WHAT CAN WATER MANAGERS DO ABOUT GLOBAL WARMING?

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ABSTRACT

Realistically, water managers (planners, designers, operators) can't do much about preventing global warming, any more than they can affect contemporary climate. Historically, water management has been a process of continuous adaptation to the considerable vagaries of climate variability, and accommodations for any uncertainties associated with our lack of understanding about climate cycles by introducing redundancies into engineering design. Adaptive management (monitoring and learning from mistakes) has been the foundation of water resources management since the time of Noah. The key point is that societal response to both conditions, variability and change, is virtually the same, i.e., to upgrade and intensify introduction of innovative and cost effective supply-side and demand-side management measures, and continue to create institutions that are more flexible in adapting to both social and physical changes. However, policy initiatives that affect legal and institutional controls on water management are likely to play a much larger role in future adaptation to climate change than technical and engineering responses. Engineers can design and operate their systems more efficiently to increase robustness and resiliency and reduce vulnerability, but institutional arrangements must be reconfigured to ensure that future water resources services can be provided in a sustainable and equitable manner under a wider range of circumstances.

There are two tiers of adaptive management changes - policy mandates and agency/utility implementation. Many of the changes that will position society to better deal with future climate change uncertainty are already being debated and implemented in the context of policies and institutional reforms to deal with an evermore complex host of issues, and include such matters as river basin compacts; defining new partnership roles between Federal, state, and local entities; nonstructural flood damage reduction; the valuation of water both as an economic and environmental good; and the increasing requirements for environmental protection and aquatic ecosystem restoration. These are the strategic policy changes that will impose or influence future water management goals, objectives, and responses on the respective water management agencies. The components of water resources management that are directly under the control of or influenced by water managers include adoption of improved methods of hydrologic analysis coupled with risk analysis, improvement of forecasting methods for system-wide analysis, and more integrated analyses of multiple watershed needs and outcomes. In addition, fundamental criteria that affect project investment analysis and the choice of more environmentally benign alternatives are being modified so that future systems will be more robust and resilient to anticipated climate change, as well as to evolving societal demands.

INTRODUCTION

Adaptation to climate change will require all levels of government and all sectors of the economy to respond in many different and, hopefully, rational ways. Sound water resources management is central to the efficient functioning of many other water dependent sectors, especially transportation (navigation), energy (hydropower), and agriculture. It is especially critical to meeting the basic need for drinking water supply of our populace, in urban and rural areas and for sustaining aquatic ecosystems which would be particularly threatened, if the most severe of the numerous possible climate change scenarios were to materialize (Stakhiv and Major, 1997).

It is not the purpose of this discussion to engage in a debate about the relative merits of the global warming and climate change phenomena or the unresolved difficulties that the large uncertainties in the predictions of the consequences of CO_2 increases impose on developing rational response strategies. These discussions have been adequately covered in many publications (e.g., Lettenmaier, *et al.*, 1996; Lins, *et al.*, 1997). The findings of the Intergovernmental Panel on Climate Change (IPCC) reports (1996; 1997), which state that there is a perceptible human influence on global warming, should alert us to the possibility that there could be a broad range of potentially adverse and beneficial effects as a consequence of a doubled CO_2 atmosphere. The question is what can (should) water management organizations, like the Corps of Engineers, do to respond to these signals, and what are the limits to adaptation, given institutional constraints and uncertainties associated with a wide range of seemingly more pertinent exogenous factors, principally dealing with the future socioeconomic structure of the U.S. and global economy? It is the thesis of this paper that progressive (autonomous) adaptation to hydrologic changes in contemporary climate variability (extremes in supply and availability), as well as in shifting demands, provides the familiar platform for most water managers, whether in federal or state agencies, utilities, irrigation districts or flood control districts, to deal with climate change. The key issue is not whether water managers are interested in or capable of preparing for climate change in their operational or strategic decisionmaking. They are continuously adapting to new information and demand-driven changes. Rather, it is more the case that the external, policy-driven institutional constraints and conditions are likely to be the larger factors in determining the direction and pace at which adaptation occurs. The fallout from the Kyoto Climate Convention and subsequent international attempts at controlling greenhouse gas emissions are likely to have far greater consequences on energy efficiency and subsequent water use than any direct management actions undertaken by the water resources sector.

As a general proposition, the IPCC itself considers that, in principal, water resources can adapt to most of the climate change scenarios:

> "*Water management is a continuously adaptive enterprise, responding to changes in demands, hydrological information, technologies, the structure of the economy, and society's perspective on the economy and the environment. This adaptation employs four broad interrelated approaches: new investments for capacity expansion; operation of existing systems for optimal use; maintenance and rehabilitation of systems; and modifications in processes and demands (e.g., conservation, pricing and institutions). These water management practices, which are intended to serve the present range of climate variability (which in itself is considerable), may also serve to ameliorate the range of perturbations such as droughts that are expected to accompany climate change. However, adaptations come at some social, economic and environmental costs" (IPCC; 1996, Vol. II, Chapter 14, pg. 471).*

Indeed, the most recent comprehensive comparative analysis of six major Corps of Engineers managed water systems and river basins shows that these systems can be effectively managed for all but the most severe climate change scenarios (Lettenmaier, 1999).

Many regions of the world and urban centers are becoming more stressed in many aspects of water resources - water supply, agricultural irrigation, sanitation, and rural water supply. As a society we have to confront these problems, which are quite daunting even in the absence of global warming induced climate changes. The very same mechanisms and approaches are the foundations for or prerequisites to adaptation to climate change. The only issue is whether this can be achieved through progressive adaptive (autonomous) management strategy or require a special strategy of coordinated anticipatory measures. There are no unique solutions or 'silver bullets' that come to mind for water management other than the distinct possibility that significant technological breakthroughs in the next 20-30 years can alleviate both the energy problems (e.g., fusion, solar energy) and scarcity of water supply (e.g., cheap energy will enhance the cost-effectiveness of desalination technology which is energy intensive). Biotechnology is expected to play a major role in future food production and agriculture. Ausubel (1995) makes a compelling case that technological innovation trajectories exist and that technical progress in many fields is quantifiable. He believes that the process of decarbonization, i.e., decreasing carbon intensity of primary energy, has been evident since 1900, but has not been taken into account in the future forecasts of IPCC.

POLICY IMPETUS

There is a good deal of autonomous adaptation in the water resources sector that is measurable. Even with a good deal of waste and inefficiency in the system, the reality is that total fresh water withdrawals in the U.S. have been decreasing since their peak of 378bgd in 1980, down to 341bgd in 1995 (Solley, *et al.,* 1998). Most of the reduction came indirectly as a result of the regulatory requirements of the Clean Water Act, as well as the Safe Drinking Water Act. This forced industries to recycle water more efficiently and the rising costs of wastewater treatment acted as an indirect pricing mechanism on municipal users. Also, innovations in agricultural irrigation had a major impact on reducing withdrawals and consumption. All this was accomplished despite a 16 percent increase in population from 1980 to 1995.

Much of the substantive future response to increasing water demands, however, will have to be met through institutional and policy changes, focusing on more coherent management of water and related natural resources at the watershed level. These changes in governance will determine the implementation effectiveness of subsidiary agencies and the private sector. Indeed, it is the institutional and legal changes that provide the impetus and sustainability for implementation of needed reforms at all levels of government, magnifying the more limited set of technical adjustments that are within the responsibilities of the agencies. Institutional changes cover a broad category of changes that only Federal, state, and local governments can implement, since they typically deal with issues of organization, authority, economic incentives, licensing or permitting, taxes and economic incentives, and legislation. The cumulative effect of mutually reinforcing initiatives lays the foundation for an effective strategy of operational and design changes. Other significant changes must come directly from the individual - changes in behavior and attitudes that affect efficient resource uses.

There are numerous external institutional changes that serve as the "drivers" or determinants of "organic" public policy changes which affect all organizations. The National Environmental Policy Act (NEPA) of 1969 is a clear example. In the area of water policy, the Water Resources Planning Act of 1965, which formed the U.S. Water Resources Council and river basin commissions, was a comparable milestone. Similarly, the National Water Commission (1973) report was instrumental in influencing subsequent legislation reforming the planning and cost sharing policies of federal water resources management agencies. There are numerous equivalent recent initiatives that will have a lasting positive effect on water resources management, setting the stage for more responsive adaptive management strategies, whether or not climate change is explicitly considered. These include the Report and the Interagency Floodplain Management Review Committee (1994), also known as the "Galloway Commission," which has already engendered a broad series of legislative and administrative reforms for flood plain management policies of Federal and state agencies. The Western Water Policy Advisory Commission (1998) released their report on a comprehensive approach to water resources management reforms in the 17 western states. They will be debated and undoubtedly many of the recommendations will influence policy initiatives. The federal establishment, under the direction of Vice President Gore, issued the "Clean Water Action Plan" (1998) for restoring and protecting the nation's waters. The National Drought Policy Act was passed by Congress in 1998 (P.L. 105-199), setting up a Commission to recommend changes in federal drought management and response policies, and improve coordination among the numerous agencies involved in this endeavor. The Congress found that there was an increasing need to emphasize preparedness, mitigation, and risk management, rather than crisis management. There are countless other comparable initiatives in the agricultural, transportation, and energy sectors which, collectively, will result in a set of reinforcing reforms that will accelerate the pace of autonomous adaptive management. All these initiatives and changes will serve to improve the responsiveness of all government and private sectors to the signals of climate change and further reduce the vulnerability of society to natural hazards.

Gleick (1998, pg. 10) recognized the marked shift in "traditional" water resources management in the following statement:

> *"Traditional approaches to water planning, while still firmly entrenched in many water-planning institutions, are beginning to change. Among the factors driving these changes are high costs of construction, tight budgets, deep environmental concerns, new technological advances, and the development of innovative alternative approaches to water management. The search for new solutions is also being pushed along in some places by the changing nature in the demand for water, particularly in North America and western Europe."*

Along with the major "organic" changes in public water resources management policies, there has been a progressive accumulation of many small economic, legal, financial, and regulatory policy changes over the past 35 years that have directed or influenced profound changes in the inherent philosophy of water management. Too little credit is given to increased non-federal cost-sharing provisions and improvements in benefit-cost analysis and other evaluation procedures that have demonstrably reduced both the number of projects, their scale and size and have resulted in more environmentally benign designs over the past decade, especially since the enactment of the Water Resources Development Act of 1986. These changes are the primary determinants of progressive (autonomous) adaptation. Now, a more holistic view of substantive institutional changes is needed to position the nation for more flexible adaptation to social, economic, and environmental changes as well as those of climate. Water management agencies and utilities, which are inherently technical in nature and responding as they do to imposed mandates, can only seek to optimize the services that they deliver under the specific sets of competing objectives and constraints imposed by those institutions.

AGENCY INITIATIVES AND IMPLEMENTATION

The Corps itself is an "institution" or organization which can exercise considerable influence on the rate of change and adaptation. However, like all other agencies, it can only respond to the policy and budgetary directives and constraints imposed by Congress and the Executive Branch. The Corps can exercise a greater degree of initiative and responsiveness in defining the pace of introducing new technologies, but even that function is limited by budgetary decisions which control the pace and direction of research programs. Yet despite all these constraints, water resources management is inexorably being driven toward a more efficient use and management of water resources, and one that is approaching a true realization of sustainable development according to the concepts contained within the President's Council on Sustainable Development (1996).

The reality is that the greatest potential for improving adaptive management in the water resources sector lies in its most politically contentious forum - the institutional settings and policy fora. Water management agencies today have less direct control than ever over water management decisions, except perhaps in the 17 western states of the U.S. There, the Federal government manages much of the surface water resources and a good deal of the land surface. Hence, the Federal government, largely through the Department of the Interior (Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, Geological Survey, and the Bureau of Reclamation) theoretically has a greater degree of influence, but not direct responsibility, for policies advocating the allocation of water supply and facilitating voluntary water transfers of water through a water market system. Furthermore, it should be recognized that the regulatory controls of the Safe Drinking Water Act and the Clean Water Act, managed by EPA, have played a major role in reducing inefficient water use in the municipal and industrial sector. Increasingly stringent non-point source pollution controls in the watersheds of America will continue to impose further restrictions on agricultural water use in the future. It is anticipated that future greenhouse gas emissions controls will require that the U.S. Government undertake a major energy efficiency and technology development initiative that will have positive benefits for the water resources sector.

Each agency at each level of government has a role to play in improving the effectiveness of contemporary adaptive management mechanisms geared to meeting contemporary demands and climate variability. Collectively, the sum of those efforts can help our society manage its way through whatever future climate scenario or trajectory is evident. The key changes that the Corps could significantly affect in its response strategy to global warming would be largely focused in the first three, largely technical and administrative approaches noted by the IPCC: (Chap. 14, pg. 471), reflecting its fundamental role in planning, design and operation, and maintenance:

(i) planning new investments for capacity expansion;
(ii) operation of existing systems for optimal use; and
(iii) maintenance and rehabilitation of existing systems.

Even changes in each of these approaches require a considerable degree of Congressional approval, since many aspects of project planning and design, including major rehabilitation of the existing infrastructure are based on a strict sequence of project approval and Congressionally mandated procedures and criteria that dictate project cost-sharing, evaluation procedures, discount rate, etc. Each potential project goes through several phases of Congressional review, direction, and approval: project feasibility planning; authorization of advanced planning, engineering and design, and appropriations for construction. These sequential controls and criteria have a profound influence on the ultimate choice of the project alternative, definition of purposes and determination of project location and size. Nevertheless, the Corps is at least an active participant in the formulation of project alternatives and the analytical process with its federal, state and local partners. Some degree of flexibility is possible in choosing and designing more robust and resilient options in anticipation of climate change impacts. The key is how to explicitly introduce future climate scenarios, or at least more variability into project planning and design, when economic efficiency requirements and cost-sharing concerns drive the selection of alternatives that are "brittle," i.e. neither robust nor resilient (Hashimoto *et al.,* 1982).

Ironically, it can be argued that the introduction of explicit risk and reliability analysis, benefit-cost analysis, and the economic discount rate as an integral feature of Corps planning, decisionmaking and infrastructure design, essentially contributes to "brittle" designs, i.e., projects that operate under increasingly narrow margins of reliability. The intention of risk analysis was to avoid over-design and eliminate redundancies - the very features that often provided the extra margins of reliability (e.g., levee freeboard) which accounted for uncertainties in hydraulic and hydrologic knowledge. On the other hand, the new risk and uncertainty analytical methods developed by the Corps of Engineers (1992, 1996) can be said to explicitly account for much of the anticipated climate change and variability through its procedures that are based on Monte Carlo simulation. The methodology computes the risk of flooding due to combinations of hydrologic events, hydrologic parameter uncertainty, uncertainty in reservoir operation, state-discharge relationships, and levee performance. The methodology allows one to investigate the influence of the uncertainties on economic outcomes and benefit-cost justification of various project features, design levels, and optimal size. One can explicitly examine the performance of various alternative designs and project scales in terms of direct measures of robustness, resiliency, and reliability. The Monte Carlo technique samples the complete flood frequency distribution (log - Pearson III) within the 95% confidence limits, for return periods beyond 1000 years. The same is true for the stage-frequency and damage-frequency combinations. The National Research Council (1995) examined the Corps methodology and concluded that "[T]he new USACE risk and uncertainty procedures are an innovative and timely development. The explicit recognition of modeling uncertainty should result in a better understanding of the uncertainty of flood risk and damage reduction estimates."

PLANNING FOR NEW INVESTMENTS FOR CAPACITY EXPANSION

There are several noteworthy initiatives within the Corps which come close to dealing with climate change through a more explicit examination of hydrologic variability and trends, and their influence on decisions. The Upper Mississippi River Flow Frequency Study, authorized by Congress in the aftermath of the 1993 flood in the upper basin, is dealing with the problem of how to better account for extreme floods in improved hydrologic forecasting models. The principal focus is on developing a better hydraulic model which can predict the river stages for given precipitation and runoff. However, the study is also trying to determine whether basic hydrologic methods need to be revised to account for seemingly increasing trends in precipitation and flood peaks over the past 50 years. This study will have long-term implications for floodplain delineations, levee certifications, and levee design throughout the region. Preliminary results, however, suggest that there is no compelling evidence to deviate from Bulletin 17B, which comprise the basic federal guidelines for performing flood frequency analysis, developed by an interagency group in 1982.

Similarly, a study of the Devil's Lake, North Dakota flooding problem relied heavily on a simulation of future probabilities of increased precipitation and runoff into a closed basin as the basis for determining whether or not to build a pumping station and outlet to the Sheyenne River, or continue to add to the system of levees protecting the town of Devil's Lake and vital infrastructure. A net investment savings of over $40 million depended on near-term climate state possibilities and future trends. A study of climate trends, including the influence of El Ninos and other longer-term oscillatory meteorological phenomena (North Atlantic Oscillation, North Pacific Decadal Oscillation, etc.) was undertaken by the Corps to better understand the relationship between "normal" climatic fluctuations and a permanent shift in the mean due to global warming. All of these inquiries are beginning to represent a significant shift toward conventional practice within the Corp's approach to examining the hydrologic response of large river basins and the relative performance of managed water resources systems under a broader spectrum of hydro meteorological stress.

One of the more comprehensive reviews of the adequacy of Corps planning criteria, procedures, and evaluation principles in light of global warming and climate uncertainty was undertaken by Resources for the Future at the behest of the Corps of Engineers. A report of that work (Frederick, Major, and Stakhiv, eds. 1997) concluded that the Corps' procedures, particularly the increased emphasis on employing risk and uncertainty analysis in all aspects of their planning studies, especially the economic justification of new investments, was consistent with the rationale required for adapting to climate change. In that report, Stakhiv and Major (1997) further concluded that the Corps' methodologies, based on the U.S. Water Resources Council's "Principles and Guidelines," complemented the approach advocated in the IPCC "Technical Guidelines for Assessing Climate Change Impacts and Adaptation" (1994) more closely than traditional NEPA environmental impact assessment guidelines.

It should be recognized that the basic planning process itself promotes the formulation of numerous alternatives consisting of location options, different technologies, operating variations, behavioral changes, institutional changes, regulations, etc. There are large uncertainties surrounding each option. Formal methods for uncertainty analysis and risk analysis are the principal means for determining the overall economic performance as well as the reliability, robustness, and resiliency of alternative measures under a variety of conditions, stresses, and future demands. This multiobjective plan formulation and evaluation process is the backbone of adaptive management.

OPERATION OF EXISTING SYSTEMS FOR OPTIMAL USE

The science of weather forecasting is improving, but not rapidly enough nor precise enough yet for reservoir operators. New forecasting procedures are being developed, but they must be tested and adapted to the needs of the practicing water managers. Too much of the theoretical development is in the hands of the researchers, with too few practical experiments and joint applications with water managers and operators. One example of a technology that holds great promise for revolutionizing operational water management was recently reported by Georgakakos et.al. (1998). Intuitively, reliable forecasts of reservoir system inflows are essential for efficient reservoir operations, increasing the flexibility for managing and adapting to regional water management needs. The authors tested and compared the standard, rule-based operational forecast with a coupled forecast-control system that employs probabilistic ensemble flow forecast. The coupled forecast-control system explicitly accounts for flexible reservoir management strategies that encompass forecasts which are uncertain. The sensitivity of reservoir management to climatic variability can therefore, be explicitly analyzed and thereby minimized. Data from the regulated 14,000 km^2 upper Des Moines river basin were used together with the operational rules of Saylorville Reservoir, operated by the US Army Corps of Engineers for flood control, recreation, low-flow augmentation (ecosystems and water quality), and water supply. The study found that current reservoir management practices cannot effectively accommodate historical climate variability. "Substantial gain in resilience to climate variability is shown to result when the reservoir is operated by a control scheme which uses reliable forecasts and accounts for their uncertainty. The study shows that such coupled forecast-control decision systems can mitigate adverse effects of climatic forcing on regional water resources" (Georgakakos *et al.*, 1998). The authors conclude that the failure to incorporate realistic reservoir operation optimization procedures in climate change impact studies, such as the one developed for the Des Moines river, would lead to overly pessimistic results and exaggerated real impacts when compared to the standard heuristic or extrapolative methods used in such studies.

A similar study is being conducted on improving the weather and event forecasting capabilities in the Ohio River basin as the prerequisite for improved operation of the water management system by the Corps of Engineers. This effort is part of a larger Global Energy and Water Cycle Experiment (GEWEX) Continental Scale International Project (GCIP), where the Mississippi River basin and its major tributaries (Missouri River, Ohio River) have been selected for a series of coordinated experiments. It is important for operating agencies like the Corps and the Bureau to participate directly in such studies and technology transfer activities, for these will provide the basis for major improvements in water management (NRC; 1998).

MAINTENANCE AND REHABILITATION OF EXISTING SYSTEMS

Most of the Corp's large construction program is concerned with major rehabilitation of the aging system of locks, dams and levees. The Corps has developed a risk analysis method for analyzing each major component of the Corps infrastructure. A diverse set of tools and procedures have been developed during the past decade for risk-based hydrologic, hydraulic, and economic analysis (IWR 1998). A new generation of risk-based techniques are also being developed for environmental restoration and remediation.

Development of methodologies and analytical procedures is a very important component of dealing with forecasting uncertainty climate variability and climate change uncertainty. A wide range of adaptive management strategies are routinely formulated during the planning process. Each has different performance characteristics under different operating ranges. The Corps has been developing tools to analyze these performance characteristics in a uniform manner, for such problems as dam safety, rehabilitation of hydropower facilities, navigation locks, levees and the disposal of contaminated dredge material. The performance of each infrastructure component is tested under a wide range of conditions that statistically include conditions and events anticipated under many of the future climate scenarios. There are 15 recently issued technical procedures (1992-1998) that provide guidance on risk, uncertainty and reliability analysis in all aspects of the Corps planning, design, and operations and maintenance programs.

CONCLUSIONS

Much of what a water management agency does to adapt to contemporary climate variability also serves as the platform for adapting to prospective climate change. The most effective components of a targeted adaptive management strategy are likely to be policy and institutional changes that are externally driven, principally as political solutions to social and technical problems.

Water management agencies such as the Corps can become agents of change and adaptation by playing a more active role in transferring technologies associated with climate forecasting. Risk and uncertainty analysis is the major avenue for explicitly considering the implications of climate variability, change and uncertainty on all aspects of Corps planning, design, operations and maintenance.

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