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SOFTWARE FOR RESERVOIR ANALYSIS (SRA)

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ABSTRACT

Because of the high time and space variability of rainfall and uncertain nature of monsoon in India, it is imperative to utilize the available water resources in the optimal and efficient manner. The reservoirs are one of the most important components of a water resources development project in this country. More than 3000 major and medium dams have already been constructed all over the country to tap the available water resources so that the water can be utilized in accordance with the requirements of mankind.

The efficient use of water resources requires not only judicious design but also proper management of the hydraulic structures. Further, in view of the increasing demands, the aim of water resources systems management is to search for operation policies so that various demands can be satisfied to the maximum extent possible. Reservoir operation forms a very important part of the planning and management of water resources system. A large number of models, generalized as well as system specific, have been developed during the last two decades. Some popular models include HEC-3 and HEC-5 of Hydrologic Engineering Centre, SIMYLD-II of Texas Water Development Board, the ACRES, the RESER and the IRIS etc.

In view of the importance of reservoir operation problem in Indian context and the non availability of a generalised software for reservoir analysis, the National Institute of Hydrology, Roorkee has taken up the task of developing a generalised software for reservoir analysis, taking particular care of the data availability and hydrological conditions in Indian context. The software contains menu driven options for reservoir analysis. Various modules included in the software for reservoir analysis are: capacity computation using sequent peak algorithm, storage-yield analysis, various methods of reservoir routing, interpolation of elevation-area-capacity table, Inflow estimation in the reservoir using the rate of rise information, simulation of hydropower analysis and estimation of firm power, determination of initial trial rule curve levels, stretched thread method of operation and simulation of a multipurpose Multireservoir system for conservation operation. Using the simulation analysis, the reliability analysis can be carried out and operation policy for a system can be refined. The software is capable of presenting the results in tabular as well as graphical form.

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CHAPTER - 1
INTRODUCTION

India is bestowed with rich water resources but more than 80% of the annual rainfall over this country falls in the four monsoon months from June to September. Because of the high time and space variability of rainfall and uncertain nature of monsoon, it is imperative to utilize the available water resources in the optimal and efficient manner. The reservoirs are one of the most important components of a water resources development project. The principal function of a reservoir is regulation of natural stream flow by storing surplus water in the rainy season and releasing the stored water in the dry season to supplement the natural river flow. Reservoirs are the most effective means of changing temporal and spatial availability of water. More than 3000 major and medium dams have already been constructed all over the country to tap the available water resources so that the water can be utilized in accordance with the requirements of mankind.

Once the structured facilities like dams, barrages, hydropower plants etc. come into being, the benefits that could be reaped depend, to a large extent, upon how well these facilities are managed. The efficient use of water resources requires not only judicious design but also proper management of the hydraulic structures. Further, in view of the increasing demands, the aim of water resources systems management is to search for operation policies so that various demands can be satisfied to the maximum extent possible. Reservoir operation forms a very important part of the planning and management of water resources system. Reservoir management involves allocating available water among multiple uses and users, minimizing the risks of water shortages and flooding, and optimizing the beneficial use of water. A reservoir operation policy specifies the amount of water to be released from the storage at any time depending upon the state of the reservoir, level of demands and any information about the likely inflows in the reservoir. Detailed guidelines are formulated to enable the operator at the dam site to take appropriate management decisions.

The management of reservoirs is a very challenging problem because it deals with a natural system with all the associated uncertainties. A tailor-made solution methodology for this problem is not available. For developing operation policies of a system of reservoirs, it is imperative to understand their integrated operation. Mathematical models are constructed to analyze and understand the systems. A number of techniques are available for reservoir operation, viz., standard linear operating policy, rule curves, concept of storage zoning etc. Systems analysis has proved to be a very powerful tool in the formulation and screening of policies for reservoir operation. There are several cases where system analysis techniques have been used to arrive at the operation policies for multipurpose reservoirs and the derived policies have shown to result in an improvement over the historic performance. The integrated operation of a complex system is necessary for efficient management of the limited resources to meet various target demands.

The system engineering techniques like simulation and optimization are extensively used in the reservoir operation problem. Among the optimization techniques, two techniques which are most frequently used now-a-days are linear programming and dynamic programming. The water resources literature contains many references as to which systems approach is better for reservoir operation analysis -- optimization or simulation. There is a consensus now that the optimization models are more suited for screening studies while simulation models provide higher flexibility in detailed and realistic representation of a complex configuration. Repeated runs of a simulation model are made to analyze the system performance under different conditions. The concepts inherent in simulation approach are easier to understand and communicate than other modelling concepts (Simonovic 1992). A large number of models, generalized as well as system specific, have been developed during the last two decades. Some popular models include HEC-3 and HEC-5 of Hydrologic Engineering Centre, SIMYLD-II of Texas Water Development Board, the ACRES (Sigvaldason 1976), the RESER (Simonovic 1992) and the IRIS (Iris 1990).

In view of the importance of reservoir operation problem in Indian context and the non availability of a generalised software for reservoir analysis, the National Institute has taken up the task of developing a generalised software for reservoir analysis, taking particular care of the data availability and conditions in India. Though a number of generalised software are available for the purpose, their source code is not available and the results of analysis are sometimes, difficult to interpret. The present software has been developed keeping all these limitations in view. The software contains menu driven options for reservoir analysis. Various modules included in the software for reservoir analysis are: capacity computation using sequent peak algorithm, storage-yield analysis, various methods of reservoir routing, interpolation of elevation-area-capacity table, Inflow estimation in the reservoir using the rate of rise information, simulation of hydropower analysis and estimation of firm power, determination of initial trial rule curve levels, stretched thread method of operation and simulation of a multipurpose Multireservoir system for conservation operation. Using the simulation analysis, the reliability analysis can be carried out and operation policy for a system can be refined. The software is capable of presenting the results in tabular as well as graphical form. Since the code of the model is available, the operation procedure or the system representation can be modified to suit to any particular set of conditions and configurations.

The purpose of the software is briefly described in Chapter 2. This chapter also contains the procedure for using the software and the hardware requirement for running the software. Chapter 3 contains a brief introduction to the theoretical background of all the modules. The desired input data format and the output results are also presented in detail in this section. The software is available on the floppy diskettes.

CHAPTER - 2
BRIEF DESCRIPTION OF THE SOFTWARE

2. PURPOSE OF THE SOFTWARE

A large number of hydrologic analyses are required to be carried out during the planning, design and construction of reservoirs. Many times, a lot of time of the design engineers is wasted in looking for the right tools. This software package, named ***SOFTWARE FOR RESERVOIR ANALYSIS*** (SRA) has been developed to mainly overcome this problem.

The main aim of the SRA package is to integrate and present the software modules for various analysis at one place. The software is capable of carrying out various kinds of analysis associated with the planning and design of reservoirs. In addition, the software also contains an option for simulating the operation of a multipurpose multireservoir system for conservation purposes. Using a trial policy, the operation of a system can be simulated and the reliability analysis can be carried out. The detailed operation table can be used to refine the policy till the optimum is reached.

2.1 DESCRIPTION OF SOFTWARE

SRA is a comprehensive, well-tuned and easy-to-use software with full-screen menus and on-line help to guide the user. The package includes many tabular and graphical options facilitating efficient reporting.

The software is a menu-driven, interactive package. The main menu, shown in Fig. 1, displays a list of the tasks that can be performed by the software. The user can select a particular option either by moving the cursor by using the four arrow keys or by pressing the first character from the option. The current option is displayed in reverse video. A one-line display at the bottom of the screen gives a brief description of the topic under the cursor. If the selected option name ends with the dots (...), it indicates that a sub-menu is associated with the current option. The selected option can be executed by pressing the ENTER key. If any sub-menu is attached to the selected option, the sub-menu is displayed and the user can make choice in the similar way. Switching from the menu to its submenu is performed by moving the cursor to the desired option and pressing the ENTER key while switching from a submenu to its master menu can be done by pressing the <Esc> key.

After the analysis to be performed has been selected, the user is prompted for the filename of the input data file. The user has two options now. If the name of the data file is known, he can type-in the name. Else, the user can enter "* *" and the list of files in the current directory is displayed in a separate window. The user can move through the file list through up- and down-arrow keys, and can also change the directories, if required. Once the cursor is placed on the desired file, that file is selected by pressing the ENTER key. After providing the input file name, the user is prompted for the name of the output file. Now the user has to enter the output file name. In case a file having the name already exists, the user is asked whether he wants to over-write the existing file. The Fig. 2 shows the screen after the input and output filenames have been specified.

The selected analysis will not be performed if either input file name or the output filename is blank. This facility can be used for exiting from the selected analysis in beginning. After completing the above steps, the user may be asked to provide some answers depending on the analysis module selected. The key points of the results of analysis are written on the computer screen and these together with detailed results are also written in the output file specified by the user. After that, the user is prompted if he wants to view the graphical presentation of the results on the screen. By default, the graph is drawn on the monitor screen, the same can also be printed on a printer.

2.2 ANALYSIS MODULES AVAILABLE

The current version of the software is capable of performing the following types of analysis :

- Reservoir Capacity Computation
- Interpolation of Elevation-Area-Capacity Table
- Hydropower Analysis
    - ➡ Firm Power Determination
    - ➡ Hydropower Simulation
- Reservoir Inflow Estimation
- Multireservoir Simulation
- Reservoir Routing
    - ⇒ Coefficient Method
    - ⇒ Goodrich Method
    - ⇒ Mass Curve Method
    - ⇒ Puls (Modified) Method
- Stretched Thread Method
- Trial Rule Curve Derivation

Reservoir Analysis

Capacity Computation
Elevation-Area-Capacity
Hydropower Analysis...
Inflow Estimation
Multireservoir Simulation
Reservoir Routing...
Stretched Thread Method
Trial Rule Curve Derivation
Yield-Storage Analysis...
DOS Command
Quit

Flow Routing Through a Reservoir Using Hydrologic Routing Methods

Fig. - 1 Main Menu of SRA

Reservoir Analysis

Capacity Computation
Elevation-Area-Capacity
Hydropower Analysis...
Inflow Estimation
Multireservoir Simulation
Reservoir Routing...
Stretched Thread Method
Trial Rule Curve Derivation
Yield-Storage Analysis...
DOS Command
Quit

Input File Name C:\RESER\S.dat

Output File Name OUT.DAT

Reservoir Routing

Coefficient Method
Goodrich Method
Mass Curve Method
Puls (Modified) Method

File OUT.DAT Already Exists. Do You Want to Overwrite it? (Y/N) : _

Reservoir Routing Using Coefficient Method

Fig. 2 Screen of SRA showing sub-menu, input and output filenames

- Yield-Storage Analysis
    - ⇒ Storage known, Yield unknown
    - ⇒ Yield known, Storage unknown
- DOS command (To execute commands like EDIT, PRINT etc.).

The flow diagram of SRA is presented in Fig. 3.

2.3 HARDWARE AND SOFTWARE REQUIREMENTS

The SRA package has been written in TURBO PASCAL and FORTRAN-77, languages. The hardware and software requirements for using SRA are:

- Minimum 640 KB memory,
- Hard Disk of 20 MB or more (required storage will depend upon the database size),
- Graphics Card,
- DOS with version 5.0 or later, and
- A compatible printer with graphical capabilities.

For fast and pleasant operation, at least a PC-386 with colour monitor is preferred.

2.4 AVAILABILITY OF SOFTWARE

The SRA package which includes the software on a floppy and the User's Manual can be purchased from NIH. For further information, please contact:

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INDIA

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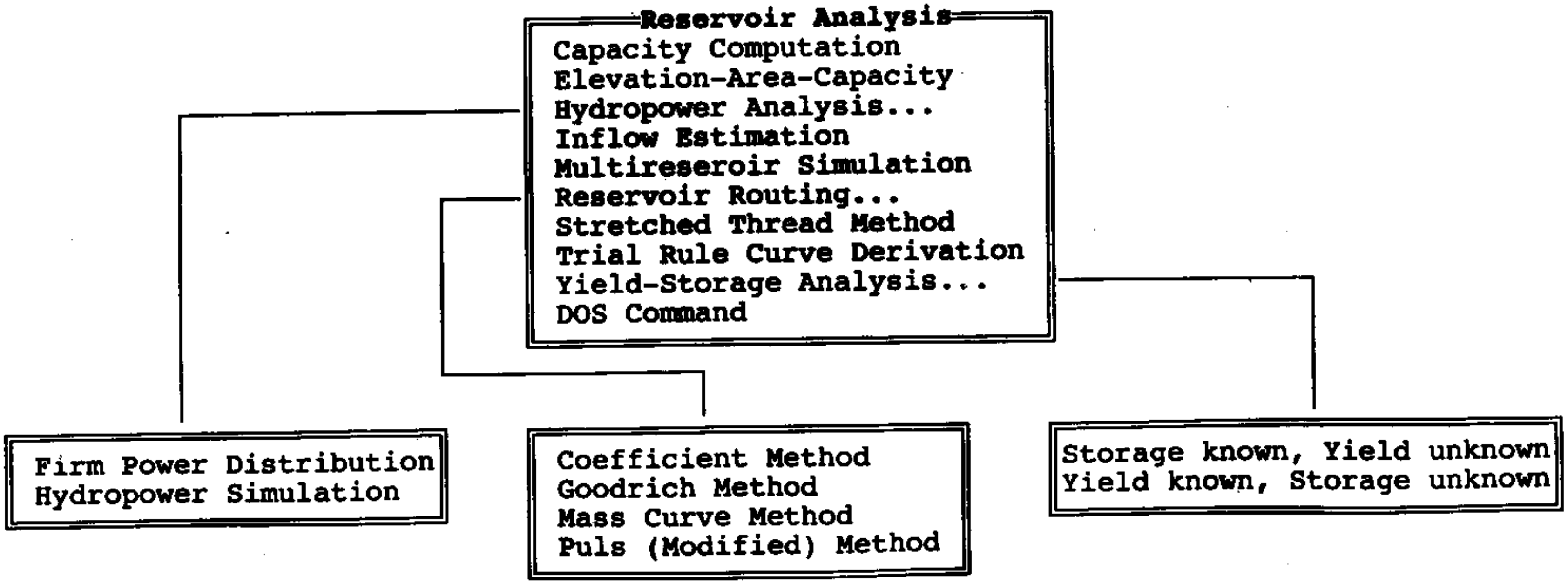

Fig. - 3 Flow Diagram of SRA

CHAPTER - 3
DESCRIPTION OF MODULES

A detailed description of the various analysis modules available in this software package is given below. The descriptions include details about how to prepare the input data file. A sample input data file and corresponding output data file for each module is also given.

3.1 CAPACITY COMPUTATION

Having estimated the water requirements for an intended project and having assessed the available water resources at a prospective site, a planning engineer is faced with one of the three situations:

a. The rate at which resources are available is always in excess of the requirements.
b. The total available resources over a time period is equal to or in excess of the overall requirements, but the rate of requirement at times exceeds available rate.
c. The total available resources are less than the overall requirements.

In first case, water can be used directly from the stream as and when needed. A storage reservoir is the solution to the second case. In third case, a supplemental source or an alternative site has to be explored. Once it is ensured that the total available resource is more than requirements and a particular site for storage reservoir is finalized, the next important decision to be taken is about the capacity of the reservoir to be constructed. This module concentrates on the Sequent-peak method of computing capacity for a reservoir.

A number of techniques are available for computing storage capacity for conservation purposes like irrigation, municipal and industrial water supply, hydropower generation etc. Depending upon the type of data and the computational technique used, the popularly used reservoir capacity computation procedures are classified into following categories:

a) Critical period techniques,
b) Optimization techniques, and
c) Simulation techniques.

Among these techniques, those based upon critical period concepts are the earliest techniques. One such method, known as the *Mass Curve Method* was the first rational method proposed to compute the required storage capacity of a reservoir. Also known as Rippl mass curve method, it is a simplified method commonly used in planning stage. The method considers the most critical period of recorded flow. The critical period is defined as the duration in which initially full reservoir depletes and passing through various states empties without spilling. In the methods based on critical period concept, a sequence of stream flow containing a critical period is routed through an initially full reservoir in presence of specified demand.

3.1.1 Sequent-peak Algorithm

The analytical solution of mass curve method is given in Sequent-peak algorithm. This method was proposed as a method which circumvents the need to choose the correct starting storage which is required in the mass curve procedure. It is particularly suited for the analysis of large data with the help of a computer. The computations are quite simple and can be carried out as described below.

Let I_t be the inflow to the reservoir in the period t, R_t be the release from the reservoir, and S_t the storage at the beginning of the period t. The reservoir is assumed to be empty in the beginning. The mass curve of cumulative net flow volume (Inflow - Outflow) against chronological time is used. This curve, shown typically in Fig. 4, will have peaks (local maximums) and troughs (local minimums). For any peak P_i, the next following peak of magnitude greater than P_i is called a sequent peak. The computations are performed for twice the length of the inflow record. It is assumed that the inflows repeat after the end of first cycle. This assumption is made to take care of the case when the critical period falls at the end of the record. The variable S_t is calculated by the following equation:

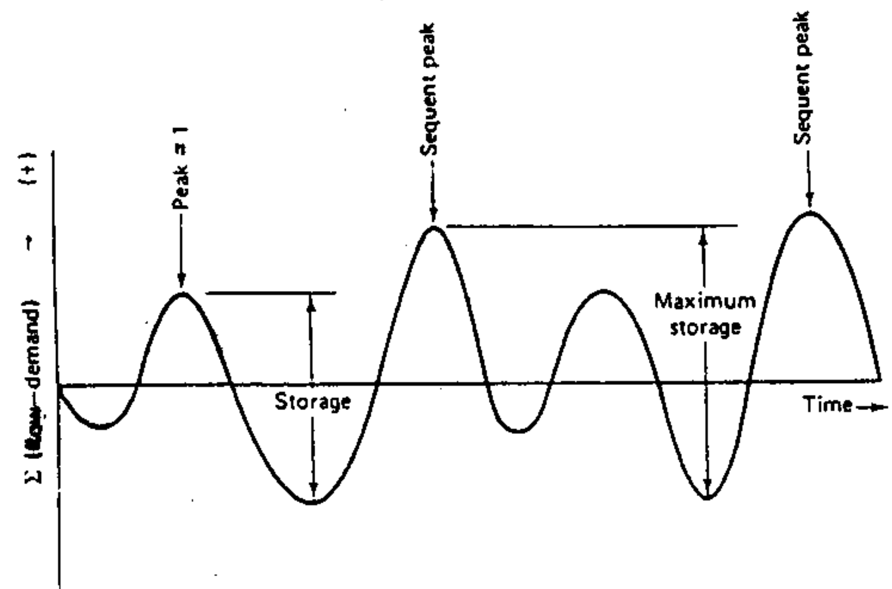

Fig. - 4 Definition Sketch for Sequent Peak Algorithm

$$S_t = \begin{cases} S_{t-1} + R_t - I_t & \text{if positive} \\ 0 & \text{if negative or zero} \end{cases} \qquad ...(1)$$

The required storage capacity is equal to the maximum of S_t values. The computations are illustrated in the sample output table.

The sequent peak algorithm can very easily consider the variable release from the reservoir. The reliability of the reservoir can be obtained indirectly. Since the reservoir would be able to meet the worst drought from the record, the implied probability of failure would be 1/(N+1). The algorithm is very fast and easy to program. A single historical record is used to compute the storage and hence the method is limited in that sense. It is also not possible to exactly consider the losses, though these can be approximately included in the releases.

3.1.2 Drawbacks of the Algorithm

This critical period technique, although very simple and straight forward, has few shortcomings. One drawback is the implicit assumption that the storage which would have been adequate in past will also be adequate in future. Although this is not clearly true, the error caused is not really serious particularly if sufficiently long flow series has been considered. However, this problem will arise in any other method since true future is not known. Some methods try to address this problem by explicitly considering the stochasticity of the inflows. Another drawback of the method is that explicit economic analysis can not be carried out. The storage size can not be related to the economic life of the project. Further, it can not be computed for a particular level of reliability.

3.1.3 Program Input & Output

The input data is mostly in free format. The organization of the input file should be as follows :

Line No(s)	Variable Name	Format	Description
1	TITL	A	Title of the problem (Maximum 60 characters)
2	N	Free	Number of periods for which analysis is to be performed (Maximum 100).
	IC	Free	A flag which equals 1 if only constant demand is to be read.

	IDO	Free	A flag which equals 1 if table of detailed computation is required.
3 onwards	FLOW(I)	Free	Inflows in the reservoir during each period for all the periods.
Next Line	REL(I)	Free	Demand values for all the period if the value of variable (IC) in line 2 is $\neq 1$.

The input data can be in any consistent system of units. A sample input file is shown below:

SAMPLE INPUT FILE

```
CAPACITY COMPUTATION FOR A RESERVOIR
 12  0  1
 600 1860 6200 9000 6200 4500 3100 2480 1680 1240  900 775
1500 1200 2000 1800 2400 2800 2100 1800 1400  800  700 500
```

SAMPLE OUTPUT FILE

RESERVOIR CAPACITY COMPUTATION USING SEQUENT PEAK ALGORITHM

CAPACITY COMPUTATION FOR A RESERVOIR

Input data available for 12 periods &
Analysis carried for 24 periods,i.e. Twice the length of record.

PERIOD	S(T)	INF(T)	REL(T)	S(T+1)
1	.00	600.00	1500.00	900.00
2	900.00	1860.00	1200.00	240.00
3	240.00	6200.00	2000.00	.00
4	.00	9000.00	1800.00	.00
5	.00	6200.00	2400.00	.00
6	.00	4500.00	2800.00	.00
7	.00	3100.00	2100.00	.00
8	.00	2480.00	1800.00	.00
9	.00	1680.00	1400.00	.00
10	.00	1240.00	800.00	.00
11	.00	900.00	700.00	.00
12	.00	775.00	500.00	.00

13	.00	600.00	1500.00	900.00
14	900.00	1860.00	1200.00	240.00
15	240.00	6200.00	2000.00	.00
16	.00	9000.00	1800.00	.00
17	.00	6200.00	2400.00	.00
18	.00	4500.00	2800.00	.00
19	.00	3100.00	2100.00	.00
20	.00	2480.00	1800.00	.00
21	.00	1680.00	1400.00	.00
22	.00	1240.00	800.00	.00
23	.00	900.00	700.00	.00
24	.00	775.00	500.00	.00

THE REQUIRED STORAGE IS : 900.00 M Cum

3.2 ELEVATION-AREA-CAPACITY INTERPOLATION

Since the primary function of reservoirs is to provide storage, their most important physical characteristic is storage capacity. Capacity of reservoirs on natural sites is usually determined from topographic surveys. An Elevation-Area curve is constructed by planimetering the area enclosed within the reservoir site. The integral of the Elevation-Area curve is the Elevation-Capacity curve for a reservoir.

The purpose of this module is to interpolate the elevation-area-capacity values for any range of elevation interval. Generally, the authorities at the dam site have some specific values (10-15) in the elevation-area-capacity table and it is desired to have the values at intermediate levels. This module facilitates calculation of intermediate values in the elevation-area-capacity table. Using this facility, the reservoir operating authorities can find out the area and capacity values for any elevation, provided the elevation lies in between the lowest and highest elevation.

Method of linear interpolation has been used for this purpose. All the available values of E-A-C are read as input by the module. The interpolation for any elevation is carried out considering its upper and lower E-A-C values. Though assumption of linear interpolation induces some error, the consideration of the actual intermediate E-A-C values reduces the error to great extent.

In addition to the input and output file names, the modules prompts for entering the initial starting storage (say 178.60 m for the sample input-output) and the subsequent elevation increments (say 0.1 m for the sample input-output) desired. Based on this input, the computations are made and the result is written in the output file.

3.2.1 Program Input & Output

The organization of the input file is as follows :

Line No(s)	Variable Name	Format	Description
1	TITL	A	Title of the problem (Maximum 60 characters)
2	NN	Free	Number of ordinates of the available Elevation-Area-Capacity table.
3 onwards	EL(I)	Free	Elevation in meters
	AR(I)	Free	Corresponding area in Million Sq. m.
	CAP(I)	Free	Corresponding capacity in Million Cu. m.

SAMPLE INPUT FILE

```
ELEVATION-AREA-CAPACITY TABLE FOR A RESERVOIR
12
170.69        8.043      29.078
173.74       11.929      58.898
176.78       18.525     103.203
179.83       32.189     180.844
182.88       50.640     304.596
185.93       73.358     497.225
188.98      100.133     763.135
189.59      105.621     829.415
190.50      113.314     926.847
192.02      125.047    1108.144
193.55      137.673    1309.163
194.00      142.000    1420.000
```

SAMPLE OUTPUT FILE

The output table, generated by the program, is written in the output file. The output file contains a maximum of 150 elevation levels for which the area and capacity values are computed. Sample output file for the above input is given in the following. The initial starting elevation of 178.60 m and increments of 0.1 m have been assumed.

ELEVATION-AREA-CAPACITY TABLE FOR A RESERVOIR

Elevation (m)	*Area (M Sq m)*	*Capacity (M Cu m)*
178.60	26.679	149.533
178.70	27.127	152.079
178.80	27.575	154.625
178.90	28.023	157.170
179.00	28.471	159.716
179.10	28.919	162.262
179.20	29.367	164.808
179.30	29.815	167.353
179.40	30.263	169.899
179.50	30.711	172.445
179.60	31.159	174.991
179.70	31.607	177.537
179.80	32.055	180.082
179.90	32.613	183.688
180.00	33.218	187.745
180.10	33.823	191.803
180.20	34.428	195.861
180.30	35.033	199.918
180.40	35.638	203.976
.	.	.
.	.	.
.	.	.
.	.	.
.	.	.
193.40	136.443	1289.574

3.3 HYDROPOWER ANALYSIS

The generation of hydroelectric power is one of the main purposes of a water resources development project. With respect to types of site development, there are three major classifications of hydroelectric projects: storage, run-of-river, and pumped storage.

Storage plants are projects that usually have heads in the medium to high range (greater than 25 m) and that have provisions for storing relatively large volumes of water during periods of high streamflow to provide water for power generation during periods of deficient streamflow. The volume of storage capacity required is determined based on the period of deficient flows.

Run-of-river plants are projects that have little or no storage and, therefore, must generate power from streamflow as it occurs with little or no benefit from at-site regulation. These projects may be either peaking projects or base-load projects. However, in order for a base-load run-of-river project to be feasible, the stream must have a relatively high baseflow. Run-of-river projects generally have productive heads in the low to medium range (5 to 30 m) and are quite frequently associated with navigation developments or other multipurpose developments. Because of the absence or near absence of storage in run-of-river projects, there is usually very little operational flexibility in these projects. The existence of one or more storage projects in the upstream portion of a river basin may make a run-of-river project in the lower portion of the basin feasible where it would not otherwise be feasible.

Pumped storage plants are projects that depend on pumped water as a partial or total source of water for generating electric energy. This type of project derives its usefulness from the fact that the demand for power is generally low at night and on weekends and therefore, pumping energy at a very low cost will be available from ideal thermal generating facilities. If there is a need for peaking capacity and if the value of peaking generation sufficiently exceeds the cost of pumping energy, the pumped storage provide an attractive alternative.

Depending on the type of load served, hydropower projects can be classified in two ways: base-load plants and peaking plants.

Base-load plants are projects that generate hydroelectric power to meet the base-load demand. The base-load demand is the demand that exists 100 percent of the time. The base-load can readily be seen on a load duration curve. Usually the base-load demand is met by thermal generating facilities. However in cases where there is a relatively abundant supply of water that is available with a high degree of reliability and where fuel is relatively scarce, hydroelectric projects may be developed to meet the base-load demands also. These projects operate at or near full capacity for long period of time. This type of development is not feasible where there is a large seasonal variation in streamflow unless the baseflow is relatively high.

Peaking plants generate hydroelectric power to supplement base-load generation during periods of peak power demands. The peaking plant is put to operation depending upon the quantity of water available and the demand. Peaking plants must supply sufficient capacity to satisfy the peak capacity demands of a system and sufficient energy to make the capacity unable on the load, that is, energy or water should be sufficient to supply peaking support for as long and as often as the capacity is needed. In general, a peaking hydroelectric plant is desirable in a system that has thermal generation facilities to meet the base-load demands. The hydroelectric generating facilities are particularly adaptable to the peaking operation because their loading can be changed rapidly.

3.3.1 Hydropower Potential

Traditionally, hydroelectric power potential is determined on the basis of the critical hydroperiod as indicated by the historical record. The critical hydroperiod is defined as the period when the limitations of hydroelectric power supply due to hydrologic conditions are most critical with respect to power demands. Thus the critical period is a function of the power demand, the streamflow, and the available storage. If a project serves more than one purpose and if, in serving another purpose, some of the storage or streamflow is not available for power production, the average streamflow should be adjusted to reflect the "loss". Losses such as evaporation, leakage, and station use must also be deducted from the available flow before calculating the potential energy.

The tailwater elevation used to compute the average head should be a representative elevation that reflects average tail water conditions during a time when power generation actually occurs. For example, in a peaking project that usually generates power at or near installed capacity for a short duration, the tailwater elevation should correspond to the discharge at installed capacity rather than to the average discharge. Likewise, if there are releases that do not pass through the generating units but which significantly affect the tailwater, the tailwater elevation should reflect the combination of power releases and other releases.

3.3.2 Firm Power Optimization for Planning Purposes

Analogous to the concept of firm water, firm power is the maximum quantity of power that can be guaranteed to be delivered each year 100% of the time according to some prescribed distribution. Critical period hydrology is used as the inflow sequence for the determination of the firm power output. The firm power output can be represented by

$\min_i \; [HE_i]$

where HE_i is the amount of hydropower produced by the reservoir during period i.

Let us consider a situation in which a reservoir exists at a particular site. The data like elevation-area-capacity table, inflow, normal evaporation depth are available. The problem is to determine the amount of firm power possible from this reservoir. Let I_i be the inflow to the reservoir during the i^{th} month and Q_i be the water released from the reservoir for the purpose of power generation.

Representing by S_i the storage content of the reservoir at the beginning of period i, the continuity equation is:

$$S_i + I_i - Q_i - E_i = S_{i+1} \qquad \ldots(2)$$

where E_i = evaporation loss during i^{th} period. This equation has to be satisfied for each of the period. The value of S_i is given as input. The evaporation loss E_i is function of both S_i and S_{i+1} and can be easily considered if the information about the depth of evaporation is available. It is also required that the amount of hydropower generated in each period must be more than or equal to the firm power. The power generated can be computed by

$$KWHR = 9.817 \; Q \; H \; T \; \eta \qquad \ldots(3)$$

in which KWHR is the hydropower generated during the period, in kwhr, H is the average head during the period in m, T is the number of hours in the period and η is the overall efficiency of the plant expressed as a ratio. The storage contents of the reservoir in each period must be within the physical limits. Hence

$$S_{min} \leq S_i \leq S_{max}$$

The maximum possible firm power which can be generated depends upon the site conditions, hydrology of the area and the capacity of generating equipment. The lower bound of firm power is zero. With the desired accuracy, specified lower bound and calculated upper bound, one dimensional binary search is carried out to reach the optimum value of firm power. In this method, first the upper and lower bounds on the capacity of the reservoir are determined. A trial value for the firm power is selected which is the mean of upper bound and lower bound.

Now the operation of the reservoir is simulated using the streamflow data. At each time interval, attempt is made to generate the power equal to the firm power if possible. If the available water in reservoir is less than S_{min}, no release is made and the storage is depleted by evaporation only. If during any period, $S_i + I_i \geq S_{max}$, the extra water over the storage capacity after meeting the hydropower demand is spilled. If there is not enough water in the reservoir to generate the required power, the power is generated to the extent possible. In this way, the reservoir operation is simulated for the entire period of record including the critical period.

The minimum of power generated in each period is computed. If this value is less than the trial value of the firm power, it means that the trial value must be decreased. The feasible region above this trial value is discarded and the trial value for the next iteration is chosen midway between the upper bound and new lower bound. If the minimum value comes out to be higher than the trial value, the region between the trial value and the lower bound is discarded for further examination. The present value becomes the new upper bound. Again the trial value for the next iteration is chosen as mean of new upper bound and old lower bound.

The computations are repeatedly performed in this manner and they are terminated when the required convergence is achieved. This method converges quite rapidly as the feasible region is halved every time. It may be mentioned that a more efficient nonlinear programming method could also be used for optimization.

3.3.3 Program Input & Output

The module has two options: a) Firm power determination and b) Hydropower simulation. For both the modules, the organization of the input file is same and is given as follows:

Line	Variable Name	Format	Description
1	TIT	A	Title of the problem (Maximum 60 characters)
2	IYEAR	Free	First year of record.
	IMON	Free	Starting month of the year.
	NMON	Free	Number of months of record.
	PMAX	Free	Power plant capacity in Kw.
3	SMIN	Free	Minimum reservoir storage in Cu. m.

	SMAX	Free	Maximum reservoir storage in Cu. m.
	SINT	Free	Initial reservoir storage in Cu. m.
	FAC	Free	Factor to convert inflows to Cu. m.
	TWL	Free	Tail water elevation in meter.
	EFF	Free	Efficiency of the plants.
	NG	Free	Number of ordinates in Elevation-Area-Capacity table.
4 onwards	EL(I)	Free	Elevation in meters
	AR(I)	Free	Corresponding area in Million Sq. m.
	VOL(I)	Free	Corresponding capacity in Million Cu. m.
Next line	EVP(I)	Free	12 values of normal monthly evaporation in cm.
Next line onwards	AINF(I)	Free	Monthly inflow values.

If firm power is to be determined, the module asks the input and output file names and then presents the possible firm power from a project for the input data. If hydropower simulation is to be carried out, then the module prompts to enter the required power demand in a month. The program assumes constant power demand for all the months. The sample input and output is presented in the following:

SAMPLE INPUT FILE

```
HYDROPOWER SIMULATION

1956  11  15  5000

50.0E+06  473.0E+06  60.0E+06  100000.0  616.0  0.85  11

      650.00       0.303       39.37
      660.00       0.405       72.45
      670.00       0.506      118.12
      680.00       0.612      174.80
      690.00       0.708      239.40
      700.00       0.820      318.15
      710.00       0.915      400.05
      717.92       1.004      466.20
      718.25       1.012      473.00
      719.90       1.022      483.00
      720.89       1.040      493.00
```

```
4.2  5.2  8.9  9.9  11.6  11.0  11.9  10.8  8.9  7.9  5.4
4.3

160.903   106.223  116.953  113.586  117.035  156.487
337.167   250.064  216.624  237.203  244.432  238.208
103.728    83.608   65.548
```

SAMPLE OUTPUT FILE

The output file is obtained assuming power demand of 2 MW in each month.

```
        RESERVOIR SIMULATION FOR HYDROPOWER

 Maximum reservoir capacity = 473.00 M Cum
 Minimum reservoir capacity =  50.00 M Cum
 Initial reservoir capacity =  60.00 M Cum

 OPERATION OF THE RESERVOIR IS TO BE SIMULATED
 Power to be generated in each month = 2.00 MW
```

Reservoir Working Table

Year-Mn	Ini_stor M Cum	IN_FLO M Cum	EVPN M Cu	OT_FLO M Cum	RES_VOL M Cum	Res_Lev M	SPILL M Cum	GEN_POWER kW
1956 11	60.00	16.09	0.02	15.58	60.49	656.386	0.00	2000.00
1956 12	60.49	10.62	0.02	16.42	54.68	654.628	0.00	2000.00
1957 1	54.68	11.70	0.01	16.36	50.00	653.213	0.00	1912.23
1957 2	50.00	11.36	0.02	11.34	50.00	653.213	0.00	1440.15
1957 3	50.00	11.70	0.03	11.67	50.00	653.213	0.00	1338.92
1957 4	50.00	15.65	0.03	15.62	50.00	653.213	0.00	1850.73
1957 5	50.00	33.72	0.04	16.28	67.39	658.471	0.00	2000.00
1957 6	67.39	25.01	0.04	14.32	78.03	661.222	0.00	2000.00
1957 7	78.03	21.66	0.05	14.09	85.55	662.868	0.00	2000.00
1957 8	85.55	23.72	0.05	13.52	95.70	665.091	0.00	2000.00
1957 9	95.70	24.44	0.04	12.46	107.64	667.705	0.00	2000.00
1957 10	107.64	23.82	0.04	12.26	119.17	670.184	0.00	2000.00
1957 11	119.17	10.37	0.03	11.61	117.90	669.951	0.00	2000.00
1957 12	117.90	8.36	0.02	12.12	114.11	669.123	0.00	2000.00
1958 1	114.11	6.55	0.02	12.36	108.29	667.847	0.00	2000.00

3.4 INFLOW ESTIMATION

Inflow to a reservoir is the basic input which is regulated by a reservoir to obtain the maximum possible benefits. For measuring the amount of inflow entering a reservoir, it is generally not possible to install a discharge gauging station in the immediate upstream of the reservoir because of the rapid water level fluctuations and back water effects. Second option is to extrapolate the observed discharge at a gauging station located far away upstream of the dam. However, in such cases, major error gets introduced in the calculation of the actual inflow rate to a reservoir. Hence, it is preferred to measure the inflow rate in a reservoir by the rate of rise method. In this method, the rate of rise is observed at the reservoir in meter/hr and this is related to the inflow rate.

The basic purpose of the present module is to prepare the inflow estimation table for different rate of rise and at different elevations. The only data required for this purpose is the elevation-area-capacity table and information about the release from the dam, if any. After entering the input and output file names, the program prompts to enter the a) Initial elevation, b) Increment in elevation, c) Initial rate of rise d) Increment in rate of rise and e) Release rate from the reservoir, if any. The output is presented in the form of a table. Inflow rate values (in cumec) for different elevations are computed for ten values of rate of rise. Thus, knowing the initial reservoir elevation, rate of rise and the outflow rate, inflow rate in the reservoir can be calculated.

3.4.1 Program Input & Output

The organization of the input file is as follows :

Line No(s)	Variable Name	Format	Description
1	TITL	A	Title of problem (Maximum 60 characters)
2	NN	Free	Number of ordinates in the Elevation-Area-Capacity table.
3 onwards	EL(I)	Free	Elevation in meters
	AR(I)	Free	Corresponding area in Million Sq. m.
	CAP(I)	Free	Corresponding capacity in Million Cu. m.

The sample input and output file is presented in the following. It is assumed that the outflow rate from the reservoir is nil.

SAMPLE INPUT FILE

```
INFLOW ESTIMATION
12
170.69        8.043      29.078
173.74       11.929      58.898
176.78       18.525     103.203
179.83       32.189     180.844
182.88       50.640     304.596
185.93       73.358     497.225
188.98      100.133     763.135
189.59      105.621     829.415
190.50      113.314     926.847
192.02      125.047    1108.144
193.55      137.673    1309.163
194.00      142.000    1420.000
```

SAMPLE OUTPUT FILE

Discharge Calculation (Cumec) for Different Rate of Rise (m/hr)

Elev.	Rate of Rise										
	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
175.00	4048.3	4453.2	4858.0	5262.9	5667.7	6072.5	6477.4	6882.2	7347.5	8054.6	8761.7
175.10	4048.3	4453.2	4858.0	5262.9	5667.7	6072.5	6477.4	6942.6	7649.8	8356.8	9064.0
175.20	4048.3	4453.2	4858.0	5262.9	5667.7	6072.5	6537.9	7244.9	7952.1	8659.1	9366.3
175.30	4048.3	4453.2	4858.0	5262.9	5667.7	6133.0	6840.2	7547.2	8254.4	8961.4	9668.6
175.40	4048.3	4453.2	4858.0	5262.9	5728.2	6435.3	7142.5	7849.5	8556.7	9263.7	9970.9
175.50	4048.3	4453.2	4858.0	5323.4	6030.5	6737.6	7444.8	8151.8	8859.0	9566.0	10273.2
175.60	4048.3	4453.2	4918.6	5625.7	6332.8	7039.9	7747.1	8454.1	9161.3	9868.3	10575.5
175.70	4048.3	4513.8	5220.9	5928.0	6635.1	7342.2	8049.4	8756.4	9463.6	10170.6	10877.8
175.80	4109.0	4816.1	5523.2	6230.3	6937.4	7644.5	8351.7	9058.7	9765.9	10472.9	11180.1
175.90	4411.2	5118.4	5825.5	6532.6	7239.7	7946.8	8654.0	9361.0	10068.2	10775.2	11482.4
176.00	4713.5	5420.7	6127.7	6834.9	7542.0	8249.1	8956.3	9663.3	10370.5	11077.5	11784.7
176.10	5015.8	5723.0	6430.0	7137.2	7844.2	8551.4	9258.6	9965.6	10672.8	11379.8	12087.0
176.20	5318.1	6025.3	6732.3	7439.5	8146.5	8853.7	9560.9	10267.9	10975.1	11682.1	12389.3
176.30	5620.4	6327.6	7034.6	7741.8	8448.8	9156.0	9863.1	10570.2	11277.4	11984.4	12691.6
176.40	5922.7	6629.9	7336.9	8044.1	8751.1	9458.3	10165.4	10872.5	11579.6	12286.7	12993.8
176.50	6225.0	6932.2	7639.2	8346.4	9053.4	9760.6	10467.7	11174.8	11881.9	12589.0	13296.1
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
189.80	30761.3	34074.6	37387.5	40700.9	44013.8	47327.1	50640.5	53953.4	57266.7	60579.6	63893.0

3.5 MULTI-RESERVOIR OPERATION SIMULATION

This model can be used to simulate the operation of a multipurpose multireservoir system for conservation operation. The various conservation purposes considered in the model are water supply for domestic and industrial purposes, irrigation, hydropower generation and minimum flow in the downstream river channel. In a multireservoir system, the model can help in finalizing the optimum rule levels for each storage location.

For each storage location, the model operates the reservoir in accordance with the given trial rule curves (given for each reservoir) and carries out the reliability analysis. Correspondingly, it calculates the time and volume reliability of each reservoir for the given set of rule curve levels and for the given period of operation. Detailed simulation table is also prepared. Based on the observation from the simulation tables, trial rule curves are modified till optimum results are achieved.

In the program, several checks have been introduced to detect the likely errors while preparing the input data. After reading a group of data items, the program displays a message on the screen showing that the corresponding data items have been read properly. This facility is immensely helpful in locating the possible error as the user knows that for which structure and at which group of data, the error is encountered. The program reads in the entire data for a structure at a time. After reading the input data, the simulation of operation for each structure is performed.

3.5.1 Methodology Adopted for Reservoir Operation

The highest priority is given to the water supply demand for domestic and industrial purposes and the minimum flow requirements in the downstream channel. The demands for irrigation and hydropower are given low priority as compared to the water supply and minimum flow demand. The priority between hydropower generation or irrigation is user specified and may change from one period (month/ten-daily) to another.

The amount of water required to produce hydropower depends on the head of water available which keeps on changing. This amount is calculated based on the mean elevation of water during a period. In the present model, four rule curve levels have been specified, namely the upper rule level, the first middle rule level, second middle rule level (if applicable) and the lower rule level.

a) Upper Rule Level

The upper rule level specifies the uppermost level up to which a reservoir should be filled if there is sufficient inflow to the reservoir. The upper rule level can be either FRL or a level below FRL. If the reservoir reaches this level then the demands for the remaining duration of that year are likely to be satisfied in full. If the level in the reservoir overtops the upper rule level, then water is spilled from the reservoir in the downstream river. Thus, it is the most desirable level and effort is made to maintain this level.

Though it is always desirable to fill a reservoir up to the maximum available capacity (up to FRL), it is recommended that some spill should be made from the reservoir to keep up the downstream river channel and to avoid encroachment in the river bed. Keeping the upper rule level below FRL can give extra room for flood absorption in the reservoir also. However, lowering the upper rule level below FRL should not affect the performance of the reservoir for conservation demands.

b) First Middle Rule Level

The middle and lower rule levels are used in the situation when water is scarce and full supply for the various demands cannot be made throughout the year. Supply for some demands (with lower priority) can be curtailed to some extent so that the partial demands can be satisfied for longer duration. The underlying assumption is that it would always be better to supply less water for longer duration rather than to meet free demand for some time and then stop the supply.

Based on the priority between irrigation and hydropower, the first middle rule level can be critical for irrigation or power generation which are given low priority as compared to domestic and industrial water supply demands and minimum flow requirements. If irrigation is at higher priority, this rule level corresponds to hydropower rule level and vice-versa. If the water level in the reservoir is above the first middle rule level, full supply of water is made for all the demands. However, if the water level in a reservoir falls below the first middle rule level, reduced supply (based on the curtail factor) is made for the least priority demand and full supply is made for other demands. The release is made at the reduced rate so that the partial demands can be met for longer duration.

c) Second Middle Rule Level

The second middle rule levels are derived when the purposes from a reservoir include, both, irrigation and hydropower in addition to the water supply demands. It is used in a situation when water is so scarce that even after curtailing demands for least priority demands, release for other higher priority demands can not be made in full.

The second middle rule level is critical for second higher priority demand (irrigation or hydropower). If the water level in the reservoir falls below the second middle rule level, the supply for the least priority demand is completely curtailed, reduced supply (based on the curtail factor) is made for the second least priority demand and full supply is made for the highest priority water supply demands. The release is made at the reduced rate so that these partial releases can be maintained throughout the water year.

d) Lower Rule Level

The lower rule level is critical for water supply demands and minimum flow requirements in the downstream river. If the reservoir level falls below the lower rule level, then supply is made to meet full demands of water supply and minimum flow only. No water is released for irrigation or hydropower generation in this situation. If this water passes through the power plants, then some incidental hydropower may also get generated.

3.5.2 Data Requirement of the Model

The data requirements of the model are quite modest and such type of data are generally available with the operating authorities at the dam sites. Some data pertain to the information about each structure viz. full reservoir level, dead storage level, elevation-area-capacity table, various conservation demands from the reservoir like water supply for domestic and industrial purposes, irrigation, hydropower demands and minimum flow requirements in the downstream channel, evaporation depths and local inflow from the intermediate/free catchment area. If the concerned location is to meet some demands of a downstream structure also, then the number of the node whose demands are to be met and the percentage of demands is also specified in the input data. Some data like defining the configuration of the system and the trial rule curve are specified by the user.

The model can be used for a system having any number of control points. If the number of control points in the system is larger than the dimensional limits specified, the parameter *I1* of the program should be increased and the program must be compiled again. In the present form, it can perform analysis for 6 nodes for 400 periods of record.

For defining initial conditions at each location, data in the form such as initial year, initial month and initial storage in each storage location is specified.

For structures operated for hydropower generation, details regarding the method of water supply through the power plants, installed capacity of the plants, minimum level for power production, tail level elevation and efficiency of the plants are to be specified. Four methods of supply of water through the power plant have been considered. In the first case, all the releases from the reservoir including irrigation (partial or full) and water supply for domestic and industrial purposes are routed through the power plant. In the second case, releases for domestic and industrial water supply and partial irrigation (if any) bypass the power plant and the rest of release is passed through the power plant. In the third case, release for irrigation purpose bypasses the power plant and rest of supply passes through the plant. In the fourth case, no release, except minimum downstream flow requirement, pass through the power plants. It has been assumed that release made for maintaining minimum flow for satisfying demands of any downstream structure always passes through the power plant. In addition, in case of deficiency of water in the reservoir, priority between irrigation or power is also to be specified for each period. Generally, it has been observed that two irrigation canals emerge from a dam (LBC and RBC) and power houses are installed at one of the canals. For this condition, irrigation demands have been bifurcated in two parts (say left bank canal demands and right bank canal demands). Those irrigation demands that pass through power plant are to be input in the data file for the RDMD1(I,J) variable. If all or non of the irrigation demands pass through the power plant, then all irrigation demands (for LBC and RBC together) must be input for the variable RDMD1(I,J) and zero (0) values must be input for the variable RDMD2(I,J).

The model can simulate operation of a system either for monthly operation or for ten-daily operation. In case of monthly operation, the various demands, evaporation depths, trial rule curves and local inflows are given at monthly interval. For ten-daily operation, all these are specified at an interval of ten days for one water year. A variable (IFMON) in the model defines whether operation is to be carried out monthly or ten-daily.

Configuration of the System

It is generally a healthy practice to prepare the line diagram of the system under study. Line diagram should highlight the location of reservoir and diversion weirs/barrages and the location and direction of the connecting rivers and streams. For defining the system configuration in the model, node numbers must be assigned to each structure starting from the upstream structure. The node numbers are assigned in numeric starting from 1. Take care that all downstream structures should have node number higher to that of their upstream structures. The model recognizes each structure by its node number. Those structures that are contributing to a given structure is recognized from the node numbers of control points just upstream of the present location. In this way, the configuration of the system is read by the model. For each location, the model reads the name of the structure, its node number, number of nodes immediately upstream of the present node and their node numbers. Factor for reducing irrigation demands and hydropower demands in case of scarcity of water is also to be specified for each structure. Similarly, a factor for defining critical conditions (release less than a specified percentage of total demands) is also input for each structure.

3.5.3 Output of the Model

The model simulates the operation of the system for the specified period. Based on the trial rule curve levels, it calculates the monthly time and volume reliability for each structure. In addition, it also calculates the total number of months of failure, irrigation or power failure and water supply failure. It also calculates the number of months when the release from the reservoir is less than a specified percentage of the total demands and thus calculates the "Critical Failure" months.

In addition to calculating the reliability, a detailed operation table for each structure is optionally prepared. For each period, the table gives the year, month and period of operation, the initial storage, flow from intermediate catchment, evaporation, irrigation demand, water supply demand, hydropower and downstream demands, actual release made for these demands, power generated, spill from the structure, end level and middle and upper rule levels. Based on the observations from the tabular presentation, rule curve levels can be modified till the best operation performance is achieved.

Graphical Presentation

A module for analysing the operation results in the graphical form has been added in the program. For each control point in the system, four types of graphs can be visualized. These are: plot of reservoir inflow vs release, plot of reservoir level vs rule level, plot of reservoir storage vs inflow and plot of demand vs release. Based on the visual inspection of results also (in addition to the tabular form), the trial policy can be revised and rules for better management of the system can be developed.

3.5.4 Steps for Model Application

The recommended steps to be performed for applying this model to a system and for deriving the optimum rule curves are as follows:

1. Prepare the diagram of the system showing the name of reservoirs and diversion weirs/barrages, their location and the length and direction of the rivers and tributaries.

2. Give node numbers in numeric form to all the control points (storage reservoir,

diversion weir, barrage etc.) starting from the upstream node. Take care to see that node number of a particular control point should always be higher than that of all the structures situated upstream.

3. Get general details about the operation like the number of control locations in the system, initial month, initial year, total number of periods of operation, whether operation is to be carried out monthly or ten-daily.

4. Get general details about each control structure like the name of the structure in alphanumeric, node number of its location in the system, number of nodes immediately upstream, their node numbers, method of supply of water through the power plants (if non, write 0), factors for curtailing irrigation demands and hydropower demands and a factor for defining critical conditions (release less than a specified percentage of total demands).

5. If a reservoir location is operated for hydropower, get power production details which include installed capacity of power plant, tail water elevation, minimum level for power production, efficiency of the power plant, priority between irrigation and power in all periods of water year and power demands for all periods.

6. Get further details about each structure like the maximum capacity up to the full reservoir level, capacity up to the intake of water supply outlet, initial storage, number of points in the elevation-area-capacity table (0 in case of weir and barrage), downstream location whose demand is to be satisfied (if any) and the percentage of demands to be satisfied, irrigation demands (LBC and RBC separately), water supply demands, minimum flow demands in the downstream channel, trial upper, middle and lower rule curve levels (two middle rule curves in case irrigation and hydropower demands) in all the periods and the evaporation depths in all the periods of the water year.

7. For each structure, calculate the local flow coming from the free catchment area at that structure for all the periods of operation. If inflow is to be obtained by multiplying the inflow data of some other structure by some number, then the node number whose data are to be used for calculation of local inflow at present structure and the multiplication factor needs to be mentioned in the data file.

8. Prepare the data file, node-by-node for all the locations. The data must be entered in

in correct units as specified.

9. Keep the upper rule level at FRL and the middle and lower rule level as derived and operate the system. Find the failure months and the months of critical failure. First, adjust the lower rule level such that water supply failure months are reduced to the least possible. After finalising the lower rule levels, modify the second middle rule levels and then the first middle rule levels such the failure months can be reduced without increasing the number of critical failure months. The middle rule levels are modified till the required reliability is achieved without increasing the number of critical failure months.

10. After optimizing the middle rule curve levels, lower the upper rule levels for all periods (especially in the monsoon months) till the reliability of the system is affected.

3.5.5 PROGRAM INPUT & OUTPUT

Line	Variable Name	Format	Description
1	TITL	A	Title of the problem
2	NLOC	Free	Total number of controlling locations in the system.
	IMON(1)	Free	Initial month of operation.
	IYR(1)	Free	Initial year of operation.
	NMON	Free	Number of months of operation.
	IFMON	Free	A factor for specifying length of a period = 1 for monthly operation, = 3 for ten-daily operation).
3	-	-	Blank line
4	NAME(I)	A	Name of location in alphanumeric.
5	ICP(I)	Free	Node Number of the control point.
	ICP1(I)	Free	Number of control points immediately upstream of the present control.
	ICON(I)	Free	A flag to specify the way of supply of water through the power plants: = 0 -- no power plants, = 1 -- All release pass through plants,

			= 2 -- Irr. release bypasses the plants,
			= 3 -- WS release bypasses the plants.
			= 4 -- All release bypass the plants.
	FIR(I)	Free	A factor for reducing demands of irrigation in case of insufficient water.
	FPOW(I)	Free	A factor for reducing demands of hydropower in case of insufficient water (if icon(i) = 0, then 0).
	FCRI(I)	Free	a factor for defining critical conditions (release less than a specified percentage of total demands).
	ICP2(I)	Free	Node number of ICP1 control points upstream of the present control point.
If ICON(I) is Greater Than 0, Then			
6	PINST(I)	Free	Installed capacity of the power plants in MW.
	ETAIL(I)	Free	Tail water elevation (m).
	PLMIN(I)	Free	Minimum level for power production in meter.
	EFF(I)	Free	Efficiency of the power plants.
7	IPRIO(I,J)	Free	Priority index for irrigation & power = 0 if irrigation has higher priority, = 1 if power has higher priority.
8	POW(I,J)	Free	Monthly/ten-daily hydropower demand in MKwh.
Endif			
9	SMAX(I)	Free	Gross capacity up to FRL (m^3).
	SMIN(I)	Free	Gross capacity up to intake of WS outlet (m^3).
	STOR(I,1)	Free	Initial reservoir storage (m^3).
	NN(I)	Free	Number of points in Elevation-Area-Capacity table. NN = 0 for non-reservoir locations like weirs & barrage.
	IDP(I)	Free	A flag controlling simulation table printing: = 1 for detailed simulation table in output file; = 0 for no simulation table.
10 onwards	ELEV(I,J)	Free	Elevation in the Elevation-Area-Capacity table (m).
	AREA(I,J)	Free	Corresponding area in Million Sq. m.
	CAP(I,J)	Free	Corresponding capacity in Million Cu. m.

Next line	INFL	Free	A flag for reading/calculating local inflows: = 1, if inflow data of present location is to be read; = 2, if inflow data of present location is to be computed from the inflow data of some other location.
	FAC(I)	Free	Multiplication factor to convert inflow values in Cu. m.
	IDDP(I)	Free	Node number of the downstream location whose partial demands are to be satisfied by the present location.
	DFC(I)	Free	%age of downstream location demands to be satisfied.
	RETF(I)	Free	Return flow expressed as fraction of the irrigation release from the present location that will join the downstream location.
Next line	RDMD1(I,J)	Free	Irrigation demand from a canal (LBC or RBC) which passes through the power house (if applicable) in M Cum (either monthly or ten-daily) starting from January. If there is no power house or all irrigation demand (LBC + RBC) passes through the power house, then this represents total irrigation demand (LBC+RBC).
Next line	RDMD2(I,J)	Free	Irrigation demand from other canal which does not pass through the power house (if applicable) in M Cum (either monthly or ten-daily) starting from January. If there is no power house or all irrigation demand (LBC + RBC) passes through the power house, then this represents zero (0) irrigation demand.
Next line	WDMD(I,J)	Free	Total domestic and industrial water supply demand in Million Cu. m (either monthly or ten-daily) starting from January.
Next line	AMFLO(I)	Free	Minimum flow demand in the downstream channel in M Cum (One value only).

Next line	RULE(I,J)	Free	Upper rule levels in meter (either monthly or ten-daily) starting from January.
Next line	AIL(I,J)	Free	First middle rule levels critical for irrigation or hydropower demands (depending on priority) in meter (either monthly or ten-daily) starting from January.

If both, Irrigation and Hydropower are to be Served, Then

Next line	POL(I,J)	Free	Second middle rule levels critical for irrigation or hydropower demands (depending on priority) in meter (either monthly or ten-daily) starting from January.

Endif

Next line	WPL(I,J)	Free	Lower rule levels critical for water supply and minimum flow demands in meter (either monthly or ten-daily) starting from January.
Next line	EVPD(I,J)	Free	Evaporation depth in meter/month (either monthly or ten-daily) starting from January.
Next line	FLOW(I,J)	Free	Inflow values at the location in Million Cu. m for all the periods of record (either monthly or ten-daily). If INFL is ≠ 1, then node number of the location whose inflow data is to be used for calculating the inflows at the present node must be specified here.

Note:

a) Data for each structure is added one by one. First, entire data of a location point is entered and then input for next location is taken up.

b) Before entering the name of a subsequent structure, a blank line is a must.

c) For each variable, except for FLOW(I,J), ELEV(I,J), AREA(I,J) and CAP(I,J), the index (I) refers to the structure while the index (J) refers to the period of operation of a water year. For the variable FLOW(I,J), (I) represents the same as above but the index (J) refers to the total period of operation and is equal to NMON*IFMON. Similarly for variables ELEV(I,J), AREA(I,J) and CAP(I,J), J is equal to NN(I).

SAMPLE INPUT FILE

Sample input file for the program is shown for hypothetical system. The line diagram of the system is presented in Fig. 5. The system has four reservoirs, one weir and one barrage as shown below:

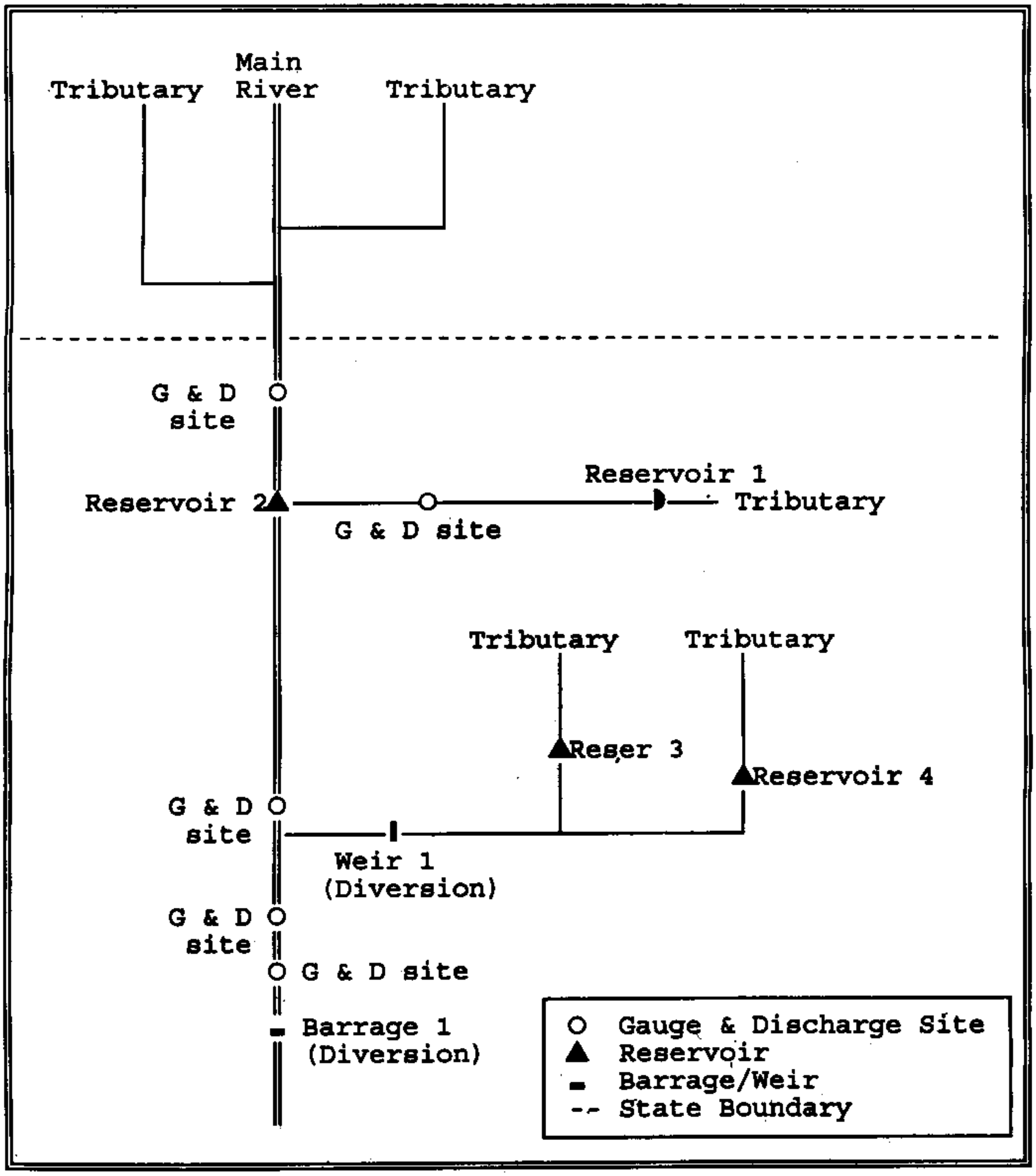

Fig. - 5 Line Diagram of the System

```
     Monthly Operation Simulation of a System

  6  6  1967  31  1

  Reservoir 1

  1  0  0  0.75  0.0  0.75  0

  24.2176E+06   1.7E+06  13.0E+06   10   1

    311.00     0.097       0.0892
    314.00     0.200       0.5257
    317.00     0.389       1.3957
    317.50     0.445       1.7000
    320.00     0.728       5.5959
    323.00     1.066       8.2696
    326.00     1.499      12.0996
    329.00     1.989      17.3176
    332.00     2.626      24.2176
    335.00     3.802      33.8056

  1  1000000   0   0   0

  2.360  1.380  0.00  0.00  0.00  0.00  0.00  2.774  3.193  1.723
  1.981  2.78    IRR1_DEMAND

  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00   0.00   0.00
  0.00   0.00   IRR2_DEMAND

  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00   0.00   0.00
  0.00   0.00    WS_DEMAND

  0.00          MIN_FLOW

  330.25  329.50  328.75  328.25  328.00  330.00  331.00  332.00  332.00  332.00
  331.50  331.00  UPPER RULE CURVE

  318.25  317.50  317.50  317.50  317.50  322.00  324.00  325.00  326.25  324.50
  322.50  320.00  MIDDLE RULE CURVE

  317.50  317.50  317.50  317.50  317.50  317.50  317.50  317.50  317.50  317.50
  317.50  317.50  LOWER RULE CURVE

  0.1402  0.1402  0.1890  0.2408  0.3048  0.2164  0.1524  0.1524  0.1524  0.1524
  0.1524  0.1524  EVAP_DEPTH

                                            0.00     9.84     3.75    17.91     0.04     0.00     0.00
0.00     0.00     0.00     0.00     0.00     0.00    27.13    45.59     0.01     0.00     0.00     0.00
0.00     0.00     0.00     0.00     0.00     0.00     0.81     1.36     0.00     0.00     0.00     0.00

  Reservoir 2

  2  1  1  0.80  0.9  0.75  1

  90.0  370.00  403.55  0.90

  0  0  1  1  1  1  0  0  0  0  0  0

  20.0  20.0  20.0  20.0  20.0  20.0  40.0  60.0  60.0  60.0  30.0  30.0

  3657.4890E+06  740.0178E+06  3000.00E+06  9  1

    402.336         33.7481        295.2354
    403.550         42.3247        740.0178
    408.432         77.1263       1205.4404
```

```
411.480      113.2015     1450.5711
414.528      153.5700     1949.4692
417.576      194.3948     2478.7512
420.624      236.8414     3138.7994
422.760      272.9351     3657.4890
423.000      278.0000     3766.2700

1  1000000  0  0  0

322.70  200.40  79.20  53.40  76.90  55.90  192.50  69.30  240.00  435.90
191.00  274.74    IRR1_DEMAND

4.50    4.50    4.50   4.50   4.50   4.50   4.50   4.50   4.50   4.50
4.50    4.50      IRR2_DEMAND

4.50  4.50   4.50   4.50   4.50  4.50   4.50  4.50   4.50   4.50
4.50  4.50        WS_DEMAND

0.00              MIN_FLOW

419.50  418.00  416.50  415.00  413.00  415.00  418.00  422.50  422.76  422.76
422.00  420.50    UPPER RULE CURVE

416.25  414.00  412.00  409.25  406.25  410.50  414.00  417.50  419.00  420.50
419.75  418.50    FIRST MIDDLE RULE CURVE

412.50  411.25  408.00  406.25  404.75  404.50  408.00  415.50  417.00  417.50
415.25  414.00    SECOND MIDDLE RULE CURVE

403.85  403.80  403.75  403.70  403.70  403.70  403.85  403.95  404.00  404.00
403.95  403.90    LOWER RULE CURVE

0.0682   0.07  0.1271   0.177  0.2387  0.198  0.1426  0.1147  0.099  0.1085
0.078  0.0682  EVAP_DEPTH

                                    35.63    98.66  2307.07  1164.30  355.60  51.70  31.60
14.86   9.93   6.43   3.10   0.81  116.30  2023.00  3745.08  2068.22  224.45  63.76  34.61
34.12  21.74   7.77   2.15   0.91    0.40  1688.15  2524.94  1060.35  213.65  65.56  36.22

Reservoir 3

3  0  0  0.75  0.0  0.75  0

829.415E+06   89.941E+06  400.737E+06  12  1

    170.69     8.043     29.078
    173.74    11.929     58.898
    176.78    18.525    103.203
    179.83    32.189    180.844
    182.88    50.640    304.596
    185.93    73.358    497.225
    188.98   100.133    763.135
    189.59   105.621    829.415
    190.50   113.314    926.847
    192.02   125.047   1108.144
    193.55   137.673   1309.163
    194.00   142.000   1420.000

1  1000000   5  0.5   0

42.017  36.289   0.066   0.000   0.000   6.878   1.504  4.141  19.786  31.095
42.103  30.235   IRR1_DEMAND

0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.00     IRR2_DEMAND
```

```
18.960  20.550  26.545  25.689  26.545  22.018  18.960  0.000  0.000  0.000
18.349  18.960   WS DEMAND

0.00             MIN_FLOW

188.75  188.25  187.75  187.25  186.75  188.75  189.25  189.59  189.59  189.59
189.59  189.25   UPPER RULE CURVE

183.80  182.75  180.65  180.65  180.65  178.80  180.50  181.95  184.50  186.25
185.70  184.90   MIDDLE RULE CURVE

183.25  182.75  180.65  180.65  180.65  178.80  180.25  181.75  183.50  184.25
183.85  183.50   LOWER RULE CURVE

0.1402  0.1402  0.1890  0.2408  0.3048  0.2164  0.1524  0.1524  0.1524  0.1524
0.1524  0.1524   EVAP_DEPTH


                                        13.54  333.79  172.37  263.22  45.29  12.31  14.30
0.47   0.89   0.86   0.50   0.27   0.46  229.22  630.41   21.94   5.99   2.66   1.77
0.24   2.62   0.32   0.10   0.73   4.75   81.74   55.61   33.45   2.60   0.56   0.27

Reservoir 4

4  0  0  0.65  0.0  0.6  0

152.513E+06  3.513E+06  83.513E+06  23  1

     168.86    0.550    0.940
     169.47    0.950    1.564
     170.08    1.500    2.324
     170.38    1.950    2.812
     170.69    2.378    3.513
     170.99    2.787    4.375
     171.60    3.950    6.132
     172.21    5.295    8.274
     172.82    6.689   11.600
     173.43    7.989   15.725
     174.04    9.104   20.462
     174.65   10.544   26.140
     175.26   11.799   32.762
     175.87   13.750   40.633
     176.48   16.072   49.962
     177.09   18.023   60.527
     177.70   20.160   71.955
     178.31   22.297   85.012
     178.61   23.133   92.243
     178.92   24.434   99.696
     179.53   27.732  115.940
     180.14   30.054  133.367
     180.75   32.144  152.759

1   1000000   0   0   0

4.190   1.800   0.000   0.000   0.000   1.050   0.390   1.210   3.980  4.960
4.520   4.800   IRR1_DEMAND

0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.00    IRR2_DEMAND

3.45    1.45    0.00    0.00    0.00    4.19    2.56    7.73    18.20   20.44
9.58    4.00    WS_DEMAND

0.00            MIN_FLOW
```

```
180.74  180.74  180.74  180.74  180.74  180.74  180.74  180.74  180.74  180.74
180.74  180.74    UPPER RULE CURVE

172.00  171.25  170.69  170.69  170.69  171.25  172.50  174.75  178.25  177.25
176.00  174.75    MIDDLE RULE CURVE

171.75  171.00  170.69  170.69  170.69  171.00  172.25  174.25  177.75  176.00
174.75  173.50    LOWER RULE CURVE

0.113   0.125   0.200   0.275   0.300   0.275   0.195   0.188   0.163   0.150
0.113   0.118     EVAP_DEPTH

                                        6.48    4.26    3.80  12.83    4.82    0.00    0.00
 0.00    0.00    0.00    0.00    0.00    0.00 145.33   50.68    5.29    3.11    0.00    0.00
 0.00    0.00    0.00    0.00    0.00    0.00  12.43    1.82    4.92    0.00    0.00    0.00

 Weir 1

 5  2  0  0.75  0.0  0.65  3  4

 17.784E+06  10.0E+06  0  0  1

 2   0.5714  0  0  0

 7.46     3.13    0.00    0.00    0.00    6.28    3.89    11.78    27.38   37.30
20.68     8.65   IRR1_DEMAND

 0.00     0.00    0.00    0.00    0.00    0.00    0.00    0.00     0.00    0.00
 0.00     0.00   IRR2_DEMAND

 4

 Barrage 1

 6  2  0  0.75  0.0  0.65  2  5

 5.35E+06  3.0E+06  0.0  0  1

 1  1000000   0   0   0

 0.00  0.00  0.00  0.00  0.00  0.33   30.36   53.93   70.12   42.84
 0.00  0.00   IRR1_DEMAND

 0.00  0.00  0.00  0.00  0.00  0.00    0.00    0.00    0.00    0.00
 0.00  0.00   IRR2_DEMAND

                                      4.55  149.28  103.54  130.98   22.19    5.83    3.35
1.91    1.21    1.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
1.25    0.95    0.87    0.57    0.33    4.08   12.38   16.65    2.74    1.97    0.98    0.76
```

SAMPLE OUTPUT FILE

```
      Monthly Operation Simulation of a System

Location No.  1,     Reservoir 1
Max. Storage     =  .242E+08 Cubic m,
Dead Storage     =  .170E+07 Cubic m,
Initial Storage =  .130E+08 Cubic m
Multiplication factor for inflows = .100E+07

Location No.  2,     Reservoir 2
Upstream Location Number(s) =   1
Max. Storage     =  .366E+10 Cubic m,
```

Dead Storage = .740E+09 Cubic m,
Initial Storage = .200E+10 Cubic m
Installed Capacity of Power Plant = 90.0 MW
Multiplication factor for inflows = .100E+07

Location No. 3, Reservoir 3
Max. Storage = .829E+09 Cubic m,
Dead Storage = .899E+08 Cubic m,
Initial Storage = .401E+09 Cubic m
Multiplication factor for inflows = .100E+07
This node is also operated to meet 50.00 % demand of location 5

Location No. 4, Reservoir 4
Max. Storage = .153E+09 Cubic m,
Dead Storage = .351E+07 Cubic m,
Initial Storage = .835E+08 Cubic m
Multiplication factor for inflows = .100E+07

Location No. 5, Weir 1
Upstream Location Number(s) = 3 4
Max. Storage = .178E+08 Cubic m,
Dead Storage = .100E+08 Cubic m,
Initial Storage = .000E+00 Cubic m
Flow at this node = Flow at node 4 * .57

Location No. 6, Barrage 1
Upstream Location Number(s) = 2 5
Max. Storage = .535E+07 Cubic m,
Dead Storage = .300E+07 Cubic m,
Initial Storage = .000E+00 Cubic m
Multiplication factor for inflows = .100E+07

System Operation Simulated for 31 Months, Beginning 1967 6

RESULTS FOR LOCATION NO. 1 - Reservoir 1

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1967-06-0	13.00	.00	.34	.00	.00	.00	.00	.00	326.32	322.00	330.00
1967-07-0	12.66	9.84	.30	.00	.00	.00	.00	.28	331.00	324.00	331.00
1967-08-0	21.92	3.75	.37	2.77	.00	.00	2.77	.00	331.26	325.00	332.00
1967-09-0	22.52	17.91	.39	3.19	.00	.00	3.19	12.63	332.00	326.25	332.00
1967-10-0	24.22	.04	.39	1.72	.00	.00	1.72	.00	331.10	324.50	332.00
1967-11-0	22.15	.00	.35	1.98	.00	.00	1.98	.00	330.09	322.50	331.50
1967-12-0	19.81	.00	.32	2.78	.00	.00	2.78	.00	328.65	320.00	331.00
1968-01-0	16.72	.00	.25	2.36	.00	.00	2.36	.00	327.15	318.25	330.25
1968-02-0	14.10	.00	.23	1.38	.00	.00	1.38	.00	326.23	317.50	329.50
1968-03-0	12.50	.00	.29	.00	.00	.00	.00	.00	326.06	317.50	328.75
1968-04-0	12.21	.00	.36	.00	.00	.00	.00	.00	325.80	317.50	328.25
1968-05-0	11.85	.00	.44	.00	.00	.00	.00	.00	325.46	317.50	328.00

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1968-06-0	11.41	.00	.30	.00	.00	.00	.00	.00	325.22	322.00	330.00
1968-07-0	11.11	27.13	.29	.00	.00	.00	.00	16.03	331.00	324.00	331.00
1968-08-0	21.92	45.59	.38	2.77	.00	.00	2.77	40.13	332.00	325.00	332.00
1968-09-0	24.22	.01	.38	3.19	.00	.00	3.19	.00	330.45	326.25	332.00
1968-10-0	20.66	.00	.34	1.72	.00	.00	1.72	.00	329.56	324.50	332.00
1968-11-0	18.60	.00	.30	1.98	.00	.00	1.98	.00	328.42	322.50	331.50
1968-12-0	16.31	.00	.27	2.78	.00	.00	2.78	.00	326.67	320.00	331.00
1969-01-0	13.27	.00	.21	2.36	.00	.00	2.36	.00	324.90	318.25	330.25
1969-02-0	10.70	.00	.18	1.38	.00	.00	1.38	.00	323.69	317.50	329.50

1969-03-0	9.15	.00	.22	.00	.00	.00	.00	.00	323.52	317.50	328.75
1969-04-0	8.93	.00	.27	.00	.00	.00	.00	.00	323.30	317.50	328.25
1969-05-0	8.66	.00	.33	.00	.00	.00	.00	.00	323.04	317.50	328.00

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1969-06-0	8.32	.00	.23	.00	.00	.00	.00	.00	322.80	322.00	330.00
1969-07-0	8.10	.81	.16	.00	.00	.00	.00	.00	323.37	324.00	331.00
1969-08-0	8.74	1.36	.16	2.77	.00	.00	2.08I	.00	322.54	325.00	332.00
1969-09-0	7.86	.00	.13	3.19	.00	.00	2.39I	.00	319.83	326.25	332.00
1969-10-0	5.33	.00	.10	1.72	.00	.00	1.29I	.00	318.94	324.50	332.00
1969-11-0	3.94	.00	.08	1.98	.00	.00	1.49I	.00	317.93	322.50	331.50
1969-12-0	2.37	.00	.07	2.78	.00	.00	.60C	.00	317.50	320.00	331.00

Number of Failures for WS. = 0, Time Reliability = 1.00

Number of Failures for IRR. = 5, Time Reliability = .839

Number of Critical Failures = 1
(Release < .75 * Total Demand)

Volume Reliability for IRR. & WS. = .90

RESULTS FOR LOCATION NO. 2 - Reservoir 2

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Us_Flo m m3	Evapr m m3	Tir_Dem m m3	Pw_Dem mw	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	PW_Gen mw	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1967-06-0	2000.0	35.6	.0	29.7	60.4	20.0	4.5	.0	190.5	20.0	.0	413.71	410.50	415.00
1967-07-0	1815.4	98.7	.3	18.6	197.0	40.0	4.5	.0	388.5	40.0	.0	411.83	414.00	418.00
1967-08-0	1507.3	2307.1	.0	20.8	73.8	60.0	4.5	.0	535.9	60.0	.0	421.11	417.50	422.50
1967-09-0	3257.6	1164.3	12.6	25.6	244.5	60.0	4.5	.0	480.0	60.0	271.5	422.76	419.00	422.76
1967-10-0	3657.5	355.6	.0	29.1	440.4	60.0	4.5	.0	475.3	60.0	.0	422.15	420.50	422.76
1967-11-0	3508.8	51.7	.0	19.9	195.5	30.0	4.5	.0	243.3	30.0	.0	421.28	419.75	422.00
1967-12-0	3297.3	31.6	.0	16.3	279.2	30.0	4.5	.0	288.2	30.0	.0	420.10	418.50	420.50
1968-01-0	3024.6	14.9	.0	14.9	327.2	20.0	4.5	.0	336.2	20.0	.0	418.54	416.25	419.50
1968-02-0	2688.1	9.9	.0	14.1	204.9	20.0	4.5	.0	213.9	20.0	.0	417.53	414.00	418.00
1968-03-0	2470.1	6.4	.0	23.7	83.7	20.0	4.5	.0	179.8	20.0	.0	416.39	412.00	416.50
1968-04-0	2273.1	3.1	.0	30.0	57.9	20.0	4.5	.0	184.6	20.0	30.1	415.00	409.25	415.00
1968-05-0	2031.4	.8	.0	35.0	81.4	20.0	4.5	.0	191.6	20.0	106.3	413.00	406.25	413.00

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Us_Flo m m3	Evapr m m3	Tir_Dem m m3	Pw_Dem mw	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	PW_Gen mw	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1968-06-0	1699.4	116.3	.0	25.5	60.4	20.0	4.5	.0	197.4	20.0	.0	412.35	410.50	415.00
1968-07-0	1592.7	2023.0	16.0	23.2	197.0	40.0	4.5	.0	368.9	40.0	669.1	418.00	414.00	418.00
1968-08-0	2570.6	3745.1	40.1	26.9	73.8	60.0	4.5	.0	495.9	60.0	2238.6	422.50	417.50	422.50
1968-09-0	3594.4	2068.2	.0	26.8	244.5	60.0	4.5	.0	473.7	60.0	1504.6	422.76	419.00	422.76
1968-10-0	3657.5	224.4	.0	28.5	440.4	60.0	4.5	.0	477.8	60.0	.0	421.60	420.50	422.76
1968-11-0	3375.6	63.8	.0	19.2	195.5	30.0	4.5	.0	245.7	30.0	.0	420.77	419.75	422.00
1968-12-0	3174.5	34.6	.0	15.7	279.2	30.0	4.5	.0	288.2	30.0	.0	419.54	418.50	420.50
1969-01-0	2905.1	34.1	.0	14.4	327.2	20.0	4.5	.0	336.2	20.0	.0	418.08	416.25	419.50
1969-02-0	2588.6	21.7	.0	13.6	204.9	20.0	4.5	.0	213.9	20.0	.0	417.02	414.00	418.00
1969-03-0	2382.8	7.8	.0	22.8	83.7	20.0	4.5	.0	181.7	20.0	.0	415.89	412.00	416.50
1969-04-0	2186.1	2.2	.0	29.0	57.9	20.0	4.5	.0	186.3	20.0	.0	414.66	409.25	415.00
1969-05-0	1973.0	.9	.0	34.5	81.4	20.0	4.5	.0	192.3	20.0	47.8	413.00	406.25	413.00

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Us_Flo m m3	Evapr m m3	Tir_Dem m m3	Pw_Dem mw	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	PW_Gen mw	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1969-06-0	1699.4	.4	.0	24.6	60.4	20.0	4.5	.0	199.0	20.0	.0	412.64	410.50	415.00
1969-07-0	1476.1	1688.2	.0	22.5	197.0	40.0	4.5	.0	371.8	40.0	199.4	418.00	414.00	418.00
1969-08-0	2570.6	2524.9	.0	26.9	73.8	60.0	4.5	.0	495.9	60.0	978.3	422.50	417.50	422.50
1969-09-0	3594.4	1060.3	.0	26.8	244.5	60.0	4.5	.0	473.7	60.0	496.7	422.76	419.00	422.76
1969-10-0	3657.5	213.6	.0	28.5	440.4	60.0	4.5	.0	478.0	[illegible].0	.0	421.55	420.50	422.76
1969-11-0	3364.7	65.6	.0	19.2	195.5	30.0	4.5	.0	245.9	30.0	.0	420.73	419.75	422.00
1969-12-0	3165.1	36.2	.0	15.7	279.2	30.0	4.5	.0	288.2	30.0	.0	419.51	418.50	420.50

Number of Failures for WS. = 0, Time Reliability = 1.00

Number of Failures for POW. = 0, Time Reliability = 1.000

Number of Failures for IRR. = 0, Time Reliability = 1.000

Number of Critical Failures = 0
(Release < .75 * Total Demand)

Volume Reliability for IRR. & WS. = 1.00

RESULTS FOR LOCATION NO. 3 - Reservoir 3

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1967-06-0	400.74	13.54	13.01	6.88	22.02	3.14	32.04	.00	183.90	178.80	188.75
1967-07-0	369.23	333.79	11.35	1.50	18.96	1.95	22.41	.00	187.90	180.50	189.25
1967-08-0	669.26	172.37	14.88	4.14	.00	5.89	10.03	.00	189.47	181.95	189.59
1967-09-0	816.72	263.22	16.02	19.79	.00	13.69	33.48	201.04	189.59	184.50	189.59
1967-10-0	829.41	45.29	15.97	31.09	.00	18.65	49.74	.00	189.40	186.25	189.59
1967-11-0	808.99	12.31	15.34	42.10	18.35	10.34	70.79	.00	188.66	185.70	189.59
1967-12-0	735.18	14.30	14.42	30.24	18.96	4.32	53.52	.00	188.04	184.90	189.25
1968-01-0	681.54	.47	12.35	42.02	18.96	3.73	64.71	.00	187.17	183.80	188.75
1968-02-0	604.95	.89	11.32	36.29	20.55	1.57	58.40	.00	186.38	182.75	188.25
1968-03-0	536.12	.86	14.22	.07	26.55	.00	26.61	.00	185.91	180.65	187.75
1968-04-0	496.14	.50	17.03	.00	25.69	.00	25.69	.00	185.24	180.65	187.25
1968-05-0	453.92	.27	19.97	.00	26.55	.00	26.55	.00	184.51	180.65	186.75

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1968-06-0	407.67	.46	13.02	6.88	22.02	3.14	32.04	.00	183.81	178.80	188.75
1968-07-0	363.08	229.22	10.45	1.50	18.96	1.95	22.41	.00	186.64	180.50	189.25
1968-08-0	559.44	630.41	14.12	4.14	.00	5.89	10.03	336.29	189.59	181.95	189.59
1968-09-0	829.41	21.94	15.92	19.79	.00	13.69	33.48	.00	189.34	184.50	189.59
1968-10-0	801.96	5.99	15.35	31.09	.00	18.65	49.74	.00	188.75	186.25	189.59
1968-11-0	742.85	2.66	14.32	42.10	18.35	10.34	70.79	.00	187.80	185.70	189.59
1968-12-0	660.40	1.77	13.19	30.24	18.96	4.32	53.52	.00	187.06	184.90	189.25
1969-01-0	595.47	.24	11.14	42.02	18.96	3.73	64.71	.00	186.19	183.80	188.75
1969-02-0	519.86	2.62	10.09	36.29	20.55	1.57	58.40	.00	185.25	182.75	188.25
1969-03-0	453.99	.32	12.47	.07	26.55	.00	26.61	.00	184.63	180.65	187.75
1969-04-0	415.23	.10	14.76	.00	25.69	.00	25.69	.00	183.99	180.65	187.25
1969-05-0	374.88	.73	17.19	.00	26.55	.00	26.55	.00	183.31	180.65	186.75

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1969-06-0	331.88	4.75	11.13	6.88	22.02	3.14	32.04	.00	182.61	178.80	188.75
1969-07-0	293.46	81.74	7.95	1.50	18.96	1.95	22.41	.00	183.52	180.50	189.25
1969-08-0	344.84	55.61	8.77	4.14	.00	5.89	10.03	.00	184.10	181.95	189.59
1969-09-0	381.65	33.45	9.07	19.79	.00	13.69	28.53I	.00	184.03	184.50	189.59
1969-10-0	377.50	2.60	8.97	31.09	.00	18.65	.00C	.00	183.93	186.25	189.59
1969-11-0	371.13	.56	8.68	42.10	18.35	10.34	18.35C	.00	183.51	185.70	189.59
1969-12-0	344.67	.27	8.20	30.24	18.96	4.32	18.96C	.00	183.09	184.90	189.25

Number of Failures for WS. = 0, Time Reliability = 1.00

Number of Failures for IRR. = 4, Time Reliability = .871

Number of Critical Failures = 3
(Release < .75 * Total Demand)

Volume Reliability for IRR. & WS. = .90

RESULTS FOR LOCATION NO. 4 - Reservoir 4

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1967-06-0	83.51	6.48	5.96	1.05	4.19	.00	5.24	.00	178.02	171.25	180.74
1967-07-0	78.79	4.26	4.10	.39	2.56	.00	2.95	.00	177.89	172.50	180.74
1967-08-0	76.00	3.80	3.77	1.21	7.73	.00	8.94	.00	177.44	174.75	180.74
1967-09-0	67.09	12.83	3.01	3.98	18.20	.00	18.20I	.00	176.99	178.25	180.74
1967-10-0	58.71	4.82	2.36	4.96	20.44	.00	20.44I	.00	175.88	177.25	180.74
1967-11-0	40.73	.00	1.39	4.52	9.58	.00	12.12I	.00	174.75	176.00	180.74
1967-12-0	27.23	.00	1.15	4.80	4.00	.00	7.12I	.00	173.85	174.75	180.74
1968-01-0	18.96	.00	.85	4.19	3.45	.00	7.64	.00	172.61	172.00	180.74
1968-02-0	10.47	.00	.65	1.80	1.45	.00	3.25	.00	171.72	171.25	180.74
1968-03-0	6.57	.00	.79	.00	.00	.00	.00	.00	171.48	170.69	180.74
1968-04-0	5.77	.00	.94	.00	.00	.00	.00	.00	171.15	170.69	180.74
1968-05-0	4.84	.00	.85	.00	.00	.00	.00	.00	170.85	170.69	180.74

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1968-06-0	3.98	.00	.67	1.05	4.19	.00	.00W	.00	170.60	171.25	180.74
1968-07-0	3.32	145.33	3.25	.39	2.56	.00	2.95	.00	180.43	172.50	180.74
1968-08-0	142.45	50.68	5.94	1.21	7.73	.00	8.94	25.81	180.74	174.75	180.74
1968-09-0	152.44	5.29	5.04	3.98	18.20	.00	22.18	.00	180.04	178.25	180.74
1968-10-0	130.52	3.11	4.13	4.96	20.44	.00	25.40	.00	179.09	177.25	180.74
1968-11-0	104.10	.00	2.71	4.52	9.58	.00	14.10	.00	178.40	176.00	180.74
1968-12-0	87.29	.00	2.56	4.80	4.00	.00	8.80	.00	177.89	174.75	180.74
1969-01-0	75.94	.00	2.25	4.19	3.45	.00	7.64	.00	177.38	172.00	180.74
1969-02-0	66.04	.00	2.32	1.80	1.45	.00	3.25	.00	177.09	171.25	180.74
1969-03-0	60.48	.00	3.54	.00	.00	.00	.00	.00	176.88	170.69	180.74
1969-04-0	56.94	.00	4.66	.00	.00	.00	.00	.00	176.61	170.69	180.74
1969-05-0	52.28	.00	4.79	.00	.00	.00	.00	.00	176.32	170.69	180.74

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Ws_Dem m m3	Tds_Dem m m3	Releas m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1969-06-0	47.49	.00	3.94	1.05	4.19	.00	5.24	.00	175.69	171.25	180.74
1969-07-0	38.31	12.43	2.73	.39	2.56	.00	2.95	.00	176.16	172.50	180.74
1969-08-0	45.06	1.82	2.57	1.21	7.73	.00	8.94	.00	175.46	174.75	180.74
1969-09-0	35.37	4.92	1.75	3.98	18.20	.00	18.20I	.00	174.02	178.25	180.74
1969-10-0	20.34	.00	.86	4.96	20.44	.00	15.97W	.00	170.69	177.25	180.74
1969-11-0	3.51	.00	.26	4.52	9.58	.00	.00W	.00	170.58	176.00	180.74
1969-12-0	3.25	.00	.25	4.80	4.00	.00	.00W	.00	170.46	174.75	180.74

Number of Failures for WS. = 4, Time Reliability = .87

Number of Failures for IRR. = 9, Time Reliability = .710

Number of Critical Failures = 3
(Release < .60 * Total Demand)

Volume Reliability for IRR. & WS. = .81

RESULTS FOR LOCATION NO. 5 - Weir 1

YYYY-Mn-D	Loc_Flo m m3	US_Flo m m3	Tir_Dem m m3	Diversion m m3	Spill m m3	Storage m m3
1967-06-0	3.70	3.140	6.280	6.280	.000	.563
1967-07-0	2.43	1.945	3.890	3.890	.000	1.052
1967-08-0	2.17	5.890	11.780	9.113I	.000	.000

1967-09-0	7.33	214.726	27.380	27.380	176.893	17.784
1967-10-0	2.75	18.650	37.300	37.300	.000	1.888
1967-11-0	.00	10.340	20.680	12.228C	.000	.000
1967-12-0	.00	4.325	8.650	4.325C	.000	.000
1968-01-0	.00	3.730	7.460	3.730C	.000	.000
1968-02-0	.00	1.565	3.130	1.565C	.000	.000
1968-03-0	.00	.000	.000	.000	.000	.000
1968-04-0	.00	.000	.000	.000	.000	.000
1968-05-0	.00	.000	.000	.000	.000	.000

YYYY-Mn-D	Loc_Flo m m3	US_Flo m m3	Tir_Dem m m3	Diversion m m3	Spill m m3	Storage m m3
1968-06-0	.00	3.140	6.280	3.140C	.000	.000
1968-07-0	83.04	1.945	3.890	3.890	63.313	17.784
1968-08-0	28.96	367.990	11.780	11.780	385.168	17.784
1968-09-0	3.02	13.690	27.380	27.380	.000	7.117
1968-10-0	1.78	18.650	37.300	27.544I	.000	.000
1968-11-0	.00	10.340	20.680	10.340C	.000	.000
1968-12-0	.00	4.325	8.650	4.325C	.000	.000
1969-01-0	.00	3.730	7.460	3.730C	.000	.000
1969-02-0	.00	1.565	3.130	1.565C	.000	.000
1969-03-0	.00	.000	.000	.000	.000	.000
1969-04-0	.00	.000	.000	.000	.000	.000
1969-05-0	.00	.000	.000	.000	.000	.000

YYYY-Mn-D	Loc_Flo m m3	US_Flo m m3	Tir_Dem m m3	Diversion m m3	Spill m m3	Storage m m3
1969-06-0	.00	3.140	6.280	3.140C	.000	.000
1969-07-0	7.10	1.945	3.890	3.890	.000	5.158
1969-08-0	1.04	5.890	11.780	11.780	.000	.307
1969-09-0	2.81	13.690	27.380	16.809C	.000	.000
1969-10-0	.00	.000	37.300	.000C	.000	.000
1969-11-0	.00	.000	20.680	.000C	.000	.000
1969-12-0	.00	.000	8.650	.000C	.000	.000

Number of Failures for WS. = 0, Time Reliability = 1.00

Number of Failures for IRR. = 16, Time Reliability = .484

Number of Critical Failures = 14
(Release < .65 * Total Demand)

Volume Reliability for IRR. & WS. = .64

RESULTS FOR LOCATION NO. 6 - Barrage 1

YYYY-Mn-D	Loc_Flo m m3	US_Flo m m3	Tir_Dem m m3	Diversion m m3	Spill m m3	Storage m m3
1967-06-0	4.55	125.562	.330	.330	124.432	5.350
1967-07-0	149.28	187.036	30.360	30.360	305.956	5.350
1967-08-0	103.54	457.605	53.930	53.930	507.215	5.350
1967-09-0	130.98	502.432	70.120	70.120	563.292	5.350
1967-10-0	22.19	30.383	42.840	42.840	9.733	5.350
1967-11-0	5.83	43.268	.000	.000	49.098	5.350
1967-12-0	3.35	4.500	.000	.000	7.850	5.350
1968-01-0	1.91	4.500	.000	.000	6.410	5.350
1968-02-0	1.21	4.500	.000	.000	5.710	5.350
1968-03-0	1.01	91.591	.000	.000	92.601	5.350
1968-04-0	.00	152.385	.000	.000	152.385	5.350

1968-05-0	.00	211.980	.000	.000	211.980	5.350

YYYY-Mn-D	Loc_Flo m m3	US_Flo m m3	Tir_Dem m m3	Diversion m m3	Spill m m3	Storage m m3
1968-06-0	.00	132.490	.330	.330	132.160	5.350
1968-07-0	.00	836.512	30.360	30.360	806.152	5.350
1968-08-0	.00	2656.245	53.930	53.930	2602.315	5.350
1968-09-0	.00	1729.278	70.120	70.120	1659.159	5.350
1968-10-0	.00	32.856	42.840	38.206I	.000	.000
1968-11-0	.00	45.726	.000	.000	40.376	5.350
1968-12-0	.00	4.500	.000	.000	4.500	5.350
1969-01-0	1.25	4.500	.000	.000	5.750	5.350
1969-02-0	.95	4.500	.000	.000	5.450	5.350
1969-03-0	.87	93.483	.000	.000	94.353	5.350
1969-04-0	.57	123.901	.000	.000	124.471	5.350
1969-05-0	.33	154.193	.000	.000	154.523	5.350

YYYY-Mn-D	Loc_Flo m m3	US_Flo m m3	Tir_Dem m m3	Diversion m m3	Spill m m3	Storage m m3
1969-06-0	4.08	134.114	.330	.330	137.864	5.350
1969-07-0	12.38	369.717	30.360	30.360	351.737	5.350
1969-08-0	16.65	1395.972	53.930	53.930	1358.692	5.350
1969-09-0	2.74	721.409	70.120	70.120	654.029	5.350
1969-10-0	1.97	33.061	42.840	40.381I	.000	.000
1969-11-0	.98	45.923	.000	.000	41.553	5.350
1969-12-0	.76	4.500	.000	.000	5.260	5.350

Number of Failures for WS. = 0, Time Reliability = 1.00

Number of Failures for IRR. = 2, Time Reliability = .935

Number of Critical Failures = 0
*(Release < .65 * Total Demand)*

Volume Reliability for IRR. & WS. = .99

3.6 RESERVOIR ROUTING

The passage of flood hydrograph through a reservoir is an unsteady flow phenomenon. The equation of continuity is used in all hydrologic routing methods as primary equation. The reservoirs can be either controlled or uncontrolled. The controlled reservoirs have spillway with gates operated for making releases at the desired rates. The uncontrolled reservoirs are those whose spillway is not controlled by the gate operation. Reservoir routing requires the relationship between the reservoir elevation, storage and discharge to be known. This relationship is a function of the topography of reservoir site and the characteristics of the outlet facility. Several methods for routing a flood wave through a reservoir have been developed, namely:

⇨ The Mass Curve Method,
⇨ The Modified Puls Method,

⇨ The Goodrich Method,

⇨ The Coefficient Method,

⇨ The Steinberg Method, and

⇨ The Wisler-Brater Method.

In the present software, the first four routing methods have been incorporated.

3.6.1 The Mass Curve Method

This is one of the most versatile methods of reservoir routing, various versions of which include: (i) direct, (ii) trial and error, and (iii) graphical.

For the solution by trial and error method, continuity equation is rewritten as:

$$M_2 - (V_1 + Q_m \Delta t) = S_2 \qquad \ldots(4)$$

where, M is the accumulated mass inflow, and V is the accumulated mass outflow.

A storage-discharge relationship and the mass curve of inflow should be plotted before obtaining trial and error solution. Necessary adjustments are made to show zero storage at the beginning elevation and, correspondingly, spillway discharge is obtained. The following steps are involved in the trial and error solution:

a) A time is chosen and Δt is computed. Mass inflow is also computed.

b) Mass outflow is assumed. As a guideline, it is a function of accumulated mass inflow.

c) Reservoir storage is computed by deducting mass outflow from mass inflow.

d) The instantaneous and average spillway discharges are calculated.

e) Outflow for the time period Δt is computed by multiplying Δt with average discharge. Then the mass outflow is computed.

f) Now, computed mass outflow is compared with assumed mass outflow. If the two values agree within an acceptable degree of accuracy, then the routing is complete. If this agreement is not acceptable, then another mass outflow is assumed and the above procedure is repeated.

3.6.2 The Modified Puls Method

The basic law used in the Modified Puls method states: *The inflow minus outflow is equal to the rate of change in storage*. This is also referred to as the Storage-Indication method. Assuming $I_m = (I_1 + I_2)/2$, $Q_m = (Q_1 + Q_2)/2$ and $\Delta S = S_2 - S_1$, continuity equation is written as:

$$(I_1 + I_2)\Delta t/2 - (Q_1 + Q_2)\Delta t/2 = S_2 - S_1 \qquad \ldots(5)$$

where, suffixes 1 and 2 denote the beginning and end of time interval Δt and Q may incorporate controlled discharge as well as uncontrolled discharge. Here the time interval Δt must be sufficiently small so that the inflow and outflow hydrographs can be assumed to be linear in that time interval. Further, Δt must be shorter than the time of transit of flood wave through the reservoir. Separating the known quantities from the unknown ones and rearranging:

$$(I_1 + I_2) + (2S_1/\Delta t - Q_1) = (2S_2/\Delta t + Q_2) \qquad \ldots(6)$$

Here, the known quantities are I_1 (inflow at time 1), I_2 (inflow at time 2), Q_1 (outflow at time 1) and S_1 (storage in the reservoir at time 1), and the unknown quantity are S_2 and Q_2. Since one equation with two unknowns can not be solved, therefore, one must have another relation that relates between storage, S, and outflow, Q. As the outflow from the reservoir takes place through the spillway, the discharge passing through the spillway can be conveniently related with the reservoir elevation which, in turn, can be related to the reservoir storage. Such a relationship is invariably available for any reservoir. Also, it can be computed from the following relation:

$$Q = C_d\, L\, H^{1.5} \qquad \ldots(7)$$

where, Q is the outflow discharge (cumec); C_d is the coefficient of discharge (=1.70 in metric unit); L is the length of spillway (m); and H is the depth of flow above the spillway crest (m).

Thus, the left side of equation (6) contains the known terms and the right side is unknown. The inflow hydrograph is known. The discharge Q, which may pass through the turbines, outlet works, or over the spillway is also known. The uncontrolled discharge goes freely over the spillway. It depends upon the depth of flow over the spillway and the spillway geometry. Further, the depth of flow over the spillway depends upon the level of water in the reservoir. Therefore:

$$S = S\,(Y)$$

$$Q = Q(Y)$$

where, Y represents the water surface elevation. The right side of equation (6) can be written as:

$$2S/\Delta t + Q = f(Y) \qquad \ldots(8)$$

Adding the crest elevation with the depth of flow, the elevation for which storage in the reservoir is known can be computed. Therefore, one can develop a relation between storage and outflow. This storage outflow relation is used to develop the storage indication [(2S/Δt) + Q] vs. outflow relation. To develop this relation, it is necessary to select a time interval such that the resulting linearisation of the inflow hydrograph remains a close approximation of the actual non-linear (continuous time varying) shape of the hydrograph. For smoothly rising hydrographs, a minimum value of $t_p/\Delta t = 5$ is recommended, in which t_p is the time to peak of the inflow hydrograph. In practice, a computer aided calculation would normally use a much greater ratio, say 10 to 20.

In order to utilize equation (8), the elevation storage and elevation-discharge relationship must be known. Before routing, the curves of (2S/Δt ± Q) versus Q are constructed. The routing is now very simple and can be performed using the above equation.

3.6.3 The Goodrich Method

In this method, the continuity equation is expressed as:

$$2S_1/\Delta t + I_1 + I_2 - Q_1 = 2S_2/\Delta t + Q_2 \qquad \ldots(9)$$

The Goodrich method involves construction of a family of routing curves for [(2S/Δt) ± Q] against Q for various values of I. As all the terms on the left side of the above equation are known, the right side can be obtained for a routing period Δt. The value of Q_2 can now be read from the routing curves against [$2S_2/\Delta t + Q_2$] and then S_2 can be computed. The routing can be carried out for subsequent time periods in a similar manner.

3.6.4 The Coefficient Method

In the coefficient method, the reservoir is represented by a single conceptual storage element assuming storage S to be directly proportional to outflow Q :

$$S = K\,Q \qquad \ldots(10)$$

where K is a proportionality factor equal to the reciprocal of the slope of the storage curve that can be a constant or a variable function of outflow. If K is constant, then the reservoir is linear, otherwise the reservoir is non-linear.

For flood routing, a finite difference approximation is normally employed. Equation (1) and (2) can be combined and written as:

$$\Delta t(I_1 + I_2)/2 - (Q_1 + Q_2)\Delta t/2 = K(Q_2 - Q_1)$$

or

$$Q_2 = Q_1 + C(I_1 - Q_1) + C(I_2 - I_1)/2 \qquad \ldots(11)$$

in which,

$$C = \Delta t/\,(K + 0.5\Delta t) \qquad \ldots(12)$$

If K is variable, then C can be derived and plotted as a function of Q. For each routing period, the appropriate value of C must be obtained corresponding to the outflow under consideration.

3.6.5 Data Requirements

For obtaining solution of a reservoir routing problem, the following data are needed:

(a) Storage volume vs. elevation curve for the reservoir,
(b) Water surface elevation vs. outflow discharge curve,
(c) Inflow hydrograph,
(d) Initial values of storage, inflow and outflow,
(e) For the coefficient method, the value of proportionality constant K, which is the reciprocal of the slope of the storage curve, is also needed.

3.6.6 Program Input & Output

The organization of the input file should be as follows:

Line	Variable Name	Format	Description
1	TIT	A	Title of problem (Maximum 60 characters)

2	N	Free	Number of values in Elevation-Capacity-Release capacity table.
	NRT	Free	Number of periods for which routing analysis is to be carried out.
	FAC	Free	Factor to convert units of inflows.
	DT	Free	Time interval of computations in hours.
3 onwards	TA(I,1)	Free	Elevation in meters.
	TA(I,2)	Free	Corresponding capacity in Million Cu. m.
	TA(I,3)	Free	Corresponding release capacity in cumecs.
Next line	FIN(I)	Free	Inflows to the reservoir in cumecs for all the periods.
Next line	ELE(1)	Free	Starting reservoir elevation in meter.

For the Coefficient method, the value of coefficient is required which is prompted to be supplied from the screen.

SAMPLE INPUT FILE

The sample input and output file is shown for the Mass Curve method of reservoir routing.

```
 FLOOD ROUTING PROGRAM
  13   16   1   6
  56        14         10
  58        21         81
  60        30        100
  62        40        115
  64        50        128
  66        60        141
  66.2      61        156
  66.4      62        183
  66.7      63.5      238
  66.9      64.5      282
  67        65        306
  67.5      67.5      443
  68        70        605
  50   75   180   350   450   520   505   445   360   290   180   160
140 120   100   80
  57.0
```

SAMPLE OUTPUT FILE

RESERVOIR ROUTING

Reservoir Routing by MASS CURVE METHOD

Computations for Initial Elevation 57.000 meter

Time Hr	Dt Hr	Inflow Cumec	Cumulative Inflow MCum	Average Outflow Cumec	Cumulative Outflow MCum	Reservoir Storage MCum	Reservoir Elevation m
0.0	6.0	50.00	1.080	50.00	1.080	17.500	57.000
6.0	6.0	75.00	2.700	48.33	2.142	18.058	57.159
12.0	6.0	180.00	6.588	64.69	3.362	20.726	57.922
18.0	6.0	350.00	14.148	86.67	4.997	26.651	59.256
24.0	6.0	450.00	23.868	100.75	7.021	34.347	60.869
30.0	6.0	520.00	35.100	113.21	9.332	43.268	62.654
36.0	6.0	505.00	46.008	124.67	11.901	51.607	64.321
42.0	6.0	445.00	55.620	134.52	14.700	58.420	65.684
48.0	6.0	360.00	63.396	152.37	17.799	63.097	66.619
54.0	6.0	290.00	69.660	260.08	22.253	64.907	66.981
60.0	6.0	180.00	73.548	261.50	27.886	63.162	66.632
66.0	6.0	160.00	77.004	197.97	32.849	61.655	66.331
72.0	6.0	140.00	80.028	162.03	36.737	60.791	66.158
78.0	6.0	120.00	82.620	147.26	40.077	60.043	66.009
84.0	6.0	100.00	84.780	140.44	43.184	59.096	65.819
90.0	6.0	80.00	86.508	138.99	46.202	57.806	65.561

3.7 THE STRETCHED THREAD RULE

Mass curve method has been used since long to estimate the required storage capacity of a reservoir. A new idea of ***Stretch Thread Rule***, a variant of the mass curve method, has been in use for quite some time. Optimal operation policy for maximum flow equalization can be derived for a reservoir using the stretched thread rule. This method offers a simple, computationally efficient and exact solution to the problem of derivation of reservoir operation rule curves. It has been shown that this method is superior to linear programming and dynamic programming techniques.

3.7.1 The Stretched Thread Method

The essence of the rule is illustrated in Fig. 6. The upper Fig. 6(a) shows two residual inflow mass curves called primal and dual curves placed wide apart one another so that a string is spanned horizontally in between them without touching either of them. A residual mass curve is a mass curve in which the horizontal axis represents the mean river flows. From the inflow series in the reservoir, residual inflow mass curve is plotted and two such curves are placed parallel to each other congruently. Now, if these primal and dual curves are brought close to each other, until the distance between them equals the effective storage capacity, then the string will be pushed up and down by the curves and will attain the final shape as shown in Fig. 6(b). This shape of the string is the residual outflow mass curve. For the objective of flow equalization, this is the most desirable outflow mass curve. Thus given the inflow mass curve and the effective storage capacity, outflow mass curve can be obtained.

Some properties of the optimal release policy obtained using the stretched thread method are as follows:

a) The optimal release at any time depends not only on the past inflows but on future ones also.
b) The optimal release directly depends on the immediate past and future flows but dependence on the flows in the remote past and future is limited to the location of the corner or turning points.
c) The optimal release does not depend on the current value of storage.
d) Difficulty in specifying the optimal release increases with the increase in reservoir capacity though in such situation, optimal release is better approximated by value of long term mean inflow.

3.7.2 Advantages of Stretched Thread Method

The stretched thread rule demonstrates in the clearest possible way the importance of flow forecasting as well as value of historic flow record. It shows why small reservoirs need forecasts with shorter lead time and vice versa. It explains why it is not so much the inflow rates that are important for optimal operation but rather the total inflow volumes for the reservoir. It is these volumes which determine the location of corner points which are crucial for the determination of optimum outflows.

Past inflows at a reservoir site are generally available and the optimum outflow for the past periods can be obtained using this module. However, for determining the optimum release in the present conditions and in future, short and medium term forecasting of inflows is necessary. Using the total inflow series (including the forecasted inflow) as input, optimum release in present and future conditions can be ascertained. This module prompts on the

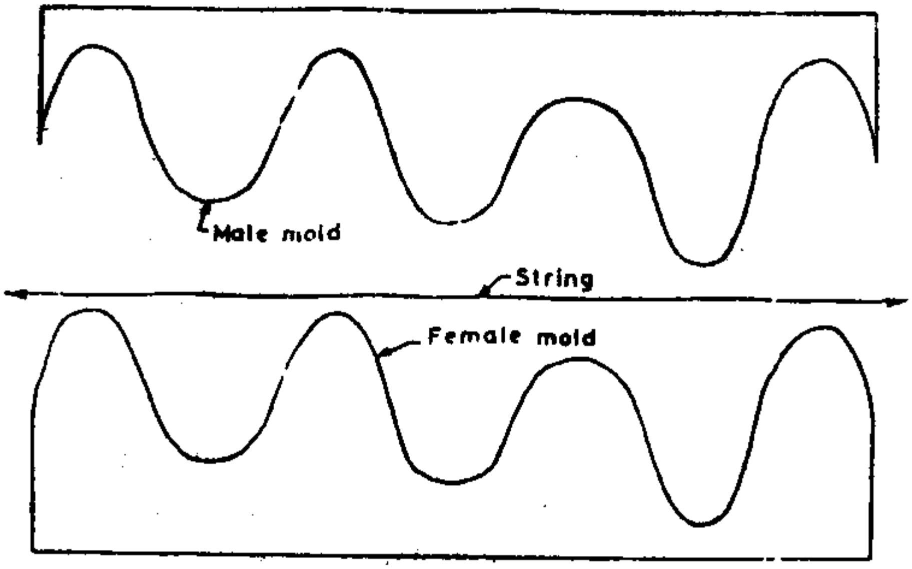

Fig. - 6a Primal and Dual Residual Inflow Mass Curves

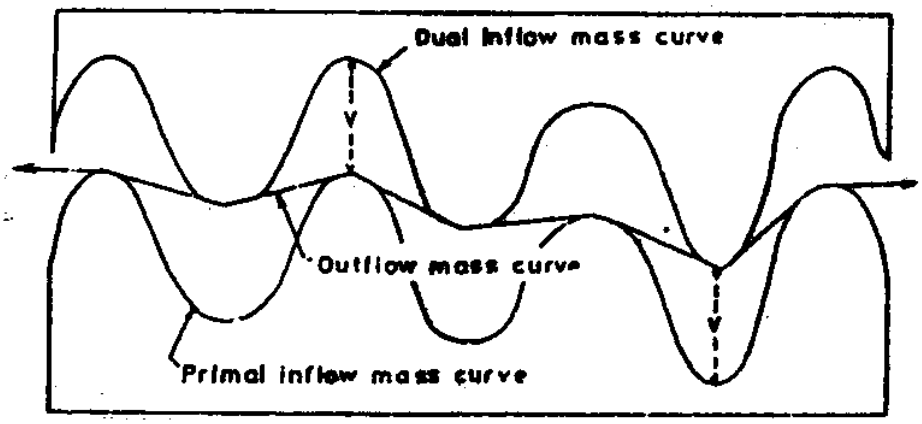

Fig. - 6b Residual Outflow Mass Curve

screen to enter the number of periods of forecast available and the values of the forecast inflows. Based on these values, it calculates the optimum release from the reservoir in the prevailing conditions and displays them on the screen.

3.7.3 Program Input & Output

The organization of the input file is as follows :

Line No(s)	Variable Name	Format	Description
1	TITL	A	Title of the problem (Maximum 60 characters)
2	IYR	Free	Initial year.
	IM	Free	Initial month.
	NM	Free	Number of periods of record.
	SCAP	Free	Effective storage capacity of the reservoir in Million Cu. m.
3 onwards	AINF(I)	Free	Inflows in the reservoir for all the periods of record in Million Cu. m.

SAMPLE INPUT FILE

```
STRETCHED THREAD METHOD
1951  1  120   20000
 333   2684    500   2818   436   133    64    46    25     8     4     3
 495    155    386    337   124    32     5     0     0     0     0     0
 103   6136    997   1671   376   130    89    78    62    47    34    30
1804   1284    808    206    59    30    40    50    54    52    49    47
  15    321    760   1140    57    47    45    47    43    47    28    21
1287    582    607    135    65    19     0     0     0     0     0     0
 678   7077  11981    709   151    71    52    53    34    15     6    19
  37  11528   5485   6872   323   167    32    24     8     3     2    45
 797  18460   6800   2752   399    55    32    26    14     6     3    74
 990   9858   4209  14017   440   181   168   103    71    32    17     8
```

SAMPLE OUTPUT FILE

```
                    STRETCHED THREAD METHOD

 Monthly mean inflow  =     1058.07

 Final results
```

Flow values are in Million cubic meter.

S. No.	Cumulative Low_Bound	Cumulative Opt_Outflo	Cumulative Upr_Bound
1	333.00	333.000	20333.00
2	3017.00	3017.000	23017.00
3	3517.00	4676.000	23517.00
4	6335.00	6335.000	26335.00
5	6771.00	6949.044	26771.00
6	6904.00	7563.088	26904.00
7	6968.00	8177.132	26968.00
8	7014.00	8791.176	27014.00
9	7039.00	9405.220	27039.00
10	7047.00	10019.260	27047.00
11	7051.00	10633.310	27051.00
12	7054.00	11247.350	27054.00
13	7549.00	11861.400	27549.00
14	7704.00	12475.440	27704.00
15	8090.00	13089.480	28090.00
16	8427.00	13703.530	28427.00
17	8551.00	14317.570	28551.00
18	8583.00	14931.620	28583.00
19	8588.00	15545.660	28588.00
20	8588.00	16159.700	28588.00
21	8588.00	16773.750	28588.00
22	8588.00	17387.790	28588.00
23	8588.00	18001.840	28588.00
24	8588.00	18615.880	28588.00
25	8691.00	19229.930	28691.00
26	14827.00	19843.970	34827.00
27	15824.00	20458.020	35824.00
28	17495.00	21072.060	37495.00
29	17871.00	21686.110	37871.00
30	18001.00	22300.150	38001.00
31	18090.00	22914.200	38090.00
32	18168.00	23528.240	38168.00
33	18230.00	24142.290	38230.00
34	18277.00	24756.330	38277.00
35	18311.00	25370.380	38311.00
36	18341.00	25984.420	38341.00
37	20145.00	26598.470	40145.00
38	21429.00	27212.510	41429.00

39	22237.00	27826.560	42237.00
40	22443.00	28440.600	42443.00
.	.	.	.
.	.	.	.
.	.	.	.
119	132966.00	147564.000	152966.00
120	132974.00	149794.000	152974.00

3.8 TRIAL RULE CURVE DERIVATION

Since more than 80% of the annual rainfall in India occurs in the four monsoon months from June to September, it is general tendency to fill up the reservoirs during the monsoon months and then to use this stored water for the remaining months of the water year. On the other hand, most of the flood situations also arise in the monsoon months and reservoirs should be kept empty so that they can effectively control any flood situation and prevent the downstream area from flooding. An optimum operation policy is derived keeping in view both these conflicting purposes to attain the maximum possible benefits from the reservoir. The reservoirs are frequently operated in India, using the rule curves.

A rule curve or a rule level specifies the storage or empty space to be maintained in a reservoir during different times of the year. Here the assumption is that a reservoir can best satisfy its purposes if the storage specified by the rule curve are maintained at different times. The rule curve as such does not give the amount of water to be released from the reservoir. This amount will depend upon the inflows to the reservoir, the storage space available in the reservoir and the demands from the reservoir. The rule curves are generally derived by operation studies using historic or generated flows. The operation of a reservoir by strictly following the rule curves becomes quite rigid. Often, to provide flexibility in operation, different rule curves are followed in different circumstances.

The computations for deriving various rule curve levels are made using the monthly inflow series for different probability levels along with the average monthly demands. Using the monthly dependable inflow series, the water availability is assumed as corresponding to particular monthly inflow series. Computations of end-of-month reservoir levels are made for 12 months after allowing for water demands in full or partial and the evaporation losses from the reservoir surface. The Elevation-Area-Capacity table is used and intermediate values are linearly interpolated whenever required. The evaporation losses are considered at normal monthly rate over the surface area of the reservoir corresponding to a particular elevation.

In India, the reservoirs are constructed to serve conservation purposes like water supply for domestic and industrial use, irrigation and hydropower generation and minimum downstream flow requirements. Therefore, in the present module, provision has been made to derive four rule curves: a) Upper rule curve, b) Rule curve for Irrigation, c) Rule curve for Hydropower and d) Rule curve for Water supply.

3.8.1 Upper Rule Curve

The upper rule level represents a level in the reservoir such that if it is maintained throughout the year, all the demands can be met in full. Though it is always desirable to fill a reservoir up to the maximum available capacity (up to FRL), it is generally recommended that some spill should be made from the reservoir to keep up the downstream river channel and to avoid encroachment in the river bed. Keeping the upper rule level below FRL can give extra room for flood absorption in the reservoir also. However, the upper rule level should be lowered such that the conservation performance of the reservoir is not affected. Thus, the upper rule level represents a trade off between the conservation demands and the flood control requirements. If this level is overtopped in any month, water is spilled and the reservoir is brought back to this level. The upper rule levels are calculated for the case when the reservoir level reaches to the full reservoir level at the end of September. For computing this level in months after the monsoon, 50% reliable inflow, full demands and evaporation from the reservoir have been assumed. Forward calculations have been carried out from the end of September using the following formula:

$$Storage_{end} = Storage_{begin} + Inflow - Demand - Evaporation \qquad \ldots(13)$$

Based on the simulation results, the levels in the monsoon months are lowered from the full reservoir level and levels in other months are modified as long as it does not have any effect on the conservation performance of the reservoir. Thus, using this rule level, it is tried to conserve water to such an extent that the conservation demands can be satisfied in full and some room can be kept in the reservoir for flood moderation also.

3.8.2 Rule Curve for Irrigation/Hydropower

This rule curve, critical for irrigation or Hydropower demands (based on priority), is calculated for the case when there is scarcity of water in the reservoir and it is not possible to meet all the demands in full throughout the year. Rule curve levels for this demand are calculated assuming that the reservoir level reaches to the dead storage level by the end of May. For computing these levels, 75% reliable inflows, full target demands and evaporation from the reservoir are assumed. Backward calculations are carried out starting from the end of May using the following formula:

$$Storage_{begin} = Storage_{end} - Inflow + Demand + Evaporation \qquad ...(14)$$

Using this rule curve, it is tried to find such a lower level in different months up to which all the demands can be met in full and if reservoir level goes below this level, the supply for irrigation or hydropower will have to be curtailed so that the reduced supply can be maintained for a longer duration. The underlying assumption is that it would always be better to supply less water for longer duration rather than to meet full demand for some time and then stop the supply suddenly.

As mentioned in the section 3.5 also, irrigation demands have been bifurcated into two parts: one going through the power plant (AIRD1) and the other bypassing it (AIRD2). If all or non of the irrigation demands pass through the power plants, then total demands are represented by AIRD1 and values of AIRD2 become zero (0). Hydropower demands are to be specified in terms of energy in MKwh. However, if these are available in MW, the same can be converted in to MKwh for a month by multiplying by 0.72.

3.8.3 Rule Curve for Hydropower/Irrigation

This rule curve, critical for hydropower or irrigation demands (depending on priority), is calculated for the case when the scarcity of water is so severe that even after curtailing water for least priority demands, the supply for meeting full higher priority demands can not be made throughout the year. For computing these levels, 75% reliable inflows, full higher priority demands (say hydropower/irrigation demands and domestic supply demands) and evaporation from the reservoir are assumed. Backward calculations are carried out in the same way as for irrigation.

Based on the priorities between irrigation and hydropower, it determines the demands to be considered for deriving a rule curve. If the hydropower is being generated, then details of the plants like efficiency, maximum capacity, tail water elevation, method of supply of water and relative priority are also input to the program.

Using this rule curve, it has been tried to find such a lower level in different months up to which all the higher priority demands can be met in full and if reservoir level goes below this level, the supply for the demand next to water supply demand, will have to be curtailed. Below this rule level, no supply is made for lower priority demand in that month.

3.8.4 Rule Curve for Domestic & Industrial Supply

This rule curve, critical for domestic and industrial water supply, has been calculated for the case when the scarcity of water is so severe that even after cutting supply for other demands (say irrigation and hydropower), the supply for meeting full water supply demands can hardly be made throughout the year. Domestic and industrial demand are accorded the highest priority. For computing these levels, 90% reliable inflows, only domestic and industrial demand and evaporation from the reservoir are assumed. Backward calculations are carried out the same way as for irrigation and hydropower.

Using this rule curve, it is tried to find such a lower level in different months up to which all domestic and industrial demands can be met in full and if reservoir level goes below this level, the supply for other demands will have to be stopped completely. Below this rule level, no supply is made for other demands.

Using these initial trial rule curve levels, a number of simulation runs can be taken for a reservoir to evaluate the performance of the reservoir, if it is operated in accordance with these trial rule curve levels. Based on the results of simulation, the rule curves can be modified till optimum operation is achieved.

3.8.5 Program Input & Output

The organization of the input file is as follows :

Line No(s)	Variable Name	Format	Description
1	TITL	A	Title of problem (Maximum 60 characters)
2	FRL	Free	Full reservoir level in meter.
	DSL	Free	Dead storage level in meter.
	ICON	Free	A flag to specify the method of supply of water through the power plants: = 0 -- no power plants, = 1 -- All release pass through plants, = 2 -- Irr. release bypasses the plants, = 3 -- Ws release bypasses the plants. = 4 -- Release for Irr. & Ws bypass plants.
If ICON is Greater Than 0, Then			
3	PINST	Free	Installed capacity of power plants in MW.
	ETAIL	Free	Tail water elevation (m).

	PLMIN	Free	Minimum level for power production (m).
	EFF	Free	Efficiency of the power plants.
	IPRIO	Free	Priority index for irrigation & hydropower = 1, if irrigation has higher priority, = 0, if power has higher priority.
Endif			
4	RIN5(I)	Free	12 values of the 50% dependable monthly inflow to the reservoir.
5	RIN7(I)	Free	12 values of the 75% dependable monthly inflow to the reservoir.
6	RIN9(I)	Free	12 values of the 90% dependable monthly inflow to the reservoir.
7	AIRD1(I)	Free	12 values of the target monthly irrigation demands from canal passing through the power plants (if any) in Million Cu. m.
8	AIRD2(I)	Free	12 values of the target monthly irrigation demands from canal bypassing the power plants (if any) in Million Cu. m.
If ICON is Greater Than 0, Then			
9	POWD(I)	Free	12 values of the target monthly hydropower demands in MKwh.
Endif			
10	WSD(I)	Free	12 values of the target monthly water supply demands in Million Cu. m.
11	EVAP(I)	Free	12 values of the normal monthly evaporation depths in meter.
12	NN	Free	Number of ordinates of the E-A-C table.
13 onwards	EL(I)	Free	Elevation in meters
	AR(I)	Free	Corresponding area in Million Sq. m.
	CAP(I)	Free	Corresponding capacity in Million Cu. m.

SAMPLE INPUT FILE

The sample input file for a reservoir is shown in the following. The reservoir has only irrigation and water supply demands.

```
RULE CURVE DERIVATION FOR BARGI RESERVOIR
422.76  403.55  3
90.0  370.00  403.55  0.90  0
41.75  27.01  16.15  7.71  3.27  42.91  1264.77  3191.52  1526.87  323.68  94.45  52.37
26.95  16.20   9.86  4.53  1.87  12.69   699.49  2375.18   888.49  174.07  60.91  35.50
18.25  10.39   6.13  2.79  1.08   4.24   368.30  1650.75   476.86   93.06  38.78  25.48
322.70  200.40  79.20  53.40  76.90  55.90  192.50  69.30  240.00  435.90  191.00  274.74
 0.00    0.00   0.00   0.00   0.00   0.00    0.00   0.00    0.00    0.00   0.00   0.00
 20.0    20.0   20.0   20.0   20.0   20.0    40.0   60.0    60.0    60.0   30.0   30.0
 4.50    4.50   4.50   4.50   4.50   4.50    4.50   4.50    4.50    4.50   4.50   4.50
0.0682  0.07  0.1271  0.177  0.2387  0.198  0.1426  0.1147  0.099  0.1085  0.078  0.0682
9
    402.336        33.7481       295.2354
    403.550        42.3247       740.0178
    408.432        77.1263      1205.4404
    411.480       113.2015      1450.5711
    414.528       153.5700      1949.4692
    417.576       194.3948      2478.7512
    420.624       236.8414      3138.7994
    422.760       272.9351      3657.4890
    423.000       278.0000      3766.2700
```

SAMPLE OUTPUT FILE

```
                    DERIVATION OF INITIAL RULE CURVES


UPPER RULE LEVELS (Jan...Dec)
----------------------------
  416.6  413.7  411.3  408.5  406.0  422.8  422.8  422.8  422.8  422.8
  421.0  419.2

IRRIGATION RULE LEVELS (Jan...Dec)
---------------------------------
  416.6  413.7  411.3  408.5  406.0  415.8  414.3  415.0  422.8  422.8
  421.0  419.2

HYDROPOWER RULE LEVELS (Jan...Dec)
---------------------------------
  413.7  412.6  411.3  408.5  406.0  403.5  403.5  403.5  416.7  418.5
  416.5  415.2

DOMESTIC SUPPLY RULE LEVELS (Jan...Dec)
---------------------------------------
  403.7  403.8  403.8  403.8  403.7  403.5  403.5  403.5  403.5  403.5
  403.5  403.5
```

3.9 YIELD-STORAGE ANALYSIS

Storage yield analysis is used to determine the volume of reservoir storage required to augment river flow in order to provide a specified water demand with a stated reliability.

It is also used to reassess the water demand which can be satisfied by existing reservoirs. Storage volume depends upon the volume of demand D, specified reliability R and the hydrograph of the catchment supplying the reservoir. Reliability R is an index in the range O - 1 which indicates how satisfactorily the reservoir performs. If storage required is to be calculated then yield is known otherwise the storage capacity is known. The Fibonacci search technique is used for the computation of dependent variable, reservoir capacity or annual yield, till desired reliability is achieved with permissible tolerances, supplied by the user.

When a sufficient long record of monthly or annual flows is available, then analysis of that series using suitable methods can provide the required storage capacity estimates once the levels of demand and reliability are specified. The following steps are followed:

a) At the beginning of iteration, the upper bound of the variable is kept equal to the average inflow volume in a year. The lower bound of storage is taken as dead storage S_{min} , whereas for annual yield lower bound is taken as zero.

b) Reservoir is initially assumed to be full.

c) Continuity eqn. is applied for each time unit

$$S_{t+1} = S_t + I_t - E_t - L_t \qquad ...(15)$$

d) The resulting Storage value series can be plotted versus time to show the behavior of the reservoir for the chosen trial capacity.

e) From above results, reliability is calculated.

f) If these values are too small, a large capacity is chosen and steps 1 to 5 are repeated.

g) If reliability values are large, and a smaller value is acceptable, then a smaller capacity is chosen and steps 1 to 5 are repeated.

h) This trial and error is performed till desired value of reliability is achieved.

With the desired accuracy, specified lower bound and calculated upper bound, one dimensional search is carried out to reach the optimum value of variable. The reliability achieved is computed after complete reservoir operation computations, based on mass balance equation. The evaporation loss E_i is function of both S_i and S_{i+1}. Hence an iterative method is applied using elevation-area-capacity table till absolute difference between two successive relative evaporation losses are less than a value supplied by the user. At each time interval, attempt is made to satisfy the demand to the extent possible. If the available water in reservoir is less than S_{min}, no release is made and the storage is depleted by evaporation only and the reservoir is assumed to have failed during that particular month. If during any period, $S_i + I_i \geq C$, the extra water over the storage capacity after meeting the demand is spilled. If there is not enough water in the reservoir to meet the demand any period, the demand is met to the extent possible and the month is treated as failure month.

The reliability achieved (REL) is computed by

$$REL = 1.0 - FAIL/n \qquad \ldots(16)$$

where FAIL = number of failures (number of periods when $R_i < D_i$).

The objective function used in Fibonacci search is

$$OF = |REL - RELI| \qquad \ldots(17)$$

where RELI is the reliability desired.

The detail of Fibonacci search method, which is a unidirectional search method for nonlinear optimization problems, can be found in texts such as Rao (1979). The choice of this method over other univariate nonlinear programming techniques is somewhat subjective.

3.9.1 Program Input & Output

The organization of the input file should be as follows :

Line	Variable Name	Format	Description
1	TIT	A	Title of problem (Maximum 60 characters).
2	NMONTH	Free	Number of months of record.
	IFM	Free	Starting month.
	IFY	Free	Starting year.
	FAC	Free	Multiplication factor to convert inflows to Cu. m.
	SMIN	Free	Dead storage of the reservoir in Cu. m.
	RELI	Free	Required reliability.
	EVFAC	Free	Multiplication factor to convert evaporation values to Cu. m.
3	ALP(I)	Free	12 distribution factors for converting annual yield to monthly yield.
4	NDT	Free	Number of values in Elevation-Area-Capacity table.
	ST(1)	Free	Initial reservoir storage.
5 onwards	EL(I)	Free	Elevation in meters
	AR(I)	Free	Corresponding area in Million Sq. m.
	CAP(I)	Free	Corresponding capacity in Million Cu.m.

Next line	EVAP(I)	Free	12 values of normal monthly evaporation in m.
Next line	DIFMAX	Free	Required accuracy in computing evaporation loss.
	ACC	Free	Desired overall accuracy.
Next line onwards	AINF(I)	Free	Monthly inflow values for all the months.

SAMPLE INPUT FILE

```
STORAGE DETERMINATION
55    6  1935    1000000  119287380   0.90 1 2 1
0.0914 0.0914 0.0914 0.0914 0.0914 0.09 0.06 0.06 0.057 0.093 0.0914 0.0914
12  200000000
        170.69       8.043      29.078
        173.74      11.929      58.898
        176.78      18.525     103.203
        179.83      32.189     180.844
        182.88      50.640     304.596
        185.93      73.358     497.225
        188.98     100.133     763.135
        189.59     105.621     829.415
        190.50     113.314     926.847
        192.02     125.047    1108.144
        193.55     137.673    1309.163
        194.00     142.000    1420.000

0.1402   0.1402   0.1890   0.2408   0.3048   0.2164   0.1524   0.1524   0.1524
0.1524  0.1524  0.1524

0.001   0.0001
                                          13.54  333.79  172.37  263.22   45.29 12.31   14.30
0.47     0.89     0.86     0.50     0.27   0.46  229.22  630.41   21.94    5.99  2.66    1.77
0.24     2.62     0.32     0.10     0.73   4.75   81.74   55.61   33.45    2.60  0.56    0.27
3.88     2.11     0.98     0.50     0.23  50.46  238.98  318.37  419.99   74.79  26.83  15.51
0.32     0.76     0.44     0.33     0.17  56.67  182.10   93.93   36.90    9.92  2.59    1.76
```

SAMPLE OUTPUT FILE

```
STORAGE-YIELD ANALYSIS

Yield to be calculated
The input data is in metric system

 No. of months =  55, First month =  6, First yr= 1935
```

INPUT DATA IS IN METRIC UNITS

Multiplication Factor for Inflows = 1000000.0

Multiplication Factor for Evapor. = 1.0

Dead Storage = 119.3 M Cum

Initial Reservoir content = 200.0 M Cum

Reliability Required = 0.9

Req. Accuracy in Fibonacci Search = 0.00010

Monthly Yield Distribution Factors (Jan...Dec)

0.0914	0.0914	0.0914	0.0914	0.0914	0.0900
0.0600	0.0600	0.0570	0.0930	0.0914	0.0914

Monthly Inflows (M Cum)

13.54	333.79	172.37	263.22	45.29	12.31	14.30	0.47
0.89	0.86	0.50	0.27	0.46	229.22	630.41	21.94
5.99	2.66	1.77	0.24	2.62	0.32	0.10	0.73
4.75	81.74	55.61	33.45	2.60	0.56	0.27	3.88
2.11	0.98	0.50	0.23	50.46	238.98	318.37	419.99
74.79	26.83	15.51	0.32	0.76	0.44	0.33	0.17
56.67	182.10	93.93	36.90	9.92	2.59	1.76	

Elevation-Area-Capacity Table

Elevation m	Area M Sqm	Capacity M Cum
170.69	8.04	29.08
173.74	11.93	58.90
176.78	18.52	103.20
179.83	32.19	180.84
182.88	50.64	304.60
185.93	73.36	497.23
188.98	100.13	763.13
189.59	105.62	829.41
190.50	113.31	926.85
192.02	125.05	1108.14
193.55	137.67	1309.16
194.00	142.00	1420.00

Monthly Evaporation Data (m)

0.1402	0.1402	0.1890	0.2408	0.3048	0.2164
0.1524	0.1524	0.1524	0.1524	0.1524	0.1524

Maximum Difference in Evaporation = 0.001

******************** RESULTS ********************

POSSIBLE ANNUAL YIELD = 485.09 M Cum

Number of Failures = 28

Reliability Achieved = 0.91

RESERVOIR MONTHLY WORKING TABLE
(All values are in volume (M Cum))

Month	Ini_Sto	Inflow	Demand	Release	Evap	End_Sto
1	200.00	13.540	43.658	43.658	6.922	162.96
2	162.96	333.790	29.105	29.105	7.470	460.18
3	460.18	172.370	29.105	29.105	11.573	591.87
4	591.87	263.220	27.650	27.650	14.262	813.17
5	813.17	45.290	45.113	45.113	15.892	797.46
6	797.46	12.310	44.337	44.337	15.693	749.74
7	749.74	14.300	44.337	44.337	15.055	704.65
8	704.65	0.470	44.337	44.337	13.213	647.57
9	647.57	0.890	44.337	44.337	12.407	591.71
10	591.71	0.860	44.337	44.337	15.100	533.14
11	533.14	0.500	44.337	44.337	17.724	471.57
12	471.57	0.270	44.337	44.337	20.281	407.23
13	407.23	0.460	43.658	43.658	12.853	351.18
14	351.18	229.220	29.105	29.105	10.204	541.09
15	541.09	630.410	29.105	156.575	14.922	1000.00
16	1000.00	21.940	27.650	27.650	17.991	976.30
17	976.30	5.990	45.113	45.113	17.757	919.42
18	919.42	2.660	44.337	44.337	17.180	860.56
19	860.56	1.770	44.337	44.337	16.471	801.52
20	801.52	0.240	44.337	44.337	14.484	742.94
21	742.94	2.620	44.337	44.337	13.754	687.47
22	687.47	0.320	44.337	44.337	16.900	626.55
23	626.55	0.100	44.337	44.337	20.012	562.31
24	562.31	0.730	44.337	44.337	23.325	495.37
25	495.37	4.750	43.658	43.658	15.129	441.34
26	441.34	81.740	29.105	29.105	10.175	483.80
27	483.80	55.610	29.105	29.105	10.938	499.36
28	499.36	33.450	27.650	27.650	11.213	493.95
29	493.95	2.600	45.113	45.113	11.121	440.32
30	440.32	0.560	44.337	44.337	10.157	386.38
31	386.38	0.270	44.337	44.337	9.188	333.13
32	333.13	3.880	44.337	44.337	7.571	285.10
33	285.10	2.110	44.337	44.337	6.181	236.69
34	236.69	0.980	44.337	44.337	6.939	186.39
35	186.39	0.500	44.337	44.337	6.893	135.66

36	135.66	0.230	44.337	9.219	7.388	119.29*
37	119.29	50.460	43.658	43.658	4.621	121.47
38	121.47	238.980	29.105	29.105	5.704	325.64
39	325.64	318.370	29.105	29.105	10.460	604.44
40	604.44	419.990	27.650	27.650	15.316	981.47
41	981.47	74.790	45.113	45.113	17.808	993.34
42	993.34	26.830	44.337	44.337	17.925	957.90
43	957.90	15.510	44.337	44.337	17.575	911.50
44	911.50	0.320	44.337	44.337	15.717	851.77
45	851.77	0.760	44.337	44.337	15.055	793.13
46	793.13	0.440	44.337	44.337	18.843	730.39
47	730.39	0.330	44.337	44.337	22.502	663.89
48	663.89	0.170	44.337	44.337	26.392	593.33
49	593.33	56.670	43.658	43.658	17.969	588.37
50	588.37	182.100	29.105	29.105	13.648	727.72
51	727.72	93.930	29.105	29.105	14.717	777.82
52	777.82	36.900	27.650	27.650	15.446	771.63
53	771.63	9.920	45.113	45.113	15.367	721.07
54	721.07	2.590	44.337	44.337	14.615	664.71
55	664.71	1.760	44.337	44.337	13.750	608.38

* DENOTES FAILURE MONTHS.

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