ) *  .01
      KKX=KX
      RETURN
      END
```

APPENDIX E

EVAPORATION FROM UTAH LAKE

Simulation of Evaporation From a Shallow Lake

by

Bi-Huei Wang
J. Paul Riley

Introduction

In an attempt to simulate the hydrologic process of the Utah Lake basin in central Utah, it was noted that the evaporation from an open water surface plays an important role in the total hydrology of the area. The outflow from the basin is regulated by a large lake at its outlet. Because of the moderate water yield of the basin and the large area of the lake, a small change in the depth of evaporation from the lake causes a large change in the outflow from the lake. This sensitivity of the total hydrology to evaporation clearly indicates that, in simulating the hydrology of an area of this nature, a small error in estimating evaporation from open water surface may result in considerable departure of the simulated hydrology from its actual magnitude. The need for an adequate method to estimate the evaporation is, therefore, rather obvious and, in fact, motivated the present study.

There are numerous empirical and theoretical methods available for estimating evaporation from open water surfaces. Since Dalton (1802) first recognized that the rate of evaporation is proportional to deficit in vapor pressure, there have been many evaporation equations proposed on this basis. Some important ones are those proposed by Dalton (1802), Meyer (1915), and Harbeck (1954, 1958, 1962). Blaney and Criddle (1950) proposed a procedure using temperature and duration of possible sunshine. Jensen and Haise (1963), based on measured evapotranspiration and estimates of solar radiation for the periods involved, calculated the ratios of evapotranspiration to solar radiation and correlated the ratio to mean air temperature. Practicing engineers often estimate lake evaporation by applying a coefficient to pan evaporation. All of these methods have been meaningfully applied to particular areas, but are not applicable for locations where the empirical coefficients are not available.

The theoretical approach to the evaporation problem includes applications of mass-transfer theory and energy balance analysis. By applying the mass-transfer theory, Thornthwaite and Holzman (see Linsley, Kohler, and Paulhus, 1958, page 97) were able to arrive at the following equation:

$$E = \frac{833k^2 (e_1 - e_2)(u_2 - u_1)}{(T + 459.9) \ln(z_2/z_1)^2} \quad . \; . \; . \; (E\text{-}1)$$

in which

E = rate of evaporation in inches per hour
k = von Karman's constant
e = vapor pressure in inches of mercury
u = wind speed in miles per hour
T = mean air temperature in $^{\circ}$F
z_1 = lower level
z_2 = upper level

The energy budget approach to the problem leads to the following equation:

$$E = \frac{Q_s - Q_r - Q_b + Q_v - Q_\theta}{\rho L_e (1 + R)} \quad . \; . \; . \; (E\text{-}2)$$

in which

E = rate of evaporation
ρ = density of water
Q = rate of the energy components associated with the evaporation process
L_e = latent heat of vaporization
R = Bowen ratio

Penman (1948), through simultaneous solution of an empirical mass-transfer equation and the energy budget equation, derived the following equation:

$$E = \frac{1}{\Delta + \gamma} (Q_n \Delta + \gamma E_a) \quad . \; . \; . \; . \; . \; (E\text{-}3)$$

in which

Δ = slope of the saturation-vapor-pressure vs. temperature curve at the air temperature, T_a

E_a = evaporation rate given by an empirical mass-transfer equation, assuming the water temperature $T_s = T_a$

Q_n = net energy exchange expressed in the same unit as evaporation E.

γ = is defined by the Bowen ratio equation

$$R = \gamma \frac{T_s - T_a}{e_s - e_a} \quad \text{. . . . . (E-4)}$$

in which

e_s = saturation vapor pressure corresponding to T_s

e_a = vapor pressure of the air at T_a

Each of the theoretical equations described above has a sound theoretical basis and, therefore, is expected to have a more general applicability to the evaporation problem. However, the Thornthwaite-Holzman equation needs vapor pressure and wind speed data at two levels which are usually not available and the energy budget and Penman equations contain empirical functions which limit the applicability of the equations.

Van Bavel (1966) improved the Penman equations by eliminating the requirement for the empirical function. He tested the resulting equation with the experimental data in Phoenix, Arizona, and claimed an excellent agreement between the calculated and measured values on both an hourly and a daily basis. The present study follows essentially the same method but incorporates an equation describing the variation of reservoir water temperature, and thereby provides for an improved estimation of energy and water exchange between the water surface and the over-lying air.

Mathematical Model

As was mentioned in the previous section, there are two fundamental approaches to the theoretical study of evaporation from open water surfaces. One involves application of mass-transfer theory and the other involves keeping an energy budget.

Assuming a steady, uniform flow of air across a free-water surface of infinite extent and a logarithmic distribution of wind speed, the following equation can be derived by considering the vertical flux of water vapor and momentum,

$$E_o = \frac{\rho \epsilon}{p c_1^2} \frac{(u_2 - u_1)(e_1 - e_2)}{\ln^2 (z_2/z_1)} \quad \text{. . (E-5)}$$

in which

E_o = rate of evaporation in g cm^{-2} sec^{-1}

c_1 = a dimensionless constant in the wind velocity distribution equation

e = vapor pressure in the same unit as p

p = total pressure in the same unit as e

u = wind velocity in cm sec^{-1}

ρ = density of moist air in g cm^{-3}

ϵ = ratio of the densities of water vapor and dry air at the same temperature and pressure (=0.622)

z = height above the water surface; and the larger subscript indicates the higher elevation

From an energy balance consideration, the following equation can be obtained

$$E = \frac{I_s - I_r - I_b + I_v - I_\theta}{\rho_e L_e (1 + R) A} \quad \text{. . . . . (E-6)}$$

in which

E = evaporation rate in cm sec^{-1}

A = water surface area in cm^2

I_s = rate of incoming sun and sky short-wave radiation in cal sec^{-1}

I_r = rate of reflected short-wave radiation in cal sec^{-1}

I_b = rate of net outgoing long wave radiation in cal sec^{-1}

I_v = rate of energy advected into the water body in cal sec^{-1}

I_θ = rate of increase in energy storage in cal sec^{-1}

L_e = latent heat of vaporization in cal g^{-1}

ρ_e = density of evaporated water in g cm^{-3}

R = the Bowen ratio

Combining Equations E-5 and E-6 by using the following relationship,

$$I_e = L_e E_o A \quad \text{. . . . . (E-7)}$$

in which

I_e = rate of energy used for evaporation in cal sec^{-1}, and by letting $I_R = I_s - I_r - I_b - I_\theta + I_v$, the following equations are formed:

$$E = \frac{1}{\rho_e L_e} \frac{(\Delta/\gamma) I_R/A + L_e B e_d}{(\Delta/\gamma) + 1} \quad \text{. . (E-8)}$$

$$B = \frac{\rho \epsilon}{p c_1^2} \frac{u_2}{\ln^2 (z_2/z_o)}$$

in which

e_d = saturation vapor deficit at height z_2

z_o = surface roughness parameter as defined by Van Bavel (1960) and the other terms are as previously defined

The application of Equation E-8 requires temperature at the water surface in order to evaluate some of the component energy terms included in I_R. Water surface temperature data are usually not available. However, for shallow reservoirs, considering the stirring action by wind and inflowing streams, it seems reasonable to assume that the temperature distribution is fairly uniform. On the basis of this assumption, the variation of water temperature with respect to time can be expressed as

$$\frac{dT_s}{dt} = \frac{I_\theta}{c\rho_w V} \quad \text{. . . . . (E-9)}$$

in which

T_s = water temperature in degrees C

c = specific heat of the water in cal g^{-1} $^oC^{-1}$

V = volume of the reservoir storage in cm^3

t = time in sec

ρ_w = density of the water in g cm^{-3}

Let $I_t = I_s - I_r - I_b - I_h - I_e$

then $I_\theta = I_s - I_r - I_b - I_h - I_e + I_v = I_t + I_v$ . . (E-10)

Assuming that the temperature of the outflow from the reservoir is essentially the same as that of the reservoir storage and that the temperature of the precipitation can be approximated by the wet-bulb temperature, the rate of net advected energy, I_v, can be estimated by

$$I_v = c\rho_w \left[\sum_{i=1}^{n} Q_i (T_i - T_s) + P_r A (T_w - T_s)\right] \quad \text{. . . . (E-11)}$$

in which

n = number of inflowing surface and underground tributaries

Q_i = rate of tributary inflow in cm^3 sec^{-1}

T_i = temperature of the inflowing water in ^oC

T_w = wet-bulb temperature in ^oC

P_r = precipitation rate in cm sec^{-1}

Substituting Equation E-10 and E-11 into Equation E-9,

$$\frac{dT_s}{dt} = \frac{I_t + c\rho_w \left[\sum_{i=1}^{n} Q_i (T_i - T_s) + P_r A (T_w - T_s)\right]}{c\rho_w V} \quad \text{. (E-12)}$$

The evaporation rate, E, then can be obtained by solving Equations E-8 and E-12 simultaneously. The advantages of the proposed method over the existing methods are that it requires no empirical coefficient or function and needs only measurements at a single level, z_2. The method also simulates water temperature in the reservoir which allows an improved estimation of long wave radiation and net advected energy in Equation E-8, and at the same time provides another check on the validity of the model.

Application

In applying the proposed method, careful determination of the energy components in Equation E-8 is important. To estimate the short-wave radiation received on the water surface, I_s, it is essential to have actual measurements. The Weather Bureau has collected solar radiation measurements at various locations throughout the United States. Of the total amount of short-wave radiation that reaches the water surface, a portion, I_r, is returned to the air by reflection. The reflectivity of a plane water surface is a function of the angle of incidence of the energy and the index of refraction of the water (see List, 1968, page 444) and may be computed from the reflection law of Fresnel,

$$r = \frac{1}{2}\left[\frac{\sin^2(\theta_i - \theta_r)}{\sin^2(\theta_i + \theta_r)} + \frac{\tan^2(\theta_i - \theta_r)}{\tan^2(\theta_i + \theta_r)}\right] \quad \text{. (E-13)}$$

in which

r = reflectivity of the water surface

θ_i = angle of incidence = $\sin^{-1}(\sin\Phi \sin\delta + \cos\Phi \cos\delta \cos h)$

θ_r = angle of refraction

Φ = latitude of the site

δ = declination of the sun

h = hour angle of the sun

θ_i and θ_r are related to the index of refraction, n, of water by

$$n = \sin\theta_i / \sin\theta_r \quad \text{. . . . . (E-14)}$$

in which

n = 1.333 for pure water

Net back radiation, I_b, is defined as the difference between the long wave radiation leaving the water surface and the long wave radiation absorbed by the water surface. Raphael (1962) suggested that it can be estimated by

$$I_b = 0.970\,\sigma\,(T_{sa}^4 - \beta\, T_a^4)\,A \quad \text{. . . (E-15)}$$

in which

T_a = absolute temperature of the air in ^oK

T_{sa} = absolute temperature of the water in ^oK

β = a radiation factor as shown by Figure E-1

σ = Stafan-Boltzman constant, 8.132 x 10^{-11} cal cm^{-2} min^{-1} $^oK^{-4}$

Δ/γ in Equation E-8 is a dimensionless constant depending on the ambient temperature and pressure shown in Table E-1 and Equation E-16

$$\frac{\Delta}{\gamma} = \frac{1,000}{p}\left(\frac{\Delta}{\gamma}\right)_o \quad \text{. . . . . (E-16)}$$

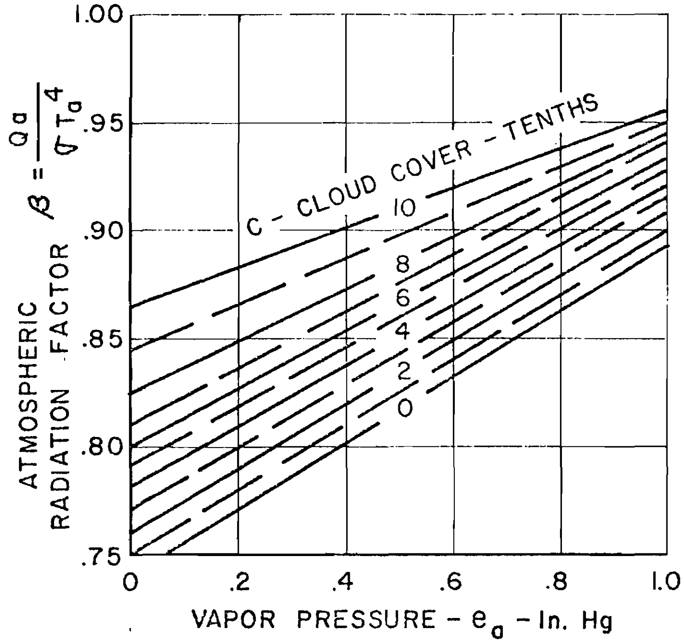

Figure E-1. Atmospheric radiation factor, β (see Raphael, 1962).

in which

p = ambient pressure in m bar; and (Δ/γ) = value in Table 1

With Equation E-13 through E-16 and Table E-1 available at hand, the mathematical model, Equations E-8 and E-12, was programmed on the EAI 590 computer and incorporated in the hydrologic model for the Utah Lake in Central Utah. The hydrologic model was constructed so as to have lake storage and water temperature as outputs for comparison with the corresponding observed data. The model was operated on a daily basis for the period from October 1965 to September 1968. Reliable solar radiation, wind speed, temperature, precipitation and streamflow records are available for that period. The validity of the model was tested by comparing the simulated and the observed lake storage (see Figure E-2b for the period October 1965 to September 1968). The limited water temperature records were also used to check the variation pattern of the simulated temperature as shown in Figure E-3. Some temperatures observed in the summers were not plotted in the figure because they were observed nearly at the water surface and believed to be greatly affected by the high temperature of the over-lying air and, therefore, not representative of the average temperature simulated. Water temperatures were not observed during the winter months. However, if measurements were made

Table E-1. Values of $(\Delta/\gamma)_0$ at 1,000 mbar, temperature T°C.

T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$
0.0	0.67	10.0	1.23	20.0	2.14	30.0	3.57	40.0	5.70	50.0	8.77
0.5	0.69	10.5	1.27	20.5	2.20	30.5	3.66	40.5	5.83	50.5	8.96
1.0	0.72	11.0	1.30	21.0	2.26	31.0	3.75	41.0	5.96	51.0	9.14
1.5	0.74	11.5	1.34	21.5	2.32	31.5	3.84	41.5	6.09	51.5	9.33
2.0	0.76	12.0	1.38	22.0	2.38	32.0	3.93	42.0	6.23	52.0	9.52
2.5	0.79	12.5	1.42	22.5	2.45	32.5	4.03	42.5	6.37	52.5	9.72
3.0	0.81	13.0	1.46	23.0	2.51	33.0	4.12	43.0	6.51	53.0	9.92
3.5	0.84	13.5	1.50	23.5	2.58	33.5	4.22	43.5	6.65	53.5	10.1
4.0	0.86	14.0	1.55	24.0	2.64	34.0	4.32	44.0	6.80	54.0	10.3
4.5	0.89	14.5	1.59	24.5	2.71	34.5	4.43	44.5	6.95	54.5	10.5
5.0	0.92	15.0	1.64	25.0	2.78	35.0	4.53	45.0	7.10	55.0	10.8
5.5	0.94	15.5	1.68	25.5	2.85	35.5	4.64	45.5	7.26	55.5	11.0
6.0	0.97	16.0	1.73	26.0	2.92	36.0	4.75	46.0	7.41	56.0	11.2
6.5	1.00	16.5	1.78	26.5	3.00	36.5	4.86	46.5	7.57	56.5	11.4
7.0	1.03	17.0	1.82	27.0	3.08	37.0	4.97	47.0	7.73	57.0	11.6
7.5	1.06	17.5	1.88	27.5	3.15	37.5	5.00	47.5	7.90	57.5	11.9
8.0	1.10	18.0	1.93	28.0	3.23	38.0	5.20	48.0	8.07	58.0	12.1
8.5	1.13	18.5	1.98	28.5	3.31	38.5	5.32	48.5	8.24	58.5	12.3
9.0	1.16	19.0	2.03	29.0	3.40	39.0	5.45	49.0	8.42	59.0	12.6
9.5	1.20	19.5	2.09	29.5	3.48	39.5	5.57	49.5	8.60	59.5	12.8
10.0	1.23	20.0	2.14	30.0	3.57	40.0	5.70	50.0	8.77	60.0	13.1

(From Van Bavel, C. H. M.: Potential Evaporation: The Combination Concept and Its Experimental Verification, Water Resources Res., Vol., no. 3, pp. 455-67, 1966)

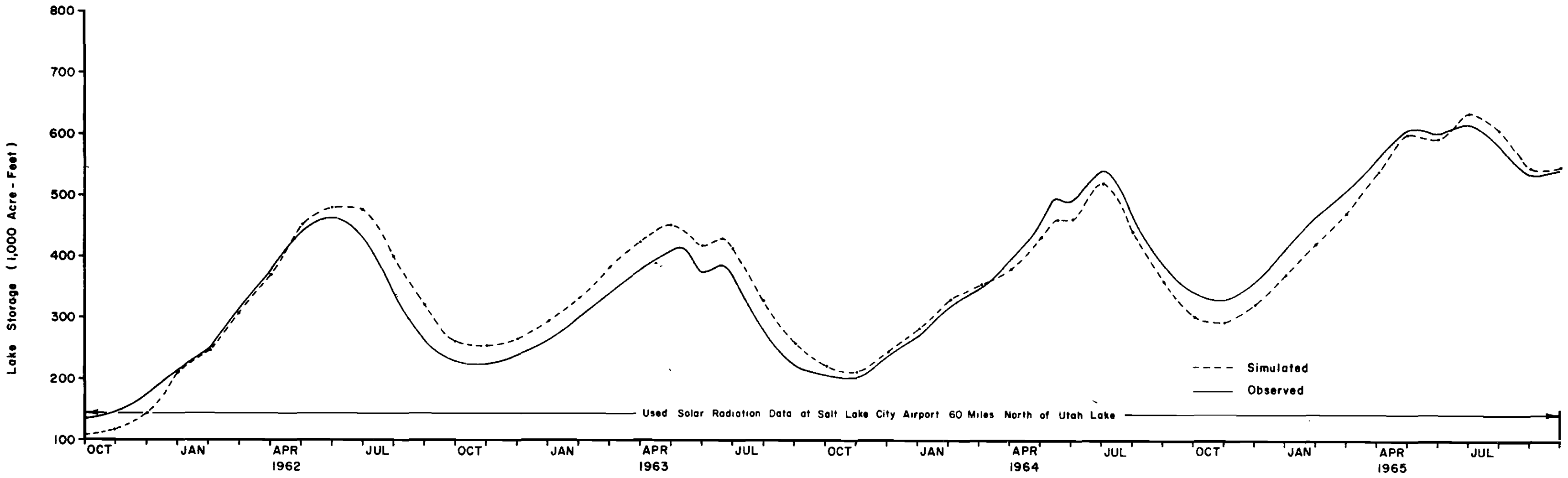

Figure E-2a. The comparison of simulated and observed lake storage, Utah Lake.

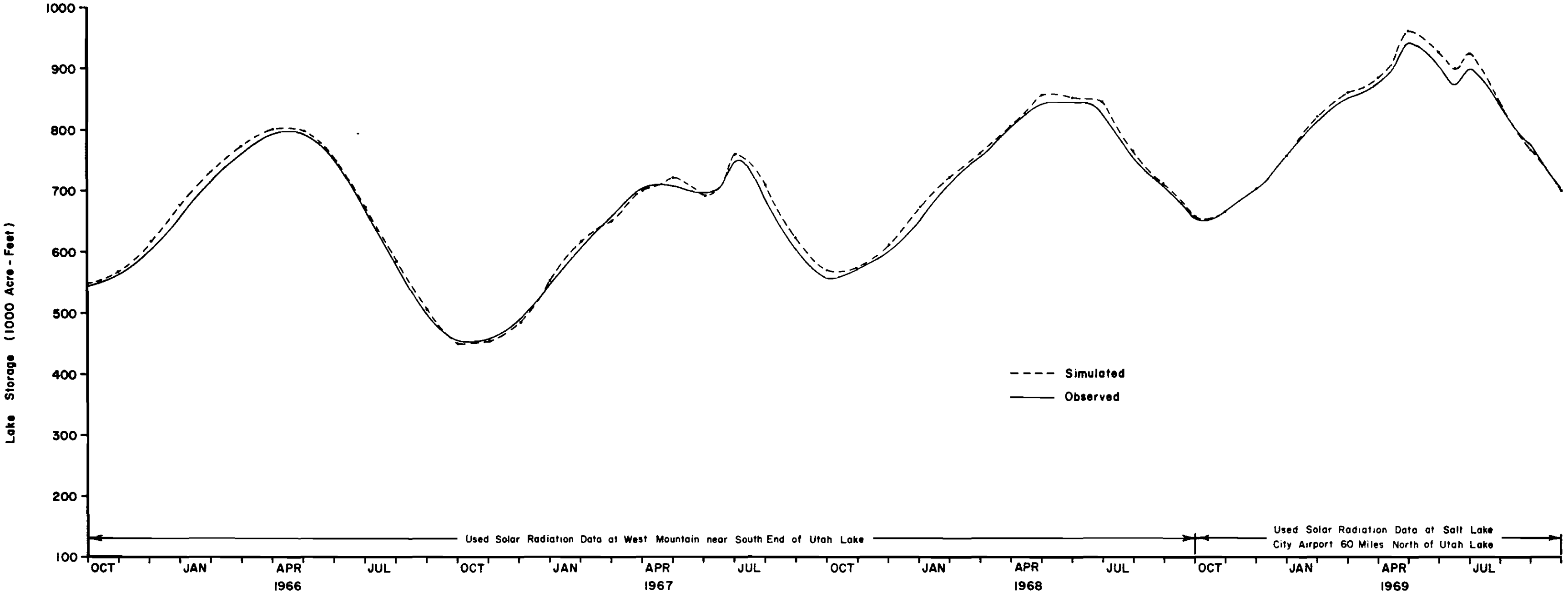

Figure E-2b. The comparison of simulated and observed lake storage, Utah Lake.

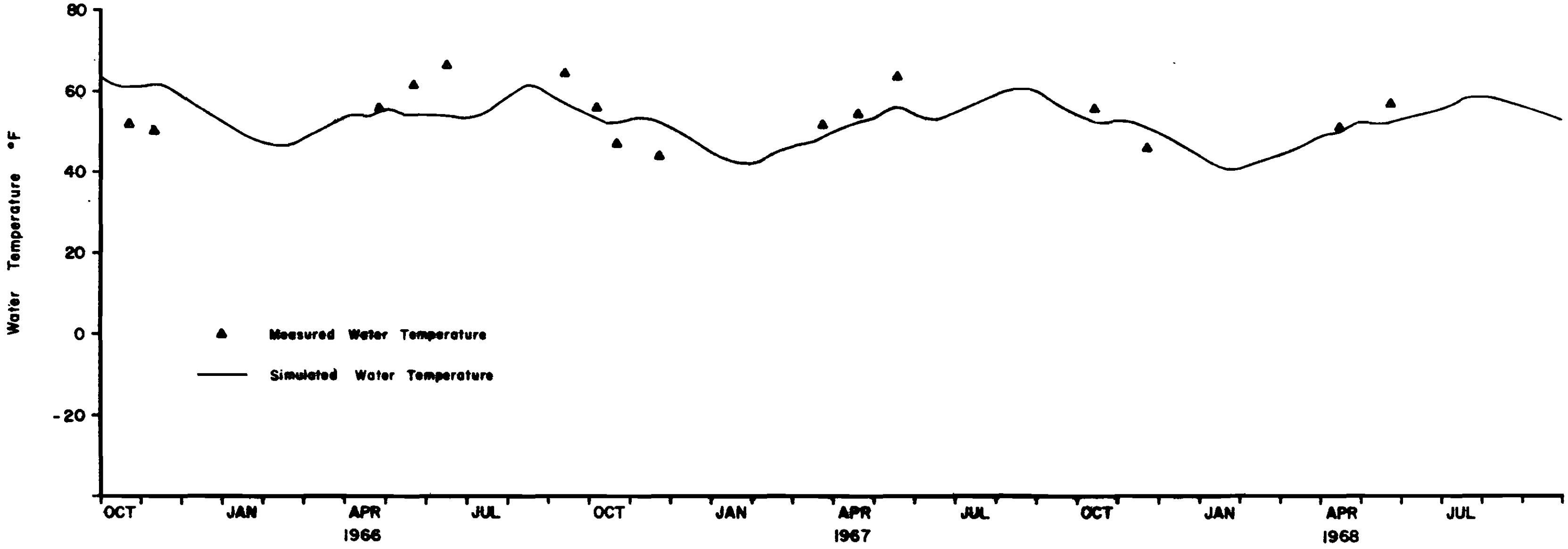

Figure E-3. The comparison of simulated and observed water temperature, Utah Lake.

at the water surface, it is believed that they would plot mostly below the simulated water temperature because of the influence of the cold over-lying air.

The excellent agreement between the simulated and observed storage hydrographs, and the reasonable agreement between the simulated and observed water temperatures indicate the adequacy of the model in simulating evaporation from the lake.

Unfortunately, for many areas, the amount of available solar radiation data is limited. To extend the application of the proposed model to periods for which no such data are available, the following procedure was adopted:

1. Operate the model for the period in which solar radiation and the other necessary data are available.
2. Assume that the simulated evaporation estimates accurately the actual evaporation, and correlate this simulated evaporation to readily available data such as pan evaporation.
3. Apply the resulting regression equation to estimate evaporation for periods in which the proposed model, Equations E-8 and E-12, is not directly applicable.

For the area under consideration in this study, there were three years of sufficient data available for operating the model. An additional five years of data were made available by approximating the local insolation with measurements at Salt Lake City Airport which is located 40 miles to the north. Figures E-2a and E-2b indicate the simulation results for the additional five-year period in terms of the lake storage hydrograph. The observed storage variation for the corresponding period is also shown by the same figure. These results were considered to be acceptable and the simulated evaporation was, therefore, assumed to approximate the actual evaporation. Monthly simulated evaporation data were then correlated to corresponding pan evaporation data. Pan evaporation measurements have been made at Lehi near the lake since 1923. Figure E-4 shows that relationship between the simulated lake evaporation and the observed pan evaporation. It is interesting to note that on the basis of this relationship, the conventional constant "pan coefficient" method of estimating lake evaporation tends to underestimate actual evaporation in the winter and overestimate it in the summer.

Discussion

The model described by this paper satisfactorily simulated evaporation from an open water surface. The model requires no highly empirical functions or coefficients and is easily incorporated in any hydrologic simulation model. However, in the operation of the model, it was necessary to set maximum limits on the rate of water temperature change and on the rate of evaporation. Without these limitations, the simulated water temperature and evaporation performs wild variations which are not physically realistic. This is probably due to the assumption that the water temperature distribution is uniform throughout the entire lake. The thermal conductivity of water may limit immediate conduction of heat from surface to bottom or from bottom to surface, and thus, limits the maximum rate of change in average water temperature. Similar conditions may exist in the water vapor transfer between the water surface and the over-lying air. The maximum limits established by the model for the rate of temperature change and evaporation serve to make some compensation for the possible errors introduced by the assumption of uniform water temperature distribution. The maximum limits were identified through the model calibration procedure.

The lake and pan evaporation relationship shown in Figure E-4 is interesting in that it differs from the general assumption of linear relationship between the two variables. As mentioned at the beginning of this paper, it has long been the practice among many engineers to estimate lake evaporation by applying a constant coefficient to the corresponding pan evaporation. However, during winter months, water temperatures in a large lake may be higher than those in a nearby evaporation pan, and a higher than annual average ratio between lake and pan evaporation amounts is expected. In summer, the condition reverses, and a smaller coefficient is, therefore, expected. The relationship in Figure E-4 reflects this expected variation of pan coefficient with respect to season.

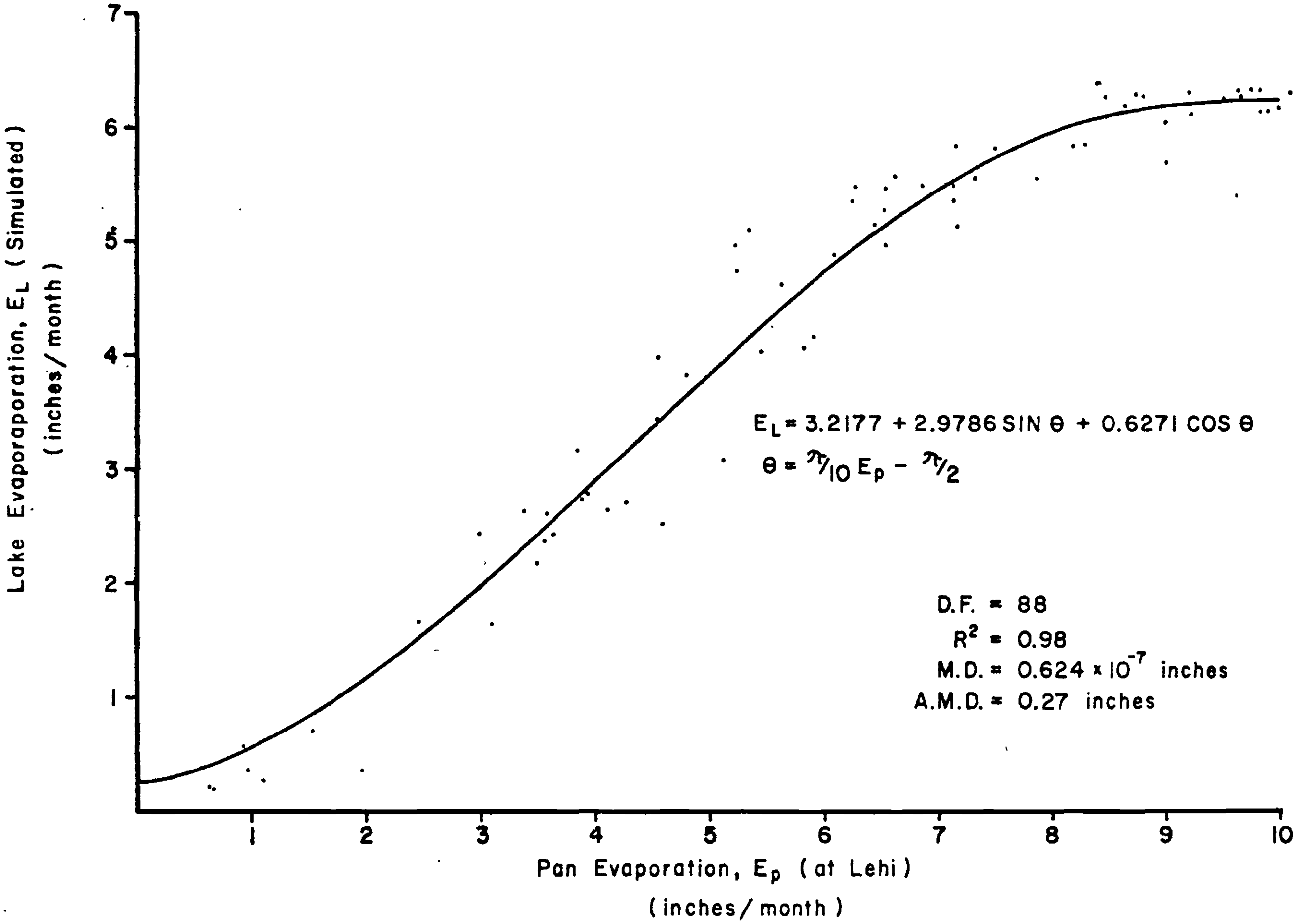

Figure E-4. Lake and Pan Evaporation Relationship, Utah Lake