TRAINING COURSE

ON

RESERVOIR OPERATION

(UNDER WORLD BANK AIDED HYDROLOGY PROJECT)

<u>Module 13</u>

NIH Multireservoir

Simulation Model

BY

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NIH MULTIRESERVOIR SIMULATION MODEL

1.0 DEFINITION OF SIMULATION

Simulation is the process whereby one attempts to represent the performance of some real-world system. It is the process of designing a model of a system and conducting experiments with this model either for better understanding of the behavior of the system or for evaluating various strategies for its operation. The essence of simulation is to reproduce the behavior of the system in every important aspect.

The principal reason for doing this is to learn as much as possible about how the existing or proposed system will react to conditions that may be imposed on it or that might be expected to occur in the future. If a simulation model can be developed and proved to represent a prototype system, then it can provide, in seconds or less, answers about how the real system might perform over years and under many conditions of stress. Thus, costly proposed projects may be evaluated to judge whether their performance would be adequate before investments are made. In like manner, operating policies can be tested before they are implemented in actual control situations. Where proposed designs and/or operating procedures do not meet the test, usually it is a straight forward matter to revise the model to reflect changed policies and/or structural configuration.

Simulation models may be physical (a scale model as a spillway operated in a hydraulics laboratory), analog (a system of electrical components, resistors and capacitors, arranged to act as analog of pipe resistances and storage elements), or mathematical (a compilation of equations that represent the actions of a system's elements). The vehicle used to operate models of this type is normally the digital computer. In the area of water resources management, the computerized models are becoming very popular nowadays. Although the physical models are in use for a very long time, these are not suitable for analysis of water resources systems. The model building for the water resources systems is a time consuming and costly affair and the testing of different operating policies is not possible through these models. Further complications arise in the physical models in case it is required to evaluate the alternate configurations and sizes of the facilities. In such situations, mathematical models are the most convenient to use.

A simulation model of a water resource system is a mathematical technique expressing by arithmetical and logical procedures (algorithms) the dynamic behavior of the water resource system in discrete time steps. The advantage of the simulation model, however, lies in its relatively accurate description of the simulated reality; the method is suitable for communication between technicians as it uses the same principles as the traditional concept of water resource system design, and the output of the simulation models complies with familiar ideas. Simulation is reproducible and therefore it is easy to check.

1.1 Time Management in Simulation

The two common ways of time management in simulation models are periodic scanning and event scanning. In the period scanning or fixed time scanning, the whole computation time is divided into smaller time periods. The simulation is incremented by the predetermined step and the procedure is repeated till the end of period of analysis. For example, in case of simulation of operation of a reservoir system, the time horizon may be divided into months. A judicious choice of time increment is necessary in the periodic scanning approach. This increment should be small enough so that no significant information is lost.

In the event scanning approach, the clock is advanced by the amount of time which is required for the occurrence of next event. In many natural phenomena, the periods of high activity are separated by long periods in which the system lies inactive. This approach is suitable for these type of situations. It requires some scheme to determine the time when the events take place.

2.0 DEVELOPING A SIMULATION MODEL

A simulation model reflects the processes in water resource systems by a series of "snapshots" in specified time steps. For conservation purposes, monthly/ten daily periods are generally used. These periods make it possible to reflect the seasonal variability of demand and hydrological data. In developing a simulation model, the following steps are necessary:

a) definition of the problem,
b) determination of model input and output, data requirement, availability and processing,
c) description of the water resource system and its hydrological relationships, design of the model,
d) design of the operational policy of the system, and
e) debugging of the program, model tests.

Defining the problem for a simulation model is a matter of prior systems analysis. This definition is not an isolated act but a continuous process of clarifying objectives and achieving precision, leading from verbal expression to a technical and quantitative specification.

There are two main types of input data for the simulation model: (1) the variables given by the natural conditions, e.g. the monthly flows in a system of gauging stations, and (2) parameters of water engineering structures and demands on the system, either existing or in the design stage. The parameters of the system include not only the storage capacities of reservoirs but also the acceptable minimum releases from reservoirs, the transfer of regulated flows, or of unregulated flows upstream of reservoirs for the enlargement of basins (transverse diversion), the requirements for water quality, etc. The input data include the demands in the demand centers and diversion points where these demands on water resource systems are summarized and covered (together with the minimum discharges) by operation of the systems.

The outputs of the simulation model are either technical or economic. The technical variables comprise the minimum values of reservoir storage, the deficits in the required reservoir releases at demand centers and diversion points, especially deficits in firm water supply. Some deficits cannot be allocated to a particular reservoir as they are covered by several reservoirs in the water resource system. Reliability indices are evaluated on the basis of volume deficits, e.g. their duration in time or their relative frequency. Water resource systems, at certain periods, fail to meet the target outputs. Therefore, the simulation model outputs include the water supply deficits for various targets, energy deficits, reservoir level fluctuations, the duration, relative magnitude and total volume of the deficits, and the number of users concerned.

2.1 Interpretation of Results

The interpretation of simulation output is a very important step in the simulation analysis. It is also very much necessary for proper choice of variables to be changed for the next steps of computations. Before interpretation of results, the analyst must specify a performance criterion to evaluate the alternate strategies. In case of reservoir operation, the concept of reliability is used quite often. An operation policy is considered satisfactory or otherwise depending upon how well the various demands are satisfied. The relative impact of various decision variables on the performance of the system should be known.

In most of the computer based models, the user has options open to determine as to how detailed results he wants. Too many details in the printout may tend to hide the important aspects besides making the output unwieldy and too few variables may lead to wrong interpretations. Thus a clear balance has to be maintained. It is often very useful to have the summary of results for quick interpretations. The details needed for interpretation also vary depending upon the stage of analysis. For example, if the performance of the various operation policies is being studied, then in the intermediate stages only brief results may be sufficient. After a satisfactory policy has been arrived at, detailed results may be required for the purpose of presentation.

3.0 PROS AND CONS OF SIMULATION MODELS

Simulation and other types of models can be valuable aids in decision making but their advantages and disadvantages must be weighed for the circumstances of concern. Some advantages of the use of simulation models include:

a) they impose a logic and structure to analyses,
b) they provide insights into systems behavior,
c) their structure is ideally suited to experimental work,
d) they may be designed to accommodate many options,
e) projections into the future are facilitated with their use, and
f) they can aid in communications between analysts and policymakers.

Some common drawbacks of simulation models are:

a) oversimplifying real systems,
b) data requirements that cannot be met,

c) difficulty in handling of intangibles,
d) high costs of development and/or use,
e) problems of interpreting output, and
f) problems of user acceptance.

Furthermore, the use of models is sometimes inhibited because potential users fail to see their relevance, there are doubts about a model's validity, documentation may be poor, prospective users may lack understanding of a model or lack the resources to be able to use it, and there is often a mistrust of mathematical representations.

4.0 NIH SIMULATION MODEL

Since it is not possible to do experiment with the real system, models of a system are developed. Experiments can be conducted using these model to provide insight into the problem. For reservoir operation, the model studies bring into focus certain aspects of operation which serves to improve the manager's ability to manage system wisely. The various categories of models which are used for reservoir management problems are: optimization models and simulation models. The ultimate goal of all such models is to improve the system operation, directly or indirectly.

The National Institute of Hydrology, Roorkee, has developed a model for simulating the operation of a multireservoir system for multiple conservation purposes. Simulation, in essence is to duplicate the system behavior under given hydrologic and other input data. Though this approach is not useful for deriving any operation policy directly, it helps in policy evaluation. Much effort is needed to build generalized simulation models. It is a general opinion that simulation is the best approach for analyzing a complex water resources systems. With this view in mind, a generalized computer program for simulation of a multireservoir system, particularly useful in Indian conditions, has been developed. The various conservation purposes which have been considered in the model are: water supply for domestic and industrial purposes, irrigation, hydropower generation, and minimum flow in the river reach downstream of a reservoir. The model allows evaluation of reservoir operation policy through system reliability. Additionally, the model prepares detailed simulation tables which can be used to improve the trial policy. The concept of "Rule Curves" has been adopted in the model which is briefly described in the following section.

4.1 Operation of Reservoirs Using Rule Curves

The reservoirs are frequently operated 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.

Often, due to various reasons viz. low inflows, minimum requirements for demands etc., it is not possible to maintain the reservoir levels according to the rule curves. However, it is possible to return to the rule levels in several ways. Some possibilities are: a) return to the rule curve by curtailing the release beyond the minimum required if the deviation is negative; b) make release more than the demand but less than the safe carrying capacity, if the deviation is positive. The operation of a reservoir by strictly following rule curves becomes quite rigid. Often, to provide flexibility in operation, different rule curves are followed in different circumstances.

In India, the reservoirs are constructed to serve conservation purposes like water supply for domestic and industrial use, irrigation and hydropower generation. Therefore, in the present model, three rule curve levels have been specified, namely the upper rule level, the middle rule level 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) Middle Rule Level

The middle and lower rule levels are use in the situation when water is scarce and full supply for the various demands cannot be made. Supply for the various demands 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..

The middle rule level is critical for irrigation and power generation which are given low priority as compared to water supply and minimum flow requirements. If the water level in the reservoir is above the middle rule level, full supply of water is made for all the demands. However, if the water level in a reservoir falls below the middle rule level, based on relative priority, reduced supply is made either for irrigation or for hydropower generation. The release is made at the reduced rate so that the demands can be met for longer duration. Different rule levels for irrigation and power can also be specified.

c) Lower Rule Level

The lower rule level is critical for water supply 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.

4.2 Release of Water for Various Demands

Based on the level of water in the reservoir corresponding to the rule curve levels specified above, the operation policy adopted for satisfying various demands is described below.

a) Water Supply Demand

The highest priority is given to the water supply demand for domestic and industrial purposes. This demand is met in full as long as the water level in the reservoir is above the minimum drawdown level of water supply outlet.

b) Minimum Flow in Downstream Channel

This requirement is also given top priority along with the water supply demand. Attempt is made to meet this demand in the same manner as the water supply demand.

c) Hydropower Generation Demand

Hydropower generation demand is given in MW. The amount of water required to produce hydropower depends on the head of water available which keeps on changing. The amount of water required to produce desired demand of power is calculated based on the mean elevation of water during a period.

It is assumed that release for maintaining minimum flow will always pass through the power plant. Three ways in which release of water from the reservoir can pass/bypass the plant have been considered. First, all the supply of water from the reservoir is passed through the power plant. Second, only water supply release passes through the power plant and supply for irrigation bypasses the plant. Third, the supply for water supply bypasses the plant and irrigation supply passes through the plant. If the present location serves demand of any downstream location also, then supply for meeting such demand will also pass through the power plant.

At the time of water scarcity, the hydropower generation gets low priority as compared to water supply for domestic and industrial purposes and minimum flow requirements. For reservoir level above the middle rule level, based on the system of supply of water, total demand of water is worked out. Then water is released from the reservoir for meeting all the demands in full. However, for reservoir level below the middle rule level, based on the relative priority, curtailed release either for irrigation or for hydropower generation is made. It may happen that water is not released for power generation but some incidental power is generated if these releases pass through the power plant. At or below the lower rule level, water is supplied only for domestic and industrial purposes and for maintaining minimum flow. Based on the system configuration, some power may get generated in this case also.

d) Irrigation Demand

The demand for irrigation is 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 to another. Like power, the demand for irrigation is met in full if the reservoir level is above the middle rule level. Below the middle rule level, curtailed supply for irrigation depends on the priority. Below the lower rule level, supply for irrigation is stopped completely.

4.3 Purpose of the Simulation Model

The purpose of the developed model is to simulate 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.

4.4 Description of the Variables

The description of the input variables used in the program is as follows:

titl	-	Title of the problem
nloc	-	Total number of control locations in the system
imon(1)	-	Initial month of operation
iyr(1)	-	Initial year of operation
nmon	-	Number of months of operation
ifmon	-	A factor for specifying length of a period = 1 for monthly operation, = 3 for ten-daily operation)
fir	-	A factor for reducing demand of irrigation or hydropower in case of insufficient water
name	-	Name of location in alphanumeric
icp	-	Node Number of the control point

icp1	-	Number of control points immediately upstream of the present control point
icp2	-	Node number of icp1 control points upstream of the present control point
icon	-	A flag to specify the method of supply of water through the power plant
	-	= 0 -- no power plant,
	-	= 1 -- All release pass through plant,
	-	= 2 -- Irr. release bypasses the plant,
	-	= 3 -- WS release bypasses the plant.
etail	-	Tail water elevation (m)
plmin	-	Minimum level for power production (m)
pinst	-	Installed capacity of power plants (MW)
eff	-	Efficiency of the power plants
iprio	-	Priority index for irrigation & power
		= 0 if irrigation has higher priority,
		= 1 if power has higher priority)
pow	-	Hydropower demand for the period in MW
smax	-	Gross capacity up to FRL (m^3)
smin	-	Gross capacity up to intake of WS outlet (m^3)
stor(1)	-	Initial reservoir storage (m^3)
nn	-	Number of points in Elevation-Area-Capacity table, nn = 0 for non-reservoir locations like weirs,
idp	-	A factor controlling simulation table printing
		= 1 gives detailed simulation table in output file &
	-	= 0 detailed simulation table is not printed
elev	-	Elevation in E-A-C table (m)
area	-	Area at corresponding elev. in E-A-C table (sq. m)
cap	-	Capacity at corresponding elev. in E-A-C table (cu. m)
infl	-	A factor 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	-	Multiplication factor to convert inflow data in m^3
inod	-	Node Number whose inflow data is to be used for computing inflow at the present location
iddp	-	Node number of downstream location whose partial demands are to be satisfied by present location
demd	-	Total demand for irrigation in Mm^3
wdmd	-	Total demand of water supply for domestic and industrial purposes in Mm^3
amflo	-	Minimum flow demands in downstream channel in Mm^3
rule	-	Upper rule levels (m)
ail	-	Middle rule levels critical for irrigation and hydropower demands (m)
wpl	-	Lower rule levels critical for WS and minimum flow demands (m)

evpd - Evaporation depth in meter/month

4.5 Data Requirement of the Model

The data requirement of the model is 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 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 % age of demands is also to be specified in the input data. Some data like defining the configuration of the system and the trial rule curve are specified by the user. Description for defining the configuration of the system is as follows:

4.5.1 Representation of the System Configuration

It is a healthy practice to first prepare the line diagram of the system under study. Line diagram should highlight the location of reservoir, diversion weirs/barrages and the location and direction of the connecting rivers and streams. For defining the system in the model, node numbers are required to be assigned to each structure starting from the upstream structure. The node numbers are assigned in numeric starting from 1. Take care such that all downstream structures should have node number higher to that of their upstream structures. The model recognizes each structure by its node number. Location of each 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.

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 *l1* of the program should be increased.

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. A factor for reducing irrigation or hydropower demands in case of scarcity of water is also to be specified in the input data.

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 also to be specified. Three methods of supply of water through the power plant have been considered. In the first case, all the releases from the reservoir including irrigation and water supply for domestic and industrial purposes are routed through the power plant. In the second case, releases for irrigation bypass the power plant and the rest of release is passed through the power plant. In the third case, release for domestic and industrial purpose bypasses the power plant and rest of water supply passes through the plant. 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.

The model has been developed for simulating 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.

4.6 Output of the Model

The model simulates the operation of a system of reservoirs for the specified period. Based on the trial upper, middle and lower rule 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 then 75 % of the total demands and thus calculates "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, water supply, hydropower and downstream demands, release made, 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 in particular period can be modified till the best operation performance is achieved.

4.6.1 Graphical Presentation

A module for analyzing 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.

4.7 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 and reduction factor in case of scarcity of water.
4. Get general details about each location which include whether a location has power plant or not, if yes, then the mode of operation of the plant, tail water elevation, minimum level for power production, installed capacity of power plant, efficiency of the power plant, priority between irrigation and power in all periods of water year, power demands for all periods, 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, downstream location whose demand is to be satisfied and the percentage of demands to be satisfied, irrigation demands, water supply demands, minimum flow demands in the downstream channel and the evaporation depths in all the periods of the water year.
5. 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.
4. Derive the initial trial upper, middle and lower rule levels. Prepare the data file, node-by-node for all the locations. The data must be entered in correct units as specified.
7. 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. Adjust the middle rule level such that failure months are 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.
8. After optimizing the middle rule curve levels, adjust the upper rule levels for all periods to obtain the required results.

4.8 Input Data File in Variable Form

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Titl
nloc  imon(1)  iyr(1)  nmon  ifmon  fir
name(i)
icp(i)  icp1(i)  icon(i)  icp2(i,j)
pinst(i)  etail(i)  plmin(i)  eff(i)          {Only if icon(i).gt.0}
iprio(i,j)                                    {Only if icon(i).gt.0}
pow(i,j)                                      {Only if icon(i).gt.0}
smax(i)  smin(i)  stor(i,1)  nn(i)  idp(i)
elev(i,j)  area(i,j)  cap(i,j)                {Only if nn(i).gt.0}
infl  fac(i)  iddp(i)  dfc(i)  retf(i)
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demd(i,j)
wdmd(i,j)
mflo(i)
rule(i,j)
ail(i,j)
wpl(i,j)
evpd(i,j)
flow(i,j) {if infl.ne.1, then inod instead of flow(i,j)}

Note:

a) Entire data for each structure is entered at a time.

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).

For further details of the model, the Users Manual of the model, Jain & Goel (1994), can be referred.

5.0 REFERENCES

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