WEATHER FORECASTS ARE FOR WIMPS:[1] WHY WATER RESOURCE MANAGERS DON'T USE CLIMATE FORECASTS.

FINAL REPORT TO NOAA OFFICE OF GLOBAL PROGRAMS

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[1] Advertising slogan for Oldsmobile "Bravura".

Chapter One: Introduction

Over the course of the decade beginning in the mid 1980s, scientists achieved remarkable advances in probabilistic forecasting of seasonal and inter-annual variation in climate conditions associated with the El Niño Southern Oscillation (ENSO). Acquisition of this capability raises the question how (or even whether) this information can be incorporated into societal decision making for the benefit of affected communities, regions, and economic sectors.

The research described here examined the question of why water resource managing institutions in the United States do or do not use probabilistic forecast information about seasonal and inter-annual climate variability in their planning. The study sought to describe 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. Better hydrologic management strategies may not only improve viability of local water supplies, but also help mitigate tensions in areas where there is competition for water rights. The research methodology for this study was developed in such a way that the approach may be modified for application to other resource management systems, such as forestry, and in other countries, such as those of the tropical and sub-tropical regions that are most directly affected by ENSO-related climate fluctuations.

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.

However, sociological studies (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). 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.

This report describes how a broad range of technical and nontechnical information is incorporated into, or excluded from, the deliberations of water managing institutions. We look at how 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. We also suggest ways of packaging and presenting such information to improve its appropriate incorporation into decision making.

Problem Statement

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.

The decade from 1985 to 1995 saw remarkable progress in scientists' ability to monitor and forecast short-term climate variability associated with the ENSO phenomenon. Techniques available in the early 1980s were inadequate to fully monitor the evolution of an ENSO event already in progress. In the mid 1990s, 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 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 experimental forecasts up to one year ahead for some parts of the world.

Skill in prediction of climatic variation remains geographically limited and the pace of improvement in that skill appears to have slowed, at least for the moment. However, probabilistic forecasts of seasonal and inter-annual 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 options (see, for example, Waggoner 1990). Yet, even in the face of current policies that emphasize meeting demand by more efficient use of existing facilities rather than investing in new ones, US water resource managers have been slow to take notice of probabilistic forecasts that could improve their operational decision making. This research set out to identify the institutional factors affecting water resource managers' interest, willingness, and ability to adopt probabilistic tools, in general, and seasonal to inter-annual climate predictions, in particular.

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. The rational choice approach suggests that ENSO forecast information will be readily incorporated in decision making (Beyer and Trice 1982). Although it is based on individualistic assumptions of utility maximization which render it unsuitable for collective decision making (Arrow 1951), 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).

However, studies of actual decision making in public and private sector organizations indicate that the rational choice model may not be the appropriate one for institutional decision making (Douglas 1986). In particular, the knowledge use literature suggests that 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 upon such information directly (Starling 1979), (Weiss and Bucuvalas 1980), (Whiteman 1985), (House and Shull 1988). For example, Feldman and March:174 have pointed out that:

> (1) Much of the information that is gathered and communicated by individuals and organizations has little decision relevance. (2) Much of the information that is used to justify a decision is collected and interpreted after the decision has been made, or substantially made. (3) Much of the information gathered in response to requests for information is not considered in the making of the decisions for which it was requested. (4) Regardless of the information available at the time a decision is first considered, more information is requested. (5) Complaints that an organization does not have enough information to make a decision occur while available information is ignored. (6) The relevance of the information provided in the decision-making process to the decision being made is less conspicuous than is the insistence on the information.

Specifically focusing on water resources in the Pacific Northwest, a pilot study (Lach, et al. 1994; Lach and Quadrel 1995) confirmed that many water resource managers do not readily incorporate new information and forecasts about global-level processes in their decision making. The study provided several insights into the relationship between scientific information and decision making:

- Scientific and technical information is not privileged in organizational decision making. It competes with local knowledge, political mandates and pressures, stakeholder pressures, and internal organizational needs.
- Decision processes are often severely limited by political circumstances or existing regulatory requirements that overwhelm improvements in scientific information.
- Organizational decision routines often undervalue externally generated information, or find it difficult to integrate.
- Successful integration of scientific information often depends on the presence of an internal translator, who can convert general information into organizationally relevant specifics.

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

The research described in this report differs from most existing studies in that it is both regional and comparative. It focuses on the regional nesting of water resource decision making rather than on specific management decisions. In doing so, we sought to expose the complex overlapping frameworks of responsibility and authority that constrain decision makers. We also set out to conduct a comparative analysis that could reveal the affects of both climatic and institutional variation on the range of options available to decision makers. We adopted the approach developed in the Pacific Northwest pilot study, referred to above, but focused specifically on the use of probabilistic forecasting of seasonal to inter-annual climate variation.

We also extended coverage of the approach to cover two additional regions, the greater metropolitan areas around Los Angeles and Washington DC respectively. Both of which have very different water supply and use characteristics, management arrangements, and potential to incorporate seasonal to inter-annual forecast information.

Methodology

The research team for this project was initially drawn from the staff of Pacific Northwest National Laboratory (PNNL) and the faculties of Oregon State University, the University of California, Irvine, and George Mason University. In the later stages of the project, the co-PI from PNNL moved to the International Research Institute for Climate Prediction located at Columbia University's Lamont-Doherty Earth Observatory. The team consisted of an anthropologist, sociologist, political scientist, and water resource engineer, all with previous experience of research in resource management decision making.

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. The research addressed four questions:

- How and to what extent is probabilistic climate forecasting information used by water resource managers in federal, state, and local government agencies, nongovernmental organizations (NGOs) and the private sector?
- 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 which 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?

A multi-method research design was used to characterize the range and depth of water resource decision makers' expectations of, requirements for, and constraints upon the use of seasonal and inter-annual 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 the Pacific Northwest, we interviewed individuals at relevant federal agencies, selected regional compacts,[1] state agencies responsible for management in the Columbia River Basin,[2] and local water utilities. The sample also included environmental groups and tribal representatives.

In the Greater Washington DC Metropolitan Region, we also interviewed regional staff of relevant federal agencies, the Interstate Compact on the Potomac River Basin, the Chesapeake Bay Commission, state agencies responsible for water resource management, water supply authorities,[3] environmental and recreational groups.

In the Metropolitan Water District (MWD), we interviewed regional staff of relevant federal agencies, staff of the MWD, state and local agencies with water management responsibilities, water retailers, and environmental groups.

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[4] we identified individuals who currently use or potentially could use seasonal or inter-annual 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. Respondents were asked to identify other individuals who fit the knowledge-use criteria. Nonprobabilistic 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.

The individual semi-structured interviews were usually conducted face-to-face by two researchers to reduce individual interviewer bias. Some interviews were conducted in small groups. Each interview took 90 minutes or more. The interview protocol consisted of open-ended questions to collect information about:

[1] Regional coalitions or compacts include the Bonneville Power Administration, the Northwest Power Planning Council, the Pacific Northwest Utilities Conference Committee, the Columbia Basin Fish and Wildlife Authority, the Pacific Fisheries Management Council, the Pacific States Marine Fisheries Commission, the Columbia River Compact, Pacific Northwest Waterways Association, and the Columbia River Inter-Tribal Fish Commission.

[2] State agencies include Oregon Department of Fish and Wildlife, Washington Department of Fisheries, Montana Department of Fish, Wildlife, and Parks, Alaska Department of Fish and Game, Idaho Department of Fish and Game, Washington Department of Wildlife.

[3] Fairfax County Water Authority, Washington Suburban Sanitary Commission, and the Washington Aqueduct Division of the US Army Corps of Engineers

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

- descriptions of intra- and inter-organizational decision processes that currently or potentially could utilize climate forecasting information;
- respondents' experience with or knowledge of probabilistic forecasting information; and
- perceptions about institutional constraints upon and opportunities to use of forecasting information.

Demographic information and background information about individual respondents was also collected.

Team leaders in each region formulated provisional results for that region and the whole research team participated in a series of meetings to analyze these results, compare findings across the regions and develop recommendations. 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 several US indicated that the findings would find widespread acceptance among the water resource management community in the United States.

Chapter Two: Water, 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 US 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 inter-annual climate forecasts have the potential to improve historically based water management decisions. In other instances (for example the Washington DC study 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 inter-annual variation. To identify opportunities for increasing the use of this probabilistic information about climate variation we set out to develop a conceptual model 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:

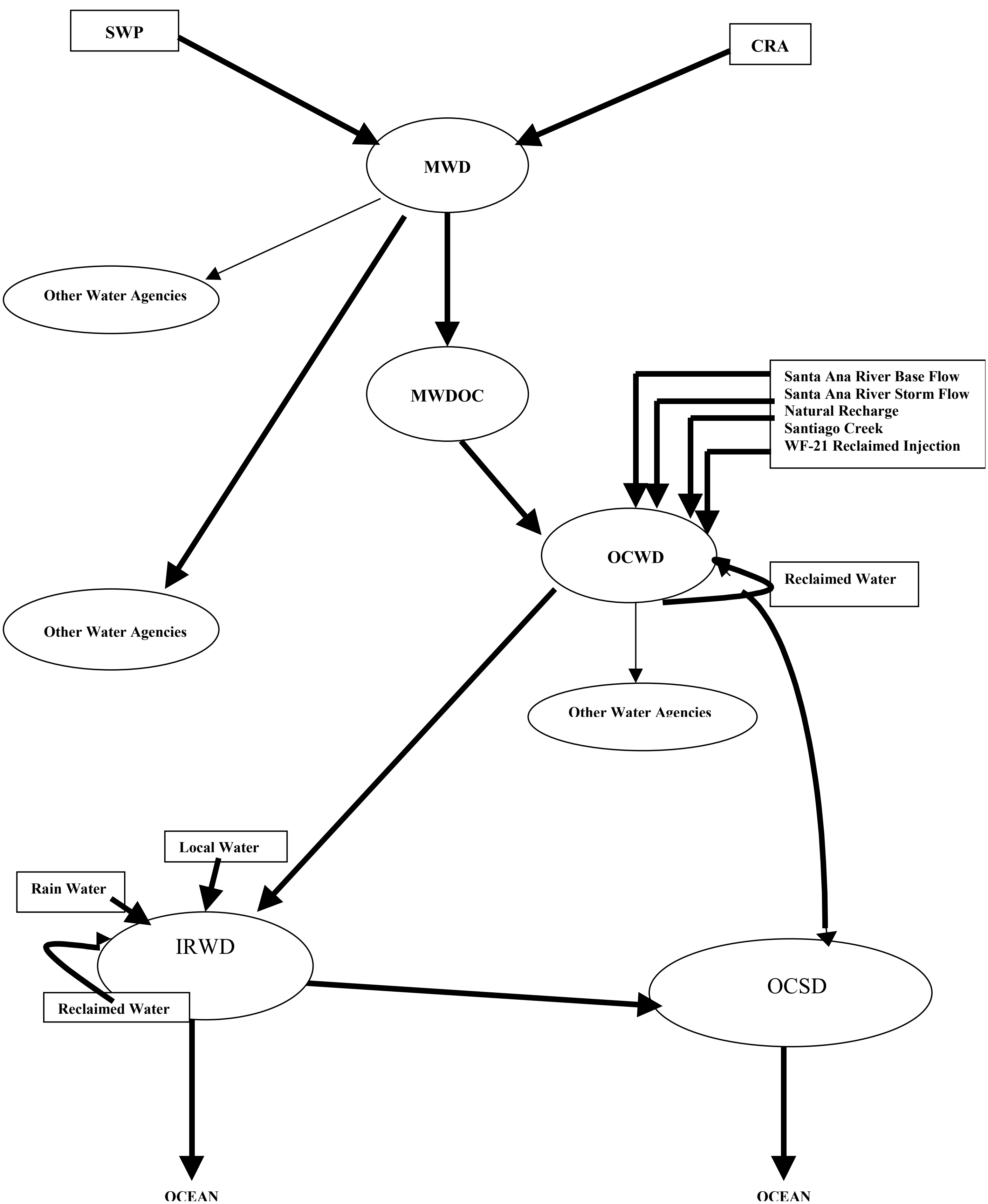
- consist of both surface and groundwater supplies;
- contain a variety of infrastructure components such as dams, wells, levees, etc;
- cross political and hydrologic boundaries;
- have multiple purposes including water supply, hydropower generation, recreation, flood control, fisheries, wildlife enhancement; 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. They are the Metropolitan Water District of Southern California, the Potomac River-Chesapeake Bay region, and the Pacific Northwest.

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. *Figure 2.1* represents a single slice through the tangled web of water flows among these agencies. As such, the figure does not begin to convey the incredible complexity of both the water flows and the organizational landscape in California. This is a classic case of a crowded organizational field with pyramiding and overlaying of organizations, and multiple, highly differentiated water sources. Therefore, in producing *Figure 2.1* we have sacrificed inclusiveness for improved clarity and comprehensibility. We trace only the movement of water ultimately supplied to

FIGURE 2.1 ORGANIZATION TRANSECT OF WATER FLOWS IN SOUTHERN CALIFORNIA



Tracing the movement of water of OCWD and IRWD. Key: Sources of water=Boxes; Water Agencies=circles.

consumers in the Municipal Water District of Orange County (MWDOC- usually pronounced "mowdoc"), Orange County Water District (OCWD), and Irvine Ranch Water District (IRWD). While this transect is limited in geographic scope, by addressing only Orange County and the City of Irvine, it includes quite different types of organizations and a rich array of water sources.

Looking first at sources of water, represented by the boxes, the figure reflects significant information about differential reliability, quality, and cost. 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) of Colorado River Water per year. Agriculture has first priority and receives 3.85 maf. The remainder of the water, 550,000 acre-feet, is designated urban use and goes to Metropolitan Water District of Southern California (MWD) via the Colorado River Aqueduct (CRA). However, California presently uses about 5.2 maf per year, with about 1.2 maf going to MWD.

In terms of reliability, it is important to recognize that the Colorado River is drought prone and moderately sensitive to El Niño/La Niña events. The historic annual flow of the Colorado River has ranged between 5 maf to 24 maf. Moreover, California presently uses far more than its entitlement, and the other basin states are actively lobbying the Secretary of Interior, who is the main water manager for the Colorado River, to restrict California's uses. Ultimately, California is going to have to reduce its use of the Colorado River, or use its power in the Congress to change the Law of the River. Insecurity of supply is mitigated by the large amount of storage on the Colorado River (approximately three years at present rates of use) and the Law of the River which guarantees that California gets its 4.4 maf first, even though that may mean great sacrifices to the 2.7 maf allocated by court decree to Arizona. Threats to reliable supplies for the Los Angeles area are further mitigated by multiple sources of supply including water from Northern California through the SWP, surface supplies, natural recharge, and reclaimed water.

The SWP, operated by the California Department of Water Resources, is designed to transport 4.2 maf of water per year from Northern California to Southern California. Like the Colorado River, the SWP is not a reliable source of supply. Environmentalists blocked the construction of planned surface water storage facilities, and the project now delivers only about one-half of what its sponsors anticipated. Moreover, supplies depend upon snow pack in the High Sierras, which is highly variable and sensitive to El Niño/La Niña events. In addition, deliveries can be interrupted when pumping affects the environmental health of the San Francisco Bay/ Sacramento River Delta region.

The CRA delivers relatively low quality water with high levels of salinity. As a sole source of supply, the Colorado River is not attractive. Far better quality water is available through the SWP and through surface water supplies. Reclaimed water is the least acceptable in terms of water quality, although, it is a highly reliable source of supply.

In terms of costs, surface water and natural recharge water are least expensive. Water from the Colorado River is more expensive than surface water but relatively inexpensive. SWP water and artificially recharged water are more expensive. Reclaimed water is the most expensive.

Variations in the reliability, quality, and cost of different sources of water present significant water management challenges to utilities. There are strong incentives for municipal water utilities to use as much of the high quality, low cost water as possible and to postpone uses of low quality, expensive water. Capturing all the surface water flows, which are of high quality and relatively low cost, is an important priority even though these flows are highly variable. This means regulating surface flows by dams or berms, and storage in reservoirs or recharge basins. Reclaimed water, which is suitable for outdoor watering and toilets, is the most reliable water supply in Southern California. Reclaimed water must be blended with other water sources in order to be potable. Health regulations specifying blending rules, therefore, also affect the reliability, quality, and cost of water supplies.

The circles on *Figure 2.1* represent water agencies. Not only does *Figure 2.1* trace the movement of water, it also indicates the degree of dependence of one agency upon another with regard to the resource. The hierarchical arrangements of institutions are a characteristic response to uncertainty. This map has been simplified by labeling a large number of organizations as "other water agencies" in order to concentrate only on a few utilities within Orange County. Also, for simplicity, some organizations that have indirect influence upon water have been left out. For instance, the Army Corps of Engineers operates dams on the Santa Ana River, and various Federal and state environmental and health agencies regulate reclaimed water quality.

Water agencies generally seek autonomy or control, at least, of their organizational environment, as well as complete security when it comes to reliability of water supplies. Autonomy is increased when dependence upon other agencies is decreased. In Southern California no water utility can survive on the water naturally occurring in a contiguous geographic area. However some degree of autonomy can be achieved by developing multiple sources of water and multiple ties to different organizations. There is security in redundancy.

In terms of control over sources of water supply, the most powerful water agency in Southern California is the MWD. Today, the MWD has evolved into a regional water management agency composed of many member agencies. The MWD was most influential when development of new sources of water supply and expansion of its service area were underway. However, as demands began to outstrip what the MWD could deliver, the incentive increased for member water utilities to develop their own, independent water strategies. The City of San Diego, for example, has made an independent deal with an irrigation district to buy water. Different local utilities are more or less successful in developing new sources. The City of San Juan Capistrano has neither groundwater nor independent sources of surface water, and is completely dependent upon MWDOC and thus, MWD.

The Municipal Water District of Orange County (MWDOC) became a member of the Metropolitan Water District (MWD) in 1951, and buys all of its water from MWD. Without physically touching a drop of the water, MWDOC sells the water to its member agencies, including the OCWD and IRWD, to help supplement local water supplies. Because MWDOC is only one of a large number of water wholesalers and retailers that the MWD supplies, MWDOC is anxious about its influence within MWD and about MWD's accountability to its members. There has been continuing controversy over voting rights, and the rights of and cost to individual members using MWD system aqueducts for water transfers apart from regular deliveries. The municipal water utilities served by MWDOC, represented in *Figure 2.1* by the Irvine Ranch Water District (IRWD) and the Orange County Water District (OCWD), are at the ends of a chain of more or less uncertain relationships.

If OCWD and IRWD use less imported water and more local sources, they benefit financially as well as gain independence. First, groundwater costs approximately one third the price of imported water. Second, although MWDOC does not physically handle any of the water it buys from MWD, it adds a $5 surcharge to every acre foot of water it sells. OCWD currently buys approximately 200,000 acre-feet of water per year from MWDOC, which equates to $1 million in surcharges alone.

Water which is not captured, recharged, or reclaimed is delivered to the Orange County Sanitation District (OCSD). OCSD discharges approximately 736 acre-feet of water per day into the ocean. This outfall is a mixture of primary and secondary treated wastewater. The water outfall can be affected by tides, emergencies, and weather. To compensate for tidal influence, OCSD has installed a surge tower and pumping system at one of their plants. For emergencies, there are back-up pumps, as well as back-up power, that can help process wastewater. Weather affects the quality of water disposal by increasing the amount of water that infiltrates the collection system during a rain storm.

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. The traditional responses still reflect solutions for tame problems, particularly in defining water supply and allocation problems in Southern California in ways that limit agency responsibility – and focus responses to the problem - to the explicit missions of specific organizations. The agencies involved at all levels of water management in this region remain focused on the explicit missions of their own organizations, and their efforts at coordination are directed towards discharging their individual agency responsibilities.

The Potomac River-Chesapeake Bay

The Potomac River is the major source of water supply to the Metropolitan Washington Region (*Figure 2.2*). In recognition that 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, the Interstate Commission on the Potomac River Basin (ICPRB) was created in 1940 as one of the initial federal interagency river commissions. The ICPRB's explicit mission is to coordinate agencies and organizations around various issues.

throughout the basin as a whole. The ICPRB is a non-regulatory interstate commission established to cooperatively address water quality and related land resources issues in the Potomac basin. Its goal is the enhancement, protection, and conservation of the Potomac River and its tributaries through regional and interstate cooperation.

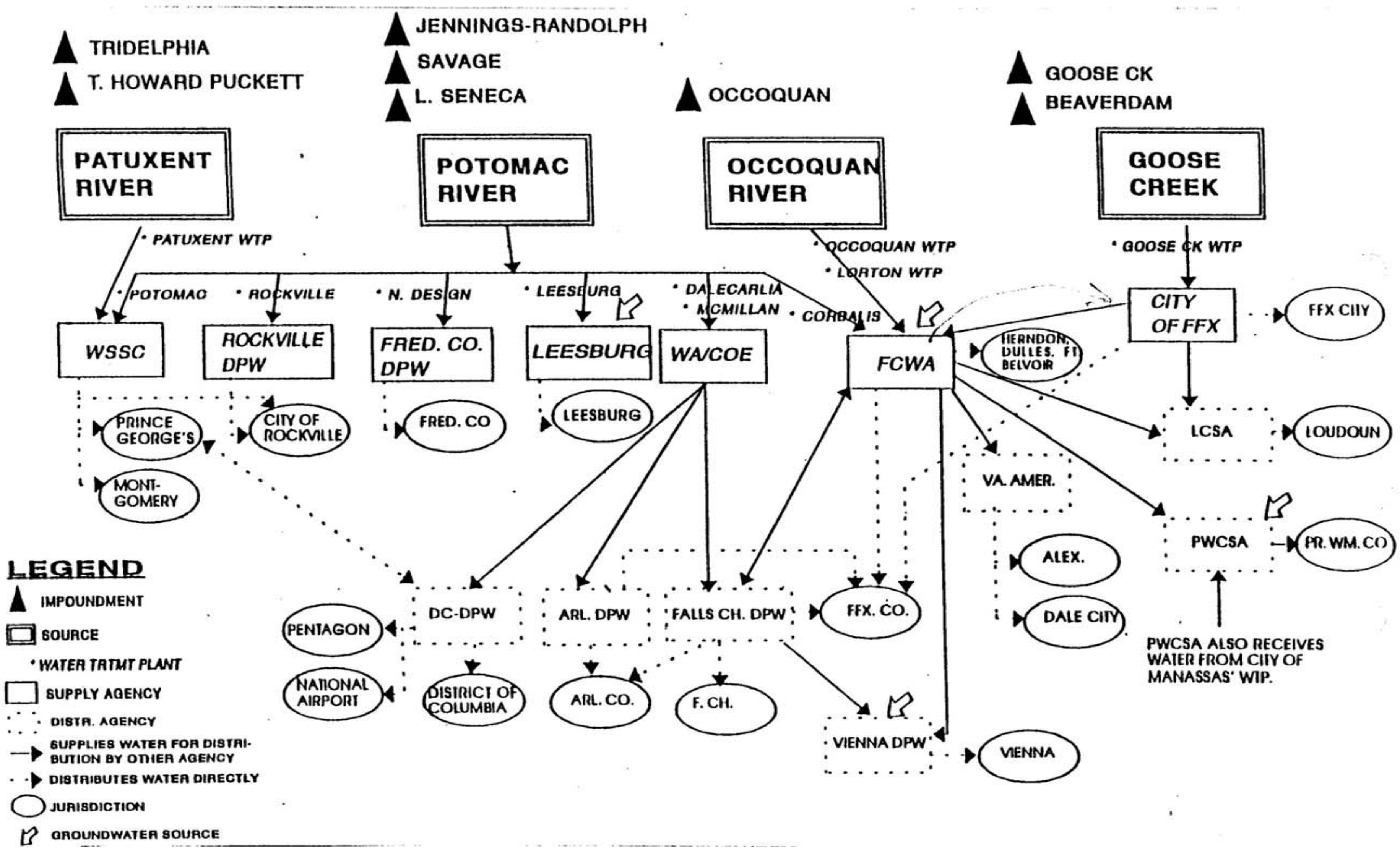


Figure 2.2 MAJOR WATER SUPPLY SYSTEMS DRAWING RAW WATER FROM THE POTOMAC IN THE METROPOLITAN WASHINGTON REGION
(Utilities which withdraw water from sources other than the Potomac are not illustrated here

More specifically the ICPRB is charged to:

- collect, analyze, interpret, and distribute technical and other data and conduct studies, sponsor research, and prepare reports on pollution and other water problems;
- assist and provide liaison for and among agencies and organizations and sponsor cooperative action in formulating plans, programs, and other activities relating to stream pollution and utilization, conservation, and development of water and associated land resources; and
- disseminate to the public information relating to stream pollution problems and to the utilization, conservation, and development of the water and associated land uses. (University Council on Water Resources 2000 - website)

Responsibilities include planning, researching, and talking about issues related to the river basin with more than 200 watershed organizations and agencies operating within the Potomac basin.

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).

When the Potomac River fell to a low flow of 388 million gallon per day during the drought of 1966, several studies concluded that increasing population and water use in the region meant that the free-flowing Potomac River could no longer be relied upon to meet demand. Conventional solutions were promulgated including the construction of up to 16 new reservoirs and dams. These plans were not popular with environmentalists or residents and they carried a high price tag. Research by the Johns Hopkins Department of Geography and Environmental Engineering suggested that coordination of withdrawals and management of the basin would better meet forecasts of increasing demand and concerns about low flows.

This increased knowledge about the river system led to the Low Flow Allocation Agreement of 1982. Instead of responding incrementally with standard engineered solutions, the ICPRB was instrumental in creating a space that allowed for non-incremental solutions to be created.

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. In 1976, acting at the behest of high-ranking regional officials, the US Congress directed the federal Environmental Protection Agency (EPA) to launch a major study of the bay's decline. The $27m research program released its findings and recommendations in 1982, targeting three areas for immediate remedial action: nutrient enrichment; dwindling sub-aquatic vegetation; and toxic pollution. These findings laid the foundation for the historic Chesapeake Bay Agreement, 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 agreement bound the parties to "improve and protect water quality and the living resources of the Chesapeake estuarine system." It set the goal of reducing nitrogen and phosphorus loading in the bay by 40% by the year 2000. Other goals have since been added, such as reducing presence of toxics. The CBP has undertaken more than 30 commitments to improve the management of fish and wildlife, restore water quality, plan for development, increase public awareness and access, and improve intergovernmental cooperation.

The CBP, began in 1983 and rapidly grew into an extensive network of federal, state, and local bureaucracies. *Figure 2.3* describes the organizational structure of the CBP, which includes representatives (both legislators and agency staff) from Maryland; Pennsylvania (which has no bay-front land); Virginia; and Washington DC. Also represented are the Chesapeake Bay Commission (a tri-state legislative commission); the US Environmental Protection Agency; various participant advisory groups (e.g., universities, NGOs such as the Center for Watershed Protection; and Chesapeake Bay Trust); and a citizens advisory group. As one of our interviewees described it:

> The program has a complex organizational structure. There is a high-level of buy-in. Governors of Maryland, Pennsylvania, and Virginia, the Mayor of Washington, D.C., the Chairman of the Chesapeake Bay Commission, and the EPA Administrator are the board of directors for the CBP. This means that the states run the show and therefore they like it.

In addition to the politicians on the Executive Council, 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. A CBP official told us that:

> The Local Government Advisory Committee is very active, with oversight for a community grants program. There has been a major effort to get local governments involved but it has been difficult because local government varies by state. Maryland has large counties, Virginia has cities and counties that are small, and Pennsylvania has townships and boroughs that are tiny.

This statement highlights one of the major difficulties with coordination as a strategy for responding to complex systems. Participants from multiple levels of jurisdiction beyond state and federal agencies, create an extremely diverse type and range of regulatory and enforcement authority. In response to managing conflicts among differences in worldviews and missions, the CBP strategy also provides for different advisory groups for different interests, to "get things done without always arguing about everything" (CBP staff).

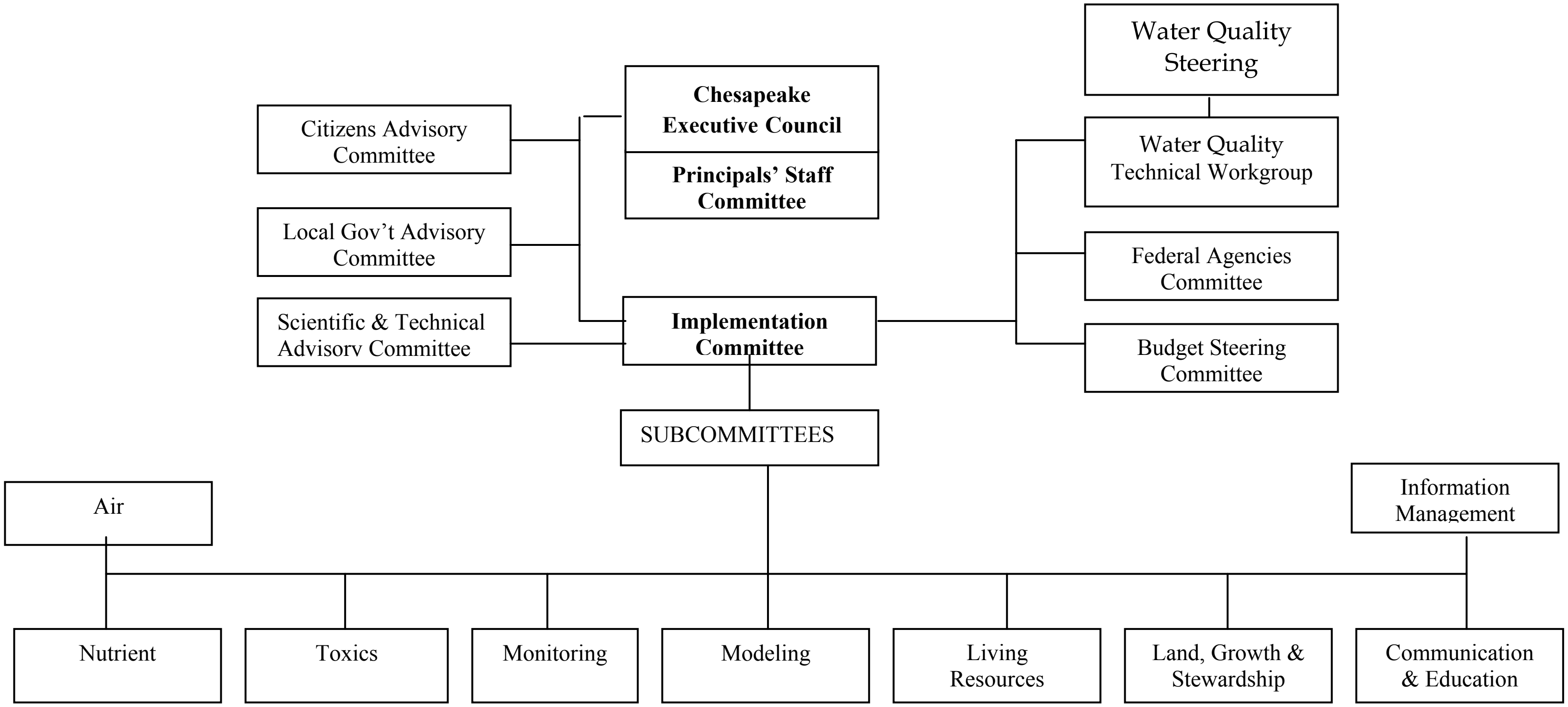


Figure 2.3 CHESAPEAKE BAY PROGRAM ORGANIZATIONAL STRUCTURE

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 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.

The utilities and federal agencies in the Pacific Northwest have long coordinated Columbia River system operations and planning across state and national boundaries under the terms of the Northwest Coordination Agreement and the Canadian Treaty. Interagency committees have also been in place since the 1940s under various Acts and Commissions (NRC 1999).

Until the 1970's, 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 to assure the region an adequate, efficient, economical and reliable power supply and to protect, mitigate and enhance fish and wildlife, and related spawning and rearing grounds, of the Columbia River and its tributaries that have been impacted by the construction and operation of hydroelectric dams (NPPC 2000).

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). These unique authorities are one of only a few instances in which the federal government has given states significant power over federal agencies.

The NPPC consists of eight board members, two each from Washington, Oregon, Idaho, and Montana, appointed by and responsible to the respective Governors.[1] Also by statute, the fish and wildlife agencies of the four states and the Native American Indian Tribes are given special

[1] By statute, the NPPC is responsible for decision-making. In practice, however, if any issue is important enough, the Governor may elect to step in and instruct his/her members how to vote. The Governor may also remove a board members at his or her will.

significance by Congress.[2] Several federal agencies, mentioned by name in the Act, are required to comply with NPPC plans to the fullest degree possible. These agencies include the Bonneville Power Administration (BPA), the Army Corps of Engineers, the Federal Energy Regulatory Commission (FERC), and the Bureau of Reclamation (BREC).[3]

Figure 2.4. is a "map" that describes the relationships among the major organizational actors responsible for managing the Columbia River Basin. On the figure, single-headed lines describe unilateral relationships of influence, while the double-headed lines describe relationships of reciprocal influence. Dotted lines distinguish organizations that have informal access to the decision process.

This map describes how the multiple agencies and governments coordinate their activities to manage the water resources of the Columbia River. 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 has spent an estimated $3 billion since 1980, trying to find ways to restore salmon to the Columbia River (Brinkman 1999). 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.

Sources of Complexity

As the foregoing brief sketches indicate, water resource management in the US 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

Natural System Complexity

Water resources depend upon 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

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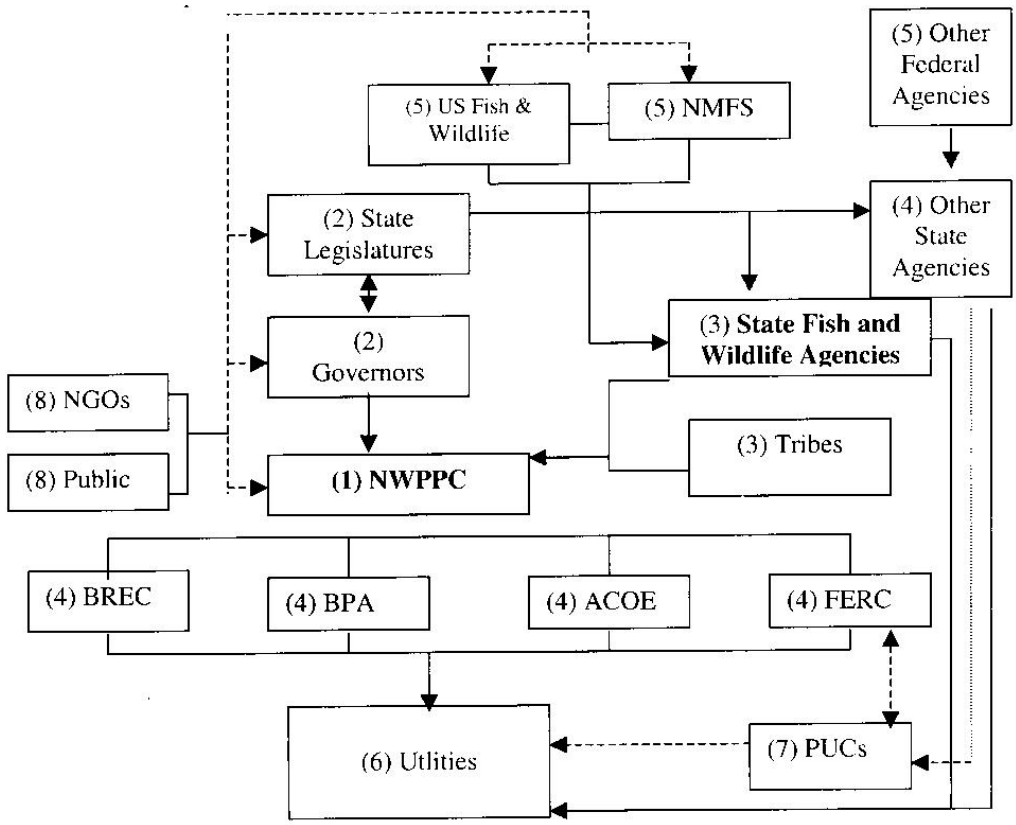
[2] The NPPC was told to pay particular attention to the views and information provided by the tribes. Tribes also have special treaty rights on certain river reaches for certain fish species, all of which must be respected by any NPPC decision.

[3] Other federal agencies, including the US Forest Service and the Bureau of Land Management, are not required by statute to comply with NPPC plans. Instead, they, along with the US Fish and Wildlife Service and the National Marine Fishery Service, are involved in implementing other federal legislation such as the Endangered Species Act.



ORGANIZATIONAL KEY: (1) NWPPC, created through NPPA 1980 (2) Makes appointments to the NWPPC Board (3) Organizational given special significance by NPPA (4) Organizations required to comply with NWPPC plans	(5) Organizational not required to comply with plans, but must coordinate responses to other rules, regulations, and legislation (6) Organizations which rely on hydropower and subject to NWPPC plans (7) PUCs oversee utilities, but are limited in their power by FERC (8) Organizations from whom NWPPC must elicit input
--------- Indirect Influence	——— Direct Influence

Figure 2.4 INFLUENCE MAP FOR COLUMBIA RIVER DECISIONS

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 six years compared with only one year for the Potomac, which is the primary water source for Washington DC. 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.

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 California Water Plan transfers water from north to south. Other water is imported from the Colorado River and distributed through the Metropolitan Water District. Water also comes through 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 environment of the Pacific Northwest, involving many more structures than in Washington DC, is made particularly complex by the importance of hydropower.

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 limited scope. In response to multiple demands including fisheries, hydropower, recreation etc, different agencies have been established to serve different constituencies. Each of these agencies has relatively narrow jurisdiction and while pursuing their overall mission requires systematic management of the resource, each individual agency has only a narrow span of control. The mandate of the agency 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, which can be characterized as the externalization of the originating agency's problems.

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 upon 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 not about resulting flooding due to pulsed releases through turbines at a dam to meet peak energy demands. The range of functions performed by agencies is described in Appendix A.

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: their 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.

The Routinization of the Irregular

Water resource management systems in the US, 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, 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 ICPRB was formed as a super agency to guide overall response to drought in the watershed. 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. Once planned, these facilities may take even more time to construct. 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 be yield benefits on a comparable scale.

The time horizon for some water agencies is changing. The focus of some 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. At one level, this seems to present an ideal opportunity for incorporating probabilistic climate forecast information. However, the process to vet new methods and tools for use in these agencies involves a period of extensive analysis and testing. Furthermore, new kinds of people may need to be recruited. Personnel turnover in agencies is slow. All of these factors may lead to stress within and between agencies.

Craft Skills and Local Knowledge

US water systems are extraordinarily diverse and are perceived by their managers to be sensitive to specific local conditions. It is not unusual for new personnel to be expected to take between 3 and 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 State Department of Water Resources in California, an official told us long, intense interaction with the models was the only way to comprehend them well.

Values: Reliability + Quality + 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: reliability, quality, and 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.
- 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 description 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 do not become 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 lighting, heating and cooling, transportation, and telecommunication.

Cost 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 inexpensive and not subject to sudden, unexpected, or large increases. Sharp rate increases and/or perceived high rates are likely to make customers hypercritical. One utility in our study has increased its rates to the point where it was among the ten highest priced suppliers in the US. 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 is given to the public schools, for example. A 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 the treatment process 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? But as we saw with some state and local agencies, the threat of anomalous weather events was used to obtain resources for desired equipment and personnel.

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.

This conservative disposition combined with the limited focus or mission of these agencies leads them to favor incremental adaptation (such as seeking new sources of supply) rather than innovation (such as demand side management). For example, reclaimed water that is not treated to potable standards is emerging 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 flushing toilets."

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 inter-annual 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.

Conclusion

Hence, we characterize the U.S. water resource management field as a highly complex one consisting 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. To understand how this might be achieved we turn in the next chapter to the question of how innovation can and does take place under these conditions.

Chapter 3: Innovation in Water Resource Agencies

In this chapter, we frame the issue of climate forecast use as a problem of the adoption of technological innovation. How is it that conservative water resources agencies innovate? As we established in the previous chapter, water resource management agencies are reluctant to make large changes or to take risks. Practically every agency official we talked to articulated some version of the following statement made by a municipal water utility director: “We cannot optimize. We must be conservative in our decisions to protect the public health.” 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 (*Figure 3.1*) indicating that they perceived very strong incentives to avoid any risk associated with innovation. 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.”

	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”

Figure 3.1 IMPLICIT OUTCOME MATRIX SHOWING PERCEIVED POTENTIAL CONSEQUENCES OF TECHNICAL INNOVATION.

In the sections that follow, we will define innovation and distinguish it from incremental changes. The common drivers of innovation will be identified along with their strength and limitations. A distinction will be made between trying out an innovation, or putting a new techno-scientific advance to some use, and actually relying upon it in policy and practice. The pathways by which innovations come to affect policy and behavior will be explored. It is in the process through which water management utilities bury innovation in current practice wherein lies the secret of how conservative water agencies innovate.

Incremental and Innovative Change

Innovation has a positive connotation, and few agency leaders would admit to not being innovative. In talking to agency officials, however, we quickly learned that what many identified as important technical, organizational or behavioral changes, were more accurately characterized as incremental modifications. Incremental change involves an agency action very much like what has occurred previously, except to a greater or lesser degree. Such change does not involve any new conceptual or organizational alterations. For example, among the innovations cataloged by interviewees was the purchase of additional sand bag filling devices in preparation for El Niño, installation of propellers in reservoir tank structures to discourage the build up of bacteria on reservoir walls, and the acquisition of a silt removal machine to improve recharge in infiltration basins.

There are circumstances where the magnitude of change is sufficiently large that, even without a shift in organizational principle or practice, innovation can be said to have occurred. If a budget increase for emergency preparedness is adequate to purchase a large amount of new machinery as well as hire and train new staff to operate and maintain it, and that increase becomes a permanent fixture, then an innovation can be said to have been adopted. Large decreases can also be counted as innovations if cuts affect performance and are of sufficient duration.

More fundamental innovation extends beyond changes in magnitude to encompass changes in kind. An organization can be said to innovate if it abandons an accepted practice or technology in favor of some alternative. Innovations in this basic sense involve discontinuities such as real shifts in resource allocations. Innovation implies dependence upon new techniques and procedures that involve different kinds of information, and/or demand different skills and training. Such change may be technical or organizational, and, typically, real innovation involves both because new techniques require different kinds of people skills and organizational routines. There is an inverse relationship between risk and innovation. For an organization to move away from the path of incremental change is to venture into the uncertain. The organizational fields that are highly innovative, the information technology sector for example, are also characterized by a high rate of failure. Losses are more than compensated for in this sector by the overall very large gains.

It is the aversion toward risk that makes water resources agencies so reluctant to innovate and to be satisfied with incremental change. In practically every case in which we asked for an explanation of criteria against which adoption of significant change might be measured, we were told that innovations had to deliver results that were no worse than current conditions. It was not acceptable, for example, for a utility to adopt a water treatment technology which would, in the long run, result in better water quality, if, in the short, run a visible sacrifice was made in the smell, clarity, or taste of water supplies to households. Delivering “junky” water, even if perfectly safe to drink, might well provoke the kind of public outcry that water utilities wish most ardently to avoid.

A further basic requisite for any innovation is that it be compatible with the current craft skills of the organization. As we explained in Chapter 2, water management is as much craft, as science, and agency officials talk frequently of it taking years for a new official to get used to a water system. The place specific nature of watersheds combined with the longevity of infrastructures means that operators must be sensitive to and adjust to idiosyncrasies. While a lot of ideas and technologies are copied from one utility to another, and there is an industry standard of good practice, most new techno-scientific changes are vetted by “old timers” before they are put into practice. If they do not “feel” right, that is they are not compatible with the “way things need to be done here,” innovations remain on the shelf rather than in service. One person we interviewed related a story of how he had acquired some data regarding stream flows over the Internet. A long time colleague looked not just at the averages and variance, but also at the daily numbers and said something was wrong. He was aware that the creek referred to never ran at the reported level during July. As it turned out, some of the data had been entered incorrectly, leading the interviewee to conclude, "you have to know your own system."

Sources of Innovation

The existence of an established technology or well worked through idea is a precondition for innovation among water agencies. Conservative organizations are not likely to enter pathways of change without well-informed conceptions of the benefits and details of the change. Incremental change may well originate from the inside, and as long as the agency is moving away from where it has been and stays on the same trajectory: a rich information base of experience is available. Emergency preparedness for El Niño in the Orange County Sanitation District, for example, involved the adoption of a high-flow emergency response plan utilizing color codes to relate to forecasted and actual conditions and required preparations and actions. This innovation was a large change from normal seasonal and storm preparations, but was an extension, not a replacement, of activities. Procedures emerged from discussions among staff within the organization. When asked about innovations, water agency officials frequently responded with claims about the numbers of new patents held by the organizations for devices invented to solve on-the-ground problems. Such devices were mainly mechanical alterations that made improvements in ongoing operations.

New techno-scientific changes enter water agencies from sources outside the organization, such as universities, think tanks, and consultant firms. The operational missions of most water organizations do not include much emphasis on research, and the kinds of people employed in water agencies are not often research oriented, neither does their job description encourage the development of innovations. There are, of course, a number of important exceptions. The National Water Resources Research Institute (NWRI) within the Army Corps of Engineers was set up with the specific charge of discovering means to improve the Corps' performance. The NWRI not only employs researchers, but augments its capacity by regularly employing visiting scholars from universities who bring with them the latest thinking from the academic world. The water resources research community, outside the kinds of agencies we talked to in this research, is large and diverse. Water is an important subject in a variety of academic disciplines and programs, and there are interdisciplinary water resources research centers set up at most land grant colleges. The Universities Council on Water Resources publishes a journal, hosts an annual meeting, awards prizes to members for their contributions to research, and lobbies the federal government to increase water resources research funding. Water research is applied science, and academic attention is directed toward making new discoveries that have real world implications.

Graduates from universities with advanced degrees in water related subjects, who do not enter the teaching profession, are hired by research organizations and consultant firms. The Washington DC think tank, Resources for the Future, has housed many water resources researchers, mainly economists, for nearly half a century. The largest number of water researchers with doctorates outside academic institutions can be found in environmental and engineering consultant firms, including such huge organizations with offices worldwide as Dames and Moore or CH2M Hill. There are thousands of smaller firms. These businesses have not only their services but often their products to sell. As a consequence, there is a good deal of outside push from consultant firms, think tanks, and universities upon water agencies to adopt new technologies. Innovations, therefore, tend to driven by changes in techno-scientific capability rather than decision-maker need. The push comes from the research community rather than the pull coming from the conservative water industry.

Context for Innovation

Water agencies are risk averse, but the context in which these organizations find themselves makes it risky not to engage in some innovation despite their reluctance to abandon tried and true methods. When asked what precipitated significant changes in agency operations, water agency officials we interviewed responded very frequently that events occurred which required them to change, often by bringing them to public attention. The drought, which lasted from 1986 to 1992 in the Colorado River Basin, was credited by many for initiating a number of changes. The failure of standard operational procedures to perform as they should caused a search for alternatives. Examples of such failures include the poor quality water which came out the taps of water customers of one utility, and the inability of a waste treatment plant to get rid of its effluent during high rainfall and high tide events. A fire in Oakland Hills compelled state-wide emergency management upgrades in California. Population growth in the Potomac and in Southern California forced agencies to address impending shortages of water supplies. The increasing salinity and unreliability of Colorado River Water necessitated the search for alternative sources. An outbreak of pfisteria that killed large numbers of fish put water quality on the front burner in Maryland. The deregulation of the electric utility industry has changed the opportunity and risks associated with hydropower generation at a number of facilities. The vulnerability of declining fish populations in several locations has forced water agencies to make changes to protect their habitat. Clearly, warnings of impending El Niño related storms initiated a number of significant changes among water agencies in California.

The mounting difficulties water agencies face in serving multiple and partially conflicting goals, many of which were summarized in chapter one, suggest that the climate for innovation by water agencies is improving. Growing competition for the benefits associated with water will make water agencies search for ways to continue to provide reliability and quality at reasonable cost. Even if there turns out not to be any techno-scientific improvements that can substantially relieve the pressures under which water agencies operate, they must appear to have been open to all reasonable alternatives.

External Drivers for Innovation

Environmental and health regulations were frequently mentioned as agents for change. The legal requirement of the Chesapeake Bay Program to make a 40% reduction in phosphorus and nitrates loading, which led to large scale modeling and monitoring efforts, is illustrative. We encountered frequent references to the Endangered Species Act and the extent to which water agencies had been forced to make accommodations to the strictures of the law. Water deliveries to the Central Valley of California were interrupted for a considerable period because Delta Smelt were being drawn into the intake valves of pumps. Such problems are leading to a basic reconsideration of policy and organizational issues though the CALFED process. The clear failure of some environmental regulations has been cause for innovation. The poor coastal water quality in Southern California, in the face of huge expenditures in large urban waste treatment facilities, led to a recognition of and increased emphasis upon identification and control of non-point sources of pollution. While many water agencies are themselves environmental regulators, environmental regulations tended to be identified as "external" drivers. Very often new regulations emerged from litigation, citizen suits, and popular referendums. A consent decree, for example, forced an expensive upgrade of Washington DC's Blue Plains waste treatment plant that otherwise would not have been funded. The California Coastal Zone Commission was the result of a citizen initiative, and while clearly a water agency, it has an outsider role in promulgating regulations that impose innovation upon other water agencies. The ratcheting up of water quality and wildlife protection regulations by some water quality and environmental agencies means that routines and standard operating procedures of other water supply and waste treatment agencies need to be continually reexamined, altered, and sometimes changed innovatively.

Court suits are another external driver. Most of the river basins in Southern California have been adjudicated and allocations are monitored by court appointed water masters. The threat of court battles is widely used as a weapon in negotiations among local water agencies. To be on the losing end of such a suit limits the options of a water agency and often dictates large change. One California informant explained that while an upstream utility probably had the right to reclaim discharges from their waste treatment plants rather than allowing wastewater to flow downstream into a neighbors recharge basin, such action would result in an expensive court suit neither party could afford to lose. When the Metropolitan Water District in California lost a court battle to impose high wheeling charges for buyers and sellers using its facilities as conduits to convey marketed water, the MWD responded quite innovatively by announcing that the huge agency itself would move into the water marketing business.

Decisions by courts and regulatory agencies are governmental sources driving innovation that can be classified as political. There are other drivers that are political in the sense of mobilizing popular support or opposition more directly. Pressures for change can come through governing bodies and advisory boards. As a result of an incident involving delivery of poor quality water through the Washington Aqueduct, the Corps of Engineers was placed under scrutiny by an investigative committee of the Metropolitan Washington Council of Governments (MWCOG) which operated between 1995 and 1997. The subsequent MWCOG recommendations made the Corps responsible to a series of advisory bodies. The high price of water charged by the Washington Suburban Sanitation Commission has increased the visibility of the agency to uncomfortable levels and raised the prospect of privatization as a real alternative. The annual budget cycle has become for this agency, and some others we talked to, a forum for public exposure that may result in significant changes in direction. Raising charges of any kind elevates the visibility of water agencies and the potential for increase in public pressures. The desire to raise replenishment fees to member utilities was one of the drivers for a new Municipal Water Utility of Orange County Comprehensive Plan.

The periodic review mandated in laws requiring updating of plans or reauthorization of legislation can lead to public exposure, reframing of issues, and the adoption of innovations. The California State Water Quality Control Board must update its California Oceans Plan every three years, and the obligation provides the agency staff, advisory committees, and commissioners opportunities to suggest changes. The quarterly meetings of the customer advisory committee, financial committee and technical committee which oversee the Washington Aqueduct keep the Corps accountable and provide some venue for new initiatives.

Political pressures emanating from one water management institution may be drivers for innovation in others. Initiatives by the Irvine Ranch Water District to supply water to its expanding service area has caused the Municipal Water District of Orange County to engage in a long-term planning effort to assess what such annexation would mean for water quality and water rates for other municipal water utilities within the district. Agencies serving the Central Valley in California, as well as environmentalists, have put pressures upon municipal water utilities that would prefer to have more water directed southward from the State Water Project to demonstrate the efficiency of current water management. This pressure has increased efforts in demand management and conservation which might not have otherwise occurred. One informant talked about the "sympathetic" droughts that occur in Southern California when real drought hits the north. Forced to export water, even when supplies are scarce, northern Californians are especially likely to be critical of imprudent use of water at such times. Consequently, municipal water utilities in the south step up visible conservation activities to forestall campaigns to reduce exports through the State Water Project.

The political cover provided by the 1997 El Niño, called "El Media" by some we interviewed, allowed a number of agencies to do things they had long wanted to do, but lacked the resources. The added attention given to emergency planning before and during the El Niño season led to significant and sustained organizational changes. The opportunity to gain political credit led elected leaders to compete with each other in California by urging new investments in physical and organizational infrastructure. The capacity of water management agencies to deflect any blame for expensive and time consuming preparations in the event El Niño failed to live up to its media billing is the key to their willingness to innovate in this case. Agencies could point to politicians under whose mandate such preparations were made, and politicians in turn could blame the scientists who certainly sounded the warning, but had little influence over the particular measures adopted in response. A conference held by prestigious scientists at the Scripps Oceanographic Institute during which reputable scientists warned of a severe El Niño contributed a good deal to making extraordinary preparation measures credible.

Nominations and appointments of new members to governing boards, commissions, and advisory bodies may alter the political signals received by water management agencies and lead to change. Who gets to make such appointments is important. The California Coastal Commission, for example, was shielded from a change in direction that might have been initiated by appointees of a unsympathetic governor, such as Pete Wilson, by the fact that commissioners are chosen not just by the governor but also by the leaders of the legislature. The need to satisfy conflicting goals of multiple member boards can be both an incentive and a constraint to innovation. The Washington Suburban Sanitation Commission reports to six commissioners, three from Prince George County and three from Montgomery County. As part of compromises struck among commissioners, who often do not agree, the utility finds itself putting in hiking trails and other facilities not really associated with its objectives. Further, stalemates can occur. The need to forge consensus on the governing board of the Chesapeake Bay Program has sometimes led to least-common-denominator kinds of solutions.

Internal Drivers of Innovation

While water management agencies admit to being conservative when it comes to taking risks concerning core goals of reliability, quality and cost, they are determined not to be thought of as backward or not up to date technologically. Agency identity, notion of self worth, and professionalism are all bound up with keeping current. Moreover, should problems arise, it would be enormously damaging for utilities to be vulnerable to charges of having allowed their technology or organizational procedures to have become antiquated. There is a "keeping up with the Joneses" pressure upon water management agencies. If one water utility in an area begins to use Geographic Information Systems to map locations of its service lines, then other utilities in the general area are likely to feel they need GIS capability as well, even though the technology requires expenditure on software, data entry, upkeep, and operator training. One water utility official spoke to us about wanting "bragging rights" to claim that his was the most advanced municipal water utility in the region and perhaps the nation.

Individual agency officials we talked with were anxious to avoid being caught in error, and consequently eager to make improvements when possible. Despite competition among agencies over reputation for excellence, water engineers feel as if they all belong to the same fraternity and treat each other like colleagues. One federal agency planner told us he was forced to admit that he mistook the possible effects of a new flood control dam upstream upon a downstream structure for which he was designing an enlargement. He treated challenges to his work as professional peer review, and while he found flaws in the criticism to which he was subjected, he willingly altered his analysis.

Water management agency professionals are graduates of universities to which they often maintain ties. They turn to former professors when awarding grants, consulting contracts, and in seeking advice. They attend professional meetings, such as the American Waterworks Association, where they listen to research papers and look at displays of latest advances in water technology. They read professional journals and newsletters. When technological or organizational innovations are introduced with the imprint of a respected source of professional expertise, they are especially likely to get attention and serious consideration. A senior specialist in planning in the Metropolitan Water District in Southern California explained how he and his colleagues introduced a substantial innovation into their modeling of water supplies and demand by putting into practice ideas to which they had been introduced at a professional meeting. Their effort was facilitated by a contract to a hydrology professor at a prestigious state university. They explained their willingness to consider significant modifications of what had been longstanding ways of doing things by their training in economics which made them more sensitive to the importance of demand forecasting. These resource specialists were also new to the organization. Recruitment of new blood into the organization brought along the latest training and was identified as a source of innovation in a number of organizations we studied. For example, each significant departure from previous modes of analysis performed by the Interstate Commission on the Potomac River Basin could be associated with the turnover in a junior staff position. A succession of new people brought the latest methods directly from the graduate school classrooms into the agency.

The Interaction of External and Internal Drivers

The adoption or use of a techno-scientific innovation very often is the result of interaction between external and internal drivers. Pressures from outside for a particular change are most likely to be effective when there is support building from the inside. On occasion interactions between outside and inside become so complex that it is difficult to distinguish the source of drivers. This was the case we encountered in Sacramento where a number of offices of different agencies were located in a single building. Informants from the Bureau of Reclamation, California State Department of Water Resources and the National Weather Service River Forecasting Center were unanimous in their contention that co-location had greatly enhanced information transfer and reciprocal influence.

Figure 3.2. portrays the interaction of external and internal drivers of innovation in water agencies. The diffusion of programs providing subsidies and rebates for installation of low flow toilets is an example of the reinforcement of innovation, which comes when external and internal drivers are combined. The extended drought in the Southwest between 1987 and 1992 caused a large number of municipal water utilities to consider demand management alternatives. Municipal Water Utilities, which had previously relied on developing sources of new supplies, began to hire staff whose job it was to encourage conservation. While some new staff members were people in public relations, others were water professionals trained in multiple methodologies for reducing water use. Research and experience extending back to the previous serious drought in the 1970s showed that a significant percentage of household water use could be reduced by placing bricks or water filled plastic bags in toilet reservoirs. Plumbing manufacturers began to market low flow toilets, and with the support of water management professionals, such appliances were made mandatory in new building construction in many cities.

The difficulty was to convince homeowners to replace an existing functioning appliance. Since the cost of water is so low, there is little financial encouragement for the homeowner to make such a change without extra incentives. Outside pressure from environmentalists, often expressed through members of city councils, resulted in a number of new municipal ordinances that subsidized or fully funded the costs to homeowners of replacements. These regulations were fully supported and often initiated by water utilities. In response to our questions about innovations, several individuals we interviewed mentioned toilet replacement programs as evidence of the progressiveness of their organization. While such programs are expensive and opposed by many economists, they are easy for water agencies to justify. A water official need only say that the program has been tried and found to be popular and successful in many cities.

Pathways for Innovation in Water Management

There is often a huge disconnect between the science activities within water management organizations and actual policymaking. Water agencies expend an enormous amount of time collecting and analyzing data of all sorts, yet it is often not clear whether or how this information is actually used. Moreover, some uses seem very far removed from policymaking. Water management organizations are required by law and practice to produce numbers of documents including periodic updates of plans, regulatory compliance reports, projections of alternative futures, annual reports, environmental impact statements, and economic impact assessments. In any large water organization, dozens of studies are ongoing simultaneously. It is often very difficult to ascertain what difference all this analytical effort actually makes. In numerous interviews, when we asked analysts what happened to the data or reports they produced, they would respond with some variation of, "I gave it to my boss." When we asked what the organizational superior did with the information, we were typically told that it went into a report, or became part of agency records.

In a similar vein, chief executive officers and other top officials we talked to in water management organizations were similarly unable to tell us how analysis and scientific activities actually informed their decision making. For example, we were told that a master plan produced within a regional water district was used as "a bible" by member utilities. But when queried as to what that meant, it appeared that the document was used as a source of data and facts, not as a guide to action. It was far from clear that member agency behavior was at all changed by the plan. The left side of *Figure 3.3* portrays, by the use of a broken arrow, the uncertain pathway between techno-scientific adoption or use and actual agency change.

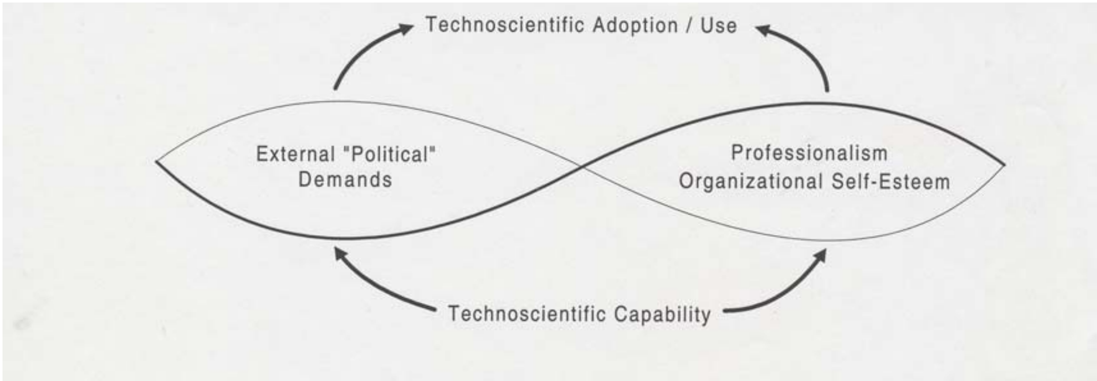


Figure 3.2 DRIVERS OF INNOVATION IN WATER MANAGEMENT AGENCIES

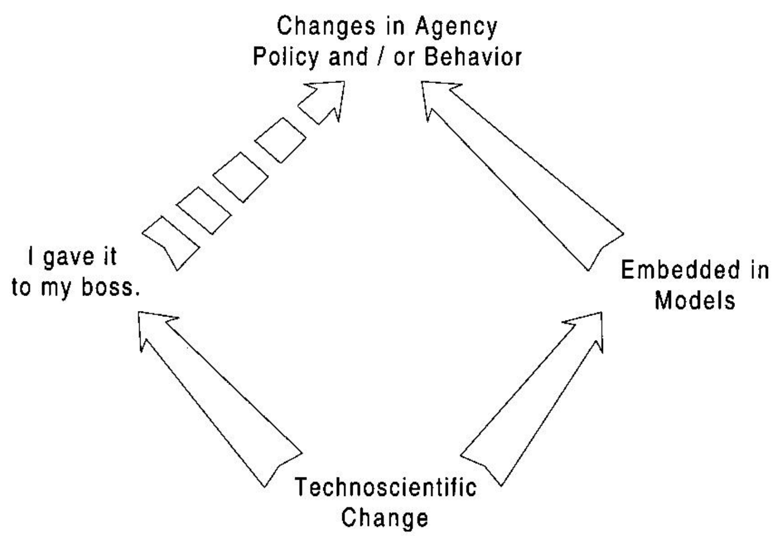


Figure 3.3 PATHWAYS FOR INNOVATION IN WATER MANAGEMENT

There is another, stealthier, pathway for actualizing agency policy or behavioral change. There are various routines or models upon which agencies regularly depend in their operations. The builders and guardians of these models are the highly trained professionals who make the defining assumptions and establish the relationships among variables required to construct a model. Relatively large changes can occur in the kinds of assumptions, data and even models themselves without top executives or decision-makers necessarily knowing or caring. So long as everything continues to run smoothly, and a good quality water product is delivered cheaply, there is little reason for top administrators to question detailed operational issues. We were told by a number of modelers and resource specialists that higher level administrators depended upon, but did not really understand, their work. The right side of *Figure 3.3* illustrates this pathway of change.

In 1992, the Metropolitan Water District in Southern California undertook to integrate demand and supply into a single model. While such models were common in the electric power industry, they were not used in water agencies. Previously, historical data were used to estimate demand separately. Between 1992 and 1996, two new integrated resource planning models were developed in quick succession with the help of a consultant from the University of California at Los Angeles. As a consequence of these models, the MWD was able to convert itself from a pass through agency, with little prior knowledge of what supplies or demands it might face, into an active overseer. While top management, which was experiencing rapid turn over, may have been cognizant of the change, it is unlikely they knew or cared much about the mechanics of the modifications.

The window or gateway for innovation in water management agencies is narrow and difficult to pass through, as is indicated by the small boxes in *Figure 3.4*. One visible route for innovation is the crisis pathway. Changes that take this course begin as techno-scientific changes that are adopted and used, but which no one really depends upon. Much of the data gathering, analysis, and redundancy practiced for no clear purpose now may provide the basis and justification for policy change. When a crisis occurs or water management agencies are placed under unusual pressures to change behavior or policy directions, they reach down into their myriad activities and unearth something they can rely upon as a basis and rationalization for changing policy behavior, often claiming that they have been doing it all along. Big changes are therefore masked as being, at most, incremental. What was once a kind or useless, rudimentary appendage to the standard operating procedures of water agency activity becomes more robust and meaningful.

An example of crisis innovation is the conservation rate structure adopted by three small public water utilities during the drought in the early 1990's in California. The Otay Water District, City of San Juan Capistrano Water District, and the Irvine Ranch Water District adopted a highly unusual conservation rate structure. Rather than a cost of service structure, which is standard for public utilities, this rate structure funds all current operations by the base rate. The conservation rate structure is therefore revenue neutral. However, each water sector is allocated a conservation use target. For example, residential target use is based on a combination of factors among which are size of the

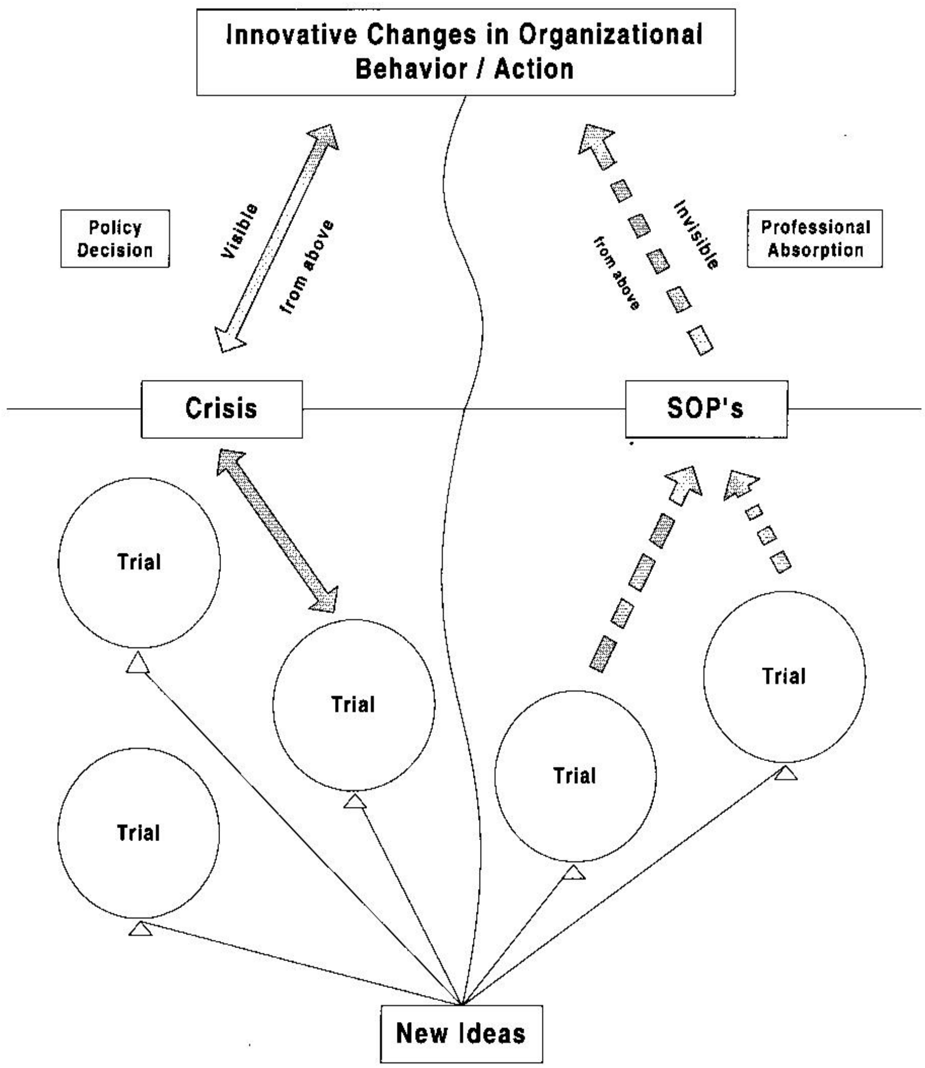


Figure 3.4 PATHWAYS TO INNOVATION

lot, housing characteristics, and daily calculations of evapotransporation. Customers using over the target are assessed sharply escalating penalty fees. When first implemented as a kind of emergency measure during the drought, some residential customers so far exceeded their target rate that they were billed as much as $300 a month.

This rate structure has continued to be in force, with what informants called a lot of "wiggle room". One utility assesses penalties to only 1-2 percent of customers. However, work proceeds to define and allocate the conservation water rate to different sectors of water customers including utility cooling towers, hotels, and hospitals. Because the rate does not have much bite and seems, on its face to be fair and science based, it is seldom challenged. Should serious drought require significant reduction of demand, it is anticipated that the wiggle room in the conservation use targets will be substantially tightened. Rather than an across the board water rationing that is more traditional in the industry, these utilities will engage in much more advanced demand management methods. The long track record, however, will likely make them appear to be business as usual.

Water agencies are highly resistant to making changes that involve any risk to their ability to meet goals of reliability, quality, and low cost. They are highly concerned with minimizing the maximum loss in core values. Moreover, they avoid shifts which would bring public attention to their activities. Yet, the changing context in which they work requires that they make constant and sometimes large adjustments. One of the avenues, therefore, through which necessary change is possible is the stealth pathway through modifications to standard operating procedures. Such routinized change is most likely to simply go unnoticed, and slip through the gateway without problems. Innovations appear to be business as usual.

The Potomac River Low Flow Agreement is another example of this stealth pathway to change. At the time of our interviews, the emergency conditions which would trigger this agreement had never occurred. In the meantime, however, the staff of the commission had steadily updated the twenty year plan required in the agreement, engaged in drought prediction and coordinated drought exercises. The commission has authority over several jointly held reservoirs, regularly produces forecasts, and conducts 8-10 day real time drought exercises to maintain regional preparedness. Over time, federal agencies and municipal water utilities have become dependent upon the commission for information and for drought related operations. Drought planning and management engages a quite different and more cooperative decision making structure than do the day to day fragmented multiple utility operations. Should a catastrophic drought occur, a quite innovative structure would be engaged, but may not be perceived as such.

These stealth pathways explain why so many of our respondents emphasized how long it took for a water management agency to bless the use of a new idea. Change, we were told, only comes if an idea has been routinized into the culture of the organization over time and experience. The gestation time for a new idea to affect policy was estimated by one respondent to be somewhere between ten and twenty years. Alternatively the accepted venue for overt adoption of an innovation is typically the solution to a problem situation that is not adequately dealt with by standard operating procedures. The tool kit water decision makers turn to when what they have at hand will not do the job is likely to be something picked up for a variety of reasons some time ago, got familiar with, but never put into full use.

Locales of Innovation

Contrary to much organizational literature, we found no relationship between size of organization and propensity to innovate. While it would seem logical to expect that only large organizations might have the diversity and the redundancy that characterizes innovation in water management institutions, this turned out not to be the case. Instead, we found that the presence of organizational resources was more critical. Rich organizations with wealthy customers can afford to try out techno-scientific changes while continuing to perform standard operations without much sacrifice. Less well off agencies were more likely to tell us that they had wanted to try something new, but simply lacked the time, people, and money. The age of organizations may well matter. Relatively new municipal water utilities, like the Irvine Ranch Water District, which is building its infrastructure from the ground up, can implement such things as dual delivery systems, one for potable and the other for irrigation water. People open to new ideas can be recruited to organizations of any size or age, but some moderate rate of turnover would seen to have a positive relationship to trying out new ideas.

Conclusion

In summary, we can say that US water resource management organizations face many counter incentives to innovation which always carries the danger of attracting unwanted visibility. Water agencies are highly resistant to making changes that involve any risk to their ability to meet goals of reliability, quality and low cost. They are highly concerned with minimizing the maximum loss in core values. Moreover, they avoid shifts which would bring public attention to their activities. Yet, the changing context in which they work requires that they make constant and sometimes large adjustments. One of the avenues, therefore, through which necessary change is possible is the stealth pathway, through piecemeal modifications to standard operating procedures. Such routinized change is most likely to simply go unnoticed, and slip through the gateway without problems. They appear to be business as usual. Where it occurs, innovation is likely to be incremental and buried in changes within the black box models and other information tools that are serviced by technical staff. This conclusion strongly suggests that the incorporation of climate forecast information is unlikely to occur as an explicit, wholesale innovation. If it occurs at all, it will be more likely to be adopted piecemeal by cautious, gradual incorporation in existing models, and tools such as streamflow models, and will not be visible either to users of those models or decision makers. We turn to the topic of managers' current perceptions of the usefulness of climate predictions in the next chapter.

Chapter 4: Why Water Managers Don't Use Climate Forecasts

In this section, we review what water resources managers told us about why they don't use forecasts and how they might use forecasts in the future. A first level analysis of our data suggested the following results, which were presented in our interim progress report to NOAA and various presentations to research institutions and scholarly meetings:

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 minutes 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 stream flows.

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 web site 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 California Governor Wilson.

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 three to five day forecasts were adequate to prepare for storm events and if they were going to spend money (that they didn't 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 (five or more years) showing that the probabilistic forecasts are more reliable than the forecasts they currently use.

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.

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, as described in chapter 2. These include the 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 region 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. 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, 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 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 were 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 regarded their constrained situation as unique to their sector and 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 different from the present. Most of us can only describe a future that is primarily more (or less) of and/or better (or worse) than 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 change what we have now 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 jobs 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. Hypothetically, they 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 couldn't exactly name what the usefulness might be. At one site, for example, a respondent described how new technology - global satellite images - allowed for the production of immense amounts of data about snow pack. He chuckled when he compared this new technology with the old - having the reservoir superintendent go up into the mountains and stick a marking pole in the snow at various sampling sites. When asked, he could not offer any evidence that the new information was more accurate or more useful than the low-tech readings. But, he was sure that the new method was better because it provided more data.

The Perceived Reliability of Forecasts

The most frequently offered reason for not using probabilistic climate forecasts was that they are unreliable. However, our experience confirmed 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 level of reliability of 90% 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 three 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 (upon which they were actually based). However, his contractor delivered forecasts every Friday at 4:00 pm, 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 stormwater infiltration) also told us that they had executed those very measures in response to public concern during the 1997 El Niño event.

Although most respondents' ideas for future use of the forecasts were extensions of current practices, a few were able to suggest how reliable forecasts might significantly challenge one of the sector's highest values: ensuring enough water for multiple uses. By answering questions about the quantity of water available in the short to intermediate term, water infrastructure could be managed with less redundancy, thus freeing otherwise impounded water for other uses, such as wildlife and recreation.

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). 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 priority for the organization.

Although most respondents' ideas for future use of the forecasts are extensions of current practices, a few are able to suggest how reliable forecasts might significantly challenge one of the sector's highest values: ensuring enough water for multiple uses.. By answering questions about the quantity of water in the short to intermediate term, the forecasts could be used to justify reallocations for other uses.

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 two to three 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 isn't 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 three 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.

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 to 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. Both of these 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 wide-spread 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.

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, skillful forecasting because he can claim that uncertainty in the forecasts mean that they don't 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, in principle, 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.

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.

Summary of Initial Conclusions

The 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

The research essentially confirmed 1994 pilot study regarding both the structure of decision-making in water resource management and regulation and the career of new information, of which probabilistic climate information is an example, within management organizations.

Specifically, we found that scientific and technical information is indeed treated as only one input into decision-making. 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. Externally generated scientific information is likely to be even less influential in decision making unless it is incorporated in internal reporting in a fashion that renders its origins almost invisible to its ultimate users. Translators, whether on staff (especially newly recruited graduates) or employed as external consultants, play a key role in getting information into organizational decision processes.

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, thus confirming our expectation that managers will formulate negative perceptions of information reliability will hinder acceptance if it indicates a departure from past experience.

With respect to organizational decision processes, 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.

Indeed, the organizations that we examined used information for many purposes, including instrumental problem solving, guidance on new conceptual ideas, and political support or refutation of ideas and positions. There was strong confirmation that various stakeholders adhere to traditional or improved forecasting methods selectively to promote their respective interests and agendas. In particular, we convincingly confirmed that resource managers will 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.

Such an account of institutional decision making suggests a dramatic departure from the purely 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.

Recommendations

Based on these findings we offer the following recommendations to those working to enhance the application of climate forecasts:

1) Seek to develop ways to convey information in appropriate language about what the forecasts are and what forecast capabilities might be. Multiple "translations" of forecast information may help dissemination and implementation of the forecasts. Translations for certain audiences (e.g., managers, non-technical decision makers) must include not only user-friendly language, but also guidance on how to interpret the forecasts and ideas of how the forecasts may and may not be used.

2) Find ways to talk about significant opportunities for probabilistic forecasts to make a difference in the way users do their business. Early adopters in organizations can help describe these opportunities so they can be translated for others in site-specific ways. Do not measure forecast performance by dollar value of current use in systems.

3) Learn to live with the fact that potential users do not clearly distinguish between climate and weather. Focus on producing forecast products that are relevant to the temporal and spatial scale of their decision making irrespective of their underlying methodology.

4) Accept the fact that improved forecast reliability will not necessarily lead to greater forecast use. Timing and form of forecasts, and access to expertise to help implement the forecasts in decision-making processes may be more important to individual users than improved reliability.

5) Remember that decision-makers will balance desire for high skill with public attention. Periods of heightened public concern (e.g. about an El Niño event) present opportunities for innovation.

6) Improve the weather variability forecast skill at 10-day timescale, focusing on increasingly finer spatial resolution at the watershed or basin resolution. Even finer spatial resolution, at the 4th- or 5th-order watershed, may be more valuable to our respondents than highly reliable general forecasts. Climate trend forecasts, (e.g., continuing drought over multiple years) may be more useful for long-term planning than variability forecasts.

7) Expect established agencies to challenge the accuracy of forecasts and to resist forecast use in the near to medium term as they may be perceived as challenges to their decision authority. Innovative applications are more likely to appear in those organizations with fewer options for managing the resource.

8) Seek to routinize forecasts through their incorporation into professional and industry wide standards. Forecasts will be used regularly when they are not perceived as institutionally, organizationally, or personally risky by users. Work closely with legitimating agencies to disseminate information about the forecasts and with individual users at specific sites to integrate forecasts into existing models or other decision-making tools. In other words, present innovation as an extension of established routines and procedures.

9) Expect widespread adoption to be a relatively slow process (15-20 years), dependent not only on the skill level of the forecast but also on the "peer" and "practice" review of the water resource sector. Also expect that integration can be practiced with willing partners.

10) Distinguish between situations in which the reduction of uncertainty will support existing goals and members will seek out more reliable information from those in which continuing uncertainty supports organizational members' ability to deal with mutually exclusive goals. Focus efforts on the former.

Conclusion

These findings, conclusions, and recommendations, confirmed by the focus panel of industry insiders, seems credible, and potentially useful in guiding those seeking to apply probabilistic prediction of climate variability in the water resource sector. However, upon deeper analysis of the data, we concluded that our initial analysis left many unanswered questions and unsatisfactory gaps in our understanding. We also became increasingly concerned that the pace of improvement in the forecasting technology that characterized the decade prior to our proposing this research was not being maintained during the period that we were conducting it. Our perspective on the problem that we were addressing changed from one of "How to interject climate forecasts into current water resource decision making?" into one of "How can the water sector increase its flexibility and adaptability to climatic variations in the face of increasing physical constraints (including a growing gap between demand and sources of supply) and institutional change (including pressures towards privatization of water supply)?" Telling people how to get climate information into the current system of decision making is inadequate because the system is changing in potentially profound ways. Since some members of our research team studied organization of innovation among electric utilities in the early to mid 1980s, we are acutely aware of the pitfalls of evaluating the usefulness of tomorrow's information in the context of today's institutions. In the final chapter of this report, we will sketch out a conceptual model of change in the US water resource management regime over the next two decades and to assess the implications of such changes for the use of climate information.

Chapter Five: Back to the Future

In Chapter 2, we described how the field of water resource management has traditionally responded to uncertainty through infrastructural and institutional complexity and conservativism. In chapter three we described the plausible innovation paths through a complex and conservative industry and regulatory structure. Chapter four presented a snapshot of the industry as it is presently constituted and assessed the potential for climate forecast use in that context.

Our final chapter brings us full circle, back to the problems of institutional responses to uncertainty. As we delved deeper into the potential use of climate forecast information, we uncovered three institutional strategies for managing uncertainty, each of which has interesting and important implications for the future development of water resource management in the US. Each strategy carries different implications for the future use of climate forecast information.

However, these three strategies are not simple alternative paths along which the field of water resource management might evolve. Neither are they distinct developmental stages through which the field can be expected to pass. They are rather coexisting strategies, depending on different types of expertise, that play off each other in complex ways that we tend lose sight of as soon as we try to identify and describe them. Each may become a dominant mode of operation as circumstances change. This final chapter is a retelling of the story we have already told. It draws on the same data. Only the interpretation is different. Whereas the story so far presents a static snapshot across the water management sector, this chapter teases out the dynamics of institutional responses to uncertainty among water resource managers. We present three modes of response to uncertainty in the natural system an increasing incompatibility of expectations in the social systems that together constitute water resource management.

The First Order Mode

The first mode for managing uncertainty in water resource management involves the reduction of natural system complexity to reflect only those purposes which humans at a particular time and location deem essential. Water becomes a resource to serve domestic, agricultural and other needs. The human tasks to which water is dedicated become defined as the missions of particular agencies and the geographical and subject matter jurisdiction of agencies are established to serve these fairly narrowly defined purposes. Municipal water agencies and irrigation districts are bounded by the service area of their customers. These organizations focus upon removing as much risk as they can to those whom they serve, regardless of the impacts to others outside their functional and geographic jurisdictions.

The kinds of experts who characterize the first order organizational response to complex water problems tend to be engineers to create infrastructure, lawyers to secure water allocation rights, and economists to develop equitable and/or profitable allocation schemes. One prominent water consultant noted:

> When I went to work for the California Division of Water Resources in l953 the staff consisted of several hundred engineers, one or two economists, no water quality professionals, no biologists, (ecology was not yet recognized) no political scientists, and no land use planners.

The solution set for experts with such limited backgrounds tend to be the construction of structural facilities such as dams, reservoirs, canals, levees, and pipes, all designed to reliably deliver water to the clients of the agency.

The organization of water agencies in the first mode to uncertainty is hierarchical with clear lines of responsibility. Challenges to organizational hierarchies in the first mode come horizontally, from other parallel organizations, and not from the bottom of the hierarchy or the grass roots. Competing hierarchies challenge each other over the control of the resource and the imposition of their particular narrow vision. Such battles are often fought out in the courts to determine the allocation of water rights. Like their fellow engineers who dominate organizations in the first mode, the solution set of water lawyers and judges is limited. They see the allocation of secure property rights as the means to reduce risk and impose order upon variable water in nature. Organizational boundaries are defended or enlarged on the grounds of legal authority.

The vision of water in such organizations is of a benign and controllable resource, given the appropriate organizational resources of authority, expertise, equipment and money. The engineers' perspective is that water is simply a product that can be manufactured to the customer's needs through the application of technology. The lawyer's vision is that water, like land, can be owned and that rights and responsibilities of individuals and agencies for management depend upon the application of laws, legal precedent and reasoning. The notion that all water problems have a solution is exemplified in the response of an experienced water official who we asked if aridity was the ultimate limit to growth in Southern California. After explaining the redundancy in the constructed water system in which multiple sources of supply existed, he stated that there was plenty of water in the ocean, and that desalinization was becoming more technically feasible and less expensive. By the time population growth pressed close upon available supplies, desalinization of seawater would be an attractive source.

The notion that nature is controllable leads hierarchical organizations to enlarge jurisdictions, pyramiding one water agency over another where mutually convenient. Multiple agencies often cooperate in the pursuit of additional sources of water supply. While some agencies may prosper much more than others in such arrangements, agreements are rationalized on the basis that there are no losers and it is simply a matter of relative gains. As the size of water systems increases in terms of numbers of participating agencies and geographic spread, the potential for unintended and negative side effects also increases. Such side effects are translated into limitations upon the exploitation of particular water sources. A search is then initiated to identify additional sources. The result becomes very large systems with many redundant sources of supply and very serious side effects.

The products of the first mode response to uncertainty are large-scale engineering structures and compacts, court decisions and laws that allocate and manage water in highly inflexible ways. The consequences of structures include high levels of damage to the environment and to other interests not taken into account in narrow decision making processes. Such structures permanently alter the natural environment and have many irremediable long-term consequences. Legal instruments very often are blind to the equity claims of indigenous and disadvantaged populations. Adjusting laws to better reflect equity is very difficult because of the resistance of various advantaged interests. Laws build up expectations that are later very difficult to disappoint.

The values of agencies in the first mode are very narrow, clear and specific. Agencies are interested in fulfilling their own missions, and take notice of other affected parties of the water policies they pursue only when such effects are likely to impinge on their own success. On the whole, water agencies ascribe to what might be termed the "dental theory of agency administration". That is, they pursue painless administration and eschew any kind of public controversy. The fundamental importance of water to survival, growth and development means that water should never be raised to the level of public controversy. This is especially the case when it comes to reliability of water in arid lands where water is thought to have a kind of "Midas touch." Cities that have secure water supplies have a future, while those without it are doomed to dry up and blow away.

A classic example of first mode is to be found in the water history of the City of Los Angeles and Southern California. As early as the 1870's the City of Los Angeles laid claim to the total supply of the Los Angeles River. The city declared war upon upstream users, and won a series of court victories. What it could not achieve through the courts, it won by an aggressive campaign of annexation. Expanding the city's boundaries was at once seen as a way of justifying - indeed requiring - more water to build an even more magnificent metropolis. As one official noted, "if you don't get the water, you won't need it." As we described in chapter two, this expansion required massive physical infrastructure and evolved a tangled web of institutions charged with overlapping jurisdictions and claims.

As established in earlier chapters, water resources agencies are reluctant to make large changes or to take risks. Practically every agency official we talked to articulated some version of the following statement made by a municipal water utility director: "We cannot optimize. We must be conservative in our decisions to protect the public health." 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. 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, as described in Chapter 3, most of the "cutting edge" organizations engaged primarily in incremental innovation, tweaking the existing structures to address problems as they emerged. Innovation has a positive connotation, and few agency leaders would admit to not being innovative. In talking to agency officials, however, we quickly learned that what many identified as important technical, organizational or behavioral changes, were more accurately characterized as incremental modifications. Incremental change involves an agency action very much like what has occurred previously, except to a greater or lesser degree. Such change does not involve movement to a different order of response to uncertainty. Movement to the second or third orders of response to uncertainty, described below, requires discontinuities of values and practices. Incremental change is of a lesser degree. For example, included among the incremental changes cataloged by interviewees were the purchase of additional sand bag filling devices in preparation for El Niño, installation of propellers in reservoir tank structures to discourage the build up of bacteria on reservoir walls, and the acquisition of a silt removal machine to improve recharge in infiltration basins. Incremental innovation can also involve growth and expansion of organizations and rearrangement of power relationships within and among organizations.

Aversion to risk makes water resources agencies satisfied with incremental change. In practically every case in which we asked for an explanation of criteria against which adoption of significant change might be measured, we were told that changes had to deliver results that were no worse than current conditions. It was not acceptable, for example, for a utility to adopt a water treatment technology, which in the long run would result in better water quality, if in the short run a visible sacrifice was made in the smell, clarity or taste of water supplies to households. Delivering "junky" water, even if perfectly safe to drink, might well provoke the kind of public outcry that water utilities wish most ardently to avoid.

We have already described how a basic requisite for any incremental change is that it be compatible with the current craft skills of the organization. Water management is as much craft, as science, and agency officials talk frequently of it taking five years or so for a new official to get used to a water system. The place specific nature of watersheds combined with the longevity of infrastructures means that operators must be sensitive to and adjust to idiosyncrasies.

The scope and depth of change that is possible in water agencies engaged in the first mode response is quite limited. Only incremental change takes place, but such change is not insignificant and is not without possibilities for the adoption of techno-scientific ideas. Incremental changes take a long time to work their way into altered decision making. Such changes may well come from middle level technical people who can bury change into standard operating procedures. The impact of change on actual decision making can be expected to be marginal at first. Favorable contexts for innovation, such as decreasing options under existing approaches, do not translate directly into the adoption of innovations. Innovations must audition alongside existing tools for decision making. Conservative organizations have a lot of redundancy, and they are likely to adopt something that they are already familiar with, but do not yet rely heavily upon, as preferable to something new with which they have no experience.

Techno-scientific changes need to have professional credibility and it is worthwhile to invest in applied research in universities, think tanks and consultant firms. Familiarity with techno-scientific change must come before there is any chance for adoption within water management agency. Demonstrations of all kinds, at all levels of the organization, are worthwhile contributions to innovation. Incremental change in first mode is likely to be a two stage process with techno-scientific changes first taken up by universities, think tanks, and consultants, and then slowly disseminated to operational agencies.

While water agencies have the capacity to adapt to changing conditions within the confines of the first mode, ultimately incremental innovation simply does not allow for the magnitude of change that is required. The pursuit of further additional sources of supply results in agencies colliding and struggling for control over ever increasingly scarce water supplies, especially in arid areas. Moreover, all development of new water sources for human use have externalities and negative consequences to the natural environment and to water quality. The collaboration and pyramiding of water agencies becomes difficult because sources of additional supply which promise benefits to all participants become impossible to identify. The legal accommodations among agencies imposed by the courts or negotiated among parties become too rigid to respond to the magnitude of change necessary.

The problems created by first modes are too large to be resolved by incremental change. Moreover, shifts in public tastes and values result in the passage of laws which make it impossible for water agencies to continue with business as usual because there are other actors with authority that do not share or put the same priorities upon service to their narrow missions. The need to make real shifts in values and decision-making processes was acknowledged in a number of our interviews. Such pressures are leading to second and third mode responses to uncertainty, which are the focus of discussions below.

Among the agents leading to changes that go beyond the first mode are concerns for public health and the natural environment. Environmental and health regulations were frequently mentioned as agents for change. The legal requirement of the Chesapeake Bay Program to make a 40% reduction in phosphorus and nitrate loading, which led to large scale modeling and monitoring efforts, is illustrative. We encountered frequent references to the Endangered Species Act and the extent to which water agencies had been forced to make accommodations to the strictures of the law. Water deliveries to the Central Valley of California were interrupted for a considerable period because Delta Smelt were being drawn into the intake valves of pumps. Such problems are leading to a basic reconsideration of policy and organizational issues though a federal/state negotiation process called CALFED. In response to the ESA listing of salmon species in high population areas, water resource agencies in Oregon developed a highly innovative strategy, the "Oregon Plan," provisionally accepted by EPA as an appropriate response to the listing. The Oregon Plan creates and supports local and voluntary watershed activities. Local water agencies work with citizens to restore and maintain healthy salmon habitat through a variety of technological and social measures.

The clear shortfall in achieving stated goals of environmental regulations has also been cause for shifts to other levels of response. The poor coastal water quality in Southern California, in the face of huge expenditures in large urban waste treatment facilities, led to a recognition of and increased emphasis upon identification and control of non-point sources of pollution.

New agencies that have missions in fundamental conflict with those of the water industry, and the growing strength of parks, recreation, fisheries, and wildlife agencies that formerly had little clout are voicing demands that can not be accommodated by first modes. The California Coastal Commission, which regulates development along shoreline, was the result of citizen initiative, and it plays a role in promulgating regulations that impose innovation upon other water agencies. The ratcheting up of water quality and wildlife protection regulations by some water quality and environmental agencies means that routines and standard operating procedures of other water supply and waste treatment agencies need to be continually reexamined, altered, and sometimes changed innovatively.

Finally, the kinds of expectation among various publics which first mode encourage are ultimately unrealistic and self-defeating. The notion that plentiful, good quality water can come out of the tap simply by turning on a faucet is a false expectation. Water consumers have not been encouraged to believe that any behavioral change on their part will be necessary. Consequently, they react negatively when water service becomes a public issue. Yet, options are not available within first order decision making to allow water to be a non-issue. Other levels of response are required.

Potential Use of Probabilistic Forecast Information in the First Mode

The use of probabilistic forecasting by water resource organizations is constrained by the products of their historic commitment to incremental innovation. In our interviews with water agency officials we encountered a good deal of skepticism about use of 30 to 90 day forecasts on several grounds. Most importantly, existing water management systems are quite redundant. Water utilities have many back- up sources of supply. Should one water supply source fail because of seasonal shortage in supplies, other sources are brought on line. Should seasonal variations cause flooding, water agencies are already prepared for improbable flood events. Even extreme variations in seasonal weather are almost always well within the tolerance of existing overbuilt water management systems.

In the first mode, water agency officials are further reluctant to rely on probabilistic forecasts because of the value of invisibility. Should they rely on such forecasts, and actual weather turned out to be quite different from that predicted, the "mistake" might well result in unwanted publicity. It is interesting from this perspective to note that the one instance in which a number of water officials indicated that long term forecasting was important to them was the 1997 El Niño event in California. It this case, the high profile given to this event by politicians, notably Senator Barbara Boxer and Governor Pete Wilson, provided cover for water agencies. Should the winter storms not have materialized as predicted, NOAA and elected officials would have taken the blame for unneeded and costly precautionary measures. It is also important in this regard to note that it was the emergency response units within water agencies that engaged in El Niño planning, not the more mainstream planners and operators who do long term planning or day to day operations.

Water officials will not adopt techno-scientific changes that do not promise to be at least as good as the technologies presently in use. For most water officials, it is not at all clear that long- term forecasts are better than the historic record upon which they presently rely. In fact, lack of reliability was the most frequently voiced concern about NOAA forecasts which one official termed "no better than a coin toss." When asked, however, how reliable such forecasts needed to be, there was little consensus about the answer. Instead, what officials seemed to be articulating was conservative agency reluctance to move away from tried and true methods, whatever their flaws might be, in favor of something different which could not promise to be immediately better whatever the long term potential.

The lack of spatial specificity was another reason water officials gave us for not relying upon probabilistic forecasts. The fairly narrow, geographic specific, purpose specific missions of water agencies results in concern for hydrologic sub basins or basins, not the large regions that NOAA presently uses in its forecasts. Water officials were quite willing to sacrifice length of forecasts for more reliability on the shorter term in more localized areas. There is no substitute for detailed knowledge of local conditions, according to water officials, and at least at present, NOAA forecasts do not serve this need well.

There is some potential, however, that probabilistic forecast information will find an audience among first mode water agencies. Where attending to such information has advantages and few risks, conservative organizations have adopted and will make future use of such information. During the El Niño event in California, water agencies collaborated with others in elaborate emergency preparations. It is important to note, however, that response measures were often the sort which agency officials were in favor of anyway, but lacked the support or resources to implement.

First mode water agencies change incrementally, and the adoption of long term, probabilistic forecasts can be expected to take considerable time. However, water agencies want to be up to date with the latest technological advance. Especially among those agencies with redundant systems and greater vulnerability to extreme events, it will be regarded as risky not to have the latest forecasting technology on hand, even if it is not fully relied upon. It can be expected that more vulnerable water agencies, such as financially well-off, suburban water utilities with less secure water supplies in places in California, like the City of San Juan Capistrano, will take probabilistic forecasts into account in their planning and operations. Spokespersons for such utilities told us that reliable, locally specific long-term forecasts would be useful in adjusting rate structures and other water conservation strategies.

The adoption of probabilistic forecasts is likely to be a two step process. Since there is such a strong norm toward professionalism within the water industry, forecasts very often must be through intermediaries, such as university researchers, think tanks, and consultant firms. The credibility of the El Niño forecasts in California was greatly enhanced by the workshop endorsement of scientists at Scripps. Weather consultants who are able to tailor NOAA information to meet the needs of particular local utilities may facilitate the adoption of probabilistic forecasts. Agency informants told us that they contracted with a private weather prediction service because it interpreted information to the scale and delivered it during the times most useful to the utility. Marketing climate forecast information to private firms may, therefore, facilitate its wider adoption by public utilities.

Probabilistic forecasts may well enter agencies through one of the pathways described in Chapter 3. Adoption may come first as a low level experiment, and then after some time and during some crisis it may emerge as a tool water agencies depend upon heavily. Adoption may take place through expert information channels. Senior level officials may not even be aware that such forecasting has found its way into agency operating procedures because the transfer may well take place at the technical level.

In first mode response regimes, it may well be the agencies representing outside interests and the critics of the practices of conservative water agencies that have the greatest use for long-term probabilistic forecasts. Because conventional water utility infrastructure planning has not taken the needs of the environment into account, the natural system is not well protected, especially in extreme events. Therefore, parks, fish and game, and environmental agencies are likely to be sensitive to the implications of forecasts for the protection of their missions. Agency officials in California Environmental Protection Agency and the California Coastal Commission stated that forecasts that highlighted the risks of damage to coastal areas and near coast oceans would be used to bolster enforcement of regulations. Fewer permits for development would be approved if an especially wet season were predicted. Regulations to protect against non-point sources of water pollution would be more strongly enforced. Similarly, interest groups representing surfers are likely to use probabilistic forecasts for especially wet seasons as a wedge against wastewater management agencies with ocean outfalls. Of course, whatever strengthens the hand of such actors moves the system away from first mode toward other levels.

As a system continues to overbuild infrastructure and policy regimes as described above, its flexibility for responding to new demands is reduced. Incremental innovation is no longer enough to manage a system designed primarily to meet concerns of variation in water surplus and shortage for allocation schemes. For example, (Miles, et al. 2000): 410 describe the Columbia River system

> with more than 250 reservoirs and 100 hydroelectric projects, [as] one of the most highly developed in the world. It is generally considered to be a mature water management system with little room for future expansion or development. Under current conditions and institutions there are very limited possibilities for changes in infrastructure, such as adding additional reservoir storage capacity to better meet conflicting demands

Even as infrastructure and administrative structures are created and implemented to meet existing conditions, new demands are placed on water systems. The demands can be the result of the new and robust structures themselves or emerging requirements of phenomena once considered external to the system such as wildlife habitat or recreation. The constraints on physical, built, and institutional systems make it increasingly difficult for water service providers to respond through the sorts of incremental and routinized innovation described above. If constituents notice changes in the reliability, safety, or cost of their once taken-for-granted sources of water, agencies are in the position of violating their value of invisibility. As incremental innovations are less successful, water service providers increasingly seek new strategies: new ways to share the responsibility for managing the system and spreading the risk that the water service provider is solely responsible for any failure.

The Second Mode

As illustrated in the Los Angeles Basin example, organizations within a system that has reached the current limits of its infrastructure and/or administrative arrangements look for other ways to respond to the challenges of a complex, but now overbuilt system. A second mode of response to uncertainty is to recognize that the boundaries drawn around responsibilities and authorities in the first mode are inadequate for solving emerging problems and to invite new players to bring in additional expertise and authority. At early stages this may be coordination among agencies that are responsible for managing different aspects of the system; bringing in agencies responsible for managing species and/or habitat protection to supplement water control systems; or at different scales of governance by bringing in state and federal governments/agencies to complement local agencies. Historically, however, coordination has not solved the problems presented by an overbuilt system, but instead amplified and made visible a new suite of issues. As the type and number of issues grow with the addition of participants, including non-governmental organizations (NGOs) from the public and private sectors as well as members of the public, contentious issues may be "domesticated," or removed from the decision space temporarily. This is often done through the appointment of a commission, council, work group, or research team who are tasked to study the issue further, find or create new knowledge for the system, and develop alternative solutions that continue to support the values of water service providers.

The natural complexity of water systems has always been exacerbated by the inter-jurisdictional nature of rivers and other sources of water, particularly in the three case study areas. Water agencies in these areas have overbuilt infrastructure to manage variable systems, overlapping responsibilities, and demands for multiple uses (e.g., flood control, municipal, hydropower) and have also created an accompanying administrative system to manage interagency relationships. By the 1940's, informal federal interagency committees were being formed to coordinate the management of large river systems including the Columbia (1946) and Pacific Southwest (1948), although these earliest efforts at coordination have been described as "ineffective" (Featherstone 1996). Title II of The Water Resources Planning Act of 1965 created and funded seven river basin commissions until 1981, replacing the interagency committees. Governance of the commissions included state agencies responsible for water resources as well as the federal agencies.[1] Concerns and missions of federal water development agencies (e.g.,

[1] The Potomac, Susquehanna, and Delaware Basin Commissions were also created pursuant to this Act.

Army Corps of Engineers, Bureau of Reclamation, and Soil Conservation Service) continued to dominate early commissions.

These early multi-agency coordination efforts reflect the “durable myth of optimization” (Chapter 4): a belief that it is possible to manage systems more effectively if redundancies and other efficiencies can be eliminated. (This is ironic in face of individual agency risk management strategies for overbuilding water systems to ensure their operation through variable conditions.) One supposed way to optimize a multi-partner system is to coordinate efforts, increase communication, and share decision-making among partners. In addition, new partners can bring new information and/or knowledge to an organization at low or no cost. All three water systems we examined exhibited histories of coordination at the national and local levels.

Early coordination efforts were designed to complement increasingly robust infrastructure by reducing the possibility that constituents would fail to receive needed water services because of overlapping and conflicting responsibilities of providers. They attempted to coordinate the fragmented responsibilities of state and federal government for water systems including regulatory authority, taxation, and enforcement. And, they were meant to manage disputes among different levels of government and agencies responsible for differing aspects of water services such as coordinating the dam building with the power needs; the municipal and industrial requirements with agricultural needs; the flood control with drought protection. Early coordination efforts were considered legitimate methods by the public and the water sector for reducing fragmentation among multi-level government agencies, thus ensuring reliable water services.

The earliest interagency commissions were replaced with River Basin Commissions, which were disbanded by 1981. The regional commissions, created to coordinate among multiple agencies and organizations, themselves duplicated duties and activities already existing in various federal and state agencies (Ingram 1973). For new commissions to effectively manage water services, the decision authority of federal and state agencies would have to shrink – they would have to allow other agencies or constituents input into agency policy and decision-making. It has been suggested that this agency fear of loss of control, in combination with the perceptions of non-federal partners’ that the primary allegiance of the commissions was to federal water development goals and agencies, doomed the regional commissions (NRC 1999).

Demands on water systems continued to increase as population concentrated in urban areas, regulations for clean water and habitat protection were enacted, and infrastructure aged. The emerging problems faced by water service providers went far beyond existing areas of concern into arenas previously considered external to their responsibilities. For example, the Clean Water Act extended clean water requirements and the Endangered Species Act drove aqueous habitat protection. Along with new requirements came new constituents, particularly environmental agencies and non-governmental organizations. Instead of invisible water agencies, challenges to system practices, decisions about allocation and supply, and other issues became more commonplace and controversial.

The problems and issues raised by new constituents were not easily addressed by water systems over-built to meet demands of flood control, hydropower, and a reliable, low cost water supply. And, over-built systems like the Columbia River described above, were unlikely to have the water resources, system knowledge, or institutional arrangements to accommodate the challenges through incremental changes. By the mid-1970's, with the creation of EPA and the enactment of several environmental protection acts, water service providers were facing increasingly visible challenges to their ability to deliver the quantity and quality of water required by existing and new constituents. And they, along with scientists and other agencies, were unsure how to address the problems and constituents that threatened their core values.

New constituents brought water service providers problems that were more likely to be "wicked" (Pacanowsky 1995) than the problems they faced in the past. Wicked problems are described as those that cannot be solved within the given worldviews or operating conditions, are usually not linear in nature so traditional problem solving techniques and tools are not useful, and unlikely to be solved in the long run through incremental innovations.[2] Solving wicked problems requires

> cycl[ing] through the phases of problem definition, information gathering, solution, and outcome. It can be said that we do not really 'solve' wicked problems; rather, we 'design' more or less effective solutions based on how we define the problem. (Pacanowsky 1995) :36.

In its latest report on the status of watershed health, the National Research Council recognizes that water service providers are facing problems that will "not likely be achieved through the construction of additional control works, more regulations, or more money" (NRC 1999): viii. Instead, the new problems require exponential increases in our scientific and social understanding of complex systems. Yet, at the same time, the water service providers must continue to safely deliver reliable water at a low cost.

In response, a strategy emerges that echoes earlier efforts to coordinate federal and state agencies. The new strategy creates a council, commission, or some other type of group (either legally recognized or ad hoc, but acceptable to the parties) that removes the issue from visible decision space in order to study the problem and develop alternative solutions. These councils include federal and state water agencies as appropriate, but their distinguishing feature is the inclusion of new constituents (including different agency members) and recognition that coordination alone will not solve the problems they face. They must explicitly coordinate a search for some new knowledge or technique that is acceptable to all constituents.

We call this response "domestication" to suggest that agencies and other water service providers are still trying to find some way to control or tame problems much as they were earlier able to control water systems with engineering and administrative solutions. In the case of problems needing "domestication," however, there is no easy or inexpensive administrative or engineering solution. Recognizing this, the problem is set aside and

[2] Incremental innovations may allow a temporary solution that quells the contentious issue.

taken out of the limelight by agreement among constituents, often asking challengers to switch from criticizing the system to helping solve the problems. When asked about progress towards resolving domesticated problems, it is possible to say, "we're studying the problem" or the "commission is considering all alternatives."

Agreement for tabling the problem is secured from constituents by invitation to participate in finding solutions. Given legitimacy and access through their participation, the new players – including environmental groups, neighborhood associations, environmental protection and regulation agencies – are invited to sit down with the water control interests who have historically made decisions about the system. In effect, these parties now share responsibility for finding acceptable solutions.

When new partners come to the table, however, they bring new perspectives and expectations that challenge current thinking about problems and solutions. The decision frame of water service providers, which has been dominated by the value of reliably providing high quality water at low cost, is challenged by partners representing new values and phenomena that have often been externalized by existing values.

With rare exception, partners in coordination efforts were working within a dominant understanding of water and development that promoted the growth of water infrastructure to support growing populations. Conflicts in earlier coordination efforts are best described as conflicts of mission – one state agency may oppose a dam proposed by a federal agency; one municipality may be looking for ways to manage storm run-off that has negative impacts for another down stream. With the introduction of new players, the lack of a common mission may itself become the source of conflict. Conflicts are now more likely to be about worldviews: how problems are framed, who counts as stakeholders, what counts as evidence, and why decisions are made the way they are. These conflicts were recognized the National Research Council in its recommendations for managing water resources:

> …apparent contradictions among agencies are inevitable in a government structure that by design, represents varies stakeholder groups. However, in general, the various levels of government are in pursuit of common goals. Certainly those who are empowered to act may have some jealousies about their authorities, but these conflicts are far less significant than the conflicts that arise over how the land and water of a watershed may be used. (NRC 1999): 165.

The inclusion of multiple worldviews into the decision frame is the price that water service providers pay for spreading the risk of managing these complex systems. However, these worldviews are destabilizing hierarchical responses in multiple ways and raising the visibility of water systems in new ways about new issues; For example, communitarians are promoting the fundamental "right" to water and vehemently oppose rationing by price. They argue, that rich people will still be able to water their lawns but poor people may not even be able to afford potable drinking water. While promoting just such schemes, individualists are also pressing for closer tolerances on systems they perceive as bloated and ripe for efficiency efforts. There are now "new ways to notice" water service providers, challenging their core values.

The problems and solutions defined by water service providers are larger and more complex than imagined when impacts on once externalized components are considered. As water service issues are domesticated, new cross-sector networks and alliances are formed to address the complexity but also to gain new, risk-bearing partners. Constraints on autonomy become obvious and the need for coordination, cooperation, and collaboration with others using, responsible for, and affected by the water system are seen as possible sources of solutions. Agencies and organizations are able to pool information about a common system, bringing new knowledge to all. Modeling and monitoring strategies are made possible and even desirable by domestication efforts seeking new information about how the system works as a whole. These and other efforts bring new types of employees – biologists, social scientists – to organizations once dominated by engineers or hydrologists. These employees and new constituents promote new indicators of success that complement or challenge the primary value of providing reliable and low cost water services. Any proposed changes to the system are likely to be "staged" due to cost, but also due to greater reluctance to imagine that large-scale responses are any hope of a solution. Solutions to problems may be innovative social, physical, or organizational re-arrangements of the existing system.

The primary limitation of the domestication strategy is that physical system limitations remain during an often-extended period while solutions are explored and created. Water service providers may experience increased violations of invisibility through challenges to the physical limitations but also to their value system by public and repeated discourse about water management. Water service providers are faced with individuals and organizations with incompatible worldviews, which take energy and other resources to manage, if acceptable solutions are to be created. Some critics are unlikely to ever participate in finding solutions, but will have increased access to discussions about problems and solutions. All three cases in our research provide examples of domestication.

Potential Use of Probabilistic Forecast Information in the Second Mode

Even for organizations like the ICPRB and CBP that are explicitly created to seek, develop, and/or use new knowledge to generate innovative solutions to complex problems, the probabilistic forecast information presents special difficulties. Almost without exception, managers and others in the ICPRB and CPB told us they were reluctant to use the probabilistic forecasts. They were concerned that the forecasts were unreliable and their use could jeopardize safe and reliable operations in the basin; the forecasts were too uncertain and their use in any decision process or model would be merely "noise," and that the forecasts are provided at the wrong scale - their use would require modifications to either the forecasts or the existing models. While any or all of these concerns may be legitimate, our respondents were hard pressed to talk in any detail about their concerns about existing forecast skill and scale (see, Chapter 3).

Modelers and other research-oriented staff in the coordinating and domesticating organizations were familiar with the forecasts, and may even have incorporated them into a subroutine in a model. However, we found no evidence that they made the use of forecasts visible to others (e.g., to legitimate outcomes of models). The few examples of use were buried deep in the technical realms of the organizations.

Staff at the ICPRB view the organization as a “very research oriented agency,” near the cutting edge of technology and knowledge in the field. They believe it enjoys a reputation among partners for providing an unbiased source of analysis that can be used by everyone in the network. Models of water quality and supply are created, maintained, and updated; regional preparedness for drought response is managed; and operational agreements are administered by the ICPRB. These coordinating efforts benefit all water service providers in the basin.

Current models are based on historical data, but there is rising concern that historical stream flow may not be a reliable guide for future operations because of changing climate patterns. Modelers at the ICPRB would like to be able to modify historically based information, but do not seem ready to abandon it totally. ICPRB has been introduced to innovations in modeling as recent graduates come to work with experience and/or knowledge of current ideas. The probabilistic forecasts for El Niño were examined, for example, but found not specific enough for ICPRB use (they would like watershed scale information). Also, colleagues had told ICPRB modelers that the forecasts are not very reliable and are they therefore reluctant to begin using them. Any difficulties that the ICPRB has with the forecasts appear to be rooted in technical issues (e.g., forecast skill and scale). If those technical concerns are allayed, it appears that forecast use at the ICPRB would be considered to help address existing problems.

Because the ICPRB enjoys high credibility with its networked organizations, is strongly research/knowledge oriented, and is a primary provider of information for both tamed and domesticated issues, ICPRB may be an effective site for introducing probabilistic forecasts and models into decision making in the larger Potomac River Basin. However, at early stages, this information would be most likely to condition historical probabilities rather than replace the historical record as a basis for decision-making.

The domestication role of the Chesapeake Bay Program (CBP), which includes stakeholders with multiple worldviews and conflicting ways of defining problems, presents somewhat different difficulties with the use of forecast information. The original CBP charter included commitments to comprehensive and coordinated monitoring, and that information has been used to assess current status as well as the impact of any project on the Bay. Monitoring data has been used to assess the effectiveness of meeting program goals, analyze the effectiveness of water quality control programs, set public targets for the politically favored “living resources,” and only recently to calibrate newly developed models. Information produced by the CBP is not always seen as beneficial to water service providers who may be limited by findings or recommendations.

Over several years, the monitoring data and discussions have been, and are continuing to be, used to identify a series of “working indicators” that describe the relative health of the

Bay. The Implementation Committee has currently approved about 100 parameters, each of which is tracked by the monitoring subcommittee. The monitoring data, with a 95% confidence level, captures information about the Chesapeake Bay that constituents have negotiated as being critical. The indicators were socially constructed through political discussion and are managed bureaucratically. The Implementation Committee must approve new indicators, which is the main operating committee of the CBP.

New tools and information for decision making must be acceptable to a diverse group of constituents with differing worldviews. In recent years, the CBP has sponsored an extensive modeling program (with four primary models) that has been based on historical data, not information about potential futures. The complex and opaque models with subroutines that are themselves complex and opaque engage a wide array of individuals and organizations, each with its own relationship to the validity of the information and models. One subcommittee chair told us that he was very concerned that increasing importance of modeling within the CBP has not been accompanied by any discussion about the "believability of the model outputs." He fears that constituents, who don't understand or agree with the assumptions built into the model, including the probabilistic forecasts, could challenge any results. Before forecast use is widely acceptable, there will need to be "lots of discussion on ensuring buy-in from jurisdictions in the process and the conclusions".

The Third Mode

Water agencies that have become involved in large-scale coordination and long-term domestication activities to manage the complexities of water systems that are oversubscribed and facing changing social values, eventually find this response to uncertainty unsatisfactory as illustrated above. Cracks in the credibility of the research, or the inability of policy (based on the research) to deliver safe and low-cost water reliably in the face of increasing uncertainty again raises the visibility of water resource agencies.

One possible institutional solution that has been suggested is the idea of civic or vernacular science (Lee 1993) (O'Riordan and Rayner 1993) where the existing and conventional responses are subject to open negotiations from a wide variety of participants including stakeholders (i.e., those affected by the agencies' decisions). New partners insist upon what appear to be incommensurable demands and the existing committees and research reveal few possibilities for alterations that will satisfy diverse demands without challenging the assumption and operations of existing systems.

Just as biologists and ecologists challenged the conservatism of the first order water responses to uncertainty, new participants bring different needs, expectations, and world views when water resource managers move to coordination and domestication strategies. These new participants challenge the power of traditional expertise to solve local problems without their explicit involvement. Conveners, mediators, and other intermediaries are likely to play substantial roles in managing adaptive systems. For example, citizens expect decision-making processes to be transparent and clear, and for that they need information that is accessible and understandable and related to the problem at hand. Expertise in decision-making, conflict resolution, and scientific translation/interpretation will all be necessary for meaningful participation by the new type of stakeholders. In recognition of these new challenges, some actors have started to think about new ways of responding to the uncertainty of large water systems.

In the Pacific Northwest, with its highly complex water systems, allocation strategies, and legally mandated but conflicting priorities, (Lee 1993) has suggested what he calls a strategy of "adaptive management." This strategy recognizes the limitations of human control of unpredictable and dynamic natural and social systems. In addition to trying to capture reality with complex models, he suggests that planning also attend reflexively to local experience and knowledge. That is, problem-specific information is continuously generated and integrated into the decision process, making possible problem-specific responses in a relatively short time.

Social responses (e.g., values and behaviors) complement the engineering, legal, organizational, and biological strategies common to the first two responses to uncertainty. Yet social definitions and values challenge the traditional discussions about alternatives, costs, and limitations, making this adaptive strategy difficult to implement in existing institutions.

While an adaptive strategy may bring responsiveness to water management, it is information and decision intensive. It requires a great deal of information about a whole range of different problems: in addition to water flow, allocation, and distribution criteria, information is needed about local and specific preferences, needs, and interactions with natural and built systems. It also necessitates structures for collecting and integrating such information including meetings, public forums, outreach activities and other social processes for consultation and decision making. Not only must participants become better informed about water, they must attend to value differences and conflicts within the relevant community. The process requires an openness and willingness of individuals to shift their attitudes and expectations to accommodate the new demands on the physical system and the diverse attitudes of other users. Moreover, organizations must change as well. As a result of the need for public consultation the visibility of the organization is elevated and this contradicts the longstanding organizational norms of invisibility of water bureaucracies.

Adaptive management decisions may focus on local and context-specific problems, rather than the system-wide approaches to uncertainty promoted in the first and second modes described above. For example, adaptive decisions may include variable pricing of water for different uses; access to a range of sources appropriate to different kinds of uses; and locally appropriate and flexible technology that complements the existing large scale, long term infrastructures. Likely climate events take their place among the many kinds of contingencies adaptive management is open to consider.

However, staff of the Northwest Power Planning Council (NPPC) told us that they use different strategies to process "professional" and "political" information. Professional input is sought from scientific and technical contractors, and through workshops and working groups with relevant scientists, extensive reviews of current scientific literature, and attendance at professional meetings. The NPPC sponsors or co-sponsors many professional activities including individual research projects, agency initiatives, and networking workshops. Professional information is elicited throughout the process as issues are formed, rules are drafted and finalized, and the program is evaluated. This external source of information complements internal sources of information from technical and legal staff, supporting the worldview of the agency, which has been dominated by the need to produce reliable and low cost electricity.

External information is also elicited from what staff members labeled as "political" sources. These include stakeholders such as members of the affected public, representatives of affected federal and state agencies, environmental and other interest groups, and lobbyists. Although political information is elicited at the same time as professional information, external information sources have different levels of credibility. While understanding on some conceptual level the value of multiple perspectives in decision-making and creating a decision-making structure to elicit those perspectives, the NPPC continues to rely on those perspectives that most reflect the traditional responses to uncertainty –infrastructure modifications, coordination, and domestication.

For example, the NPPC staff told us that input elicited during public hearings carries less weight in decision-making than information elicited through contracted professional work. Even though the NPPC is mandated by law to consider multiple perspectives when making its plans, observers have suggested that very few non-traditional solutions have been produced.

As years of domestication efforts dragged on without solution, however, strategies that were once politically unacceptable began to surface, especially the idea of breaching or removing dams on the main stem river. This concept was such anathema to most water service providers that it was ridiculed as impossible only a few years ago. With the removal of smaller dams on other tributaries across the country and continuing questions raised by environmental and other groups about the assumptions underlying dam removal schemes, the concept took on new life and was seriously considered by the Army Corps of Engineers in its recovery plan. The plan released on July 28, 2000, however, rejects breaching four federal dams on the Lower Snake River and relies on more traditional technological fixes including barging young salmon around dams, improving hatchery practices, freezing harvest levels, releasing more water from reservoirs,[3] and studying the results before making any recommendations that might include dam breaching.

This round of domestication involves a monitoring program that includes setting goals for fish return and promises to re-examine other options at regular intervals. However, opponents of dam breaching are proposing legislation to stop funding for any feasibility studies (*Oregonian* July 29, 2000). At great expense, approximately $400 million per year, managing the Columbia River for conflicting interests is still being domesticated with research, commissions, and legislation.

[3] This last proposal will require a $20-30 million risk assessment.

Potential Use of Probabilistic Forecast Information in the Third Mode

As described and shown in *Figure 2.4* there are multiple places on the NPPC's decision "map" where probabilistic climate forecasting information can be expected to have impact on NPPC decisions. Obviously, probabilistic climate forecasts can be introduced to both the internal and external professional staff. Forecast information that is provided for professional staff can also be shared with those "political" participants who can use the information in their own analyses. Understanding the iterative decision process used by the NPPC can help determine how forecast information can be most effectively presented at different stages.

One staff member told us that fish scientists pushed to include forecasting data in a population and stream flow models. The Army Corps of Engineers (ACOE) re-ran the model with a forecasting prediction about a La Niña event. Acceptable water levels in reservoirs were changed to allow the releasing of more water during the spawning season. The BLM, however, didn't accept the findings produced with the new information; a decision was made by the NPPC to go ahead with the new plan.

The high-tech, expensive, and visible NPPC monitoring and modeling programs are conducted within a decision process that integrates multiple sources of information and worldviews (see discussion above). In addition, the NPPC works with organizations historically suspicious of each other. For example, Bonneville Power Administration (BPA) uses long-range forecasts (90+ days) to develop its stream flow forecasts. This forecast, however, is not acceptable to other parties and must be "managed" in conjunction with other information that is more acceptable to all constituents. The Northwest River Forecasting Center is responsible for providing river forecasts to water agencies in the Pacific Northwest. Its staff has been resistant to developing any forecast beyond three days because they believe uncertainty is too high after that; they have also not been convinced that short-term climate forecasts will have any influence on the existing models. The Northwest Tribes choose not to rely on non-tribal analyses for long-term planning, although they have been using NOAA and Army Corps of Engineer information to develop their own 30-90 day forecasts.

All federal and tribal agencies in the Pacific Northwest met during 1998 to discuss the use of probabilistic forecasts. One of our interviewees said the meeting "went over like a lead balloon." Currently all the users, including NPPC, have their own deterministic and historically based models; there may be interest in incorporating probabilistic forecasting but no one believes that there re enough resources to help with the extensive overhaul that will be required.

While highly politicized, the NPPC also mandates the collection and consideration of external information at several points in the decision process. As discussed above, professional information is credible and highly valued by Council staff and members. External information is integrated into NPPC decisions at four entry points: initial information collection, issue paper development, external review, and mandated evaluation (Lach, et al. 1994). However, because the Councils' decision space is so unbounded, information becomes more helpful when it is formatted to affect the analysis of the decision process by refining the uncertainty estimates, show the sensitivity of different parameters, or reframe the decision.

While the NPPC recognizes the need to integrate new sources of information and understands that it must work to meet conflicting needs and expectations of Columbia River management, it has been a difficult process to find ways that legitimate discussion of ideas brought in by non-professional participants. The "new challengers" of the coordination and domestication strategy (i.e., ecologists, biologists, and modelers) have been pretty well integrated into the discussions about river management over that past twenty years. The challengers to the conservatism, coordination and domestication strategies, however, are just starting to be heard in the Pacific Northwest.

In sum, use of probabilistic climate forecasting can be promoted in the third mode through the design of forecast products that are accessible to wide audiences. This means that the forecasts need to be not only at the appropriate local scale, but probabilities must be expressed in terms of the sectors of immediate concern. For example, in some situations focus on the probabilities of extreme events may be most relevant. In other situations, forecasts must be expressed in terms of changes in seasonal flow, snow pack, or temperature.

Conclusions

It appears that agencies and other organizations have access to a range of qualitatively different responses to uncertainty. We observed that as decision constraints grow, new organizational forms, structures, and responses are created. These emerging responses do not displace existing routines; they rather introduce additional strategies for dealing with uncertainty. We are not suggesting a model of successive displacement of one organizational strategy for another; instead it is a model of accretion where new response strategies are grafted on to existing structures, norms, and behaviors. Inevitably, the emergent responses create tension with existing responses as they overlay, without displacing, traditional organizational missions and strategies.

Figure 5.1. describes spaces within which organizations take up strategies for managing uncertainty. A single organization can actually be using different mode strategies simultaneously for different, or even the same, problems. The first mode, which we found is typically preferred by organizations, assumes that uncertainty can be managed within the individual agency through routinizing both regular and irregular system events. Often this requires developing redundant infrastructure and operating procedures; all designed to reduce the impact of unusual events. Once the infrastructure and routines are in place, the system is relatively easy to manage. Change to the infrastructure and routines are typically incremental, improvements to rather than replacement of the existing system. Expertise to manage system uncertainty is found in the knowledge bases of engineers, lawyers, and economists who can help water resource agencies meet their missions of safe, reliable, and low cost water. Any external information must be able to support standard operating procedures that have been developed over the life of the agency or organizations.

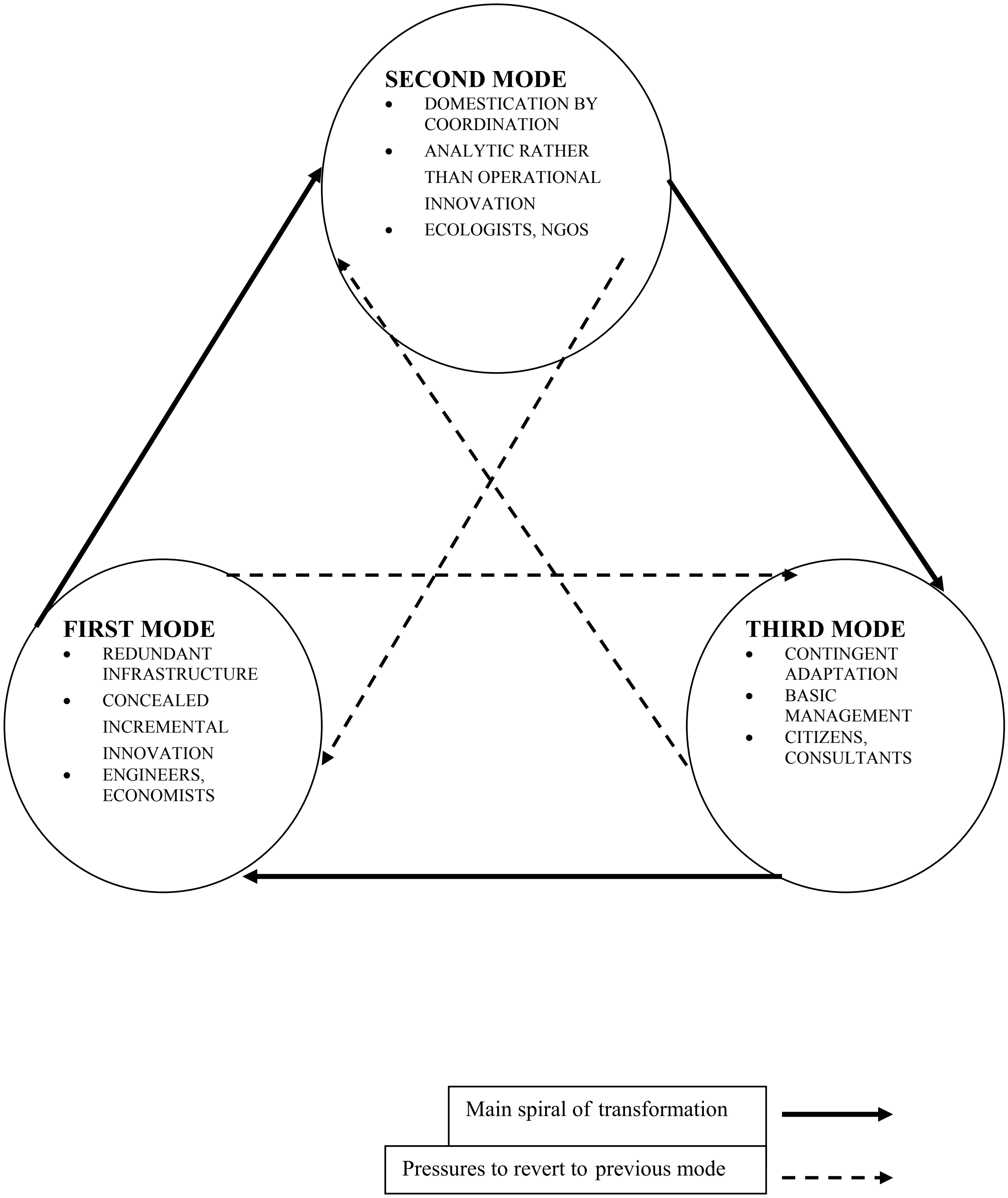


Figure 5.1 COMPLEX SPIRAL OF TRANSFORMATION IN THE US WATER RESOURCE SECTOR

Thus, the picture that emerges in Figure 5.1 is one of organizations initially seeking to discreetly routinize the natural irregularities of water availability for a variety of purposes such as domestic supply, irrigation, flood control and recreation. Here, knowledge is overwhelmingly of the "black box" variety. Even senior managers in an organization may not know what information is actually being used for operational decision making.

However, competing expectations from society result in organizations with different missions tripping over each other until their invisibility is threatened by political attention. In response, they form coordinating bodies that domesticate the problems of managing for competing uses, but without really resolving them. Agency staffs peek into each other's black boxes, but retain strong reservations about the quality or usefulness of what they see inside.

Adaptive management is an effort to move the agencies beyond domestication through greater coordination, redefinition of responsibilities to conform to watershed boundaries rather than political jurisdictions, and increased public scrutiny. However, the sustained effort required from non-professionals in the third response mode leads them to seek out the services of expert consultants with their own black boxes.

Each stage in this cycle may present different opportunities for the integration of climate forecast information. In the first, the opportunities are limited to incremental changes, discreetly introduced by new recruits into the technical ranks of the organization. Climate forecast information may be introduced in modifications to existing tools an models. However, such innovation has only marginal impacts and goes largely unrecognized. In the second mode, the harmless experiments of junior staff may increasingly be plucked up in response to crises or to the extent that they can be represented as improving coordination among the actors. To the extent that climate forecast information provides opportunities for coordination they may be able to make inroads. The third mode would seem to present more opportunities for radical innovation, however, we note the tendency of agents operating in the third mode to resort to the first mode response mode when the stresses and strains of high levels of engagement and negotiation take their toll.

In short, our diagnosis is very consistent with that of (Miles, et al. 2000), who found the fragmentation of water resource management in the Pacific Northwest to be so extreme as to render unusable even close to perfect information about climate. However, we are pessimistic that their prescription of greater coordination among agencies would greatly improve the prospects for climate forecast information. We are certainly skeptical that there will be any radical departures from current practices. We are mindful of the injunction that innovations cannot be tolerated if they produce even temporary declines in service quality to consumers that result in violations of water managers' preference for invisibility.

Second mode responses reflect recognition by the organization of the need for coordination and cooperation with and among other organizations, as constraints on water grow through demand or regulation. In particular, we found that environmental and wildlife habitat claims have been added to the mix of water system demands. So, in addition to ensuring a predictable local system response, organizations and agencies take on the chore of coordinating their activities with actors who often have missions, needs, and expectations in conflict. Multi-agency committees are formed and system-wide issues are articulated, often resulting in attempts to "model" the needs of all system constituents (including wildlife). Conflicts are smoothed over through delay with the promise of making science-based (i.e., "objective) decisions sometime in the future. The coordination and domestication activities bring change to the participating institutions through expectations that multiple missions must be met. Expertise is found in the knowledge bases of ecologists, biologists, and modelers who can help the agencies meet the demands of environmental rules and regulations. This expertise supplements the need for engineering, legal, and economic knowledge, rather than displacing it. New information is needed to understand system interactions and create the models.

The Third mode emerges as water agencies and organizations open themselves to new partners and expectations in attempts to create adaptive and flexible responses to growing uncertainty. Resolving such uncertainty comes through negotiation of self-identified needs for local and situational problems. Now organizations take on the task of integrating new kinds of information and new partners – often conflicting – who bring fundamental challenges to the way decisions are made. New definitions of "risk" emerge, including "how fair is safe-, reliable-, and low-cost enough?" Creating adaptive organizations may bring rapid and major changes to the way water resources are managed, allocated, and distributed. Additional expertise bases include citizens, mediators, and conveners who bring knowledge and experience with the local situation and problems, but also bring demands for local solutions. Integrating this knowledge with other expertise bases is one of the major tasks facing organizations adopting adaptive management strategies. Information must be accessible by multiple parties and focused on specific problems of interest.

The summaries above are static and isolated pictures of first, second, and third mode responses of organizations and agencies to uncertainty. By "freezing" the dynamic organizations, we are able to create a conceptual framework for thinking about managing uncertainty. These three different strategies for managing uncertainty reflect a general trend from infrastructure-intensive strategies to social interaction-intensive strategies. Instead of managing the uncertainty of physical structures and organized routines, water resource agencies are beginning to "manage" ambiguous relationships with partners who have conflicting demands and needs.

Organizations, however, inconveniently refuse to stay frozen and we found a general tendency among organizations of resisting the shift to social interaction strategies. Attempts to move back to structural solutions were prevalent. For example, while the NPPC was attempting a conscious move to an adaptive management strategy, the large number of participants stimulated the development of formal coordinating structures to manage conflicting needs. This may be a function of the fundamental reluctance to change the decision arena from the entire Columbia River Basin to more local problems. As long as the problem was framed as a basin-wide issue, players were reluctant to remove themselves from the decision structures created through coordination efforts.

In another Pacific Northwest experiment, the state of Oregon created local and voluntary watershed councils throughout the state in an attempt to avoid listing of several salmonid species as threatened or endangered under the Endangered Species Act (ESA). This domestication effort directed each council to conduct a basin assessment and develop a plan to address the identified needs. The National Marine Fisheries Service (NMFS) was not convinced that the Oregon Plan would adequately protect the salmon and proceeded to list several species of salmon as threatened or endangered. Watershed Councils, however, remain the mechanism for developing and implementing recovery strategies in Oregon. In another study sponsored by the Oregon Sea Grant (Lach and Cummings 2001), we found that watershed councils themselves were creating structures that would institutionalize and routinize their local problems through hierarchical bureaucracies. Local watershed councils on the Oregon coast have organized themselves into three regional coordinating councils that are then organized into a single coastal coordinating council. They believe that they will be unable to solve their local watershed problems without coordinating with other groups, and without bureaucratic structures in place that institutionalize practices, routines, and decision making. Although developed to domesticate the problem of ESA listings, the actual watershed councils themselves are more interested in finding first mode responses to uncertainty in their local areas but recognize that coordination will also be required.

These institutional dynamics allow us to expand our earlier conclusion that climate forecast information will only be introduced into decision making through piecemeal incorporation in existing models and routines. There is also potential for such information to be used politically to destabilize an existing mode of response to uncertainty and so propel the organizational complex of managers into the next mode. Whether this proves to be the case only time and further research will tell.

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Appendix A
Functions of water resource agencies

The following list illustrates the range of functions performed by water resource agencies within our three study areas and throughout the United States. Examples of agencies that perform each function are provided. Agencies come in many forms and sizes. Some perform only part of one of the functions listed below; others perform several of the functions listed.

Supply water for drinking, commerce, industry, or agriculture

Water supply includes the collection of raw water from one or more surface and/or groundwater sources, treatment of the water to whatever quality is demanded by the end user, and delivery of the treated water to the customer. A specific agency may perform all of these tasks, or may perform only part of the overall water supply function and work in cooperation with other agencies to complete the collection, treatment, and delivery tasks of water supply. Examples of water supply organizations encountered in our research include the following:

For example, the Fairfax County Water Authority (FCWA) is the water supply agency for 1.2 million customers in northern Virginia, and collects water from multiple sources, treats the water at multiple treatment plants, and delivers the water through an extensive distribution network. In some cases, FCWA functions as a water wholesaler by selling water to other agencies that then deliver it to the end user, and in other cases functions as a water retailer by delivering water directly to the end user.

On the regional scale of water supply, the State Water Project (SWP) in California is charged with moving water from sources in northern California to southern California. It delivers water to 29 other water supply agencies which then distribute the water to customers. Approximately half the water SWP delivers to southern California is for the Metropolitan Water District of Los Angeles (MWD).

Control floods

Flooding problems range from the highly localized (e.g., ensuring the local rainstorm does not inundate the basement of private dwellings) to the regional scale (e.g., preventing the destruction of New Orleans due to a major flood of the Mississippi River. At the local level, many cities and counties control floods in multiple ways. They typically legislate rules for the design and construction of new facilities that require the new facility to be out of any flood prone area, and also to ensure that the new construction will not increase flooding downstream. They also provide flood control infrastructure and emergency flood management services. Most often this responsibility is housed in the locality’s department of public works, as in the case of Huntingdon Beach, California. At a larger scale, the Corps of Engineers functions to control flooding on major waterways throughout the nation and in all three case study areas. The Corps regularly manages reservoir/dam systems to attenuate flows and in particular to reduce extreme high flows to minimize loss of life and property.

Maintain navigability of waterways

Water borne commerce and travel are important to the nation. Approximately $1 billion per year is spent on dredging channels to ensure adequate draft for ships to pass. Dams are managed to ensure adequate flow to float the barges and ships in many waterways. In fact, one of the earliest charges to the Corps of Engineers was to maintain the navigation ability of US waterways. It remains a fundamental charge to the Corps.

Generate energy

Generation of hydroelectric energy is especially important in the US to meet peak energy demands. Hydropower generation can complement other uses such as water supply if the water used to generate energy can subsequently be withdrawn downstream of the dam to meet water supply needs. The conversion of the potential energy of the water stored behind a dam into electrical energy means that the area affected by the management of the water resource may be greatly expanded. For example, electricity generated at Hoover Dam on the Colorado River is routinely shipped to Los Angeles and to Phoenix. One of Canada's largest exports to the United States is energy generated at hydropower plants. Examples of energy agencies that manage hydropower production in our study areas include the Bonneville Power Administration which among other things produces electric power that is marketed across the western US. The California State Water Project, while mainly a conduit of water southward for the purpose of water supply, also generates electric power.

Maintain water quality

Water quality is a major concern because it affects human health, fish and wildlife habitat, and the aesthetics of the water body. Water quality is not only a concern for surface water but also groundwater in which pollutants may migrate. Pollutants enter a water body from point sources such as outfalls from sewage treatment plants, or non-point sources such as runoff from agricultural fields. Pollutants include: pathogens, biochemical oxygen demand (BOD), heat, solids, pesticides, polycyclic hydrocarbons (PCHs), polychlorinated biphenyls (PCBs), heavy metals (nickel, cadmium, arsenic, lead, etc.), and others. Indicators of the quality of the water include: dissolved oxygen (DO), pH, turbidity, temperature, concentrations of various chemicals, and benthic and water column biological activity. Examples of regional agencies in our study areas concerned with water quality include the Chesapeake Bay Program described above. The CBP is interested in all aspects of water quality and its effects on aquatic biota and human health. A west coast example would be the California Water Quality Control Board manages groundwater, surface water and near-shore ocean water quality by issuing discharge permits.

Protect habitat for fish and wildlife

Protection of the land and water that is the habitat for terrestrial and aquatic animals is an important environmental goal. There is a collection of federal, state, and local agencies that are charged with fulfilling this goal. For example, the Office of Spill Prevention and Response of the Department of Fish and Game of California responds to oil spills that threaten habitat. They have limited police power in addition to technical clean-up capability.

Collect, treat, and dispose of wastewater

The sources of wastewater are widespread and diverse, and include residences and industry. There are many physical, chemical, and biological treatment options. And there are many disposal options including discharge to a stream, lake, aquifer, or ocean. In a few cases, the wastewater is recycled directly to a water supply, and more often is recycled after a short residence time in the stream, lake, or aquifer that was the original disposal site. Disposal of the solids resulting from treatment is typically to agricultural fields, recharge basins, landfills, or incinerators. The Washington Suburban Sanitary Commission (WSSC) collects, treats, and disposes of wastewater produced in Prince George's and Montgomery Counties in Maryland. These are the counties bordering the District of Columbia on the north. WSSC collects the wastewater through a large sanitary sewer system, treats the wastewater at several large treatment plants, and disposes of the treated wastewater to local streams. WSSC is a multifunction agency with responsibility as the water supplier for these two counties also.

Cities and counties throughout the country also control the collection, treatment and disposal of a major source of wastewater through regulation. A large amount of wastewater is treated and disposed of close to the source. Septic systems which are localized—for example, each house in a subdivision may have its own septic system—represent collection (wastewater from the house is piped to the septic system), treatment through natural processes in the ground, and disposal through recharge of the groundwater. Septic system design, construction and maintenance are the responsibility of the homeowner or developer. But they must typically satisfy criteria established by the local city, county, or state.

Provide for recreational opportunity

Recreation occurs in streams, on lakes, and on land adjacent to water. It includes boating, swimming, picnicking, rafting, and many other activities made possible or enhanced by proximity to water. It is currently the fastest growing use of water in the country. The Corps of Engineers is occasionally involved with recreation. For example, at Jennings Randolph Lake in the headwaters of the Potomac, the Corps owns and manages a picnic area, a camp ground, an overlook and a boat ramp, in addition to operating the dam/reservoir. When feasible within the original purposes of the facility, the Corps also attempts to operate the dam in support of fishing and rafting downstream. This presents an interesting case study of conflict 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.

Respond to emergencies

Water related emergencies are typically short duration, critical events that require extraordinary efforts to protect life and property. These emergencies include floods, hurricanes, hazardous material spills, fires, and droughts. For instance, the Maryland Emergency Management Agency is patterned after the Federal Emergency Management Agency and has responsibility for coordinating and managing emergency response, including water related emergencies. On the west coast, the Office of Emergency Services has the mission of anticipating, responding to, and cleaning up after disasters throughout California. The OES reports directly to the Governor.