CHAPTER XII

CONCEPT OF FUZZY CONTROL AND A SUGGESTIVE EXAMINATION OF ITS APPLICATION IN THE WATER QUALITY MANAGEMENT OF A NON TIDAL RIVER

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12.0 Abstract :

This chapter offers a conceptual examination of the possibilities of fuzzy control application for water quality management of a non-tidal river. In the present work a systematic approach of fuzzy control has been introduced rather as an analytical tool than as an immediately applicable closed loop control strategy.

12.1 Introduction :

In this work the application of fuzzy control techniques to the problem of combined real time control of river discharge and water quality of a river has been considered. It offers a speculative examination of the possibilities of fuzzy control application in the operation of river system management.

A few cases of real time control of water quality of a non-tidal river have been demonstrated in practice. The most important of the reasons for this lack of practical application is "a lack of clearly defined objectives for the management of water quality in a river basin and a lack of precisely specified standards of stream quality to be maintained by the application of real time control." In the present work a systematic approach incorporating fuzzy control has been introduced rather as an analytical tool than as an immediately applicable closed loop control strategy. The approach has been briefly outlined in the following section.

The success of the mechanistic system to unravel the secrets of the physical world has enabled us to build better and better machines to harness the natural resources for the benefit of mankind. This has been possible because the advent of the computer age has stimulated a rapid expansion in the use of quantitative techniques for the analysis of physical systems. But in the absence of clearly defined objective or of imprecisely defined objectives the conventional quantitative techniques of cybernetics are unsuitable or are unable to give any tangible results. As the complexity of a system increases the imprecision in objective creeps in. And this is defined as the fuzziness in system behaviour.

Viewed in this perspective, the traditional techniques of system analysis are not well suited for dealing with complex system with imprecisely defined objectives because they fail to come to the grips of the fuzziness of the system's behaviour. To deal with such system in realistic sense we need approaches which employ methodological framework quite tolerant of imprecision in objectives, rather than rigorous mathematical formulation.

Three main distinguishing features which define the fuzzy approach are :-

(i) use of linguistic variables in place of or in addition to numerical variables, (ii) characterisation of simple relations between variables by conditional fuzzy statements; and (iii) characterisation of complex relation by fuzzy algorithms.

A linguistic v ariable is defined as a variable whose values are a collection of words in a natural or artificial language. To illustrate, the values of the fuzzy variable height might be expressed as tall, not tall, somewhat tall, very tall, not very tall, etc. Thus height is a linguistic variable. The linguistic variables provide systematic means for an approximate characterisation of complex system with ill defined objectives.

In quantitative approach to system theory, a dependence between two numerically valued variables x and y is usually characterised by a conditional statement as IF x is 5 THEN y is 8, IF x is 10 THEN y is 16 etc. If x and y are fuzzy variables the fuzzy conditional statements are of the form IF x is LARGE THEN y is Small.

A fuzzy algorithm is an ordered sequence of instructions which may contain fuzzy conditional statements, e.g. Reduce x slightly if y is large. Increase x very slightly if y is not very large and not very small. If x is small then stop; otherwise increase x by 2. The execution of such instruction is governed by the compositional rule of inference.

Let X be a space of points with generic elements of X denoted by x, $X = \{x\}$

A fuzzy set A in X is characterised by a membership function $f_A(x)$ which associates with each point in X a real number in the interval $[0, 1]$ with the value of $f_A(x)$ at x representing the grade of membership of x in A.

Union of two fuzzy sets A and B with respective membership functions $f_A(x)$ and $f_B(x)$ is a fuzzy set C, written as $C = A \cup B$ whose membership function is related to those of A and B $f_C(x) = \text{Max}\,[f_A(x), f_B(x)], \quad x \in X$

or, in abbreviated from

$$f_C = f_A \vee f_B$$

Intersection of two fuzzy sets A & B with respective membership function $f_A(x)$ and $f_B(x)$ is a fuzzy set C, written as $C = A \cap B$, whose membership function is related to those of A & B by $f_C(x) = \min\,[f_A(x), f_B(x)], \quad x \in X$,

or, in abbreviated from

$$f_C = f_A \wedge f_B$$

Other properties of fuzzy control have been discussed in references 91 to 96.

12.2. The Concept of Fuzzy Control in Water Quality Management :

The idea of using fuzzy control as a means of water quality management of a river system is due to Beck (98).

Let us define three fuzzy sets A, B, C as

A = DO concentration much less than 4 gm^{-3}

B = Satisfactory DO concentrations

C = High DO concentrations

Fig 12.2.1 shows a membership function μ_D (.) which expresses the degree of membership of any given DO concentration in the fuzzy set of DO concentration.

With a suitable discretization of the continuum of DO concentrations the membership functions of Fig 12.2.1 can be approximated as shown in Table 12.2.1.

To illustrate the principal features of fuzzy control algorithm let us consider a river system as shown in Fig 12.2.2. Control decisions can be implemented through the setting of reservoir releases and through effluent discharge manipulation. A suitable fuzzy control algorithm is depicted in Fig 12.2.3. Let us assume the reservoir release set as same as Table 12.2.1. and is depicted in Table 12.2.2.

The effect of reservoir release on the DO concentration is a fuzzy relation $P \triangleq R \circ S$

where $R = \{\mu_D(.)\}$ and $S = \{\mu_r(.)\}$

The composition of fuzzy relations R and S is fuzzy relation P and is defined as $\vee \{\wedge$ of cartesan product of R and S$\}$ of Supremum {minimum of cartesan product terms on R and S}

i.e.

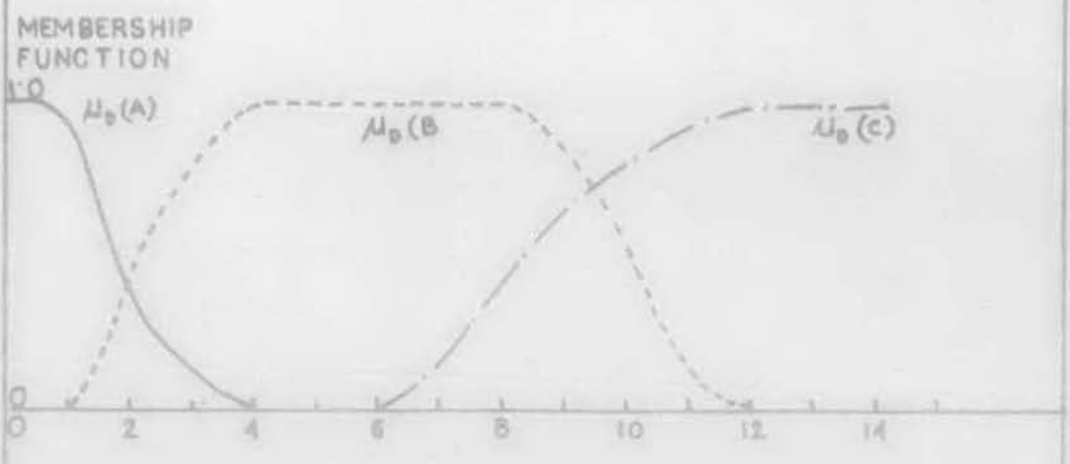

FIG 12.2.1 DISSOLVED OXYGEN CONCENTRATION (GM^{-3})

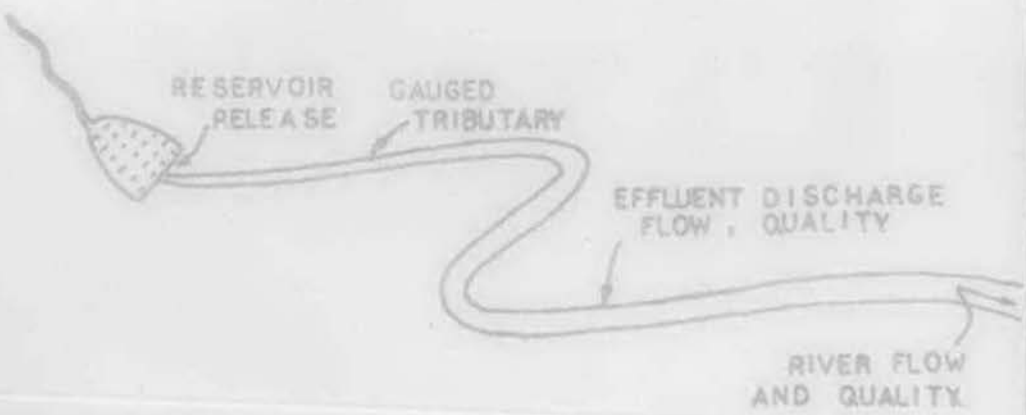

FIG 12.2.2. A RIVER SYSTEM

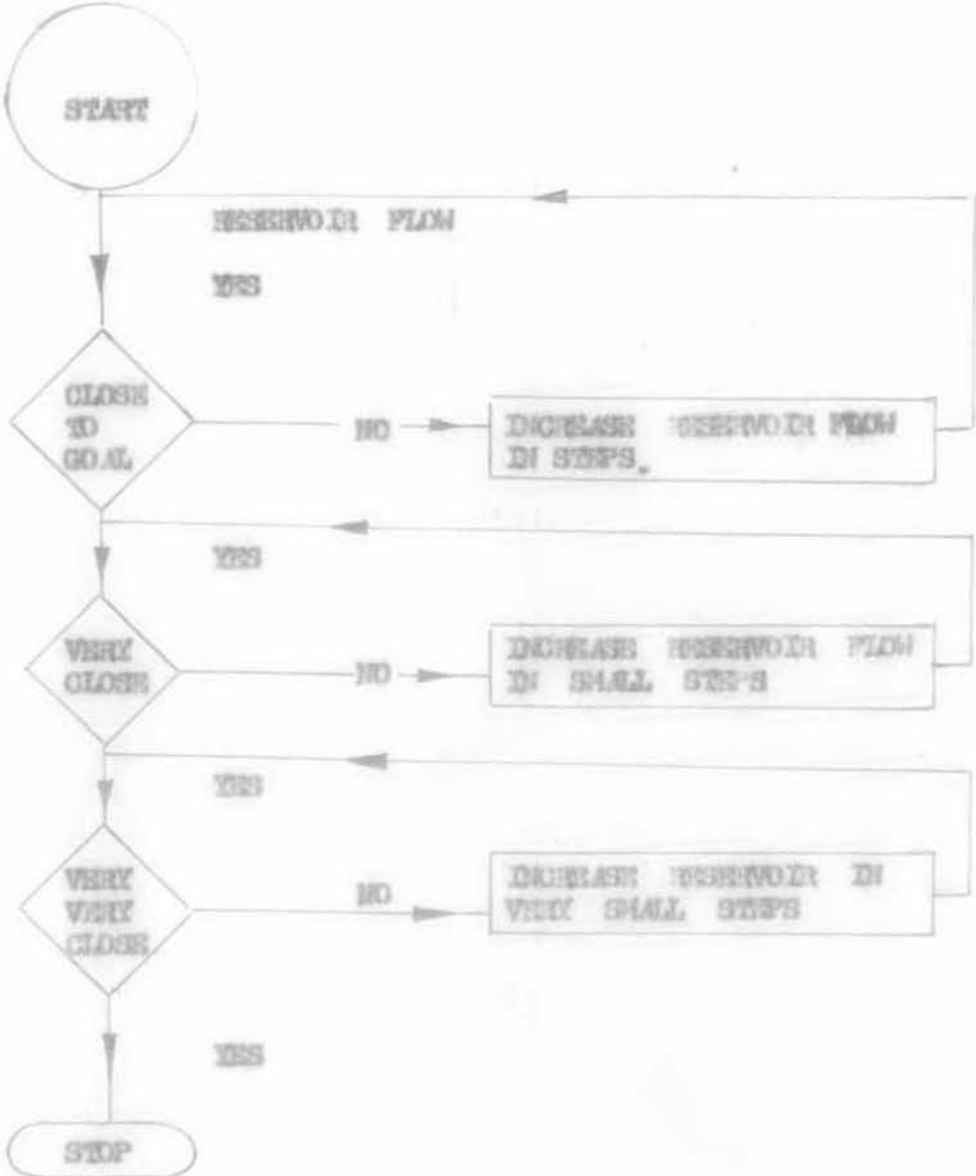

Fig 12.2.3. FUZZY CONTROL ALGORITHMS.

Table 12.2.1 Dissolved Oxygen Concentration.

DO concn (gm^{-3})	2.0	2.0-3.0	3.0-4.0	4.0-6.0	6.0-8.0	8.0-10.0	10.0-12.0	12.0
$D^{(A)}$	1.0	0.7	0.2	0	0	0	0	0
$D^{(B)}$	0	0.3	0.6	1.0	1.0	0.7	0.1	0
$D^{(C)}$	0	0	0	0	0.2	0.8	0.9	1.0

Table 12.2.2 Fuzzy set deffination for reservoir release.

Reservoir release $m^3 s^{-1}$	2.0	2.0-3.0	3.0-4.0	4.0-6.0	6.0-8.0	8.0-10.0	10.0-12.0	12.0
$r^{(X)}$	1.0	0.7	0.2	0	0	0	0	0
$r^{(X)}$	0	0.3	0.6	1.0	1.0	0.7	0.1	0
$r^{(Z)}$	0	0	0	0	0.2	0.8	9	1.0

$$
\text{Sup. min} \begin{bmatrix} 1.0 & 0.7 & 2.0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.3 & 0.6 & 1.0 & 1.0 & 0.7 & 0.1 & 0 & \\ 0 & 0 & 0 & 0 & 0.2 & 0.8 & 0.9 & 1.0 & \end{bmatrix} \begin{bmatrix} 1.0 & 0 & 0 \\ 0.7 & 0.3 & 0 \\ 0.2 & 0.6 & 0 \\ 0 & 1.0 & 0 \\ 0 & 1.0 & 0.2 \\ 0 & 1.7 & 0.8 \\ 0 & 0.1 & 0.9 \\ 0 & 0 & 1.0 \end{bmatrix}
$$

$$
= \begin{bmatrix} 1.0 & 0.3 & 0 \\ 0.3 & 1.0 & 0.8 \\ 0 & 0.7 & 1.0 \end{bmatrix}
$$

The nine discrete points of fuzzy composition RCS in defined as

ROW	x	COLM	VALUE		
1	x	1	1.0	=	Reservoir release < 2.0 $m^3 s^{-1}$ D0 2.0 gm^{-3} in set A.
1	x	2	0.3	=	Reservoir release 3.0 - 4.0 $m^3 s^{-1}$ DO approximate 3.0 gm^{-3} in set A
1	x	3	0.0	=	Reservoir release > 4 $m^3 s^{-1}$ DO 4 gm^{-3} in Set A
2	x	1	0.3	=	Reservoir release < 2.0 $m^3 s^{-1}$ DO 2.0 to 3.0 gm^{-3} in set B.
2	x	2	1.0	=	Reservoir release 4.6 $m^3 s^{-1}$ DO 4.6 gm^{-3} in set B
2	x	3	0.8	=	Reservoir release 8.10 $m^3 s^{-1}$ DO approx. 8 gm^{-3} in set B

3 x 1	0.8	=	Reservoir release 0 $m^3 s^{-1}$ DO concentration 2.0 - 6.0 gm^{-3}
3 x 2	0.7	=	Reservoir release 8.10 x $m^3 s^{-1}$ DO approx 8 gm^{-3}
3 x 3	1.0	=	Reservoir release $>$ 12 $m^3 s^{-1}$ DO $>$ 12 gm^{-3}

12.3 Conclusion :

In the preceeding discussion an approach has been sketched for water quality management of a river system with imprecise and ill defined objectives. Speculation has been centered on a realistic and optimistic application of fuzzy control. It is emphasised that further investigational efforts are needed to implement fuzzy control algorithms in practice to synthesise a fuzzy controller.

Fuzzy set theory, originally developed by Zadeh, deals with processes containing uncertainties only qualitatively described. The proposed model to describe such processes is based on the association of a membership function $\mu(A)$ to each set A of imprecisely defined quantities and the use of logic operations on the measures of membership for fuzzy reasoning. Because of the qualitative nature of the processes involved, linguistic methods developed for advanced computer software are also applicable to fuzzy analysis and decision making. Its adaptability and simplicity of implementations on a digital computer using the linguistic version of fuzzy set theory make it a very promising approach to the problem of control with uncertainties [113].