CLIMATE CHANGE AND WATER RESOURCES: THE ROLE OF RISK MANAGEMENT METHODS

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ABSTRACT

Risk management methods in water resources in the United States and elsewhere have been applied within the context of highly developed sets of planning criteria. In considering these methods, many of which are listed here, it is helpful to distinguish between the use of these techniques to *assess* risk and to *manage* risk. While the use of risk assessment and management methods for water resources planning varies widely among agencies, the robustness and resiliency of existing methods for risk management in water planning have the potential to serve effectively as the basis for adapting to changes in the supply and demand for water resulting from climate change. There are, however, substantial research, application, and technology transfer issues to be confronted.

BACKGROUND

Risk management methods in water resources in the United States and elsewhere have been applied within the context of highly developed sets of planning criteria. In the United States, for example, primarily because of the important role played by Federal agencies in the water resources sector, there has long been official criteria for water resources planning (see, for example, U.S. Inter-agency River Basin Committee 1958, originally issued in 1950 and widely influential internationally; U.S. Water Resources Council 1973, 1983). The traditional economic benefit-cost methods and the more general multiobjective methods embodied in these criteria have both been developed to a high level of rigor (see Eckstein 1958; Hirshleifer *et al.*, 1960; Maass *et al.*, 1962; Marglin 1967; United Nations Industrial Development Organization 1972). Risk assessment and management methods have been applied within the contexts of each of these U.S. sets of standards, and have developed over the decades into an elaborate set of procedures.

The development of water resources planning criteria, including risk criteria, has reflected not only the government's interest but also two other circumstances. First, the production function for water resources for many of the standard project purposes such as flood control and hydroelectric power generation is fairly well understood. (To be sure, the production function relating to ecosystem management and restoration is less well known, but much work is underway relating to these purposes.) Second, the hydrologic inputs to water management systems can be reasonably described as stochastic; as a result, the water resources planning community has been dealing with variability in a formal sense for many decades. Both of these circumstances have facilitated the application of risk management methods. It is of interest also that over the decades the water resources planning sector has expanded to encompass new purposes, such as water quality and aquatic ecosystem management (on the latter, see Stakhiv and Major 1997).

RISK MANAGEMENT METHODS IN CURRENT USE

Some of the principal risk management methods currently used by water resources planners are given here. In considering the application of such techniques, it is conventional to distinguish between risk, where a probability distribution is known or can reasonably be assumed, and uncertainty, where no probability distribution can reasonably be assumed. The latter situation may be the more relevant with respect to global climate change, but many formal risk management techniques can nonetheless be helpful in considering climate uncertainties. In addition, it is helpful to distinguish between the use of these techniques to *assess* risk and to *manage* risk.

The use of risk assessment and management methods for water resources planning is currently widespread in some agencies (for example, U.S. Army Corps of Engineers 1992, 1993, 1996a, 1996b, 1997; for a summary see Stakhiv, forthcoming); on the other hand, these methods are not widely used in many agencies and jurisdictions. The degree of use depends on the institutional framework, the nature of the problems under consideration, and the availability of staff and other resources. A recent IPCC assessment (IPCC 1998) reviews the current state of risk management techniques across sectors, including water; (see also IPCC 1996b, ch. 14; IPCC 1996c, ch. 3; and Carter *et al.*, 1994). Frederick, Major and Stakhiv 1997, summarized in Frederick, this volume, presents analyses of climate change and water resources planning criteria from a variety of theoretical and applied perspectives.

While there appears to be no canonical list of risk assessment and management techniques in water resources, the following list, for which examples of applications can be found, includes many if not most of the techniques available.

Interconnection of systems to provide additional backup for changing regional conditions.

Incremental construction where possible and economically feasible (e.g., a number of small systems rather than one large one) to allow for adaptation to changing circumstances.

Choice of robust designs in which the chosen design will be fairly good under a wide range of outcomes rather than optimal under one outcome.

Postponement of irreversible (or very costly to reverse) decisions.

Use of a range of formal decision techniques, including scenario analysis, sensitivity analysis, Monte Carlo methods, and others.

Designing for extreme conditions. Using historical or synthesized flows, the water resource planner can suggest approaches that deal with extreme events (floods and droughts) rather than simply maximizing the expected value of net benefits.

Reallocation of storage. After projects are constructed, and circumstances change, storage can be reallocated to improve project performance under changed climatic conditions.

Reallocation of supply through the development of water markets.

Development of non-structural measures such as warning systems. Flood and storm warning systems (inland and coastal) can be used to adjust to the risks and uncertainties of flooding.

Demand management measures. These measures, such as implementing pricing schemes, requiring low-flow toilets, or formulating drought contingency plans, can be used to control demand and thus provide a measure of safety in available supplies.

Shoreline planning schemes to provide adaptability to rising sea levels.

Physical project changes to account for sea-level changes (e.g., raising outflow levels).

Preservation of ecosystems. As an adjustment to uncertainty, areas can be reserved to protect against the uncertain effects of climate change on ecosystems.

OBSERVATIONS AND CONCLUSIONS

The robustness and resiliency of existing methods for risk management in water resources, as suggested by the list of methods given above, have the potential to serve effectively as the basis for adapting to changes in the supply and demand for water resulting from climate change. A central conceptual issue is whether the consideration of climate change requires planning criteria that are in some sense different than existing criteria dealing with climate variability, or whether climate change simply represents "*one more exogenous factor to consider* in a multipurpose and multiobjective tradeoff analysis" (Stakhiv 1993, p. IV-24). One recently completed study (Frederick, Major and Stakhiv 1997) lends a degree of support to the latter view. Although very substantial surprises are possible (and we know very little about how to deal with these), the climate-related uncertainties relating to water resources are not currently expected to be qualitatively different from those stemming from changes in other factors such as population, incomes, technology, and social values that have traditionally played a central role in water planning and project evaluation. If this is true, the risk management methods encouraged by U.S. and international criteria appear to be generally appropriate for planning and project evaluation under the prospect of climate change.

There are, however, substantial research, application, and technology transfer issues to be confronted. In research, a challenging issue is that of nonstationarity. Much applied work in hydrology assumes stationarity in hydrologic processes, but one of the main lessons of global climate change is that this assumption will no longer be tenable, and the significance of this remains to be fully assessed (Matalas 1997). In applications, with climate change in effect a new exogenous variable, it will be necessary to provide guidance for planners as to: (1) those climate-related factors that should be of concern and need to be monitored; (2) the conditions under which the prospect of climate change should receive particular attention in water resource planning and project evaluation; and (3) the best ways of adapting to the uncertainties and possible impacts of climate change (Frederick, Major and Stakhiv 1997, p. 308; see several similar recommendations in IPCC 1998, p. 2). Moreover, it is essential to insure that the available methods are used for true assessment, including the evaluation of trade-offs through both planning and market techniques, rather than simply collapsed into arbitrary regulations. The failure to undertake adequately the evaluation of trade-offs has been a notable weakness of risk management in the United States and elsewhere. In technology transfer, it will be important to encourage the wide use of available methods and their adaptation to new regional circumstances as appropriate. This implies an effort at technology sharing, both among agencies and countries, and among sectors where a wide disparity in the use of risk assessment and management methods exists (IPCC 1998, pp. 2-8 and the papers in App. A and B of that report). The resources required to undertake this effort will be substantial.

In conclusion, the robustness and resiliency of existing methods for risk management in water resources have the potential to serve effectively as the basis for adapting to changes in the supply and demand for water resulting from climate change. The immediate challenge for water resources planners is therefore to insure the widespread and appropriate application of available techniques. At the same time, new research and the development of additional methods must be encouraged.

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REFERENCES

Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka: 1994, *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*, Department of Geography, University College London, and Center for Global Environmental Research, National Institute for Environmental Studies, Japan.

Eckstein, 0.: 1958, *Water-Resource Development,* Harvard University Press, Cambridge MA.

Frederick, K. D., D. C. Major, and E. Z. Stakhiv, eds.: 1997, *Climate Change and Water Resources Planning Criteria,* Kluwer Academic Publishers, Dordrecht, The Netherlands.

Hirshleifer, J., J. W. Milliman and J. C. DeHaven: 1960, *Water Supply: Economics, Technology and Policy*, University of Chicago Press, Chicago, IL.

Intergovernmental Panel on Climate Change: 1996a, *Climate Change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press.

Intergovernmental Panel on Climate Change: 1996b, *Climate Change 1995: Impacts, Adaptations, and Mitigation: Contribution of Working Group II to the Second Assessment Report*, Cambridge University Press.

Intergovernmental Panel on Climate Change: 1996c, *Climate Change 1995: Economic and Social Dimensions of Climate Change: Contribution of Working Group III to the Second Assessment Report* *of the Intergovernmental Panel on Climate Change*, Cambridge University Press.

Intergovernmental Panel on Climate Change: 1998, *Expert Meeting on Risk Management Methods: Report*, Toronto, Ontario, Canada, April 30-May 1, 1998.

IPCC, *see* Intergovernmental Panel on Climate Change.

Maass, A. *et al.*: 1962, *Design of Water-Resource Systems,* Harvard University Press, Cambridge, MA.

Marglin, S. A.: 1967, *Public Investment Criteria*, MIT Press, Cambridge, MA.

Matalas, N. C., "Stochastic Hydrology in the Context of Climate Change," in K. D. Frederick, D. C. Major, and E. Z. Stakhiv, eds.: 1997, *Climate Change and Water Resources Planning Criteria,* Kluwer Academic Publishers, Dordrecht, The Netherlands.

Stakhiv, E. Z.: 1993, "Water Resources Planning and Management Under Climate Uncertainty," in T. M. Ballentine, and E. Z. Stakhiv, eds., *Proceedings of the First National Conference on Climate Change and Water Resources Management,* U.S. Army Corps of Engineers Institute for Water Resources, Fort Belvoir, VA, IV-20-35.

Stakhiv, E. Z., forthcoming, "Risk Analysis: Assessment and Management of Environmental Pollution," in North Atlantic Treaty Organization, *Public Health Conference on Environmental Pollution: Priorities and Solutions*, Springer-Verlag, New York.

Stakhiv, E. Z. and D. C. Major, "Ecosystem Evaluation, Climate Change, and Water Resources Planning," in K. D. Frederick, D. C. Major, and E. Z. Stakhiv, eds.: 1997, *Climate Change and Water Resources Planning Criteria,* Kluwer Academic Publishers, Dordrecht, The Netherlands.

United Nations Industrial Development Organization: 1972, *Guidelines for Project Evaluation*, New York: United Nations.

United States Army Corps of Engineers: 1992, *Guidelines for Risk and Uncertainty Analysis in Water Resources Planning*, Vols. 1, 2, Institute for Water Resources Report 96-R-25, March 1992, Fort Belvoir, VA.

United States Army Corps of Engineers: 1993, *Guidebook for Risk Perception and Communication in Water Resources Planning*, Institute for Water Resources Report 93-R-13, November 1996, Fort Belvoir, VA.

United States Army Corps of Engineers: 1996a, *Risk-Based Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability and Economics in Flood Damage Reduction Studies*, Regulation No. 1105-2-101, March 1, 1996, Washington, D.C.

United States Army Corps of Engineers: 1996b, *Risk-Based Evaluation of Flood Warning and Preparedness Systems*, Vols. 1, 2, Institute for Water Resources Report 96-R-25, November 1996, Fort Belvoir, VA.

United States Army Corps of Engineers: 1997, *Introduction to Probability and Reliability Methods for Use in Geotechnical Engineering*, Technical Letter No. 1110-2-547, September 30, 1997, Washington, D.C.

United States Inter-Agency River Basin Committee, Subcommittee on Benefits and Costs, Report to the Federal Inter-Agency River Basin Committee: 1958, *Proposed Practices for Economic Analysis of River Basin Projects,* rev. ed., Washington, D.C., originally published 1950.

United States Water Resources Council: 1973, *Water and Related Land Resources: Establishment of Principles and Standards for Planning*, Federal Register 38 (174), 24,778-27,869.

United States Water Resources Council: 1983, *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*, Washington, D.C.