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Building New Water Resources Projects or Managing Existing Systems?

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Abstract: *The planning of regional water resources systems and their subsequent management has to rest firmly on three foundations: availability of water of adequate quality, demand for water expressed quantitatively for specific periods of time, and direct, indirect, and externality costs. Mathematical models of hydrosystems represent only a segment of the real world. The basic science of hydrology is an empirical discipline, and its basic law is the continuity equation. Optimization of operating rules based on this law of conservation of matter may face difficulties when the objective function is expressed in economic terms. Overcoming this obstacle requires the use of targets (for water releases and stored volumes) expressible in physical units. The optimization objective can then be expressed as the sum of the squares of the differences between the results of the analysis and the targets. An additional complexity is created by parties who are interested in regional hydrosystems for purposes other than the traditional water supply and flood control. They may require certain elevations of water levels in streams and reservoirs for wildlife or recreational purposes or minimal flows needed for fishing and fisheries. All these complexities lead to an expansion of regional water resources models so as to enable the manager to investigate factors and decision alternatives not included in the model. A regional water resources system is relevant only in so far as it advances the solution of socio-economic and political issues and promotes development rather than growth. Management of existing systems should take precedence over building new water resources projects.*

Keywords: *Regional water resources, model limitations, stakeholder participation, decision support systems.*

Introduction

The 20th century opened with a major impetus of constructing water resources projects, to a large extent in the United States. The passing of the Reclamation Act in 1902 by the US Congress provided the necessary legal and institutional basis for a "flood" of projects that, were built during the following six or seven decades. This law established also the Bureau of Reclamation that, under the leadership of the Department of the Interior, had almost free rein to plan, design, construct, operate and manage water resources projects west of the Mississippi River, a region extending over more than half of the area of the USA. In some parts of this vast region, the Bureau of Reclamation faced the US Army Corps of Engineers (established by Congress shortly after Independence and led by the Department of Defense) in competitive situations.

To be sure, the scientific and technological foundations for water resources projects were laid down in the previous century. Darcy's Law (1850) is the basis of much of the work that contributed (and still contributes) to the advancement of our understanding and knowledge of subsurface hydrological phenomena. Rippl's analysis of streamflow data (1883) became the foundation for planning, designing, and constructing numerous projects utilizing exclusively surface hydrosystems. The central paradigm in almost all cases was to meet a specified demand for water and/or water derivatives using the least amount of available resources – funds, labor, steel, concrete, etc.

Today, at the threshold of the third millenium of the current era, we realize that the design of regional water resources projects and their subsequent management has to rest firmly on three foundations:

(1) The availability of water, its location, quantity, quality and existing institutional framework.

(2) The demand for water and/or water derivatives, expressed quantitatively for specific periods of time (seasons, months, weeks, etc.). *Water demand* is an analytical concept, as contrasted with *water requirement*, which is primarily descriptive.

(3) Cost, direct, indirect, or generated outside the service area of the project (externalities). In connection with this, two comments are relevant:

(a) Externalities cannot usually be handled by market activities; hence, they are very often the subject of regulatory agencies.

(b) Benefits may be viewed as the negative of costs. If so, planning and operating models may use either of them. In many instances, one prefers costs because benefits may be more difficult to quantify accurately.

Models and Their Limitations

Models, whether mathematical, numerical or analog, represent only part of the real world. Often we latch onto them, ignoring that a major part of the region of concern is not included. Sometimes, these approximations are satisfactory; at other times, the results of their analysis can be misleading.

A main difficulty in mathematically modeling regional water resources systems is that *hydrology*, the basic science of water resources, is primarily an empirical discipline. Efforts are currently being made to change this contention and to formulate fundamental physical laws (Dooge, 1999). A basic law is the *continuity equation*, which is, in fact, the Law of Conservation of Matter. However, this is only an initial step.

Hydrological phenomena and their consequences for managing regional water resources cover a very broad range. For example, the mighty Huang He (the Yellow River) generates floods that produce severe damages in Inner Mongolia (an autonomous region of China) while freezing during the five cold months of winter, November to March. Large blocks of ice tend to pile up one on top of another in some places, thus impeding the flow of the river and flooding adjacent lands. Clearly, scientific study of these phenomena will be at the cutting edge of hydrology, producing, hopefully, satisfactory mathematical or numerical models.

Formulating mathematical models, we often find it easier to write constraining conditions, expressing clearer physical or economic relationships, rather than objective functions. The difficulty with the objective function is that the analyst tends to optimize either benefits or costs, variables that can be often quantified only approximately. It is more convenient, therefore, to use physical units in objective functions (Buras, 1985). To do so, one has to establish targets for releases of water from storage and for water remaining in storage at the end of each operation stage, operate the reservoir on the basis of a hydrological record, and minimize the sum of the squares of the differences between the targets and the best decisions obtained.

Participation of Stakeholders

During World War II, decision sciences were developed to the extent that management and utilization of scarce or limited resources were clarified considerably. Mathematical expressions were formulated that included the objective (or purpose) for which decisions had to be made, as well as the conditions that defined the space and/or time of the decision process. These models were quickly adapted after the conclusion of the war to water-related problems, especially to issues of regional water development. It was quite gratifying to produce numerical results that could be claimed to be "optimal" within the boundaries specified by the model.

The rapid economic development of most of the western world following the Second World War renewed the impetus of building water resources projects on many continents. The scale of these projects varied from rather small local structures (for example, the Cachuma dam north of Santa Barbara in Southern California) through medium sized systems (the development of the Jordan River within the Israeli water plan) to large-scale dams and reservoirs (the Kariba dam on the Zambezi and the Aswan High Dam on the Nile). It is important to emphasize that in most of the cases the planning, design, and construction of these structures were done with minimal, if any, participation from people who were to be served by the projects. This situation led to conflicts within the river basin, whether it was located in one country or shared by several sovereign nations. For example, the Kariba dam on the Zambezi river and its reservoir were shared by two former British colonies, Northern Rhodesia and Southern Rhodesia. The two governments did not coordinate their policies and treated the people who had to be relocated when the reservoir was filling in different ways. In one case, the relocation was essentially peaceful; in the other case, more forceful methods had to be used.

During the second half of the 20th century, the planning, design, construction, and operation of regional water resources systems underwent a major change. Gradually, it was realized by the authorities commissioning water resources projects that individuals and organizations were interested in hydrosystems not only as sources of water for agricultural or municipal uses, hydropower facilities for the generation of electricity, or for mitigating possible flood damages. They were interested in the same hydrosystem for recreational purposes (swimming, boating), fishing, maintaining wildlife, aesthetic purposes, or other reasons. These may be the *stakeholders* in regional water resources systems. Farmers, for example, who grow agricultural products for export, may, in fact, be exporting water or its equivalent. The local, regional, or national levels of government must consider this possibility when commissioning a water resources system.

The participation of stakeholders in the planning, design, and management of regional water resources systems became increasingly important. Two specific examples will illustrate this point.

In the mid-1970s, the government of Mexico embarked on the formulation of its first National Water Plan. This was an extremely ambitious project for a country that spans very diverse hydrological and socio-economic environments (Buras, 1976). The political environment at that time did not consider the necessity of consulting with users of the projects, the building of structures or the operating of them, so that the National Water Plan was, in effect, a *diktat*, perhaps even a benevolent one, of the Federal Mexican Government. Of course, this was not a satisfactory solution. It took almost 15 years until this policy was radically changed, establishing self-financing and administratively autonomous water utilities that would provide water services in cities and irrigation districts (Comision Nacional del Agua, 1990). It is interesting to note that initially only two irrigation districts became autonomous and self-financing: one near Mexico City, which was a major supplier of vegetables and fruits to the metropolitan area; the other at Hermosillo in the state of Sonora, which was close to the Los Angeles market.

The other example is the Narmada River basin in India. The Narmada is a large river flowing west into the Indian Ocean and having a mean annual discharge of about 40 billion cubic meters. The development of this river basin involved the construction of a number of dams, creating reservoirs of various sizes. The last reservoir downstream would have been created by a concrete dam 1,210 m long and 163 m high. The lake would have required the resettlement of about 200,000 people, most of whom belonged to local tribes. Clearly, these people were very important stakeholders who should have been consulted very closely while the project was still in the planning stage. This has not been done (Morse and Berger, 1992). The project currently is at a practical standstill.

Integrating stakeholders within the planning process is a delicate activity, and it may take considerable time. For example, analyzing the operation of the West Branch of the Penobscot River in the state of Maine in the USA, an industry that was mostly interested in generating hydropower spent considerable time and effort in order to establish an informal stakeholder group that directly influenced the formulation of an operating policy for the hydrosystem (Peng, 1998). This operating policy attained more than one objective in a balanced way, although the objectives were expressed in non-commensurate dimensions.

Reaching out to individuals and/or organizations who may have an interest in the utilization and management of regional water resources, whether surface streams or subsurface aquifers, is a very important activity. Adjusting the modeling and analysis of the hydrosystem under consideration may facilitate the acceptance of the recommendations of the water resources analysts by the public and its governing authorities.

Decision Support Systems

Surveying the water resources scene during the 20th century, one can observe a gradual progression that started from building structures for the attainment of various objectives and targets related to water. These activities used mathematical modeling and analysis of varying sophistication; however, they neglected to a considerable extent whatever opinions and expectations the public who were to be served by these systems may have held.

In spite of the sophistication of the water resources models and their analysis, we must realize that these mathematical formulations represent, at best, only a limited segment of the real world. Operators, managers, and other decision makers working with these systems for some time often felt frustrated that some of the socioeconomic details and decision alternatives that they considered to be of importance were not expressed explicitly in these models. As a result, we find a plethora of very interesting mathematical expressions and analyses published in the scientific literature, yet, at the same time, only a few actual applications were implemented in the field. An example of field work performed by senior faculty members is the study of the salinity and waterlogging problems generated by the Indus Valley Irrigation System in Pakistan in the 1960s. A strong team of scientists from Harvard spent considerable time and effort in studying these complex problems. An intricate decision model was constructed, focused on alternatives for treating the salinity of the root zone of the valley soils and restoring lands to agricultural production. The additional amounts of water necessary for leaching the salts accumulated in the soils could be obtained either by the appropriate management of groundwater aquifers or by building a major dam, Tarbela, on the upper reaches of the Indus River. The outcome of this sophisticated analysis indicated that the substantial investment in the construction of the dam yielded a lower value of the objective function; thus, this alternative was considerably sub-optimal. However, from the point of view of public relations of the governmental agencies commissioning the study, the inauguration of a major dam has a greater psychological value than turning on a valve and having water flow from a well field. Without communicating with the scientific team, who were still writing the summarizing report, the ruler of Pakistan at that time had reached an agreement with an international financial organization to invest in the dam construction (Dorfman, 1966). Such unpleasantly equivocal and contradictory situations can be avoided by decision support systems.

A *decision support system* is an instrument that enables the operator or manager of a water resources system to investigate the influence of factors or of decision alternatives that are not included in a model. It is a family of integrated software packages that has interfaces with which the decision maker can interact comfortably. To emphasize again: a model, however intricate, represents only a fragment of the real world; thus, its usefulness is rather limited. At the same time, managers of water resources systems who have been operating them for some time acquire knowledge and understanding in an intuitive way. They "know" that certain activities could yield better results than those indicated by the model; a decision support system enables the decision maker to test these assumptions.

A decision support system is currently in its final phases of development for a hydrosystem in the northeastern United States (Peng and Buras, 1999). The essence of this system is that the operator (dispatcher) can obtain at the beginning of each month (however the month is defined calendar-wise) the best decisions to make regarding releases of water, so as to maximize the hydropower generation (on a yearly basis) at the downstream lake and maintain desired levels of water at the upstream lakes. The model yielding these decisions is quasi-deterministic, since the analysis is based on the most recently acquired data regarding flows and storage levels. The output also includes the ensuing 11 months, given an operational (synthetic) hydrological series. The operator can examine the output and, if accepted, it can be implemented. If not, the operator can easily use the interactive interfaces of the software to introduce into the model factors not considered initially and/or alternative decisions. Within a relatively short time, a new computer output is produced. The operator can repeat this action until a satisfactory output is yielded. Better operative decisions can then be made.

The spectacular progress in the field of computing in the last decade is evident in both hardware and software. The current processors are at least one order of magnitude faster than ten years ago. As a result, we can make within reasonable time calculations related to more complex and intricate models. The sophisticated software packages recently developed allow us to produce very attractive computer outputs. As a result, many water resources analysts and consulting engineers submit to their clients computer outputs of decision models or of simulations in attractive forms that are called "decision support systems" although they are not. The fact that "decision support systems" became a buzz-word is hardly surprising in the current cultural and business environment. Other ideas viewed as having the potential to be useful and desirable became, in time, mere buzzwords.

Concluding Remarks

Considerable progress was made during the 20th century in building and managing water resources systems. This progress was due to a large extent to advances in decision sciences (operations research) and to rapid improvements in computer hardware and software.

Nevertheless, our current knowledge and understanding of the physics, chemistry, and biology of phenomena in nature in which the hydrosphere, atmosphere, lithosphere, and biosphere interact are still sketchy. This knowledge and understanding are the foundations of hydrology. At the same time, our knowledge and understanding of socio-economic and political phenomena in various countries and continents are very limited. This knowledge and understanding are the foundations of water resources: an assembly of disciplines that study human interference in the hydrological cycle and evaluate the results in terms of benefits and costs. Hopefully, the 21st century will yield significant advances in knowledge and understanding of these extremely complex phenomena.

After the euphoric state in which many water resources systems analysts found themselves during the decade-and-a-half following the Second World War when sophisticated models were built, many of them became rather disappointed that so few of these models were actually used in the field. Some analysts even questioned the relevance of regional water resources systems. The answer seems to be that *a regional water resources system is relevant only in so far as it advances the solution of socio-economic or political issues.* This attitude still seems to be valid.

Today we are in an era of managing regional (however the region is defined) water resources systems. Meeting the demand at minimum cost is not a sufficient criterion for operating these systems. We have to consider very seriously the problems that our current management of regional waters may impose on future generations. We also have to take into account the impact of our management policies on the quality of the environment. To do so, we need to make a very clear distinction between *growth* and *development*. Growth, the continuous accumulation of goods and services, is finite, because the planet Earth is finite and has finite resources. Development, however, means using more efficiently the available resources, minimizing waste, and maximizing quality of life. Development, therefore, has no limit and depends mostly on our imagination and daring.

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