New Directions in Water Resources Planning and Management

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Introduction

Hydrologic units are logical spatial entities for water resources planning and management. Unfortunately, political and hydrologic boundaries seldom coincide. Thus, contemporary water resources planning and management systems are typically hybrid units which reflect efforts to devise compromise jurisdictional boundaries. It is axiomatic that comprehensive planning is a good idea. We should look at the entire hydrologic unit as a unified system since it is interdependent. We should also look at multiple purposes and objectives. These goals have been codified in most planning efforts. Contemporary systems need to be holistic, fully integrated, environmentally sensitive, self-sustaining, etc. While these goals are laudable, it is often difficult, if not impossible, to reach agreement on a single plan because of the myriad of interest groups and associated laws and policies at the local, regional, state, and federal levels. This situation has led to policy "gridlock."

The purpose of this paper is to review previous approaches to watershed planning and management. The focus is on methodologies that have been used and to suggest new paradigms for future efforts. Companion papers in this volume provide complementary insights. The next section of this paper provides a brief historical perspective on watershed planning and management. The following section describes analytical methods for evaluating alternatives. Then, suggestions for new approaches are presented.

Historical Perspective

Viessman and Welty (1985) provide a comprehensive overview of water resources planning and management in the United States and elsewhere including a chronology of milestones in water planning. Watershed planning has followed cycles of interest and disinterest for more than a century. The current wave of interest in planning results from a combination of factors including the following:

(1) a collective frustration with the fragmented command and control approach which has been in favor for more than a decade;

(2) a significant shift of power has occurred during this same time period with non-federal entities emerging as more important partners due to the federal government withdrawing financial support for planning activities;

(3) the growing concern over cost-effectiveness, especially with regard to environmental management, in light of heavy deficits and tight budgets;

(4) related planning approaches have worked well in the electric energy field where Integrated Resources Planning is an accepted approach;

(5) the watershed planning approach is the preferred approach from a technical and economic point of view.

(6) the growing realization that decentralized water markets can be an effective alternative to central control over water allocation (e.g. Summer 1993 issue of *Water Resources Update* on Water Pricing and Marketing).

With watershed planning having such obvious technical advantages, then why wasn't it adopted years ago? Some reasons are listed below:

(1) Watershed planning, and planning in general, has been presented as a static process that leads to the formulation and adoption of a master plan. However, groups seldom can agree to accept a master plan that will bind them to a single course of action.

(2) Watershed boundaries typically do not coincide with political boundaries. Thus, serious problems often arise in establishing a watershed commission or authority.

(3) Planning models have often been based on weak databases. Consequently, the results were not realistic and had little credibility.

(4) As we move towards more holistic approaches to planning, the complexity of the analysis increases exponentially, especially when environmental impacts are included.

(5) The planning process is too slow. People grow impatient waiting for the answer and move to other approaches.

(6) Direct regulation is felt to be more cost-effective.

Feasibility Tests

An increasingly sophisticated array of techniques have been developed for water resources planning and management during the past sixty years. Much of the development of new methods has been supported by various federal water agencies who have a need for standardized methodologies to have a consistent basis for comparing alternatives. Overall, a proposed water resources project should be evaluated based on the five feasibility tests listed below (James and Lee, 1971).

Feasibility Test	Description
Technical	Can it be built?
Economic	Should it be built?
Financial	Who will pay for it?
Environmental	Can its impacts be mitigated?
Socio-Political	Will the public support it?

Each of these feasibility tests is discussed briefly below.

Technical Feasibility

The most fundamental feasibility test is whether it is technically possible to pursue the alternative. An example of a technologically infeasible goal is the elimination of pollution. It is technically impossible to eliminate all residuals based on the laws of conservation of mass and energy. However, clean water and clean air legislation have in fact mandated technically infeasible options such as zero discharge of water pollutants and eliminating all carcinogenic air pollutants.

Economic Feasibility

Do the benefits to whomsoever they may accrue exceed the costs to whomsoever they may accrue? The objective of the economic feasibility test is to maximize net benefits, or the present value of the future stream of benefits and costs. The analysis does not address issues of the incidence of these benefits and costs across the affected parties. Principles of benefit-cost analysis have been widely used in evaluating federal investments in water resources projects for water supply, flood control, navigation, recreation, and fish and wildlife enhancement. It has not been used to any great extent in environmental management because of the relative difficulty in quantifying the benefits of environmental improvement.

Financial Feasibility

Financial feasibility addresses the fundamental question of who will pay for the project. From the early 1900's through the 1970's, the federal government dominated the financial aspects of water resources development and management activities. By federal policy, if the benefits were widespread in nature, then the federal government paid a large share, if not all, of the initial costs of projects.

Overall, the federal government has dominated the financial aspects of water resources until the past decade when they greatly curtailed their financial support. When the Federal government underwrote the majority of project costs because the benefits were considered to be widespread in nature, the local sponsors naturally supported such federal largesse. Accordingly, the financial feasibility aspects of these projects were relatively simple.

However, with the federal government making drastic cuts in directly underwriting project costs during the past decade, the financial aspects have become much more critical. Also, with improved information systems, it is much more feasible to identify the actual beneficiaries of water resources projects and to argue that these beneficiaries should help pay these costs. The financial feasibility of projects remains a vital issue of the 1990's because of tight money at all levels of government.

Environmental Feasibility

The environmental feasibility of projects has been evaluated since the National Environmental Protection Act (NEPA) of 1969. These environmental impact statements (EIS's) have become a major component of feasibility studies. Methods for doing EIS's have evolved from being extensive lists of possible impacts to contemporary approaches which explicitly quantify the risks associated with alternative courses of action. The benefit-cost-risk framework for environmental impact assessments has made EIS's much more useful since they relate directly to the determination of technical feasibility.

A major component of environmental feasibility evaluations is to determine the safety, reliability, or risk associated with alternative courses of action. Every engineering design makes explicit or implicit determinations of reliability. Engineering design standards are a codified judgment regarding the reliability of a proposed alternative.

Socio-Political Feasibility

The last feasibility test is whether the affected publics will support the proposed project. Much research and activity has been included in project evaluation to properly incorporate citizen input. The classic model of letting the expert make the decision has been replaced by a wide variety of administrative and legal forums for addressing these considerations. These activities include public hearings, committee reviews, formal litigation, dispute resolution techniques, etc. The socio-political feasibility test is related to the other tests because public attitudes are strongly influenced by who pays the costs of the project, the incidence of benefits and costs across the affected populace, attitudes towards further development, etc.

Planning Methodologies

The National Resources Planning Board conducted comprehensive regional assessments of water and land resources in the 1930's. These studies were landmarks in federal efforts to promote the wise development of natural resources. General planning principles were articulated as part of these studies. The objective of these studies was to solve the problem by developing a master plan which would then serve as a blueprint to guide future development.

Selecting Among Discrete Alternatives

The simplest planning problem is to compare mutually exclusive alternatives and to choose the best one. The most basic principle needed to evaluate alternatives is to have a way to convert a stream of benefits and costs which occur at different time periods to a common base for comparison. Money has a time value and future benefits and costs are not worth as much as if they occurred today. Students in engineering are taught how to do these calculations in classes in engineering economics. Students in economics and business learn the same methods in courses in economics and management accounting and finance.

Early applications of engineering economics in water resources were stimulated by 1936 federal flood control legislation which mandated the use of benefit-cost techniques to prioritize flood control projects. In 1950, the first version of the "Green Book" was published which promulgated consistent sets of engineering-economic principles for all water resources agencies. A nice example of comparing discrete alternatives is the methodologies developed for evaluating water conservation alternatives (Planning and Management Consultants, Ltd. 1980).

The major challenge in economic feasibility evaluations is to develop reasonable estimates of future benefits and costs and to select appropriate values for the discount rate and the period of analysis. Some benefits are relatively easy to quantify, e.g., flood damages to structures, while others such as the value of a human life are difficult to measure. While active debate has occurred for years in the economics literature on the proper discount rate to use, federal agencies have adopted a standard discount rate. Similarly, the service life should be selected based on a benefit-cost analysis. The project should be continued as long as the incremental benefits exceed the incremental costs. In practice, standard service lives are used to evaluate alternatives, e.g., assume that a dam has a service life of 50 years. Costs are relatively simple to estimate for a single purpose project. However, most projects are multi-purpose which raises the difficult, and often unanswerable, question of how common costs should be apportioned. For example, how should the total costs of a stormwater pond which provides flood control, water quality control, and fish and wildlife enhancement be apportioned?

Selection Among Mixes of Alternatives-Microeconomics

The next level of sophistication is to find the optimal mix of alternatives wherein the choice set includes combinations of the alternatives. The classic solution to this problem was to use theory from microeconomics including production economics. For example, a city is considering three sources of water supply: a river, a lake, and groundwater. Using engineering economics, one could find the present value of the costs of each of these three choices and then choose the least expensive of the three available discrete choices. However, a better solution may be to select a combination of these three options. Using marginal cost analysis principles, the optimal solution is to select a blend of the three options such that the marginal cost of the three sources is equal. While this approach is conceptually sound, it was difficult computationally to consider more than a few alternatives in the pre-computer age.

Systems Analysis

In the late 1950's, a group of faculty in engineering, economics, and public policy at Harvard developed the Harvard Water Program in cooperation with major federal water agencies (Maass et al. 1962). The main purpose of this major effort was to evaluate the applicability of the newly emerging computer-based techniques of systems analysis including simulation and optimization methods to solving water resources problems. High-level engineers and planners from government agencies came to Harvard for a year or two to develop comparative case studies.

This initial effort launched a wide interest in the potential value of systems analysis methods in addressing complex water resources planning problems. For the first time, we had the computing capability to do long-term simulations of reservoir operations and find optimal solutions using mathematical programming to evaluate complex watershed problems. The simulation techniques were the first to be implemented since they were straightforward conversions of existing manual engineering calculations. A very important component of the Harvard Water Program was the direct involvement of social and policy scientists. They were able to clearly articulate the conceptual relationship between linear programming and classic microeconomic theory thus enabling the solution of much larger, more realistic optimization problems. Policy scientists were able to provide strong intellectual leadership in addressing institutional issues.

The initial effort at Harvard spawned systems analysis programs at Northwestern, Cornell, UCLA, Johns Hopkins, and other universities. By the end of the 1960's, the systems approach was the primary thrust of water resources planning in universities. The fit of systems analysis into university curriculum was a natural. The logical consistency between systems analysis and economic theory had been established. It was a rigorous area of applied mathematics and thus had a high degree of credibility within graduate programs. Also, it seemed capable of addressing realistic water resources planning problems. Loucks, Stedinger, and Haith (1981) summarize the state of the art as of a decade ago. Mays and Tung (1992) provide a more recent summary of the systems approach. During the past decade, interest in the "systems" approach has grown with the advent of much more user friendly PC-based software. For example, state of the art spreadsheets such as Excel, Lotus, and Quattro have built-in linear and non-linear optimization packages. Thus, it is now possible to teach undergraduates techniques which, prior to the advent of microcomputers, were the sole purview of specialized graduate courses.

The application of the systems approach to the water field has been a mixed success. The very process of translating a water resources problem into a mathematical model causes much of the reality of the problem to be lost. Geoffrion (1992) describes this phenomenon for the operations field in general. Johnson and Kaplan (1987), in a major critique of the management accounting field, titled *Relevance Lost*, cite the negative influence of economic theory and systems analysis in causing universities to place over reliance on these analytical techniques to the exclusion of developing more relevant information-based approaches that address the actual problems facing managers. They argue that researchers have serviced an audience of fellow academics and the editors of prestigious journals instead of working with policy makers in a more meaningful way to address their problems in ways which are more relevant to them.

Decision Support Systems

In response to some disenchancement with mathematical modeling techniques and associated prescriptive approaches, analysts turned their attention to more user-focused descriptive approaches. Expert systems, an offshoot of long-term research in artificial intelligence, offered promise of developing more user centered approaches (Maher, 1987). The focus on mathematical modeling switched to developing user-defined heuristic decision rules. Thus, with expert systems, the first order of business was to write an expert system program which replicates the actual decision processes currently being used by the decision maker. The descriptive approach had one major advantage over the prescriptive approach. It forced the analyst to spend much more time with the client in defining the problem as viewed by the client. Furthermore, "success" was measured in terms of the client being satisfied that the output did accurately depict how he made decisions.

Early experience with expert systems indicated that the most important need for a decision support systems was a user friendly database management system. Many of the heuristics developed by users were simple analytical methods to make a forecast given some recent data. For example, the flood control operator turned on the pump if the water level in the canal had been rising at a rate greater than one inch per hour for the past six hours.

During the past six years, major advances have been made in developing decision support systems because of concurrent developments in hardware and software, e.g., Geographical Information Systems (GIS), object-oriented database management systems, real-time acquisition of operations data, much more powerful PC's and work stations, and greatly improved Graphical User Interfaces (GUI). Thus, a formidable arsenal of tools is available to examine contemporary water resources problems. Where we have lost our way is in not having a conceptual framework for effectively directing the use of these tools. At least with economic theory and the associated systems analysis techniques we had a solid conceptual foundation within which we felt that our work was respectable, at least in academic circles.

Lessons Learned

Water Resources planning and management has advanced significantly during the past 60 years. Sound principles of planning were articulated in early planning efforts of the 1930's. However, it was difficult to implement these principles due to lack of technology and associated analytical methods to analyze alternatives. The advent of computer hardware and software has had a major impact on our analytical capabilities since the 1960's. We are now blessed with simulation and optimization models for analyzing virtually all areas of water resources from reservoir operations to regional groundwater management. Leadership in developing these analytical methods has come from the universities which have been on the cutting edge of new developments in numerical methods, optimization techniques, natural resource economics, and related areas.

Interest in planning has waxed and waned during the past sixty years. When the federal government dominated water resources planning funding, they encouraged the development of new planning tools so that the desirability of alternative investments could be prepared. Thus, we now have extensive guidance on how to do benefit-cost-risk analysis for a wide variety of water resources projects. The current state of the art is summarized in U.S. Corps of Engineers publications (1991, 1992). The Institute for Water Resources of the Corps of Engineers continues to support the development of new tools for this purpose. As another example, the U.S. E.P.A. supported about $350 million in so-called 208 areawide wastewater planning studies in the 1970's. The purpose of these studies was to develop consistent assessments of the relative importance of wastewater and stormwater quality problems in urban areas. These efforts were designed to encourage local communities to develop cost-effective areawide water quality management plans. Without an approved plan, the local area would not receive approval for construction grant funding of approximately 85% of the cost of the proposed projects. With the federal government paying most of the cost of both the planning study and the subsequent construction, it is not surprising that a high degree of cooperation was obtained.

Interest in watershed and environmental planning waned in the 1980's as the federal government moved forward more aggressive regulatory approaches. Thus, the carrot and the sword approach now relied much more heavily on the sword. The regulatory, or command and control, approach relies on enforcement of federal legislation for specific cases of violations. This regulatory approach does not consider the area-wide or watershed implications of its actions.

The perceived short sightedness of the regulatory approach has led to a major rekindling of interest in watershed approaches. For example, over 1100 people attended a national conference on watershed planning in Washington, D.C. in March 1993. All of the federal water agencies were represented along with a very good cross section of local, regional, and state water agencies. While support for watershed planning seemed almost unanimous, how to conduct such studies remained an open question. The American Water Works Association and the U.S. EPA are supporting a related concept which they have dubbed Integrated Resource Planning. Its purpose is to develop water supply plans which provide an optimal balance of demand and supply side management. Very strong support for water conservation has stimulated this initiative. Integrated Resource Planning has been used in the electric utility industry for a number of years. With strong support from the Electric Power Research Institute (EPRI), many useful planning methodologies have been developed, e.g., Hirst (1992). The stimuli for the IRP activity in the electric utility industry are the strong desire for energy conservation to forestall the construction of additional capacity, and legislative mandates that require IRP investigations.

Thus, in 1993, the timing is right to make major advances in watershed planning and management. The big question is what strategy to use. The next section proposes a different paradigm for water resources planning and management of the 1990's. Some new tools are needed to properly introduce these innovative ideas. They are addressed in the next section.

Future Directions for Watershed Planning and Management

There is good reason to be optimistic that we can improve the success of watershed planning activities. Technologically, we are much better prepared to accurately analyze and evaluate problems due to the marvels of contemporary computer technology and related databases. The availability of large databases makes it feasible to take an information driven, rather than a model driven approach to these problems. With contemporary software and hardware, we can now solve complex simulation and optimization problems that were unthinkable a decade ago. Thus, technologically we have a definite advantage over earlier efforts. However, technology alone will not bring success. We need to change our attitudes regarding the nature and purpose of the watershed planning and management activities. In my opinion, the key change is to redirect our energies from trying to "solve the problem" to focus on continuous process improvement with frequent feedback. The concepts of continuous quality improvement have been articulated by Deming, Juran, and Crosby among others.

While there are numerous variations, the central theme is to examine problems as continuous processes wherein the objective is to attain continuous improvement in the performance of the process or processes of concern. The evaluation proceeds iteratively through a series of four step cycles of plan, do, check and act.

One missing ingredient in making real progress in watershed planning is a clear motivation and funding source or sources to make it happen. It happened in the electric energy field due to legislative mandates. Electric utilities tend to be investor owned as opposed to water utilities which are predominantly publically owned (Hanemann 1993). They also have the advantage of a relatively large source of funding through the Edison Electric Power Institute. Similar leadership is needed in the water field if we are to make significant progress.

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