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Decadal Climate Information Needs of Stakeholders for Decision Support in Water and Agriculture Production Sectors: A Case Study in the Missouri River Basin

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ABSTRACT

Many decadal climate prediction efforts have been initiated under phase 5 of the World Climate Research Programme Coupled Model Intercomparison Project. There is considerable ongoing discussion about model deficiencies, initialization techniques, and data requirements, but not much attention is being given to decadal climate information (DCI) needs of stakeholders for decision support. Here, the authors report the results of exploratory activities undertaken to assess DCI needs in water resources and agriculture sectors, using the Missouri River basin as a case study. This assessment was achieved through discussions with 120 stakeholders.

Stakeholders' awareness of decadal dry and wet spells and their societal impacts in the basin are described, and stakeholders' DCI needs and potential barriers to their use of DCI are enumerated. The authors find that impacts, including economic impacts, of decadal climate variability (DCV) on water and agricultural production in the basin are distinctly identifiable and characterizable. Stakeholders have clear notions about their needs for DCI and have offered specific suggestions as to how these might be met. However, while stakeholders are eager to have climate information, including decadal climate outlooks (DCOs), there are many barriers to the use of such information. The first and foremost barrier is that the credibility of DCOs is yet to be established. Second, the nature of institutional rules and regulations, laws, and legal precedents that pose obstacles to the use of DCOs must be better understood and means to modify these, where possible, must be sought. For the benefit of climate scientists, these and other stakeholder needs are also articulated in this paper.

1. Introduction

Decadal climate variability (DCV) phenomena influence hydrometeorology, water availability, food production, and other societal sectors and interests in many ways. For well over a century, and in various parts of the world, scientists (and pseudoscientists) have attempted to predict climate at multiyear-to-decadal and longer time scales. Under phase 5 of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP5; Meehl et al. 2009; Murphy et al. 2010) and encouraged by initial results from

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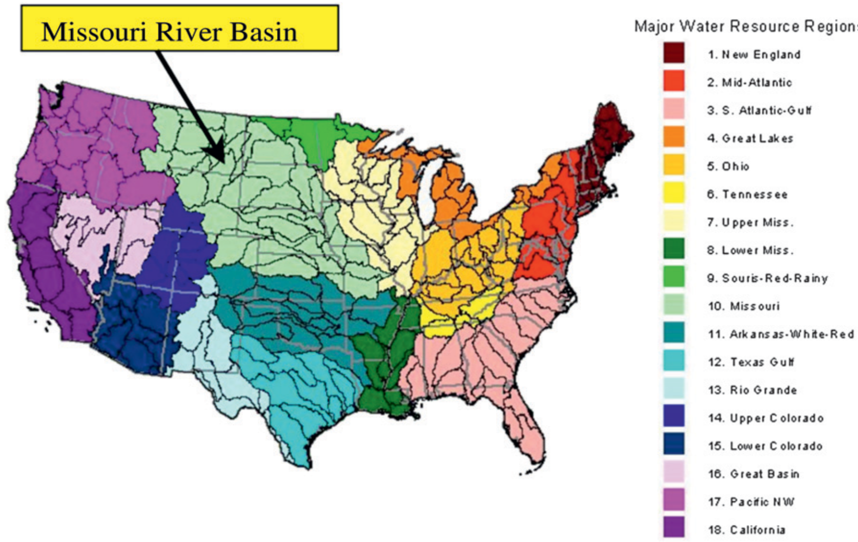

FIG. 1. The Missouri River basin is one of 18 major water resource regions of the conterminous United States. Other ''4 digit'' hydrologic unit areas as defined by the U.S. Geological Survey are also shown.

experimental decadal climate prediction efforts with global coupled models (e.g., Keenlyside et al. 2008; Pohlmann et al. 2009; Smith et al. 2007), an international effort is now under way to make decadal climate predictions. CMIP5 includes research on improving global coupled models, developing model initialization techniques, and assessing impacts of various kinds of observed data on predictions. These scientific efforts are proceeding, however, with little knowledge of just who and which groups and sectors might be the users of such forecasts. Also, not much is known about what decadal climate information (DCI) these potential users will need (Mehta et al. 2011a). We have conducted a series of exploratory activities to identify and work with stakeholders, particularly in the water and agriculture production sectors, to address these unknowns. Our efforts to this time have been focused on the Missouri River basin.

In this paper, we describe what we have learned of 1) stakeholder perceptions of the impacts of recent decadal-length dry and wet spells in the basin from the mid-twentieth century to the first decade of the twenty-first century; 2) DCI needs of stakeholders in the water and agriculture production sectors in the basin; 3) potential barriers to stakeholder use of DCI; and 4) stakeholder recommendations for further action. Here, as in our previous research (Mehta et al. 2011b, 2012) and that of others, ''interannual'' is used to denote oscillation periods of year-to-year variability up to approximately a 7-yr oscillation period and ''multiyear to decadal'' is used to denote longer than 7 yr but less than 20 yr.[1]

This paper is organized as follows: After this introduction, the importance of the basin, DCV phenomena, and their impacts on the basin and the role of the six major U.S. Army Corps of Engineers (USACE) operated dams on the Missouri River's ''main stem'' are described in section 2. Techniques employed in our interactions with basin stakeholders are described in section 3. Stakeholder-reported impacts of decadal dry and wet spells are described in section 4. Usefulness of climate outlooks at decadal and longer time scales are outlined in sections 5 and 6, respectively. Potential barriers to the use of decadal climate outlooks are described in section 7. Recommendations made by stakeholders for future actions with respect to DCI are described in section 8. Major conclusions of this study are presented in section 9.

2. The Missouri River basin in context

a. Land and industry

The basin, shown in Fig. 1, covers more than 500 000 square miles (1 300 000 km^2) including a part or all of

[1] The climatic events described throughout this paper are documented in *Climatological Data Annual Summaries* (by state), published by the NOAA/National Climate Data Center (Ashville, North Carolina).

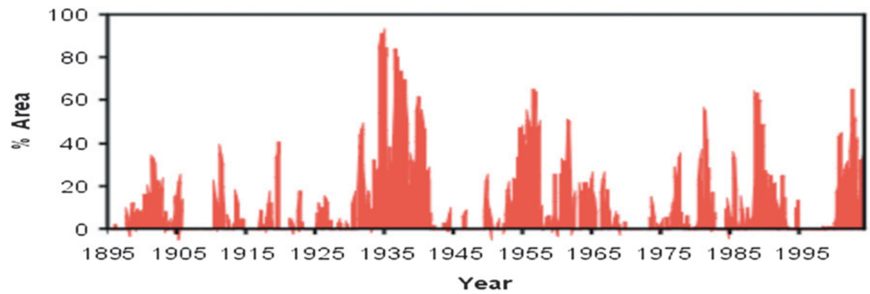

FIG. 2. Percent area of the Missouri River basin experiencing severe to extreme drought between January 1895 and March 2004. Based on data provided by the NOAA/National Climatic Data Center.

10 U.S. states and two Canadian provinces; it is also home to 28 Native American tribes. Inhabitants of the basin depend on the Missouri River system for drinking water, irrigation and industrial needs, hydroelectricity, recreation, navigation, and fish and wildlife habitat. The basin contains some of the United States' most sparsely populated agrarian counties, as well as more than 2000 urban communities, including large metropolitan areas such as Omaha, Kansas City, and Denver. The basin is a very important agricultural region producing approximately 46% of U.S. wheat, 22% of its grain corn, and 34% of its cattle (USDA 2012). Approximately 117 million acres (47.3×10^6 ha) are in cropland, with 12 million acres (4.9×10^6 ha) under irrigation, much of it dependent upon water withdrawals from the High Plains (Ogallala) Aquifer, the most intensively used aquifer in the United States (USGS 2005). In terms of economic importance, the approximate value of crops and livestock produced in the basin was over $100 billion in 2008. Thus, almost 90% of the basin's cropland is entirely dependent on precipitation. Directly or indirectly, that precipitation is also the source of water for municipalities and industry, with both greatly influenced by climate variability and change.

b. *Manifestations of decadal climate variability in the Missouri River basin*

Impacts of major global-scale DCV phenomena such as the Pacific decadal oscillation (PDO; Mantua et al. 1997), the tropical Atlantic sea surface temperature gradient oscillation (TAG; Mehta 1998), and the west Pacific warm pool variability (WPWP; Wang and Mehta 2008) on U.S. climate are reasonably well documented and quantified by analyses of climate observations. There are indications that large-scale climate forcings by the PDO (see, e.g., Ting and Wang 1997; McCabe et al. 2004; Mehta et al. 2011b), the TAG (Schubert et al. 2004; Mehta et al. 2011b), the Atlantic multidecadal oscillation (McCabe et al. 2004), and the WPWP variability (Wang and Mehta 2008; Mehta et al. 2011b) also influence precipitation variability in the basin. Interannual ENSO variability explains less than 20% while decadal timescale variability explains approximately 40%–50% of the total precipitation, runoff, and streamflow variances within the basin (Guetter and Georgakakos 1993; Lins 1997; Cayan et al. 1998). Approximately 20%–40% of precipitation variance in the basin is explained by the PDO and TAG individually, and 10%–20% is explained by the WPWP. Gurdak et al. (2007) have established a linkage between PDO and groundwater recharge rates and mechanisms in the High Plains Aquifer, which underlies much of the basin. These hydrologic variability estimates are also reflected in the percentage area of the basin under severe to extreme drought conditions; the fraction of the basin experiencing severe to extreme drought in the twentieth century ranged from 20% to 60% or more at interannual-to-decadal time scales (Fig. 2). Portions of the basin also experienced a multiyear to near-decadal drought during the first decade of the twenty-first century. The droughts have alternated with multiyear-to-decadal wet spells.

Recently, Mehta et al. (2011b, 2012) conducted analyses of associations between the three aforementioned DCV phenomena, hydrometeorology in the basin, and their consequent impacts on water resources and crop yields. Objectively analyzed, gridded (from historical station observations) hydrometeorological observations consisting of monthly precipitation rate, surface air temperature, surface wind speed, and relative humidity from 1950 to 1999 at $1/8°$ longitude $\times$ $1/8°$ latitude resolution (Maurer et al. 2002) were used for this purpose. Streamflow observations from the U.S. Geological Survey were also used in these analyses. It was found that PDO, TAG, and WPWP are associated significantly with decadal precipitation and temperature variability in the basin, with combinations of positive and negative phases of several DCV phenomena associated with drought, flood, or neutral hydrometeorological conditions. Three extreme hydrologic events—droughts in the mid-1950s and mid- to late 1980s and floods in the early to mid-1990s—were reconstructed by means of these statistical analyses.

With the aforementioned as background, Mehta et al. (2011b, 2012) used the Hydrologic Unit Model of the United States (HUMUS; Srinivasan et al. 1993)–Soil and Water Analysis Tool (SWAT; Arnold and Allen 1992; Arnold et al. 1999) system and the Erosion Productivity Impact Calculator (EPIC; Williams 1995) to simulate DCV influences at 75 locations on yields of water, dry-land corn, and winter and spring wheat in the basin. The simulations revealed major impacts on these variables, with locally specific variations as great as 50% of average yield. The basin-aggregated water yield changes in the positive and negative phases of the three DCV phenomena can be substantial for typical values of the three DCV indices (Mehta et al. 2011b). Similarly, the basin-aggregated crop yield changes in response to typical values in opposite phases of the three DCV indices can also be substantial (Mehta et al. 2012).

c. *Importance of Missouri River main stem dams*

The Missouri River is a managed river system with six dams on its main stem. The total storage capacity of the reservoirs created by these dams is 73.4 million acre-feet (MAF; 1 MAF = 1233.5×10^6 m^3), approximately 3 times the annual runoff upstream of the dams. The great storage capacity of the reservoirs provides opportunity for carryover from year to year. Authorized purposes of the reservoir system are flood control, hydropower generation, navigation, recreation, irrigation, assurance of water supply and water quality, and maintenance of fish and wildlife habitat. These uses must be balanced to meet various seasonal demands. Clearly, the ability to meet these demands is affected by variations within the basin.

A major purpose of the reservoirs is to prevent or reduce flood damages to the extent possible. The top zone in each reservoir (4.7 MAF in the system or 6% of total storage) is reserved exclusively for flood storage. It is used to capture runoff during extreme and unpredictable floods; that space is emptied as soon as downstream conditions permit. In addition, the upper part of the normal operating zone (11.6 MAF in system or 16% of storage), used to store annual floods, is normally emptied prior to onset of the annual flood season. There are two primary flood seasons in the basin: (i) late February–April, when precipitation falls as rain and the snow in the plains melts, and (ii) May through July, when the mountain snow melts and additional rainfall occurs in the basin (USACE-NWD 2006). The evacuation of the annual flood control zone is scheduled to meet the other aforementioned uses.

A carryover multiple-use zone of the reservoirs (39.0 MAF or 53% of storage) provides storage for irrigation, navigation, hydropower production, water supply, recreation, and fish and wildlife habitat. The water stored in this zone can support downstream flows during an extended period of drought. The remaining storage (18.1 MAF or 25%) is called the "permanent pool zone" and is used for minimum power head and future sediment storage.

Major services provided by the Missouri River dam system include hydropower generation, maintenance of navigation, municipal water supply, and thermal power cooling. Hydropower is generated at the dams throughout the year. Peak demands for electricity occur during the winter heating season (mid-December–mid-February) and the summer air-conditioning season (mid-June–mid-August). The peak power-generation season extends from mid-April to mid-October. The navigation season in the lower Missouri River generally runs from 1 April to 30 November. During drought years, the navigation season may be curtailed. Releases from the main stem reservoirs also maintain a minimum flow on the Missouri River downstream of the Gavins Point Dam in southeastern South Dakota to support water quality and water intakes for municipal water supply and for cooling thermal electric power plants.

The main stem dams also provide recreational amenities and ecological benefits in their reservoirs and in the downstream Missouri River as well. Maintenance of existing flora and fauna, particularly threatened and endangered species, is a major concern for water management in the basin. The current master manual for operating the main stem dams calls for releasing spring pulses to replicate the natural hydrograph of spring floods in support of downstream ecosystems. Each year, the USACE develops an annual operating plan that takes into account inputs received from a wide range of stakeholders in the basin. The plan lays out just how the reservoirs will be regulated given current conditions in the basin. For example, spring pulses may be foregone during drought years in order to save water for other uses.

Records of Missouri River flow are available since 1898, and the time series of the flow, combined with inflows into the basin's main stem dams following their construction, is shown in Fig. 3. The time series of basin inflows shows substantial interannual-to-decadal variability. Since 1898, the annual runoff into the basin above Sioux City, Iowa, has varied from a low of 10.7 MAF in 1931 to 49.0 MAF in 1997. As shown in Fig. 3, the basin has been affected over the past 113 yr by four multiyear-to-decadal droughts; these occurred during 1930–41, 1954–61, 1987–92, and 2000–07. The basin experienced periods of extremely high runoff during

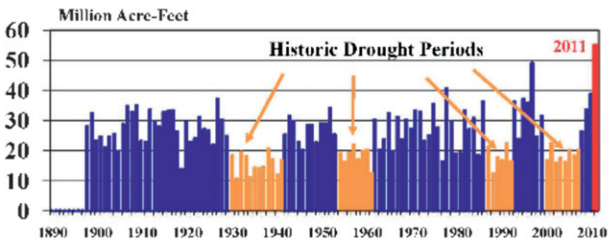

FIG. 3. Inflows into the Missouri River main stem dams from 1898 to 2011 (courtesy of Kevin Grode, USACE).

1907–09, 1975–78, 1993–97, and 2008–11, as indicated in Fig. 3. As described above, there is substantial decadal variability in water yield (runoff) and crop yields in the basin associated with such events, variability that appears to be associated with three major DCV phenomena.

3. Interactions with stakeholders

The study reported here was undertaken to assess knowledge of the impacts of DCV phenomena in the basin and to develop an understanding of the information that stakeholders will need to help cope with the impacts of future DCV occurrences. To that end, we interviewed a wide range of expert stakeholders with knowledge of the water and food production sectors in the basin. We began in 2006 with a pilot study involving interviews with 30 stakeholders in Nebraska and western Iowa. These stakeholders represented private sector, nongovernmental, and governmental organizations, as well as various departments and centers within the University of Nebraska at Lincoln system. Insights gained in this pilot project guided the design and management of three workshops held in 2009 and 2010 in the basin. Ninety stakeholders participated in these workshops. The pilot study and techniques for interactions with stakeholders in the workshops are described in this section.

a. *The pilot study*

Our aim in the pilot study was to gain an initial understanding of the complex nature of the impacts of DCV on the basin; the sensitivities of the agriculture and water sectors, in particular, to these impacts; the data and information sources currently available to these sectors to cope with DCV-driven climate events; and the constraints that currently exist to coping with them.

Members of the project team interviewed 30 stakeholders responsible for managing and studying the effects of climate variability on agriculture and water resources in the basin. The groups and agencies represented were USACE, Bureau of Reclamation (BoR), National Park Service, Central Nebraska Public Power and Irrigation District, TriBasin Natural Resources District, Nebraska Farm Bureau, American Rivers, Nebraska City Adaptive Management Group, and relevant departments and institutes of the University of Nebraska at Lincoln.

Time and budgetary constraints limited the pilot study to agencies located in eastern and central Nebraska, with two exceptions: a meeting with the Nebraska City Adaptive Management Group held in southwest Iowa, across the river from Nebraska City, and a meeting with the Bureau of Reclamation personnel in Grand Island, Nebraska, that included agency staff members in McCook, Nebraska, and Billings, Montana, by conference call.

Each interview began with a short briefing in which we explained the concept of DCV and described the PDO, TAG, and other ocean–atmosphere phenomena that influence climate in the basin. We explained how these phenomena, alone or in combination, may affect weather and climate patterns around the world in general and the basin in particular. Results of project research done to that time were displayed, showing the coincidence of specific DCV events with well-documented multiyear-to-decadal dry and wet spells in the basin (e.g., 1950s drought, late-1980s drought, and mid-1990s wet spell). Following questions and discussion of the materials presented, information needed to guide our research was elicited through semistructured discussions aimed at gaining perspectives on the impacts of past DCV events, the vulnerability of basin water and food production systems to DCV, and the potential uses of DCV outlooks, should such become available in the future.

Major conclusions of the pilot study were as follows:

1) Impacts of persistent, multiyear-to-decadal hydrometeorological anomalies differ from those associated with anomalies that persist for only a few seasons.
2) Geography determines which sectors are most sensitive to a given DCV. For example, water availability is critical for the recreation sector in Montana and in North and South Dakota; for the irrigation sector in Nebraska and Kansas; and for the navigation sector in the downstream Missouri River states.
3) The basin is much less resilient to multiyear-to-decadal droughts than to those of shorter duration.
4) Vulnerability of the agriculture sector to year-to-year hydrometeorological anomalies is decreasing because of the introduction of improved drought- and heat-resistant crop cultivars.
5) Multiyear-to-decadal hydrometeorological anomalies have adverse impacts on municipalities and power plants throughout the basin.
6) There exists a need for multiyear-to-decadal predictions of basin hydrometeorology that requires that DCVs be forecastable at this time scale.

7) Many agricultural producers and advisors would be receptive to information that identifies increased probabilities for future climate anomalies, and DCV outlooks have the potential for being applied to a variety of management and planning activities if they are presented in a manner that is understandable to users and shown to be credible.
8) Agencies such as USACE and BoR, responsible for management of large water resource infrastructure, would have difficulty applying long-term DCV forecasts (even if credible) because of legal constraints.
9) A more detailed information elicitation effort with information and questions focusing on individual sectors, stakeholders, and subregions of the basin was warranted.

b. Stakeholder workshops

Guided by insights and feedback gained in the pilot study, we carried out a series of three geographically dispersed workshops to gain a deeper understanding of the regional and sectoral effects of DCV on agriculture and water resources in the basin and of the climate information needed by stakeholders to cope with impacts of DCV. The first workshop was held in Kansas City, Missouri, in April 2008; the second was in Helena, Montana, in June 2009; and the third was in Lincoln, Nebraska, in November 2010. The objectives of these workshops were to:

1) demonstrate to stakeholders the relationship between DCV and major historic droughts and wet spells in the basin;
2) gather sector-specific information on impacts of the droughts of the 1980s and the 2000s and the prolonged wetness of the 1990s; and
3) evaluate the potential for developing future decadal climate outlooks as well as management options useful in preparing for and coping with protracted dry and wet spells.

The Kansas City and Helena workshops involved using a purposeful sampling technique to recruit a broad range of expert stakeholders from the lower and upper basin (i.e., federal, state, tribal, and local government; academics; agricultural and environmental groups; and private industry) representing agriculture, water, and other natural resource sectors. The Lincoln workshop targeted medium and large municipalities; state and federal water resource agencies; and consultants and university researchers from Colorado, North Dakota, South Dakota, Nebraska, Kansas, and Montana. In addition to the project investigators purposefully identifying key stakeholders to participate in the workshops, stakeholders were also able to identify other relevant experts that should participate in a ''snowball'' sampling effect to ensure adequate coverage of the sectors under investigation. In total, 90 stakeholders participated in the three workshops (i.e., 25 stakeholders in Kansas City; 43 stakeholders in Helena; and 22 stakeholders in Lincoln). Full affiliations of the stakeholders are described in reports of individual workshops (Mehta et al. 2010a,b,c).

A standardized methodology for exchange of information was employed at each of these workshops. Information about the project was provided to participants in advance of the workshops through *The Missouri Basin Climateer,* a newsletter initiated in our project. Further information was provided through a website (http://missouri.crces.org) established specifically for this project. A preliminary description of workshop's objectives and a list of questions to be discussed were provided to the participants a few days prior to the event. As in the pilot study, each workshop began with presentations by project team members. These dealt with the concept of DCV, statistical associations of DCV phenomena with basin hydrometeorology, and observed and simulated DCV impacts on water resources and crop yields in the basin.

To help ensure stakeholder comprehension of the materials presented, participants were asked to rate their understanding of the information conveyed to them. A handheld device, or ''clicker,'' allowed participants to answer questions posed to them instantaneously and anonymously. A summary of their answers was then projected on a screen. The responses identified topics that required further clarification; these were addressed in open discussion between the project team and stakeholders.

With a good level of understanding of DCV achieved, a number of facilitated sessions to gather additional stakeholder feedback followed. In the first of these, participants were asked to record their recollections of the impacts of the 1980s drought, 1990s wet spell, and 2000s drought. These were written on notecards and placed onto a ''sticky wall'' (a large piece of adhesive fabric hung on a wall) where the impacts were arranged by theme under the relevant time period. Then, in open discussions, the recollected impacts were elaborated on and/or challenged by stakeholders to help ensure the primary themes were adequately identified.

Small group discussions followed in which stakeholders presented their ideas on the potential use of DCI, and summaries were reported out to the full group by the individual group leaders. This was followed by a ''world café'' facilitation exercise (see Brown et al. 2007) where small groups rotate among tables to provide perspectives on the development and dissemination of decadal outlooks, as well as potential barriers to using such outlooks, with a different set of questions posed at each table.

4. DCV impacts in the basin

Workshop discussions yielded valuable information on the impacts of recognized DCV events on river flows, reservoir operations, urban water supply, and agricultural production in the basin. Participants agreed in general with the findings of the pilot study reported above. The inventory of DCV impacts identified, however, was much richer in detail than in the pilot study.

a. Impacts of decadal dry spells in the basin

1) Reservoir management

The decadal drought of the 1980s was the first real test of the Missouri River reservoir system since it became fully operational in the 1960s; the overall impact of this decadal drought led the basin states to compete and lobby for water stored in the six main stem reservoirs. Perhaps for the first time, states and stakeholders began to question the rationale underlying the reservoir system. Workshop participants reported that during decadal dry spells in the 1980s (approximately 1982/83–90) and the first decade of the twenty-first century (approximately 2001–08), sparse precipitation affected river flows and reservoir levels in the basin, with runoff into reservoirs reduced by as much as 50% in certain locations. This recollection is consistent with the main stem inflow data shown in Fig. 3. During both time periods, participants identified a number of related impacts on river-based activities and management. For example, stakeholders reported that low reservoir levels reduced the utility of infrastructure developed for recreation (e.g., water receded from boat docks and ramps, making them unusable in many locations) and that there were both increased fish kills in many rivers and streams and reductions in fish spawns as flows in tributaries diminished or ceased entirely. The low-flow conditions also resulted in a shortening of the navigation season on the Missouri River and in restrictions on drafts and tow lengths of barges to accommodate the more shallow channels. Hydropower production was also reduced during drought years, requiring users to purchase more expensive power from thermal power plants. These thermal power plants, themselves, had difficulty meeting downstream maximum water temperature requirements imposed by the National Environmental Policy Act (NEPA) of 1970.[2] During the years of low flow, some municipal and industrial intakes could no longer reach their regular water supplies.

Workshop participants also noted that the droughts of the 1980s fostered the enactment of federal legislation to increase water efficiency requirements in order to reduce overall demand for water. States were also reportedly prompted to enact relevant legislation. The Nebraska Unicameral, for example, acknowledged the linkage of surface water to groundwater and ultimately, in the 1990s, enacted LB-108, a law requiring each natural resource district in the state to maintain a groundwater management plan based upon the best available information. It was also noted that 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 U.S. Drought Monitor (available from http://droughtmonitor.unl.edu) gained recognition as an official trigger for activating drought response programs with its inclusion in the U.S. Farm Bill (Public Law 110-246, http://www.gpo.gov/fdsys/pkg/PLAW-110publ246/pdf/PLAW-110publ246.pdf).

The droughts of the first decade of this century (''the oughts'') were interrupted by floods in 2003–04 and 2009. Stakeholders noted similar impacts of previous droughts but also reported that forecasts of this mixture of droughts and floods were uncertain, and the causes of this uncertainty were not explained well to the public. As a result, public and official reactions were confused and fragmented. On the other hand, it was reported that these droughts led affected states to participate more actively in the Missouri River Recovery Implementation Committee (http://www.mrric.org), whose purpose is to help guide the prioritization, implementation, monitoring, evaluation, and adaptation of recovery actions and to ensure that public values are incorporated in recovery and mitigation plans.

2) Urban water

Stakeholders from several small, medium, and large urban communities cited a range of drought-related effects on municipal water systems. Major impacts and actions from the 1980s drought cited by the workshop participants are listed in Table 1. Because the 2000s drought was still fresh in their minds, stakeholders were able to provide more detail on the effects of this most recent drought on urban water supplies (listed in Table 2) Only a very small fraction of the more than 2000 urban communities in the basin are represented in these tables; however, they demonstrate substantial social and economic impacts of both the 1980s and the 2000s droughts. Among the impacts reported: water systems in many small urban areas throughout the basin were unable to operate because of low reservoir levels, and industries

[2] The NEPA of 1970 established national environmental policy and goals for the protection, maintenance, and enhancement of the environment, and it provides a process for achieving these goals within federal agencies.

TABLE 1. Summary of reported impacts of the 1980s drought on urban water systems in the Missouri River basin.

Impact	City (state)	Action	Consequences
Water shortage	Bozeman (Montana); Lincoln (Nebraska); Lawrence, Manhattan, Topeka, Kansas City (Kansas)	Water-use restriction; reduced lawn watering; additional water treatment facilities	Inadequate water supply for fire fighting
Increased water pollution	Bozeman (Montana); Omaha (Nebraska)	Addition of new water treatment facility	Additional burden on water treatment facilities
Intake/pumping modification	Urban water systems in the basin	Modification of intakes for lower water levels in rivers	Urban water systems in small urban areas in the basin unable to operate due to low reservoir levels
Restrictions on power plant operations	Many thermal power plants in the basin	Increased effluent monitoring and modification	Difficulty meeting National Pollutant Discharge Elimination System permit requirements
Reduced groundwater recharge and well-water level	Sioux Falls (South Dakota); Lincoln (Nebraska)	Installation of several temporary wells	Additional costs

had difficulty meeting National Pollutant Discharge Elimination System (NPDES)[3] permit requirements. In addition to low-flow impacts on water quantity and quality, higher than acceptable water temperatures in the Missouri River threatened power plant operations, especially those of nuclear plants operating under the Environmental Protection Agency's stringent effluent water temperature criteria.

The impacts of decadal droughts in the basin were stated to be widespread, both geographically and sectorally. Floods, on the other hand, were reported by participants to have primarily caused damage to more localized areas along rivers and streams. As previously discussed, it is to be noted that participants perceived that major changes in legislation and water management practices are initiated during periods of drought, especially during or after multiyear-to-decadal droughts. They commented that droughts of decadal duration cause friction in small agricultural communities among farmers, nearby communities, and responsible public officials because each of these interests requires water and generally from the same limited sources. In such circumstances, smaller communities often have to construct new wells or rely on larger water systems in nearby urban communities. It was reported that the droughts of the 2000s prompted efforts among competing users to develop such alternative sources of water. In addition, participants stressed that surface and groundwater declines led to water-use restrictions in many communities. Furthermore, the combination of water-use restrictions and public awareness programs increased water-use efficiency and reduced water demand during and following the drought years in many communities, resulting in economic losses to the water providers. It was also noted that water supply issues and the need for water restrictions prompted many cities to increase efforts to plan for coping with long-term droughts and governments to establish thresholds for assembling the governor's response team.[4] Another observation of the 2000s drought made by participants across the basin was that, while precipitation was reduced, storms, when they occurred, were more intense. This situation overwhelmed storm sewers and water treatment facilities in many urban areas, which is also discussed later in the article when referencing the 1990s wet period.

3) AGRICULTURAL PRODUCTION

Reduction in crop yield is another important impact of decadal drought, which was consistently reported by workshop participants. Basin-aggregated corn yields

[3] The NPDES permit program controls water pollution by regulating point sources such as pipes or manmade ditches that discharge pollutants into waters of the United States. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters.

[4] A typical state governor's response team/committee serves as a "clearinghouse" for information by bringing together federal partner agency representatives to report on water supply and moisture/crop conditions, while the state member agency officials take note of the federal reports as it pertains to their respective areas of agency purview and implement proactive mitigative measures as necessary or appropriate. Progress of such actions is reported back to the team/committee at the next monthly meeting or to team/committee staff if urgent in nature. Staff would report to the governor's office if warranted by the nature and importance of the situation.

reported by the National Agricultural Statistics Service (NASS) decreased by 30% in some years. Simulations of DCV impacts on crop yields in the basin at 75 locations in the basin by Mehta et al. (2012) are consistent with these observations/recollections. Drought-induced reductions in grass production and hay availability were largely responsible, according to the participants, for the increased selloffs of livestock that occurred during such years.

Participants also noted that droughts in the 1980s reduced crop production to the extent of causing a financial crisis that lead to an increase in farm consolidations. Lacking preplanning for prolonged droughts, disaster relief programs of an ad hoc nature were typically invoked. However, the droughts were also reported to have stimulated increased investments in center-pivot sprinkler irrigation systems and an increased interest in conservation tillage methods including no-till farming. Reduced water supplies also led to an increased use of groundwater and stored surface water for irrigation.

Additionally, participants stated that the decadal drought of the 2000s caused widespread water shortages that led to the exercise of legal rights for water usage and a curtailment of some users, such as farmers using irrigation, in order to protect senior rights and minimum stream flows. As was the case with the 1980s drought, the prolonged drought of 2000–08 resulted in low crop and forage yields as well as increased sales of cattle, increased investments in center-pivot irrigation systems, and an increase in no-till farming.

4) Ecological impacts

Low-flow conditions in the basin's streams and rivers were also reported to have had significant ecological consequences: for example, declines in the population of sauger (*Sander canadensis*; a food fish typical of rivers), waterfowl, and deer and increases in spruce bud infestation. Low water levels in the upper Missouri River also reportedly resulted in a lack of paddlefish spawn upstream of Fort Peck, Montana, and a decline in other recovering fish populations. Such low-flow conditions caused many streams to be closed to fishing. Participants also noted that several waterfowl dieoffs also occurred in rivers, streams, and marshes because of the generally dry conditions.

b. *Impacts of decadal wet spells in the basin*

1) River flows and reservoirs

As evidenced by average streamflow in the basin nearly doubling compared to the previous decade, the 1990s were wet in the basin. Flooding was widespread in 1993, 1995, and 1997, with the latter lingering in some areas into October 1998. Saturated soils carried over from 1992 exacerbated and accelerated the floods in 1993. According to workshop participants, floods impeded navigation on the Missouri River for several months in 1993 and again in 1995. The Kansas River and numerous streams also flooded during these years with consequent damage to farms, homes, crops, and dam spillways. It was reported that cities and towns that had never before experienced floods were inundated. Some metropolitan areas in the basin suffered major damage and have yet to recover from the effects of these floods. Participants stressed that weather and climate forecasts were largely uncertain and the reasons for this uncertainty were not explained to the public. As a result, reactions of responsible agencies and private interests were confused and disjointed. The fact that rainfall in the basin was below average from October 1993 to the end of 1994 also delayed public recognition that the region was experiencing a decadal wet spell.

2) Urban water

As reported previously, wet conditions prevailed across the entire basin during the mid-1990s. Unusually heavy precipitation in Montana led not only to flooding but also to increased turbidity in water supplies. Workshop participants stated that the imposition of flood control measures led to a reduction in hydropower generation for short periods because of the need to release large amounts of water rapidly from the reservoirs. They also noted that, in the upper basin, flooding resulted in the initiation of flood disaster mitigation planning in communities such as Bozeman, Montana. Further downstream, wells in Sioux Falls, South Dakota, were flooded during the 1990s; the water purification plant and pumping stations were sandbagged to protect them from floodwaters; and the wet spell reduced revenues for the city's water system.

Similarly, the wet period produced a large surplus of water where the South Platte River, a tributary of the Missouri, flows through Denver, Colorado. Participants stated that reservoirs were full and spilling-over well into the summer seasons; demand for water was low. Further downstream on the Platte, river flows were high; Lincoln, Nebraska, had no difficulty in meeting water demands. However, a reduction in water consumption decreased revenues, requiring the Lincoln Water System to cut its costs. Concerns about water quality also arose because of the possibility that large fluxes of pesticide in runoff water would infiltrate supply wells. Floodwaters also threatened to interrupt piped water supply. In nearby Omaha, the Platte River flooding threatened the well supply but did not curtail water use because water treatment plants were able to cope with the increased load of impurities in well water.

TABLE 2. Summary of reported impacts of the 2000s drought on urban water systems in the Missouri River basin.

Impact	City (state)	Action	Consequences
Water shortage	Cities in Montana	Public awareness program	Increase in water-use efficiency
	Bozeman (Montana)	Increased water treatment operations to avoid state regulation violation; aggressive leak detection and repair program	
	Lincoln (Nebraska)	Mandatory water-use restrictions	Customer confidence reduced; economic development negatively affected; lower water system revenue; elected officials reluctant to implement mandatory restrictions fearing adverse impacts on future development and next elections
	Omaha (Nebraska)	Curtailment of water use due to limitations in supply and distribution	Water treatment facilities strained to meet increased demand; high summer water demand increased revenue
	Denver (Colorado)	Water-use restrictions imposed to meet increased water demand and reduced water availability	Lower water demand after drought because of increased water-use efficiency; systems maintenance backlog due to reduced demand and revenue; \$50 million yr^{-1} loss during the 2000s drought years; postdrought revenue reduction prompting water system to consider water price increases
	Rural communities in Missouri	Transport of water to rural communities and for livestock operations necessary in many locations due to inadequate rural water supply	Municipalities along the Kansas River suffered due to low-flow conditions and low water tables; water quality also deteriorated
Increased water pollution	South Platte River watershed (Colorado, Nebraska)	—	A large and intense wildfire during 2002 drought caused water quality and sediment problems that are not yet solved
	Nebraska	Increased water treatment to filter out increased nitrate levels due to reduced water levels in wells	Increased water treatment costs to filter out increased nitrates
Intake/pumping modification	Small communities in South Dakota	Water imports from larger water systems; modification of water intakes from rivers	Warned by the USACE before the drought about deep-enough intake placement but costly modifications not done; postdrought cleaning of sand-clogged intakes by the BoR at a considerable expense
	St. Louis County (Missouri)		Missouri River level so low that municipal and other intakes became exposed, leading to concern that water would have to be drawn from alluvial wells
Restrictions on power plant operations	The basin	—	Higher water temperature affected power plant operations, especially those of nuclear power plants

Increased natural arsenic in stream flows	Ennis, Three Forks, Helena, Cascade, Great Falls (Montana)	Increased water treatment	—
Amendment/enactment of water laws	Nebraska	Amendment of water laws to require public water systems to monitor and report monthly on amounts of water pumped and on static water levels in wells; small communities allowed option to appropriate agriculture irrigation wells to provide water to domestic users; enactment of state law LB-962 requiring a sustainable balance between water uses and supplies, including public water provision and including surface and groundwater in future development; possible restriction on drilling new wells and adding more areas to irrigation if a stream/river basin is fully appropriated by the state	—
Urban development politics	Missouri	Formation of drought assessment committee and production of Missouri drought response plan	—

Still further downstream on the Missouri River, the Kansas City area reportedly suffered 10–15-ft of river bank erosion; intakes to the area's urban water systems had to be modified. Similarly, it was stated that most of Jefferson City, Missouri (the state capital), was flooded and water supply was almost lost for some time. 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 increasing rates to consumers. Prolonged wet spells also tax water treatment systems because they increase sedimentation rates that shorten the useful life of reservoirs. Intense storms, especially during wet spells, overwhelm storm sewer systems, making it difficult to evacuate water from urban areas.

Also, prolonged wet spells, especially when storms are frequent, can damage or destroy water supply and treatment infrastructure and damage wells, requiring costly repairs. Additionally, it was reported that floods during the 1990s wet spell damaged or destroyed many bridges, making it difficult for water systems staff to reach their work places or field locations. As a consequence, restoration of water service to consumers was often delayed. Participants also stressed that a prolonged wet spell can also make water system planners and consumers complacent about the eventual need to develop alternative sources of water. For example, it was highlighted that an initiative proposed by communities during the 1980s droughts to purchase more water from the USACE was deferred because of complacency about water security induced by the 1990s wet spell. As a result, water problems that developed during the 2000s droughts could not be dealt with effectively.

3) AGRICULTURAL PRODUCTION

Workshop participants commented 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.

It was also noted that crop losses occur in wet and dry spells. In wet spells, these result from late planting, leaching of nutrients from the soil, compaction of the soil by farm machinery, difficulties in weed control, and late and difficult harvest. For example, it was reported that bottom lands on the Iowa side of the Missouri River across from Nebraska City, Nebraska, were repeatedly flooded during the 1990s. The Natural Resources Conservation Service funded conversion of cropland there to wetlands and wildlife habitat. Another reported consequence of the 1990s wet spell was a significant increase in acreage under crop and flood insurance coverage.

5. Usefulness of decadal climate outlooks

As a part of this study, we also elicited stakeholder perceptions of the possible usefulness of decadal climate outlooks (DCOs). Workshop participants were shown mock climate forecasts of the 1980s and the 2000s drought periods and asked to treat them as if they were perfect forecasts, providing multiyear to a decade lead times. Asked to describe how such DCOs could have been applied, workshop participants came up with reasonably specific tactics and strategies.

It was the stakeholders' unanimous opinion that planning in all sectors would benefit greatly from DCOs, even from reliable information about the current state (or ''nowcast'') of each DCV phenomenon relevant to the basin. Moreover, as the reliability and lead time of useful prediction skill of the DCOs increase, the greater will be their role in decision making in all impacted sectors.

Since impacts on many societal sectors occur as a result of weather variability, it was stated that the DCOs should include some information about intraseasonal weather statistics over the DCO period. In general, participants judged that DCOs could be very useful in guiding a broad range of short- and long-term decision making. They might serve, as well, as an educational tool to foster awareness of the inevitability of future climate variability and extreme events, and help justify proactive management and associated expenditures. More specific potential uses of DCOs in the management of river flows and reservoirs, urban water supply, and agricultural production are described in the following sections.

a. River flows and reservoirs

Workshop participants judged that DCOs would help with large-scale water management in a variety of ways that would allow proactive, rather than reactive, management of river flows and reservoirs. In the realm of annual reservoir operations, for example, DCOs might be used to determine the water levels to be maintained and when and how much water should be released (particularly in spring). They might also be used to provide early warning of the potential for flooding so that steps might be taken to protect people and critical infrastructure in flood plains such as levees. DCOs might also affect decisions with regard to flood insurance coverage.

For purposes of long-term planning, DCOs might be coupled with hydrology models to predict reservoir inflows. If so, changes in agricultural, industrial, municipal, ecosystem, and fishery requirements for water might be better predicted. Workshop participants judged that DCOs longer than 10–20 yr in advance might not be actionable, except in the case of reservoir and other water infrastructure construction. On the other hand, a reliable estimate of expected inflows over the coming 5–10 yr could be useful because irrigation and fisheries water rights are based on 10-yr forecasts. Reliable DCOs would also enable tradeoffs among agricultural, wildlife, and recreational uses of water, which all affect prospects for tourism.

Participants opined that DCOs that indicate a high probability of a lengthy wet spell forthcoming would encourage and guide significant changes in flood protection strategies: that is, whether to build new levees, install internal drainage infrastructure, or encourage flood zone buyouts. By allowing estimates of possible damage due to climate variability, such DCOs could aid urban water agencies in budgeting exercises and in justifying capital outlays. Similarly, the river- and reservoir-based recreation industry might use DCOs predicting a wet/dry spell in management of existing marinas (e.g., dredging) and in design and construction of new ones (e.g., ramp design and placement).

As they bear on the sustainability of navigation on the Missouri River, it was stated that DCOs may also be useful in making investment decisions by barge and rail companies. The electricity-generation industry might also use DCOs to make decisions with respect to the location and construction of new plants, placement of water intakes, wholesale purchase of fuel, and marketing of electricity. Since thermal power plants, especially nuclear power plants, must meet very stringent regulations about the temperature of cooling water released into the rivers from which it is drawn, DCOs could be used in planning operations of such plants and in management of effluent water temperatures.

b. Urban water

With regard to urban water systems, workshop participants described how DCOs could be used in water management and planning, land-use planning, budgeting, and public education. However, it was also reported that, within a DCO, monthly and seasonal climate predictions are also needed for decision making in the face of impending droughts and floods. Nonetheless, participants stated that a DCO predicting dry conditions could foster community efforts to optimize the conjunctive use of surface and groundwater, where possible. This could include preparations for invoking restrictions on water use and initiating or strengthening water conservation campaigns. It could justify water audits and system upgrades, encourage the acquisition of alternative water supplies, and assist in water management. In the case of groundwater sources, the DCO might help in determination of which well fields to use. If a drought is predicted, aquifers near a river would be used first in anticipation of reductions in aquifer levels as the river flow decreases in response to drought; those farther away would be used later. Similarly, for outlooks of a wet spell, communities could foster emergency preparations for flood events with information campaigns, prepositioning materials for levee reinforcement, and adjustments in reservoir regulation to accommodate an increased volume of water in storage through programmed releases.

Participants reported that a DCO predicting long-term dry conditions could foster support for construction of new reservoirs and development of new well fields, aquifer recharge facilities, and water treatment plants. Cities might also use the DCO to prompt the acquisition of additional water rights or participate in water trading where applicable. The DCOs might also guide reallocation of water stored in federally managed reservoirs for urban use. Such action, however, would require political authorization, possibly triggering demands from other regions and societal sectors. Such predictions might also be used to justify severe water-use restrictions at the onset of a drought, rather than invoking emergency measures after water security has already been endangered.

In terms of land-use planning, a prediction of extended drought might also be used in landscape design: for example, the conversion of city parkland to native vegetation requiring less water for its maintenance. Conservation policies could also be updated, developed, or expanded through new ordinances and incentive programs to increase water-use efficiency and reduce overall water use.

c. *Agricultural production*

As a whole, workshop participants mentioned many potential uses of DCOs by agricultural producers, such as aiding in the selection of crops and cultivars for planting; for changes in crop rotation and/or tillage practices; and for irrigation planning, including arrangements for access to water supplies and numbers of intakes and types of irrigation equipment to provide. Similarly, for shorter-term decision making, planning for the types and quantities of fertilizers to lay by and possibly the timing of their application (fall and spring) can be aided by DCOs. The decision to purchase or not to purchase crop insurance coverage might also be guided by DCOs. Livestock producers might also use DCOs to determine herd size and whether alternative feeding options may be required (rangeland grazing, supplemental feeding, or feedlots). DCOs could also be used by agencies responsible for wildfire control to guide the purchase of the types and quantities of firefighting equipment that may be needed; for estimating the number of firefighters required; for prepositioning firefighters and firefighting equipment and supplies; and for determining the appropriateness of controlled burns.

It was stated that agricultural producers could also use DCOs for more long-term decision making, such as deciding between dry land or irrigated cropping systems and what types of crops to produce; whether to expand or modify irrigation and water systems; the implementation of conservation measures; if their livestock production system should be modified (e.g., buy or lease more land, make more use of feedlots for cattle, change management practices, etc.); and whether their operation will be viable under projected conditions such as an extended drought. On a larger scale, DCOs could also influence decisions with respect to biofuel production: that is, whether to convert from conventional crops that are heavy water users or that suffer great loss of yields in drought to the more conservative water-using grasses or other types of vegetation that are usable in the production of biofuels. The possible role of DCOs in commodities trading and international agricultural trade agreements is yet to be explored, but DCOs should certainly have a major role.

It was also noted that DCOs would also be useful for decision making on general issues of water and land management. The need for enhanced management efforts to protect habitat critical for fisheries and other wildlife and for protecting the quality of surface and groundwater resources vital to human populations are examples of these issues.

6. Potential barriers to using decadal climate outlooks

Stakeholders at the workshop expressed considerable interest in the possibility of using DCOs but also identified several potential barriers to their use. The lack of knowledge about the likely reliability of the DCOs was the most mentioned and the most important of these potential barriers. Scientists must help build confidence in the users in DCV science and DCI through demonstrations of DCO prediction skill. At this time, this can only be done by "retrocasting" (climate modelers call it "hindcasting") the climatic conditions and impacts (e.g., crop yields) of past DCV events. There was a general consensus in the workshops that it is also very important to frame the accuracy of DCOs within probability limits. It was noted that the overall decision-making process in many sectors is complex and sensitive to risk perception, and a combination of subjective and objective hedging to minimize risk is involved. It was also stated that climate is just one of the variables considered in the decision-making process; it can become more influential in that process as forecast accuracy improves. The consequences of a wrong forecast are also considered by decision makers, including the possibility of litigation brought on by actions based on inaccurate DCI.

Institutional barriers to the use of DCOs are also an important concern. For example, water release decisions by the USACE are based on actual water in storage and past history of weather and climate variability in the region; weather/climate forecasts are not generally used in deciding when and how much water to release. A clear demonstration of climate forecast accuracy and reliability might reduce this institutional barrier. However, the use of climate forecasts in USACE reservoir regulation could require formulation of a new environmental impact statement under NEPA, which could be a long and expensive process. Similarly, because of legislative mandates, there is limited flexibility in changing the amount of reservoir storage space allocated for flood storage. Certain changes in a reservoir's authorized uses may require action by the U.S. Congress.

Also expressed was an acute need for communities of climate scientists, water resource scientists and managers, and other involved stakeholders to educate one another to develop a mutual understanding of their perspectives and a common language for communicating ideas and needs. Clarity in information delivery is also very important; explanations of sources of potential predictability and limits of predictions are essential. Nonetheless, the general consensus of workshop participants was that, even if of limited accuracy, DCOs would be useful if they are clearly defined within levels of uncertainty and provide the kinds of information (described in section 7) needed by stakeholders.

Lack of clarity about the relationship between DCV phenomena and greenhouse-warming-driven climatic change can also pose a barrier to the use of DCOs. Participants stressed that current controversies regarding global warming confuse the general public and make it more difficult for scientists to convey 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, which is also expressed as ''first in time, first in right'') that does not allow flexibility in reservoir and water system operations. It was stated that the unwillingness of politicians and business boosters to acknowledge the existence of water problems in a specific urban area could also create a barrier to effective use of DCOs; however, this may vary by urban area and the judgment of elected officials and other community leaders in those areas.

It was noted that social, political, and cultural factors; a natural resistance to change; and a lack of the financial means necessary to implement needed changes may also pose barriers to the use of DCOs. Public resistance to government funding for infrastructure change and inflexible farm benefit programs would also limit the use of DCOs. It may also be that the general public will consider climate less important in resource management than other factors. It was stated that the possibility of incorrect predictions, especially if a history of skillful predictions has not been established, may predispose the public to ignore DCOs. Additionally, ''acts of nature'' that do not seem consistent with predicted trends (e.g., one or more 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. Finally, a suspicion that scientific misinformation is (for whatever reason) being deliberately promulgated would also predispose the public to ignore DCOs.

7. Stakeholder recommendations

Stakeholders made many recommendations about how their needs for DCI might be met. The main recommendations are described below. More details are given in Mehta et al. (2010a,b,c).

a. *Decadal climate variability*

Causes of DCV should be described in terms that laymen can understand. Impacts of past DCV instances should be documented fully, and the USACE and BoR should be involved in compiling information on impacts of DCV on the water sector. The difference between climate scenarios and forecasts should also be made clear, and climate scientists and climate information should be readily accessible to stakeholders at key decision-making times for various sectors.

b. *Decadal climate information*

Climate forecasters should pay much more attention to the DCI needs of stakeholders in the basin. A concerted effort is needed to define DCI requirements in close partnership with users in various sectors, and social scientists should be more engaged in the assessment of DCV impacts. Scenario-planning exercises involving user communities and climate scientists are also needed. Greater engagement of existing user networks and news media is also needed to channel DCI to users. To convey the usefulness of DCI to prospective user communities, early efforts should be focused on a few promising sectors and subbasins.

c. *Decadal climate outlook*

DCOs should be produced at the spatial and temporal resolutions required by each societal sector and geographical region, and involvement of decision makers is critical in incorporating the DCOs into the overall water-planning process. Perhaps a three-category framework of classification of temperature and precipitation (below average, average, and above average) would convey the confidence of forecasters in their DCOs, and greater credibility may accrue to DCOs were they incorporated in a decision support system provided to users by a federal agency such as NOAA. USACE and BoR should also be involved in disseminating DCO and information on anticipated impacts.

8. Conclusions

The basin covers over 1.3×10^6 km^2 in northern United States and southern Canada. It is home to over 2000 urban communities and 28 Native American tribes. The basin produces approximately 46% of wheat, 22% of grain corn, and 34% of cattle produced by the United States and is therefore a ''bread basket'' not only of the United States but also of the world. There are clear and quantifiable influences of DCV on the basin hydrometeorology and water and crop yields.

This study presents the results of interactions between climate, water resources, and agricultural scientists and 120 stakeholders representing the water and agricultural production sectors in the basin. These interactions occurred in individual interviews and three facilitated workshops in the basin. It was found that impacts of decadal climate variability are qualitatively different from those associated with seasonal to interannual climate variability. There are substantial impacts of decadal dry and wet spells on infrastructure, recreation, power, river navigation, state and national legislation for water management and efficiency, urban water systems, crop production, hay and grass production, livestock, ecology, and the economy. Intrastate and interstate conflicts in the basin also arise about the use of water stored in the basin's reservoirs.

Stakeholders have clear notions about their needs for decadal climate information, including ''nowcasts,'' in all affected sectors and have offered specific suggestions as to how these might be met. Long-term decision making, especially in infrastructure investments, the agricultural sector, and water and land management, would benefit greatly by 5–10-yr climate outlooks, especially if provided as a part of a decision support system for affected sectors. However, while stakeholders are eager to have decadal climate information, including outlooks, there are many potential barriers to the use of such information. The first and foremost barrier is that the credibility of decadal climate outlooks is yet to be established by forecasts of past decadal climate variability, known as decadal hindcasts in the climate modeling community. Second, the nature of institutional rules and regulations, laws, and legal precedents that pose obstacles to the use of decadal climate information must be better understood and means to modify these, where possible, must be sought. This study also revealed the need for mutual education of stakeholders and climate scientists and for combined scenario-planning exercises by the two. This study has also shown the need for more quantitative studies of decadal climate variability impacts and the need to draw more generalizable and detailed conclusions from such studies because of the importance of understanding, predicting, and adapting to such impacts in the basin and elsewhere.

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