SIM-V

Multireservoir Simulation and Optimization Model

Program Documentation

And

Users Manual

TEXAS DEPARTMENT OF WATER RESOURCES

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MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL

SIM-V

Program Documentation and User's Manual

by

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FOREWORD

The SIM-V Model described in this document is a computer program that simulates and optimizes the operation of an interconnected system of reservoirs, hydroelectric generating plants, pump canals, pipelines, and river reaches.

SIM-V is an improved version of the previously developed Multibasin Simulation and Optimization Model SIM-V (TWDB, 1972). The major improvements to the previous model consisted of incorporating hydroelectric power generation as one of the functions of reservoir operation and incorporation of reservoir evaporation, channel seepage, and consumptive use directly into the mathematical model as system variables.

The SIM Model was originally developed in 1969 by Water Resources Engineers, Inc. under contract to the Texas Water Development Board, with subsequent improvements and modifications made by the staff of the Texas Water Development Board. The improved network representation using "gain" parameters is possible utilizing a network optimization algorithm developed and written by Dr. Paul Jensen of the University of Texas at Austin.

The model was developed on the UNIVAC 1100/41 computer systems but is designed to be essentially machine independent. Core requirements are approximately 60,000 decimal words. Computation time is a function of the size of the problem being analyzed; however, for the San Antonio-Guadalupe River System example problem discussed herein, approximately 10 seconds of UNIVAC 1100/41 execution time is required to obtain a solution.

Any inquiries concerning the use of this program should be directed to Quentin W. Martin, Texas Department of Water Resources, P.O. Box 13087, Austin, Texas 78711. Copies of TDWR computer programs may be obtained by contacting the Information Systems and Services Section of the Department at the above address.

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INTRODUCTION

The efficient management of surface water resources is a continuing concern of the part of numerous federal, state, and local agencies charged with providing water for power generation, water supply and other purposes. The random changes in nature's hydrologic cycle have led to difficulties in determining the proper method to operate surface water storage and conveyance facilities so as to achieve the greatest efficiency. This report describes a solution procedure for determining the optimal operation of an interconnected system of surface water conveyance and storage facilities over a time period under which deterministic steady-state hydrologic and water use conditions may reasonably be assumed to occur. Depending on the size and areal extent of the system being considered, such steady-state time periods may vary from as short as a week to several months. The solution to this short-term operational problem is of course not the optimal solution to the problem of management through a multiple year drought period. The long-term operational problem has been treated and solved by a compatible solution technique coded into the Water Allocation Model AL-V (8). The report describing AL-V provides extensive detail into the previous investigations concerned with solving the optimal operational problem.

The solution procedure is consistent with the solution incorporated in the AL-V program except that this procedure considers a single time period as the operational interval of study instead of multiple interconnected periods as does AL-V. The methodology seeks to overcome the various shortcomings of the currently available methods by extending the capabilities of the SIM-V Model developed by the Texas Water Development Board (14) to include the evaluation of hydroelectric power generation from reservoir systems. The technique developed divides the operational problem into network (linear) and nonlinear subproblems and utilizes separate solution procedures tailored to each subproblem. The computer program SIM-V, containing the solution procedure described here (see Appendix A), is designed to be used in concert with the AL-V program to determine optimal monthly operating policies for the optimal operation of surface water systems over the critical period of drought and may be used for actual operational control on a month- by-month basis. SIM-V analyzes the entire time horizon by finding the optimal operation for each of a succession of single time periods. Each period is evaluated independently of the others. The storages at the end of a given month are used as the initial storages for the next month.

The surface water resources systems considered in this analysis consist of water storage impoundments, hydroelectric power generating facilities, natural stream reaches, and artificial water conveyance links (i.e., pipelines and canals). The benefits derived from the operation of such systems include water supply, low flow maintenance, and hydroelectric power generation. Other beneficial purposes, such as recreation or flood control, are not explicitly evaluated by the procedure to be developed in this report.

Before describing the solution procedure, it is necessary to fully detail the modeling assumptions utilized in mathematically representing surface water systems.

PROBLEM DESCRIPTION

Water Storage and Conveyance

Conservation of Flow

The steady-state passage of water through a system of impoundments and natural or artificial channels requires that the principal of conservation of mass be followed. Therefore, for each water storage or stream junction point, the total inflow must equal the total outflow during each time period. This relationship can be expressed mathematically for each junction j by the following equation:

$$\sum_{i=1}^{m} A_{ji}q_{ik} + \sum_{i=1}^{m} A_{ji}q'_{ik} - \frac{(S_{j,k+1} - S_{jk})}{\Delta t} = D_{jk} + E_{jk}(S_{j,k+1}, S_{jk}) - U_{jk} - I_{jk} \quad \ldots\ldots(1)$$

where

$$A_{ji} = \begin{cases} +1, \text{ if flow in channel } i \text{ enters junction } j \\ -1, \text{ if flow in channel } i \text{ leaves junction } j \\ 0, \text{ if link } i \text{ is not directly connected to junction } j, \end{cases}$$

D_{jk} is the local water demand at junction j satisfied in time period k,

E_{jk} is the evaporation loss from junction j during time period k, as a function of the water storage,

I_{jk} is the quantity imported directly into junction j during period k,

m is the number of channels,

q_{ik} is the flow entering channel i during time period k,

q'_{ik} is the flow leaving channel i during time period k,

S_{jk} is the storage contents of junction j at the start of time period k,

$S_{j,k+1}$ is the storage contents of junction j at the end of time period k+1,

U_{jk} is the unregulated inflow into junction j in time period k, and

Δt is the length of time period.

The flow rate entering a channel may not equal the discharge from the channel due to water gains or losses from evapotransporation, groundwater recharge, or spring inflow. While the changes in flow rates along river reachs or canals are highly complex, a reasonable approximation is to express the rate of flow change as a fraction of the inflow, with the proportionality factor allowed to vary for each period of simulation (i.e., monthly or seasonally). This is expressed mathematically for each channel i in period k as

$$q'_{ik} = (1 - \alpha_{ik})\, q_{ik} \quad \text{......................(2)}$$

where α_{ik} is the fraction of the water entering channel i that is lost in the time period k. The above equation represents only the change in the flow entering a channel as it passes out of the channel. Any additional inflow from the intervening contributing drainage area that might enter at some point along the channel may be added as unregulated inflow to the terminal junction for the conveyance channel.

Bounds on Water Storages and Stream and Canal Flow Rates

The water storage in an impoundment will vary within the design storage capacities depending upon the seasonal limits desired for activities such as water conservation, recreation, flood control or fisheries enhancement. Thus the storage in junction j at the end of any time period k must satisfy the constraint relationship

$$V_{jk}^{min} \leq S_{j,k+1} \leq V_{jk}^{max} \quad \text{......................(3)}$$

where

V_{jk}^{max} is the maximum allowable water storage in junction j at the end of time period k and

V_{jk}^{min} is the minimum permissible water storage in junction j at the end of time period k.

In a similar manner it may be desirable for navigation, flood control, wildlife enhancement, water rights, or other purposes to specify upper and lower limits on the flow rates in natural or artificial conveyance channels on a seasonal basis. Such constraints can be expressed for each channel i in time period k by the inequalities

$$\ell_{ik} \leq q_{ik} \leq u_{ik} \quad \text{..........................(4)}$$

where

ℓ_{ik} is the lower limit on the flow entering channel i in time period k and

u_{ik} is the upper limit on the flow entering channel i in time period k.

Water Conveyance Costs

In terms of economic impact, the operation of pumps and motors at water pumping stations is by far the most significant of all the operating and maintenance costs for a conveyance system. The energy requirements for a pump pipeline or canal varies proportionally with the flow rate and the Total Dynamic Head (TDH) over which the water must be pumped. The TDH is the sum of the static lift (i.e., the elevation difference between the intake water surface and the highest point on the conveyance line) and the friction losses in the pipe or channel.

Friction Losses in Pipelines and Canals

A variety of empirical relationships have been proposed to quantify the friction losses incurred by water flowing under pressure through closed conduits. The commonly used Hazen-Williams equation may be utilized to obtain the head loss in a pipe due to friction. Thus, the head loss h_L (ft.) over a distance L (ft.) due to a flow rate Q (ft^3/sec.) in a completely filled pipe of diameter D (feet) is given by

$$h_L = \frac{4.73 \ L}{C_H^{1.852}} \frac{Q^{1.852}}{D^{4.87}} \quad \text{.......................(5)}$$

where C_H is the Hazen-Williams coefficient of the pipe material.

Steady-state flow of water in an open channel occurs when the energy loss due to friction equals the energy gained through gravitational acceleration, which is equal to the vertical slope of the channel bed. Since the channel slopes are assumed to be prespecified for all open channels in the system, the friction losses on any open-channel reach will be a constant for any positive flow rate within the maximum flow capacity. That is, for different flow rates the velocity and depth of water in an open channel will adjust naturally so as to balance the acceleration and friction forces, and hence the net head loss will be unchanged.

Pumping Energy Requirements and Costs

For a pipeline or open channel designed to deliver a maximum flow Q (ft^3/sec.) over a lift (TDH) H (ft.) the required pumping power H_p (horsepower) is given by

$$H_p = \frac{\gamma QH}{550e} \quad \text{............................(6)}$$

where

- γ is the density of water (lb/ft^3) at the known water temperature,
- e is the pump-motor combined efficiency and

550 is the constant of proportionality in foot-pounds per second per horsepower.

The energy requirement E (kilowatts) for pumping is specified by

$$E = \frac{\gamma QH}{737.6e} \quad \ldots\ldots (7)$$

where

737.6 is the constant of proportionality in foot-pounds per sec per kilowatt.

The monthly pumping expenditure PE ($/month) is calculated by the following expression

$$PE = vCE \quad \ldots\ldots (8)$$

where

C is the electricity cost ($/kilowatt-hour) and

v is the conveyance channel utilization factor (hours of operation at flow rate Q per month).

A water pumping plant is generally designed to operate at or near a specific design flow rate. Lower flow rates do not consume significantly less energy since the motor efficiency also decreases with flow rates less than the system design rate. To deliver a net flow less than the design rate, water will usually be pumped at the design rate for the necessary period and then pumping will cease. Thus the pumping cost can be represented as a linear function of the net flow rate over the period.

Water Storage Benefits

Fluctuations in the hydrologic cycle of rainfall and runoff occur periodically on a seasonal basis, as well as over drought periods covering many years. The monthly operation of water storage and conveyance systems must consider these cyclic inflow variations if the systems are to be managed most efficiently. It is assumed that these long-term cycles are considered by the specification of monthly target storage levels and a unit storage benefit at each impoundment. The storage benefit applies to all water retained in a reservoir up to the target level, with no direct benefit for further storage. The unit benefit need not be direct economic measure of the "opportunity" for saving water for use in a less abundant period, but may be a somewhat arbitrary value needed to reflect priorities for storage in competing reservoirs.

For the development of the short-term optimal operation model described herein, it is assumed that the target storages and unit benefits are specified. The selection of these parameters depends upon assessing the long-term operation of the system using techniques described in the applications section of this report.

Water Supply Benefits

The benefit for meeting a portion of a total water demand, in the municipal, manufacturing or irrigation water use sectors, is generally a concave function of the water supplied (12). That is, the most important (beneficial) water uses are met first if not all water demands can be satisfied. The water benefit function may be approximated by a connected piecewise linear function. The slope of each linear component decreases as the amount of water supplied approaches that of the maximum amount needed. This reflects the decreasing marginal benefit for supplying additional water up to the maximum desired. The total water demand may thus be represented by a number of separate water demands, each having a linear benefit function. Therefore, it is without loss of generality that the water demand benefit function WB_{jk} can be expressed as:

$$WB_{jk} = p_{jk}\, D_{jk} \qquad (9)$$

where

p_{jk} is the benefit per unit of water supplied to junction j in time period k and

D_{jk} is the total volume of water demand at junction j in time period k.

Hydroelectric Power Generation

Hydroelectric Generating Plants

Hydroelectric power facilities convert the potential and kinetic energy in flowing water to electrical energy by means of mechanical turbines and generators. A typical power generating system (Figure 1) consists of one or more turbine-generator units located in a powerhouse. Water from an adjacent impoundment enters through a tunnel or pipe, called a penstock, and flows under pressure to a turbine. The water exits the turbine, after having lost most its energy, through a pipe known as a draft tube and is discharged in a downstream channel, termed a tailrace.

The amount of power P(kilowatts) generated by the passage of water at a rate Q(ft^3/sec), under a constant net head $\bar{H}$ (feet), through a turbine is given by

$$P = \varepsilon(P)\, \bar{H}\, Q/11.8 \qquad (10)$$

where $\varepsilon(P)$ is the energy conversion efficiency and 11.8 is a conversion factor from foot-pounds to kilowatts based upon a water density of 62.5 pounds per cubic foot.

The combined conversion efficiency ε of the turbine and generator unit is a function of the power (loading) produced by the unit. This function depends upon the characteristics and age of the power generation equipment. The efficiency of a power plant similarly depends upon the combined efficiencies

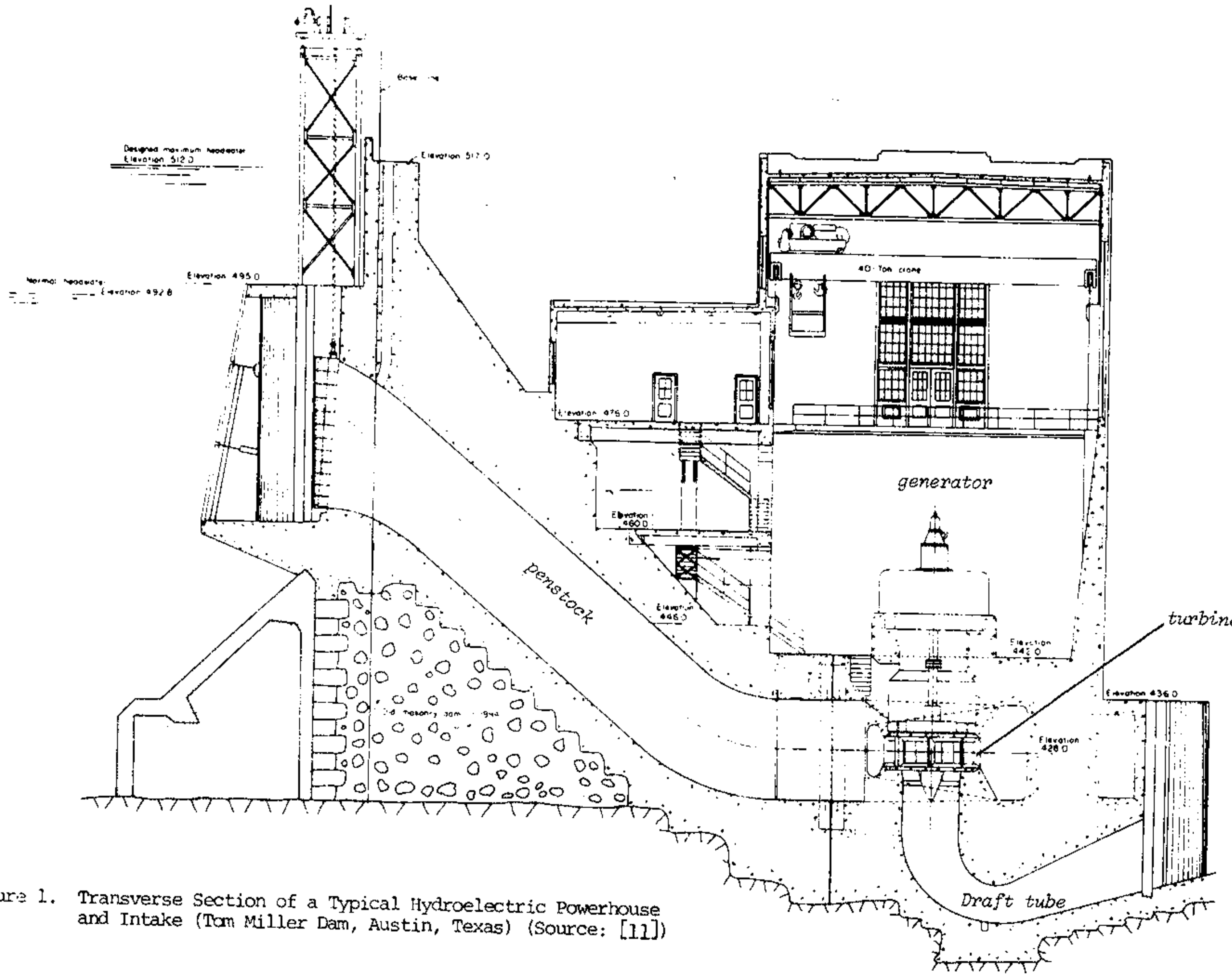

Figure 1. Transverse Section of a Typical Hydroelectric Powerhouse and Intake (Tom Miller Dam, Austin, Texas) (Source: [11])

of the units used to generate a given loading. As depicted in Figure 2, the optimal power plant efficiency increases rapidly with initial increments of power generation, but remains relatively constant as more generating units are are added to increase power production.

The net head is the difference between the water surface elevations at the entrance (forebay) and exit (tailrace) of the generating system less the usually minor energy losses in the penstock and draft tube, which will be ignored in this analysis. If the water utilized for energy production is released from a water storage impoundment then $\bar{H}$ is a function of the water storage volume.

The average power generation P_{rt} over a given time period t for power plant at reservoir r can be approximated by the relationship

$$P_{rt} = \varepsilon(P_{rt})\, Q_{rt}\, \bar{H}_{rt}/11.8 \qquad (11)$$

where

$\bar{H}_{rt}$ is the average net water head (feet) at the power plant at reservoir r during time period t and

Q_{rt} is the constant rate of water release (ft^3/sec) through the power plant at reservoir r during time period t.

The approximating equation (11) is exact if the net head varies uniformly between its initial and terminal values during the time period.

The average net head is defined by the equation

$$\bar{H}_{rt} = \bar{E}_{rt} - ET_{rt}\,(Q_{rt}, \bar{E}_{r't}) \qquad (12)$$

where,

$\bar{E}_{rt}$ is the average of the water surface elevations in reservoir r at the beginning and end of time period t,

ET_{rt} is the tailrace water surface (tailwater) elevation for reservoir r during time period t, and

r' is the reservoir immediately downstream of reservoir r.

The tailwater elevation is a function of the discharge flow rate downstream of the power plant, the storage content in any downstream reservoir which impounds water back up to the power plant, and the backwater effects due to tributaries entering the tailrace downstream of the power plant. For the purposes of long-term simulation of reservoir operation, it is believed that only the first two factors will significantly affect the power generation estimates. In the large majority of reservoirs, the controlled flow release from a reservoir is the only significant factor influencing the tailwater elevation. However, where navigational works are part of a reservoir system

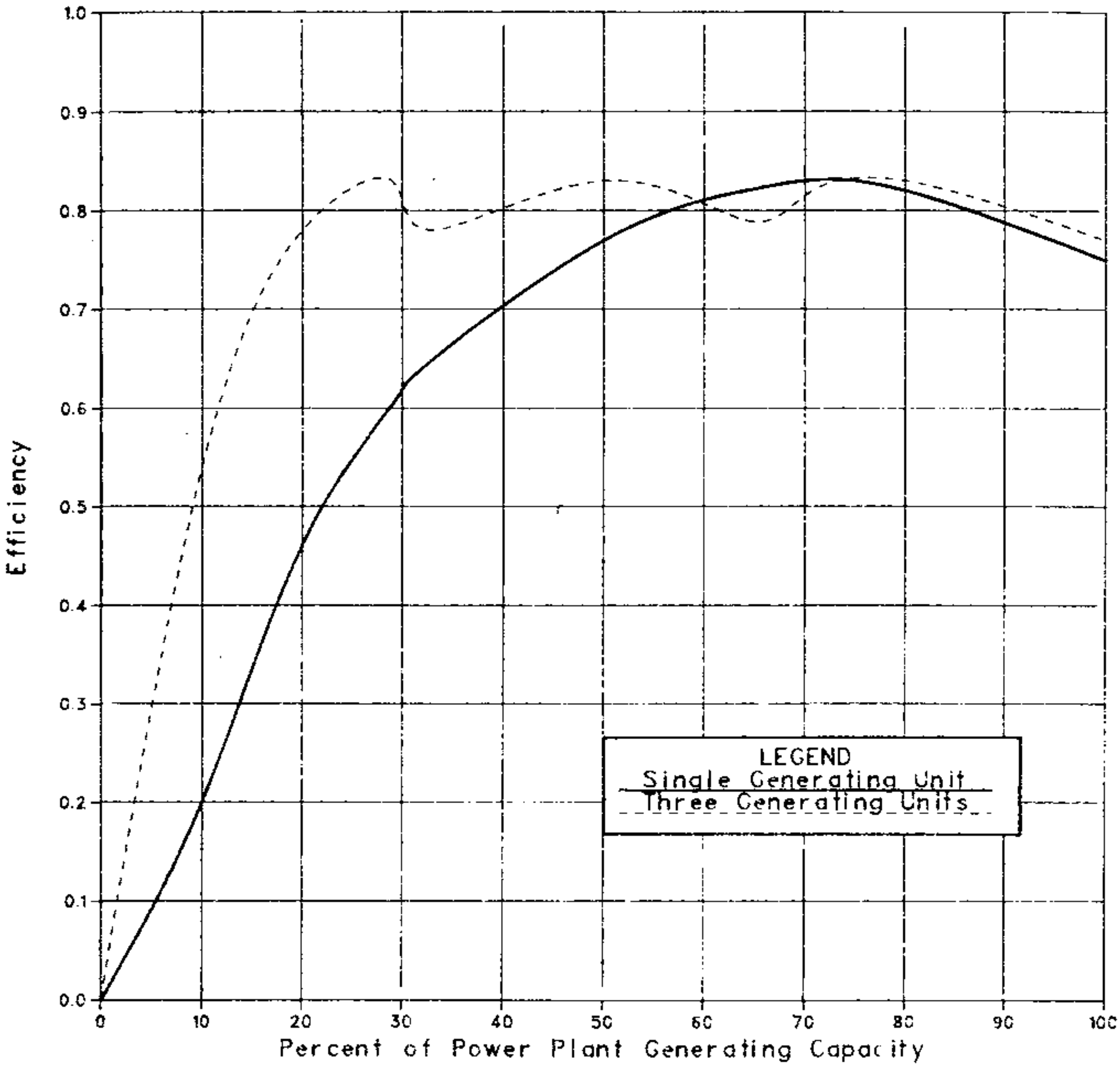

Figure 2. Variation in Power Generation Efficiency with Power Generation

or extensive development has placed reservoirs in close proximity to each other, the tailwater elevation may be partially or completely controlled by the storage levels in downstream impoundments.

The upper limit on the power generation rate is the minimum of the design generating capacity of the plant and the power produced by the maximum discharge rate, under a given head, through the turbines. Since the maximum turbine discharge is a function of the water surface elevation, then the power rate limit for each reservoir r can be represented by a function $PMAX_r(\bar{E})$.

Hydroelectric Power Benefits

The economic benefit for hydroelectric power generation is dependent upon economic market conditions. Electricity usage during daylight and early evening hours (termed peak periods) generally yields a greater monetary return per kilowatt than consumption during other periods (nonpeak periods) simply because of the greater demand during the former periods.

The objective function selected for evaluating the benefits of hydroelectric power generation is based upon a constant value for each unit of electricity generated up to the seasonal or monthly peak power requirement (firm power) specified for the system. This unit benefit is referred to as the unit peak period power benefit. Any additional unit of power generated by the system has a lower benefit reflecting the value of additional energy units above the firm power load, and is commonly termed dump energy. While this objective function is a rather simplistic view of daily operating benefits from hydroelectric power generation, it is believed to be adequate for determining the long-term firm power capacity of a multi-reservoir system and is thus useful in determining optimal power generation capacity allocation between various facilities in multiple fuel (i.e., nuclear, coal, hydro, etc.) power generating systems (1). By setting the annual firm energy requirement to a specific value, the operation of a reservoir system may then be simulated to determine if the system is capable of meeting the specified target over an extended drought period. By incrementally increasing the system firm power target, a maximum firm power loading from the system can thus be established.

Should conflicts arise between various water uses, such as water supply competing with hydroelectric power, then a parametric analysis may be undertaken when it is not possible to realistically reflect the value of the competing uses on a common economic basis. This parametric analysis may be accomplished by specifying maximum and minimum values for: reservoir releases, stream flow rates, water demands, and target hydroelectric generation rates.

PROBLEM STATEMENT

The steady-state operational problem for a system of reservoirs and conveyance links under deterministic hydrologic conditions for a given time period consists of determining the outflow of each reservoir over that period so as to maximize the net benefit from water supply, hydroelectric power generation, water conveyance, and water storage in the time period while satisfying the constraints indicated below:

- Conservation of flow is observed at all stream junctions and reservoirs,

- Reservoir storages are between minimum and maximum seasonal storage levels,
- Channel flows are between minimum and maximum seasonal flow rates,
- Electrical power generation at each reservoir is not in excess of generation capacity,
- Maximum level of usable peak period hydroelectric power, and
- Minimum and maximum demands for water supply.

MATHEMATICAL PROBLEM FORMULATION

Let an existing surface water storage and conveyance system consist of n storage and nonstorage junctions, of which R are reservoirs, and m conveyance links. Let k be the index for the operational time period. Also, let Q'_{rk} and Q''_{rk} be the instantaneous releases from reservoir r in time period k during peak and nonpeak periods, respectively, for hydroelectric power generation; and let q_{ik} be the inflow to conveyance link i in period k.

The minimum-cost operating flow for the system is the set of releases Q'_{rk}, Q''_{rk} and q_{ik} for all reservoirs and conveyance links which

$$\text{maximizes} \underbrace{\sum_{r=1}^{R} C_p\, HP_k\, PP_{rk} + C_f\, HF_k\, PF_{rk}}_{\text{HYDROELECTRIC POWER GENERATION BENEFITS}} \quad + \underbrace{\sum_{r=1}^{R} a_{rk}\, S'_{r,k+1}}_{\text{RESERVOIR STORAGE BENEFITS}}$$

$$- \underbrace{\sum_{i=1}^{m} c_{ik}\, q_{ik}}_{\text{PUMPING COSTS}} \quad + \underbrace{\sum_{j=1}^{m} P_{jk}\, D_{jk}}_{\text{WATER SUPPLY BENEFITS}} \quad \ldots\ldots(13)$$

subject to

material balance at junction points,

$$\sum_{i=1}^{m} A_{ji}\, q_{ik} + \sum_{i=1}^{m} A_{ji}\, q'_{ik} - \frac{(S_{j,k+1} - S_{jk})}{\Delta t} = D_{jk} + E_{jk}\,(S_{j,k+1}, S_{jk}) - U_{jk} - I_{jk},\ j=1,\ldots,n \ldots(14)$$

junction and reservoir storage bounds,

$$V_{jk}^{min} \leq S_{j,k+1} \leq V_{jk}^{max} \quad j=1,\ldots,n \ldots\ldots(15)$$

channel inflow constraints,

$$\ell_{ik} \leq q_{ik} \leq u_{ik} \quad i=1,\ldots,m \ldots\ldots (16)$$

flow losses along channels,

$$q'_{ik} = (1-\alpha_{ik})\, q_{ik} \quad i=1,\ldots,n \ldots\ldots (17)$$

maximum rates of power generation during peak and nonpeak periods from power generating plants,

$$PP_{rk} \leq PMAX_{rk}\,(\bar{H}_{rk}) \quad r=1,\ldots,R \ldots\ldots (18)$$

$$PF_{rk} \leq PMAX_{rk}\,(H_{rk}) \quad r=1,\ldots,R \ldots\ldots (19)$$

maximum firm rate of power generation during peak period in each time period,

$$\sum_{r=1}^{R} PP_{rk} \leq PT_k \ldots\ldots (20)$$

total downstream release from a reservoir must be no less than the release for power generation,

$$\sum_{i=1}^{m} \delta_{ir}\; q_{ik} \geq \frac{a}{HT_k}\,(Q'_{rk}\, HP_k + Q''_{rk}\, HF_k) \quad r=1,\ldots,R \ldots\ldots (22)$$

upper limit on storage in the target storage portion of reservoir storage,

$$S'_{j,k+1} \leq T_{jk} \quad j=1,\ldots,n \ldots\ldots (21)$$

minimum and maximum demands for water at each junction in each period

$$D^{min}_{jk} \leq D_{jk} \leq D^{max}_{jk} \quad j=1,\ldots,n \ldots\ldots (23)$$

and positivity of all flows,

$$Q'_{rk} \geq 0 \quad r=1,\ldots,R$$

$$Q''_{rk} \geq 0 \quad r=1,\ldots,R$$

$$q_{ik} \geq 0 \quad i=1,\ldots,m$$

$$q'_{ik} \geq 0 \quad i=1,\ldots,m \ldots\ldots (24)$$

where

a is the constant for converting the units of instantaneous flow (Q'_{rk} and Q''_{rk}) into the units of flow for the period (q_{ik}).

$A_{ji} = \begin{cases} +1 & \text{if flow in link } i \text{ enters junction } j \\ -1 & \text{if flow in link } i \text{ leaves junction } j \\ 0 & \text{if link } i \text{ is not directly connected to junction } j \end{cases}$

c_{ik} is the cost per unit of flow transmitted along link i in time period k,

C_p is the benefit per unit of energy produced during peak periods,

C_f is the benefit per unit of energy produced during nonpeak periods,

D_{jk} is the local water demand satisfied from junction j in time period k,

D_{jk}^{max} is the maximum local water demand at junction j in time period k,

D_{jk}^{min} is the minimum local water demand at junction j in time period k,

E_{jk} is the evaporation loss from junction j during time period k, as a function of the storage,

$\bar{H}_{rk}$ is the average net head at the power plant at reservoir r in time period k,

HF_k is the number of hours of nonpeak period power generation for time period k,

HP_k is the number of hours of peak period power generation for time period k,

HT_k is the number of hours in time period k,

I_{jk} is the quantity imported directly into junction j during period k,

ℓ_{ij} is the lower limit on the flow in link i during time period k,

L is the number of time periods,

m is the number of links, either pump-canals or rivers,

n is the number of reservoirs and non-storage junctions,

P_{jk} is the unit shortage cost for failure to meet the demand at junction j during time period k,

PF_{rk} is the rate of power production (defined by equation (11)) during nonpeak generating periods by the power plant associated with reservoir r during time period k,

$PMAX_{rk}$ is the maximum rate of power production from reservoir r in time period k and is dependent upon the water surface elevation and power plant design capacity,

PP_{rk} is the rate of power production (defined by equation (11)) during peak generating periods by the power plant associated with reservoir r during time period k,

PT_k is the maximum usable rate of power production during peak generating periods in time period k,

q_{ik} is the flow entering link i during time period k,

q'_{ik} is the flow leaving link i during time period k,

Q'_{rk} is the instantaneous flow rate out of reservoir r during peak generating period for power generation in time period k,

Q''_{rk} is the instantaneous flow rate out of reservoir r during nonpeak generating period for power generation in time period k,

S_{jk} is the storage content of junction j at the start of time period k,

S'_{jk} is the storage content in the target storage portion of storage in junction j at the start of time period k,

T_{jk} is the target storage in junction j at the end of time period k,

u_{ij} is the upper limit on the flow in link i during time period k,

U_{jk} is the unregulated inflow into junction j in time period k,

V^{max}_{jk} is the maximum allowable storage at junction j at the end of time period k,

V^{min}_{jk} is the minimum allowable storage at junction j at the end of time period k,

Δt is the length of time period,

$$\delta_{ir} = \begin{cases} 1, & \text{if link i directly receives the flow discharged from reservoir r for power generation,} \\ 0, & \text{otherwise.} \end{cases}$$

α_{ik} is the fraction of the water entering link i that is lost in time period k.

SOLUTION METHODOLOGY

The reservoir system operational problem given by equations (13) through (24) represents a nonlinear programming problem, with both linear and nonlinear terms in the objective function and constraints. Further, the objective function in nonconvex and thus a number of local optimum may exist. Numerous generalized computer codes (5, 7) have been developed to solve for local optimum of such nonlinear mathematical programming problems. While any one of the applicable computational procedures could be utilized it was believed that large-scale problems of the scope encountered in regional water resources planning could be solved more efficiently with a procedure developed specifically to exploit the problem's unique mathematical structure.

Problem Decomposition and Network Structure

An examination of the problem structure reveals distinct linear and nonlinear components. Specifically, the basic configuration of conveyance links, river channels, and reservoirs can be represented as a network. In a network, the real system's physical elements are represented as a combination of two possible network components - nodes and links. As the nomenclature implies, a node is a connection and/or branching point within the network. Therefore, a node is analogous to either a reservoir or a non-storage junction (i.e., canal junctions, major river intersections, etc.) in the physical system. Additionally, a node is a network component which is considered to have the capacity to store a finite and bounded amount of material moving in the network. Reservoirs are represented by nodes which have a storage capacity as well as the ability to serve as branching points. A non-storage junction is handled similarly to a capacitated junction (reservoir) except that its storage capacity is always zero. Demands placed on the system must be located at nodal points. Also, any water entering the system, such as might occur naturally from runoff or artificially through import, must also be introduced at a nodal point.

The transfer of water among the various network nodes is accomplished by transfer components called links. Typically a link is a river reach, canal, or closed conduit with a specified direction of flow and fixed maximum and minimum capacities. Figures 3 and 4 illustrate a network representation for the spatial configuration of a water resources system in the Cypress Creek Basin in Texas.

Water storage is represented in the network analogue by "storage arcs" which carry flow corresponding to water impounded at the end of a period. The upper and lower limits of storage at a reservoir control the maximum and minimum flow in these arcs.

The solution technique developed here for the operational problem involves the iterative solution of a least-cost network flow problem, where at

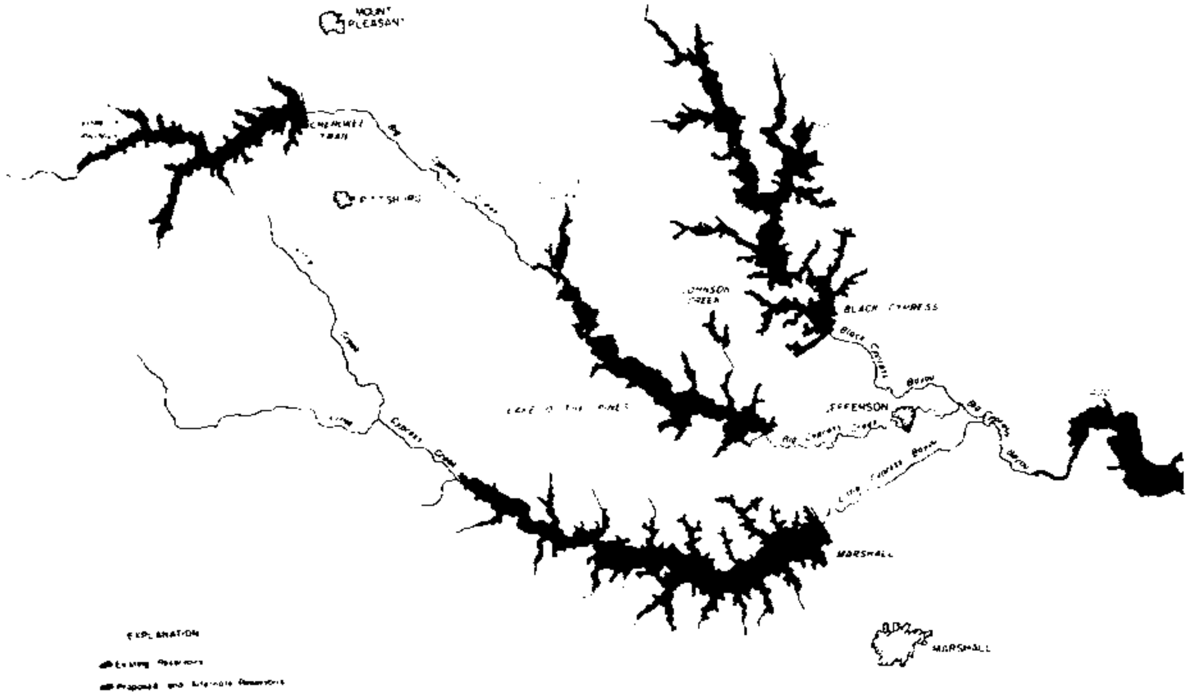

Figure 3. Cypress Creek Basin

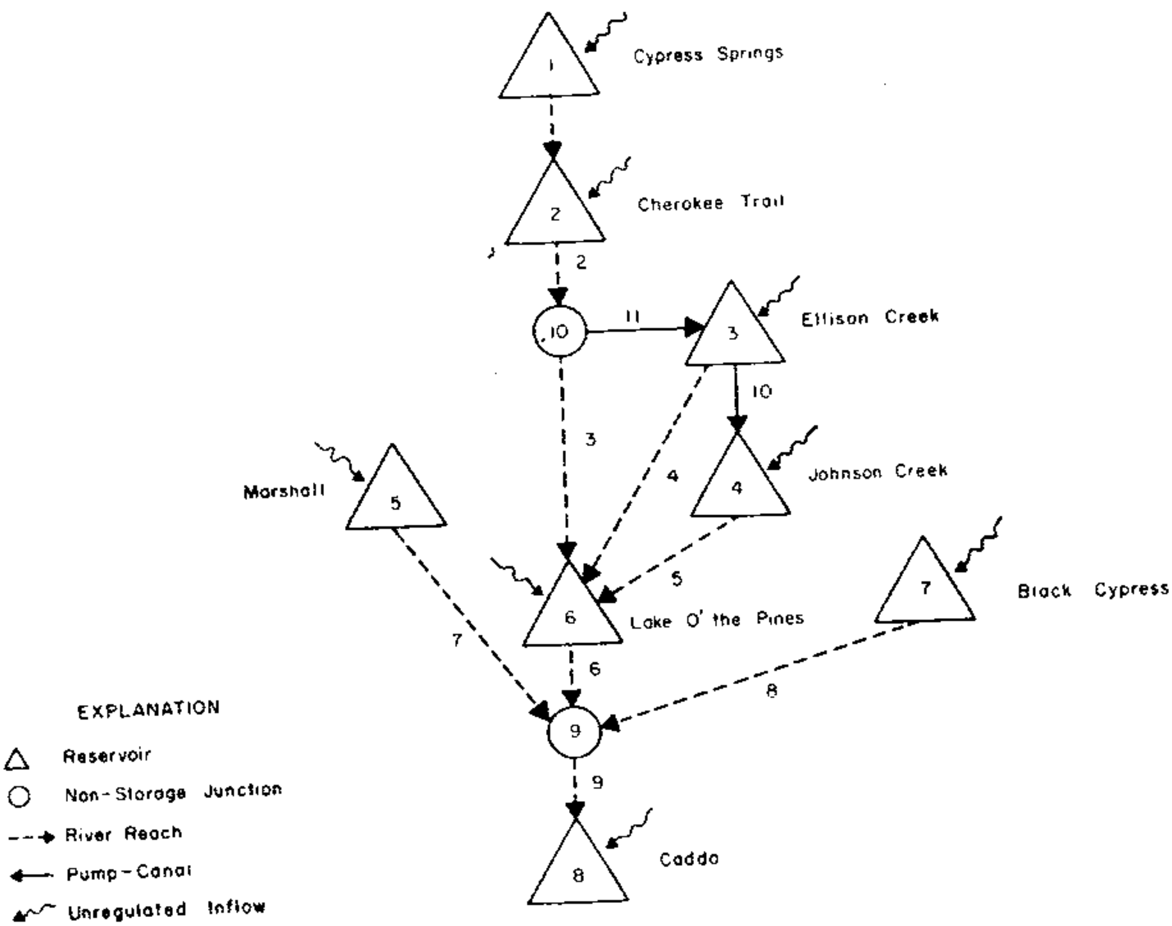

Figure 4. Node-Link Configuration, Cypress Creek Basin

each iteration the problem formulation is revised to incorporate the factors for hydroelectric power production. First-order Taylor series approximations are made of the nonlinear terms and substituted into the network problem. Bounds are placed on the discharge rates from the hydroelectric generating arcs to ensure that the linearized equations remain reasonable approximations.

The network subproblem will first be described in detail and the iterative procedure then will be developed.

Network Problem Formulation

As noted above, a physical system of water storage and conveyance facilities may be represented as a capacitated network. To clearly describe the network problem, it is necessary to specify the origin and terminal nodes and the four parameters associated with each arc. The term generalized network is used to distinguish network models having a fourth parameter per arc from the pure network formulations with the three arc parameters of minimum flow, maximum flow and unit cost of flow. The fourth arc parameter in a generalized network is the flow gain factor which is the ratio of the flow leaving to the flow entering the arc. A link having a gain of .9 will transmit 90 percent of the inflow at its origin node to its terminal node, while losing the remaining ten percent in transmission.

Incorporation of the gain factor enhances the ability of the network model to more accurately account for water losses which are flow dependent. Such losses occur in actual water distribution systems through evaporation, channel seepage, and consumptive use. For water conveyance links, the value $1 - \alpha$ represents the gain factor, where α is the water loss (evapotranspiration and groundwater recharge) per unit of flow. For network arcs corresponding to demands, the value of the gain factor is the user's sewerage to water (S/W) ratio.

The use of the gain factor is somewhat more complicated for the losses due to reservoir evaporation since evaporation is proportional to the water surface area and not directly proportional to storage volume. However, by approximating the area-capacity curve for each reservoir with two continuous piecewise linear segments, evaporation losses can be expressed as proportional to reservoir storages. To illustrate, the area-capacity curve for the potential Cuero I Reservoir in the Guadalupe River Basin of Texas can be approximated by several connected line segments as shown in Figure 7. This approximating function, $A(S)$, for the Cuero I reservoir capacity-area relationship is defined by

$$A(S) = \begin{cases} C_1 \, S & , \; 0 \leq S \leq 130 \\ C_2 \, (S-130) + 130C_1, & 130 \leq S, \end{cases} \qquad \text{............(25)}$$

where

$A(S)$ is the water surface area (1,000 acres),
S is the reservoir storage volume (1,000 acre-feet),

C_1 = .0923, and

C_2 = .0311.

By separating the storage variable S into two components, one corresponding to the storage below 130,000 acre-feet (S_1) and another to storage above 130,000 acre-feet (S_2), the evaporation loss can be reasonably approximated as proportional to storage. The approximate evaporation loss E (1,000 acre-feet/month), as a function of reservoir storage, is given by

$$E = \bar{e} (C_1 S_1 + C_2 S_2) \quad \text{.....................(26)}$$

where e is the average evaporation rate (feet/period). The fractional losses due to evaporation for each of the storage segments S_1 and S_2 are thus $\bar{e}C_1$ and $\bar{e}C_2$, respectively. The two storage components S_1 and S_2 are represented in the network by two storage arcs (see Figure 6). These gains may vary by month according to the monthly average evaporation rate $\bar{e}$.

It should be noted that the typical reservoir area-capacity relationship in Figure 4 is concave. Hence, the upper segment (S_2) of storage is more efficient in storing water (i.e., fewer surface acres per increment of storage) than the lower segment (S_1). Thus, it is possible that under a water shortage condition the optimal distribution of flow may specify that the network arc corresponding to S_2 have storage volume even though the arc corresponding to S_1, is not at its maximum capacity. This, of course, would violate physical laws. Unfortunately, a constraint specifying that the arc for S_1 be full before storing water in S_2 cannot be specified in the network model.

A $1/acre-feet benefit is assigned in the network for the lower range storages (S_1), while a benefit of $1/100 acre-feet occurs for storage retained in the upper storage range (S_2). This helps insure that the arcs corresponding to the lower storage range are saturated before flow is allowed through the links representing the upper storages. Under some circumstances, however, the algorithm may attempt to put water in the upper range of storage before the lower segment of storage capacity is full. Remedies for this difficulty include setting the minimum storage in the impoundment equal to the storage level where the linear segments join, or specifying operating rules designed to require the lower segment of storage to be full at certain periods of low total storage. These and other corrective procedures are described in the section dealing with model limitations in Appendix A.

Network Problem Mathematical Description

The mathematical structure of the network model is described by four sets of constraint equations and an objective function. One set of constraint

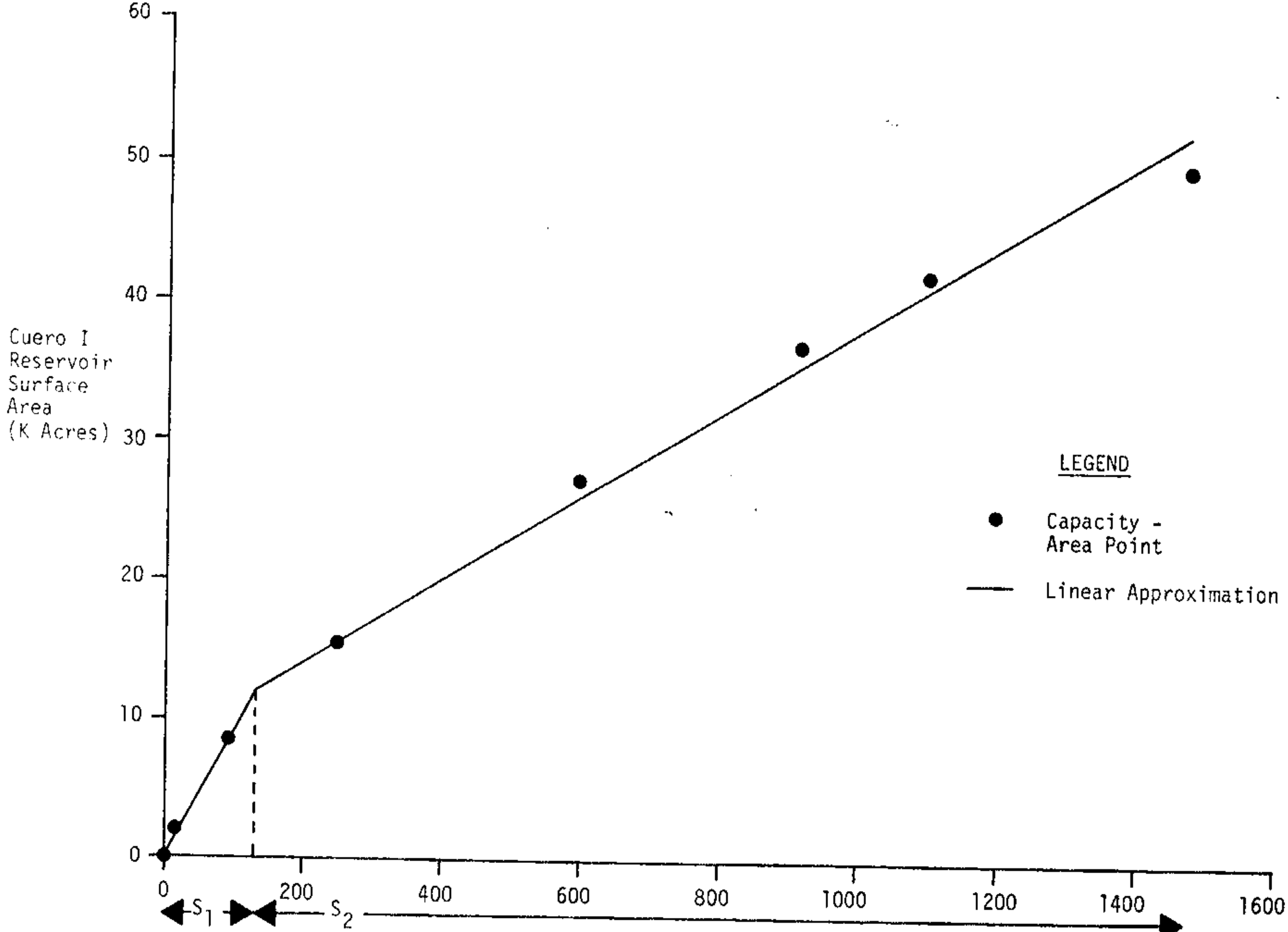

Figure 5. Piece-wise Linear Approximation of a Capacity-Area Curve

equations requires that continuity be satisfied at all nodes in the network, except at the source and sink nodes. The second set of constraints indicates the amount of water lost during conveyance through each of the arcs. The remaining two sets of equations describe the upper and lower limits on flow in all arcs in the network. Thus, there is one equation for each node and three equations per arc.

The mathematical statement of the network flow subproblem may be expressed as finding the set of arc flows q_{ij} which

$$\text{minimizes} \sum_{i=1}^{N} \sum_{j=1}^{N} q_{ij} \; C_{ij} \ldots\ldots\ldots\ldots\ldots\ldots (27)$$

COST OF FLOW TRANSMISSION

subject to

material balance at all nodal points,

$$\sum_{i=1}^{N} q_{ij} - q'_{ij} = 0, \; j=1,\ldots\ldots,N \ldots\ldots\ldots\ldots\ldots\ldots (28)$$

material losses along arcs,

$$q'_{ij} - (1 - \alpha_{ij}) \, q_{ij} = 0, \text{ for all } i \text{ and } j, \ldots\ldots\ldots (29)$$

and bounds on material conveyed along arcs,

$$L_{ij} \leq q_{ij} \leq U_{ij}, \text{ for all } i \text{ and } j, \ldots\ldots\ldots\ldots\ldots (30)$$

where

q_{ij} = flow entering arc from node i to j,

q'_{ij} = flow leaving arc from node i to node j,

L_{ij} = lower bound on flow from node i to node j,

U_{ij} = upper bound on flow from node i to node j,

C_{ij} = cost of moving one unit of flow from node i to node j, and

N = number of nodes in the network.

The generalized network model above may be solved to establish the minimum cost flow circulation in the network. That solution is equivalent to computing the optimal operation of the reservoir system. Existing primal and dual method generalized network optimization computer codes developed by Jensen (6) are utilized to solve for the least costly arc flows.

Computation of Hydroelectric Power Benefits

The solution to the network problem given above provides steady-state (i.e., weekly, monthly, or seasonal) reservoir storages and outflows. However, the benefits from power generation must be computed on an instantaneous flow basis for both peak and nonpeak periods during a day (see equation 10). Therefore, the network model reservoir storages and outflows must be converted to instantaneous levels and rates during peak and nonpeak periods in each period.

In determining the benefit from hydroelectric power generation, it is necessary to consider the number of hours in a monthly period during which peak power is needed. Since the peak power usage is required over a limited portion of the day, usually a twelve to fourteen hour period, any water released for power generation during normal (i.e., nonflooding) operation will be during these peak hours. Production of power during nonpeak periods would most likely occur only when water releases are mandatory. Thus, the mean discharge rate from a reservoir during a month must reflect the varying discharge rates between peak and nonpeak periods within the month. That is, if for a third of the month peak power is required then the release during peak periods will be three times the average discharge during the month, assuming no releases are made during nonpeak hours. Any additional power generated above that needed for peak generation, but generated during the peak periods, is considered nonpeak power. This restriction represents the inability of the power consumer to use peak power generated above its anticipated needs.

The energy produced during nonpeak periods is generally of such low economic value that it is generated usually as a by-product of flow releases, for water supply or low flow augmentation, in excess of that needed solely for peak energy production. In actual operation, it is likely that any volume of water used for dump or secondary power generation will be discharged at a high flow rate so as to generate at a high efficiency level, since, in contrast with firm energy generation, it is not necessary to generate dump energy at a constant rate over all nonpeak hours. Therefore, the nonpeak period power generation is calculated, for a given volume of outflow in a period, by multiplying the maximum possible generation rate for the current reservoir storage level by the number of hours that water is released to give that rate.

Iterative Solution Procedure

The solution to the network flow subproblem provides the minimum cost (maximum benefit) operation for a system with linear cost functions for specified constraints on reservoir storage and channel flow rates. To solve the full operational problem, however, it is necessary to include the benefits and constraints for hydroelectric power generation as well.

The solution technique described herein utilizes an iterative approach whereby the network flow subproblem is solved iteratively. The unit costs and bounds or flows discharges are changed to reflect incremental benefits for hydroelectric generation.

The solution algorithm proceeds in the following manner:

Step 1. The hydroelectric power generation benefits are assumed to be zero initially. The network algorithm is executed for the system to determine the set of flows both spatially and temporally which meets all the desired constraints and maximizes the benefits (except hydroelectric) for the system. These flows are assumed to be the current solution to the problem.

Step 2. The link flows and reservoir storages from the current problem solution are used to derive an incremental benefit for power generation per unit of outflow at each hydroelectric plant in the system. Constraints are imposed upon the flows in links generating hydroelectric power so that they may vary within only a certain percentage of the current flow rate.

Step 3. The revised network is solved to determine the optimal storages and flows for the system. If the net cost to operate the system for this tentative solution has increased from the current solution, then the size of the allowable percentage flow change is reduced by half. If the percentage flow change has reached a minimum value, then execution ceases. Otherwise, go to Step 2. If the net system cost is lower for the solution to the revised network then replace the problem solution with the revised solution and go to Step 2.

Taylor Series Approximations

The defining equation (10) for power generation is a nonlinear function of the net head and the flow discharge rate. To incorporate this term into the linear network model, the nonlinear functions are approximated as linear functions in the neighborhood of a given solution by first-order Taylor series.

The net head $\overline{H}$ is a function of flow and storage. Thus, the power generation for a discharge rate Q (ft^3/sec) and storage level S(acre-feet) can be approximated, by deleting second order and higher terms, for values of Q and S near flow rate Q* and storage S* by

$$P(Q,\overline{H}(S,Q)) = P(Q^*, \overline{H}(S^*, Q^*)) + \frac{\partial P}{\partial Q}\Big|_{S^*,Q^*}(Q-Q^*)$$

$$+ \frac{\partial P}{\partial H}\frac{\partial \overline{H}}{\partial S}\Big|_{S^*,Q^*}(S-S^*) \qquad (31)$$

Evaluating the partial derivatives gives

$$P(Q,\overline{H}(S,Q)) = P(Q^*,\overline{H}(S^*,Q^*)) + [\frac{\varepsilon}{11.8}(\overline{H}(S^*,Q^*) - \frac{\partial(ET)}{\partial Q}|_{S^*,Q^*}) \quad (Q-Q^*) + \frac{\varepsilon}{11.8} \; Q^* \frac{\partial \overline{H}}{\partial S}|_{S^*,Q^*} \; (S-S^*)]/(1 - \frac{\partial \varepsilon}{\partial P}\frac{\overline{H}^*Q^*}{11.8}) \ldots\ldots (32)$$

The rates of change of P with respect to Q and S are therefore given by the coefficients of Q and S in the above equation. The storage variable in equation (32) is actually two variables: the initial and final storages in the time period. Thus, it is necessary to expand equation (32) not only to include these storage variables but also to consider power production at all plants in the system. Thus the coefficients for the individual flow and storage variables are the sum of the coefficients in the various Taylor series approximations for all the power plants.

The maximum power generation functions in equations (18) and (19) are also nonlinear. These equations may be approximated as linear equations in the network model by substituting the value of the maximum power generation for the current solution. This is a reasonable approximation since maximum possible power generation at a power plant is a function of the reservoir storage and the rated plant capacity, where the latter is a constant and the former generally changes little with small changes in reservoir discharge rates.

Bounds of Flow Variables

If the change in flow discharge at each reservoir from specified rates Q* is not too large, then it can be expected that the approximation in equation (31) of the power generating function as a linear function of the flow rate and storage is reasonably accurate. This linearization procedure yields, of course, only an approximation to the actual problem. It is therefore necessary to bound the allowable change in the hydroelectric power flow discharge rates so that conditions do not change radically from those of the point of approximation. There is a tradeoff, however, between retaining a highly accurate approximation by allowable only small changes in flow and reduced computational efficiency. A large changes in the flow rate may allowable the solution to converge more rapidly to the optimal solution or may cause the network problem to be a poor approximation to the true problem formulation. A compromise was selected which begins with a relatively large allowable percentage flow change and uses that value until a solution is found which is more costly than the previous solution. The percentage flow change is then decreased by one half and the process repeated. Experimentally, it was established that starting maximum flow changes of 50 percent give rapid initial convergence. The algorithm terminates when the allowable flow change was reduced to less than one percent.

The bounds on the flows were restricted to be less than the allowable flow percentage change when such a flow change has the potential for changing incremental power generation between peak and nonpeak. That is, if the system peak power generation rate target for a month is 90 megawatts and the system generation is slightly less than 90 megawatts, then each power generation facility can not increase its generation in that month more than .1 megawatts since to do so might cause excessive nonpeak power to be produced.

Convergence of the Algorithm

The method described in this report is analogous to the Successive Linear Programming (SLP) technique, whereby a nonlinear programming problem is solved by a sequence of equivalent linear programs based upon linearizing the non-linear variables about successive feasible solutions. The allowable ranges of the variables are restricted to be "near" the current solution at each iteration. For the reservoir operation problem, the structure of the physical system allows further reduction in complexity of the SLP sub-problem to that of a capacitated generalized network. Recently, the theoretical properties of SLP have been studied by Palacios-Gomez (9). Based on the results reported by Palacios-Gomez and Lasdon (10) certain properties of SLP can be derived which are applicable to the iterative algorithm developed in this report. These authors report that a SLP algorithm which yields a feasible solution at each iteration will converge to a local optimum solution as the step size is reduced if the objective function is continuously differentiable. Since the operational problem structure and the Allocation algorithm satisfy these conditions, it can be proven that the algorithm will converge to a local optimum. However, the objective function in this problem is not in general convex, thus termination of the algorithm at the global optimum solution cannot be guaranteed.

Computational Efficiency of the Algorithm

The implementation of the algorithm described herein has a variety of conceptual and computational advantages over other procedures proposed to solve the long-term operational problem for surface water resources systems. By utilizing a network structure, very efficient network flow algorithms can be employed to perform the bulk of the calculations. Further, the representation of the physical system as a network provides a readily identifiable link for the analyst between the mathematical model and the physical system. In addition, far larger problems could be considered than would be possible using other techniques due to the smaller computer storage requirements for network flow algorithms.

The optimal system operation algorithm described above was coded in FORTRAN V for automated execution as part of the Water Allocation Program - SIM-V. Appendix A contains the users manual and program documentation for SIM-V.

APPLICATIONS OF THE ALGORITHM

To illustrate the capabilities of the SIM-V program, four surface water resources systems were analyzed. The initial example considers only water supply while the latter three include hydroelectric power generation.

San Antonio and Guadalupe River System

The Guadalupe and San Antonio River Basins (Figure 6) are situated in the southern Coastal Bend area of Texas. From their headwaters in the Edwards Plateau region of Central Texas, the two rivers cross the Gulf Coastal Plains and combine into a single stream shortly before entering San Antonio Bay. The average annual rainfall over the two drainage basins varies from 35 inches near the Gulf Coast to 25 inches in the area of the headwaters.

The water needs in the basins are presently supplied largely from groundwater formations underlying the region, with the principal source of groundwater being the Edwards and associated Limestone Aquifer. This underground reservoir is a water supply source for irrigation and for many municipalities, including the City of San Antonio. The Edwards Aquifer is also the source of water for the Comal and San Marcos Springs. These springs provide the major portion of the base flow in the Guadalupe River.

Canyon Reservoir is the only existing major storage reservoir in the Guadalupe River Basin. The reservoir provides both water supply and flood control storage. Six small hydroelectric dams on the Guadalupe River downstream from New Braunfels constitute the only other significant impoundments in the Guadalupe Basin.

The major reservoirs in the San Antonio River Basin include Medina Lake, providing water supply for irrigation in the San Antonio and adjoining Nueces River Basins, and Victor Braunig and Calaveras Creek Reservoirs, which are utilized for cooling water for steam-driven electric generating plants. The Olmos Reservoir north of San Antonio is used exclusively for flood control storage.

Water Supply Problem

The consumptive water requirements within the San Antonio and Guadalupe River Basins are currently being adequately supplied from a combination of surface and subsurface sources. However, with the greatly increased water demands projected for these basins, it is evident that judicious water resources management will be essential in order to fully supply future water needs.

The major demand center in the two basins is the San Antonio metropolitan area. The city and adjoining suburbs have experienced rapid population growth in the past several decades, and are projected to have greatly increased populations in the future. The area's water needs in the past have been supplied exclusively by pumpage from the Edwards Aquifer; however, this municipal and industrial pumpage added to the irrigation pumpage in the Balcones Escarpment area to the west of the city is presently approaching the average annual recharge into the Edwards formation. Should the increased future irrigation, municipal and industrial water requirements continue to be supplied from groundwater, the Edwards Aquifer will undergo drastic reductions in water levels, diminished springflows and severe deterioration in water quality.

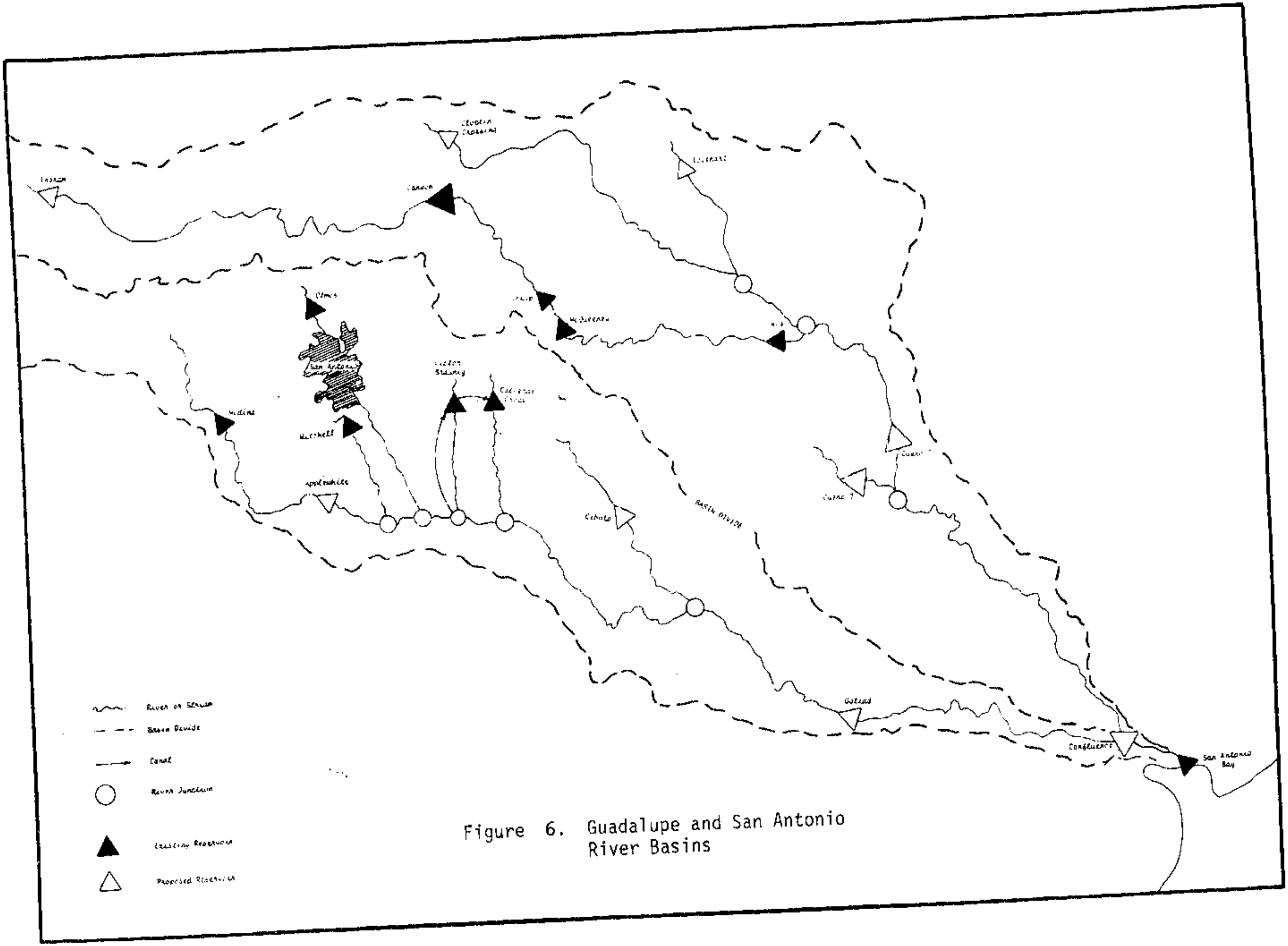

Figure 6. Guadalupe and San Antonio River Basins

As an alternative to this depletion of the Edwards Aquifer, the Texas Water Plan (13) has proposed the development of a conjunctive ground and surface water resources system to supply the San Antonio area. The plans calls for limiting San Antonio pumpage to 215,000 acre-feet annually, and supplying the remaining water requirements with surface water conveyed through pipelines from a system of reservoirs in the San Antonio and Guadalupe River Basins.

Network Representation and Solution

The application of the SIM-V Program to a given water resources system requires that the significant elements in the physical system be assigned to corresponding elements in a network model. For the San Antonio and Guadalupe River Basins, the associated network model is illustrated in Figure 7.

The SIM-V program was used to analyze the operation of a particular system of proposed reservoir and pipelines consisting of the proposed Cuero (Stages I and II) and Cibolo Reservoirs, and interconnecting pipelines between the two reservoirs and between Cibolo and San Antonio. Projected water demands for the years 2000 to 2010 were imposed upon the system, with the hydrology corresponding to that of the critical drought period from 1947 through 1957. The eleven year time horizon was analyzed by a succession of monthly network solutions.

The efficient application of SIM-V to establish the long-term optimal operation this water system, as well as other complex systems, depends upon anticipating hydrologic conditions many months or years in the future. This may be achieved by applying the Water Allocation Program AL-V (8) to the operation of the system. AL-V solves the same problem as SIM-V except over many time periods simultaneously. To achieve the system operation offered by solutions given by AL-V, it is necessary to translate the "perfect knowledge" solution into desired monthly storage targets for the SIM-V single-period model. Since SIM-V can not see a future drought, it is necessary to restrict the use of waters from some reservoirs when storage falls below seasonal levels desired in the AL-V solution. It was found that seasonal target storages could be developed through examining graphical plots of the optimal storage levels derived by AL-V.

Examination of the graphical plots of storage in the significant impoundments during the critical period should reveal two characteristic features needed to determine monthly storage targets and unit storage benefits: (1) seasonal variations with the year and (2) storage withdrawal priorities between reservoirs within the system. The first characteristic provides some indication of the desired target storage levels needed to compensate for seasonal variations in runoff and water demands. The storage plots based upon the AL-V optimal solution may not indicate for every reservoir a consistent seasonal storage pattern. However, this lack of seasonal pattern will generally occur for reservoirs that either release water first when water is needed within a system or are used as a final reserve in the last few seasons of the critical period. In either case, the storage retention policy of AL-V can be followed in SIM-V by the appropriate selection of a unit storage benefit.

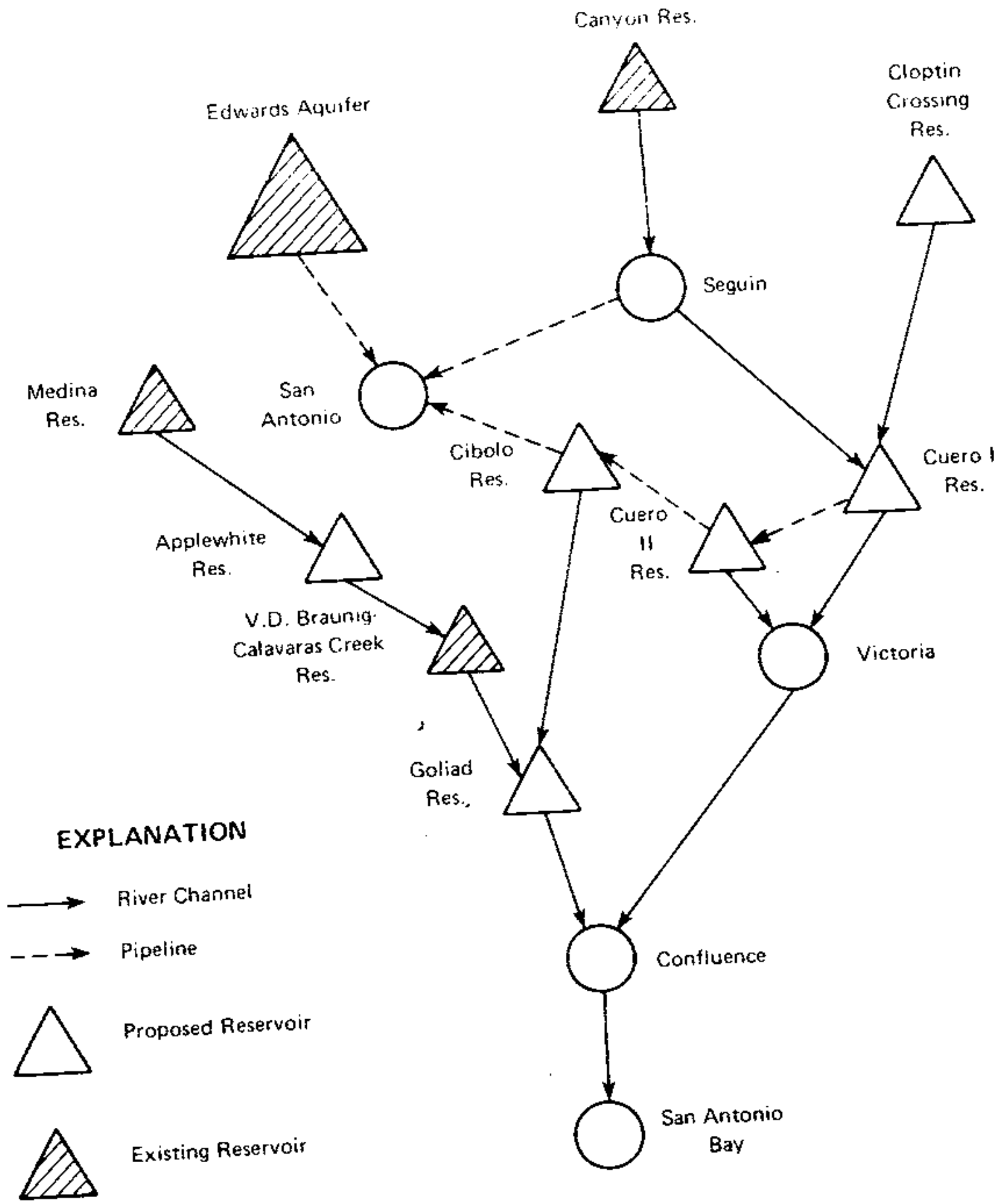

Figure 7. Network Representation of the San Antonio-Guadalupe River System

The unit storage benefit for water storage up to a specified (target) storage volume allows for the desired sequential selection of the reservoirs to make releases. That is, the AL-V policy for a system will generally call upon certain reservoirs to release flow to meet demands prior to other reservoirs doing so. Thus, whenever the normal releases do not meet target demands for hydroelectric power generation or water supply needs, water must be released from storage to satisfy those needs. The selection of a sufficiently larger unit storage benefit for one reservoir over another will cause water to be released from storage in the reservoir having the greatest net benefit for flow discharge. The value of the unit benefit need not correspond to an identifiable economic measure. It may be necessary to adjust the unit target storage benefits several times before the proper coordination of releases is achieved. This occurs since the benefit for flow releases particularly for hydroelectric power generation, varies with the storage level and release rate. Further, the flow released from one reservoir may be passed through additional reservoirs, thereby providing a much larger net flow release benefit than may be apparent. It is suggested that reasonable variations in unit benefits be tried initially to achieve the proper distribution of flow releases. Options are possible in SIM-V so that the reservoir target storage benefits may be temporarily reduced if it is necessary in a particular time period to release more water, than would otherwise be discharged, to meet the target peak power generation rate. SIM-V allows some reservoirs to be independent of the system by having a high unit storage benefit, while allowing others to hold water in reserve for release when other reservoirs cannot meet the need.

It is recognized that the procedure indicated above is not a rigorous, precise means of determining target storage levels. It would, of course, be preferable to have a self-generated set of target storages from the AL-V program. However, since the Allocation program is manipulating the system with complete freedom, it is unlikely that a single set of target storage levels for each reservoir would properly explain the optimal policy. It is to be expected that the complicated allocation of water by AL-V will not fit into a simplistic, static set of storage retention policies.

The network flow solution for the Guadalupe-San Antonio system obtained by AL-V (8) indicated that the optimal policy was to use water from Cibolo Reservoir without pumping water from Cuero II, thereby reducing the storage in Cibolo to near its lowest limit. However, when the storage in Cibolo had dropped to less than 60 thousand acre-feet (30 percent of capacity) then the optimal policy was to pump water from the Cuero II project at the maximum possible rate. The simulation using SIM-V indicated that the water needs in San Antonio were met with little excess reservoir storage remaining at the end of the drought utilizing this operating policy.

The application of AL-V to the San Antonio-Guadalupe system utilized information concerning the long term (10 year) desired end-of-year reservoir storages derived by the TDWR Capacity Expansion Model DPSIM-I (15). This was necessary since the drought period is approximately 8 years in length, which is longer than the 4 year maximum time horizon for each network model in AL-V. DPSIM-I and AL-V are designed to be complementary programs.

The SIM-V solution to the Guadalupe and San Antonio River systems required 30 seconds of execution time on the Texas Department of Water Resources (TDWR) Univac 1100/41 Series computer.

Shasta-Folsom System

To illustrate the SIM-V Model application for systems of reservoirs with water supply and hydroelectric power generation, the problem of the operation of Shasta and Folsom Reservoirs in Northern California described by Hall, and his associates (4) was coded and executed using SIM-V on the TDWR UNIVAC 1100/41 Computer System. These two reservoirs were assumed to operate separately to meet individual water supply demands and minimum monthly streamflows, but jointly to meet a single power generation need. The network spatial representation of the system is given in Figure 8. The inflow, evaporation and water demand data on a monthly basis consisted of the same data as utilized by Hall (4). The simulation period covered twelve years, with the hydrologic data corresponding to the drought period 1924-1935.

The electric generating characteristics of the system were represented somewhat differently in the SIM-V model than was presented by Hall and his associates. However, the system characteristics were incorporated into the SIM-V input data format as consistently as possible with the published relationships given by Hall.

The combined firm power generation from the two reservoirs was computed for annual water demands of 3.5 million acre-feet and 700.0 thousand acre-feet from the Shasta and Folsom reservoirs, respectively. The maximum rate of power generation calculated using SIM-V amounted to 504 megawatts (MW) of peak generation, compared to 503.8 MW computed by Hall. The maximum rate of 504MW was derived by iteratively increasing the rate of generation until the system could no longer meet the generation target.

The SIM-V analysis utilized a previous application of AL-V to provide monthly reservoir operating rules for this system (8). The procedure described in the previous section on the Guadalupe-San Antonio system for establishing target storages was applied to the Shasta-Folsom system and resulted in monthly reservoir target storage levels. Examination of the monthly storage levels calculated by AL-V in simulated year 1934 (see Figure B-1 in Appendix B) provided the initial target storages. Simulated operation using SIM-V under these targets gave shortages in meeting the target generation rate of 500MW because insufficient water was stored in the primary power generating facility, Shasta. The Shasta storage targets was increased and the Folsom targets adjusted generally lower during several further simulation runs until the 500MW firm generating target was satisfied. The firm power rate was raised to 504MW, which the system generated, but with very little excess capacity. The final target storage levels, as decimal fractions of the maximum conservation storage capacity, for Shasta are .8, .8, .95, .95, .95, .85, .75, .70, .50, .50, .50, and .50 in January through December respectively. Folsom's target storage fractions are .56, .60, .60, .61, .56, .48, .4, .33, .33, .33, .33, and .33. The unit storage benefit for both reservoirs was set at $10 per acre-ft., however the reservoirs were simulated under the operating policy that successively, in each month, reduced the unit benefit by $1/acre-foot until full peak power generation was achieved or the benefit went to zero.

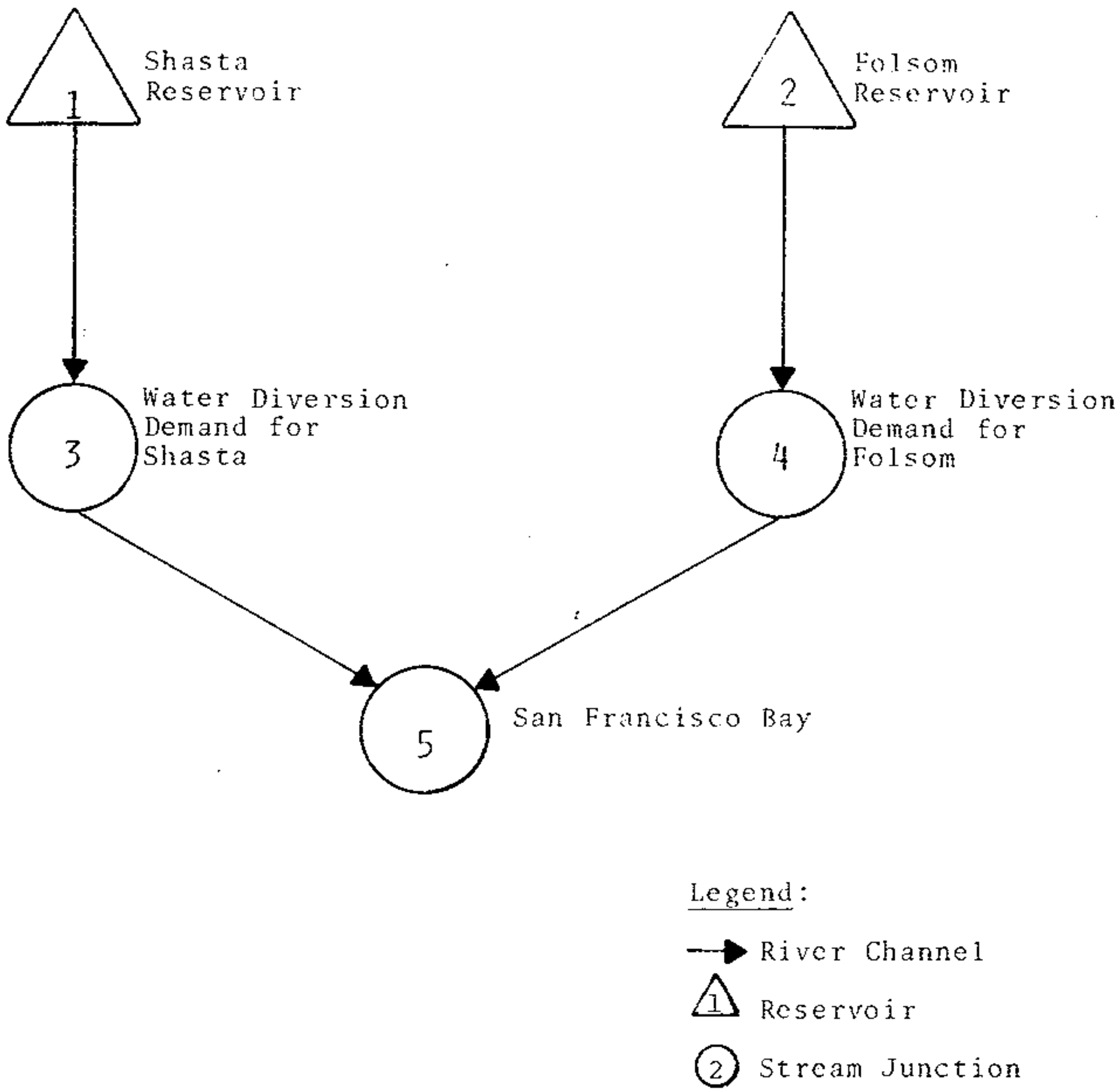

Figure . Network Representation of Shasta-Folsom Reservoir System.

The monthly firm and secondary energy generation computed by SIM-V for the two reservoirs is indicated on Figure 9. The optimal monthly storages calculated by SIM-V are depicted in Figure 10.

Execution of the SIM-V program required approximately 18 seconds of execution time for the solution of the 12 year simulated operation for a given level of target hydroelectric power generation, using network models consisting of monthly periods.

White River System

Another application of the SIM-V program was the analysis of the operation of five reservoirs (Beaver, Table Rock, Bull Shoals, Norfork, and Greers Ferry) on the White River and adjacent tributaries in northeastern Arkansas and southwestern Missouri. These reservoirs provide storage and releases for flood control, water supply and hydroelectric power generation. In addition, the reservoir system must release water to maintain a flow rate in the lower White River of at least 3000 ft^3/sec. The White River Reservoir system is part of the Southwest Power Pool Reservoir System in the Arkansas, White and Red River Basins (Figure 11) studied by Claure-Pereiro (2).

Data describing the White River system was obtained from a published report of the U.S. Army Corps of Engineers (3) and modified to fit into the SIM-V input data format. A schematic of the network model of the system is shown in Figure 12.

To develop monthly target reservoir storage levels and associated unit storage benefits for the optimal operation of the White River System, it is necessary that the results of the AL-V simulation (8) of the system be examined in detail. Particularly, a graphical plot of the end-of-month storage levels determined by AL-V is needed. Examination of the AL-V optimal storage levels for the five reservoirs (see Figure B-2 in Appendix B) gives an indication of the factors affecting storage retention. The plot indicates that Beaver Reservoir is consistently kept well below its conservation storage level throughout the years of simulation. Beaver is not allowed to refill except after maximum storage is attained in all the other reservoirs. It is also noted that storage in Table Rock is reduced before water is withdrawn from storage in Bull Shoals. This may be noted particularly in years 1953 through 1956 in the summer and autumn seasons.

Seasonal patterns of fluctuating storage are evident in all the reservoirs except Bull Shoals. To incorporate seasonally varied reservoir storages as target storages, values should be selected that correspond to the storage that is required at time of minimum storage (i.e., the height of the drought). Note that the system experiences minimum storage in the reservoirs in 1954. Therefore, the initial selection of seasonal target storages corresponded to the storages needed during that year. Subsequent changes in the target levels are discussed below.

A unit benefit value of $10 per acre-foot was selected as a tentative unit benefit for reservoir storage at or below the target monthly storage levels. All reservoirs were operated under the option which repetitively allowed for the unit storage benefit to be reduced by one unit and the solution to the systems operation to be computed until all of the unit benefits have a value of zero. Thus the unit storage benefit of a reservoir would not

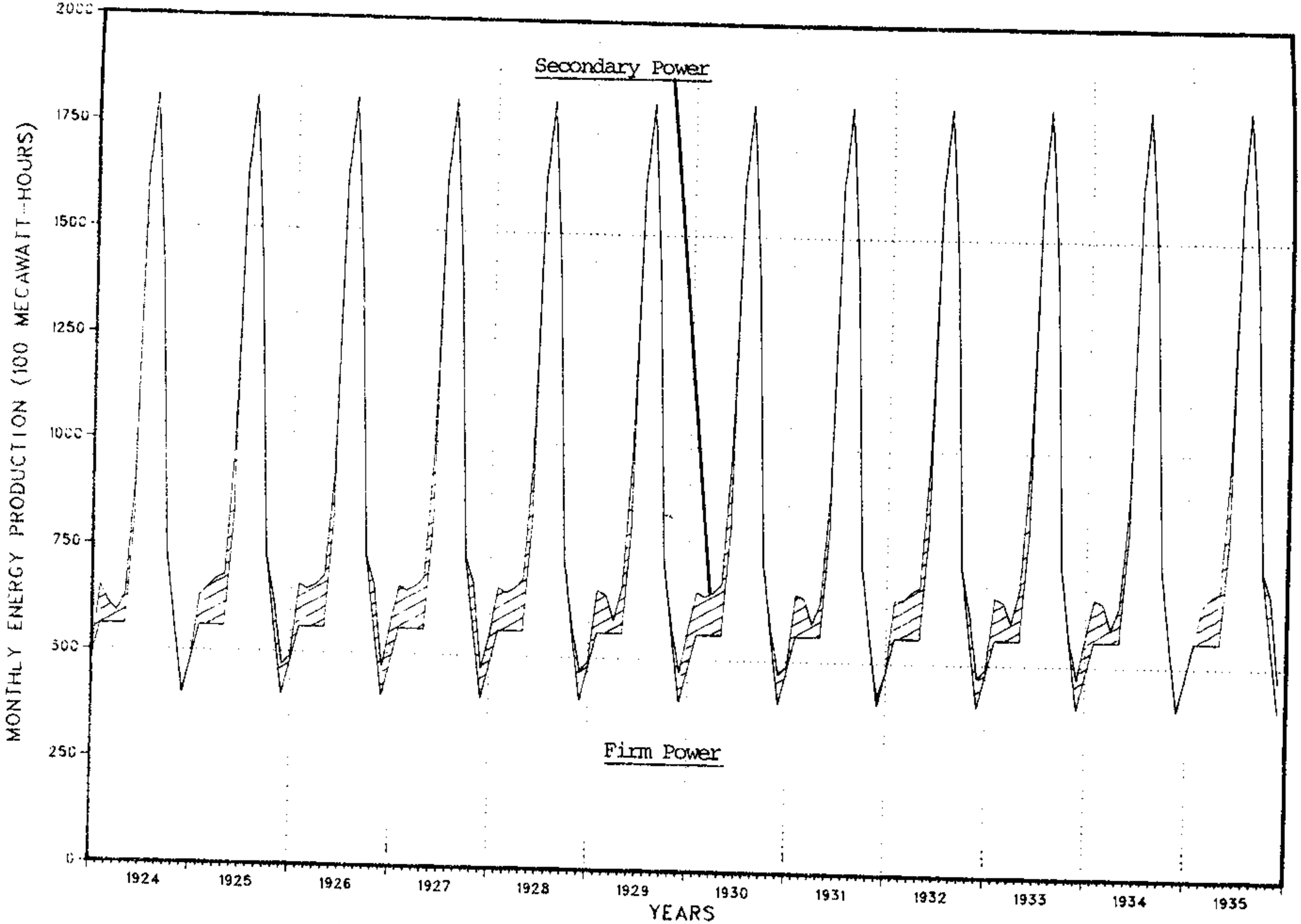

Figure 9. Energy Generation for Shasta-Folsom System.

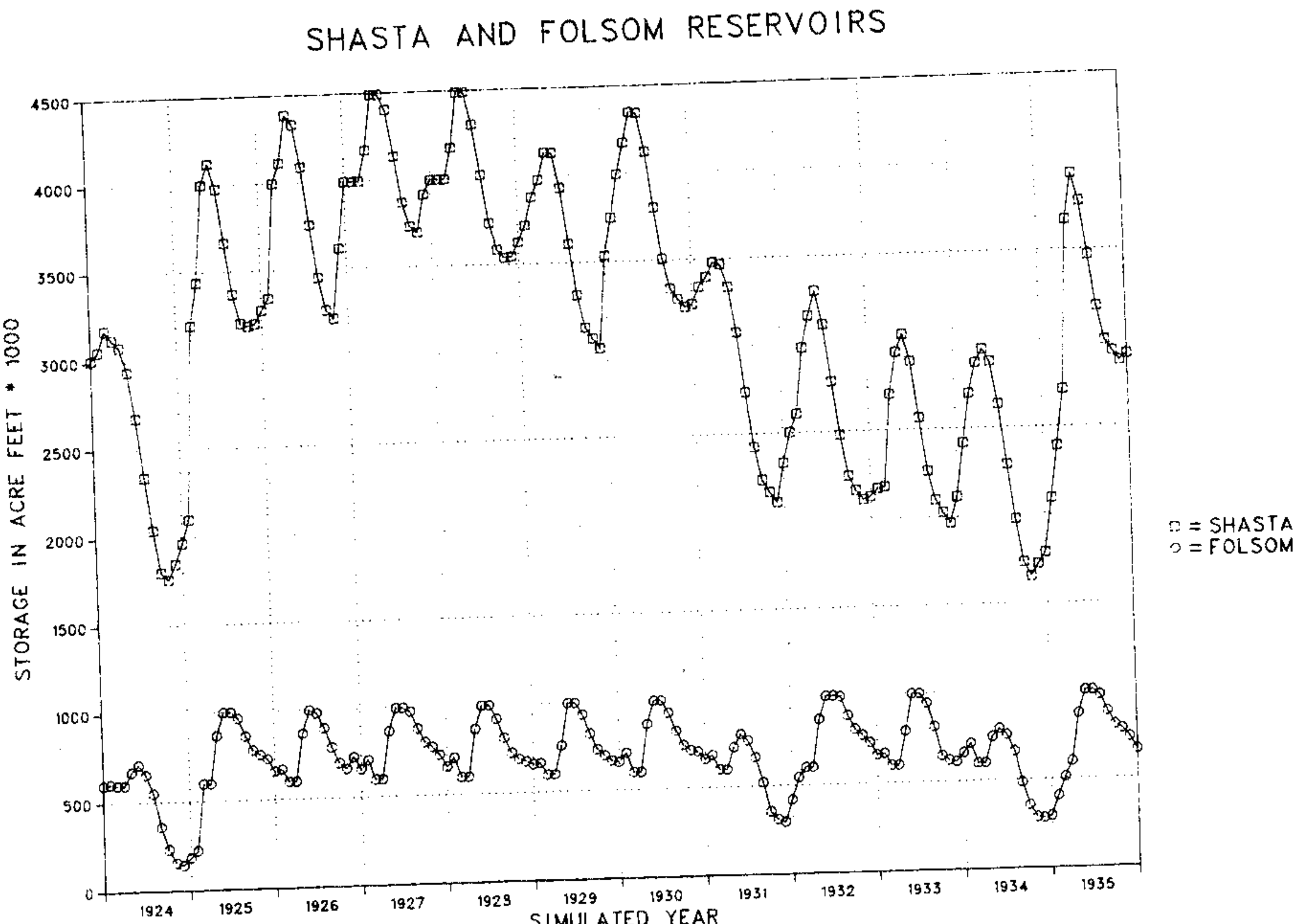

Figure 10. Optimal Monthly Storage Levels for Shasta and Folsom Reservoirs (Under Power Generation Rate of 504 MW).

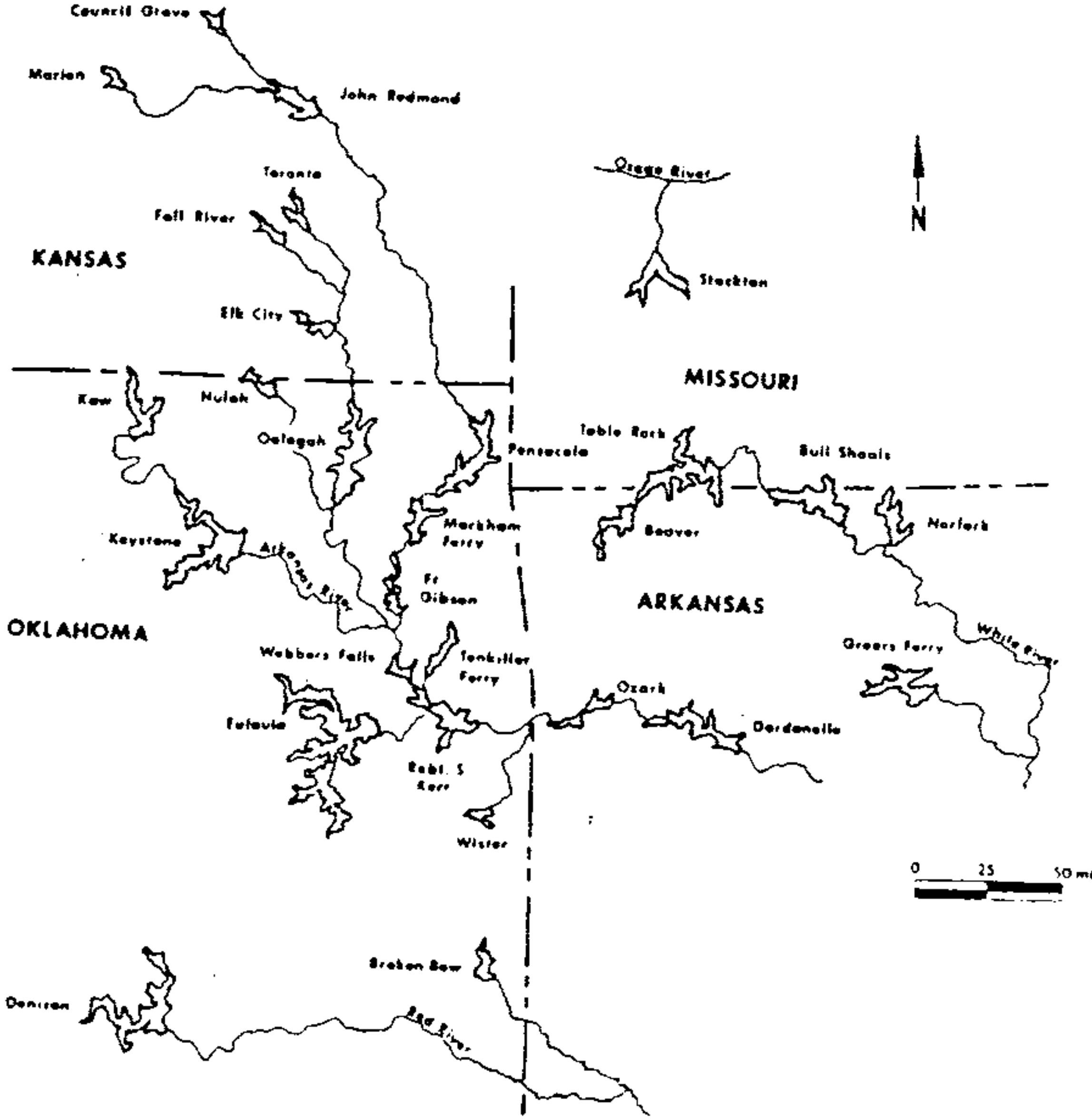

Figure 11. Southwest Power Pool Reservoir System
(Source, Ref. 2)

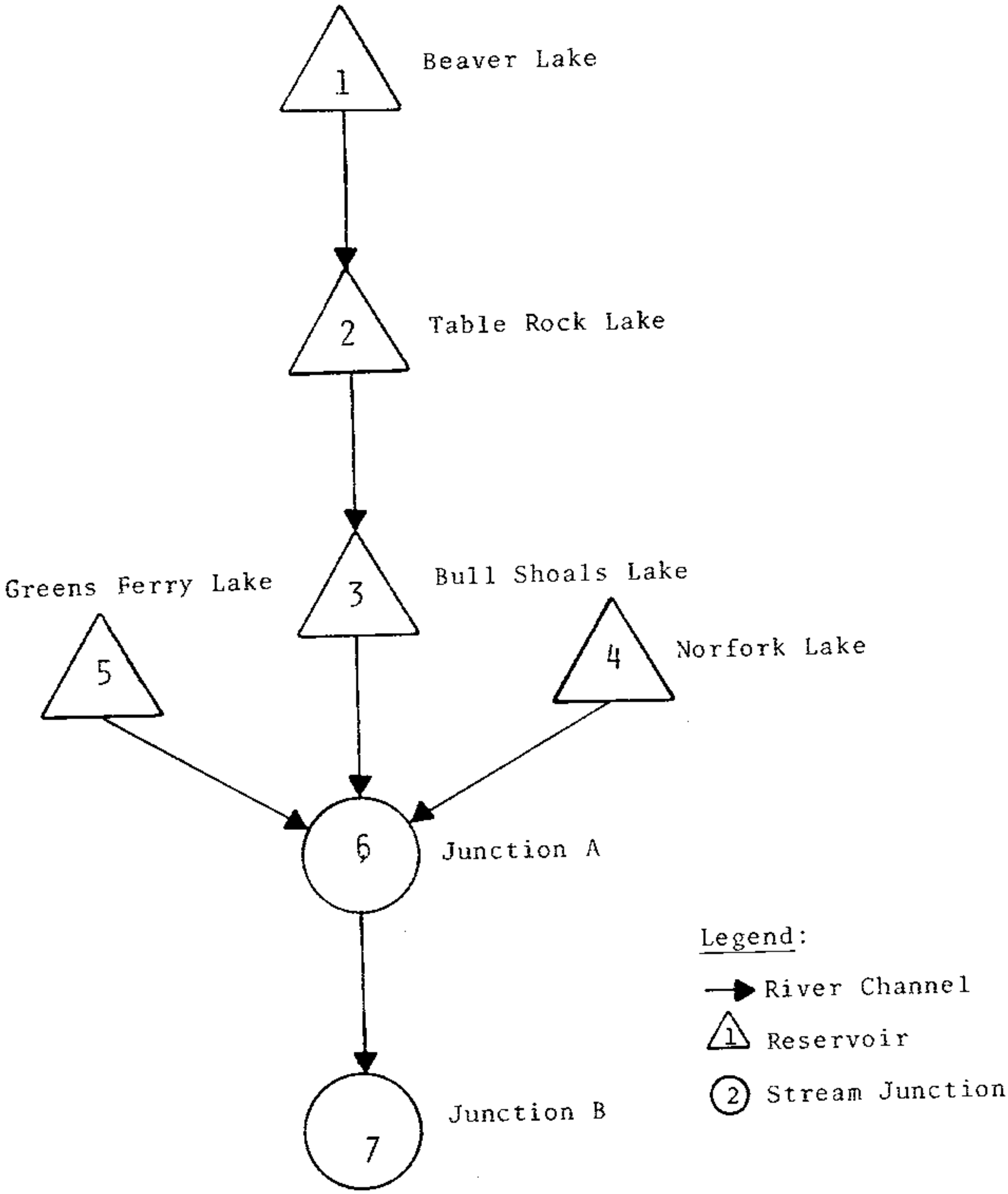

Figure 12. Network Representation of White River System

keep the reservoir from releasing waters for hydropower generation if such waters are needed.

Examining the optimal storage levels (Figure B-2) during 1954 indicates that Greers Ferry and Norfolk were the first reservoirs to experience reductions in storage, followed by Beaver and Table Rock one month later. Bull Shoals was the last reservoir to be called upon the release flow from storage. The storage levels of Bull Shoals Reservoir fluctuate more than those of the others and were smoothed out in the month of August to be equidistant between the July and September storage levels. It is clearly evident from examining the plot of reservoir storages that Beaver is characteristically held far below its conservation storage level throughout the critical period. This allocation of water essentially allows storage in Bull Shoals and Table Rock to be held close to maximum capacity.

The SIM-V program was executed iteratively using a succession of monthly periods to determine the annual firm power available from the five reservoirs operated as a system. Five years of monthly operations were executed covering the critical hydrologic period of 1953 through 1957.

The operation of the system was first simulated using SIM-V with a system demand of 1600 total megawatts (the sum of the monthly generating rates) from the system annually. Examination of the resulting optimal storages indicated that a smoothing of the Bull Shoals reservoir targets from December through January would provide a more realistic operating plan. The finalized target storage levels for each month are given by reservoir in Table 1. The simulated operation of the system was able to adequately meet the above power demand from the system. Further, storage retained in the reservoirs indicated that further additional power could be generated from the system.

The White River reservoir system was again simulated using SIM-V with a revised total power demand of 1800 megawatts. The system met the power generation needs without shortages and with only minimal usable storage left in the system reservoirs at the most extreme drawdown month of November 1954. The small amount of storage left in the system clearly indicated that very little additional power could be generated over the 1800 megawatt firm generation requirement. This generation rate without shortages compares very favorably with the maximum generation of 2000 megawatts derived from AL-V (8). The Corps of Engineers estimated schedule of power generation from these reservoirs totals some 950 megawatts annually, thus the simulated operation policy developed by SIM-V provides almost a doubling of the firm power available from the system. It is to be expected that other considerations, such as recreation, may influence reservoir release policies. However, the benefit for such recreational considerations can only be compared with the reduced revenue from other purposes, such as water supply hydroelectric power generation if the maximum of the latter benefits is known. Thus, the tradeoff for other purposes can be more adequately assessed if the total benefit for the primary project purposes are calculated.

The monthly production of firm and secondary power for the system over the critical period is given in Figure 13. The optimal monthly storage levels for each reservoir are indicated in Figure 14.

Table 1. Monthly Target Storage Levels for White River System Reservoirs (in Thousands of Acre-Feet).

Month	Reservoir				
	Beaver	Table Rock	Bull Shoals	Norfork	Greers Ferry
January	1110	2000	2410	900	1700
February	1210	2000	2200	950	1800
March	1210	2110	2290	1000	1800
April	1210	2110	2410	1000	1800
May	1160	2350	2410	950	1800
June	1010	2410	2440	950	1800
July	840	2110	2500	950	1600
August	790	2000	2560	800	1510
September	790	1590	2590	800	1200
October	790	1590	2410	800	1200
November	890	1590	2350	800	1200
December	1010	1590	2410	800	1200

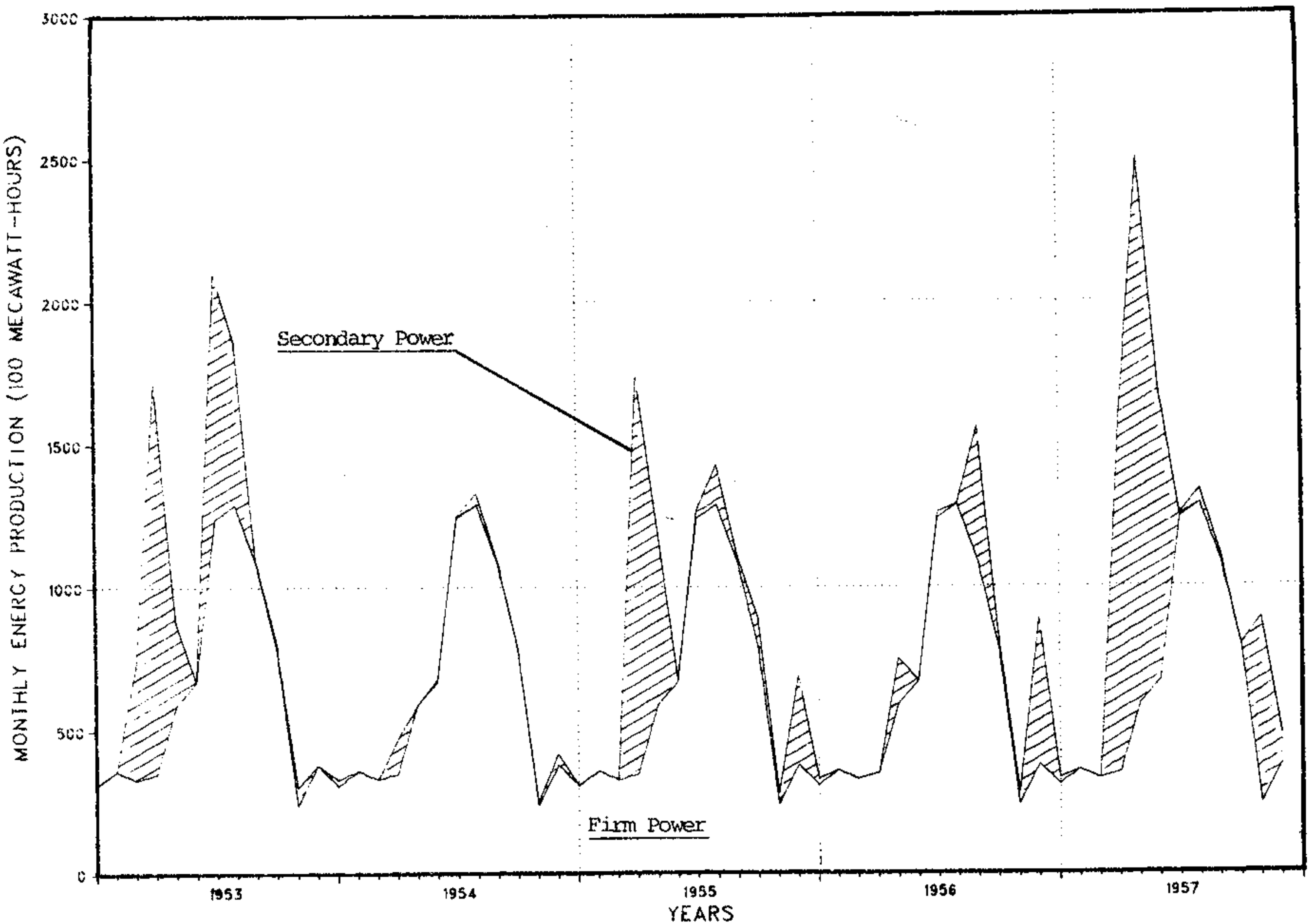

Figure 13. Energy Generation for White River System.

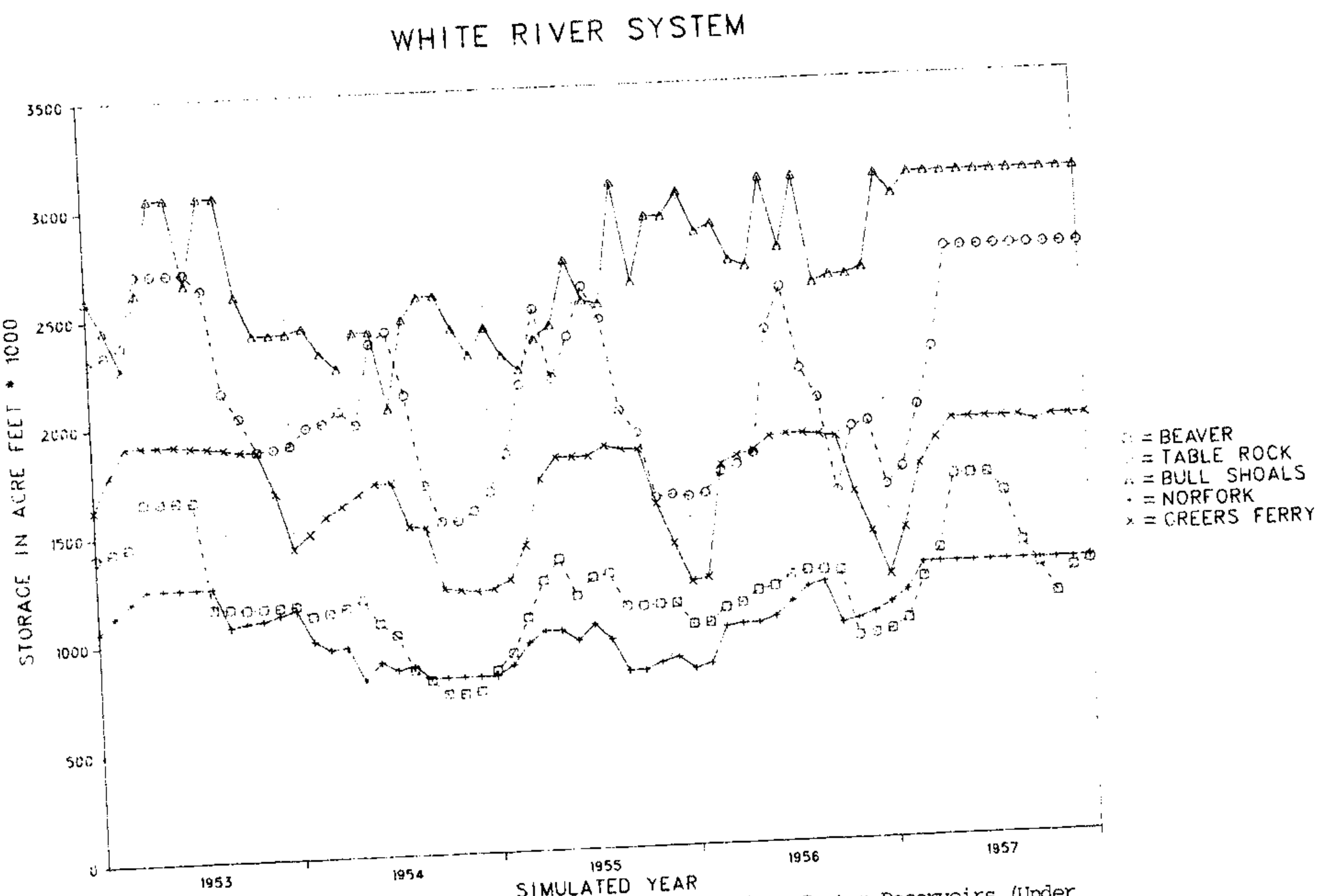

Figure 14. Optimal Monthly Storages Levels for White River System Reservoirs (Under Average Monthly Power Generate Rate of 150 MW [1800 MW Annually]).

Execution times averaged approximately 20 seconds, for each five year simulation at a given target power generation level, on the TDWR UNIVAC 1100/41.

Arkansas, White and Red River System

The SIM-V program was further utilized to analyze the operation of a large scale multi-river basin water supply, navigation and power generation system. The surface water system considered was the Arkansas, White and Red River Basins in Texas, Arkansas, Oklahoma, Missouri, and Kansas (Figure 11). These projects and their spatial inter-connections are represented as a network (Figure 15). This system has been studied extensively by state and federal government organizations (1, 2, 3) and the reader is referred to (2) for a more detailed description of these basins.

It is desired to analyze the reservoir system to determine the maximum power that can be generated without violating minimum flow requirements and water diversion demands throughout the system. Hydroelectric power generating facilities occur at 12 reservoirs in this system. Two of these projects are owned by private interests, but were included in establishing the optimal operation for power generation. Based upon prior studies, the critical period of historical hydrology corresponds to the period 1953 thru 1957. By simulating the operation of these projects over this 5 year period, the response of the system to demands for power and water during the critical drought period may be assessed.

The network model of the multiple river basin system consists of 30 nodes, 27 of which are reservoirs, and 28 links, of which all are natural channels. Monthly operational periods were added for analyzing the system preformance. The water demands, minimum flow requirements, and seasonal power generation distribution were those given by Claure-Perrira (2).

A prior application of AL-V to this system (8) provided optimal seasonal water storage levels over the five year critical period (see Figure B-3 in Appendix B) under a monthly average peak power generation rate of 324MW. Analysis of the seasonal storages calculated by AL-V led to the selection of seven key reservoirs to have monthly varying target storages. These were Broken Bow, Oologah, Eufaula, Tenkill Ferry, Beaver, Bull Shoals, and Greers Ferry. The remaining reservoirs had target storages equal to their maximum conservation capacities for all months. Several simulations were needed to refine the monthly target levels and unit storage benefits to their final values (Table 2). The resulting maximum firm power generation rate for the system amounted to a monthly average of 316MW, or 8.1 percent greater than that given by Claure. The details of the data used in analyzing the AWR system are given in the sample output sections in Appendix A. The optimal monthly reservoir storages calculated by SIM-V are given in Figures 16a and 16b.

Execution time for each simulation of the five year period required approximately 2 minutes on the TDWR UNIVAC 1100/41.

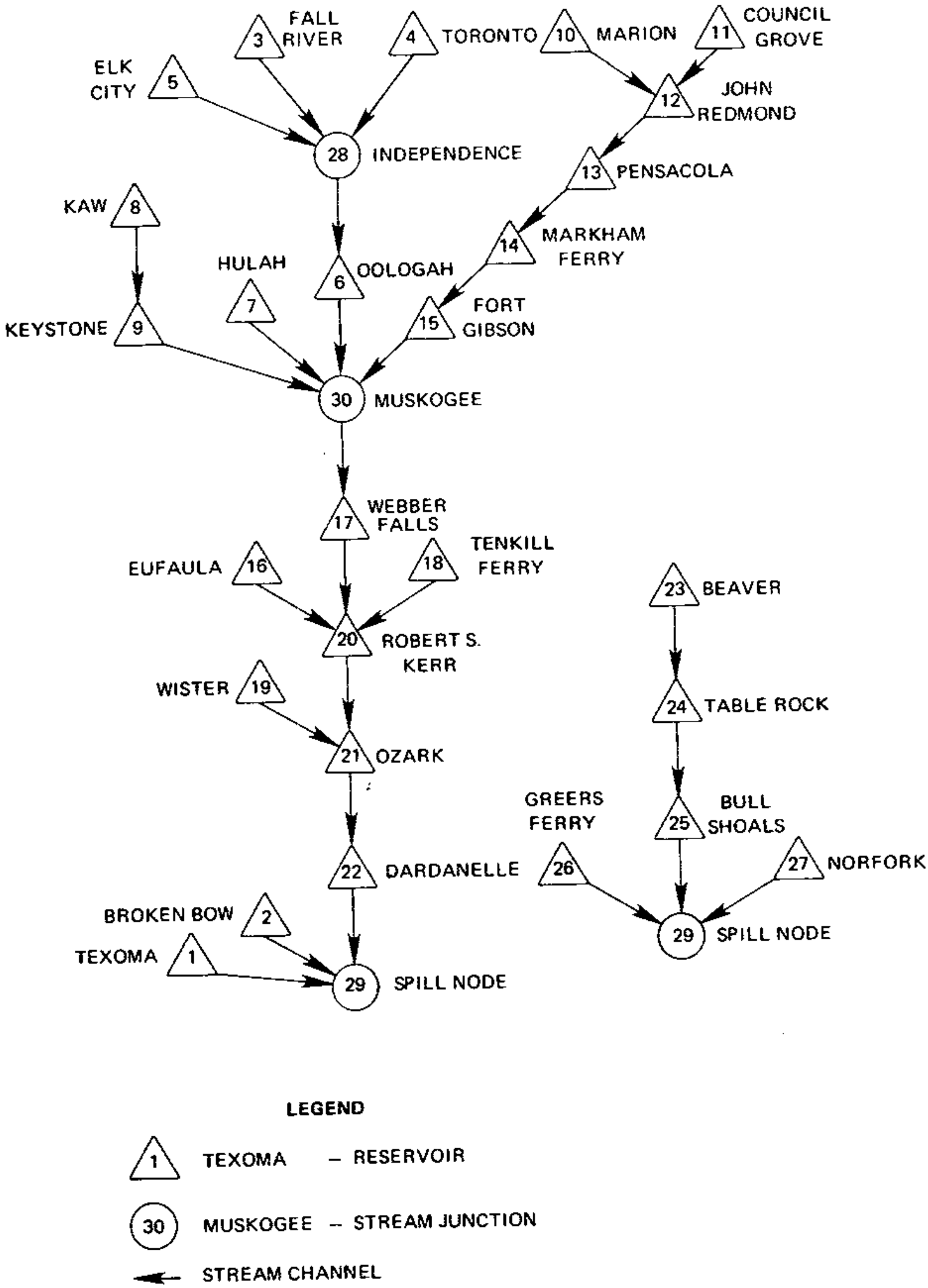

Figure 15. Network Model of Arkansas-White-Red River System.

Table 2. Monthly Target Storage Levels for Arkansas-White-Red River System Reservoirs (in Thousands of Acre-Feet).

Month	Reservoir a/						
	Broken Bow	Oologah	Eufaula	Tenkill Ferry	Beaver	Bull Shoals	Greers Ferry
January	510	140	1930	460	1040	2410	1340
February	550	140	1900	500	1040	2530	1410
March	610	140	1740	530	1040	2620	1470
April	660	140	1550	550	1040	2740	1550
May	710	140	1380	580	1040	2830	1620
June	720	140	1710	520	1170	2740	1620
July	730	140	2050	470	1310	2650	1620
August	730	140	2380	400	1450	2530	1620
September	640	140	2260	400	1320	2410	1490
October	540	140	2120	400	1190	2290	1360
November	440	140	1970	400	1040	2130	1200
December	480	140	1950	430	1040	2010	1260

a/ The remaining reservoirs in the system had monthly target storages set equal to their maximum conservation storage capacity.

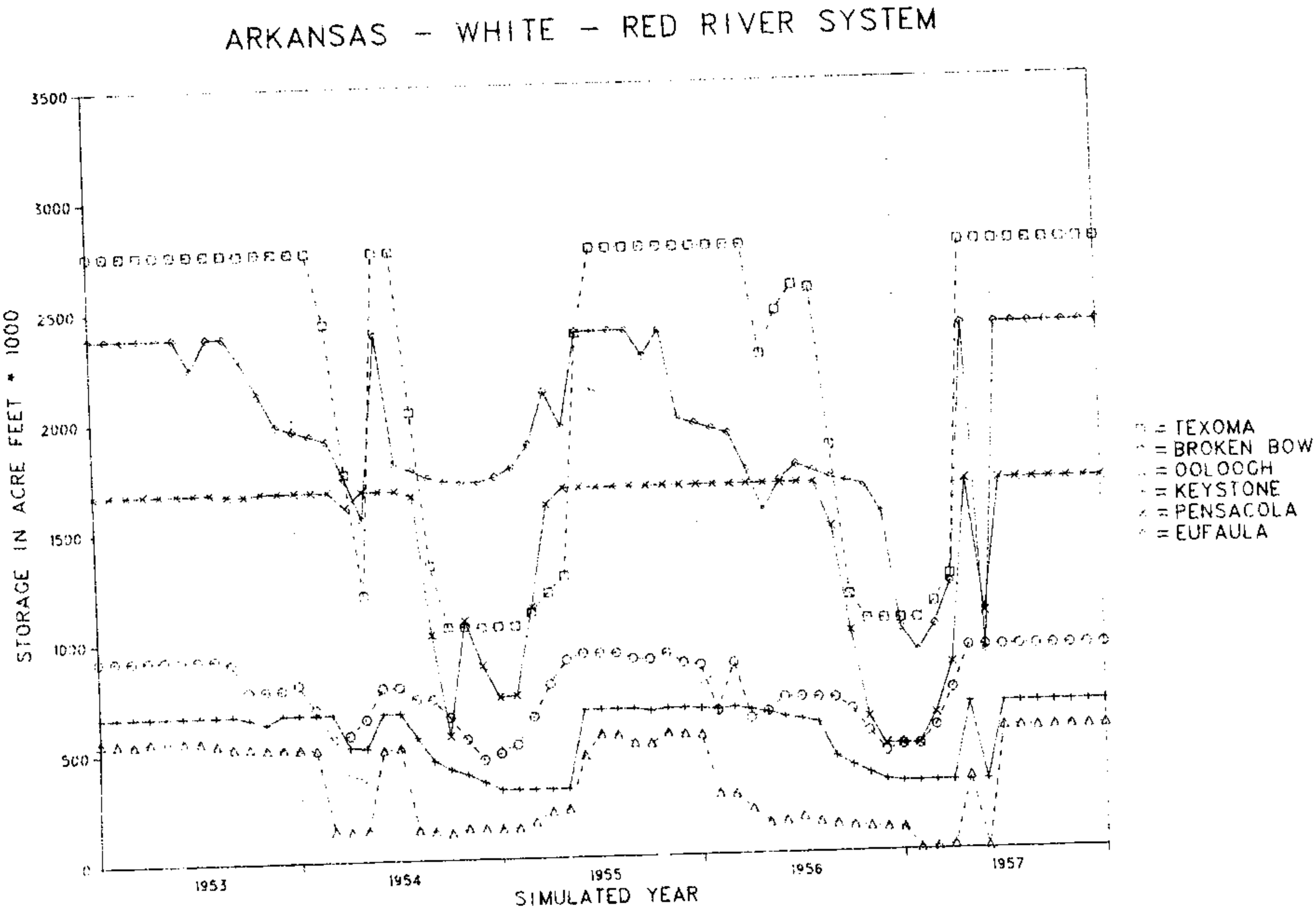

Figure 16a. Optimal Monthly Storages for Twelve Major Reservoirs in the AWR System (Under an Average Monthly Power Demand of 316 MW (Continued)).

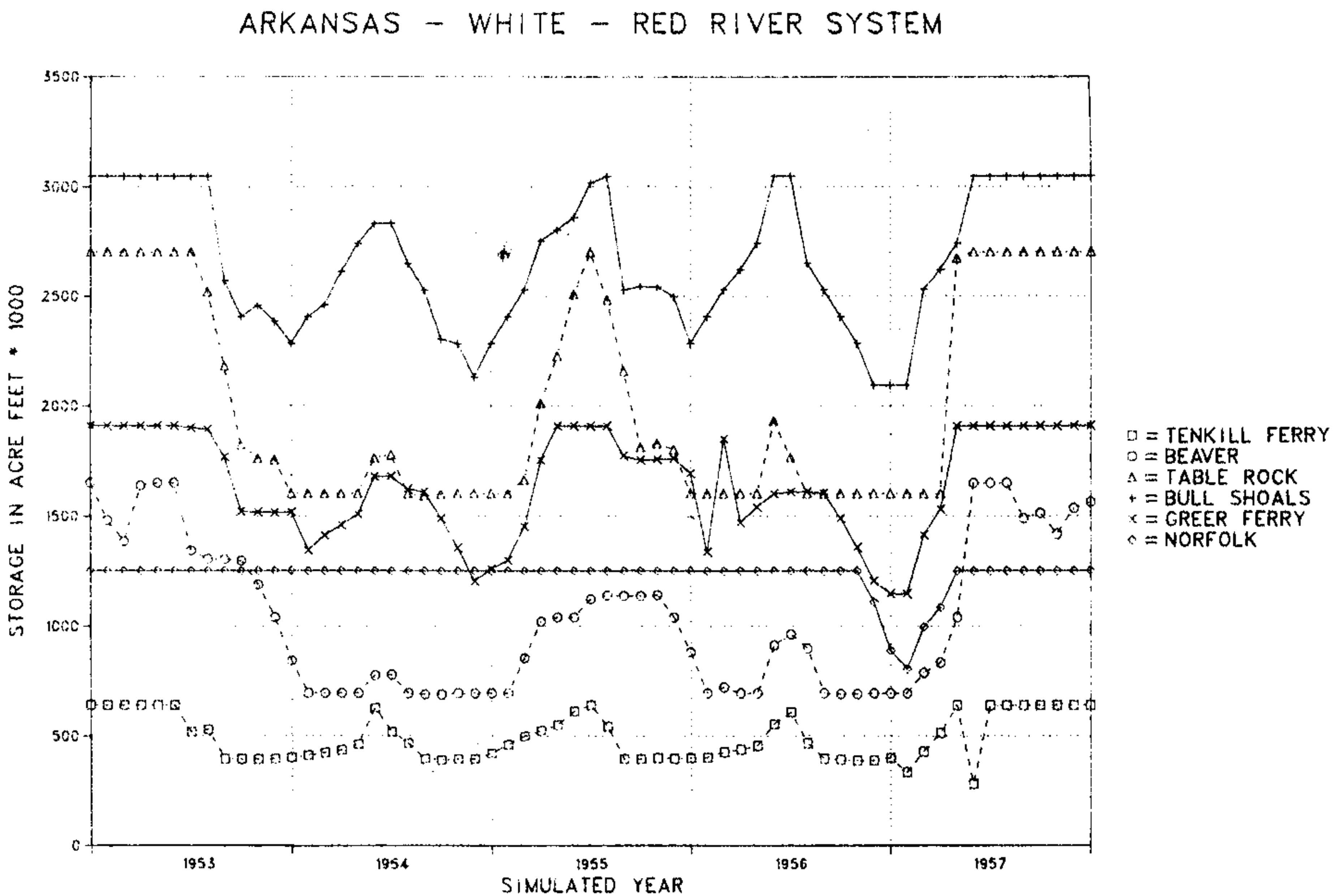

Figure 16b. Optimal Monthly Storages for Twelve Major Reservoirs in the AWR System (Under an Average Monthly Power Demand of 316 MW (Continued)).

Operational Forecasting Using SIM-V

The procedure described previously and coded into the SIM-V program could be used not only to analyze the optimal long-term operating policies but also could be used to implement those policies on a weekly or monthly basis. Conceptually, at the beginning of each time period, projections of water demands, power requirements, and inflow characteristics or quantities could be inserted into a data file consisting of a single period. SIM-V would then be executed using the optimal monthly target storage and benefit for each reservoir and the resulting optimal discharges and reservoir storages could be computed. Sensitivity of the optimal policy to changes in demands and inflows could be executed by varying the inflow quantities depending upon the anticipated probability of their occurrence. Thereby any number of simulations could be executed and the risk associated with the optimal policy could be considered in determining a final control policy for actual implementation.

SUMMARY AND CONCLUSIONS

A computational procedure has been developed to solve the problem of obtaining the best short-term, steady-state operation of a surface water resources system so as to meet the purposes of water supply, streamflow maintenance, and hydroelectric power generation, while satisfying within operational constraints for the system. The procedure is based upon the representation of the operation of a general surface water system of reservoirs, stream junctions, natural waterways, pipelines, and canals, under deterministic hydrologic and water demand conditions, as a network flow problem. The incorporation of hydroelectric power generation benefits are undertaken by solving successive minimum-cost network flow problems, where flow bounds and unit costs are modified between successive iterations to reflect first order changes in hydroelectric power generation with flow release rates. The procedure is shown to converge to a stationary or local optimum solution. Convergence to the global optimum could not be guaranteed since the benefit function is not convex.

The algorithm, as coded in the SIM-V program, was applied to four surface water systems, thereby demonstrating the flexibility and generality of the model to solve for the optimal operation of general surface water systems. Significant increases in system production in hydroelectric power generation were calculated for the White River and the Arkansas, White, and Red River systems. The latter system had a computed increase of 8 percent in the estimated maximum annual firm power generation.

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ACKNOWLEDGMENTS

The water supply allocation model, SIM-V, was adapted from previous versions of the model. The Network-With-Gains algorithm was developed by Dr. Paul Jensen of the University of Texas at Austin and Dr. Gora Bhaumik of the University of California at Fullerton. A source deck of the GAIN and PRIMAL Programs were graciously provided by Dr. Jensen. Mrs. Donna Tiemann of the Engineering and Environmental Systems Section typed and assisted in editing the manuscript. Mr. Nick Carter of the Engineering and Environmental Systems Section assembled the program documentation. The author wishes to express his thanks to Dr. W.W.G. Yeh for providing the monthly inflow and net evaporation data for the Shasta-Folsom System.

APPENDIX A

SIM-V PROGRAM DESCRIPTION

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MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL

PURPOSE

The multireservoir simulation program, SIM-V, is a general hydrologic model of surface water resources systems. It is designed to analyze the simulated multi-period operation of any interconnected configuration of reservoirs, hydroelectric power generating plants, pump and gravity canals, and pipelines on a steady-state monthly or seasonal basis. The program may be utilized, by itself or in conjunction with the AL-V program (4), to find:

1) the minimum cost operating plan for a system of reservoirs, river junctions, canals and river reaches or;

2) the minimum cost sizing of individual reservoirs, canals, or closed conduits;

CONCEPTS

The general concept behind this program is to describe the structure of a surface water resources system in terms of a network flow model. The minimum cost operation of the prototype system is thus established by solving the associated network representation for the least costly set of flows through the network. A solution is produced for a finite time interval (usually one month) and the analysis moves forward in time in a stepwise fashion until the desired time period is covered. The structure of this network model is described in the following paragraphs.

First, the physical system is represented in space by a node-link configuration. For the physical system, nodes represent either storage reservoirs or nonstorage link junctions, and links portray either river reaches, pipelines, or canals. An example of such a spatial representation is shown in Figure 4. This example system consists of ten nodes (eight reservoirs and two link junctions) and eleven links (two canals and nine river reaches). All reservoirs that do not have a river reach leaving them must have an outlet for spilling any excess water that enters them. These spills leave the network and are no longer available for use.

This system network still does not completely represent the network flow problem. The system must have initial reservoir storage contents; inputs to and demands from the system must be made; imports must be allowed to enter and spills must leave; and allowance be made for the final reservoir storage contents. However, all of these considerations are accommodated by adding additional arcs and nodes. The complete network, including these arcs and nodes, is as shown schematically in Figure A-1. The user is required only to specify the system network and SIM-V will automatically create the necessary additional nodes and arcs.

Initial storage contents and unregulated inflows enter the system through a set of arcs that are connected to all storage and junction nodes. Since the inflows are input data, the "inflow arc" flows are fixed and are not system variables.

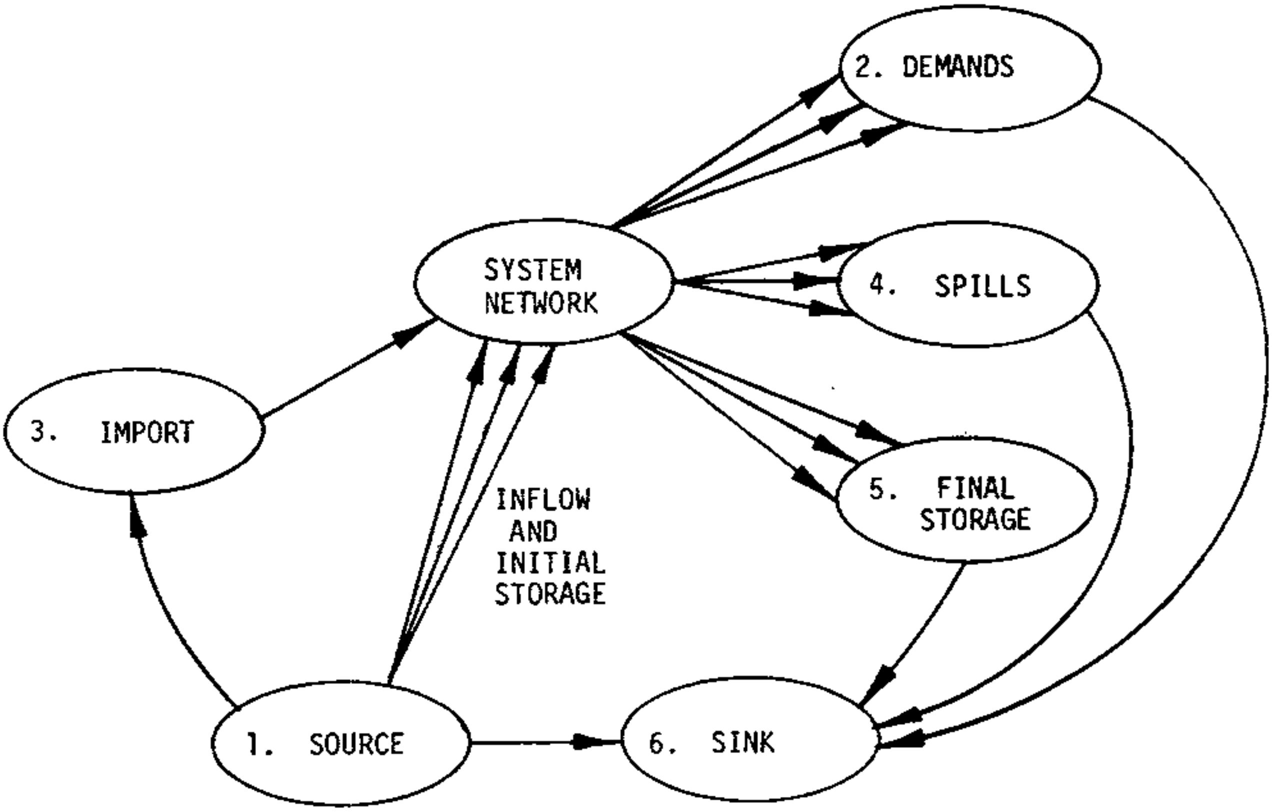


FIGURE A-1

THE NETWORK FOR THE SIM-V PROBLEM

Contrary to the fixed flow arcs are the demand, import, spill, and final storage arcs. Flow in these arcs is variable. Demands (water intake requirements) are extracted from the system through a set of demand arcs. If required, import water can enter the system to the same node in all time periods. Also, all junctions from which spills occur must have an arc leaving them. And finally, the storage contents at the end of the time period leave the system through a set of arcs, three for each reservoir.

These arcs, both fixed flow and variable flow, are connected through six nodes and five additional arcs. Five of these six nodes represent the nodes from which the initial storage and inflow arcs and import arcs originate, and to which the demand arcs, spill arcs, and final storage arcs terminate. The five arcs either leave or enter these nodes and represent the total flow going into or leaving the nodes, respectively. These five arcs are connected to the fifth and sixth nodes, the source and sink, respectively.

There are altogether eight different types of nodes within the network. These are:

1. source node,
2. a demand node,
3. an import node,
4. a spill node,
5. a final storage node,
6. a sink node,
7. reservoir nodes, and
8. non-storage nodes.

The total number of nodes in a network is

$$N = n_n + 6$$

where n_n is the number of nodes in the spatial representation of the problem (reservoirs plus non-storage nodes), and 6 is the number of special nodes in the problem (items 1 through 6 above).

Connecting these eight nodes are ten different types of arcs; they are listed in Table A-1. Flow in these arcs is constrained to be within lower and upper limits. These limits are also summarized in Table A-1.

Flow in river arcs is permitted to be between zero and the maximum river capacity. If there are low flow requirements for water quality control or other purposes, the lower limit can be set to satisfy these needs. Canal and pipeline flows and reservoir storage contents are both constrained to be between a minimum level and their design capacities. This upper limit can also be used to stage or time their addition to the system, which is accomplished by placing an upper limit of zero on those elements not yet built and, in the year each is constructed, increasing the constraint to the design capacity of the element.

Both the initial storage arcs and the input arcs have equal upper and lower bounds. This forces the initial storage contents and inputs of the system to be constants. The demands (water intake requirements) withdrawn from the system can range from a lower bound that permits a tolerable shortage to the maximum needed. The amount of shortage allowed can be different for

Table A-1. Arc Types and Definitions of Their Upper and Lower Bounds

ARC TYPE	LOWER BOUND	UPPER BOUND
1. River	Minimum Required Flow	River Capacity
2. Canal/Pipeline	Minimum Required Flow	Canal/Pipeline Capacity
3. Storage	Zero	Reservoir Capacity minus Target Storage
4. Target Storage	Minimum Storage	Target Reservoir Storage
5. Initial Storage and Unregulated Runoff	Initial Storage plus Unregulated Inflow	Initial Storage plus Unregulated Inflow
6. Demand	Required Portion of Demand to be Met	Water Demand
7. Import	Zero	Maximum Available
8. Spill	Zero	Maximum Permis-sible
9. Distribution/ Collection		
a. Total Import	Zero	Maximum Import
b. Total Demands	Zero	Demands
c. Total Spills	Zero	Maximum Spills
d. Total Final Storage	Zero	Reservoir Capacities
e. Flow By-Pass	Zero	Large Positive Value

every month and every node. The amount of water imported is allowed to be anywhere between zero and the maximum quantity available. The latter depends on the season of the year. Flow in spill arcs is limited to between zero and an arbitrarily high value that will not be reached.

An additional arc, called a flow by-pass link, is inserted into the network between the flow sources and sink. The solution technique used to solve the network model requires that a fixed flow level be supplied to the sink. The by-pass arc supplies, directly from the source node, whatever portion of the water requirement at the sink that is not furnished through the system network. Since it is important to put as much beneficial flow as possible through the system network, a small unit cost ($.001/acre-foot) is placed on flow through the by-pass arc. Thus, flow will go through the by-pass link only after the net cost to put additional flow through the system network exceeds $.001 per unit of flow.

The total number of arcs in the network to be solved by the SIM-V Model is expressed as

$$\text{Number of Arcs} = n_L + 4\,n_r + n_n + n_s + n_d + 6$$

where n_L is the number of links (canals and pipelines plus river reaches); n_r is the number of reservoir nodes; n_n is the number of storage and non-storage junctions: n_s is the number of nodes from which spills can occur; and 6 represents the single import arc in each time period plus the 5 net balance arcs.

To make the best use of SIM-V, it is important to understand the concept of the solution once the real system is represented as a suitable network. Briefly, the procedure follows the four following steps in moving from a known set of state variables at the beginning of a time step to the solution for the required set of state variables at the end of the time step.

1. The present status of the network is evaluated and all currently included system elements are given an appropriate parametric description. Ultimate system elements not built are given zero capacities which effectively prevent them from influencing the network.

2. All specified hydraulic and hydrologic inputs and demands are accounted for, and the mass balance for the entire network system is determined. Bounds are placed on system demands, spills, and storage levels.

3. The flows necessary to meet the levels required by 2, and at the same time maximize the system's total benefit of water use, are determined through the application of an optimization procedure.

4. All necessary state variables have now been determined, and the status of the system at the conclusion of the current time step becomes the status at the beginning of the next time step.

This procedure is repeated in a stepwise fashion until a specified simulation interval has been spanned.

MODELING ASSUMPTIONS

It is generally known that modeling is the process of approximating the prototype for the purpose of evaluating the latter's performance. Because prototypes are generally more complex than models can ever be, certain simplifying modeling assumptions must be made in order to provide a practical and cost effective problem analysis capability.

As a consequence of this simplification, various assumptions and limitations were imposed on the development of the simulation model. These assumptions thus limit the generality of the resulting model and place restrictions on its valid use. The major assumptions of the network approach utilized by the SIM-V Program are described below.

- Only surface water quantity is modeled. That is, no water quality parameters or conjunctive use of groundwater is included in the modeling capability.
- Monthly time increments are generally the shortest steady-state time increments which may be used to simulate the system; thus, operations of canals and reservoirs for routing flood waves is not considered.
- All demands for and inputs of water must be pre-specified except for the case of import waters where the maximum available will be pre-specified. Thus, runoff, evaporation rates, and intake demands for water are forced upon the system, but import water is drawn upon only when needed.
- Import can occur at any one storage or non-storage junction in the system during any limited part of the year up to the maximum monthly availability that was pre-specified. Import water has a constant unit cost.
- A minimum cost objective function is used in conjunction with penalty cost functions. Thus, if these two parameters are properly used, a net benefits maximization criterion can be imposed.
- Because an economic objective criterion is specified, it is assumed that demands for water will be met only if the value for meeting demands is greater than the penalty for not meeting them. The value of having water in specific reservoirs on a seasonal basis can be specified.
- Unit penalty costs for incurred shortages can be varied by node by season whereas storage arc pricing preferences can be varied by reservoir only.
- Demands for water, reservoir inflow quantities, and evaporation rates are capable of being varied on a month-by-month basis to permit accounting for a demand build-up, runoff depletion, and stochastic variability in all of these quantities.
- Canal costs must be divided into two components - that component which cannot be staged (e.g., ditch and right-of-way costs) and that component which can be staged (e.g., pump, motor, and housing costs).

- Both reservoirs and canals can be added to the network of active facilities at any given year in the simulation period.

- Both minimum and maximum flow and storage capacities must be specified by season for conveyance links and reservoirs, respectively.
- The physical system is represented by a set of interconnected nodes and links. Links correspond to river reaches, pump-canals and pipelines, while nodes represent reservoir and link junction points.

- All demands for water and runoff quantities occur at nodes.

- Canal and river reach evaporation and seepage losses are computed as a percentage of the flow entering the conveyance link.

- Initial storage contents of all reservoirs are known.

- Lower bound constraints can be set on demand arcs to reflect, at each node, how much of a pre-specified demand must be met regardless of the magnitude of shortages incurred. If the lower bounds are set too high, an infeasible solution may result.

- Spills out of the system can be controlled to occur only at those reservoirs specified as spill nodes.

- Only reservoir storage allocated for "conservation" purposes can be used for re-regulation.

- The unit cost of pumping is the product of a monthly power cost per unit of flow per foot of lift and a constant lift. These parameters are under input control.

- A pumping energy efficiency of .8 is assumed for all artificial conveyance links in the computation of energy consumption.

- Hydroelectric power generation is associated only with reservoirs (storage junctions). Each reservoir may have at most one power generating facility.

- Hours of peak and nonpeak period power generation must be specified individually for each season.

- Hydropower generation efficiency at a reservoir power plant is a function of the power generation (or load) and may be varied by reservoir.

- Tailwater elevation of a reservoir power plant is a function of the flow rate from the reservoir and/or the water surface elevation of a user designated downstream reservoir, and may be varied by reservoir.

- Maximum instantaneous flow discharge at a reservoir power plant is a function of the reservoir storage level.

- Hydroelectric power is priced at a constant rate for power generated during peak periods, but not in excess of scheduled peak period power generation.

- Hydroelectric power generation during peak periods is scheduled by season for the reservoir system as a whole and not by individual reservoirs.

- Power generation is priced at a constant rate for power generated during nonpeak periods and during peak period in excess of target (scheduled) peak period power production. This nonpeak production unit benefit must be less than that for peak generation.

- All reservoir outflow in a season is assumed to be released at a uniform rate for power generation during peak hours up to the maximum extent possible. Any flow in excess of that needed at the maximum power generation discharge capacity during peak hours is discharged during as many nonpeak hours as needed, at the maximum power generation discharge rate, to make the total power generation outflow equal the total volume of flow released from the reservoir in the season.

MATHEMATICAL DESCRIPTION

The mathematic statement of the network flow problem may be expressed as

$$\text{minimize} \sum_{i=1}^{N} \sum_{j=1}^{N} q_{ij} \, C_{ij}$$

subject to

material balance at all nodal points,

$$\sum_{i=1}^{N} (q_{ij} - q'_{ji}) = 0, \; j=1, \ldots, N$$

material losses along links,

$$q'_{ij} - (1 - \alpha_{ij}) \, q_{ij} = 0, \text{ for all i and j,}$$

and bounds on material conveyed along links,

$$L_{ij} \leq q_{ij} \leq U_{ij}, \text{ for all i and j,}$$

where the terms are as defined in Table A-2.

The mathematical structure is described by four sets of constraint equations and an objective function. One set of constraint equations requires that continuity be satisfied at all nodes in the network, except at the source and sink nodes. The second set of constraints indicates the amount of water lost by conveyance through each of the arcs. The remaining two sets of equations describe the upper and lower limits on flow in all arcs in the

Table A-2. Definition of Terms in the SIM-V Problem Formulation

Network Flow Variable			Units
q_{ij}	=	flow entering arc from node i to node j	L^3/t
q'_{ij}	=	flow leaving arc from node i to node j	L^3/t
L_{ij}	=	lower bound on flow from node i to node j	L^3/t
U_{ij}	=	upper bound on flow from node i to node j	L^3/t
C_{ij}	=	cost of moving one unit of flow from node i to node j	$\$/L^3/t$
N	=	number of nodes in the network	
α_{ij}	=	Fraction of flow lost along the arc from node i to node j	

network. Thus, there is one equation for each node and three equations for each arc.

The objective function that must be satisfied while solving these equations is the minimization of the cost of transferring water through the network.

In this network, the canal, demand, storage, spill and hydroelectric power generating arcs are the only types of arcs which have cost associated with them. In the canal arc the unit cost represents the cost of power needed to pump one unit of flow while in the demand arc there is a negative unit cost associated with each unit of water demand. Reservoir storage arcs take on user-designated costs according to the operating rule option desired; however, to prevent reservoirs from spilling when they could be storing water, a minimum unit benefit of $.01 per acre-foot is assigned to water stored in the system. Similarly, the unit spillage cost is specified by the user.

SOLUTION METHODOLOGY

The flow optimization problem described above represents a more general problem formulation than was considered in previous versions of the SIM Program. The prior models failed to incorporate hydroelectric power generation as a benefit for system operation. The SIM-V program solves the operational problem by linearizing the nonlinear components and solving the resulting approximation to the problem as a generalized minimum cost, constrained network flow optimization formulation. The solution to the network problem is then taken as the solution about which the nonlinear terms are linearized. The generalized network model is solved using dual and primal Network Algorithms developed by Dr. Paul Jensen and Dr. Gora Bhaumik (3).

The SIM-V program utilizes two solution techniques for the network problem. Initially, an optimal flow solution, excluding hydropower benefits, is determined using the GAIN subroutine. After the arc bounds and costs for those links generating hydropower have been modified to reflect hydropower operations and benefits, the current optimal solution is taken as a starting point for Subroutine PRIMAL. Each successive change in the hydropower arc bounds and costs requires that PRIMAL be called to determine the optimum flow distribution based upon the new costs and bounds. Thus, the program does not require that the network problem be solved at each iteration from the initial "trivial" solution (i.e., all flows equal to zero) required by GAIN, but uses the current optimal solution as a starting point for deriving a new solution. Based upon computational experience, it was found that generally fifty percent of the total execution time to achieve the optimal solution was required to obtain the first intermediate solution derived by GAIN.

It is anticipated that SIM-V may be used to determine the maximum annual production of hydroelectric power from a given system while meeting required demands and flow discharges. To accomplish that objective, the program would be executed for successively greater levels of target peak (firm) hydropower generation. This would require trial and error on the part of the user to achieve the largest generating level while retaining a feasible operating policy for water demands and minimum flows. To reduce the computer time required for operating the program in this manner, the user has the option of storing the past intermediate optimal solutions for a given simulation and reusing those solutions as starting points (initial solutions) to restart the problem for a new (increased) level of firm power production. This advanced restart capability may decrease substantially the time needed to achieve a optimal solution over separate, independent executions of SIM-V.

The advanced restart capability requires that an initial solution be feasible for use in restarting the algorithm. In addition, the solution for the entire set of network models for a simulation period must be specified, and not a partial set of solutions. That is, the storage file to be used as a restart file must be generated by the execution of the SIM-V program without encountering an infeasible solution and giving full solutions to each of successive monthly network models over the period of simulation. The program will terminate at any point for which data is unavailable for use in restarting the program. Further, the algorithm will test the feasibility of the initial solution and, if it is infeasible, will use the GAIN subroutine to find a feasible solution.

INPUT REQUIREMENTS

The following physical, economic, and water usage data elements are utilized as input into the SIM-V Program.

System Structure Data

(1) The network's dimensions.

(2) A list of each link entering each node.

(3) A list of the nodes at the end of each link (link direction implied).

Junction (Node) Data

(1) A literal name for each junction.

(2) The maximum storage capacity at each junction.

(3) The minimum storage allowed at each junction.

(4) The storage versus area relationship for each junction.

(5) The return flow S/W ratio (effluent to influent ratio) and number of the node where the return flow will be discharged.

(6) The simulation year each reservoir is built.

(7) Target storage levels and unit storage benefit at the end of each season or month of the year. (If hydroelectric power is generated from this reservoir then the following is needed:)

(8) The storage versus water surface elevation relationships.

(9) Nameplate (i.e., design) power generating capacity.

(10) Generation efficiency versus power generated.

(11) Tailwater surface elevation versus flow discharge.

(12) Maximum flow discharge for power production versus reservoir storage.

Reach (Link) Data

(1) A literal name for each reach.

(2) The maximum flow capacity for each reach.

(3) The minimum flow allowed for each reach.

(4) The unit cost of pumping in each reach.

(5) The total dynamic pumping head of each reach.

(6) The simulation year each canal is built.

(7) Average annual percentage conveyance loss along each reach.

Cost Data

(1) Interest rates and repayment periods.

(2) Capital and operating cost for each reservoir.

(3) Capital and operating cost for each canal and pipeline.

(4) The unit cost of water deficit at each demand node by season.

(5) Peak and nonpeak unit power generation benefits.

Hydraulic and Hydrologic Data

(1) The unregulated inflow to each junction site for each time period.

(2) The maximum and minimum intake demand at each junction for each time period.

(3) The net evaporation rate at each reservoir for each time period.

System Simulation Data

(1) Delimiters for time interval and total simulation span.

(2) A list of nodes where spills may occur and a unit cost of spills.

(3) Total annual amount, seasonal distribution and unit cost of available import water.

(4) Fraction full for each reservoir at start of simulation.

(5) Number of peak and nonpeak hours in each season.

(6) Annual firm power generation requirement and its seasonal distribution.

CAPABILITIES

The SIM-V Program is capable of analyzing the operation of an interconnected system of as many as 50 reservoirs and non-storage junctions and 75 artificial and natural water conveyance channels. Up to twelve periods within a year may be considered in simulating the operation of a surface water resources system. The entire simulation time horizon may be as much as 50 years in length.

The single-period network model solved by SIM-V may contain as many as 500 arcs and 60 nodes. For a particular problem, the number of nodes and arcs are computed according to the equations on pages A-3 and A-5. The user should verify before executing the program that the spatial dimension of the problem do not generate a network model which exceeds the specified limits. SIM-V will terminate if the arc or node limit is exceeded.

The SIM-V Program is capable of performing a number of analytical functions either single or in conjunction with the Texas Department of Water Resources Model AL-V. Included in the model's capabilities are (1) determining the minimum cost operating policy for a multiple reservoir system over a finite time horizon and (2) sizing reservoir or canal projects. Details of how these capabilities are achieved are presented in the following paragraphs.

Minimum Cost Operating Plan

A minimum cost operating plan for a single time period, such as a month, can be found for any development plan. The link-node configuration and the length of the planning horizon define the network. Reservoir and canal capacities, inputs, and demands describe the major constraints. A set of deterministic inflows and return flows describe the inputs. Projected water and power demands constitute the water requirements. The solution to the network flow problem associated with these conditions is a minimum cost operating plan. It represents the least costly method of transferring water through this network.

The network model solved by the SIM-V Program does not have the ability to look ahead in time to operate the system. SIM-V must be used in conjunction with the AL-V multiperiod optimization program to develop monthly target storage levels and unit storage benefits that will guide the month-by-month operation of a reservoir system to achieve optimal performance during multiyear drought periods. The monthly target storages can be developed through analyzing the graphical plots of the optimal storage policies calculated by AL-V. The user is referred to the applications section of the main report for further details as to how these reservoir operating rules were derived for the Guadalupe-San Antonio; Shasta-Folsom: White River; and Arkansas, White, and Red River systems.

Canal and Reservoir Sizing

The optimal sizing of a single reservoir or conveyance projects within a large-scale water resources system may be determined by using the SIM-V program in conjunction with the AL-V Allocation program or in a stand alone mode. The sizing can be achieved by utilizing an iterative process requiring manual intervention and engineering judgements to converge on an optimal solution. Results from AL-V and SIM-V include the marginal costs of the canal and reservoir sizes (constraints). The marginal cost of a capacity constraint increases as the constraint decreases because the increment of water associated with the decrease in capacity must find another route to its destination. Since the solution with the higher constraint is the least costly, the lower constraint must increase operating costs. This increase in cost is the marginal cost of the constraint. It represents the savings that would result if the upper bound (maximum) capacity constraints were increased by one unit of flow or, conversely, if the lower bound (minimum) capacity constraints were reduced by one unit of flow.

The manual procedure begins by setting the upper bound constraints at arbitrarily high values that will not be reached. As a result, all marginal costs will be zero. The solution to this problem, which is essentially unconstrainted, is characterized by high ratios of maximum to mean arc flows. These ratios are reduced by decreasing the canal and reservoir sizes until their marginal costs become non-zero. These sizes can be further reduced until the increase in their marginal costs becomes equal to the decrease in their marginal capital costs.

Since power costs are incurred in each time interval and capital costs occur only once, the two items are not directly comparable. With a system that experienced increasing demands over time, the power cost for each time period should be discounted and all accumulated before making a comparison with incremental capital cost.

A recommended procedure is to initially size the canal or reservoir under some assumed design conditions and refine them in the later evaluation process. For example, canal size could be preliminarily found under conditions of average hydrology and maximum demand. Reservoir size, on the other hand, could be estimated for extreme hydrologic and demand conditions. This initial size would be refined by interactively reducing or enlarging the conveyance or storage capacity of the facility according to the variations in operating costs computed by the SIM-V Program.

LIMITATIONS

The SIM-V Program is designed to optimize the simulated single-period operation of a general configuration of water storage and conveyance facilities. The characteristics of the Generalized Network Algorithm (3) utilized to solve the associated network model does, however, place some restriction on the type of configurations that can be analyzed.

Networks Containing Loops

The Generalized Network Algorithm requires that an initial solution be provided which is optimal for a particular level of inflow into the sink node. SIM-V specifies an initial solution having all flows set to zero. It is assumed that this set of flows is the minimal cost solution for an inflow into the sink of zero. This assumption will not be valid if the network model contains any closed loops or circuits having arcs with negative unit costs either entering or within the circuit. The term closed circuit is defined here to be any internal set of nodes and linking arcs through which a path may be directed back to any starting node.

A valid use of the SIM-V Program thus requires that the network model, corresponding to the spatial representation of physical system, contain no closed circuit along which flow may move. Unfortunately, such circuits do arise in actual water resource systems, usually in the form of pump canals or pipelines. To analyze the operation of water storage and distribution network having such characteristic structures, the network representation of the system must be modified to remove the circuit. This is possible by adding artificial junctions and links to the network to redirect the flows. Figure A-2 indicates how this may be done for a simple circuit between two junction

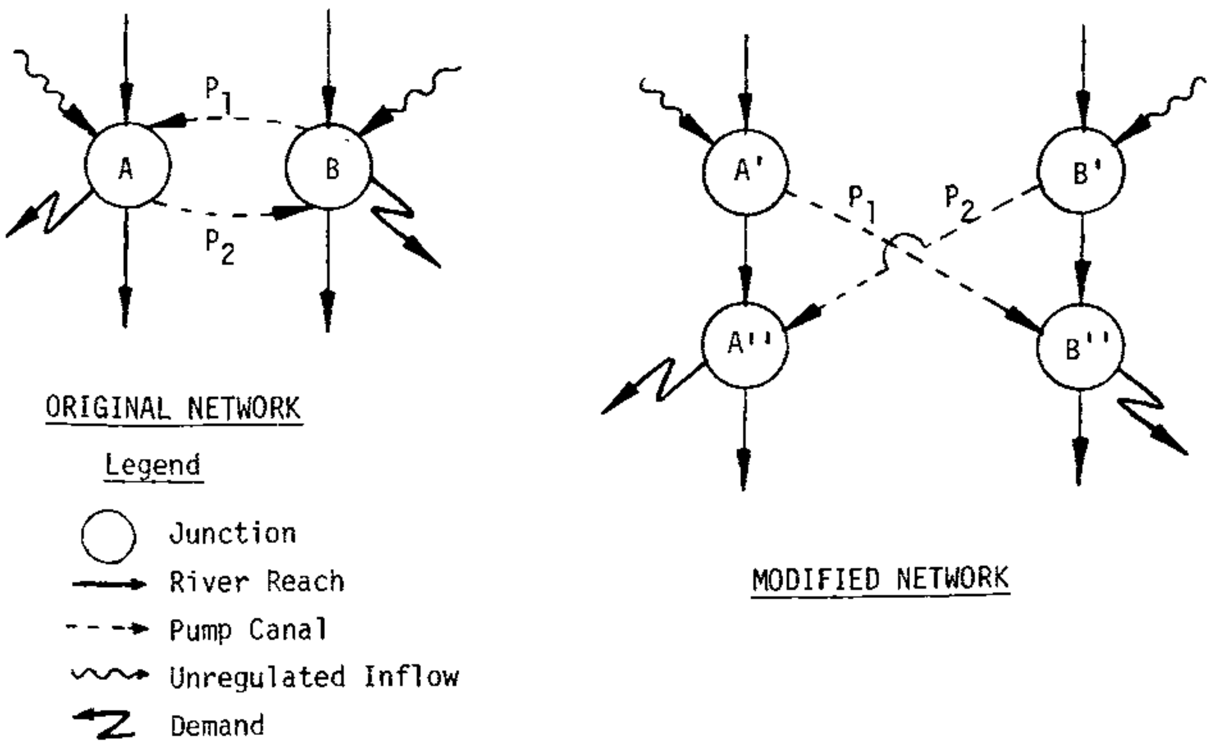


Figure A-2
Method to Eliminate Loops Between Junctions

points. Nodes A and B are joined by two pump-conveyance links (P_1 and P_2) moving water in opposite directions. By adding two pseudo-junctions A' and A" and B' and B". The circuit between A and B is removed. All inflows into A are now directed into A' and all demands on A are located at node A".

A similar procedure may be utilized to remove closed circuits containing reservoirs. Figure A-3 illustrates how additional nodes and arcs may be included in the network to remove such circuits. The artificial node A' is a reservoir with no storage capacity. This approach is, however, not completely satisfactory since an upstream reservoir will be unable to make downstream releases using water stored in previous time periods. For example, reservoir A" in the modified network in Figure A-3 has no outlet for discharging stored water except to meet local demands, although unregulated inflow (into A') in any given period may be routed downstream or impounded.

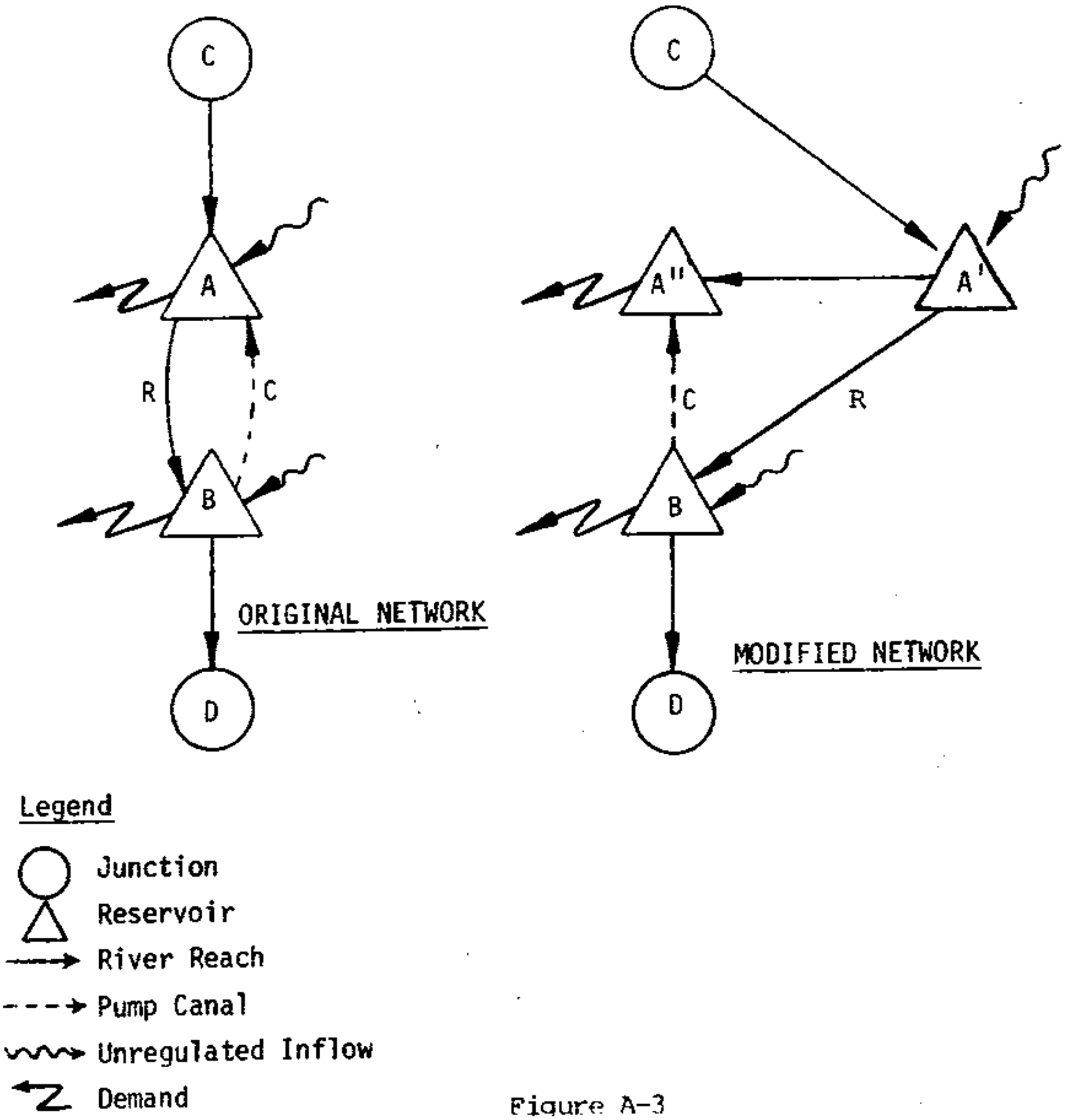


Figure A-3
Method to Eliminate Loops Between Reservoirs

To completely overcome this difficulty, a slight modification is required in the program as presented in this documentation. At any given time interval, initial storage for reservoir A would originate at node A' and all water entering node A' could either be stored in A" or released downstream. The required modifications in the computer code would occur in Subroutines PREPAR and would involve transferring the final storages in A" to be the initial storage in A' in the next period.

Possible Reservoir Storage Errors

The SIM-V Program has an additional limitation which the prospective user should be prepared to deal with. As noted previously, the network model divides the storage in each reservoir into two segments so that evaporation losses may be more accurately computed. The lower segment of storage (represented by S_1 in Figure 5) will invariably be less efficient (in terms for evaporation losses) in storing water than the upper storage segment (S_2 in Figure 5). That is, a unit of volume added to the upper range of storage will add less surface area to the reservoir than would be added if the lower storage segment were augmented by the same volume. Hence, if a shortage occurs in the system, SIM-V may attempt to take advantage of this storage efficiency by placing water in the upper segment of storage without first filling the lower segment.

This, of course, is physically impossible and will result in underestimating the losses due to evaporation. A unit benefit of $1/acre-foot is assigned in the model to water held in the lower segment of storage. This benefit will tend to keep the lower storage range full except possibly when shortages occur in the system. When such conditions are likely to occur the user may force the program to fill the lower storage segment by setting the minimum pool equal to the breakpoint storage for the reservoir piecewise linear area-capacity approximation curve. Additional options in the form of reservoir operating rules are available for requiring the proper filling sequence in the reservoirs. These are discussed in detail in the description of INPUT FILE R found under "SIM-V Input File Description". The user should note that the $1/acre-foot benefit assigned for storage in the lower storage range may affect conveyance between reservoirs when water levels are low. The terminal storage benefits indicated in INPUT FILE R may require adjustment to compensate for this automatic seasonal benefit.

Should the Generalized Network Algorithm give a solution which violates the storage segmentation constraint, the program will print an appropriate message, redefine the bounds on the reservoir storage arcs, and again solve the network model. The upper and lower bounds on the storage arcs are set to force flow through the upper storage segment only after the arc corresponding to the lower storage range is saturated. This artificial minimum storage constraint may force water to be retained in storage rather than used for the beneficial purposes of water supply or hydropower production.

This problem of storage allocation can be solved without difficulty if the minimum storage in a reservoir is always greater than the breakpoint storage level in the piecewise linear area-capacity approximation (Figure 5). This assumption must, or course, be valid with regard to the accuracy of the area-capacity approximation chosen and the minimum storage selected. It is probably justified in most cases to set the "breakpoint" storage to the minimum storage level and thus overestimate the area (and hence the evaporation) for low levels of storage, thereby providing a more conservative estimate of water availability.

REFERENCES

1. Bhaumik, G. and P.A. Jensen, "Optimum Operating Policies of a Water Distribution System with Losses", in Network Modeling of Multireservoir Water Distribution Systems, Center for Research in Water Resources, University of Texas at Austin, Report 107, 1974.

2. Ford, L.R., Jr., and D.R. Fulkerson, Flows in Networks, Princeton University Press, 1962.

3. Jensen, P.A. and G. Bhaumik, "A Computationally Efficient Algorithm for the Network With Gains Problem", presented at the 45th National Meeting of ORSA, Boston, April 1974.

4. Martin, Q.W., "Surface Water Resources Allocation Model - AL-V Program Documentation and Users Manual", Texas Department of Water Resources, Austin, Texas, October, 1981.

5. Texas Water Development Board, "Economic Optimization and Simulation for Management of Regional Water Resource Systems", Report 179, February, 1974. Supplementary to Report 179 are six computer program documentation volumes:

AL-III	Program Description
DES	Program Description
MOSS-III	Program Description
QNET-I	Program Description
SIM-IV	Program Description
SIMYLD-II	Program Description

SIM-V PROGRAM DESCRIPTION

The SIM-V Model consists of one main program and 26 subroutines, each of which is described in the following sections. A schematic of the interaction between subprograms is given on the following page. The SIM-V Program was coded in Fortran IV for execution on the UNIVAC 1100/41 Computer. Approximately 60,000 decimal words of storage are required to execute the program. Modification of some constants in Subroutine GAIN may be necessary if the number of significant figures carried by the user's computer is fewer than the nine significant digits in the UNIVAC 1100 Series machines. A further discussion of the possible alterations is provided in the section below describing Subroutine GAIN.

Main Program

This is the executive program that controls execution of the functions and subroutines. It consists of three basic steps. Step 1 reads the basic input data through execution of Subroutine INPUT. Subroutine INPUT reads the general system data with the exception of the unregulated inflows, annual demands, and net evaporation rates, all of which are read in Subroutine ARC. All input data are described in the "SIM-V Input File Description".

Step 2 involves executing those subroutines that solve the water allocation problem. These include Subroutines ARC, GAIN, HYDRO, PRIMAL, START, RESTART, PREPAR, APRINT, ADJUST and SETNET. In this step the network is constructed for a single time period. The model then solves the problem and assigns the final storages to the initial storages for the next period. After the final month has been encountered and the associated problem solved, step 3 is performed. This consists of a calculation of costs and a final print of the annual summaries for the total time horizon. Involved in this step are Subroutines COSTX and SPRINT. If at any time an infeasible solution is encountered, a complete dump of the network structure and data is printed and execution is terminated.

Subroutine ADSUB

This subroutine adds an arc to the triple label representation of the flow augmenting tree.

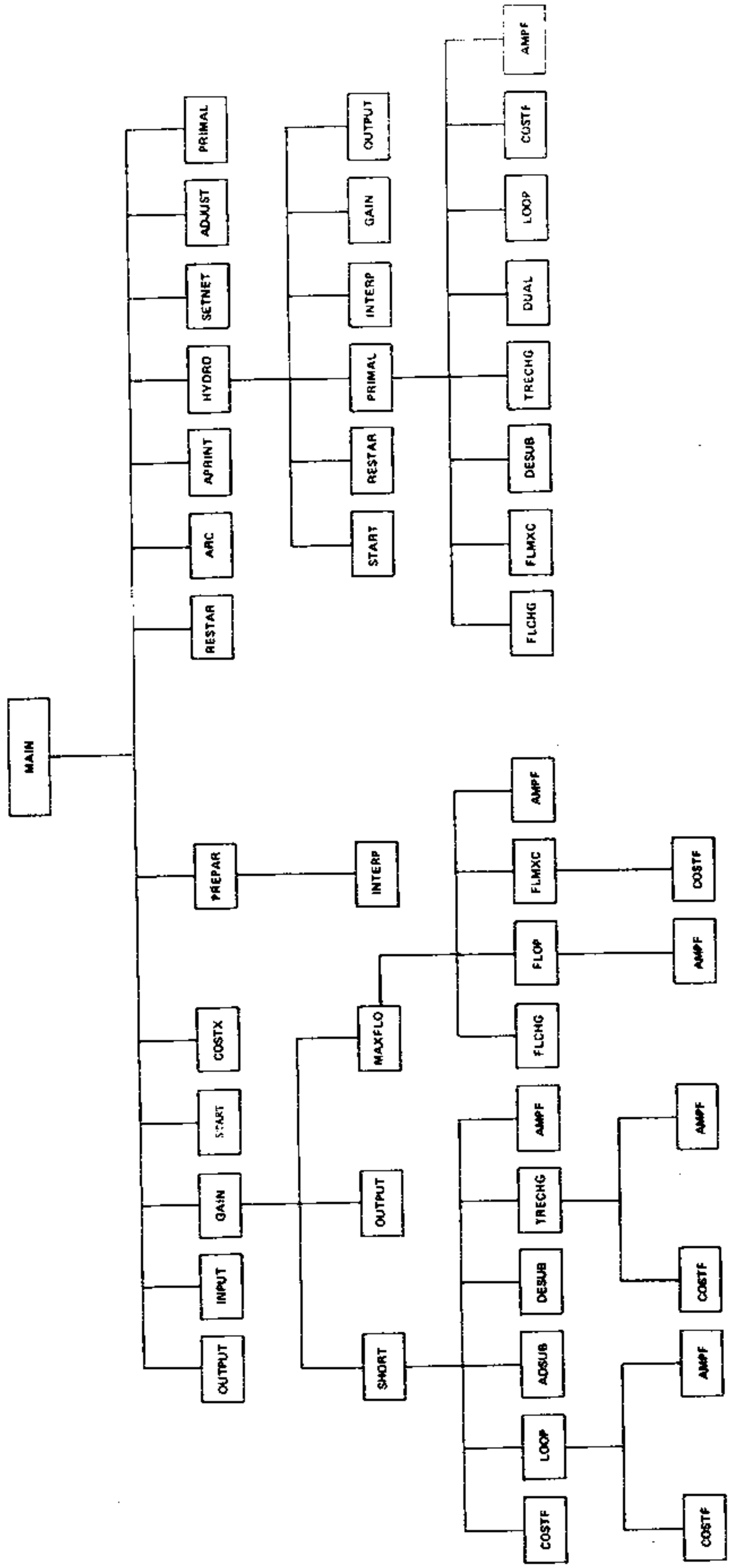
Function AMPF

This function computes the flow amplitude of all arcs and their mirror arcs.

Subroutine APRINT

Subroutine APRINT prints the compiled annual results of the monthly networks as obtained from PREPAR. APRINT consists of fifteen steps: each of which prints a specific type of results. The correspondents between steps and results in as follows:

SIM-V SUBPROGRAM ORGANIZATION



Step 1 - Prints Link Flows
Step 2 - Prints Link Pumping Costs, Import Costs, Penalty Costs
Step 3 - Prints Peak Power Generation
Step 4 - Prints Non-Peak Power Generation
Step 5 - Prints Total Power Generation
Step 6 - Prints Generating Capacity Utilization
Step 7 - Prints Generating Efficiency
Step 8 - Prints Marginal Link Costs
Step 9 - Prints Reservoir Storage Levels
Step 10 - Prints Reservoir Surface Elevation
Step 11 - Prints Water Deficits and Demands
Step 12 - Prints Marginal Reservoir Costs
Step 13 - Prints Marginal Costs of Continuity Equations
Step 14 - Prints System Spills
Step 15 - Prints Maximum Link Flows

The reader should review "SIM-V Output File Description" for more detailed explanations of the output and examples of the formats used in printing.

Subroutine ARC

Subroutine ARC converts the input data into arc data as required by the Jensen-Bhaumik Algorithm in Subroutine GAIN. ARC consists of seven steps. In step 1 the variables are set to their initial values. In step 2 the hydrologic inflows and demands for a year are read from the input tape and data for the initial storage arcs are defined. After the tape is read, ARC defines in steps 3 through 6 the upper and lower bounds on the flow in each arc, HI(A) and LO(A); the unit cost of flow in each arc, COST(A): and the amplitude (gain) factor for the flow in each arc, AMP(A). These arcs define the paths for inputs, demands, imports, reservoir storage, canals and river reaches, and spills from the system. Step 7 defines this same data for the net balance arcs.

The net balance arcs are the first five arcs in the arc numbering system and they represent the following:

1. Source to sink by-pass arc,
2. Total demands from the network,
3. Total imports to the network,
4. Total spills from the network, and
5. Total final storage in the reservoirs.

The initial storage and unregulated inflow arcs follow the net balance arcs and are numbered from 6 to 5+NRES (or AMIN). Following these arcs is an arc sequence. This arc sequence and its relation to the entire arc numbering system is shown in Figure A-4 on the following page where:

NRES = number of reservoirs
NJ = number of link junctions
NL = number of links
NS = number of spills
AMIN = NJ + 5

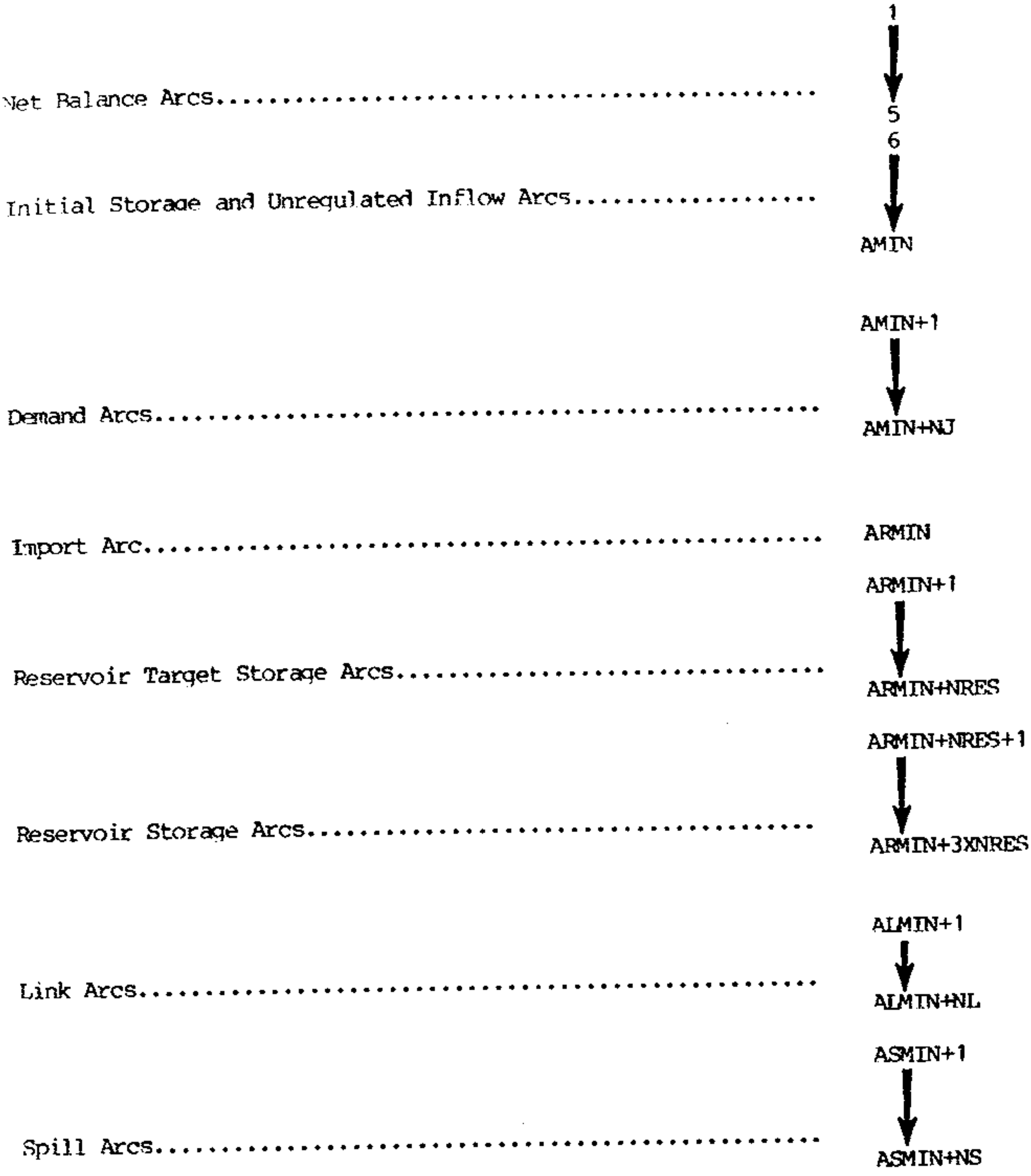


Figure A-4
Arc Numbering System

ARMIN = AMIN + (NJ + 1)
ALMIN = ARMIN + 3(NRES)
ASMIN = ALMIN + NL
ASMINS = ASMIN + NS

ARC initializes the flows in all arcs in the network each time a new season is encountered. Flows in all arcs are set to zero.

Subroutine COSTF

This subroutine computes the unit cost of flow transmitted along an arc. If the current flow in the arc is less than the lower bound on the flow in that arc then a large negative cost is put on the arc to drive more flow through it. For flows greater than the upper bound, a similar high positive cost is imposed to drive flow out of the arc. The specified unit cost assigned in Subroutine ARC is used if the flow is within the upper and lower bounds.

Subroutine COSTX

Subroutine COSTX computes the actual cost, the present worth, and the average annual cost of the plan being evaluated. Reservoir capital costs are given as input data and their operation and maintenance costs are expressed as a fraction of their capital costs. Canal capital costs are based on maximum canal flow, and operation and maintenance costs are a fraction of this value. Power and imported water costs are determined from the figures developed in PREPAR. Present worth is obtained from the actual cost (sum of the costs of actual capital, operation and maintenance, power, imported water, and deficit minus the hydroelectric power benefits) by the equation:

$$P = S \frac{1}{(1+i)^m}$$

and the annual cost is found from the present worth by the equation

$$A = \frac{P\ i(1+i)^n}{(1+i)^n-1}$$

where S equals actual cost, P equals present worth, A equals annual cost, i equals interest rate, m equals discount period, and n equals repayment period.

Subroutine DESUB

This subroutine deletes a constraining arc from the triple label representation of the current flow augmenting path.

Subroutine DUAL

This subroutine calculates the potentials for the nodes in the network solution tree. This subroutine is called iteratively as the solution tree for the network is changed to delete and add arcs as flow is increased from the source to the sink nodes.

Subroutine FLCHG

This subroutine increases the flow in an arc by a specified amount. If a mirror arc is considered then the flow in that arc is decreased.

Subroutine FLMXC

This subroutine searches all the arcs in the flow augmenting tree and determines the maximum change in flow that is possible for each arc. The minimum value of all of these maximum flow changes is then the maximum change in the flow in the current flow augmentation path.

Subroutine FLOP

This subroutine determines the flow amplitude in a flow generating cycle in the current flow augmenting path. The maximum flow change in the cycle is also computed, as is the constraining arc on maximum flow augmentation.

Subroutine GAIN

This subroutine executes the solution procedure for the linear programming dual problem formulation developed by Dr. Paul Jensen and Dr. Gora Bhaumik (3) for the network-with-gains problem.

The network-with-gains algorithm is executed by iteratively calling the Subroutines SHORT and MAXFLO in a two step sequence. In step 1, SHORT determines, on the first iteration, a set of connected arcs providing a minimum cost path for flow from the source to the sink. In each successive iteration, Subroutine SHORT deletes a saturated arc from the current flow augmenting path and adds the most promising available arc to create a new path. In step 2, Subroutine MAXFLO examines the current minimum cost path and determines the maximum flow that can be directed through that path into the sink. Flows in the appropriate arcs are then increased to the levels needed to increase the flow into the sink the maximum computed amount. If the total flow into the sink is equal to the required inflow then the procedure is terminated; otherwise, the algorithm returns to step 1 and the process is repeated.

Upon completion of steps 1 and 2, GAIN calls Subroutine OUTPUT to determine if the network flow solution satisfies the required minimum and maximum link flow and reservoir storage constraints. If the solution is infeasible (i.e., violates any constraints) then an appropriate message is printed, the network model is dumped and execution of the program is terminated.

The algorithm for solving the network model requires that an initial solution be provided which is optimal for a given flow into the sink. The set of zero arc flows is used as a starting solution under the assumption that this is the minimal cost set of flows for an input of zero into the sink. This is a valid supposition if the network model has no directed loops or circuits. Modification of the basic network model will generally eliminate any directed circuits and allow the operational analysis of the system by the SIM-V Program. A further discussion of this problem may be found under the section entitled "Limitations".

The original version of the GAIN Program was written for the CDC 6600 computer which carries fourteen significant figures. The SIM-V Program documented herein was developed on a UNIVAC 1108 which is limited in accuracy to nine significant digits. This difference in machine precision required that the constants EPS and BIG in Subroutine GAIN be redefined from 10^{-6} and 10^{6} to 10^{-4} and 10^{5}, respectively. By resetting these small and large tolerance values, the program was allowed to ignore small differences (less than .0001) between flow rates. Roundoff errors generated by the machine had been responsible for introducing small differences between supposedly equal values. These discrepancies sometimes resulted in the program trying to remove from the flow augmenting path the identical arc to be added into the path. When such a condition occurred the program began to cycle and would terminate only when the time limit for execution was exceeded.

Subroutine HYDRO

The impacts of hydroelectric production in the system are calculated in this subroutine. Should hydroelectric power not be produced from any of the reservoirs then this subroutine is bypassed. An initial feasible solution to the network flow problem is needed by this subroutine. Given that initial solution, HYDRO determines the amount of energy produced from the current solution and the benefit for further HYDRO production in the period from each reservoir. Bounds are placed upon the flows in the arcs generating hydroelectric power. These bounds are adjusted as a percentage of the current flow rate except where the current flow rate is less than 10,000 acre-feet per season or the efficiency rate is less than 20 percent, in which case the upper bound of flow release is equal to either a proportion of the maximum generating capacity or, if the peak power generation target has not been achieved, the incremental power needed to achieve the peak period production schedule. The percentage factor for the flow limits initially starts at 20 percent, however if a solution is produced in which the total benefits for hydropower generation are less than the benefits achieved from a prior solution then the percentage factor is divided by two and the previous best solution is used as a starting point with new bounds on the arc flows. The repeated adjustments of arc flow bounds and costs are continued until the percentage factor for flow changes is less than one percent.

To increase computational efficiency, the previous solution giving the greatest benefit is used as a starting point for changes in cost and flow bounds. This advanced starting solution is taken by Subroutine HYDRO and used as the basis for adjusting arc bounds and costs to give a new network linearization of the problem. Subroutine PRIMAL then solves this network formulation using the advanced solution as the initial solution.

Subroutine INPUT

Subroutine INPUT reads from cards all the system data except the unregulated inflows, demands and the net evaporation rates. Reading these data involves twelve basic steps. Each step reads one or more records related to the type of data being read. These types of data pertain to (1) system constants, (2) nodes, (3) links, (4) economic parameters, (5) seasonal variations in power costs, import availability, channel losses, link flow limits, and reservoir storage bounds (6) annual print control options, (7) spills, (8) reservoir and canal construction times, (9) reservoir operating rules, (10) shortage costs, (11) scheduled hydropower generation, and (12) reservoir power generation characteristics. These data elements are all described in the "SIM-V Input File Description" section. INPUT also prints, in tabled form, all data read in the subroutine.

Function INTERP

This subroutine performs piecewise linear interpolation between adjacent sets of paired variables to determine the value of a dependent variable based upon the value of an independent variable.

Subroutine LOOP

This subroutine is utilized in the first iteration of the GAIN subroutine to determine if the flow augmenting three includes a flow generating cycle. Should such a cycle be found then the node potentials are adjusted.

Subroutine MAXFLO

This subroutine calculates the maximum increase in flow into the sink along the arcs in the current flow augmenting tree. The constraining (flow saturated) arc in the path is also established. The flow in the augmenting tree is increased by the computed maximum amount.

Subroutine OUTPUT

Subroutine OUTPUT prints all the arcs and network data when the program encounters an infeasible problem. A message is printed noting the problem cannot be solved and a dump of the data follows. This includes arc numbers, gain factors, connecting nodes, upper and lower bounds, unit costs, and arc flows when infeasibility was realized.

Subroutine PREPAR

Subroutine PREPAR makes all unit conversions and stores the results from HYDRO and GAIN in matrices for printing in Subroutine APRINT. It performs these operations in five steps. Step 1 initiates the values for the variables in the print routine, APRINT, to zero. In step 2 the link flows, their maximum values, and their average annual values are converted to cubic feet per second and stored in the matrix LQ; link power costs and their average annual values are stored in the matrix LP in terms of thousands of dollars: and the marginal link power costs are converted to thousands of dollars per cfs and stored in the matrix LC. Also, annual power costs, APOW, and annual import quantities, AIMP, are determined in step 2. Step 3 places the reservoir storage levels and their annual averages in the matrix RS in units of thousands of acre-feet, and the marginal reservoir power costs in the matrix RC in units of dollars per acre-foot. In step 4, the Subroutine computes the marginal costs of the continuity constraints and puts them in the matrix CC in units of dollars per acre-foot, stores the deficit quantities in matrix IDEF and ISHORT in units of thousands of acre-feet, and computes the annual cost of the deficits, ICOST, in dollars per acre-foot. Lastly, step 5 stores the spills in the matrix JQ in units of thousands of acre-feet. All of these matrices are then used in APRINT, the annual print routine.

Subroutine PRIMAL

This subroutine solves the linear programming primal version of the generalized network problem using an algorithm and computer code developed by Dr. Paul Jensen of the University of Texas at Austin, 1975. As compared with the DUAL subroutine, PRIMAL takes an initial feasible solution and solves the generalized network formulation. This subroutine begins by finding the arc in the network which most violates the mathematical condition required to ensure an optimal solution. If there are no such arcs then the network optimal solution has been obtained. The arc most violating the optimality condition is forced to enter the current basis of the network. The basis tree is then modified to include that arc and flow through the tree is increased until one of the arcs is driven to either its upper or lower low limit. The arc attaining its flow limit is then removed from the tree and the node potentials for all nodes connected by the tree are changed to reflect the new flow condition. This process is then repeated by again finding the arc which most violates the optimality condition.

Subroutine RESTAR

Given a basis solution to a generalized network, this subroutine calculates node potentials in that network. Subroutine RESTAR is used to restart the PRIMAL subroutine by taking a basis and providing the necessary node potentials. RESTAR must be run prior to executing Subroutine PRIMAL.

Subroutine SETNET

Subroutine SETNET defines the single-period network for the system by creating the directed arcs, A, in the network and the nodes at both ends of each of these arcs, NF(A) and NT(A). SETNET is called only once at the beginning of execution.

Subroutine SHORT

This subroutine establishes the least-cost path from the source to the sink by utilizing a shortest path algorithm. After the initial flow augmenting path is determined, the subroutine constructs additional flow augmenting trees by deleting saturated arcs and inserting new arcs into the current tree.

Subroutine SPRINT

Subroutine SPRINT prints an annual summary of the actual costs, present worth, and annual costs of the development plan. This summary includes capital costs, operation and maintenance costs (for both reservoirs and canals), imported water costs, power (pumping and generation) costs, and penalty costs for deficits. The reader is referred to the "SIM-V Output File Description" for a detailed description of the output format.

Subroutine START

This subroutine reads an initial feasible solution to the network problem and then modifies the network model to ensure conservation of flow throughout the network. START is called to read an advanced restart solution to a network problem and adds extra arcs where necessary to guarantee that the basic arcs in the solution remain basic in the new network.

Subroutine TRECHG

This subroutine updates the flow augmenting tree by deleting a flow saturated arc and inserting an addition arc. In this manner the tree is continually changed to enable more flow transmission between the source and the sink.

SIM-V INPUT FILE DESCRIPTION

All input data for the SIM-V Program is read in card image form and is divided into 28 files labeled from A to ZB. A detailed description of the individual data files and their associated input parameters is provided in Figure A-5. The required formats for the cards in each file are specified on the input coding sheets (Figure A-6). Figure A-7 displays the sequence in which the card files must be arranged for input into the computer. All data is assumed to be integer and must be right justified in each field, unless a decimal point is indicated.

A number of the data files require tabular information relating one variable as a function of another variable (see FILE V). In these tables, the user should supply a range of values for the independent variable that completely encompasses the expected values. For example, the data read in FILE V relates the water surface elevation in each reservoir to the storage volume. Thus the largest storage value read must be greater than the maximum permissible storage and the smallest storage less than the minimum allowable storage. It is suggested that the largest independent variable read in these tabular data files be at least 50 percent greater than the maximum value expected for the variable during the execution of the program.

FILES M and N specify the characteristics of the spill nodes for the system. However, the user is not required to have system spill nodes; in which case, FILE N is ignored.

The user is alerted that extra care should be taken in the selection of the unit benefits for reservoir storage below a target level (FILE R). If the benefit for storage is larger than the benefit for water diversion or hydropower production then water will be retained in storage and not released. The benefit for hydropower generation varies depending upon the unit price of electricity, flow release rate, and water elevation. The user should compute the incremental unit benefit (equation 31), convert the unit benefit to thousand acre-feet of peak period release, and compare against the unit storage benefit. It may be necessary to iteratively adjust the unit benefits and costs of electricity, water demands, and/or reservoir storage until the user achieves the release policy he desires.

INPUT FILE DESCRIPTION

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	FILE A - SYSTEM PARAMETERS	
PARAMETERS	Listed below are detailed descriptions of the variables defining some of the spatial and temporal dimensions of the physical system and its associated network formulation (one card).	
NJ	Number of nodes (reservoir and non-storage junctions) in the system (maximum of 50). Columns (11-15)	NJ
NRES	Number of reservoirs in the system (maximum of 30). Columns (16-20)	NRES
NJUNC	Number of non-storage junctions in the system (maximum of 50). Columns (21-25)	NJUN
NL	Number of conveyance links (canal, pipelines, and river channels) in the system (maximum of 75). Columns (26-30)	NL
NC	Number of artificial conveyance links (canals and pipelines) in the system (maximum of 75). Columns (31-35)	NC
NR	Number of river reaches in the system (maximum of 75). Columns (36-40)	NR
NYR	Number of years of simulated operation (maximum of 50). Columns (41-45)	NYEAR
NSEAS	Number of equal length subdivisions of a year used in analyzing the operation of the system (maximum of 12). Columns (46-50)	NSEAS
IDATE	Calendar year corresponding to the first year of simulated operation. Also calendar year to which present value costs are referenced. Columns (51-55)	IDATE
IMP	Number of the junction (node) where import into the system may occur. Leave blank if no import is desired. Columns (56-60).	IMP
ND	Number of nodes having positive water diversion demands (maximum of 50). Columns (61-65).	ND
KAPE1	FORTRAN logical Input/Output unit for input file containing a set of initial feasible solutions for advanced restart of the program. A zero value must be entered if no initial solutions are to be entered. Columns (66-70)	KAPE1
KAPE2	FORTRAN logical Input/Output unit for output file containing optimal solutions to network problems which may be used for advanced restarting of the program. A zero value must be entered if optimal solutions are not to be stored. This value must not equal the value of KAPE1 (FILE A) unless both are zero. Columns (71-75)	KAPE2

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	FILE B - STREAM JUNCTION DESCRIPTION Listed below are detailed descriptions of the variables describing the system junctions (storage and non-storage). Consecutive numbering of the junctions (nodes) is required with the reservoirs being numbered first followed by the non-storage junctions. There must be one card for each of the NJ (FILE A) junctions.	
NODE NO.	Numerical designation of the junction. Columns (1-2)	J
IDENT	Alphanumeric descriptor of the junction. Columns (3-10)	RNAME
MAXIMUM STORAGE	Maximum storage capacity of the junction (in 1000 acre-feet). Columns (11-20)	RCAP
MINIMUM STORAGE	Minimum allowed storage capacity of the junction (in 1000 acre-feet). Columns (21-30)	RMIN
RESER. COST	Cost of constructing the storage facility at the junction (in millions of dollars). This field may be left blank if the user does not require an analysis of the capital cost over time for the system. Columns (31-35)	CRES
DWNST. RES.	Node number of the downstream reservoir from this junction which either fully or partially controls the tailwater surface elevation below this junction. This value is ignored by the program if the junction is not a reservoir. Columns (36-40)	NDWN
S/N RATIO FOR DEMAND	Decimal fraction of water removed from the junction (to satisfy the demands at the junction) that is not consumptively used. This fraction must be greater than zero and should be set to 1 if the return flow does not re-enter the system. Columns (41-45)	RETSN
RETURN FLOW NODE	Numerical designation of the junction where the effluent from the demand at this junction is discharged back into the stream system. Leave this field blank if the effluent does not re-enter the system. Columns (46-50)	NLINK
MINIMUM DEMAND FRACTION	Fraction of water demand at the junction which must be met. A decimal value between 0 and 1 is required. The value in this field imposes a constraint on the network model that requires the indicated fraction of the intake demand to be supplied. Should the system be unable to meet any of these minimum demands then the program will stop with an infeasible solution. Columns (51-55)	DLO
BREAKPOINT STORAGE	Reservoir storage (in 1000 acre-feet) where the two linear segments join, in the piecewise linear approximation of surface area-storage capacity curve for this junction (see Figure 5). Leave this field blank if the junction is not a reservoir. This storage value should not be smaller than the minimum seasonal storage nor greater than the maximum season storage of the reservoir. Columns (56-65)	BHO
POWER GEN. CAP.	Design capacity for hydroelectric power generation (in megawatts) at the junction. This value is ignored if the junction is not a reservoir. Columns (66-70)	MLOAD

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
LOWER STORAGE SLOPE	Slope of line approximating the area-capacity curve in the lower range of storage (see S_1 in Figure 5). Columns (71-75)	ACO(1)
UPPER STORAGE SLOPE	Slope of line approximating the area-capacity curve in the upper range of storage (see S_2 in Figure 5). Columns (76-80)	ACO(2)
	FILE C - LINK DESCRIPTION AND SYSTEM CONFIGURATION Listed below are detailed descriptions of the data associated with the various links in the system. One data card is required for each of the NL (FILE A) conveyance links. Links should be numbered consecutively from one, beginning with river reaches followed by pump conveyance links. The user is directed to the prior section dealing with the limitations in the program for a discussion of the considerations required if the network contains circuits or loops.	
LINK NO.	Numerical designation of the conveyance link. Columns (1-2)	
IDENT	Alphanumeric descriptor of the conveyance link. Columns (3-10)	[illegible]
MAXIMUM FLOW CAPACITY	Maximum flow rate for the link [illegible]. Columns (11-20)	[illegible]
MINIMUM FLOW ALLOWED	Minimum flow rate for the link [illegible]. Columns (21-30)	[illegible]
TOTAL DYNAMIC HEAD	Total dynamic head (in feet) which must be overcome when pumping water along the link. Leave this data field blank if the link is a natural river channel. Columns (31-40)	CLIFT
LINK CONVEYANCE FACTOR	Fraction of water entering the link which also leaves the link. This value should represent the yearly average fraction of water conveyed through the link, and must have a value greater than zero. Set = 1 if and only if link is a pipeline. Columns (41050)	EL
HYDRO LINK	Binary (0, 1) variable set to 1 if the link is capable of generating hydroelectric power and set 0 otherwise. A link can produce hydroelectric power if it has as its origin node (FILE C) a reservoir having generating capability. However, only one link originating at such a reservoir may be designed as producing hydroelectric power. Columns (51-55)	
ORIGIN NODE	Originating node for the link. Columns (71-75)	LNODE(1)
TERMINAL NODE	Terminal node for the link. Columns (76-80)	LNODE(2)

Figure A-5a. SIM-V Input File Description

INPUT FILE DESCRIPTION

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	<u>FILE D - CONVEYANCE LINK CONSTRUCTION COST COEFFICIENTS</u>	
	Listed below are detailed descriptions of the data associated with the construction cost versus flow capacity of the conveyance links in the system. Each link is assumed to have two associated second-order polynominal capital cost equations: 1) Canal ditch cost (in dollars) vs. flow capacity (in acre-feet/year) and 2) Canal pump station cost (in dollars) vs. flow capacity (in acre-feet/year).	
	The first equation could be utilized to represent the cost of installed pipe if the link is a closed conduit. There must be one card for each of the NL (FILE A) links, however those cards corresponding to natural river channels should have blanks in the coefficient data fields. Should the user not require any output concerning the time history of capital costs over the simulated operating horizon then all coefficient data fields should be left blank.	
LINK NO.	Numerical designation for the link. Columns (1-2)	L
IDENT	Alphanumeric descriptor for the link. Columns (3-10)	
CANAL DITCH COST VS. CAPACITY	Construction cost equation of the form Ditch Cost ($) = A + B*Q + C*Q^2 where A, B, and C are constants and Q is the conveyance capacity of the link in acre-feet/year.	
INTERCEPT COEFF.	Constant coefficient A in the above equation. Columns (11-20)	CLINK (1, L, 1)
1st ORDER COEFF.	Constant coefficient B in the above equation. Columns (21-30)	CLINK (1, L, 2)
2nd ORDER COEFF.	Constant coefficient C in the above equation. Columns (31-40)	CLINK (1, L, 3)
CANAL PUMP STATION COST VS. CAPACITY	Construction cost equation of the form Pump Station Cost ($) = A + B*Q + C*Q^2 where A, B, and C are constants and Q is flow in acre-feet/year.	
INTERCEPT COEFF.	Constant coefficient A in the above equation. Columns (41-50)	CLINK (2, L, 1)
1st ORDER COEFF.	Constant coefficient B in the above equation. Columns (51-60)	CLINK (2, L, 2)
2nd ORDER COEFF.	Constant coefficient C in the above equation. Columns (61-70)	CLINK (2, L, 3)

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	<u>FILE E - ECONOMIC PARAMETERS</u>	
ECON PARMS	Listed below are detailed descriptions of the data required to specify the economic parameters for the system. There must be one card in this file.	
ANNUAL DISCOUNT RATE	Annual discount rate used in computing present value. Columns (11-20)	PCRINT
DEPT REPAYMENT PERIOD	Period (in years) over which debts, incurred for constructing reservoirs and conveyance links, must be repayed. Columns (21-30)	NPAY
ELECTRICAL POWER COST	Average annual unit cost of electricity in $/KW-HR. Columns (31-40)	POWR
ANNUAL OM&R COST FOR RES	Annual fixed operating, maintenance, and replacement cost for reservoir facilities as a decimal fraction of the construction cost of the reservoir. Columns (41-50)	RESONM
ANNUAL OM&R COST FOR CANALS	Annual fixed operating, maintenance, and replacement cost for conveyance facilities as a decimal fraction of the construction cost of the canal or pipeline. Columns (51-60)	CONONM
UNIT COST OF IMPORTED WATER	Unit cost of water imported into the system in $/acre-foot. Columns (61-70)	CIMP
CONSTRUCTION PERIOD FOR RES	Time period (in years) required between initiation of construction and final completion of reservoir projects. Columns (71-75)	LAGR
CONSTRUCTION PERIOD FOR CANALS	Time period (in years) required between initiation of construction and final completion of canal and pipeline projects. Columns (76-80)	LAGC
	<u>FILE F - SEASONAL VARIATIONS IN POWER COSTS</u>	
POWER DIST	Listed below are detailed descriptions of the data specifying the variations in unit electrical power costs within a year. There must be one card in this file.	
SEASONAL ELECTRICAL POWER COST FACTORS	List of decimal fractions corresponding to the seasonal variations in the average annual power cost specified in FILE E. Columns (11-15; 16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70)	POWFAC

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	<u>FILE G - SEASONAL AVAILABILITY OF IMPORT WATER</u>	
IMPORT	Listed below are detailed descriptions of the data specifying the seasonal availability of import water into the system. There must be one card in this file.	
MAXIMUM IMPORT	Maximum volume (in 1,000 acre-feet) of water available for import into the system in each year. Columns (11-15)	TIMP
SEASONAL DISTRIBUTION OF AVAILABLE WATER IMPORT	List of decimal fractions specifying the portion of the total annual import water that is available in each season of the year (maximum of 12 values). Columns (16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75)	XX
	<u>FILE H - SEASONAL VARIATION OF LINK CONVEYANCE FACTORS</u>	
TRAN FACTRS	Listed below are detailed descriptions of the data describing the variations within the year of the conveyance ratios for the links. There must be one card in this file. Pipelines are not effected by these factors.	
SEASONAL CORRECTION FACTORS FOR CONVEYANCE COEFFICIENTS	List of decimal fractions specifying the seasonal transmission factors (ratios of flows leaving link to flows entering link) as fractions of the average annual link conveyance factor (FILE C) (maximum of 12 nonzero values). Columns (11-15; 16-20; 21-25; 26-30; 31-35; 36-40; 41-45, 46-50; 51-55; 56-60; 61-65; 66-70)	FLF
	<u>FILE I - SEASONAL VARIATION OF MAXIMUM AND MINIMUM RESERVOIR STORAGE</u>	
	Listed below are detailed descriptions of the data describing the variations within the year of the upper and lower limits of water storage in reservoir nodes. There must be two records (cards) for each of the NRES (FILE A) storage junctions. The data records concerned with maximum storage limits must be read for all reservoirs before those pertaining to minimum storage limits are read. The data may be read, by reservoir, in any order, except where noted in previous sentence, but may only pertain to storage junctions.	
MAX. STOR.	Maximum storage bound seasonal variations. NRES (FILE A) data records.	I
RESERVOIR NUMBER	Numerical identifier for storage junction (FILE B). Columns (11-15)	
SEASONAL MAXIMUM RESERVOIR STORAGE CONTENT	List of percentages of maximum storage capacity NCAP (FILE B) corresponding to maximum storage content for the reservoir in each season. There must be NSEAS (FILE A) values on each data record, and they must be sequential beginning with the first season. Columns (16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75)	RMAXC

Figure A-5b. SIM-V Input File Description

INPUT FILE DESCRIPTION

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
MIN. STOR.	Minimum storage bound seasonal variations. NRES (FILE A) data records.	
RESERVOIR NUMBER	Numerical identifier of the junction (FILE B). Columns (11-15)	I
SEASONAL MINIMUM RESERVOIR STORAGE CONTENT	List of percentages specifying the percentage of the minimum reservoir storage RMIN (FILE B) that is allowable as the minimum storage content in the reservoir in each season. Seasonal percentages must be read in sequential order, beginning with the first season. There must be NSEAS (FILE A) values on each data record. Columns (16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55- 56-60; 61-65; 66-70; 71-75)	RMINC
	FILE J - SEASONAL VARIATION OF MAXIMUM AND MINIMUM LINK FLOW RATES	
	Listed below are detailed descriptions of the data describing the variations within the year of the upper and lower bounds on water flow rates in system conveyance links. There must be two records (cards) for each of the NL (FILE A) links. The data records concerned with maximum flow rates must be read for all links before those pertaining to minimum flow rates are read. The data may be read in any ordering of the links except as noted in the previous sentence.	
MAX FLOW	Maximum flow rate seasonal variations. NL (FILE A) data records.	
LINK NUMBER	Numerical identifier for link (FILE C): Columns (11-15)	I
SEASONAL MAXIMUM FLOW RATE	List of percentages of maximum flow rate CCAP (FILE C) corresponding to maximum flow rate in each season. There must be NSEAS (FILE A) values on each data record, and they must be sequential beginning with the first season. Columns (16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75)	CHAXC
MIN. FLOW	Minimum storage bound seasonal variations. NRES (FILE A) data records.	
LINK NUMBER	Numerical identifier for link (FILE C). Columns (11-15)	I
SEASONAL MINIMUM FLOW RATE	List of percentages specifying the percentage of the minimum flow rate CMIN (FILE C) that is allowable as the minimum flow rate in the link in each season. Seasonal percentages must be read in sequential order, beginning with the first season. There must be NSEAS (FILE A) values on each data record. Columns (16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75)	CMINC

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	FILE K - PROGRAM OUTPUT CONTROL	
CONTROL	Listed below are detail descriptions of the data designating the type of output information to be provided for each of the years in the operating horizon. There must be one card in this file.	
ANNUAL OUTPUT CONTROL	List of integer values defining the output mode for each year of the simulation. The print options are as indicated below: 0 - Print all output from the solution of the network model but not the network model itself; 1 - Print all output from the solution of the network model and the model formulation. 2 - Print all output specified under option "0" except marginal costs. 3 - Suppress all output for this year A maximum of 45 values may be listed with one value per column. It is assumed that the yearly print options are read sequentially beginning with the first year of simulation in column 15. Columns (15-59)	IPRNT
	FILE L - SYSTEM WATER DEMAND NODES	
DEMAND NDS	Listed below are detailed descriptions of the data elements describing the location of water diversion demands in the system. There must be ND (FILE A) nodes listed in this file. If ND = 0 then this input file is not read by the program. The demand nodes are read with thirteen (13) nodes numbers on each data record (card) upto a maximum of four (4) records. All data fields on a record must be utilized before additional records are used.	
NODE NUMBERS OF THE DESIGNATED DEMAND NODES	Numerical designation of the nodes which are specified as locations in the system where water diversion demands occur. These nodes may correspond to either reservoirs or non-storage junctions. Columns (11-15; 16-20; 21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75).	JD
	FILE M - SYSTEM SPILL DESCRIPTION	
SPILLAGE	Listed below are detailed descriptions of the data associated with specifying the unit cost and maximum magnitude of spills from the system. There must be one card in this file.	

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
MAXIMUM NODE SPILLAGE	Maximum rate of spillage (in 1,000 acre-feet per season) from each spill nodes. A large value (e.g., 5,000) should be used to insure that water can leave the system. If the value is too small then an infeasible solution may result. Columns (11-20)	SCAP
UNIT SPILL COST	Cost of each unit of water spilled from the system (in $1/acre-foot). The program specifies a minimum unit cost of $.001. Columns (21-30)	KSPILL
NUMBER OF SPILL NODES	Total number of nodes in the system which are allowed to spill water from the system (maximum of ten (10) nodes). Columns (31-40)	NSPNDS
	FILE N - SYSTEM SPILL NODES	
SPILL NDS	Listed below are detailed descriptions of the data defining the locations within the system where spills may occur. Care should be taken in specifying the spill nodes so that excess water will be able to exit the system. Infeasible solutions may occur if the spill nodes are improperly located. The spill nodes are read five nodes per card with a maximum of two cards in this file. The number of spill nodes must correspond to the number indicated in FILE X.	
NODE NUMBER OF THE DESIGNATED SPILL NODES	Numerical designation of the nodes which are specified as system spill nodes. These nodes may correspond to either reservoir or non-storage junctions. Columns (19-20; 29-30; 39-40; 49-50; 59-60)	JS
	FILE O - RESERVOIR CONSTRUCTION TIMES	
RES START	Listed below are detailed descriptions of the data defining the installation time of reservoirs within the simulation period. Starting times for up to four reservoirs are read per card. There must be enough cards in this file to read data for all NR (FILE A) reservoir facilities.	
NUMBER	Numerical designation of the reservoir. Columns (19-20; 34-35; 49-50; 64-65)	I
YEAR	Simulation year for completion of the reservoir. Columns (21-25; 36-40; 51-55; 66-70)	JBLT

Figure A-5c. SIM-V Input File Description

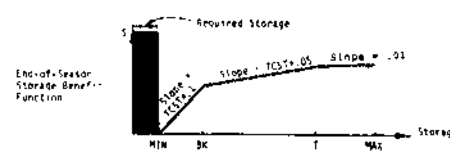
CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
	FILE P - LINK CONSTRUCTION TIMES	
LINK START	Listed below are detailed descriptions of the data elements specifying the installation times of all conveyance links in the system. Starting times for as many as 4 links are read per card. There must be sufficient cards in this file to read data for all NL (FILE A) links.	
NUMBER	Numerical designations for link. Columns [illegible]	I
YEAR	Simulation year for completion of the link. Columns (21-25; 36-40; 51-55; 66-70)	LBLT
	FILE Q - INITIAL RESERVOIR STORAGE	
PCT FULL	Listed below are detailed descriptions of the data elements specifying the storage conditions to be assigned to the reservoirs upon their installation in the system. There must be a sufficient number of cards in this file to provide starting storages for all NRES (FILE A) reservoirs, with a maximum of four (4) storage values per card.	
NUMBER	Numerical designation for the reservoir. Columns (19-20; 34-35; 49-50; 64-65)	I
PERCENT	Percentage of maximum storage capacity corresponding to the initial storage level desired in the reservoir. Columns (21-25; 36-40; 51-55; 66-70)	FSTART
	FILE P - RESERVOIR OPERATING RULES	
RES OPER	Listed below are detailed descriptions of the data elements required to specify the manner in which the reservoirs in the system are to be operated. The SIM-V Program allows the user to specify one of three general operating policies for each of the reservoirs in the system. These rules control the storage level in the reservoirs by specifying the end-of-month target storage conditions. The monthly target storages may be either fixed at individual monthly values or dependent upon initial monthly storages in user specified "key" reservoirs. The three reservoir policies will be designated as the "upper bound", "lower bound", and "flexible benefit" terminal storage rules. These rules are predicated on dividing the available storage space in each impoundment into three storage segments. Complete description of these rules are provided below. There must be NRES (FILE A) cards in this file.	

<u>"Upper Bound" Storage Rule (Option 1)</u> -

This operating policy option requires that the user specify for each season of the year a level of storage (T) for which an explicit benefit is assessed for all water storage upto that level. These storage volumes must be no greater than the maximum water conservation capacity of the impoundment. In addition, a unit benefit (TCST) ($/acre-foot) must be assigned by the user to the seasonal terminal storages in the reservoir. This number should reflect the relative desirability of storing water in this reservoir as opposed to storing the water in another impoundment or releasing it to meet demands. This need not reflect a strictly monetary measure of opportunity gained through storing water.

In the network model, the reservoir storage at the end of each season is assigned various benefit values. The associated benefits for this operating rule option are indicated in the figure below. The BK storage level in this figure corresponds to the breakpoint storage in the piecewise linear approximation to the area-capacity curve (FILE B).

"UPPER BOUND" OPERATING RULE

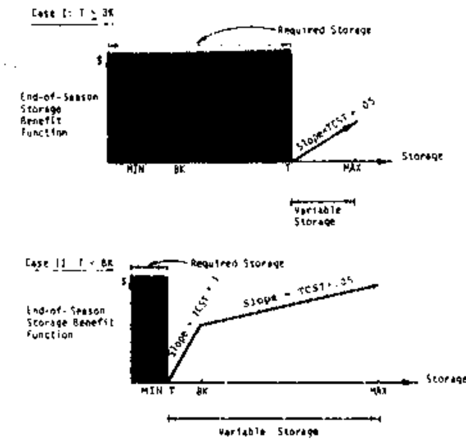


<u>"Lower Bound" Storage Rule (Option 2)</u> -

In contrast with the previous operating option that varies the maximum amount of beneficial storage, this option requires that the user specify target terminal storages that are required to be met or exceeded. In contrast with Option 1, the unit storage benefit is assigned for seasonal terminal storages between the target and maximum storages.

The manner in which this operating option functions is illustrated in the figure below. The variable range of storage is controlled by the target storage (T) designated. If the required target level is set too high, however, it is possible that either an infeasible solution may result or a shortage may occur in the demands supplied from the reservoir.

"LOWER BOUND" OPERATING RULE



<u>"Flexible Benefit" Storage Rule (Option 3)</u> -

This operating option is identical to Option 1 with the exception that the unit benefit for storage is not fixed at the user-designated value. The unit benefit is allowed to decrease from the input value to zero in increments of $1 per acre-foot. Each monthly operating problem is treated by solving a succession of network models where the unit storage benefit for all reservoirs operated under this option is repeatedly reduced by the above increment. When all reservoirs operated under this option have unit storage benefits less than $1/acre-foot then the process stops and the least-cost solution obtained is treated as the optimal solution for that month. <u>This operating rule is exercised by the program only for systems generating hydroelectric power. If power production capacity does not exist in the system then this option is identical to Option 1.</u>

The concept behind this operating policy is to allow the firm hydropower generation requirement to be met as long as water remains in storage in the system. By incrementally dropping all the unit benefits by an equal amount, those reservoirs designated by the user to have lower unit storage benefits will be utilized for increased hydropower production before those reservoirs having unit storage benefits of greater value, assuming that all initial unit benefits exceed benefit for peak production. Thus the user can select which reservoirs should be drawn upon first for hydrogeneration if the system cannot normally meet both the firm power generation requirement and the designated storage targets for the reservoirs operated under this option.

Figure A-5d. SIM-V Input File Description

INPUT FILE DESCRIPTION

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
NUMBER	Numerical designation of the reservoir. Columns (14-15)	J
OPER OPT	Operating Option for the reservoir. A value of either 1 (for "Upper Bound" Rule), 2 (for "Lower Bound" Rule), or 3 (for "Flexible Benefit" Rule) must be used. Columns (19-20)	IOPT(J)
STORAGE BENEFIT	Unit storage benefit (in $/acre-foot) for water stored at the end of each season in the reservoir. Columns (21-25)	TCST(J)
END-OF-SEASON TARGET RESERVOIR STORAGE LEVELS	Set of as many as 12 seasonal target terminal storage levels for the reservoir as decimal fractions of the maximum reservoir storage (FILE B). Each value must be no greater than 1 and no less than the fraction associated with the minimum storage pool (FILE B). Columns (26-29; 30-33; 34-37; 38-41; 42-45; 46-49; 50-53; 54-57; 58-61, 62-65; 66-69; 70-73)	TFAC(J)
NO. OF KEY RES.	Number of key reservoirs used to compute target monthly storage levels for the reservoir (maximum of 4). Columns 74-46).	NKEY(J)
KEY RES.	This data entry defines the key reservoirs used for determining the target terminal storage in the current reservoir J in each season of the year. There must be one (1) data record (card) in this file for every reservoir having the number of key reservoirs (NKEY(J)) in (FILE R) greater than zero.	
NODE NUMBERS OF KEY RESERVOIRS	Numerical designation of each of the reservoir nodes used in computing the seasonal target terminal storage for reservoir J. These node numbers may be read in any order but must equal NKEY(J) (FILE R). Columns (11-15; 16-20; 21-25, 26-30).	NRKEY(J,L)
KEY RES.EQ	This data entry defines the coefficients of the equation used to calculate the target terminal storage in reservoir J in each season of the year. There must be NSEAS (FILE A) data records (cards) in this file for every reservoir J having NKEY(J) (FILE R) greater than zero. The equation for computing the target storage ST (1000 acre-feet) at the end of a season is $$ST = A + \sum_{L=1}^{NKEY(J)} B_L S_L$$ Where A and B_L are constants, NKEY(J) is the number of key reservoirs, and S_L is the beginning of season storage in the L-th key reservoir (in 1000 acre-feet).	
CONSTANT VALUE	The constant value A in above storage equation for season 1. Column (11-15)	RKEY(J,1,1)

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
COEFFICIENTS OF KEY RESERVOIR STORAGES	The constant coefficient multipliers B_L of the beginning storage in season 1 for the L-th key reservoir. These multipliers must be read in the same order as their corresponding reservoir node numbers NRKEY(J,L) (FILE R) and must equal NKEY(J) (FILE R) in number. Columns (16-20; 21-25; 26-30; 31-35).	RKEY(J,L,1)
	FILE S - DEMAND SHORTAGE COSTS	
SHORT COST	Listed below are detailed descriptions of the data specifying the unit cost incurred at each junction for failing to supply the maximum intake demand. The unit shortage costs must be provided for each season of the year, with a maximum of four seasons on each card.	
NUMBER	Numerical designation for the junction Columns (19-20)	J
SEASON	Numerical designation of the season within the year. This must be a positive integer value no greater than 12. Columns (21-25, 36-40; 51-55; 66-70)	t
UNIT COST	Unit Cost of shortage in the demand (in $/acre-foot) at the junction in the indicated season Columns (26-35, 41-50; 56-65, 71-78)	CST (T, J)
	FILE T - ANNUAL FIRM POWER REQUIREMENT	
POWER	Listed below are detailed descriptions of the data required to specify the annual firm hydroelectric power generation requirement (target) for the reservoir system, the seasonal distribution of that target, and the unit benefits for peak (firm) and non-peak (dump) power. If there are no power generation links (FILE C) in the system then this file is not read by the program. Otherwise, there must be one (1) input record in the file.	
ANNUAL TARGET	Annual rate of firm power generation (in megawatts) by the system. This is the target rate of generation during peak period hours only (FILE U). Columns (6-10)	ANNPOW
SEASONAL DISTRIBUTION OF ANNUAL FIRM POWER REQUIREMENT	List of decimal fractions of the annual firm power requirement specifying the firm power generation rate target for each season of the year. There must be as many values as there are seasons NSEAS (FILE A). Values are read sequentially beginning with the first season. Columns (11-15; 16-20; 21-25; 26-30, 31-35; 36-40; 41-45; 46-50; 51-55; 56-60, 61-65; 66-70)	NPOWF
PEAK BENEFIT	Unit benefit (in $/kilowatt-hour) for electricity produced during peak hours in a season (FILE U) up to the firm power requirement for that season (FILE T). Columns (71-75)	ONPKC

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
NON PEAK BENEFIT	Unit benefit (in $/kilowatt-hour) for electricity produced either during non-peak hours (FILE U) or during peak hours but in excess of the seasonal firm power requirement (FILE T). This value must be less than the value read for the unit peak power benefit ONPKC (FILE T). Columns (76-80)	OPPKC
	FILE U - SEASONAL PEAK AND NON-PEAK PERIOD HOURS OF POWER GENERATION	
	Listed below are detailed descriptions of the data required to specify the hours of peak and non-peak power generation in each season of the year. The hours of peak generation must be specified first on one (1) data record, followed by the non-peak hours on one (1) data record. There must be two (2) data records in this file. This file is read only if hydroelectric power generating links are specified in FILE C	
PEAK HOURS	Hours of peak power production by season.	
HOURS FOR PEAK GENERATION	List of hours in each season during which peak power may be generated. NSEAS (FILE A) seasonal values are read sequentially beginning with the first season. Columns (11-15; 16-20; 21-25; 26-30; 31-35; 36-40; 41-45, 46-50; 51-55; 56-60; 61-65; 66-70)	IHRSP
NON-PK HRS	Hours of non-peak power production by season	
HOURS FOR NON-PEAK GENERATION	List of hours in each season during which only non-peak power is generated. NSEAS (FILE A) seasonal values are read sequentially beginning with the first season. Columns (11-15; 16-20; 21-25; 26-30; 31-35; 36-40, 41-45, 46-50; 51-55; 56-60; 61-65; 66-70)	[illegible]
	FILE V - RESERVOIR WATER SURFACE ELEVATION-CAPACITY DATA	
	Listed below are detailed descriptions of the data required to specify the water surface elevation at a reservoir as a function of the storage volume in the reservoir. There must be six (6) data records for each of the NRES (FILE B) reservoirs in the system, with each record containing three (3) pairs of matched elevation-storage points. Each successive pair of elevation-storage values must represent a greater storage volume than the previous pair. The user may supply as many elevation-storage points as desired, however, blank records must be inserted to supply the required six (6) input records for each reservoir. Data may be read in any ordering of the reservoirs. If hydroelectric power generation arcs are not located in the system (FILE C) then this input file will not be read by the program.	

Figure A-5e. SIM-V Input File Description

INPUT FILE DESCRIPTION

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
RESERVOIR NAME	Alphanumeric identifier for the reservoir. This input field is for the user's benefit only and is not read by the program. Columns (1-10)	
RESERVOIR NO.	Numerical identifier for the reservoir (FILE B). This input field is read only on the first card of each set of six (6) cards per reservoir. Columns (11-15)	J
DATA POINTS	Three pairs of water surface elevation (feet) and associated reservoir storage volume (acre-feet) values. Columns (16-75)	VOTAB
SEQ	Sequence number for each of the six (6) water surface elevation-storage records. This data field is not read by the program, but is intended to aid in preventing card sequencing errors. Column (80)	

FILE W - ELECTRICAL POWER GENERATION EFFICIENCY DATA

Listed below are detailed descriptions of the data required to specify the power generation efficiency of the powerplant at a reservoir as a function of the power generated at the plant. There must be six (6) data records for each of the NRES (FILE B) reservoirs in the system, with each record containing three (3) pairs of matched efficiency-power values. Each successive pair of efficiency-power values must represent a greater power generation than the previous pair. The user may supply as many efficiency-power points as desired, however, blank records must be inserted to supply the required six (6) input records for each reservoir. Data may be read in any ordering of the reservoirs. If hydroelectric power generation arcs are not present in the system (FILE C) then this input file will not be read by the program. Each linear segment must not have zero efficiency for zero generation.

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
RESERVOIR NAME	Alphanumeric identifier for the reservoir. This input field is for the user's benefit only and is not read by the program. Columns (1-10)	
RES. NO.	Numerical identifier for the reservoir (FILE B). This input field is read only on the first card of each set of six cards per reservoir. Columns (11-15)	J
DATA POINTS	Three pairs of generation efficiency (percent) and associated power generation (kilowatt) values. Columns (16-75)	TEFF
SEQ	Sequence number for each of the six (6) efficiency power records. This data field is not read by the program, but is intended to aid in preventing card sequencing errors. Column (80)	

FILE X - TAILRACE WATER SURFACE ELEVATION-FLOW DISCHARGE DATA

Listed below are detailed descriptions of the data required to specify the water surface elevation of the tailrace downstream of a reservoir as a function of the flow discharge from the reservoir. There must be six (6) data records for each of the NRES (FILE B) reservoirs in the system, with each record containing three (3) pairs of elevation-discharge points. Each successive pair of elevation-discharge values must represent a greater discharge rate than the previous pair. The user may supply as many elevation-discharge points as desired; however, blank records must be inserted to supply the required six (6) input records for each reservoir. Data may be read in any ordering of the reservoirs. If hydroelectric power generation arcs are not present in the system (FILE C) then this input file will not be read by the program.

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
RESERVOIR NAME	Alphanumeric identifier for the reservoir. This input field is for the user's benefit only and is not read by the program. Columns (1-10)	
RES. NO.	Numerical identifier for the reservoir (FILE B). This input field is read only on the first card of each set of six cards per reservoir. Columns (11-15)	J
DATA POINTS	Three pairs of tailrace water surface elevation (feet) and associated reservoir discharge rate (cfs) values. Columns (16-75)	ITELEV
SEQ	Sequence number for each of the six (6) elevation-discharge records. This data field is not read by the program, but is intended to aid in preventing card sequencing errors. Column (80)	

FILE Y - MAXIMUM FLOW DISCHARGE-RESERVOIR STORAGE DATA

Listed below are detailed descriptions of the data required to specify the maximum flow discharge through the power generation plant at a reservoir as a function of the storage volume in the reservoir. There must be six (6) data records for each of the NRES (FILE B) reservoirs in the system, with each record containing three (3) pairs of matched maximum discharge-storage points. Each successive pair of discharge-storage values must represent a greater storage volume than the previous pair. The user may supply as many discharge-storage points as desired; however, blank records must be inserted to supply the required six (6) input records for each reservoir. Data may be read in any ordering of the reservoirs. If power generation arcs are not present in the system (FILE C) then this input file will not be read by the program.

CARD OR FIELD ID	DESCRIPTION	PROGRAM VARIABLE
RESERVOIR NAME	Alphanumeric identifier for the reservoir. This input field is for the user's benefit only and is not read by the program. Columns (1-10)	
RES. NO.	Numerical identifier for the reservoir (FILE B). This input field is read only on the first card of each set of six cards per reservoir. Columns (11-15)	J
DATA POINTS	Three pairs of maximum discharge flow rates (cfs) and associated reservoir storage volume (acre-feet) values. Columns (16-75)	IMAXD
SEQ	Sequence number for each of the six (6) maximum discharge-storage records. This data field is not read by the program, but is intended to aid in preventing card sequencing errors. Column (80)	

FILE 2 - JUNCTION UNREGULATED INFLOWS

CARD OR FIELD TO	DESCRIPTION	PROGRAM VARIABLE
UNREG INF	Listed below are detailed descriptions of the data specifying the seasonal unregulated (natural) inflow into all junctions in one simulation year. Each card contains up to twelve seasonal inflow values for a single junction. There must be NJ (FILE A) cards in this data file, and junction inflows must be read in sequential order beginning with junction number 1.	
YEAR NO.	Simulation year in which the seasonal inflows on the card occur. Columns (13-15)	
NODE NO.	Numerical designation for the junction. Columns (19-20)	
SEASONAL INFLOW VALUES	List of unregulated seasonal inflows into the junction (in 1,000 acre-feet). The user is cautioned that negative inflow values may cause the program to fail under some circumstances. Columns (21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75; 76-80)	U

FILE 2A - JUNCTION WATER DEMANDS

CARD OR FIELD TO	DESCRIPTION	PROGRAM VARIABLE
DEMANDS	Listed below are detailed descriptions of the data specifying intake demands (not the consumptive use) of the reservoir and non-storage junctions in the system for a single year. The demands at any junction may vary by season by year over the simulation period. There must be NJ (FILE A) cards in this file, with junctions read in sequential order.	
YEAR NO.	Year in the simulation in which the seasonal demands on the card occur. Columns (13-15)	
NODE NO.	Numerical designation for the junction. Columns (19-20)	
SEASONAL INFLOW VALUES	List of seasonal intake demands at the junction (in 1,000 acre-feet). Columns (21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75; 76-80)	D

FILE 2B - RESERVOIR NET EVAPORATION RATES

CARD OR FIELD TO	DESCRIPTION	PROGRAM VARIABLE
EVAP RATE	Listed below are detailed descriptions of the data specifying the seasonal net evaporation rates in a single year at the reservoirs in the system. There must be NRES (FILE A) cards in this file, with the reservoirs read in sequential order.	
YEAR NO.	Year in the simulation in which the seasonal evaporation rates on the card occur. Columns (13-15)	
NODE NO.	Numerical designation for the reservoir. Columns (19-20)	
SEASONAL EVAPORATION RATES	List of seasonal net evaporation rates at the reservoir (in feet/season). Columns (21-25; 26-30; 31-35; 36-40; 41-45; 46-50; 51-55; 56-60; 61-65; 66-70; 71-75; 76-80)	E

Figure A-5f. SIM-V Input File Description

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SYSTEM PARAMETERS

				NS	NJ	NR	NYP	NSEAS	ITAPE	IMP				
PARAMETER														

STREAM JUNCTION DESCRIPTION

	IDENT	MAXIMUM STORAGE (1000 ACRE-FEET)	MINIMUM STORAGE (1000 ACRE-FEET)	RESERVOIR COST ($10^6)	DWNST. RES	S/W RATIO FOR DEMAND	RETURN FLOW NODE	MINIMUM DEMAND FRACTION	BREAKPOINT STORAGE (1000 AC-FT)	POWER GEN. CAP. (MW)	PIECEWISE APPROX. LOWER SLOPE	PIECEWISE APPROX. UPPER SLOPE

LINK DESCRIPTION AND SYSTEM CONFIGURATION

LINK NO.	IDENT	MAXIMUM FLOW CAPACITY (CFS)	MINIMUM FLOW ALLOWED (CFS)	TOTAL DYNAMIC HEAD (FEET)	LINK CONVEYANCE FACTOR			ORIGIN NODE	TERMINAL NODE

CONVEYANCE LINK CONSTRUCTION COST COEFFICIENTS

LINK NO.	IDENT	CANAL DITCH COST VS. CAPACITY: INTERCEPT COEFF.	CANAL DITCH COST VS. CAPACITY: 1st ORDER COEFF.	CANAL DITCH COST VS. CAPACITY: 2nd ORDER COEFF.	CANAL PUMP STATION COST VS. CAPACITY: INTERCEPT COEFF.	CANAL PUMP STATION COST VS. CAPACITY: 1st ORDER COEFF.	CANAL PUMP STATION COST VS. CAPACITY: 2nd ORDER COEFF.

ECONOMIC PARAMETERS

	ANNUAL DISCOUNT RATE	DEBT REPAYMENT PERIOD	ELECTRICAL POWER COST ($/KW-HR)	ANNUAL OM&R COST FOR RESERVOIRS	ANNUAL OM&R COST FOR CANALS	UNIT COST OF IMPORTED WATER ($/ACRE-FOOT)	RES. CONSTR. PER. (YEARS)	CANAL CONSTR. PER. (YEARS)
ECON FACTOR								

SEASONAL VARIATION IN POWER COSTS

SEASONAL ELECTRICAL POWER COST FACTORS

	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
POWER DIST												

SEASONAL AVAILABILITY OF IMPORT WATER

SEASONAL DISTRIBUTION OF AVAILABLE WATER IMPORT

	MAXIMUM IMPORT (1000 AC-FT)	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
IMPORT													

SEASONAL VARIATION OF LINK CONVEYANCE FACTORS

SEASONAL CORRECTION FACTORS FOR CONVEYANCE COEFFICIENTS

	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
TRAN FCTRS												

Note: All numeric fields without decimals are integer

Figure A-6a. SIM-V Input Data Sheets

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SEASONAL VARIATION IN MAXIMUM AND MINIMUM RESERVOIR STORAGE

	RESERVOIR NUMBER	SEASONAL MAXIMUM RESERVOIR STORAGE CONTENT (PERCENTAGE OF MAXIMUM STORAGE CAPACITY)											
		SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
MAX. STOR.													
MAX. STOR.													
MAX. STOR.													
MAX. STOR.													
MAX. STOR.													
MAX. STOR.													

	RESERVOIR NUMBER	SEASONAL MINIMUM RESERVOIR STORAGE CONTENT (PERCENTAGE OF MINIMUM STORAGE CAPACITY)											
		SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
MIN. STOR.													
MIN. STOR.													
MIN. STOR.													
MIN. STOR.													
MIN. STOR.													
MIN. STOR.													

SEASONAL VARIATION IN MAXIMUM AND MINIMUM LINK FLOW RATE

	LINK NUMBER	SEASONAL MAXIMUM FLOW RATE (PERCENTAGE OF FLOW CAPACITY)											
		SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
MAX. FLOW													
MAX. FLOW													
MAX. FLOW													
MAX. FLOW													
MAX. FLOW													
MAX. FLOW													

	LINK NUMBER	SEASONAL MINIMUM FLOW RATE (PERCENTAGE OF FLOW CAPACITY)											
		SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
MIN. FLOW													
MIN. FLOW													
MIN. FLOW													
MIN. FLOW													
MIN. FLOW													
MIN. FLOW													

PROGRAM OUTPUT CONTROL

		ANNUAL OUTPUT CONTROL [illegible]
CONTROL		

SYSTEM WATER DEMAND NODES

	NODE NUMBERS OF THE DESIGNATED DEMAND NODES											
	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER
DEMAND NDS												
DEMAND NDS												
DEMAND NDS												

SYSTEM SPILL DESCRIPTION

	MAXIMUM NODE SPILLAGE (1000 AC-FT/SEASON)	UNIT SPILL COST [illegible]	NUMBER OF SPILL NODES
SPILLAGE			

SYSTEM SPILL NODES

		NODE NUMBERS OF THE DESIGNATED SPILL NODES				
		NUMBER	NUMBER	NUMBER	NUMBER	NUMBER
SPILL NDS		RES	RES	RES	RES	RES
SPILL NDS		RES	RES	RES	RES	RES

Note: All numeric fields without decimal are integer

Figure A-6b. SIM-V Input Data Sheets

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RESERVOIR CONSTRUCTION TIMES

		RESERVOIR START TIMES										
		NUMBER	YEAR		NUMBER	YEAR		NUMBER	YEAR		NUMBER	YEAR
RES START		RES			RES			RES			RES	
RES START		RES			RES			RES			RES	
RES START		RES			RES			RES			RES	
RES START		RES			RES			RES			RES	
RES START		RES			RES			RES			RES	
RES START		RES			RES			RES			RES	

LINK CONSTRUCTION TIMES

		[illegible]										
		NUMBER	YEAR		NUMBER	YEAR		NUMBER	YEAR		NUMBER	YEAR
LINK START		LINK			LINK			LINK			LINK	
LINK START		LINK			LINK			LINK			LINK	
LINK START		LINK			LINK			LINK			LINK	
LINK START		LINK			LINK			LINK			LINK	
LINK START		LINK			LINK			LINK			LINK	
LINK START		LINK			LINK			LINK			LINK	

INITIAL RESERVOIR STORAGE

		INITIAL RESERVOIR STORAGE CONDITIONS (PERCENTAGE OF MAXIMUM STORAGE)										
		NUMBER	PERCENT		NUMBER	PERCENT		NUMBER	PERCENT		NUMBER	PERCENT
PCT FULL		RES			RES			RES			RES	
PCT FULL		RES			RES			RES			RES	
PCT FULL		RES			RES			RES			RES	
PCT FULL		RES			RES			RES			RES	
PCT FULL		RES			RES			RES			RES	
PCT FULL		RES			RES			RES			RES	

RESERVOIR OPERATING RULES

	NUMBER	OPER. OPTION NO. 0, OR 2	STORAGE BENEFIT ($/AC-FT)	END-OF-SEASON TARGET RESERVOIR STORAGE LEVELS (DECIMAL FRACTION OF MAXIMUM STORAGE)												NO. OF KEY RES.
				SEAS 1	SEAS 2	SEAS 3	SEAS 4	SEAS 5	SEAS 6	SEAS 7	SEAS 8	SEAS 9	SEAS 10	SEAS 11	SEAS 12	
RES OPER	RES	OPT														
RES OPER	RES	OPT														
RES OPER	RES	OPT														
RES OPER	RES	OPT														
RES OPER	RES	OPT														
RES OPER	RES	OPT														

	NODE NUMBERS OF KEY RESERVOIRS			
	RES. NO. 1	RES. NO. 2	RES. NO. 3	RES. NO. 4
KEY RES				

	CONSTANT VALUE	COEFFICIENTS OF KEY RESERVOIR STORAGE			
		RES. 1	RES. 2	RES. 3	RES. 4
KEY RES EQ					

DEMAND SHORTAGE COSTS

		SEASONAL SHORTAGE COSTS FOR NODE DEMANDS								
		NUMBER	SEASON	UNIT COST ($/AC-FT)	SEASON	UNIT COST ($/AC-FT)	SEASON	UNIT COST ($/AC-FT)	SEASON	UNIT COST ($/AC-FT)
SHORT COST		JCT								
SHORT COST		JCT								
SHORT COST		JCT								
SHORT COST		JCT								
SHORT COST		JCT								
SHORT COST		JCT								

Note: All numeric fields without decimals are integer

Figure A-6c. SIM-V Input Data Sheets

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ANNUAL FIRM POWER REQUIREMENT

FILE T

	ANNUAL TARGET (MEGAWATTS)	SEASON DISTRIBUTION OF ANNUAL FIRM POWER REQUIREMENT (FRACTION)												PEAK BENEFIT ($/KW-HR)	NON-PEAK BENEFIT ($/KW-HR)
		SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12		
POWER															

SEASONAL PEAK AND NON-PEAK PERIOD HOURS OF POWER GENERATION

FILE U

	HOURS FOR PEAK GENERATION											
	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
PEAK HOURS												
	HOURS FOR NON-PEAK GENERATION											
	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
NON-PK HRS												

RESERVOIR WATER SURFACE ELEVATION - CAPACITY DATA

FILE V

RESERVOIR NAME	RESERVOIR NO.	DATA POINTS 1, 4, 7, 10, 13, 16		DATA POINTS 2, 5, 8, 11, 14, 17		DATA POINTS 3, 6, 9, 12, 15, 18		SEQ
		ELEVATION (FEET)	CAPACITY (ACRE-FEET)	ELEVATION (FEET)	CAPACITY (ACRE-FEET)	ELEVATION (FEET)	CAPACITY (ACRE-FEET)	
								1
								2
								3
								4
								5
								6

ELECTRICAL POWER GENERATION - EFFICIENCY DATA

FILE W

RESERVOIR NAME	RESERVOIR NO.	DATA POINTS 1, 4, 7, 10, 13, 16		DATA POINTS 2, 5, 8, 11, 14, 17		DATA POINTS 3, 6, 9, 12, 15, 18		SEQ
		GEN. EFFIC. (PERCENT)	ENERGY GENERATION (KW)	GEN. EFFIC. (PERCENT)	ENERGY GENERATION (KW)	GEN. EFFIC. (PERCENT)	ENERGY GENERATION (KW)	
								1
								2
								3
								4
								5
								6

TAILRACE WATER SURFACE ELEVATION - FLOW DISCHARGE DATA

FILE X

RESERVOIR NAME	RESERVOIR NO.	DATA POINTS 1, 4, 7, 10, 13, 16		DATA POINTS 2, 5, 8, 11, 14, 17		DATA POINTS 3, 6, 9, 12, 15, 18		SEQ
		TAILRACE ELEV. (FT.)	FLOW DISCHARGE (CFS)	TAILRACE ELEV. (FT.)	FLOW DISCHARGE (CFS)	TAILRACE ELEV. (FT.)	FLOW DISCHARGE (CFS)	
								1
								2
								3
								4
								5
								6

MAXIMUM FLOW DISCHARGE-RESERVOIR STORAGE DATA

FILE Y

RESERVOIR NAME	RESERVOIR NO.	DATA POINTS 1, 4, 7, 10, 13, 16		DATA POINTS 2, 5, 8, 11, 14, 17		DATA POINTS 3, 6, 9, 12, 15, 18		
		MAX. DISCHARGE (CFS)	STORAGE (AC-FT)	MAX. DISCHARGE (CFS)	STORAGE (AC-FT)	MAX. DISCHARGE (CFS)	STORAGE (AC-FT)	
								1
								2
								3
								4
								5
								6

Note. All numeric fields without decimals are integer

Figure A-6d. SIM-V Input Data Sheets

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JUNCTION UNREGULATED INFLOWS

SEASONAL INFLOW VALUES (1000 ACRE-FEET) *

	YEAR NO.	JCT NO.	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												
UNREG INF	YR	JCT												

JUNCTION WATER DEMANDS

SEASONAL DEMAND VALUES (1000 ACRE-FEET) *

	YEAR NO.	JCT NO.	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												
DEMANDS	YR	JCT												

RESERVOIR NET EVAPORATION RATES

SEASONAL EVAPORATION RATES (FEET/SEASON) *

	YEAR NO.	RES NO.	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SEASON 7	SEASON 8	SEASON 9	SEASON 10	SEASON 11	SEASON 12
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												
EVAP RATE	YR	RES												

* Left justify and insert decimal points, all other numeric fields integer

Figure A-6e. SIM-V Input Data Sheets

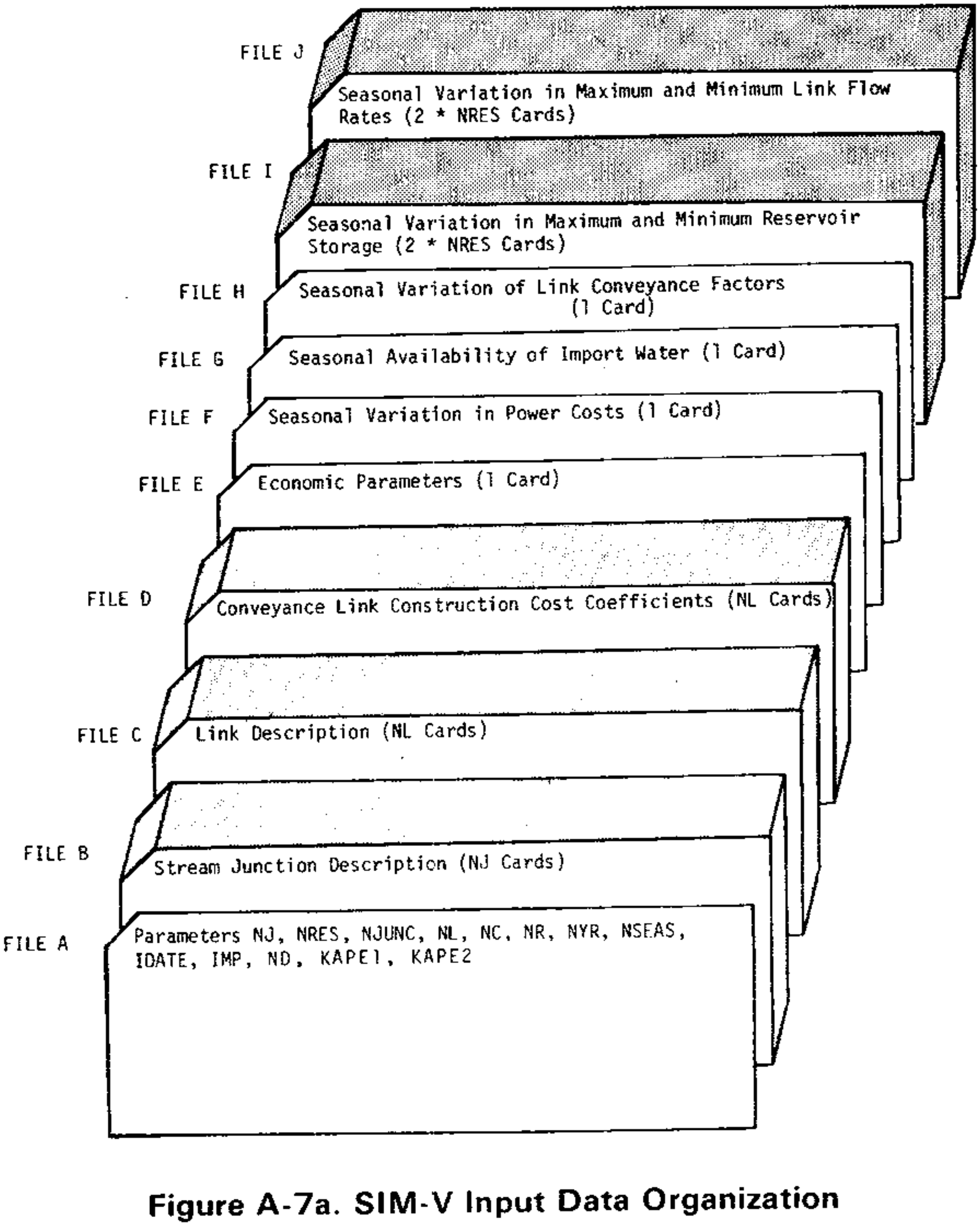

Figure A-7a. SIM-V Input Data Organization

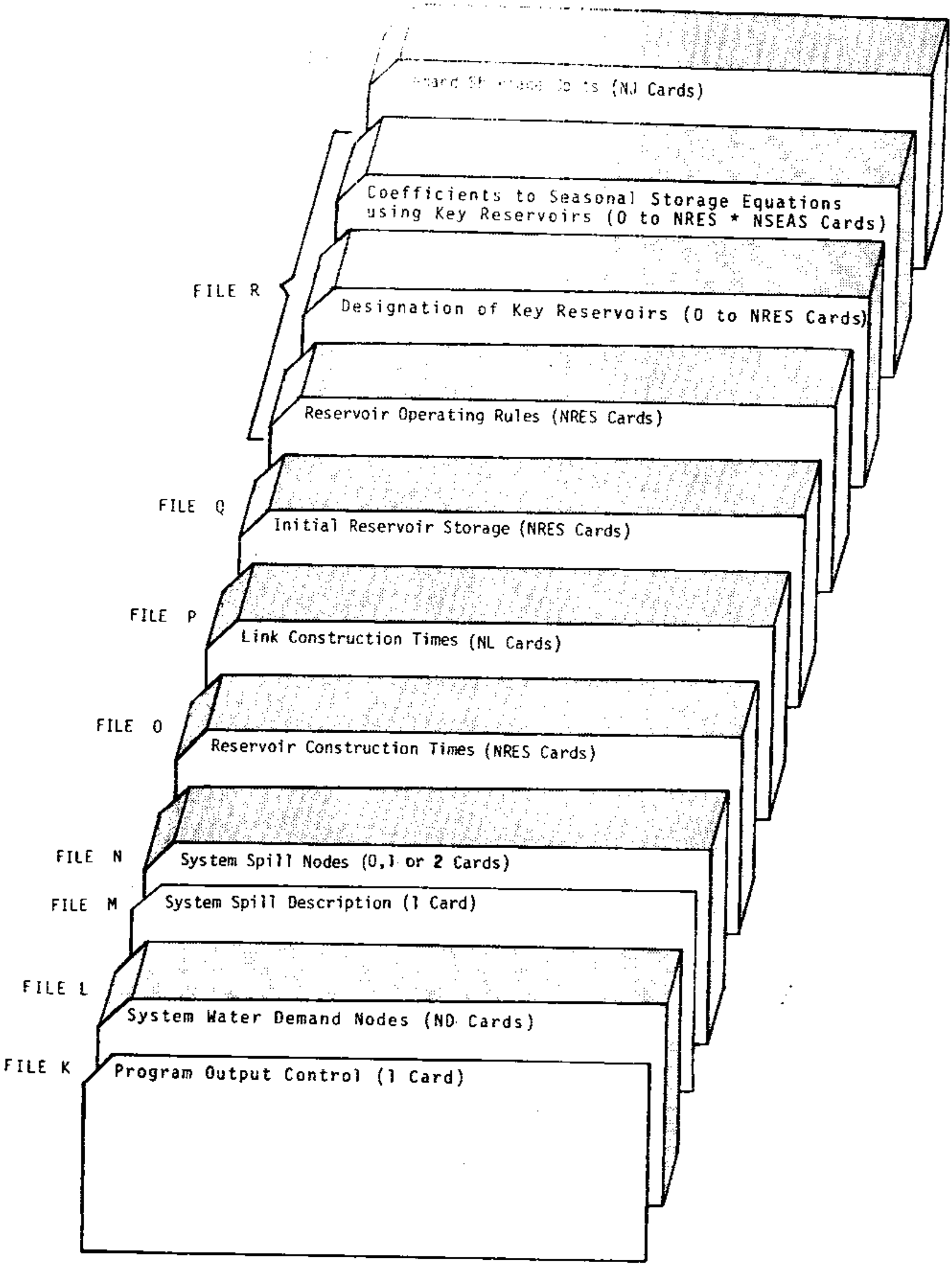

Figure A-7b. SIM-V Input Data Organization

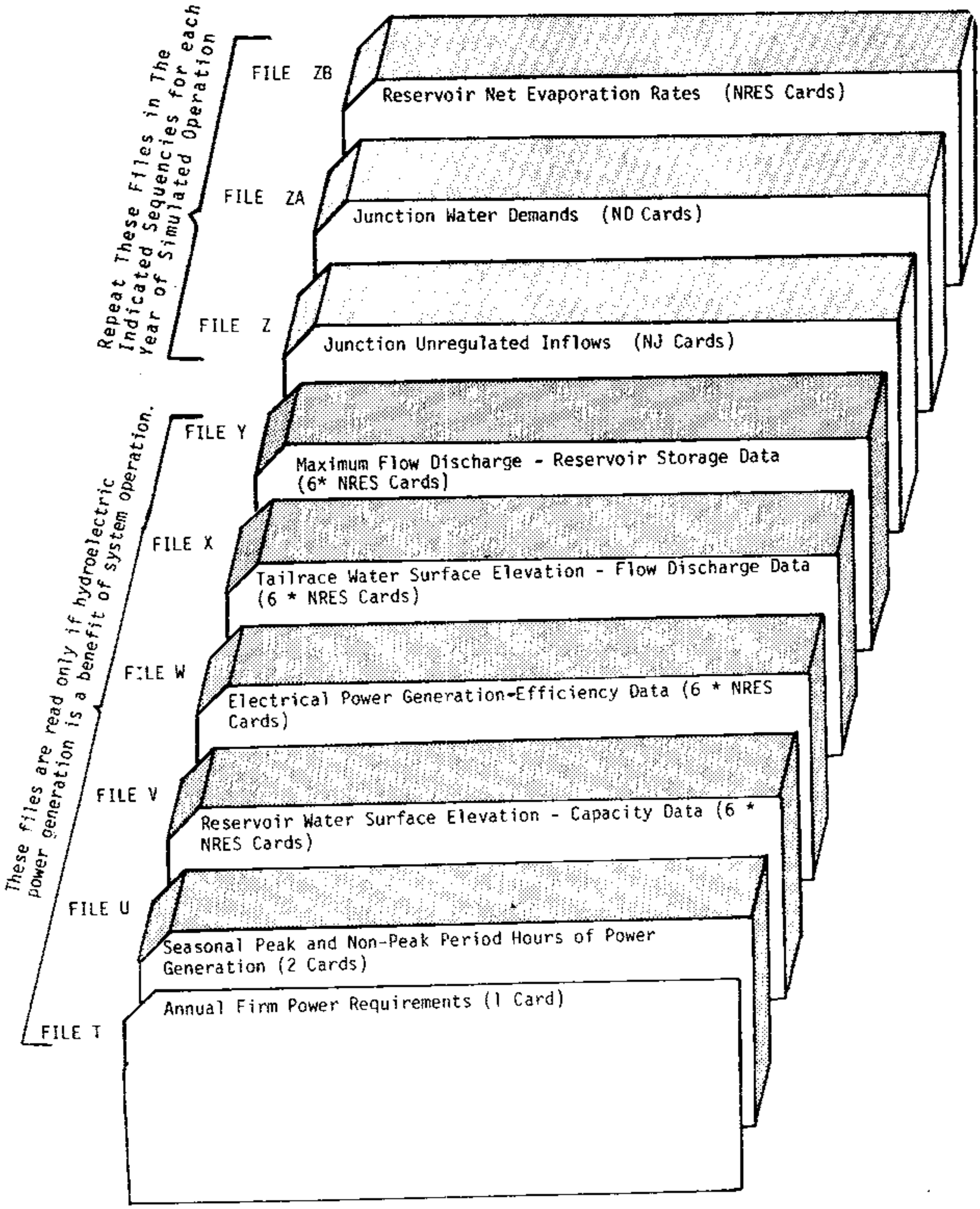

Figure A-7c. SIM-V Input Data Organization

SIM-V OUTPUT FILE DESCRIPTION

The initial output of the SIM-V Model consists of printing the card input data and a summary of the structure of the problem. Following this is output from Subroutine APRINT describing the annual simulation results. As previously described, this output is controlled by the variable IPRNT. Data that can be printed for each year of the simulation are described in the following sections. At the end of the simulation output, Subroutine SPRINT prints total costs, present values of total costs, and average annual costs.

INPUT DATA

Table A-3 (page A-53 to A-84) illustrates a sample printing of the card input data. Information on the problem is grouped by junctions, links, the beginning year, the number of seasons in each year and the number of years in each network.

ANNUAL SIMULATION RESULTS

Link Flows

Table A-4 (page A-85) shows seasonal and yearly average link flows and is printed for each year of the simulation. Flows are expressed in cubic feet per second for each link by season. An arithmetic average of all seasonal link flows is printed to the right of the seasonal flow. All of the links represent river reaches. Water imported to the junction specified in Table A-3 is the last entry in this table.

Link Power Costs

Table A-5 (page A-86) shows seasonal and yearly average link power costs that can be printed for each year of the simulation. Costs are given in thousands of dollars. An arithmetic average of all seasonal power costs is printed to the right of all seasonal costs. Since the links are river reaches, no pumping costs are incurred. Power costs in Table A-5 correspond to link flows in Table A-4; however, when the power costs is less than one thousand dollars the cost is truncated to zero. The total annual pumping, import water, and water shortage cost (in thousands of dollars) is printed at the bottom of this table.

Power Generation During Peak Periods

Table A-6 (page A-87) shows the rate of power generation at each reservoir during the peak hours of power generation in each season. The units are in megawatts. The total generation rate for each season is given, as in the seasonal target firm power generation rate. An asterisk to the right of a generation rate indicates that the associated reservoir power plant is generating at the maximum possible peak period power production rate in that season. This maximum rate includes any assumed overload factor in the data. A message is printed for each season in the year in which the system peak power production is less than the target peak production. Secondary (excess or off-peak) power may be producted during peak periods when the rate of generation exceeds the target rate. The economic benefits (in thousands of dollars) for peak and off-peak power production during peak period hours of the year are also given.

Power Generation During Nonpeak Periods

Table A-7 (page A-88) shows the rate of power generation at each reservoir during the nonpeak hours of power generation in each season. The units are in megawatts. The generation rate at each reservoir power station represents the average rate of generation over the nonpeak hours during the season. That is, the nonpeak or secondary energy production is at an instantaneous rate equal to the maximum power plant generation capacity, but it will generally not sustain that rate but for a portion of the nonpeak hours in the season. The remainder of the nonpeak period will have no secondary power production. The benefits for power production during the nonpeak periods are given in thousands of dollars. These benefits represent the total annual revenue from power generation sales.

Total Power Generation

Table A-8 (page A-89) shows the maximum rate of power generation for each reservoir in each period. The units are in megawatts. The annual peak and nonpeak power benefits are totalled for the system and given in thousands of dollars. The total annual hydroelectric power generation benefits or revenues are also given in thousands of dollars. The monthly or seasonal peak power generation and total generation in 100 megawatt-hours may be punched by removing the comment designation from the PUNCH statements in Subroutine APRINT.

Utilization of Power Generating Capacity

Table A-9 (page A-90) shows the percentage of the instantaneous power generating capacity at each reservoir utilized to produce peak period (firm) power in each season of the year. The average utilization rate for each reservoir during the year and the average utilization in each season for the system are also given. The average seasonal utilization is based upon the total system generating capacity.

Efficiency of Hydroelectric Power Generating Plants

Table A-10 (page A-91) shows the power generating efficiency at each reservoir in each season of the year. This factor represents the conversion percentage of the available potential energy into electrical energy at each power generating plant during peak period production. The yearly average efficiency for each reservoir is based upon all seasons, not just the seasons in which energy was produced at the power plant. The seasonal average efficiency is based upon the average efficiency over all power plants in the system, whether or not they produced energy in that season. A power plant that does not produce energy in a season will have a zero value for percentage efficiency.

Marginal Costs for Link Constraints

Table A-11 (page A-92) shows the costs that would be incurred if it was necessary to change the link constraints by one cfs. These costs are termed "marginal costs for link constraints". They can be printed by season at the end of each year in the simulation period or suppressed entirely. The values may be positive, negative, or zero. Positive marginal costs are associated with the lower flow (bound) constraints. For example, if it is necessary to provide a minimum flow in a particular link and the optimum (minimum cost) solution is constrained by this minimum flow, the penalty (cost) we pay for having that constraining flow is the marginal cost. Since the cost of one cfs in a link is dependent on the status of the entire system network, the marginal cost refers only to the last unit increment (one cfs) of link flow.

Negative marginal costs relate to upper flow (bound) constraints. For example, if the flow in a particular link is at its upper limit and the optimum (minimum cost) solution is constrained by this condition, a negative marginal costs indicate the saving that would be achieved if the upper flow constraint was increased by one cfs.

Zero marginal cost indicates that the link flow is not being constrained.

Reservoir Storage Levels

Table A-12 (page A-93) shows seasonal and yearly average storage for reservoirs and is printed for each year of the simulation. Seasonal and yearly average storage is expressed in thousands of acre-feet. Of the 30 nodes within the network, the first 27 are reservoirs capable of storing water. The remaining 3 nodes are junctions that cannot store water, and hence there is no output for them. The final storage levels in each season may be punched as output by removing the comments card designation from the PUNCH commands in Subroutine APRINT.

Reservoir Water Surface Elevations

Table A-13 (page A-94) shows the average water surface elevation in each reservoir over each season and the yearly average water elevation for a reservoir over the entire year. The elevation values are in feet above a user-designated base or datum level. The user will generally designate mean sea level as the datum point. The average yearly elevation is computed by taking the average of the seasonal average elevations.

Water Diversion Shortages and Demands

Table A-14 (page A-95) shows the shortages or deficits in the water diversion requirements in the system during each season of the year. In addition. the total diversion requirement at each junction is printed for each season of the year. The units for both water diversion and demands and water shortages are in thousands of acre-feet. The water diversion demands are printed for only those junctions having one or more seasons in which the demands are greater than zero. Junction deficits are printed only for those junctions having a water shortage in one or more seasons of the year.

Marginal Costs for Reservoir Constraints

Table A-15 (page A-96) shows the costs that would be incurred if it were necessary to change the volume of water stored in a particular reservoir by one acre-foot. These costs are termed "marginal costs for the reservoir constraints". They are printed by season at the end of year in the simulation period. These values may be positive. negative or zero. Positive marginal costs relate to lower storage (bound) constraints. For example. if it is necessary to maintain a minimum pool elevation, and the optimum (minimum cost) solution is constrained by that elevation, the marginal cost is the cost of retaining the last acre-foot of water in the reservoir. Because the cost of storage depends on the status of the entire network, the marginal cost refers only to the last acre-foot of storage.

Negative marginal costs are associated with upper storage (bound) constraints. For example, if a pool elevation is at its upper limit. and the optimum (minimum cost) solution is constrained by this elevation, a negative marginal cost indicates the saving that could be realized if that reservoir could storage an additional acre-foot of water.

Zero marginal costs indicate that the reservoir storage is between its upper and lower bound (elevations) for an optimum solution and that no gain or loss will occur if the constraints are changed.

Marginal Costs for Continuity Constraints

Table A-76 (page A-97) shows the cost of delivering one additional acre-foot of water to each node in the network. These values, termed "marginal costs for continuity constraints", are expressed in dollars per acre-foot.

Average Spills

Table A-17 (page A-98) shows the seasonal and yearly average spills from those nodes whose spills leave the system. These results may be printed for each year in the simulation period or they can be suppressed. The nodes are identified in Table A-3. Seasonal and yearly average spills are expressed in thousands of acre-feet.

Maximum Link Flows

Table A-18 (page A-99) shows the maximum link flows that have occurred up to and including the year being printed. Values are in cubic feet per second.

COST RESULTS

Total Costs

Table A-19 (page A-100) summarizes total costs at the end of the simulation. Costs in thousands of dollars are accumulated by year. Costs are shown separately for physical facilities and for capital and operation and maintenance. Negative costs represent power generation revenues (benefits).

Present Values of Total Costs

Table A-20 (page A-101) summarizes the present values of the total costs in Table A-19. Present values refer to the base year shown in the title of this table. Link total costs, present values are accumulated. Costs are shown separately for physical facilities and for present values of capital and operation and maintenance. The entry corresponding to the last yer in this table shows the present value of total costs to construct, operate, and maintain all the facilities, including the cost of imported water over the simulation period. Negative costs represent power generation revenues.

Annual Costs

Table A-21 (page A-102) summarizes annual costs for construction, operation, maintenance, imported water, and power for the duration of the simulation period. The repayment period is shown in the title of this table. The totals at the end of this table summarize the estimated total annual cost outlay over the indicated repayment period. Negative costs are the power generation benefits.

PROBLEM INFEASIBILITY

The program will terminate if any solution to the network problem is found to be infeasible (i.e., fails to satisfy all constraints). Solution infeasibility is generally due to one or more of the following conditions:

- improper specifications of the desired system configuration,
- inadequate number of spill nodes,
- a minimum river or canal capacity that is too binding,
- an unregulated inflow occurring where there is no possible outlet for the water, and
- improper specification of the basic hydrologic and demand data.

If problem infeasibility occurs then the user should examine the input specifications and the network dump printed by the program to verify the accuracy of the input data.

SIM-V EXAMPLE PROBLEM

The SIM-V Program was executed for a typical water resources system to provide a demonstration of the program's capabilities. The example system treated in this analysis is a portion of Arkansas, White and Red River Basins in Texas, Oklahoma, Kansas, Arkansas, and Missouri. The major water storage projects in these basins are depicted in Figure 11. The physical elements in this system were aggregated into an associated network representation as shown in Figure 15.

The period of simulation covered five years corresponding to the historical period of 1953-1957. Monthly periods were used as the time intervals for determining optimal operation.

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EXAMPLE OUTPUT

Table A-3. Tabled Printing of Input Data

```
****************************************************************************************************

                    TEXAS DEPARTMENT OF WATER RESOURCES
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                                SIM - V

                   ARKANSAS, WHITE AND RED RIVER SYSTEM

****************************************************************************************************

DETAILS OF THE PROBLEM ARE AS FOLLOWS

 1) THERE ARE 30 JUNCTIONS, OF THESE

   A) THE FIRST 27 ARE RESERVOIRS
   B) THE LAST   3 ARE LINK JUNCTIONS
   C) IMPORTED WATER ENTERS AT NODE  0
   D) SPILLS FROM THE SYSTEM CAN OCCUR AT 1
      NODES, THESE ARE NODES
              29
   D) WATER SUPPLY DEMANDS FROM THE SYSTEM CAN OCCUR AT  9
      NODES, THESE ARE NODES
               4    6    7    8    9   15   16   18   19

 2) THERE ARE 29 LINKS,OF THESE

   A) THE FIRST 29 ARE RIVER REACHES
   B) THE LAST   0 ARE PUMP-CANALS

 3) THERE ARE  5 YEARS IN THE PROBLEM
   A) THE FIRST YEAR IS  1
   B) EACH YEAR HAS 12 SEASONS
   C) CALENDAR YEAR OF STARTING YEAR OF SIMULATION IS 1957

    LOGICAL UNIT FOR INITIAL SOLUTION FILE KAPE1 IS  0

    LOGICAL UNIT FOR STORING SOLUTION FILE KAPE2 IS  0
```

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NODE DATA, EITHER RESERVOIR OR JUNCTION

NODE NO.	RES OR JNC NAME	RESEVR MAX 1000AF	RESEVR MIN 1000AF	RESEVR COST 1000$	RETURN FLOW NODE	RETURN FLOW S/W	MIN DMD FCT	BRKPT STORAGE 1000AF	LOWER STORAGE SLOPE	UPPER STORAGE SLOPE	SIMULATION YEAR RES BUILT	MAXIMUM POWER GENERATION (MEGAWATTS)
1	TEXOMA	2755.4	1049.2	.0	0	1.00	1.00	1049.2	.0418	.0268	1	70
2	BRKN BOW	918.2	448.7	.0	0	1.00	1.00	448.7	.0205	.0106	1	100
3	FALL RIV	23.9	8.0	.0	0	1.00	1.00	8.0	.1768	.0754	1	0
4	TORONTO	21.9	13.0	.0	0	1.00	1.00	13.0	.1538	.0685	1	0
5	ELK CITY	38.0	4.4	.0	0	1.00	1.00	4.4	.2500	.0853	1	0
6	OOLOGAH	553.4	9.3	.0	0	1.00	1.00	9.3	.6699	.0428	1	0
7	HULAH	38.1	4.4	.0	0	1.00	1.00	4.4	.3119	.0734	1	0
8	KAW	482.0	233.5	.0	0	1.00	1.00	233.5	.0503	.0282	1	25
9	KEYSTONE	663.0	312.0	.0	0	1.00	1.00	312.0	.0497	.0308	1	70
10	MARION	95.2	9.6	.0	0	1.00	1.00	9.6	.2833	.0452	1	0
11	COUNCIL	42.0	4.7	.0	0	1.00	1.00	4.7	.1915	.0601	1	0
12	REDMOND	61.9	8.4	.0	0	1.00	1.00	8.4	.4248	.0389	1	0
13	PENSACLA	1672.0	480.0	.0	0	1.00	1.00	480.0	.0306	.0243	1	86
14	MARKHAM	200.3	200.3	.0	0	1.00	1.00	200.3	.0544	.0000	1	100
15	FT.GIBSN	365.2	311.3	.0	0	1.00	1.00	311.3	.0546	.0538	1	45
16	EUFAULA	2378.0	897.0	.0	0	1.00	1.00	897.0	.0535	.0366	1	90
17	WEBBERS	165.2	135.2	.0	0	1.00	1.00	135.2	.0627	.0807	1	60
18	TENKILLR	641.4	283.1	.0	0	1.00	1.00	283.1	.0259	.0150	1	34
19	WISTER	30.0	12.5	.0	0	1.00	1.00	12.5	.1600	.1143	1	0
20	ROBT.KER	493.6	414.1	.0	0	1.00	1.00	414.1	.0906	.0566	1	110
21	OZARK	148.4	129.0	.0	0	1.00	1.00	129.0	.0682	.0928	1	100
22	DARDENLE	486.2	420.9	.0	0	1.00	1.00	420.9	.0737	.0499	1	124
23	BEAVER	1651.9	696.2	.0	0	1.00	1.00	696.2	.0217	.0137	1	112
24	TABLE RK	2702.0	1604.0	.0	0	1.00	1.00	1604.0	.0177	.0131	1	200
25	BULL SHS	3048.0	2096.0	.0	0	1.00	1.00	2096.0	.0164	.0117	1	340
26	GREERS F	1910.5	1147.0	.0	0	1.00	1.00	1147.0	.0201	.0110	1	96
27	NORFORK	1251.2	806.1	.0	0	1.00	1.00	806.1	.0200	.0132	1	70
28	INDEPEND	.0	.0	.0	0	1.00	1.00	.0	.0000	.0000	0	0
29	SPILL ND	.0	.0	.0	0	1.00	1.00	.0	.0000	.0000	0	0
30	MUSKOGEE	.0	.0	.0	0	1.00	1.00	.0	.0000	.0000	0	0

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SEASONAL MAXIMUM AND MINIMUM ALLOWABLE RESERVOIR STORAGE, AS PERCENTAGES OF MAX. AND MIN. CAPACITIES

RESERVOIR NUMBER		SEASON 1	2	3	4	5	6	7	8	9	10	11	12
1	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
2	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
3	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
4	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
5	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
6	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
7	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
8	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
9	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
10	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
11	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
12	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100

13	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
14	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
15	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
16	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
17	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
18	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
19	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
20	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
21	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
22	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
23	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
24	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
25	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
26	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
27	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100

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LINK DATA CANAL OR RIVER

LINK NO.	LINK NAME	ORIGIN NODE	TERMINAL NODE	MAXIMUM FLOW CFS	MINIMUM FLOW CFS	TOTAL DYNAMIC PUMPING HEAD FT	SEASONAL LOSS COEFF.	SIMULATION YEAR LINK BUILT	HYDROELECTRIC GENERATION LINK (1 = YES)
1	FR-INDEP	3	28	99999.0	6.0	.0	.99990	1	0
2	TOR-INDP	4	28	99999.0	4.0	.0	.99990	1	0
3	ELK-INDP	5	28	99999.0	6.0	.0	.99990	1	0
4	IND-OOLO	28	6	99999.0	24.0	.0	.99990	1	0
5	OOLO-MUS	6	30	99999.0	90.0	.0	.99990	1	0
6	HULA-MUS	7	30	99999.0	6.0	.0	.99990	1	0
7	KAW-KEYS	8	9	99999.0	113.0	.0	.99990	1	1
8	KEYS-MSK	9	30	99999.0	750.0	.0	.99990	1	1
9	DARD-SPL	22	29	410000.0	.0	.0	.99990	1	1
10	MSK-WEBR	30	17	299999.0	315.0	.0	.99990	1	0
11	WEBR-KER	17	20	299999.0	.0	.0	.99990	1	1
12	EUF-KERR	16	20	99999.0	.0	.0	.99990	1	1
13	TENK-KER	18	20	99999.0	67.0	.0	.99990	1	1
14	KERR-OZK	20	21	299999.0	526.0	.0	.99990	1	1
15	WIST-OZK	19	21	99999.0	12.0	.0	.99990	1	0
16	OZK-DARO	21	22	299999.0	.0	.0	.99990	1	1
17	MAR-REDM	10	12	99999.0	1.0	.0	.99990	1	0
18	C.G.-RED	11	12	99999.0	7.0	.0	.99990	1	0
19	REDM-PEN	12	13	99999.0	21.0	.0	.99990	1	0
20	PEN-MARK	13	14	99999.0	.0	.0	.99990	1	1
21	MAR-GIBS	14	15	99999.0	.0	.0	.99990	1	1
22	GIB-MUSK	15	30	99999.0	.0	.0	.99990	1	1
23	BEA-TABR	23	24	99999.0	.0	.0	.99990	1	1
24	TABR-BUL	24	25	99999.0	.0	.0	.99990	1	1
25	GF.-SPIL	26	29	99999.0	.0	.0	.99990	1	1
26	NOR-SPIL	27	29	99999.0	.0	.0	.99990	1	1
27	BS.-SPIL	25	29	99999.0	.0	.0	.99990	1	1
28	BBW-SPIL	2	29	99999.0	.0	.0	.99990	1	1
29	TEX-SPIL	1	29	99999.0	.0	.0	.99990	1	1

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL MAXIMUM AND MINIMUM ALLOWABLE LINK FLOW,ASPERCENTAGESOFMAX.ANDMIN.CAPACITIES//1X,1

LINK NUMBER		SEASON 1	2	3	4	5	6	7	8	9	10	11	12
1	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
2	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	150	167	167	133	100	100	100
3	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	117	167	183	267	267	167	133	66	66
4	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	104	129	179	213	213	158	108	100	100
5	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
6	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	117	117	100	100	100	100
7	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
8	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
9	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
10	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
11	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
12	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
13	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100

	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
14	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
15	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
16	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
17	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	200	700	900	1300	1300	900	700	200	200
18	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	114	143	186	229	229	171	114	100	100
19	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	114	143	186	229	229	171	114	100	100
20	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
21	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
22	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
23	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
24	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
25	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
26	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
27	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
28	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100
29	MAXIMUM	100	100	100	100	100	100	100	100	100	100	100	100
	MINIMUM	100	100	100	100	100	100	100	100	100	100	100	100

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

CANAL COST COEFF.

	DITCH			PUMP		
	C1	C2	C3	C1	C2	C3
1	.0000	.0000	.0000	.0000	.0000	.0000
2	.0000	.0000	.0000	.0000	.0000	.0000
3	.0000	.0000	.0000	.0000	.0000	.0000
4	.0000	.0000	.0000	.0000	.0000	.0000
5	.0000	.0000	.0000	.0000	.0000	.0000
6	.0000	.0000	.0000	.0000	.0000	.0000
7	.0000	.0000	.0000	.0000	.0000	.0000
8	.0000	.0000	.0000	.0000	.0000	.0000
9	.0000	.0000	.0000	.0000	.0000	.0000
10	.0000	.0000	.0000	.0000	.0000	.0000
11	.0000	.0000	.0000	.0000	.0000	.0000
12	.0000	.0000	.0000	.0000	.0000	.0000
13	.0000	.0000	.0000	.0000	.0000	.0000
14	.0000	.0000	.0000	.0000	.0000	.0000
15	.0000	.0000	.0000	.0000	.0000	.0000
16	.0000	.0000	.0000	.0000	.0000	.0000
17	.0000	.0000	.0000	.0000	.0000	.0000
18	.0000	.0000	.0000	.0000	.0000	.0000
19	.0000	.0000	.0000	.0000	.0000	.0000
20	.0000	.0000	.0000	.0000	.0000	.0000
21	.0000	.0000	.0000	.0000	.0000	.0000
22	.0000	.0000	.0000	.0000	.0000	.0000
23	.0000	.0000	.0000	.0000	.0000	.0000
24	.0000	.0000	.0000	.0000	.0000	.0000
25	.0000	.0000	.0000	.0000	.0000	.0000
26	.0000	.0000	.0000	.0000	.0000	.0000
27	.0000	.0000	.0000	.0000	.0000	.0000
28	.0000	.0000	.0000	.0000	.0000	.0000
29	.0000	.0000	.0000			

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

CONSTANT COST DATA

INTEREST RATE =	.0000	REPAYMENT PERIOD YRS =	0 YRS
POWER COST =	.0000 $/KW-HR	O+M ANN DEC PCT RESVR =	.0000
O+M ANN DEC PCT CANAL =	.0000	COST OF IMPORT WATER =	.0000 $/AF
RESVR FINANCE LAG TIME =	0 YRS	CANAL FINANCE LAG TIME=	0 YRS
HYDROPOWER PEAK PRICE =	.0500 $/KW-HR	HYDRO OFF PEAK PRICE =	.0000 $/KW-HR

SEASONS

ANNUAL GENERATION = 316.00

	1	2	3	4	5	6	7	8	9	10	11	12
TARGET GENERATION (MEGAWATTS)	310.06	261.71	277.45	268.00	279.50	369.09	411.12	421.54	344.76	276.37	265.95	306.08
ON-PEAK HOURS	729	729	729	729	729	729	729	729	729	729	729	729
OFF-PEAK HOURS	0	0	0	0	0	0	0	0	0	0	0	0
PUMPING POWER COST ADJUSTMENT	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
IMPORT COEFFS	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
LOSS COEFFS	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

UNIT SHORTAGE COST
($/AC-FT)

SEASONS

NODE NO.	1	2	3	4	5	6	7	8	9	10	11	12
1	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
2	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
3	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
4	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
5	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
6	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
7	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
8	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
9	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
10	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
11	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
12	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
13	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
14	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
15	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
16	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
17	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
18	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
19	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
20	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
21	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
22	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
23	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
24	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
25	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
26	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
27	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
28	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
29	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

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TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

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RESERVOIR START CONTENTS

****

NODE NO.	RES OR JNC NAME	INITIAL STORAGE (PERCENT FULL)
1	TEXOMA	100.0000
2	BRKN BOW	100.0000
3	FALL RIV	100.0000
4	TORONTO	100.0000
5	ELK CITY	100.0000
6	OOLOGAH	100.0000
7	HULAH	100.0000
8	KAW	100.0000
9	KEYSTONE	100.0000
10	MARION	100.0000
11	COUNCIL	100.0000
12	REDMOND	100.0000
13	PENSACLA	100.0000
14	MARKHAM	100.0000
15	FT.GIBSN	100.0000
16	EUFAULA	100.0000
17	WEBBERS	100.0000
18	TENKILLR	100.0000
19	WISTER	100.0000
20	ROBT.KER	100.0000
21	OZARK	100.0000
22	DARDENLE	100.0000
23	BEAVER	100.0000
24	TABLE RK	100.0000
25	BULL SHS	100.0000
26	GREERS F	100.0000
27	NORFORK	100.0000

TEXAS DEPARTMENT OF WATER RESOURCES
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SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR OPERATING POLICIES

RES. NO.	OPERATING OPTION	STORAGE BENEFIT	END-OF-SEASON TARGET STORAGE LEVELS BY SEASON (FRACTION OF MAX. STORAGE) 1	2	3	4	5	6	7	8	9	10	11	12	NO. OF KEY RESERVOIRS
1	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
2	3	10.0	.56	.60	.66	.72	.77	.78	.79	.80	.70	.59	.48	.52	0
3	1	450.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
4	1	500.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
5	1	450.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
6	3	10.0	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	0
7	1	500.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
8	1	500.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
9	1	10.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
10	1	600.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
11	1	500.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
12	1	500.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
13	3	17.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
14	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
15	1	10.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
16	3	12.0	.81	.80	.73	.65	.58	.72	.86	1.00	.95	.89	.83	.82	0
17	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
18	3	14.0	.72	.78	.82	.86	.90	.81	.73	.62	.62	.62	.62	.67	0
19	1	500.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
20	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
21	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
22	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
23	3	10.0	.63	.63	.63	.63	.63	.71	.79	.88	.80	.72	.63	.63	0
24	1	.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
25	3	10.0	.79	.83	.86	.90	.93	.90	.87	.83	.79	.75	.70	.75	0
26	3	10.0	.70	.74	.77	.81	.85	.85	.85	.85	.78	.71	.63	.66	0
27	3	10.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR ELEVATION - CAPACITY TABLES

POINT	RESERVOIR NO. 1		RESERVOIR NO. 2		RESERVOIR NO. 3		RESERVOIR NO. 4		RESERVOIR NO. 5		RESERVOIR NO. 6	
	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)
1	590	1049200	559	448700	0	0	0	0	0	0	0	0
2	602	1650800	580	666500	0	0	0	0	0	0	0	0
3	609	2095300	588	763800	0	0	0	0	0	0	0	0
4	612	2311500	592	815500	0	0	0	0	0	0	0	0
5	615	2536400	596	869400	0	0	0	0	0	0	0	0
6	640	5392900	600	918200	0	0	0	0	0	0	0	0
7	0	0	628	1368000	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR ELEVATION - CAPACITY TABLES

POINT	RESERVOIR NO. 7 ELEV (FT)	RESERVOIR NO. 7 CAPACITY (AC-FT)	RESERVOIR NO. 8 ELEV (FT)	RESERVOIR NO. 8 CAPACITY (AC-FT)	RESERVOIR NO. 9 ELEV (FT)	RESERVOIR NO. 9 CAPACITY (AC-FT)	RESERVOIR NO. 10 ELEV (FT)	RESERVOIR NO. 10 CAPACITY (AC-FT)	RESERVOIR NO. 11 ELEV (FT)	RESERVOIR NO. 11 CAPACITY (AC-FT)	RESERVOIR NO. 12 ELEV (FT)	RESERVOIR NO. 12 CAPACITY (AC-FT)
1	0	0	996	233500	706	312000	0	0	0	0	0	0
2	0	0	1004	334900	714	454200	0	0	0	0	0	0
3	0	0	1006	364320	716	495800	0	0	0	0	0	0
4	0	0	1008	393740	718	540000	0	0	0	0	0	0
5	0	0	1010	423150	720	579480	0	0	0	0	0	0
6	0	0	1013	482000	723	663000	0	0	0	0	0	0
7	0	0	1045	1348000	754	1879000	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR ELEVATION - CAPACITY TABLES

POINT	RESERVOIR NO. 13		RESERVOIR NO. 14		RESERVOIR NO. 15		RESERVOIR NO. 16		RESERVOIR NO. 17		RESERVOIR NO. 18	
	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)
1	730	1086500	619	200300	551	311300	565	897000	487	135200	595	283100
2	737	1320600	619	200300	554	365200	570	1168000	490	165200	604	358200
3	742	1554600	0	0	582	1284400	574	1410000	541	684200	610	415100
4	745	1672000	0	0	0	0	577	1655000	0	0	616	471200
5	755	2197000	0	0	0	0	580	1903000	0	0	622	528500
6	0	0	0	0	0	0	585	2378000	0	0	631	641400
7	0	0	0	0	0	0	597	3848000	0	0	667	1230000
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR ELEVATION - CAPACITY TABLES

POINT	RESERVOIR NO. 19 ELEV (FT)	RESERVOIR NO. 19 CAPACITY (AC-FT)	RESERVOIR NO. 20 ELEV (FT)	RESERVOIR NO. 20 CAPACITY (AC-FT)	RESERVOIR NO. 21 ELEV (FT)	RESERVOIR NO. 21 CAPACITY (AC-FT)	RESERVOIR NO. 22 ELEV (FT)	RESERVOIR NO. 22 CAPACITY (AC-FT)	RESERVOIR NO. 23 ELEV (FT)	RESERVOIR NO. 23 CAPACITY (AC-FT)	RESERVOIR NO. 24 ELEV (FT)	RESERVOIR NO. 24 CAPACITY (AC-FT)
1	0	0	458	414100	370	129000	334	361900	1050	368100	846	769700
2	0	0	460	493600	372	148400	336	420900	1075	696200	884	1604000
3	0	0	480	1758000	374	171900	338	486200	1088	912200	896	1976000
4	0	0	0	0	0	0	342	636600	1094	1026900	900	2114000
5	0	0	0	0	0	0	0	0	1098	1109300	904	2923000
6	0	0	0	0	0	0	0	0	1104	1242100	932	3514000
7	0	0	0	0	0	0	0	0	1108	1336900	942	4075000
8	0	0	0	0	0	0	0	0	1116	1541700	0	0
9	0	0	0	0	0	0	0	0	1120	1651900	0	0
10	0	0	0	0	0	0	0	0	1137	2182500	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR ELEVATION - CAPACITY TABLES

POINT	RESERVOIR NO. 25 ELEV (FT)	CAPACITY (AC-FT)	RESERVOIR NO. 26 ELEV (FT)	CAPACITY (AC-FT)	RESERVOIR NO. 27 ELEV (FT)	CAPACITY (AC-FT)	RESERVOIR NO. ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)	ELEV (FT)	CAPACITY (AC-FT)
1	568	964400	428	1035000	510	544200						
2	630	2096000	447	1500000	528	806100						
3	641	2500000	453	1668000	542	1044800						
4	652	2958000	456	1757000	552	1251200						
5	667	3682000	460	1879000	554	1295700						
6	672	3953000	466	2071000	0	0						
7	678	4299000	0	0	0	0						
8	0	0	0	0	0	0						
9	0	0	0	0	0	0						
10	0	0	0	0	0	0						
11	0	0	0	0	0	0						
12	0	0	0	0	0	0						
13	0	0	0	0	0	0						
14	0	0	0	0	0	0						
15	0	0	0	0	0	0						
16	0	0	0	0	0	0						
17	0	0	0	0	0	0						
18	0	0	0	0	0	0						

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR EFFICIENCY - POWER GENERATION TABLES

	RESERVOIR NO. 1		RESERVOIR NO. 2		RESERVOIR NO. 3		RESERVOIR NO. 4		RESERVOIR NO. 5		RESERVOIR NO. 6	
POINT	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)
1	83	0	86	0	0	0	0	0	0	0	0	0
2	63	11000	86	16000	0	0	0	0	0	0	0	0
3	83	28000	86	40000	0	0	0	0	0	0	0	0
4	83	100000	86	130000	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR EFFICIENCY - POWER GENERATION TABLES

	RESERVOIR NO. 7		RESERVOIR NO. 8		RESERVOIR NO. 9		RESERVOIR NO. 10		RESERVOIR NO. 11		RESERVOIR NO. 12	
POINT	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)
1	0	0	86	0	86	0	0	0	0	0	0	0
2	0	0	86	7000	86	11000	0	0	0	0	0	0
3	0	0	86	12500	86	28000	0	0	0	0	0	0
4	0	0	86	33000	86	100000	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR EFFICIENCY - POWER GENERATION TABLES

POINT	RESERVOIR NO. 13 EFF. (PERCENT)	RESERVOIR NO. 13 POWER (KW.)	RESERVOIR NO. 14 EFF. (PERCENT)	RESERVOIR NO. 14 POWER (KW.)	RESERVOIR NO. 15 EFF. (PERCENT)	RESERVOIR NO. 15 POWER (KW.)	RESERVOIR NO. 16 EFF. (PERCENT)	RESERVOIR NO. 16 POWER (KW.)	RESERVOIR NO. 17 EFF. (PERCENT)	RESERVOIR NO. 17 POWER (KW.)	RESERVOIR NO. 18 EFF. (PERCENT)	RESERVOIR NO. 18 POWER (KW.)
1	85	0	86	0	86	0	86	0	86	0	86	0
2	85	4000	86	7000	86	3150	86	8400	86	5600	86	4760
3	85	10000	86	17500	86	7875	86	21000	86	14000	86	11900
4	85	100000	86	130000	86	60000	86	120000	86	90000	86	50000
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR EFFICIENCY - POWER GENERATION TABLES

POINT	RESERVOIR NO. 19 EFF. (PERCENT)	RESERVOIR NO. 19 POWER (KW.)	RESERVOIR NO. 20 EFF. (PERCENT)	RESERVOIR NO. 20 POWER (KW.)	RESERVOIR NO. 21 EFF. (PERCENT)	RESERVOIR NO. 21 POWER (KW.)	RESERVOIR NO. 22 EFF. (PERCENT)	RESERVOIR NO. 22 POWER (KW.)	RESERVOIR NO. 23 EFF. (PERCENT)	RESERVOIR NO. 23 POWER (KW.)	RESERVOIR NO. 24 EFF. (PERCENT)	RESERVOIR NO. 24 POWER (KW.)
1	0	0	86	0	86	0	87	0	87	0	87	0
2	0	0	86	7700	86	5600	87	8680	87	15680	87	14000
3	0	0	86	19250	86	14000	87	21700	87	39200	87	35000
4	0	0	86	140000	86	130000	87	160000	87	150000	87	250000
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR EFFICIENCY - POWER GENERATION TABLES

POINT	RESERVOIR NO. 25 EFF. (PERCENT)	POWER (KW.)	RESERVOIR NO. 26 EFF. (PERCENT)	POWER (KW.)	RESERVOIR NO. 27 EFF. (PERCENT)	POWER (KW.)	RESERVOIR NO. EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)	EFF. (PERCENT)	POWER (KW.)
1	87	0	87	0	87	0						
2	87	11200	87	13440	87	9800						
3	87	28000	87	33600	87	24500						
4	87	400000	87	120000	87	100000						
5	0	0	0	0	0	0						
6	0	0	0	0	0	0						
7	0	0	0	0	0	0						
8	0	0	0	0	0	0						
9	0	0	0	0	0	0						
10	0	0	0	0	0	0						
11	0	0	0	0	0	0						
12	0	0	0	0	0	0						
13	0	0	0	0	0	0						
14	0	0	0	0	0	0						
15	0	0	0	0	0	0						
16	0	0	0	0	0	0						
17	0	0	0	0	0	0						
18	0	0	0	0	0	0						

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR TAILRACE WATER ELEVATION - FLOW DISCHARGE RATF TABLES

POINT	RESERVOIR NO. 1 ELEV (FT)	RESERVOIR NO. 1 FLOW (CFS)	RESERVOIR NO. 2 ELEV (FT)	RESERVOIR NO. 2 FLOW (CFS)	RESERVOIR NO. 3 ELEV (FT)	RESERVOIR NO. 3 FLOW (CFS)	RESERVOIR NO. 4 ELEV (FT)	RESERVOIR NO. 4 FLOW (CFS)	RESERVOIR NO. 5 ELEV (FT)	RESERVOIR NO. 5 FLOW (CFS)	RESERVOIR NO. 6 ELEV (FT)	RESERVOIR NO. 6 FLOW (CFS)
1	511	0	415	0	0	0	0	0	0	0	0	0
2	511	100000	415	300000	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR TAILRACE WATER ELEVATION - FLOW DISCHARGE RATE TABLES

POINT	RESERVOIR NO. 7 ELEV (FT)	RESERVOIR NO. 7 FLOW (CFS)	RESERVOIR NO. 8 ELEV (FT)	RESERVOIR NO. 8 FLOW (CFS)	RESERVOIR NO. 9 ELEV (FT)	RESERVOIR NO. 9 FLOW (CFS)	RESERVOIR NO. 10 ELEV (FT)	RESERVOIR NO. 10 FLOW (CFS)	RESERVOIR NO. 11 ELEV (FT)	RESERVOIR NO. 11 FLOW (CFS)	RESERVOIR NO. 12 ELEV (FT)	RESERVOIR NO. 12 FLOW (CFS)
1	0	0	918	0	638	0	0	0	0	0	0	0
2	0	0	918	800000	638	900000	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR TAILRACE WATER ELEVATION - FLOW DISCHARGE RATE TABLES

POINT	RESERVOIR NO. 13 ELEV (FT)	RESERVOIR NO. 13 FLOW (CFS)	RESERVOIR NO. 14 ELEV (FT)	RESERVOIR NO. 14 FLOW (CFS)	RESERVOIR NO. 15 ELEV (FT)	RESERVOIR NO. 15 FLOW (CFS)	RESERVOIR NO. 16 ELEV (FT)	RESERVOIR NO. 16 FLOW (CFS)	RESERVOIR NO. 17 ELEV (FT)	RESERVOIR NO. 17 FLOW (CFS)	RESERVOIR NO. 18 ELEV (FT)	RESERVOIR NO. 18 FLOW (CFS)
1	623	0	565	0	494	0	485	0	460	0	490	0
2	623	900000	565	15000	494	400000	486	400000	462	24000	490	400000
3	0	0	565	17500	0	0	0	0	464	42000	0	0
4	0	0	568	24500	0	0	0	0	466	60000	0	0
5	0	0	571	37500	0	0	0	0	468	85000	0	0
6	0	0	576	62000	0	0	0	0	470	110000	0	0
7	0	0	581	97000	0	0	0	0	472	142000	0	0
8	0	0	586	140000	0	0	0	0	476	215000	0	0
9	0	0	593	200000	0	0	0	0	490	700000	0	0
10	0	0	601	770000	0	0	0	0	500	1400000	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR TAILRACE WATER ELEVATION - FLOW DISCHARGE RATE TABLES

POINT	RESERVOIR NO. 19		RESERVOIR NO. 20		RESERVOIR NO. 21		RESERVOIR NO. 22		RESERVOIR NO. 23		RESERVOIR NO. 24	
	ELEV (FT)	FLOW (CFS)	ELEV (FT)	FLOW (CFS)	ELEV (FT)	FLOW (CFS)	ELEV (FT)	FLOW (CFS)	ELEV (FT)	FLOW (CFS)	ELEV (FT)	FLOW (CFS)
1	0	0	416	0	337	0	284	0	929	0	710	0
2	0	0	416	21500	337	10000	285	7000	929	300000	710	300000
3	0	0	418	35500	338	20000	286	11000	0	0	0	0
4	0	0	420	50500	339	30000	289	26000	0	0	0	0
5	0	0	422	65000	342	60000	292	48000	0	0	0	0
6	0	0	424	82000	347	100000	296	91000	0	0	0	0
7	0	0	426	100000	351	140000	300	135000	0	0	0	0
8	0	0	428	122000	356	200000	305	210000	0	0	0	0
9	0	0	430	145000	359	240000	310	305000	0	0	0	0
10	0	0	464	1600000	0	0	318	485000	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR TAILRACE WATER ELEVATION - FLOW DISCHARGE RATE TABLES

POINT	RESERVOIR NO. 25 ELEV (FT)	RESERVOIR NO. 25 FLOW (CFS)	RESERVOIR NO. 26 ELEV (FT)	RESERVOIR NO. 26 FLOW (CFS)	RESERVOIR NO. 27 ELEV (FT)	RESERVOIR NO. 27 FLOW (CFS)	RESERVOIR NO. ELEV (FT)	RESERVOIR NO. FLOW (CFS)	ELEV (FT)	FLOW (CFS)	ELEV (FT)	FLOW (CFS)
1	458	0	276	0	377	0						
2	456	400000	276	400000	377	400000						
3	0	0	0	0	0	0						
4	0	0	0	0	0	0						
5	0	0	0	0	0	0						
6	0	0	0	0	0	0						
7	0	0	0	0	0	0						
8	0	0	0	0	0	0						
9	0	0	0	0	0	0						
10	0	0	0	0	0	0						
11	0	0	0	0	0	0						
12	0	0	0	0	0	0						
13	0	0	0	0	0	0						
14	0	0	0	0	0	0						
15	0	0	0	0	0	0						
16	0	0	0	0	0	0						
17	0	0	0	0	0	0						
18	0	0	0	0	0	0						

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR MAXIMUM FLOW DISCHARGE - RESERVOIR WATER STORAGE TABLES

POINT	RESERVOIR NO. 1 FLOW (CFS)	STORAGE (AC-FT)	RESERVOIR NO. 2 FLOW (CFS)	STORAGE (AC-FT)	RESERVOIR NO. 3 FLOW (CFS)	STORAGE (AC-FT)	RESERVOIR NO. 4 FLOW (CFS)	STORAGE (AC-FT)	RESERVOIR NO. 5 FLOW (CFS)	STORAGE (AC-FT)	RESERVOIR NO. 6 FLOW (CFS)	STORAGE (AC-FT)
1	0	0	0	0	0	0	0	0	0	0	0	0
2	10050	1049200	7480	448700	0	0	0	0	0	0	0	0
3	10940	1650800	8250	666500	0	0	0	0	0	0	0	0
4	11160	1872200	8400	720300	0	0	0	0	0	0	0	0
5	11380	2095300	8480	763800	0	0	0	0	0	0	0	0
6	11350	2311500	8600	815500	0	0	0	0	0	0	0	0
7	11040	2536400	8660	869400	0	0	0	0	0	0	0	0
8	10771	2755400	8552	918200	0	0	0	0	0	0	0	0
9	8871	5392900	7425	1368000	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR MAXIMUM FLOW DISCHARGE - RESERVOIR WATER STORAGE TABLES

POINT	RESERVOIR NO. 7		RESERVOIR NO. 8		RESERVOIR NO. 9		RESERVOIR NO. 10		RESERVOIR NO. 11		RESERVOIR NO. 12	
	FLOW (CFS)	STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	4000	233500	12570	312000	0	0	0	0	0	0
3	0	0	4000	334900	13120	454200	0	0	0	0	0	0
4	0	0	4020	364320	13180	495800	0	0	0	0	0	0
5	0	0	4020	393740	13280	540000	0	0	0	0	0	0
6	0	0	4020	423150	13520	579480	0	0	0	0	0	0
7	0	0	4010	452580	13220	621700	0	0	0	0	0	0
8	0	0	4152	482000	12994	663000	0	0	0	0	0	0
9	0	0	3106	1348000	9521	1879000	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR MAXIMUM FLOW DISCHARGE - RESERVOIR WATER STORAGE TABLES

POINT	RESERVOIR NO. 13 FLOW (CFS)	RESERVOIR NO. 13 STORAGE (AC-FT)	RESERVOIR NO. 14 FLOW (CFS)	RESERVOIR NO. 14 STORAGE (AC-FT)	RESERVOIR NO. 15 FLOW (CFS)	RESERVOIR NO. 15 STORAGE (AC-FT)	RESERVOIR NO. 16 FLOW (CFS)	RESERVOIR NO. 16 STORAGE (AC-FT)	RESERVOIR NO. 17 FLOW (CFS)	RESERVOIR NO. 17 STORAGE (AC-FT)	RESERVOIR NO. 18 FLOW (CFS)	RESERVOIR NO. 18 STORAGE (AC-FT)
1	0	0	0	0	0	0	0	0	0	0	0	0
2	10960	1086500	32202	200300	12440	311300	14190	897000	41163	135200	3670	283100
3	10610	1231800	32202	444500	11834	365200	14700	1168000	35000	165200	4090	358200
4	10430	1320600	0	0	11834	500000	15480	1410000	35000	200000	4080	415100
5	10200	1439700	0	0	0	0	15600	1655000	0	0	4070	471200
6	10000	1554600	0	0	0	0	15100	1903000	0	0	4070	528500
7	9840	1672000	0	0	0	0	14700	2130000	0	0	3930	584600
8	10449	2197000	0	0	0	0	14344	2378000	0	0	3800	641400
9	0	0	0	0	0	0	14344	3000000	0	0	3800	700000
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0.	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESEROIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR MAXIMUM FLOW DISCHARGE - RESERVOIR WATER STORAGE TABLES

POINT	RESERVOIR NO. 19 FLOW (CFS)	RESERVOIR NO. 19 STORAGE (AC-FT)	RESERVOIR NO. 20 FLOW (CFS)	RESERVOIR NO. 20 STORAGE (AC-FT)	RESERVOIR NO. 21 FLOW (CFS)	RESERVOIR NO. 21 STORAGE (AC-FT)	RESERVOIR NO. 22 FLOW (CFS)	RESERVOIR NO. 22 STORAGE (AC-FT)	RESERVOIR NO. 23 FLOW (CFS)	RESERVOIR NO. 23 STORAGE (AC-FT)	RESERVOIR NO. 24 FLOW (CFS)	RESERVOIR NO. 24 STORAGE (AC-FT)
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	44500	414100	55900	129000	43000	420900	11965	696200	6274	1604000
3	0	0	42330	493600	51000	148400	41000	486200	10987	912200	5870	1976000
4	0	0	42330	600000	51000	200000	41000	600000	10587	1026900	5746	2114000
5	0	0	0	0	0	0	0	0	10337	1109300	5628	2259000
6	0	0	0	0	0	0	0	0	9982	1242100	5514	2413000
7	0	0	0	0	0	0	0	0	9759	1336900	5432	2534000
8	0	0	0	0	0	0	0	0	9342	1541700	5199	2923000
9	0	0	0	0	0	0	0	0	9146	1651900	0	0
10	0	0	0	0	0	0	0	0	9146	2000000	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

RESERVOIR MAXIMUM FLOW DISCHARGE - RESERVOIR WATER STORAGE TABLES

POINT	RESERVOIR NO. 25 FLOW (CFS)	RESERVOIR NO. 25 STORAGE (AC-FT)	RESERVOIR NO. 26 FLOW (CFS)	RESERVOIR NO. 26 STORAGE (AC-FT)	RESERVOIR NO. 27 FLOW (CFS)	RESERVOIR NO. 27 STORAGE (AC-FT)	RESERVOIR NO. FLOW (CFS)	RESERVOIR NO. STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)	FLOW (CFS)	STORAGE (AC-FT)
1	0	0	0	0	0	0						
2	30832	2096000	9851	1035000	7206	806100						
3	28979	2500000	8756	1508000	6617	1044800						
4	27336	2958000	8459	1668000	6239	125200						
5	25374	3682000	8318	1757000	6239	1400000						
6	0	0	8137	1879000	0	0						
7	0	0	7880	2071000	0	0						
8	0	0	0	0	0	0						
9	0	0	0	0	0	0						
10	0	0	0	0	0	0						
11	0	0	0	0	0	0						
12	0	0	0	0	0	0						
13	0	0	0	0	0	0						
14	0	0	0	0	0	0						
15	0	0	0	0	0	0						
16	0	0	0	0	0	0						
17	0	0	0	0	0	0						
18	0	0	0	0	0	0						

Table A-4. Seasonal and Yearly Average Link Flows

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL AND YEARLY AVERAGE LINK FLOWS IN CFS - YEAR 1

SEASON / LINK	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	13	11	7	6+	36	6+	10	6+	23	6+	6+	6+	11
2	13	12	24	54	4+	6+	25	7	5+	4+	4+	4+	13
3	12	7	19	7+	80	31	16+	38	10+	16	14	14	21
4	38	30	48	67	120	43	51+	51+	38	26	24+	24+	46
5	90+	90+	237	1037	1643	90+	90+	90+	90+	90+	90+	90+	310
6	6+	6+	6+	99	6+	6+	7+	7+	6+	6+	6+	6+	13
7	791	773	1062	1273	2229	570	534	703	124	113+	397	513	758
8	1134	1168	2728	2922	4485	1254	4806	2003	750+	750+	926	1483	2034
9	7150	9578	53806	72884	53125	7691	13472	6208	4167	6542	6535	4972	20510
10	1823	1920	7400	13351	11707	2034	5554	2099	846	846	1022	1578	4181
11	1823	1917	7396	13346	11703	2030	5550	2096	843	843	1019	1575	4178
12	231	263	5951	11546	7730	2310	5219	1538	3220	5730	5094	2375	4267
13	217	191	2452	3218	2809	2338	67+	2286	67+	67+	83	67+	1155
14	2474	2551	18143	14095	27976	6950	12152	6298	4025	6575	6202	4143	10965
15	703	346	4390	6138	2916	35	1050	12+	12+	12+	12+	12+	1344
16	5403	7105	44434	43698	45774	7482	13717	6425	4123	6590	6353	4783	17990
17	8	1+	1+	2+	98	9+	13+	13+	9+	7+	2+	2+	13
18	12	8	18	8	10+	13+	16+	16+	12	8	7+	7+	11
19	141	107	183	160	626	130	64	48+	36	24	21+	21+	130
20	498	613	3358	6536	4297	675	826	0+	0+	35	114	153	1425
21	542	636	3841	7757	4871	690	769	0+	0+	35	114	153	1617
22	593	657	4429	9294	5575	684	651	0+	0+	0+	0+	0+	1823
23	3215	1944	0+	3805	3559	5132	744	0+	0+	1802	2502	3347	2170
24	3862	2549	5594	8820	8235	5338	4438	5572	5869	2939	2734	6103	5171
25	2655	2260	7528	3830	3848	0+	0+	1931	3937	0+	0+	0+	2165
26	1166	1035	3609	2673	2188	722	493	274	231	265	355	369	1115
27	4731	3129	10588	11826	10783	5231	4325	13222	8338	2049	3952	7802	7164
28	1347	1749	3269	5174	4012	32	2314	413	2089	0+	0+	0+	1699
29	0+	0+	1723	3081	1928	217	3215	1069	0+	9506	4188	1620	2212
IMP	0	0	0	0	0	0	0	0	0	0	0	0	0

* ASTERISK INDICATES SEASONAL FLOW IS AT MAXIMUM ALLOWABLE RATE.

\+ PLUS SIGN INDICATES SEASONAL FLOW IS AT MINIMUM ALLOWABLE RATE.

Table A-5. Seasonal and Yearly Average Link Pumping Costs

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TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

SEASONAL AND YEARLY AVERAGE LINK PUMPING COSTS IN THOUSAND DOLLARS - YEAR 1

SEASON / LINK	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL PUMPING COST ($ 1000) = 0
TOTAL IMPORT COST ($ 1000) = 0
TOTAL SHORTAGE COST($ 1000) = 0

TOTAL COST ($ 1000) = 0

Table A-6. Seasonal and Yearly Average Electrical Power Generation During Peak Periods

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL AND YEARLY AVERAGE ELECTRICAL POWER GENERATION DURING PEAK PERIODS IN MEGAWATTS - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	.0	.0	12.8	22.9	14.4	1.6	23.9	8.0	.0	70.8	31.2	12.1	16.5
2	16.2	23.6	44.1	69.7	54.1	.4	31.2	5.5	27.2	.0	.0	.0	22.8
3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8	5.5	5.3	7.5	8.8	15.4	3.9	3.7	4.9	.9	.8	2.7	3.6	5.3
9	7.0	7.2	16.9	18.1	27.8	7.8	29.8	12.4	4.6	4.6	5.7	9.2	12.6
10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13	4.4	5.4	29.5	57.4	37.8	5.9	7.3	.0	.0	.3	1.0	1.3	12.5
14	2.1	2.5	15.1	30.5	19.2	2.7	3.0	.0	.0	.1	.4	.6	6.4
15	2.6	2.9	19.4	40.6	24.4	3.0	2.8	.0	.0	.0	.0	.0	8.0
16	1.7	1.9	43.4	84.1	56.3	16.7	37.7	11.2	23.3	40.9	35.8	16.5	30.8
17	4.0	4.2	15.8	28.1	24.8	4.4	12.0	4.6	1.8	1.8	2.2	3.4	8.9
18	2.2	2.0	25.2	33.1	28.9	23.2	.6	20.8	.6	.6	.7	.6	11.5
19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	7.9	8.2	58.2	104.9	88.1	22.3	39.0	20.2	12.9	21.1	19.9	13.3	34.7
21	13.8	18.1	102.2	114.9*	104.9	19.1	34.6	16.4	10.5	16.8	16.2	12.2	40.0
22	27.9	37.1	141.9*	141.9*	141.9*	30.0	51.2	24.3	16.4	25.6	25.6	19.6	57.0
23	44.5	26.2	.0	53.5	50.1	70.0	9.8	.0	.0	23.2	31.2	39.6	29.0
24	54.9	36.2	75.8*	75.8*	75.8*	75.8*	63.0	78.5*	80.3*	39.0	36.1	79.4	64.2
25	68.3	45.2	152.9	170.8	155.7	75.5	62.4	185.5	112.2	27.4	52.7	102.7	100.9
26	36.2	30.8	102.7	52.2	52.5	.0	.0	26.0	51.1	.0	.0	.0	29.3
27	15.0	13.4	46.6	34.5	28.2	9.3	6.4	3.5	3.0	3.4	4.6	4.8	14.4
TOT	316.3	270.1	909.9	1142.0	1000.2	371.8	418.5	421.7	344.8	276.5	266.1	318.8	504.7
TARGET	310.1	261.7	277.4	268.0	279.5	369.1	411.1	421.5	344.8	276.4	265.9	306.1	316.0

* ASTERISK INDICATES PRODUCTION OF MAXIMUM POSSIBLE HYDROELECTRIC POWER FROM THAT RESERVOIR IN THAT SEASON.

TOTAL ON-PEAK BENEFITS FOR POWER GENERATED DURING PEAK PERIODS ($ 1000) = 138205.

TOTAL OFF-PEAK BENEFITS FOR POWER GENERATED DURING PEAK PERIODS ($ 1000) = 0.

Table A-7. Seasonal and Yearly Average Electrical Power Generation During Nonpeak Periods

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TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

SEASONAL AND YEARLY AVERAGE ELECTRICAL POWER GENERATION DURING NON-PEAK PERIODS IN MEGAWATTS - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
14	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
16	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
17	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
18	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
21	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
22	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
24	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
26	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
27	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TOT	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TOTAL OFF-PEAK BENEFITS FOR POWER GENERATED DURING OFF-PEAK PERIODS ($ 1000) = 0.

Table A-8. Seasonal and Yearly Average Electrical Power Generation

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL AND YEARLY AVERAGE ELECTRICAL POWER GENERATION IN MEGAWATTS OVER PEAK AND NONPEAK HOURS COMBINED - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	.0	.0	12.8	22.9	14.4	1.6	23.9	8.0	.0	70.8	31.2	12.1	16.5
2	18.2	23.6	44.1	69.7	54.1	.4	31.2	5.5	27.2	.0	.0	.0	22.8
3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8	5.5	5.3	7.5	8.8	15.4	3.9	3.7	4.9	.9	.8	2.7	3.6	5.3
9	7.0	7.2	16.9	18.1	27.8	7.8	29.8	12.4	4.6	4.6	5.7	9.2	12.6
10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13	4.4	5.4	29.5	57.4	37.8	5.9	7.3	.0	.0	.3	1.0	1.3	12.5
14	2.1	2.5	15.1	30.5	19.2	2.7	3.0	.0	.0	.1	.4	.6	6.4
15	2.6	2.9	19.4	40.6	24.4	3.0	2.8	.0	.0	.0	.0	.0	8.0
16	1.7	1.9	43.4	84.1	56.3	16.7	37.7	11.2	23.3	40.9	35.8	16.5	30.8
17	4.0	4.2	15.8	28.1	24.8	4.4	12.0	4.6	1.8	1.8	2.2	3.4	8.9
18	2.2	2.0	25.2	33.1	28.9	23.2	.6	20.8	.6	.6	.7	.6	11.5
19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	7.9	8.2	58.2	104.9	88.1	22.3	39.0	20.2	12.9	21.1	19.9	13.3	34.7
21	13.8	18.1	102.2	114.9	104.9	19.1	34.6	16.4	10.5	16.8	16.2	12.2	40.0
22	27.9	37.1	141.9	141.9	141.9	30.0	51.2	24.3	16.4	25.6	25.6	19.6	57.0
23	44.5	26.2	.0	53.5	50.1	70.0	9.8	.0	.0	23.2	31.2	39.6	29.0
24	54.9	36.2	75.8	75.8	75.8	75.8	63.0	78.5	80.3	39.0	36.1	79.4	64.2
25	68.3	45.2	152.9	170.8	155.7	75.5	62.4	185.5	112.2	27.4	52.7	102.7	100.9
26	36.2	30.8	102.7	52.2	52.5	.0	.0	26.0	51.1	.0	.0	.0	29.3
27	15.0	13.4	46.6	34.5	28.2	9.3	6.4	3.5	3.0	3.4	4.6	4.8	14.4
TOT	316.3	270.1	909.9	1142.0	1000.2	371.8	418.5	421.7	344.8	276.5	266.1	118.8	504.7

TOTAL ON-PEAK POWER BENEFIT ($ 1000) = 138205.
TOTAL OFF-PEAK POWER BENEFIT ($ 1000) = 0.

TOTAL HYDROPOWER BENEFIT ($ 1000) = 138205.

Table A-9. Seasonal and Yearly Average Percentage Utilization of Hydroelectric Power Generation Capacity During Peak Periods

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TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

SEASONAL AND YEARLY AVERAGE PERCENTAGE OF UTILIZATION OF HYDROELECTRIC GENERATING CAPACITY DURING PEAK PERIODS - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	0	0	18	32	20	2	34	11	0	101	44	17	23
2	18	23	44	69	54	0	31	5	27	0	0	0	22
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	21	21	29	35	61	15	14	19	3	3	10	14	20
9	10	10	24	25	39	11	42	17	6	6	8	13	17
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	5	6	34	66	43	6	8	0	0	0	1	1	14
14	2	2	15	30	19	2	3	0	0	0	0	0	6
15	5	6	43	90	54	6	6	0	0	0	0	0	17
16	1	2	48	93	62	18	41	12	25	45	39	18	33
17	6	6	26	46	41	7	19	7	3	3	3	5	14
18	6	5	74	97	84	68	1	61	1	1	2	1	33
19	0	0	0	0	0	0	0	0	0	0	0	0	0
20	7	7	52	95	80	20	35	18	11	19	18	12	31
21	13	18	102	114	104	19	34	16	10	16	16	12	39
22	22	29	114	114	114	24	41	19	13	20	20	15	45
23	39	23	0	47	44	62	8	0	0	20	27	35	25
24	27	18	37	37	37	37	31	39	40	19	18	39	31
25	20	13	44	50	45	22	18	54	33	8	15	30	29
26	37	32	106	54	54	0	0	27	53	0	0	0	30
27	21	19	66	49	40	13	9	5	4	4	6	6	20
AVG	16	14	49	61	54	19	22	22	18	14	14	17	26

Table A-10. Seasonal and Yearly Average Percentage Efficiency of Hydroelectric Power Generating Plants

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL AND YEARLY AVERAGE PERCENTAGE EFFICIENCY OF HYDROELECTRIC POWER GENERATING PLANTS - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	0	0	83	83	83	83	83	83	0	83	83	83	62
2	86	86	86	86	86	86	86	86	86	0	0	0	64
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	86	86	86	86	86	86	86	86	86	86	86	86	86
9	86	86	86	86	86	86	86	86	86	86	86	86	86
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	85	85	85	85	85	85	85	0	0	85	85	85	70
14	86	86	86	86	86	86	86	0	0	86	86	86	71
15	86	86	86	86	86	86	86	0	0	0	0	0	50
16	86	86	86	86	86	86	86	86	86	86	86	86	86
17	86	86	86	86	86	86	86	86	86	86	86	86	86
18	86	86	86	86	86	86	86	86	86	86	86	86	86
19	0	0	0	0	0	0	0	0	0	0	0	0	0
20	86	86	86	86	86	86	86	86	86	86	86	86	86
21	86	86	86	86	86	86	86	86	86	86	86	86	86
22	87	87	87	87	87	87	87	87	87	87	87	87	87
23	87	87	0	87	87	87	87	0	0	87	87	87	65
24	87	87	87	87	87	87	87	87	87	87	87	87	87
25	87	87	87	87	87	87	87	87	87	87	87	87	87
26	87	87	87	87	87	0	0	87	87	0	0	0	50
27	87	87	87	87	87	87	87	87	87	87	87	87	87
AVG	54	54	54	57	57	54	54	44	41	47	47	47	51

Table A-11. Marginal Costs for Link Constraints

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TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

SEASONAL DUAL VALUES FOR THE LINK CONSTRAINTS IN THOUSAND DOLLARS PER CFS - YEAR 1

SEASON / LINK	1	2	3	4	5	6	7	8	9	10	11	12
1	-.0	-.0	-.0	27.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
2	-.0	-.0	-.0	-.0	30.1	3.0	-.0	3.0	3.0	3.0	3.0	3.0
3	-.0	-.0	-.0	27.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
4	-.0	-.0	-.0	-.0	-.0	27.1	27.1	27.1	27.1	27.1	27.1	27.1
5	.0	.0	-.0	-.0	-.0	.0	.0	.0	.0	.0	.0	.0
6	30.1	30.1	30.1	-.0	30.1	30.1	30.1	30.1	30.1	30.1	30.1	30.1
7	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	29.5	-.0	-.0
8	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	.6	.6	-.0	-.0
9	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
10	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
11	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
12	-.0	-.0	-.0	-.0	-.0	.0	-.0	-.0	-.0	-.0	-.0	-.0
13	-.0	-.0	-.0	-.0	-.0	.0	.0	-.0	.8	.8	.0	.8
14	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
15	-.0	-.0	-.0	-.0	-.0	-.0	-.0	30.1	30.1	30.1	30.1	30.1
16	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
17	-.0	36.1	36.1	36.1	-.0	36.1	36.1	6.0	6.0	6.0	6.0	6.0
18	-.0	-.0	-.0	30.1	30.1	30.1	30.1	.0	.0	.0	.0	.0
19	-.0	-.0	-.0	-.0	-.0	-.0	-.0	29.1	29.1	29.5	29.5	29.5
20	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
21	-.0	-.0	-.0	-.0	-.0	-.0	-.0	.4	.4	-.0	-.0	-.0
22	-.0	-.0	-.0	-.0	-.0	-.0	-.0	.6	.6	.6	.6	.6
23	-.0	-.0	.0	-.0	-.0	-.0	-.0	.6	.6	-.0	-.0	.6
24	-.0	-.0	-.0	-.0	-.0	.0	.0	.0	-.0	.0	.0	.0
25	-.0	-.0	-.0	-.0	-.0	.0	.0	.0	.0	.0	.0	.0
26	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
27	.0	.0	-.0	-.0	-.0	-.0	.0	.0	.0	.0	.0	-.0
28	-.0	-.0	-.0	-.0	-.0	-.0	-.0	.0	.0	.0	.0	.0
29	.0	.0	-.0	-.0	-.0	-.0	-.0	-.0	.0	-.0	-.0	-.0

Table A-12. Seasonal and Yearly Average Reservoir Storage

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TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

END OF SEASON AND AVERAGE YEARLY RESERVOIR STORAGE LEVELS IN THOUSAND ACRE-FEET - YEAR 1

SEASON / RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	2755	2755	2755	2755	2755	2755	2755	2755	2749	2755	2755	2755	2754
2	918	918	918	918	918	918	918	898	773	774	777	799	870
3	24*	24*	24*	24*	24*	23	22	20	18	18	18	18	21
4	22*	22*	22*	22*	22*	22*	22*	20	19	18	17	17	20
5	38*	38*	38*	37	38*	36	34	30	28	26	26	26	32
6	549	544	553	553	553	551	537	521	521	512	513	511	534
7	38	37	37	38	38	38	36	34	33	32	31	30	35
8	482*	482*	482*	482*	482*	482*	482*	482*	482*	481	482*	482*	481
9	663*	663*	663*	663*	663*	663*	663*	663*	647	626	663*	663*	658
10	95	95	94	92	95	92	88	84	82	81	81	81	88
11	42*	42*	42*	41	40	39	37	34	32	31	30	29	36
12	62*	62*	62*	62*	62*	62*	62*	59	56	54	53	53	59
13	1672*	1672*	1672*	1672*	1672*	1672*	1672*	1662	1661	1672*	1672*	1672*	1670
14	200+	200+	200+	200+	200+	200+	200+	195+	192+	192+	192+	193+	197
15	365	365	365	365	365	365	365	356	350	349	356	365	360
16	2378*	2378*	2378*	2378*	2378*	2237	2378*	2378*	2259	2116	1974	1950	2265
17	165	165	165	165	165	165	165	165	165	165	165	165	165
18	641	641	641	641	641	520	530	398	397	396	398	404	520
19	30*	30*	30*	30*	30*	30*	30*	29	29	28	27	30*	29
20	494*	494*	494*	494*	494*	494*	494*	494*	494*	494*	494*	494*	494
21	148	148	148	148	148	148	148	148	148	148	148	148	148
22	486	486	486	486	486	486	486	486	486	486	486	486	486
23	1482	1386	1640	1652*	1652*	1344	1305	1303	1297	1189	1041	844	1344
24	2702*	2702*	2702*	2702*	2702*	2702*	2519	2183	1824	1763	1757	1604+	2321
25	3048*	3048*	3048*	3048*	3048*	3048*	3048*	2571	2408	2459	2387	2286	2787
26	1910	1910	1910	1910	1910	1901	1894	1769	1522	1518	1517	1519	1765
27	1251	1251	1251	1251	1251	1251	1251	1251	1251	1251	1251	1251	1251

* ASTERISK INDICATES SEASONAL STORAGE IS AT MAXIMUM ALLOWABLE VOLUME.

\+ PLUS SIGN INDICATES SEASONAL STORAGE IS AT MINIMUM ALLOWABLE VOLUME.

Table A-13. Seasonal and Yearly Average Reservoir Water Surface Elevations

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL AVERAGE AND YEARLY AVERAGE RESERVOIR WATER SURFACE ELEVATION IN FEET - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
1	616.9	616.9	616.9	616.9	616.9	616.9	616.9	616.9	616.9	616.9	616.9	616.9	616.9
2	600.0	600.0	600.0	600.0	600.0	600.0	600.0	599.2	593.5	588.8	588.9	589.9	596.7
3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0	1013.0
9	723.0	723.0	723.0	723.0	723.0	723.0	723.0	723.0	722.7	722.0	722.3	723.0	722.9
10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
13	745.0	745.0	745.0	745.0	745.0	745.0	745.0	744.9	744.7	744.9	745.0	745.0	745.0
14	619.0	619.0	619.0	619.0	619.0	619.0	619.0	619.0	619.0	619.0	619.0	619.0	619.0
15	554.0	554.0	554.0	554.0	554.0	554.0	554.0	553.7	553.3	553.1	553.3	553.7	553.8
16	585.0	585.0	585.0	585.0	585.0	584.3	584.3	585.0	584.4	583.0	581.5	580.6	584.0
17	490.0	490.0	490.0	490.0	490.0	490.0	490.0	490.0	490.0	490.0	490.0	490.0	490.0
18	631.0	631.0	631.0	631.0	631.0	626.0	621.6	615.2	608.1	608.0	608.1	608.5	620.9
19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0	460.0
21	372.0	372.0	372.0	372.0	372.0	372.0	372.0	372.0	372.0	372.0	372.0	372.0	372.0
22	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0
23	1116.8	1111.8	1114.7	1119.8	1120.0	1114.1	1107.5	1106.6	1106.4	1104.0	1098.1	1089.3	1109.1
24	902.9	902.9	902.9	902.9	902.9	902.9	902.5	901.2	895.7	890.1	889.0	886.5	898.5
25	653.9	653.9	653.9	653.9	653.9	653.9	653.9	648.3	640.6	639.2	638.9	636.5	648.4
26	461.0	461.0	461.0	461.0	461.0	460.8	460.6	458.4	452.1	447.7	447.6	447.6	456.6
27	552.0	552.0	552.0	552.0	552.0	552.0	552.0	552.0	552.0	552.0	552.0	552.0	552.0

Table A-14. Seasonal Water Diversion Shortages and Demands

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL JUNCTION DEFICITS IN THOUSANDS OF ACRE-FEET YEAR- 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12

SEASONAL JUNCTION DEMANDS IN THOUSANDS OF ACRE-FEET YEAR- 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12
4	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
6	.70	.70	.70	.70	.70	.94	.94	.94	.70	.70	.70	.70
7	.90	.90	.90	.90	.90	.90	.90	.90	.90	.90	.90	.90
8	4.82	4.82	4.82	4.82	4.82	7.24	7.24	7.24	4.82	4.82	4.82	4.82
9	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
15	.75	.75	.75	.75	.75	.10	1.12	1.12	.90	.80	.75	.75
16	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12
18	.33	.33	.33	.33	.33	.33	.33	.33	.33	.33	.33	.33
19	.02	.02	.02	.02	.02	.02	.02	.03	.02	.02	.02	.02

Table A-15. Marginal Costs for Reservoir Constraints

****

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

SEASONAL DUAL VALUES FOR THE RESERVOIR CONSTRAINTS IN DOLLARS PER ACRE-FOOT - YEAR 1

SEASON RES.	1	2	3	4	5	6	7	8	9	10	11	12
1	-.0	-.0	-.1	-.1	-.1	-.1	-.1	-.1	-.0	-.1	-.1	-.1
2	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.0	-10.0	-10.0	-.0	-10.0
3	-450.0	-450.0	-450.1	-.0	-450.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0
4	-500.0	-500.0	-500.1	-500.1	-.0	-.0	-50.0	-.0	-.0	-.0	-.0	-.0
5	-450.0	-450.0	-450.1	-.0	-450.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0
6	-10.0	-10.0	-10.1	-10.1	-10.1	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
7	-.0	-.0	-.0	-500.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
8	-500.1	-500.1	-500.1	-500.1	-500.1	-500.1	-500.1	-500.1	-490.0	-.0	-500.1	-500.1
9	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-.0	-.0	-10.1	-10.1
10	-600.1	-.0	-.0	-.0	-600.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0
11	-500.1	-500.1	-500.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0	-.0
12	-500.1	-500.1	-500.1	-500.1	-500.1	-500.1	-500.1	-.0	-.0	-.0	-.0	-.0
13	-17.1	-17.1	-17.1	-17.1	-17.1	-17.1	-17.1	-.0	-.0	-7.0	-7.0	-7.0
14	-.1	-.1	-.1	-.1	-.1	-.1	-.1	17.0	17.0	10.0	10.0	10.0
15	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-.0	-.0	-.0	-.0	-.0
16	-12.1	-12.1	-12.1	-12.1	-12.1	-12.0	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1
17	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1
18	-14.1	-14.1	-14.1	-14.1	-14.1	-14.0	-14.0	-14.1	-.0	-.0	-14.0	.0
19	-500.0	-500.0	-500.0	-500.0	-500.0	-500.0	-500.0	-.0	-.0	-.0	-.0	.0
20	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1
21	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1
22	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.1
23	-10.0	-10.0	-10.0	-10.1	-10.1	-10.0	-10.0	-.0	-.0	-10.0	-10.0	.0
24	-.0	-.0	-.1	-.1	-.1	-.0	-.0	-.0	-.0	-.0	-.0	-.0
25	-10.0	-10.0	-10.1	-10.1	-10.1	-10.1	-10.0	-10.0	-10.0	-10.0	-10.0	-10.1
26	-10.1	-10.1	-10.1	-10.1	-10.1	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
27	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1

Table A-16. Marginal Costs for Continuity Constraints

****

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

SEASONAL DUAL VALUES FOR THE CONTINUIY CONSTRAINTS IN DOLLARS PER ACRE-FOOT - YEAR 1

SEASON NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	.1	.1	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0
2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3	.0	.0	.0	450.1	.0	450.1	450.1	450.1	450.1	450.1	450.1	450.1
4	.0	.0	.0	.0	500.1	500.1	450.1	500.1	500.1	500.1	500.1	500.1
5	.0	.0	.0	450.1	.0	450.1	450.1	450.1	450.1	450.1	450.1	450.1
6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7	500.1	500.1	500.1	.0	500.1	500.1	500.1	500.1	500.1	500.1	500.1	500.1
8	.0	.0	.0	.0	.0	.0	.0	.0	10.0	500.1	.0	.0
9	.0	.0	.0	.0	.0	.0	.0	.0	10.1	10.1	.0	.0
10	.0	600.1	600.1	600.1	.0	600.1	600.1	600.1	600.1	600.1	600.1	600.1
11	.0	.0	.0	500.1	500.1	500.1	500.1	500.1	500.1	500.1	500.1	500.1
12	.0	.0	.0	.0	.0	.0	.0	500.1	500.1	500.1	500.1	500.1
13	.0	.0	.0	.0	.0	.0	.0	17.1	17.1	10.0	10.0	10.0
14	.0	.0	.0	.0	.0	.0	.0	17.1	17.1	10.0	10.0	10.0
15	.0	.0	.0	.0	.0	.0	.0	10.1	10.1	10.1	10.1	10.1
16	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
17	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
18	.0	.0	.0	.0	.0	.0	.0	.0	14.1	14.1	.0	14.1
19	.0	.0	.0	.0	.0	.0	.0	500.1	500.1	500.1	500.1	500.1
20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
21	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
22	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
23	.0	.0	.0	.0	.0	.0	.1	10.1	10.1	.1	.1	10.1
24	.0	.0	.0	.0	.0	.0	.1	.1	.1	.1	.1	.1
25	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0
26	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
27	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
28	.0	.0	.0	.0	.0	450.1	450.1	450.1	450.1	450.1	450.1	450.1
29	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
30	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Table A-17. Seasonal and Yearly Average Spills

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

SEASONAL AND YEARLY AVERAGE SPILLS FROM THE SYSTEM IN THOUSAND ACRE-FEET - YEAR 1

SEASON NODE	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
29	1026	1069	4850	5991	4570	836	1434	1392	1130	1106	905	889	2099

Table A-18. Maximum Link Flows

****

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

ARKANSAS, WHITE AND RED RIVER SYSTEM

****

MAXIMUM LINK FLOWS IN CFS - YEAR 1

LINK	FLOW	LINK	FLOW
1	36	2	54
3	80	4	120
5	1643	6	99
7	2229	8	4806
9	72884	10	13351
11	13346	12	11546
13	3218	14	34095
15	6138	16	63698
17	98	18	18
19	626	20	6536
21	7757	22	9294
23	5132	24	8820
25	7528	26	3609
27	13222	28	5174
29	9506		

Table A-19. Total Costs at the End of the Simulation

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

TOTAL CUMULATIVE COSTS IN THOUSAND DOLLARS

YEAR	RESERVOIRS CAPITAL	RESERVOIRS O AND M	CONDUITS CAPITAL	CONDUITS O AND M	IMPORTS	POWER(CONSUMED/GENERATED) CONSUMED	POWER(CONSUMED/GENERATED) GENERATED	DEFICITS	TOTAL
1	0.	0.	0.	0.	0.	0.	-138205.	0.	-138205.
2	0.	0.	0.	0.	0.	0.	-276409.	0.	-276409.
3	0.	0.	0.	0.	0.	0.	-414614.	0.	-414614.
4	0.	0.	0.	0.	0.	0.	-552818.	0.	-552818.
5	0.	0.	0.	0.	0.	0.	-691023.	0.	-691023.

Table A-20. Present Values of the Total Costs

****

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

****

CUMULATIVE PRESENT VALUES IN THOUSAND DOLLARS (1953 BASE)

YEAR	RESERVOIRS CAPITAL	RESERVOIRS O AND M	CONDUITS CAPITAL	CONDUITS O AND M	IMPORTS	POWER(CONSUMED/GENERATED)		DEFICITS	TOTAL
1	0.	0.	0.	0.	0.	0.	-138205.	0.	-138205.
2	0.	0.	0.	0.	0.	0.	-276409.	0.	-276409.
3	0.	0.	0.	0.	0.	0.	-414614.	0.	-414614.
4	0.	0.	0.	0.	0.	0.	-552818.	0.	-552818.
5	0.	0.	0.	0.	0.	0.	-691023.	0.	-691023.

Table A-21. Annual Costs

****

TEXAS DEPARTMENT OF WATER RESOURCES
MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL
SIM - V

****

CUMULATIVE AVERAGE ANNUAL COSTS IN THOUSAND DOLLORS (0-YEAR PAYMENTS)

YEAR	RESERVOIRS CAPITAL	RESERVOIRS O AND M	CONDUITS CAPITAL	CONDUITS O AND M	IMPORTS	POWER(CONSUMED/GENERATED)		DEFICITS	TOTAL
1	0.	0.	0.	0.	0.	0.	-138205.	0.	-138205.
2	0.	0.	0.	0.	0.	0.	-276409.	0.	-276409.
3	0.	0.	0.	0.	0.	0.	-414614.	0.	-414614.
4	0.	0.	0.	0.	0.	0.	-552818.	0.	-552818.
5	0.	0.	0.	0.	0.	0.	-691023.	0.	-691023.

DATA IGNORED - IN CONTROL MODE

@BRKPT PRINT$

SIM - V

PROGRAM LISTING

```
C**********************************************************************
C
C
C                     MULTIRESERVOIR SIMULATION AND OPTIMIZATION
C                                MODEL  -  SIM-V
C
C                     AUTHOR - QUENTIN W. MARTIN
C                              ENGINEERING AND ENVIRONMENTAL SYSTEMS
C                                       SECTION
C                              TEXAS DEPARTMENT OF WATER RESOURCES
C                                      JULY  1981
C**********************************************************************
C
C                 THIS IS THE MAIN PROGRAM FOR SOLVING THE SINGLE
C                 PERIOD RESERVOIR OPERATING PROBLEM. ALL SUBROUTINES
C                 ARE CALLED FROM IT.  THE RESULTS ARE THE LEAST COSTLY
C                 WAY TO OPERATE, IN EACH TIME PERIOD, A SYSTEM
C                 OF RESERVOIRS AND CHANNELS TO MEET A GIVEN SET OF
C                 DEMANDS FOR WATER SUPPLY, MINIMUM FLOWS, AND HYDRO-
C                 ELECTRIC POWER GENERATION.
C**********************************************************************
      COMMON /ADATA/ NF(1000),NT(1000),COST(500),AMP(500),FLOW(500)
     1,HI(500),LOWER(500),ARCS
      COMMON /HYDRO/ IEFF(50,20,2),LHYDRO(75),MLOAD(50),ITELEV(50,20,2)
     1               ,ECTAB(50,20,2),IMAXD(50,20,2),HPOWF(12),
     2                ONPKC,OFPKC,IHRSP(12),IHRSO(12),NOWN(50)
      COMMON /JDATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
     1INK(50,8),FSTART(50),DLO(50),RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CCAP(75),CPUMP(75),CMIN(4
     75),CLIFT(75),EL(75),LNODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /MDATA/ XX(12),ELF(12),XTMP,KSPILL
      COMMON /NDATA/ NYEAR,NS,SCAP,NC,NPEAD,MAXTOL
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IPUOT,EPS,BIG,NOLG,NLOP,STCH,ITER,NPRIT,ITMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),
     1 DISSET( 60),FAN( 60),ICHN( 60),LIST( 60)
      COMMON HIC(50),ALO(50)
      INTEGER BARC,FARC,RARC,DISSET
      REAL LOWER,MAXTOL
      INTEGER ARCS,SOURCE,SINK,RMAXC,RMINC,CMAXC,CMINC,SCAP,ECTAB
C**********************************************************************
C                 READ SYSTEM INPUT DATA FROM CARDS
C**********************************************************************
      NREAD=1
      CALL INPUT
      IFIG=1
C**********************************************************************
C
C                 CREATE THE NETWORK REPRESENTATION OF THE SYSTEM
C**********************************************************************
      CALL SETNET
C**********************************************************************
C
C                 SOLVE THE SINGLE PERIOD, MULTIRESERVIOR PROBLEM.
C                 FIRST CONSTRUCT A NETWORK REPRESENTING THE SPATIAL
C                 INTERRELATIONSHIPS OF THE SYSTEM.  THEN PROCEED
C                 THROUGH TIME BY MODIFYING THE NETWORK TO REPRESENT
C                 THE DATA FOR EACH PERIOD (IE, MONTH OR SEASON)
C                 AND SOLVING THE NETWORK PROBLEM. EACH SOLUTION
C                 PROVIDES THE RESULTS FOR THAT PERIOD.
C**********************************************************************
      DO 180 IYEAR=NREAD,NYEAR
      DO 170 ISEAS=1,NSEAS
      CALL ARC
      NNCS=ARCS
C**********************************************************************
C
C                 IF AN INITIAL FEASIBLE SOLUTION (INCLUDING A BASIS)
C                 IS PROVIDED IN FILE KAPE1 THEN THE PRIMAL ALGORITHM
C                 SOLVES FOR THE OPTIMAL FLOWS IN THE NETWORK.
C                 IF NO FEASIBLE SOLUTION IS AVAILABLE THEN THE
C                 DUAL ALGORITHM IS USED TO SOLVE THE PROBLEM.
C**********************************************************************
      IF (KAPE1.GT.0) GO TO 40
   20 CALL GAIN
   30 CALL OUTPUT
      GO TO 70
C**********************************************************************
C
C                 IF HYDROELECTRIC POWER GENERATION IS TO
C                 BE CONSIDERED THEN EXECUTE SUBROUTINE HYDRO
C                 DIRECTLY.
C**********************************************************************
   40 CALL START
      IF (ONPKC) 50,50,80
   50 CALL RESTAR
C**********************************************************************
C
C                 CHECK THAT THE RESTART SOLUTION IS ACTUALLY
C                 FEASIBLE FOR THE NETWORK PROBLEM AND PRINT
C                 MESSAGE AND STOP, IF IT IS NOT.
C**********************************************************************
      CALL OUTPUT
      IF (ITMAX-1.) 60,20,60
   60 CALL PRIMAL
      CALL OUTPUT
      IF (ITMAX-1.) 110,90,110
C**********************************************************************
C
C                 INITIATE RESTART PROCEDURE FOR NETWORK MODEL
C                 IF RESERVOIR STORAGE SEGMENTATION CONSTRAINTS
C                 ARE VIOLATED.  OTHERWISE SOLVE FOR HYDRO OPERATIONS.
C**********************************************************************
   70 IF (ITMAX-1.) 80,90,80
   80 CALL HYDRO
      CALL OUTPUT
C**********************************************************************
C
C                 INITIATE RESTART PROCEDURE FOR NETWORK MODEL
C                 IF RESERVOIR STORAGE SEGMENTATION CONSTRAINTS
C                 ARE VIOLATED
C**********************************************************************
      IF (ITMAX-1.) 110,90,110
   90 CONTINUE
      DO 100 I=1,ARCS
  100 FLOW(I)=0.
      GO TO 20
C**********************************************************************
C
C                 WRITE NETWORK SOLUTION FOR LATER POSSIBLE USE, IF
C                 LOGICAL UNIT NUMBER KAPE2 HAS A VALUE GREATER
C                 THAN ZERO.
C**********************************************************************
  110 IF (KAPE2.LT.1) GO TO 160
      IF (ARCS.EQ.(NNCS+2*NRES)) GO TO 150
C**********************************************************************
C
C                 ADD EXTRA ARCS TO CARRY WATER INTO AND OUT OF THE
C                 INITIAL RESERVOIR STORAGE NODES TO PRESERVE
C                 THE MATERIAL BALANCE IN THE ADVANCED SOLUTION.
C**********************************************************************
      IF (NRES.LT.1) GO TO 130
      NRES2=NRES*2
      DO 120 I=1,NRES2
      ARCS=ARCS+1
      FLOW(ARCS)=0.
  120 CONTINUE
  130 CONTINUE
C**********************************************************************
C
C                 READJUST ARC NUMBERS IN THE BASIS TO COMPENSATE
C                 FOR THE ARCS JUST ADDED TO THE NETWORK.
C**********************************************************************
      ICOR=2*NRES
      DO 140 I=1,NODES
      IF(BARC(I).GT.NNCS)BARC(I)=BARC(I)+ICOR
      IF(RARC(I).GT.NNCS)RARC(I)=RARC(I)+ICOR
      IF(FARC(I).GT.NNCS)FARC(I)=FARC(I)+ICOR
  140 CONTINUE
  150 WRITE (KAPE2) ARCS,NODES,NRES,NSEAS,(FLOW(I),I=1,ARCS),(HIO(NX),AL
     1O(NX),NX=1,NRES),(BARC(I),RARC(I),FARC(I),I=1,NODES)
```

```
C*************************************************************************
C                     PREPAR AND PRINT OUTPUT FOR SYSTEM OPERATION
C*************************************************************************
160   CALL PREPAR
170   CONTINUE
      CALL APRINT
180   CONTINUE
C*************************************************************************
C                     CALCULATE COSTS AND PRINT
C                     ANNUAL SUMMARIES.
C*************************************************************************
      CALL COSTX
      CALL SPRINT
      IF (KAPE2.GT.0) END FILE KAPE2
      STOP
      END
```



```
      SUBROUTINE ADSUB (I,II)
C*************************************************************************
C                     SUBROUTINE TO ADD AN ARC TO THE TRIPLE LABEL
C                     REPRESENTATION OF THE FLOW AUGMENTING TREE.
C*************************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODFS,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      INTEGER ARCS
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF
C*************************************************************************
C                     ADDS ARC I TO THE LIST OF SUBSEQUENT ARCS TO NODE II.
C*************************************************************************
      IF (FARC(II).NE.0) GO TO 20
      FARC(II)=I
      GO TO 50
20    CONTINUE
      MM=FARC(II)
30    CONTINUE
      MN=JARC(MM)
      IF (RARC(MN).NE.0) GO TO 40
      RARC(MN)=I
      GO TO 50
40    CONTINUE
      MM=RARC(MN)
      GO TO 30
50    CONTINUE
      RETURN
      END
```

AMPF

```
      FUNCTION AMPF (I)
C*********************************************************************
C                     THIS FUNCTION COMPUTES THE AMPLITUDE (GAIN) OF
C                     ARC I
C*********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IRDOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRTT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      IF (I.GT.NARC) GO TO 20
      AMPF=AMP(I)
      RETURN
 20   CONTINUE
      AMPF=1./AMP(I-NARC)
      RETURN
      END
```

APRINT

```
      SUBROUTINE APRINT
C*********************************************************************
C                     THIS SUBROUTINE PRINTS THE ANNUAL SUMMARIES OF THE
C                     LINK FLOWS,    POWER COSTS AND DUAL VALUES,THE
C                     RESERVOIR STORAGE LEVELS AND  DUAL VALUES,AND THE
C                     DUAL VALUES FOR THE CONTINUITY EQUATIONS
C*********************************************************************
      COMMON /APRNT/ APOW(50),AIMP(50),QM(75),ISHORT(50),ICOST(50)
     1,AGEN(50)
      COMMON/HDATA/ D(12,50),U(50,12),E(12,50),MLOAD(50),ITELEV(50,20,2)
      COMMON /HYDRO/ IEFF(50,20,2),LHYDRO(75),IMAXD(50,20,2),MPOWF(12),
     1                 ,ECTAB(50,20,2),IHRSP(12),IHRSQ(12),NDWN(50)
     2                  DNPKC,OFPKC,IHRSP(12),IHRSQ(12),NDWN(50)
      COMMON /JDATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
     1INK(50),FSTART(50),OLO(50),RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CCAP(75),CPUMP(75),CMIN(7
     15),CLIFT(75),EL(75),LNODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON/PRINT/ LQ(13,76),LP(13,75),LC(12,75),RS(13,50),RC(12,50)
     1,CC(12,50),JQ(13,10),IDEF(13,50),IMPC(50),ITOT(50)
      COMMON /PRT/ IPRNT(50),TITLE(10)
      COMMON /PRTHYD/ IRE(13,50),LPG(13,50),IPCU(13,50),IPPE(13,50)
     1 ,LOPG(13,50)
      COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON      IAVGS(13),
     1 AVGS(13),MAXIND(13),HELCT(12),HELCTT(12)
      INTEGER AIMP,RS,QM,CMAXC,CMINC,RMAXC,RMINC,ECTAB,SCAP
      INTEGER APOW
      REAL LC,LPG,LOPG,IRE,IDEF,MAXTOL
C*********************************************************************
C                     SET CONSTANTS
C*********************************************************************
      ROFF=.005
      IL=NL+1
      MAXIND(NSEAS+1)=1H
      M=NSEAS+1
      IYR=IYEAR
C*********************************************************************
C                     PRINT SEASONAL AND YEARLY
C                     AVERAGE LINK FLOWS.
C*********************************************************************
      IF (IPRNT(IYR).EQ.3) GO TO 80
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,580) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,690)
      DO 60 L=1,NL
      DO 50 I=1,NSEAS
      MAXIND(I)=1H
      VALUE=LQ(I,L)-CCAP(L)*CMAXC(L,I)/100.
      IF (VALUE) 30,20,20
 20   MAXIND(I)=1H*
      GO TO 50
 30   VALUE=LQ(I,L)-CMIN(L)*CMINC(L,I)/100.
      IF (VALUE) 40,40,50
 40   MAXIND(I)=1H*
 50   CONTINUE
      WRITE (6,790) L,(LQ(I,L),MAXIND(I),I=1,M)
 60   CONTINUE
      WRITE (6,720) (LQ(I,IL),I=1,NSEAS),AIMP(IYR)
      PRINT 820
      PRINT 830
C*********************************************************************
C                     PRINT SEASONAL AND YEARLY
C                     AVERAGE LINK POWER COSTS.
C*********************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,590) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,690)
```

```
      DO 70 L=1,NL
      WRITE (6,750) L,(LP(I,L),I=1,M)
70    CONTINUE
      WRITE (6,840) APOW(IYR),IMPC(IYR),ICOST(IYR),ITOT(IYR)
C*********************************************************************
C                    PRINT SEASONAL AND YEARLY AVERAGE HYDROELECTRIC
C                    POWER GENERATION DURING PEAK PERIODS
C*********************************************************************
80    CONTINUE
      IF (ONPKC) 360,360,90
90    CONTINUE
      IF (IPRNT(IYR).EQ.3) GO TO 120
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,850) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 110 L=1,NRES
      DO 100 I=1,NSEAS
      MAXINO(I)=1H
      IF (LPG(I,L).GE.0) GO TO 100
      MAXINO(I)=1H*
      LPG(I,L)=-LPG(I,L)
100   CONTINUE
      WRITE (6,780) L,(LPG(I,L),MAXINO(I),I=1,M)
110   CONTINUE
120   HTOTPW=0.
      DO 140 J=1,M
      AVGS(J)=0
      HTOTPW=HTOTPW+HPOWF(J)
      DO 130 L=1,NRES
      IF(LPG(J,L).LT.0)LPG(J,L)=-LPG(J,L)
130   AVGS(J)=AVGS(J)+LPG(J,L)
      IAVGS(J)=AVGS(J)
140   CONTINUE
      HTOTPW=HTOTPW/NSEAS
      IF (IPRNT(IYR).EQ.3) GO TO 150
      WRITE (6,800) (AVGS(J),J=1,M)
      WRITE (6,880) (HPOWF(J),J=1,NSEAS),HTOTPW
      WRITE (6,890)
      PRINT 900
150   ONPBN=0
      OFPBN=0
      DO 190 J=1,NSEAS
      IF (AVGS(J)+ROFF-HPOWF(J)) 160,170,170
160   ONPBN=ONPBN+AVGS(J)*ONPKC*IHRSP(J)
      HELCT(J)=AVGS(J)*IHRSP(J)/1000.
      HELCTT(J)=HELCT(J)
      IF (IPRNT(IYR).LT.3) WRITE (6,910) J,AVGS(J),HPOWF(J)
      GO TO 180
170   CONTINUE
      ONPBN=ONPBN+HPOWF(J)*ONPKC*IHRSP(J)
      HELCT(J)=HPOWF(J)*IHRSP(J)/1000.
      OFPBN=OFPBN+(AVGS(J)-HPOWF(J))*OFPKC*IHRSP(J)
      HELCTT(J)=(AVGS(J)-HPOWF(J))*IHRSP(J)/1000.+HELCT(J)
180   CONTINUE
      IH2P=IHRSP(J)
      IH2O=IHRSO(J)
      IH2TOT=IH2P+IH2O
      DO 190 I=1,NRES
      LPG(J,I)=(LPG(J,I)*IH2P+LOPG(J,I)*IH2O)/IH2TOT
190   CONTINUE
      DO 200 J=1,NRES
200   LPG(M,J)=LPG(M,J)+LOPG(M,J)
      IF (IPRNT(IYR).LT.3) WRITE (6,920) ONPBN,OFPBN
      OFPKI=OFPBN
      IF (IPRNT(IYR).EQ.3) GO TO 240
C*********************************************************************
C                    PRINT SEASONAL AND YEARLY AVERAGE HYDROELECTRIC
C                    POWER GENERATION DURING NON-PEAK PERIODS
C*********************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,930) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 210 L=1,NRES
      WRITE (6,760) L,(LOPG(I,L),I=1,M)
210   CONTINUE
      DO 230 J=1,M
      AVGS(J)=0
      DO 220 L=1,NRES
220   AVGS(J)=AVGS(J)+LOPG(J,L)
230   CONTINUE
      WRITE (6,800) (AVGS(J),J=1,M)
240   CONTINUE
      OFPBN=0
      DO 250 J=1,NSEAS
      HELCTT(J)=HELCTT(J)+AVGS(J)*IHRSO(J)/1000.
      OFPBN=AVGS(J)*OFPKC*IHRSO(J)+OFPBN
250   CONTINUE
      IF (IPRNT(IYR).EQ.3) GO TO 290
      WRITE (6,940) OFPBN
C     PUNCH 950, (HELCT(I),I=1,NSEAS)
C     PUNCH 960, (HELCTT(I),I=1,NSEAS)
C*********************************************************************
C                    PRINT SEASONAL AND YEARLY AVERAGE HYDROELECTRIC
C                    POWER GENERATION
C*********************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,970) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 260 L=1,NRES
      WRITE (6,760) L,(LPG(I,L),I=1,M)
260   CONTINUE
      DO 280 J=1,M
      AVGS(J)=0
      DO 270 L=1,NRES
270   AVGS(J)=AVGS(J)+LPG(J,L)
280   CONTINUE
      WRITE (6,800) (AVGS(J),J=1,M)
C     PUNCH 950, (AVGS(I),I=1,NSEAS)
290   OFPBN=OFPBN+OFPKI
      TOTPB=ONPBN+OFPBN
      AGEN(IYR)=TOTPB
      IF (IPRNT(IYR).EQ.3) RETURN
      WRITE (6,980) ONPBN,OFPBN,TOTPB
C*********************************************************************
C                    PRINT SEASONAL AND YEARLY
C                    AVERAGE PERCENTAGE OF GENERATING CAPACITY
C                    UTILIZED
C*********************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,990) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      MM=0
      DO 300 L=1,NRES
      WRITE (6,750) L,(IPCU(I,L),I=1,M)
      MM=MM+MLOAD(L)
300   CONTINUE
      DO 320 J=1,M
      IAVGS(J)=0
      DO 310 L=1,NRES
310   IAVGS(J)=IAVGS(J)+LPG(J,L)
      IAVGS(J)=IAVGS(J)*100/MM
320   CONTINUE
      WRITE (6,740) (IAVGS(J),J=1,M)
C*********************************************************************
C                    PRINT SEASONAL AND YEARLY
C                    AVERAGE GENERATING EFFICIENCY
C*********************************************************************
```

```
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,1000) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 330 L=1,NRES
      WRITE (6,750) L,(IPPE(I,L),I=1,M)
330   CONTINUE
      DO 350 J=1,M
      IAVGS(J)=0
      DO 340 L=1,NRES
340   IAVGS(J)=IAVGS(J)+IPPE(J,L)
      IAVGS(J)=IAVGS(J)/NRES
350   CONTINUE
      WRITE (6,740) (IAVGS(J),J=1,M)
C*******************************************************************
C                    PRINT SEASONAL DUAL VALUES FOR
C                    THE LINK CONSTRAINTS. THESE ARE
C                    THE COST OF MOVING ONE MORE TAF
C                    THROUGH THE LINK.
C*******************************************************************
360   CONTINUE
      IF (IPRNT(IYR).EQ.3) RETURN
      IF (IPRNT(IYR).EQ.2) GO TO 380
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,600) IYR
      WRITE (6,680) (I,I=1,NSEAS)
      WRITE (6,690)
      DO 370 L=1,NL
      WRITE (6,760) L,(LC(I,L),I=1,NSEAS)
370   CONTINUE
380   CONTINUE
C*******************************************************************
C                    PRINT SEASONAL AND YEARLY AVERAGE
C                    RESERVOIR STORAGE LEVELS.
C*******************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,610) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 440 J=1,NRES
      DO 420 I=1,NSEAS
      MAXIND(I)=1H
      VALUE=RS(I,J)-RCAP(J)*RMAXC(J,I)/100.
      IF (VALUE) 400,390,390
390   MAXIND(I)=1H*
      GO TO 420
400   VALUE=RS(I,J)-RMIN(J)*RMINC(J,I)/100.
      IF (VALUE) 410,410,420
410   MAXIND(I)=1H*
420   CONTINUE
      WRITE (6,790) J,(RS(I,J),MAXIND(I),I=1,M)
430   CONTINUE
440   CONTINUE
      DO 450 I=1,NSEAS
C     PUNCH 1010, (RS(I,J),J=1,NRES)
450   CONTINUE
      PRINT 1020
      PRINT 1030
C*******************************************************************
C                    PRINT SEASONAL AND YEARLY
C                    AVERAGE RESERVOIR WATER SURFACE ELEVATIONS
C*******************************************************************
      IF (UNPKC) 480,480,460
460   CONTINUE
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,1040) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 470 L=1,NRES
      WRITE (6,760) L,(IRE(I,L),I=1,M)
470   CONTINUE
C*******************************************************************
C                    PRINT SEASONAL JUNCTION DEFICITS
C*******************************************************************
480   CONTINUE
      IF (ND.LE.0) GO TO 530
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,1050) IYR
      WRITE (6,680) (I,I=1,NSEAS)
      WRITE (6,700)
      JJ=NSEAS+1
      DO 500 JF=1,ND
      J=JD(JF)
      IF (IDEF(JJ,J)) 500,500,490
490   WRITE (6,770) J,(IDEF(I,J),I=1,JJ)
500   CONTINUE
C*******************************************************************
C                    PRINT SEASONAL JUNCTION WATER DEMANDS
C*******************************************************************
      WRITE (6,1060) IYR
      WRITE (6,680) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 520 JF=1,ND
      J=JD(JF)
510   WRITE (6,770) J,(D(I,J),I=1,NSEAS)
520   CONTINUE
530   CONTINUE
C*******************************************************************
C                    PRINT SEASONAL DUAL VALUES FOR
C                    THE RESERVOIR CONSTRAINTS. THESE
C                    REPRESENT THE COST OF ONE MORE
C                    AF  OF STORAGE.
C*******************************************************************
      IF (IPRNT(IYR).EQ.2) GO TO 560
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,620) IYR
      WRITE (6,680) (I,I=1,NSEAS)
      WRITE (6,700)
      DO 540 J=1,NRES
      WRITE (6,760) J,(RC(I,J),I=1,NSEAS)
540   CONTINUE
C*******************************************************************
C                    PRINT SEASONAL DUAL VALUES FOR
C                    THE CONTINUITY CONSTRAINTS.
C                    THESE REPRESENT THE COST OF
C                    PUMPING ONE MORE AF TO THE NODE.
C*******************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,630) IYR
      WRITE (6,680) (I,I=1,NSEAS)
      WRITE (6,710)
      DO 550 J=1,NJ
      WRITE (6,760) J,(CC(I,J),I=1,NSEAS)
550   CONTINUE
560   CONTINUE
C*******************************************************************
C                    PRINT SEASONAL AND YEARLY AVERAGE
C                    SPILLS FROM THE SYSTEM.
C*******************************************************************
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,640) IYR
      WRITE (6,670) (I,I=1,NSEAS)
      WRITE (6,710)
      DO 570 J=1,NS
      WRITE (6,750) JS(J),(JQ(I,J),I=1,M)
570   CONTINUE
C*******************************************************************
C                    WRITE MAXIMUM LINK FLOWS
C*******************************************************************
```

```
      WRITE (6,810) (TITLE(J),J=1,10)
      WRITE (6,650) IYR
      WRITE (6,660) (L,QH(L),L=1,NL)
      RETURN
C
560   FORMAT (/5X,45HSEASONAL AND YEARLY AVERAGE LINK FLOWS IN CFS,8H -
     1YEAR ,I4/)
590   FORMAT (/5X,47HSEASONAL AND YEARLY AVERAGE LINK PUMPING COSTS ,27H
     1IN THOUSAND DOLLARS - YEAR ,I4/)
600   FORMAT (/5X,45HSEASONAL DUAL VALUES FOR THE LINK CONSTRAINTS,36H I
     1N THOUSAND DOLLARS PER CFS - YEAR ,I4/)
610   FORMAT (/5X,50HEND OF SEASON AND AVERAGE YEARLY RESERVOIR STORAGE,
     137H LEVELS IN THOUSAND ACRE-FEET - YEAR ,I4/)
620   FORMAT (/5X,45HSEASONAL DUAL VALUES FOR THE RESERVOIR CONSTR,38HAI
     1NTS IN DOLLARS PER ACRE-FOOT - YEAR ,I4/)
630   FORMAT (/5X,45HSEASONAL DUAL VALUES FOR THE CONTINUITY CONSTR,38HAI
     1NTS IN DOLLARS PER ACRE-FOOT - YEAR ,I4/)
640   FORMAT (/5X,44HSEASONAL AND YEARLY AVERAGE SPILLS FROM THE ,37HSYS
     1TEM  IN THOUSAND ACRE-FEET - YEAR ,I2/)
650   FORMAT (/5X,33HMAXIMUM LINK FLOWS IN CFS - YEAR ,I2/)
660   FORMAT (17X,4HLINK,16X,4HFLOW,17X,4HLINK,16X,4HFLOW//(4I20))
670   FORMAT (7H SEASON,I4,11I8,4X,4HYEAR)
680   FORMAT (7H SEASON,I4,11I8)
690   FORMAT (5H LINK)
700   FORMAT (5H RES.)
710   FORMAT (5H NODE)
720   FORMAT (4H IMP,13I8)
730   FORMAT (4H TOT,13I8)
740   FORMAT (4H AVG,13I8)
750   FORMAT (1H I3,13I8)
760   FORMAT (1H I3,13F8.1)
770   FORMAT (1H I3,13F8.2)
780   FORMAT (1H I3,1X,13(F7.1,A1))
790   FORMAT (1H I3,1X,13(I7,A1))
800   FORMAT (4H TOT,13F8.1)
810   FORMAT (1H1,125(1H*)//45X,35HTEXAS DEPARTMENT OF WATER RESOURCES/3
     17X,51H MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL  /55X,15H
     2  SIM - V       //35X,10A6//125(1H*)/)
820   FORMAT (//7X,3H*  ,46HASTERISK INDICATES SEASONAL FLOW IS AT MAXIM
     1UM/10X,15HALLOWABLE RATE./)
830   FORMAT (7X,3H+  ,47HPLUS SIGN INDICATES SEASONAL FLOW IS AT MINIMU
     1M/10X,15HALLOWABLE RATE.//)
840   FORMAT (//33H TOTAL PUMPING COST ( $ 1000 ) = ,I12/33H TOTAL IMPOR
     1T  COST ( $ 1000 ) = ,I12/33H TOTAL SHORTAGE COST( $ 1000 ) = ,I12
     2,//33H TOTAL              COST ( $ 1000 ) = ,I12)
850   FORMAT (/5X,88HSEASONAL AND YEARLY AVERAGE ELECTRICAL POWER GENERA
     1TION DURING PEAK PERIODS IN MEGAWATTS,8H - YEAR ,I4/)
860   FORMAT (1X,16HPEAK   MW-HR/1000,3X,12F5.0)
870   FORMAT (1X,16HTOTAL MW-HR/1000,3X,12F5.0)
880   FORMAT (//7H TARGET,F5.1,12F8.1)
890   FORMAT (/)
900   FORMAT (7X,3H*  ,49HASTERISK INDICATES PRODUCTION OF MAXIMUM POSSI
     1BLE/10X,55HHYDROELECTRIC POWER FROM THAT RESERVOIR IN THAT SEASON.
     2/)
910   FORMAT (/,5X,101(1H*),5X,38HTHE HYDROELECTRIC GENERATION IN SEASON,
     1I3,2X,3HOF ,F8.2,40H MEGAWATTS IS BELOW TARGET GENERATION OF,F8.2)
920   FORMAT (/78H TOTAL ON-PEAK BENEFITS FOR POWER GENERATED DURING PEA
     1K PERIODS ( $ 1000 )   : ,F8.0//78H TOTAL OFF-PEAK BENEFITS FOR POW
     2ER GENERATED DURING PEAK PERIODS ( $ 1000 ) : ,F8.0)
930   FORMAT (/5X,92HSEASONAL AND YEARLY AVERAGE ELECTRICAL POWER GENERA
     1TION DURING NON-PEAK PERIODS IN MEGAWATTS,8H - YEAR ,I4/)
940   FORMAT (///83H TOTAL OFF-PEAK BENEFITS FOR POWER GENERATED DURING
     1OFF-PEAK PERIODS ( $ 1000 )  : ,F8.0)
950   FORMAT (1X,16HPEAK   MW-HR/1000,3X,12F5.0)
960   FORMAT (1X,16HTOTAL MW-HR/1000,3X,12F5.0)
970   FORMAT (/5X,105HSEASONAL AND YEARLY AVERAGE ELECTRICAL POWER GENER
     1ATION IN MEGAWATTS OVER PEAK AND NONPEAK HOURS COMBINED,8H - YEAR
     2,I4/)
980   FORMAT (///43H TOTAL ON-PEAK POWER BENEFIT ( $ 1000 )  : ,F12.0/43
     1H TOTAL OFF-PEAK POWER BENEFIT ( $ 1000 ) : ,F12.0//43H TOTAL HYDR
     2OPOWER BENEFIT     ( $ 1000 )  : ,F12.0)
990   FORMAT (/5X,110HSEASONAL AND YEARLY AVERAGE PERCENTAGE OF UTILIZAT
     1ION OF HYDROELECTRIC GENERATING CAPACITY DURING PEAK PERIODS,8H -
     2YEAR ,I4/)
1000  FORMAT (/5X,90HSEASONAL AND YEARLY AVERAGE PERCENTAGE EFFICIENCY O
     1F HYDROELECTRIC POWER GENERATING PLANTS,8H - YEAR ,I4/)
1010  FORMAT (1CX,1CI7)
1020  FORMAT (//7X,3H*  ,49HASTERISK INDICATES SEASONAL STORAGE IS AT MA
     1XIMUM/10X,18HALLOWABLE VOLUME. /)
1030  FORMAT (7X,3H+  ,50HPLUS SIGN INDICATES SEASONAL STORAGE IS AT MIN
     1IMUM/10X,18HALLOWABLE VOLUME. /)
1040  FORMAT (/5X,77HSEASONAL AVERAGE AND YEARLY AVERAGE RESERVOIR WATER
     1 SURFACE ELEVATION IN FEET,8H - YEAR ,I4/)
1050  FORMAT (///,5X,45H SEASONAL JUNCTION DEFICITS IN THOUSANDS OF A,17
     1HCRE-FEET     YEAR-,I4/)
1060  FORMAT (///,5X,44H SEASONAL JUNCTION DEMANDS IN THOUSANDS OF A,17H
     1CRE-FEET     YEAR-,I4/)
      END
```

ARC

```
      SUBROUTINE ARC
C*******************************************************************
C                 THIS SUBROUTINE CONVERTS THE INPUT DATA INTO
C                 ARC DATA AS REQUIRED BY SUBROUTINE GAIN.
C                 THESE DATA ARE
C                     1) LOWER BOUND ON FLOW = LO(A)
C                     2) UPPER BOUND ON FLOW = HI(A)
C                     3) UNIT COST OF FLOW   = COST(A)
C                     4) GAIN FACTOR         = AMP(A)
C*******************************************************************
      COMMON /ACDATA/ NF(1000),NT(1000),COST( 500),AMP( 500),FLOW( 500),H
     1I( 500),LO( 500),ARCS
      COMMON /CDATA/ PEHINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC,POWFA
     1C(12)
      COMMON/HCDATA/ D(12,50),U(50,12),E(12,50)
      COMMON /JDATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
     1INK(50),FSTART(50),DLO(50),RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CCAP(75),CPUMP(75),CMIN(7
     15),CLIFT(75),EL(75),LNODL(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /MDATA/ XX(12),ELF(12),XIMP,KSPILL
      COMMON /MISC/ AMIN,AIMIN,ARMIN,ALMIN,ASMIN
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /PRT/ IPRNT(50),TITLE(10)
      COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NE,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /SHORTS/ BND(50),CST(12,50),ACO(50,2),TFAC(12,50),TCST(50),
     1IOPT(50),NKEY(50),RKEY(50,5,12),NRKEY(50,5)
      COMMON /W/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICM,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /WRKO/ START(50),STEND(50),USE(50),UREG(50)
     1,IELEV(50),
     2ELEVX(50),EOISC(50)
      INTEGER AMIN,AIMIN,ARMIN,ALMIN,ASMIN,START,STEND,USE,UREG
      INTEGER  SCAP,ARCS,A
      INTEGER AB,SOURCE,SINK,AC
      REAL LO,MAXTOL
      INTEGER RMAXC,RMINC,CMAXC,CMINC
C*******************************************************************
C                         INITIALIZE VARIABLES
C*******************************************************************
      NPRIT=0
      KIN=5
      KOUT=6
      ARCS=4*NRES+NL+NS+ND+6
      AMIN=NRES+5
      SUBS=12./NSEAS
      EFF=.8
      CPUMP(1)=(30.2*24.0*62.4*.746*POWR)/(EFF*550.)/1000.
      DO 20 J=1,NL
   20 CPUMP(J)=CPUMP(1)
      IF (ISEAS.GT.1) GO TO 70
C*******************************************************************
C                  READ NATURALIZED INFLOWS, PROJECTED DEMANDS,
C                  AND NET EVAPORATION RATES
C                  - INPUT FILES  2,2A,78
C*******************************************************************
      DO 30 J=1,NJ
   30 READ (KIN,450) (U(J,I),I=1,12)
      IF (ND.LE.0) GO TO 50
      DO 40 J=1,ND
   40 READ (KIN,440) JF,(D(I,JF),I=1,12)
   50 CONTINUE
      DO 60 J=1,NRES
   60 READ (KIN,450) (E(I,J),I=1,12)
C*******************************************************************
C                 GENERATE DATA FOR INFLOW AND INITIAL STORAGE ARCS
C*******************************************************************
   70 CONTINUE
      DO 90 J=1,NRES
      A=J+5
      LO(A)=0
      HI(A)=0
      AMP(A)=1.
      COST(A)=0.
      IF (JBLT(J).GT.IYEAR) GO TO 80
      LO(A)=START(J)+U(J,ISEAS)
      IF(IYEAR.EQ.1.AND.ISEAS.EQ.1)LO(A)=FSTART(J)*RCAP(J)/100.+U(J,ISEA
     1S)
      IF(IYEAR.EQ.JBLT(J).AND.ISEAS.EQ.1)LO(A)=FSTART(J)*RCAP(J)/100.+U(
     1J,ISEAS)
      HI(A)=LO(A)
      START(J)=LO(A)-U(J,ISEAS)
   80 CONTINUE
   90 CONTINUE
  100 CONTINUE
      DO 110 J=1,ARCS
  110 FLOW(J)=0
C*******************************************************************
C                GENERATE DATA FOR INPUT, DEMAND, AND IMPORT ARCS
C*******************************************************************
      IF (ND.EQ.0) GO TO 150
      DO 140 JF=1,ND
      A=AIMIN+JF
      J=JD(JF)
      HI(A)=D(ISEAS,J)
      LO(A)=DLO(J)*HI(A)
      IF(LO(A).GT.HI(A))LO(A)=HI(A)
      AMP(A)=RETSW(J)
      IF (AMP(A)) 120,120,130
  120 AMP(A)=1.
  130 CONTINUE
      COST(A)=-CST(ISEAS,J)
  140 CONTINUE
  150 CONTINUE
      A=ARMIN
      LO(A)=0
      HI(A)=XIMP*XX(ISEAS)
      COST(A)=CIMP
      AMP(A)=1.
C*******************************************************************
C                 GENERATE DATA FOR RESERVOIR STORAGE ARCS
C*******************************************************************
      DO 330 J=1,NRES
      RMX=RCAP(J)*RMAXC(J,ISEAS)/100.
      RMN=RMIN(J)*RMINC(J,ISEAS)/100.
      BBND=BND(J)
      JF=J
      A=ARMIN+J
      LO(A)=0
      HI(A)=0
      COST(A)=0.
      AB=ARMIN+NRES+J
      LO(AB)=0
      HI(AB)=0
      COST(AB)=0.
      AC=AB+NRES
      LO(AC)=0.
      HI(AC)=0.
      COST(AC)=0.
      AMP(A)=1.-(E(ISEAS,J)*ACO(J,1))
      AMP(AB)=1.-(E(ISEAS,J)*ACO(J,2))
      AMP(AC)=AMP(AB)
      IF(AMP(A).LT..6)AMP(A)=1./(1.+E(ISEAS,J)*ACO(J,1))
      IF(AMP(AB).LT..6)AMP(AB)=1./(1.+E(ISEAS,J)*ACO(J,2))
      IF(AMP(AC).LT..6)AMP(AC)=AMP(AB)
      IF (JBLT(J).GT.IYEAR) GO TO 320
      TF=TFAC(ISEAS,J)
      IF(TF.GT.1.)TF=1.
      TF=TF*RMX
      IF(TF.LT.RMN)TF=RMN
      IF (NKEY(J).LE.0) GO TO 180
```

```
C*******************************************************************
C                    TARGET STORAGE COMPUTED BY KEY RESERVOIRS.
C*******************************************************************
      KY=NKEY(J)+1
      STOR=RKEY(J,1,ISEAS)
      DO 160 JX=2,KY
      JN=NRKEY(J,JX)
160   STOR=STOR+RKEY(J,JX,ISEAS)*START(JN)
170   IF(STOR.GT.RMX)STOR=RMX
      IF(STOR.LT.RMN)STOR=RMN
      TF=STOR
180   CONTINUE
C*******************************************************************
C                    RESERVOIR OPERATING RULE - OPTION 1
C*******************************************************************
      COST(A)=-TCST(J)-.1
      COST(AB)=-TCST(J)-.05
      COST(AC)=-.01
      IF (RMN-BBND) 190,220,250
190   LO(A)=RMN/AMP(A)
      IF (TF-BBND) 200,200,210
200   HI(A)=TF/AMP(A)
      AMP(AB)=AMP(A)
      HI(AB)=(BBND-TF)/AMP(AB)
      HI(AC)=(RMX-BBND)/AMP(AC)
      COST(AB)=-.05
      GO TO 260
210   HI(A)=BBND/AMP(A)
      HI(AB)=(TF-BBND)/AMP(AB)
      HI(AC)=(RMX-TF)/AMP(AC)
      GO TO 260
220   LO(A)=BBND/AMP(A)
      HI(A)=LO(A)
      IF (TF-BBND) 230,230,240
230   HI(AC)=(RMX-BBND)/AMP(AC)
      GO TO 260
240   HI(AB)=(TF-BBND)/AMP(AB)
      HI(AC)=(RMX-TF)/AMP(AC)
      GO TO 260
250   LO(A)=BBND/AMP(A)
      HI(A)=LO(A)
      LO(AB)=(RMN-BBND)/AMP(AB)
      HI(AB)=(TF-BBND)/AMP(AB)
      HI(AC)=(RMX-TF)/AMP(AC)
260   II=IOPT(J)
      IF (II.EQ.2) GO TO 270
      GO TO 320
C*******************************************************************
C                    RESERVOIR OPERATING RULE - OPTION 2
C*******************************************************************
270   LO(A)=HI(A)
      IF (TF-HI(A)) 280,280,290
280   COST(AB)=-TCST(J)-.1
      COST(AC)=-TCST(J)-.05
      GO TO 320
290   LO(AB)=HI(AB)
      COST(AC)=-TCST(J)-.05
320   CONTINUE
C*******************************************************************
C                    MINIMUM STORAGE MUST BE NO GREATER THAN THE INFLOW
C                    PLUS THE INITIAL STORAGE.
C*******************************************************************
      IF(LO(A).GT.LO(J+5))LO(A)=LO(J+5)
330   CONTINUE
C*******************************************************************
C                    GENERATE DATA FOR CANAL AND RIVER ARCS
C*******************************************************************
      DO 380 L=1,NL
      JF=LNODE(L,1)
      JT=LNODE(L,2)
      A=ALMIN+L
      LO(A)=0
      HI(A)=0
C*******************************************************************
C                    CONVEYANCE FACTORS FOR PIPELINES ARE NOT
C                    ADJUSTED SEASONALLY
C*******************************************************************
      IF (EL(L)-1.) 350,340,350
340   AMP(A)=EL(L)
      GO TO 360
350   AMP(A)=EL(L)*ELF(ISEAS)
360   CONTINUE
      IF(LBLT(L).LE.IYEAR)HI(A)=CCAP(L)/1660.*SUBS*CMAX(L,ISEAS)
      IF(LBLT(L).LE.IYEAR)LO(A)=CMIN(L)/1660.*SUBS*CMIN(L,ISEAS)
      COST(A)=CPUMP(L)*CLIFT(L)*POWFAC(ISEAS)*16.6
      IF (COST(A)) 370,370,380
370   COST(A)=.0
380   CONTINUE
C*******************************************************************
C                    GENERATE DATA FOR SPILL ARCS
C*******************************************************************
      DO 390 J=1,NS
      JF=JS(J)
      A=ASMIN+J
      LO(A)=0
      HI(A)=SCAP
      AMP(A)=1.
      COST(A)=KSPILL
      IF(KSPILL.LT.1)COST(A)=.0E0
390   CONTINUE
C*******************************************************************
C                    CHECK FOR NON-POSITIVE GAIN FACTORS (AMP).
C*******************************************************************
      IERROR=0
      DO 400 I=1,ARCS
      IF (AMP(I)) 410,410,400
400   CONTINUE
      IF (IPRNT(IYEAR).EQ.1.AND.KAPE1.LT.1) GO TO 420
      RETURN
410   PRINT 460
      IERROR=1
C*******************************************************************
C                    PRINT NETWORK MODEL
C*******************************************************************
420   PRINT 470, IYEAR,ISEAS
      PRINT 480
      PRINT 490
      DO 430 I=1,ARCS
      PRINT 500, I,NF(I),NT(I),LO(I),HI(I),COST(I),AMP(I),FLOW(I)
430   CONTINUE
      IF (IERROR.EQ.1) STOP
      RETURN
C
440   FORMAT (18X,I2,12F5.0)
450   FORMAT (20X,12F5.0)
460   FORMAT (///10X,12H----- ERROR //10X,68HA ZERO OR NEGATIVE GAIN FAC
     1TOR (VARIABLE - AMP) IS IN THE NETWORK.  //10X,50HCHECK DATA FOR I
     2NCORRECT OR IMPROPER DATA ENTRY.  ////10X,57HEXECUTION TERMINATED
     3FOLLOWING PRINTING OF NETWORK MODEL.)
470   FORMAT (1H1//24H *****NETWORK MODEL*****/7X,9HFOR YEAR ,I2,12H AND
     1 SEASON ,I2//)
480   FORMAT (86H         ARC       START        END        LOWER       UPPER
     1    COST    AMPLIFICATION   FLOW)
490   FORMAT (52H         NO.       NODE         NODE       BOUND       BOUND//)
500   FORMAT (3I10,7F11.3)
      END
```

COSTF

```
      FUNCTION COSTF (I)
C*****************************************************************
C                     FUNCTION TO CALCULATE THE COSTS ON ARC I
C                     CONSIDERING UPPER AND LOWER BOUNDS
C*****************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      IF (I.GT.NARC) GO TO 60
      IF (FLOW(I)-LOWER(I)) 20,40,40
C*****************************************************************
C                    COMPUTE COST ON FORWARD ARC
C*****************************************************************
20    CONTINUE
      COSTF=-BIG
      RETURN
30    CONTINUE
      COSTF=COST(I)
      RETURN
40    CONTINUE
      IF (UPPER(I)-FLOW(I)) 50,30,30
50    CONTINUE
      COSTF=BIG
      RETURN
C*****************************************************************
C                    COMPUTE COST ON MIRROR ARC
C*****************************************************************
60    CONTINUE
      K=I-NARC
      IF (FLOW(K)-LOWER(K)) 90,70,80
70    CONTINUE
      COSTF=-COST(K)/AMP(K)
      RETURN
80    CONTINUE
      IF (UPPER(K)-FLOW(K)) 100,70,70
90    CONTINUE
      COSTF=BIG/AMP(K)
      RETURN
100   CONTINUE
      COSTF=-BIG/AMP(K)
      RETURN
      END
```

COSTX

```
      SUBROUTINE COSTX
C*****************************************************************
C                     THIS SUBROUTINE COMPUTES THE ECONOMIC COSTS
C                     OF THE CURRENT SYSTEM CONFIGURATION
C*****************************************************************
      COMMON /APRNT/ APOW(50),AIMP(50),QM(75),ISHORT(50),ICOST(50)
     1,AGEN(50)
      COMMON /CDATA/ PERINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC,POWFA
     1C(12)
      COMMON /JDATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
     1INK(50,8),FSTART(50),DLO(50),RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CCAP(75),CPUMP(75),CMIN(7
     15),CLIFT(75),EL(75),LNODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,MAPE1,KAPE2,ISEAS
      COMMON CRESC(50),CRESOM(50),CLINKC(50),CLINOM(50),CIMPT(50),CPOWR(
     150),CTOTAL(50),PVRES(50),PVROM(50),PVLINC(50),PVLIOM(50),PVIMP(50)
     2,PVPOWR(50),PVTOT(50),ANRESC(50),ANRESO(50),ANLINC(50),ANLINO(50),
     3ANIMP(50),ANPOWR(50),ANTOT(50),CPEN(50),PVPEN(50),ANPEN(50)
     4 ,CGEN(50),PVGEN(50),ANGEN(50)
      INTEGER QM,AIMP,APOW,CMAXC,CMINC,RMAXC,RMINC,SCAP
      REAL MAXTOL
C*****************************************************************
C                    INITIALIZE SUMS AND COMPUTE INTEREST
C                    RATE FACTORS FOR PRESENT VALUE AND AVG.
C                    ANNUAL COST COMPONENTS
C*****************************************************************
      CRESC(1)=0.
      CRESOM(1)=0.
      CLINKC(1)=0.
      CLINOM(1)=0.
      CIMPT(1)=0.
      CPOWR(1)=0.
      CGEN(1)=0.
      PVRES(1)=0.
      PVROM(1)=0.
      PVLINC(1)=0.
      PVLIOM(1)=0.
      PVIMP(1)=0.
      PVPOWR(1)=0.
      PVGEN(1)=0.
      ANRESC(1)=0.
      ANRESO(1)=0.
      ANLINC(1)=0.
      ANLINO(1)=0.
      ANIMP(1)=0.
      ANPOWR(1)=0.
      ANGEN(1)=0.
      ANPEN(1)=0.
      PVPEN(1)=0.
      CPEN(1)=0.
      IPAY=-NPAY
      IF (NPAY.EQ.0) GO TO 30
      IF (PERINT) 40,40,20
20    ANFAC=PERINT/(1.-(1.+PERINT)**IPAY)
      GO TO 50
30    ANFAC=1.
      GO TO 50
40    ANFAC=1./NPAY
50    CONTINUE
C*****************************************************************
C                    SET UP DO LOOP FOR ANNUAL VALUES AND
C                    COMPUTE COST FACTORS WITH RESERVOIR
C                    AND CONDUIT CAPITAL COSTS INCURRED
C                    LAGR AND LAGC YEARS EARLIER RESPECTIVELY
C*****************************************************************
```

```
      DO 130 IYR=1,NYEAR
      J=IYR+1
      IF (IYR.EQ.1) GO TO 60
      IYR1=IYR-1
      PVFAC=1./(1.+PERINT)**IYR1
      GO TO 70
60    PVFAC=1.0
      CMPO=1.0
70    CONTINUE
C*********************************************************************
C                   COMPUTE RESERVOIR COST COMPONENTS
C*********************************************************************
      ANSUM=0.
      ANSUMO=0.0
      DO 90 K=1,NRES
      IF (JBLT(K).GT.IYR) GO TO 80
      ANSUMO=ANSUMO+CRES(K)*RESONM
80    CONTINUE
      IBL=JBLT(K)-LAGR
      IF(IBL.LT.1)IBL=1
      IF (IBL.NE.IYR) GO TO 90
      ANSUM=ANSUM+CRES(K)
90    CONTINUE
      CRESC(J)=CRESC(J-1)+ANSUM
      CRESOM(J)=CRESOM(J-1)+ANSUMO
      PVRES(J)=PVRES(J-1)+ANSUM*PVFAC
      PVROM(J)=PVROM(J-1)+ANSUMO*PVFAC
      ANRESC(J)=CRESC(J)*ANFAC
      ANRESO(J)=CRESOM(J)
C*********************************************************************
C                   FIND MAXIMUM LINK FLOWS AND
C                   COMPUTE CONDUIT COST COMPONENTS
C                   NOTE*** ZERO CAPITAL COST FOR
C                   MAXIMUM LINK-FLOW.LT.1 CFS
C*********************************************************************
      ANSUM=0.
      ANSUMO=0.0
      DO 120 L=1,NL
      CONCAP=0.
      Q=QM(L)
      IF (Q.LT.1.) GO TO 100
      Q=Q*723.6
      CONCAP=CLINK(1,L,1)+CLINK(1,L,2)*Q+CLINK(1,L,3)*Q**2
100   CONTINUE
      IBL=LBLT(L)-LAGC
      IF(IBL.LT.1)IBL=1
      IF (IBL.NE.IYR) GO TO 110
      ANSUM=ANSUM+CONCAP
110   IF (LBLT(L).GT.IYR) GO TO 120
      ANSUMO=ANSUMO+CONCAP*CONONM
120   CONTINUE
      CLINKC(J)=CLINKC(J-1)+ANSUM
      CLINOM(J)=CLINOM(J-1)+ANSUMO
      PVLINC(J)=PVLINC(J-1)+ANSUM*PVFAC
      PVLIOM(J)=PVLIOM(J-1)+ANSUMO*PVFAC
      ANLINC(J)=CLINKC(J)*ANFAC
      ANLINO(J)=CLINOM(J)
C*********************************************************************
C                   COMPUTE IMPORT WATER COST COMPONENTS
C*********************************************************************
      XIMP=AIMP(IYR)
      ANSUM=XIMP*CIMP
      CIMPT(J)=CIMPT(J-1)+ANSUM
      PVIMP(J)=PVIMP(J-1)+ANSUM*PVFAC
      ANIMP(J)=CIMPT(J)
C*********************************************************************
C                   COMPUTE PUMP-POWER COST COMPONENTS
C                   AND PENALTY COSTS
C*********************************************************************
      ANSUM=APOW(IYR)
      CPOWR(J)=CPOWR(J-1)+ANSUM
      PVPOWR(J)=PVPOWR(J-1)+ANSUM*PVFAC
      ANPOWR(J)=CPOWR(J)
      CPEN(J)=CPEN(J-1)+ICOST(IYR)
      PVPEN(J)=PVPEN(J-1)+FLOAT(ICOST(IYR))*PVFAC
      ANPEN(J)=CPEN(J)
C*********************************************************************
C                   COMPUTE HYDROELECTRIC POWER BENEFIT
C                   COMPONENTS
C*********************************************************************
      ANSUM=AGEN(IYR)
      CGEN(J)=CGEN(J-1)-ANSUM
      PVGEN(J)=PVGEN(J-1)-ANSUM*PVFAC
      ANGEN(J)=CGEN(J)
C*********************************************************************
C                   SUM COST COMPONENTS TO GET CUMULATIVE
C                   ANNUAL TOTALS
C*********************************************************************
      CTOTAL(J)=CRESC(J)+CRESOM(J)+CLINKC(J)+CLINOM(J)+CIMPT(J)+CPOWR(J)
     1+CPEN(J)+CGEN(J)
      PVTOT(J)=PVRES(J)+PVROM(J)+PVLINC(J)+PVLIOM(J)+PVIMP(J)+PVPOWR(J)+
     1PVPEN(J)+PVGEN(J)
      ANTOT(J)=ANRESC(J)+ANRESO(J)+ANLINC(J)+ANLINO(J)+ANIMP(J)+ANPOWR(J
     1)+ANPEN(J)+ANGEN(J)
130   CONTINUE
C*********************************************************************
C                   END OF ANNUAL COST COMPUTATIONS
C*********************************************************************
      RETURN
      END
```

DESUB

```
      SUBROUTINE DESUB (I,II)
C**********************************************************************
C                    SUBROUTINE TO DELETE AN ARC FROM THE TRIPLE LABEL
C                    REPRESENTATION OF THE FLOW AUGMENTING TREE.
C**********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,STCH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      EXTERNAL FLMAC,AMPF,COSTF
C**********************************************************************
C                    DELETES ARC I FROM THE LIST OF SUBSEQUENT ARCS
C                    TO NODE II.
C**********************************************************************
      JJ=JARC(I)
      IF (FARC(II).NE.I) GO TO 20
      FARC(II)=RARC(JJ)
      RETURN
20    CONTINUE
      MM=FARC(II)
30    CONTINUE
      MN=JARC(MM)
      IF (RARC(MN).NE.I) GO TO 40
      RARC(MN)=RARC(JJ)
      RETURN
40    CONTINUE
      MM=RARC(MN)
      GO TO 30
      END
```

DUAL

```
      SUBROUTINE DUAL (JX)
C**********************************************************************
C                    THIS SUBROUTINE CALCULATES THE NODE POTENTIALS
C                    FOR A GIVEN NETWORK BASIS.
C**********************************************************************
      COMMON/ADATA/IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW( 500)
     1,UPPER( 500),LOWER( 500),ARCS
      COMMON/V/SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,STCH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),
     1 DISSET( 60),GAN( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET,ARCS
      REAL LOWER
      EXTERNAL AMPF,COSTF
C**********************************************************************
C                    SEARCH THROUGH THE TREE AND SET POTENTIAL FOR
C                    EACH NODE ENCOUNTERED.
C**********************************************************************
      IROOT=JX
      II=JX
20    I=FARC(II)
      IF (I.EQ.0) GO TO 40
      JJ=JARC(I)
      IF (ICHK(JJ).EQ.1) GO TO 30
      V(JJ)=(V(II)+COSTF(I))/AMPF(I)
      ICHK(JJ)=1
      II=JJ
      GO TO 20
30    II=JJ
40    J=RARC(II)
      IF (J.EQ.0) GO TO 50
      KK=JARC(J)
      IF (ICHK(KK).EQ.1) GO TO 50
      II=KK
      K=BARC(II)
      JJ=IARC(K)
      V(II)=(V(JJ)+COSTF(K))/AMPF(K)
      ICHK(II)=1
      GO TO 20
50    K=BARC(II)
      IF (II.EQ.IROOT) GO TO 60
      II=IARC(K)
      GO TO 40
60    CONTINUE
      RETURN
      END
```

FLCHG

```
      SUBROUTINE FLCHG (II,FLONOW)
C***********************************************************************
C                     SUBROUTINE TO INCREASE THE FLOW IN AN ARC BY A
C                     GIVEN AMOUNT
C***********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,EPSO,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF
      IF (II.GT.NARC) GO TO 20
C***********************************************************************
C                     CHANGE FLOW IN A FORWARD ARC.
C***********************************************************************
      FLOW(II)=FLOW(II)+FLONOW
      IF(ABS(FLOW(II)-LOWER(II)).LT.EPSO)FLOW(II)=LOWER(II)
      IF(ABS(FLOW(II)-UPPER(II)).LT.EPSO)FLOW(II)=UPPER(II)
      CSTNOW=CSTNOW+FLONOW*COST(II)
      GO TO 30
C***********************************************************************
C                     CHANGE FLOW IN A MIRROR ARC.
C***********************************************************************
20    CONTINUE
      KK=II-NARC
      FLONOW=FLONOW/AMP(KK)
      FLOW(KK)=FLOW(KK)-FLONOW
      IF(ABS(FLOW(KK)-LOWER(KK)).LT.EPSO)FLOW(KK)=LOWER(KK)
      IF(ABS(FLOW(KK)-UPPER(KK)).LT.EPSO)FLOW(KK)=UPPER(KK)
      CSTNOW=CSTNOW-FLONOW*COST(KK)
30    CONTINUE
      RETURN
      END
```

FLMXC

```
      FUNCTION FLMXC (I,S)
C***********************************************************************
C                     FUNCTION TO DETERMINE MAXIMUM FLOW CHANGE IN AN ARC
C***********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      EXTERNAL COSTF,AMPF
      II=IARC(I)
      JJ=JARC(I)
      IF (S) 20,20,70
C***********************************************************************
C                     FLOW IS TO BE DECREASED
C***********************************************************************
20    CONTINUE
      IF (I.GT.NARC) GO TO 40
      IF (FLOW(I).GT.UPPER(I)) GO TO 30
      FLMXC=FLOW(I)-LOWER(I)
      RETURN
30    CONTINUE
      FLMXC=FLOW(I)-UPPER(I)
      RETURN
40    CONTINUE
      K=I-NARC
      IF (FLOW(K).LT.LOWER(K)) GO TO 60
      FLMXC=(UPPER(K)-FLOW(K))*AMP(K)
      RETURN
60    CONTINUE
      FLMXC=(LOWER(K)-FLOW(K))*AMP(K)
      RETURN
C***********************************************************************
C                     FLOW IS TO BE INCREASED
C***********************************************************************
70    CONTINUE
      IF (I.GT.NARC) GO TO 100
      IF (FLOW(I).GE.UPPER(I)) GO TO 130
      IF (FLOW(I).LT.LOWER(I)) GO TO 90
      FLMXC=UPPER(I)-FLOW(I)
      RETURN
90    CONTINUE
      FLMXC=LOWER(I)-FLOW(I)
      RETURN
100   CONTINUE
      K=I-NARC
      IF (FLOW(K).GT.UPPER(K)) GO TO 120
      IF (FLOW(K).LE.LOWER(K)) GO TO 130
      FLMXC=(FLOW(K)-LOWER(K))*AMP(K)
      RETURN
120   CONTINUE
      FLMXC=(FLOW(K)-UPPER(K))*AMP(K)
      RETURN
130   CONTINUE
      FLMXC=0.0
      RETURN
      END
```

FLOP

```
      SUBROUTINE FLOP (JJ,FLMAX,GN,IROOTL)
C***********************************************************************
C                   SUBROUTINE TO DETERMINE THE GAIN, MAXIMUM FLOW
C                   CHANGE, AND ROOT OF A FLOW GENERATING CYCLE
C                   IN THE FLOW AUGMENTING TREE.
C***********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF
C***********************************************************************
      FLMAX=9999999999.0
      GN=1
      IJ=JJ
20    CONTINUE
      IJK=BARC(IJ)
      GN=GN*AMPF(IJK)
      FLMXT=FLMXC(IJK,1.)*GN
      IF (FLMXT.GT.FLMAX) GO TO 30
      FLMAX=FLMXT
      IROOTL=JARC(IJK)
30    CONTINUE
      IF (IARC(IJK).EQ.JJ) GO TO 40
      IJ=IARC(IJK)
      GAN(IJ)=GAN(JJ)*GN
      GO TO 20
40    CONTINUE
      FLMAX=FLMAX*(1.-1./GN)
      RETURN
      END
```

GAIN

```
      SUBROUTINE GAIN
C***********************************************************************
C                   PROGRAM TO SOLVE THE DUAL NETWORK WITH GAINS PROBLEM
C                   FOR A GIVEN QUANTITY OF OUTPUT FLOW.
C                   PROGRAM BY P. JENSEN AND GORA BHAUMIK, UNIVERSITY
C                   OF TEXAS, 1973.
C***********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /PRT/ IPRNT(50),TITLE(10)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET,SCAP
      REAL LOWEP,MAXTOL
      EXTERNAL FLMXC,AMPF,COSTF
C***********************************************************************
C                   INITIALIZE COUNTERS AND CONSTANTS
C***********************************************************************
      MAXTOL=0.
      EP2=EPS
      TIME2=TIME
20    CONTINUE
      ISICH=0
      SICHK=1.
      NARC=ARCS
      NDEG=0
      NLOP=0
      ITER=0
      FLONET=0.C
      TOTCST=0.C
      IFS=0
C***********************************************************************
C                   CREATE MIRROR ARCS.
C***********************************************************************
      DO 30 I=1,NARC
      NN=NARC+I
      IARC(NN)=JARC(I)
      JARC(NN)=IARC(I)
30    CONTINUE
40    CONTINUE
C***********************************************************************
C                   EXECUTE ITERATIVE SOLUTION PROCEDURE
C***********************************************************************
      CALL SHORT (IENTER,ILEAV)
      IF (IENTER.EQ.0) GO TO 110
      CALL MAXFLO
      TOTCST=TOTCST+CSTNOW
      ITER=ITER+1
      IF (IPRINT) 60,60,50
50    PRINT 160, ITER,FLONET,TOTCST
      PRINT 170, ILEAV,IENTER,STCH
60    CONTINUE
C***********************************************************************
C                   PRINT DIAGNOISTIC MESSAGES IF NUMBER OF ITERATIONS
C                   IS GREATER THAN 2000.
C***********************************************************************
      IF (ITER.LE.2000) GO TO 100
      PRINT 120
      TIME=TIME/2
      EPS=EPS/2.
      MAXTOL=.0009
      IF (TIME-1.E-7) 70,80,80
70    PRINT 130
      STOP
80    CONTINUE
```

```
C*********************************************************************
C                    INITIALIZE ARC FLOWS
C*********************************************************************
      DO 90 IQ=1,NARC
90    FLOW(IQ)=0.
      GO TO 20
C*********************************************************************
C                    DETERMINE IF DESIRED FLOW INTO SINK NODE IS ACHIEVED
C*********************************************************************
100   IF (ABS(FLOWLT+OUTFLO).LE.EPS) GO TO 110
      GO TO 40
110   CONTINUE
      EPS=EPZ
      TIME=TIMEZ
      MINTOL=0.
      RETURN
C
120   FORMAT (1H1////20X,40(1H*)//20X,14HATTENTION USER,5X,20(1H-)////20
     1X,52HTHE DUAL NETWORK-WITH-GAINS ALGORITHM HAS FAILED TO /20X,54HC
     2ONVERGE IN 2000 ITERATIONS.   IT IS LIKELY THAT THE  /20X,55HALGOR
     3ITHM IS CYCLING (UNLESS THE PROBLEM IS VERY LARGE)/20X,56HAND WILL
     4 NOT CONVERGE. SELECTED TOLERANCE PARAMETERS    /20X,57HWILL BE AD
     5JUSTED IN VALUE, AND THE PROGRAM WILL RESTART  /20X,55HIN AN ATTEM
     6PT TO FIND THE OPTIMAL SOLUTION.             ///20X,55HEXECUTION WI
     7LL TERMINATE IF THE TOLERANCE PARAMETERS   /20X,40HREACH THEIR LOW
     8ER LIMITS.                    )
130   FORMAT (///20X,20(1H*),1X,38HEXECUTION TERMINATED DUE TO FAILURE
     1 /41X,58HOF DUAL ALGORITHM TO SOLVE THE NETWORK PROBLEM.
     2 /41X,58HPOSSIBLE REMEDY IS TO INCREASE THE MAXIMUM NUMBER OF
     3 /41X,58HITERATIONS TO GREATER THAN 2000, IF THE NUMBER OF
     4 /41X,58HARCS AND/OR NODES IN PROBLEM ARE NEAR ALLOWABLE UPPER
     5 /41X,10HLIMITS.    )
140   FORMAT (///,21H *****TOTAL COST*****,F20.4)
150   FORMAT (22H NUMBER OF ITERATIONS ,I10/33H NUMBER OF DEGENERATE ITE
     1RATIONS ,I10/27H NUMBER OF LOOP ITERATIONS ,I10/)
160   FORMAT (11H ITERATION ,I5,5X,6H FLOW ,F10.2,5X,6H COST ,F20.2)
170   FORMAT (7H REMOVE,I5,5X,5HENTER,I5,5X,5HDELTA,F20.5)
      END
```

```
      SUBROUTINE HYDRO
C*********************************************************************
C                    THIS SUBROUTINE DETERMINES THE OPTIMAL
C                    OPERATING COST FOR A SYSTEM OF RESERVOIRS
C                    WITH HYDROELECTRIC GENERATING CAPACITY
C*********************************************************************
      COMMON /ADATA/ NF(1000),NT(1000),COST( 500),AMP( 500),FLOW( 500),H
     1I( 500),LC( 500),ARCS
      COMMON /CDATA/ PERINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC,
     1  POWFAC(12)
      COMMON/HDATA/ O(12,50),U(50,12),E(12,50)
      COMMON /HYDRO/ IEFF(50,20,2),LHYOPO(75),MLOAD(50),ITELEV(50,20,2)
     1                ,ECTAB(50,20,2),IHAXO(50,20,2),HPOWF(12),
     2                 ONPKC,OFPKC,IHRSP(12),IHRSO(12),NOWN(50)
      COMMON /HYDROA/ LHYORS(50),ISTEFF(50),LHYOA(50)
      COMMON /JCATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
     1INK(50),FSTART(50),CLO(50)   ,RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CMAX(75),CPUMP(75),CMIN(7
     15),CLIFT(75),EL(75),LNODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /MDATA/ XX(12),ELF(12),XIMP,KSPILL
      COMMON /MISC/ AMIN,AIMIN,ARMIN,ALMIN,ASMIN
      COMMON /NDATA/ NYEAR,NS,SCAP,NU,NREAD,MAXTOL
      COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /SHORTS/ GNO(50),CST(12,50),ACO(50,2),TFAC(12,50),TCST(50),
     1IOPT(50),NKEY(50),RKEY(50,5,12),NRKEY(50,5)
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,STCH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /WPKO/ START(50),STEND(50),USE(50),UREG(50)
     1,IELEV(50),
     2ELEVX(50),EDISC(50)
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),
     1 DISSET( 60),GAN( 60),ICHK( 60),LIST( 60)
      COMMON    MIO(50),LOO(50),
     1ITEFF(50),IPOST(50),IPUSO(50),ITEMP(50)
     2,RPOIST(50),RPOIS(50),EDISCP(50),DHUS(50),TCSTI(50)
      DIMENSION  NAVEL(50),NAVST(50),RCOST1(50),RCOST2(50)
     1 ,RCOST3(50)
      DIMENSION QHYD(50),FARCJT(60),BARCJT(60),
     1  RARCJT(60),FLOWJT(500),ISTEJT(50)
      INTEGER ARCS,SOURCE,A,AA,AAA,SINK,BARC,FARC,RARC,DISSET,ECTAB,A4
      REAL LO,IAVEL,NAVEL
      DATA IONCE/0/
      INTEGER RPOIST,RPOIS
      INTEGER AIMIN,ARMIN,ALMIN,SCAP,ASMIN,RMAXC,RMINC,CMAXC,CMINC,AMIN
      INTEGER START,STEND,USE,UREG
      REAL LOO,IPOST,IPOSO,ITEFF,IELEV,MAXTOL
      EXTERNAL INTERP,PRIMAL,RESTAR
C*********************************************************************
C                    INITIALIZE VARIABLES AND ARRAYS
C*********************************************************************
      IF (ONPKC) 20,20,30
20    RETURN
30    CONTINUE
      ROFF=.499
      CONFLO=60.3*12./NSEAS
      SUBS=12./NSEAS
      HPSEAS=24.*30.4*12./NSEAS
      ADJF=.20
      IF(KAPE1.GT.0)ADJF=.1
C*********************************************************************
C                    GENERATE SURFACE AREA, ELEVATION OF WATER SURFACE, ETC.
C                    OF MAXIMUM AND MINIMUM RESERVOIR STORAGE
C*********************************************************************
40    CONTINUE
      NHYARS=0
      DO 50 I=1,NRES
      A=I+5
      START(I)=LO(A)-U(I,ISEAS)
      RPOIST(I)=0
      LHYORS(I)=0
```

```
      ITCMP(I)=MLOAD(I)
      ISTEFF(I)=95
50    CONTINUE
C*********************************************************************
C                    STORE RESERVOIR UNIT STORAGE BENEFITS
C                    FOR LATER RETRIEVAL
C*********************************************************************
      DO 60 J=1,NRES
      IESTI(J)=ICST(J)
      A=ARMIN+J
      AA=A+NRES
      AAA=AA+NRES
      RCOST1(J)=COST(A)
      RCOST2(J)=COST(AA)
      RCOST3(J)=COST(AAA)
60    CONTINUE
C*********************************************************************
C                    DETERMINE WHICH RESERVOIRS ARE UTILIZED
C                    FOR HYDROELECTRIC POWER GENERATION
C*********************************************************************
      DO 70 L=1,NR
      LHYOX=LHYDRO(L)
      IF (LHYOX.EQ.0) GO TO 70
      JK=LNODE(L,1)
      LHYDRS(JK)=1
      LHYDA(JK)=L
      NHYARS=NHYARS+1
70    CONTINUE
      HYDRC=1.E10
      GO TO 110
C*********************************************************************
C                    EXECUTE PRIMAL ALGORITHM TO SOLVE NETWORK-WITH-
C                    GAINS USING CURRENT FEASIBLE SOLUTION
C*********************************************************************
80    CONTINUE
      CALL PESTAR
      CALL PRIMAL
      IF (ITER.GT.0) GO TO 100
C*********************************************************************
C                    EXECUTE DUAL ALGORITHM TO SOLVE NETWORK-WITH-
C                    GAIN SINCE THE PRIMAL ROUTINE FAILED TO CONVERGE.
C*********************************************************************
      DO 90 IL=1,NAFC
90    FLOW(IL)=0.
      CALL GAIN
      CALL OUTPUT
100   CONTINUE
      NTIME=NTIME+1
110   CONTINUE
C*********************************************************************
C
C                             CORRECT FOR CHANGES IN THE PRICE OF
C                             HYDROELECTRICITY GENERATED
C
C*********************************************************************
120   CONTINUE
      HCOST=0
      SHORC=0.
      PUMPC=0.
      I=ISEAS
      HOURP=IHRSP(I)
      HOURO=IHRSO(I)
      HOURG=HOURP
      IF (HOURP) 130,130,140
130   HOURG=HOURO
      IF (HOURG) 430,430,140
140   HOURPP=HOURG/HPSEAS
C*********************************************************************
C                    CALCULATE RESERVOIR STORAGE LEVELS
C*********************************************************************
      DO 150 J=1,NRES
      A=ARMIN+J
      AA=A+NRES
      AAA=AA+NRES
      STEND(J)=FLOW(AAA)*AMP(AAA)+FLOW(AA)*AMP(AA)+FLOW(A)*AMP(A)+ROFF
C*********************************************************************
C                    RETRIEVE THE UNIT BENEFIT FOR STORAGE.
C*********************************************************************
      COST(A)=RCOST1(J)
      COST(AA)=RCOST2(J)
      COST(AAA)=RCOST3(J)
150   CONTINUE
C*********************************************************************
C                    CALCULATE WATER SURFACE ELEVATIONS AND MAXIMUM
C                    DISCHARGE THROUGH HYDROPOWER GENERATION FACILITIES
C*********************************************************************
      CALL INTERP (START,ELEVX,ECTAB)
      CALL INTERP (STEND,IELEV,ECTAB)
      CALL INTERP (START,IPOST,IMAXD)
      CALL INTERP (STEND,IPOSD,IMAXD)
C*********************************************************************
C                    COMPUTE FLOW IN HYDROPOWER LINKS
C*********************************************************************
      DO 210 J=1,NRES
      RPDIST(J)=0.
      IF (LHYDRS(J).EQ.0) GO TO 210
      A=LHYDA(J)
      IF (A) 200,200,160
160   A=ALMIN+A
      QMX=(IPOST(J)+IPOSD(J))*.5
      QQ=FLOW(A)*1000./CONFLO/HOURPP
      IF (QQ-QMX) 170,170,180
170   RPDIST(J)=QQ/1000.+ROFF
      GO TO 190
180   RPDIST(J)=QMX/1000.+ROFF
      QQ=QMX
190   QHYD(J)=QQ
200   CONTINUE
210   CONTINUE
C*********************************************************************
C                    CALCULATE TAILRACE WATER SURFACE ELEVATION
C*********************************************************************
      CALL INTERP (RPDIST,EDISC,ITELEV)
      DO 230 J=1,NRES
      NDD=NDWN(J)
      IF (NDD) 230,230,220
220   ETEMP=(IELEV(NDD)+ELEVX(NDD))*.5
      IF(ETEMP.GT.EDISC(J))EDISC(J)=ETEMP
230   CONTINUE
C*********************************************************************
C                    COMPUTE POWER LOADING AND EFFICIENTS FOR HYDRO-
C                    ELECTRIC POWER GENERATING RESERVOIRS
C                    USING SUCCESSIVE APPROXIMATION.
C*********************************************************************
240   CONTINUE
      DO 250 J=1,NRES
      IF (LHYDRS(J).EQ.0) GO TO 250
      IAVEL=(IELEV(J)+ELEVX(J))*.5
      ITEMP(J)=QHYD(J)*(IAVEL-EDISC(J))*ISTEFF(J)/1180000.
      IF(ITEMP(J).LT.0)ITEMP(J)=0
250   CONTINUE
      CALL INTERP (ITEMP,ITEFF,IEFF)
      ICONVR=1
C*********************************************************************
C                    CHECK FOR UPDATE IN POWER PLANT EFFICIENCY AND
C                    CORRECT FOR NEW GENERATING EFFICIENCY
C*********************************************************************
      DO 260 J=1,NRES
      IF (LHYDRS(J).EQ.0) GO TO 260
      IF (IABS(ITEFF(J)-ISTEFF(J)).LE.1) GO TO 260
      ISTEFF(J)=ITEFF(J)
      ICONVR=0
260   CONTINUE
      IF (ICONVR.EQ.0) GO TO 240
```

```
C***********************************************************************
C                    COMPUTE HYDROELECTRIC GENERATION ON EACH POWER ARC
C***********************************************************************
      PKON=0.
      PKOF=0.
      PKOFS=0.
      DO 380 L=1,NR
      IF (LHYDRO(L).EQ.0) GO TO 380
      JF=LNODE(L,1)
      IF (RCAP(JF)) 380,380,270
270   CONTINUE
      A=ALMIN+L
      CCOST=COST(A)
      COST(A)=0
C***********************************************************************
C                    COMPUTE THE AVERAGE ELEVATION AND POWER GENERATED.
C***********************************************************************
      IAVEL=(IELEV(JF)+ELEVX(JF))*.5
      QMX=(IPOST(JF)+IPOSD(JF))/2.
      POWCOF=(IAVEL-EDISC(JF))*ITEFF(JF)/1180000.
      POWMX=QMX*POWCOF
      POWER=QHYD(JF)*POWCOF
      QFLOW=QHYD(JF)
      ISTEFF(JF)=ITEFF(JF)
C***********************************************************************
C                    COMPUTE THE ON-PEAK AND OFF-PEAK POWER GENERATION
C***********************************************************************
      IF (HOURP) 280,280,290
280   QFLOW=FLOW(A)*1000.
      GO TO 320
290   CONTINUE
      IF (QFLOW-QMX) 300,310,310
300   PKON=PKON+POWER
      GO TO 380
310   PKON=PKON+POWMX
      QQ=FLOW(A)*1000.
      QFLOW=QQ-QMX/12.1*HOURG
320   IF (QFLOW) 330,340,340
330   QFLOW=0.
340   IF (HOURO) 380,380,350
350   IF (QMX) 380,380,360
360   HPORS=QFLOW*12.1/QMX
      IF(HPORS.GT.HOURO)HPORS=HOURO
370   PKOFS=PKOFS+POWMX*HPORS
380   CONTINUE
C***********************************************************************
C                    COMPUTE SEASONAL ON- AND OFF-PEAK POWER
C                    GENERATION AND ECONOMIC BENEFITS
C***********************************************************************
      POWONP=PKON
      IF (PKON-HPOWF(I)) 400,390,390
390   CONTINUE
      PKOF=PKOF+(PKON-HPOWF(I))
      PKON=HPOWF(I)
400   CONTINUE
      HCOST=HCOST-PKON*ONPKC*HOURP-PKOF*OFPKC*HOURP-PKOFS*OFPKC
C***********************************************************************
C                    COMPUTE PUMPING AND WATER SHORTAGE COSTS.
C***********************************************************************
      DO 410 J=1,ND
      A=AIMIN+J
410   SHORC=-COST(A)*(HI(A)-FLOW(A))+SHORC
      DO 420 L=1,NL
      A=ALMIN+L
420   PUMPC=COST(A)*FLOW(A)+PUMPC
430   CONTINUE
C***********************************************************************
C                    COMPUTE TOTAL SYSTEM BENEFIT.
C***********************************************************************
      HCOST=HCOST+SHORC+PUMPC
C***********************************************************************
C                    IF NEW ARCS WERE ADDED TO BALANCE THE
C                    INITIAL RESERVOIR STORAGES IN AN ADVANCED
C                    RESTART THEN FIRST SOLUTION COMPUTED MUST
C                    BE SELECTED AS A BEST INITIAL SOLUTION.
C***********************************************************************
      IF (NPRIT-1) 440,450,440
C***********************************************************************
C                    IF THE CURRENT SOLUTION HAS A LOWER COST
C                    THAN THE PREVIOUS SOLUTION THEN THE SOLUTION
C                    IS STORED FOR LATER RETRIEVAL
C***********************************************************************
440   IF (HCOST.GE.HYDRC) GO TO 1030
450   NPRIT=0
C***********************************************************************
C                    IF ANY OF THE INITIAL STORAGE BALANCE ARCS
C                    ARE NOT AT THEIR MAXIMUM CAPACITY THEN
C                    IRREGARDLESS OF THE SYSTEM COST, THE CURRENT
C                    SOLUTION IS RETAINED AS THE BEST INTERMEDIATE
C                    SOLUTION.
C***********************************************************************
      NNCS=ARCS
460   IF (COST(NNCS)+BIG) 500,470,500
470   IF (FLOW(NNCS)+EPS-HI(NNCS)) 480,490,490
480   NPRIT=1
      GO TO 500
490   NNCS=NNCS-1
      GO TO 460
500   CONTINUE
      HYCRC=HCOST
C***********************************************************************
C                    STORE THE CURRENT BEST SOLUTION
C***********************************************************************
      DO 520 L=1,NR
      IF (LHYDRO(L).EQ.0) GO TO 520
      JF=LNODE(L,1)
      A=ALMIN+L
      IF (RCAP(JF)) 520,520,510
510   CONTINUE
      HIO(JF)=HI(A)
      LOO(JF)=LO(A)
      POWONT=POWONP
520   CONTINUE
      DO 530 J=1,NARC
530   FLOWJT(J)=FLOW(J)
      DO 540 J=1,NODES
      RARCJT(J)=RARC(J)
      FARCJT(J)=FARC(J)
540   BARCJT(J)=BARC(J)
      DO 550 J=1,NRES
550   ISTEJT(J)=ISTEFF(J)
C***********************************************************************
C                    THE BOUNDS AND COSTS ON THE HYDRO ARCS AND RESERVOIR
C                    STORAGE ARCS ARE ADJUSTED.
C***********************************************************************
560   CONTINUE
      HRSP=IHRSP(I)
      HOURP=HRSP/HPSEAS
      HOURPP=HOURP
      HRSO=IHRSO(I)
      HOURO=HRSO/HPSEAS
      IF (HOURP) 570,570,590
570   IF (HOURO) 1020,1020,560
580   HOURPP=HOURO
590   CONTINUE
C***********************************************************************
C                    COMPUTE STORAGE VOLUMES AND MAXIMUM RATES OF POWER.
C***********************************************************************
      DO 640 J=1,NRES
      A=ARMIN+J
      AA=A+NRES
      AAA=AA+NRES
```

```
      STEND(J)=FLOW(AAA)*AMP(AAA)+FLOW(AA)*AMP(AA)+FLOW(A)*AMP(A)+ROFF
      RPDIST(J)=0.
      IF (LHYDRS(J).EQ.0) GO TO 640
      A=LHYDA(J)
      IF (A) 640,640,600
600   A=ALMIN+A
      QMX=(IPDST(J)+IPDSO(J))*.5
      QQ=FLOW(A)*1000./CONFLO/HOURPP
      IF (QQ-QMX) 610,610,620
610   RPDIST(J)=QQ/1000.+ROFF
      GO TO 630
620   RPDIST(J)=QMX/1000.+ROFF
      QQ=QMX
630   QHYD(J)=QQ
640   CONTINUE
C*********************************************************************
C                   COMPUTE INITIAL AND FINAL WATER SURFACE ELEVATION,
C                   MAXIMUM TURBINE DISCHARGE, AND TAILWATER ELEVATION
C                   DUE TO RESERVOIR DISCHARGE, FOR EACH RESERVOIR IN
C                   EACH SEASON.
C*********************************************************************
      CALL INTERP (START,ELEVX,ECTAB)
      CALL INTERP (STEND,IELEV,ECTAB)
      CALL INTERP (STEND,IPDSO,IMAXO)
      CALL INTERP (RPDIST,EDISC,ITELEV)
C*********************************************************************
C                   COMPUTE AND STORE AVERAGE WATER COLUMN HEIGHT
C                   AND CHANGE IN ELEVATION WITH RESPECT TO CHANGES
C                   IN WATER STORAGE.
C*********************************************************************
      DO 650 JF=1,NRES
      NAVEL(JF)=(IELEV(JF)+ELEVX(JF))*.5
      NAVST(JF)=STEND(JF)-1
650   RPDIS(JF)=RPDIST(JF)+1
      CALL INTERP (NAVST,ELEVX,ECTAB)
      CALL INTERP (RPDIS,EDISCP,ITELEV)
C*********************************************************************
C                   COMPUTE NEW UPPER AND LOWER BOUNDS ON FLOWS ON HYDRO.
C                   ARCS.  CHECK TO INSURE THAT THE MAXIMUM GENERATION
C                   DOES NOT EXCEED THE INSTALLED GENERATION CAPACITY.
C*********************************************************************
      PKNET=POWONP-HPOWF(I)
      DO 1010 L=1,NR
      IF (LHYDRO(L).EQ.0) GO TO 1010
      JF=LNODE(L,1)
      IF (RCAP(JF)) 1010,1010,660
660   IAVEL=NAVEL(JF)
      A=ALMIN+L
      DHUS(JF)=IELEV(JF)-ELEVX(JF)
      CORR=.5*QHYD(JF)*ISTEFF(JF)/1180000.
      STCORR=DHUS(JF)*CORR
C*********************************************************************
C                   COMPUTE TAILWATER ELEVATION.
C*********************************************************************
      TAILEV=EDISC(JF)
      DTEV=EDISCP(JF)-EDISC(JF)
      IF (NDWN(JF)) 680,680,670
670   KF=NDWN(JF)
      IF (TAILEV.GT.NAVEL(KF)) GO TO 680
      TAILEV=NAVEL(KF)
      DTEV=0.
      DHUS(KF)=IELEV(KF)-ELEVX(KF)
      STC=-DHUS(KF)*CORR
680   CONTINUE
C*********************************************************************
C                   COMPUTE RATE OF CHANGE IN EFFICIENCY WITH POWER LOAD.
C*********************************************************************
      DELF=0.
      ITEFX=ISTEFF(JF)
      PG=(IAVEL-TAILEV)*QHYD(JF)*ITEFX/1180.
      DO 690 JTX=1,18
      ITX=IEFF(JF,JTX,2)
      IF (ITX.LE.PG) GO TO 690
      EFT=IEFF(JF,JTX,1)
      DELF=(EFT-IEFF(JF,JTX-1,1))/(100.*(ITX-ITXO))
      GO TO 700
690   ITXO=ITX
      PRINT 1150, PG,JF
      STOP
700   CONTINUE
C*********************************************************************
C                   COMPUTE POWER GENERATION PER UNIT OF FLOW DISCHARGE.
C*********************************************************************
      POWGM=(IPDST(JF)+IPDSO(JF))/2.*CONFLO/1000.
      TLO=FLOW(A)*(1.-ADJF)
      THI=FLOW(A)*(1.+ADJF)
      EFFACT=1.-DELF*QHYD(JF)*(IAVEL-TAILEV)/11.8
      IF (EFFACT) 710,710,720
710   CONTINUE
      PRINT 1160, JF,PG
      EFFACT=.5
720   POWER=((IAVEL-TAILEV)-DTEV*QHYD(JF)/1000.)*ISTEFF(JF)/1180./EFFACT
      DP=POWER/CONFLO
      HINT=POWGM*HOURP
      FLDPP=FLOW(A)-PKNET/DP*HOURP
      CPKC=-ONPKC*HRSP
      TPWT=DP
      POWGM=POWGM*(HOURP+HOURO)
      IF (PKNET) 730,770,810
C*********************************************************************
C                   UPDATE HYDRO GENERATION BENEFIT PER UNIT FLOW
C                   --- WHEN TARGET ON-PEAK HYDRO IS NOT MET.
C*********************************************************************
730   COST(A)=-ONPKC*TPWT*HRSP
      IF (FLOW(A)-HINT) 740,750,760
740   SHI=AMIN1(HINT,FLDPP)*1.001
      SLO=0.
      GO TO 850
750   SHI=HINT
      SLO=0.
      GO TO 850
760   SLO=HINT*.99
      SHI=POWGM
      CPKC=-OFPKC*HRSO
      COST(A)=-OFPKC*TPWT*HRSO
      GO TO 850
C*********************************************************************
C                   UPDATE HYDRO GENERATION BENEFIT PER UNIT FLOW
C                   --- WHEN TARGET ON-PEAK HYDRO IS MET EXACTLY.
C*********************************************************************
770   CPKC=-OFPKC*HRSO
      COST(A)=-OFPKC*TPWT*HRSO
      IF (FLOW(A)-HINT) 780,790,800
780   SHI=HINT
      SLO=.999*FLOW(A)
      GO TO 850
790   SHI=POWGM
      SLO=.999*HINT
      GO TO 850
800   SHI=POWGM
      SLO=HINT*.99
      GO TO 850
C*********************************************************************
C                   UPDATE HYDRO GENERATION BENEFIT PER UNIT FLOW
C                   --- WHEN TARGET ON-PEAK HYDRO IS EXCEEDED.
C*********************************************************************
810   CPKC=-OFPKC*HRSO
      COST(A)=-OFPKC*TPWT*HRSO
      IF (FLOW(A)-HINT) 820,830,840
820   SHI=HINT
      SLO=FLDPP
      GO TO 850
```

```
830   SHI=POWGM
      SLO=FLOPP
      GO TO 850
840   SHI=POWGM
      SLO=HINT*.99
850   CONTINUE
      IPOWGM=POWGM
      HI(A)=AMIN1(THI,SHI)
      LO(A)=AMAX1(TLO,SLO)
C*****************************************************************
C                   CHECK TO INSURE THAT THE MAXIMUM AND MINIMUM
C                   LINK FLOW BOUNDS ARE OBSERVED.
C*****************************************************************
      FMAX=CMAX(L)/1660.*SUBS*CMAXC(L,I)
      FMIN=CMIN(L)/1660.*SUBS*CMINC(L,I)
      IF(HI(A).GT.FMAX)HI(A)=FMAX
      IF(LO(A).LT.FMIN)LO(A)=FMIN
      IF(HI(A).LT.FLOW(A))HI(A)=FLOW(A)
      IF(FLOW(A).LT.LO(A))LO(A)=FLOW(A)
      IF(HI(A).LT.LO(A))LO(A)=HI(A)
C*****************************************************************
C                   IF THE FLOW IN A HYDRO ARC IS LESS THAN 10000 AC-FT
C                   OR EFFICIENCY IS .LE. 20 PERCENT THEN A NONZERO UPPER
C                   BOUND ON FLOW IS SET FOR THE ARC.
C*****************************************************************
      IF (FLOW(A)-10.) 870,870,860
860   CONTINUE
      IF (ISTEFF(JF).LL.20) GO TO 870
      GO TO 920
870   CONTINUE
      ISTEFF(JF)=95
      IF (PKNET) 880,890,890
C*****************************************************************
C                   IF THE ON-PEAK HYDRO TARGET IS NOT MET, THE ARC
C                   COST IS SET TO ON-PEAK PRICE. ALSO, UPPER BOUND ON
C                   FLOW IS SET TO FLOW RATE NEEDED TO GENERATE POWER
C                   EQUAL TO TARGET DEFICIT MULTIPLIED BY THE ADJUST-
C                   MENT FACTOR - ADJF.
C*****************************************************************
880   CONTINUE
      FLOPP=FLOW(A)-(PKNET/DP)*ADJF*HOURP
      HI(A)=AMIN1(HINT,FLOPP)
      GO TO 910
C*****************************************************************
C                   IF THE ON-PEAK HYDRO TARGET IS MET OR EXCEEDED,
C                   THE ARC COST IS SET TO OFF-PEAK PRICE. ALSO, UPPER
C                   BOUND ON FLOW IS SET TO FLOW RATE GENERATING A
C                   PROPORTION - ADJF - OF THE MAX. POWER CAPACITY
C                   OF THE RESERVOIR.
C*****************************************************************
890   CONTINUE
      PMXAJ=POWGM*ADJF
      IF (FLOW(A)-PMXAJ) 900,910,910
900   HI(A)=PMXAJ
910   CONTINUE
      IF(HI(A).GT.FMAX)HI(A)=FMAX
      IF(HI(A).LT.FLOW(A))HI(A)=FLOW(A)
      IF(FLOW(A).LT.LO(A))LO(A)=FLOW(A)
      IF(HI(A).LT.LO(A))LO(A)=HI(A)
920   CONTINUE
C*****************************************************************
C                   CHECK TO INSURE THAT A BASIC OR NONBASIC ARC REMAINS
C                   OF THE SAME TYPE AFTER THE ADJUSTMENT OF FLOW BOUNDS.
C*****************************************************************
      AF=FLOW(A)
      AHIO=HIO(JF)
      ALOO=LOO(JF)
      IF (AF-AHIO) 950,930,980
930   IF (AF-HI(A)) 940,990,980
940   LO(A)=AF
      GO TO 990
950   IF (AF-ALOO) 980,960,990
960   IF (AF-LO(A)) 980,990,970
970   HI(A)=AF
      GO TO 990
980   PRINT 1170, A,AF,AHIO,ALOO
990   CONTINUE
      AA=ARMIN+JF
      AAA=AA+NRES
      AN=AAA+NRES
C*****************************************************************
C                   COMPUTE THE UPDATED UNIT STORAGE BENEFIT FOR
C                   STORAGE IN THE CURRENT TIME PERIOD IN A
C                   RESERVOIR PRODUCING HYDROELECTRIC POWER.
C*****************************************************************
      PSTCP=STCORR*CPKC/EFFACT
      COST(AA)=PSTCP*COST(AA)
      COST(AAA)=PSTCP*COST(AAA)
      COST(AN)=PSTCP*COST(AN)
C*****************************************************************
C                   IF A DOWNSTREAM RESERVOIR CONTROLS THE TAILWATER
C                   ELEVATION FOR THE RESERVOIR - JF - THEN UPDATE
C                   THE UNIT STORAGE BENEFITS.
C*****************************************************************
      NNO=NDWN(JF)
      IF (NNO) 1010,1010,1000
1000  IF (EOTSC(JF).GT.NAVEL(NNO)) GO TO 1010
      AA=ARMIN+NNO
      AAA=AA+NRES
      AN=AAA+NRES
C*****************************************************************
C                   COMPUTE THE UPDATED UNIT STORAGE BENEFIT FOR
C                   STORAGE IN THE CURRENT TIME PERIOD IN A
C                   RESERVOIR INFLUENCING THE TAILWATER ELEVATION
C                   OF A RESERVOIR PRODUCING HYDROELECTRIC POWER.
C*****************************************************************
      PSTCP=STC*CPKC/EFFACT
      COST(AA)=PSTCP*COST(AA)
      COST(AAA)=PSTCP*COST(AAA)
      COST(AN)=PSTCP*COST(AN)
1010  CONTINUE
1020  CONTINUE
      GO TO 80
1030  CONTINUE
C*****************************************************************
C                   RETRIEVE THE UNIT BENEFIT FOR STORAGE.
C*****************************************************************
      DO 1040 J=1,NRES
      A=ARMIN+J
      AA=A+NRES
      AAA=AA+NRES
      COST(A)=RCOST1(J)
      COST(AA)=RCOST2(J)
      COST(AAA)=RCOST3(J)
1040  CONTINUE
      IF (HYDRC-1.E10) 1050,450,1050
1050  CONTINUE
C*****************************************************************
C                   REDUCE STEP SIZE BY HALF
C*****************************************************************
      ADJF=ADJF/2.
C*****************************************************************
C                   THE LOWEST COST SOLUTION IS RETRIEVED FOR
C                   USE IN RECOVERING FROM A HIGHER COST SOLUTION
C*****************************************************************
      DO 1060 J=1,NARC
1060  FLOW(J)=FLOWJT(J)
      DO 1070 J=1,NODES
      FARC(J)=FARCJT(J)
      RARC(J)=RARCJT(J)
1070  BARC(J)=BARCJT(J)
      DO 1080 J=1,NRES
1080  ISTEFF(J)=ISTEJT(J)
      POWONP=POWONT
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C*********************************************************************
C                   CHECK IF STEP SIZE IS BELOW SMALLEST ALLOWABLE LENGTH
C*********************************************************************
      IF (ADJF.LT..01) GO TO 1090
      GO TO 560
1090  CONTINUE
C*********************************************************************
C                   CHECK IF FIRM POWER GENERATION TARGET HAS
C                   BEEN MET. IF SO, EXIT SUBROUTINE.
C*********************************************************************
      IF (PKNET) 1100,1140,1140
1100  CONTINUE
C*********************************************************************
C                   CHECK IF ADJUSTED TARGET RESERVOIR STORAGE UNIT
C                   BENEFIT FOR ALL RESERVOIRS OPERATING UNDER OPTION 3
C                   IS LESS THAN 1. IF SO, EXIT SUBROUTINE.
C                   OTHERWISE, REDUCE TARGET STORAGE UNIT BENEFIT
C                   BY $1/AC-FT FOR ALL RESERVOIRS OPERATED UNDER
C                   OPERATING RULE OPTION 3.
C*********************************************************************
      ICT=0
      DO 1130 J=1,NRES
      IF (IOPT(J).NE.3) GO TO 1130
      IF (TCSTI(J)+1.) 1130,1110,1110
1110  ICT=1
      A=ARMIN+J
      TCSTI(J)=TCSTI(J)+1.
      DO 1120 KL=1,3
      IF (COST(A).GT.+1.) GO TO 1120
      COST(A)=COST(A)+1.
      IF(KL.EQ.1)RCOST1(J)=RCOST1(J)+1.
      IF(KL.EQ.2)RCOST2(J)=RCOST2(J)+1.
      IF(KL.EQ.3)RCOST3(J)=RCOST3(J)+1.
      A=A+NRES
1120  CONTINUE
1130  CONTINUE
      IF (ICT.EQ.0) GO TO 1140
      ADJF=.2
      IF(KAPE1.GT.0)ADJF=.1
      GO TO 560
C*********************************************************************
C                   GRADIENT PROCEDURE HAS TERMINATED.
C*********************************************************************
1140  CONTINUE
      RETURN
C
1150  FORMAT (//10X,16HFATAL ERROR ----//10X,35HCURRENT VALUE OF POWER G
     1ENERATION (,F8.0,14H) IN KILOWATTS/10X,34HEXCEEDS THE MAXIMUM VALU
     2E IN TABLE/10X,14HFOR RESERVOIR ,I3,1H.,5X,21HEXECUTION TERMINATED
     3.)
1160  FORMAT (//1X,50HTHE COMPUTATION OF DERIVATIVES IN SUBROUTINE HYDRO
     1,/1X,53HINDICATES THAT THE EFFICIENCY-POWER GENERATION TABLE ,/1X,
     230HMAY BE IN ERROR FOR RESERVOIR ,I2,2H .,/1X,53HTHE RATE OF CHANG
     3E OF EFFICIENCY FOR POWER GENERATION,/1X,16HIN THE RANGE OF ,F8.0,
     425H KILOWATTS IS TOO LARGE. ,/1X,56HTHE RATE OF CHANGE OF EFFICIEN
     5CY IS ADJUSTED TEMPORARILY,/1X,56HTO WITHIN REALISTIC RANGE TO ENA
     6BLE PROGRAM TO CONTINUE.)
1170  FORMAT (//10X,13HERROR --- ARC,I3,22H WAS CHANGED IN BASIS,/20X,5H
     1FLOW-,E15.5,5H HI= ,E15.5,5H LO= ,E15.5)
      END
```

```
      SUBROUTINE INPUT
C*********************************************************************
C                   THIS SUBROUTINE READS ALL THE SYSTEM DATA,THE
C                   COST DATA, AND THE FIXED MONTHLY COEFFICIENTS.
C*********************************************************************
      COMMON /ADATA/ NF(1000),NT(1000),COST( 500),AMP( 500),FLOW( 500),H
     1I( 500),LOWER( 500),ARCS
      COMMON /CDATA/ PERINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC,POWFA
     1C(12)
      COMMON /HYDRO/ IEFF(50,20,2),LHYDRO(75),HLOAD(50),ITELEV(50,20,2)
     1              ,ECTAB(50,20,2),IMAXD(50,20,2),HPOWF(12),
     2               ONPKC,OFPKC,IHRSP(12),IHRSO(12),NOWN(50)
      COMMON /JDATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
     1INK(50),FSTART(50),DLO(50),RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CCAP(75),CPUMP(75),CMIN(7
     15),CLIFT(75),EL(75),LNODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /HDATA/ XX(12),ELF(12),XIMP,NSPILL
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /PRT/ IPRNT(50),TITLE(10)
      COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /SHORTS/ BND(50),CST(12,50),ACO(50,2),TFAC(12,50),TCST(50),
     1IOPT(50),NKEY(50),RKEY(50,5,12),NRKEY(50,5)
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      INTEGER SCAP,ARCS,ECTAB,SOURCE,SINK
      INTEGER RMAXC,RMINC,CMAXC,CMINC
      REAL LOWER,MAXTOL
C*********************************************************************
C                   SET PROBLEM CONSTANTS
C*********************************************************************
      DO 20 J=1,NRES
      JBLT(J)=-999999
      FSTART(J)=-999999
20    CONTINUE
      DO 30 L=1,NL
      LBLT(L)=-999999
30    CONTINUE
      DO 40 J=1,NJ
      DO 40 M=1,NSEAS
40    CST(M,J)=-999999.
      KEY=0
      ERROR=0.
      BIG=1.E5
      EPS=.000101
      TIME=.000101
      IPRINT=-1
      SOURCE=1
      SINK=6
      OUTFLO=199999.
      INCRD=5
      IPAGE=6
      KOUT=6
      KIN=5
C*********************************************************************
C                   READ SYSTEM DATA
C                   - INPUT FILE A
C*********************************************************************
      READ (KIN,1100) (TITLE(I),I=1,10)
      READ (5,1110) NJ,NRES,NJUNC,NL,NC,NR,NYEAR,NSEAS,IDATE,IMP,ND,KAPE
     11,KAPE2
      IF (NJ.GT.50.OR.NJ.LT.1.OR.NRES.GT.50.OR.NRES.LT.0.OR.NJUNC.GT.50.
     1OR.NJUNC.LT.0.OR.NL.GT.75.OR.NL.LT.0.OR.NC.GT.75.OR.NC.LT.0.OR.NR.
     2GT.75.OR.NR.LT.0.OR.NSEAS.GT.12.OR.NSEAS.LT.1.OR.NYEAR.GT.50.OR.NY
     3EAR.LT.1) GO TO 70
      IF (ND.GT.50.OR.ND.LT.0.OR.ND.GT.NJ) GO TO 50
      GO TO 60
50    WRITE (KOUT,1120)
      ERROR=1.
      GO TO 80
60    CONTINUE
```

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      IF (KAPE1.EQ.KAPE2.AND.KAPE1.NE.0) GO TO 70
      GO TO 80
70    WRITE (KOUT,1130)
      ERROR=1.
80    IF (NJ.NE.(NRES+NJUNC).OR.NL.NE.(NC+NR)) GO TO 90
      GO TO 100
90    WRITE (KOUT,1140)
      ERROR=1.
C*********************************************************************
C                   READ NODE DATA
C                   - INPUT FILE B
C*********************************************************************
100   CONTINUE
      DO 120 M=1,NJ
      READ (5,1160) J,(RNAME(J,K),K=1,2),RCAP(J),RMIN(J),CRES(J),NDWN(J)
     1,RETSW(J),NLINK(J),DLO(J),BNO(J),MLOAD(J),ACO(J,1),ACO(J,2)
      IF (J.LT.1.OR.J.GT.NJ) GO TO 110
      GO TO 120
110   WRITE (6,1150)
      ERROR=1.
120   CONTINUE
      DO 140 J=1,NJ
      IF (RETSW(J).LE.0..AND.NLINK(J).GT.0) GO TO 130
      IF (DLO(J).GT.1..OR.DLO(J).LT.0.) GO TO 130
      GO TO 140
130   WRITE (KOUT,1170) J
      ERROR=1.
140   CONTINUE
C*********************************************************************
C                   READ LINK DATA (CANAL OR RIVER)
C                   - INPUT FILE C
C*********************************************************************
      DO 160 M=1,NL
      READ (5,1180) L,(CNAME(L,K),K=1,2),CCAP(L),CMIN(L),CLIFT(L),EL(L),
     1LHYDRO(L),(LNODE(L,K),K=1,2)
      IF (L.LT.1.OR.L.GT.NL) GO TO 150
      GO TO 160
150   WRITE (6,1190)
      ERROR=1.
160   CONTINUE
      DO 180 M=1,NL
      IF (EL(M).LT.0..OR.EL(M).GT.1..OR.LNODE(M,1).GT.NJ.OR.LNODE(M,2).G
     1T.NJ.OR.CCAP(M).LT.CMIN(M)) GO TO 170
      GO TO 180
170   WRITE (KOUT,1200) M
      ERROR=1.
180   CONTINUE
C*********************************************************************
C                   READ LINK COST DATA
C                   - INPUT FILE D
C*********************************************************************
      DO 200 M=1,NL
      READ (5,1210) L,((CLINK(I,L,K),K=1,3),I=1,2)
      IF (L.LT.1.OR.L.GT.NL) GO TO 190
      GO TO 200
190   WRITE (6,1220)
200   CONTINUE
C*********************************************************************
C                   READ ECONOMIC DATA
C                   - INPUT FILE E
C*********************************************************************
      READ (5,1230) PERINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC
C*********************************************************************
C                   READ POWER FACTOR COEFFS
C                   - INPUT FILE F
C*********************************************************************
      READ (5,1240) (POWFAC(I),I=1,NSEAS)
C*********************************************************************
C                   READ SEASONAL IMPORT COEFFS
C                   - INPUT FILE G
C*********************************************************************
      READ (5,1250) XIMP,(XX(I),I=1,NSEAS)
C*********************************************************************
C                   READ SEASONAL CHANNEL LOSS ADJUSTMENT
C                   FACTORS
C                   - INPUT FILE H
C*********************************************************************
      READ (5,1240) (ELF(I),I=1,NSEAS)
C*********************************************************************
C                   READ SEASONAL RESERVOIR MAXIMUM AND
C                   MINIMUM STORAGE FACTORS
C                   - INPUT FILE I
C*********************************************************************
      DO 220 K=1,NRES
      READ (5,1110) I,(PMAXC(I,M),M=1,NSEAS)
      IF (I.GT.NRES.OR.I.LT.1) GO TO 210
      GO TO 220
210   WRITE (KOUT,1260)
      ERROR=1.
220   CONTINUE
      DO 240 K=1,NRES
      READ (5,1110) I,(RMINC(I,M),M=1,NSEAS)
      IF (I.GT.NRES.OR.I.LT.1) GO TO 230
      GO TO 240
230   WRITE (KOUT,1260)
      ERROR=1.
240   CONTINUE
C*********************************************************************
C                   READ SEASONAL LINK FLOW MAXIMUM AND
C                   MINIMUM FLOW RATE FACTORS
C                   - INPUT FILE J
C*********************************************************************
      DO 260 K=1,NL
      READ (5,1110) I,(CMAXC(I,M),M=1,NSEAS)
      IF (I.LT.1.OR.I.GT.NL) GO TO 250
      GO TO 260
250   WRITE (KOUT,1270)
      ERROR=1.
260   CONTINUE
      DO 280 K=1,NL
      READ (5,1110) I,(CMINC(I,M),M=1,NSEAS)
      IF (I.LT.1.OR.I.GT.NL) GO TO 270
      GO TO 280
270   WRITE (KOUT,1270)
      ERROR=1.
280   CONTINUE
C*********************************************************************
C                   READ ANNUAL OUTPUT CONTROL OPTIONS
C                   - INPUT FILE K
C*********************************************************************
      READ (5,1280) IPRNT
C*********************************************************************
C                   READ NUMBER AND LOCATION OF WATER DEMAND NODES
C                   - INPUT FILE L
C*********************************************************************
      IF (ND.EQ.0) GO TO 290
      READ (KIN,1290) (JD(I),I=1,13)
      IF (ND.GT.13) READ (KIN,1290) (JD(I),I=14,26)
      IF (ND.GT.26) READ (KIN,1290) (JD(I),I=27,39)
      IF (ND.GT.39) READ (KIN,1290) (JD(I),I=40,50)
C*********************************************************************
C                   READ SPILL COST AND MAXIMUM SPILL RATES
C                   - INPUT FILE M
C*********************************************************************
290   READ (KIN,1300) SCAP,KSPILL,NSPNOS
      NS=NSPNOS
      IF(NS.LT.0)NS=0
      IF (NSPNOS.LE.10.AND.NSPNOS.LE.NJ) GO TO 300
      ERROR=1.0
      WRITE (IPAGE,1310)
300   CONTINUE
C*********************************************************************
C                   READ NODE NUMBERS OF NODES THAT CAN SPILL
C                   - INPUT FILE N
C*********************************************************************
```

```
      IF (NS.EQ.0) GO TO 310
      READ (KIN,1320) (JS(I),I=1,NS)
C************************************************************************
C                     READ THE YEARS THAT RESERVOIRS WERE BUILT
C                     - INPUT FILE O
C************************************************************************
310   NRS4=NRES
320   NLOOP=MIN0(4,NRS4)
      READ (KIN,1340) (I,JBLT(I),J=1,NLOOP)
      NRS4=NRS4-4
      IF (NRS4) 330,330,320
330   CONTINUE
      DO 350 I=1,NRES
      IF (JBLT(I)+999999) 340,340,350
340   WRITE (6,1330) I
      ERROR=1.
350   CONTINUE
C************************************************************************
C                     READ THE YEARS THAT CANALS WERE BUILT
C                     - INPUT FILE P
C************************************************************************
      NRS4=NL
360   NLOOP=MIN0(4,NRS4)
      READ (KIN,1340) (I,LBLT(I),J=1,NLOOP)
      NRS4=NRS4-4
      IF (NRS4) 370,370,360
370   CONTINUE
      DO 390 I=1,NL
      IF (LBLT(I)+999999) 380,380,390
380   WRITE (6,1350) I
      ERROR=1.
390   CONTINUE
C************************************************************************
C                     READ THE INITIAL RESERVOIR STORAGE CONTENTS
C                     AS A PERCENTAGE OF MAXIMUM STORAGE VOLUME
C                     - INPUT FILE Q
C************************************************************************
      NRS4=NRES
400   NLOOP=MIN0(4,NRS4)
      READ (KIN,1360) (I,FSTART(I),J=1,NLOOP)
      NRS4=NRS4-4
      IF (NRS4) 410,410,400
410   CONTINUE
      DO 430 I=1,NRES
      IF (FSTART(I)+999999) 420,420,430
420   CONTINUE
      WRITE (6,1370) I
      ERROR=1.
430   CONTINUE
C************************************************************************
C                     READ RESERVOIR OPERATING RULES AND OPTIONS
C                     - INPUT FILE R
C************************************************************************
      READ (KIN,1380) (J,ICPT(J),TCST(J),(TFAC(I,J),I=1,12),NKEY(J),K=1,
     1NRES)
      DO 465 J=1,NRES
      IF (NKEY(J).LE.0) GO TO 465
      NRK=NKEY(J)
      IF (NRK) 450,465,440
440   IF (NRK-4) 460,460,450
450   WRITE (KOUT,1390) J
      ERROR=1.
460   READ (KIN,1400) (NRKEY(J,L),L=1,NRK)
465   CONTINUE
      DO 500 J=1,NRES
      NRK=NKEY(J)
      IF(NRK.LE.0) GO TO 500
      NRL=NRK+1
      DO 470 I=1,NSEAS
      READ (KIN,1410) (RKEY(J,L,I),L=1,NRL)
470   CONTINUE
500   CONTINUE
C************************************************************************
C                     READ SHORTAGE COSTS
C                     - INPUT FILE S
C************************************************************************
      NCRDS=NSEAS/4
      IF(4*NCRDS.LT.NSEAS)NCRDS=NCRDS+1
      DO 530 K=1,NJ
      NST=1
      NSTP=4
      DO 530 L=1,NCRDS
      READ (KIN,1430) J,(I,CST(I,J),M=NST,NSTP)
      IF (J.LT.1.OR.J.GT.NJ) GO TO 510
      GO TO 520
510   WRITE (KOUT,1420) J
      ERROR=1.
520   NST=NST+4
      NSTP=NSTP+4
530   CONTINUE
      DO 550 J=1,NJ
      DO 550 I=1,NSEAS
      IF (CST(I,J)+999999) 540,540,550
540   WRITE (6,1440) J,I
      ERROR=1.
550   CONTINUE
C************************************************************************
C                     CHECK IF HYDROPOWER ANALYSIS IS NEEDED
C************************************************************************
      DO 560 J=1,NL
      IF (LHYDRO(J).EQ.1) GO TO 570
560   CONTINUE
      ONPKC=0.
      KEY=1
      GO TO 670
570   CONTINUE
C************************************************************************
C                     READ TARGET POWER GENERATION FROM SYSTEM AND
C                     UNIT BENEFIT PER KW-HR FOR POWER GENERATED ABOVE
C                     AND BELOW THE TARGET
C                     - INPUT FILE T
C************************************************************************
      READ (KIN,1450) ANNPOW,(HPOWF(I),I=1,12),ONPKC,OFPKC
C************************************************************************
C                     READ NUMBER OF ON-PEAK AND OFF-PEAK HOURS
C                     IN EACH SEASON FOR HYDROELECTRIC POWER GENERATION
C                     - INPUT FILE U
C************************************************************************
      READ (KIN,1460) (IHRSP(I),I=1,NSEAS)
      READ (KIN,1460) (IHRSO(I),I=1,NSEAS)
C************************************************************************
C                     READ TABLES SPECIFYING RESERVOIR WATER SURFACE
C                     ELEVATION AS A FUNCTION OF RESERVOIR WATER STORAGE
C                     - INPUT FILE V
C************************************************************************
      DO 590 I=1,NRES
      READ (KIN,1470) J,((ECTAB(J,K,L),L=1,2),K=1,18)
      IF (J.LT.1.OR.J.GT.NRES) GO TO 580
      GO TO 590
580   WRITE (6,1490) J
      ERROR=1.
590   CONTINUE
C************************************************************************
C                     READ TABLES GIVING ELECTRICITY GENERATION EFFICIENCY
C                     AS A FUNCTION OF THE ELECTRICITY GENERATED
C                     - INPUT FILE W
C************************************************************************
      DO 620 I=1,NRES
      READ (KIN,1470) J,((EFF(J,K,L),L=1,2),K=1,18)
      IF (J.LT.1.OR.J.GT.NRES) GO TO 600
      GO TO 610
600   WRITE (6,1490) J
      ERROR=1.
610   IF (MLOAD(J).LE.0) GO TO 620
```

```
      IF (IEFF(J,1,1).GT.0) GO TO 620
      PRINT 1480, I
      IEFF(J,1,1)=-1
620   CONTINUE
C*************************************************************************
C                  READ TABLES GIVING TAILRACE WATER SURFACE ELEVATION
C                  AS A FUNCTION OF THE FLOW DISCHARGE RATE
C                  -  INPUT FILE X
C*************************************************************************
      DO 640 I=1,NRES
      READ (KIN,1470) J,(((TELEV(J,K,L),L=1,2),K=1,18)
      IF (J.LT.1.OR.J.GT.NRES) GO TO 630
      GO TO 640
630   WRITE (6,1490) J
      ERROR=1.
640   CONTINUE
C*************************************************************************
C                  READ TABLES GIVING MAXIMUM FLOW DISCHARGE RATE
C                  THROUGH POWER PLANT TURBINES
C                  AS A FUNCTION OF RESERVOIR WATER STORAGE
C                  -  INPUT FILE Y
C*************************************************************************
      DO 660 I=1,NRES
      READ (KIN,1470) J,((IMAXD(J,K,L),L=1,2),K=1,18)
      IF (J.LT.1.OR.J.GT.NRES) GO TO 650
      GO TO 660
650   WRITE (6,1490) J
      ERROR=1.
660   CONTINUE
C*************************************************************************
C                  PRINT THE DETAILS OF HOW THE
C                  PROBLEM IS BEING APPROACHED
C*************************************************************************
670   WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (6,1500)
      WRITE (6,1510) NJ,NRES,NJUNC,IMP,NS,(JS(K),K=1,NS)
      WRITE (6,1520) ND,(JD(K),K=1,ND)
      WRITE (6,1530) NL,NR,NC
      WRITE (6,1540) NYEAR,NREAD,NSEAS,IDATE,KAPE1,KAPE2
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1550)
      WRITE (KOUT,1560)
      DO 680 J=1,NJ
      CRES(J)=CRES(J)*1000.
      IF(J.GT.NRES)JBLT(J)=0
      WRITE (KOUT,1570) J,(RNAME(J,K),K=1,2),RCAP(J),RMIN(J),CRES(J),NLI
     1NK(J),RETSW(J),DLO(J),BND(J),ACO(J,1),ACO(J,2),JBLT(J),MLOAD(J)
680   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1580) (I,I=1,NSEAS)
      DO 710 I=1,NRES
      WRITE (KOUT,1590) I,(RMAXC(I,M),M=1,NSEAS)
      WRITE (KOUT,1600) (RMINC(I,M),M=1,NSEAS)
      DO 700 M=1,NSEAS
      XMAX=RMAXC(I,M)*RCAP(I)/100.
      XMIN=RMINC(I,M)*RMIN(I)/100.
      IF (BND(I).GE.XMIN) GO TO 690
      WRITE (KOUT,1610) I,M
      ERROR=1.
690   IF (XMAX.GE.XMIN) GO TO 700
      WRITE (KOUT,1620) I,M
      ERROR=1.
700   CONTINUE
710   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1630)
      WRITE (KOUT,1640)
      DO 720 L=1,NL
      WRITE (KOUT,1650) L,(CNAME(L,K),K=1,2),(LNODE(L,K),K=1,2),CCAP(L),
     1CMIN(L),CLIFT(L),EL(L),LBLT(L),LHYDRO(L)
720   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1660) (I,I=1,NSEAS)
      DO 730 I=1,NL
      WRITE (KOUT,1670) I,(CMAXC(I,M),M=1,NSEAS)
      WRITE (KOUT,1680) (CMINC(I,M),M=1,NSEAS)
730   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (6,1080)
      WRITE (6,1690)
      DO 740 L=1,NL
740   WRITE (6,1700) L,((CLINK(I,L,K),K=1,3),I=1,2)
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1710) PERINT,NPAY,POWR,RESONM
      WRITE (KOUT,1720) CONONM,CIMP,LAGR,LAGE
      WRITE (KOUT,1730) ONPKC,OFPKC
      IF (KEY) 750,750,770
750   IF (ONPKC-OFPKC) 760,760,770
760   ERROR=1.
      WRITE (KOUT,1740)
770   CONTINUE
      WRITE (KOUT,1750) (I,I=1,NSEAS)
      DO 780 I=1,NSEAS
780   HPOWF(I)=ANNPOW*HPOWF(I)
      WRITE (KOUT,1760) ANNPOW,(HPOWF(I),I=1,NSEAS)
      WRITE (KOUT,1770) (IHRSP(I),I=1,NSEAS)
      WRITE (KOUT,1780) (IHRSO(I),I=1,NSEAS)
      WRITE (KOUT,1790) (POWFAC(I),I=1,NSEAS)
      WRITE (6,1800) (XX(I),I=1,NSEAS)
      WRITE (6,1810) (ELF(I),I=1,NSEAS)
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1820) (J,J=1,12)
      DO 790 J=1,NJ
      WRITE (KOUT,1830) J,(CST(I,J),I=1,NSEAS)
790   CONTINUE
      DO 810 J=1,NJ
      IF (CST(1,J)-BIG) 810,800,800
800   WRITE (KOUT,1840) J,1,BIG
      ERROR=1.
810   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1850)
      WRITE (KOUT,1860) (J,(RNAME(J,K),K=1,2),FSTART(J),[illegible])
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1080)
      WRITE (KOUT,1870) (J,J=1,NSEAS)
      DO 820 J=1,NRES
      WRITE (KOUT,1930) J,IOPT(J),TCST(J),(TFAC(I,J),I=1,12),NKEY(J)
820   CONTINUE
      JFF=1
      DO 840 J=1,NRES
      IF (IOPT(J).NE.3) GO TO 840
      NNX=NKEY(J)
      IF (NNX.EQ.0) GO TO 840
      IF (JFF.EQ.1) WRITE (KOUT,1880) (JG,JG=1,4)
      JFF=2
      WRITE (KOUT,1910) J,(NRKEY(J,L),L=1,NNX)
      WRITE (KOUT,1890)
      NNX=NNX+1
      DO 830 IS=1,NSEAS
      WRITE (KOUT,1900) IS,(RKEY(J,L,IS),L=1,NNX)
830   CONTINUE
840   CONTINUE
      DO 860 J=1,NRES
      IF (TCST(J)-BIG) 860,850,850
850   WRITE (KOUT,1920) J,BIG
      ERROR=1.
860   CONTINUE
```

```
      IF (ONPHC) 1050,1050,870
870   WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1940)
      K=0
      N2=0
880   K=K+1
      N1=N2+1
      N2=K*6
      IF(N1.GT.NRES)N1=0
      IF(N2.GT.NRES)N2=NRES
      IF (N1.EQ.0) GO TO 910
      IF (K.LE.1) GO TO 890
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1940)
890   CONTINUE
      WRITE (KOUT,1950) (KRS,KRS=N1,N2)
      WRITE (KOUT,1960)
      DO 900 NPT=1,18
900   WRITE (KOUT,1970) NPT,((ECTAR(JN,NPT,KK),KK=1,2),JN=N1,N2)
      GO TO 880
910   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1980)
      K=0
      N2=0
920   K=K+1
      N1=N2+1
      N2=K*6
      IF(N1.GT.NRES)N1=0
      IF(N2.GT.NRES)N2=NRES
      IF (N1.EQ.0) GO TO 950
      IF (K.LE.1) GO TO 930
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,1980)
930   CONTINUE
      WRITE (KOUT,1950) (KRS,KRS=N1,N2)
      WRITE (KOUT,1990)
      DO 940 NPT=1,18
940   WRITE (KOUT,1970) NPT,((TEFF(JN,NPT,KK),KK=1,2),JN=N1,N2)
      GO TO 920
950   CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,2000)
      K=0
      N2=0
960   K=K+1
      N1=N2+1
      N2=K*6
      IF(N1.GT.NRES)N1=0
      IF(N2.GT.NRES)N2=NRES
      IF (N1.EQ.0) GO TO 990
      IF (K.LE.1) GO TO 970
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,2000)
970   CONTINUE
      WRITE (KOUT,1950) (KRS,KRS=N1,N2)
      WRITE (KOUT,2010)
      DO 980 NPT=1,18
980   WRITE (KOUT,1970) NPT,((TELEV(JN,NPT,KK),KK=1,2),JN=N1,N2)
      GO TO 960
990   CONTINUE
      DO 1010 NPT=1,NRES
      NND=NDWN(NPT)
      IF (NND.LT.1) GO TO 1010
1000  WRITE (KOUT,2020) NPT,NND
      IF (NND.LE.NRES) GO TO 1010
      ERROR=1.
      WRITE (KOUT,2030)
1010  CONTINUE
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,2040)
      K=0
      N2=0
1020  K=K+1
      N1=N2+1
      N2=K*6
      IF(N1.GT.NRES)N1=0
      IF(N2.GT.NRES)N2=NRES
      IF (N1.EQ.0) GO TO 1050
      IF (K.LE.1) GO TO 1030
      WRITE (KOUT,1090) (TITLE(JQ),JQ=1,10)
      WRITE (KOUT,2040)
1030  CONTINUE
      WRITE (KOUT,1950) (KRS,KRS=N1,N2)
      WRITE (KOUT,2050)
      DO 1040 NPT=1,18
1040  WRITE (KOUT,1970) NPT,((IMAXD(JN,NPT,KK),KK=1,2),JN=N1,N2)
      GO TO 1020
1050  CONTINUE
      IF (ERROR) 1070,1070,1060
1060  WRITE (IPAGE,2060)
      STOP
1070  CONTINUE
      IF (KAPE1.GT.0) REWIND KAPE1
      IF (KAPE2.GT.0) REWIND KAPE2
      RETURN
C
1080  FORMAT (/125(1H*)/)
1090  FORMAT (1H1,125(1H*)//45X,35HTEXAS DEPARTMENT OF WATER RESOURCES/3
     17X,51H MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL    /55X,15H
     2  SIM - V       //35X,10A6//125(1H*)/)
1100  FORMAT (10A6)
1110  FORMAT (10X,14I5)
1120  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,52HNUMBER OF DEMAN
     1D NODES EXCEEDS NUMBER OF JUNCTIONS  /20X,52HOR IS LESS THAN ZERO.
     2  ERROR IN INPUT FILE A.          )
1130  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,57HONE OR MORE OF
     1THE VARIABLES IN INPUT FILE A EXCEED THEIR/20X,56HALLOWABLE RANGES
     2.  CONSULT PROGRAM DOCUMENTATION MANUAL.)
1140  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,58HTHE NUMBER OF J
     1UNCTIONS AND REACHES DO NOT TOTAL CORRECTLY/20X,34HBASED UPON INPU
     2T DATA FROM FILE A.)
1150  FORMAT (//40(1H*)//20X,33HNODE NUMBER IS EITHER LESS THAN 1/20X,50
     1HOR GREATER THAN THE NUMBER OF NODES IN THE SYSTEM./20X,21HERROR I
     2N DATA FILE B.)
1160  FORMAT (I2,2A4,2F10.0,F5.2,I5,F5.2,I5,F5.0,F10.0,I5,2F5.4)
1170  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,51HONE OR MORE VAR
     1IABLES IN INPUT FILE B EXCEED THEIR /20X,29HALLOWABLE RANGES FOR J
     2UNCTION,I3,1H./20X,29HCONSULT DOCUMENTATION MANUAL.)
1180  FORMAT (I2,2A4,3F10.0,F10.3,I5,15X,2I5)
1190  FORMAT (//40(1H*)//20X,33HLINK NUMBER IS EITHER LESS THAN 1/20X,50
     1HOR GREATER THAN THE NUMBER OF LINKS IN THE SYSTEM./20X,21HERROR I
     2N DATA FILE C.)
1200  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,51HONE OR MORE VAR
     1IABLES IN INPUT FILE C EXCEED THEIR /20X,25HALLOWABLE RANGES FOR L
     2INK,I3,1H./20X,29HCONSULT DOCUMENTATION MANUAL.)
1210  FORMAT (I2,8X,6E10.4)
1220  FORMAT (//40(1H*)//20X,33HLINK NUMBER IS EITHER LESS THAN 1/20X,50
     1HOR GREATER THAN THE NUMBER OF LINKS IN THE SYSTEM./20X,21HERROR I
     2N DATA FILE D.)
1230  FORMAT (10X,F10.4,I10,4F10.4,2I5)
1240  FORMAT (10X,12F5.3)
1250  FORMAT (10X,F5.0,12F5.3)
1260  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,61HSTORAGE LIMITS
     1WERE READ FOR A NON-STORAGE JUNCTION IN FILE I)
1270  FORMAT (///10X,25HINPUT DATA ERROR ---------/20X,55HFLOW LIMITS WER
     1E READ FOR A NONEXISTANT LINK IN FILE J.)
1280  FORMAT (14X,50I1)
1290  FORMAT (10X,14I5)
1300  FORMAT (10X,31I0)
1310  FORMAT (1X,48HERROR---NUMBER OF SPILL NODES EXCESSIVE ---ERROR)
1320  FORMAT (10X,5(8X,I2))
1330  FORMAT (//20X,10(1H*)/20X,26HINPUT DATA ERROR IN FILE O/20X,38HCON
     1STRUCTION YEAR FOR RESERVOIR NUMBER,I4/20X,44HIS INCORRECTLY SPECI
     2FIED.  CHECK DATA INPUT.)
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1340  FORMAT (10X,4(8X,I2,I5))
1350  FORMAT (//20X,10(1H*)/20X,26HINPUT DATA ERROR IN FILE P/20X,33HCON
     1STRUCTION YEAR FOR LINK NUMBER,I4/20X,44HIS INCORRECTLY SPECIFIED.
     2  CHECK DATA INPUT.)
1360  FORMAT (10X,4(8X,I2,F5.0))
1370  FORMAT (//20X,10(1H*)/20X,26HINPUT DATA ERROR IN FILE Q/20X,36HPER
     1CENTAGE FULL FOR RESERVOIR NUMBER,I4/20X,44HIS INCORRECTLY SPECIFI
     2ED.  CHECK DATA INPUT.)
1380  FORMAT (13X,I2,3X,I2,F5.0,12F4.2,I3)
1390  FORMAT (//20X,10(1H*)/20X,26HINPUT DATA ERROR IN FILE R/20X,38HNUM
     1BER OF KEY RESERVOIRS FOR RESERVOIR,I4
     2                              /20X,      47HIS GREATER THAN 4.  CHECK INPUT
     3 DATA.            )
1400  FORMAT (10X,10I5)
1410  FORMAT (10X,10F5.2)
1420  FORMAT (///10X,25HINPUT DATA ERROR --------/20X,51HSHORTAGE COSTS
     1WERE READ FOR A NONEXISTANT JUNCTION,I4/20X,17HIN INPUT FILE S. )
1430  FORMAT (18X,I2,4(I5,F8.2,2X))
1440  FORMAT (//20X,10(1H*)/20X,26HINPUT DATA ERROR IN FILE S/20X,34HSHO
     1RTAGE COST FOR RESERVOIR NUMBER,I4,10H IN SEASON,I4/20X,44HIS INCO
     2RRECTLY SPECIFIED.  CHECK DATA INPUT.)
1450  FORMAT (5X,15F5.3)
1460  FORMAT (10X,12I5)
1470  FORMAT (10X,I5,6I10/(15X,6I10))
1480  FORMAT (///1X,14(1H*),14H  USER WARNING,2X,20(1H*)//5X,49HIT IS RE
     1QUIRED THAT THE EFFICIENCY FOR ZERO POWER/5X,56HPRODUCTION BE SET
     2TO A SMALL POSITIVE VALUE (SUCH AS 1).//5X,45HEFFICIENCY HAS BEEN
     3RESET TO 1 FOR RESERVOIR ,I3,1H.)
1490  FORMAT (///80(1H*)//10X,39HA RESERVOIR NUMBER ON ONE OF INPUT DATA
     1/10X,51HFILES V THROUGH Y HAS A VALUE EITHER LESS THAN 1 OR/10X,55
     2HOR GREATER THAN THE NUMBER OF RESERVOIRS IN THE SYSTEM./10X,29HTH
     3E RESERVOIR NUMBER READ IS ,I4,1H.)
1500  FORMAT (37X,30H DETAILS OF THE PROBLEM ARE AS FOLLOWS)
1510  FORMAT (1H0,37X,13H 1) THERE ARE,I3,20H JUNCTIONS, OF THESE//37X,1
     16H    A) THE FIRST,I3,15H ARE RESERVOIRS/37X,16H    B) THE LAST ,I
     23,19H ARE LINK JUNCTIONS/37X,36H    C) IMPORTED WATER ENTERS AT NO
     3DE,I3/37X,42H    D) SPILLS FROM THE SYSTEM CAN OCCUR AT,I2/37X,29H
     4         NODES, THESE ARE NODES/(50X,10I4))
1520  FORMAT (37X,57H    D) WATER SUPPLY DEMANDS FROM THE SYSTEM CAN OCC
     1UR AT ,I2/37X,29H         NODES, THESE ARE NODES/(50X,10I4))
1530  FORMAT (1H0,37X,13H 2) THERE ARE,I3,15H LINKS,OF THESE//37X,16H
     1 A) THE FIRST,I3,18H ARE RIVER REACHES/37X,16H    B) THE LAST ,I3,
     216H ARE PUMP-CANALS)
1540  FORMAT (1H0,37X,13H 3) THERE ARE,I3,21H YEARS IN THE PROBLEM/37X,2
     14H    A) THE FIRST YEAR IS,I3/37X,20H    B) EACH YEAR HAS,I3,8H SE
     2ASONS/37X,55H    C) CALENDAR YEAR OF STARTING YEAR OF SIMULATION I
     3S ,I4,///42X,47HLOGICAL UNIT FOR INITIAL SOLUTION FILE KAPE1 IS,I3
     4//42X,47HLOGICAL UNIT FOR STORING SOLUTION FILE KAPE2 IS,I3)
1550  FORMAT (34X,39HNODE DATA, EITHER RESERVOIR OR JUNCTION//125(1H*)//
     1/4X,16HNODE  RES OR JNC,5X,6HRESEVR,4X,6HRESEVR,3X,6HRESEVR,2X,6HR
     2ETURN,2X,6HRETURN,3X,3HMIN,2X,5HBRKPT,4X,5HLOWER,4X,5HUPPER,3X,10H
     3SIMULATION,2X,13HMAXIMUM POWER)
1560  FORMAT (5X,3HNO.,5X,4HNAME,9X,3HMAX,7X,3HMIN,7X,4HCOST,
     1  4X ,4HFLOW,4X,4HFLOW,3X,3HDMD,2X,7HSTORAGE,2X,7HSTORAGE,2X,7
     2HSTORAGE,2X,      8HYEAR RES,5X,10HGENERATION  /
     3                    25X,6H1000AF,4X,6H1000AF,3X,5H1000$,5X,4HNODE,
     4 4X,4H S/W,3X,3HFCT,2X,6H1000AF,3X,5HSLOPE,4X,5HSLOPE ,5X,    5HRUL
     5LT,6X,11H(MEGAWATTS)  /)
1570  FORMAT (3X,I5,3X,2A4,2X,F9.1,1X,F9.1,1X,F9.1,4X,I3,4X,F4.2,2X,F5.2
     1,F8.1,2F9.4,I8,I14)
1580  FORMAT (18X,49HSEASONAL MAXIMUM AND MINIMUM ALLOWABLE RESERVOIR ,9
     1HSTORAGE, ,43HAS PERCENTAGES OF MAX. AND MIN. CAPACITIES //1X,125(
     21H*)//5X,9HRESERVOIR,55X,6HSEASON/6X,6HNUMBER,16X,12I7/32X,84(1H*)
     3/)
1590  FORMAT (/5X,I5,5X,7HMAXIMUM,7X,12I7)
1600  FORMAT (15X,7HMINIMUM,7X,12I7)
1610  FORMAT (///10X,26HINPUT DATA ERROR -------- /20X,58HBREAKPOINT(BRK
     1PT) STORAGE MUST BE GREATER THAN OR EQUAL TO/20X,44HMINIMUM RESERV
     2OIR STORAGE, BUT IT IS NOT FOR/20X,9HRESERVOIR,I3,10H IN SEASON,I3
     3,1H.)
1620  FORMAT (///10X,26HINPUT DATA ERROR -------- /20X,55HMINIMUM RESERV
     1OIR STORAGE LEVEL EXCEEDS MAXIMUM STORAGE/20X,19HLEVEL FOR RESERVO
     2IR,I3,10H IN SEASON,I3,1H.)
1630  FORMAT (43X,24HLINK DATA CANAL OR RIVER//125(1H*)///,10X,15HLINK
     1LINK NAME,3X,77HORIGIN   TERMINAL    MAXIMUM    MINIMUM    TOTAL DYNAM
     2IC    SEASONAL     SIMULATION,4X,13HHYDROELECTRIC)
1640  FORMAT (11X,3HNO.,15X,4HNODE,5X,4HNODE,5X,4HFLOW,7X,4HFLOW,5X,12HP
     1UMPING HEAD,6X,4HLOSS,7X,9HYEAR LINK,3X,15HGENERATION LINK/48X,3HC
     2FS,8X,3HCFS,10X,2HFT,10X,6HCOEFF.,8X,5HBUILT,8X,9H(1 = YES)/)
1650  FORMAT (10X,I3,3X,2A4,4X,I5,4X,I5,4X,F8.1,2X,F8.1,5X,F11.1,3X,F8.5
     1,I10,I15)
1660  FORMAT (18X,49HSEASONAL MAXIMUM AND MINIMUM ALLOWABLE LINK FLOW,42
     1HASPERCENTAGESOFMAX.ANDMIN.CAPACITIES//1X,125(1H*)//7X,4HLINK,55X,
     26HSEASON/6X,6HNUMBER,15X,12I7/32X,84(1H*)/)
1670  FORMAT (/5X,I5,5X,7HMAXIMUM,6X,12I7)
1680  FORMAT (15X,7HMINIMUM,6X,12I7)
1690  FORMAT (50X,17HCANAL COST COEFF.//125(1H*)//42X,5HDITCH,32X,4HPUMP
     1/33X,2HC1,9X,2HC2,9X,2HC3,13X,2HC1,9X,2HC2,11X,2HC3/)
1700  FORMAT (22X,I5,2X,3(G10.4,1X),4X,3(G10.4,1X))
1710  FORMAT (45X,18HCONSTANT COST DATA//125(1H*)///15X,13HINTEREST RATE
     1,10X,1H=,F10.4,15X,23HREPAYMENT PERIOD YRS   =,5X,I5,1X,3HYRS,/15X,
     210HPOWER COST,13X,1H=,F10.4,8H $/KW-HP,7X,23HO+M ANN DEC PCT RESVR
     3 =,F10.4,)
1720  FORMAT (15X,24HO+M ANN DEC PCT CANAL  =,F10.4,15X,23HCOST OF IMPOR
     1T WATER  =,F10.4,1X,4H$/AF,/15X,24HRESVR FINANCE LAG TIME =,5X,I5,
     21X,3HYRS,11X,23HCANAL FINANCE LAG TIME=,5X,I5,1X,3HYRS)
1730  FORMAT (15X,24HHYDROPOWER PEAK PRICE  =,F10.4,1X,7H$/KW-HR,7X,23HH
     1YDRO OFF PEAK PRICE  =,F10.4,1X,7H$/KW-HR)
1740  FORMAT (///1X,30(1H*),2X,14HATTENTION USER,2X,30(1H*)//35X,55HTHE
     1UNIT BENEFIT FOR PEAK POWER PRODUCTION IS LESS THAN/35X,55HOR EQUA
     2L TO THE UNIT BENEFIT FOR NONPEAK POWER PRODUCT-/35X,58HION. THIS
     3VIOLATES THE ASSUMPTIONS OF THE PROGRAM AND MUST/35X,13HBE CORRECT
     4ED.///)
1750  FORMAT (////71X,7HSEASONS//32X,12I7/32X,84(1H*)/)
1760  FORMAT (/1X,29HTARGET GENERATION (MEGAWATTS),20X,20HANNUAL GENERAT
     1ION = ,F7.2/30X,2X,12F7.2/)
1770  FORMAT (1X,13HON-PEAK HOURS,18X,12I7/)
1780  FORMAT (1X,14HOFF-PEAK HOURS,17X,12I7/)
1790  FORMAT (1X,29HPUMPING POWER COST ADJUSTMENT,2X,12F7.4/)
1800  FORMAT (1X,13HIMPORT COEFFS,18X,12F7.4/)
1810  FORMAT (1X,11HLOSS COEFFS,20X,12F7.4)
1820  FORMAT (48X,18HUNIT SHORTAGE COST/52X,9H($/AC-FT)/125(1H*)///51X,7
     1HSEASONS//12X,12I7/5X,4HNODE/6X,3HNO./)
1830  FORMAT (6X,I2,5X,12F7.0)
1840  FORMAT (//20X,80(1H*)/20X,34HTHE BENEFIT FOR MEETING DEMAND AT 9HJ
     1UNCTION,I3,10HIN SEASON ,I3/20X,49HIS NOT LESS THAN THE MAXIMUM PE
     2RMISSIBLE VALUE OF,F8.1,35H $/ACRE-FOOT AND MUST BE DECREASED.//)
1850  FORMAT (42X,24HRESERVOIR START CONTENTS//125(1H*)///29X,4HNODE,16X
     1,10HRES OR JNC,10X,16HINITIAL STORAGE /30X,4HNO. ,18X,4HNAME,13X,1
     25H(PERCENT FULL) /)
1860  FORMAT (29X,I3,17X,2A4,10X,F10.4)
1870  FORMAT (44X,28HRESERVOIR OPERATING POLICIES//125(1H*)///10X,4HRES.
     1,21H  OPERATING    STORAGE,4X,72HEND-OF-SEASON TARGET STORAGE LEVEL
     2S BY SEASON (FRACTION OF MAX. STORAGE),3X,10HNO. OF KEY/11X,24HNO.
     3   OPTION       BENEFIT,79X,10HRESERVOIRS//37X,12I6/)
1880  FORMAT (////4X,113HLIST OF KEY RESERVOIRS AND WEIGHTING FACTORS DE
     1TERMING TARGET STORAGE FOR ALL RESERVOIRS OPERATED UNDER OPTION 3
     2//10X,4HRES.,32X,19HKEY RESERVOIR INDEX/11X,3HNO./34X,8HCONSTANT,4
     3I7/32X,12H(1000 AC-FT))
1890  FORMAT (17X,17HWEIGHTING FACTORS)
1900  FORMAT (14X,10H    SEASON,I3,9X,F7.2,6F7.4)
1910  FORMAT (10X,I3/17X,17HKEY RESERVOIR NO.,8X,6I7)
1920  FORMAT (//20X,80(1H*)/20X,37HTHE BENEFIT FOR STORAGE AT RESERVOIR
     1,I3/20X,49HIS NOT LESS THAN THE MAXIMUM PERMISSIBLE VALUE OF,F8.1,
     235H $/ACRE-FOOT AND MUST BE DECREASED.//)
1930  FORMAT (10X,I3,I8,5X,F9.1,3X,12F6.2,4X,I5)
1940  FORMAT (/30X,60(1H*)//40X,38HRESERVOIR ELEVATION - CAPACITY TABLES
     1 //30X,60(1H*)/)
1950  FORMAT (10X,6(4X,13HRESERVOIR NO.,I3)/)
1960  FORMAT (3X,5HPOINT,2X,6(5X,4HELEV,1X,2X,8HCAPACITY)/10X,6(5X,4H(FT
     1),3X,8H(AC-FT) )/)
1970  FORMAT (3X,I2,5X,6(I9,1X,I10))
1980  FORMAT (/30X,70(1H*)//40X,63HRESERVOIR EFFICIENCY - POWER GENERATI
     1ON TABLES                    //30X,70(1H*)/)
```

```
 1990  FORMAT (3X,5HPOINT,2X,6(5X,4HEFF.,1X,2X,6H POWER  )/10X,6(9H(PERCE
      1NT),3X,8H (KW.)   )/)
 2000  FORMAT (/30X,82(1H*)//40X,66HRESERVOIR TAILRACE WATER ELEVATION -
      1FLOW DISCHARGE RATE TABLES    //30X,82(1H*)/)
 2010  FORMAT (3X,5HPOINT,2X,6(5X,4HELEV,1X,2X,8H  FLOW  )/10X,6(5X,4H(FT
      1),3X,8H (CFS)   )/)
 2020  FORMAT (//10X,37HTHE TAILWATER ELEVATION FOR RESERVOIR,I3,52H IS P
      1ARTIALLY CONTROLLED BY THE STORAGE IN RESERVOIR,I3,2H .)
 2030  FORMAT (//10X,21HINPUT ERROR ---- NODE,I3,20H MUST BE A RESERVOIR,
      115H BUT IT IS NOT./)
 2040  FORMAT (/30X,85(1H*)//40X,70HRESERVOIR MAXIMUM FLOW DISCHARGE - RE
      1SERVOIR WATER STORAGE TABLES      //30X,85(1H*)/)
 2050  FORMAT (3X,5HPOINT,2X,6(5X,4HFLOW,1X,2X,8HSTORAGE )/,10X,6(4X,5H(C
      1FS),3X,8H(AC-FT) )/)
 2060  FORMAT (/////10X,45HERRORS ENCOUNTERED IN DATA DECK---JOB STOPPED)
       END
```

INTERP

```
      SUBROUTINE INTERP (X,Y,Z)
C*********************************************************************
C                   THIS SUBROUTINE TAKES A SET OF RESERVOIR VALUES X AND
C                   INTERPOLATES BETWEEN VALUES OF ARRAY Z TO
C                   ESTABLISH THE VALUES Y CORRESPONDING TO VALUES X.
C*********************************************************************
      COMMON /HYDRGA/ LHYDRS(50),ISTEFF(50),LHYDA(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      INTEGER X(50), Z(50,20,2) ,XXX
      DIMENSION Y(50)
C*********************************************************************
C                   BEGIN RESERVOIR LOOP
C*********************************************************************
C     PRINT 3333,(X(K),K=1,NRES)
      DO 60 J=1,NRES
      IF (LHYDRS(J).EQ.0) GO TO 60
      DO 20 I=1,18
      IF ((1000*X(J)-Z(J,I,2)) 40,30,20
 20   CONTINUE
      XXX=X(J)*1000
      PRINT 80, J,XXX,((Z(J,I,K),K=1,2),I=1,18)
      STOP
 30   Y(J)=Z(J,I,1)
      GO TO 60
C*********************************************************************
C                   IF X BETWEEN POINTS INTERPOLATE
C                   FOR Y
C*********************************************************************
 40   IF (I.EQ.1) GO TO 50
      X1=Z(J,I,2)-Z(J,I-1,2)
      Y1=Z(J,I,1)-Z(J,I-1,1)
      X2=X(J)*1000-Z(J,I-1,2)
      X3=(X2/X1)*Y1
      Y(J)=Z(J,I-1,1)+X3
      GO TO 60
 50   Y(J)=Z(J,I,1)
 60   CONTINUE
      RETURN
C
 70   FORMAT (10X,10I10)
 80   FORMAT (/10X,50HATTEMPT TO INTERPOLATE BEYOND RANGE OF INPUT DATA
     1/10X,13HFOR RESERVOIR,I3,25H.  INTERPOLATED VALUE IS ,I10//10X,21H
     2EXECUTION TERMINATED.///10X,55HTHE DATA TABLE FOR WHICH INTERPOLAT
     3ION FAILED IS BELOW.//(10X,I8,18))
      END
```

LOOP

```
      SUBROUTINE LOOP (I,JJ)
C*****************************************************************
C                     SUBROUTINE TO DETERMINE IF THE FLOW AUGMENTING TREE
C                     INCLUDES A  FLOW GENERATING CYCLE.  IF SO NODE
C                     POTENTIALS ARE ADJUSTED ACCORDINGLY. USED ONLY IN
C                     THE FIRST ITERATION.
C*****************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1),UPPER( 500),LOWER( 500),ARCS
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SIGM,ITER,NPRIT,TIMAX,TIME,IPRINT
      DIMENSION ICHT( 60)
      INTEGER ARCS
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF
C*****************************************************************
C                     DETERMINE IF POINTERS INDICATE A LOOP.
C*****************************************************************
      DO 20 K=1,NODES
      ICHT(K)=0
20    CONTINUE
      ICHT(JJ)=1
      IJ=JJ
30    CONTINUE
      IJK=BARC(IJ)
      IF (IJK.EQ.0) RETURN
      IA=IARC(IJK)
      IF (IA.EQ.JJ) GO TO 40
      IF (ICHT(IA).EQ.1) RETURN
      ICHT(IA)=1
      IJ=IA
      GO TO 30
40    CONTINUE
      TEMP=0
      GN=1
      IJ=JJ
C*****************************************************************
C                     CALCULATE THE COST TO OBTAIN ONE UNIT OF FLOW INTO JJ
C*****************************************************************
50    CONTINUE
      IJK=BARC(IJ)
      GN=GN*AMPF(IJK)
      TEMP=TEMP+COSTF(IJK)/GN
      IA=IARC(IJK)
      IF (IA.EQ.JJ) GO TO 60
      IJ=IA
      GO TO 50
60    CONTINUE
C*****************************************************************
C                     CALCULATE COST TO OBTAIN ONE UNIT OF FLOW OUT OF
C                     LOOP AT JJ
C*****************************************************************
      V(JJ)=TEMP/(1.-1./GN)
   70 CONTINUE
      IJ=IA
      IJK=BARC(IJ)
      IA=IARC(IJK)
      IF (IA.EQ.JJ) RETURN
      V(IA)=V(IJ)*AMPF(IJK)-COSTF(IJK)
      GO TO 70
      END
```

MAXFLO

```
      SUBROUTINE MAXFLO
C*****************************************************************
C                     SUBROUTINE TO CALCULATE THE MAXIMUM FLOW INCREASE
C                     INTO THE SINK. ARC TO LEAVE THE TREE IS ALSO
C                     DETERMINED. THE FLOW IS CHANGED IN THE AUGMENTING
C                     PATH.
C*****************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SIGM,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET,ARCS
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF
C*****************************************************************
C                     FIND OUT IF THERE IS A LOOP. IF SO JJ IS THE
C                     ROOT OF THE LOOP.
C*****************************************************************
      DO 20 I=1,NODES
      ICHK(I)=0
20    CONTINUE
      JJ=SOURCE
      I=SINK
30    CONTINUE
      ICHK(I)=1
      IF (I.EQ.SOURCE) GO TO 50
      II=BARC(I)
      IF (II.EQ.0) GO TO 150
      I=IARC(II)
      IF (ICHK(I).EQ.1) GO TO 40
      GO TO 30
40    CONTINUE
      JJ=I
      NLOP=NLOP+1
C*****************************************************************
C                     FIND MAXIMUM FLOW CHANGE POSSIBLE.
C*****************************************************************
50    CONTINUE
      FLMX=999999.
      GN=1
      I=SINK
      GAN(I)=1.
60    CONTINUE
      IF (I.EQ.JJ) GO TO 70
      KK=BARC(I)
      GN=GN*AMPF(KK)
      FLMXT=FLMXC(KK,1.)*GN
      I=IARC(KK)
      GAN(I)=GN
      IF (FLMXT.GT.FLMX) GO TO 60
      FLMX=FLMXT
      IROOT=JARC(KK)
      GO TO 60
70    CONTINUE
      IF (JJ.EQ.SOURCE) GO TO 80
      CALL FLOP (JJ,FLMAX,GLOOP,IROOTL)
      FLMXT=FLMAX*GN
      IF (FLMXT.GT.FLMX) GO TO 80
      FLMX=FLMXT
      IROOT=IROOTL
80    CONTINUE
C*****************************************************************
C                     INCREASE TOTAL FLOW BY THE MAXIMUM FLOW CHANGE.
C*****************************************************************
      FLO=OUTFLO-FLONET
      IF(FLO.GT.FLMX)FLO=FLMX
      IF(FLO.LT.TIME)NDEG=NDEG+1
      CSTNOW=0.0
      IF (FLO) 140,140,90
90    FLONET=FLONET+FLO
```

```
C*********************************************************************
C                  CALCULATE FLOW CHANGE ON EACH ARC.
C*********************************************************************
      I=SINK
100   CONTINUE
      IF (I.EQ.JJ) GO TO 110
      II=BARC(I)
      IF (II.EQ.0) GO TO 150
      I=IARC(II)
      FLONOW=FLO/GAN(I)
      CALL FLCHG (I,FLONOW)
      GO TO 100
110   CONTINUE
      IF (JJ.EQ.SOURCE) GO TO 140
      FLOOP=FLO/(GAN(I)*(1.-(1./GLOOP)))
      I=JJ
      FLGA=FLOOP*GAN(JJ)
120   CONTINUE
      II=BARC(I)
      I=IARC(II)
      FLONOW=FLGA/GAN(I)
      IF (I.NE.JJ) GO TO 130
      J=JARC(II)
      FLONOW=FLGA/(GAN(J)*AMPF(II))
130   CONTINUE
      CALL FLCHG (II,FLONOW)
      IF (I.EQ.JJ) GO TO 140
      GO TO 120
140   CONTINUE
      RETURN
150   CONTINUE
      PRINT 160, FLONET,TOTCST
      CALL OUTPUT
      CALL EXIT
C
160   FORMAT (///10X,20HEXECUTION TERMINATED//10X,23HPROBLEM IS INFEASIB
     1LE. /10X,28HTHE MAXIMUM FLOW TO SINK IS ,E12.6/10X,19HAT A TOTAL C
     2OST OF ,E12.6)
      END
```

```
      SUBROUTINE OUTPUT
C*********************************************************************
C                  THIS SUBROUTINE WRITES THE RESULTS FROM
C                  SUBROUTINE GAIN IF THE NETWORK PROBLEM IS
C                  INFEASIBLE
C*********************************************************************
      COMMON /ADATA/ NF(1000),NT(1000),COST( 500),AMP( 500),FLOW( 500),H
     1I( 500),LO( 500),ARCS
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /PRT/ IPRNT(50),TITLE(10)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      DATA DASH,DOT/2H**,2H++/
      DATA BLANK/2H  /
      REAL LO,LOCF,MAXTOL
      INTEGER SCAP,A,ARCS,SOURCE,SINK,AB,AC
C*********************************************************************
C                  DETERMINE IF THE FLOW IN ANY ARC VIOLATES THE
C                  UPPER OR LOWER BOUNDS ON THE FLOW IN THAT ARC
C*********************************************************************
      EP=.01
      EPP=.1
      KOUT=6
      TIMAX=0.
      DO 30 I=1,ARCS
      F=FLOW(I)
      IF (F-HI(I)-EP) 20,20,190
20    IF (LO(I)-F-EP) 30,30,190
30    CONTINUE
C*********************************************************************
C                  PRINT OPTIMAL SOLUTION FOR NETWORK PROBLEM
C*********************************************************************
      IYR=IYEAR
      IF (IPRNT(IYR).EQ.1) GO TO 40
      GO TO 60
40    PRINT 280
      PRINT 290
      DO 50 I=1,NARC
      PRINT 300, I,NF(I),NT(I),LO(I),HI(I),COST(I),AMP(I),FLOW(I)
50    CONTINUE
60    CONTINUE
C*********************************************************************
C                  DETERMINE IF CONSTRAINTS ON RESERVOIR STORAGE
C                  SEGMENTATION HAVE BEEN VIOLATED
C*********************************************************************
      I=ISEAS
      AIMIN=NRES+5
      ARMIN=AIMIN+ND+1
      DO 160 J=1,NRES
      A=ARMIN+J
      AB=A+NRES
      AC=AB+NRES
      IF (FLOW(A)-HI(A)+EPP) 70,90,90
70    IF (FLOW(AB)-EPP) 80,80,110
80    IF (FLOW(AC)-EPP) 160,160,110
90    IF (FLOW(AB)-HI(AB)+EPP) 100,160,160
100   IF (FLOW(AC)-EPP) 160,160,110
110   IF (TIMAX) 120,120,130
120   WRITE (KOUT,310)
130   WRITE (KOUT,490) J,I,FLOW(A),FLOW(AB),HI(A)
      TIMAX=1.
      IF ((FLOW(A)+FLOW(AB)).GT.HI(A)) GO TO 150
140   HI(AB)=0.
      LO(AB)=0.
      GO TO 160
150   LO(A)=HI(A)
160   CONTINUE
      IF (TIMAX-1.) 180,170,180
170   WRITE (KOUT,500)
180   RETURN
```

```
C**********************************************************************
C                        WRITE ARC DATA FOR AN INFEASIBLE SOLUTION
C**********************************************************************
190   CONTINUE
      SUBS=12./NSEAS
      WRITE (6,340)
      WRITE (KOUT,320)
      IF (KAPE2.LT.1) GO TO 200
      WRITE (6,330)
      NSTOP=-1
      REWIND KAPE2
      WRITE (KAPE2) NSTOP
200   WRITE (6,350) NODES,ARCS
      IOSEA=1
      IPAGE=1
      WRITE (KOUT,310)
      WRITE (KOUT,370)
      WRITE (KOUT,390)
      DO 270 A=1,ARCS
      NDUM=5*NRES
      IF (A.NE.IPAGE*40) GO TO 210
      WRITE (6,380)
      WRITE (KOUT,360)
      WRITE (KOUT,370)
      IPAGE=IPAGE+1
210   CONTINUE
      IF (A.EQ.6) WRITE (6,400)
      IF (A.NE.(NDUM+1)) GO TO 220
      WRITE (6,410) IYEAR,ISEAS
220   CONTINUE
      IF (A.EQ.(NDUM+(ND+1))) WRITE (6,420) IYEAR,ISEAS
      IF (A.EQ.(NDUM+ND+2)) WRITE (6,430) IYEAR,ISEAS
      IF (A.EQ.(NDUM+ND+2+3*NRES)) WRITE (6,440) IYEAR,ISEAS
      IF (A.EQ.(NDUM+ND+2+3*NRES+NL)) WRITE (6,450) IYEAR,ISEAS
      FLOWC=FLOW(A)*16.6/SUBS
      LOCF=LO(A)*16.6/SUBS
      HICF=HI(A)*16.6/SUBS
      IF (FLOWC.LT.(LOCF-EP).OR.FLOWC.GT.(HICF+EP)) PRINT 460, A
      DASHO=BLANK
      IF (FLOWC-HICF) 240,230,260
230   DASHO=DASH
      GO TO 260
240   IF (FLOWC-LOCF) 260,250,260
250   DASHO=DOT
260   WRITE (KOUT,480) A,NF(A),NT(A),FLOW(A),FLOWC,DASHO,COST(A),AMP(A),
     1HI(A),HICF,LO(A),LOCF
270   CONTINUE
      STOP
C
280   FORMAT (1H1///,83H*****OPTIMAL FLOW PATTERN (POSSIBLY INCLUDING HY
     1DRO POWER GENERATION, IF ANY)******///)
290   FORMAT (99H  ARC  START   END          LOWER            UPPER
     1    COST              GAIN             FLOW          )
300   FORMAT (I5,2X,2I5,5F15.5)
310   FORMAT (1H1)
320   FORMAT (//8X,71HASTERISKS IN OUTPUT BELOW PINPOINT FLOWS WHERE FLO
     1WS=MAXIMUM CAPACITY  //8X,71HPLUS SIGNS IN OUTPUT BELOW INDICATE F
     2LOWS WHERE FLOWS=MINIMUM CAPACITY.)
330   FORMAT (///10X,60HTHE RESULTS STORED ON LOGICAL UNIT KAPE2 SHOULD
     1NOT BE USED.)
340   FORMAT (53H1* * *  S O L U T I O N    I N F E A S I B L E  * * *)
350   FORMAT (18H1NUMBER OF NODES =,I5//18H NUMBER OF ARCS  =,I5)
360   FORMAT (7X,3HARC,6X,4HFROM,6X,4H TO ,6X,4HFLOW,6X,4HFLOW,6X,4HCOST
     1,5X,4HAMP ,5X,14H---MAX FLOW---,3X,3X,14H---MIN FLOW---,3X)
370   FORMAT (7X,3HNO ,6X,4HNODE,6X,4HNODE,4X,6H1000AF,7X,3HCFS,3X,8H
     1 $/AF,13X,6H1000AF,7X,3HCFS,4X,6H1000AF,7X,3HCFS/)
380   FORMAT (1H1)
390   FORMAT (/40X,16HNET BALANCE ARCS/)
400   FORMAT (/,40X,20HINITIAL STORAGE ARCS/)
410   FORMAT (/,40X,20HDEMAND ARCS FOR YEAR,I3,8H ,SEASON,I3/)
420   FORMAT (/,40X,19HIMPORT ARC FOR YEAR,I3,8H ,SEASON,I3/)
430   FORMAT (/,40X,27HRESERVOIR STORAGE ARCS,YEAR,I3,8H ,SEASON,I3/)
440   FORMAT (/,40X,18HLINK ARCS FOR YEAR,I3,8H ,SEASON,I3/)
450   FORMAT (/,40X,19HSPILL ARCS FOR YEAR,I3,8H ,SEASON,I3)
460   FORMAT (////,17H INFEASIBLE ARC -,I4////)
470   FORMAT (1X,3E25.10)
480   FORMAT (3I10,2F10.2,A2,2F9.3,4F10.2)
490   FORMAT (/125(1H*)//50X,19HCOMPUTATIONAL ERROR//1X,52HTHE LOWER SEG
     1MENT OF CARRY-OVER STORAGE IN RESERVOIR,I3,1X,9HIN SEASON,I3,62H W
     2AS NOT FULL BEFORE THE UPPER SEGMENT OF STORAGE WAS UTILIZED//5X,3
     31HSTORAGE IN THE LOWER SEGMENT = ,F6.1,4X,31HSTORAGE IN THE UPPER
     4SEGMENT = ,F6.1,4X,38HMAXIMUM STORAGE IN THE LOWER SEGMENT =,F6.1/
     5//20X,42HRESERVOIR OPERATING RULES MAY BE ADJUSTED ,21HIF ERROR IS
     6 FREQUENT./20X,95HEITHER OPTION 2 MAY BE USED  OR  THE UNIT STORAG
     7E BENEFIT MAY BE INCREASED IF OPTION 1 IS USED./20X,55HALTERNATIVE
     8LY, THE BREAKPOINT STORAGE LEVEL FOR THE     /20X,55HSEGMENTATION O
     9F THE AREA-CAPACITY CURVE MAY BE CHANGED /20X,55HTO ELIMINATE  THE
     $ CONVEX SHAPE OF THE SEGMENTATION     /20X,55HOF STORAGE BETWEEN M
     $AXIMUM AND MINIMUM STORAGE LEVELS. /20X,56HSEE PAGE A-20 OF PROGRA
     $M DOCUMENTATION AND USERS MANUAL,//125(1H*)//)
500   FORMAT (1H1///125(1H*)//50X,27HRESTART PROCEDURE INITIATED//40X,63
     1HSTORAGE BOUNDS HAVE BEEN REDEFINED AND NETWORK WILL BE SOLVED. //
     240X,56HTHE STORAGE BOUND ADJUSTMENTS TO THE NETWORK MODEL MAY  /40
     3X,56HCAUSE A SOLUTION CALLING FOR WATER TO BE KEPT IN STORAGE/40X,
     456HRATHER THAN BE RELEASED FOR HYDROPOWER OR WATER SUPPLY. /40X,56
     5HTHIS MAY RESULT IN A SHORTAGE IN MEETING EITHER THE      /40X,56HP
     6OWER PRODUCTION TARGET OR THE WATER DIVERSION DEMANDS. /40X,56HCAR
     7E SHOULD BE TAKEN TO DETERMINE THE CAUSE OF SUCH      /40X,56HSHORT
     8AGES. EXAMINATION OF END-OF-SEASON RESERVOIR        /40X,56HSTORAGE
     9 CONTENTS SHOULD BE PARTICULARILY HELPFUL IN      /40X,56HTHIS EFFO
     $RT.                                              /40X,56H SEE PAGE A
     $-20 OF DOCUMENTATION MANUAL FOR CORRECTIVE    /40X,12HPROCEDURES./
     $/125(1H*),1H1)
      END
```

```
      SUBROUTINE PREPAR
C**********************************************************************
C                   THIS SUBROUTINE TAKES THE RESULTS FROM GAIN AND
C                   PREPARES THEM FOR PRINTING IN SUBROUTINE APRINT.
C**********************************************************************
       COMMON /ADATA/ NF(1000),NT(1000),COST(500),AMP(500),FLOW(500),H
      1I(500),LOWER(500),ARCS
       COMMON /APRNT/ APOW(50),AIMP(50),QM(75),ISHORT(50),ICOST(50)
      1 ,AGEN(50)
       COMMON /CDATA/ PERINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC,POWFA
      1C(12)
       COMMON /HYDRO/ IEFF(50,20,2),LHYDRO(75),MLOAD(50),ITELEV(50,20,2)
      1                .ECTAB(50,20,2),IMAXO(50,20,2),HPOWF(12),
      2                 ONPKC,OFPKC,IHRSP(12),IHRSO(12),NDWN(50)
       COMMON /HYDROA/ LHYDRS(50),ISTEFF(50),LHYDA(50)
       COMMON /JDATA/ RNAME(50,2),RCAP(50),RETSW(50),CRES(50),RMIN(50),NL
      1INK(50),FSTART(50),DLO(50),RMAXC(50,12),RMINC(50,12)
       COMMON /MISC/ AMIN,AIMIN,ARMIN,ALMIN,ASMIN
       COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
       COMMON/PRINT/ LQ(13,76),LP(13,75),LC(12,75),RS(13,50),RC(12,50)
      1,CC(12,50),JQ(13,10),IDEF(13,50),IMPC(50),ITOT(50)
       COMMON /PATHYC/ IRE(13,50),LPG(13,50),IPCU(13,50),IPPE(13,50)
      1,LOPG(13,50)
       COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
       COMMON /SDATA/ NJ,NPES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
      1,KAPE1,KAPE2,ISEAS
       COMMON /V/ SOURCE,SINK,NARC,OUTFLD,FLONET,SCTNOW,TOTCST,NODES,IFS,
      1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
       COMMON /WRKO/ START(50),STEND(50),USE(50),UREG(50)
      1,IELEV(50),
      2ELEVX(50),EDISC(50)
       COMMON /XDATA/ PI( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),G
      1AR( 60),ICHK( 60),LIST( 60)
       INTEGER A,AL,AIMP,APOW,AMIN,ALMIN,ARMIN,ASMIN,QM,RS,ARCS,AB,SOURCE
      1,SINK,BARC,RARC,FARC,DISSET,AIMIN
       COMMON RR(50),RPOIST(50),IPCUA(50),IPPEA(50),IPOSO(50),IPOST(50)
       INTEGER START,ECTAB,STEND,USE,UREG,
      1 RPOIST,RR,RMAXC,RMINC,SCAP,AC
       REAL LC,LOWER,LPG,LOPG,IELEV,IPOSO,IPOST,IPPEA,IRE,IDEF
      1 ,MAXTOL
       EXTERNAL INTERP
C**********************************************************************
C                   INITIALIZE VARIABLES
C**********************************************************************
      IF (ISEAS.GT.1) GO TO 70
      IYR=IYEAR
      SUBS=12./NSEAS
      HPSEAS=30.4*24.*SUBS
      IZYX=1
      ROFF=.499
      KOUT=6
      IL=NL+1
      CONFLO=60.3*SUBS
      M=NSEAS+1
      AP=0
      AI=0
      SH=0
      CO=0
      PC=0
      DO 20 L=1,NL
      LQ(M,L)=0
      LP(M,L)=0
      IF(IYR.EQ.1)QM(L)=0
   20 CONTINUE
      DO 30 J=1,NRES
      IRE(M,J)=0.
      LPG(M,J)=0
      IPCU(M,J)=0
      IPPE(M,J)=0
      RS(M,J)=0
   30 CONTINUE
      IF (NS.EQ.0) GO TO 50
      DO 40 J=1,NS
      JQ(M,J)=0
   40 CONTINUE
   50 CONTINUE
      IF (ND.EQ.0) GO TO 70
      DO 60 J=1,ND
      JF=JD(J)
   60 IDEF(M,JF)=0
   70 CONTINUE
      CALL INTERP (START,IELEV,ECTAB)
      CALL INTERP (START,IPOST,IMAXO)
C**********************************************************************
C                        BEGIN SEASONAL RESULTS
C**********************************************************************
      I=ISEAS
      HOURP=IHRSP(I)/HPSEAS
      HOURO=IHRSO(I)/HPSEAS
      AL=ARMIN
C**********************************************************************
C                       PREPARE LINK FLOWS,POWER COSTS,
C                       AND DUAL VALUES FOR PRINTING.
C**********************************************************************
      DO 90 L=1,NL
      A=ALMIN+L
      IA=NF(A)
      JA=NT(A)
C**********************************************************************
C                       16.6 CONVERTS TAF/MON TO CFS
C**********************************************************************
      LQ(I,L)=FLOAT(FLOW(A))*16.6/SUBS+ROFF
      LQ(M,L)=LQ(M,L)+LQ(I,L)
      IF(LQ(I,L).GT.QM(L))QM(L)=LQ(I,L)
      LP(I,L)=FLOW(A)*COST(A)
      IF (LP(I,L).LE.0) GO TO 80
      LP(M,L)=LP(M,L)+LP(I,L)
   80 CONTINUE
C**********************************************************************
C                       16.6 CONVERTS $1000/TAF/MON TO
C                                     $1000/CFS
C**********************************************************************
      LC(I,L)=COST(A)+PI(IA)-PI(JA)
      LC(I,L)=LC(I,L)/16.6*SUBS
      AP=AP+FLOW(A)*COST(A)
      IF(I.EQ.NSEAS)LQ(M,L)=LQ(M,L)/NSEAS
      IF(I.EQ.NSEAS)LP(M,L)=LP(M,L)/NSEAS
   90 CONTINUE
      LQ(I,IL)=FLOAT(FLOW(AL))*16.6/SUBS+ROFF
      AI=AI+LQ(I,IL)/NSEAS
      PC=PC+FLOW(AL)*CIMP
C**********************************************************************
C                       PREPARE RESERVOIR STORAGE LEVELS
C                       AND DUAL VALUES FOR PRINTING.
C**********************************************************************
      DO 100 J=1,NRES
      A=ARMIN+J
      AB=A+NRES
      AC=AB+NRES
      IA=NF(A)
      JA=NT(A)
      RS(I,J)=FLOW(A)*AMP(A)+FLOW(AB)*AMP(AB)+FLOW(AC)*AMP(AC)+ROFF
      RS(M,J)=RS(M,J)+RS(I,J)
      RC(I,J)=COST(AB)+PI(IA)-PI(JA)
      IF(I.EQ.NSEAS)RS(M,J)=RS(M,J)/NSEAS
  100 CONTINUE
C**********************************************************************
C                  COMPUTE RESERVOIR AVERAGE WATER LEVEL ELEVATION
C**********************************************************************
      IF (ONPKC) 270,270,110
  110 CONTINUE
      DO 120 J=1,NRES
  120 RR(J)=RS(I,J)
      CALL INTERP (RR,ELEVX,ECTAB)
      CALL INTERP (RR,IPOSO,IMAXO)
```

```
      DO 130 J=1,NRES
      IRE(I,J)=(ELEVX(J)+IELEV(J))*.5
      IRE(M,J)=IRE(M,J)+IRE(I,J)
      IF(I.EQ.NSEAS)IRE(M,J)=IRE(M,J)/NSEAS
130   IELEV(J)=ELEVX(J)
C**********************************************************************
C                    COMPUTE FOR EACH RESERVOIR THE POWER
C                    GENERATION FACTORS.
C**********************************************************************
      DO 170 J=1,NRES
      IA=LHYDRS(J)
      IF (IA.EQ.0) GO TO 170
      QMX=(IPOST(J)+IPOSD(J))/2000.
      IA=ALMIN+LHYDA(J)
      QHYDRO=FLOW(IA)/CONFLO/HOURP
      IF (QHYDRO-QMX) 140,140,150
140   RPOIST(J)=QHYDRO
      GO TO 160
150   RPOIST(J)=QMX
160   CONTINUE
170   CONTINUE
      CALL INTERP (RPOIST,EDISC,ITELEV)
      DO 230 J=1,NRES
      IA=LHYDRS(J)
      IF (IA.EQ.0) GO TO 230
      QMX=(IPOST(J)+IPOSD(J))/2.
      IPOST(J)=IPOSE(J)
      IA=ALMIN+LHYDA(J)
      QHYD=FLOW(IA)*1000./CONFLO/HOURP
C**********************************************************************
C                    COMPUTE TAILWATER ELEVATION.
C**********************************************************************
      TAILEV=EDISC(J)
      IF (NDWN(J)) 190,190,160
160   KF=NDWN(J)
      TAILEV=IRE(I,KF)
C**********************************************************************
C                    COMPUTE POWER GENERATION.
C**********************************************************************
190   POWCOF=(IRE(I,J)-TAILEV)*ISYEFF(J)/1180000.
      POWER=QHYD*POWCOF
      POWMX=QMX*POWCOF
      IF (QHYD-QMX) 200,210,210
200   LPG(I,J)=POWER
      POWERM=POWER
      LOPG(I,J)=0.
      GO TO 220
210   LPG(I,J)=-POWMX
      POWERM=POWMX
      LOPG(I,J)=POWCOF*(QHYD-QMX)*HOURP/HOURO
220   CONTINUE
C**********************************************************************
C                    COMPUTE PERCENTAGE UTILIZATION OF POWER
C                    GENERATING CAPACITY.
C**********************************************************************
      IPCU(I,J)=POWERM*100./MLOAD(J)
      IPCUA(J)=POWERM
      LPG(M,J)=LPG(M,J)+IABS(LPG(I,J))
      LOPG(M,J)=LOPG(M,J)+LOPG(I,J)
      IPCU(M,J)=IPCU(M,J)+IPCU(I,J)
      IF (I.NE.NSEAS) GO TO 230
      IPCU(M,J)=IPCU(M,J)/NSEAS
      LPG(M,J)=LPG(M,J)/NSEAS
      LOPG(M,J)=LOPG(M,J)/NSEAS
230   CONTINUE
C**********************************************************************
C                    COMPUTE POWER GENERATION EFFICIENCIES.
C**********************************************************************
      CALL INTERP (IPCUA,IPPEA,IEFF)
      DO 260 J=1,NRES
      IF (LPG(I,J)) 250,240,250
240   IPPEA(J)=0
250   CONTINUE
      IPPE(I,J)=IPPEA(J)
      IPPE(M,J)=IPPE(M,J)+IPPEA(J)
      IF(I.EQ.NSEAS)IPPE(M,J)=IPPE(M,J)/NSEAS
260   CONTINUE
C**********************************************************************
C                    PREPARE DUAL VALUES OF CONTINUITY
C                    CONSTRAINTS FOR PRINTING.   THESE
C                    REPRESENT THE VALUE OF ONE MORE
C                    ACRE-FOOT OF WATER DELIVERED TO THE NODE.
C                    ALSO COMPUTE WATER DEFICIT VOLUMES AND COSTS.
C**********************************************************************
270   CONTINUE
      DO 280 J=1,NJ
      N=6+J
280   CC(I,J)=PI(N)
      DO 290 JF=1,ND
      J=JD(JF)
      A=AIMIN+JF
      SH=SH+HI(A)-FLOW(A)
      CO=CO+ICOST(A)*(HI(A)-FLOW(A))
      IDEF(I,J)=HI(A)-FLOW(A)
      IDEF(M,J)=IDEF(M,J)+IDEF(I,J)
290   CONTINUE
C**********************************************************************
C                    PREPARE THE SPILLS THAT LEAVE THE
C                    SYSTEM FOR PRINTING.
C**********************************************************************
      DO 300 J=1,NS
      A=ASMIN+J
      JQ(I,J)=FLOW(A)
      JQ(M,J)=JQ(M,J)+JQ(I,J)
      IF(I.EQ.NSEAS)JQ(M,J)=JQ(M,J)/NSEAS
300   CONTINUE
310   CONTINUE
      NTZ=51
      NZ=0
      IF (I.LT.NSEAS) GO TO 320
      AIMP(IYR)=AI+ROFF
      APOW(IYR)=AP+ROFF
      ICOST(IYR)=CO+ROFF
      ISHORT(IYR)=SH+ROFF
      IMPC(IYR)=PC+ROFF
320   CONTINUE
      ITOT(IYR)=APOW(IYR)+ICOST(IYR)+IMPC(IYR)
C**********************************************************************
C                    ADJUST THE RESERVOIR STORAGE INPUT ARCS
C**********************************************************************
      DO 330 J=1,NRES
330   START(J)=RS(I,J)
      RETURN
      END
```

```
      SUBROUTINE PRIMAL
C*********************************************************************
C                    SUBROUTINE TO MAKE A PRIMAL ITERATION FOR NETWORK-
C                    WITH-GAINS PROBLEM.
C                    MODIFIED VERSION OF ORIGINAL SUBROUTINE WRITTEN BY
C                    DR. PAUL JENSEN, UNIV. OF TEXAS AT AUSTIN, 1975.
C*********************************************************************
      COMMON/ADATA/IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW( 500)
     1,UPPER( 500),LOWER( 500),ARCS
      COMMON/V/SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SIGH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),
     1 DISSET( 60),GAN( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET,ARCS
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF,RESTAR
      REAL MXFLT,MXFL
      DATA EPX,ESS/.0009,1.E-3/
C*********************************************************************
C                    SET ITERATION INDICES
C*********************************************************************
      ITERX=ITER
      NDEGX=NDEG
      NTERX=30
 20   CONTINUE
C*********************************************************************
C                    TERMINATE PRIMAL ALGORITHM IF MORE THAN 1
C                    NONDEGENERATE ITERATIONS OR 30 DEGENERATE
C                    ITERATIONS ARE REQUIRED TO SOLVE PROBLEM
C                    BETWEEN SUCCESSIVE ARC BOUND CHANGES IN HYDRO.
C*********************************************************************
      IF ((NDEG-NDEGX).LT.NTERX) GO TO 40
      IFLC=ITER-ITERX
      IF (IFLC.EQ.0) GO TO 30
      IF (IFLC.GT.5) RETURN
      NTERX=NTERX+10
      IF (NTERX.GT.60) RETURN
      GO TO 50
 30   NTERX=NTERX+10
      IF (NTERX.LE.100) GO TO 50
      RETURN
 40   CONTINUE
      IF ((ITER-ITERX).LT.1) GO TO 50
      RETURN
 50   CONTINUE
C*********************************************************************
C                    FIND AN ARC WHICH VIOLATES THE OPTIMALITY CONDITION
C                    TO THE GREATEST DEGREE.
C*********************************************************************
      POTX=EPX
      DO 100 I=1,NARC
      JJ=JARC(I)
      II=IARC(I)
      IF ((BARC(JJ).EQ.I).OR.(BARC(II).EQ.(NARC+I))) GO TO 100
      POT=(V(II)+COSTF(I))/AMP(I)-V(JJ)
      IF ((POT.LT.-EPX).AND.(FLOW(I).LT.(UPPER(I)-ESS))) GO TO 70
      K=I+NARC
      POT=(V(JJ)+COSTF(K))/AMPF(K)-V(II)
      IF ((POT.LT.-EPX).AND.(FLOW(I).GT.(LOWER(I)+ESS))) GO TO 60
C*********************************************************************
C                    IF NO ARCS ARE FOUND TO ENTER BASIS THEN EXIT
C                    SINCE THE OPTIMAL SOLUTION HAS BEEN FOUND.
C*********************************************************************
      GO TO 100
 60   IENTER=I+NARC
      GO TO 80
C*********************************************************************
C                    ARC I SHOULD ENTER THE BASIS
C*********************************************************************
 70   IENTER=I
 80   CONTINUE
      IF (POT-POTX) 90,100,100
 90   IENTEX=IENTER
      POTX=POT
 100  CONTINUE
      IF (POTX-EPX) 110,700,700
 110  CONTINUE
      IENTER=IENTEX
C*********************************************************************
C                    CREATES LISTS OF SOURCE AND SINK PATHS FOR IENTER.
C*********************************************************************
      DO 120 I=1,NODES
 120  ICHK(I)=0
      NLIST=0
      I=IARC(IENTER)
      JJSS=SOURCE
      JSL=0
      JSE=0
      JINT=0
 130  ICHK(I)=1
      IF (I.EQ.SOURCE) GO TO 170
      II=BARC(I)
      NLIST=NLIST+1
      LIST(NLIST)=II
      I=IARC(II)
      IF (ICHK(I).EQ.1) GO TO 140
      GO TO 130
 140  JJSS=I
      II=BARC(I)
      DO 150 J=1,NLIST
      IF (II.EQ.LIST(J)) GO TO 160
 150  CONTINUE
 160  JSL=J
 170  JSE=NLIST
      I=JARC(IENTER)
      JJKK=SOURCE
      JKL=0
      JKS=NLIST+1
      IF (ICHK(I).EQ.1) GO TO 190
 180  ICHK(I)=1
      IF (I.EQ.SOURCE) GO TO 260
      II=BARC(I)
      NLIST=NLIST+1
      LIST(NLIST)=II
      I=IARC(II)
      IF (ICHK(I).EQ.1) GO TO 190
      GO TO 180
 190  KK=BARC(I)
      IF (KK.EQ.0) GO TO 260
      IF (JSE.EQ.0) GO TO 210
      DO 200 J=1,JSE
      IF (KK.EQ.LIST(J)) GO TO 240
 200  CONTINUE
 210  CONTINUE
      DO 220 J=JKS,NLIST
      IF (KK.EQ.LIST(J)) GO TO 230
 220  CONTINUE
 230  JKL=J
      JJKK=I
      GO TO 260
 240  JINT=J
      IF (JSL.EQ.0) GO TO 260
      IF (JINT.LE.JSL) GO TO 250
      JKL=J
      JJKK=I
      GO TO 260
 250  JKL=JSL
      JJKK=JJSS
 260  JKE=NLIST
C*********************************************************************
C                    CALCULATE LOOP GAIN FOR SOURCE PATH
C*********************************************************************
      GLOOPS=0
      IF (JSL.EQ.0) GO TO 280
      GN=1.
```

```
      DO 270 J=JSL,JSE
      KK=LIST(J)
      GN=GN*AMPF(KK)
270   CONTINUE
      GLOOPS=GN
C**********************************************************************
C                  CALCULATE FLOW INCREASE REQUIRED PER UNIT CHANGE ON
C                   IENTER ON EACH ARC OF THE FORWARD PATH
C**********************************************************************
280   CONTINUE
      GN=1.
      KEND=JSE
      IF(JSL.GT.0)KEND=JSL-1
      IF (KEND.EQ.0) GO TO 300
      DO 290 J=1,KEND
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=1./GN
290   CONTINUE
C**********************************************************************
C                  CALCULATE THIS QUANTITY FOR ARCS IN LOOP
C**********************************************************************
300   IF (JSL.EQ.0) GO TO 320
      GN=GN*(1.-1./GLOOPS)
      DO 310 J=JSL,JSE
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=1./GN
310   CONTINUE
320   CONTINUE
C**********************************************************************
C                  CALCULATE LOOP GAIN FOR SINK PATH
C**********************************************************************
      GLOOPK=0
      IF (JKL.EQ.0) GO TO 350
      IF (JKL.LT.JKS) GO TO 340
      GN=1.
      DO 330 J=JKL,JKE
      KK=LIST(J)
      GN=GN*AMPF(KK)
330   CONTINUE
      GLOOPK=GN
      GO TO 350
340   GLOOPK=GLOOPS
350   CONTINUE
C**********************************************************************
C                  CALCULATE FLOW DECREASE REQUIRED FOR EACH ARC ON SINK
C                  PATH PER UNIT FLOW CHANGE IN IENTER
C**********************************************************************
      KEND=JKE
      GN=1./AMPF(IENTER)
      IF(JKL.GE.JKS)KEND=JKL-1
      IF (KEND.LT.JKS) GO TO 370
      DO 360 J=JKS,KEND
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=-1./GN
360   CONTINUE
370   CONTINUE
C**********************************************************************
C                  CALCULATE NON-LOOP FLOW DECREASES FOR PARTS OF SOURCE
C                  AND SINK PATHS WHICH ARE NOT LOOPS BUT WHICH
C                  INTERSECT
C**********************************************************************
      IF (JINT.EQ.0) GO TO 390
      IF ((JSL.GT.0).AND.(JINT.GE.JSL)) GO TO 390
      KEND=JSE
      IF(JSL.GT.0)KEND=JSL-1
      IF (KEND.LT.JINT) GO TO 390
      DO 380 J=JINT,KEND
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=GAN(J)-1./GN
380   CONTINUE
390   CONTINUE
C**********************************************************************
C                  CALCULATE FLOW REDUCTION IN LOOP
C**********************************************************************
      IF (JKL.EQ.0) GO TO 440
      GN=GN*(1.-1./GLOOPK)
      IF (JKL.LT.JKS) GO TO 410
      DO 400 J=JKL,JKE
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=-1./GN
400   CONTINUE
      GO TO 440
410   CONTINUE
C**********************************************************************
C                  CALCULATE FLOW REDUCTION IF LOOP IS IN SOURCE PATH
C**********************************************************************
      DO 420 J=JKL,JSE
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=GAN(J)-1./GN
420   CONTINUE
      IF (JKL.EQ.JSL) GO TO 440
      KEND=JKL-1
      DO 430 J=JSL,KEND
      KK=LIST(J)
      GN=GN*AMPF(KK)
      GAN(J)=GAN(J)-1./GN
430   CONTINUE
440   CONTINUE
C**********************************************************************
C                  CALCULATE THE MAXIMUM FLOW CHANGE THAT CAN BE MADE
C                  IN IENTER
C**********************************************************************
      ILEAV=IENTER
      MXFL=FLMX(IENTER,1.)
      MXFLT=MXFL+1.
      DO 480 J=1,JKE
      KK=LIST(J)
      IF (GAN(J)) 460,480,450
450   MXFLT=FLMX(KK,GAN(J))/GAN(J)
      GO TO 470
460   MXFLT=-FLMX(KK,GAN(J))/GAN(J)
470   CONTINUE
      IF (MXFLT.GT.MXFL) GO TO 480
      ILEAV=KK
      MXFL=MXFLT
480   CONTINUE
      CSTNOW=0
      IF (MXFL-1.E-4) 490,490,500
490   CONTINUE
      NDEG=NDEG+1
      GO TO 520
500   CONTINUE
C**********************************************************************
C                  CHANGE FLOW IN ARCS
C**********************************************************************
      FLONOW=MXFL
      CALL FLCHG (IENTER,FLONOW)
      DO 510 J=1,JKE
      KK=LIST(J)
      FLONOW=MXFL*GAN(J)
      CALL FLCHG (KK,FLONOW)
510   CONTINUE
      ITER=ITER+1
      TOTCST=TOTCST+CSTNOW
```

```
C*********************************************************************
C                    REARRANGE THE BASIS TO DELETE THE LEAVING ARC AND
C                    INSERT THE ENTERING ARC
C                    IF ILEAV IS IN THE SOURCE PATH ONLY THE MIRROR OF
C                    IENTER MUST ENTER
C
C                    IF ILEAV IS IN THE SINK PATH ONLY IENTER MUST ENTER
C
C                    IF ILEAV IS COMMON TO BOTH THE SOURCE AND SINK
C                    PATH IENTER FORMS A LOOP.  ENTER IT IN A DIRECTION
C                    WHICH GIVES THE LOOP A GAIN GREATER THAN 1
C
C                    DELETE ILEAV FROM BASIS
C
C*********************************************************************
520   CONTINUE
      IF (IENTER.EQ.ILEAV) GO TO 610
      ILOOP=0
      II=JARC(ILEAV)
      I=ILEAV
      IA=IARC(ILEAV)
      CALL DESUB (I,IA)
      RARC(II)=0
      BARC(II)=0
C*********************************************************************
C                    FIND ILEAV ON LIST
C*********************************************************************
      DO 530 J=1,NLIST
      KK=LIST(J)
      IF (KK.EQ.ILEAV) GO TO 540
530   CONTINUE
540   IF (JINT.GT.0) GO TO 550
      IF (J.LE.JSE) GO TO 580
      GO TO 570
550   IF (JSL.GT.0) GO TO 560
      IF (J.LT.JINT) GO TO 580
      IF (J.GE.JKS) GO TO 570
      GO TO 610
560   IF ((J.LT.JINT).AND.(J.LT.JSL)) GO TO 580
      IF (J.GE.JKS) GO TO 570
      GO TO 610
C*********************************************************************
C                    ENTER IENTER IN THE BASIS
C*********************************************************************
570   CALL TRECHG (IENTER,ILEAV)
      GO TO 670
C*********************************************************************
C                    ENTER THE MIRROR OF IENTER IN THE BASIS
C*********************************************************************
580   IF (IENTER.LE.NARC) GO TO 590
      IENTER=IENTER-NARC
      GO TO 600
590   IENTER=IENTER+NARC
600   CONTINUE
      CALL TRECHG (IENTER,ILEAV)
      GO TO 670
C*********************************************************************
C                    IENTER FORMS A LOOP.  PUT IENTER IN THE BASIS.
C                    CHECK GAIN OF LOOP.IF GAIN IS LESS THAN 1,
C                    PUT THE MIRROR IN THE BASIS
C*********************************************************************
610   CALL TRECHG (IENTER,ILEAV)
      ILOOP=1
      JJ=JARC(IENTER)
      I=IARC(IENTER)
      GN=AMPF(IENTER)
620   IF (I.EQ.JJ) GO TO 630
      II=BARC(I)
      GN=GN*AMPF(II)
      I=IARC(II)
      GO TO 620
630   IF (GN-1.) 640,640,670
640   ILEAV=IENTER
      IF (IENTER.LE.NARC) GO TO 650
      IENTER=IENTER-NARC
      GO TO 660
650   IENTER=IENTER+NARC
660   CONTINUE
      II=JARC(ILEAV)
      I=ILEAV
      IA=IARC(ILEAV)
      CALL DESUB (I,IA)
      RARC(II)=0
      BARC(II)=0
      CALL TRECHG (IENTER,ILEAV)
      GN=1./GN
670   CONTINUE
      IGNMXP=GN*1000.
C*********************************************************************
C                    CHANGE THE POTENTIALS ON ALL NODES
C                    ORIGINATING FROM IENTER
C*********************************************************************
      IF (IENTER.EQ.ILEAV) GO TO 20
      IF (ILOOP.EQ.0) GO TO 680
      JJ=JARC(IENTER)
      CALL LOOP (IENTER,JJ)
      CALL DUAL (JJ)
      GO TO 20
680   CONTINUE
      II=IARC(IENTER)
      JJ=JARC(IENTER)
      IF (IENTER.GT.NARC) GO TO 690
      V(JJ)=(V(II)+COST(IENTER))/AMP(IENTER)
      CALL DUAL (JJ)
      GO TO 20
690   V(JJ)=V(II)*AMP(IENTER-NARC)-COST(IENTER-NARC)
      CALL DUAL (JJ)
      GO TO 20
700   RETURN
      END
```

RESTAR

```
      SUBROUTINE RESTAR
C*************************************************************************
C
C                   SUBROUTINE TO CALCULATE NODE POTENTIALS
C                   (DUAL VARIABLES) GIVEN A BASIS.
C*************************************************************************
      COMMON/ADATA/IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW( 500)
     1,UPPER( 500),LOWER( 500),ARCS
      COMMON/V/SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),
     1 DISSET( 60),GAN( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET,ARCS
      REAL LOWER
      EXTERNAL FLMXC,AMPF,COSTF
C*************************************************************************
C
C                   INITIALIZE ARRAYS
C
C*************************************************************************
      DO 20 I=1,NODES
      ICHK(I)=0
      V(I)=BIG
20    CONTINUE
C*************************************************************************
C
C
C                   MOVE THROUGH NETWORK COMPUTING INDIVIDUAL POTENTIALS
C*************************************************************************
      ICHK(SOURCE)=1
      V(SOURCE)=0
      CALL DUAL (SOURCE)
      DO 60 I=1,NODES
      IF (ICHK(I).EQ.1) GO TO 60
      GO 30 J=1,NODES
      LIST(J)=0
30    CONTINUE
      II=I
40    LIST(II)=1
      JJ=BARC(II)
      II=IARC(JJ)
      IF (LIST(II).EQ.1) GO TO 50
      GO TO 40
50    JJ=II
      CALL LOOP (BARC(JJ),JJ)
      CALL DUAL (JJ)
60    CONTINUE
      TOTCST=0
      DO 70 I=1,NARC
      TOTCST=TOTCST+FLOW(I)*COST(I)
70    CONTINUE
      RETURN
      END
```

SETNET

```
      SUBROUTINE SETNET
C*************************************************************************
C
C                   THIS SUBROUTINE CREATES THE BASIC SINGLE [illegible]
C                   GENERALIZED NETWORK MODEL OF THE SPATIAL
C                   DIMENSIONS OF THE PHYSICAL SYSTEM.
C                   THE INTERRELATIONSHIPS ARE GIVEN BY
C                      1) ORIGIN NODE          : NF(A)
C                      2) DESTINATION NODE     : NT(A)
C*************************************************************************
      COMMON /ADATA/ NF(1000),NT(1000),COST( 500),AMP( 500),[illegible]
     1I( 500),LO( 500),ARCS
      COMMON /CDATA/ PERINT,NPAY,POWR,RESONM,CONONM,CIMP,[illegible]
     1C(12)
      COMMON /JDATA/ RNAME(50,2),RCAP(50),WETSW(50),[illegible]
     1INK(50),FSTART(50),OLO(50),RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),[illegible]
     15),CLIFT(75),EL(75),NODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /MDATA/ XX(12),ELF(12),XIMP,XSPILL
      COMMON /MISC/ AMIN,AIMIN,ARMIN,ALMIN,ASMIN
      COMMON /NDATA/ NYEAR,NS,SCAP,NG,NREAD,MAXTOL
      COMMON /PRT/ IPRNT(50),TITLE(10)
      COMMON /RDATA/ JS(10),JBLT(50),LBLT(75),JD(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,ND,NYR,NSEAS,[illegible]
     1,KAPE1,KAPE2,ISEAS
      COMMON /SHORTS/ BNC(50),CST(12,50),ACO(50,2),YFAC(12,50),TCST(50),
     1IOPT(50),NKEY(50),RKEY(50,5,12),NRKEY(50,5)
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSTNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      INTEGER AMIN,AIMIN,ARMIN,ALMIN,ASMIN
      INTEGER SCAP,ARCS,A
      INTEGER AB,SOURCE,SINK,AC
      REAL LO,MAXTOL
      INTEGER RMAXC,RMINC,CMAXC,CMINC
C*************************************************************************
C                   INITIALIZE VARIABLES
C*************************************************************************
      ARCS=4*NRES+NL+NS+ND+6
      IF (ARCS.GT.500) GO TO 20
      KOUT=6
      NODES=NJ+6
      IF (NODES.GT.60) GO TO 20
      GO TO 30
20    WRITE (KOUT,100) ARCS,NODES
      STOP
30    CONTINUE
      AMIN=NRES+5
C*************************************************************************
C
C                   GENERATE DATA FOR INITIAL STORAGE
C                   AND MONTHLY INFLOW ARCS
C*************************************************************************
      DO 40 J=1,NRES
      A=J+5
      NF(A)=1
      NT(A)=J+6
40    CONTINUE
C*************************************************************************
C
C                   GENERATE  DEMAND AND IMPORT ARCS
C*************************************************************************
      AIMIN=AMIN
      ARMIN=AIMIN+NC+1
      ALMIN=ARMIN+3*NRES
      ASMIN=ALMIN+NL
      DO 50 J=1,ND
      A=AIMIN+J
      JX=JD(J)
      NF(A)=6+JX
      NT(A)=6+NLINK(JX)
      IF(NLINK(JX).EQ.0)NT(A)=2
50    CONTINUE
      A=ARMIN
      NF(A)=3
      NT(A)=6+IMP
      IF(IMP.EQ.0)NT(A)=6
```

```
C***********************************************************************
C                    GENERATE RESERVOIR STORAGE ARCS
C***********************************************************************
      DO 60 J=1,NRES
      A=ARMIN+J
      NF(A)=6+J
      NT(A)=5
      AB=ARMIN+NRES+J
      NF(AB)=NF(A)
      NT(AB)=NT(A)
      AC=AB+NRES
      NF(AC)=NF(A)
      NT(AC)=NT(A)
60    CONTINUE
C***********************************************************************
C                    GENERATE CANAL AND RIVER ARCS
C***********************************************************************
      DO 70 L=1,NL
      JF=LNODE(L,1)
      JT=LNODE(L,2)
      A=ALMIN+L
      NF(A)=6+JF
      NT(A)=6+JT
70    CONTINUE
C***********************************************************************
C                    GENERATE SPILL ARCS
C***********************************************************************
      DO 80 J=1,NS
      JF=JS(J)
      A=ASMIN+J
      NF(A)=6+JF
      NT(A)=4
      HI(A)=199999.
80    CONTINUE
90    CONTINUE
C***********************************************************************
C                    GENERATE NET BALANCE ARCS AND ASSOCIATED PARAMETERS
C***********************************************************************
      A=1
      NF(A)=1
      NT(A)=6
      HI(A)=199999.
      AMP(A)=1.
      COST(A)=.001
C***********************************************************************
C                    TOTAL DEMAND ARC
C***********************************************************************
      A=2
      NF(A)=2
      NT(A)=6
      LO(A)=0.
      HI(A)=199999.
      AMP(A)=1.
      COST(A)=0.
C***********************************************************************
C                    TOTAL IMPORT ARC
C***********************************************************************
      A=3
      NF(A)=1
      NT(A)=3
      LO(A)=0
      HI(A)=199999.
      AMP(A)=1.
      COST(A)=0
C***********************************************************************
C                    TOTAL SPILL ARC
C***********************************************************************
      A=4
      NF(A)=4
      NT(A)=6
      LO(A)=0
      HI(A)=199999.
      AMP(A)=1.0
      COST(A)=0
C***********************************************************************
C                    TOTAL FINAL RESERVOIR STORAGE
C***********************************************************************
      A=5
      NF(A)=5
      NT(A)=6
      LO(A)=0
      HI(A)=199999.
      AMP(A)=1.
      COST(A)=0
      RETURN
C
100   FORMAT (10X,71HTHE PROBLEM FORMULATION HAS EITHER MORE THAN   500
     1 ARCS OR   60  NODES//20X,17HNUMBER OF ARCS = ,I5,5X,19H NUMBER OF
     2 NODES = ,I5//)
      END
```

```
      SUBROUTINE SHORT (IENTER,ILEAV)
C***********************************************************************
C                    SUBROUTINE TO FIND THE INITIAL AND SUBSEQUENT FLOW
C                    AUGMENTING TREE
C***********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSINOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET,ARCS
      REAL LOWER,MAXTOL
      EXTERNAL FLMXC,APPF,COSTF
C***********************************************************************
C                    SET UP POINTERS TO FIND INITIAL TREE.
C***********************************************************************
      IF (IFS.NE.0) GO TO 160
      DO 20 I=1,NODES
      BARC(I)=0
      FARC(I)=0
      RARC(I)=0
      DISSET(I)=1
      GAN(I)=1
      V(I)=9999.
20    CONTINUE
      V(SOURCE)=0
      ICHANG=0
      IENTER=1
      ITF=0
      IFS=1
C***********************************************************************
C                    SET UP SHORTEST PATH TREE FOR FIRST ITERATION.
C***********************************************************************
30    CONTINUE
      DO 90 K=1,NARC
      IF ((UPPER(K)-FLOW(K)).GT.EPS) GO TO 40
      IF ((FLOW(K)-LOWER(K)).LT.EPS) GO TO 90
      II=JARC(K)
      JJ=IARC(K)
      POT=V(II)*AMP(K)-COST(K)
      I=K+NARC
      GO TO 60
40    CONTINUE
      I=K
      JJ=JARC(I)
      II=IARC(I)
      IF ((LOWER(I)-FLOW(I)).GT.EPS) GO TO 50
      POT=(V(II)+COST(I))/AMP(I)
      GO TO 60
50    CONTINUE
      POT=(V(II)-BIG)/AMP(I)
60    CONTINUE
      IF (V(JJ)-POT) 90,90,70
70    V(JJ)=POT
      BARC(JJ)=I
      IF (ITF.EQ.0) GO TO 80
      CALL LOOP (I,JJ)
80    CONTINUE
      ICHANG=1
90    CONTINUE
      IF (ICHANG.EQ.0) GO TO 100
      ICHANG=0
      ITF=1
      GO TO 30
100   CONTINUE
C***********************************************************************
C                    CALCULATE FORWARD POINTERS FOR FIRST ITERATION.
C***********************************************************************
      DO 140 I=1,NODES
      IF (DISSET(I).EQ.0) GO TO 140
      KK=BARC(I)
      IF (KK.EQ.0) GO TO 140
      LL=IARC(KK)
      IF (FARC(LL).NE.0) GO TO 110
      FARC(LL)=KK
      GO TO 140
110   CONTINUE
      MM=FARC(LL)
120   CONTINUE
      MN=JARC(MM)
      IF (RARC(MN).NE.0) GO TO 130
      RARC(MN)=KK
      GO TO 140
130   CONTINUE
      MM=RARC(MN)
      GO TO 120
140   CONTINUE
150   CONTINUE
      RETURN
C***********************************************************************
C                    FIND NEW FLOW AUGMENTING TREE AFTER THE FIRST
C                    ITERATION.
C***********************************************************************
160   CONTINUE
      DO 170 I=1,NODES
      DISSET(I)=0
170   CONTINUE
C***********************************************************************
C                    DELETE BRANCH FROM BASIS AFTER THE FIRST ITERATION.
C***********************************************************************
      II=IROOT
      I=BARC(II)
      ILEAV=I
      IA=IARC(I)
      CALL DESUB (I,IA)
      RARC(II)=0
      BARC(II)=0
C***********************************************************************
C                    SET NEW NODE GAINS ON DISCONNECTED NODES.
C***********************************************************************
180   CONTINUE
      I=FARC(II)
      IF (I.EQ.0) GO TO 190
      JJ=JARC(I)
      IF(I.GT.NARC)GAN(JJ)=GAN(II)*AMP(I-NARC)
      IF(I.LE.NARC)GAN(JJ)=GAN(II)/AMP(I)
      II=JJ
      IF (II.EQ.IROOT) GO TO 190
      GO TO 180
190   CONTINUE
      J=RARC(II)
      DISSET(II)=1
      IF (J.EQ.0) GO TO 200
      II=JARC(J)
      K=BARC(II)
      JJ=IARC(K)
      IF(K.GT.NARC)GAN(II)=GAN(JJ)*AMP(K-NARC)
      IF(K.LE.NARC)GAN(II)=GAN(JJ)/AMP(K)
      GO TO 180
200   CONTINUE
      K=BARC(II)
      IF (II.EQ.IROOT) GO TO 210
      II=IARC(K)
      GO TO 190
210   CONTINUE
C***********************************************************************
C                    DETERMINE THE NEW BRANCH TO ENTER THE BASIS.
C***********************************************************************
      SICH=1.E+10
      IENTER=0
      DO 280 K=1,NARC
      IF ((UPPER(K)-FLOW(K)).GT.EPS) GO TO 220
```

```
C***********************************************************************
C                  LOOKING AT A BACKWARD BRANCH
C***********************************************************************
      IF ((FLOW(K)-LOWER(K)).LT.EPS) GO TO 280
      JJ=IARC(K)
      IF (DISSET(JJ).EQ.0) GO TO 280
      II=JARC(K)
      I=K+NARC
      IF (DISSET(II).EQ.0) GO TO 270
C***********************************************************************
C                  CHECK IF NEW BRANCH FORMS A LOOP
C***********************************************************************
      GO TO 230
220   CONTINUE
      I=K
      JJ=JARC(I)
      IF (DISSET(JJ).EQ.0) GO TO 280
      II=IARC(I)
      IF (DISSET(II).EQ.0) GO TO 270
C***********************************************************************
C                  NEW BRANCH FORMS A LOOP.
C***********************************************************************
230   CONTINUE
      GALPIV=GAN(II)/(GAN(JJ)*AMPF(I))
      IF (GALPIV-1.0000) 240,280,280
240   TERM=((V(II)+COSTF(I))/AMPF(I))-V(JJ)
      POTCH=TERM/((1.-GALPIV)*GAN(JJ))
250   CONTINUE
      IF (POTCH.GE.SICH) GO TO 260
      IF (POTCH-MAXTOL) 280,260,260
260   SICH=POTCH
      IENTER=I
      GO TO 280
C***********************************************************************
C                  NEW BRANCH DOES NOT FORM A LOOP.
C***********************************************************************
270   CONTINUE
      POTCH=(((V(II)+COSTF(I))/AMPF(I))-V(JJ))/GAN(JJ)
      GO TO 250
280   CONTINUE
      IF (SICH) 290,300,300
290   SICH=0.
300   CONTINUE
      IF (IENTER.EQ.0) GO TO 320
C***********************************************************************
C                  CHANGE NODE LABELS AND POINTERS TO REFLECT
C                  ENTERING BRANCH.  CHANGE POINTERS.
C***********************************************************************
      CALL TRECHG (IENTER,ILEAV)
C***********************************************************************
C                  CHANGE NODE POTENTIALS.
C***********************************************************************
      DO 310 II=1,NODES
      IF (DISSET(II).EQ.0) GO TO 310
      V(II)=SICH*GAN(II)+V(II)
310   CONTINUE
      GO TO 150
320   CONTINUE
      PRINT 330, FLONET
      II=IARC(ILEAV)
      CALL ADSUB (ILEAV,II)
      JJ=JARC(ILEAV)
      BARC(JJ)=ILEAV
      GO TO 150
C
330   FORMAT (1X,20H MAXIMUM FLOW FOUND ,F20.10)
      END
```

```
      SUBROUTINE SPRINT
C***********************************************************************
C                  THIS SUBROUTINE PRINTS AN ANNUAL SUMMARY OF ACTUAL
C                  COSTS, PRESENT VALUES, AND AVERAGE ANNUAL COSTS
C***********************************************************************
      COMMON /CDATA/ PERINT,NPAY,POWR,RESONM,CONONM,CIMP,LAGR,LAGC,POWFA
     1C(12)
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON CRESC(50),CRESOM(50),CLINKC(50),CLINOM(50),CIMPT(50),CPOWR(
     150),CTOTAL(50),PVRES(50),PVROM(50),PVLINC(50),PVLIOM(50),PVIMP(50)
     2,PVPOWR(50),PVTOT(50),ANRESC(50),ANRESO(50),ANLINC(50),ANLINO(50),
     3ANIMP(50),ANPOWR(50),ANTOT(50),CPEN(50),PVPEN(50),ANPEN(50)
     4 ,CGEN(50),PVGEN(50),ANGEN(50)
      INTEGER SCAP
      REAL MAXTOL
C***********************************************************************
C                  PRINT ACTUAL COSTS BY YEARS
C***********************************************************************
      WRITE (6,80)
      WRITE (6,50)
      WRITE (6,90)
      DO 20 IYR=1,NYEAR
      J=IYR+1
      WRITE (6,100) IYR,CRESC(J),CRESOM(J),CLINKC(J),CLINOM(J),CIMPT(J),
     1CPOWR(J),CGEN(J),CPEN(J),CTOTAL(J)
20    CONTINUE
C***********************************************************************
C                  PRINT PRESENT VALUE BY YEARS
C***********************************************************************
      WRITE (6,80)
      ICAL=IDATE
      WRITE (6,60) ICAL
      WRITE (6,90)
      DO 30 IYR=1,NYEAR
      J=IYR+1
      WRITE (6,100) IYR,PVRES(J),PVROM(J),PVLINC(J),PVLIOM(J),PVIMP(J),P
     1VPOWR(J),PVGEN(J),PVPEN(J),PVTOT(J)
30    CONTINUE
C***********************************************************************
C                  PRINT AVERAGE ANNUAL COST COMPONENTS
C                  BY YEARS
C***********************************************************************
      WRITE (6,80)
      WRITE (6,70) NPAY
      WRITE (6,90)
      DO 40 IYR=1,NYEAR
      J=IYR+1
      WRITE (6,100) IYR,ANRESC(J),ANRESO(J),ANLINC(J),ANLINO(J),ANIMP(J)
     1,ANPOWR(J),ANGEN(J),ANPEN(J),ANTOT(J)
40    CONTINUE
      RETURN
C
50    FORMAT (1X,20X,42HTOTAL CUMULATIVE COSTS IN THOUSAND DOLLARS)
60    FORMAT (1X,20X,47HCUMULATIVE PRESENT VALUES IN THOUSAND DOLLARS (,
     1I5,6H BASE))
70    FORMAT (1X,20X,53HCUMULATIVE AVERAGE ANNUAL COSTS IN THOUSAND DOLL
     1ARS (,I3,15H-YEAR PAYMENTS))
80    FORMAT (1H1,125(1H*)//45X,35HTEXAS DEPARTMENT OF WATER RESOURCES/3
     17X,51H MULTIRESERVOIR SIMULATION AND OPTIMIZATION MODEL  /55X,15H
     2  SIM - V     //125(1H*)/)
90    FORMAT (1H0,14X,10HRESERVOIRS,15X,8HCONDUITS,10X,7HIMPORTS,4X,25HP
     1OWER(CONSUMED/GENERATED),6X,8HDEFICITS,9X,5HTOTAL/18H  YEAR      CA
     2PITAL,5X,31HO AND M     CAPITAL       O AND M)
100   FORMAT (I6,3X,4(F9.0,3X),4(F9.0,5X),F10.0)
      END
```

```
      SUBROUTINE START
C***********************************************************************
C                   THIS SUBROUTINE READS AN INITIAL FEASIBLE
C                   SOLUTION TO THE NETWORK PROBLEM AND ADJUSTS
C                   THE NETWORK MODEL TO CONSERVE FLOW FOR
C                   EACH NODE IN THE NETWORK.
C***********************************************************************
      COMMON /ADATA/ NF(1000),NT(1000),COST( 500),AMP( 500),FLOW( 500),H
     1I( 500),LO( 500),ARCS
      COMMON /HYDRO/ IEFF(50,20,2),LHYDRO(75),HLOAD(50),ITELEV(50,20,2)
     1              ,ECTAB(50,20,2),IMAXO(50,20,2),HPOWF(12),
     2               ONPKC,OFPKC,IHRSP(12),IHRSO(12),NDWN(50)
      COMMON /JDATA/ PNAME(50,2),RCAP(50),RETSW(50),CRES(50),PMIN(50),NL
     1INK(50),FSTART(50),DLD(50)   ,RMAXC(50,12),RMINC(50,12)
      COMMON /LDATA/ CNAME(75,2),CLINK(2,75,3),CMAX(75),CPUMP(75),CMIN(7
     15),CLIFT(75),EL(75),LNODE(75,2),CMAXC(75,12),CMINC(75,12)
      COMMON /MISC/ AMIN,AIMIN,ARMIN,ALMIN,ASMIN
      COMMON /NDATA/ NYEAR,NS,SCAP,ND,NREAD,MAXTOL
      COMMON /PRT/ IPRNT(50),TITLE(50)
      COMMON /SDATA/ NJ,NRES,NJUNC,NL,NC,NR,NYR,NSEAS,IYEAR,IDATE,IMP,IN
     1,KAPE1,KAPE2,ISEAS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONET,CSNOW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLOP,SICH,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),
     1 DISSET( 60),GAN( 60),ICHN( 60),LIST( 60)
      COMMON HIO(50),ALO(50)
      INTEGER ARCS,SOURCE,A,SINK,BARC,FARC,RARC,DISSET,SCAP,AI,AA
      REAL LO,MAXTOL
      INTEGER AIMIN,ALMIN,ASMIN,RMAXC,RMINC,CMAXC,CMINC,AMIN,ARMIN
C***********************************************************************
C                   READ PREVIOUS SOLUTION FROM LOGICAL UNIT
C                   KAPE1 IF ADVANCED RESTART OPTION DESIRED.
C***********************************************************************
      READ (KAPE1) NNCS,NNDS,NRES,NSEAS,(FLOW(I),I=1,NNCS),(HIO(NX),ALO(
     1NX),NX=1,NRES),(BARC(I),RARC(I),FARC(I),I=1,NNDS)
C***********************************************************************
C                   IF THE NUMBERS OF ARCS AND NODES READ FROM FILE
C                   KAPE1 DO NOT EQUAL THOSE OF THE NETWORK PROBLEM
C                   THEN A MESSAGE IS PRINTED AND EXECUTION IS STOPPED.
C***********************************************************************
      IF (NNCS.EQ.(ARCS+2*NRES).AND.NNDS.EQ.NODES) GO TO 20
      IF (NNCS.GT.0) WRITE (6,140) KAPE1
      IF (NNCS.LE.0) WRITE (6,150)
      STOP
20    CONTINUE
C***********************************************************************
C                   SET PARAMETERS FOR EXTRA ARCS TO CARRY WATER INTO
C                   AND OUT OF THE INITIAL RESERVOIR STORAGE NODES TO
C                   PRESERVE MATERIAL BALANCE IN THE ADVANCED SOLUTION.
C***********************************************************************
      IYR=IYEAR
      ARCS=NNCS
      IF (NRES.LT.1) GO TO 70
      INARCS=ARCS-2*NRES
      DO 60 I=1,NRES
      A=INARCS+I
      AA=INARCS+I+NRES
      NF(A)=1
      NT(A)=I+6
      NF(AA)=I+6
      NT(AA)=6
      HI(A)=FLOW(A)
      HI(AA)=FLOW(AA)
      LO(A)=FLOW(A)
      LO(AA)=FLOW(AA)
      AI=I+6
      HR=HI(AI)
      FI=FLOW(AI)+FLOW(A)-FLOW(AA)
      IF (FI-HR) 30,50,40
30    HI(A)=HR-FI+HI(A)
      GO TO 50
40    HI(AA)=FI-HR+HI(AA)
50    HI(AI)=FLOW(AI)
      LO(AI)=HI(AI)
      COST(A)=-BIG
      COST(AA)=-BIG
      AMP(A)=1.
      AMP(AA)=1.
60    CONTINUE
70    CONTINUE
C***********************************************************************
C                   SET THE HYDRO POWER ARCS TO THEIR BOUNDS FROM
C                   THE STORED INITIAL SOLUTION.
C***********************************************************************
      I=ISEAS
      DO 90 L=1,NR
      IF (LHYDRO(L).EQ.0) GO TO 90
      JF=LNODE(L,1)
      A=ALMIN+L
      IF (RCAP(JF)) 90,90,80
80    CONTINUE
      HI(A)=HIO(JF)
      LO(A)=ALO(JF)
90    CONTINUE
C***********************************************************************
C                   SET COUNTERS TO ZERO AND SPECIFY FINAL OUTFLOW.
C***********************************************************************
      NARC=ARCS
      NDEG=0
      NLOP=0
      ITER=0
      FLONET=199999.
      NPRIT=1
C***********************************************************************
C                   CREATE MIRROR ARCS.
C***********************************************************************
      DO 100 I=1,NARC
      NN=NARC+I
      NF(NN)=NT(I)
      NT(NN)=NF(I)
100   CONTINUE
110   CONTINUE
      IF (IPRNT(IYR).EQ.1) GO TO 120
      RETURN
C***********************************************************************
C                   PRINT NETWORK MODEL
C***********************************************************************
120   PRINT 170, IYR
      PRINT 180
      PRINT 190
      DO 130 I=1,ARCS
      PRINT 200, I,NF(I),NT(I),LO(I),HI(I),COST(I),AMP(I),FLOW(I)
130   CONTINUE
      RETURN
C
140   FORMAT (///1X,30(1H*)//10X,49HADVANCED RESTART OPTION USING LOGICA
     1L UNIT KAPE1=,I3,1X,22HIS NOT CORRECTLY USED./10X,98HNUMBER OF ARC
     2S OR NODES ON FILE KAPE1 DOES NOT EQUAL THAT OF ARCS OR NODES IN T
     3HE CURRENT PROBLEM.//10X,21HEXECUTION TERMINATED.)
150   FORMAT (///1X,30(1H*)//10X,67HDATA FROM KAPE1 CAN NOT BE USED DUE
     1TO INFEASIBLE NETWORK SOLUTION.//10X,21HEXECUTION TERMINATED.)
160   FORMAT (2I5,4F10.3)
170   FORMAT (1H1//24H *****NETWORK MODEL*****/7X,9HFOR YEAR ,I2,//)
180   FORMAT (66H         ARC       START        END       LOWER      UPPER
     1    COST       AMPLIFICATION    FLOW)
190   FORMAT (52H          NO.       NODE        NODE       BOUND      BOUND//)
200   FORMAT (3I10,7F11.3)
      END
```

```
      SUBROUTINE TRECHG (IENTER,ILEAV)
C*********************************************************************
C                    SUBROUTINE TO FORM THE FLOW AUGMENTING TREE BY
C                    DELETING ONE ARC FROM THE TREE AND INSERTING
C                    A NEW ARC INTO THE TREE
C*********************************************************************
      COMMON /ADATA/ IARC(1000),JARC(1000),COST( 500),AMP( 500),FLOW(500
     1 ),UPPER( 500),LOWER( 500),ARCS
      COMMON /V/ SOURCE,SINK,NARC,OUTFLO,FLONE1,CSINDW,TOTCST,NODES,IFS,
     1IROOT,EPS,BIG,NDEG,NLCP,SICM,ITER,NPRIT,TIMAX,TIME,IPRINT
      COMMON /XDATA/ V( 60),BARC( 60),RARC( 60),FARC( 60),DISSET( 60),GA
     1N( 60),ICHK( 60),LIST( 60)
      INTEGER SOURCE,SINK,BARC,FARC,RARC,DISSET
      REAL LOWER
      INTEGER ARCS
      EXTERNAL FLMXC,AMPF,COSTF
      IROOT=JARC(ILEAV)
      NLIS=0
      JJ=JARC(IENTER)
C*********************************************************************
C                    DELETE PATH FROM JARC(IENTER) TO IROOT
C*********************************************************************
20    CONTINUE
      JB=BARC(JJ)
      IF (JJ.EQ.IROOT) GO TO 30
      NLIS=NLIS+1
      II=IARC(JB)
      CALL DESUB (JB,II)
      IF(JB.LE.NARC)II=JB+NARC
      IF(JB.GT.NARC)II=JB-NARC
      ICHK(NLIS)=I
      BARC(JJ)=0
      RARC(JJ)=C
      JJ=II
      GO TO 20
30    CONTINUE
C*********************************************************************
C                    ADD IN THE REVERSE OF THE PATH JUST DELETED
C*********************************************************************
      IF (NLIS.EQ.0) GO TO 40
      I=ICHK(NLIS)
      NLIS=NLIS-1
      II=IARC(I)
      JJ=JARC(I)
      CALL ADSUB (I,II)
      BARC(JJ)=I
      GO TO 30
40    CONTINUE
      II=IARC(IENTER)
      CALL ADSUB (IENTER,II)
      JJ=JARC(IENTER)
      BARC(JJ)=IENTER
      RARC(JJ)=C
      RETURN
      END
```

SIM - V

VARIABLE DESCRIPTIONS

BLOCK COMMON

SUBROUTINES	ADATA	APRNT	CDATA	HDATA	HYDRO	HYDROA	JDATA	LDATA	MDATA	MISC	NDATA	PRT	PRINT	PRTHYD	RDATA	SDATA	SHORTS	V	WRKD	XDATA	BLANK 1	BLANK 2	BLANK 3	
MAIN	●				●		●	●	●		●					●		●		●	●			
ADSUB	●																	●		●				
AMPF	●																	●		●				
APRINT		●		●	●		●	●			●	●	●	●	●	●						●		
ARC	●		●	●			●	●	●	●	●	●			●	●	●	●	●					
COSTF	●																	●		●				
COSTX		●	●				●	●			●				●	●							●	
DESUB	●																	●		●				
DUAL	●																	●		●				
FLCHG	●																	●		●				
FLMXC	●																	●		●				
FLOP	●																	●		●				
GAIN	●										●	●				●		●		●				
HYDRO	●		●	●	●	●	●	●	●	●	●				●	●	●	●	●	●	●			
INPUT	●		●		●		●	●	●		●	●			●	●	●	●						
INTERP						●										●								
LOOP	●																	●		●				
MAXFLO	●																	●		●				
OUTPUT	●										●	●				●		●						
PREPAR	●	●	●		●	●	●			●	●		●	●		●		●	●	●	●			
PRIMAL	●																	●		●				
RESTAR	●																	●		●				
SETNET	●		●				●	●	●	●	●	●			●	●	●	●						
SHORT	●										●							●		●				
SPRINT			●								●					●							●	
START	●				●		●	●		●	●	●				●		●		●	●			
TRECHG	●																	●		●				

SIM-V PROGRAM

BLOCK COMMON USAGE IN SUBROUTINES

Variable Descriptions for Subroutine APRINT

Variable Name	Definition
IL	Link Number for Imports
IYR	Year for which Results are Being Printed
M	Subscript for Mean Values to be Printed

Variable Descriptions for Subroutine ARC

Variable Name	Definition
A, AB, AC	Arc Number
EFF	Pump and Motor Efficiency (Set to .8)
I	Season Number in the Network
JF	Node Number
KIN	Fortran Logical Unit Assigned to Input File
TF	Target Reservoir Storage in Thousands of Acre-Feet
II, STOR	Working Variables

Variable Descriptions for Subroutine FLMXC

Variable Name	Definition
I	Arc Number
FLMXC	Maximum Allowable Change in the Flow in Arc I
S	$\leq$ 0, if Flow is to be Decreased > 0, if Flow is to be Increased
II, JJ K	Working Variables

Variable Descriptions for Subroutines FLOP

Variable Name	Definition
FLMAX	Maximum Possible Change in Flow for a Flow Generating Cycle
GN	Gain Factor for a Flow Generating Cycle
IROOTL	Root Node for a Flow Generating Cycle
JJ	Initial Node in Flow Generating Cycle
IJ,IJK, FLMXT	Working Variables

Variable Descriptions for Subroutine HYDRO

Variable Name	Definition
A,AA,AAA,A4	Arc Number
ADJF	Factor for determining Changes in Flow Bounds at Each Iteration as a Decimal Fraction of Current Flow Rate
BARCJT,ISTEST, FARCJT, RARCJT	Temporary Storage Arrays
CONFLO	Conversion Factor of (Acre-Feet per Season)/(cubic feet per second)
FLOWJT	Array for Temporary Storage of Network Flows
HCOST	Total Cost
HPSEAS	Hours per Season
I	Season Number
NAVEL(I)	Average Water Surface Elevation in Current Season for Reservoir in Feet
NAVST(I)	Average Water Storage in Current Season for Reservoir I in Feet
PKOF	Off-Peak Power Generation
PKON	Peak Power Generation
POWONP	Peak Period Power Generated by System in Season in Megawatts.
POWONT	Temporary Storage for POWONP
PUMPC	Pumping Cost
QHYD(J)	Flow Discharge for Hydropower Generation in Current Season from Reservoir J in Cubic Feet per Second
QMX	Maximum Flow through Powerplant
RCOST1, RCOST2, RCOST3	Temporary Storage Arrays for Reservoir Storage Arcs Unit Benefits
ROFF	Roundoff factor (=.499)

SHORC	Water Shortage Cost
SUBS	Months per Season
JF,JT,K,KK, LHYDX,QQ, NDD, ICONVR, CCOST, POWCOF, POWMX, POWER, QFLOW, HRORS, NNCS, STC, DTEV	Working Variables

Variable Descriptions for Subroutine
PREPAR

Variable Name	Definition
A	Arc Number
AL	Link Number for Import Art
IYR	The Year for which Output is Being Printed
MINP	Minimum Value in the Vector PI(N)
IA, IL, JA, M	Working Variables

Variable Descriptions for Subroutine
SETNET

Variable Name	Definition
A,AB,AC	Arc Numbers
AIMIN	Working Variable
JF,JT,JX	Node Numbers

Variable Descriptions for Subroutine SHORT

Variable Name	Definition
IENTER	Arc Entering the Flow Augmenting Tree
IFS	1, if Flow Augmenting Trees Subsequent to the First Tree are being Found 0, if Otherwise.
ILEAV	Arc Leaving the Flow Augmenting Tree
ITF	1, if the Initial Flow Augmenting Tree is to be Found 0, Otherwise.
POTCH	Change in Node Potential for Node I
AMX,CSTX, GALPIV,II, JJ,KK,LL,I,K, POT,ICHANG	Working Variables

Variable Descriptions for Subroutine SPRINT

Variable Name	Definition
ICAL	Calendar Date (Year) to which Present Value Costs are Referenced
J	Working Variable

Variable Descriptions for Subroutine TRECHG

Variable Name	Definition
IENTER	Arc to Enter Flow Augmenting Tree
ILEAV	Arc to Leave Flow Augmenting Tree
NLIS,JJ, JB, II	Working Variables

Variable Descriptions for Block Common /ADATA/

Variable Name	Definition
AMP(A)	Amplitude Factor for flow in Arc (A) (Must be positive value greater than zero)
ARCS	Number of Arcs in the Network
COST(A)	Unit Cost of Flow in Arc (A) in Thousands of Dollars per Thousand Acre-Foot
FLOW(A)	Flow entering Arc (A) in Thousands of Acre-Feet
HI(A)	Upper Bound on Flow entering Arc (A) in Thousands of Acre-Feet
LO(A)	Lower Bound on Flow entering Arc (A) in Thousands of Acre-Feet
NF(A)	Origin Node of Arc (A)
NT(A)	Destination Node of Arc (A)

VARIABLE DESCRIPTIONS FOR BLOCK COMMON

/APRNT/

VARIABLE NAME	DEFINITIONS
AIMP(IYR)	Annual Power Cost in Year (IYR) in Thousands of Dollars
APOW(IYR)	Annual Imports in Year (IYR) in Acre-Feet
QM(L)	Maximum Flow in Link (L) in CFS
ISHORT(IYR)	Junction Shortage Costs in Year (IYR) in Thousands of Dollars
ICOST(IYR)	Total Penalty Costs in Year (IYR) in Thousands of Dollars
AGEN(IYR)	Annual Power Generation Benefit in Year (IYR) in Thousands of Dollars

Variable Descriptions for Block Common /CDATA/

Variable Name	Definition
CIMP	Unit Cost of Imported Water in Dollars per Acre-Foot
CONONM	Conduit Annual Operation and Maintenance Cost Factor as a Fraction of Construction Cost
LAGC	Number of Years Lag Between Incurring Construction Cost for Conduits and First Year of Operation
LAGR	Number of Year Lag Between Incurring Construction Cost for Reservoirs and First Year of Operation
NPAY	Repayment Period in Years, Used to Compute Average Annual Costs
PERINT	Interest Rate (Decimal) for all Incurred Costs
POWFAC(I)	Seasonal Power Cost Coefficient
POWR	Unit Cost of Power in Dollars per Kilowatt-Hour
RESONM	Reservoir Annual Operation and Maintenance Cost Factor as a Fraction of Construction Cost

Variable Descriptions for Block Common

/HDATA/

Variable Name	Definition
D(ISEAS,J)	Seasonal Water Demand for Junction J in Thousands of Acre-Feet in Period ISEAS
E(ISEAS,J)	Seasonal Evaporation Coefficients for Reservoir J in Period ISEAS
U(J,ISEAS)	Seasonal Unregulated Inflow to Junction J in Period ISEAS in Thousands of Acre-Feet

Variable Descriptions for Block Common

/HYDRO/

Variable Name	Definition
ECTAB(I,J,K)	Water Surface Elevation (K=1) in feet above mean sea level, Corresponding to Level J for Water Storage (K=2) in thousand acre-feet, in Reservoir I
HPOWF(I)	Target Power Generation for the Reservoir System in Peak Periods during Season I in megawatts
IEFF(I,J,K)	Power Generating Efficiency (K=1) in Reservoir I Corresponding to Level J in Power Generated (K=2) by the Reservoir I
IHRSO(I)	Hours of Non-Peak Power Generation during Season I
IHRSP(I)	Number of Hours of Peak Power Generation in Season I
IMAXD(I,J,K)	Maximum Possible Flow Discharge (K=1) for Power Generation Purposes, in cubic feet per second, Corresponding to Level J of Water Storage (K=2), in thousand acre-feet, in Reservoir I
ITELEV(I,J,K)	Elevation of the Tail Water (K=1) in feet above mean sea level, Corresponding to Level J of Flow Discharge (K=2), in cubic feet per second, from Reservoir I
LHYDRO(I)	1, if Reservoir I Produces Hydroelectric Power 0, Otherwise
MLOAD(I)	Maximum Design Pow er Generation Capacity at Reservoir I in Megawatts
NDOWN(I)	Node Number of the Downstream Reservoir which partially or Completely Controls the Tail Water Elevation of Reservoir I through Storage Changes

OFPKC	Unit Benefit, in Dollars per Kilowatt-Hour, for Electricity Generated during Non-Peak Usage Periods
ONPKC	Unit Benefit, in Dollars per Kilowatt-Hour, for Power Generated in Peak Periods, but not in Excess of Scheduled Total Peak Period Power Production

VARIABLE DESCRIPTIONS FOR BLOCK COMMON

/HYDROA/

VARIABLE NAME	DEFINITION
ISTEFF (J)	Temporary Storage for the Power Generating Efficiency in Network Reservoir J
LHYDA (I)	Arc Number Corresponding to the Hydroelectric Generating Arc Associated with Reservoir I
LHYDRS (I)	Reach Number for Stream Reach Producing Hydroelectric Power by Releasing Water from Reservoir I

Variable Descriptions for Block Common

/JDATA/

Variable Name	Definition
CRES(J)	Capital Cost of Reservoir J in Thousands of Dollars
DLO(J)	Fraction of Seasonal Demand at Junction J which Must be Met
FSTART(J)	Fraction of Reservoir Full for Starting Storage
NLINK(J)	Node Number for Effluent Discharge of Wastewater Generated by Water Demand at Node J
RCAP(J)	Reservoir J Capacity in Thousands of Acre-Feet
RMIN(J)	Minimum Capacity of Reservoir J in Thousands of Acre-Feet
RNAME(J)	Reservoir or Junction Name
RETSW(J)	Effluent S/W Ratio (Sewage to Intake Water Ratio) for Demand at Node J
RMAXC(J,I)	Maximum Allowable Storage in Season I as Percentage of RCAP(J) for Reservoir J.
RMINC(J,I)	Minimum Allowable Storage in Reservoir J in Season I as a Percentage of RMIN(J).

VARIABLE DESCRIPTIONS FOR BLOCK COMMON
/LDATA/

VARIABLE NAME	DEFINITION
CCAP(L)	Maximum Capacity of Link L in CFS
CLIFT(L)	Pump Lift of Link L in Feet
CLINK(K,L,J)	Cost-Capacity Coefficients for a Second-Order Polynomial for Link L
CMIN(L)	Minimum Capacity of Link L in CFS
CNAME(L)	Link Name
CPUMP(L)	Unit Cost of Pumping in Thousands of Dollars Per CFS Per Foot
EL(L)	Fraction of Flow Entering Link L Which Leaves Link L (Amplitude of Link L)
LNODE(L,K)	Node Numbers at the Ends of Link L
CMAXC(L,I)	Maximum Allowable Flow Rate in Link L in Season I as a Percentage of CCAP(L)
CMINC(L,I)	Minimum Permissible Flow Rate in Link L in Season I as a Percentage of CMIN(L)

Variable Descriptions for Block Common /MDATA/

Variable Name	Definition
ELF(ISEAS)	Seasonal Coefficient for Link Amplitudes in Period ISEAS
KSPILL	Spill Cost in Dollars per Acre-Foot
XIMP	Maximum Annual Available Import in Thousands of Acre-Feet
XX(ISEAS)	Seasonal Import Coefficient for Period ISEAS

Variable Descriptions for Block Common /MISC/

Variable Name	Definition
AIMIN	Not Used
ALMIN	Number of Final and Initial Storage, Demand, Net Balance, and Import Arcs
ARMIN	Arc Number for Importation Arc
ASMIN	Total Number of Arcs Exclusive of Spill Arcs

VARIABLE DESCRIPTIONS FOR BLOCK COMMON

/NDATA/

VARIABLE NAME	DEFINITION
MAXTOL	Tolerance level for arcs to enter basis
ND	Number of Nodes with Water Diversion Demands in the Network Flow Problem
NS	Total Number of Nodes from Which Spills can Occur
NYEAR	The Last Year of the Problem to be Solved
SCAP	Capacity of Spill Arcs in Thousands of Acre-Feet

VARIABLE DESCRIPTIONS FOR BLOCK COMMON

/PRT/

VARIABLE NAME	DEFINITION
IPRNT(IYR)	0, 1, 2, or 3 If 0 -- Print All Output for Year (IYR) except the Network Model If 1 -- Print All Output for Year (IYR)and Print the Network Model If 2 -- Omit Printing of Dual Values for Year (IYR) If 3 -- Omit All Printing for Year (IYR)
TITLE	Alphanumeric Title for the Problem

Variable Descriptions for Block Common

/PRINT/

Variable Name	Definition
CC(I,J)	Dual Value for the Reservoir J Continuity Constraints in Season I in Dollars per Acre-Foot
IDEF(I,J)	Deficits at Node J in Season I in Thousands of Acre-Feet
IMPC(IYR)	Cost of Imported Water in Year IYR in Thousands of Dollars
ITOT(IYR)	Total Cost of Deficits Plus Imports Plus Pumping in Year IYR in Thousands of Dollars
JQ(I,J)	Spills Leaving System from Node JS(J) in Season I in Thousands of Acre-Feet
LC(I,L)	Dual Value for Link L in Season I in Thousands of Dollars per CFS
LP(I,L)	Power Cost in Link L During Season I in Thousands of Dollars
LQ(I,L)	Flow in Link L During Season I in CFS
RC(I,J)	Dual Value for the Reservoir J Storage Contents in Season I in Dollars per Acre-Foot
RS(IJ)	Reservoir J Storage Contents for Season I in Thousands of Acre-Feet

Variable Descriptions for Block Common /PRTHYD/

Variable Name	Definition
IPCU(I,J)	Percentage of Utilization of Generating Capacity at Reservoir J in Season I
IPPE(I,J)	Generating Efficiency at Reservoir J in Season I as a Percentage
IRE(I,J)	Average Water Surface Elevation in Reservoir J in Season I in Feet
LOPG(I,J)	Non-Peak Power Generation Rate for Reservoir J in Season I in Megawatts
LPG(I,J)	Peak Power Generation Rate for Reservoir J in Season I in Megawatts

Variable Descriptions for Block Common /RDATA/

Variable Name	Definition
JBLT(J)	Year Reservoir J is Built
JD(J)	Node J from which Water Diversion Demand Occurs
JS(J)	Node J from which Spills can Occur
LBLT(L)	Year Link L is Built

Variable Descriptions for Block Common /SDATA/

Variable Name	Definition
IDATE	Calendar Starting Date of the Problem
IMP	Import Node Number
IN	Input Tape Number
ISEAS	Number of Current Season
IYEAR	First Year
NC	Number of Canals
NJ	Number of Nodes (Reservoirs and Junctions)
NJUNC	Number of Junctions
NL	Number of Links
NR	Number of River Reaches
NRES	Number of Reservoir
NSEAS	Number of Seasons per Year
NYR	Number of Years
KAPE1	Logical Unit Number for Initial Basis Solution Input
KAPE2	Logical Unit for Storage of Optimal Basis for each Network

Variable Descriptions for Block Common

/SHORTS/

Variable Name	Definition
ACO(I,J)	Slope of Lines Approximating the Area-Capacity Curve for Reservoir I in the Lower (J=1) and Upper (J=2) Range of Storage
BND(J)	Fraction of Maximum Storage in Reservoir I Corresponding to the Junction Point between the Line Segments Approximating the Area-Capacity Curve
CST(J,I)	Unit Cost of Demands from Junction I in Season J in Dollars per Acre-Foot
IOPT(I)	Bivalued variable specifying the operating option (1, 2, or 3) for Reservoir I
NKEY(I)	Number of Key Reservoirs used to Determine Target Storage for Reservoir I
NRKEY(I,K)	Node Number of K-th Key Reservoir for Reservoir I
RKEY(I,K,J)	Coefficient of Initial Reservoir Storage in Key Reservoir K+1 for Reservoir I in Season J.
TCST(I)	Unit Benefit of Storage at Target Capacity in Reservoir I in Dollars per Acre-Foot
TFAC(J,I)	Fraction of Full Reservoir I to Obtain Target Capacity in Season J

Variable Descriptions for Block Common

/V/

Variable Name	Definitions
BIG	Large Positive Value (Set to 1000 in Subroutine GAIN)
CSTNOW	Cost for the Network Flows in the Current Solution
EPS	Small Positive Value (Set to .001 in Subroutine GAIN)
FLONET	Inflow into the Sink Node for the Current Solution
IFS	Used as a Counter to Indicate First and Subsequent Calls to Subroutine SHORT
IPRINT	Print Option Variable for Providing Intermediate Results from Network With Gains Algorithms: -1, No Intermediate Printing Executed 0, Print Only Total Network Cost and Number of Iterations Required for Solution 1, Print All of Above Plus Summary by Iteration giving Inflow into Sink, Network Cost, Arc Leaving Flow Augmeting Path, Arc Entering Path, and Increase in Potential at the Sink 2, Print All of Above Plus Summary by Iteration of forward, backward and right pointers, Nodes in the Flow Tree, Node Potentials, Node Gains, and Arc Flows
IROOT	Terminal Node for Arc Leaving the Flow Augmenting Path
ITER	Number of Iterations Required in Subroutine GAIN to Solve the Network Model
NARC	Number of Arcs in the Network Model
NDEG	Number of Degenerate Iterations Executed by the Program in Obtaining the Solution

NLOP	Number of Loop Iterations in Obtaining the Solution
NODES	Total Number of Nodes in the Network Model (Including Source and Sink)
NPRIT	Not Used
OUTFLO	Required Flow into the Sink Node
SICH	Increase in the Node Potential at the Sink for the Current Iteration in Subroutine GAIN
SINK	Node Number for the Flow Sink (Set to 7 in Subroutine GAIN)
SOURCE	Node Number for the Supply of Flow to the Network (Set to 1 in Subroutine GAIN)
TIMAX	Switch Used to Restart Algorithm when Storage Segmentation Constraints are Violated in any Network Solution
TIME	Flow Tolerance Variable
TOTCST	Total Cost of the Optimal Solution to the Network Problem

VARIABLE DESCRIPTIONS FOR BLOCK COMMON

/WRKD/

VARIABLE NAME	DEFINITION
EDISC(I)	Average Elevation of Tailwater of Reservoir I during Current Season
ELEVX(I)	Water Surface Elevation in Reservoir I at Beginning of Season in Feet
IELEV(I)	Water Surface Elevation at Reservoir I at End of Season
START(I)	Storage in Reservoir I at the Beginning of Season, in Thousands of Acre-Feet
STEND(I)	Storage in Reservoir I at End of Season, in Thousands of Acre-Feet
UREG(I)	Unregulated Inflow to Node I during Season, in Thousands of Acre-Feet
USE(I)	Demand for Water at Node I during Season, in Thousands of Acre-Feet

Variable Descriptions for Block Common /XDATA/

Variable Name	Definition
BARC(I)	Backward Arc Pointer for Node I in the Three Label Tree Representation
DISSET(I)	1, if Node I is in the Flow Augmenting Path, 0, if Otherwise
FARC(I)	Forward Arc Pointer for Node I
GAIN(I)	Gain Factor for Node I
ICHK(I)	Counter Array Used in Determining Loops in the Network
LIST(I)	List of Nodes
RARC(I)	Right Arc Pointer for Node I
V(I)	Node Potential for Node I

Variable Description for Block Common

1

Variable Name	Definition
DHUS(I)	Difference in Water Surface Elevation in Reservoir I from Beginning to End of Current Season in Feet
EDISCP(I)	Tail Water Elevation due to Flow Discharge below Reservoir I in Previous Season in Feet
HIO(I)	Upper Bound on Flow in Power Generating Arc Leaving Node I, in Thousand Acre-Feet.
IPCUA(I)	Temporary Storage Array
IPDSD(I)	Maximum Discharge Rate Through Hydroelectric Generating Facilities at End of Current Season at Reservoir I in cubic feet/second
IPPEA(I)	Temporary Storage Array
ITEFF(I)	Power Generation Efficiency at Reservoir I in Current Season in Percentage
ITEMP(I)	Power Generation Load at Reservoir I in Current Season
LOO(I)	Lower Bound on Flow in Power Generating Arc Leaving Node I, in Thousand Acre-Feet.
RPDIS(I)	Equals RPDIS(I) + 1
RPDIST(I)	Maximum Rate of Flow for Hydropower Generation from Reservoir I in Current Season in Thousands of Cubic Feet per Second
RR(I)	Temporary Storage Array for Reservoir I Storage
TCSTI(I)	Temporary Storage Array for Reservoir I Unit Storage Benefit Value

VARIABLE DESCRIPTIONS FOR BLANK COMMON

2

VARIABLE NAME	DEFINITION
AVGS(J)	Average Value in Season J (over Year if J = 13)
HELCT(J)	Number of 100 Megawatt-Hours of Energy Produced during Peak Periods in Season J
HELCTT(J)	Number of 100 Megawatt-Hours of Energy Produced in Season J
IAVGS(J)	Interger Value of AVGS(J)
MAXIND(J)	Hollerith field Set to Indicate if a Value is Equal to its Maximum (*), Minimum (+), or Within Bounds (Blank)

Variable Descriptions for Blank Common

3

Variable Name	Definition
CGEN (IYR) PVGEN(IYR) ANGEN(IYR)	Hydropower Benefits in Thousands of Dollars
CIMPT(IYR) PVIMP(IYR) ANIMP(IYR)	Input Cost in Thousands of Dollars
CLINKC(IYR) PVLINC(IYR) ANLINC(IYR)	Construction Cost for Link in Thousands of Dollars
CLINOM(IYR) PVLION(IYR) ANLINO(IYR)	Operation and Maintenance Costs for Link in Thousands of Dollars
CPOWR(IYR) PVPOWR(IYR) ANPOWR(IYR)	Power Costs in Thousands of Dollars
CRESC(IYR) PVRES(IYR) ANRESC(IYR)	Reservoir Construction Costs in Thousands of Dollars
CRESOM(IYR) PVROM(IYR) ANRESO (IYR)	Reservoir Operation and Maintenance Costs in Thousands of Dollars
CPEN(IYR) PVPEN(IYR) ANPEN(IYR)	Penalty Costs for Deficits Taken in Thousands of Dollars
CTOTAL(IYR) PVTOT(IYR) ANTOT(IYR)	Total for Cost Components Listed in Thousands of Dollars

NOTE: Prefix C stands for cumulative costs through year IYR
Prefix PV stands for Present values through year IYR
Prefix AN stands for average annual costs through year IYR

APPENDIX B

OPTIMAL AL-V RESERVOIR STORAGE PLOTS

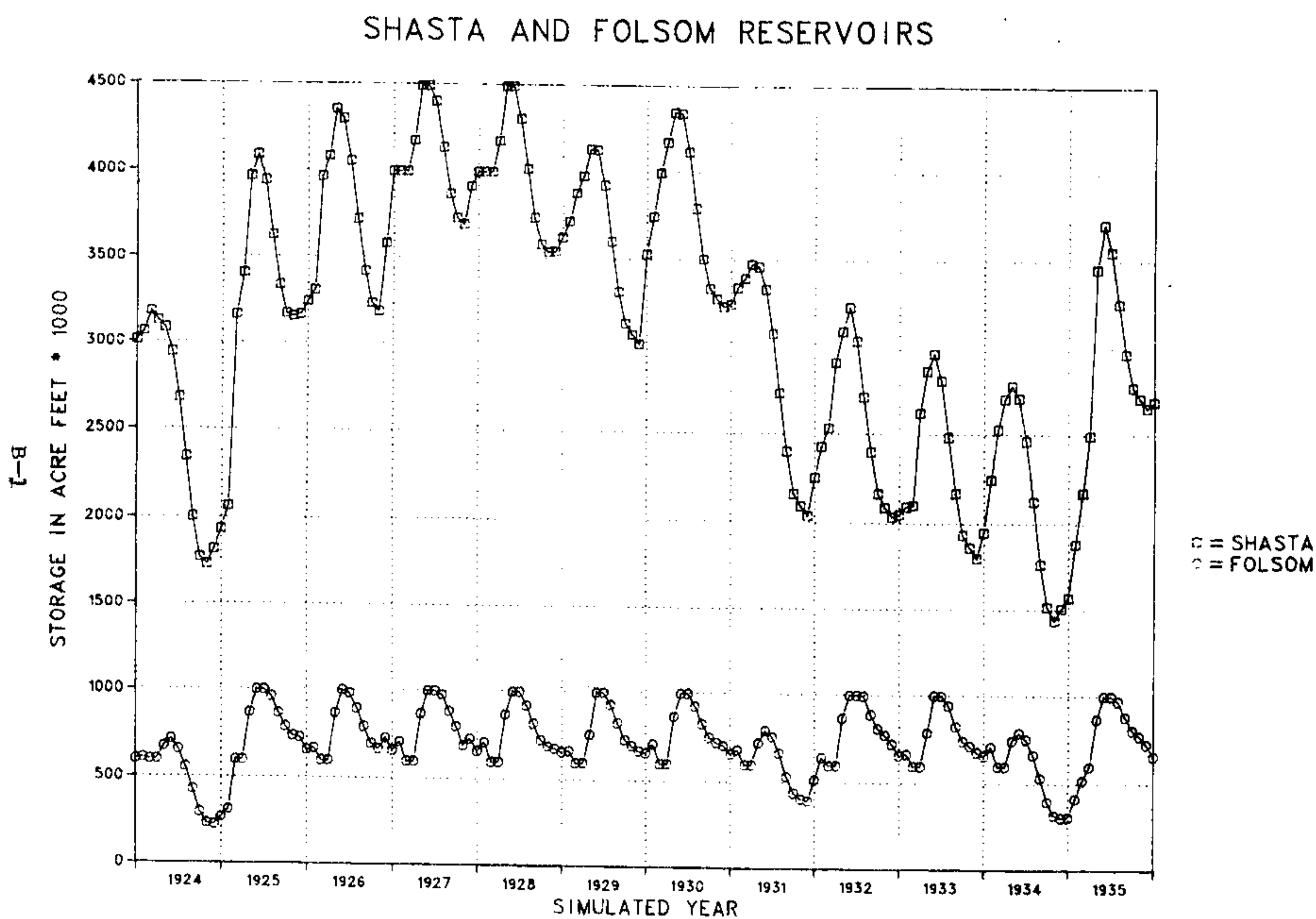

Figure B-1. Optimal Monthly Storages Computed by AL-V for Shasta and Folsom Reservoirs (Under Monthly Power Generation Rate of 500 M . (Source:Ref. 8)).

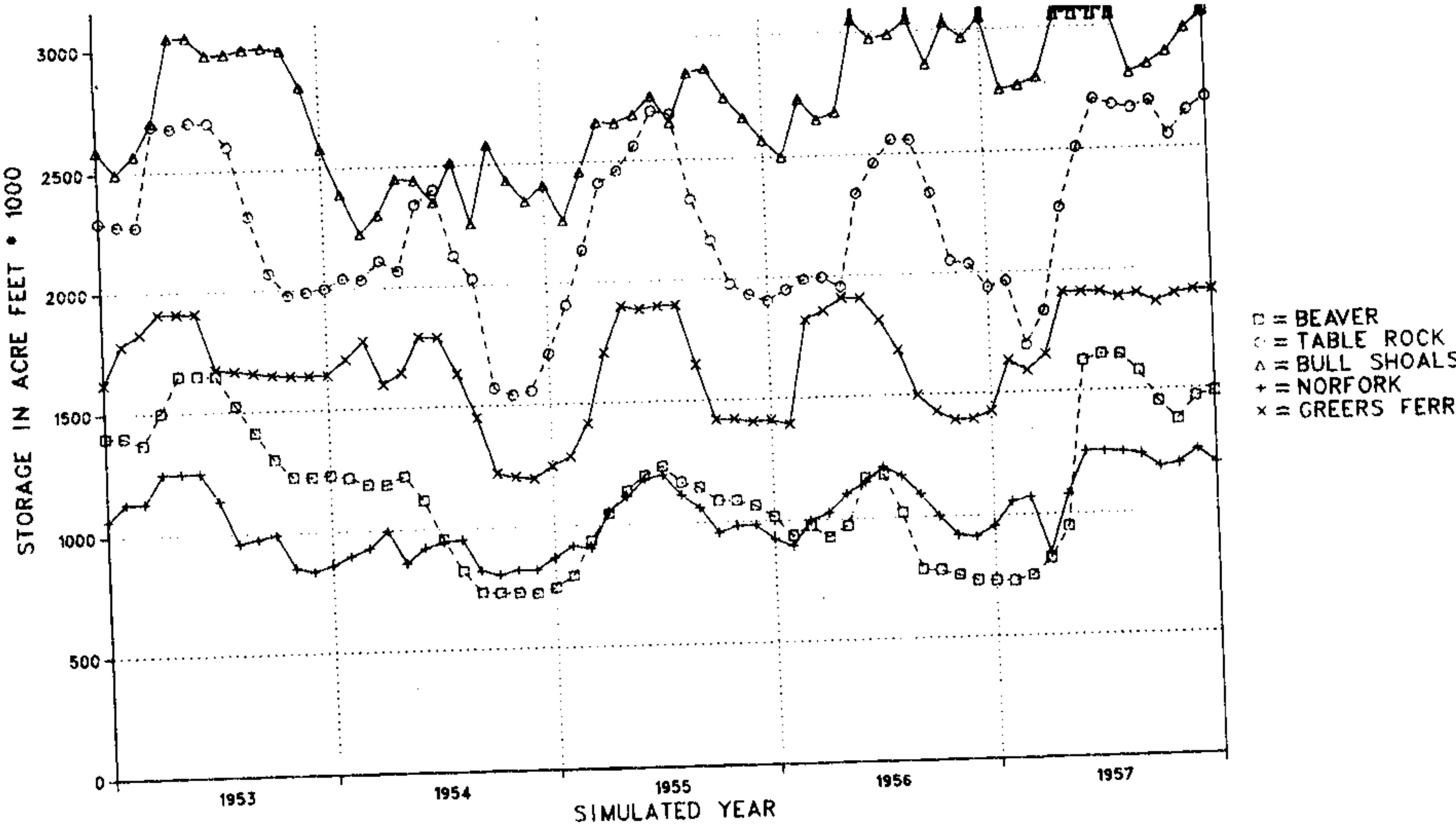

Figure B-2. Optimal Monthly Storages Computed by AL-V for White River Reservoirs (Under Average Monthly Power Generation Rate of 167 MW (2000 MW Annually). (Source: Ref. 8)).

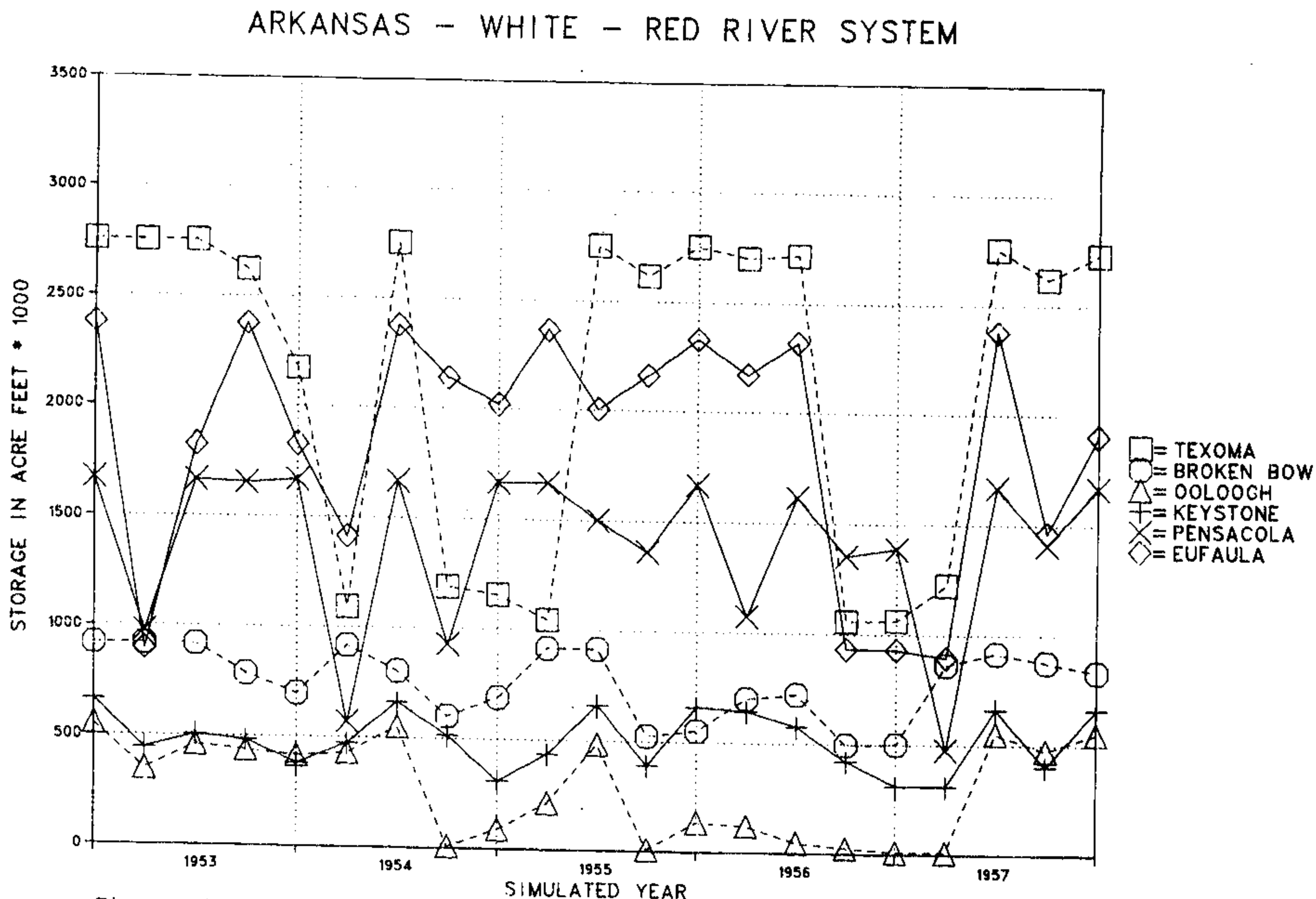

Figure B-3a. Optimal Seasonal Storages Computed by AL-V for Twelve Major Reservoirs in the AWR System (Under an Average Monthly Power Demand of 319 MW (Continued). (Source: Ref. 8)).

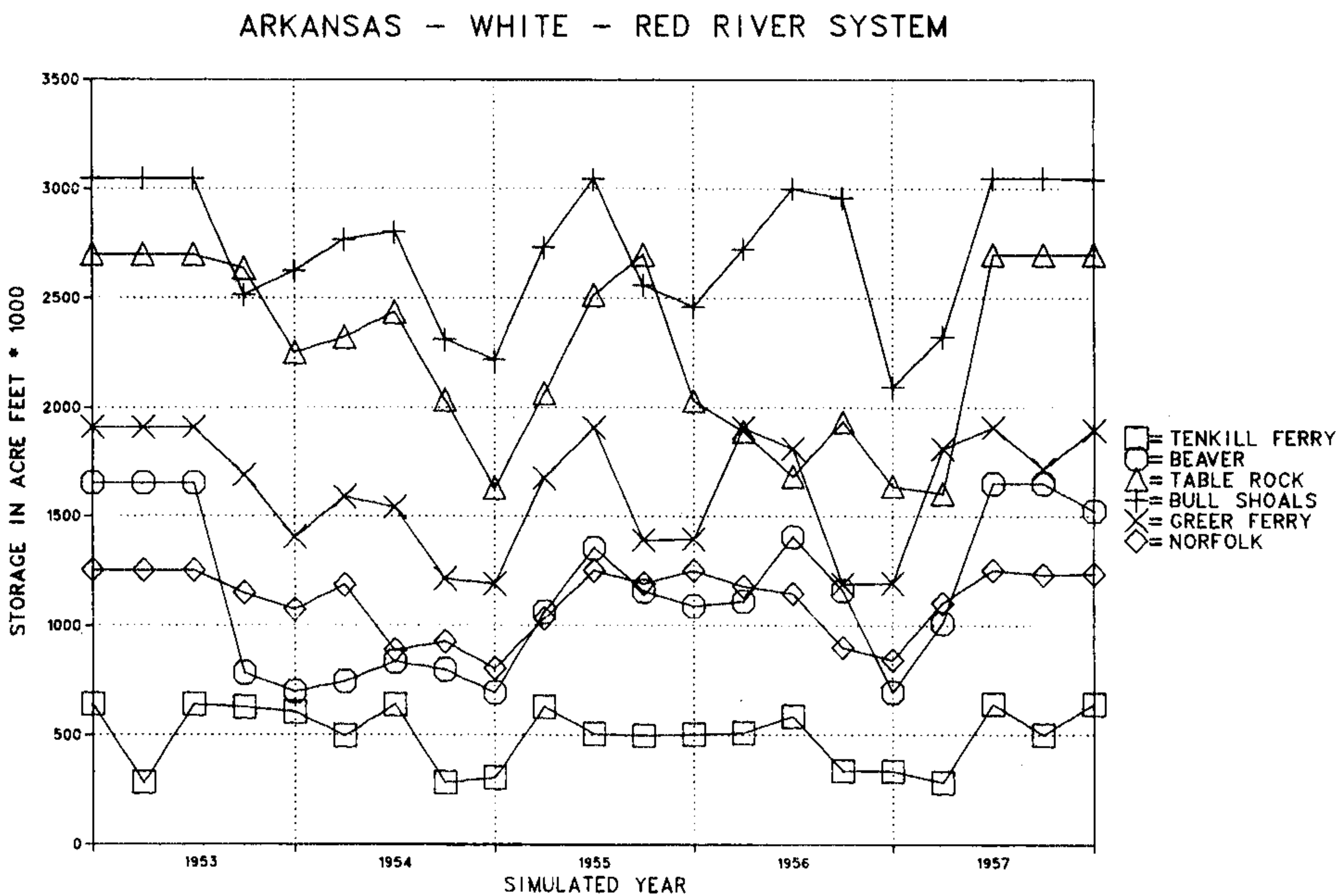

Figure B-3b. Optimal Seasonal Storages Computed by AL-V for Twelve Major Reservoirs in the AWR System (Under an Average Monthly Power Demand of 319 MW (Continued). (Source: Ref. 8)).