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Reducing our vulnerability to climate depends upon our ability to bridge the gap between climate science and implementation of that science in our management of critical resources, arguably the most important of which is water.

This brochure summarizes a recent assessment that focuses on the scientific ability to predict climate on seasonal and year-to-year timescales and the opportunity to incorporate such information into water resource management decisions.

WHY WATER AND WHY NOW?

In addition to the need for clean and abundant drinking water—a fundamental requirement of life—the availability of water also influences a number of other sectors of the U.S. economy, such as energy production[i], agriculture[ii], health[iii], transportation[iv], hazard management, national security, and recreation. Water is also fundamental to the health of all ecosystems, from aquatic environments to the Arctic desert.

The security of water supplies is of particular concern to us as our population continues to increase and expand into new areas and as climate continues to change, largely as a result of human activity. Consequently, our ability to incorporate good science into management of water and other natural resources is now even more critical. For example, precipitation is generally becoming heavier (a trend that is expected to continue), meaning that floods that previously had a probability of 1-in-100 years, may now be more frequent in some areas[v]. Snowpack in areas of the West—the dominant source of fresh water for the region—is lower in volume and melting earlier in the spring on average; the impacts on water supplies affect a variety of decision makers from farmers (who will have to plan their irrigation schedules accordingly) to water utility planners (who will have to plan ahead for potential decreases of supply in summer months). These more recent and obvious phenomena provide us with an understanding of our vulnerability to a varying climate. It is this understanding, in part, along with widespread reporting of natural events such as hurricanes and droughts, that has catalyzed attention to how climate science is or can be used in making better decisions (see Timeline graphic).

CAN WE PREDICT CHANGING WATER RESOURCES?

The ability to predict many aspects of climate and hydrologic (water) variability on seasonal and year-to-year time scales is a significant success in Earth systems science.

Climate prediction

Over the past quarter-century, there have been significant advances in the ability to monitor and predict important aspects of seasonal and multiseasonal variations in climate, especially those associated with variations of the El Niño-Southern Oscillation (ENSO) cycle. Predictions of climate variability on seasonal time scales are now routine and operational, and consideration of these forecasts in making decisions has become more commonplace.

However, it is important to emphasize that seasonal climate forecasting skill is still quite limited, and varies considerably depending on lead time, geographic scale, target region, time of year, status of the ENSO cycle, and various other issues. Despite that, the potential usefulness of this new scientific capability is enormous, particularly in the water resources sector. Seasonal climate forecasts seek to predict the state of the atmosphere for a region over a specified window of time, typically from one month to a few seasons in advance. Observations of the slowly varying boundary conditions on the atmosphere, including upper ocean temperatures, snow cover, and soil moisture are critical to the accuracy of climate forecasts. Climate forecasts can also address the expected probabilities for extreme events (floods, freezes, blizzards, hurricanes, *etc.*), and the expected range of climate variability.

Hydrologic prediction

Federal, regional, state, and local agencies, as well as private sector companies, such as utilities, produce hydrologic forecasts. Hydrologic forecasts tend to focus on elements such as runoff volume, streamflow, lake levels, groundwater recharge and the like (see Lake Superior Graphic). Key predictors of hydrological forecasts are such things as snowpack, soil moisture, large scale features of climate such as ENSO, and seasonal precipitation regimes (such as the summer maximum of rainfall in the U.S. Southwest).

In contrast to climate forecasts, hydrologic forecast products more directly target end use sectors—such as water, energy, natural resource or hazard management—and are often region-specific. Prediction methods and forecast products vary from region to region and are governed by many factors, but depend in no small measure on the physical characteristics of the locations, institutional ability to incorporate climate information, and other influences specific to their region.

Timeline from 1970 to present of key events contributing to a widespread increase in awareness of climate issues, providing a change in context for water resource decisions.

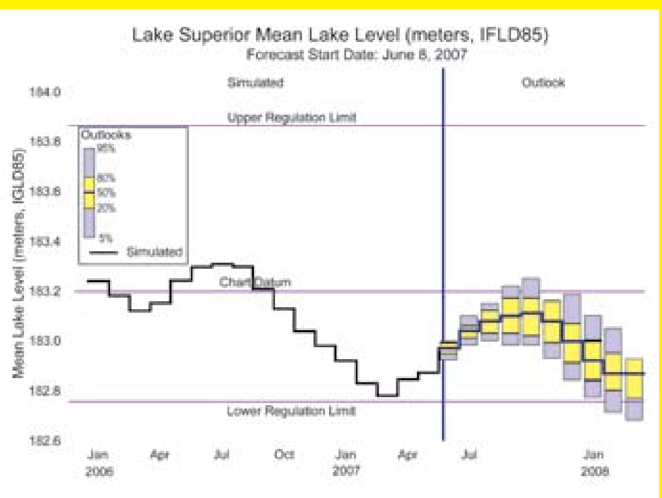
What are the major factors that affect water resources in the United States?

Water resources are directly dependent on climate, primarily through the distribution and abundance of rain and snow, and how we store and use the amount of water available. For example, changes in the amount of snow, and the speed and timing of melting are all important factors in the way snowpack contributes to water supply. Along with total rainfall, changes in the way rainfall occurs (a few heavy storms or more numerous light rain events) are also critical determinants of water availability. Equally important is the demand for water.

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

- Increasing demand for water in terms of potable drinking water, agricultural/food requirements, and energy needs.
- Greater political power of recreational and environmental interests that insist on minimum flows in rivers.
- Diminishing groundwater reserves that are the result of development, which enabled the expansion of agriculture in the western United States and is the basis for the development of several urban regions. As groundwater reserves are depleted, pressure increases on other water sources.
- Persistent water quality problems in many places, despite decades of regulations and planning.

The best-documented pressure is population growth, which is occurring in the United States as a whole, and especially in the South and Southwest regions where water resources are also among the scarcest.



Example of a hydrologic forecast product projecting lake levels for Lake Superior. This is disseminated by the Great Lakes Environment Research Laboratory <http://www.glerl.noaa.gov/wr/ahps/curfcst/>.

HOW DO WE INCORPORATE CLIMATE AND HYDROLOGIC PREDICTIONS INTO WATER RESOURCE MANAGEMENT?

Useful climate science is not just the product of science, but also incorporates an understanding of decision-maker needs and concerns.

While much progress has been made, conveying climate and hydrologic forecasts in a form useful to real world decision making introduces complications that call upon the skills of not only climate scientists, hydrologists, and water resources experts, but also social scientists with the capacity to understand and work within the dynamic boundaries of organizational and social change.

Supporting decision making requires more than a one-time exchange, rather it must be an ongoing process that links scientists with decision makers, building perceptions of credibility, legitimacy and trust between scientists and managers. Effective climate forecasts are co-produced by climate scientists and water managers working together to translate, communicate and disseminate information. Organizations that span two different communities (*i.e.*, include participants from the climate science and water management communities), are essential in helping to build the necessary bridges to transform climate science into information that is relevant, credible, and trusted.

Despite the challenges in incorporating forecasts into decision making in the water resource sector, there are numerous examples where organizations have attempted to do just that. They illustrate how to articulate user needs, overcome communication barriers, and operationalize forecast tools.

- The effective integration of climate information in water resource decisions requires long-term collaboration between scientists and decision makers and sustained investment and support in developing networks of professionals.
- The national-scale production of data must be wed with customized products for local users. This requires a wide range of participants to be engaged.
- The process of forecast tool development must be inclusive, interdisciplinary, and provide ample dialogue among researchers and users. To achieve this, there needs to be professional reward systems that recognize people who develop, use, and translate such systems for use by others.
- Information generated by these tools must be implementable in the short term for decision-makers to foresee progress and support further development.

HOW THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT USES CLIMATE INFORMATION

In an attempt to restore the Everglades ecosystem of South Florida, a team of state and federal agencies is engaged in the world's largest restoration program. A cornerstone of this effort is the understanding that seasonal and year-to-year climate variability (as well as climate change) could have significant impacts on the region's hydrology over the program's 50-year lifetime. The South Florida Water Management District (SFWMD) is actively involved in conducting and supporting climate research to improve the management of South Florida's complex water system.

Research relating climate variability to Lake Okeechobee inflow started at SFWMD more than a decade ago. Since that time, SFWMD has been able to apply climate forecasts to its understanding of climate-water resources relationships in order to assess and communicate risks associated with seasonal and multiseasonal operations of the water management system to agency partners, decision makers, and other stakeholders. The SFWMD has since established a regulation schedule for Lake Okeechobee that formally uses seasonal and multi-seasonal climate outlooks as guidance for regulatory release decisions.

The district has also learned that, given the decades needed to restore the South Florida ecosystem, adaptive management is an effective way to incorporate seasonal and multiseasonal climate variation into its modeling and operations decision-making processes, especially since longer term climate change is likely to exacerbate operational challenges.

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HOW SEATTLE PUBLIC UTILITY DISTRICT USES CLIMATE INFORMATION TO MANAGE RESERVOIRS

Seattle Public Utilities (SPU) provides drinking water to 1.4 million people living in the central Puget Sound region of Washington State, and has responsibility for river flow resources, flood control, and habitat management. Over the past several years SPU has taken numerous steps to improve the incorporation of climate, weather, and hydrologic information into management of its mountain water supply system.

Through cooperative relationships with agencies such as NOAA's National Weather Service, U.S. Department of Agriculture, Natural Resource Conservation Service, and the U.S. Geological Survey (USGS), SPU has secured real-time access to snow-depth measurements, streamflow gages and weather stations in and around Seattle's watersheds. Access to this information has helped to reduce the uncertainty associated with making real-time and seasonal operational decisions, and has allowed greater management flexibility for making these decisions in response to changing weather and hydrologic conditions, including abnormally low levels of snowpack or precipitation.

As a consequence, SPU is able to undertake reservoir operations with higher degrees of confidence than in the past. For example, during the winter of 2005 when the lowest snowpack on record was realized in Seattle's watersheds, the probability of reduced spring flooding, coupled with their ongoing understanding of local and regional climate and weather patterns, enabled SPU water managers to safely capture more water in storage earlier in the season than normal. As a result, Seattle was provided with enough water to return to normal supply conditions by early summer despite the record low snowpack.

Specific lessons from this example include: (1) access to skillful seasonal forecasts enhances credibility of using climate information in the Pacific Northwest, even with relatively long lead times; (2) monitoring of snowpack moisture storage and mountain precipitation is essential for effective decision making and for detecting long-term trends that can affect water supply reliability; and (3) while SPU has worked with the research community and other agencies, it also has significant capacity to conduct in-house investigations and assessments. This provides confidence in the use of information.

WATER RESOURCE ISSUES IN THE FIRE-PRONE WEST

Improvements in ENSO-based climate forecasting, and research on interactions between climate and wildland fire occurrence, have generated opportunities for improving use of seasonal climate forecasts by fire managers. They can now better anticipate annual fire risk, including potential damage to watersheds over the course of the year.

Climate information can help managers plan for fire risk in the context of watershed management and post-fire impacts, including impacts on water resources. One danger is inundation of water storage and treatment facilities with sediment-rich water, creating potential for significant expense for pre-treatment of water or for facilities repair. Post-fire runoff can also raise nitrate concentrations to levels that exceed the federal drinking water standard. Mudslides and soil stability are also a concern after wildland fire.

A continuing effort to produce fire-climate outlooks was initiated through a workshop held in Tucson, Arizona, in late winter 2000. The project, now called the National Seasonal Assessment Workshop (NSAW), continues to produce annual fire-climate outlooks (*e.g.*, Crawford *et al.*, 2006). The interactions between climate scientists and fire managers clearly demonstrated the utility of climate information for managing watershed problems associated with wildfire. This experiment is enduring. It is now part of accepted practice by agencies, and has produced spin-off activities managed and sustained by the agencies and new participants. The use of climate forecast information in fire management began because decision makers within the wildland fire management community were open to new information, due to legal challenges, public pressure, and a "landmark" wildfire season in 2000. The National Fire Plan (2000) and its associated 10-year Comprehensive Strategy reflected an increased receptiveness for new ways of coping with vulnerabilities; it called for a community-based approach to reducing wildland fires that is proactive and collaborative.

HOW DO WE APPLY LESSONS LEARNED IN WATER RESOURCES TO OTHER AREAS?

Our ability to respond and adapt to climate depends greatly on our understanding of climate science, but even more importantly, how well this information is integrated into decisions.

Only recently have climate scientists come to realize that improving the skill and accuracy of climate forecasts does not necessarily make them more useful or more likely to be adopted. Better technical skill must be accompanied by better communication and stronger linkages between forecasters and potential users. The production of climate information to support decision making is not a single product or a suite of products, but a process, involving leadership, innovation, communication, equitable access to information, and an involved and science-literate citizenry. These are lessons that are equally applicable to climate information to inform management of other resources, such as energy, agriculture, hazard management, or city planning.

A Selection of Water Resource Decisions Related to Seasonal Climate Forecasts

Water resource decision/topic	Agency/organizations responsible	Activities affected	Climate forecast information needed
Dam and reservoir management and reservoir allocation	• U.S. Army Corps of Engineers • U.S. Dept. of Interior, Bureau of Reclamation • Tennessee Valley Authority • Federal Energy Regulatory Commission (FERC) and its licensed projects • Federal power marketing agencies • State, local, and regional water management entities and utilities, irrigation districts	Distribution of inflows and outflows for: • Agriculture • Public supply • Industry • Power • Flood control • Navigation • Instream flow maintenance • Protecting reserved waters for resources/other needs	• Total reservoir inflow • Long-range precipitation • Long-range temperature • Flow data • Snow melt data • Flood forecasts • Shifts in "phase" in decadal cycles
Public water supply/ wastewater management	• Municipalities • Special water districts • Private water utilities • Water supply/wastewater utilities/ utility districts	• Needs for new reservoirs, dams, wastewater treatment facilities, pumping stations, groundwater management areas, distribution systems • Needs for long term water supply and demand management plans • Drought planning	• Changes in temperature/ precipitation effect water demand; reduction in base-flows, increased demands, and greater evaporation rates • Predictive information at multiple scales and multiple time frames
Power production	• Federal water and power agencies; FERC; private utilities with licensed hydropower projects; private utilities using power from generation facilities	• Water for hydropower • Water for steam generation in fossil fuel and nuclear plants • Water for cooling	• Temperature (and relationships to demand for power) • Precipitation • Stream flow and runoff
Flooding/floodplain management	• Floodplain managers; flood zone agencies; insurance companies; risk managers, land use planners	• Infrastructure needs planning • Emergency management	• Short and long-term runoff predictions, especially long term trends in intensity of precipitation, storm surges

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All reports below can be found at http://www.climatescience.gov/sap/sap-summary.html, or http://www.gcrio.org/library/sap-final-reports.htm

[i]See CCSP report 4.5: Effects of Climate Change on Energy Production and Use in the United States.

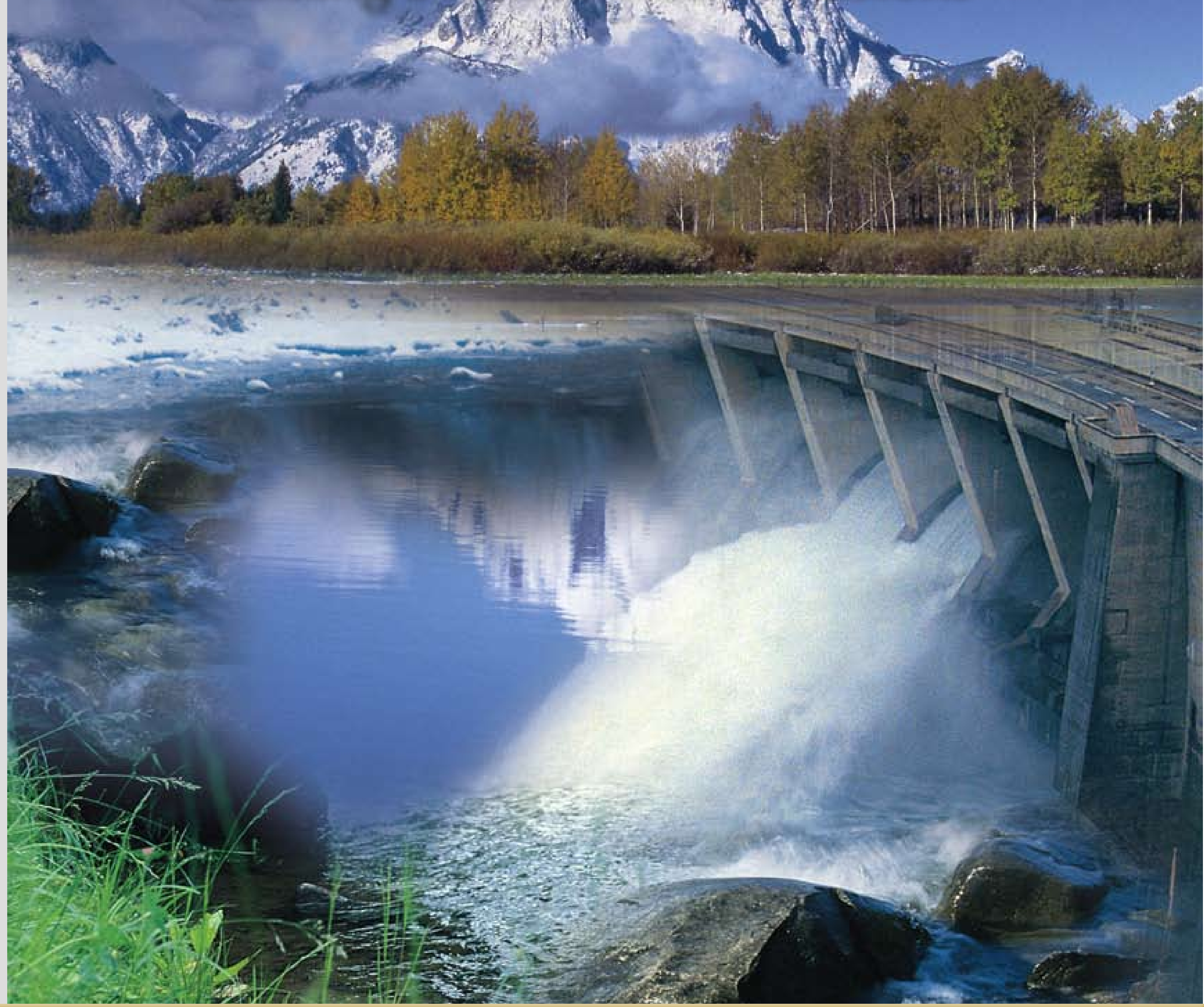
[ii]See CCSP report 4.3: The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States.

[iii]See CCSP report 4.6: Analyses of the effects of global change on human health and welfare and human systems

[iv]See CCSP report 4.7: Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study

[v]See CCSP report 3.3: Weather and Climate Extremes in a Changing Climate

Water Resources and Climate Prediction: Linking Science with Decisions



Findings and Summary of the U.S. Climate Change Science Program
Synthesis and Assessment Product 5.3
Decision-Support Experiments and Evaluations using Seasonal-to-Interannual Forecasts and Observational Data