NIH_ReSyP – A Reservoir Systems Package Developed at NIH

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Synopsis

Because of the high time and space variability of rainfall and uncertain nature of monsoon in India, reservoirs play an important role in the efficient utilization of water resources. More than 4500 major and medium dams have already been constructed in our country. The basic aim of a reservoir is to match temporal and spatial availability of water in accordance with demands. Once the structured facilities like dams, barrages, hydropower plants etc. come into being, the benefits depend, to a large extent, upon how well these facilities are managed. Reservoir operation forms a very important part of 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.

In view of the importance of reservoir operation problem in Indian context and the non availability of indigenous software for reservoir analysis, continuous efforts have been made at the National Institute of Hydrology (NIH), Roorkee to develop computer programs in FORTRAN for various kind of reservoir analyses such as sequent-peak analysis, storage-yield analysis, reservoir routing, hydropower analysis, rule curve derivation, reservoir sedimentation analysis, and operation of a system of reservoirs for conservation and flood control purposes. Recently, a WINDOWS based Graphical User Interface (GUI) named *“NIH_ReSyP – Reservoir Systems Package”* has been developed in Visual BASIC to provide a user-friendly environment for carrying out various reservoir-related analyses with the computer programs already developed. The computer programs have been used for the analysis of a number of Indian reservoir systems such as Sabarmati river system, Periyar-Vaigai system, Ken-Betwa link system etc. This paper presents a brief description of *NIH_ReSyP* along with a case study for the conservation operation of a reservoir system.

1. Introduction

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. Reservoirs are the most effective means of changing temporal and spatial availability of water and therefore, more than 4500 major and medium dams have already been constructed in India to tap the available water resources so that the water can be utilized in accordance with the requirements of mankind. Further, the efficient use of water resources requires not only judicious design but also proper management of the hydraulic structures. Therefore, reservoir operation forms a very important part of the planning and management of water resources system.

The management of reservoirs is a very challenging problem because it deals with a natural system with all the associated uncertainties and a tailor-made solution methodology for this problem is not available. Further, 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. A large number of models, generalized as well as system specific, have been developed, some of which include HEC-5 (1982) of Hydrologic Engineering Centre, US Army Corps of Engineers and SIMYLD-II of Texas Water Development Board. Subsequently, to follow WINDOWS software development standards, a user-friendly interface, named *HEC-ResSim 3.0* (2007), has been developed to aid engineers and planners in performing water resources studies in predicting the behavior of reservoirs and to help reservoir operators in planning releases in real-time during day-to-day and emergency operations. In addition, other computer-aided tools that have been developed to analyze the multi-reservoir system at the basin scale some of which include RIBASIM [developed by Delft Hydraulics, The Netherlands (2004)], and MIKE BASIN [developed by DHI, Denmark (2004)].

In view of the importance of reservoir operation problem in Indian context and the non availability of a generalized software for reservoir analysis, the National Institute of Hydrology (NIH), Roorkee developed a generalized software named "*SRA – Software for Reservoir Analysis*" for reservoir analysis [Jain et. al (1996)] for carrying out various kind of reservoir analysis such as capacity computation, storage yield analysis, hydropower simulation, reservoir routing, elevation-area-capacity (EAC) interpolation, inflow estimation using rate of rise method, initial rule curve derivation, and operation of a system of multiple reservoirs for conservation purposes. Subsequently a GUI, named *"NIH_ReSyP – Reservoir Systems Package"*, has been developed in Visual BASIC platform [Goel and Chalisgaonkar (2011)] to provide a user-friendly environment for carrying out various hydrological analyses related to reservoirs. This paper presents the general details of the software and a brief introduction to the various modules. The software can be freely obtained from NIH. Training courses on the software are also conducted annually for its wide-spread use.

2. Description of basic features of *NIH_ReSyP*

The software is a WINDOWS based comprehensive and easy-to-use menu-driven interactive package with on-line help to guide the user for various analytical modules. The package includes many tabular and graphical options facilitating efficient analysis and reporting. The opening banner (given in Figure – 1) shows the various kind of hydrological analysis that can be performed for a reservoir with the software. After the opening banner, the main menu screen appears as shown in Figure – 2 which displays the names of various analytical options that can be used with the software.

By clicking on a particular module, various sub-modules related with the selected analytical option appears on the screen. For each analysis module, four sub-modules are invoked for: filling the data form, analysis, view tabular/graphical results, and help on that module. A data form has been designed for each module depending on its data requirement. Various options such as retrieving an existing file, generating a new file, making changes in the retrieved file and saving it with a new name are provided. Each analytical module is given specific and related input and output file extensions.

Figure – 1: Opening Banner of *NIH_ReSyP*

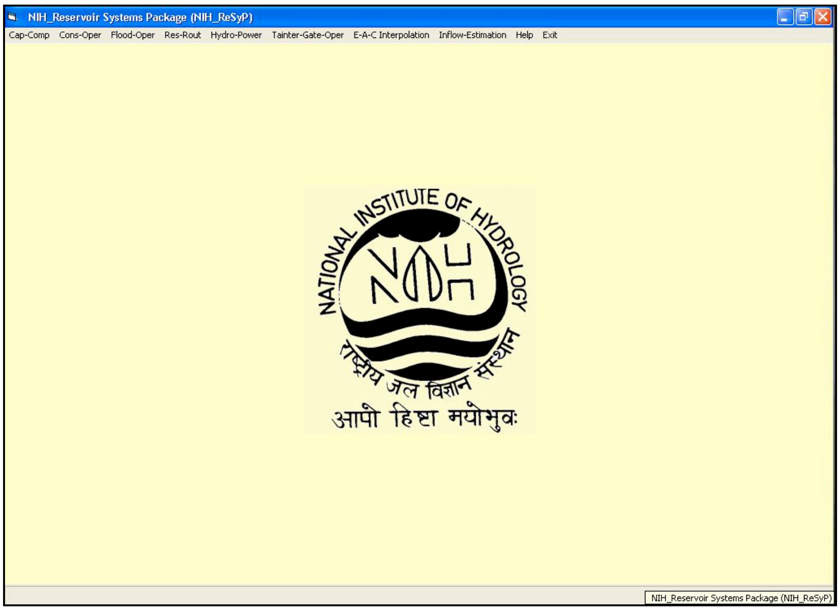

Figure – 2: Main-menu Screen

After the data file is generated for the selected module, corresponding computer program is run with the "Analysis" sub-module. Clicking on this section invokes a window for specifying the input and output files along with their path. “Run” button on this window executes the computer program on the data file and generates the result file with the specified name. The software has an editor for presenting the input data and result files in tabular form. Results are graphically presented through a built-in graphics routine. Different graphical options are provided for different kind of reservoir analysis. In addition, one section related to “Help” for each module is provided which gives details about the methodology of the analytical module, description of various data items, and steps of using the module.

2.1 Analysis modules available

The current version of the software is capable of performing the following types of analyses related to reservoirs:

- Reservoir capacity computation using sequent-peak and storage-yield-reliability analysis
- Hydropower analysis either for firm power determination or hydropower simulation
- Reservoir routing using any of the four methods: Mass Curve method, Modified Puls’ method, Goodrich method, or Coefficient method
- Probable flow estimation for deriving initial rule curve levels for conservation purposes
- Initial rule curves derivation for various conservation purposes for specification in the reservoir operation analysis
- Operation analysis of a multi-purpose multi-reservoir system for conservation purposes
- Operation analysis of a multi-reservoir system for flood control
- Reservoir sedimentation assessment (new-zero elevation and sediment deposition profile) using empirical area reduction method
- Two utility modules for interpolation of elevation-area-capacity table and reservoir inflow estimation using rate of rise method

The computer programs (in FORTRAN language) for various reservoir analyses have been developed at NIH in the past and the same have been linked in *NIH_ReSyP* through their executable files. Program for power transformation technique for probable flow estimation has been developed by Seth and Perumal (1982). The program for sequent-peak analysis has been developed by Jain (1985). For storage yield analysis, the computer program developed by Jain (1986) has been utilized. Reservoir routing analysis model has been adopted from Jain and Gupta (1989). Software for simulation of a multi-reservoir system for conservation has been developed by Jain and Goel (1994) while such program for flood control has been developed by Jain and Goel (1999).

3. Brief description of analytical modules

A brief description of the various analysis modules of the package is given below.

3.1 Capacity computation using Sequent Peak analysis

Sequent-peak method represents analytical solution of mass curve method and has been used in this module to compute the capacity for a reservoir. The detail of Sequent-Pak method can be found in texts such as Jain and Singh (2003). The algorithm is very fast and easy to program. The method can easily consider the variable demand pattern from the reservoir. Since the reservoir would be able to meet the worst drought from the inflow record, the implied probability of failure would be 1/(N+1) where N is the number of years of inflow sequence considered. Some limitations of this method include the implicit assumption that the storage which would have been adequate in past will also be adequate in future, storage size cannot be related to the economic life of the project and cannot be computed for a particular level of reliability. Major input requirements for the module include inflow and demand sequence. As an output, the module generates a sequence of desired reservoir storage to meet the specified inflow and demand sequence. The results can be presented in tabular and graphical form.

3.2 Capacity computation using Storage-Yield 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. On the other hand, it can also be used to reassess the water demand which can be satisfied by existing reservoir. The Fibonacci search technique is used in this module for the computation of dependent variable (reservoir capacity or annual yield) till desired reliability is achieved with permissible tolerances, supplied by the user. 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). 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 which are based on mass balance equation. Representing S_t as storage, I_t as inflow volume, E_t as evaporation loss volume, and R_t as reservoir release for meeting various demands in time unit *'t'*, continuity eqn. is applied for each time unit as:

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

The evaporation loss 'E_t' is function of both 'S_t' and 'S_{t+1}'. Hence, an iterative method is applied using elevation-area-capacity (EAC) 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, '$S_i + I_i \geq$ storage capacity '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 in any period, the demand is met to the extent possible and the month is treated as failure month.

The input requirement of the module includes general details of the reservoir such as full reservoir level (FRL), dead storage level (DSL), EAC table, normal monthly evaporation depths, target monthly demands, and inflow sequence to the reservoir at monthly time step. The output of the modules contains the reservoir working table for the optimum value of the variable obtained by search algorithm.

3.3 Probable flow estimation

Derivation of initial rule curves for a reservoir requires probable inflows corresponding to different reliabilities (say 50%, 75%, and 90%) for different months. This module is used to compute the probable monthly inflow values using statistical approach. The computations are made with the original data series as per rank analysis, log-transformed series, and power-transformed series. The input data for this module includes the long term inflow series for the month under consideration and output is the probable flow values in the month corresponding to six specified reliability levels.

3.4 Initial rule curve derivation

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 assuming that a reservoir can best satisfy its purposes if the storage specified by the rule curve are maintained at different times. This module computes the initial rule curve levels for various purposes (irrigation, hydropower, domestic supply etc.) which can be specified in the operation analysis of a reservoir and which can be fine-tuned for deriving optimum operation policy. The computations for deriving various rule curve levels are made using the monthly inflow series for different probability levels (computed in module under section 3.3) along with the average monthly demands.

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. 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. Rule curve for irrigation/hydropower 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 for domestic supply is calculated for the case when the scarcity of water is so severe that even after cutting supply for other lesser priority demands (say irrigation and hydropower), the supply for meeting full domestic water demands can hardly be made throughout the year.

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. Input data requirement of this module includes general details of the reservoir such as FRL, DSL, EAC table, normal monthly evaporation depths, target monthly demands for different purposes, monthly inflow sequence corresponding to different reliabilities, and hydropower details (if any) such as capacity of power plant, tail water level, minimum level for power generation, and efficiency of plants.

3.5 Reservoir routing

The passage of flood hydrograph through a reservoir is an unsteady flow phenomenon. 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: Mass curve method, Modified Puls' method, Goodrich method, Coefficient method etc. In the present module, these methods of flood routing through a reservoir have been incorporated.

The basic law used in these methods states: *The inflow minus outflow is equal to the rate of change in storage*. Further, outflow from the reservoir takes place through the spillway or uncontrolled section and the discharge can be related with the reservoir elevation which, in turn, can be related to the reservoir storage. Using the storage – outflow relationships in conjunction with continuity equation, the outflow hydrograph from a reservoir corresponding to an inflow hydrograph can be obtained in this module. Input data requirement of this module includes general details of the reservoir such as FRL, DSL, elevation-capacity-release capacity table, and inflow hydrograph. The module computes the outflow hydrograph from the reservoir.

3.6 Hydropower analysis

The generation of hydroelectric power is one of the main purposes of a water resources project. The hydroelectric power potential is determined on the basis of the critical hydro-period when the limitations of hydroelectric power generation due to hydrologic conditions are most critical with respect to power demands. Firm power is the maximum quantity of power that can be guaranteed each year 100% of the time according to some prescribed distribution. Two analysis options are available in this module: hydropower simulation and firm power determination. Under first option, the power demand is specified and the model simulates the reservoir operation with the given set of demands and hydrologic input to the system.

Under second option, the module calculates the firm power that can be generated under given conditions. This module uses a search technique to find the firm power from the project. A trial value of firm power is assumed and operation of 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, $S_t + I_t > S_{max}$, 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 required power, the power is generated to the extent possible. The minimum of power generated in each period is computed. If this value is less than the trial value of the firm power, the same is decreased and vice versa. The computations are repeated and they are terminated when the required convergence is achieved. Input data requirement of this module includes general details of the reservoir such as FRL, DSL, EAC table, and inflow series at monthly time step and hydropower details such as capacity of power plant, tail water level, minimum level for power generation, and efficiency of plants.

3.6 Reservoir sedimentation

At the time of designing the storage capacity of a reservoir, it is important to keep some additional storage capacity for sedimentation in the reservoir so that the reservoir can perform its functions at full efficiency for assigned number of years. This volume of storage is referred to as dead storage and is a major criterion in fixing the minimum drawdown level (MDDL) of reservoir. Further, the distribution pattern of sediments in the entire depth of a reservoir depends on many factors, such as slope of valley, length of reservoir, sediment characteristics, reservoir capacity-inflow ratio etc. It is necessary to assess the revised areas and capacities at various reservoir elevations in future (after sedimentation) so that the same can be used in simulation studies to test the reservoir performance. In this module, the empirical area reduction (EAR) method has been programmed, which is one of the commonly used methods recommended by IS:5477-Part 2, for assessing the new-zero elevation and assessing the deposition pattern of a known amount of sediments in a reservoir.

In *NIH_ReSyP*, this module is divided in two sub-modules. First sub-module helps to ascertain the new-zero elevation while sediment deposition profile and revised elevation-area-capacity table is generated in second sub-module. Input data requirement of this module includes general details of the reservoir such as FRL, DSL, EAC table, and total sediment volume that would be deposited during a specified period in the reservoir. Same input data form is used in both sub-modules except that in second sub-module, an additional information for new zero elevation needs to be specified.

3.8 Elevation-Area-Capacity interpolation

The purpose of this module is to interpolate the EAC values for any range of elevation interval, provided the elevation lies in between the lowest and highest elevation. Generally, authorities at dam site have some specific values (10-15) in the EAC table and it is sometimes desirable to have the values at intermediate levels. This module facilitates calculation of intermediate values in the elevation-area-capacity table using linear interpolation. All the available values of EAC are read as input by the module.

3.9 Inflow estimation

Inflow to a reservoir is the basic input which is regulated by a reservoir to obtain the maximum possible benefits. Sometimes, inflow rate in a reservoir is computed 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 purpose of this module is to prepare the inflow estimation table for different rates of rise at different reservoir levels. The only data required for this purpose is the EAC table and information about the release from the dam, if any. The output is presented in the form of a table. Inflow rate values (in cumec) at different elevations are computed for different values of rate of rise (m/hr). Knowing the initial reservoir elevation, rate of rise and the outflow rate, inflow rate in the reservoir can be picked up from the table.

3.10 Operation of a multi-reservoir system for flood control

Among the measures of flood control, a storage reservoir with gates to control the outflow is perhaps one of the most effective means. The moderation of a flood through storage is achieved by storing a part of flood volume in the rising phase of the hydrograph and releasing the same gradually in the receding phase of flood. However, this is an ideal operation which is possible only if the perfect fore-knowledge of inflow hydrograph is available. In absence of such information, the release curve may deviate from the ideal shape.

The operation of a reservoir for flood control usually begins as soon as the water level in the reservoir exceeds some specified level, say FRL, or inflow rate exceeds some threshold value. The operation for flood control regulation could be based on the concept of a specified reservoir level, specified inflow magnitude, or the nature of inflow (i.e. rising or falling). While developing flood regulation policy, it is assumed that the operator has the following objectives:

(a) to attain FRL at the earliest and to maintain it;

(b) to control the rise of reservoir level above FRL to the extent possible;

(c) to utilize the reservoir storage capacity to the extent possible before releasing water at rates exceeding the safe channel capacity, and

(d) to release water at rates above the safe channel capacity in the downstream river reaches for the least possible time.

The procedure, followed in this module for flood control operation, is based on three variables: a) reservoir critical level (RCL), b) critical flood inflow (CFI), and c) the nature of inflow (rising or falling). Based on the combination of these variables, two conditions (normal and emergency) are defined and flood release policy under both conditions is established. Simulation of the operation of the reservoir is then carried out with either the design flood hydrograph or a major flood that has occurred in the past. The detailed working table is generated which can be used to fine-tune the RCL and CFI values to best attain the stated objectives of flood control operation.

In case of a multi-reservoir system, this procedure is first carried out for individual reservoirs and then the entire system is studied. A line diagram is prepared and numeric node numbers are assigned to each structure for defining the system configuration. Flood hydrographs are estimated for independent catchment of all hydraulic structures and outflow hydrograph from any upstream reservoir is routed through the channel (using Muskingum method) to define its shape at the downstream structure. The model simulates the operation of the system for specified period. Based on the specified RCL and CFI values for different flood control reservoirs, the operation of each reservoir in the system is simulated in accordance with the flood control procedure and releases from the reservoirs are determined. Next, those circumstances are analyzed in which releases from any reservoir exceeded the downstream safe channel capacity. The operation parameters (RCL and CFI) are fine-tuned by trial and error so that best possible operation policy of the reservoir system (causing least downstream flooding and maintaining the safety of all structures) is obtained.

3.11 Operation of a multi-purpose multi-reservoir system for conservation purposes

This module is developed to simulate the operation of a multi-purpose multi-reservoir system for conservation operation. The various conservation purposes considered in the module include water supply for domestic and industrial purposes, irrigation, hydropower generation and minimum flow in the downstream river reach. The highest priority is given to the water supply demand for domestic and industrial purposes and the minimum downstream flow demands while priority between hydropower or irrigation is user-specified and may change from one period to another. The model can simulate operation of a system either for monthly operation or for ten-daily operation.

For each period (monthly/ten-daily), total water demands and availability at each hydraulic structure is computed. The amount of water required for hydropower depends on the available head of water which keeps on changing. This amount is calculated based on the mean elevation of water during a period. The release policy for meeting various demands depends on the specified operation policy (in terms of rule curve levels for various purposes derived using initial rule curve derivation module). Four rule curve levels, namely, the upper rule level, the first middle rule level, second middle rule level (applicable if hydropower is also a demand in addition to the irrigation and domestic supply demand) and the lower rule level need to be specified for all the periods (monthly/ten-daily). If the reservoir level rises above upper rule curve level in any month, the extra water is spilled and reservoir is brought back to upper rule curve level. Above the middle rule curve levels, full demands are met for all purposes during a period. If the reservoir level falls below middle rule curve levels, supply for lower priority demands is curtailed by a specified percent so as to meet reduced demands for full water year. If the reservoir reduces below the lower rule curve level, supply for lower priority demands is stopped and supply is made only for domestic demands and minimum flow requirements.

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 levels are specified by the user. In the present form, the model can be used for a system having 50 nodes and analysis can be carried out for 2000 periods (months/ten-daily) of record.

The model operates each storage reservoir in the system in accordance with the given trial rule curves. Each diversion structure is operated in accordance with the inflow availability and diversion demands. 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 failure months, 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 upstream structure (if any), flow from intermediate catchment, evaporation, irrigation demand, water supply demand, hydropower and downstream demands, actual release made for these demands, level of failure (if any), power generated, spill from the structure, and end level. Based on the observations from the tabular presentation, rule curve levels can be fine-tuned till the best operation performance is achieved. It is also possible to simulate scenarios for inter-basin water transfer or water transfer among various hydraulic structures within the system.

3.11.1 Case study of a proposed reservoir in Betwa basin for conservation operation

One major reservoir is proposed in the Betwa river basin. The operation analysis of this reservoir has been carried out using the conservation operation module of NIH_ReSyP. The total catchment area at the dam site is 1843 sq. km and the live and dead storage capacities of the reservoir (as per revised capacity plan after 50 years) are 337.906 (at FRL 380.00 m) and 8.664 M Cum (at DSL 356.50 m) respectively. The purposes of the reservoir are to satisfy domestic and industrial demands, ecological demands, irrigation demands, peripheral pumping demands, and water supply to a barrage for irrigation. In addition, there will be some transmission losses which need to be accounted in demands. The target demands have been regrouped in two broad categories: domestic supply, ecological demands, and transmission losses have been taken as high priority demands while irrigation demands, irrigation in vicinity through pumping and diversion to barrage have been accorded comparatively low priority demands. Annual high priority demands are 34.41 MCM while low priority demands are 346.78 MCM. Annual evaporation depth at the dam site is of the order of 1.745 m. Inflow series at the dam site are available at monthly time step from June 1970 to May 2009.

For the high and low priority demands, two critical rule curves have been derived using initial rule curve derivation module. The upper rule curve levels have been kept at FRL. Monthly simulation analysis has been carried out for the reservoir from June 1970 to May 2009. Initially, the operation was simulated with initial trial rule curve levels. On the basis of simulation results, the lower rule curve, critical for high priority demands, was fine-tuned so that these demands could be met to the extent possible. After finalizing the lower rule curve, the middle rule curve was modified such that the critical failure months and the failure months could be reduced to the minimum. A part of the simulation table generated for the reservoir is shown in Table – 1. The middle and lower rule curves fine-tuned for the reservoir are specified in Table – 2 and plotted in Figure – 3.

It is seen from the working table that the rule curve based operation tries to distribute the much deficit in advance so that critical failures can be avoided and high priority demands can be met in full to the extent possible. As soon as deficit conditions are anticipated, reduced supply for low priority demands (@ of 90% of the demands) is made so that reduced demands could be maintained throughout the water year. It needs to be mentioned here, that any month that meets 90% of its target demands is designated as a successful month and any year, which

Table - 1

Monthly operation simulation of a proposed reservoir

Year-Mon	Initial storage (MCM)	Inflow (MCM)	Evap. Loss (MCM)	Low priority demands (MCM)	Release for low priority demands (MCM)	High priority demands (MCM)	Release for high priority demands (MCM)	Spill (MCM)	End reservoir level (m)	Success (S)/ Failure (F)	
										Month	Year
1981-06	26.52	0.03	1.286	43.63	9.88	3.94	3.94	0.00	357.20	F	
1981-07	11.45	64.36	0.658	48.04	43.24	4.19	4.19	0.00	360.06	S	
1981-08	27.72	215.36	1.178	35.25	31.73	4.19	4.19	0.00	374.24	S	
1981-09	205.99	66.09	2.430	26.12	23.51	2.98	2.98	0.00	376.07	S	
1981-10	243.16	0.12	2.663	20.35	18.32	2.19	2.19	0.00	374.97	S	
1981-11	220.11	0.99	1.905	26.52	23.87	2.60	2.60	0.00	373.51	S	
1981-12	192.73	0.98	1.361	32.26	29.03	2.87	2.87	0.00	371.57	S	
1982-01	160.45	0.99	1.244	46.21	41.59	3.32	3.32	0.00	368.50	S	
1982-02	115.28	0.94	1.314	39.75	35.78	3.28	3.28	0.00	365.35	S	
1982-03	75.86	1.79	1.827	15.37	13.83	1.66	1.66	0.00	363.87	S	
1982-04	60.33	0.59	2.185	5.91	5.32	1.56	1.56	0.00	363.00	S	
1982-05	51.85	0.39	2.578	7.37	6.63	1.63	1.63	0.00	361.82	S	F
1982-06	41.40	0.03	1.464	43.63	24.58	3.94	3.94	0.00	357.20	F	
1982-07	11.45	73.95	0.717	48.04	43.24	4.19	4.19	0.00	361.31	S	
1982-08	37.25	515.46	1.608	35.25	35.25	4.19	4.19	173.77	380.00	S	
1982-09	337.90	51.31	3.277	26.12	26.12	2.98	2.98	18.93	380.00	S	
1982-10	337.90	0.12	3.369	20.35	18.32	2.19	2.19	0.00	379.10	S	
1982-11	314.15	2.65	2.492	26.52	23.87	2.60	2.60	0.00	378.04	S	
1982-12	287.84	2.44	1.888	32.26	29.03	2.87	2.87	0.00	376.68	S	
1983-01	256.48	4.72	1.772	46.21	41.59	3.32	3.32	0.00	374.68	S	
1983-02	214.52	5.88	1.927	39.75	35.78	3.28	3.28	0.00	372.74	S	
1983-03	179.42	2.75	2.825	15.37	13.83	1.66	1.66	0.00	371.79	S	
1983-04	163.85	0.80	3.523	5.91	5.32	1.56	1.56	0.00	371.17	S	
1983-05	154.25	0.52	4.391	7.37	6.63	1.63	1.63	0.00	370.37	S	F
1983-06	142.12	0.03	3.152	43.63	39.27	3.94	3.94	0.00	367.03	S	
1983-07	95.79	136.87	1.720	48.04	43.24	4.19	4.19	0.00	372.99	S	
1983-08	183.51	271.68	2.019	35.25	35.25	4.19	4.19	75.83	380.00	S	

Year-Mon	Initial storage (MCM)	Inflow (MCM)	Evap. Loss (MCM)	Low priority demands (MCM)	Release for low priority demands (MCM)	High priority demands (MCM)	Release for high priority demands (MCM)	Spill (MCM)	End reservoir level (m)	Success (S)/ Failure (F)	
										Month	Year
1983-09	337.90	389.16	3.277	26.12	26.12	2.98	2.98	356.78	380.00	S	
1983-10	337.90	118.78	3.478	20.35	20.35	2.19	2.19	92.76	380.00	S	
1983-11	337.90	8.94	2.664	26.52	23.87	2.60	2.60	0.00	379.23	S	
1983-12	317.71	6.58	2.031	32.26	31.90	2.87	2.87	0.00	378.02	S	
1984-01	287.48	0.70	1.925	46.21	41.59	3.32	3.32	0.00	375.99	S	
1984-02	241.35	0.64	2.107	39.75	35.78	3.28	3.28	0.00	373.97	S	
1984-03	200.83	1.04	3.063	15.37	15.37	1.66	1.66	0.00	372.89	S	
1984-04	181.77	0.35	3.754	5.91	5.91	1.56	1.56	0.00	372.23	S	
1984-05	170.90	0.26	4.608	7.37	7.37	1.63	1.63	0.00	371.38	S	S
1984-06	157.55	0.03	3.318	43.63	39.27	3.94	3.94	0.00	368.19	S	
1984-07	111.06	0.00	1.367	48.04	43.24	4.19	4.19	0.00	364.07	S	
1984-08	62.26	287.61	1.620	35.25	31.73	4.19	4.19	0.00	379.03	S	
1984-09	312.34	54.62	3.164	26.12	23.51	2.98	2.98	0.00	379.98	S	
1984-10	337.31	0.12	3.364	20.35	18.32	2.19	2.19	0.00	379.07	S	
1984-11	313.56	0.98	2.483	26.52	23.87	2.60	2.60	0.00	377.94	S	
1984-12	285.59	0.96	1.875	32.26	29.03	2.87	2.87	0.00	376.51	S	
1985-01	252.77	1.38	1.736	46.21	41.59	3.32	3.32	0.00	374.32	S	
1985-02	207.50	6.50	1.869	39.75	35.78	3.28	3.28	0.00	372.36	S	
1985-03	173.08	3.30	2.764	15.37	13.83	1.66	1.66	0.00	371.42	S	
1985-04	158.12	0.90	3.467	5.91	5.32	1.56	1.56	0.00	370.81	S	
1985-05	148.68	0.57	4.327	7.37	6.63	1.63	1.63	0.00	370.00	S	S

has no failure month is considered as a successful year. Using such simulation analysis, rule curves can be fine-tuned and operation policy for a reservoir or a system of reservoirs can be optimized.

Table – 2

Middle and lower rule curve levels (m) for proposed reservoir

Month	Middle Rule curve levels (m) critical for low-priority demands	Lower Rule curve levels (m) critical for high - priority demands
January	377.05	361.75
February	375.00	361.25
March	372.60	360.75
April	371.85	360.40
May	371.10	360.00
June	378.00	357.20
July	378.80	358.30
August	379.15	360.20
September	380.00	361.40
October	380.00	362.50
November	379.65	362.50
December	378.50	362.10

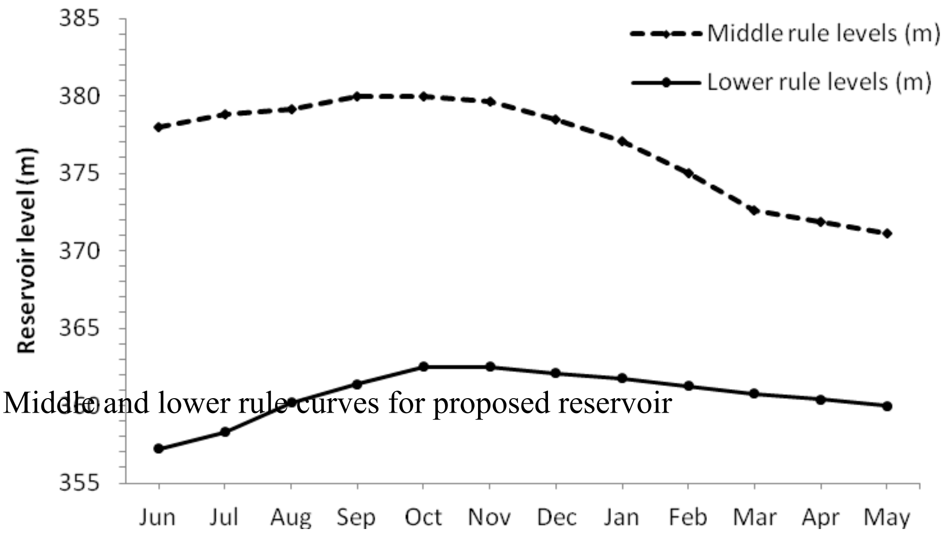

Figure – 3: Middle and lower rule curves for proposed reservoir

4. Conclusions

Because of the high time and space variability of rainfall and uncertain nature of monsoon in India, reservoirs form one of the most important components of a water resources development project. The efficient use of water resources requires judicious design and proper management and operation of reservoir systems. In this context, reservoir operation for conservation and flood control purposes forms a very important part of the planning and management of water resources system. A large number of hydrologic analyses are required for planning, design and operation of reservoirs. In view of the importance of reservoir operation problem in Indian context and due to non-availability of generalized software for reservoir analysis, a number of computer programs have been developed at NIH for various kind of reservoir analysis. Subsequently, a generalized software named "*SRA – Software for Reservoir Analysis*" was developed to integrate the individual programs. Recently, a WINDOWS based GUI, named ***"NIH_ReSyP – Reservoir Systems Package",*** has been developed in Visual BASIC platform which links the individual computer programs and provides a user-friendly environment for carrying out various kind of reservoir analysis. The interface has menu screens for various analytical modules and on-line help to guide the user for each module. Data forms have been provided for easy preparation of data files and many tabular and graphical options facilitating efficient analysis and reporting have been introduced. The software is in continuous stage of updating for making it a comprehensive tool for various kinds of reservoir analysis. It is also planned to make it available at the web site of Institute for free download and mass utilization.

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