An Assessment of Decadal Drought Information Needs of Stakeholders and Policymakers in the Missouri River Basin for Decision Support

Part III: Urban Water Security in the Missouri River Basin

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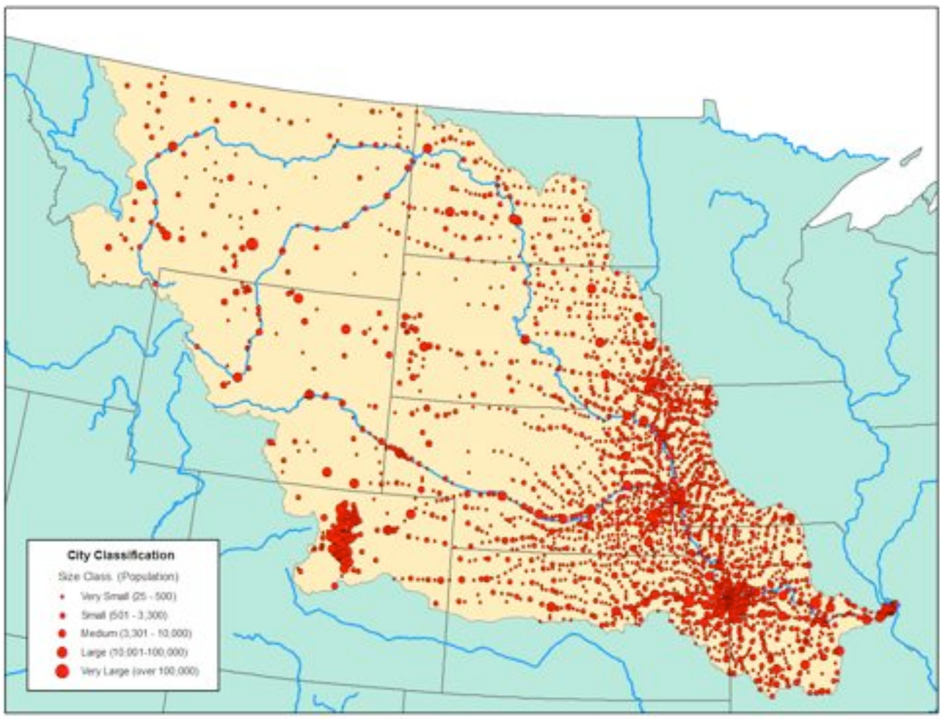

Classification of Urban Areas in the Missouri River Basin

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The Center for Research on the Changing Earth System CRCES

National Drought Mitigation Center

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Summary

The Missouri River Basin (the Basin hereafter) is the largest river basin in the United States. The Basin produces approximately 46% of wheat, 22% of grain corn, and 34% of cattle in the U. S.; and is thus a major "bread basket" not only of the U.S., but also of the world. Moreover, the Basin is home to over 2000 urban communities of various sizes. Three decadal climate variability (DCV) phenomena -- the Pacific Decadal Oscillation, the tropical Atlantic sea-surface temperature (SST) gradient oscillation, and the west Pacific Warm Pool SST variability -- significantly impact the hydro-meteorology of the Basin. Hydro-meteorological records available from 1950 to 2000 show that decadal droughts and wet spells in the Basin are correlated with various combinations of these three DCV phenomena in both their positive and negative phases.

The investigators have undertaken a project entitled "*An Assessment of Decadal Drought Information Needs of Stakeholders and Policymakers in the Missouri River Basin for Decision Support.* " This project was funded by the NOAA-Climate Program Office-Sectoral Applications Research Program (now the Climate and Societal Interactions – Water program). The objectives of the project were to (1) conduct workshops involving stakeholders in the Basin to assess their decadal drought information needs; (2) develop retrospective drought and wet spell scenarios using statistical modeling of DCV indices and their associations with hydro-meteorological variables in the Basin; and (3) develop sectoral impact evaluations through use of the Hydrologic Unit Model of the United States (HUMUS) and the Erosion Productivity Impact Calculator model (EPIC) driven by the retrospective scenarios.

The first workshop in this project, focused on DCV effects on water and agriculture in Missouri, Iowa, Nebraska, and Kansas, and was held in Kansas City, Missouri on April 27-28, 2009; twenty five stakeholders and policy-makers attended. Forty stakeholders and policy-makers participated in the second workshop, focusing on DCV impacts on water in the northern Missouri River Basin, held in Helena, Montana on June 24-25, 2009. The third and final workshop, focusing on DCV impacts on urban water security, was held in Lincoln, Nebraska on November 16-17, 2010 and was attended by twenty two urban water managers from federal, state, and local governments; universities; and private sector organizations. The purpose of the final workshop was threefold: (1) to demonstrate that decadal scale climatic events including major droughts and wet spells have major effects in the Basin; (2) to gather information about the effects of droughts in the 1980s and the most recent drought period during the 2000s decade; as well as the prolonged wet spell of the 1990s on urban water security in the Basin; and (3) to explore the potential for developing future decadal climate outlooks and potential management options that would be useful in preparing for and coping with droughts and wet spells to ensure urban water security.

This report describes major conclusions and recommendations stemming from the third workshop.

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1. Introduction

The Missouri River Basin (the Basin hereafter) covers more than 500,000 square miles and a part or all of 10 states (Montana, Wyoming, Colorado, North Dakota, South Dakota, Minnesota, Iowa, Nebraska, Kansas, and Missouri), numerous Native American reservations, and parts of the Canadian provinces of Alberta and Saskatchewan. People living in the Basin depend on the Missouri River for drinking water, irrigation and industrial needs, hydro-electricity, recreation, navigation, and fish and wildlife habitat. The Basin contains some of the country's most sparsely populated agrarian counties, and a number of large metropolitan areas such as Omaha and Kansas City on the Missouri River and Denver on the South Platte River, a tributary of the Missouri River at the foothills of the Rocky Mountains. As shown in the figure on the cover of this report, there are approximately 2000 urban communities of various sizes in the Basin. Grain crops for food and feed contribute a large portion of the Basin's agricultural income. About 117 million acres are in cropland in the U.S. portion of the Basin. Of that total, about 12 million acres are irrigated. The Basin produces approximately 46% of wheat, 22% of grain corn, and 34% of cattle in the U.S. Thus, it is a major "bread basket" not only for the U.S. but also for the world. Of the 18 Major Water Resource Regions (MWRRs) of the U.S., shown in Figure 1, freshwater withdrawals for irrigation are greatest in California, the Pacific Northwest and the Missouri Basin.

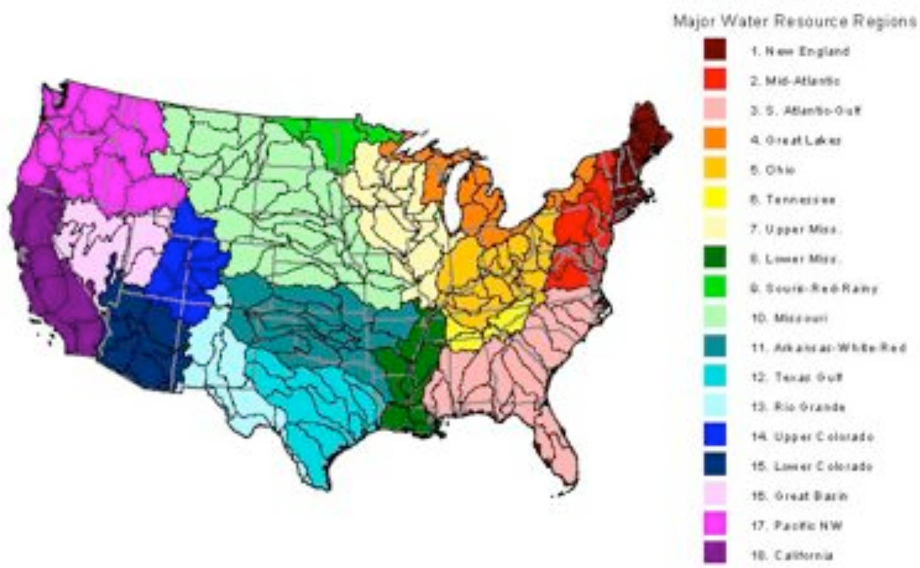

Figure 1: The 18 MWRRs of the Conterminous USA showing, as well, the ("4-digit") Hydrologic Unit Areas as Defined by the US Geological Survey.

The vulnerability of the Basin changes, of course, with precipitation variability forced by large-scale climate variability, especially at interannual and decadal timescales. These explain 60-70% of the total variance of annual-average precipitation. For example, during a major multiyear-to-decadal (hereafter referred to as decadal) drought, such as those in the late 1980s and from 2000-01 to 2008, inflows in the Basin were insufficient to fully support reservoir-based recreation and Missouri River navigation. Conversely, too much water in the Basin reservoir system during above-average precipitation years of the 1990s resulted in greater than normal water releases from the reservoirs, which threatened farms and homes in the Basin's floodplains. Decadal-scale droughts in the Basin deplete supplies of water stored in reservoirs, creating tensions over competing water uses between upstream and downstream states.

In a project titled "*An Assessment of Decadal Drought Information Needs of Stakeholders and Policymakers in the Missouri River Basin for Decision Support*", funded by the NOAA-Climate Program Office-Sectoral Applications Research Program (SARP; now the Climate and Societal Interactions -

Water Program), the investigators conducted workshops involving stakeholders and policymakers in the Basin. Retrospective decadal drought and wet spell scenarios were developed using statistical modeling of three major DCV indices (the Pacific Decadal Oscillation, PDO; the tropical Atlantic sea-surface temperature gradient, TAG; and the west Pacific Warm Pool, WPWP) and their associations with hydro-meteorological variables in the Basin. Sectoral impact evaluations were developed through the use of the Hydrologic Unit Model of the United States (HUMUS) and the Erosion Productivity Impact Calculator (EPIC) driven by the retrospective scenarios. Retrospective scenarios of hydro-meteorological variables, crop yields, and water flows were compared with records of actual hydro-meteorological variables, crop yields, and streamflow; and observations and model results were a part of the DCV-related drought information provided to users in the three workshops convened. The third and final workshop in this project was held in Lincoln, Nebraska on November 16-17, 2010 and its design, proceedings and findings are reported here. Further details of this project and a predecessor SARP-funded project are given in Appendix 1.

The objectives of the third workshop were threefold: (1) to show that climatic events on the decadal scale -- including major droughts and wet spells -- have major effects in the MRB; (2) to gather information about the effects of multiyear to decadal droughts and wet spells on urban water security in the MRB (e.g., droughts in the 1980s and the first decade of the 21st century, and the wet spell of the 1990s); and (3) to explore the potential for developing future decadal climate outlooks and potential management options that would be useful in preparing for and coping with droughts and wet spells to aid in ensuring urban water security.

Twenty two stakeholders representing federal, state, and local governments; universities; and private sector organizations in the Basin participated in the workshop. Workshop participants and their affiliations are listed in Appendix 2.

2. Stakeholder Interaction Techniques

The project team used a variety of techniques to engage the stakeholders. Initial information about the project was provided via a quarterly newsletter -- *The Missouri Basin Climateer*. A web site (www.DecVar.org/MRB_project/MRB_project.html) was also created to provide information to workshop participants and others (the site will be maintained after project completion). A few days prior to the event, a preliminary description of the workshop's purposes and a list of questions to consider were provided to the participants.

Figure 2: Dr. Cody Knutson of the National Drought Mitigation Center, University of Nebraska – Lincoln explaining participant interaction techniques.

Project team members made a series of presentations (e.g., Figures 2, 3, and 4) during the workshop to familiarize participants with the topic of DCV. Sufficient time was allotted to answer questions and discuss related topics. Several additional interaction techniques were used during the workshop. For example, participants were asked to write down the effects of historical wet and dry spells on their community water systems and to organize this information on a public participation "sticky wall".

Other techniques such as polling the audience with "clickers" (hand-held audience response units) were used to encourage rapid feedback and to stimulate discussions. Topics related to the use of DCV information were also discussed in break-out groups (e.g., Figure 5) and through a "World Café" technique. In a "World Café" setting, the plenary is broken into sub-groups that move from table to table. A reporter responsible for discussion of the question assigned to a table remains in place as the groups circulate. He/she collects individual responses from members of (in this case) the four groups and summarizes the answers obtained for later presentation to the reassembled plenary. At the end of the workshop, participants were also asked to respond to a final questionnaire about the workshop content and offer suggestions for improvement in future workshops.

3. Information Provided to Stakeholders

In a presentation made by the project team, stakeholders were introduced to various definitions of DCV and then to the three major DCV phenomena -- the PDO, the TAG, and the WPWP variability. Spatial patterns and time histories of these phenomena were shown, and major hypotheses as to their causes were briefly described.

Figure 3: Dr. Vikram Mehta of the Center for Research on the Changing Earth System describing major DCV phenomena.

Statistical associations between each of the DCV phenomena and hydro-meteorological variables such as rainfall and surface air temperature were used to show how each contributes to hydro-meteorological variability at decadal timescales in the Basin. Rainfall and temperature patterns associated with three recent, multi-year to decadal timescale hydrological events -- droughts in the 1980s and the 2000s, and a prolonged wet spell in the 1990s -- reconstructed from the aforementioned statistical associations, were shown to workshop participants.

The information imparted to participants was discussed in several sessions. Participant recollections of these events were elicited. The question of future evolution of the DCV phenomena and their possible impacts on the Basin was discussed. The project team initiated this series of discussions by reviewing the current status of efforts of several major climate modeling groups around the world to produce decadal climate outlooks. The manifold difficulties of producing such outlooks were also described and discussed.

Figure 4: Dr. Rolf Olsen of the U.S. Army Corps of Engineers describing impacts of Missouri River Basin droughts.

4. Workshop Results

4.1 Participant Recollections

In one exercise, participants were asked to develop a list of effects on urban water systems in the Missouri River Basin of the 1980s drought, the 1990s wet spell, and the 2000s drought. The recollections elicited were many and varied, and are presented below.

4.1.1 The 1980s Drought

One stakeholder noted that the 1980s droughts led to the enactment of national legislation to increase water efficiency requirements that resulted in reduced demands for water. States also were prompted to enact relevant legislation. The Nebraska Unicameral, for example, acknowledged the linkage of surface water to ground water and ultimately, in the 1990s, enacted LB-108, a law requiring each natural resource district to maintain a ground water management plan based upon the best available information.

Stakeholders from several communities also cited a range of drought-related effects on municipal water systems. In the headwaters region of the Missouri River Basin, drought in the late 1980s forced cities such as Bozeman, MT, to restrict water use and there were concerns that water supplies for fire control were inadequate. Pollutant concentrations also increased in-stream water drawn into Montana's urban water treatment plants. Similarly, drought predisposed the Yellowstone National Park to fires, stream dewatering, adverse impacts on fisheries, and a decrease in supplies of water for irrigation.

Downstream, mean summer flow in the Big Sioux River running through Sioux Falls, SD, was less than 10 cubic feet per second. Water yield from wells was also reduced as aquifer levels dropped, requiring the city to install several temporary wells. Similarly, Missouri and Platte River flows were low, limiting well-field recharge for the Lincoln, NE, water system. The System had to urge its customers to reduce lawn watering and undertake other water conservation measures. Omaha, NE was prompted to build a new water treatment facility which finally became operational in 2008.

Summer droughts were also severe in Kansas. Lawrence, Manhattan, Topeka, and Kansas City imposed water use restrictions and began to plan for new water treatment plants, On the other hand, a critical situation developed during low winter flow in 1989 when the Missouri River froze. As a result of low river flows, intake and pumping facilities in Missouri were modified to allow water intake in urban water systems at lower river stages.

Many water systems in small urban areas throughout the MRB were unable to operate due to low reservoir levels, and industries (e.g., thermal power plants, etc.) had difficulty meeting National Pollutant Discharge Elimination System (NPDES) permit requirements.

4.1.2 The 1990s Wet Spell

During the mid-1990s, wet conditions were reported across the Missouri River Basin. In Montana, unusually heavy precipitation led to flooding and increased turbidity in water supplies. Flood control measures resulted in reduced hydro-power generation for short periods. Flood disaster mitigation planning was initiated in communities such as Bozeman. Overall, the wet spell of the 1990s in Montana was interspersed with dry periods, impacting dryland farming, stream flows, and forest fires.

Figure 5: Small groups of stakeholders and policymakers discussing their decadal climate information needs.

In Sioux Falls, SD, wells were flooded; the water purification plant and pump stations had to be sand-bagged. The wet spell resulted in reduced revenues for the city's water system.

Along the South Platte River tributary in Denver, CO, the wet spell produced large quantities of surplus water; reservoirs were full and spilling well into the summer seasons and demand for water was low. Further downstream, river flows were high and water demands were also met in Lincoln, NE. However, a reduction in water consumption decreased revenues for the Lincoln Water System requiring it to cut costs. Concerns about water quality also arose because of the possibility that large fluxes of pesticide in runoff water would infiltrate supply wells. Flood waters threatened to interrupt piped water supply. In nearby Omaha, NE, Platte River flooding threatened well supply but did not curtail water use.

Along the mainstem Missouri River, bottom lands on the Iowa side of the river near Nebraska City, NE, were completely flooded. Thereafter, the Natural Resources Conservation Service (NRCS) funded conversion of cropland to wetlands and wildlife habitat. A little further downstream, Kansas City suffered 10-15 feet of erosion and intakes to the urban water system had to be modified. Similarly, most of Jefferson City, MO (the State capital) was flooded and water supply was almost lost. Private water wells were also flooded, reducing or cutting off supplies to homes and industries.

In general, it was reported that multiyear to decadal wet spells result in reduced revenues for urban water systems, making it difficult to maintain and improve infrastructure without rate increases. Prolonged wet spells also tax water treatment systems because they increase sedimentation rates that shorten the useful life of the reservoirs.

4.1.3. The Droughts of the 2000s

Because it was still fresh in people's minds, stakeholders were able to provide a good deal of detail about the effects of recent drought on urban water supplies. For example, stakeholders described how reduced agricultural water supply during the droughts in Montana reduced groundwater recharge with consequent impacts on municipal well and water supply. The Bozeman water system had to intensify waste water treatment to avoid violations of state regulations. An aggressive leak detection and repair program was initiated to conserve water. Restricted water supplies during the droughts also increased concern that there might not be adequate water flows to fight fires in urban areas. However, due to a public information program and news media coverage of the droughts, no water use restrictions were actually imposed. It was also noted that several cities (e.g., Ennis, Three Forks, Helena, Cascade, Great Falls) experience elevated levels of natural arsenic in their water supplies, especially when drought resulted in low water flows in rivers and streams.

Similarly, the groundwater in South Dakota is of poor quality and hard to treat. Historically, municipalities near Corps of Engineers or Bureau of Reclamation Missouri River reservoirs were tapping into them because of the poor quality of accessible ground water. The Corps of Engineers has explained to these municipalities that reservoirs levels vary according to inflow variability and has encouraged them to set their reservoir intakes and/or wells at a sufficient depth so that water level variations do not affect their access to water supplies. But, millions of dollars are sometimes required for construction of deep intakes. Unable to afford these improvements, some small towns continued to place intake pipes too close to shore and ran out of water during the 2000s droughts. Lake Oahe in North and South Dakota has an area of 75 square miles when full. During the 2000s droughts, the reservoir level dropped and receded completely from North Dakota. After the droughts ended, the increased water and sand levels in the reservoir buried municipal water intakes; the Bureau of Reclamation had to clean them.

In the South Platte watershed, the water supply to Denver, CO, was reduced due to a 60% reduction in average runoff. The droughts increased water demand, triggering restrictions on water use. A large, intense wildfire in the South Platte River watershed area, in 2002, caused subsequent water quality and sediment problems that continue to this day. The Denver Water System (DWS) lost approximately $50 million per year in revenue during the drought period. Since the drought ended, the water demand has remained approximately 20% lower than before -- likely due to increases in the efficiency of water use stimulated by the drought. The droughts have left in their wake a lingering systems maintenance backlog that is still not cleared because of reduced demand for water in the wetter years after the droughts. The accompanying reductions in revenues are prompting the DWS to consider imposing substantial increases in the price of water.

Water use for irrigation intensified during the 2000s droughts in Nebraska. Water tables were lowered and urban well capacity was reduced. One reported consequence was an increased concentration of nitrates in drinking water and an increase in water treatment costs. The State of Nebraska's Climate Assessment and Response Committee (CARC) met as needed to prepare reports on impacts of the drought for the Governor's office. Nebraska also amended drinking water regulations, requiring that public water systems monitor and report monthly on amounts of water pumped and on static water levels in wells. Small communities in the State were made aware of their option to appropriate agricultural irrigation wells to provide water for domestic users. The State enacted LB-962, a law requiring a sustainable balance between water uses and supplies that include public water provisions. In Lincoln, NE, mandatory water restrictions had to be enforced for the first time since 1974 because the Lincoln Water System (LWS) could not obtain enough water from its well fields. Customer confidence was reduced and economic development was negatively affected. Water use in the city had increased prior to the enforcement of restrictions. The temporary increase in revenues during that period induced a false sense of financial security at LWS. Enforcement of water restrictions reduced customers' water use, but also lowered LWS revenues. Elected officials were reluctant to implement mandatory restrictions thinking that to do so would imply that the city suffers from water problems and that this would deter growth of the city. Officials also feared that the displeasure of its residents would become a factor in the next scheduled elections. Low rainfall resulted in higher summer water demands in the Omaha Metropolitan Utilities District (MUD). This, in turn, resulted in increased revenues for the utility company. Water use, however, had to be curtailed at times due to limitations in supply and distribution. Also in Omaha, water treatment and production facilities were strained to meet increased demands prior to the 2008 start-up of the new water treatment facility, its third.

Spurred on by the 2000s droughts, the Nebraska Legislature in 2004 passed LB-962 law, a major overhaul to the State's water law. Under LB-962, a river basin's surface water and groundwater are both taken into account when deciding whether the water supply can sustain further development for irrigation and other high-volume water uses. If a basin is assessed to be fully appropriated by the Nebraska Department of Natural Resources, drilling new wells or adding more areas to irrigation may be restricted. Municipal public water supplies are featured in the laws as are Missouri River power plants and municipal water intakes.

Figure 6: Participant recollections of the 1980s and the 2000s droughts, and the 1990s wet spell, posted on the "sticky wall".

In St. Louis County, Missouri, the Missouri River water level was so low that municipal and other water intakes became exposed, leading to the concern that the county's water system would be required to draw water from alluvial wells. The 2000s droughts caused \$500 million impact per year and led to formation of a drought assessment committee and production of a "Missouri Drought Response Plan". Even during winter, water supplies were reduced in Kansas City due to restricted flows caused by ice and because of reduced water release from reservoirs. Rural water supplies also became inadequate; the transport of water to communities and for livestock operations became necessary in many locations. Municipalities drawing water from the Kansas River suffered due to low surface water and falling water tables, and water quality also deteriorated.

In general, low flows also affected water temperature in the Missouri River and threatened power plant operations, especially those of nuclear power plants operating under the Environmental Protection Agency's temperature criteria. Low flows in the Missouri River during winters also led to concerns about ice jams and disruptions in river water intakes.

4.1.4. Basin-wide Consequences of Decadal Droughts and Wet Spells

The economic impacts of decadal droughts in the MRB are typically widespread, both geographically and sectorally, whereas floods cause much more focused damage. Several workshop participants noted that major changes in legislation and water management practices are initiated during periods of drought, especially during or after multiyear to decadal droughts. Droughts of decadal duration cause friction to develop in small agricultural communities among farmers, nearby communities, and responsible public officials because all require water, generally from the same limited sources. In such circumstances, smaller communities often have to sink new wells or rely on nearby urban water systems. The droughts of the 2000s have prompted efforts among competing users to develop alternate sources of water supply.

Public awareness programs are increasing water use efficiency in communities of all sizes in the MRB and it is becoming less difficult for governmental and utility groups to restrict water use when necessary.

One MRB-wide observation of the 2000s droughts holds that, while precipitation was reduced, storms when they occurred were more intense. This situation overwhelmed storm sewers and water treatment facilities in urban areas. The 1990s wet spell also pushed sewer systems to or over their operational limits.

Regional and national consequences of the 2000s droughts included passage of the National Integrated Drought Information System Act of 2006 (Public Law 109-430), which provides funds and authority to assist in the coordination of national drought-related activities. In addition, the US Drought Monitor gained recognition as an official drought declaration trigger with its inclusion in the U.S. farm bill (Farm Bill, 2008, SEC.531.Supplemental Agricultural Disaster Assistance).

Stakeholders also noted that during wet spells of decadal duration, large amounts of pesticides can run off into rivers and streams and, consequently, into rural and urban water systems. These pollutants degrade water quality and increase costs of water treatment. Also, prolonged wet spells, especially frequent storms, can damage or destroy water supply and treatment infrastructure and damage wells, requiring costly repairs. Additionally, floods during the 1990s wet spell damaged or destroyed many bridges, requiring water systems staff to make detours to reach their places of work. As a consequence, restoration of water service to consumers was often delayed. On the other hand, a prolonged wet spell can also make water system planners and consumers complacent about the ultimate need to develop alternate sources of water. For example, an initiative proposed by communities during the 1980s droughts to purchase more water from the USACE was delayed by complacency during the 1990s wet spell, exacerbating water problems that developed during the 2000s droughts.

4.2 Usefulness of Decadal Climate Outlooks

Observations on climate and impacts from the 1980s and the 2000s drought periods were presented to the workshop participants as though they were accurate climate outlooks with lead times of a number of years to a decade in advance. Participants were asked to explain how they would have used these decadal climate outlooks (DCO) had they been available just before the aforementioned droughts and wet spells. In general, DCOs can be used to educate legislators and legislative research officials in state capitals, governors and their staffs, county and local level decision makers, and the general public. Reasonably specific ideas about how DCOs could be used in decision making also issued from this discussion. Some are presented here:

Near-Term (1-3 years) Activities

Workshop participants felt that DCOs can help in the near-term (1-3 years) in: conservation activities, estimating rates to be charged for various water uses, preparations for invoking restrictions on water use, planning for maintenance of water infrastructure, and in designing public awareness programs and campaigns. In addition, the DCOs could guide development of building codes, zoning codes, subdivision design, appliance efficiency, grey water and storm water drainage, landscape design, street or parking standards, public information, budgeting, reservoir operation, water treatment planning, and emergency reserve funding.

Drought predictions are needed monthly and seasonally for determining whether surface or ground water (or both) is to be used and, if ground water, which well fields to use. Seasonal to annual predictions are needed to plan for the allocation of water to the agricultural, municipal and industrial sectors and to predict revenue requirements for infrastructure construction and/or maintenance; for purchase of water, water rights and other needed resources and commodities; for the updating of conservation/plumbing ordinances; and in general contingency planning.

What are the specific climatic variables about which information is most needed for short-term urban water security applications? The participants felt that **precipitation** is useful for projecting demand and collection system operation; **temperature** is useful in projecting demand for water and conservation measures; **stream flow** is useful in collection system operation, maintenance projects, and treatment operations; **snowfall** is useful in collection system operation, budgeting snow removal costs, and water conservation measures; **ground water recharge** is useful in projecting demand and treatment requirements; **evapotranspiration** is useful in projecting demand, water conservation, and rates for and revenue from water sales; and **groundwater level** is useful in collection system operation and maintenance projects.

Long-Term (5 years and longer) Activities

DCOs of five years and longer would be useful in planning and constructing infrastructure facilities, estimating and augmenting capacity, determining building codes and zoning requirements, land use planning, aquifer recharge planning, urban water reservoir management, demand management, and watershed planning and management. If a DCO indicates an oncoming multiyear to decadal drought, cities holding senior water rights might use the DCO to guide their purchases of additional water rights. The DCOs can guide reallocation of storage space for urban use in federal reservoirs. This tactic, however, would require political authorization, possibly triggering demands from other interests and types of users. A long-term drought prediction might also be used to convert city parks to native vegetation, thereby reducing consumptive use of water. A long-term drought prediction might also be used to justify severe water use restrictions from the beginning of a drought rather than relying on emergency measures after water security had already become critical. DCOs might also inform decision-making about surface or ground water use because ground water is less expensive to treat than surface water. In terms of water resource management, if a drought is predicted, aquifers near a river would be used first and those further away used later. A DCO predicting a wet spell might be used to defer investment in water treatment plants.

Workshop participants were asked to identify the specific climatic and related variables, the prediction of which would be most useful for assuring long-term urban water security. **Precipitation** was deemed generally most useful in infrastructure planning including water sources, water treatment, transmission and distribution, collection system operation policy, maintenance, and water leasing. **Temperature** outlooks would be useful in water demand projection, leasing, and financial budgeting. **Stream flow** outlooks would be useful in infrastructure planning, collection system operation policy, and maintenance. **Groundwater** is useful in infrastructure, collection system operation policy, maintenance, and water leasing. Snowfall is useful in financial budgeting of snow removal costs. **Evapotranspiration** is useful in projecting water demand.

Examples of DCO Application Scenarios

Building and Zoning Codes

It takes a lot of work to get people to agree to changes in building and zoning codes and sub-division design. Some of the issues and options factored into the decision include: water efficient fixtures and appliances, grey water (wastewater from bath tubs, sinks, washing machines, etc. that can be reused for other purposes) and storm water irrigation, drought-tolerant landscape design, and other measures to reduce water consumption. Increased recharge of aquifers can be facilitated by, for example, minimizing paved area in favor of open land. Credible DCOs can provide the impetus to make such changes that cost a lot of money but are possible with incentives for public involvement. For example, citizens of Las Vegas are paid to convert their water-consuming lawns to gravel-surfaced desert gardens, thereby reducing the demand on that city's water supply system.

Water Use Restrictions

DCOs would be helpful in providing information relevant to the imposition of water use restrictions. Were several dry summers to be predicted, authorities might recommend voluntary restrictions. A warning might be issued that if the droughts worsen, then water use restrictions could be made mandatory. An aware public, confident in the value of DCOs and in the integrity of their water utilities, is likely to comply with restrictions, if imposed.

Reservoir Planning

DCOs can be very useful in reservoir planning. If, on the basis of the DCO information, a multiyear to decadal wet spell is predicted, reservoirs would contract with irrigators to assure delivery of specified quantities of water. If a dry period is predicted, and the reservoirs do not have water reserves adequate to last for several years, contracts between the reservoirs and irrigators would have to be deferred.

4.3 Potential Barriers to the Use of Decadal Climate Outlooks

Workshop participants were also asked to identify potential barriers to the use of DCOs. It was felt that the unknown reliability, accuracy, and spatial and temporal resolutions of DCOs would be the major barriers to their adoption and use. It was also felt that a lack of clarity as to the relationship of DCV phenomena and greenhouse-warming-driven climatic change would also pose a barrier to the use of DCOs. Current controversies regarding global warming confuse the general public and make it difficult to understand the distinction between natural DCV and anthropogenic climate change.

Another barrier might result from the ‘prior appropriation doctrine’ (a legal concept of establishing the right to use scarce water from rivers and streams, also expressed as "first in time, first in right") does not allow for much flexibility in reservoir and water system operations. As mentioned earlier in section 4.1.3, the unwillingness of politicians and business-boosters to publicize water problems in a specific urban area would also be a barrier to effective use of DCOs; however, this may vary by urban area and the judgment and sophistication of elected officials and other community leaders in those areas.

Social, political, and cultural factors; a natural resistance to change; and a lack of the financial means necessary to make changes may also pose barriers to the use of DCOs. Legal barriers such as water rights, public resistance to government funding for infrastructure change, and inflexible farm benefit programs may also be obstacles to the adoption and use of DCOs. The general public may also consider climate less important than other factors in resource management. Finally, the (not unreasonable) possibility of incorrect projections or a suspicion that scientific misinformation is (for whatever reason) being deliberately promulgated, may predispose the public to ignore DCOs. Additionally, “acts of nature” that do not seem consistent with predicted trends (e.g., a heavy rainfall event during a long-term drought) would also lessen the credibility of climate forecasts and, hence, the adoption of strategies consistent with DCO projections.

4.4 Specific Recommendations for Providing Decadal Climate Outlooks

The workshop participants made the following recommendations:

1. The Missouri River Basin website, developed for this project, should be enhanced with links to relevant sites; and provide user-friendly DCV information needed by stakeholders (e.g., probabilities of occurrence), user-definable preferences (including resolutions), GIS capabilities, and explanations of data and information in terms that a broad range of stakeholders can understand. The information should be organized according to watersheds in the MRB and it should be downloadable in presentation formats developed in collaboration with users.

2. Along with climate data and information that can help in interpretation of the data, the above-mentioned website should present projections of the following variables/parameters:

- Inches of water needed per growing season (lawn, irrigation purposes)
- Number of days without precipitation or number of days following the last rain event
- Flood frequency
- Soil moisture and stream flow
- Snowfall and snow pack
- Probability of ENSO events of various types and severity during the occurrence of DCV events
- Precipitation, temperature, stream flow, groundwater levels, snowfall, and evapotranspiration
- Population growth; and local, regional, and national economic trends

3. The participants provided the following insights regarding required probability and accuracy of the DCO and its interpretation by urban water managers:

- DCV outlooks must be at least 50% accurate to be useful at all for any purpose.
- For purposes of city budgeting, an outlook of 90% or greater accuracy is required.
- Outlooks should be accompanied by text and contingency tables.
- Power companies may be better equipped than most other entities to use DCOs for trading decisions.
- Case law may be the best indicator of the accuracy required of forecasts or outlooks.
- A three-category framework (below average, average, above average) may be the best for representing confidence in outlooks. Confidence in these categories should be estimated in percentage terms. Colors could change in 5 percent increments. Data should be displayed in color-coded national and local maps where color indicates confidence in the projection. Local, watershed scale maps will be of greatest interest for those responsible for water distribution.
- Outlooks of 70-80% accuracy could indicate a *probable* need for action; outlooks of even greater accuracy would indicate a near *certain* need for action. If urban water managers gain confidence in the accuracy of outlooks in the first year or so with observations, then they would decide what future action should take place, such as the size or area needed for water mining.
- The involvement of decision makers will be critical in incorporating the outlooks into the overall water-planning process. Outlooks would gain in credibility were they made a part of a 'toolkit' provided by a federal agency such as NOAA.
- Workshop participants emphasized that "Long term outlooks for long term decisions" and "We would use it (outlooks) in the planning of long term infrastructure and water distribution strategies if we knew 7 years out that it would be a wet or dry spell".
- DCOs should use terms such as percent of average wet or dry conditions.
- Unless the USACE and Bureau of Reclamation are involved in planning and providing DCOs and related impacts information, they may not use the DCOs.

4. Climate scientists and climate information should be readily accessible to stakeholders and policymakers when decisions need to be made. Communication between climate scientists and decision makers must be improved. The distinction between *scenarios* and *forecasts* must be made clear to users of climate information.

5. Climate scientists should select a few promising urban areas and work together with decision-makers in those areas to develop approaches for testing and conveying the usefulness of DCV information. Climate scientists should attend user community meetings and conferences as often as possible.

6. Information on the current state of the various DCV phenomena that affect the MRB should be posted on the MRB website and updated frequently. The potential impacts of the DCVs should also be described on the website. Subscribers should be alerted by email to the availability of newly posted outlooks and other significant developments.

7. Existing user networks, as well as extension services, should be engaged to channel climate information to users. Coverage of climate-related matters on TV and other local and regional news media should be encouraged.

5. Next Steps

It was recommended by the workshop participants that experimental decadal climate and impacts information be provided in a regular, reliable way to users in the MRB, and that the network of stakeholders and policymakers in the MRB be further developed via the "*Missouri Basin Climateer*" newsletter and the already-existing website. Workshop participants also expressed a keen interest in assessing the usefulness of experimental DCOs. Participants recommended email with a link to the website as the best way for them to receive information. Printable maps available at the website would also be useful. Other recommended modalities for conveying and discussing DCV information are:

- State conferences
- Webinars, text messages, and pod casts
- News releases
- Really Simple Syndication (RSS) feeds for up-to-date information
- Communication via postal service where internet service is non-existent or very limited

6. Conclusions

The Lincoln Workshop was a unique and intense interaction of decadal climate and water resources scientists with urban water managers and policymakers in the MRB. Free and frank exchange of views and the relatively small number of participants in the Lincoln workshop helped establish a common language and the mutual understanding required for effective interaction. As described in this report, all participants agreed that there are identifiable and quantifiable impacts, including economic impacts, of DCV on urban water security in the MRB. The water managers and policy-makers made many important and specific suggestions to climate scientists about their needs for DCV information and how it should be provided. There are over 2000 urban communities of various sizes in the MRB. While some impacts can be generalized according to size of community, certain other impacts may be very specific to individual communities. It is also clear that while the urban water managers are eager to use climate information, including DCOs, there are many potential barriers to such use. These include the need to first establish the credibility of climate information, and the nature of institutional rules and regulations, laws, and legal precedents. The participants have experienced DCV impacts on urban water security in the past and know that credible climate information can be useful in their work. Because of their own interest in DCV impacts and because of their perceived need for DCV information, the participants expressed a keen interest in continuing this discussion and participating in future research and outreach projects.

Appendix 1: Projects on Impacts of Decadal Climate Variability on Water and Agriculture in the Missouri River Basin

SARP I

In our previous project funded by NOAA-Climate Program Office-SARP, referred to as SARP I here, we used century-long precipitation time series over the basin and found that interannual El Niño-Southern Oscillation (ENSO) variability explains less than 20% and that decadal (>7 years) timescale variability explains approximately 40-50% of the total variance in precipitation. The interannual and decadal precipitation variability thus accounts for 60-70% of the total precipitation variance in the basin. These precipitation (and snow accumulation and stream discharge) estimates are also reflected in the percentage area of the basin under severe to extreme drought conditions. As shown in Figure 2, the fraction of the basin experiencing severe to extreme drought in the 20th century has ranged from 20% to 60% or more at interannual to decadal timescales. From 2000-01 to 2008 much of the basin experienced such a drought.

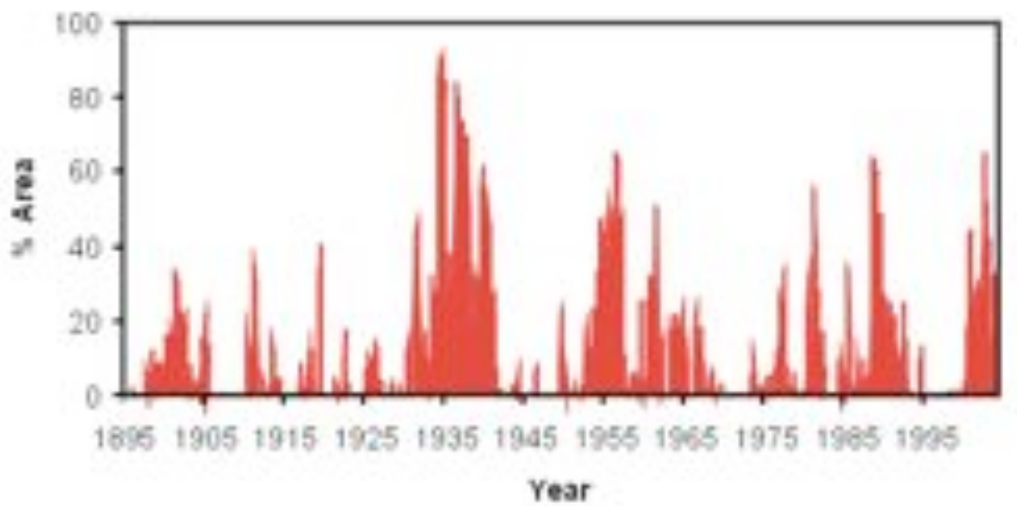

Figure A1: Percent of total Missouri River Basin area experiencing severe to extreme drought between January 1895 and March 2004. Based on data provided by the National Climatic Data Center, NOAA; Copyright 2004 National Drought Mitigation Center.

The climate of the continents is sensitive to what happens over the oceans. Unusual warming and cooling of vast oceanic areas creates such phenomena as the Pacific Decadal oscillation (PDO), the tropical Atlantic sea-surface temperature (SST) gradient (TAG for brevity) oscillation, and the west Pacific Warm Pool (WPWP). In SARP I we found that these three decadal climate variability (DCV) phenomena significantly impact the hydro-meteorology of the Missouri River Basin. Records available from 1950 to 2000 show that decadal droughts and wet spells in the Basin are correlated with various combinations of these three DCV phenomena in their positive and negative phases.

In December 2006, a representative cross-section of Nebraska stakeholders and policymakers was interviewed by the project researchers to gather information about perceived needs for climate information. Discussions were held with over 30 local and regional water managers, policymakers, farmers, and researchers in Nebraska and western Iowa. Some of the major organizations represented in this study were Central Nebraska Public Power and Irrigation District, Bureau of Reclamation, Army Corps of Engineers, Nebraska Farm Bureau, Tri-Basin Natural Resource District, National Park Service, and various departments and centers within the University of Nebraska–Lincoln system. Very positive and articulate responses to our questions by the various stakeholders, policymakers, and academic researchers with whom we met led to the following major conclusions: (1) impacts of persistent decadal hydro-meteorological anomalies are qualitatively different compared to impacts of year-to-year anomalies; (2) agriculture, water resources for municipalities, power plants, and navigation in the MRB are much more vulnerable to decadal drought events than to year-to-year events; (3) there is an evident need for decadal drought outlooks; (4) any particular DCV-related drought or flood event can have differing sectoral and economic impacts in the various geographical portions of the MRB (e.g., recreation in Montana and the Dakotas, irrigation in Nebraska and Kansas, and navigation in the downstream States); (5) municipalities and industry, particularly power generation, are sensitive to drought and flood-related changes in water supply everywhere in the MRB; (6) farms along the Missouri River are much more vulnerable to persistent floods than to persistent droughts; (7) while crops are, of course, sensitive to changes in weather associated with year-to-year hydro-meteorological anomalies, modern crop breeding is increasing their resilience to short-term climate variations; (8) research must be extended to consideration of: the role of groundwater in the total impacts of droughts and floods on water availability; the very important impacts on unmanaged ecosystems; , and land-use changes in response to the Conservation Reserve Program and the introduction of biomass cropping in the region; and (9) a much more detailed study, with questions focused on individual groups and a wider range of economic sectors, is needed for the entire MRB.

The research undertaken in SARP II (the current program) has been guided by the findings listed above.

SARP II

The primary purpose of the SARP II project is to broaden our understanding of drought information needs that were gathered in the earlier phase. This was done by soliciting, evaluating, and documenting stakeholder knowledge of DCV phenomena across the entire basin. In order to achieve this purpose, we are undertaking systematic assessments of the DCV-related perceptions and drought information needs of various types of stakeholders (such as local/regional water managers, farmers and cattle ranchers and feeders, researchers, local/regional business people, and policymakers) in the basin for decision support by means of a series of workshops, surveys, and web-based communication methods.

To help demonstrate the relationships between DCV and associated impacts in the basin, we also developed retrospective scenarios for three DCV-related hydrologic events in the basin; the multiyear-to-decadal drought event in the mid-to-late 1980s and the recent drought (2000-01 to 2008) and the multiyear-to-decadal wet spell in the 1990s; and are assessing their possible impacts on hydro-meteorology, water and crop yields, and regional economy. This work is essential to: (a) help provide credibility of the DCV-societal impacts relationships to stakeholders, (b) be useful in fostering discussions on the effects of DCV, and (c) provide a starting point for discussion on the information needed to better understand and effectively adapt to and cope with DCV-related droughts and excessive wetness. Interconnected components of this project are shown in Figure A2.

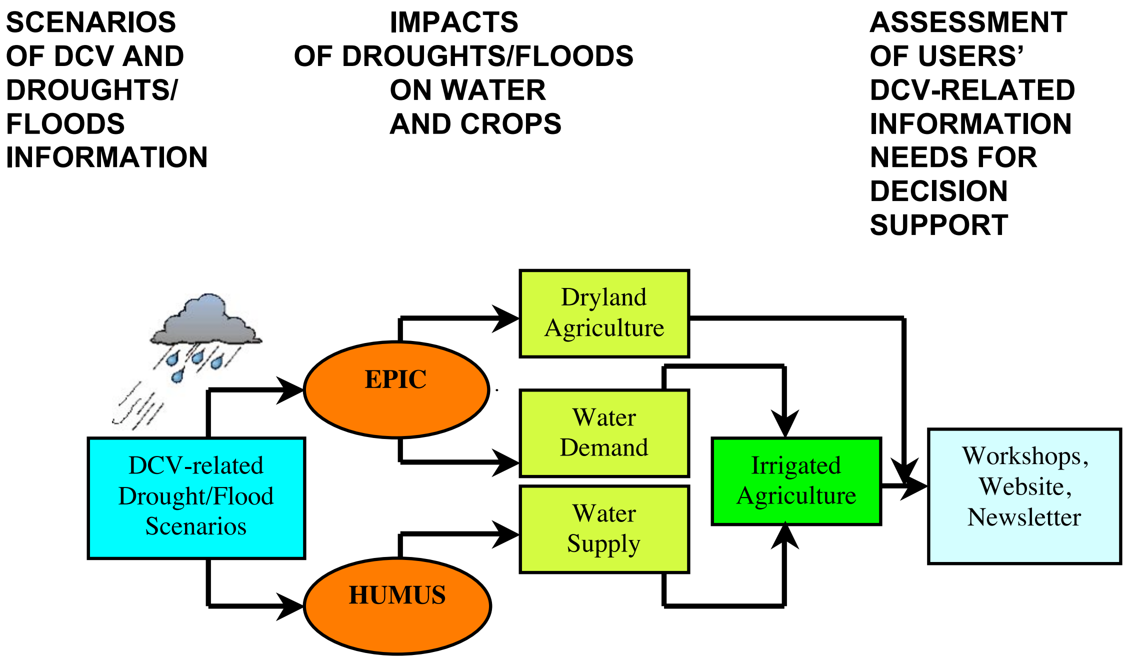

Figure A2: From scenarios of DCV-related droughts/floods to assessment of users' drought information needs.

Appendix 2: List of Participants in the Lincoln, Nebraska Workshop

Name	Title	Agency Name
Jesse Aber	Water Resources Planner	Montana DNRC Water Resources Division
Adnan Akyuz	North Dakota State Climatologist	North Dakota State University
Joel Christensen	Vice President of Water Operations	Metropolitan Utilities District, Omaha, Nebraska
Larry Cieslik	Senior Project Manager	HDR Engineering, Omaha, Nebraska
Jack Daniel	Administrator of the Office of Drinking Water and Environmental Health	Nebraska Department of Health and Human Services
Ken Deason	Geologist	US EPA Region 7 Drinking Water Management Branch
Andy Epple	Community Planner, Educator	Great Falls, Montana
Brent Esplin	Deputy Area Manager	Bureau of Reclamation NE and KS Area Office
Steve Gaul	Division Head Planning and Assistance	Nebraska Department of Natural Resources
Chuck Haines	Professor of Biology	Haskell Indian Nations University, Lawrence, Kansas
Rachael Herpel	Water Education and Outreach Specialist	University of Nebraska Water Center
Jake Kandelin	Hydrologist	Montana DEQ Public Water Supply
Doug Kluck	NOAA Regional Climate Service Director, Central Region	NOAA, Kansas City, Missouri
Eric Obert	Environmental Engineering Department Manger	JEO Consulting Group, Inc., Nebraska, Iowa
Jerry Obrist	Chief Engineer of Water Works	Lincoln Water System, Nebraska
Steve Owen	Superintendent of Water Distribution	Lincoln Water System, Nebraska
Bob Peters	Senior Water Resource Engineer	Denver Water, Colorado
Gene Siadek	Water Supply Engineer	Metropolitan Utilities District, Omaha, Nebraska
Scott Sprague	-	Nebraska Health and Human Services
Tim Stefanich	Environmental Engineer	Water Purification Plant, Sioux Falls, South Dakota
Bob Swanson	Director	USGS Nebraska Water Center
Nathan Westrup	MoRAST for Kansas	Kansas Water Office

Project Investigators		
Tonya Bernadt	Research and Outreach Specialist	National Drought Mitigation Center
Cody Knutson	Water Resources Scientist	National Drought Mitigation Center
Vikram Mehta	President and Executive Director	The Center for Research on the Changing Earth System
Rolf Olsen	Water Resources Systems Engineer	US Army Corps of Engineers
Norman Rosenberg	Senior Scientist	The Center for Research on the Changing Earth System
Nicole Wall	Public Participation Specialist	National Drought Mitigation Center