CHAPTER 1

The Changing Context

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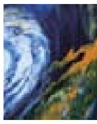
1.1 INTRODUCTION

Increasingly frequent headlines such as "UN Calls Water Top Priority" (*The Washington Post, January 25, 2008*), "Drought-Stricken South Facing Tough Choices" (*The New York Times, Oct 15, 2007*), and "The Future is Drying Up" (*The New York Times, October 21, 2007*), coupled with the realities of less-available water, have alerted decision makers, from governors and mayors to individual farmers, that climate information is crucial for future planning. Over the past quarter-century, there have been significant advances in the ability to monitor and predict important aspects of seasonal-to-interannual (SI) variations in climate, especially those associated with variations of the El-Niño Southern Oscillation (ENSO) cycle. Predictions of climate variability on SI time scales are now routine and operational, and consideration of these forecasts in making decisions has become more commonplace. Some water resources decision makers have already begun to use seasonal, interseasonal, and even longer time scale climate forecasts and observational data to assess future options, while others are just beginning to realize the potential of these resources. This Product is designed to show how climate and hydrologic forecast and observational data are being used or neglected by water resources decision makers and to suggest future pathways for increased use of this data.



The Climate Change Science Program (CCSP) included a chapter in its 2003 Strategic Plan that described the critical role of decision support in climate science; previous assessment analyses and case studies have highlighted the importance of assuring that climate information and data would be used by decision makers and not be produced without knowledge of its application. Since that time, there has been increased interest and research in decision-support science focused on organizations using SI forecasts and observational data in future planning. Since the release of the 2003 Strategic Plan, one of the main purposes of CCSP continues to be to "provide information for decision-making through the development of decision-support resources" (CCSP, 2008[1]). As a result, CCSP has charged this author group to produce a Synthesis and Assessment Product (SAP) that directly addresses decision-support experiments and evaluations in the water resources sector. This is that Product.

The authors of this Product concentrated their efforts on discussing SI forecasts and data products. In some cases, however, longer-range forecasts are discussed because they have become a part of the context for decision-making processes. We provided a range of

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[1] According to this same document, "Decision-support resources, systems, and activities are climate-related products or processes that directly inform or advise stakeholders to help them make decisions".

domestic case study examples, referred to as "experiments and/or evaluations", and have also provided some international examples, where appropriate.

1.2 INCREASING STRESS AND COMPLEXITY IN WATER RESOURCES

Under global warming conditions and an accelerating demand for abundant water supplies, water management may become an increasingly politically charged issue throughout the world in the coming century. Emerging challenges in water quantity, quality, pricing, and water management in relation to seasonal climate fluctuations may increase as the demand for water continues to rise. Though the total volume of water on the planet may be sufficient for societal needs, the largest portion of this water is geographically remote, misallocated, wasted, or degraded by pollution (Whiteley *et al*., 2008). At the same time, there are shifts in water usage, the societal value of natural water systems, and the laws that govern management of this resource. Accordingly, the impact of climate on water resource management has far-reaching implications for everyone, from the farmer who may need to change the timing of crop planting/harvesting or the crop type itself, to citizens who may have to relocate because their potable water supply has disappeared.

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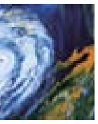
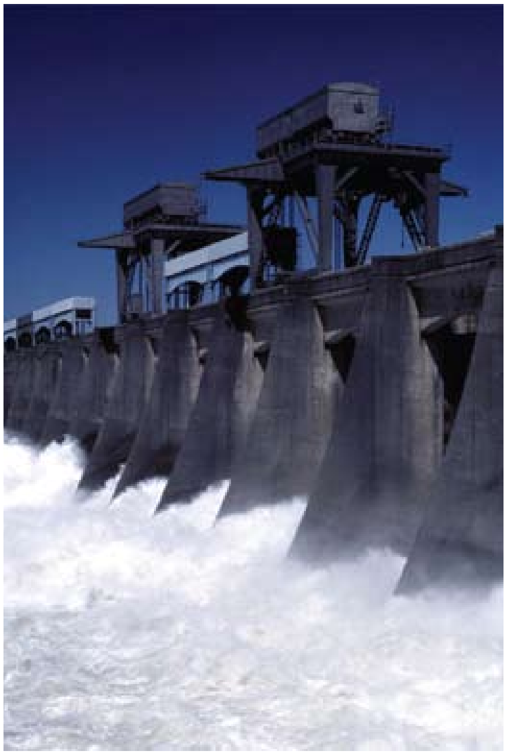




In the United States, water resource decisions are made at multiple levels of government and, increasingly, by the private sector. Water is controlled, guided, governed, or measured by a gamut of federal agencies that oversee various aspects from quality (*e.g.,* U.S. Environmental Protection Agency [EPA]) to quantity (*e.g.*, U.S. Geological Survey [USGS], Bureau of Reclamation [Reclamation], and U.S. Army Corps of Engineers [USACE]). This is complicated by state, regional, and jurisdictional boundaries and responsibilities. Defining a "decision maker" is equally difficult given the complexity of water's use and the types of information that can be used to make decisions. Our challenge in writing this Product is to reflect the various models under which water is managed and the diverse character of decisions that comprise water management. To illustrate, the term "water management" encompasses decisions made by: a municipal water entity regarding when to impose outdoor water restrictions; a federal agency regarding how to operate a storage facility; the United States Congress regarding funding of recovery efforts for an endangered species; and by state governments regarding water purchases necessary to ensure compliance with negotiated compacts.

These types of decisions may be based on multiple factors, such as cost, climate (past trends and future projections), community preferences, political advantage, and strategic concerns for future water decisions. Further, water is associated with many different values including economic security, opportunity, environmental quality, lifestyle, and a sense of place (Blatter and Ingram, 2001). Information about climate variability can be expected to affect some of these decisions and modify some of these values. For other decisions, it may be of remote interest or viewed as entirely irrelevant. For instance, the association of access to water with respect to economic security is relatively fixed while the association of water to lifestyle choices such as a preference for water-based sports may vary with additional information about variability in climate.

The rapidly-closing gap between usable supplies and rising demand is being narrowed by a myriad of factors, including, but not limited to:

- Increasing demand for water with population growth in terms of potable drinking water, agricultural/food requirements, and energy needs.
- Greater political power of recreational and environmental interests that insist on minimum instream flows in rivers.
- Groundwater reserves where development enabled the expansion of agriculture in the

western United States and is the basis for the development of several urban regions. As groundwater reserves are depleted, pressure increases on other water sources.

- Water quality problems that persist in many places, despite decades of regulations and planning.

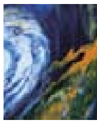
At the same time, there are some compensating innovations taking place in some areas (see Section 5.2.5).

The best-documented pressure is population growth, which is occurring in the United States as a whole, and especially in the South and Southwest regions where water resources are also among the scarcest. Water rights are afforded to the earliest users in many states, and new users without senior rights often must search for additional supplies. Las Vegas, Nevada is a case study of the measures required to provide water in the desert, but Phoenix, Albuquerque, Denver, Los Angeles and a host of other western cities provide comparable examples. In the southeastern United States, rapid population growth in cities (*e.g.*, Atlanta), combined with poor management and growing environmental concerns that require water to sustain fish and wildlife habitats, have led to serious shortages.

Recreational and environmental interests also have a direct stake in how waters are managed. For example, fishing and boating have increased in importance in recent decades as recreational uses have expanded and the economic basis of our economy has shifted from manufacturing to service.

Groundwater mining is a wild card in national water policy. Water resource allocation is generally a matter of state, not federal, control, and states have different policies with respect to groundwater. Some have no regulation; others permit mining (also referred to as groundwater overdrafting). Because groundwater is not visible and its movement is not well understood, its use is less likely to be regulated than surface water use. The effects of groundwater mining become evident not only in dewatering streams, but also impact regions that must search for alternative sources of water when sources diminish or disappear.

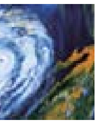
Historically, the solution for a supply-side response to increasing demand has focused on building new reservoirs, new pipelines to import water from distant basins, and new groundwater extraction systems. In the recent past, the United States engaged in an extended period of big dam and aqueduct construction (Worster, 1985) in which most of the appropriate construction sites were utilized. Other options have also been explored such as water reuse. As rivers have become fully appropriated, or over appropriated, there is no longer "surplus" water available for development. Environmental and recreational issues are impacted by further development of rivers, making additional water projects more difficult. Increasing demands for water are not likely to lead to the development of major additional water sources, although additional storage as well as other conservation tools (possibly including but not limited to water reuse, best management practices, and wetland banking) are being considered by water managers; however, it is too early in their evolution and adoption to determine what their impact will be on water supply.



In response to the growing imbalance between demand and supply, water utilities and jurisdictions have been investing in new sources of water and improved system efficiency for decades Reuse of municipal wastewater has become a significant component of the water supply picture in the Southwestern US (California, Arizona, New Mexico, and Texas) and Florida, and is quickly expanding in other regions. It is viewed as a particularly important resource in areas where the population is growing, since production of wastewater generally expands in proportion to the number of households involved as other sources are diminished. Other jurisdictions have tried options such as con-

servation, capturing rainwater for on-site use, improving capture and retention of floodflows, conjunctive management of groundwater and surface water, *etc*.

Many utilities have found that in the absence of a public perception of imminent threat to the adequacy of the water supply, that it is difficult to provide incentives to cause changes in human behavior leading to substantial water conservation because despite its actual value to society, water is relatively inexpensive. Politicians have found that the public does not welcome sharp increases in the price of water, even if the rationale for price increases is well described (Martin, 1984).



Water usage may also be examined by the relative flexibility of each demand. Municipal and industrial demands can be moderated through conservation or temporary restrictions, but these demands are less elastic than agricultural use. Agricultural uses, which comprise the largest users by volume, can be restricted in times of drought without major economic dislocations if properly implemented; however, the increasing connection between water and energy may limit this flexibility. Greater reliance on biofuels both increases competition for scarce water supplies and diverts irrigated agriculture from the production of food to the production of oilseeds such as soybeans, corn, rapeseed, sunflower seed, and sugarcane, among other crops used for biofuel. This changes the pattern of agricultural water use in the United States (Whiteley *et al.,* 2008).

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The rationalization of U.S. policies concerning water has been a goal for many decades. Emergent issues of increased climate variability and change may be the agents of transformation for United States water policies as many regions of the country are forced to examine the long term sustainability of water related management decisions (NRC, 1999b; Jacobs and Holway, 2004).

1.2.1 The Evolving Context: The Importance of Issue Frames

In order to fully understand the context in which a decision is made, those in the decision support sciences often look at the "issue frame" or the factors influencing the decision makers, including society's general frame of mind at the time. A common denominator for conceptualizing a frame is the notion that a problem can be understood or conceptualized in different ways (Dewulf *et al*., 2005). For the purpose of this Product, an issue frame can be considered a tool that allows us to understand the importance of a problem (Weick, 1995). Thus, salience is an important part of framing. Historically low public engagement in water resource decisions was associated with the widespread perception that the adequate delivery of good quality water is within the realm of experts. Further, the necessary understanding and contribution to decisions takes time, commitment, and knowledge that few possess or seek to acquire as water appears to be plentiful and is available when needed. It was understood that considerable variations in water supply and quality can occur, but it was accepted that water resource managers know how to handle variation.

A series of events and disclosures of scientific findings have profoundly changed the framing of water issues and the interaction between such framing and climate variability and change. As illustrated in Figure 1.1, natural disasters, including Hurricane Katrina and recent sustained droughts in the United States, have raised awareness of society's vulnerability to flood, drought, and degradation of water quality. Such extreme events occur as mounting evidence indicates that water quantity and quality, fundamental components of ecological sustainability in many geographical areas, are threatened (*e.g.*, deVilliers, 2003). The February 2007 Intergovernmental Panel on Climate Change, Working Group 1, Fourth Assessment Report (IPCC, 2007a) reinforced the high probability of significant future climate change and more extreme climate variation, which is expected to affect many sectors, including water resources.

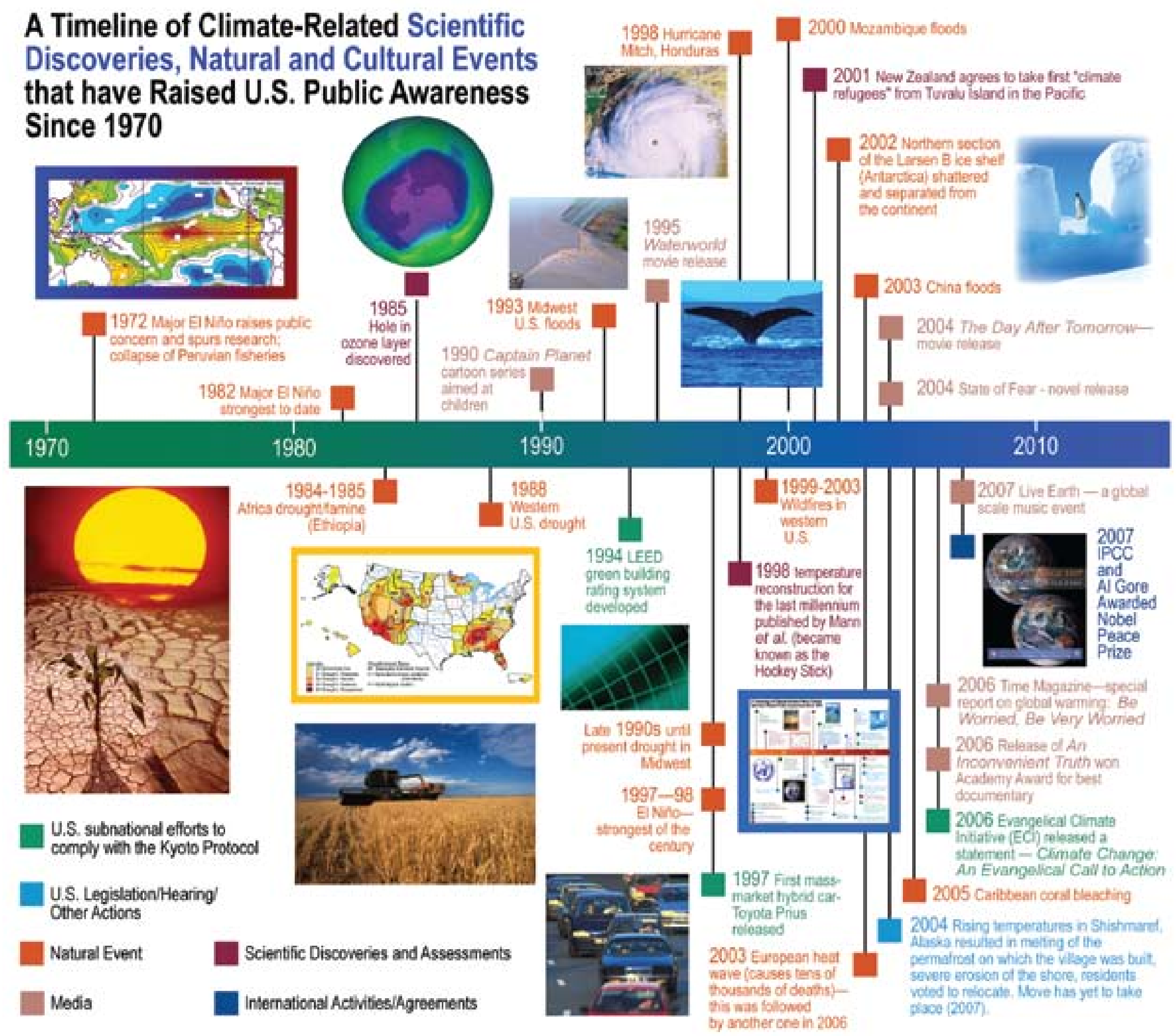
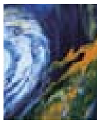


Figure 1.1 Timeline from 1970 to present of key natural and cultural events contributing to a widespread change in context for increasing awareness of climate issues.



The Report received considerable press coverage and generated increased awareness among the public and policy makers. Instead of being a low visibility issue, the issue frame for water resources has become that of attention-grabbing risk and uncertainty about such matters as rising sea levels, altered water storage in snow packs, and less favorable habitats for endangered fish species sensitive to warmer water temperatures. Thus, the effects of global warming have been an emerging issue-frame for water resources management.

Along with greater visibility of water and climate issues has come greater political and public involvement. At the same time, with an increase in discovery and awareness of climate impacts, there has been a deluge of policy actions in the form of new reports and passage of climate-related agreements and legislation (see Figure 1.2). Higher visibility of climate and water variability has put pressure on water managers to be proactive in response to expected negative effects of climate variability and change (Hartmann, *et al.,* 2002; Carbone and Dow, 2005). Specifically, in the case of water managers in the United States, perception of risk has been found to be a critical variable for the adoption of innovative management in the sector (O'Connor *et al.*, 2005).

Frames encompass expectations about what can happen and what should be done if certain predicted events do occur (Minsky, 1980). The emergent issue frame for water resource management is that new knowledge (about climate change and variability) is being created that warrants management changes. Information and knowledge about climate variability experienced in the recent historical past is no longer

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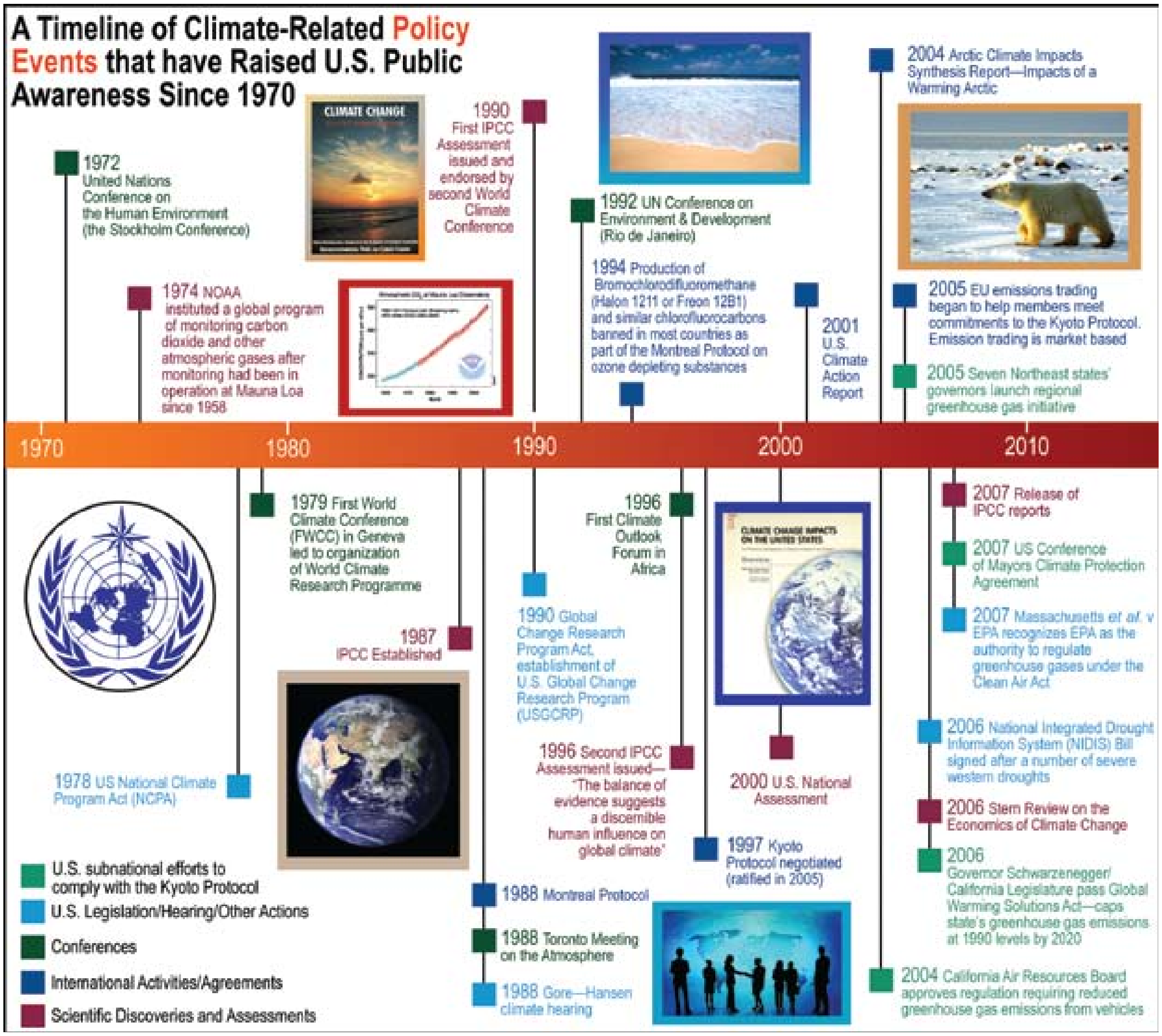
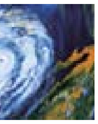


Figure 1.2 Timeline from 1970 to present of key policy events contributing to a widespread change in context for increasing awareness of climate issues.



as valuable as once it was, and new knowledge must be pursued (Milly *et al.*, 2008). Organizations and individuals face a context today where perceived failure to respond to climate variation and change is more risky than maintaining the status quo.

1.2.2 Climate Forecasting Innovations and Opportunities in Water Resources

Only in the last decade or so have climate scientists become able to predict aspects of future climate variations one to a few seasons in advance with better forecast skill than can be achieved by simply using historical averages for those seasons. This is a fundamentally new scientific advance (NRC, 2008).

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It is important to emphasize that SI climate forecasting skill is still quite limited, and varies considerably depending on lead time, geographic scale, target region, time of year, status of the ENSO cycle, and many other issues that are addressed in Chapter 2. Despite that, the potential usefulness of this new scientific capability is enormous, particularly in the water resources sector. This potential is being harvested through a variety of experiments and evaluations, some of which appear in this Product. For instance, reservoir management changes in the Columbia River Basin in response to SI climate forecast information have the potential to generate an average of $150 million per year more hydropower with little or no loss to other management objectives (Hamlet *et al.*, 2002). Table 1.1 illuminates the potential of SI climate forecasts to influence a wide range of water-related decisions, potentially providing great economic, security, environmental quality, and other gains.

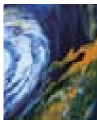
BOX 1.1 Seasonal-to-Interannual Climate Forecasts

Weather forecasts seek to predict the exact state of the atmosphere for a specific time and place at lead-times ranging from nowcasts (e.g., severe weather warnings) out to a maximum of two weeks. Observations that can be used to accurately characterize the initial state of the atmosphere are crucial to the accuracy of these short-term weather forecasts. In contrast, seasonal-to-interannual climate forecasts seek to predict the statistics of the atmosphere for a region over a specified window of time, typically from one month to a few seasons in advance.

Observations of the slowly varying boundary conditions on the atmosphere, including upper ocean temperatures, snow cover, and soil moisture are critical to the accuracy of climate forecasts. Climate forecasts can also address the expected probabilities for extreme events (floods, freezes, blizzards, hurricanes, *etc.*), and the expected range of climate variability. Much of the skill in seasonal-to-interannual climate forecasts for the United States derives from an ability to monitor and accurately predict the future evolution of El Niño-Southern Oscillation (ENSO), however, the actual skill demonstrated is not yet high. As a general principle, all climate forecasts are probabilistic. They are probabilistic both in the future state of ENSO and in the consequences of ENSO for remotely influenced regions like the United States. For example, a typical ENSO-related climate forecast for the Pacific Northwest region of the United States might be presented as follows:

> *Based on expectations for continued El Niño conditions in the tropical Pacific, we expect increased likelihoods for above average winter and spring temperatures with below average precipitation, with small but non-zero odds for the opposite conditions (i.e., below average likelihoods for below average winter and spring temperatures and above average precipitation) in the Pacific Northwest.*

At lead times of a few decades to centuries, climate change scenarios are based on scenarios for changes in the emissions and concentrations of atmospheric greenhouse gases and aerosols that are important for the Earth's energy budget. Climate change scenarios do not require real-time observations needed to accurately initialize the atmosphere or slowly-evolving boundary conditions (upper ocean temperatures, snow cover, *etc.*). However, a recent study by Keenleyside *et al.* (2008) demonstrates that there is potential for improving the forecast skill in decadal climate predictions made within longer-term climate change scenarios by initializing global climate models with ocean observations.



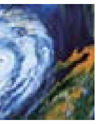
Aside from the potential applications suggested in Table 1.1, there are other overarching opportunities for use of SI climate and hydrologic forecasts recently introduced to the water resources sector. Adaptive Management and Integrated Water Resources Management are examples of reforms that are still in relative infancy (discussed in further detail in Chapters 3 and 4) but could gain considerable momentum through fostering continuous feedback from forecasts to changes in practice and improved performance. Adaptive management embraces the need for continuous monitoring and feedback. Information provided by forecasts can prompt real time adaptations by public and private agencies and water users (NRC 2004). Integrated Water Resources Management provides a more holistic view of water supply or demand and is based around the concepts of flexibility and adaptability, using measures that can be easily reversed or are robust under changing circumstances (IPCC, 2007b). Such potential flexibility and adaptability extends not only to water agencies, but also to the general public. Advances in climate forecast skills and their applications provide an opportunity to give the public a deeper understanding about the relationship of climate variability to increased risk, vulnerability, and uncertainty related to water that now tends to be perceived in terms of a replication of the past. In addition, tuning water management more closely to real time climate prediction allows for reducing the lead time for response to climate variation.

Adaptive management embraces the need for continuous monitoring and feedback. Information provided by forecasts can prompt real time adaptations by public and private agencies and water users.

Table 1.1 Examples of Water Resource Decisions Related to seasonal-to-interannual Climate Forecasts.

Decision/topic	Agency/organization Responsible	Activities Affected	Climate Forecast Information Relevance
Dam and reservoir management and reservoir allocation	• U.S. Army Corps of Engineers • U.S. DOI*, Bureau of Reclamation • Tennessee Valley Authority • FERC* and its licensed projects • Federal power marketing agencies • State, local, and regional water management entities and utilities, irrigation districts	Distribution of inflows and outflows for: • Agriculture • Public supply • Industry • Power • Flood control • Navigation • Instream flow maintenance • Protecting reserved waters for resources/other needs	• Total reservoir inflow • Long-range precipitation • Long-range temperature • Flow data • Snow melt data • Flood forecasts • Shifts in "phase" in decadal cycles
Irrigation/water allocation for agriculture/ aquaculture	• Federal, state, and regional facility operators • Irrigation districts • Agricultural cooperatives • Farmers	How much water and when and where to allocate it.	• Long/short-range precipitation • Long-range temperature
Ecosystem protection/ ecosystem services	• Federal and state resource agencies*, *e.g.,* • U.S. DOI, Fish and Wildlife Service • U.S. DOA, Forest Service, U.S. DOI, Park Service, U.S. DOI, BLM, U.S. DOC, NMFS, *etc.* • State, regional and watershed-based protected areas NGOs, *e.g.,* Nature Conservancy, local and regional land trusts	• Instream flow management • Riverine/riparian management • Wildlife management	• Climate cycles • Long-term climate predictions
Pubic water supply/ wastewater management	• Municipalities • Special water districts • Private water utilities • Water supply/wastewater utilities/ utility districts	• Needs for new reservoirs, dams, wastewater treatment facilities, pumping stations, groundwater management areas, distribution systems; • Needs for long term water supply and demand manage ment plans; • Drought planning.	Changes in temperature/ precipitation effect water demand; reduction in base-flows, increased demands, and greater evaporation rates (Gleick *et al.*, 2000; Clarkson and Smerdon, 1989). Predictive information at multiple scales and multiple time frames.
Coastal zones	• Regional coastal zone management agencies • Corps of Engineers • NMFS, other federal agencies • Local/regional flood control agencies • Public supply utilities	• Impacts to tidal deltas, low lying coastal plains • Changes to fish production/ coastal food systems, salt water intrusion • Erosion; deterioration of marshes • Flood control, water supply and sewage treatment implications	Predicted sea level rise & land subsidence; fluctuation in surface water temperature; tropical storm predictions; change to precipitation patterns; wind & water; storm surges and flood flow circulation patterns (Davidson, 1997).
Navigation	• Harbor managers • River system and reservoir managers, barge operators	• River and harbor channel depth; flow	• Stream flow, seasonality, and flooding potential
Power production	• Federal water and power agencies; FERC; private utilities with licensed hydropower projects; private utilities using power from generation facilities	• Water for hydropower • Water for steam generation in fossil fuel and nuclear plants • Water for cooling	• Temperature (and relation ships to demand for power) • Precipitation • Stream flow and runoff
Flooding/ floodplain management	• Floodplain managers; flood zone agencies; insurance companies; risk managers, land use planners	• Infrastructure needs planning • Emergency management	Short and long-term runoff predictions, especially long term trends in intensity of precipitation, storm surges, *etc.*

*Abbreviations used in table: BLM: Bureau of Land Management: DOA: Department of Agriculture; DOC: Department of Commerce; DOI: Department of the Interior; FERC: Federal Energy Regulatory Commission; NGO: Non-Governmental Organization; NMFS: National Marine Fisheries Service.



1.2.3 Organizational Dynamics and Innovation

The flow of information among agencies and actors in the complex organizational fields of climate forecasting and water resources is not always effective. Even as skill levels of climate and hydrologic forecasts have improved, resistance to their use in water resources management both exists and persists (O'Connor *et al.*, 1999; Rayner *et al.*, 2005; Yarnal *et al.*, 2006). Such resistance to innovation is to be expected, according to organizational and management literature that addresses the management of information across boundaries of various kinds that include organizations, disciplines, fields, and practices (Carlile, 2004; Feldman *et al.*, 2006). The same specialization that makes organizations effective in meeting internal organizational goals can make them resistant to innovation (Weber, 1947). Creating a product or service requires experience, terminologies, tools, and incentives that are embedded in a specific organization. Because knowledge requires time, resource, and opportunity cost investments, it constitutes a kind of "stake", and therefore significant costs are associated with acquiring new knowledge across boundaries (Carlile, 2002). Further, if the kind of knowledge that needs to be coordinated across boundaries is so different that a bridge of a common language must be created to allow translation, then the barriers are more difficult to overcome. Finally, demands made by sharing information across boundaries may be so novel that an organization must make a fundamental readjustment that challenges everything it knows.

Figure 1.3, adapted from Carlile (2004), depicts the challenges that must be addressed in order to share knowledge across boundaries, and conveys the challenge of innovation through information sharing across different organizations, levels of government, and public and private sectors. The lowest level of the inverted triangle shows information transfer is relatively simple between climate forecasters from different organizations. Forecasters generally share common knowledge, and know each others' language and levels of expertise regardless of organizational ties. Because a common lexicon exists, knowledge transfer is relatively simple. The usual barriers to smooth information flow apply, including information overload, availability of storage and retrieval technologies and other information processing challenges. Unfortunately, because agencies tend to use their own terminology and information, because they know and trust the sources, before using terminology and information from outside, the adoption of SI climate forecast information in the water resource sector rarely fits this simple transfer profile.

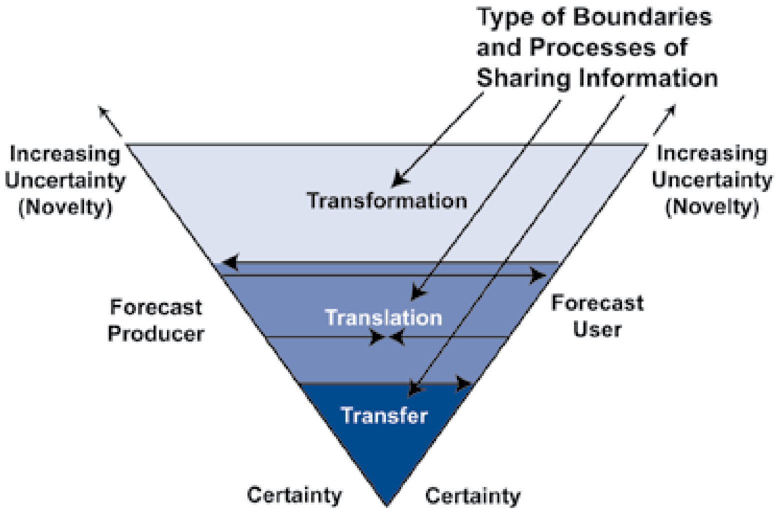
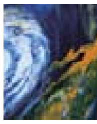


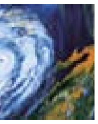
Figure 1.3 Illustration of information sharing processes. At the tip of the triangle forecast producers and forecast users are sharing a common syntax and framework, and therefore knowledge is simply transferred. As the products and uses become increasingly different and novel, a process of learning has to occur for information to be translated (middle of inverted triangle). Finally, information will need to be transformed in order for knowledge to be accessible to very different parties (top of the inverted triangle). Adapted from Carlile, 2004.



At the second, or translation, level of information management, language issues become problematic and development of shared information is more difficult. This level of information sharing typifies the relationships between climate forecasters and water resource forecasters who have long predicted water futures using data such as snowpack, soil moisture, and basin and watershed models. Efforts to communicate at this level involve a large expenditure of effort that must be justified within the organization and may encounter resistance unless offset by some considerable worthwhile pay-off. Successful efforts for communication could include the creation of a lexicon with common definitions, the development of shared methodologies, the formulation of cross-organizational teams, the engagement in strategies such as collocation of offices, and the employment of individuals who can act as translators or brokers.

The third, or transformation, level of managing information requires considerable change in the ways in which organizations presently process and use information. Currently, climate forecasters tend to follow what has been termed the "Loading Dock Model", or simply issuing forecasts with little notion of whether they will be used by other organizations (Cash and Buizer, 2005). Knowledge at this third level (ultimately at all levels) must be created collaboratively, that is, coproduced with outside organizations, interests and entities, rather than delivered; and must be clear, credible and legitimate to all engaged actors. Information is likely to be more salient if it comes from known and trusted sources (NRC, 1989, 2008). Credibility is not just credibility of scientists, but also to users; information is more credible if it recognizes and addresses multiple perspectives. Legitimacy relates to even-handedness and the absence of narrow organizational or political agendas (Cash *et al.*, 2003; NRC, 2007, 2008). Almost all of the important applications of SI climate forecasts involve information management at the third level.

Decision support is defined here as creating conditions that foster the appropriate use of information. The primary objective of decision-support activities is to foster transformative information exchange that will both change the kind of information that is produced and the way it is used.



1.2.4 Decision Support, Knowledge Networks, Boundary Organizations, and Boundary Objects

A recent National Academy of Sciences Report (2008) observed that decision support is widely used but definitions of what constitutes that support vary. Following the lead of this Product, decision support is defined here as creating conditions that foster the appropriate use of information. This definition presumes that the climate scientists who generate SI climate forecasts often do not know what type of useful information they could provide to water resources managers, and that water managers do not necessarily know how they could apply SI climate forecasts and related information (NRC, 2008). The primary objective of decision-support activities is to foster transformative information exchange that will both change the kind of information that is produced and the way it is used (NRC 1989, 1996, 1999a, 2005, 2006, 2008).

Decision support involves engaging effective two-way communication between the producers and users of climate information (Jacobs *et al.*, 2005; Lemos and Morehouse, 2005; NRC, 1999a, 2006) rather than just the development of tools and products that may also be useful though less functional. This conception of decision support brings into focus human relationships and networks in information utilization. The test of transformed information is that it is trusted and considered reliable, and is fostered by familiarity and repeated interaction between information collaborators and the working and reworking of relationships. A knowledge network is built through such human interactions across organizational boundaries, creating and conveying information that is useful for all participants, ranging from scientists to multiple decision makers.

A variety of mechanisms can be employed to foster the creation of knowledge networks and the coproduction of knowledge that transcends what is already available. Among such mechanisms are boundary organizations that play an intermediary role between different organizations, specializations, disciplines, practices, and functions; including science and policy (Cash, 2001; Guston, 2001). These organizations can play a variety of roles in decision support, such as convening together, collaboration among users and producers, mediation for the various parties and the production of boundary objects. A boundary object is a prototype, model or other artifact through which collaboration can occur across different kinds of boundaries. Collaborative participants may come to appreciate the contribution of other kinds of knowledge, perspectives, expertise or practices and how they may augment or modify their own knowledge through engagement (Star and Griesemer, 1989). For example, a fish ladder is a kind of boundary object since it is an add-on to a dam structure. It must be integrated into the structural design, so hydrologists and engineers must collaborate on design decisions. At the same time, it serves fish species, so the insight of biologists about fish behavior is necessary for the ladder to work as it is intended.

1.3 OUTLINE OF THE REPORT AND WHERE PROSPECTUS QUESTIONS ARE ADDRESSED

This Chapter addresses the types of SI forecast-related decisions that are made in the water resources community and the role that such forecasts could play. It describes the general contextual opportunities and limitations to innovations that could limit the use of SI forecast information.

Chapter 2 answers the question: What are SI forecast products and how do they evolve from a scientific prototype to an operational product? It also addresses the issue of forecast skill, the impediments to progress in improving skill, and the steps necessary to ensure a product is needed and will be used in decision support. It describes the level of confidence about SI forecast products in the science and decision-making communities.

Chapter 3 focuses on the obstacles, impediments, and challenges in fostering close collaboration between scientists and decision makers in terms of theory and observation. Researchers have documented why and how resource decision makers use information, Chapter 3 addresses the following kinds of questions: How are hazards and risks related to climate variability perceived and managed? What are the challenges related to determining and serving the needs of decision makers, emphasizing the importance of reliability and trust, and suggesting how decision support could leverage scientific and technological advances?

Chapter 4 provides examples of a range of decision support experiments in the context of SI forecast information. It describes the limitations on the kinds of information available and the need to employ logical inference. It also discusses how decision support tools can be improved.

Chapter 5 provides a summary of this Product, especially identifying overarching themes. It suggests the kinds of research and action needed to improve progress in this area. Finally, it addresses how the knowledge gained in water resources might be useful to other sectors.

The prospectus for this study contained a series of questions that were to direct this study, vetted by the Climate Change Science Program office and by public review. Table 1.2 summarizes the questions and specifies which chapter section they are addressed. Table 1.3 is a summary of the case studies provided in this Product.

Table 1.2 Questions To Be Addressed in Synthesis and Assessment Product 5.3.

Prospectus Question	Report Location where Question is Addressed
What seasonal-to-interannual (*e.g.*, probabilistic) forecast information do decision makers need to manage water resources?	2.1
What are the seasonal-to-interannual forecast/data products currently available and how does a product evolve from a scientific prototype to an operational product?	2.2
What is the level of confidence of the product within the science community and within the decision-making community, who establishes these confidence levels and how are they determined?	2.2
How do forecasters convey information on climate variability and how is the relative skill and level of confidence of the results communicated to resource managers?	2.3
What is the role of probabilistic forecast information in the context of decision support in the water resources sector?	2.3
How is data quality controlled?	2.3
What steps are taken to ensure that this product is needed and will be used in decision support?	2.5
What types of decisions are made related to water resources?	3.2
What is the role that seasonal-to-interannual forecasts play and could play?	3.2
How does climate variability influence water resource management?	3.2
What are the obstacles and challenges decision makers face in translating climate forecasts and hydrology information into integrated resource management?	3.2
What are the barriers that exist in convincing decision makers to consider using risk-based hydrology information (including climate forecasts)?	3.2
What challenges do tool developers have in finding out the needs of decision makers?	3.3
How much involvement do practitioners have in product development?	4.1
What are the measurable indicators of progress in terms of access to information and its effective uses?	4.3
Identify critical components, mechanisms, and pathways that have led to successful utilization of climate information by water managers.	4.4
Discuss options for (a) improving the use of existing forecasts/data products and (b) identify other user needs and challenges in order to prioritize research for improving forecasts and products.	4.4 and 5
Discuss how these findings can be transferred to other sectors.	5

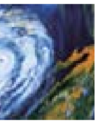
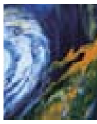
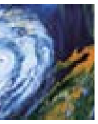


Table 1.3 Summary of Case Studies (*i.e.*, Experiments and Evaluations) presented in this Product.

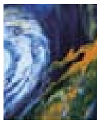
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
CPC Seasonal Drought Outlook (DO)	2, Box 2.3	DO is a monthly subjective consensus forecast between several agencies and academic experts, of drought evolution for three months following the forecast date.	Primary drought-related agency forecast produced in US; widely used by drought management and response community from local to regional scales. Research is ongoing for product improvements.
Testbeds	2, Box 2.4	Testbeds are a mix of research and operations, and serve as a conduit between operational, academic and research communities. NOAA currently operates several testbeds (*e.g.*, Hazardous Weather, Climate and Hurricanes).	Testbeds focus on introducing new ideas and data to the existing system and analyzing the results through experimentation and demonstration. Satisfaction with testbeds has been high for operational and research participants alike.
Advanced Hydrologic Prediction Service (AHPS)	2, Box 2.5;3, Section 3.3.1.2	AHPS provides data more quickly and at smaller scale (*i.e.*, local watershed) than previous hydrographic models; directly links to local decision makers.	More accurate, detailed, and visually oriented outputs provide longer-range forecasts than current methods. Also includes a survey process and outreach, training, and educational activities.
NWS Local 3-Month Outlook for Temp & Precip (L3MO)	2, Box 2.6	Designed to clarify and downscale the national-scale CPC Climate Outlook temperature forecast product.	Outlook is new; it became operational in January 2007. The corresponding local product for precipitation is still in development as of this writing.
Southwest drought-climate variability & water management	3, Section 3.2.3.2	Regional studies of: associations between ENSO teleconnections, multi-decadal variations in Pacific Ocean-atmosphere system, and regional climate show potential predictability of seasonal climate and hydrology.	New Mexico and Arizona have been working to integrate new decision support tools and data into their drought plans; Colorado River Basin water managers have commissioned tree ring reconstructions of streamflow to revise estimates of record droughts, and to improve streamflow forecast performance.
Red River of the North—Flooding and Water Management	3, Section 3.2.4	Model outputs to better use seasonal precipitation, snowmelt, *etc.*, are being used in operations decisions; however, the 1997 floods resulted in $4 billion in losses. The River crested 5 feet over the flood height predicted by the North Central River Forecast Center; public blamed National Weather Service for a faulty forecast.	There is a need for (1) improved forecasts (*e.g.*, using recent data in flood rating curves, real-time forecasting); (2) better forecast communication (*e.g.*, warnings when rating curve may be exceeded and including user feedback in improved forecast communication); and (3) more studies (*e.g.*, reviewing data for future events).



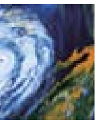
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Credibility and the Use of Climate Forecasts: Yakima River Basin/El Niño	3, Section 3.2.4	In 1997, USBR issued a faulty forecast for summer runoff to be below an established threshold. Result was increased animosity between water rights holders, loss of confidence in USBR, lawsuits against USBR.	There is a need for greater transparency in forecast methods (including issuing forecast confidence limits), better communication between agencies and the public, and consideration of consequences of actions taken by users in the event of a bad forecast.
Credibility and the Use of Climate Forecasts: Colorado Basin Case Studies	3, Section 3.2.4	In 1997, the USBR issued a forecast, based on snowpack, for summer runoff to be below the legally established threshold, resulting in jeopardized water possibilities for junior water rights holders.	Need to improve transparency in forecast methods (*e.g.*, issuing forecast confidence limits, better communication between agencies and the public, and consideration of users' actions in the event of a bad forecast), would have improved the forecast value and the actions taken by the USBR.
Southeast Drought: Another Perspective on Water Problems in the Southeastern United States	3, Section 3.3.1	A lack of tropical storms/ hurricanes and societal influences such as operating procedures, laws and institutions led to the 2007-2008 Southeast Drought, resulting in impacts to agriculture, fisheries, and municipal water supplies.	Impacts exacerbated by (1) little action to resolve river basin conflicts between GA, AL, and FL; (2) incompatibility of river usage (*e.g.*, protecting in-stream flow while permitting varied off-stream use), (3) conflicts between up- and down-stream demands (*i.e.*, water supply/wastewater discharge, recreational use), and (4) negotiating process (*e.g.*, compact takes effect only when parties agree to allocation formula).
Policy learning and seasonal climate forecasting application in NE Brazil—integrating information into decisions	3, Section 3.3.1.1	In 1992, in response to a long drought, the State of Ceara created several levels of water management including an interdisciplinary group within the state water management agency to develop and implement reforms.	Inclusion of social and physical scientists and stakeholders resulted in new knowledge (*i.e.*, ideas and technologies) that critically affected water reform, including helping poorer communities better adapt to, and build capacity for managing climate variability impacts on water resources; also helped democratize decision making.



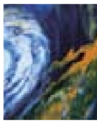
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Interpreting Climate Forecasts—uncertainties and temporal variability: Use of ENSO based information	3, Section 3.3.2	The Arizona Salt River Project (SRP) made a series of decisions based on the 1997/1998 El Niño (EN) forecast plus analysis of how ENs tended to affect their rivers and reservoirs.	SRP managers reduced groundwater pumping in 1997 in anticipation of a wet winter; storms provided ample water for reservoirs. Success was partly due to availability of climate and hydrology research and federal offices in close proximity to managers. Lack of temporal and geographical variability information in climate processes remains a barrier to adoption/use of specific products; decisions based only on forecasts are risky.
How the South Florida Water Management District (SFWMD) Uses Climate Information	4, Experiment 1	SFWMD established a regulation schedule for Lake Okeechobee that uses climate outlooks as guidance for regulatory release decisions. A decision tree with a climate outlook is a major advance over traditional hydrologic rule curves used to operate large reservoirs. This experiment is the only one identified that uses decadal climate data in a decision-support context.	To improve basin management, modeling capabilities must: improve ability to differentiate trends in basin flows associated with climate variation; gauge skill gained in using climate information to predict basin hydro-climatology; account for management uncertainties caused by climate; and evaluate how climate projections may affect facility planning and operations. Also, adaptive management is effective in incorporating SI variation into modeling and operations decision-making processes.



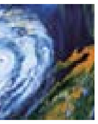
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Long-Term Municipal Water Management Planning—New York City (NYC)	4, Experiment 2	NYC is adapting strategic and capital planning to include the potential effects of climate change (*i.e.*, sea-level rise, higher temperatures, increases in extreme events, and changing precipitation patterns) on the City's water systems. NYC Department of Environmental Protection, in partnership with local universities and private sector consultants, is evaluating climate change projections, impacts, indicators, and adaptation and mitigation strategies to support agency decision making.	This case illustrates (1) plans for regional capital improvements can include measures that reduce vulnerability to sea level rise; (2) the meteorological and hydrology communities need to define and communicate current and increasing risks, with explicit discussion of the inherent uncertainties; (3) more research is needed (*e.g.*, to further reduce uncertainties associated with sea-level rise, provide more reliable predictions of changes in frequency/intensity of tropical and extra-tropical storms, *etc.*); (4) regional climate model simulations and statistical techniques used to predict long-term climate change impacts could be down-scaled to help manage projected SI climate variability; and (5) decision makers need to build support for adaptive action despite uncertainties. The extent and effectiveness of this action will depend on building awareness of these issues among decision makers, fostering processes of interagency interaction and collaboration, and developing common standards.



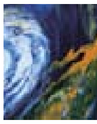
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Integrated Forecast and Reservoir Management (INFORM)—Northern California	4, Experiment 3	INFORM aims to demonstrate the value of climate, weather, and hydrology forecasts in reservoir operations. Specific objectives are to: (1) implement a prototype integrated forecast-management system for the Northern California river and reservoir system in close collaboration with operational forecasting and management agencies, and (2) demonstrate the utility of meteorological/climate and hydrologic forecasts through near-real-time tests of the integrated system with actual data and management input.	INFORM demonstrated key aspects of integrated forecast-decision systems, *i.e.*, (1) seasonal climate and hydrologic forecasts benefit reservoir management, provided that they are used in connection with adaptive dynamic decision methods that can explicitly account for and manage forecast uncertainty; (2) ignoring forecast uncertainty in reservoir regulation and water management decisions leads to costly failures; and (3) static decision rules cannot take full advantage of and handle forecast uncertainty information. The extent that forecasts help depends on their reliability, range, and lead time, in relation to the management systems' ability to regulate flow, water allocation, *etc.*
How Seattle Public Utility (SPU) District Uses Climate Information to Manage Reservoirs	4, Experiment 4	Over the past several years SPU has taken steps to improve incorporation of climate, weather, and hydrologic information into the real-time and SI management of its mountain water supply system. They are receptive to new management approaches due to public pressure and the risk of legal challenges related to the protection of fish populations	The SPU case shows: (1) access to skillful SI forecasts enhances credibility of using climate information in the region; (2) monitoring of snowpack moisture storage and mountain precipitation is essential for effective decision making and for detecting long-term trends that can affect water supply reliability; and (3) SPU has significant capacity to conduct in-house investigations/assessments. This provides confidence in the use of information.



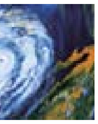
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Using Paleo-climate Information to Examine Climate Change Impacts	4, Experiment 5	Because of repeated drought, western water managers, through partnerships with researchers in the inter-mountain West have chosen to use paleoclimate records of streamflow and hydroclimatic variability to provide an extended record for assessing the potential impact of a more complete range of natural variability as well as providing a baseline for detecting regional impacts of global climate change.	Partnerships have led to a range of applications evolving from a better understanding of historical drough conditions to assessing drought impacts on water systems using tree ring reconstructed flows. Workshops have expanded applications of the tree ring based streamflow reconstructions for drought planning and water management. Also, an online resource provides water managers access to gage and reconstruction data and a tutorial on reconstruction methods for gages in Colorado and California.
Climate, Hydrology, and Water Resource Issues in Fire-Prone United States Forests	4, Experiment 6	The 2000 experiment, consisting of annual workshops to evaluate the utility of climate information for fire management, was initiated to inform fire managers about climate forecasting tools and to enlighten climate forecasters about the needs of the fire management community.	Fire-climate workshops are now accepted practice by agencies with an annual assessment of conditions and production of pre-season fire-climate forecasts. Scientists and decision makers continue to explore new questions, as well as involve new participants, disciplines and specialties, to make progress in key areas (*e.g.*, lightning climatologies).
The CALFED – Bay Delta Program: Implications of Climate Variability	4 Experiment 7	Delta requirements to export water supplies to southern California are complicated by: managing habitat and water supplies in the region, maintaining endangered fish species, making major long-term decisions about rebuilding flood control levees and rerouting water supply networks through the region.	A new approach has led to consideration of climate change and sea level rise in infrastructure planning; the time horizon for planning has been extended to 200 years. Because of incremental changes in understanding changing climate, this case shows the importance of using adaptive management strategies.



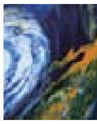
Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Regional Integrated Science and Assessment Teams (RISAs)—An Opportunity for Boundary Spanning, and a Challenge	Section 4.3.2	The eight RISA teams that are sponsored by NOAA represent a new collaborative paradigm in which decision makers are actively involved in developing research agendas. RISAs explicitly seek to work at the boundary of science and decision making.	RISA teams facilitate engagement with stakeholders and design climate-related decision-support tools for water managers through using: (1) a robust "stakeholder-driven research" approach focusing on both the supply (*i.e.*, information development) and demand side (*i.e.*, the user and her/his needs); (2) an "information broker" approach, both producing new scientific information themselves and providing a conduit for new and old information and facilitating the development of information networks; (3) a "participant/advocacy" or "problem-based" approach, involving a focus on a particular problem or issue and engaging directly in solving it; and (4) a "basic research" approach where researchers recognize gaps in the key knowledge needed in the production of context sensitive, policy-relevant information.
Leadership in the California Department of Water Resources (CDWR)	4, Case Study A	Drought in the Colorado River Basin and negotiations over shortage and surplus guidelines prompted water resources managers to use climate data in plans and reservoir forecast models. Following a 2005 workshop on paleohydrologic data use in resource management, RISA and CDWR scientists developed ties to improve the usefulness of hydro-climatic science in water management.	CDWR asked the NAS to convene a panel to clarify scientific understanding of Colorado River Basin climatology and hydrology, past variations, projections for the future, and impacts on water resources. NAS issued the report in 2007; a new Memorandum of Agreement now exists to improve cooperation with RISAs and research laboratories.



Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Cooperative extension services, watershed stewardship: the Southeast Consortium	4, Case Studies B and F	The Southeast Climate Consortium RISA (SECC), a confederation of researchers at six universities in Alabama, Georgia, and Florida, has used a top-down approach to develop stakeholder capacity to use climate information in region's $33 billion agricultural sector. Early on, SECC researchers recognized the potential of using ENSO impact on local climate data to provide guidance to farmers, ranchers, and forestry sector stakeholders on yields and changes to risk (*e.g.*, frost occurrence).	SECC determined that (1) benefits from producers use of seasonal forecasts depends on factors that include the flexibility and willingness to adapt farming operations in response to forecasts, and the effectiveness of forecast communication; (2) success in championing integration of new information requires sustained interactions (*e.g.*, with agricultural producers in collaboration with extension agents; and (3) direct engagement with stakeholders provides feedback to improve the design of the tool and to enhance climate forecast communication.
Approaches to building user knowledge and enhancing capacity building—Arizona Water Institute	4, Case Study C	The Arizona Water Institute, initiated in 2006, focuses resources of the State of Arizona's university system on the issue of water sustainability. The Institute was designed as a "boundary organization" to build pathways for innovation between the universities and state agencies, communities, Native American tribal representatives, and the private sector.	The Institute focuses on: capacity building, training students through engagement in real-world water policy issues, providing better access to hydrologic data for decision makers and assisting in visualizing implications of decisions they make, providing workshops and training programs for tribal entities, jointly defining research agendas between stakeholders and researchers, and building employment pathways to train students for jobs requiring special training (*e.g.*, water and wastewater treatment plant operators).



Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Murray–Darling Basin—sustainable development and adaptive management	4, Case Study D	1985 Murray–Darling Basin Agreement (MDBA), formed by New South Wales, Victoria, South Australia and Commonwealth, provides for integrated management of water and related land resources of world's largest catchment system. MDBA encourages use of climate information for planning and management; seeks to integrate quality and quantity concerns within a single management framework; has a broad mandate to embrace social, economic, environmental and cultural issues in decisions, and authority to implement water & development policies.	According to Newson (1997), while the policy of integrated management has "received wide endorsement", progress towards effective implementation has fallen short—especially in the area of floodplain management. This has been attributed to a "reactive and supportive" attitude as opposed to a proactive one. Despite such criticism, it is hard to find another initiative of this scale and sophistication that has attempted adaptive management based on community involvement.
Adaptive management in Glen Canyon, Arizona and Utah	4, Case Study E	Glen Canyon Dam was constructed in 1963 to provide hydropower, irrigation, flood control, and public water supply—and to ensure adequate storage for upper basin states of Colorado River Compact. When dam's gates closed, the river above and below Glen Canyon was altered. In 1996, USBR created an experimental flood to restore the river ecosystem.	Continued drought in the Southwest is placing increased stress on land and water resources of region, including agriculture. Efforts to restore the river to conditions more nearly approximating the era before the dam was built will require changes in the dam's operating regime to force a greater balance between instream flow, sediment management, power generation and offstream water supply. This will require forecast use to ensure that these various needs can be optimized.
Potomac River Basin	4, Case Study G	The Interstate Commission on the Potomac River Basin (ICPRB) periodically studies the impact of climate change on the supply reliability to the Washington metropolitan area (WMA).	A 2005 study stated that the 2030 demand in the WMA could be 74% to 138% greater than that of 1990. According to the report, with aggressive conservation and operation policies, existing resources should be sufficient through 2030; recommended incorporating potential climate impacts in future planning.



Study or Experiment	Chapter	Type of Decision Support Information Needed, Used or Delivered	Most Successful Feature(s) or Lesson(s) Learned from Case Study
Fire prediction workshops as a model for climate science–water management process to improve water resources decisions	4, Case Study H	Given strong mutual interests in improving the range of tools available to fire management, with goal of reducing fire related damage and loss of life, fire managers and climate scientists have developed long-term process to: improve fire potential prediction; better estimate costs; most efficiently deploy fire fighting resources.	Emphasis on process, as well as product, may be a model for climate science in support of water resources management decision making. Another key facet in maintaining this collaboration and direct application of climate science to operational decision making has been the development of strong professional relationships between the academic and operational partners.
Incentives to Innovate—Climate Variability and Water Management along San Pedro River	4, Case Study I	The highly politicized issue of water management in upper San Pedro River Basin has led to establishment of Upper San Pedro Partnership, whose primary goal is balancing water demands with supply without compromising region's economic viability, much of which is tied to Fort Huachuca Army base.	Studies show growing vulnerability to climate impacts. Climatologists, hydrologists, social scientists, and engineers work with partnership to strengthen capacity/interest in using climate forecast products. A decision-support model being developed by University of Arizona with partnership members will hopefully integrate climate into local decisions.