Storage Yield Functions for Sondur Reservoir in MRP Complex – A Case Study

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ABSTRACT: In Engineering, and more specifically in water resources, the need of representation of complexes natural phenomena through models is of crucial importance for water resources planning and management. Through the use of these models, it is possible to understand the natural process and to evaluate the system response to different scenarios, providing support to the decision making process. Most of the water resources and hydrology problems are characterized by multiple objectives, which often conflict and compete with one another. There is no general algorithm for all Reservoirs, and is to be tackled independently for developing the optimal operating strategies. The present study is focused on development of Monthly storage Yield Functions for Sondur Reservoir of Mahanadi Reservoir Complex (MRP) in Raipur District of Chhattisgarh State in India using Stochastic Dynamic Programming Model of Loucks et al (1981).

KEYWORDS: Stochastic dynamic programming; Dynamic Programming; Storage Yield Functions; Optimization; Reservoir operation.

I. INTRODUCTION

1.1 STUDY AREA:

In year 1989, Sondur reservoir is constructed on Sondur River in Pairi basin. Sondur Feeder Canal (SFC) with a provision of irrigation of 12260 hectares is completed in 1992. It also diverts the water of Sondur reservoir in Pairi basin to Dudhawa reservoir in Mahanadi basin. The development of the MRP system started in 1915 with the construction of a weir at Rudri and Mahanadi Main Canal (MMC) system for diverting the water of Mahanadi River. Since then, in due course of time MRP system has been enriched by the addition of various storage works, feeder canals and proliferation of irrigation canals. Murumsilli reservoir (1923) on Siliyari River, Dudhawa reservoir (1965) and Ravishankar reservoir (1978) on Mahanadi River are constructed in Mahanadi basin. Mahanadi Feeder Canal (MFC) is taken off from the Ravishankar reservoir to carry water supply for municipal water demands of Raipur and Dhamtari along with industrial demand of Bhilai Steel Plant (BSP). In addition to this, MFC commands a gross area of 20372 hectares with net Culturable Command Area (CCA) of 14810 hectares. In year 1989, Sondur reservoir is constructed on Sondur River in Pairi basin.

In Mahanadi basin the two upstream reservoirs Dudhawa and Murumsilli are served as feeder to the Ravishankar reservoir. The two upstream reservoirs namely Dudhawa and Murumsilli do not have any irrigation demands and are only storage regulation structures. Ravishankar reservoir has irrigation and municipal & industrial (M&I) demands. These demands can be made through MFC and MMC. In Pairi basin, Sondur reservoir is located at the upstream of Dudhawa reservoir. Location map of Sondur Reservoir is given in fig.1

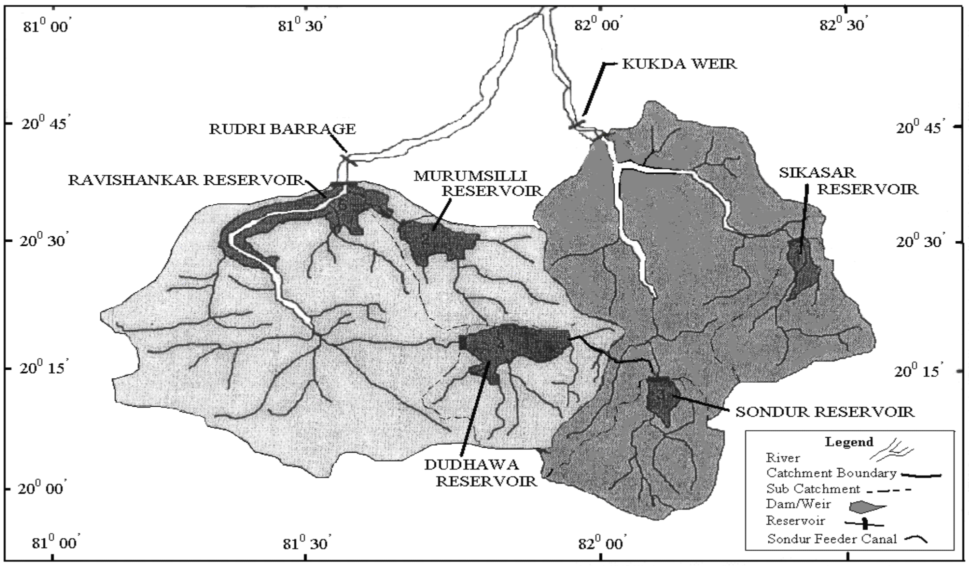

Fig.1 Location map of Sondur Reservoir.

TABLE I: Salient Features of Sondur Reservoir are given below:

S. No.	Description		Value
1	Catchment area (sq. km.)		512
2	Storage capacity (Mm^3) at	MWL	226
		FRL	198
		DSL	18
3	Live storage (Mm^3)		162
4	Canals and Command Area in ha.	Khariff	12260
		Rabi	12260

II. STOCHASTIC DYNAMIC PROGRAMMING MODEL:

An ‘operating policy’ is a time schedule of releases from reservoirs or pumpages from aquifers and /or reservoirs and of aquifers recharge operations. The ‘Operating rules’ are basically the guidelines formulation for the Reservoir Manager for operation of storage facilities and are formulated to overcome the discrepancy so often observed between the desirable amounts of water at a certain point in time and the naturally available quantities at the same point. The operating rules then helps the manager in taking decisions at different points of time to operate the Reservoir for most judiciously meeting the demands

Dynamic programming (DP) is an approach in systems analysis techniques which optimizes multistage decision processes, i.e. when the problem can be represented as a sequence of stages, where one or more decisions are required at each stage and where the decision at one stage directly attacks only the next adjacent stage. The technique is based on the Bellmen’s principle of optimality which states- “An optimal policy has the property that whatever the initial state and initial decisions are, the remaining decisions must constitute an optimal policy with regard to the one resulting from the first decision.”

There is no standard DP algorithm and it must be tailored to the individual problem. Where the sequential nature of the system can be established and where the number of state and decision variables are not too large, the computational procedures are simple and practical.

The objectives of Stochastic DP Model of Loucks et al, which has been used in the present study are a reservoir operation problem involves determination of the sequence of releases from the reservoir, given reservoir storage capacity and inflows, that maximizes the system performance. To define reservoir operating policies that specify the desired reservoir release as a function of initial storage volume and inflow in each period, several optimization models are used and the one discussed below is one of them.

2.1 Definition of Variables and Indices**:**

First the random inflows Q_t in any period‘t’ are restricted to a number of possible discrete values ordered by the index ‘i’. Thus the entire range of possible inflows in each period‘t’ is represented by a number of discrete inflows ‘Q_{it}’ each having a probability ‘PQ_{it}’ of occurrence. Similarly the possible initial storage volumes ‘S_t’ in the Reservoir are restricted to various discrete values denoted by index ‘k’ in its range. Thus S_{kt} is known but its probability ‘PS_{kt}’ is unknown operating policy. The indices used for defining inflows and storage volumes in period‘t+1’ are ‘j’ and ‘ℓ’ corresponding to ‘i’ and ‘k’ in period‘t’.

Now, given the initial storage volume S_{kt}, the inflow Q_{it} and the final storage volumes $S_{\ell,t+1}$ in period ‘t’, the releases $R_{ki\ell t}$ are determined by the continuity equation,

$$R_{ki\ell t} = S_{kt} + Q_{it} - E_{k\ell t} - S_{\ell,t+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where $E_{k\ell t}$ is the possible evaporation and seepage loss based on the initial and final storage volumes in period‘t’.

It is clear from eqn.1 that the optimal reservoir releases $R_{ki\ell t}$ or equivalently the final storage volume $S_{\ell,t+1}$ in each time period or stage depends on two state variables. The initial storage volume S_{kt} and current inflow Q_{it}. Let $B_{ki\ell t}$ be the value of system performance associated with an initial reservoir storage volume of ‘S_{kt}’, an inflow of Q_{it}, a release of $R_{ki\ell t,}$ and a final volume of $S_{\ell,t+1}$ which is to be maximized and in the objective of the Reservoir Operating problem.

2.2 Recursive Equations:

To begin the development of the recursive backward moving DP algorithm, a particular period is selected after which it is assumed that the reservoir will no longer be operated. This can be any period in any year, because the eventual Steady state Reservoir Operating Policy derived from SDP Model will be independent of this arbitrary assumption provided that the valued of system performance $B_{ki\ell t}$ and transition probabilities P_{ij} do not change from one year to the next. Let, there are ‘t’ periods in a year and the objectives is to maximize total annual benefits,

$$\text{i.e maximize} \quad \sum_{t=1}^{T} \quad B_{ki\ell t}$$

The sequential Reservoir operation process described as a multistage decision madding process is shown in fig.2 . It can be noted form fig.2 that T+1 =1 as the cycle will be repeated in cyclic solution of recursive equations.

Let the arbitrary terminal period be period ‘T’ now defining $f_t(k,i)$ as the total expected value of the system performance with ‘n’ periods to go, including the current ‘t’ given that in period ‘t’ the initial storage volume and inflow are S_{kt} and Q_{it} respectively. Then with only one period remaining

$$f_T^{1}(k,i) = \text{Max}\{\, B_{ki\ell t}\} \;\square\; k,i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

ℓ must be feasible given k,i and t With two periods remaining before the end of Reservoir operation, the maximum expected value of system performance can be calculated as:

$$f_{T-1}^{2}(k,i) \quad = maximum[B_{ki\ell t} + \sum_j p_{ij}^{T-1}\, f_T(\ell, j)] \;\square\; k,i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

ℓ feasible where, P_{ij}^{T-1} is the probability of inflow $Q_{j,T-t}$ in period ‘T’ when the inflow in period T-1 equals $Q_{i,\,T-1.}$

The function f_{T-1}^{2} (k,i) is the expected system performance in the final two periods, since the inflow in period’T’ is not known with certainty in period T-1. The probability of any flow $Q_{j,T}$ in period ‘T’ depends on the flow $Q_{j,\,T-1}$ in period T-1, and is given by the transition probability P_{ij}^{T-1}. The recursive relationship, defined by eqn 3 can be generalized as –

$$F_t^{n}(k,i) \quad = maximum[B_{ki\ell t} + \sum_j p_{ijt}\, f_t^{n+1}(\ell, j)] \;\square\; k, i$$

ℓ must be feasible where, ‘t’ refers to the within year period and ‘n’ to the total number of periods remaining before Reservoir operation terminates.

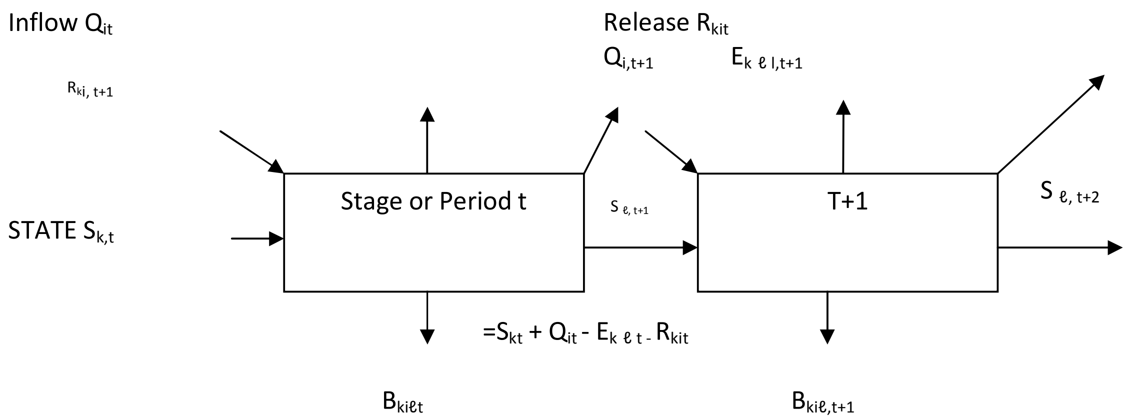

Fig. 2 Sequential Reservoir Operation Process

2.3 Steady State Operating Policy:

As these recursive equations are solved for each period in successive years, the policy ℓ (k,i,t) defined in each particular period 't' will relatively quickly, repeat in each successive year. When this condition is satisfied, and when the expected annual performance, $F_t^{n+T}(k,i) - F_t^{n}(k,i)$, is constant for all states k,i and all periods 't' within a year policy has reached a steady state.

2.4 Probability Distributions of Storage Volumes and Releases:

The steady state operating policy derived from the solution of the SDP Model defines the optimal final storage volume '$S_{\ell, t+1}$'. Let this policy be denoted by $\ell = \ell$ (k,i,t). Assuming it as a 'pure operating strategy', the index 'ℓ' is not needed for the definition of the Reservoir releases and their joint probabilities. It can ve specified by the policy $\ell = \ell$(k,I,t) for any value of k,I,t. thus the continuity equation can be written as

$$R_{kit} = S_{kt} + Q_{it} - E_{k\ell t} - S_{\ell, t+1} \;\square\; k,i \quad \ldots\ldots\ldots\ldots\ldots 4$$

$$\ell = \ell(k,i,t)$$

and probability PR_{kit} can be defined as the joint probability of the initial storage volume S_{kt} the inflow and also the final storage volume $S_{\ell, t+1}$, which is specified for each k,I,t by the function $\ell = \ell$(k,i,t) . Product of PR_{kit} with P_{tij} (stream flow transition probability) will give the joint results in the joint probability of $S_{\ell, t+1}$, and $Q_{j,t+1}$ which can be denoted by $PR_{\ell j, t+1}$.

$$\text{i.e.} \quad PR_{\ell j, t+1} = \sum_k \sum_i PR_{kit} * P_{tij} \;\ldots\ldots\; \square\; \ell,j,t \;\ldots\ldots\ldots\ldots\ldots 5$$

$$\ell = \ell(k,i,t)$$

in addition, the joint probabilities, PR_{kit} must sum to 1 in each time period 't' i.e.

$$\sum_k \sum_i PR_{kit} = 1 \;\square\; t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Simultaneous solution of the above set of equations 5, 6 will yield the values of PR_{kit}. It can be observed that one equation in 5 is redundant in each period 't' and, the number of independent equations 5 and 6 equals the number of unknowns and thus a unique solution can be obtained. Knowing PR_{kit} the corresponding marginal probability distribution of S_{kt}, Q_{it} and $S_{\ell,t+1}$ associated with any operating policy $\ell = \ell$(k,i,t) can be obtained from the following equations:

$$PS_{kt} = \sum_i PR_{kit} \;\square\; k, t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

$$PQ_{kt} = \sum_k PR_{kit} \quad \square\; i,t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

$$PS_{\ell, t+1} = \sum_k \sum_i PR_{kit} \;\square\; \ell, t \ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

$$\ell = \ell(k,i,t)$$

2.5 Reservoir Yield Function:

The results of releases obtained from the policy $\ell = \ell$ (k,i,t) are arranged in descending order of their magnitude and corresponding values of PR_{kit} are written against each value. Then cumulative probability is worked out for each value of release and a plot between them is obtained. From this plot release value for particular value of reliability can be obtained. Such plots are to be obtained for each period 't'.

III. RESULT

Table: 2 The Probability which meeting out the demand of Sondur Reservoir:

Month	Dependability	Demand	% Reliability of satisfying Demand
July	60%	29.064	0.95
	65%	29.064	0.86
	70%	29.064	0.80
	75%	29.064	0.80
	80%	29.064	0.75
	85%	29.064	0.70
	90%	29.064	0.70
August	60%	9.345	0.90
	65%	9.345	0.82
	70%	9.345	0.80
	75%	9.345	0.75
	80%	9.345	0.75
	85%	9.345	0.70
	90%	9.345	0.70
Sept.	60%	22.575	0.95
	65%	22.575	0.90
	70%	22.575	0.85
	75%	22.575	0.78
	80%	22.575	0.75
	85%	22.575	0.75
	90%	22.575	0.70
Oct.	60%	6.52	0.95
	65%	6.52	0.95
	70%	6.52	0.90
	75%	6.52	0.90
	80%	6.52	0.85
	85%	6.52	0.85
	90%	6.52	0.75

IV. CONCLUSIONS

Based on the conducted study following major conclusions are made:

1. The values of % Reliability of meeting the demands in monsoon months can be evaluated considering various % dependability of monthly net Inflows from the developed Reservoir Yield Functions.
2. It has been observed that the demands in various months can be met with 75 – 90% reliability for different values of dependable net inflows.
3. The target storage values as obtained for various values of dependable net inflows can help the Managers of Sondur Reservoir to decide about the crop pattern in Rabi season
4. The results obtained after the analysis suggest that the monthly Kharif Demands in the Sondur Reservoir Area can be met with 80% reliability corresponding to 75% Dependable values of Net Inflows.

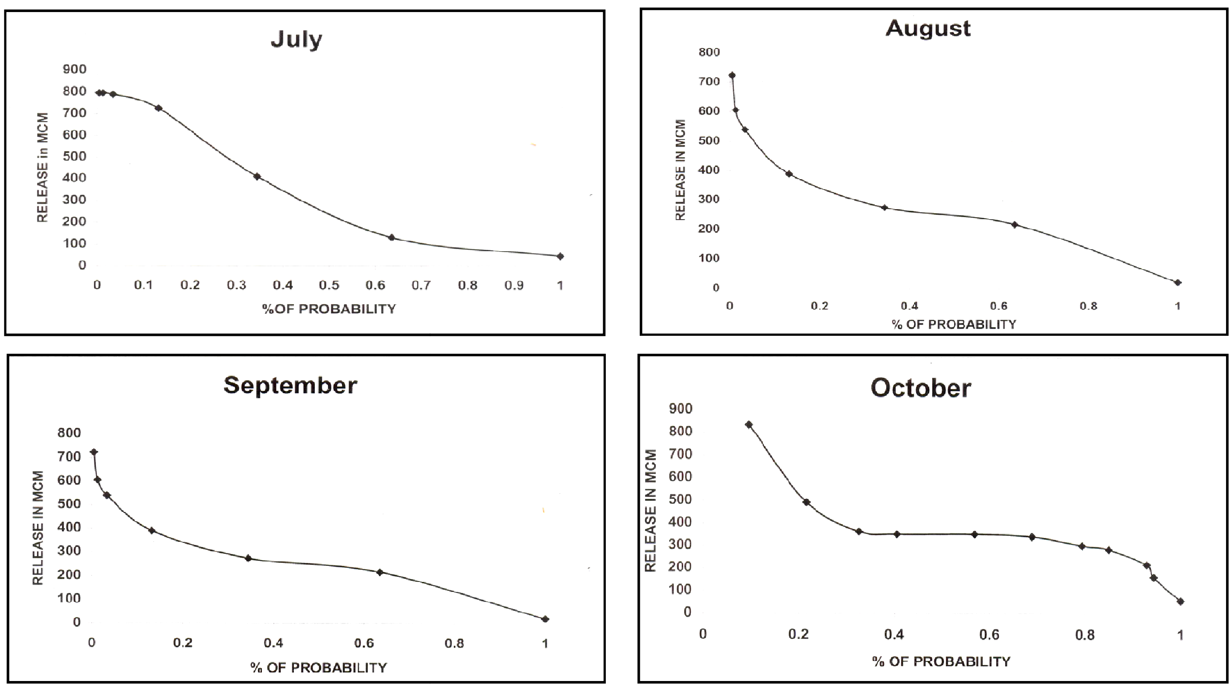

Fig. 3(a) : Storage Yield Functions for 75% Dependability Inflows:

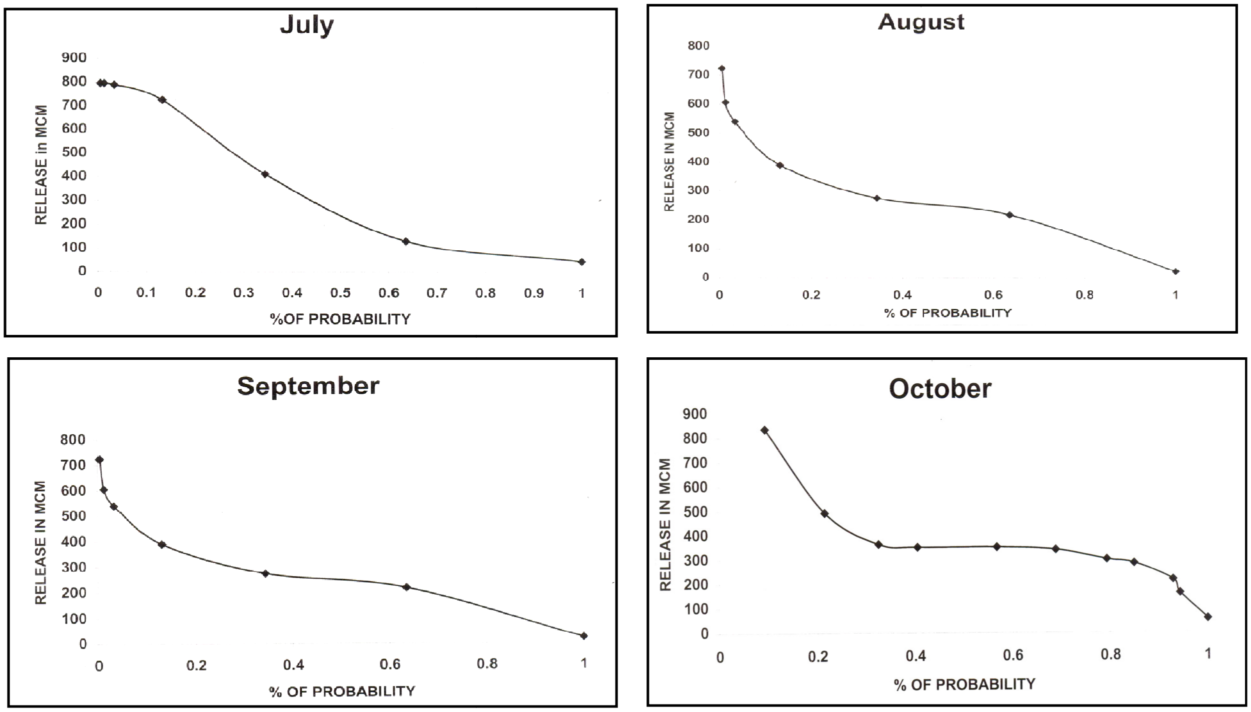

Fig. 3(b) Storage Yield functions for 90% Dependability – values of Inflows

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