Climate Change Adaptation Lessons from the Land of Dry Heat

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Abstract

The Arizona Water Institute, along with Arizona State University and the University of Arizona's Institute for the Study of Planet Earth, brought together local, State, tribal, and Federal water resources managers with agency and university scientists to identify adaptation and response strategies to climate change impacts on water supplies. The workshop participants identified the following issues and potential solutions:

- need for comprehensive water balance monitoring in anticipation of changes in the hydrologic cycle, including continuous observations of demand-side variables such as consumptive water use and evapotranspiration, in addition to perennial needs for improved groundwater, snow, and soil moisture observations;
- strong concerns about attrition of the U.S. Geological Survey streamflow network;
- concern about the implications of hydrologic non-stationarity for water management planning and infrastructure design, which will require evolution from standards-based approaches, e.g. using fixed "normals," to flexible risk-based approaches;
- need for enhanced decision-support products and processes, including innovative ways to visualize and compare the outcomes of alternative policies in the context of future climate variability;
- need for a greater emphasis on explanatory information to accompany climate projections and scenarios, and on the adoption of common decision-support tools within regions and sectors to enhance communication and consistency of analysis; and
- need for dendrohydrologic data to form the basis for improved understanding of past streamflow variability and sequences of low flows, and to plan for worst-case scenarios and to hedge bets when purchasing alternative supplies—managers need more reliable high-flow estimates and the ability to distinguish summer and winter reconstructed flows.

Keywords: climate change, adaptation, non-stationarity, water management, dendrohydrology

Introduction

On February 5, 2008, at Biosphere 2 in Oracle, AZ, the Arizona Water Institute, in collaboration with Arizona State University and the University of Arizona’s Institute for the Study of Planet Earth, brought together key water resources managers with agency and university scientists to identify specific adaptation and response strategies to climate change impacts on water supplies. The “Workshop on Climate Change Adaptation for Water Managers: Exploring Adaptation Tools and Strategies” used an informal café-style conversation format to foster an atmosphere conducive to community building and to strengthen a “knowledge network” of practitioners and researchers. Participants discussed a wide variety of options, ultimately identifying a suite of priority strategies in areas ranging from climate change monitoring to engineering challenges. In addition, invited speakers discussed the role of conservation in addressing water supply needs. This summary provides key highlights from each of the topics that were discussed.

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The participants engaged in facilitated conversations on the following topics:

- Climate prediction tools and their utility for water management;
- Strategic monitoring needs related to climate change;
- Changes in engineering practices that may be required for water, wastewater, and stormwater management, especially in the context of increased climate variability;
- Market solutions to drought, including compensated, temporary voluntary transfers from agriculture to urban uses;
- Connections between energy and water, including policy, technology, cost, and emissions considerations of alternative water and energy supplies;
- Decision support needs in the context of climate change; and
- Use of tree-ring records for understanding climate variability.

Methods

The following synthesis highlights major observations from small group sessions on each topic. The organizers and group session facilitators culled these highlights, within one week of the workshop, from their notes and notes taken by student assistants.

Results

Climate prediction tools and their utility for water management

An array of climate tools can currently be used to forecast temperature and precipitation up to a year in advance. These tools all provide probabilistic forecasts and have a range of skill that is dependent on multiple factors. Researchers observed that, with certain exceptions, there is a large gap between the climate prediction tools that water managers use and what is available.

Participants agreed that we are at the end of an era when we can use the assumption that future climate and hydrology will resemble past climate and hydrology as a foundation of water resources planning, management, and operational practices (Milly et al. 2008). This assertion, that the dynamics and statistics of the hydroclimatic system are a moving target (i.e., non-stationary), has significant implications for water management planning and infrastructure design, as well as for the utility of the existing prediction tools. Accommodating climate non-stationarity will require an evolution from standards-based approaches (based on a historic view of "normal") to more flexible risk-based approaches.

Research needs identified in the sessions include: How will accuracy of predictions of climate and hydrologic variability change with warming? What are the implications of climate change for groundwater availability and management? How can hydrologic forecasts be extended beyond annual volumes to provide information about seasonality, timing of peak surface water flows, and extremes? Can we develop better snowmelt/runoff models for operational purposes? Can climate predictions be linked to end-to-end systems that merge the analysis of major factors affecting local operational and (or) management decisions into a coherent framework?

Strategic monitoring

Participants strongly recommended improved monitoring of all aspects of the water balance, with particular emphasis on detailed, continuous observations of demand-side variables such as consumptive water use and evapotranspiration. Lack of adequate groundwater data to monitor changes in areas not influenced by pumping was universally cited as a high priority for strategic monitoring investments.

Monitoring of ecosystem responses and interactions between ecosystems and hydrology were assigned a high priority, especially given recent and projected ecosystem changes and their effect on evapotranspiration, runoff, and sediment transport. Participants also emphasized the need for strategic investment in monitoring in mountainous regions, especially with respect to snow climatology and hydrology, given observed and predicted changes in snow hydrology and melt dates.

Workshop participants voiced concerns about maintaining the current network of stream gages and noted the critical need to expand and improve observations of low flows. They raised strong concerns about continued retirement of gages from the network, which undermines society's ability to monitor climate changes, thereby increasing vulnerability to changes. Given the many large-acreage fires in Arizona during the last decade, participants expressed a need for better observations of sediment transport. Participants also noted a critical lack of water quality data in comparison with water quantity information. They noted that reliable, high quality, credible benchmark measurements are needed to discern future trends and abrupt changes.

Research needs include: better quantification of relationships between highly variable summer precipitation and recharge; improved understanding of snow hydrology, diagnostics of snowmelt, and runoff and soil moisture recharge when rain or snow events occur; and improved understanding of connections between surface water and groundwater.

Engineering for climate change

Climate change will pose a number of challenges for those who design and operate water supply, water treatment, and flood control infrastructure. Although participants felt that engineers have the tools to develop a range of adaptation options for climate change, there are limitations on fully preparing for the magnitude of anticipated changes because the risks are not well recognized and existing conventions, e.g. rule curves, limit innovation.

Workshop participants expressed strong support for more holistic and integrated planning as well as looking at a range of hard and soft approaches that consider economic and non-economic impacts and that examine direct and indirect effects of decisions. To implement some of these approaches (e.g., gray water reuse) while minimizing unintended consequences (e.g., expansion of lawn watering), the risks and trade-offs associated with various decisions must be communicated clearly to stakeholders.

Participants noted that more distributed networks of water and wastewater systems would be more reliable, sustainable, and manageable. They suggested promoting higher efficiency in water use, as well as the use of renewable alternative energy, such as solar energy. It was pointed out that the challenges of adapting existing infrastructure are different from designing new development to cope with climate change. Participants also noted that while broader, more creative engineering is essential, it must be accompanied by behavioral changes in order to realize the full benefits of innovation.

Research needs include: development of new engineering design methods that are robust as we move into less stable climate conditions; evaluations of how these new practices can best be integrated into existing institutions; and better temporal and spatial global circulation model downscaling for use in planning for future impacts of climate change.

Market solutions to water supply shortages

Market mechanisms, such as financial incentives to transfer water from agriculture and pricing structures that encourage conservation, are frequently touted as solutions to water supply problems.

Discussion in this session focused on temporary pricing signals and programs (drought surcharges, emergency transfers of water rights) versus permanent price reform (scarcity pricing). There was concern about whether we are foreclosing opportunities by permanently retiring agricultural rights because agriculture represents a buffer of water supplies that may be purchased in emergencies.

Participants also observed that there are unintended consequences of increased pricing and (or) conservation. For example, education and conservation programs reduce water use, which leads to price hikes to maintain revenue stream and, in turn, outraged customers who feel punished for conserving. To enhance the effectiveness of price signals, utilities need to do a better job of communicating to the public the issues that cause water shortages, such as growth in demand, drought, or changes in water quality standards.

Research needs include: improved methodologies and their application to valuing non-traditional goods and services, such as ecosystem flows, and community social and employment patterns that may be affected by exporting or transferring water; also, development of tools for predicting the effects of changes in price on demand in individual service areas.

The energy–water nexus

The connection between energy and water is far more intense than is generally acknowledged. Pumping, treating, and heating water are among the largest demands for energy in the United States, and generating energy is one of the largest uses of water. Further, many of the "new" water supply options, including desalination and importation, are very energy intensive.

Climate change puts bounds on the intensive use of energy for water management. The effects of water management decisions on energy and carbon emissions need to be considered, and we need to avoid promoting adaptation measures that exacerbate the emissions of carbon dioxide.

Participants noted that water conservation has low-cost, socially acceptable benefits in **both** water and energy terms, and when conservation benefits are evaluated from both perspectives, the cost effectiveness improves dramatically. Water reuse can also be surprisingly efficient from an energy perspective.

Water managers are not energy experts; they need partnerships with energy providers to identify opportunities to save water in generation of electricity and to save energy in pumping, treating, and delivering water. Opportunities need to be identified for water and energy managers to collaboratively exchange information on their decisionmaking processes, which would ultimately lead to joint water and energy planning.

Research needs include: assessment of the energy intensity of alternative water supplies in Arizona, using an approach developed for California but validated for applications in Arizona; quantification of the impacts of small-scale versus large-scale energy–water solutions; evaluation of new incentives and social market transformation mechanisms, given that market forces alone may not be sufficient to meet emissions and energy goals; and identification of alternative energy options, particularly solar photovoltaic, for water treatment.

Decision support

Decision support is a process that requires building mutual trust in equal parts among data experts, modelers, water managers, decisionmakers, and the public; the process and the decision tools must be transparent, flexible, and based on the best and most timely information. Participants agreed that much more decision support is needed in Arizona.

To improve decision tools, workshop participants recommended that more emphasis be placed on the policy inputs to the decisions: decisionmakers need innovative new ways to visualize and compare the outcomes of policy changes in the context of climate-induced variability. In addition, participants recommended more explanatory information (e.g. metadata, caveats regarding use) to accompany climate change projections and scenarios.

Managers attending the workshop recommended the following characteristics for useful decision support tools: simple interfaces; a high degree of interactivity; transparency of data sources, assumptions, and uncertainties; spatial and temporal scales relevant to decisions; the ability to visualize and contrast alternatives; the ability to locate decision points within a decision tree or context; and the ability to demonstrate potential policy changes with respect to historical situations.

One approach offered to improve regional water management planning is **shared vision modeling**—adopting common decision support tools within regions and sectors to enhance communication and consistency of analysis. For example, Texas uses standardized models for groundwater and surface water in all 16 of its planning regions. Some Arizona participants noted that collaborative learning by stakeholders and researchers in a shared vision context results in greater acceptance of the outcomes and an improved understanding of uncertainties in observations and estimates as well as the connections among models, observations, and system sensitivities.

Paleoclimate

Tree-ring records have a physical basis that can represent more certainty about conditions beyond those documented in gage records than do modeled or synthetic data. Therefore, managers place greater trust in tree-ring data than in model predictions. Participants noted that one of the best uses of tree-ring records is to demonstrate past climate and hydrologic variability to policy makers, boards of directors, and the public, which can pave the way to changes in operational management.

Water managers in the western United States have used tree-ring reconstructions to test current operational rules, developed using a relatively brief gage record, against a longer record that captures more extremes. Managers have also used tree-ring reconstructions to determine, for example, the likelihood of sequences of consecutive dry or low-flow years or the duration of drought episodes (shifting their perspectives from a 3–7 yr horizon to a 20–30 yr horizon). Streamflow reconstructions have been used to estimate long-term averages, interannual and multi-decade variability, sequences of past flows, and the likelihood of joint occurrences (e.g., joint occurrence of drought in the Upper and Lower Colorado River Basins). The results of these analyses have then been applied to management decisions regarding necessary supply reserves, planning worst case scenarios, or to hedge bets when making allocations or purchasing water from alternative supplies.

The current state-of-the-art tree-ring science methods produce more reliable estimates of low flows. A key research need is to improve the accuracy of high flow estimates. Another is to overlay projected climate change effects on paleo-estimates of natural variability of flow; this kind of approach, using a trusted data source, may be useful in some scenario planning exercises. Participants also recommended research to expand and improve summer precipitation reconstructions in order to examine joint sequences of past winter and summer precipitation. Scientists see the opportunity to use tree rings to reconstruct groundwater variations and for use in parameterizing surface/groundwater models. Tree-ring data can also be used to attribute past drought episodes to certain combinations of atmospheric circulation patterns.

Conclusions

This summary is necessarily brief and lacks most of the richness and detail of the conversations at this workshop. Comments by workshop participants provide examples specific to water management concerns. However, their comments, concerns, and insights resonate with broader assessments of adaptations necessary to address watershed and ecosystem management under climate change, such as the recent paper by Dettinger and Culberson (2008). A key conclusion of these authors that validates concerns of Workshop on Climate Change Adaptation for Water Managers participants is that climate change must be considered in the context of ongoing climate variability and an array of human alterations to watersheds, landscapes, and water supplies, such as population growth, groundwater pumping, land use changes, invasive species, and many more.

See **http://azwaterinstitute.org/index.html** for more information about the workshop and its outcomes.

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