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Fuzzy Rules in Reservoir Management

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Abstract: ***Reservoirs form a major water resources system and their optimal operation is a very important area of water resource planning and management, as the interrelationship between some of the variables is nonlinear in nature. Conflicting and complementary uses of reservoir storage have to be scientifically addressed and managed for the efficient and effective water resources management. Due to the temporal variation of inflows and multipurpose demands, the task of allocation of available water becomes more complex. The application of system analysis to reservoir system design, operation and management is very important (Biswas, 1976).The evaluation of current operating rules of existing reservoirs or forming operation rules, in case it is absent, is very important to meet the changing demands according to the public needs and objectives. The aim of this paper is to develop a Fuzzy Rule Based (FRB) model for reservoir management.***

Keywords: Fuzzy Rule Base (FRB), Membership function, MATLAB

1. Introduction

'Precision is not truth' says Henri E B Matisse 1869-1954 impressionist painter

In spite of the scientific knowledge now available, great uncertainty concerning the application of the knowledge to actual design problem still remains, primarily due to the uniqueness of each design problem, and the use of subjective judgment and relevant "rules of thumb" is unavoidable. This is why reservoir managers so quickly found a strong affinity with fuzzy set theory. Moreover, problems in reality are constraint satisfaction problems. How the designer deals with this uncertainty is crucial, because the standards of safety required by the general public regarding the allocation are extremely important. The planner has to make decisions in spite of the high uncertainty he/she faces. There by, these complexities, uncertainties and vagueness in decision making in real problems provide the main motivation for the use of fuzzy concepts.

An operation or release plan is a set of rules for deciding how much quantity of water can be made available for each purpose, under various conditions for meeting the Conflicting demands . System analysis models help to evaluate the operating plans of existing reservoir systems, Govern the water allocation systems involving water rights and agreements between water suppliers and users, Forecasting management strategies and operation plans,Perform real-time operations etc.

It is proven by the experts that the fuzzy concept is a useful tool and can be effectively applied for the real problems in order to arrive at the optimal solution. Yeh (1985) observed that, despite considerable progress, the research relating to reservoir operation has been very slow in finding its way into practice. The managers and reservoir operators are often uncomfortable with the sophisticated optimisation techniques used in the models, which are made much more complex by the inclusion of stochasticity of hydrologic variables. The fuzzy logic approach may 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. Panigrahi and Mujumdar [1] developed a fuzzy rule based model for the operation of a single purpose reservoir. The model operates on an 'if – then' principle, where 'if ' is a vector of fuzzy premises and the 'then' is a vector of fuzzy consequences. This study concludes that by fuzzy based reservoir operation model the complex optimization procedure can be avoided, linguistic statements based on expert knowledge can be incorporated and the operators feel more comfortable in using this model. Suryanarayana T.M.V., Mihir Kemkar[2] developed a Fuzzy Rule Based(FRB) model for obtaining the optimal reservoir release. The results obtained shows that the release obtained from the FRB model are satisfying the demand completely for the period of study and there is significant amount of water saving, when compared with the actual release.Sahil Sanjeev Salvi [3] developed an optimal reservoir operation model using fuzzy Inference System (FIS) and reveals that fuzzy logic model based on MATLAB is very useful for water release corresponding to the maximum level of satisfaction and more comfortable for operators.

The application of fuzzy sets theory can provide a viable way to handle situations when problems with objectives are difficult to define due to imprecision. Out of the two types of Fuzzy Inference System (FIS) named Mamdani type and Sugeno type, the fuzzy inference process named Mamdani'sfuzy inference method has been adopted as it represents the output more realistically.

In modelling of reservoir operation with fuzzy logic, the following distinct steps are planned with the aid of MATLAB package.

2. Methodology

- Fuzzification of inputs
- Formulation of fuzzy rule set
- Application of a fuzzy operator
- Implication
- Aggregation

- Defuzzification
- Application and Validation of results
- Fuzzification of inputs.

The first step in building a fuzzy inference system is to determine the degree to which the inputs belong to each of the appropriate fuzzy sets through the membership functions. The input is always a crisp numerical value limited to the universe of discourse of the input variable and the result of fuzzification is a fuzzy degree of membership generally between 0 and 1. The problem of constructing a membership function is that of capturing the meaning of the linguistic terms employed in a particular application adequately and of assigning the meaning of associated operations to the linguistic terms. Here, construction of membership functions for the inflow, storage, demand and release- where the crisp values are transformed into fuzzy variables.

- **Formulation of fuzzy rule set**

A fuzzy rule may be in the form 'if the storage is low and the inflow is medium in period t, then the release is low'. The expert knowledge available on the particular reservoir should always be used for formulating the rule base.

- **Application of a fuzzy operator**

If the premise of a given rule has more than one part , then a fuzzy operator is applied to obtain one number that represents the result of the premises of that rule. The input to the fuzzy operator may be from two or more membership functions, but the output is a single truth value.

If 'm' and 'n' are the membership values, then output of operation

	Classical	probability
Operator AND	min. of m/n	mn
Operator OR	max. Of m/n	m+n-mn

If values of 'm' and 'n' are 0.8 and 0.30 respectively, then Fuzzy OR operator simply selects the maximum of the two values 0.80 and the fuzzy operation for the rule is complete.

But if the rule uses the fuzzy probabilistic OR operator, then the result is calculated by the equation and the result works out to be 0.86.

- **Implication**

Fuzzy operator operates on the input fuzzy sets to provide a single value corresponding to the inputs in the premise. The next step is to apply this result on the output membership function to obtain a fuzzy set for the rule. The input for the implication method is a single number resulting from the premise and the result of implication is a fuzzy set.

- **Aggregation**

Aggregation is the unification of the output of each rule by merely joining them. When an input value belongs to the intersection of the two membership fuctions, fuzzy rules corresponding to both the membership functions are invoked and then the results are unified.

- **Defuzzification**

It is the conversion of a fuzzy quantity to a precise quantity. The input for the defuzzification process is a fuzzy set and the result is a single crisp number.

Application and Validation of results

3. Model Formulation

In the present study the following two and four variables are taken as input and output respectively.

Inputs

- Storage (ranges from 0-500 mcm)
- Inflow (ranges from 0-1500 m^3/sec)

Outputs

- Drinking water release (ranges from 0-100 m^3/sec)
- Irrigation water release (ranges from 0-600 m^3/sec)
- Power generation (ranges from 0-400 m^3/sec)
- spill from the reservoir (ranges from 0-500 m^3/sec)

Input

Membership functions are traced to 'low', 'medium', 'high' of storage and inflow.

Output

Theprime importance is to supply drinking water, then comes irrigation and power generation in the present case. Spill as far as possible to be avoided. Knowing the storage, inflow ('low,''medium'and 'high') appropriate fuzzy rule is invoked. The fuzzy operator, implication and aggregation together yield a fuzzy set for drinking water supply, irrigation, power generation and spilling. A crisp release is then obtained using centroid of the fuzzy set.

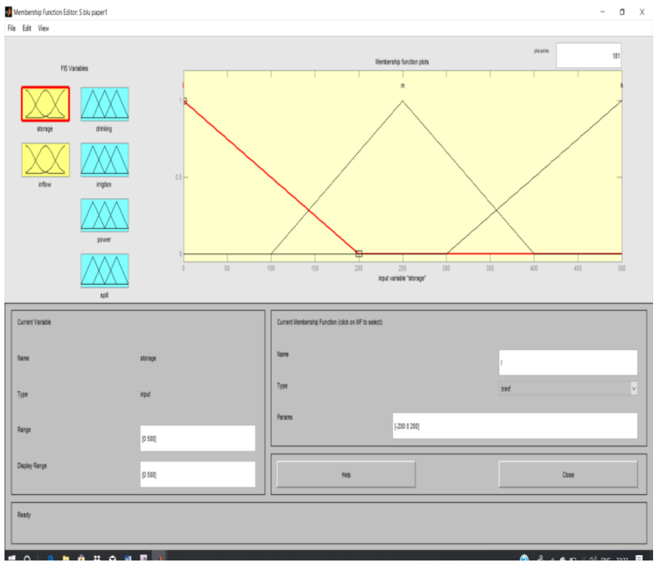

Figure 1: Fuzzy input 1(storage)

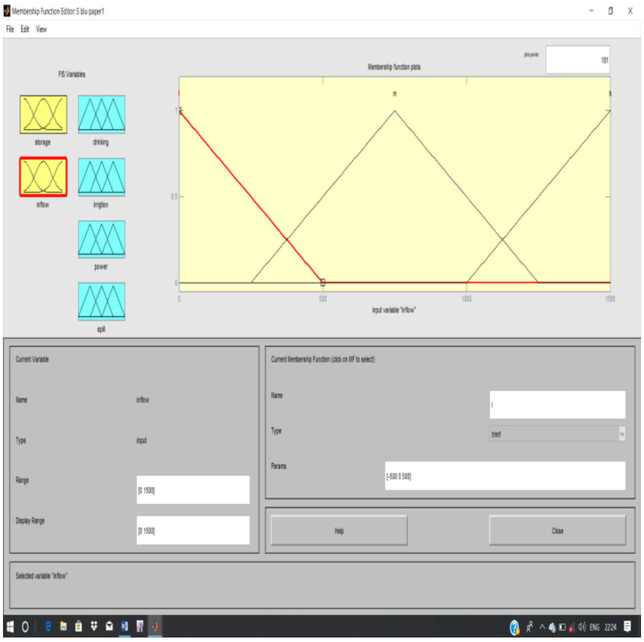

Figure 2: Fuzzy input 2(inflow)

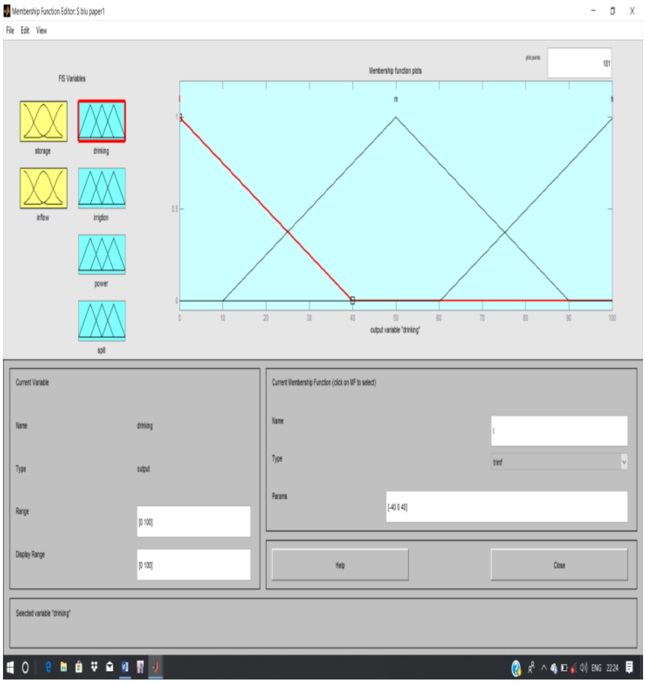

Figure 3: Fuzzy output 1(drinking)

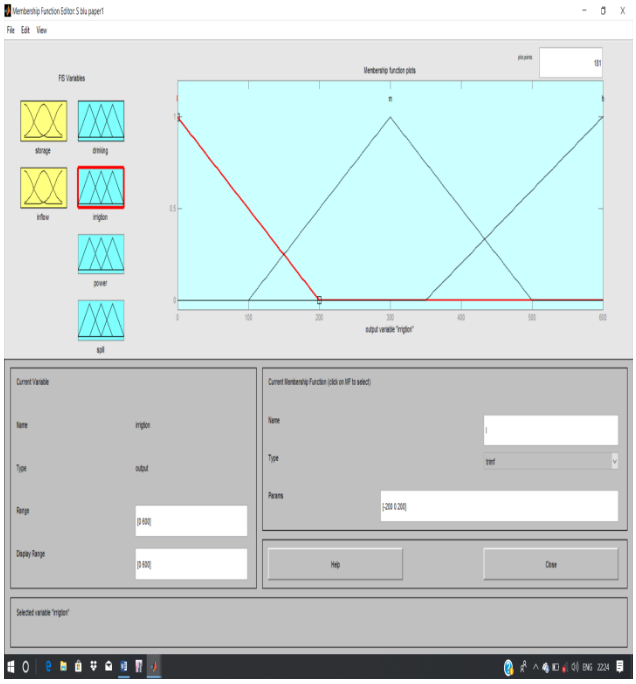

Figure 4: Fuzzy output 1(drinking)

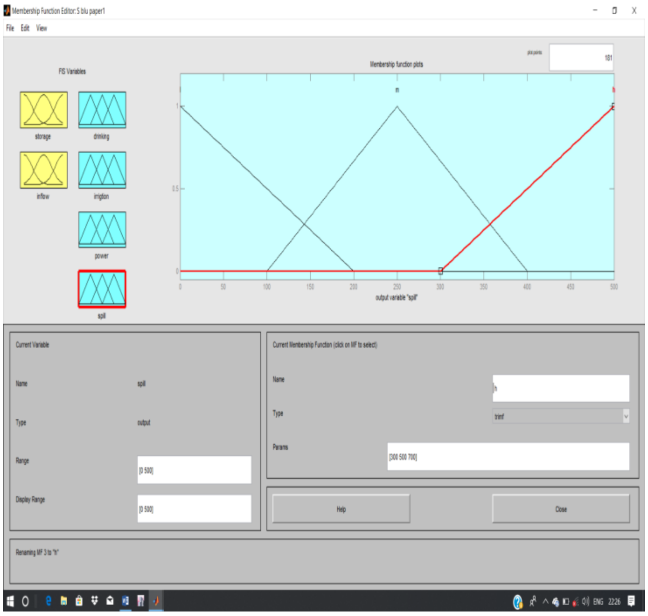

Figure 5: Fuzzy output 2(irrigation)

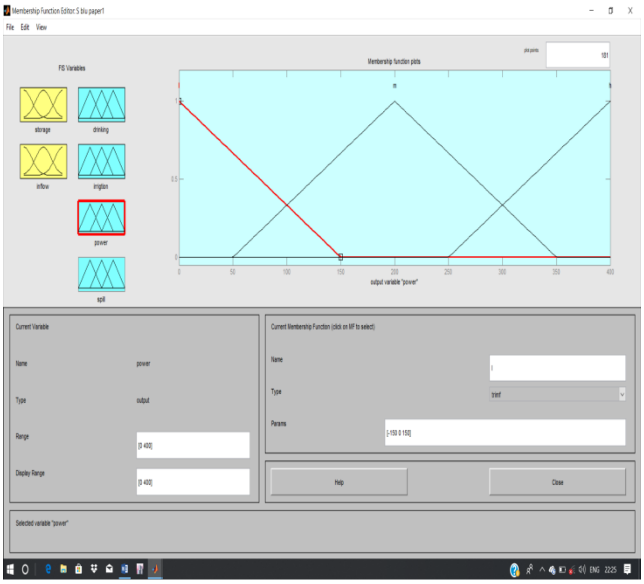

Figure 6: Fuzzy output 3(power)

Table 1: Fuzzy rules (l=low, m=medium,h=high)

Rule	Input		Output			
No.	Storage	Inflow	Drinking	Irrigation	Power	Spill
1	l	l	m	l	l	l
2	l	m	h	l	l	l
3	l	h	h	m	l	l
4	m	l	h	l	l	l
5	m	m	h	m	l	l
6	m	h	h	h	l	m
7	h	l	h	m	l	l
8	h	m	h	h	m	m
9	h	h	h	h	h	h
10	h	h	h	h	h	m

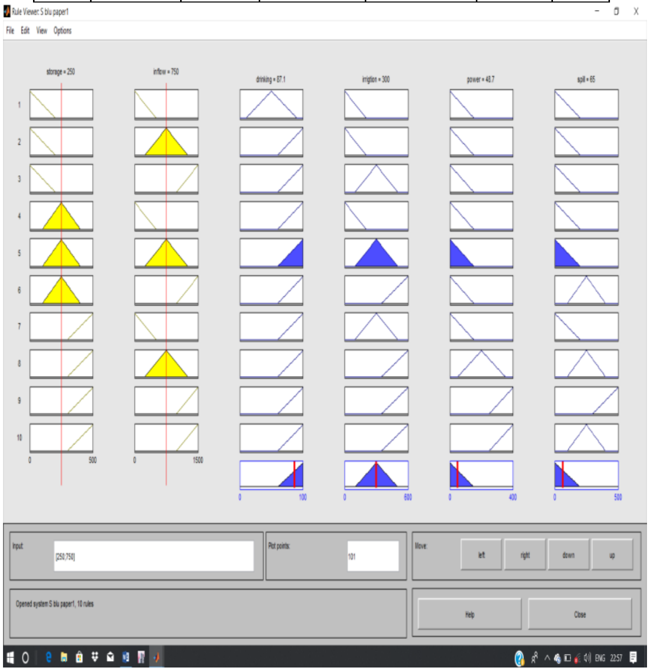

Figure 7: Generalised fuzzy rules

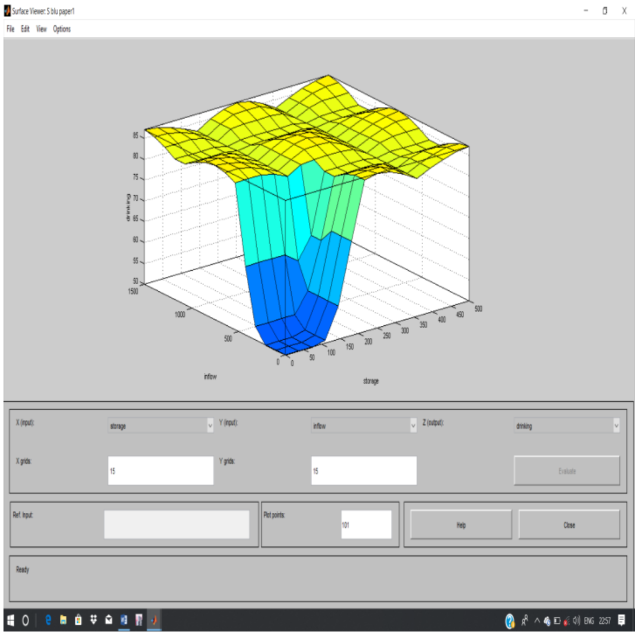

Figure 8: Influence of inputs in output 1(drinking)

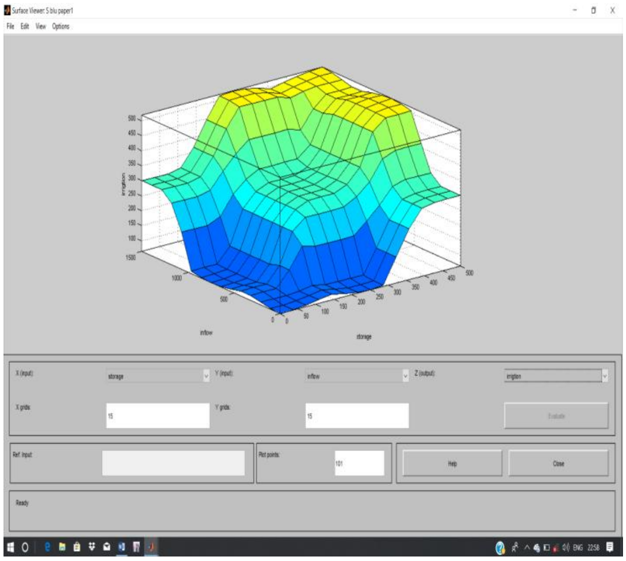

Figure 9: Influence of inputs in output 2(irrigation)

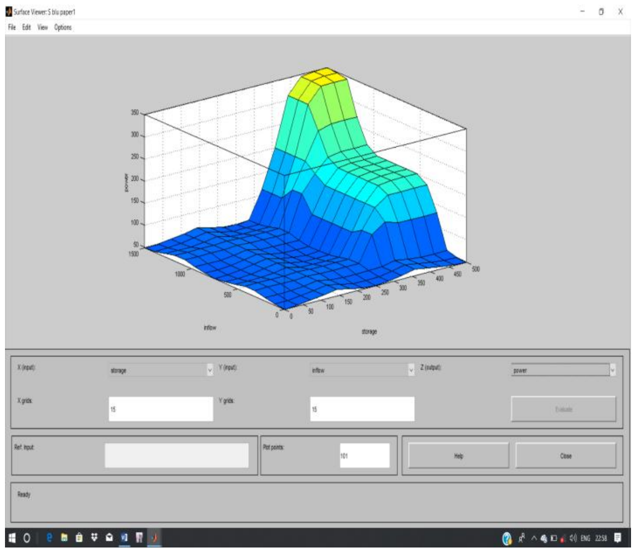

Figure 10: Influence of inputs in output 3(power)

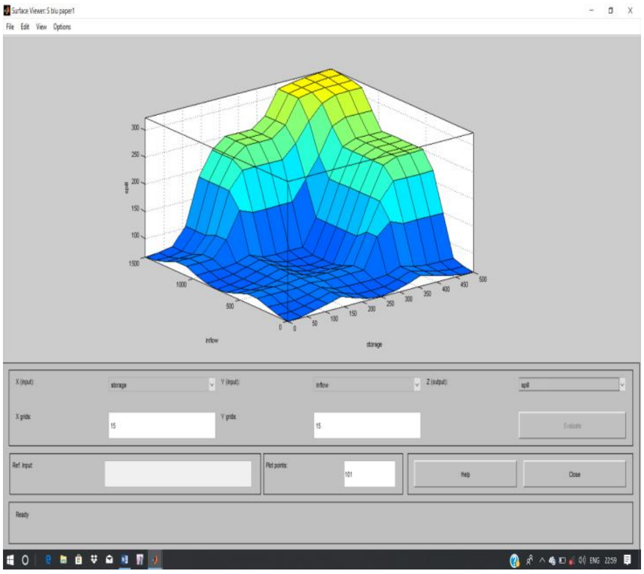

Figure 11: Influence of inputs in output 4(spill)

4. Results and Conclusion

- The prime importance is given to the unavoidable demand that is the drinking water supply. It goes below 'high' demand when the storage and inflow is within 200mcm and 500m^3/s respectively.
- The irrigation release increases as the inflow and storage increase.
- The power generation have a good scope when the inflow and storage goes beyond 1000m^3/s and 300mcm respectively.
- Spill quantity goes to its peak when storage goes beyond 420mcm and inflow goes beyond 1300m^3/s.

5. Future Scope

Rules for different seasons can be developed in the same manner for optimal allocation in conflicting and complementary use of reservoir.

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