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Authors
Rayner, Steve
Lach, Denise
Ingram, Helen

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WEATHER FORECASTS ARE FOR WIMPS*: WHY WATER RESOURCE MANAGERS DO NOT USE CLIMATE FORECASTS

STEVE RAYNER[1], DENISE LACH[2] and HELEN INGRAM[3]

[1]*James Martin Institute of Science and Civilization, Saïd Business School, University of Oxford, Park End Street, Oxford OX1 1HP, U.K.*
E-mail: steve.rayner@sbs.ox.sc.uk
[2]*Oregon State University, Corvallis OR 97331-4501, U.S.A.*
[3]*School of Social Ecology, University of California Irvine, Irvine, CA 92697-7075, U.S.A.*

Abstract. Short-term climate forecasting offers the promise of improved hydrologic management strategies. However, water resource managers in the United States have proven reluctant to incorporate them in decision making. While managers usually cite "poor reliability" of the forecasts as the reason for this, they are seldom able to demonstrate knowledge of the actual performance of forecasts or to consistently articulate the level of reliability that they would require. Analysis of three case studies in California, the Pacific Northwest, and metro Washington DC identifies institutional reasons that appear to lie behind managers' reluctance to use the forecasts. These include traditional reliance on large built infrastructure, organizational conservatism and complexity, mismatch of temporal and spatial scales of forecasts to management needs, political disincentives to innovation, and regulatory constraints. The paper concludes that wider acceptance of the forecasts will depend on their being incorporated in existing organizational routines and industrial codes and practices, as well as changes in management incentives to innovation. Finer spatial resolution of forecasts and the regional integration of multi-agency functions would also enhance their usability.

1. Introduction

"Weather Forecasts are for wimps!" was the advertising slogan for a large American SUV during the period that this research was conducted. The implication was that the macho technology represented by this vehicle effectively eliminated any need for its occupants to worry about the elements that they might encounter. This philosophy seemed to neatly encapsulate the approach to short-term climate forecasting that we encountered among managers of a wide variety of water resource operations across the United States.

The stimulus for our study was the remarkable advance in probabilistic forecasting of seasonal and interannual variation in climate conditions associated with the El Niño Southern Oscillation (ENSO) achieved by scientists over the course of the decade beginning in the mid-1980s.[1] Techniques available in the early 1980s were inadequate to fully monitor the evolution of an ENSO event already in progress. By 1995, it was possible to observe daily changes in surface winds, sea-surface temperature, upper-ocean thermal structure, and ocean current on a basin scale in

*The title of this article is taken from an advertising slogan for the Oldsmobile "Bravura" SUV.

Climatic Change (2005) 69: 197–227

the tropical Pacific. Using models ranging in complexity from purely statistical to fully coupled dynamical ocean–atmosphere models, scientists are now able to routinely issue reasonably accurate forecasts up to 1 year ahead for some parts of the world.

Since 1995, skill in prediction of climatic variation has remained geographically limited and the pace of improvement in that skill appears to have slowed, at least for the moment. The forecasts that we refer to in this study essentially offered slightly better than a 50% probability of successfully predicting that temperature and precipitation would be at, above, or below the monthly average for multi-state regions of the United States. However, probabilistic forecasts of seasonal and interannual climate variation still hold out the promise of being able to help water resource managers improve both present operations and investment decisions designed to provide greater flexibility in the future.

Hence, the makers of these new forecast tools were convinced that water resource managers would be early and eager adopters of the emerging technology. It seemed obvious that better hydrologic management strategies would not only improve viability of local water supplies, but also help mitigate tensions in areas where there is competition for water rights. Yet, by the late 1990s it was clear that the uptake of probabilistic forecasts by all manner of water resource managers was much slower than expected, even in the context of policies that emphasize meeting demand by more efficient use of existing facilities rather than investing in new ones.

The principle that resource managers ought to value even imperfect information about weather and climate has been well established at least since Nelson and Winter's (1960) landmark study of the value of weather information. According to the most popular social science model of decision making, the *rational choice* perspective, decision makers (particularly in the private sector) are strongly motivated – by the desire to optimize performance – to readily incorporate research results and forecast information into their decision making (Sarachick and Shea, 1997). Failure to incorporate such information is characterized merely as an exogenous barrier or remediable market imperfection.

The rational choice perspective suggests that resource management choices are (or at least strive to be) based on a search for information, followed by comparison and weighting of that information, leading to selection of the best alternative. Thus, the rational choice approach suggests that ENSO forecast information would be readily incorporated in decision making (Beyer and Trice, 1982). Rational choice theory makes two key assumptions. The first is that individuals are always seeking to make the most efficient decision that they can. The second is that collective decisions can be understood in the same way as individual preferences. Although Nobel prizes were awarded to Simon (1957) for discrediting the first assumption and to Arrow (1951) for demonstrating the impossibility of the second, the rational choice model is usually assumed to be applicable at the level of organizational decision making, either by breaking down organizational processes to individual decision points, or by treating each organization as if it were a unitary individual – a person writ large (Jaeger et al., 1998).

In contrast to the rational choice approach, sociological studies conducted from an *institutionalist* perspective (e.g., Powell and DiMaggio, 1991) suggest that information in organizations and institutions of all kinds is not a well-behaved commodity that can be passed between parties like water poured from one bucket to another (Diaz and Bordenave, 1972; Rogers and Kincaid, 1981). The use of information in organizations is inextricably bound up with creating collective meaning and identity as well as servicing implicit goals of organizational maintenance that are not captured by applications of the rational choice model (Douglas, 1986).

Sociological studies of actual decision making in public and private sector organizations indicate that the rational choice model may not be the most appropriate one for understanding institutional decision making (Douglas, 1986). In particular, studies of knowledge use have long suggested that technical information is not very well used in organizational decision making (Gurvitch, 1972; Argyris, 1976; Argyris and Schon, 1978; Holzner and Fisher, 1979; Caplan, 1983; Dunn, 1983; Averch, 1987). Empirical studies show that institutional decision makers have a generally positive attitude toward the use of scientific information in decision making, but rarely act on such information directly (Starling, 1979; Weiss and Bucuvalas, 1980; Whiteman, 1985; House and Shull, 1988; Feldman and March, 1981).

Research specifically focusing on the uptake and use of climate information by water-intensive industrial sectors (e.g., agriculture, water resources, and power utilities), suggests that integrating the use of uncertain climate information into complex corporate operations is difficult for managers, even where they have generally positive assessments of the potential for the information (e.g., Changnon et al., 1988; Sonka et al., 1988).

Thus, concern about the limited accuracy of scientific forecasts is only one reason why such information is not more widely used; institutional factors also play a role. Hence, even as the accuracy of forecasts improves, a host of non-technical considerations may affect their acceptance and usefulness.

The sociological perspective suggests that identifying opportunities to introduce information into real world decision processes may be a more effective policy strategy than trying to make decision processes conform more closely to the rational choice model. A few researchers have attempted to address the influence of non-technical barriers to information. For example, Janssen (1997) has proposed a strategy for incorporating new scientific information into agricultural decisions about insect pest management. Various strategies, such as computer-aided negotiation to facilitate water resource decision making involving multiple stakeholders with incommensurable objectives, have been proposed and implemented (Sheer et al., 1989).

This article examines the question of why water resource managing institutions in the United States do or do not use probabilistic forecast information about seasonal and interannual climate variability in their planning. Our research sought to explore water resource decision-making processes in sufficient detail to enable us to identify the institutional conditions under which increased use could be made of probabilistic climate forecasting information to benefit society as a whole. We investigated how a broad range of technical and non-technical information is incorporated into, or excluded from, the deliberations of water managing institutions. We examined the ways in which information is, or is not, transferred between decision-making nodes in such institutions, and how it is transformed and adapted in the process. Our goal was to identify opportunities and constraints for the incorporation of probabilistic forecasting into these decision processes.

2. Methodology

Our goal in performing these case studies was to develop a picture of regional water resource decision making to assess opportunities for improving decisions through the incorporation of probabilistic climate forecast information. Our comparative approach, using information drawn from different regions of the United States, distinguishes our work from earlier research on the use of climate information in the water sector (e.g., Lach and Quadrel, 1995; Callaghan et al., 1999; Miles et al., 2000) that focused on a single region. The research addressed four questions:

- How and to what extent do water resource managers in federal, state, and local government agencies, non-governmental organizations (NGOs) and the private sector use probabilistic climate forecasting information?
- What institutional factors affect the framing and use of probabilistic forecasting information by decision makers?
- Would increased use of probabilistic climate forecasting information lead to decisions that have superior outcomes from an overall societal perspective (i.e., judged by broader criteria than just technical or economic efficiency)?
- What changes in institutional decision processes and the type and framing of the forecasting information would increase the usability and usefulness of the information?

We set out to characterize the range and depth of water resource decision makers' expectations of, requirements for, and constraints on the use of seasonal and interannual forecasts and then to test that characterization in different settings (Yin, 1989; Robson, 1993; Marshall and Rossman, 1995). The research consisted of semi-structured ethnographic interviews (Spradley, 1979) in three locations. These were the Columbia River system in the Pacific Northwest, the Metropolitan Water District of Southern California, and the Potomac River Basin and Chesapeake Bay in the greater Washington DC metropolitan region. Over 120 interviews were conducted among staffs of water management institutions, including regional staff of federal government agencies, regional management organizations, water supply companies, wastewater disposal companies, and emergency management organizations.

The goal in each case was to sample a transect through water management institutions from local to regional levels (Johnson, 1990). In each case, we interviewed individuals at relevant federal agencies, selected regional compacts, state agencies responsible for management in the Columbia River Basin, and local water utilities. The sample also included environmental groups, recreational groups and, in the Pacific Northwest, tribal representatives.

Sampling for these interviews was non-random, variously described as theoretical (Glaser and Strauss, 1967; Agar, 1980) or purposeful (Kuzel, 1992) sampling. With the assistance of key informants at relevant institutions[2] we identified individuals who currently use or potentially could use seasonal or interannual climate forecasting information in the course of their decision making. We used snowball sampling (asking interviewees in the original sample to identify other individuals with appropriate knowledge or experience) to identify the social networks along which information travels within and among organizations. Non-probabilistic sampling was appropriate for this task because the objective was to map information flows and learn about how people understand both the content and processes. The purpose of this sample design was not to subject formal hypothesis to statistical testing or (at this stage) to generalize to other settings. The goal was to develop an empirical description of the information networks that make up the institutional decision-making processes.

We used the interview data to characterize decision processes in terms of institutional goal setting and information flows in each of the institutions, as well as the overall societal decision framework that results from their combination and interaction. This information was used to construct the decision context in which climate forecasting information was used or not used where respondents believe that it could have been used effectively.

The results of our research were presented to a focus panel of water resource managers at the Annual Meeting of the Water Resources Planning and Management Division of the American Society of Civil Engineers in 1999. Panel members, drawn from a cross-section of the industry in several regions of the United States indicated that the findings would find widespread acceptance among the water resource management community in the United States.

3. Water Management: Complexity and Conservatism

Water management and planning agencies often base decisions regarding future water use on climatological records (i.e., they assume that the future will resemble the past). However, records alone are very imperfect predictors of anomalous or extreme weather events and so provide an inadequate basis for policy decisions. For example, the framers of the Colorado River Compact based their allocation of withdrawal rights between the United States and Mexico on years of unusually high precipitation, resulting in over allocation with serious implications for downstream water supplies (Frederick and Kneese, 1990). Seasonal to interannual climate forecasts have the potential to improve historically based water management decisions. In other instances (for example, the Washington DC metropolitan area) various short-term probabilistic forecasts are already used routinely in real time operations. In principle, these forecasts could be improved by the incorporation of probabilistic information on seasonal to interannual variation. To identify opportunities for increasing the use of this probabilistic information about climate variation, we set out to develop a broad understanding of how water management decisions are currently made.

US water management systems are highly diverse. They range from small community water supplies with limited control facilities, for example, San Juan Capistrano, California; to widespread, multi-purpose systems such as the greater metropolitan areas of Washington DC and Los Angeles. These systems present several challenges to their managers. They may:

- consist of both surface and groundwater supplies;
- contain a variety of infrastructure components such as dams, wells, levees, etc.;
- cross political and hydrologic boundaries;
- have multiple purposes including water supply, hydropower generation, recreation, flood control, fisheries, wildlife enhancement; and
- have multiple stakeholders with different views of the resource and incommensurable criteria for judging the quality of management decisions.

The three regional water systems that we chose to examine exhibit this diversity to the full. In addition to demonstrating the wide range of institutional and infrastructural variety of the US water resources sector, two of the regions, Southern California and the Pacific Northwest experience a relatively strong El Niño signal and forecast skill is correspondingly higher than in the Washington DC area. We considered that this contrast might also lead to differences in managers' behavior. Another reason for including the Washington DC case is that the Potomac and Chesapeake Bay management regimes already have significant experience of integrating computer modeling and forecasting techniques for decision making.

4. The Metropolitan Water District

The Metropolitan Water District (MWD), the most powerful water agency in Southern California, is an administrative regime composed of many member agencies engaged in municipal water supply across the region. This is a classic case of a crowded organizational field with pyramiding and overlaying of organizations, and multiple, highly differentiated water sources. Local water supplies are inadequate to meet the water demands of 16 million Southern Californian residents, so about 55% of the water is imported from either the Colorado River or the State Water Project (SWP). According to the Law of the River, California is allocated a minimum of 4.4 million acre feet (maf) [5.43 billion m^3] of Colorado River Water per year. Agriculture has first priority and receives 3.85 maf [4.75 billion m^3]. The remainder of the water, 550,000 acre ft [678.5 million m^3], is designated urban use and goes to Metropolitan Water District of Southern California (MWD) *via* the Colorado River Aqueduct (CRA). However, California has been using about 5.2 maf [6.4 billion m^3] per year, with about 1.2 maf [1.5 billion m^3] going to MWD. In recent years, the federal government under both the Clinton and Bush administrations has pressed the state to implement planned cutbacks in its use of Colorado water over a 15-year period.

Much of the MWD's water is supplied to municipal utilities, such as the city of San Juan Capistrano, through intermediaries such as the Municipal Water District of Orange County (MWDOC), which became a member of the MWD in 1951. MWDOC buys all of its water from MWD. Without physically touching a drop of the water, it sells the water on to its member agencies, including the Orange County Water District and the Irvine Ranch Water District, to supplement local water supplies.

The water supply districts continue to look for technological improvements that will let them supply their customers' increasing needs. Improvements identified by respondents, however, seemed incremental in scale and unlikely to provide adequate amounts of safe, reliable, and low-cost water in the face of continued growth. Southern California agencies define water resource management almost entirely in terms of supply and allocation problems. At all levels, they remain focused on the explicit missions of their own organizations, and their efforts at coordination are directed towards discharging their individual agency responsibilities.

5. The Potomac River–Chesapeake Bay

The Potomac River is the major source of water supply to the metropolitan Washington region. Withdrawals from the river are made by multiple agencies including the Washington Aqueduct Division of the US Corps of Engineers (The Aqueduct); the Washington Suburban Sanitary Commission (WSSC), serving suburban Maryland; and the Fairfax County Water Authority (FCWA) of northern Virginia. Although WSSC deals with its own wastewater, the District of Columbia, not the Corps of Engineers, manages its sewage.

The river must be managed for multiple and conflicting purposes as it travels more than 400 miles through four states and the District of Columbia. In recognition of this, the Interstate Commission on the Potomac River Basin (ICPRB) was created in 1940 as one of the initial federal interagency river commissions. The ICPRB is a non-regulatory interstate commission established to cooperatively address water quality and related land resources issues in the Potomac basin as a whole. Its goal is the enhancement, protection, and conservation of the Potomac River and its tributaries through regional and interstate cooperation.

The tasks of the ICPRB are at least one remove from actions that will lead to cleaner and more reliable, low-cost water. Its job is to be a visible source of coordination and information regarding the basin. The ICPRB has proven to be a durable institutional mechanism to manage a complex system with a history and infrastructure devoted to problems that no longer exist in isolation (e.g., water supply and control).

Because the Potomac River runs into the southern reaches of the Chesapeake Bay, the ICPRB has also been instrumental in the Chesapeake Bay Program (CBP), which has evolved over the years as the primary means for coordinating approaches to restoration of the bay. In the mid-1970s, it was widely recognized that human impacts from settlement, recreation, and unsustainable agricultural and fishing practices were severely reducing the productivity of the bay and threatening its health. The CBP came into being through the historic Chesapeake Bay Agreement, which was signed in 1983 by the states of Maryland, Pennsylvania, and Virginia, the Chesapeake Bay Commission (a tri-state legislative agency), the District of Columbia, and the US EPA.

The CBP, rapidly grew into an extensive network of federal, state, and local bureaucracies. In addition to the politicians on the Board of Directors, the CBP provides numerous opportunities for other types of participation and input. Steering committees are the primary way the CPB organizes disparate participation, with separate advisory committees for citizen, local government, and scientific and technical input.

6. The Pacific Northwest

Throughout the 20th century, growth in demand for electric power, irrigated farmland, and flood control in the west were met by increasingly large infrastructures on the rivers of the Pacific Northwest. With the last of 18 federal main stem dams on the Columbia-Snake system going in at John Day in 1968, the Columbia river was tamed by more than 250 reservoirs, about 150 dams (ACOE, 2000), and bureaucratic institutions – the best known being the Bonneville Power Administration (BPA) created in 1937. The BPA markets electric power and energy from federal hydroelectric projects to public and private industries as well as some industries.

Until the 1970s, power and other services provided by the system were viewed as beneficial and critical to the region's growth (Lee, 1993). By then, however, the benefits of the system were increasingly questioned as the environmental and social costs of construction, loans due on unneeded facilities, and increasing evidence of environmental degradation were raising questions throughout the country, most particularly in the Pacific Northwest. In response to increasingly visible critiques by environmentalists and Native American Tribes that salmon and riparian habitat were not considered in system planning, the Northwest Power Act of 1980 was implemented. As part of this complex legislation, the Northwest Power Planning Council (NPPC) was created to implement an electric power plan for the Northwest and a fish and wildlife program for the Columbia River Basin. Thus the challenge to the NPPC is to reconcile economical and reliable power supply with the spawning needs of the region's iconic salmon that have been adversely affected by the construction and operation of hydroelectric dams.

A unique feature of the NPPC is its authority to guide the actions of federal agencies. The BPA, for example, is required to ensure that its own actions are consistent with the NPPC plans and initiatives. Other federal agencies are required to consider the Council's programs "at each and every relevant state of decision making processes to the fullest degree possible" (Northwest Power Act, 1980). This is one of only a few instances in which the federal government has given states significant power over federal agencies.

The challenge of balancing the needs of multiple stakeholders and enhancing the fishery resource while minimizing impact on power production is being played out within the framework of the 1980 Northwest Power Planning Act, court rulings regarding Indian fishing rights, and listing of various salmonid species under the Endangered Species Act. To meet these challenges, the NPPC spent an estimated \$3.5 billion in the two decades from 1980, trying to find ways to restore salmon to the Columbia River (Hansen, 2001). This money has mostly been spent on research, pilot projects, and public involvement activities. NPPC has juggled the conflict between power and fish for the last 20 years, so that low-cost and reliable water services continue to support growth and development in the region.

7. Sources of Complexity

As these brief sketches indicate, water resource management in the United States is a complicated business. The natural hydrology is complex. The built systems of supply, use, and recovery are equally complicated. The institutional system is highly fragmented. The result of these multiple complexities added to the multi-layered value system is difficult to comprehend and describe. Combined, these complexities present a daunting challenge to the use of probabilistic climate forecast information.

7.1. NATURAL SYSTEM COMPLEXITY

Water resources depend on highly complex natural systems that are far from fully understood. Surface hydrology involves nonlinear, highly variable, site-specific interactions of precipitation, landform, and runoff. Groundwater systems are similarly intricate. The interaction between surface and groundwater is physically, biologically and chemically complex. Extreme events – floods and droughts – have important consequences for the health of humans, terrestrial and aquatic wildlife. Furthermore, they are by nature infrequent. Hence, their occurrence and affects are difficult to predict.

The natural physical and hydrologic conditions in the three case studies are varied. The southern California and Pacific Northwest areas are geographically much larger than the Washington DC area. The western cases contain mountain ranges that bifurcate distinctly different climatic regions with dryer, hotter areas to the east of the mountains. Southern California is much dryer than either the PNW or Washington DC, with the worst drought on record lasting 6 years compared with only 1 year for the Potomac. Along with the stronger El Niño signal, these hydrological patterns might suggest that skillful climate forecasts would be viewed as more critical to water management in California. The total per capita volume of precipitation or natural streamflow entering southern California is far less than for PNW or the Washington DC area. Our three study areas were physically distinct in these and many other ways.

7.2. BUILT SYSTEM COMPLEXITY

The built environment also is complex and highly varied in our three study areas. For example, in the California water system huge quantities of water are moved from two remote areas over long distances to southern California. The State Water Project and the Central Valley Project transfer water from north to south. Other water is imported from the Colorado River and distributed through the Metropolitan Water District. Water also comes across the mountains to Los Angeles from the Owens Valley. Groundwater and recharge water provide other sources. This water system is very different from the one encountered in the greater Washington DC metropolitan area, where the physical system is much less extensive, and relies on local sources of supply. The built system of the Pacific Northwest, involving many more physical structures than in Washington DC, is made particularly complex by the importance of hydropower.

7.3. INSTITUTIONAL COMPLEXITY

The complexity of these physical characteristics is exacerbated by their institutional fragmentation and specialization. Water has been compartmentalized into multiple agencies each with its own specialist focus and accountable to different constituencies. The mandate of each of these agencies contains only a subset of the full range of relevant water objectives and uses. To do its job, each agency must deal with a multitude of other actors. This leads to a very dense network of interactions among agencies. Making progress toward one agency's mission often involves negative impacts on other agencies.

In each system, we encountered different institutional actors performing different functions, but all exhibited conflicts. For example, many existing water agencies focus on only a portion of the entire water resource system on which they must rely. A water supply company may be principally concerned with acquiring rights to a source of clean water, such as a river, but not be concerned with the resulting effects on downstream biota due to the withdrawal of that water. Departments of fish and wildlife are concerned about maintaining and enhancing natural habitat but not about hydroelectric energy production that may suffer from a resulting loss of control of the water system. Power companies are concerned about how hydroelectric power can best be incorporated in the energy system for a region of the country but less concerned than other agencies about the biological or recreational impacts of timing water releases through turbines at a dam to meet peak energy demands.

In some cases, agencies have been forced to adopt new roles, not originally envisaged in their mandates. For example, recreation is the fastest growing use of water in the Unied States, but rarely was it incorporated as part of the original purpose of dams constructed by the federal government. In the greater Washington DC metropolitan region, the US Corps of Engineers manages Jennings Randolph Dam on the Potomac. The original purposes of the dam were to ensure water quality, water supply, and flood control. However, the Corps owns and manages a picnic area, a campground, an overlook and a boat ramp, in addition to operating the dam and reservoir. While fulfilling the original purposes of the dam, the Corps supports, when possible, recreational use of the Potomac downstream of the dam. This presents an interesting case study of conflict and accommodation even within recreation because white water enthusiasts prefer high flows while fishermen prefer more moderate flows that allow them to wade into the river. (This is referred to locally as row v. wade.) When feasible, the Corps will make releases that accommodate fishermen during part of the day and the kayakers during the other part.

8. Sources of Conservatism

Not only are water resource management systems complex, their operating institutions tend to be extremely conservative in their approach to risk and decision making. This conservatism appears to derive from three sources: the evolution of their function of routinization of the irregular; their dependency on craft skills and local knowledge; and their hierarchy of values designed to ensure political invisibility.

8.1. THE ROUTINIZATION OF THE IRREGULAR

Water resource management systems in the United States, whatever their functions, have evolved precisely to attenuate the impacts of weather and other factors in shaping the irregularity of water availability and water quality. Whether focused on drinking water supply, flood control, navigation, or ecosystem health, the goal is to smooth out fluctuations. For drinking water, irrigation, and electrical generation the principal means by which this has been achieved is through redundancy in capacity. Thus, routinization of the irregular is an important characteristic of water agencies.

Irregular or infrequent events then become part of the routine decision making of the water agency. In the Potomac watershed, which supplies Washington DC, each agency considers the worst drought on the historical record in planning, designing, and operating its system. In addition, the Interstate Commission on the Potomac River Basin was formed as a super agency to guide overall response to drought in the watershed, even though, at the time of our research, the conditions under which the emergency provisions of the Potomac Low Flow Agreement would come into force had only occurred once since its inception in 1982.

Water agencies generally operate with very long time horizons. Historically, large-scale infrastructure, such as dams, levees, canals, dredging, etc., has been the principal tool of water agencies. Planning major structures often requires decades of preparatory reconnaissance and feasibility studies. This is partially necessary because of the enormous complexity of the natural water system. To understand the effects of perturbations to the natural system introduced by human made structures, it is first necessary to understand the natural system. This is a daunting task as already described. Once planned, facilities may take even more time to construct. Any physical changes to the system potentially have effects that last a long time, with costs and benefits assumed to accrue for up to 50 or even 100 years, during which time the facilities must be operated and maintained. Infrastructure may also be incredibly expensive, measured in both money and disruption of the physical and biological systems. Planning must ensure that the investment will yield benefits on a comparable scale.

The time horizon for some water agencies is changing. The focus of these agencies is moving from structural to non-structural means of serving reliability, quality, and cost (e.g., improving operating efficiency, demand side management). One expert we interviewed reported that this is a result of many factors, including reduction in available dam sites and a dramatic improvement in the ability to develop and test better operating and management strategies for complex water systems. A consequence of this change is that agencies such as the US Corps of Engineers or the Bureau of Reclamation may need to change radically the tools they use to achieve their mission. The skill sets of agencies may no longer match the tools they are attempting to use. The process to vet new methods and tools for use in these agencies involves a period of extensive analysis and testing. Further, new kinds of people may need to be recruited. Personnel turnover in agencies is slow. All of these factors may lead to slow, incremental innovation and delayed adoption of new ideas and tools including climate forecasts.

8.2. CRAFT SKILLS AND LOCAL KNOWLEDGE

US water systems are perceived by their managers to be highly sensitive to specific local conditions. It is not unusual for new personnel to be expected to take 3–10 years to become familiar with the peculiarities of a system. Craft skill, or the problem-solving ability born of experience with a particular problem in a particular locale, seems to be needed and valued by water agencies. A direct result of this belief is that new employees are mentored in the ways of the agency for a period of time until they are imbued with the outlook of the agency. This tends to ensure long-term stability in the decision process, a focus on the long-term mission of the agency, and potentially a lack of innovation.

The need for craft skills was voiced throughout the three study areas. One official at a water supply utility in northern Virginia told us that it took several years for employees to become fully versed in the system. On a completely different level, in the Department of Water Resources in California, an official told us long, intense interaction with the models was the only way to comprehend them well.

8.3. VALUES: RELIABILITY + QUALITY + LOW COST = INVISIBILITY

US society expects water systems to be fail-safe. Water is often considered too important for politics as usual and its management is separated from ordinary political and governmental structures. Water agencies are set apart, highly professionalized, and given long-term missions that are independent of other priorities. While variations in maintenance of roads and buildings can be tolerated, that is not the case with water. Uniform excellence in the delivery of water is widely demanded.

These performance expectations give rise to a particular configuration of values. Water managers at all levels and all organizations we interviewed consistently described a common hierarchy of values for managing water resources: high reliability, high quality, and low cost.

Reliability for these managers means meeting several, often conflicting, demands:

- there must always be water when the customer opens the faucet;
- on the most critical days of the growing season there is water for the crops;
- at the lowest streamflow, there is enough water for the fish;
- when the demand for electricity is at a peak, there is water to generate needed hydroelectric power; and
- in the worst flood, there will be no substantial loss of life or property.

At one California water supply agency, officials said that their agency had a mission statement that included: customer satisfaction, reliability, good service, cost effectiveness, and employee satisfaction. When pressed to explain the source of customer satisfaction, reliability was identified as critical. One official of a water supply agency in the greater Washington DC metropolitan region told us that 100% reliability was expected. This necessity for reliable water supplies holds true even in the desert, where one California official told us his job was to make certain that limitations on water supply never become impediments to further suburban development. We heard virtually the same thing at other water utilities in all three study areas.

Agencies dealing with other functions or uses of water emphasized that reliability was their top concern although they seemed to have greater degrees of freedom with regard to performance. For example, fish populations are allowed to vary or decline so long as they are not endangered species. Supplies for agriculture can vary but only within limits; lack of availability during critical periods may mean loss of an entire crop.

The quality of water was a close second in importance behind reliability. Again, municipal water utility managers seemed the most constrained because they deliver water that must be safe for drinking. Quality means other things to other water agencies. For example, agricultural water suppliers must deliver water that is not too saline for crops. Fish and wildlife managers must be certain the water is the right temperature for fish. Groundwater is an important source of supply in many areas. One water manager in California stated: "protecting the quality of the aquifer" was among his highest concerns.

Cost trailed a long way behind reliability and quality among values. The latter two values are essential and are treated by industry as absolutely binding constraints. Cost is third in the hierarchy; to be minimized within the constraints of reliability and quality of supply. The water supply industry has historically tried to supply low-cost water to users because no one can do without it. It is a fundamental tenet of politicians and industry managers alike that equity demands that no one should be priced out of the market. Moreover, the large structural projects erected by the federal government throughout the 20th century have spread costs over a variety of purposes, many constituencies, and long periods of time. Consequently, water rates for actual users in many places are therefore lower than the cost of service. While costs are rising, they still remain very low compared to other essential or common necessities such as housing, lighting, heating and cooling, transportation, and telecommunication.

The cost of water cannot rise precipitously or unexpectedly without violating deeply embedded public expectations. Any increase must be justified in terms of reliability and quality improvements. Historically, because water is essential to human survival, its availability has been strongly influenced by considerations of equity so that at least the most basic supplies should be inexpensive and not subject to sudden, unexpected, or large increases. Sharp rate increases and/or perceived high rates are likely to make customers hypercritical. In one southwestern city, sharp increases resulted in the recall of the entire city council (Martin, 1984). One utility in our study has increased its rates to the point where it was among the 10 highest priced suppliers in the United States. An official of this utility stated that its performance was barely acceptable. Should there be "a screw-up in supply, then all hell will break loose."

Any adverse change in reliability, quality, or cost is likely to attract unwelcome attention from consumers and politicians. Declines in reliability will attract more complaints than quality, and declines in quality will attract more attention than cost increases. Because suppliers deliver a highly reliable product, customers are reminded only infrequently that the resource is in any way limited. The quality of the product is usually high; so again it is infrequent that there is any concern. Finally, the agencies can truthfully state they are concerned about cost and are constantly seeking minimum cost solutions; thus allaying any concerns from the public. The result of this successful performance is that water agencies maintain a low exposure to the public. In fact, they are practically invisible.

One of the questions that we asked in all of our interviews in all three regions was how they knew they were doing a good job. We heard variations on the following theme: "We know we are doing a good job when the customers aren't storming the building" or "the governor's not calling my boss." Success means not being noticed, and utility managers want to stay well below the radar screens of the press and environmental groups. This means that water agencies are not subject to the same kind of regular scrutiny that are given to the public schools, for example. One cost of this invisibility is that a well-run utility seldom receives public or political recognition. This may reinforce the perception that any public attention is likely to mean trouble. While one water utility legally could have disposed of solids accumulated during water treatment back into the river that was the source of the water, it routinely chose to wait until flows in the river were sufficiently high to avoid notice. Managers feared that the introduction of solids into the river from the plant would arouse negative comment or criticism.

A consequence of water agencies goal of remaining invisible is the lack of attention that these agencies may receive in the budgetary process. If an agency is perceived as doing a good job, it is difficult to martial the political resources to obtain new funds. If you are already doing a good job, why does anyone need to provide more money?

9. Conservatism and Institutional Risk Management Behavior

We have described how the decision making of water resource managers is driven by their desire to remain invisible. They gauge their success by the absence of political or public attention. The effort to avoid visibility leads to a strong focus on maintaining reliability and quality through redundancy, even if this means loss of economic efficiency.

This hierarchy of values among water resource managers, their long-rolling planning horizons and their need for local knowledge result in a highly conservative decision-making environment.

Recently some agencies, such as the Corps of Engineers have been changing focus from large infrastructure development to more efficient use of existing resources. As one interviewee put it, “The Corps mentality has changed. The move is away from a construction project development model to looking at non-structural alternatives.” In principle, this shift would seem to offer opportunities for probabilistic forecasting of seasonal to interannual climate variability. However, we found that the water supply agencies were reluctant to move into aggressive demand side management because it would make them more visible.

Mistakes are quite costly to agencies, not just due to the close association between core public values and reliability and quality of water supplies, but also because mistakes draw adverse public attention to entities that prefer to keep a low profile. Implicitly, interviewees consistently described a simple payoff matrix (Table I), indicating that they perceived very strong incentives to avoid any risk associated with innovation.

TABLE I
Implicit outcome matrix showing perceived potential consequences of technical innovation

	Established procedures	Innovative methods
Desirable outcome	Low visibility “business as usual”	Low visibility “why bother?”
Undesirable outcome	Modest visibility “soon forgotten”	High visibility “heads will roll”

At the same time, when asked to identify examples of innovation, most of the agency officials reported they could readily identify agency changes they thought were important, and many proudly told us that they thought of their organizations as being “on the cutting edge.” However, the examples offered were almost invariably incremental technical adaptations, such as seeking new sources of supply, rather than radical technical or social innovations, such as aggressive demand side management. Several agencies cited subsidies for low-flush toilets as examples of innovation. Most innovative is the emerging use of reclaimed water that is not treated to potable standards as a new source of supply in arid areas where we were told that, “We are always looking for ways to use reclaimed water, for instance, in flushing toilets.” However, inducing behavioral change or exploring more radical alternatives to flushing toilets (or the more general use of water as a medium for human waste transportation and treatment) were never mentioned.

Hence, we characterize the US water resource management field as one of highly visible physical infrastructure managed by organizations seeking to remain invisible. We conclude that the prospects for the application of seasonal climate forecasts in US water resource management depend on the challenges of integrating forecast information into a decision system constrained by both complexity and conservatism.

10. Why Water Managers Do Not Use Climate Forecasts

In this section, we review what water resources managers told us about why they do not use forecasts and how they might use forecasts in the future. The following results were presented to water resource managers themselves as well as in our interim progress report to NOAA and various presentations to research institutions and scholarly meetings.

10.1. AWARENESS AND ACCESSIBILITY OF FORECASTS

Almost without exception, the higher up our respondent is in the organizational hierarchy, the less likely he or she is able to identify the current or potential use of probabilistic climate forecasts. These managers are unaware of what type of forecasts are available, and when asked about the use of probabilistic climate forecasts, typically describe how important short-term weather forecasts are for the decisions for which they are responsible. In most systems, short-term forecasts – 15 min to several hours – are adequate for the preparations needed to secure systems. For example, water utilities' reservoir managers and wastewater treatment facility operators in all three regions consider these forecasts already provide adequate lead time to turn pumps on or off, call in additional staff, or release water from reservoirs.

In a few instances, interviewees who held technical or analytical positions in their organizations reported making some limited use of probabilistic climate forecasts. These were usually younger or newer hires as who used the forecasts to "condition" historical records that they used for modeling and decision making. For example, in an El Niño year, they may select data from historic El Niño years to calculate expected monthly streamflows.

While most respondents had no examples of the direct use of forecasts, we did hear from a few about site-specific applications of information derived from forecasts. We talked with one group of enthusiastic modelers at an urban water district, for example, who were eager to incorporate the forecasts in their sophisticated models. It turns out, however, that these models were perceived by managers not to be credible sources of information; the managers sought information from either monitoring groups who could provide observational data about current conditions in the system or disregarded the models altogether in the decision-making process.

In another example, an emergency response leader interpreted available probabilistic climate forecast information to fit the local situation. He disseminated this summary along with key maps taken directly from the NOAA website to a broad group of emergency management specialists daily. Most of the recipients did not know they were using forecasts. However, all of the respondents who knew that they were using forecast information emphasized that they did not rely on the forecasts for finalizing or even justifying the decisions they made.

Several water management organizations were actually paying private weather forecasting organizations to reinterpret National Weather Service information to fit their own particular needs. In one case, the information was provided as "real time" input to a weekly management meeting, although the inputs to the customized forecast were already several days old.

There was more awareness of probabilistic climate forecasts in California than in the other two regions. According to our interviewees, this was due to NOAA's pilot program to disseminate information prior to the forecasted El Niño season of 1997. Some of the participants in the program acted as interpreters and mediators of the NOAA information for their own constituents. One emergency preparedness manager with whom we spoke developed a list serve for his colleagues on which he posted updates about El Niño and the forecasts in language they could understand. He anticipated re-activating this system during the next El Niño event.

This level of awareness is not matched in the Pacific Northwest or the Potomac Basin, which were not targeted in the same way during the 1997 event. There we heard that information about probabilistic forecasts "went over like a lead balloon." Another respondent reported that information from the forecasts may be useful, but the forecasts as posted on the NOAA website are incoherent. The high saliency of forecast information in California may have been reinforced by several factors including the perception that the El Niño forecasts are reliable, the vulnerability of southern California infrastructure to extreme weather events, and the high level of support given to emergency preparedness by US Senator Boxer and then-Governor Wilson.

10.2. THE DURABLE MYTH OF OPTIMIZATION

Even though most of our respondents were unfamiliar with the probabilistic forecasts prepared by NOAA, after an explanation they perceived the forecasts as potentially useful – for other people.

Water suppliers reported that the fixed infrastructure and restrictive regulations they operated under made any beneficial use of the forecasts difficult to imagine. But, they told us to be sure to talk with the hydroelectric generators who could surely use the forecasts to make long-term decisions about generating, buying, and selling power. Generators told us how the legal, contractual, and regulatory constraints in their sector limited the use of long-term forecasts but they imagined that emergency managers, for example, could really benefit. Emergency managers reported that existing 3–5-day forecasts were adequate to prepare for storm events and if they were going to spend money (that they did not have), they would first update their equipment. But, they were sure that irrigators could benefit from these forecasts. And, as it turns out, irrigators had the least perceived constraints on use of the forecasts, but have already incorporated seasonal forecasts in their planning and would want a lengthy record (5 or more years) showing that the probabilistic forecasts are more reliable than the forecasts they currently use.

When interviewees were asked about their potential use of probabilistic forecasts, they consistently described three kinds of constraints that limited usefulness of the forecasts: institutional, legal, and infrastructural.

First, they identified sector-wide institutional constraints such as overlapping jurisdictions of agencies responsible for managing and regulating different water uses (municipal supply, flood control, power generation, recreation, fish and wildlife, irrigation, etc.), and increasing demand for public oversight of decisions.

Legal constraints include allocation and adjudication of water rights, especially in the MWD where scarcity of supply and the legal doctrine of prior appropriation both apply. Even in the two other regions, both commercial supply contracts and state and federal regulations also constrain the degrees of freedom that a water resource manager is able to exercise.

Infrastructural constraints include both the characteristics of built systems such as existing reservoirs and pipelines that may not be compatible with a more flexible water management strategy. However, building new or improving current water systems is highly capital intensive and it is necessary to borrow funds for large building projects, so there is political and social pressure to refrain from large infrastructure construction projects.

In several cases, managers of water supply systems said that they could do far more to increase the efficiency and reliability of their systems by replacing leaky pipes than they would achieve through increased operational efficiency from forecast use. However, there is no established methodology that enables them to measure and compare the reliability improvements from these different options. Unless this can be answered to the satisfaction of water managers, they will go with the improvements that they are most familiar with and are already part of their operational repertoire, such as pipe replacement.

In some cases, it seemed that probabilistic forecasts were seen as creating problems for the information infrastructure of agencies. The manager of one streamflow-modeling group told us that if probabilistic forecasting was to be added to existing suites of models, "the entire system would have to be overhauled. No one believes there are enough resources to do this right." When money is available for new projects, there are many maintenance or construction projects that take precedence over the re-construction of models that most perceive to be working adequately.

Interestingly, most of our interviewees spoke as if they regarded their particular sector as uniquely constrained and that other sectors were easily capable of incorporating new information that would optimize efficiency. Even as each respondent was able to describe in considerable detail the constraints they would face in implementing the forecasts, they were equally unable to imagine constraints others might face and believed that the forecasts could be optimally beneficial in some other sectors or by other users. In almost every case, managers helpfully suggested that although they would not have much use for forecasts, managers in other water resource sectors would likely find them extremely valuable.

These responses illustrate the difficulty that people have imagining a future that is anything more than incrementally different from the present. So, when asked to consider how a new product or process, such as the probabilistic forecasts, could be used in the future, many people can only see how much work it would be to make the new product fit into the old system; and, if integration is possible, how expensive it would be to merely improve, speed up, or make less expensive what we are already doing.

In addition to finding it difficult to move beyond improving current uses of the forecasts, respondents were unlikely to be able to predict changes in technology, markets, or other components of their situations in ways that allow them to estimate the future value of the forecasts. Given the current skill level of the forecasts, most of our respondents believe that there is not enough imaginable improvement to rationalize investment in re-tooling their models, decision processes, and plans.

A common assumption is to believe that more information will lead to better decisions. So, when asked to consider how a new product, such as the probabilistic forecasts could be used, all of our respondents were willing to consider that additional improved information could help them do their job better. None of the respondents, for example, told us that they would never find information from forecasts useful. Instead, they based "usefulness" of new information first on the structural constraints and costs they operated under and second on the skill level of the forecasts. From the managers' point of view, this is perfectly rational behavior. The lesson for forecast producers, however, is that improvements in the forecast quality will not be sufficient to achieve widespread application in the water sector without accompanying institutional reforms. Hypothetically, managers would say, if these constraints were removed and the skill level of the forecast was improved, they could see that the forecasts might be useful. Although, as described above, they could not exactly name what the usefulness might be.

10.3. THE PERCEIVED RELIABILITY OF FORECASTS

The most frequently offered reason for not using probabilistic climate forecasts was that they are unreliable: confirming the observation of Changnon and Kunkel (1999), who also found that water resource managers regard climate forecasts as "too uncertain for most operational applications" (p. 286). However, our experience also reinforced the finding of Callaghan et al. (1999) that water managers have no idea what the current skill level such forecasts is.

Only one of our respondents had any direct information about the current skill level of the forecasts; as part of his job he had evaluated the performance of the forecasts. Another told us he spoke to a meteorologist at the National Weather Service who had indicated that the forecasts were "not very reliable." Without exception, all of our respondents “needed the reliability of the forecasts to be higher than it is now” if they were going to use them.

When asked what “successful predictions” would look like, our interviewees understood that they would never have 100% reliability. Several demanded at least 90% confidence; but, on further questioning, could provide little basis for choosing specific levels of reliability or even understanding what a 90% level of reliability means. The water resource managers we interviewed also associated climate forecasts with weather forecasts, which they talk about as unreliable. There is widespread folk humor around the topic. One respondent told us, “I’ve never seen a weather forecast that is worthwhile; they’ve been wrong so long and, amazingly, they’re always finding new ways to be wrong.” Another told us, “Forecasts are no better than tossing a coin. Kids in Bakersfield are just as good as the National Weather Service.”

Regardless of the skill level of kids in Bakersfield or other medium-sized towns, the water resource managers we interviewed associated climate forecasts with weather forecasts, which they talk about as unreliable. Interestingly, however, most respondents also report extensive and widespread use of short-term weather forecasts (less than 3 days) and describe those forecasts as highly reliable and crucial to their decision processes and models. One California emergency preparedness manager we talked with, for example, doubted whether the forecasts he received from his consultant were any more accurate than the NOAA forecasts (on which they were actually based). However, his contractor delivered forecasts every Friday at 4:00 p.m., so that his agency might plan for weekend staffing. These conveniences, as much as site specificity of the custom forecasts, made the expenditure on private forecasts seem worthwhile at this agency.

When interviewees did distinguish between weather and short-term climate forecasts, they stressed the necessity for forecasts that are reliable at multiple spatial and temporal scales. When pushed, however, “reliability” was a difficult concept for most water resource managers to talk about, especially in the absence of a specific application. For respondents who agreed in principle that more climate information would be beneficial to decision making, the combination of existing structural constraints that limit the utility of the forecasts and the perception that current forecasts are unreliable provides a reasonable defense for not using the forecasts.

While most decision makers told us that they would require a very high forecasting skill level before they would be willing to make use of probabilistic climate forecasts, this demand was readily attenuated in the face of public attention towards and concern about possible extreme weather events. For example, emergency managers who stated that they would need demonstrated accuracy before implementing emergency measures (such as sandbagging buildings and plugging holes in manhole covers to prevent storm water infiltration) also told us that they had executed those very measures in response to public concern during the 1997 El Niño event. This fieldwork result is consistent with the findings of Sonka et al.

(1988) in an experimental setting, where managers in the agricultural sector indicated that they would only respond to forecasts of severely adverse conditions, which they would then take into account in decision making even at only 50% accuracy.

A few respondents suggested that if the forecasts were more reliable, they may be able to take more "risks" with a system that is over-designed to provide safety and enough quality water at the right price. For example, they believe it might be possible, with reliable forecasts, to raise or lower, as appropriate, reservoir or aquifer levels to meet other demands such as power production, species habitat, and recreation resources. One respondent told us that water resource mangers are "most conservative when dealing with the quality of water." If water quality can be guaranteed, these respondents suggest that their organizations may be willing to use data and science (e.g., the NOAA forecasts) in planning for intermediate and long-term water storage.

Reservoirs behind flood-control structures, for example, need to be drawn down seasonally to provide sufficient storage capacity during high-flow events. In California, the design for enlarging Prado Dam on the Santa Ana River was challenged by the Orange County Water District as being too conservative. The OCWD argued that a new upstream flood-control structure, along with reliable forecasts, reduced the risk of flooding enough that the conservation pool could be larger. This meant that more water would be available for use and less wasted to the sea.

The more reliable the forecasts, these respondents argue, the more flexible their agencies will be in creating strategies for meeting the multiple, but often mutually exclusive values, identified by regulatory and legal requirements, and the public.

Most often, however, respondents described future uses of the forecasts that reflected how they would do their job – as currently defined – better (i.e., faster, more cost effective, and more responsive to public). This is a possible answer to the earlier question for successfully invisible water resource managers, "If you are already doing a good job, why does anyone need to give you more money?" Many suggested that with early warning from forecasts, they might be able to justify early mobilization of resources to prepare for weather events. A municipal emergency response planner told us, for example, that they were able to justify buying an automatic sandbagger using NOAA climate forecasts. Money for this purchase only became available to the emergency department when that forecast became publicized. While this sandbagging machine was provided as a significant example of how the forecasts were utilized to the benefit of the organization, the machine has not been used since.

Respondents were pretty clear, however, that a good forecast by itself is unlikely to generate money for new projects. The forecast would provide supporting information for projects already identified as priorities for the organization.

10.4. TEMPORAL AND SPATIAL SCALES OF FORECASTS

The water systems we examined are over-built and designed for quick response during emergency situations. When asked about the usefulness of the short-term climate forecasts, most managers reported they were more interested in improving the spatial resolution of weather forecasts on the time scales that are currently provided (1–14 days). Water resource managers are easily able to identify significant increases in safety, distribution, or profit if these weather forecasts could be improved.

Hourly, and 2–3-day forecasts were most often identified as useful because they allowed systems operators to prepare for storms, mechanical outages, and minor maintenance and construction outages. While one respondent said that a 30-day forecast could help schedule contractors on maintenance or construction projects, he also allowed that timing is not as critical as it sounds because the design of the system allows for many outages to be completed within 24 hours which means that they can be scheduled around contractors' calendars as weather permits. A water supply operations manager who has access to detailed forecast information on the internet told us that he regularly calls his brother-in-law 60 miles southwest to check on weather conditions, "Because whatever they are getting down there we get a couple of hours later." He finds that this is a perfectly adequate lead-time for most operational decisions. Forecasts beyond 3 days were generally described as "too vague for use," "sometimes incoherent," and "not localized" enough for use in planning.

In general, water resource managers had a very difficult time identifying significant opportunities for short-term climate forecasts. They talk about immediate responses to weather variability and more vaguely about "long-term planning" – 20 years and more – for infrastructure development, energy costs, and process development. These long-term planning efforts require climate trend information rather than the climate variability information provided by short-term climate forecasts. Short-term climate forecasts do not appear to solve the problems they define for themselves or support the systems they have created.

Closely related to concerns about timescale of weather forecasts, is the spatial resolution of forecasts. In the three water basins we examined, orography and microclimatic conditions have significant impacts on the state of water systems. For example, precipitation coming into the MWD region off the Pacific Ocean may fall in one valley while its neighbor enjoys bright sunshine. As a long-time municipal water utility official in Southern California told us "it can rain in one canyon, but not in the next watershed. Unless I know what's going to happen in exact places I can't use the forecasts."

General climate forecasts for regional (or larger) areas are not very useful to the managers and technicians we talked with. Of those respondents who are concerned about spatial resolution, all expressed a preference for forecasts to be reported at the watershed or basin scale.

10.5. THE IMPORTANCE OF INCORPORATION IN CERTIFIED STANDARD INDUSTRY PRACTICES

A few of our respondents talked cogently about the process that will be required to institutionalize the use of forecasts in this sector. We were told that techniques and procedures that have been tested, certified, and used by the Corps of Engineers often become adopted by federal, state, and local agencies as well as the private sector. A very restrictive example is that the Corps determines specific "rule curves" that must be used by dam operators in managing the water level in reservoirs that have a designated flood-control function. However, other measures and procedures are merely adopted as certified "best practice." The Corps endorsement of such an action, whether voluntary or regulated, provides protection for the practitioner who has to justify his or her actions to regulators, legislators, or the public. The legitimacy of this particular agency to vet new techniques is rooted in a long, conservative history of changing best practices in the water resources sector. As we found in our interviews, new technology and techniques are often a black box or even invisible to operators and decision makers; they trust who ever made the decision to use the new techniques without questioning the change or the innovation.

Respondents at the Corps of Engineers confirmed their role, but told us it takes a very long time – 10–15 years – to integrate innovations into current practices. This is a function of thorough testing as well as "peer review" of field practice at specific sites. A river forecast center official told us that his agency is currently running probabilistic forecasts parallel to more traditional forecasts and will begin sharing the results with users soon. He cautions that it may take 15 years or more before operators and decision makers are comfortable with the new forecasts. Those respondents also stressed how they were working with water resource managers from the beginning of the introduction of new techniques.

Most of our respondents believe that they may be able to use probabilistic forecasts in their decision processes–at some point in the future when they are more reliable – only with training that includes how to interpret the forecasts, how to use the forecasts in existing management tools and models, and the creation of new models. We heard from many people that NOAA is "pretty good at making sure needs are supplied when personal relationships have developed with individual contact people." There appears to be widespread general goodwill toward NOAA, especially those NOAA individuals who interact directly with water resource managers, and a general belief that forecast use will be supported by the agency as it becomes adopted.

10.6. THE VALUE OF MAINTAINING UNCERTAINTY

Some interviewees described how they used the existing uncertainty in weather and short-term climate forecasts to meet organizational, political, or operational goals.

These individuals described how information has the ability to "limit their decision space." For instance, the construction manager of one California utility described additional erosion protection measures that he is required to implement if a storm is forecast. These measures are very disruptive of construction schedules. However, if an unforecasted event occurs, he is not held responsible for failing to "button down the site." His perceived self-interest suggested to him that he would be happier with less, rather than more, skilful forecasting because he can claim that uncertainty in the forecasts mean that they do not provide adequate information to prepare for weather events. Thus, the construction industry can transfer the erosion problem away from its current practices and attach it to the issue of forecast reliability. Similarly, in the Chesapeake Bay, forecasts could be used to control the timing of fertilizer or manure spreading on fields to avoid the runoff that occurs when heavy rain falls on freshly applied nutrients. While this would be beneficial for those seeking to reduce nutrient loading in the bay, farmers do not necessarily welcome the loss of autonomy.

10.7. CHALLENGES TO EXISTING INSTITUTIONAL ARRANGEMENTS

Organizations with little power to affect others' decisions or with weaker water rights are using the forecasts to get their issues raised in regional decision-making bodies. These challenges to currently accepted practices were raised by agencies or organizations with limited power over system-wide decisions. For example, forecasts are being used in Los Angeles annexation controversies to predict how climate will affect the availability of water. In the Pacific Northwest, fish scientists representing native American interests pushed to include probabilistic climate forecasting in Columbia River streamflow models. The Corps of Engineers re-ran their model with forecast information and revised their position on water levels for the spawning season. The BLM declined to include the forecasts in their model, but was ultimately overridden by the Corps and other agencies that had accepted the changes.

Credible forecast information contributed to increased flexibility in systems that traditionally have been fairly rigid. As pressures for water quality and quantity increase in these basins, forecast use may provide significant opportunities for lower-cost solutions to supply and distribution problems.

11. Conclusions and Recommendations

In presenting our conclusions and recommendations, we return to the four questions that motivated our study.

- How and to what extent do water resource managers in federal, state, and local government agencies, NGOs and the private sector use probabilistic climate forecasting information?

Our study suggests that there is very limited use of climate forecasts in both the operations and maintenance activities of an industry that traditionally relies heavily on large infrastructure to "routinize the irregular" and ensure reliability of supply. The potential for planning infrastructural change to rely on greater predictability of short-term climate fluctuations is almost completely unrecognized.

We found that scientific and technical information is indeed treated as only one input into decision making. Climate information is only one among many scientific and technical elements making up this input. Although a great deal of information is generated in these organizations about the availability of water supply and projected consumption, the information gatherers and translators who produce it have very little notion of how, or even if it is used by operational or strategic decision makers. In fact, those decision makers seldom make much use of such information at all, since they are heavily constrained by contracts, regulations, and economic concerns that essentially drive the decision or, more properly, managerial negotiation process.

There is some interest in using probabilistic forecasting at a fairly gross level to condition historical hydrological records used for decision making, for example, by selecting and averaging monthly streamflow figures for El Niño or La Niña years, rather than using the averages derived from complete record. However, at the time of our research, this was not highly developed.

- What institutional factors affect the framing and use of probabilistic forecasting by decision makers?

Conservatism and complexity are the principal factors affecting the use of new information. In particular, we convincingly confirmed that resource managers defensively rely on traditional planning methods so that if their decisions do not lead to improved outcomes they may at least avoid the risk of public criticism (or stronger sanctions) for using a new and unproven approach.

Conservatism is also reinforced by the need to adhere to industry standards and procedures, such as Corps of Engineers' rule curves for governing releases from dams with flood-control functions. Standard operating procedures can be hard to change, even when they only represent best practice and do not have regulatory force. Managers are reluctant to depart from certified best practice for the same defensive reasons descried above.

When they are aware of it, managers dub probabilistic forecast information as unreliable, even though they seldom have any idea what the skill level of such forecasting is. This confirms our expectation that managers formulate negative perceptions of information reliability that hinder acceptance if the new information indicates a departure from past experience and established procedures. An exception to this general rule arises when the potential consequences of a forecast event could be characterized as very severe or catastrophic. In this situation, the desire to avoid blame for having ignored an advance warning leads managers to overcome their skepticism and act on predictions with probabilities as low as 50%.

We confirmed the generalizability of the finding of Callaghan et al. (1999) and Miles et al. (2000) in the Pacific Northwest that the water management decision processes is inordinately complex with organizations and responsibilities crossing horizontal and vertical jurisdictional boundaries with differing access to and use of information. While decision-makers may intuitively understand the jurisdictional complexity of water resource decision making, they frequently found it hard to describe comprehensively. Most of the staff of water management agencies has only a very partial or localized view of the career of information within the organization. Hence, it is not readily apparent to participants in the complex decision process which types of decisions may be sensitive to improved information.

Even within single organizations, decision processes for water resource management were more reminiscent of negotiating than instrumental decision making as described by classical decision analysis. Interviewees described a normative consensus building process, not a single choice, or even an orderly sequence of choices, made by isolated decision makers. Instead, they described the anticipated elements of an organizational decision process made up of several reiterative steps in which individuals take part over a long period of time. Managers and policy makers described their roles in organizational policy decisions as participation in a process that moved the organization toward an outcome that was discussed, debated, revised, and debated again within the organization and with external stakeholders.

Conservatism and complexity are exacerbated by institutional resistance to externally generated information and the need for a translator, who is often a relatively recent recruit from university and thus occupies a junior position in the organization.

However, our study also suggests that various stakeholders adhere to traditional or improved forecasting methods selectively to promote their respective interests and agendas. While this has the potential to enhance as well as constrain the penetration of forecast information, it is more likely to be an obstacle in a sector characterized by conservatism and complexity.

- Would increased use of probabilistic forecasting information lead to decisions that have superior outcomes from an overall societal perspective (i.e., judged by broader criteria than just technical or economic efficiency)?

While it may seem incontrovertible that forecasts have the potential to improve routine technical efficiency, it is not so clear that, at their present level of development, relying on forecasts would lead to superior outcomes from an economic or societal perspective. There is considerable room for concern that economic benefits from improved routine operational efficiency could be wiped out by lower probability, but nevertheless high consequence events such as droughts or floods. Enhanced operational efficiency may also encourage further development in metropolitan areas where concerns about reliability are already an issue. In other words, society may be legitimately concerned about a water sector operating closer to the margins of reliability than it does at present. In any case, convincing gains in operational efficiency would seem to depend on the availability of reliable forecasts at a much finer grained spatial scale than the ones we were working with – perhaps even a watershed scale.

In other words, to be seen to be offering a clear societal benefit, forecasts would have to be seen to be contributing to improved reliability of water supply as well as improved efficiency of its provision.

- What changes in institutional decision processes and the type and framing of forecasting information would increase the usability and usefulness of the information?

Externally generated scientific information, such as the NOAA climate forecasts we were concerned with, is unlikely to be influential in an organization's decision making unless it is incorporated in internal reporting in a fashion that renders its origins almost invisible to its ultimate users. In other words, it needs to be built-in to existing decision tools that are already well accepted. Translators, whether on staff (especially newly recruited graduates) or employed as external consultants, play a key role in getting information into organizational decision processes. Based on our interviews, we would estimate that it is likely to take at least 15 years to integrate probabilistic climate information effectively into streamflow models, water demand modeling, etc.

Another important change would be the revision of industry codes and practices so that existing regulations and codes of best practice do not obstruct the incorporation of new information and use of new tools, such as probabilistic climate forecasting. Of course, this would have to be done in a manner that ensured that there were not unacceptable compromises in reliability and public safety.

A third institutional change with the potential to increase the usability of forecasts would be the reform of water resource management institutions to reduce the current high levels of functional specialization in favor of integration at a regional, possibly large, watershed level.

Finally, a critical factor would seem to be changes in the incentive structure for water mangers that would reward them for innovation, rather than expose them to criticism or recrimination.

Overall, our account of institutional decision making suggests a dramatic departure from the rational choice view of information use in decision processes. It moves information providers, such as NOAA, towards a more realistic model of the organizational decision process into which they would like to see predictive climate information incorporated. Integration of new information into this decision process is a challenge of articulating that information within an organization's frameworks of meanings and collective action, not merely a problem of removing exogenous barriers to information.

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Notes

[1]Probabilistic ENSO forecasting is a recent addition to a fairly wide range of tools that have been proposed to introduce stochastic processes into many aspects of water resource engineering and management. Many of these approaches were the subject of a major review paper more than a decade ago (Yeh, 1985). Models for long range planning of river basin development using implicit and explicit stochastic streamflow models have been proposed for more than 20 years (e.g., see Houck and Cohon, 1978). Strategies ranging from expert systems to optimization and simulation modeling for incorporating forecast information into real-time operations of complex, multipurpose water resource systems have also been widely developed (e.g., Palmer, et al., 1982; Yazicigil, et al., 1983; Houck, 1992; Sheer, et al., 1992). However, probabilistic tools in general have achieved only limited penetration into the daily world of water resource decision-makers.

[2]Key informants were identified by principal investigators during earlier pilot research.

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