MANAGING DROUGHT:
A ROADMAP FOR CHANGE IN THE UNITED STATES

A Conference Report from

Managing Drought and Water Scarcity in Vulnerable Environments

— Creating a Roadmap for Change in the United States

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NOTICE

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EXECUTIVE SUMMARY

Economic, environmental, and societal impacts of drought are severe and extremely costly. For 1988 alone, the Climate Prediction Center calculated that drought cost the US$39 billion (in 1988 dollars). Vulnerability to drought—a routinely occurring part of the natural hydrologic cycle—is increasing in all parts of the United States due to: population growth and population shifts, especially in the water-short western states and in the Southeast; land-use changes; global climate change; and increased water resource demands. The U.S. population has increased by about 50% since 1970 to more than 300 million, much of that occurring in water-scarce western regions. Land use changes due to development and other activities reduce water storage and degrade water quality. Global climate change directly and indirectly impacts the hydrologic cycle, reducing water availability and increasing vulnerability to drought in many regions of the United States. Increased demand comes from all sectors—agriculture, municipal uses, energy, ecosystem habitat maintenance, and recreation. Considered together, all of these factors call for development of collaborative, science-based, and risk-informed water resource assessments in pursuit of effective drought management and mitigation in the United States.

Background

The findings presented here are the product of a conference sponsored by the Geological Society of America (GSA) in cooperation with 20 other organizations. The conference report is available online at http://www.geosociety.org/meetings/06drought/roadmap.pdf. Conference attendees collaborated in identifying promising science and science policy solutions to managing and mitigating the impacts of drought. Physical scientists, life scientists, social scientists, Native Americans, policy-makers, water managers, water users, and students found that enhanced data and analyses are needed to improve: the fundamental understanding of the causes of droughts; the prediction of droughts; and drought mitigation and management. To be useful to decision-makers, drought analysis reports must be timely and at appropriate spatial scales. Including measures of confidence or uncertainty helps decision-makers to assess the credibility and usefulness of the information.

A few key observations about present-day drought and vulnerability to future drought in the United States:

- Multiple severe droughts since 1996 have had substantial economic, social, and environment impacts in many regions of the country. No part of the country is immune to the impact of drought. In the first half of 2007, vast areas of the nation are experiencing severe to exceptional drought. The extent of drought will likely increase as water demand increases in the summer months.
- Global climate change is expected to increase the frequency, intensity, and duration of droughts in the United States. Already, the mountain snowpacks upon which many water users depend disappear earlier, and reduced stream flow, lower reservoir levels, higher temperatures, and greater precipitation variability have been observed.
- Government is poorly prepared for drought. The drought management plans that do exist are often ineffective and tend to reinforce the status quo. Federal, state, local, and tribal

governments need to collaborate with water managers and water users in a shift from crisis-based, reactive drought management to risk-based, proactive drought management, with greater emphasis on drought monitoring and early warning, prediction, mitigation, and preparedness planning.

- Although the present-day accounting of availabe water resources is poor, in many areas it appears that the demand for water may be nearing the available supply—assuming average precipitation. Water in many river basins is fully or over-appropriated.

Science and Water Management Policy Recommendations

Participants in this national conference urge Congress and the administration, along with state, local, and tribal governments, to move forward immediately in implementing the ten recommendations identified below, thereby fostering a new paradigm for drought management.

1. Implement drought mitigation planning at the local, state, federal, and regional (hydrologic basin) levels, as called for in the Report of the National Drought Policy Commission in 2000. Drought policies that foster a high level of cooperation and coordination at all levels of government can lead to greater social and economic security for the United States.
2. Include in drought risk mitigation planning potential impacts from certain temperature rises due to global climate change.
3. Create a new "national water culture" that promotes sustainable water management practices to meet long-term societal needs. A broad educational initiative can foster partnership and collaboration among local, state, tribal, and federal governments, educational and research institutions, energy and industrial users, and the public. Increased public education may be the single most effective enabling element of long-term drought mitigation and water resources management.
4. Engage stakeholders within common hydrologic basins in development of water resource management plans and implementation of drought mitigation plans.
5. Foster place-based science with community stakeholder involvement as a part of public education and outreach. Place-based science can result in better understanding of local climate conditions and variability and can provide information at space and time scales relevant to resource decision-makers.
6. Maintain and enhance hydrologic and meteorologic data collection capabilities and existing data sets, and develop new data needed to improve assessments. Automate data collection to the maximum practical extent, and collect data at the frequency and scale needed to support model analyses and decision-making. Fully fund and implement the National Integrated Drought Information System (NIDIS) passed by Congress in 2006.
7. Encourage the use of risk-based approaches for assessment of multiple potential future climate and water management scenarios in support of decision-making.
8. Support research that improves fundamental scientific understanding of drought. Enhanced understanding through better data and improved representation of underlying physical, chemical, and biological processes will lead to more reliable and more useful drought

assessment and management tools.

9. Value water at its full worth in the development of water resource management and drought mitigation plans. That valuation must include recognition of water resource services in economic, environmental, recreational, and public health contexts.
10. Harmonize roles and responsibilities of cooperating institutions and reduce conflicts in applicable policies in order to yield more useful data, more efficient analyses, and more effective decision-making.

URGENT ACTION NEEDED ON DROUGHT

Drought is an extended shortfall of precipitation that results in water supplies insufficient to meet the needs of humans and the environment (Wilhite and Buchanan-Smith, 2005) and occurs routinely as part of the natural hydrologic cycle. Increased demand for finite water supplies has resulted from: population growth; migration of people from rural to urban settings and from more humid to more arid environments; changes in land use; and increased environmental awareness, among other factors. Increased competition arising from increased demand has created greater and more complex impacts than ever experienced in the past, increasing vulnerability to drought and exacerbating the impacts of drought in the United States.

A convergence of factors has created an urgent need for the Administration, Congress, federal agencies, and state, local, and tribal governments to take immediate action to improve drought and water resource management in the United States:

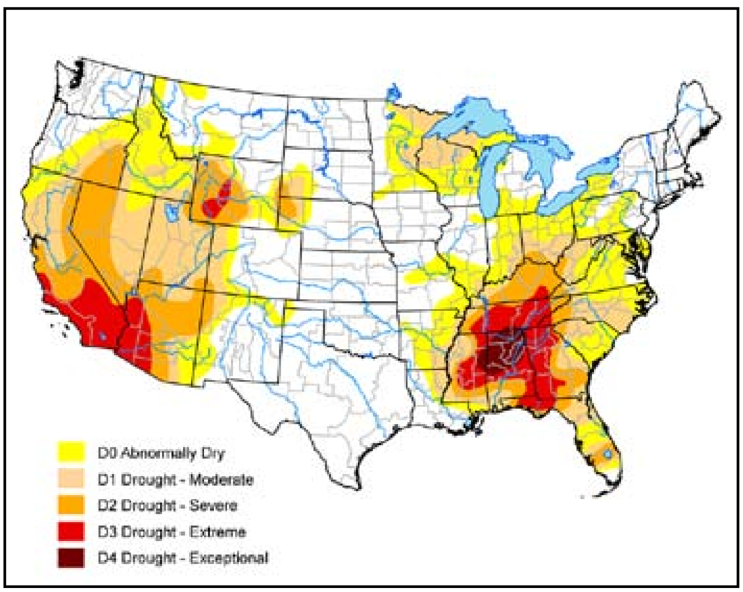
- Multiple severe droughts since 1996 have had substantial economic, social, and environment impacts in many regions of the country. No part of the country is immune to the impact of drought. In the summer of 2006, more than 50% of the nation was affected by severe drought. As of this writing in the summer of 2007, nearly 15% of the nation is experiencing severe to exceptional drought. The current area affected will very likely increase as water demand increases in the summer months.
- The population of the United States is growing, increasing by approximately 50% from 1970 to over 300 million in 2007, much of that growth occurring in water-scarce western regions.
- Although the present-day accounting of availabe water resources is poor, in many areas it appears that the demand for water may be nearing the available supply—assuming average precipitation. Water in many river basins is fully or over-appropriated.
- Land use changes accompanying urbanization—or suburbanization—often cause environmental degradation that diminishes the quantity and quality of available water. Highways, parking lots, and other paved surfaces increase storm water runoff, reduce surface-water and ground-water storage, and degrade water quality. Maintaining habitable ecosystems for wildlife creates additional water demands.
- Global climate change is expected to increase the frequency, intensity and duration of droughts in all parts of the United States. Already, reduced snowpacks disappear earlier in the spring and summer, and reduced stream flow, lower reservoir levels, higher temperatures, and greater precipitation variability have been observed (IPCC, 2007).
- Existing water laws are based on outmoded values and goals. For example, western water law, based on the doctrine of prior appropriation, successfully engendered population of a sparsely inhabited region. Existing laws should evolve in order to balance the needs of the public and the environment with private and agricultural uses while encouraging conservation.
- Government is poorly prepared for drought. The drought management plans that do exist

are often ineffective and tend to reinforce the status quo. Federal, state, local, and tribal governments need to collaborate with water managers and water users in a shift from crisis-based, reactive drought management to risk-based, proactive drought management, with greater emphasis on drought monitoring and early warning, prediction, mitigation, and preparedness planning.

Human survival depends on a safe and reliable water supply. In many situations, drought has prompted water managers to assess their preparedness for extended periods of dryness and to investigate regional cooperation in order to avoid conflicts (Wilhelmi et al., 2004). A collaborative, diverse water value dialog is extremely important to ensure societal readiness for drought-induced water shortages certain to occur in the future. *Managing Drought and Water Scarcity in Vulnerable Environments*, a participatory conference sponsored by the Geological Society of America and held in September 2006, provided a forum for scientists, policy-makers, natural resource managers, special interest groups, and other practitioners to develop a roadmap for change in drought management policy for the United States. The diversity of sponsoring organizations listed in Appendix A and participating organizations listed in Appendix B is testimony to the broad concern over this issue. Major findings and recommendations reported in this document can be used to help establish the basis for effective, science-based drought management policy for the United States.

IMPACTS OF RECENT DROUGHTS

At present, no comprehensive methods or databases exist that can be used to assess long-term losses resulting from drought (Kunkel et al., 1999; Hayes et al., 2004). Instead, on the basis of case studies, in 1995 the Federal Emergency Management Agency (FEMA) estimated that annual average drought cost to the United States ranges from US$6 to $8 billion (FEMA, 1995). According to estimates by the Texas Agriculture Extension Service, the 1996 Texas drought was estimated to cost producers there US$1.9 billion, reducing the overall state economy by about US$5 billion. For 1988 alone, the Climate Prediction Center calculated that drought cost the United States nearly US$39 billion (in 1988 dollars).



Drought in the conterminous United States, June 26, 2007. Courtesy of the National Drought Mitigation Center.

The National Drought Mitigation Center found that the 1995 FEMA estimate was based primarily on the agricultural sector, and was likely to have underestimated total losses associated with drought. A lack of consistent methodologies and operational definitions among states, sectors, and drought events exacerbates the difficulty of monitoring trends in drought losses and therefore of developing effective drought and water management strategies. Drought loss estimates are hampered by the lack of methods for valuation of non-agricultural losses, such as social and environmental impacts, and almost certainly underestimate the total costs of drought. Arguably, drought impacts to society and to the environment are of the highest intrinsic value, and yet the lack of meaningful metrics for these impacts impedes their accurate valuation in integrated drought impact, vulnerability, and risk assessments.

Current examples of non-agricultural losses from drought can be found in states as diverse as Minnesota and Florida. Three years of drought in Minnesota have left some Boundary Water lakes so low that boats cannot navigate them, leading vacationers to cancel their travel plans. Record low levels in Florida's Lake Okeechobee have left boat docks sitting on dry lake beds, creating a financial burden on resort operators there, and reducing the backup water supply for 5 million Floridians (O'Driscoll, 2007).

The impact of drought largely depends on societal vulnerability and adaptive capacity at the time and place where drought occurs. During the 2002 drought in the United States, the combined effect of decreased precipitation, evaporation losses, increased temperatures, and higher than average municipal and agricultural water demands resulted in a drought that not only affected Colorado's economy and environment but led to the conclusion by a prominent group of scientists that "Colorado society is now more vulnerable to … drought than in the past" (Pielke et al., 2005).

VULNERABILITY TO FUTURE DROUGHTS

Vulnerability to drought can be assessed for each watershed, river basin, or geographic region. For example, the vulnerability of the Colorado River Basin has been described in great detail (NRC, 2007a). With the fastest growing population in the United States, any reduction in water supply there is of great concern. Scientists have found troubling indications that the slow northward movement of the storm-bearing winter jet stream, which would reduce rainfall and snowpack in the basin, may have already begun. That observation is consistent with computer model predictions (Seager, 2007). In the Southwest, some scientists have suggested that the drought that started around the turn of the millennium should not be viewed as one of the occasional large droughts that have visited the region over the past 500 years (Woodhouse et al., 2006), but rather as a harbinger of things to come, a chronic situation and the "new norm."

Virtually all sectors of society, the economy, and the environment are vulnerable to impacts from drought, and in many areas, that vulnerability is increasing with time.

Agriculture

The agricultural sector may have the most significant vulnerability to drought impacts. Drought reduces crop yield, which can reduce revenue. Drought increases the potential for pest infestations and crop diseases, reducing the crop quality. Crops may fail completely. Even when drought has ended, weed infestation can leave fallowed lands less productive. Farmers may have to dig emergency wells or pay increased costs for irrigation. Drought reduces the quantity and quality of forage available on range lands and pastures, and consequently reduces livestock production. Banks and other dependent merchants in the farming community lose revenue as agricultural productivity falters.

Private, Municipal, and Industrial Water Supplies

Most people in the United States rely on managed water supply systems, which insulate users from the natural variability of precipitation. Population growth, especially in the arid southwestern United States, has increased the vulnerability to drought for municipal and industrial users. Droughts impact municipal and industrial supplies by reducing the water supply to a level that does not meet water demand, and by stimulating the search for and development of new sources of water to ensure reliability. Consumers on public water supply systems experience drought impacts when voluntary or mandatory restrictions are placed on water usage. People who rely on private ground-water wells may have to pay to have wells deepened or to drill new wells. Public water supply utilities lose revenue while having to cope with increased operating costs. Those increased operating costs associated with drought response are eventually passed on to consumers.

Power

The power sector in the United States is vulnerable to drought. For example, hydroelectric power is generated by river water flowing through turbines. As the flow of that water diminishes during drought, the hydropower sector can incur severe economic losses. Lower water flows reduce the amount of power generated and the revenues for the industry, increasing costs associated with purchasing replacement power, and increasing electricity rates for the customer. Fossil fuel and nuclear plants typically require large volumes of water to generate steam for turbines and to use as cooling water. When in-stream flow is lowered by drought, thermal discharge limits can potentially limit the operating capacity of some of these plants. Biofuels have substantial water requirements. For example, the United Nations Food and Agriculture Organization (FAO) estimated that growing[1] a crop of corn requires approximately 400,000 to 750,000 gallons

Prolonged shortages of flow in the Colorado River coupled with increased water demand lower water levels in the Lake Mead reservoir, which provides water to homes and industry, power generation, and recreation. Photo courtesy of National Park Service, Lake Mead Recreation Area.

[1]An acre of corn can yield approximately 325 gallons of ethanol (Patzek, 2004).

of water per acre, or about 16 inches to 30 inches of precipitation (Gleick, 1993). Additional process water requirements for making ethanol from corn are smaller but not negligible (Patzek, 2004).

Environmental Needs

Drought has a profound effect on the natural world, and native flora and fauna are vulnerable to drought. On land, plant life is controlled by soil water availability, which is a function of the temperature and precipitation. The effects of recent droughts are seen in forests where many trees have died, contributing to increased risk of wildfire. Aquatic systems are more affected by factors that influence hydrology, stream characteristics, and temperature. Reduced stream flow diminishes aquatic habitat and degrades water quality. Those changes reduce the habitability of the ecosystem for fish and increase the vulnerability of species populations up and down the food chain. Aquatic systems have been affected by reduced stream discharge, alteration of the natural flow patterns and decreased water quality (Naiman and Turner, 2000; Baron et al., 2002). Water to sustain habitat is vital to species survival, and valuation of environmental needs is a challenging element of drought mitigation planning.

The National Drought Policy Act of 1998 recognized the need to prepare for and lessen the severe impacts of drought on the American people and the environment (NDPCR, 2000). Witnesses to the National Drought Policy Commission (NDPC) noted that "environmental resources often receive inadequate attention during drought emergencies and in drought planning, not so much because of lack of concern but because of lack of expertise in this arena, lack of adequate financial resources, and sometimes lack of awareness." The NDPC then concluded that "it is doubly important that environmental resource issues be included in drought preparedness efforts." The NDPC therefore drew a conclusion dealing specifically with the need to balance environmental and human impacts: "Effective plans should consider the allocation of water to meet the need to protect the environment and to meet immediate human needs."

Recreation

Recreational activities are vulnerable to drought. Low stream flows in rivers result in decreased sport fishing opportunities, as well as fewer opportunities for kayakers, canoeists, rafters, and others. When reservoir levels decline, it is harder to launch boats and to make use of other lakeside amenities. Visits to lakes and reservoirs are sharply reduced, which substantially reduces tourism revenue for resorts and other related businesses. Sales of fishing and hunting permits can be significantly reduced. Reduced snowfall impacts ski resorts, reducing skier visits and driving up costs for making snow. During the 2005 drought in Washington, ski areas reported 1 million fewer skier visits, almost 70% less than the 10-year average. Drought impacts to recreation can have a significant impact on local and regional economies.

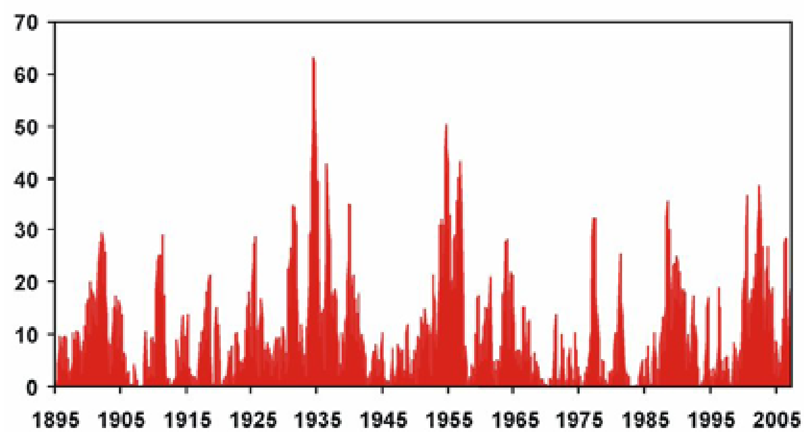
Indirect and Societal Effects

Local, regional, and, increasingly, national economies are vulnerable to drought impacts. Economic impacts of drought include decreased land value, reduced economic development, loss of revenue to federal, state and local governments, unemployment, and rural population loss.

Socially, drought negatively impacts human health—both physical and mental—increases conflicts among water users (especially those with differing water values), reduces the quality of life, and can ultimately result in changes in lifestyle. Droughts disrupt cultural belief systems, bring to the forefront the re-evaluation of social values, equity and human rights issues, and increase recognition of institutional constraints on water use. Although difficult to quantify, the social costs of drought can be extreme.

DROUGHT HAZARD AND PREDICTION OF FUTURE DROUGHTS

Drought hazard is the likelihood that an area will be affected by drought in the future. Virtually all parts of the United States are drought-prone, and drought occurs somewhere in the country each year. Since 1895, approximately 15% of the United States has been affected by drought in any given year. Droughts of the 1930s, 1950s, and 1999 to present were particularly severe and long, affecting vast areas. At its peak spatial extent in 1934, 65% of the contiguous United States was affected by severe to extreme drought conditions (National Drought Mitigation Center analysis of National Climate Data Center/NOAA data).



Percent of the U.S. in severe to extreme drought, 1895 to present. National Drought Mitigation Center analysis of National Climate Data Center/NOAA data.

Recent severe droughts in the United States—beginning in 1996 and affecting nearly all parts of the country—are indicative of the growing drought hazard. For many regions, drought has occurred for five or more consecutive years. Montana and surrounding states and portions of the Great Plains experienced severe drought for seven or more consecutive drought years. Arizona and New Mexico experienced five consecutive years of drought during this same period. In 2006, drought was particularly severe in the Great Plains region, extending from Texas and Oklahoma in the south to the Dakotas in the north. Parts of Nebraska have also experienced seven consecutive years of drought. At its peak spatial extent and severity in late July 2006, drought affected more than 50% of the United States. Drought is not just a southwestern issue. For example, Florida, Georgia, North Carolina, and South Carolina all experienced three to four consecutive years of drought between 1999 and 2002. Drought conditions have recurred in that region in 2007, affecting most of Alabama, Florida, Georgia, Mississippi, and Tennessee. Severe drought has also struck Minnesota and Wisconsin, areas many regard as water-rich.

Impact of Global Climate Change on Drought Hazard

Global climate change is now recognized as a major new factor that must be considered in assessing future drought hazard. Climate has changed many times over Earth's history, and climate will continue to change in the future. The current pace of global climate change, which is unprecedented in recorded human history, is likely to significantly influence future drought hazard. Because of the magnitude of global climate change, historical data may not be as useful an indicator in estimating future drought hazard as it has been traditionally viewed (e.g., NRC, 2007b; Redmond, 2007). Despite the complexity of the coupled and interacting phenomena, there exists broad scientific consensus that global climate change will affect temperature, precipitation, evaporation, transpiration of water by plants, surface-water flow, and ground-water recharge. In particular, there is high confidence that global climate change will lead to higher average temperatures nearly everywhere (e.g., Dettinger, 2005).

Higher temperatures tend to increase evaporation and vegetative demand for water (transpiration) and consequently are likely to reduce water available for stream flow and ground-water recharge. Estimates for the Colorado River Basin that consider the influence of temperature range from small to quite significant reductions of flow (Nash and Gleick, 1991; Gleick, 2000; Christensen et al., 2004; Christensen and Lettenmaier, 2006; Hoerling and Eischeid, 2006; Seager et al., 2007; Seager, 2007). Increased evaporation results in greater losses from surface-water bodies and reservoirs.

In the United States, annual average precipitation is expected to change less than 10%, with slight increases on the northern border and slight decreases on the southern border (Seager, 2007; Hamlet and Lettenmaier, 1999; Hayhoe et al., 2007). Local regions such as the Sierra Nevada and Rocky Mountains, however, may see more (and warmer) precipitation in winter and less in spring and early summer (Cayan et al., 2007). When the character of precipitation changes from slowly melting winter snowpacks or regular seasonal rains to short-duration, high-intensity storms, stream flows are more erratic, less ground-water recharge occurs, and the reliability of ground-water and surface-water reservoirs declines (see, for example, Trenberth et al., 2003).

Prospects for Predicting Drought

At present, scientists have limited ability to predict drought. Lead times of interest range from a week or two to a season or two for "operational" purposes. Drought likelihood on multi-year and decadal scales represents a different type of prediction. Water managers and operators of large reservoir systems are interested in multi-year and decadal predictions because they have sufficient storage capacity to allow them to make operational adjustments over that time period.

The most important droughts in any region are usually those that affect the main precipitation season(s). Causes vary: winter snowpack, summer convection, the Southwest monsoon, tropical storms, cool season cyclones, "the pineapple express" on the West Coast, spring instability showers, frontal passages, sea breezes, nor'easters, lake effect snow, and others. In regions where multiple causes produce multiple precipitation seasons, lengthy droughts are less likely.

Drought prediction can improve with intensive investigations of key processes that control or interact with climate. Better understanding in these areas may lead to more reliable, less uncertain drought predictions:

- More accurate predictions of soil moisture—based on predictions of precipitation, demand for water by vegetation, infiltration, and recharge—will be of great value in improving drought predictions. An integrated combination of models and measurements is needed, and higher spatial resolution will yield more reliable answers.
- Because the El Niño-Southern Oscillation (ENSO) changes the likelihood of precipitation in certain seasons and regions of the United States, improved understanding of ENSO can improve drought prediction.
- Because it is related to ENSO and other climate conditions, accurate predictions of ocean temperatures throughout its depth are integral to better drought prediction.
- Better model representation of the air-sea interaction in general is needed and is important to accurate depiction of phenomena that operate at time scales of 40–70 days (CPC; 2007a, 2007b). This behavior is not well captured in most models and is absent in many.
- In winter, the presence or absence of just a few major storms can significantly alter the total seasonal precipitation, especially in the southwestern United States. Better understanding of the "weather-climate connection" is widely thought to be important for weekly to monthly and seasonal forecasts.
- Improvements are needed in connecting global and regional climate models with basin-scale and watershed-scale hydrologic models. Efforts have been made to couple models in the Pacific Northwest, California, and the Colorado Basin, but more work is needed.

ESTIMATION OF DROUGHT RISK

Drought risk is the product of both drought hazard—the likelihood that a drought of a given intensity will occur in an area—and drought vulnerability—the impact on the farmers, ranchers, homeowners, wildlife, and others that would be affected. Risk-based analyses are the best available approach for planning for, managing, and mitigating drought. Risk-based analyses can consider a full range of potential drought scenarios and their likelihood and can help identify those scenarios that contribute the most to the risks. Risk-based approaches incorporate both scientific knowledge and uncertainty, and can provide water managers with a rigorous quantitative framework to evaluate costs and benefits of different resource allocation and risk mitigation approaches.

Typically, risk analyses are based on computer models. The risk models serve as an organizing structure, explicitly containing the assumptions, the empirical data, and the scenarios that have been developed. When used effectively, the input and results of risk-based computer models can be highly valuable as tools for communication with broad and diverse audiences.

Predictions of drought risk are only as reliable as the understanding that supports the prediction. Major scientific challenges remain before a full assessment of drought risk can be realized. For example, the effect of drought on the integrity of ecosystems is not well understood. Is there a threshold beyond which the ecosystems will fail and fragment? What effect does drought have on the water chemistry in these ecosystems, and how do the creatures inhabiting the ecosystems respond? Although few drought plans address water quality issues at present, answers to these questions will help to determine the value and demonstrate the need for doing so.

Timely and Continuous Data Are Needed for Reliable Assessment and Prediction of Drought

Data are the empirical basis both for understanding of present drought conditions and for prediction of future drought risk.

- Longer records are almost always more valuable than shorter records. In the United States, the longest records are those from the National Weather Service (NWS) cooperative network (NRC; 1998, 1999) and from the stream gage records of the U.S. Geological Survey (NRC, 2004).
- Data must be collected in a consistent and well-documented manner so as to minimize uncertainty arising from methodological artifacts and to reduce the ambiguity of interpreting observed changes and variability.
- The spatial density of observations must be high enough to capture the spatial variability of the measured parameter, especially when that parameter varies rapidly over small distances, for example in mountainous terrain (CIRMOUNT, 2006).
- Beyond precipitation and temperature, it is desirable to measure quantities that are relevant to assessment of the impacts of drought, such as soil moisture.
- Information must become available in a timely manner. Drought should never arrive as a surprise. Phone (IV-ROCS) and Web (WeatherCoder) entry of manual NWS observations are examples of how data can be quickly acquired and made available. Many U.S. Geological Survey stream gages produce online reports in near real-time.
- To the extent possible, data collection should be automated and not require human intervention.
- High-resolution data collected over short time periods over large areas by satellite can potentially be of great value in change detection and drought risk assessment. Satellite data must be validated by ground measurements.

ENHANCING RELIABILITY AND USABILITY OF DROUGHT INFORMATION

Resource managers at multiple scales, including local, regional, and federal, consistently indicate that the types of climate information that are available to them are not tailored properly for decision-making. Although in many cases the issue is that the resource managers are unaware of tools that have been developed to assist them, in many other cases the managers are familiar with the available tools and yet have not been able to use information that has been produced.

They are frequently frustrated by information presented in the form of statistical likelihood and uncertainty, although they routinely make judgments based on incomplete or uncertain information. Even those comfortable with statistics find that drought-related climate information is of limited value for their specific decisions, because that information is not developed at a scale that is consistent with their operations and needs. Scale issues continue to plague applications based on global climate models.

In a series of workshops, conferences, and forums, managers have indicated that they would like:

Longer Lead Times and More Certainty in Climate and Drought Predictions. The timing of when information is available versus when decisions are made on an annual basis is also critical. For example, knowledge that a drought is expected in the next water year is most valuable to farmers in the early fall, before they make financial commitments regarding the next year's crops. In surface-water–dominated systems in the West, however, there is very little certainty regarding runoff volumes until January, and the highest level of certainty is in April and May, when the snowpack volume is well known (Gleick, 2000).

Information at an Appropriate Scale. The time- and space-scales of information need to match the scale of specific decisions. This requires enhancements in scientific data and analyses at regional and watershed scales where land and water managers, hydropower generators, farmers, and recreation facility operators make decisions.

Consistent Long-Term Data and Environmental Monitoring. Hydrologic monitoring and documentation of drought impacts would have immediate payoff. Hydrologic conditions, soil moisture, snowpack and other basic observations increase our adaptive capacity. Such information increases understanding and is critical in evaluating climate trends and in refining model predictions so that they can become more reliable and less uncertain. In order to evaluate the impact of drought on species dependent on aquatic ecosystems, physical hydrologic data observations must be complemented by biological and chemical water quality data. Recent funding reductions have resulted in ending the monitoring of some U.S. Geological Survey stream gages that have produced data for decades. These data are invaluable, and it is imperative that the United States stream-gaging network be enhanced, not diminished.

Sector-Specific, Interdisciplinary Decision-Support Tools. Scientific advances in understanding the nature and timing of decisions are also important, and this requires sector-specific, focused interdisciplinary evaluations of the types of decisions that are made, the information that is needed to make those decisions, and the tools that can best support the decision-makers. For example, reservoir managers need to optimize their decisions, but many are constrained by operational criteria that do not take into account full knowledge of climate variability and multi-objective reservoir management decision support options, including economic evaluations of alternative outcomes.

Climate Information Linked to Simultaneous Management of Multiple Water Supplies. Drought preparedness requires scientific information that can support innovative approaches to managing water supplies. Tools which allow managers to use improved climate information to conjunctively manage multiple water supplies, such as ground-water, surface-water and municipal effluent, are not well developed. Optimizing water supply and demand management across regions can have significant benefits, since climate effects are not always synchronous across large areas. Further investigation of how to tailor demand-side strategies to respond to drought while supporting long-term water management objectives is also needed.

Make Information Relevant for Managers

The challenge of communicating already-uncertain climate information is compounded by climate change. The main messages that managers are given today are (1) it is definitely getting warmer (virtually all climate models agree on this), and (2) though we expect that the hydrologic cycle will be enhanced due to more energy in the atmosphere, we really don't know how precipitation patterns will be affected. Given only this information, managers are liable to respond with, "I need more information before I will invest in adaptation activities—I don't know how to respond to this much uncertainty."

If, however, the same information is reframed in terms of combining the effect of temperature on demand (which increases human demands for water for human, agricultural and the environment, among other sectors) with impacts on supply (increased evaporation from reservoirs, increased consumption by plants, decreased snowpack, etc.), and managers are told that if it does rain more in a warmer climate, it is likely to rain harder rather than more often, the message to managers becomes, "though we don't know much about whether total precipitation will increase or decrease, the implications of global warming for water management likely are a reduction in average supply availability and an increase in extreme events, including both droughts and floods." This is a message that managers can respond to because it is framed in terms of risk to their systems.

There is a significant need for "integrated and adaptive decision support systems able to explicitly account for system uncertainty" (NRC, 2005). Such systems incorporate institutional, political, and economic considerations into translating physical science findings into relevant information for specific types of decisions within specific sectors. It is important to invest in integrating prediction with institutional decision processes to provide true decision support.

Understand Context

Communication of scientific and risk-based information requires that the users perceive the information to be salient (answering the right questions), credible (coming from a trusted source), and legitimate (accurate) (Cash et al., 2003). Further, the information needs to be provided in ways that are accessible to decision makers through information channels that they find usable. A way to significantly enhance communication to decision-makers is to train integrators to assist in providing information to specific regions and sectors. Examples of such efforts can be found in each of the National Oceanic and Atmospheric Administration (NOAA) Regional Integrated Science Assessments (RISA), which focus on enhancing the use of climate predictions in specific decision contexts (http://www.climate.noaa.gov/cpo_pa/risa/).

Encourage Managers to Assess Reliability of Regional Predictions

There are multiple ways of assessing the quality of climate predictions. One of the ways to measure confidence or reliability is to use skill scores. For example, the NOAA Climate Prediction

Center produces monthly forecasts of climate conditions that focus on whether conditions will be wetter or drier, warmer or colder than the average condition in the past 30 years. It is possible to measure the accuracy of these predictions using skill scores. (In many cases, it has been found that these predictions have very little skill.) By being familiar with the skill scores, it is possible to know where in the country and in which seasons the predictions are most likely to be accurate (Hartmann et al., 2002).

Through continuous assessment of prediction-decision processes, it is possible to engage in adaptive management and, through iterative feedback, to continually improve the information that is being produced and the ways that it is communicated. This approach requires proactive monitoring and real-time incorporation of lessons learned.

PUBLIC POLICY RESPONSES TO DROUGHT— PAST PRACTICES AND FUTURE OPPORTUNITIES

From a scientific perspective, drought planning is most soundly implemented at the scale of watersheds and hydrologic basins. Because watersheds and hydrologic basins often span multiple geopolitical jurisdictions—including international boundaries—drought planning can and should occur at local, state, federal, and tribal levels. Drought planning consists of monitoring (recognizing) drought, understanding vulnerability, and identifying measures to reduce the impacts of drought. The National Drought Mitigation Center advocates "mitigation," that is, implementing measures to reduce vulnerability before drought occurs. This is most likely to be effective when drought planning is incorporated into other resource and hazard planning processes, into land- and water-use planning, and into agricultural policy. Perhaps the biggest challenge facing policy-makers at all levels is balancing short-term revenue generation with long-term sustainability of cities, land, and ecosystems, some of which may be approaching their maximum carrying capacity.

Current drought policy is an ad hoc patchwork across multiple federal agencies and programs, occasionally embodying conflicting objectives. It is desirable to develop a policy framework that supports and coordinates drought planning at federal, state, local, and tribal levels, while recognizing and providing for conflicting values and goals.

Land-use decisions have a direct impact on drought vulnerability and are typically made at the municipal and or county levels. Federal and state governments are usually reluctant to engage in that decision-making, and their involvement does not guarantee optimal outcomes for drought mitigation. On the other hand, because the public is engaged at the level where decisions are made, widespread and sustained public education has the potential to be very effective in reducing vulnerability to drought.

Agricultural policy has traditionally relied on crisis management rather than risk management, mostly in the form of emergency bailouts. The crisis-management approach to drought is costly and has been demonstrated to be largely ineffective because the response is untimely, poorly coordinated, and poorly targeted. Drought assistance or relief reinforces resource management methods that often increase vulnerability to drought and worsen the impacts of drought. Crisis management decreases self-reliance and increases dependence on government and donors. Policy-makers and agricultural producers are seeking ways to shift to a risk-management approach, but this will require considerable political will.

Resilience to drought can be enhanced through improved drought monitoring, including the creation of an integrated early warning system, improved mitigation measures, and preparedness plans that incorporate an organizational structure or framework for improved coordination between government agencies. Some of those goals will be addressed by NIDIS, the National Integrated Drought Information System (WGA, 2004). Managed by NOAA, NIDIS seeks to create an integrated information resource for drought and water supply monitoring, drought impacts, drought education, and drought planning tools.

Past Policy Calls for Action

There have been numerous "calls for action" for the development of drought mitigation plans and a national drought policy for the United States. These calls for action have come from prestigious organizations such as the Western Governors' Association (WGA), General Accounting Office, National Academy of Sciences, Great Lakes Commission, American Meteorological Society, and the Interstate Council on Water Policy. In its report to Congress, the National Drought Policy Commission (NDPC) concluded "we can reduce this nation's vulnerability to the impacts of drought by making preparedness the cornerstone of a national drought policy." (NDPC, 2000) Among the goals issued by the NDPC were to:

- Incorporate planning and the implementation of plans and proactive mitigation measures, risk management, resource stewardship, environmental considerations, and public education as key elements of effective national drought policy;
- Improve collaboration among scientists and managers to enhance the effectiveness of observation networks, monitoring, prediction, information delivery, and applied research and to foster public understanding of and preparedness for drought;
- Develop and incorporate comprehensive insurance and financial strategies into drought preparedness plans;
- Maintain a safety net of emergency relief that emphasizes sound stewardship of natural resources and self-help; and
- Coordinate drought programs and response effectively, efficiently, and in a customer-oriented manner.

Additionally, the NDPC recommended that Congress "pass a national drought preparedness act that would establish a nonfederal/federal partnership through a National Drought Council." The National Drought Preparedness Act was introduced but not passed in 2001, 2003, and 2005, despite the support of many national and professional organizations.

The WGA has consistently advocated for resources to be devoted to sustainable water policy. In 2006, the WGA issued "Water Needs and Strategies for a Sustainable Future" (http://www.westgov.org/wga/publicat/Water06.pdf) which contains a detailed set of recommendations focused on water policy and growth, state needs and strategies to meet future demands, water infrastructure needs, Native American water rights, the impacts of climate change, and protection of endangered species. The discussion and recommendations contained herein are largely consistent with those of the WGA.

Building a "National Water Culture" by Engaging the Public

The American Meteorological Society has recognized that drought is more than simply a hydrologic phenomenon; rather, the droughts that afflict developed societies arise from a complex interaction of natural physical phenomena and human behaviors and decisions (AMS, 2004). In other words, it is more than a scientific or water management issue; it is a function of human demands in the face of natural scarcity. There are limits to what management and science can achieve in the face of natural scarcity (drought) without the cooperation of those affected by the management choices. What is needed is a public that is engaged through participatory and place-based community efforts and informed through educational efforts. Public participation and partnership in the management of scarce resources is the necessary mechanism for securing societal permission to act. Sustainable choices are not possible without the support of an aware public that understands both the choices and the consequences of a failure to act. Public awareness that drought is natural and normal can be achieved through collective understanding of the interconnectedness of natural and human systems and through an appreciation that, individually and collectively, members of the public have common needs and shared responsibility for creating a habitable future—thus the need for developing a "national water culture." A further advantage of a national water culture is public support for long-term planning during non-emergency times.

Valuing Water

Because of the difficulty in assigning value to vital noncommercial uses, water is not easily or accurately valued in a market. The value of public goods associated with water resources—such as providing habitat for fish and wildlife and recreational uses—is subjective (e.g., Wilson and Carpenter, 1999). The value of water is highly specific to multiple factors including: the type and level of use; the user; the location of use; the timing of use; and the quality of the water (e.g., Raucher et al., 2005). Consequently, market valuations of water are generally unrepresentative of the total value of water to society.

FINDINGS AND RECOMMENDATIONS

The economic, environmental, and societal impacts of drought can be severe and extremely costly. Vulnerability to drought—a routinely occurring part of the natural hydrologic cycle—is increasing in all parts of the United States, not just in the western United States. Enhanced data and analyses can yield needed improvements in fundamental understanding of the causes of droughts, prediction of droughts, and drought mitigation and management. Global climate change will result in temperature increases that directly and indirectly impact the hydrologic cycle and will almost certainly lead to reduced water availability and increased vulnerability to drought in regions of the United States. As such, potential impacts of global climate change must be included in drought analyses. For the purpose of analysis, the hydrologic basin is a natural unit of water resources assessment and drought management, even though hydrologic basins routinely span multiple geopolitical jurisdictions. To be useful to decision-makers, water resource analyses must be timely and be reported at appropriate spatial and temporal scales. Including measures of confidence or uncertainty will help decision-makers to assess the credibility and utility of the information. Considered together, all of these factors call for development of collaborative, science-based, and risk-informed water resource assessments in pursuit of more effective water resources management in the United States.

Science and Water Management Policy Recommendations

Despite repeated calls for action to move the nation towards a more proactive, risk-based management approach for drought, little progress has been made. Participants in this national conference urge Congress and the administration, along with state, local, and tribal governments, to move forward immediately in implementing the ten recommendations identified below, thereby fostering a new paradigm for drought management.

1. Implement drought mitigation planning at the local, state, federal, and regional (hydrologic basin) levels, as called for in the Report of the National Drought Policy Commission in 2000. Drought policies that foster a high level of cooperation and coordination at all levels of government can lead to greater social and economic security for the United States.
2. Include in drought risk mitigation planning potential impacts from certain temperature rises due to global climate change.
3. Create a new "national water culture" that promotes sustainable water management practices to meet long-term societal needs. A broad educational initiative can foster partnership and collaboration among local, state, federal, and tribal governments, educational and research institutions, energy and industrial users, and the public. Increased public education may be the single most effective enabling element of long-term drought mitigation and water resources management.
4. Engage stakeholders within common hydrologic basins in development of water resource management plans and implementation of drought mitigation plans.
5. Foster place-based science with community stakeholder involvement as a part of public education and outreach. Place-based science can result in better understanding of local climate conditions and variability and can provide information at space and time scales relevant to resource decision-makers.
6. Maintain and enhance hydrologic and meteorologic data collection capabilities and existing data sets, and develop new data needed to improve assessments. Automate data collection to the maximum practical extent, and collect data at the frequency and scale needed to support model analyses and decision-making. Fully fund and implement the National Integrated Drought Information System (NIDIS) passed by Congress in 2006.
7. Encourage the use of risk-based approaches for assessment of multiple potential future climate and water management scenarios in support of decision-making.
8. Support research that improves fundamental scientific understanding of drought. Enhanced

understanding through better data and improved representation of underlying physical, chemical, and biological processes will lead to more reliable and more useful drought assessment and management tools.

9. Value water at its full worth in the development of water resource management and drought mitigation plans. That valuation must include recognition of water resource services in economic, environmental, recreational, and public health contexts.
10. Harmonize roles and responsibilities of cooperating institutions and reduce conflicts in applicable policies in order to yield more useful data, more efficient analyses, and more effective decision-making.

Summary

Drought can impose massive and severe costs to society. For example, U.N. Secretary General Ban Ki Moon identified climate change-induced drought in Darfur, Sudan, as the major contributing factor leading to the prolonged and tragic civil war in that country (Moon, 2007). In the developed world, the direct costs of drought are most often economic and environmental, but any accounting for drought impact must also consider the related indirect costs of social malaise and deterioration. At present, the second largest city in the United States—Los Angeles, California—is having the driest year in 130 years of record-keeping (Antczak, 2007). In the past 12 months, Los Angeles has only received 3.21 inches of rain out of 15.1 inches that would be expected in an average year, and the conditions that led to that dearth of rainfall have not shown any signs of abating. Some scientists have postulated that the present shortage of precipitation in the U.S. Southwest—which began over a decade ago—may be the new norm for that region. But as has been shown, drought occurs nationwide, not just in the Southwest, and so the majority of the United States is at risk of impact from future droughts. The recommendations contained in this report can substantially improve the management and mitigation of drought in the United States, and consequently lower the impacts and risks of future droughts. Failing to implement these measures will ensure substantial economic and environmental hardship for future generations of Americans.

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APPENDIX A.
DROUGHT CONFERENCE SUPPORTING ORGANIZATIONS

Geological Society of America

American Meteorological Society

American Water Resources Association

American Water Works Association

Colorado State University

Denver Museum of Nature and Science

Desert Research Institute

Ecological Society of America

Groundwater Foundation

National Center for Atmospheric Research

National Drought Mitigation Center

National Ground Water Association

National Oceanic and Atmospheric Administration
(National Climatic Data Center)

National Water Research Institute

National Institutes for Water Resources

Natural Hazards Center (University of Colorado—Boulder)

Society for Range Management

Soil Science Society of America

U.S. Army Corps of Engineers

U.S. Geological Survey—Water Resources Division

Western Rural Development Center

Western Water Assessment

APPENDIX B.
DROUGHT CONFERENCE PARTICIPATING ORGANIZATIONS

Acoma Pueblo, New Mexico

Agriculture & Agrifood, Winnipeg, Canada

Alberta Geological Survey

Anheuser-Busch, Inc.

Aquacraft, Inc., Boulder, Colorado

Arizona Department of Water Resources

Arizona State University, Department of Agronomy and Soils

Arizona State University, Department of Geology and Geography

Arizona Water Institute

Army Corps of Engineers

Auburn University

Australian National University, Department of Political Science

Barton Springs-Edwards Aquifer Conservation District

Bishop-Brogden Associates, Inc.

Blasland, Bouck & Lee, Inc.

Brown and Caldwell

California State University-Fullerton

City of Aurora, Colorado

City of Thornton, Colorado

Colorado Geological Survey

Colorado State University

Czech Republic

Denver Museum of Natural Science, Colorado

Denver Water Planning

Desert Research Institute

Eldorado Irrigation District, California

ENSR

Environment Canada

European Commission, Directorate Environment

APPENDIX B, Cont'd.
DROUGHT CONFERENCE
PARTICIPATING ORGANIZATIONS

Finland

GEI Consultants Inc.

Geological Society of America

Geological Society of America Foundation

Geological Survey of Alabama

HDR Engineering, Inc.

Illinois State Water Survey

Isleta Pueblo, New Mexico

Kansas Dept. Agriculture

Kansas State University

Lawrence Livermore National Laboratory

Malcolm Pirnie, Inc.

Mendel University Agriculture & Forestry

Minot State University, Department of Geosciences

Missouri Department of Natural Resources

Monsanto Co.

National Center for Atmospheric Research

National Drought Mitigation Center

National Water Research Institute

New Mexico State University

Northern Arizona University

Office of Senator Pete Domenici, New Mexico

Office of the State Engineer, Albuquerque, New Mexico

Oregon State University, Institute for Water & Watersheds

Pyramid Lake Paiute Tribe

Rutgers University

S.S. Papadopulos & Associates

SAIC

SAIC, Center for EROS

APPENDIX B, Cont'd.
DROUGHT CONFERENCE PARTICIPATING ORGANIZATIONS

Saskatchewan Research Council

Science Communications Studies State of Utah

Stratus Consulting

SUNY-Oneonta, Department of Earth Sciences

Texas A&M University, Department of Soil and Crop Science

TSC Group, Inc., Arvada, Colorado

U.S. Army Corps of Engineers

U.S. Bureau of Land Management — National Science & Technology Center

U.S. Bureau of Reclamation

U.S. Department of Agriculture, ARS

U.S. Department of Agriculture, Forest Service

U.S. Department of Agriculture, NRCS

U.S. Environmental Protection Agency, Climate Change Division

U.S. Fish and Wildlife Service

U.S. Geological Survey, Albuquerque, New Mexico

U.S. Geological Survey, Boulder, Colorado

U.S. Geological Survey, Denver, Colorado

U.S. Geological Survey, Klamath Falls, Oregon

U.S. Geological Survey, Reston, Virginia

U.S. Geological Survey, Sioux Falls, South Dakota

U.S. Government Accounting Office

U.S. National Aeronautics and Space Administration, Jet Propulsion Laboratory

U.S. National Oceanic & Atmospheric Administration, Climate Program Office

U.S. National Oceanic & Atmospheric Administration, ESRL

U.S. National Oceanic & Atmospheric Administration, National Climatic Data Center

U.S. National Oceanic & Atmospheric Administration, National Weather Service

APPENDIX B, Cont'd.
DROUGHT CONFERENCE PARTICIPATING ORGANIZATIONS

U.S. Nuclear Waste Technical Review Board University Corporation for Atmospheric Research, Boulder, Colorado

University of Arizona, ISPE

University of Colorado–Boulder

University of Colorado–Colorado Springs

University of Colorado, INSTAAR

University of Illinois

University of Illinois-Chicago, Department of Earth and Environment

University of Nebraska Water Center

University of Nebraska, National Drought Mitigation Center

University of Nebraska–Lincoln, School of Natural Resources

University of Nevada–Las Vegas, Harry Reid Center Environment

University of Oklahoma, Center for Spatial Analysis

University of Oklahoma, School of Geology and Geophysics

University of Saskatchewan, Department of Plant Sciences

University of South Carolina, Department of Geography

University of Texas–Dallas, Geosciences

University of Vermont

University of Washington

University of Wyoming, Department of Botany

Upper Colorado River Commission

Utah State University, Department of Geology

West Brandywine Environmental, Hydrogeology

Western Governors' Association

Western Kentucky University, Department of Geography and Geology

White House Office of Science and Technology Policy

York College of CUNY, Department of Natural Sciences