Climate change and water: Adaptation

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Abstract

In many parts of the world, climate change is anticipated to result in greater water scarcity. Future adaptations may include technical changes that improve water use efficiency, demand management (e.g. through metering and pricing), and institutional changes that improve the tradability of water rights. The availability of water for each type of use may be affected by other competing uses of the resource. Consequently a complete analysis of the effects of climate change on human water uses would consider cross-sector interactions, including the impacts of changes in water use efficiency and intentional transfers of the use of water from one sector to another. The barriers to implementing adaptation measures include the inability of some natural systems to adapt at the rate of combined demographic pressures and climate, incomplete understanding and quantifying of water demands, and impediments to the flow of timely and reliable knowledge and information relevant for decision makers. Many adaptation measures are technology and efficiency based. Early warning information, as well as decision support tools for long range planning, should be based on a mixed portfolio of experimental and scenario-based approaches for shared learning by researchers and practitioners. This becomes an integrated watershed management approach in which adaptive management is an operational tool for learning. We examine two cases from western North America (the Okanagan, and Colorado Rivers) to illustrate mechanisms for interactive learning, anticipatory coordination and communication.

Key word: adaptation, climate change and water, integrated watershed management

1. Introduction

Climate change poses major conceptual challenges to resource managers, in addition to the challenges caused by population and land use change. As is widely acknowledged, it is no longer appropriate to assume that past hydrological conditions will continue into the future. The robustness of present water resources adaptations will be tested under a changing climate. Climate information services designed to support adaptation will be important in coping with current and future climate extremes and their effects on water resources. Useful information may be available, and can produce positive results, but its effective use for adaptation can be overwhelmed by rates and magnitudes of social, economic and environmental changes.

Experience shows that:

(1) Adaptations in many cases are driven by focusing on events that induce crises, learning and redesign, and in which leadership and the public are engaged,
(2) Opportunities exist to learn from adaptive management practices that focus on social networking, and
(3) Long-term scenarios can bring focus on changes in extremes.

Adverse effects of climate change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and urbanization. Critical issues include: (1) ensuring adequate water to maintain environmental services that support economic and cultural benefits; (2) ensuring development, adoption and evaluation of efficient technologies, and (3) managing information needed to coordinate data collection and quality control, which will allow us to transform data and forecasts into accessible, credible, and usable information for early warning, risk reduction and adaptation practices in the water resources sector. Increasing demands and aging infrastructure introduce additional concerns. Adaptive measures recommended and employed to date include both demand and supply side approaches. Examples include: water recycling, reduce irrigation demand, water markets, economic incentives including metering, pricing; conjunctive surface-groundwater use, increase storage capacity, and desalination.

Flexibility in operation systems (reservoirs etc.) in terms of efficiency and buffers to climate variations requires re-examination of design criteria, operating rules, assumptions made from a limited climate record and attendant contingency planning. The greatest challenges will be in multi-objective planning and the information management needed for attendant decision-making processes and for assessing the quality of those decisions. Documenting the costs, benefits and tradeoffs in pursuing and securing diverse values of river systems (e.g. hydropower, environment, irrigation, recreation, and aesthetics) are straightforward tasks. As a result, decision-making is very much a process of negotiating acceptable outcomes among various interests as opposed to one of simply reducing the uncertainty of our knowledge of the physical system or increasing the operating efficiency of designed systems (e.g. dams).

We examine two cases from western North America (the Okanagan, and Colorado Rivers) to illustrate mechanisms for interactive learning, anticipatory coordination and communication. These two basins offer unique opportunities for identifying lessons for strategic learning on the evolution of cross-scale environmental risks over time, the development of a collaborative framework between research and water resources management, and for guidance on the development of information services in support of adaptation at the watershed scale.

2. Climate change, water scarcity, and managing for multiple objectives

Recent reviews of the state of knowledge on impacts of climate change on water resources (Kundzewicz et al., 2007; Arnell et al., 2001) have described the growing risk that climate change will lead to water scarcity in certain regions of the world. Some semi-arid and sub-humid regions, such as Australia and the Sahel have experienced more intense droughts.

Australia has responded with several water adaptation strategies, including drought relief programs, use of recycled water, replacement of open irrigation channels to reduce losses, and desalination (Henessey et al., 2007).

The long-term adaptation challenge for watersheds experiencing both acute and chronic water scarcity is the integration of concurrent driving forces into planning, design, and operation of water systems. If water systems continue to be planned with the explicit or implicit assumption of climate stationarity, surprises and conflicts may emerge. Milly et al.. (2008) have proposed that water management frameworks should be adapted to non-stationary climatic and hydrologic variables. This would require rapid flow of information from the scientific realm to water managers and practitioners.

The need for this can be illustrated by the example of the Columbia Basin. Modelling studies and surveys of water managers have indicated that concurrent changes in observed and projected regional economic development and climate patterns would affect the balancing of management objectives, including hydroelectric production, in-stream flows for aquatic ecosystems, irrigation, navigation, flood control, recreation, and domestic needs (Cohen et al., 2000; Cohen, de Löe et al., 2004). Barnett et al. (2005) illustrate how a climate change scenario of earlier snowmelt and lower minimum flows during the summer, superimposed on existing reservoir operations, could lead to 10-20% reductions in hydroelectric production because of the requirement to protect in-stream flows for fish. Imagine being forced to choose between hydroelectric production and fisheries protection as part of a climate change adaptation strategy?

Climate change will challenge existing management models that assume stationarity in climatic and hydrologic indicators. Note that this is not restricted to changes in averages. It may be possible that changes in the probability of exceeding certain thresholds, even without a change in the average, might force the alteration of operating rules for a water system. A process would therefore be needed to facilitate the testing of alternate management frameworks for water systems under various scenarios of climate change and development. This could explicitly include the evaluation of the effectiveness of individual adaptation measures, and combinations of measures.

3. Creating a framework for adapting to climate change

Various forcing factors can interact with each other, creating problems of increasing complexity. Managing water systems to meet multiple objectives requires system knowledge, both technical and quantitative, as well as experiential from the perspectives of planners, user groups, technical experts and governments. This suggests that a combination of quantitative modelling and dialogue processes should be explored to see if that provides the basis for an evaluation of climate change problems facing water systems (e.g. NeWater project—http://www.newater.info).

Two main components are needed for this approach to be carried out. The research component would be organized as a Participatory Integrated Assessment (PIA), in which dialogue processes are used as research tools that would complement quantitative models (Tansey et al., 2002) and visualization (Sheppard, 2005), and indeed could facilitate the development of decision support models (van den Belt, 2004). A PIA could engage a wide range of local and system knowledge holders, as well as researchers from various disciplinary backgrounds (Yohe et al., 2007). The implementation component would be facilitated through "mainstreaming" in which policies and measures associated with climate change are directly integrated into development planning and ongoing decision making (Klein et al., 2007). Mainstreaming climate change adaptation into existing water management systems is being considered in several case studies, but barriers have been encountered, such as a) gaps in stakeholder participation during key phases of project design and implementation, and b) post-disaster pressures to quickly return a system or place to pre-disaster conditions rather that incorporate longer-term development policies (Adger et al., 2007).

PIA and mainstreaming are not typical activities within the research and policy communities. Information flow from providers of climate information to policy makers first goes through a translation process. Figure 1A illustrates one component of this—the translation of climate information into impacts information that would be of interest to practitioners from various fields (such as engineering or public health).

Figure 1B places this within the larger context of multiple flows of information from climate science research and climate impacts research to practitioners and policy makers. The long term sustainability of these processes depends on whether they can increase local capacity to serve as champions for them. Climate change adaptation is primarily a local and regional scale activity, undertaken within a national or international discourse that provides the necessary background for such initiatives to be undertaken. If PIA and mainstreaming can succeed in providing shared learning experiences for local stakeholders, some of these individuals may become extension agents for climate change learning and action, in a way that researchers and national actors could not. Subsequently, the roles of researchers and stakeholders would eventually be reversed, and we would begin to see more locally led adaptation initiatives, in which researchers and national actors would serve as resources supporting local champions.

4. Case studies—Colorado and Okanagan Basins

The Colorado and Okanagan Basins are semi-arid regions in western North America. The Okanagan is a small sub-watershed within the Columbia Basin. In this section, we describe experiences with applying PIA in these two cases.

Case study: The Colorado River

The Colorado River (Figure 2) supplies much of the water needs of seven US states, two Mexican states, and thirty-four Native American tribes (Pulwarty et al., 2005). These represent a population of 25 million inhabitants, with a projection of 38 million by the year 2020, which receive at least some part of their water from the Colorado. In only 80 years, the population of the seven Colorado River basin states has increased by 800 percent, adding 44 million people. Nevada, Arizona, and Colorado, all in the Colorado River basin and heavily dependent on Colorado River water for municipal and agricultural uses, were the fastest growing states in the nation between 1990 and 2000. About 12 million residents live along the border, a number projected to as much as double (to 24 million) by 2020 (Bennett and Herzog, 2000).

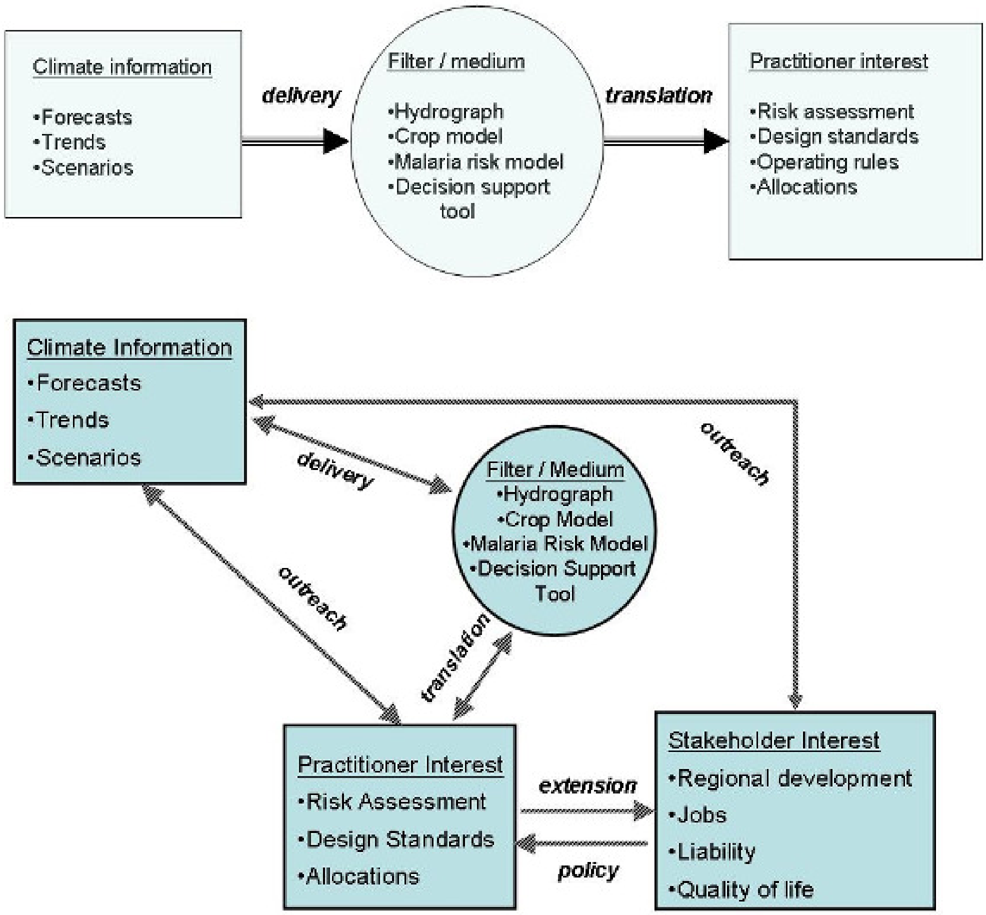

Figure 1. *A) Flow of climate change information to practitioners (upper panel), B) Additional pathways for climate information to reach decision makers (lower panel). Source: Cohen and Waddell, in press.*

The expansion of population and economic activities across the western U.S. , and concurrent responses to drought events, have resulted in significant structural adaptations, including hundreds of reservoirs, irrigation projects and groundwater withdrawals, being developed in semi-arid environments. As widely documented, the allocation of Colorado River water to basin states occurred during the wettest period in over 400 years (i.e., 1905–1925). The resulting complexity is that decisions on the Colorado Basin cross several temporal and spatial scales (see Table 1). The Colorado Basin is also home to one of the longest running adaptive environmental assessment and management programs in the country (Pulwarty and Melis, 2001).

Only a small portion of the full Colorado Basin area (about 15%) supplies most (85%) of its flow. The Colorado system has experienced below average conditions in 7 of the last 9 years. Until the last few years, the expectation of Colorado River managers was that significant shortages in the Lower Basin would not occur until after 2030. Natural inflows into the basin have been poor for several years: 62% of the 30-year average in 2000, 59% (2001), 25% in 2002, 51% (2003), 49% (2004), 105% (2005), 71% (2006), 68% (2007) and 105 (projected for 2008). The region has also experienced a 0.8°C rise in temperature over the past 50 years, which has resulted in increasing losses of snowpack exacerbating drought conditions through evaporation, vegetation stress, water demands, reduced soil moisture. It is estimated that 12-15 years of average conditions (based on the past 100 years) are needed to restore the basin to pre-2000 levels. This recent experience illustrates that 'critical' conditions already exist in the basin (Pulwarty et al., 2005).

Con formato: Inglés (Reino Unido)

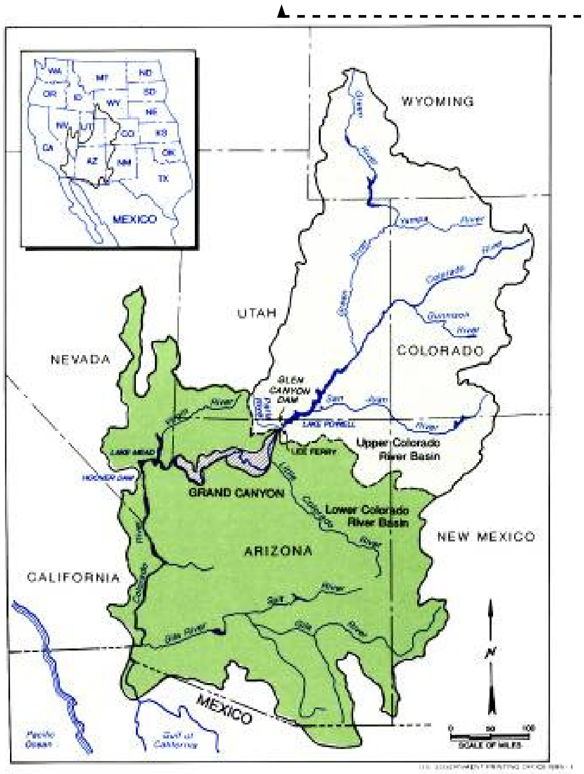

Figure 2. *Colorado River Basin.*

Estimates from 12 AR4 models show that, with increased warming and evaporation, concurrent runoff decreases could reach 20% by 2050 and 30% at the end of 21st century (Milly et al., 2005). Under such conditions, together with projected withdrawals, the requirements of the Colorado River Compact may only be met 60–75% of the time by 2025 (Christensen et al., 2004). Some studies estimate that, by 2050, the average moisture conditions in the south-western USA could equal the conditions observed in the 1950s.

Such changes could occur as a consequence of increased temperatures (through increased sublimation, evaporation and soil moisture reduction), even if precipitation levels remain fairly constant. Some researchers argue that these assessments, because of model choice and assumed adaptations, may actually underestimate future declines.

By 2004, the drought began to overwhelm planning assumptions derived from previous projections of impacts from analogues of historical extremes. Flawed demand estimates, especially induced during drought, were key to these divergent outcomes. The resulting awareness was that climate change, together with increasing development pressures, would result in drought impacts that are beyond the institutional experience in the region and would exacerbate conflicts among water users. In December 2007, new guidelines establishing rules for shortages were introduced by the U.S. Secretary of the Interior (USDoI, 2007), specifying who will accept reductions and when they take them. This is essential for prudent water planning in times of drought and included new operational rules for coordinated operation of Lake Powell and Lake Mead (the two largest reservoirs in the U.S.), encouraging new initiatives for water conservation and to begin a process of explicitly incorporating the role of climate change into planning and operations. The guidelines provide a mechanism that encourages water conservation in Lake Mead in the Lower Basin to minimize the likelihood and severity of potential future shortages through 2026.

Water managers in Colorado Basin states are explicitly considering how to incorporate the potential effects of climate change into specific designs and multi-stakeholder settings. Early warnings of changes in the physical and social systems and of thresholds or critical points that affect integrated management (watershed, coastal etc.) priorities become important. One such innovation the National Integrated Drought Information System (www.drought.gov) was signed into U.S. Public Law (109-430) in 2006. NIDIS is the direct result of the Colorado Basin drought discussions at the state level and projections of future conditions resulting from climate change. It coordinates previously independent systems of information providers, users, and organized interests on monitoring and forecasting, drought risk and impacts assessments, and communication and preparedness planning.

Most decision makers engaged in cooperative strategies addressing water scarcity have repeatedly stated the need for integrated management of existing supplies and infrastructure (Pulwarty, 2003). What is distinctive about the Colorado is that the inclusion of stakeholders in water management policy has become the norm. However, regardless of how robust civil-society institutions may be, severe drought (or flooding) can expose underlying institutional barriers to effective cooperation. Thus for large river basins the goal should not be to reify some particular scale of analysis (e.g. local, regional) but to uncover what is needed at each of these scales and to address impediments and opportunities to the flow of information and innovations between the decision making nodes.

Case study: The Okanagan

A case study on the implications of climate change for water management in the Okanagan region of British Columbia, Canada, illustrates a communications pathway designed to translate long term global climate change scenarios into local water management risks, and to lay the foundation for constructing a decision support tool for the Okanagan watershed. The approach taken was to organize and maintain a PIA, in which researchers and local experts shared information and perspectives on various aspects of this long-term issue (Cohen, Neilsen and Welbourn, 2004; Cohen et al., 2006; Cohen and Neale, 2006).

The Okanagan is a semi-arid region in southern British Columbia (Figure 3). In 2003, the region experienced a drought with accompanying forest fires which destroyed homes in several communities (Filmon, 2003). Against this background of increased awareness of the effects of climate extremes, increasing local attention was directed at a climate change impacts and adaptation study that had been initiated in 1999, and was evolving into a PIA. The first step was to apply a set of climate change scenarios to a hydrology model calibrated for the Okanagan (Cohen et al., 2004; Merritt et al., 2006).

Figure 3. *Okanagan Basin (from Cohen et al., 2004).*

The resulting hydrographs (Figure 4) became an important communications mechanism linking global climate change to impacts on streamflow in terms well understood by local water professionals and major users groups. The message from this step was that climate change would lead to earlier seasonal peak flow due to earlier snowmelt, and this would result in a longer minimum flow period during the growing season. Total annual streamflow would also decrease from historic averages. Local water supplies largely consist of many small reservoirs which capture and store spring snowmelt for release throughout the year. How would reservoir management adjust to scenarios of climate change and population growth?

The climate change scenarios were applied to a crop water demand model developed for local conditions. Projected changes in crop water demand were compared with scenario changes in water supply to determine potential changes in the frequency of high risk years, i.e. years with low supply and high demand (Figure 5). At the same time, scenarios of domestic water demand were also constructed, incorporating potential changes in climate, population, and implementation of demand side management options (Neale et al., 2007). Throughout the process of scenario construction, local water professionals and interests (e.g. irrigators, habitat protection groups, aboriginal communities, municipal governments, and regional planners) were partners in a shared learning process with the research team. This laid the foundation for moving beyond the scenarios themselves towards creating a decision support tool, the Okanagan Sustainable Water Resources Model (OSWRM), which could be used to explore various long-term response options within scenarios of climate change and population growth. This group-based approach to model

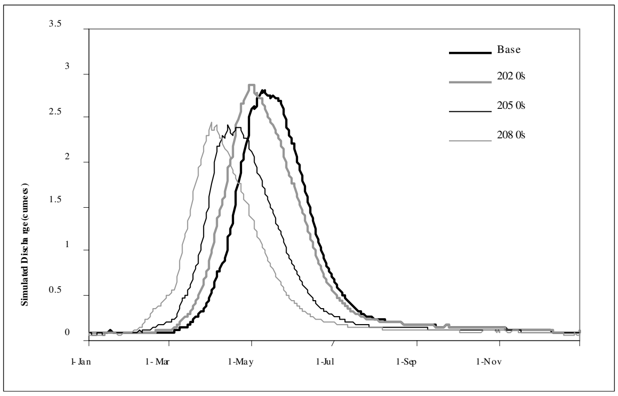

Figure 4. *Okanagan hydrology scenario, based on the CGCM2 -- A2 climate scenario; example from Whiteman Creek (Merritt et al., 2006).*

construction combined local knowledge and scenario outputs, using a STELLA™ platform to offer a tool for desktop experimentation of various combinations of scenarios and response options (Langsdale et al., 2007). Results from other study components provided important inputs for OSWRM (Cohen and Neale, 2006).

One of the results from the first version of OSWRM is that an adaptation portfolio of water demand management measures would only partially offset the increasing frequency of water deficit conditions (Table 2). The overall reliability of the Okanagan system to meet demand decreases from a historic rate of 98% to 72-82% in the 2050s, with climate change being the major cause of this decrease (Langsdale et al., 2007), as illustrated by comparison with the 'no climate change' scenario. Expansion of supplies through greater use of the region's lakes may be feasible, but it will be a difficult task to avoid depleting the resource, as well as to pay for the additional costs of distribution and water treatment. This will become an important challenge for long term water governance and sustainable development in the region (Cohen and Neale, 2006).

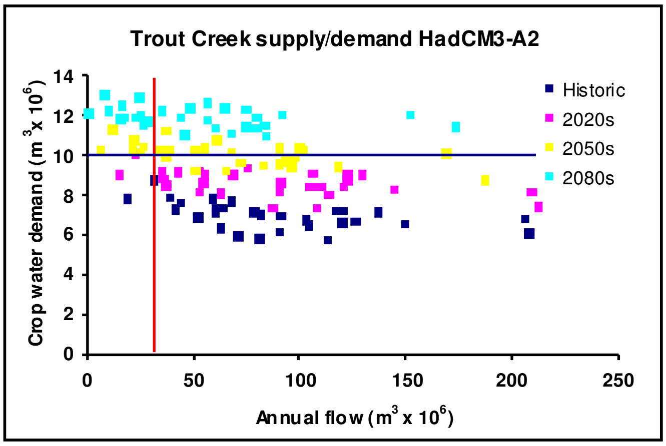

Figure 5. *Scenario changes in balance between water supply and crop water demand, Okanagan – example from Trout Creek for HadCM3 – A2 climate change scenario (Neilsen et al., 2004, 2006).*

Table 2. *Number of years out of 30 where water demand equals or exceeds water supply in the Okanagan Basin, assuming high population growth scenario (Langsdale et al., 2007). Moderate adaptation scenario includes expanded use of residential demand management, including metering with prices charged at increasing block rates, public education, and reduction of agricultural demand by 6% through improved water use efficiency.*

SCENARIO	*Historic*	*2020's*	*2050's*
No climate change	3	6	10
HadCM3 – A2	–	11	22
HadCM3 – A2 Moderate Adaptation	–	9	19
CGCM2 – B2	–	8	14
CSIRO Mk2 – B2	–	14	21

OSWRM is not a "forecasting" model, however, and one of the continuing communications challenges is to ensure consistency in description of what this tool, and other decision models, can and cannot do. This too is part of the shared learning experience. It is hoped that local participants in this process will become communications partners, providing local context for broader public discourse about climate change effects and response options in the Okanagan region. Increased awareness of potential future water supply problems led the region's water authority, the Okanagan Basin Water Board, to initiate a major assessment of the basin's water balance (www.obwb.ca). Also, a regional planning authority explicitly included climate change scenarios in a water management plan for one of the sub-basins (Summit Environmental, 2004).

5. Conclusions

A major challenge in the coming decades, given committed climate change already in the system, will be maintaining water supplies for environmental services, which support economies throughout the United States and Canada. There are significant barriers to implementing adaptation in complex settings. These barriers include the inability of natural systems to adapt at the rate and magnitude of change, as well as cognitive, behavioural, social and cultural constraints. There are also significant gaps in knowledge for adaptation, as well as impediments to flows of knowledge and information relevant for decision makers. In addition, the scale at which reliable information is produced (i.e. global) does not always match with what is needed for adaptation decisions (i.e. watershed and local). The management of the cumulative impacts of extremes (droughts, floods, hurricanes etc.) usually occurs through reactive, crisis-driven approaches. The Colorado River Basin experience shows that change in managing climate-related risks (in this drought) may be most readily accomplished when: (1) a focusing event (climatic, legal, or social) occurs and creates widespread public awareness; (2) leadership and the public are engaged; and (3) a basis for integrating research and management is established.

As the Okanagan case and others (see Pulwarty and Melis, 2001) show, a key component in developing such an integrated framework is the ability of practitioners themselves to manipulate data and to reconcile scientific claims with their own knowledge. This plays important roles in their choices. There is a strong need for the inquiry into, and development of, interactive approaches between decisive (policy and operations) and non-decisive (research) participants to take advantage of new opportunities as systems evolve.

Long -term cumulative environmental problems can seldom be dealt with by single discrete actions or policies but respond only to continuing, sustained efforts at learning, supported by steady public attention and visibility. Even where information on thresholds is available, usable and can produce positive results, the value of such information may still be overwhelmed by rates and magnitudes of social, economic and environmental changes. There is also the danger of disempowerment of stakeholders if engagement in PIA does not result in actions consistent with the assessment's findings (Yohe et al., 2007).

If lessons learned are to be actually applied, then a large part of the scientific adaptation goal should be to inform processes that can decrease impediments to the flow of information and innovations. One example of a program that links an understanding of the policy contexts (as elucidated in the Colorado case) with supporting a dynamic dialogue between researchers and
practitioners (as in the Okanagan case) is the NOAA Regional integrated Sciences and Assessments Program (Pulwarty et al, 2009). The RISA efforts show that enabling successful information interventions at any point in time requires a critical mass of accessible, credible, and legitimate information It also requires the capacity to apply knowledge and evaluate consequences of its use. This would entail: (i) Clarification of

management goals at the human-environment interface, and (ii) Construction of a cooperative foundation between research and management to distil lessons from comparative appraisals of current and past practices, and to develop effective participatory processes to ensure validity and acceptability of projections of changes in relevant system outputs i.e. robust information in practical contexts.

Developing such an integrated basis for managing water resources as climate changes requires a mixed portfolio of approaches, including:

- Mechanisms for anticipatory coordination within development plans (e.g. adaptive management within integrated watershed and coastal zone plans).
- Developing usable climate risk management triggers for early warning of potential conflicts in agriculture, water, energy, health, environment, and coastal zones.
- Developing and employing water efficient technologies.
- Actively engaging communities and states in mainstreaming climate information into practice though participatory mechanisms, such as the co-development of scenarios that link climate and development goals.
- Investing in career opportunities for climate change adaptation within local governments and water-based utilities, integrated within long-term planning for sustainability.

Future needs include greater exploration of alternate integration models and overlying policy structures that could, together, facilitate and sustain shared learning of climate change adaptation. This would ultimately transform this from a project-based activity to a long-term service. A complementary need would be for better understanding of communication for cross-scale adaptation decisions that may emerge within one level of government, multi-levels of government, and at the watershed scale with its mix of governments and utilities. This would help to maintain institutional memory of climate change adaptation, thereby improving adaptive capacity as we face the challenge of managin gwatersheds in the face of climate change.

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