CYBERNETICS IN WATER RESOURCES MANAGEMENT

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ABSTRACT

The term Water Resources is used to refer to the management and use of water primarily for the benefit of people. Hence, successful management of water resources requires a solid understanding of Hydrology. Cybernetics in Water Resources Management is an endeavor to analyze and enhance the beneficial exploitation of diverse scientific approaches and communication methods; to control the complexity of water management; and to highlight the importance of making right decisions at the right time, avoiding the devastating effects of drought and floods. Recent developments in computer technology and advancement of mathematics have created a new field of system analysis i.e. Mathematical Modeling. Based on mathematical models, several computer based Water Resources System (WRS) Models were developed across the world, to solve the water resources management problems , but these were not adaptable and were limited to computation by a well defined algorithm, with information input at various stages and the management tasks were also formalized in that well structured algorithm. The recent advancements in information technology has revolutionized every field of the contemporary world and thus, the WRS has also to be diversified by broadening the knowledge base of the system. The updation of this knowledge should be a continuous process acquired through the latest techniques of networking from all its concerned sources together with the expertise of the specialists and the analysis of the practical experiences. The system should then be made capable of making inferences and shall have the tendency to apply the rules based on the latest information and inferences in a given stage of problem solving. Rigid programs cannot adapt to changing conditions and new knowledge. Thus, there is a need for an evolutionary development based on mutual independence of computational procedure and knowledge with capability to adapt itself to the increasing complexity of problem. The subject paper is an endeavour to delineate a procedure and highlight the importance of various aspects involved in the systemization of a such a complex water resources system.

INTRODUCTION

It is commonly regarded that human societies went through three technological revolutions: The first one, related to the discovery and use of Steam Engine (James Watt, 1784); the second related to the invention of Wheel and third related to the Introduction of Computers and the Birth of Cybernetics. The first two are mechanical-energy revolution, and the third is a revolution in the information-control domain. The beginning of the new science of cybernetics is credited to Norbert Wiener, who published in 1948 the famous book "Cybernetics or Control and Communication among Humans and Machines". The name Cybernetics originates from the Greek word "κ*l*β□ρυαω" which means 'to navigate, to control'. It was first used by Plato. Wiener used this term in a broader sense, showing that the basic control principles are the same for different systems.

The classical notion about technical systems is based on a premise that they transform two kinds of resources: Matter and Energy. Cybernetics has introduced the new element, Information, without which a survival of organized large systems would not be feasible. Systems maintain, or even upgrade, their organization levels by using information and energy from their environments (Ashby 1956). Therefore, cybernetics treats information as a resource, with its value and price, to be

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used in the decision-making process. Therefore, Cybernetics may be defined as “a science on transformation of information in the process of system control”.

CYBERNETICS: THE SCIENCE OF WATER RESOURECS PLANNING & MANAGEMENT

Intensive development of water resources systems in the world, alongside with increasing scarcity of water, has in the past decades brought about radical changes in the methods of planning water resources development. Traditional methods of planning could not comply with the tasks and new methods had to be devised, based on the principles of cybernetics.

Cybernetics, the study of control systems, such as the nervous system, in living organisms and the development of equivalent systems (microprocessors) in electronic and mechanical devices. Cybernetics compares similarities and differences between living and nonliving systems (whether those systems comprise individuals, groups, or societies) and is based on theories of communication and control that can be applied to either or both.

Cybernetics developed from investigations into how information is transformed into desired performance. The science arose out of problems that were encountered in the development of so-called electronic brains and of automatic-control mechanisms for military apparatuses.

According to cybernetics, the human brain and nervous system coordinate information to determine which actions will be performed; control mechanisms for self-correction in machines serve a similar purpose. This principle, known as Feedback, is the fundamental concept of automation. One of the basic tenets of Cybernetics is that information can be statistically measured in accordance with the laws of probability. Purposive behavior in humans or in machines requires control mechanisms that maintain order by counteracting the natural tendency toward disorganization (The Encarta Desk Encyclopaedia).

The need for a scientific discipline at the borderline between hydraulic engineering and technical cybernetics comes from the development trends of Water Resources Systems (WRS). In order to meet their objectives, WRS are becoming very large and ramified, comprising large number of elements with complex functions, delicate from the point of view of efficiency and reliability. WRS are also very costly, being among the most important civil engineering undertakings of civilization. At the same time, WRS have become tied-up with other natural or man-made systems, with intensive and delicate interactions, which influence those systems essentially. As water resources of good quality are becoming increasingly scarce, a water crisis at global scale is emerging. Traditional methods of water resources planning were developed when water resources were abundant and mainly single-purpose systems were constructed, having little interaction with other systems: no wonder that such methods are becoming obsolete and inapplicable in the new circumstances (Proceedings of International Conference in Water Resources Management 2001).

WATER RESOURECES MANAGEMENT

To avoid misconceptions about the definition of water management the following definition is given. Water management is an organized control action which transforms Water and WRS:

- from a lower organizational state into a higher organizational state;
- from a lower efficiency state onto a higher efficiency state;
- from a state with lower probability of reaching the required goals onto a state with a higher probability of reaching those goals;
- from a state of higher uncertainty onto a state with a lower uncertainty, which is defined with lower entropy.

This can be symbolically presented as:

$$U \Rightarrow (R_b < R_a) \wedge (EF_b < EF_a) \wedge (P_b < P_a) \wedge (H_b < H_a) \qquad (1)$$

where U is control, R is the organizational level (indices: b – before, a – after control activity), EF is the efficiency of a WRS, P is probability of reaching a goal, H is the entropy, as a measure of cybernetic indetermination of WRS (Djordjevic 1986).

Water Resource Planning does not pertains to planning for water needs but many other aspects of human living such as agriculture, wildlife, economic, development, equity, and environment need to be considered. Thus, planning of options and management strategies must be developed on an interdisciplinary basis. Historically, water resource planning has been primarily the domain of engineers and economists, but with increasing complexities of the planning process it is no longer so.

The emphasis of the systems planning should therefore also be focussed on the effective application of automation to planning and operation of water resources systems. It must therefore include hydrology, hydraulic and environmental engineering, ecology, economy, social and political sciences, and even philosophy, or at least some basic principles of philosophy. Methods which apply to such a needed conglomerate are of deterministic, stochastic, fuzzy and other types, with ample reference to physical-mathematical or only mathematical modeling, decision making support, artificial intelligence, expert systems and other techniques.

SYSTEM

Definition of System

The following general definitions can be applied to define systems:

A system is a structure which at a certain point in time receives input (matter, energy and information) and in another point in time gives output (matter, energy and information).

A system is a collection of objects (elements) combined together in interaction. Elements transform resources while links transport matter, energy, and information.

$$E = \langle e_1, e_2, \ldots, e_n \rangle$$

$$V = \langle v_{ij} \rangle$$

$$i,j = 1,2,\ldots,n \qquad (2)$$

where E is a collection of system elements and V is a set of all links among the elements. The system C is then defined as a pair

$$C = \langle E, V \rangle \qquad (3)$$

A system is a complex structure of elements and their mutual links, which contributes to a mutual purpose. It is located in an environment with whom it interacts. The term element denotes a component of a system which is not further decomposed at the current level of analysis. Therefore, for some cases a dam and reservoir may be considered as an element of WRS. For more detailed analyses (e.g. reliability analyses), an element may be a piece of equipment (e.g. a valve for the bottom outlet).

The above definitions are introduced intentionally in order to emphasize that:

- a system is a distinguishable collection of elements in the environment,
- it reaches common goals through interaction of its parts,
- there is continual interaction with the system environment, and
- transformation and exchange of energy, matter, and information occurs inside of a system.

Components of a System

A system consists of a Physical Component (PCS), which is controlled, and a Control Component (CCS), which prepares and makes control decisions. Schematic representation of a system is given in Fig. 1. It can be seen that a PCS and a CCS are connected by control u(t), which is selected from a set of feasible control actions, U: $u \in U$, by a CCS. The selected action is transferred to PCS, which completes it and gives the output y. The input vector x, i.e. input resources, and the random vector v, which comprises all random environmental disturbances/processes, acts on PCS. CCS has the information on the required output (z) obtained from a goal definition block (Fig. 2). The decomposition of systems in PCS and CCS, introduced by Wiener, made it possible to analyze systems in general, and to compose different systems. The components of the system are connected through control (u). Information becomes a resource used in the process of selecting the appropriate control actions from the set of feasible actions U. Utilization of information in the control process increases system's efficiency and saves material and energy resources.

Direct and Feed-Back Relations in Systems

Links are parts of a system which transport matter, energy, and information. From the viewpoint of cybernetics, information control links are of utmost importance. Information flows in two directions: (1) direct information flow from the control subsystem to the controlled subsystem, which makes Direct Links, and (2) feed-back information take the opposite direction, from PCS to CCS, which makes Feedback Links.

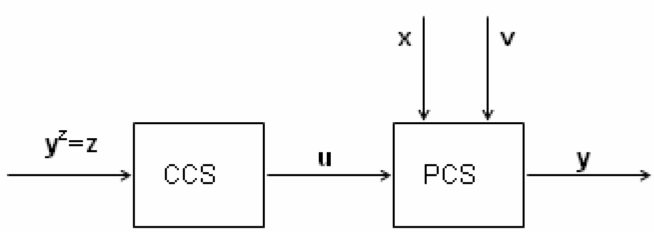

Figure 1. Schematic Representation of a System

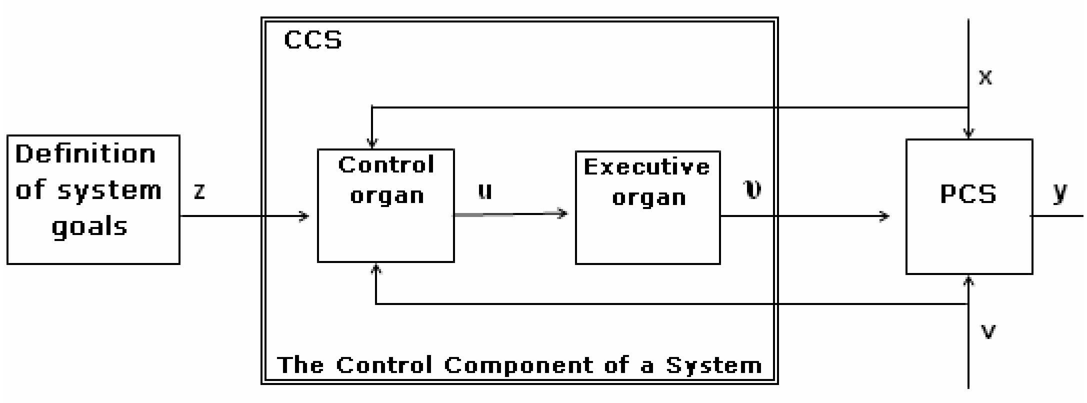

Figure 2. Structure of a System without Feedback

Systems without Feedback: are those systems which do not use information on already realized values of controlled variables (y) when making further control decisions. The control component of a system (CCS) commonly consists of a Control Organ and an Executive Organ. The control organ makes a control decision u(t), which is transferred by a direct link to the executive organ and then in the form of control action $\upsilon(t)$ to the PCS. Fig. 2 shows a structure of a system without Feedback but with input monitoring and disturbance compensation.

Systems with feed-back: are those systems which utilize information on output when making subsequent control decisions by the control subsystem. The link between output (y) and CCS is called feedback. A simple system with feedback is shown in Fig. 3.

Feedback is achieved through Information Component of a System (ICS), which in this particular case becomes Information-Control Component of a System (ICCS). The control component of a system (CCS) will be further analyzed integrally (i.e. without dividing it into the control organ and the executive organ) with u(t) denoting both the control decision and control action. For example, the person in charge of dispatching and assigning responsibility to each of the electric power generating stations for meeting a portion of the total load on the system is the control organ and the operating personnel at each of the stations are executive organs. Fig. 3 shows that a distinction is made between the actually realized output (y) and the measured output (y').

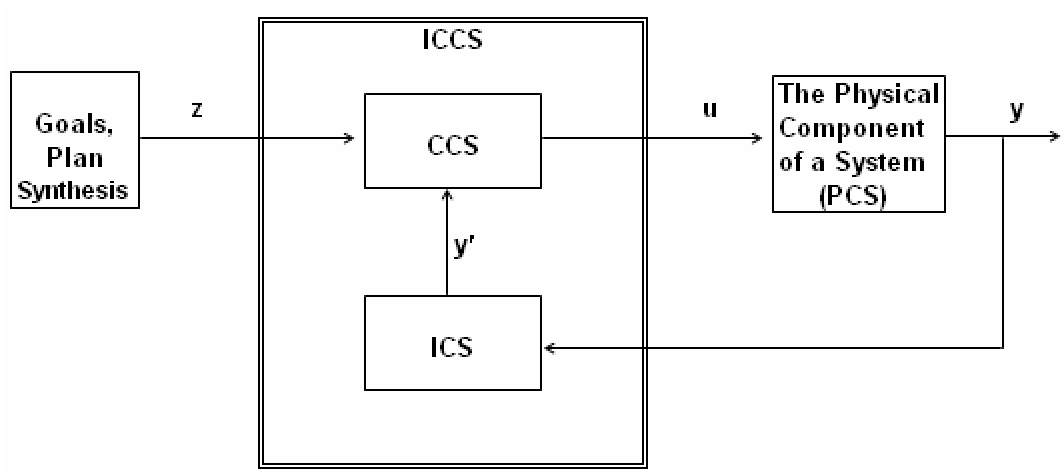

Figure 3. System with Feedback and Input Forecast

Feedback Links

Feedback links are commonly included in plans for water resources systems development. New and larger WRS employ a high-level link concept: with input forecast, learning ability and self-organization. Some of the planned WRS cannot practically exist without learning and self-organizing capabilities, as it is the case with irrigation systems, water treatment plants, etc. Even the high-level technology built in hydropower plants requires some degree of learning by using experience. WRS with reservoirs require estimators for their effective operation. A typical example is a reservoir used for flood control and hydropower generation. A good Forecasting Mechanism can predict an incoming flood and the reservoir can be emptied in time to accommodate the flood without the risk of causing the excessive damage to property, inconvenience to public or loss of life. It seems that the Wiener's definition of feedback as: “ability to adjust future actions according to previous acts” applies correctly also to WRS.

General Description of Water Resources Systems (WRS)

In general, Water Resources Systems could be described by an appropriate mapping on the relation:

Water Resources $\Rightarrow$ Water Requirements & Regulated Water Regimes (4)

Water Resources can be represented by a triplet V:

$$V = < L, Q, K > \quad (5)$$

which consists of three matrices:

L = a matrix which defines the spatial allocation of water resources, determined by the three spatial coordinates x, y, and z,

Q = a matrix which defines water resources quantities through time, and

K = a matrix which defines qualitative features of water resources.

The triplet V totally defines the available water resources according to location, quantity and quality. Similarly, Water Requirements can be defined as:

$$V_z = < L_z, Q_z, K_z > \quad (6)$$

where,

L_z = a matrix which defines location where water is needed or a specific water regime is required,

Q_z = a matrix which defines the required water quantities or water regime, and

K_z = a matrix which defines required water quality.

Having in mind the Eqs. 5 and 6, a Water Resources System can be represented by:

$$V_z = T * V \quad (7)$$

where T is the transformation operator which defines mapping of the Water Resources Triplet into the Water Requirements Triplet. This operator describes a WRS and specific operation control, which satisfy the requirements of Water Resources Management represented by V_z, if the available water resources are defined as V:

The operator T has two components:

$$T = < T_a, T_b > \quad (8)$$

where,

T_a = the component which defines the Physical Part of a WRS ("Hard-ware" of WRS), and

T_b = the component which defines the Control Part of a WRS ("Software" of WRS).

The basic problem of Water Resources Planning is to identify the operator T when V and V_z (Eq. 7) are known. In other words,

The ultimate water resources planning goal is the selection of the optimal system structure, optimal parameter values, and optimal control.

WRS Operations Control

WRS operations control is a continuous process which starts with planning (WRS synthesis) and extends into operation (WRS analysis). The only difference between the two is in the number of decision variables being considered. The planning phase, which studies the selection of the optimal configuration, optimal parameters and control, covers more decision variables than the operational phase.

The approach to operations control may be divided into following phases:

- Problem identification and definition of objectives and goal structures to be used for optimizing development strategies.
- Water resources systems planning, utilizing mathematical modeling and evaluation of alternatives.
- Implementation and organization of WRS.
- Utilization of WRS and the real-time operations planning.

Fig. 4 gives a pictorial representation of the control process. It can be noted that the operation planning and control process is an iterative process which is exceptionally adaptive. Each of the preceding stages in Fig. 4 can be accessed from the subsequent stages when necessary.

SIMULATION OF WATER RESOURCES SYSTEMS

Definitions

A simulation model is a reduced pilot system used for analysis of the real system. A pilot system formalized in the form of mathematical equations is a Mathematical Simulation Model, also called Mathematical Models (MM). If a system is represented by a reduced physical system, then it is a Physical Model.

Simulation is closely related to analogy, where analogy means total or partial similarity of different objects or systems. Objects/systems may be similar in characteristics, functions, or relations among their elements. In broader sense, analogy is a process of information transfer from the model to the real system and vice versa. This transfer enables making of judgments and conclusions in the "model – object" direction.

Simulation Rules

"The one who states something must prove it, not the one who argues against it". (Law postulate)

A model can be decomposed e.g., into a Water Resources System Model (MWRS), a model of the corresponding environment acting on the input into the system (MOX), and a model of the corresponding environment acting on the outputs (MOY). A group of simulation models can be defined as:

$$MM = \langle MWRS, MOX, MOY \rangle \quad (9)$$

Following are the simple simulation rules:

1. Start from the simple MM with the gradual increase of complexity, depending on the required level of detail and the available information. Do not hurry with complex models without enough needs and information.
2. Modeling and information gathering must be done simultaneously. Once the modeling starts, it becomes obvious what information is needed, and once the information is available it is clear what kind of model can be developed. Only through such interactive modeling process and information research, the decision how to process the "raw" information can be made.

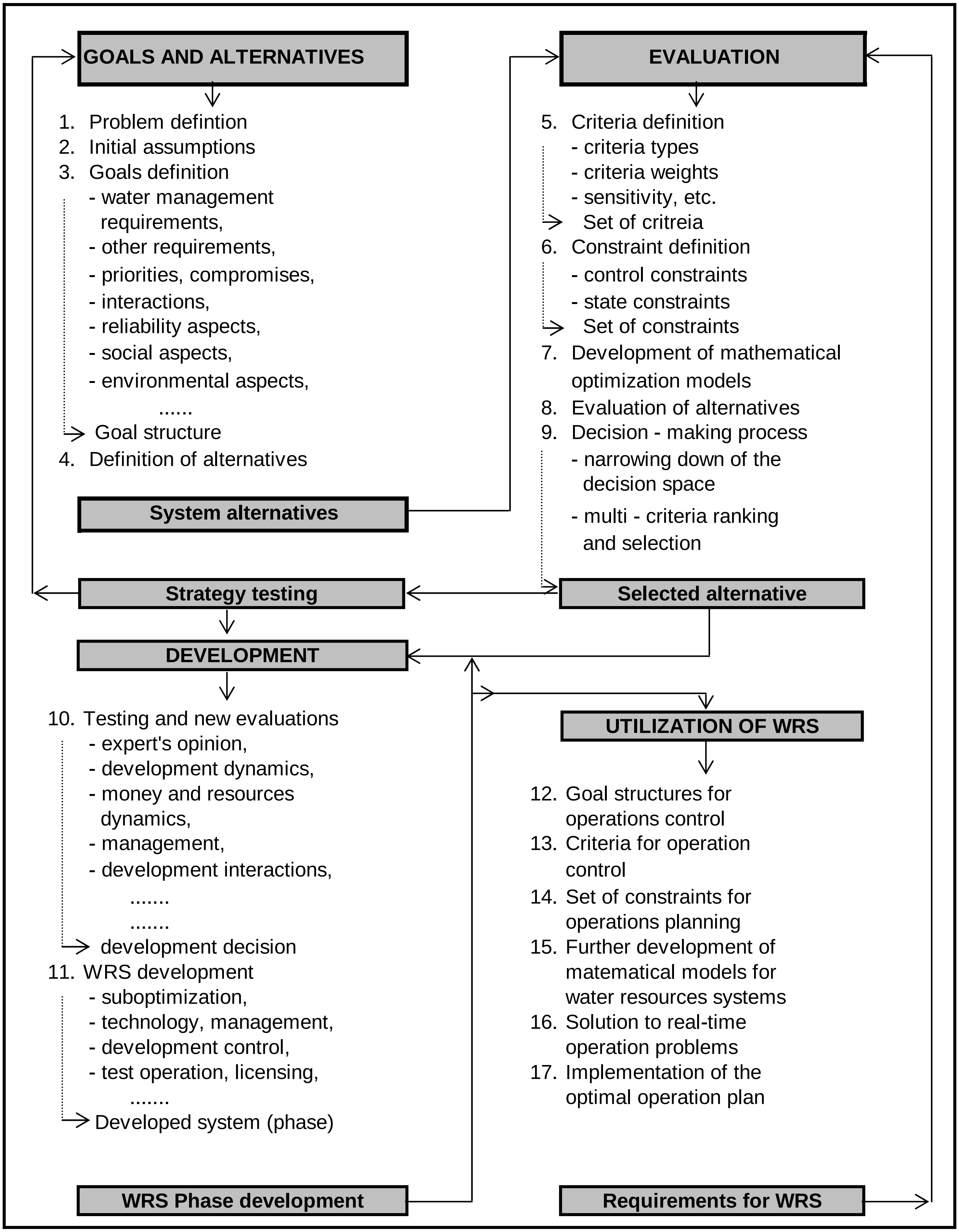

Figure 4. WRS Control Structure

3. Four kinds of decomposition (functional, spatial, temporal, and numerical) should be used for the development of a chain of MM. Models are adaptive and structured in modules. The modular structure enables easier changing of the modules, as opposed to changing the entire MM.

4. Always keep in mind what are the needs and the level of analysis for which MM is used. Very often a model is used for decision-making without considering its limitations (Biswas 1988).

SYSTEMATIZATION OF WATER RESOURCES SYSTEMS MANAGEMENT

Systematization of WRS management is related to the systematization of two main tasks of management. They include:

- Control Tasks Systematization
- Optimal Control Systematization

General controllability of water resources systems is associated with the control quadruplet:

$$U \Rightarrow \langle \Gamma, M, J, L \rangle \qquad (10)$$

which shows that the Control Problem (U) is solved by using the known Goal Structures Γ, Mathematical Models M, with the defined Objective Function J, subject to Constraints L.

A WRS is controllable if its goals, criteria and constraints are in accordance with the physical capacities and the available resources with regards to quantity, quality and location. Unrealistic goal structures, too ambitious criterion functions, or too stringent state and operations constraints may reduce the controllability of WRS. Thus, WRS with given configuration and parameters depending on hydrological conditions may be controllable or uncontrollable. The best example could be a flood control reservoir, which up to a certain level of high flows would be a controllable system but beyond that level would be uncontrollable. This increasing or decreasing of controllability is an optimization problem. Therefore, it is necessary to systematize the optimization problems together with control tasks.

Optimal Control Systematization

Two groups of WRS optimal control problems exist:

1. Optimal Analysis Problems
2. Optimal Synthesis Problems

1. The Analysis Problems:

In general, the optimal analysis problems are formulated in the following manner: WRS is known, its configuration and physical “a” and control component “b" parameters are known, i.e., a = constant and b = constant. For stochastic or deterministic inputs a set of control decisions should be found which satisfies the required WRS goals. As the goals can be met by applying various control decision schedules, from the set of feasible decisions u □ U, a control decision set is searched for, which will satisfy the required WRS goals and simultaneously secure a maximum or a minimum of the objective function to be reached.

The above presented optimal analysis problems are applicable both for existing and for planned WRS. The control problem of optimal analysis may be formulated as:

$$\text{Given: } \langle \Gamma, M, J, L \rangle; \quad \text{Find: } \underset{u}{\text{extremum}} \quad I(s, u, t), \; s \,\square\, S \qquad (11)$$

The problem is to find the optimal control u(t) which maximizes/minimizes the objective function I (s,u,t): I(s,u,t) $\Rightarrow$ extremum, for the initial state $s_0 \in$ s.

2. The Synthesis Problems:

These problems can be formulated in the following way. The goal structure Γ is defined and inputs (stochastic category) are known. The optimal configuration and parameters "a" of WRS are unknown. In other words, the optimal configuration should be found, WRS parameters, and the optimal control decision set should be determined, which will satisfy some defined synthesis criteria (an extreme value of the objective function I):

$$\text{Given: } <\Gamma, M, J, L> \quad \text{Find: } \underset{u,\,a}{\text{extremum}} \quad I(s, u, a, b, t),\ s\ s \in S \qquad (12)$$

By satisfying: $EF_1 > EF_1^z$, $\forall i : i = 1, m$; where m is the total number of required effects (EF^z) of the planned system.

Differentiation Between Synthesis & Analysis Problems

The differences between the two problems are the following:

- Complexity of Synthesis Problems: The synthesis problems are more complex than analysis problems, because the optimal configuration and optimal parameters should be determined, as well as the optimal control decisions. This problem requires the analysis of various alternative configurations with broad range of parameters a $\in$ A. At the same time, it means using the alternative models M and constraints L denoted as < Γ, M, J, L > in Eq. 12.
- Iterative Process of Synthesis Problems: The optimal synthesis problems are iterative processes. After each alternative configuration and parameters combination, the system should be evaluated for the accomplishment of requirements set up by the goal structure. The most often used reliability tests examine the probabilistic efficiency

$$P_i\,(y = y^z) \geq P_i^{min} \qquad (13)$$

$$P_z ✍ P_z^{min} \qquad (14)$$

Inequality (13) defines a probabilistic requirement that the probability of undisturbed supply (output y is equal to the required output) should be greater than the required minimum for each user. Similarly, inequality (14) is evaluated for the required safety of WRS protection functions, i.e. decided whether it is better (✍) than the required minimum. An example for this case may be the water quality protection.

Relations of inequalities (13) and (14) are goal constraints which should be evaluated after the optimal synthesis problems have been solved. New iterations are required, if the required reliability levels were not reached.

These constraints are often omitted in practice and various alternatives which are not comparable in their reliability characteristics are being compared on economic grounds. This practice is erroneous because often the inexpensive and appealing solutions cannot satisfy reliability requirements. The error can be very substantial because a very small increase in reliability requires great economic expenditures. It has been observed during Simulation Modeling that the increase in reservoir reliability from 80 to 90% requires a 2.5 times greater storage, while further increase from 90 to 97% requires a 2.2 times greater storage. The increase in reservoir volume (i.e. cost) depends on the stochastic character of inflow time series. For example, higher annual/monthly autocorrelation coefficients indicate higher possibility of accumulation of low-flow periods, thus dictating larger reservoirs.

COMPLEX WATER RESOURCES SYSTEMS

The term “complexity” in water resources systems theory has its special meaning and it comprises the following categories:

- complexity of system’s components as a result of diversity and large number of elements and subsystems within a complex WRS;
- complexity of inner element/subsystem relations;
- goal structure complexity with a large number of goals of different importance;
- complexity of relations with the environment; and
- organizational complexity of WRS within the hierarchical management structure (Baosic and Djordjevic 1998).

SYSTEM ANALYSIS OF LARGE AND COMPLEX WATER RESOURCES SYSTEMS

General

The term systems analysis is widely used but it often means different things to different people depending on their particular scientific discipline. Here the term systems analysis means a way of looking at the world. It is a way of structuring reality so that we may understand how components of the environment affect, and are affected by, other components. When using a systems approach, the challenge is to formulate a (model) system that is simple enough to understand, yet comprehensive enough to adequately capture the relevant interactions and processes observed in the real world.

A physical environmental system describes the flow and storage of the physical quantities of mass, energy and momentum. The hydrologic cycle is an excellent example of a physical environmental system.

Water resource systems, even as isolated projects, are large and complex both in terms of technological planning and mathematical modeling. The essence of the planning approach in both activities is Decomposition and Iterative Hierarchical Planning.

The technological aspects of a large scale and complex project are manifested in two ways:

- In large investments, extensive investigations, planning and design, and
- In terms of interlinkages between the environment/resources and the economic impacts.

For instance, water is constantly flowing and the consequence and implication of technological planning at any stage is interrelated with its activities upstream and downstream. Even for isolated projects, the implications of hydrological modification make the planning activity complex. It, therefore, has to be carried out sequentially. What can be emphasized is the need for professional judgment to organize a problem for analysis and synthesis of the several components.

System Analysis is thus mandatory for exploring the interactions of numerous factors and the uncertainties of the parameters, but the solution to problems involving real systems is often hampered by size. A realistic model invariably turns out to be too big. In mathematical programming, size is determined by the number of variables, the number and complexity of the system objective. What “large” means depends on the capabilities of the solution algorithm, the speed and capacity of available computing equipment, etc. However, as mathematical programming becomes more widely used, problems are formulated which test even the best algorithms and the largest computers. There has thus been an increasing effort on decomposing the system, analyzing the subsystems, and then synthesizing them to capture the implications of interlinkage. This may be done by:

(i) Heuristically,

(ii) Exploiting the system structure, or
(iii) Hierarchical multilevel decomposition.

Mathematical modeling/programming, even after decomposition, fails to capture the intricacies of a real life system, particularly, the implications of the stochastic inputs. Simulation is the answer to this. Yet, the infinite alternatives cannot be examined by simulation unless the range is bounded by mathematical programming (Chaturvedi 1987).

System Planning & Analysis Morphology

Now, we elaborate the system configuration, capacity and operational aspect of planning and analysis as a subset of the total activity. We start with the demand and resources being known, as well as the socio-economic setting and the valuation. This static division is not always correct and demand-supply integrated planning is important. We start therefore, with this decomposition to illustrate the specific activity, through a series of steps. At each stage, there is an objective, an activity and an outcome. At each stage, balance has to be maintained in disaggregation and aggregation.

The scheme discussed below is the general outline of an approach only. Depending upon the system, configuration scale and the objectives of analysis, the approach and details of analysis at each stage will vary, as the case may be.

Step I: Development of Scenario and System Reconnaissance

The first step in systems planning is collection and generation of information regarding:

- amount of water available,
- water demand, and
- schemes for their transformation.

Step II: Identification and Tentative System Configuration

Tentative system configurations emerge from the first step. For example, where groundwater should be developed, where storages can be provided, where diversion schemes with a conveyance system can be developed, what is the possibility of conjunctive development, what is the possibility of use, what are the environmental implications, etc.? In the second step, we try to proceed to a more definite idea of the system which was still embryonic in Step I.

Step III: Decomposition and Subsystem Planning

The overall view of the system at this stage is naturally diffused. At the third stage, the system is decomposed for detailed analysis of alternative candidate configurations. System dimensions and capacities, allocations, and operating policies are identified. Simultaneously, analysis of the physical system and the demand including the evaluation criteria and the socio-economic framework of analysis are also carried out with greater refinement.

Step IV: System Synthesis

The synthesis of the subsystems has next to be carried out to analyze the system as a whole.

Step V: System Simulation

In view of the complexity of the system, simplifications have to be introduced in mathematical programming models discussed so far in order to make them operational. The real life behaviour can best only be obtained by simulation. Simulation can be done by using analog computers, digital computers or hybrid computers. Simulation over the whole range may be infeasible. Mathematical programming models indicate the range for a simulation.

Step VI: Planning-Design Iteration

In the next stage of planning and design, the emphasis shifts to design. In planning, the next task is to decide the operating policies. The problems now gradually shift more into the realm of management. But this shift takes places iteratively, the guiding principle being cost of analysis up to any level of resolution and its value for the decision. First, with the likely optimum configurations, capacities and operating policies, the cost and benefit will require re-analysis. Parametric analysis will be required to assess the implication of uncertainty in hydrologic and engineering estimates. On the evaluation side in addition to the physical review, an economic-legal-social-political review must be made. More and more objectives may be introduced into the objective function through Multiobjective Analysis. Bargaining may be introduced through game theory. Systems planning is a creative activity to bring out the implication of alternative values of inputs, parameters, policy options, etc., so that a wide range is mapped for taking judgement in view of uncertainties and non quantifiable and non-commensurate objectives. The hierarchy of planning is shown in Fig. 5.

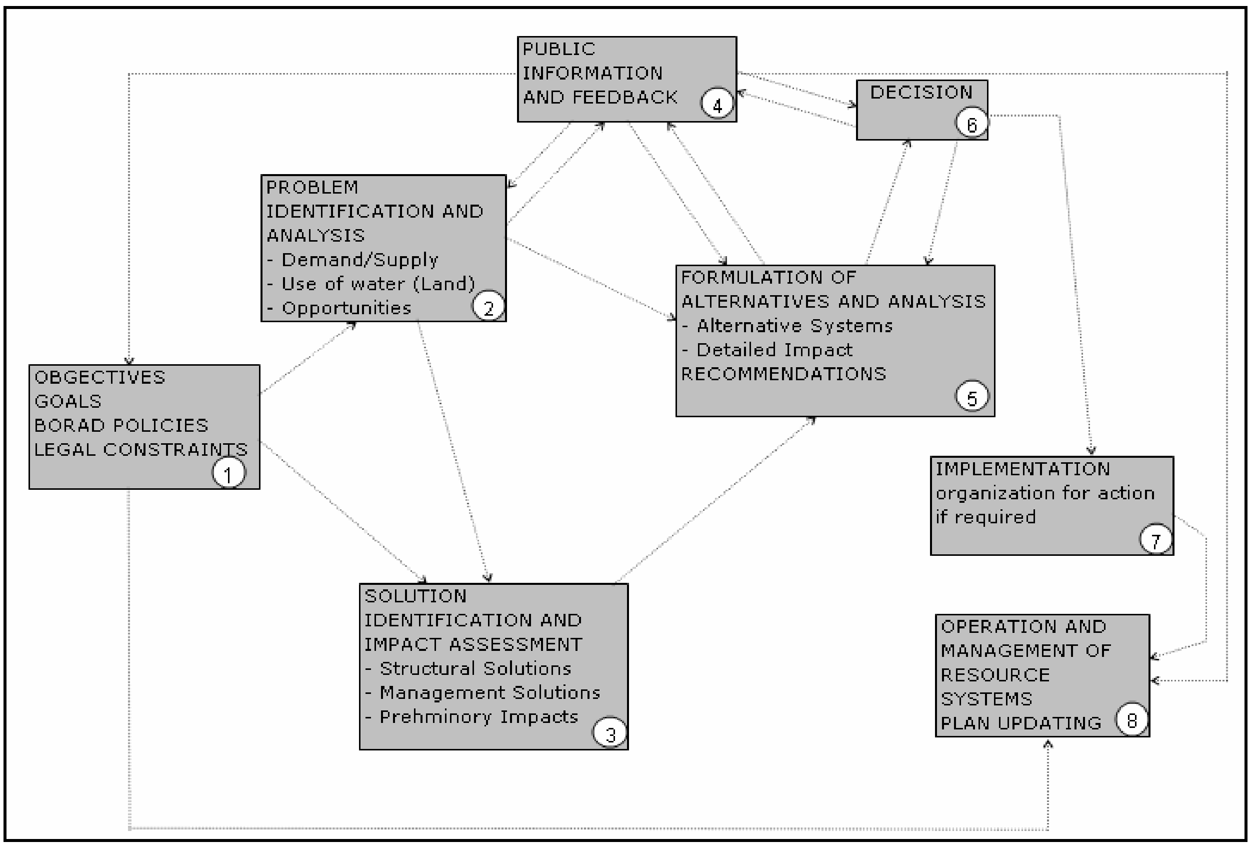

Figure 5. Hierarchy of Planning

CONCLUSIONS & RECOMMENDATIONS

The human activities have expanded in different fields of life, the information about different activities has become an asset and collection and keeping the information in accessible and interpretable mode is no more a problem with the latest Pentium 5 computers and latest storage devices. Thanks to the internet, which has made the world a global village, and has facilitated the acquisition of almost any data from any part of the world, a task of few seconds. Geographic Information Systems (GIS) and Remote sensing, must also be exploited in the WRS, which has reduced the labour and time to acquire the information about different phenomena in the earth, in a reliable manner. Apart from updating or refining different maps, vegetation cover, crop monitoring, communication network mapping and planning, much more can be done with GIS and Remote Sensing application. The incorporation of this blend of informations in the Water Resources Management can atomize the available resources only if the system is made capable of understanding all this data and should then made inferences from previous experiences and specialist advice. WRS models, capable of exploiting all these up-to-date information, previous experiences and specialist advices can only be beneficial and prudent enough to manage complex WRS and suggest alternatives to the decision makers.

Pakistan is a developing country and the rapid growth of urbanization and industrialization emphasize the development of an efficient water resources management system to control and exploit its Water Resources beneficially. She possesses the brain in computer technology and can therefore harness the Information Technology sources to develop a versatile computer program for water resources management. The prerequisite for such a program is the System Analysis of indigenous WRS based on the latest technological advancements. The subject research could provide the basics of system analysis techniques to students, researchers and scientists in the light of technical Cybernetics. The previously developed “hard-wired” programs have lost their efficiency on account of their inadaptability to changing objectives and requirements.

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