INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 3, Issue 6)
Available online at www.ijariit.com

Reservoir Operation Model for Hyderabad Water Supply System

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Abstract: The reservoir operation is a challenging task for achieving the design performance of any reservoir. Though many reservoir operation modeling techniques are available, still the reservoir mangers are adopting the conventional procedures. Hyderabad water supply system is a complex system and having multiple sources of reservoirs to supply drinking water to cater Hyderabad city and among one of them is Himayathsagar reservoir. In this paper, an attempt was made to evolve the reservoir operation strategy by developing models based on crisp concepts and fuzzy logic concepts. The initial simulation was made to understand historical storages and release curves using the inflows and evaporation from observed data. A model has been developed based on crisp concepts and later to evolve a release policy using fuzzy logic concepts. The model results were obtained. Comparisons of historic, crisp and fuzzy results were presented to demonstrate the improvement, relevance, and applicability of the developed methodology.

Keywords: Reservoir Operation, Design Performance, Simulation Models, Fuzzy Logic.

I. INTRODUCTION

Reservoir operation of any system and demand management is critical particularly during the low inflows period for ensuring the reliable drinking water supply to the command areas under the system. As such, it is important for the effective operation of the reservoir system to its maximum efficiency and performance for better releases and also to adopt strategic demand management to minimize the deficits for ensuring the reliable water supply. Some of the studies were carried out on the reservoir operations using various optimization and simulation techniques by researchers. The present case study is aimed at developing a simulation model for drinking water needs from one of the reservoirs in Hyderabad, Telangana State, India. The development of relevant models and their application in real time reservoirs operation has also been studied and reported by researchers to various water resources systems.

Panigrahi and Mujumdar (2000) [4], Studied fuzzy rule based model for a single reservoir operation using Stochastic Dynamic Programming (SDP) for framing rule base. Regulwar & Anand Raj (2009)[1] developed Multi Objective Multi-reservoir Operation model using Genetic algorithm under fuzzy environment for the reservoirs in Sub Basin of Godavari River, Maharashtra, India. Mousavi et al (2004) [5] reported reservoir operation using a Dynamic Programming Fuzzy Rule based approach to establish the general operating policies. Vedula and Mohan (1991) [6] gave a real-time multipurpose reservoir operation for irrigation and hydropower generation on Bhadra reservoir system in Karnataka using SDP. Shrestha (1996) [7] developed fuzzy relations for input and output of reservoir operating principles.
Inspite of considerable work done on reservoir operations not many attempts were made for the combined study of Reservoir Operation Policy and demand management to evolve deficit minimizing strategies, particularly to drinking water supply systems.

II. PRESENT STUDY

In this paper, a case study has been taken up on one of the reservoir sources of Hyderabad water supply system namely Himayathsagar Reservoir, which exclusively operates for the drinking water supply of the Hyderabad city the Capital of Telangana State in India.

The objective of the study is to evolve the reservoir operating policy and increase the releases and to decrease the deficits through a model study. The results were compared with historical releases. The study has been carried out in three phases. In the first phase release policy was evolved based on the sequential process simulation with crisp concepts. In the second phase, the release policy was evolved using the fuzzy logic simulation to achieve the further improvement in performance. In the third phase, suitable water allocation was made among the demand nodal centers and proposed to minimize the deficits by adopting certain strategies.

III. SYSTEM FOR STUDY

The Himayatsagar reservoir was built across the River Musi under Krishna basin being operated exclusively for drinking water supply of Hyderabad city. The reservoir has an active storage capacity of 84.75 Mm^3. It provides the water supply to various demand centers under its command area.

IV. RESERVOIR SYSTEM DATA

Monthly inflow data of Himayathsagar reservoir system for a period of 23 water years (1994-2016, water year beginning 1st January and ending 31st December) and monthly withdrawals data for 23 years (1994-2016) were used in the present study. In the Table-1 the annual inflows in Mm^3 for Himayathsagar reservoir for the period 1994-2016 are presented.

The evaporation loss data for the period from 1994-2016 were used in deriving the relationship between the evaporation and storage in each month by least squares fitting and evolved the evaporation curves and equations were used in the model. The initial Storage for Himayatsagar Reservoir was considered for the time period of January 1994 at the beginning of that month.

Table. 1 Annual Inflow in Mm^3

Year	Himayatsagar	Year	Himayatsagar
1994	284	2006	200
1995	2166	2007	135
1996	972	2008	1051
1997	200	2009	1417
1998	2839	2010	2001
1999	200	2011	200
2000	2005	2012	317
2001	1919	2013	909
2002	200	2014	1050
2003	1290	2015	200
2004	200	2016	870
2005	1612		

Source: HMWSSB Reservoir Log Records– (2016) [4]

V. WATER DEMAND

Monthly demands in the command area of Himayathsagar reservoirs and for the total Hyderabad water supply system were computed for 20 nodal demand centers based on the Liter per capita per day (LPCD) guidelines given by the Govt. of India. In the computation of demands, the basis was considered as people's access through service connection to the system, category wise consumption pattern such as domestic slum consumption pattern and quantities, domestic general, commercial, industrial, mobile tanker supply etc. in conformity with the approved norms of the applied system. The demands for various categories of domestic slums, domestic general, commercial, industrial, mobile supplies etc. showed in Table – 2 for each month. In the reservoir operation with node wise complete demands and releases are taken for monthly simulation run in the present study.

VI. RESERVOIR OPERATING MODELS

The simulation has been carried out from the beginning of time period month with the available storage in that month from the data. The model was simulated for the entire time period based on the equations given from equations 1 to 8 iteratively till a satisfactory performance was obtained to meet the demand patterns reasonably. It was carried out by modifying the constants given in the equations and also from the levels obtained during the simulation period. The results thus obtained were analysed to observe the statistics for further modifying the simulation constants and performing simulation repetitively.

The reservoir operating policy for each month is such for known values of initial storage and inflow sequences to the Himayatsagar reservoir the releases to be made. The reservoir has been divided into certain intervals of its active storages / Levels. It was considered as crisp values of the class interval of active storages / Levels. The rules were derived based on "if then" principles for sequential processing simulation (crisp model). The releases were made based on the inflows and available storage patterns with lesser storage level make restriction to releases more water for all demands from the reservoir. These rationing factors were devised based on analysis of results obtained by trial basis and also from the experiences gained from the reservoir manager's operational strategy historically for the system. The releases from Reservoir is a function of St, It. However, it can also be operated as Rt is independent of It.

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

$$S_{t+1} \leq S_{Cap} \quad (2)$$

$$Spill_t = S_{t+1} - S_{Cap} \quad (3)$$

$$R_t \leq D_t \quad (4)$$

$$Def_t = R_t - D_t \quad (5)$$

$$R_t = f(S_t, I_t) \quad (6)$$

$$Level_t \leq Reslevel_t \quad (7)$$

$$Releases_t = K_t * D_t * Days \quad (8)$$

Where:

S_{t+1} = Storage in the reservoir at the beginning of time period t+1.
S_t = Storage in the reservoir at the beginning of time period t.

$Spill_t$ = Spill in the reservoir at time period t.
S_{cap} = Storage capacity of reservoir.
R_t = Releases from the reservoir at time period t.
D_t = Demands from the reservoir at time period t.
O_t = Overflow from the reservoir at time period t.
E_t = Evaporation losses from the reservoir at time period t.

$Level_t$ = Reservoir level available at the beginning of time period.
$Releases_t$ = Monthly Release.
K_t = Constant factor based on reservoir level and month.

Table. 2 Demands in Mm^3

Month	Domestic Slum	Domestic General	Commercial	Total
January	4.000	40.837	4.925	54.51
February	3.621	36.931	4.454	49.30
March	4.022	40.956	4.932	54.67
April	3.901	40.011	4.772	53.29
May	4.041	41.501	4.932	55.24
June	3.922	40.221	4.779	53.58
July	4.067	41.625	4.944	55.45
August	4.075	41.670	4.946	55.50
tember	3.953	40.376	4.787	53.84
October	4.094	41.785	4.959	55.72
November	3.972	40.502	4.800	54.00
December	4.119	41.929	4.962	55.90
Total	47.787	488.34	58.192	651.03

Source: HMWSSB Revenue Data – (2016) [5]

The inflows were considered as deterministic as obtained from the measured records. In the first phase of modeling the operating policy derived from the crisp model is a set out of rules specifying the storage at the beginning of the next period for each combination of initial storage and inflow for the current period thus specifying the release for the current period. The objective of the model is to obtain the release values as per the defined release policy based on the crisp concepts. The model release curve is shown in Figure – 1.

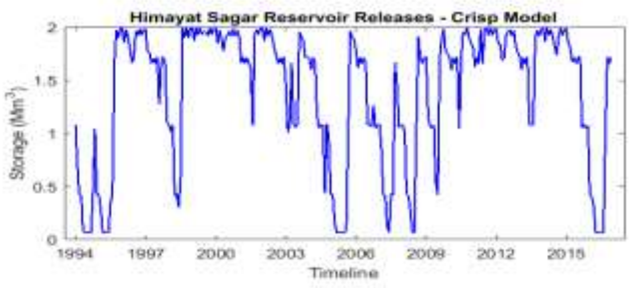

Fig.1: Crisp Model Releases

The model releases are based on the developed simulation model for the Himayathsagar reservoir and it was also compared with that of historical pattern and found that the trends obtained were satisfactory.

In the second phase, the fuzzy model simulation was performed to derive the monthly operating policy using the storages, inflows, release values as fuzzy sets, fuzzy intervals with associated membership functions, fuzzy rules, fuzzy inferences and releases were made for the system. The obtained release which is also a fuzzy variable is defuzzified using centroid defuzzification method which was reported as performing well based on literature. The model has been calibrated with part of data and also validated with the remaining data. The results thus obtained are model storages and releases. In both models the evaporation equations, storage continuity equation with the storage constraints, release constraints, demand constraints were incorporated during the calibration and validation stages. The equations adopted in this study are shown in equations 1 to 8. A typical set of fuzzy rules are shown in Table 3 for the developed model.

Table. 3 Typical Fuzzy Rules

S. No.	Storage Value	Inflow Value	Releases Value
1	If (Storage is very low)	and (Inflow is low)	then (Releases is very low)
2	If (Storage is low)	and (Inflow is low)	then (Releases is low)
3	If (Storage is medium)	and (Inflow is very high)	then (Releases is very high)
4	If (Storage is high)	and (Inflow is high)	then (Releases is very high)
5	If (Storage is very high)	and (Inflow is very high)	then (Releases is very high)

Table. 4 Comparison of Monthly Releases for Typical Period

Month/ Year	Himayathsagar (In Mm^3)	
	Crisp	Fuzzy
Jan-2011	1.82	2.11
Feb-11	1.63	1.98
Mar-11	1.71	2.11
Apr-11	1.36	1.66
May-11	1.41	1.98
Jun-11	1.36	1.66
Jul-11	1.41	1.98
Aug-11	2.00	2.11
Sep-11	1.93	2.05
Oct-11	2.00	2.11
Nov-11	1.93	2.05
Dec-11	1.98	2.11
Jan-12	1.98	2.11
Feb-12	1.84	1.98
Mar-12	1.84	2.11
Apr-12	1.69	2.05
May-12	1.71	2.11
Jun-12	1.36	1.91
Jul-12	1.96	2.11
Aug-12	1.98	2.11
Sep-12	1.91	2.05
Oct-12	1.97	2.11
Nov-12	1.82	2.05
Dec-12	1.77	2.11

Figure 2: Shows the Screen Shot of the Fuzzy Model Developed For Simulating Himayathsagar Reservoir and Figure 3: Shows Releases Based on Fuzzy Based Model Which are Found to be Superior to the Crisp Model Releases

Model Results

The model releases are shown in Table – 4 for the developed crisp and fuzzy models for typical two years time period are presented and these releases are found to be superior to the historical releases. The model releases statistical performance was evaluated through mean and variance values and shown in Table – 5. The Figure – 4 shows the fuzzy releases with mean and certain threshold limits proposed and these values found to be within the threshold limits except in two time periods during the entire simulation period.

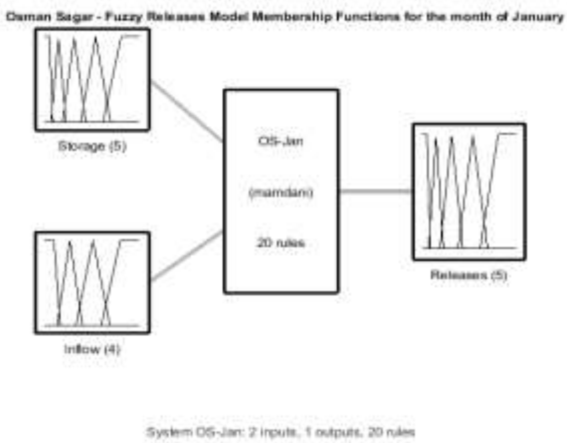

Fig. 2: Screen shot of Fuzzy Model

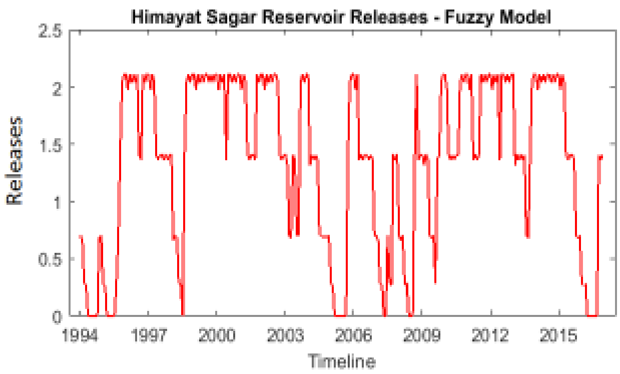

Fig.3: Releases Based on Fuzzy Based Model

Table. 5 Mean & Variance in Mm^3 of Model Releases

Reservoir	Model Releases	Mean Value	Variance Value
Himayatsagar	Crisp	1.2493	0.45893
	Fuzzy	1.5097	0.48648

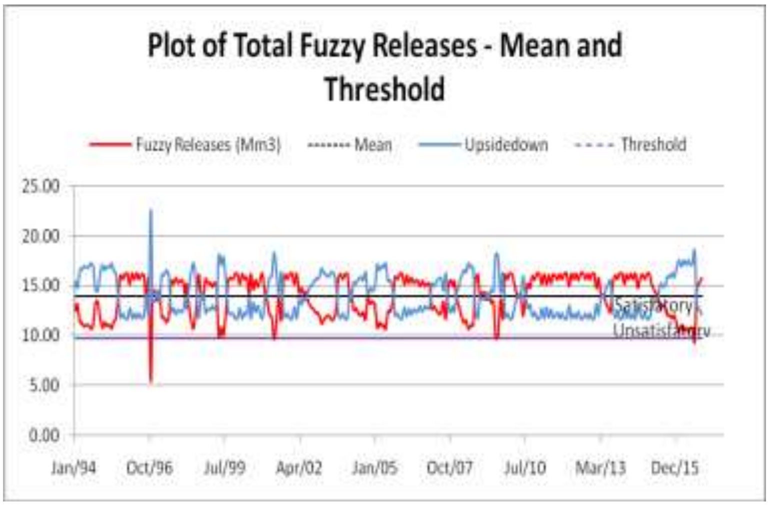

Fig.4: Mean & and Threshold of Model Releases

Table. 6: Month wise Mean and Variance in Mm^3 for Model Releases

Month-Year	Fuzzy Releases (Mm3)	Mean	SD	Variation	Upside-down	Thres hold	Lower Thres hold	Upper Thres hold	Average Thres hold
Jan-94	15.17	13.95	1.48	4.01	12.74	9.71	11.95	15.49	13.72
Feb-94	12.55	13.95	1.98	4.01	15.36	9.71	11.95	15.49	13.72
Mar-94	13.10	13.95	0.73	4.01	14.81	9.71	11.95	15.49	13.72
Apr-94	11.33	13.95	6.90	4.01	16.58	9.71	11.95	15.49	13.72
May-94	11.34	13.95	6.83	4.01	16.57	9.71	11.95	15.49	13.72
Jun-94	10.97	13.95	8.92	4.01	16.94	9.71	11.95	15.49	13.72
Jul-94	11.05	13.95	8.43	4.01	16.86	9.71	11.95	15.49	13.72
Aug-94	11.06	13.95	8.39	4.01	16.85	9.71	11.95	15.49	13.72
Sep-94	10.69	13.95	10.63	4.01	17.21	9.71	11.95	15.49	13.72
Oct-94	10.99	13.95	8.80	4.01	16.92	9.71	11.95	15.49	13.72
Nov-94	13.31	13.95	0.41	4.01	14.60	9.71	11.95	15.49	13.72
Dec-94	13.39	13.95	0.32	4.01	14.52	9.71	11.95	15.49	13.72
Jan-95	11.70	13.95	5.10	4.01	16.21	9.71	11.95	15.49	13.72
Feb-95	10.82	13.95	9.82	4.01	17.09	9.71	11.95	15.49	13.72
Mar-95	11.34	13.95	6.84	4.01	16.57	9.71	11.95	15.49	13.72
Apr-95	10.97	13.95	8.88	4.01	16.94	9.71	11.95	15.49	13.72
May-95	11.06	13.95	8.39	4.01	16.85	9.71	11.95	15.49	13.72
Jun-95	10.70	13.95	10.58	4.01	17.21	9.71	11.95	15.49	13.72
Jul-95	11.33	13.95	6.88	4.01	16.58	9.71	11.95	15.49	13.72
Aug-95	11.69	13.95	5.11	4.01	16.21	9.71	11.95	15.49	13.72
Sep-95	13.94	13.95	0.00	4.01	13.97	9.71	11.95	15.49	13.72
Oct-95	16.06	13.95	4.44	4.01	11.85	9.71	11.95	15.49	13.72
Nov-95	15.68	13.95	2.99	4.01	12.22	9.71	11.95	15.49	13.72
Dec-95	16.20	13.95	5.04	4.01	11.71	9.71	11.95	15.49	13.72

After analysis of the releases obtained from the developed models, the monthly releases recommended from the Fuzzy Model study to the supply nodes through the integrated system along with the fixed releases. Table – 6 shows the statistical analysis of mean, standard deviation and upper and lower threshold values are presented for typical two year period and it can infer from the entire results thus obtained the resulting releases are within the satisfactory limits.

VII. CONCLUSION

A reservoir operation for meeting the domestic and industrial water supply for one of the reservoirs in Hyderabad city in India using simulation model has been developed successfully. It was found that the developed model is working satisfactorily for reservoir operation and shown an increase in efficiency by 20.84% over the conventional operation.

ACKNOWLEDGEMENT

The authors gratefully acknowledged the help rendered by Hyderabad Metropolitan Water Supply & Sewerage System in providing the necessary field data for the study.

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