Chapter 5. Looking Toward the Future

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5.1 INTRODUCTION

The future context for decision support for seasonal to interannual climate forecasting-related decisions in water resources and other sectors will evolve in response to future climate trends and events, advances in monitoring, predicting and communicating information about hydrologically-significant aspects of climate, and social action. Climate related issues have a much higher profile among the public, media, and policy makers than they did even a few years ago. In water resources and other sectors, climate is likely to be only one of a number of factors affecting decision making, and the extent to which it is given priority will depend both on the experiences associated with "focusing events" such as major droughts, floods, hurricanes and heat waves, and on how strong knowledge networks have become. The utility of climate information will depend largely on how salient, credible, valuable and legitimate it is perceived to be. These qualities are imparted through knowledge networks that can be fostered and strengthened using decision-support tools. Increasingly climate forecasting and data have become integrated with water resources decisions at multiple levels, and some of the lessons learned in the water sector can improve the application of seasonal-to-interannual (SI) climate forecasts in other climate sensitive sectors. Better integration of climate forecasting science into water resources and other sectors will likely save and improve lives, reduce damages from weather extremes, and lower economic cost related to adapting to continued climate variability.

This chapter begins by highlighting a number of overarching themes that need to be emphasized as important to understanding the overall challenges facing decision support and its use. It then turns to research priorities that are critical to progress. The chapter concludes with some discussion of other sectors likely to be affected by climate variation that could profit from lessons in the water resources sector.

5.2 OVERARCHING THEMES AND FINDINGS

5.2.1 The "Loading Dock Model" of Information Transfer is Unworkable

Only recently have climate scientists come to realize that improving the skill and accuracy of climate forecasting products does not necessarily make them more useful or more likely to be adopted. Skill is a necessary ingredient in perceived forecast value, yet more forecast skill by itself does not imply more forecast value. Lack of forecast skill and/or accuracy may be one of the impediments to forecast use, but there are many other barriers. Such improvements must be accompanied by better communication and stronger linkages between forecasters and potential users. In this report we have stressed that forecasts flow through knowledge networks and across disciplinary and occupational boundaries. Thus, forecasts need to be useful and relevant in the full range from observations to applications, or "end-to-end useful." End-to-end useful also implies a broader fabric of utility, created by multiple entities that adopt forecasts for their own reasons and adapt them to their own purposes by blending forecast knowledge with know-how, practices, and other sources of information more familiar to those participants. These network participants then pass the blended information along to other participants who in turn engage in the same process. By the end of the process of transfer, translation and transformation of information, forecast information may look very different from what scientists initially envisioned.

Skill and accuracy are only two of the values important to the use of climate knowledge. Relevance is of equal importance, and to be relevant the information must be timely as well. It almost goes without saying that the benefits of using the information should be larger than the costs, but it is worth remembering that many decision makers already operate with an overload of information and therefore relevance depends on salience to specific situations that they are concerned about. Also, benefits should not be thought of as primarily economic but need also to include political, organizational and professional advantages. Salience is a product of framing in the larger political community and in the professional circles in which different decision makers' travel. Information must be credible and come from a legitimate or trusted source that has a reputation for integrity. Novel ideas are difficult for organizations to adopt, and, therefore such ideas become more credible if they are blended with and tempered by already existing information channels and organizational routines.

5.2.2 Decision Support is a Process Rather Than a Product

As knowledge systems have come to be better understood, providing decision support has come to be understood not only as information products but instead as a communications process that links scientists with users. While decision tools like models, scenarios, and other boundary objects that connect scientific forecasters to various stakeholder groups can be helpful, the notion of tools insufficiently conveys the relational aspects of networks. Relevance, credibility, and legitimacy are human perceptions built through repeated interactions. For this reason, decision support does not result in a product that can be shelved until needed or reproduced for different audiences. Clearly lessons from decisions support experience are portable from one area to another but only as the differences in context are interpreted, understood, and taken into account.

Governments are not the only producers of climate variability forecasts. Non-governmental actors including private businesses play a critical role in knowledge networks, particularly in tailoring climate forecast products to fit the needs of particular sectors and user groups. Nothing in this report should suggest that knowledge networks must be wholly or even for the most part in the public sector. Just as numerous entrepreneurs have taken National Weather Service forecasts and applied them to different sectors and user group needs, SI climate information transfer, translation and transformation may become functions largely provided by the private sector. However, as argued in the following section, there is clearly a role for the public sector because information access is related to economic and social outcomes that must be acknowledged.

Ensuring that information is accessible and relevant will require paying greater attention to the role of institutions in furthering the process of decision support – particularly *boundary spanning* activities that bring together tool developers and users to exchange information, promote communication, propose remedies to problems, foster stakeholder engagement, and conjointly develop decision-support systems to address user needs. An important facet of boundary spanning is that the co-production, transference, communication and dissemination of climate information to water decision makers requires partnerships among public and private sector entities. In short, to avoid the loading-dock model previously discussed, efforts to further boundary-spanning partnerships is essential to fostering a process of decision support (NRC, 2007; NRC, 2008; Cash and Buizer, 2005; Sarewitz and Pielke, 2007).

5.2.3 Equity May Not Be Served

Information is power in global society, and unless it is widely shared, the gaps between the rich and the poor, and the advantaged and disadvantaged may widen. Lack of resources is one of the causes of poverty, and resources are required to tap into knowledge networks so that in a vicious cycle, poverty can become its own cause. Unequal distribution of knowledge can insulate decision-making, facilitate elite capture of resources, and alienate disenfranchised groups. In contrast, an approach that is open, interactive and inclusionary can go a long way in supporting informed decisions that, in turn, can yield better outcomes from the perspective of fairness.

The emergence of seasonal climate forecasting initially raised great expectations of its potential role to decrease the vulnerability of poor farmers around the world to climate variability and the development and dissemination of forecasts have been justified in equity terms (Glantz, 1996: McPhaden *et al.*, 2006). However, ten years of empirical research on seasonal forecasting application and effect on agriculture, disaster response and water management have tempered these expectations (Klopper, 1999; Vogel, 2000; Valdivia *et al.*, 2000; Letson *et al.*, 2001; Hammer *et al.*, 2001; Lemos *et al.*, 2002; Patt and Gwata, 2002; Broad *et al.*, 2002; Archer, 2003; Lusenso *et al.*, 2003; Roncoli *et al.*, 2006; Bharwani *et al.*, 2005; Meinke *et al.*, 2006; Klopper *et al.*, 2006). Examples of applications of SI climate forecasts show that not only are the most vulnerable often unable to benefit, but in some situations may be harmed (Broad *et al.*, 2002: Lemos *et al.*, 2002: Patt and Gwata, 2002: Roncoli *et al.*, 2004: Roncoli *et al.*, 2006: O'Brien and Vogel, 2007). Some users have been able to benefit from this new information. For example, many Pacific island nations respond to El Niño forecasts and avoid potential disasters from water shortages. Similarly, agricultural producers in Australia have been better able to cope with swings in their commodity production associated with drought and water managers. In the United States Southwest, managers have been able to incorporate SI climate forecasts in their decision-making processes to respond to crisis – and this is even becoming true in more water-rich regions such as the United States Southeast that are now facing prolonged drought (Hammer, *et al.*, 2001; Hartmann, *et al.*, 2002; Pagano *et al.*, 2002; Georgia DNR, 2003). But, unless greater effort is expended to rectify the differential impacts of climate information in contexts where the poor lack resources, SI climate forecasts will not contribute to global equity.

There are several factors that help to explain when and where equity goals are served in SI climate forecasting and when they are not (Lemos and Dilling, 2007). Understanding existing levels of underlying inequities and differential vulnerabilities is critical (Agrawala *et al.*, 2001). Forecasts are useful only when recipients of information have sufficient decision space or options to be able to respond to lower vulnerability and risk. Differential levels in the ability to respond can create winners and losers within the same policy context. For example, in Zimbabwe and northeastern Brazil, news of poor rainfall forecasts for the planting season influence bank managers who systematically deny credit, especially to poor farmers they perceive as high risk (Hammer, *et al.*, 2001; Lemos, *et al.*, 2002). In Peru, a forecast of El Niño and the prospect of a weak season gives fishing companies incentives to accelerate seasonal layoffs of workers (Broad, *et al.*, 2002). Some users (bankers, businesses) who were able to act based on forecasted outcomes (positive or negative) benefited while those who could not (farmers, fishermen), lost. Financial, social and human resources are often out of reach of the poor that lack education, money and time resources to engage forecast producers (Lemos and Dilling, 2007). Even when the information is available, however, differences in resources, social status, and empowerment limit hazard management options. As demonstrated by Hurricane Katrina, for example, the poor and minorities are reluctant to leave their homes for fear of becoming victims of crime and looting – and are simply not welcome as immigrants fleeing from disaster (*e.g.*, Hartmann, *et al.*, 2002; Carbone and Dow, 2005; Subcommittee on Disaster Reduction, 2005; Leatherman and White, 2005).

Native American farmers who are unable to move their farming enterprises as do agribusinesses, and can not lease their water rights strategically to avoid planting during droughts are disadvantaged because of their small decision space or lack of alternatives. Moreover, poorer groups often distrust experts who are in possession of risk information because the latter are often viewed as elitist; focused more on probabilities rather than on the consequences of disaster; or, unable to communicate in terms comprehensible to the average person (Jasanoff, 1987; Covello *et al.*, 1990). However, other research has found that resources, while desirable, are not an absolute constraint to poor peoples' ability to benefit from seasonal forecast use. In these cases, farmers have been able to successfully use seasonal climate forecasts by making small adjustments to their decision making process (Eakin, 2000: Ingram *et al.*, 2002: Patt *et al.*, 2005: Roncoli *et al.*, 2006).

A more positive future in terms of redressing inequity and reducing poverty can take place if application policies and programs create alternative types of resources, such as sustained relationships with information providers and web-based tools that can be easily tailored to specific applications; promotion of inclusionary dissemination practices; and paying attention to the context of information applications (Valdivia *et al.*, 2000; Archer, 2003; Ziervogel and Calder, 2003; Roncoli *et al.*, 2006). Examples in the literature show that those who benefit from SI climate forecasts usually have the means to attend meetings or to access information through the media (at least through the radio). It is especially helpful if organizers of workshops where attendance is limited reach out to disadvantaged and vulnerable populations. For example, small farmers in Tamil Nadu, India (Huda *et al.*, 2004) and Zimbabwe (Patt and Gwata, 2002) benefited from climate information through a close relationship with forecast "brokers"[1] who spent considerable effort in sustaining communication and providing expert knowledge to farmers. However, the number of farmers targeted in these projects was very limited. For any real impact such efforts will need to be scaled up and sustained beyond research projects.

Equitable communication and access are critical to fairness with respect to potential benefit from forecast information, but such qualities often do not exist. Factors such as

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[1] Researchers in the India case and researchers and extension agents in the Zimbabwe case.

levels of education, access to electronic media such as the Internet, and expert knowledge critically affect the ability of different groups to take advantage of seasonal forecasts (Lemos and Dilling, 2007). While the adoption of participatory processes of communication and dissemination can defray some of these constraints, the number of positive cases documented is small (*e.g.* Patt *et al.*, 2005: Roncoli *et al.*, 2006: Vogel and O'Brien, 2006). And because forecasts are mostly disseminated in the language of probabilities, it may be difficult to assimilate by those who do not generally think probabilistically nor interpret probabilities easily, or those whose framing of environmental issues is formed through experience with extreme events, or a preoccupation with consequences due to the context in which they make decisions (Nicholls, 1999; Yarnal *et al.*, 2006; Dow *et al.*, 2007; Weingert et. al., 2000). In a situation where private enterprise is important for participants in knowledge networks, serving the poor may not be profitable, and for that reason they become marginalized.

Fostering inclusive, equitable access, therefore, will require a combination of organizational practices that empower employees, and engage agency clients, outside stakeholder groups, and the general public through providing training and outreach in tool use, and the infusion of trust in communication of risks. The latter will require use of public forums and other vehicles that provide opportunities for open, clear, jargon-free information as well as opportunity for discussion and public reaction (Freudenburg and Rursch, 1994; Papadakis, 1996; Jasanoff, 1987; Covello *et al.*, 1990; NRC, 1989). If climate science applications are to more clearly put vulnerable poor on an equal footing or to go further toward reducing inequality, decision support must target the vulnerable poor specifically. Time and funds must be invested in understanding the process through which decisions are made and resources allocated. Specific training and a concerted effort to “fit” the available information to local decision making patterns and culture can be a first step to enhance its relevance. Seasonal forecast producers and policy makers need to be aware of the broader sociopolitical context and the institutional opportunities and constraints presented by seasonal forecast use and understand potential users and their decision environment. A better fit between product and client can avoid situations in which forecast use may harm those it could help. Finally, as some of the most successful examples show, seasonal forecasting application should strive to be more transparent, inclusionary, and interactive as a means to counter power imbalances.

5.2.4 Science Citizenship Plays an Important Role in Developing Appropriate Solutions

Some scholars observe that a new paradigm in science is emerging, one that emphasizes science-society collaboration and production of knowledge tailored more closely to society’s decision making needs (Gibbons, 1999: Nowotny *et al.*, 2001: Jasanoff, 2004a). The philosophy is that, through mobilizing both academic and pragmatic knowledge and experience, better solutions may be produced for pressing problems. Concerns about climate impacts on water resource management are among the most pressing problems that require close collaboration between scientists and decision makers. Examples of projects that are actively pursuing collaborative science to address climate-related water resource problems include the Semi-Arid Hydrology and Riparian Area (SAHRA) project (http://www.sahra.arizona.edu), funded by the National Science Foundation (NSF) and located at the University of Arizona and the NSF-funded Decision Center for a Desert City, located at Arizona State University (http://dcdc.asu.edu). The regional focus of NOAA's RISA program is likewise providing opportunities for collaborations between scientists and citizens to address climate impacts and information needs in different sectors, including water resource management. An examination of the Climate Assessment for the Southwest (CLIMAS), one of the RISA projects, provided insight into some of the ways in which co-production of science and policy is being pursued in a structured research setting (Lemos and Morehouse, 2005).

Collaborative efforts to produce knowledge and policy in synchrony not only expand the envelope of the scientific enterprise, but also change the terms of the relationship between scientists and citizens. This emergence of new forms of science-society interactions has been documented from various perspectives, including the place of local, counter-scientific, and non-scientific knowledge (Eden, 1996: Fischer, 2000), links with democracy and democratic ideals (Jasanoff, 1996: Harding, 2000: Durodié, 2003), and environmental governance and decision making (Jasanoff and Wynne, 1998: Bäckstrand, 2003: Brunner *et al.*, 2005). These types of collaboration present opportunities to bridge the gaps between abstract scientific conceptualizations and knowledge needs generated by a grounded understanding of the nature and intensity of actual and potential risks and the specific vulnerabilities experienced by different populations, at different times and in different places.

Unlike the more traditional “pipeline” structure of knowledge transfer unidirectionally from scientists to citizens, processes involving coproduction of science and policy take a more circuitous form, one that requires experimentation and iteration (Lemos and Morehouse, 2005: Jasanoff and Wynne, 1998). This model of science-society interaction has a close affinity to concepts of adaptive management and adaptive governance (Pulwarty and Melis, 2001; Gunderson, 1999; Holling, 1978; Brunner *et al.,* 2005), for both of these concepts are founded on notions that institutional and organizational learning can be facilitated through careful experimentation with different decision and policy options. Such experimentation is, ideally, based on best available knowledge but allows for changes based on lessons learned, emergence of new knowledge, and/or changing conditions in the physical or social realms. The experiments described in this report offer examples of adaptive management and adaptive governance in practice.

Less extensively documented, but no less essential to bringing science to bear effectively on climate-related water resource management challenges is the notion of science citizenship (Jasanoff, 2004b), whereby the fruits of collaboration between scientists and citizens produces capacity to bring science-informed knowledge into processes of democratic deliberation, including network building, participation in policy-making, influencing policy interpretation and implementation processes, and even voting in elections. Science citizenship might, for example, involve participating in deliberations about how best to avert or mitigate the impacts of climate variability and change on populations, economic sectors, and natural systems vulnerable to reduced access to water. Indeed, water is fundamental to life and livelihood, and, as noted above, climate impacts research has revealed that deleterious effects of water shortages are unequally experienced: poorer and more marginalized segments of populations often suffer the most (Lemos, 2008). Innovative drought planning processes require precisely these kinds of input, as does planning for long-term reductions in water availability due to reduced snowpack—a problem that Seattle is beginning to plan for, as reflected in this report (Chapter 4). Issues such as these require substantial evaluation of how alternative solutions are likely to affect different entities at different times and in different places. For example, substantial reduction in snowpack, together with earlier snowmelt and longer periods before the onset of the following winter, will likely require serious examination of social values and practices as well as of economic activities throughout a given watershed and water delivery area. As these examples demonstrate, science citizenship clearly has a crucial role to play in building bridges between science and societal values in water resource management. It is likely that this will occur primarily through the types of knowledge networks and knowledge-to-action networks discussed earlier in this chapter.

5.2.5 Trends and Reforms in Water Resources Provide New Perspectives

As noted in Chapters 1 and 4, since the 1980s a "new paradigm" or frame for federal water planning has occurred that appears to reflect the ascendancy of an environmental protection ethic among the general public. The new paradigm emphasizes greater stakeholder participation in decision-making; explicit commitment to environmentally-sound, socially-just outcomes; greater reliance upon drainage basins as planning units; program management via spatial and managerial flexibility, collaboration, participation, and sound, peer-reviewed science; and, embracing of ecological, economic, and equity considerations (Hartig, et. al., 1992; Landre and Knuth, 1993; Cortner and Moote, 1994; Water in the West, 1998; May *et al.*, 1996; McGinnis, 1995; Miller, et. al., 1996; Cody, 1999; Bormann, et. al., 1994; Lee, 1993).

This "adaptive management" paradigm results in a number of climate-related SI climate information needs, including questions pertaining to the following: what are the decision-support needs related to managing in-stream flows/low flows? And, what changes to water quality, runoff and stream flow will occur in the future, and how will these changes affect water uses among future generations unable to influence the causes of these changes today? The most dramatic change in decision support that emerges from the adaptive management paradigm is the need for real-time monitoring and ongoing assessment of the effectiveness of management practices, and the possibility that outcomes recommended by decision-support tools be iterative, incremental and reversible if they prove unresponsive to critical groups, ineffective in managing problems, or both. What makes these questions particularly challenging is that they are interdisciplinary in nature[2].

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[2] Underscored by the fact that scholars concur adaptive management entails a broad range of processes to avoid environmental harm by imposing modest changes on the environment, acknowledging uncertainties in predicting impacts of human activities on natural processes, and embracing social learning (*i.e.*, learning by experiment). In general, it is characterized by four major strategies: 1) managing resources by learning, especially about mistakes, in an effort to make policy improvements, 2) modifying policies in the light of experience – and permitting such modifications to be introduced in "mid-course", 3) allowing revelation of critical knowledge heretofore missing, as feedback to improve decisions, and 4) incorporating outcomes in future decisions through a consensus-based approach that allows government agencies and NGOs to conjointly agree on solutions (Bormann et. al., 1993; Lee, 1993; Definitions of Adaptive Management, 2000).

Another significant innovation in United States water resources management that affects climate information use is occurring in the *local* water supply sector, as discussed in chapter 4, the growing use of integrated water resource planning (or IWRP) as an alternative to conventional supply-side approaches for meeting future demands. IWRP is gaining acceptance in chronically water-short regions such as the Southwest and portions of the Midwest – including Southern California, Kansas, Southern Nevada, and New Mexico (Beecher, 1995; Warren et. al., 1995; Fiske and Dong, 1995; Wade, 2001). IWRM supports the use of multiple sources of information like that of SI climate and water supply forecasts as well as feedback from experience and experiments.

IWRP's goal is to "balance water supply and demand management considerations by identifying feasible planning alternatives that meet the test of least cost without sacrificing other policy goals" (Beecher, 1995). This can be variously achieved through depleted aquifer recharge, seasonal groundwater recharge, conservation incentives, adopting growth management strategies, wastewater reuse, and applying least-cost planning principles to large investor-owned water utilities. The latter may encourage IWRP by demonstrating the relative efficiency of efforts to reduce demand as opposed to building more supply infrastructure. A particularly challenging alternative is the need to enhance regional planning among water utilities in order to capitalize on the resources of every water user, eliminate unnecessary duplication of effort, and avoid the cost of building new facilities for water supply (Atwater and Blomquist, 2002).

In some cases, short term least cost planning may *increase* long-term project costs, especially when environmental impacts, resource depletion, and energy and maintenance costs are included. The significance of least-cost planning is that it underscores the importance of long and short-term costs (in this case, of water) as an influence on the value of certain kinds of information for decisions. The most dramatic change in decision support that emerges from the adaptive management paradigm is the need for real-time monitoring and ongoing assessment of the effectiveness of management practices, and the possibility that outcomes recommended by decision-support tools be iterative, incremental and reversible if they prove unresponsive to critical groups, ineffective in managing problems, or both. Models and forecasts that predict water availability under different climate scenarios can be especially useful to least-cost planning and make more credible efforts to reducing demand. Specific questions IWRP raises for decision-support-generated climate information include: how precise must climate information be to enhance long term planning? How might predicted climate change provide an incentive for IWRP strategies? And, what climate information is needed to optimize decisions on water pricing, re-use, shifting from surface to groundwater use, and conservation?

5.2.6 Useful Evaluation of Applications of Climate Variation Forecasts Requires Innovative Approaches

There can be little argument that SI climate and hydrologic forecast applications must be evaluated just as are most other programs that involve substantial public expenditures. That said, this report has evidenced many of the difficulties of using standard evaluation techniques. While there have been some evaluations of programs, mostly from the vantage point of assessing the influence of Regional Integrated Science Assessments (RISAs) on federal climate science policy (*e.g.*, McNie *et al.*, 2007; Cash et. al., 2006), there has been little formal systematic, standardized evaluation of whether they are optimally designed to learn from experience and incorporate user feedback. Evaluation works best on programs with a substantial history so that it is possible to compare present conditions with those that existed some years in the past. The effort to promote the use of SI climate forecasts is relatively new and has been a moving target, with new elements being regularly introduced, so that it is difficult to determine what features of those federal programs charged with collaborating with decision makers in the development, use, application and evaluation of climate forecasts have which consequences. As the effort to promote greater use of SI climate and hydrologic forecasts accelerates in the future, it is important to foster developments that facilitate evaluation. It is imperative that promoting forecast use have a clear causal model that includes the complete implementation chain with credible rationales or incentives for participants to take desired actions. Setting clear goals and priorities for allocation of resources among different elements is essential to any evaluation of program accomplishments (NRC, Research and Networks for Decision Support, 2008). It is especially difficult to measure the accomplishment of some kinds of goals important to adaptive management such as organizational learning. For this reason, we believe that consistent monitoring and regular evaluation of processes and tools at different time and spatial scales will be required to assess progress.

An NRC panel addressing a closely related challenge for standard evaluation recommended that the need for evaluation should be addressed through monitoring (NRC, SARP Rpt, 2008). The language of that report seems entirely applicable here:

> Monitoring requires the identification of process measures that could be recorded on a regular (for instance, annual) basis and of useful output or outcome measures that are plausibly related to the eventual effects of interest and can be feasibly and reliably recorded on a similar regular basis. Over time, the metrics can be refined and improved on the basis of research, although it is important to maintain some consistency over extended periods with regard to at least some of the key metrics that are developed and used.

There are signals of network building and collaborative forecaster-user interaction and collaboration that can be monitored. Meetings and workshops held, new contacts made, new organizations involved in information diffusion, websites, list serves, newsletters and reports targeted to new audiences are but a few of the many activities that are indicative of network creation activity.

5.3 RESEARCH PRIORITIES

As a result of the findings in this report, we suggest that a number of research priorities should constitute the focus of attention for the foreseeable future. These priorities are: 1) improved vulnerability assessment, 2) improved climate and hydrologic forecasts, 3) enhanced monitoring to better link climate and hydrologic forecasts, 4) better integration of SI climate science into decision making, 5) better balance between physical science and social science research related to the use of scientific information in decision making, 6) better understanding of the implications of small-scale, specially-tailored tools, and 7) sustained long-term scientist-decision-maker interactions and collaborations and development of science citizenship. The following discussion identifies each priority in detail, and recommends ways to implement them.

5.3.1 A Better Understanding of Vulnerability is Essential

Case studies of the use of decision-support tools in water resources planning and management suggest that the research and policy-making communities need a far more comprehensive picture of the vulnerability of water and related resources to climate variability. This assessment must account for vulnerability along several dimensions.

As we have seen, there are many forms climate vulnerability may take – ranging from social and physical vulnerability to ecological fragmentation, economic dislocation, and even organizational change and turmoil. Vulnerability may also range across numerous temporal and spatial scales. Spatially, it can affect highly localized resources or spread over large regions. Temporally, vulnerability can be manifested as an extreme and/or rapid onset problem that lasts briefly, but imposes considerable impact on society (*e.g.*, intense tropical storms) or takes the form of a prolonged or slow-onset event, such as drought, which may produce numerous impacts for longer time periods.

In order to encompass these widely varying dimensions of vulnerability. We also need more research on how decision makers perceive the risks from climate variability and, thus, what variables incline them to respond proactively to threats and potential hazards. As in so many other aspects of decision-support information use, previous research indicates that merely delivering weather and climate information to potential users may be insufficient in those cases in which the manager does not perceive climate variability to be a hazard – at least in humid, water rich regions of the United States that we have studied (Yarnal *et al.*, 2006; Dow *et al.*, 2007). Are there institutional incentives to using risk information, or – conversely – not using it? And, in what decisional contexts (*e.g.*, protracted drought, sudden onset flooding hazards) are water managers most likely – or least likely – to be susceptible to employing climate variability hazard potential information?

5.3.2 Improving Hydrologic and Climate Forecasts

Within the hydrologic systems, accurate measures and assimilation of the initial state are crucial for making skillful hydrologic forecasts; therefore, a sustained high-quality monitoring system tracking stream flow, soil moisture, snowpack, and evaporation, together with tools for real-time data assimilation, are fundamental to the hydrologic forecasting effort. In addition, watersheds with sparse monitoring networks, or relatively short historical data series are also prone to large forecast errors due to a lack of historical and real-time data and information about its hydrologic state.

Monitoring and assimilation are also essential for climate forecasting, as well as exercises of hindcasting to compare present experience with the historical record. Moreover, monitoring is critical for adaptive and integrated water resources management, and for the more effective adoption of strategies currently widely embraced by natural resources planners and managers.

On-going improvements in the skill of climate forecasting will continue to provide another important avenue for improving the skill in SI hydrologic and water supply forecasts. For many river basins and in many seasons, the single greatest source of hydrologic forecast error is unknown precipitation after the forecast issue date. Thus, improvements in hydrologic forecasting are directly linked with improvements in forecasts for precipitation and temperature.

In addition, support for coordinated efforts to standardize and quantify the skill in hydrologic forecasts is needed. While there is a strong culture and tradition of forecast evaluation in meteorology and climatology, this sort of retrospective analysis of the skill of seasonal hydrologic forecasts has historically not been commonly disseminated. Hydrologic forecasts have historically tended to be more often deterministic than probabilistic with products focused on water supplies (stream flow, reservoir inflows, *etc.*). In operational settings, seasonal hydrologic forecasts have generally been taken with a grain of salt, in part because of limited quantitative assurance of how accurate they can be expected to be. In contrast, operational climate forecasts and many of today's experimental and newer operational hydrologic forecasts are probabilistic, and in this way contain quantitative estimates for the forecast uncertainty.

New efforts are needed to extend "forecasts of opportunity" beyond those years when anomalous ENSO conditions are underway. At present, the skill available from combining current seasonal-interannual climate forecasts with hydrologic models is limited when all years are considered, but can provide useful guidance in years having anomalous ENSO conditions. During years with substantial ENSO effects the climate forecasts have high enough skill for temperatures, and mixed skill for precipitation, so that hydrologic forecasts for some seasons and some basins provide measurable improvements over approaches that do not take advantage of ENSO information. In contrast, in years where the state of ENSO is near neutral, most of the skill in United States climate forecasts is due to decadal temperature trends, and this situation leads to substantially more limited skill in hydrologic forecasts. In order to improve this situation, additional sources of climate and hydrologic predictability must be exploited, and these sources likely include other patterns of ocean temperature change, sea ice, land cover, and soil moisture conditions.

Linkages between climate and hydrologic scientists are getting stronger as they collaboratively create forecast products. A great many complex factors influence the rate at which seasonal water supply forecasts and climate forecast-driven hydrologic forecasts are improving in terms of skill level. Mismatches between needs and information resources continue to occur at multiple levels and scales. There is currently substantial tension between providing tools at the space and time scales useful for water resources decisions and ensuring that they are also scientifically defensible, accurate, reliable, and timely. Further research is needed to identify ways to resolve this tension.

5.3.3 Better integration of climate information into decision making

It cannot be expected that information that promises to lower costs or improve benefits for organizations or groups will simply be incorporated into decisions. Scholarly research on collaboration among organizations indicates that straightforward models of information transfer are not operative in situations where a common language between organizations has not been adopted, or more challenging, when organizations must transform their own perspectives and information channels to adjust to new information. It is often the case that organizations are path dependent, and will continue with decision routines even when they are suboptimal. The many case examples provided in this report indicate that the framing of issues is important, and that framing of many climate dependent natural resources issues that emphasizes the uncertainty and variability of climate and the need for adaptive action helps in integrating forecasting information. What is needed are not more case studies, however, but better case investigations employing grounded theory approaches to make possible discerning general characteristics of decision-making contexts and their factors that impeded, or provide better opportunity for, issue framing that is not path dependent, tradition-bound, or averse to collaborating with scientists and other tool developers. The construction of knowledge networks in which information is viewed as relevant, credible, and trusted is essential, and much can be learned from emerging experiences in climate-information networks being formed among local governments, environmental organizations, scientists, and others worldwide to exchange information and experiences, influence national policy-making agendas, and leverage international organization resources on climate variability and water resources – as well as other resource - vulnerability.

Potential barriers to information use that must be further explored include: the cultural and organizational context and circumstances of scientists and decision makers; the decision space allowed to decision makers and their real range of choice; opportunities to develop – and capacity to exercise – science citizenship; impediments to innovation within institutions; and solutions to information overload and the numerous conflicting sources of already available information. As our case studies have shown, there is often a relatively narrow range of realistic options open to decision makers given their roles, responsibilities, and the expectations placed upon them.

There are also vast differences in water laws and state-level scientific and regulatory institutions designed to manage aquifers and stream-flows in the United States And, information can be both transparent and yet opaque simultaneously. While scientific products can be precise, accurate, and lucid, they may still be inaccessible to those who most need them because of proprietary issues restricting access except to those who can pay, or due to agency size or resource base. Larger agencies and organizations, and wealthier users, can better access information in part because scientific information that is restricted in its dissemination tends to drive up information costs (Pfaff *et al.*, 1999; Broad and Agrawalla, 2000; Broad *et al.,* 2002; Hartmann, 2001). Access and equity issues also need to be explored in more detail. Every facet of tool use juncture needs to be explored.

Priority in research should be toward interdisciplinary projects that involve sufficient numbers and varieties of kinds of knowledge. To this end, NOAA's Sectoral Applications Research Program is designed to support these types of interactions between research and development of decision-support tools. Although this program is small, it is vital for provision of knowledge on impacts, adaptation, and vulnerability and should be supported especially as Federal agencies are contemplating a larger role in adaptation and vulnerability assessments and in light of pending legislation by Congress.

Regional Integrated Science Assessments (RISAs) are regarded as a successful model of effective knowledge-to-action networks because they have developed interdisciplinary teams of scientists working as (and/or between) forecasts producers while being actively engaged with resource managers. The RISAs have been proposed as a potentially important component of a national climate service (NCS), wherein the NCS engages in observations, modeling, and research nested in global, national, and regional scales with a user-centric orientation (Figure 1 of Miles *et al.*, 2007). The potential for further development of the RISAs and other boundary spanning organizations that facilitate knowledge-to-action networks deserves study. Further, as they are the most successful long-term effort by the federal government to integrate climate science in sectors and regions across the United States, they merit expanded financial and institutional support

5.3.4 Better balance between physical science and social science

Throughout this report, the absence of systematic research on applications of climate variation forecasting information has required analysis to be based on numerous case study materials often written for a different purpose, upon the accumulated knowledge and wisdom of authors, and logical inference. The dearth of hard data in this area attests to the very small research effort afforded the study of use inspired social science questions. Five years ago a social science review panel recommended that NOAA should readjust its research priorities by additional investment in a wide variety of use-inspired social science projects (Anderson *et al.*, 2003). What was once the Human Dimensions of Climate Change Program within NOAA now exists only in the Sector Applications Research Program, an important and worthy endeavor, but one whose small staff and budget can hardly address these important research needs. Managers whose responsibilities may be affected by climate variability need detailed understanding of relevant social, economic, organizational and behavioral systems – as well as the ethical dilemmas faced in using, or not using information, including public trust, perceived competence, social stability and community well-being, and perceived social equity in information access, provision, and benefit. Much more needs to be known about the economic and other factors that shape demands for water, roads, and land conversion for residential and commercial development and shape social and economic resilience in face of climate variability.

A recent NRC Report (2008) set out five research topics that have direct relevance to making climate science information better serve the needs of various sectors: human influences on vulnerability to climate; communications processes; science produced in partnership with users; information overload; and innovations at the individual and organizational level necessary to make use of climate information. The last research topic is the particular charge of NOAA's Sectoral Applications Research Program and is of great relevance to the subject of this report. However, the lack of use theoretically-infused social science research is a clear impediment to making investments in physical sciences useful and used. Committed leadership that is poised to take advantage of opportunities is fundamental to future innovation, yet not nearly enough research has been done on the necessary conditions for recruitment, promotion and rewarding leadership in public organizations, particularly as that leadership serves in networks involving multiple agencies, both public and private, at different organizational levels.

5.3.5 Better understanding of the implications of small-scale, tailored decision-support tools is needed

While there is almost universal agreement that specially tailored, small scale forecast tools are needed, concern is growing that the implications of such tools for trustworthiness, quality control, and ensuring an appropriate balance between proprietary *vs.* public domain controls have not been sufficiently explored.

There is a growing push for smaller scale products that are tailored to specific users but are expensive; as well as private sector tailored products (*e.g.*, “Weatherbug” and many reservoir operations proprietary forecasts have restrictions on how they share data with NOAA) – this also generates issues related to trustworthiness of information and quality control. What are the implications of this push for proprietary *vs.* public domain controls and access? This problem is well-documented in policy studies of risk-based information in the fields of food labeling, toxic pollutants, medical and pharmaceutical information, and other public disclosure or “right-to-know” programs but has not been sufficiently explored in the context of climate forecasting tool development.

Related to this issue of custom-tailoring forecast information is the fact that future progress in making climatic forecasts useful depends upon advancing our understanding of the incorporation of available knowledge into decisions in water related sectors, since there are already many useful applications of climate variation and change forecasts at present skill levels. Here, the issue is tailoring information to the *type* of user. Research related to specific river systems, and/or sectors such as energy production, flood plain and estuary planning and urban areas is important. Customizable products rather than generic services are the most needed by decision makers. The uptake of information is more likely when the form of information provided is compatible with existing practice. It makes sense to identify decision-support experiments where concerted efforts are made to incorporate climate information into decision-making. Such experimentation feeds into a culture of innovation within agencies that is important to foster at a time when historically conservative institutions are evolving more slowly than the pace of change in the natural and social systems, and where, in those instances when evolution is taking place relatively quickly – there are few analogues that can be used as reference points for how to accommodate these changes and ensure that organizations can adapt to stress – an important role of visionary leadership (Bennis, 2003; Tichy and Bennis, 2007)

Given the diversity of challenges facing decision makers, the diverse needs and aspirations of stakeholders, and the diverse array of decision-making authorities, there is little hope of providing comprehensive climate services or a “one-stop-shop” information system to support the decision-making or risk assessment needs of a wide audience of users. Development of products to help nongovernmental communities and groups develop their own capacity and conduct their own assessments is essential for future applications of climate information.

A seasonal *hydrologic forecasting and applications testbed program* would facilitate the rapid development of better decision-support tools for water resources planning. Testbeds, as described in Chapter 2, are intermediate activities, a hybrid mix of research and operations, serving as a conduit between the operational, academic and research communities. A testbed activity may have its own resources to develop a realistic operational environment. However, the testbed would not have real-time operational responsibilities and instead, would be focused on introducing new ideas and data to the existing system and analyzing the results through experimentation and demonstration. The old and new system may be run in parallel and the differences quantified (a good example of this concept is the INFORM program tested in various reservoir operations in California described in Chapter 4). Other cases that demonstrate aspects of this same parallelism are the use of paleo-climate data in the southwest (tree-ring data being compared to current hydrology) and the South Florida WMD (using decade-scale data together with current flow and precipitation information). The operational system may even be deconstructed to identify the greatest sources of error, and these findings can serve as the motivation to drive new research to find solutions to operations-relevant problems. The solutions are designed to be directly integrated into the mock-operational system and therefore should be much easier to directly transfer to actual production. While NOAA has many testbeds currently in operation, including testbeds focused on: Hydrometeorology (floods), Hazardous Weather (thunderstorms and tornadoes), Aviation

Weather (turbulence and icing for airplanes), Climate (El Niño, seasonal precipitation and temperature) and Hurricanes, a testbed for seasonal stream flow forecasting does not exist. Generally, satisfaction with testbeds has been high, with the experience rewarding for operational and research participants alike.

5.3.6 Understand impacts of climate variability and change on other resources

Research shows the close interrelationships among climate change, deep sustained drought, beetle infestations, high fuel load levels, and forest fire activity. Serious concern about the risks faced by communities in wild land-urban interface areas as well as about the long-term viability of the nation's forests is warranted. It is important to know more about climate-influenced changes in marine environments that have significant implications for the health of fisheries and for saltwater ecosystems. Potential changes in the frequency and severity of extreme events such as tropical storms, floods, droughts, and strong wind episodes threaten urban and rural areas alike and need to be better understood. Rising temperatures, especially at night, are already driving up energy use and contributing to urban heat island effects, and they pose alarming potential for heat wave-related deaths such as those experienced in Europe a few years ago. The poor and the elderly suffer most from such stresses. Clearly, climate conditions affect everyone’s daily life. Long-term climate changes also impinge on the prospects for the next generation and generations yet unborn. Although it would be the height of hubris to say that humans are now totally in control of our biophysical and social universes, we can say that humans’ responsibility to be good stewards of planet has grown enormously.

5.4 THE APPLICATION OF LESSONS LEARNED FROM THIS PRODUCT TO OTHER SECTORS

"Climate" is gaining popularity in agencies throughout the federal government (*e.g.*, the Center for Disease Control has recently increased efforts concerning the impacts of climate on health), in national and boundary organizations across the nation (*e.g.*, there has been an increase in awareness and activity of mayors and their staffs that are members of the U.S. Conference of Mayors), and is beginning to become an important component to future planning in local jurisdictions (*e.g.*, King County, Washington has issued a guidebook for planners on adaptation to global warming). As these organizations become more aware of the potential of climate impacts on their constituents, they are responding by holding conferences, writing manuals, setting up climate-related offices to better understand the role that climate plays in their purview, and beginning to demand more of the Federal Government in terms of services in part, in the form of SI forecasts and observational data and new information about long-term climate change impacts. SI information would be helpful to a wide range of users from those in the transportation and urban realms with information on how much salt to buy for the next season's snowstorms, to health officials as they prepare for the next season's climate-influenced diseases such as those spread by mosquito or ticks, and to those employed in agriculture to help determine the type of seed, irrigation and fertilizer needs for the coming season. For some, the information they need already exists; they simply do not understand where to obtain the information or how to use it. For others, the delivery must be tweaked to provide the information in a format that would better suit their needs. For the more sophisticated user, refinements of present forecasts and data as well as more information about the data itself would satisfy their present needs.

The lessons learned and described in this report from the water sector are directly transferable to other sectors. The experiments described in Chapters 2, 3, and 4 are just as relevant to water resource managers as they are to farmers, energy planners or city planners. Of the overarching lessons described in this chapter, perhaps the most important to all sectors is that the climate forecast delivery system in the past, where climatologists and meteorologists produced forecasts and other data in a vacuum, can be improved. This report reiterates in each chapter that the loading dock model of information transfer is unworkable. Fortunately, this report highlights experiments where interaction between producers and users is successful. Similar examples can be found in other sectors such as the urban planning arena. Within New York City, a prototype information system was developed for transportation planners concerned about future climate impacts (http://ccir.ciesin.columbia.edu/nyc). The team first assessed the information needs of urban policy makers, analyzing both the ways that they obtain and use information and the kinds of information that they take into account in their work. The team gathered and organized existing climate forecast, policy, and scientific information and also tried to anticipate how urban climate change information would be maintained and used in the future. Representatives from key transportation planning groups in the area such as the Port Authority were involved in most aspects of this project.

This report has emphasized that decision support is a process rather than a product. Accordingly, we have learned that communication is key to delivering and using climate products. One example, where this is already working can be found is in the southwest with the Climate Assessment for the Southwest (RISA) project who are working with the University of Arizona Cooperative Extension to produce a newsletter that contains official and non-official forecasts, as well as other information relevant for a variety of decision makers in that area, particularly farmers (http://www.climas.arizona.edu/forecasts/swoutlook.html).

Equity is an issue that arises in other sectors as well. Emergency managers preparing for an ENSO-influenced season already understand that while some have access to information and evacuation routes, others, notably the elderly and those with financial difficulties might not have the same access. To compound this problem, information may also not be in a language understood by all citizens. While these managers already realize the importance of climate forecast information, improved climate forecast and data delivery and/or understanding will certainly help in assuring that the response to a potential climate disaster is performed equitably for all of their residents (Beller-Simms, 2004).

Finally, science citizenship is and will be increasingly important in all sectors. Science citizenship clearly has a crucial role to play in building bridges between science and societal values in all resource management arenas and increased collaboration and production of knowledge between scientists and decision makers. The use of SI and climate forecasts and observational data will continue to be increasingly important in assuring that resource-management decisions bridge the gap between climate science, and the implementation of scientific understanding in our management of critical resources.

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