Evolving Reservoir Operation Rules using Fuzzy Logic Inference System for Irrigation Management in a Sub-Basin Scale

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***Abstract*— Optimal operation and coordination of the many facets of reservoir systems need the assistance of computer modeling tools to arrive at balanced operational decisions. Reservoir simulation is an important step in developing the optimal operation policy for a reservoir. One of the recent trends to solve reservoir operation and water management issues is to resort to a Decision Support System. In this study, Decision Support Models have been evolved using fuzzy logic with different combinations of inputs for developing rules for the operation of a reservoir in South India under the prevalent varying conditions.**

Keywords*— *Decision support system, reservoir operation, simulation, fuzzy-logic

I. INTRODUCTION

Throughout the world, irrigation is probably the most important use of water and almost sixty percent of the freshwater withdrawals are for irrigation purpose. Large scale farming activities could not provide food for the entire population of the world due to the lack of available water for irrigating the crop fields from natural sources like rivers, lakes, reservoirs and wells. Optimum development and efficient utilization of the water resources are of paramount importance for meeting the requirements of growing population, urbanization and irrigation in arid and semi arid regions. Water resources development projects are vital for a country like India where population demands more food materials and fiber. Recently, the emphasis has been shifted to better management of the water potential already available, than constructing new storage structures due to non-availability of suitable sites, high initial investment and ecological and environmental consequences [1]. The purpose of reservoir management is to determine the release sequences from each system-reservoir such that sub-basin and basin-wide objectives are met as best as possible. The present study attempts to develop a Decision Support Model (DSM) using a fuzzy based model for deriving operating rules for different time periods in an irrigation reservoir located in South India for the optimal irrigation water management in the basin.

II. LITERATURE REVIEW

The basic concept of a system is that it relates to two or more devices, structures, schemes or procedures. Dooge has defined a system as ‘any structure, device, scheme or procedure, real or abstract, that interrelates in a given time reference, an input, cause or stimulus, of matter, energy, or information, and an output, effect or response, of information, energy, or matter.’ The input-output relationship of a system is controlled by the nature, parameters of the system and the physical laws governing the system [2]. In that sense, system analysis involves formalisation of the operation of the total system with all its sub-systems together, using a set of mathematical planning and design techniques. Systems analysis does not confine to an exercise in mathematical modeling but encompasses design and decision processes also [3]. Optimal management of a reservoir system needs the assistance of computer modeling tools to arrive at rational operational decisions. The basic modeling techniques applied in water resources system analysis are optimization and simulation. While optimization techniques try to attain an optimal solution, simulation is a trial and error approach leading to the identification of the best solution possible although it may not be the exact optimum solution. From 1960s several real time operation models have been evolved for optimal operation of reservoirs.

[4] proposed the use of mathematical models for the design of water resource systems. There are several studies using optimal operating policies for multiple reservoir systems based on the premise that benefits derived from the joint operation of a system of reservoirs may exceed the sum of the benefits from the independent operation of each of the reservoirs. There are two different problem aspects in multi-reservoir operation: planning and real-time operation. For the planning problem, it may be assumed that there is a perfect knowledge of inflows; but for the real time operation, inflows have to be forecasted at individual reservoirs instead of the actual inflow, while taking decisions on release. The coordinated reservoir operation is to decide the amount of releases from each reservoir to attain the target storage based on the current storage, demand requirements and inflows in the hydrologic basin [5]. Computer simulation models have been applied for several decades to reservoir system management and

operations within many river basins. Many models are customized for a particular system, but there are also general purpose models such as HEC 5 which is being updated as HEC RESSIM to include a Windows-based graphical user interface [6], [7]. These simulation or descriptive models help answer what if questions concerning the performance of alternative operational strategies. They accurately represent the system operations but are ill-suited, for prescribing the best or optimum strategies when flexibility exists in coordinated system operations. Prescriptive optimization models offer an expanded capability to systematically select optimal solutions, or families of solutions, under agreed upon objectives and constraints [8].

Integrated Water Resources Management (IWRM) has been accepted as a means to ensure equitable, economically sound and environmentally sustainable management of water resources. One of the main objectives of IWRM is to efficiently manage the water resources, while taking care of the interests of all involved parties. Public participation and stakeholder involvement across sectors and administrative levels at the catchment scale are naturally connected to river basin and reservoir management: there is a wide consensus that management of water resources without sharing information and decisions, is inefficient and might become unsustainable on the long term. It is no longer possible to design the optimal management policy by considering the single reservoir as independent unit; the entire basin must be considered instead [9].

All optimization models are algorithmic procedures, meaning that well-structured, convergent solution processes are applied to quantitative information. In contrast, heuristic programming methods are based on rules-of-thumb, experience, or various analogies which are applied to both quantitative and qualitative information. Unlike most of the optimization algorithms, heuristic programs cannot guarantee to terminate to even local optimal solutions and strive for acceptable or satisfying solutions. But they can often achieve global optimal solutions to problems where traditional algorithmic methods would fail to converge or get stuck in local optima [8].

Fuzzy Rule-Based (FRB) modeling can be effectively used for inferring operating rules by simulating historical operations. The fuzzy logic approach provide a promising alternative to the methods used for reservoir operation modelling, because, the approach is more flexible and allows incorporation of expert opinions, which could make it more acceptable to operators [10]. Fuzzy sets offer a non-frequent approach in dealing with uncertainty and vagueness that are not bound by the laws of probability measure theory. Fuzzy sets provide a means of translating linguistic descriptors into a usable numerical form and define degrees of truth of membership in a set by means of fuzzy membership functions. [11] propose that inputs to reservoir operating policies (e.g., initial storage, inflows, and demands), as well as outputs (e.g., historical release policies) can be described by fuzzy relations. Degrees of fulfillment of these fuzzy inputs are combined to produce fuzzy output relations which can be defuzzified to produce a crisp output (e.g., reservoir release decision). Excellent results were obtained in using a FRB system to replicate historical operations for Tenkiller Lake, Oklahoma. It is likely that the FRB approach could be extended to inferring operating rules for multi-reservoir systems also. Fuzzy sets have also been integrated into optimization algorithms as a means of representing vagueness and uncertainty in system characteristics and objectives. [12] used linguistically described reservoir objectives from surveys of decision makers to develop fuzzy membership functions on diverse objectives such as water supply, flood control, and recreation. These were incorporated into an implicit stochastic dynamic programming model for evaluating degrees of satisfaction and expectations of success in achieving these objectives. [13] proposed the integration of fuzzy sets into optimisation models as a means of appropriately treating uncertainty in complex systems.

Despite several decades of intensive research on the application of optimization models to reservoir systems, [14], [15] have noted a continuing gap between theoretical developments and real-world implementations. Some of the probable reasons for this disparity are (i)many reservoir system operators are doubtful about models claiming to replace their opinion and prescribing new solution strategies, and feel more comfortable with use of existing simulation models; (ii) system operators are unwilling to accept simplifications and approximations required due to the computer hardware and software limitations; (iii)optimization models are usually more mathematically complex compared to simulation models, hence more difficult to understand; (iv)many optimization models are not helpful in incorporating risk and uncertainty; (v)the enormous choice of optimization methods create confusion in the selection for a particular application; (vi)some optimization methods, such as dynamic programming, frequently need customized program development; and (vii)most optimization methods produce optimal period-of-record solutions rather than more useful conditional operating rules.

Most of these hindrances to optimization in reservoir system management can be overcome through the concept of Decision Support Systems (DSS) along with the remarkable advances in the power and affordability of desktop computing hardware and software. The development of DSS for multi reservoir operation helps to overcome many of the problems faced in the application of optimization in reservoir system management, and has been a focus of research for past many years. Many organizations are now actively incorporating optimization models into reservoir system management through the use of DSS [6]. By integrating optimization into DSS, the resistance to their use is reduced, incorporating optimization as a tool controlled by reservoir system managers, who are responsible for the success or failure of the system. This places the focus on providing support for the decision makers, instead of overly empowering computer programmers and modelers.

III. PROBLEM FORMULATION

The Parambikulam-Aliyar Project (PAP), which came into existence in 1958, is a complex multi-basin multipurpose project commissioned by Governments of Tamil Nadu and Kerala for irrigation, power generation and Drinking water supply. Seven streams-five flowing westward and two towards the east- have been dammed and their reservoirs interlinked by tunnels. [16]. It consists of reservoirs lying at an elevation of +1160m to +320m above MSL. The water is ultimately delivered to the drought-prone areas in the Coimbatore district of Tamil Nadu and the Chittur area of Kerala. The project has a command area of 0.016 million hectares and the project has 185 MW of power generation capacity. It is supposed to be one of the successful Inter Basin Water Transfer (IBWT) projects in India.

The Aliyar River has its source in the Anamalai hills and it flows in a north-westerly direction for about 37 km in Tamil Nadu and enters into Kerala, and finally joins the Bharathapuzha. The Uppar and Palar are the major tributaries of Aliyar river. The Aliyar reservoir (FRL +320.00 m), constructed across the Aliyar river has a catchment area of 198 km^2 and a gross capacity of 110 Mm^3. It is situated on the downstream reach of PAP. Apart from its own catchments, water is diverted to this reservoir through the Aliyar feeder canal and the contour canal from the Parambikulam group of reservoirs. Vettaikaranpudur (VP) and Pollachi canals take off from this reservoir and irrigate a command area of 14030 ha. This reservoir is also intended to meet the requirements of the command area in Tamil Nadu and Kerala States on the downstream side.

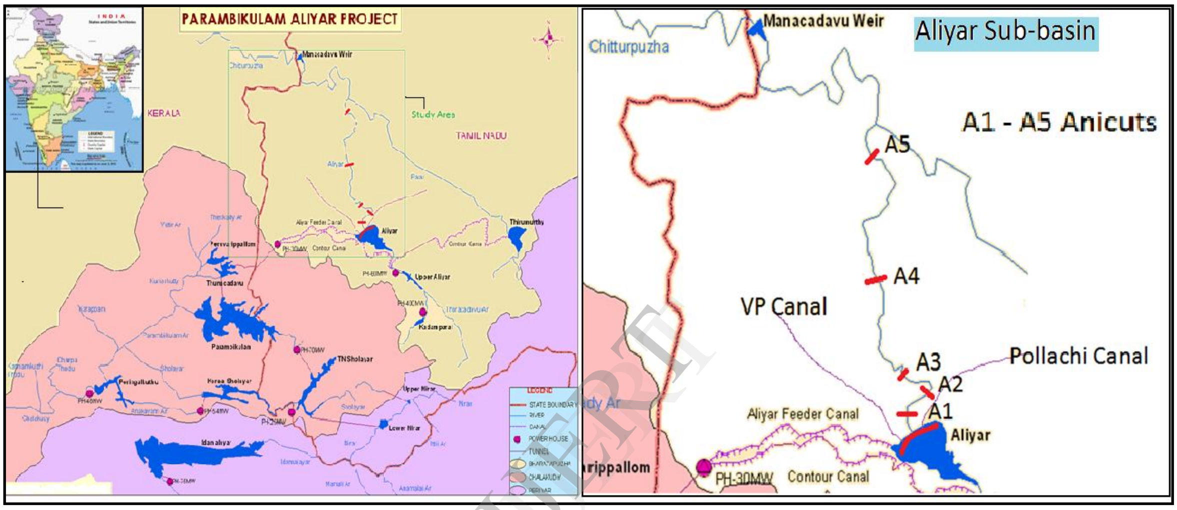

Fig.1 Map of Aliyar sub-basin

The water released to the Aliyar river from the reservoir, after meeting the requirements of 2580 ha command area in Tamilnadu by diversion through 5 regulators, flows to the Chitturpuzha Project (CPP) to meet the irrigation requirements in a command area of 24080 ha in Kerala. The release to CPP is through Manacadavu weir which is the last gauging point of PAP as per the interstate agreement. The Aliyar sub-basin has a total command area of 38100 ha. The annual average rainfall of the sub-basin is 635 mm. The map of Aliyar sub-basin is given in Fig.1.

The historical data on inflow to, and storage of the reservoir, and release to the VP canal, Pollachi canal and to the downstream river, from Aliyar reservoir for 21 years were used for the analysis.

The data on climatic parameters and details regarding the cropping pattern, cropping season, area under cultivation were also collected for the various sub-systems under the Aliyar sub-basin. The FAO Penman-Monteith method [17] was used for computing the reference crop Evapo-Transpiration (ETo) values for different months. After estimating the irrigation requirements of various crops, net monthly irrigation requirement of the command areas were computed (Table 2).

TABLE 1 Net monthly irrigation demand for sub-systems under the Aliyar sub-basin (Mm^3)

Month	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Pollachi canal	11.95	30.04	22.16	14.85	7.34	29.56	31.49	22.94	27.99	0.00	3.36	1.94
VP canal	5.69	14.30	10.55	7.07	3.49	14.07	14.99	10.92	13.32	0.00	1.60	0.92
Down stream	23.96	42.26	61.46	18.84	52.80	85.39	90.71	78.67	66.91	8.37	15.05	35.22

IV. RULE MINING USING FUZZY LOGIC

With the 21 years inflow-outflow data of the Aliyar reservoir, reservoir operation rules were derived to decide the release pattern for various inflow-storage-demand conditions. Modelling was done using fuzzy logic which provides a simple way to arrive at a definite conclusion based upon vague inputs. FRB models are developed for the operation of the Aliyar reservoir. The fuzzy inference refers to the process of formulating the mapping from a given input to an output using fuzzy logic which provides a basis for taking decisions, or discerning patterns. The process of fuzzy inference involves membership functions, fuzzy logic operators, and 'if-then' rules. There are two types of Fuzzy Interface System (FIS) that can be implemented in the fuzzy logic toolbox: Mamdani's FIS, which is the most commonly used fuzzy methodology, is adopted in this analysis. It is worthwhile to note that FIS have been successfully applied in areas such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature,

The first step in the analysis is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. Once the inputs have been fuzzified, it is possible to understand the degree to which each part of the antecedent has been satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator can be applied to obtain one number that represents the result of the antecedent for that rule. This number can then be applied to the output function. The inputs to the fuzzy operator are two or more membership values from the fuzzified input variables. The output is a single truth value. Each rule has a weight (a number between 0 and 1), which is applied to the number given by the antecedent. Generally this weight is 1, but one may like to weight one rule relative to the others by changing its weight value to something other than 1. Once proper weighting has been assigned to each rule, the implication method is implemented. Since decisions are based on the testing of all of the rules in an FIS, the rules must be combined in some manner in order to make a decision. Aggregation is the process of combining the fuzzy sets that represent the outputs of each rule to form a single fuzzy set and occurs once for each output variable, just prior to the final step, defuzzification. There are five built-in defuzzification methods of which the most popular method is the centroid calculation, which returns the center of area under the curve. This method is adopted for defuzzification in the present analysis. The fuzzy inference diagram is the composite of all the smaller diagrams and it simultaneously displays all parts of the fuzzy interference process. The Rule Viewer is a MATLAB implementation of the fuzzy inference diagram [18].

Different DSM models were developed for the study area using fuzzy logic by varying the inputs. For all the models, releases to Pollachi canal, VP canal, and D/S River were taken as the outputs. The first model DSM1 was run with the inflow and storage at the beginning as inputs. Modelling is done to capture the relationship between inputs and outputs, but when control decisions are based on policies that are not known in advance, the problem is ill posed. Hence, an attempt is made to develop operating policies, which need the known data of previous time periods as input to decide about the decision variable. DSM2 with two inputs, previous inflow and storage, is developed to examine the ability of fuzzy model to make use of previous time period data instead of that of the current time period. The downstream water demand has to be considered while releasing the water from the reservoir. Hence this is taken as an additional input in models DSM3 in which inflow, storage and demand are taken as inputs and DSM4 in which previous inflow, storage and demand are taken as inputs. The water released from the Aliyar reservoir to the downstream river reaches Manacadavu weir and then meet the irrigation requirement of CPP of Kerala. The intermediate catchment is also contributing to the flow to CPP and may be considered while deciding the release to the downstream river. This own flow is computed and is includes as a fourth input, in models DSM5 with inflow, storage, demand and own flow as inputs and DSM6 with previous inflow, storage, demand and own flow as inputs. For these models, membership functions were defined and ranges were fixed for each input and output variable. By making use of the historic data rules were generated for different models based on the relationship between the inputs and outputs and the fuzzy outputs for the given inputs were viewed and noted using the rule viewer.

V. RESULTS AND CONCLUSIONS

The percentage error and r^2 value were computed to test the performance of the model. Linear regression analysis was done using SPSS software to get the value of r^2. An F-test is used, to test if the standard deviations of two populations are equal, by comparing the ratio of two variances. Commonly, values such as 0.10 or less are used as critical levels. F-test was conducted to find out whether the fuzzy and actual releases are differing significantly. The results for the six models corresponding to the three releases are given in Table 4.

By a comparison of the fuzzy releases and the actual releases, it is observed that even after repeated trials with different ranges of membership functions, DSM1 and DSM2 are not performing in a satisfactory manner. The r^2 values obtained for both the models are very low and the F-test results show that the fuzzy releases and the actual releases are differing significantly. The DSM3 and DSM4 models with three input variables are performing in a much better way. The r^2 values obtained for all the releases are greater than 0.9 in the case of DSM3, but for DSM4 it is lesser especially for the release to downstream river. The results obtained using DSM5 and DSM6 with 4 inputs gave good results with r^2 values of more than 0.9 for all the three releases. The F-test results and the % error values for the three releases also show a better model performance for DSM5 and DSM6. As more input variables are included, the number of rules is increased and this in turn improved the performance of the model.

TABLE 2 Testing and validation of models

Model	% error			F-test			r^2		
	Pollachi	V.P	D.Str.	Pollachi	V.P	D.Str.	Pollachi	V.P	D.Str.
DSM1	10.38	3.49	1.49	0.0008	0.0001	0.0004	0.315	0.337	0.591
DSM2	4.75	1.34	1.43	0.0003	0.0001	0.0003	0.342	0.382	0.524
DSM3	5.10	1.61	1.27	0.52	0.47	0.51	0.901	0.912	0.931
DSM4	4.32	1.11	2.01	0.57	0.35	0.52	0.867	0.888	0.610
DSM5	4.06	0.63	1.50	0.52	0.80	0.47	0.986	0.980	0.955
DSM6	4.06	0.68	1.81	0.53	0.74	0.43	0.976	0.976	0.925

The Mean relative error values of models DSM3, DSM4, DSM5 and DSM6 obtained for various releases are shown in Fig 6. Comparing the MRE values of the four models, DSM3 and DSM4 are having high values compared to DSM5 and DSM6, especially for the release to Pollachi canal.

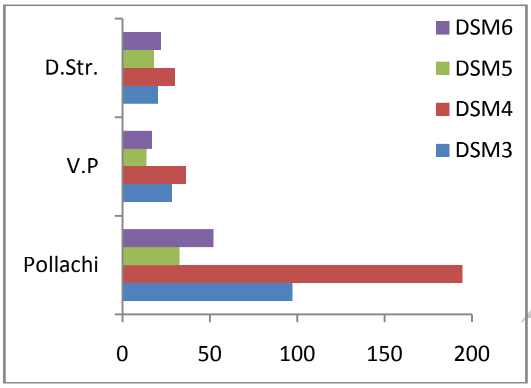

Fig 2 Mean Relative Error for the models

The actual releases and fuzzy releases of DSM5 and DSM6 for Pollachi canal, V.P canal and to down-stream river are plotted in Fig 7, 8 and 9 respectively and it is observed that the trend pattern of model releases are closely matching the pattern of actual releases.

Considering the values of various statistical parameters, the model performance in the case of release to VP canal is better than the other two releases. Comparing the two models DSM5 and DSM6, the overall performance are much closer, hence it is recommended to use DSM6, since it uses the known data of the previous time periods as the input so that the control decisions can be made prior based on the data that are known in advance.

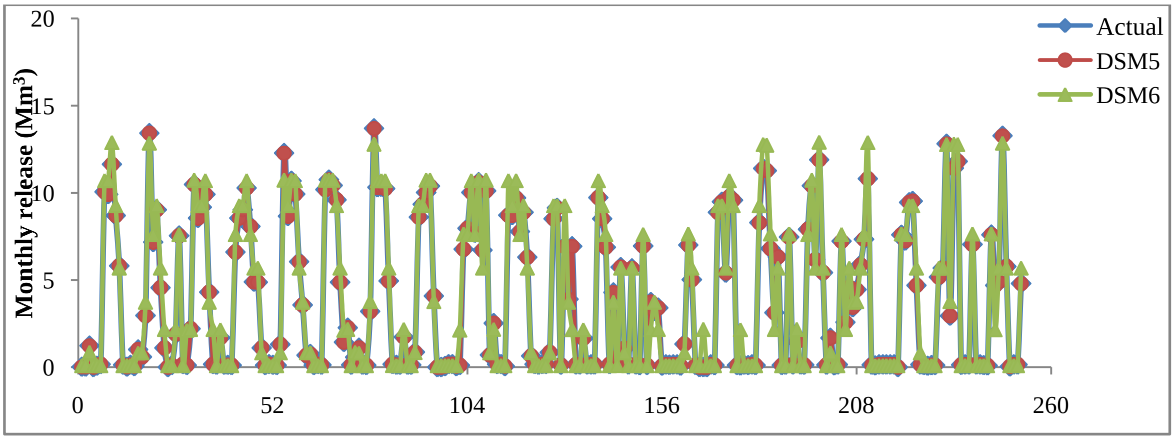

Fig 3 Comparison of model release and actual release to Pollachi canal

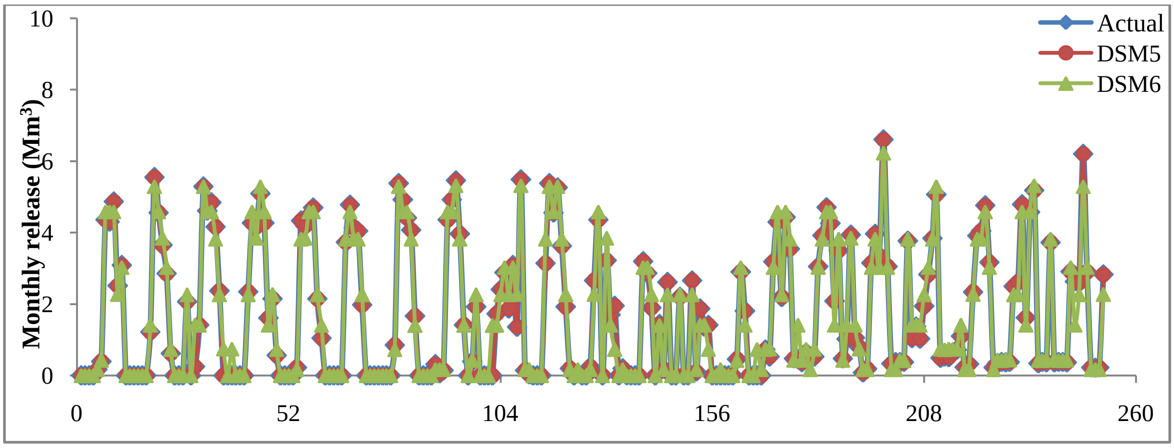

Fig 4 Comparison of model release and actual release to V.P canal

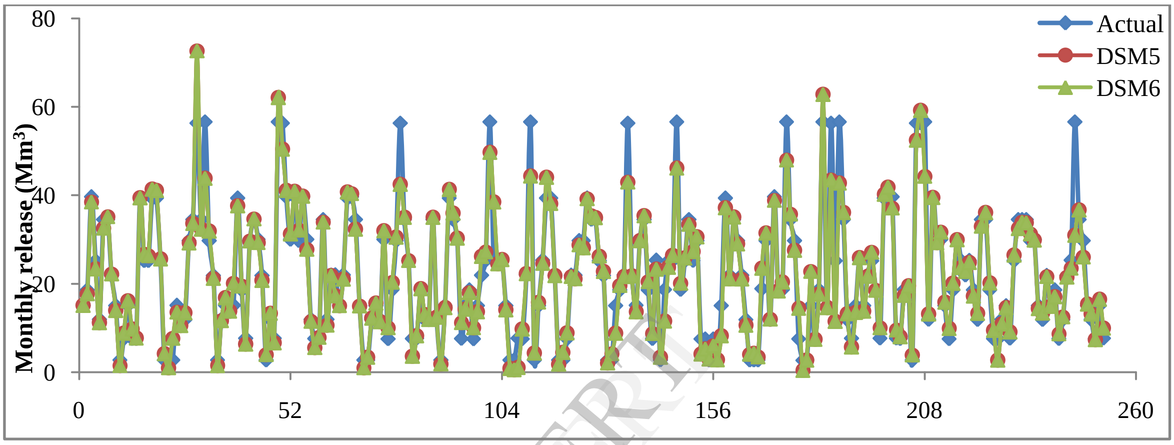

Fig 5 Comparison of model release and actual release to Downstream

VI. SUMMARY AND CONCLUSIONS

The major challenge of reservoir management is in determining the release sequences from each system reservoir such that sub-basin and basin-wide objectives are met as best as possible.

Different simulation models using fuzzy logic for evolving reservoir operation rules are attempted in this paper. The results of the analysis show that fuzzy-logic can be effectively applied for evolving reservoir operation rules. The advantage of fuzzy rule-based reservoir operation is that statements such as 'high demand' 'low storage' etc., can be readily incorporated; hence, reservoir system operators may feel more comfortable in using such models. Even though fuzzy-rule based model is easy to develop and adopt, it suffers from the curse of dimensionality, especially in the case of multi-reservoir operation.

Reservoir system operators increasingly rely on sophisticated computer modeling tools to better understand and respond to environmental, ecological and similar constraints. The implementation of reservoir optimization models can be made more effective by greater involvement of decision makers in system development, better packaging of these systems, and by providing enhanced linkage with simulation models which operators will accept more readily. For this, increased application of heuristic programming methods is needed. Difficulties in inferring operating policies can be eased through applications of fuzzy rule-based modelling and similar heuristic methods. The computational challenges of basic stochastic optimization may also be overcome through judicious application of these heuristic techniques.

REFERENCES

[1] Chandramouli, V., Paresh Deka. (2005); 'Neural Network Based Decision Support Model for Optimal Reservoir Operation', Water Resources Management 19 P 447–464

[2] Dooge J.C.I (1973);'Linear theory of Hydrologic systems', Technical bulletin No.1468; Agricultural research service; US Department of Agriculture.

[3] Vedula,S., Mujumdar,P,P (2005); 'Water Resources Systems'; Tata McGraw-Hill Publishing Co.Ltd.

[4] Mass,A., Hufschmidt,M., Dorfman,R., Thomas,H., Marglin,S., Fair,G. (1962); 'Design of water resource systems'; Harvard University Press; Cambridge; Mass.

[5] Sheung-Kown Kim., Young Joon Park., and Jae Hee Kim, (2000); 'Simulation of the Real-time Multiple Reservoir Operating Environment with a Multiple Reservoir Operation Optimization Model'; Proceedings of ASCE Joint Conference on Water Resource Engineering and Water Resources Planning and Management Sec.38(ch.3).

[6] Hydrologic Engineering Center. (1989); 'HEC-5: Simulation of flood control and conservation systems'; U.S. Army Corps of Engineers; Documentation and User's Manual; Davis; California.

[7] Klipsch, J (2002); 'HEC-RESSIM: Capabilities and plans'; Second Federal Interagency Modelling Conference, Las Vegas.

[8] Labadie,J (2004); 'Optimal Operation of Multireservoir Systems: State-of-the-Art Review'; Journal of Water Resources Planning and Management 130(2) P 93-111.

[9] Dams and Development: a new framework for decision-making, (2000); World Commission on Dams; United Nations Environment Programme Dams and Development Project.

[10] Russell,S.O., Campbell,P.F (1996); 'Reservoir operating rules with fuzzy programming'; Journal of Water Resources Planning and Management 122(3) P 165-170.
[11] Shrestha,B., Duckstein,L., Stakhiv,E. (1996) 'Fuzzy rule based modelling of reservoir operation'; Journal of Water Resources Planning and Management 122(4) P 262-269.
[12] Fontane, D., Gates, T., Moncada, E. (1997); 'Planning reservoir operations with imprecise objectives'; Journal of Water Resources Planning and Management 123(3) P 154-162.
[13] Luhandjula,M,K; Gupta,M,M (1996); 'On Fuzzy Stochastic Optimization, Fuzzy Sets and Systems 81' P 47-55.
[14] Yeh, W (1985). 'Reservoir Management and Operations Models:A state-of-the-art review', Water Resources Research 21(12) P 1797-1818.
[15] Wurbs R (1993); 'Reservoir system simulation and optimization models'; Journal of Water Resources Planning and Management 119 (4) P 455–472.
[16] Suresh,P Prabhu (2003); Interlinking of Rivers in India; Inter-Basin Water Transfer- Case Studies from Australia, United States, Canada, China and India-International Hydrology Series.
[17] Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). Crop evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and Drainage paper 56, FAO, Rome, Italy.
[18] MATLAB 7.6.0 (R2000a) © 1984-2008 The MathWorks, Inc.