Environmental and Water Decision-Making in a Changing Climate

Understanding and responding to the impacts of climate variability and change on water and environmental systems requires analysis, modeling methodologies, and tools that accommodate incomplete knowledge and uncertainty that themselves evolve over time. The broad scope of this problem necessitates a multidimensional dialogue among research and policy groups that span disciplinary boundaries. Integration of this knowledge is required to develop adaptive capacity (i.e., necessary knowledge, preparedness, and reliable decision-making capacity to act by all partners in the information chain) and resilience. In this context, resilience can be taken to mean the degree to which the environmental system can absorb both abrupt and gradual changes and build capacity for learning and adaptation.

As part of the 2005 AGU Fall Meeting, the session “Integrated environmental and water decision-making in a changing climate” was convened under the primary sponsorship of the Global Environmental Change Focus Group, with cosponsorship from other sections. The session served as a venue for a discussion of case studies, conceptual frameworks, and modeling that examined one or more components of the connected climate-water-environmental systems on local, regional, and continental scales. Combining analyses of historical hydroclimatic variations and trends with 21st-century climate change scenarios to quantify uncertainties and associated geographical sensitivities was also a key area of interest.

**Climate Variability and Change, and Resource Management**

Session organizers invited contributions that concentrated on results from ongoing studies that focus on local and regional-level analyses, and existing decision-support systems, such as those for water management, air/water quality, and fisheries. Presentations and discussion highlighted knowledge gaps in problem definitions, described instances where new information necessitated the need to reframe definitions, and described the capacities of predictive and monitoring tools. Additionally, research presented during the session identified the important role of stakeholders in problems such as water and agricultural decision-making.

Oral and poster presentations brought together researchers within the AGU community with research foci including decision process analysis, regional assessments of global change, and quantitative modeling and analysis of vulnerable regions, communities, and infrastructure across climatic timescales.

University of Colorado and U.S. National Oceanic and Atmospheric Administration (NOAA) scientists reported, for example, that the ongoing NOAA-sponsored Regional Integrated Sciences and Assessments program has developed a portfolio of research products and applications to support regional decision-making across sectors. This use-inspired research facilitates a continued dialogue between researchers and decision-makers, and also refines basic research questions aimed at informing solutions demanding lead information (such as forecasts) and better use of existing monitoring products.

Presentations on the analysis of climate change scenarios and the use of climate forecasts for water resources management highlighted the need for applying research-based knowledge effectively and the import of overarching efforts—such as the U.S. Climate Change Science Program, the Intergovernmental Panel on Climate Change, and other state-level initiatives engaged in developing usable science as timely information and products at appropriate scales—that can continually benefit from new scientific knowledge.

Session presentations also provided examples of research and methodologies to better understand decision processes in action, through retrospective and real-time analyses of emerging and historical events, such as flooding episodes. These presentations highlighted how effective learning from individual events allows an assessment of the dynamic nature of the decision-maker, institutional, and emergency responses for a particular community. How this knowledge is embedded within the longer-term flood management decision-making as well as the regional climate variability and change contexts is a significant research question for adaptation and mitigating impacts.

An understanding of the hydroclimatic trends in observations and modeled climate change scenarios were identified as important research elements that set the physical context for decision-making and adaptive management in a changing climate. Ensemble climate model simulations allow rigorous quantification of the distributional aspects of regional and global climate change. On multidecadal time horizons, changing frequency of extreme events, water supply issues, and temperature-related impacts on ecosystem health and long-term viability are some of the concerns that feed directly into the context for decision-making, especially should model climate change scenarios be realized later this century.

**Climate Variability and Change in the Western United States**

Another area of investigation discussed at the session was the multiplicity of climate change impacts on regional hydrology. In snowmelt-dominated regions, such as western North America, impacts from climate variability and change are felt through temperature and precipitation changes, which translate into modified spring-melt climatology; increased frequency of rain versus snow events, dramatic changes in the antecedent soil moisture content, and elevational changes in the magnitude of snowpack and its melt timing. As a result, water resources decision-making must resynchronize reservoir operations to changing hydrology.

This is a pressing question especially for regions such as California, where population and development-related drivers are closely tied to reliance on uninterrupted water supplies wherein legally binding statutes can further constrain flexibility, session participants noted. Furthermore, while monitored and predicted climate information promises a foreknowledge of expected hydrologic and climatic states, an understanding and characterization of uncertainty is a critical step in making effective use of climate information for water and environmental decision-making. To this end, several researchers presented simple to complex modeling methodologies that map the probabilistic nature of climate information to decision problems and analysis tools in order to aid in quantifying the relative value of climatic information. The usefulness of climate information varies from case to case. Facilitating the use of climate information can be done best with decision-maker participation defining the critical problem, and through understanding the information and decision-making context in an integrated fashion.

The pervasive nature of challenges facing managed river systems is only complicated by uncertain and changing climate. The Grand Canyon region was presented as an interesting example of a natural laboratory facing these pressures; concerns related to reliable water supplies, hydropower generation, and meeting the needs of a multistate jurisdiction stakeholder base have been framed into the Glen Canyon Dam Adaptive Management Program (AMP). The context and information needs for decision-making within the AMP are of a highly dynamic and evolving nature where many different values and needs are being balanced.

To support decision-making, current research presented at the session focused on flood-driven inputs into the Grand Canyon, showing the important role of tropical storms and hurricanes from the eastern Pacific Ocean (and as a result the larger climatic context) that modulate the
Effective Use of Information in Applications Research

One of the goals of this session was to address the problem of an inadequate fit between what the research community knows about the physical and social dimensions of uncertain environmental changes and what society chooses to do with that knowledge. There is the need to move beyond the integration of physical and societal dimensions to focus on practice and evaluation: How are impediments to the flow of information created? Where are the impediments, and how are they to be overcome? How are they defined among differentially vulnerable groups?

As noted within this session, and elsewhere, adaptability within a natural or managed system is generated through major events at smaller, faster scales, such as flooding, whereas resilience resides in slowly changing variables such as social, climatic, and landscape processes, which provide system memory. Present adjustments to hurricanes, floods, and droughts can constrain or enable vulnerability to longer-term risks induced by climate and global changes. An even larger challenge is to consider how different systems of knowledge about the physical environment and competing systems of action can be brought together in pursuit of resilience and of the processes to make such management possible. This session was an initial step in addressing the challenge.

The session, "Integrated environmental and water decision-making in a changing climate" was held on 7 December at the 2005 AGU Fall Meeting in San Francisco, Calif. A complete list of presentations given at this session is available on the AGU Web site at http://www.agu.org/meetings/fm05/fm05_sessions/fm05_GC31A.html and http://www.agu.org/meetings/fm05/fm05_sessions/fm05_GC333.html

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LETTERS

On Quantifying Freshwater Sustainability Through Multiscale Mapping

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We agree with Kanivetsky and Shmagin (Eos, 86(50) 2005) that better accounting of flows comprising the hydrologic cycle is needed and that better quantification of recharge (into groundwater) and discharge (i.e., streamflow) is important from human and environmental perspectives. However, because these authors promote their approach as being useful in assessing "sustainability" we feel compelled to offer words of caution about its applicability.

The authors suggest that the ratio of renewable water supply to water use by humans and the environment is a "key indicator" of sustainability. We think that these authors got it half right. The ratio described above is a useful indicator because it quantifies how much strain a natural system may be experiencing. However, all ecosystem water is not equivalent. The river science literature strongly indicates the need for the full range of natural intra-annual and inter-annual variation of river flows, along with associated characteristics of timing, duration, frequency and rate of change, to sustain the biotic integrity of aquatic ecosystems [Postel and Richter, 2003]. In this context, only when an adequate assessment of ecosystem needs is performed and compared to net water availability after subtracting human uses will we know if we are truly managing for sustainability.

Understanding how much water (and its associated temporal pattern) a river ecosystem needs—essential in managing for true ecological sustainability—will require assessments with much finer degrees of spatial and temporal resolution than that provided by the approach of Kanivetsky and Shmagin. For example, the authors suggest that St. Louis County, Minnesota's use of only 81% of the renewable water supply is "sustainable." However, if all of that water were taken from a single or even a few small streams, the ecological effects would likely be devastating. Our point is that hydrologic accounting methods based on spatially averaged conditions across geographic areas the size of counties or ecoregions provides only a coarse-scale indication of the potential for human impacts on natural ecosystems. These results can be very misleading because water extractions and other hydrologic alterations are not spatially uniform.

The science of determining water flows needed to sustain healthy river ecosystems, known as 'instream flow science', is a rapidly evolving field driven by the urgent need to provide defensible guidelines in a highly charged sociopolitical context in which stakeholders often hold opposing views of what constitutes the 'beneficial' use of surface water and how much, if any, water needs to be left in the river for ecological purposes. Many rivers have been altered to the point where it may be biologically, socially, or financially impossible to restore their ecological health, and significant legal obstacles exist in many places to retain water in rivers for its ecological purpose. While scientific emphasis needs to be placed on better accounting of water flows through hydrologic cycles, we want to emphasize that the dearth of information relating flow regimes to biological processes is also a significant hindrance to the attainment of sustainability. Everyone interested in promoting ecologically sustainable water management will benefit from more research focused on relating hydrology, geomorphology, and water quality to aquatic and riparian biology.

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