FACTORS INFLUENCING THE USE OF CLIMATE INFORMATION BY COLORADO MUNICIPAL WATER MANAGERS

Running head: Climate information use by water managers

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ABSTRACT:

Water supplies in Colorado are sensitive to climate variability. Throughout the study period (2004-2009), there was an increase in demand for climate products and climate education by water management decision makers, which we attribute to a severe drought beginning in 2002 that changed the decision makers' perception of risk. Once decision makers' recognized that they were vulnerable to water supply shortages, they sought out information and education from the Western Water Assessment (WWA). Building on relationships established prior to the 2002 drought, WWA improved the climate literacy of water managers through enhanced interaction, which resulted in an increased use of climate information, outlooks and projections in water

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planning. In addition, in the way that climate science can inform decision-making, we documented how decision makers can inform climate science in the need for additional research. In this article, we show the evolution of the use of different types of climate products and explain the connections among drought, perception of risk, climate literacy, and interactions with climate information providers.

Key words: climate information, climate products, climate services, water management, western U.S., drought

INTRODUCTION

Rapid population growth, finite water resources, and increasing climate variability are making the western U.S. increasingly vulnerable to drought (U.S. Department of Interior 2005). Yet water management decision makers (hereafter 'water managers') have not been taking advantage of all the climate information and forecasts available from the National Oceanic Atmospheric Administration (NOAA), and other Federal agencies and research institutions (CCSP 2008). The use of climate information[3] alone cannot decrease a water provider's vulnerability to water shortages; however, historic observations and climate projections at seasonal to decadal timescales can potentially help them prepare for drought. Given the impact of climate on water supplies, this study was motivated by interest in how climate information providers communicate with municipal water managers, who in turn might use the information to better prepare for water supply shortages on interannual and longer (30–50 year) time scales.

Previous studies have shown that 1- or 3-month seasonal climate outlooks[4] issued by the NOAA Climate Prediction Center (CPC) are hard to locate on the web, they are hard to understand, they do not address relevant climate variables, and they do not have high enough skill and long enough lead times (Callahan et al., 1999; Carter & Morehouse 2003; Gamble et al. 2003; Hartmann et al. 2002; Pagano et al. 2001, 2002; Rayner et al. 2005; Steinemann 2006). These studies suggested that water managers would be more likely to incorporate that information into

[3] We define *climate information* as current conditions or historic records of climate-related variables such as temperature, precipitation, snow water equivalent, streamflow and soil moisture.
[4] The previous studies cited here use 'climate forecasts' to refer to seasonal climate outlooks, but we are using the official NOAA term for the products (O'Lenic et al 2008). *Climate outlooks* are projections (often called forecasts) of temperature and precipitation for months or seasons in the future at the scale of climate divisions.

their operational models if forecasters produce evaluations of seasonal climate outlooks that water managers could understand, and if they combined climate outlooks with streamflow forecasts that intersect with the existing knowledge base of water managers (Carter and Morehouse 2003; Gamble et al. 2003; Hartmann et al. 2002; Huppert et al. 2002; Pagano et al. 2001, 2002; Rayner et al. 2005; Steinemann 2006). In addition, these studies suggested that increased communication between forecasters and water managers was necessary for water managers to appreciate the utility of climate outlooks and for climate scientists to recognize the uses and needs of forecasts by water managers (Callahan et al. 1999; Carter & Morehouse 2003; Gamble et al. 2003; Hartmann et al. 2002; Huppert et al. 2002; O'Conner et al. 1999; Pagano et al. 2001, 2002).

These studies had focused on the following regions of the U.S.[5]: Pennsylvania (O'Conner et al. 1999), the Pacific North West (Callahan et al. 1999, Rayner et al. 2005), Arizona (Pagano et al. 2001, 2002,; Carter & Morehouse 2003), California (Rayner et al. 2005), Washington D.C. (Rayner et al. 2005) and Georgia (Steinemann 2006). These studies were not directly applicable to Colorado because several climatological and societal factors distinguish the state from previous study regions. In Colorado, water managers have both an established relationship with climate scientists and experience with a recent drought. In addition, whereas the previous studies had looked only at the use of climate outlooks in annual water management operations, the use

[5] There are six independent studies with distinct time periods and groups of managers studied, as well as several additional papers that reference or build on these six studies.

of climate information, seasonal climate outlooks, and climate change projections[6] in both annual and long-term (30–50 year) decision processes is also important in Colorado.

This research focuses on six water providers in the Colorado Front Range, an area that extends about 100 miles along the eastern side of the Rocky Mountains from Fort Collins in the north to Colorado Springs in the south. Five water providers are affiliated with cities: Aurora Water, the City of Boulder Water Utility, Colorado Springs Utilities, Denver Water, and the City of Westminster Water Resources and Treatment Division; the last is a conservancy district: Northern Colorado Water Conservancy District (Northern Water) [7]. We chose these water management agencies based on their size and the proportion of the total Colorado population they serve (Table 1). Together, these organizations provide water to about 60% of Colorado's population.

This study sought to identify the uses and needs for climate information, outlooks and projections among the six large water providers in Colorado and to evaluate the factors affecting their annual and long-term decisions. Our study period started after the severe drought in 2002 which caused water managers to rethink their long-term supply plans. We evaluated how the drought affected and possibly changed water management decisions and highlighted why Colorado is unique in terms of water management challenges and adaptation to climate.

[6] *Climate change projections* are the output from General Circulation Models (GCMs) that provide climate scenarios for 50–100+ years in the future at the scale of large areas (300km grids).

[7] Northern Water, Colorado's first water conservancy district, provides water for agricultural, municipal, domestic and industrial uses in northeastern Colorado. Thirty-three towns and cities own shares of Northern's water, including Boulder.

BACKGROUND

Our study capitalized on an ongoing iterative process of communication and education between WWA and municipal water managers in Colorado that was already in place when this study began. WWA began in 1999, as the third of ten Regional Integrated Sciences and Assessments (RISAs) now funded by NOAA. The WWA was established with the purpose of identifying regional vulnerabilities to climate variability and change and the goal of developing products that will help water managers in the Intermountain West (Colorado, Wyoming, and Utah) adapt to this change. Through research, education and communication efforts over the last decade, WWA fostered relationships between water managers and scientists in order to educate the water managers about available climate information and forecasts and to help NOAA develop climate products useful to water managers (http://wwa.colorado.edu).

The State of Colorado developed a means to disseminate information on drought conditions with the establishment of the Water Availability Task Force (WATF) in 1981. Since then, WATF meetings have been held at least three times per year, and monthly in times of drought. At the WATF meeting, representatives from the State Climatologist's Office, the Natural Resources Conservation Service (NRCS), the State Engineer's Office, Reclamation, and NOAA provide information on observations and forecasts of water supply, snowpack, precipitation, and streamflows. Scientists affiliated with WWA are also involved with the WATF, typically presenting seasonal climate outlooks and contributing to assessments of drought conditions. Drought conditions in Colorado began in 2000 and intensified in 2002. This study documents that water providers' interest in climate outlooks, projections, and other climate information increased after that turning point. Prior to the 2002 drought, representatives from water providers did not regularly attend the WATF meetings, with attendees primarily from State and Federal agencies. Water managers began regularly attending the WATF during the 2002 drought (Figure 1), and the WATF is now an important source of climate and water supply information for the six Colorado Front Range water providers included in this study.

The majority of annual water supplies in Colorado come from spring runoff of snowpack, which represents between 50–70% of annual precipitation in the mountainous regions of the state (Hunter et al. 2006; Serreze et al. 1999). The IPCC (2007b) defines sensitivity as "the degree to which a system is affected, either adversely or beneficially, by climate variability or change." We define the sensitivity of water supplies to climate variability as the "impact of natural variability of streamflows on annual water availability." Thus, while sensitivity to climate variability can be hard to quantify, most water supplies in Colorado are inherently sensitive to climate variability due to variations in winter snowpack that dominates water supplies, recent and anticipated population growth, and fully appropriated rivers (Nichols and Kenney 2003). Water managers have used current and historic climate information and streamflow forecasts[8] to prepare for interannual variability in supplies.

Colorado water providers rely on reservoirs to store spring runoff and insure an adequate water supply all year long. Thus water availability is based on both the quantity of water in the streams and aquifers and on the ability to divert, store and use that water. The water management community distinguishes between water *supplies* in the streams and rivers and water that is *available* to divert and use. Water *supply* is water in all states of the hydrologic cycle (except

[8] *Streamflow forecasts* are distinct from climate outlooks because they are projections of a unique parameter that is influenced by climate variables like temperature and precipitation.

water vapor): rain, snow, streamflows, soil moisture and groundwater. Water *availability* includes only the fraction of water supply that is accessible and sufficient to meet demands. Thus each water provider has a different water availability based on water rights and storage potential (Table 1). Whereas there are three common definitions of drought (meteorological, hydrological, and agricultural) (Pielke et al. 2005), the water management definition of drought is when water availability is not sufficient to meet demand (without enforcing water use restrictions) on an annual basis. A water provider whose annual water availability is more sensitive to climate variability relative to other providers is more vulnerable to water shortages and drought. The water providers in this study represent a range of sensitivities and abilities to meet demand in times of water shortages.

The variability and timing of precipitation in water supply basins, water rights priorities, and the ratio of average storage to annual demand affect the sensitivity of water supplies to climate variability. Most rivers in Colorado are dependent on runoff from spring snowmelt in the mountains for much of their streamflow. The degree to which a stream experiences large seasonal variability increases toward the Continental Divide. In addition, the topography and elevation in Colorado contribute to variations in winter snowfall and resulting annual water supplies across the different river basins (Ray et al. 2008). For example, a water provider who only has water supplies on the west side of the Continental Divide may be more sensitive to water supply shortages than a water provider that has supplies on both the east and west sides of the divide. This provider may be more vulnerable to drought when a water supply shortage or a call for water from a senior water right affects the west side, whereas a provider with supplies on both sides of the Continental Divide may be able to make up for shortages on one side with supplies on the other.

Water rights administration also affects annual water availability for cities because available streamflow is allocated to Colorado water users in order of seniority of water rights.. Most rivers in Colorado are fully appropriated, meaning sufficient water rights exist to claim all available streamflow during all but the very wettest periods. New water rights are only be able to take water in years that anomalously high snowfall in the mountains results in high spring runoff or during extraordinarily large rainstorms.

Most Colorado river basins experience a high degree of annual variability. Water systems across the state adjust to annual variability through use of reservoir storage to carry over water from wet years to dry years. Water providers that hold relatively senior water rights will be able to continue diverting during years with reduced streamflow and are not as dependent on reservoir storage as those with more junior water rights. A provider with a 1:1 ratio of reservoir storage to annual demand and no ownership of senior direct flow water rights might have a higher sensitivity to climate variability than a provider whose storage ratio is 2:1. One year of below average water supply may cause a significant drawdown of reservoirs in Westminster (1:1 ratio), while Aurora (~4:1) will be able to carry much more water over from one dry year into another because it can supply more than one year’s worth of demand with water stored in its reservoirs (Table 1). However, Westminster’s senior water rights enable diversions even in a dry year, while Aurora has more junior water rights, which it must offset with additional reservoir storage space to maintain a reliable supply.

In summary, Water managers in the Front Range of Colorado face many challenges in annual operating decisions as they plan ahead several decades to ensure water supply reliability. Their water supplies are inherently sensitive to climate, and a growing population means that they will continue to be vulnerable to droughts that decrease their annual water availability. In this study, we were able to use established connections between WWA and these water managers in order to observe their interest in climate information and ask them detailed questions about their decision processes and uses of climate products.

METHODS

This research was conducted between 2004 and 2009 using an 'interactive model' (Lemos & Morehouse 2005), which strives to facilitate ongoing relationships between researchers and stakeholders to achieve flows of information in both directions. The goal of the interactive model is to produce usable science, which requires stakeholder interactions and interdisciplinarity. According to Lemos and Morehouse, interdisciplinarity involves "scientists from different disciplines working together to tackle problems whose solutions cannot be achieved by any single discipline" (2005, p.62). The multi-disciplinary WWA umbrella comprises scientists from social sciences (policy, law, and economics) and physical sciences (atmospheric dynamics, climatology, geology, and hydrology). Our research structure was guided by the explicit needs of the stakeholders (water managers) so that the results will meet their informational needs. By understanding the uses and needs for climate information, outlooks and projections, information providers (e.g. NOAA) can produce more useful climate products and services.

Through out the study period, we interacted with several water managers from each of the six providers in interviews, meetings and workshops, as well as published accounts about this area (Klein et al. 2007; Kenney et al. 2004; Kenney et al. 2008; Klein & Kenney, 2005). These water managers have expertise in annual and long-term operations and management, supply planning and modeling, and demand management/conservation (Table 2). The interviews conducted specifically for this research took place between 2006 and 2007, although the study involved discussions at meetings and workshops with water providers over a five year period. In addition, since 2004 these providers have received a WWA publication, the *Intermountain West Climate Summary* eight times per year, which is partly intended to increase climate literacy. This publication provided annotated maps of current and forecasted climate conditions including streamflows and snowpack and other information to educate on climate. The goal of these efforts – workshops and the Summary – has been to improve water managers' climate literacy so they can better understand the sensitivity of their water supplies to climate variability and change and take advantage of the climate information, outlooks and projections from NOAA, NRCS and other climate information providers.

We synthesized information from the interviews, evaluations of public documents, and informal communications at meetings and workshops. The information obtained from water managers can be grouped into three categories: perception of risk, decision processes, and climate literacy, defined as their knowledge of the climate system and the impact of climate variability on water availability relative to annual operating decisions and long-term plans (Niepold et al. 2008). We wanted to understand perceptions of individual water managers because decision makers combine personal and subjective assessment of their systems' adaptability and vulnerability to climate variability or change with objective evidence (Ray 2004). Their perceptions includes opinions on the vulnerability of a water supply system to shortages due to climate variability, as well as the skill of climate outlooks and projections. During interviews, we asked questions about experiences with climate and weather events and using climate information to deal with those events (Appendix). During discussions at meetings and workshops, we assessed how water managers perceive climate variability and change, and how these perceptions differed among individual water managers. In particular, we wanted to know how water managers perceive that their vulnerability to water shortage might change with possible future climate change and how the 2002 drought influenced these perceptions.

We followed the policy sciences framework as described by Lasswell (1956) to assess how water managers use climate information to deal with the effects of climate variability on their water supplies. We identified points in both annual and long-term decision processes where climate information, outlooks, and projections either help or could potentially help water managers make decisions about water availability or demand management. First, we evaluated planning and policy documents, and city council meeting minutes to identify annual and long-term projections, operations, and plans (Table 3). We then used open-ended interviews based on a set of questions to speak with water managers at, or consultants for, each of the six providers (Appendix). Through these interviews, we gathered specific information about operational and planning models, decision processes, projections, and the uses and needs for climate information. We interviewed people responsible for different parts of the planning process, and identified times when climate information was currently being used and where it potentially could be used to help increase the reliability of the water supply system to make better decisions, both during the drought in 2002 and after.

Finally, we used an institutional analysis framework (Ray 2004; Ingram et al. 1984) to identify factors that affect the use of climate information and forecasts in annual and long-term decisions, including perception of risk, the drought of 2002, and interest in climate variability and change. By hosting meetings and workshops, WWA was actively trying to improve the climate literacy of water managers through the study period, and we analyzed how these interactions affected the water managers' use of climate information, outlooks and projections.

RESULTS & DISCUSSION

Our analysis shows that water managers in these six agencies now use climate information in both annual operating decisions and long-term (30–50 year) planning (see Table 4, which provides the source of all subsequent results except where noted). The results show that water providers' current interest in climate information, outlooks and projections was instigated after a severe drought, which elevated their perception of risk. These water managers use current and historic climate data in quantitative annual and long-term water availability and demand models, but they use climate outlooks only qualitatively in non-quantitative annual supply and demand projections (Table 5). They are working to figure out how to incorporate climate change projections in quantitative long-term supply reliability models. Since the drought of 2002, which caused water supply shortages across Colorado and the need for water use restrictions (Table 4; Pielke et al. 2005; Kenney et al. 2004), the six water managers have increased their use of climate information and projections and their climate literacy (Figure 1). They also have expressed an interest in additional climate education on the climate system, natural variability, and the skill and methodology of climate and streamflow forecasts (Table 6).

"Perception of risk" is the way a water manager understands the sensitivity of water availability to climate variability and the provider's vulnerability to drought. Water managers in this study indicated that they use information gained from their own experiences, anxieties about the uncertainty of the future, and media coverage of climate to define the risk their water supply systems face to the threat of changing climate variability. Water managers combine objective evidence, prior experiences and a subjective assessment of their systems' vulnerability to climate variability or change to make both annual and long-term decisions. This includes perceptions about the influence of climate on water supplies or about the skill of climate outlooks. The climate system is not fully understood and confidence among scientists in the ability of GCMs to predict future hydrologic conditions is low (IPCC 2007a), so water managers cannot assess future vulnerabilities to drought. Many scholars have found that a decision maker's perception of risk is just as important in the crafting of climate-related policy as the results of a quantitative risk assessment (Slovic 1987; Dessai et al. 2004; Grothmann & Patt, 2005; Leiserowitz 2005, 2006).

Annual Versus Long-Term Climate Information

Water managers in Colorado make decisions about water availability and demand to address annual operating decisions and planning for long-term system reliability. Annual operating decisions include consideration of the number of years associated with the longest drought period contained in the operating criteria or historic record of the water provider. The time frame encompassed in annual operating decisions will vary from one water provider to another based on the seniority of the provider's water rights and the degree to which its water system reliability depends on carry-over of reservoir storage from wet years to dry years. The annual operating decisions ensure a sufficient supply each year for the demands of people, business, industry, or in Northern Water's case, agriculture, throughout a period that might correspond to the number of years expected to be encompassed in a typical dry period. Inputs into these decisions include reservoir storage levels, tunnel and pipeline operations, water treatment, water source selection, and water distribution. Water managers in Colorado are accustomed to dealing with highly variable annual streamflows and have a level of confidence in the ability of water systems to perform as designed based on historic long-term averages. The water managers have an interest in interannual and shorter-term conditions to manage water systems for the expected dry periods for which they were designed. During the winter, water managers look at the accumulation of snow in the mountains and estimate how much runoff will be available to divert into reservoirs during the spring and summer. To make annual water availability projections, they use snowpack data from the NRCS SNOTEL gauges throughout the winter, and spring/summer streamflow forecasts from NRCS and the National Weather Service Colorado Basin River Forecast Center (CBRFC). This information is used to estimate annual water supplies, and quantitatively in annual operations models, which incorporate streamflow forecasts and historic water rights administration to project water availability for reservoir operations.

Long-term decisions or plans involve estimating future population growth and water demands and securing adequate water supplies to meet additional demands. Securing new supplies enables water providers to take additional water from the streams and rivers, and these may include building new reservoirs and conveyance systems and purchasing existing water rights. These efforts take many decades to accomplish, so water managers typically plan ahead 30–50 years. As discussed below, long-term decision-making is increasingly incorporating information on long-term climate variability and climate change.

Water managers' perception of risk and the climate factors they consider are different for annual operating decisions and long-term planning. Even though the risk of drought is renewed every year, one year of below average supplies may be mitigated by use of water stored from a previous wetter year or overcome by enforcing water use restrictions or other demand management strategies. The availability of supplies in one year may affect supplies in following years because water managers use reservoir storage to even fluctuations between wetter and drier years. A drought year could be followed by another drought year, a year of abundant supplies, or an average year. Therefore, the risk of annual shortages changes every year and it can improve or decrease each year depending on the extent to which a particular water system can accommodate the fluctuations of the previous few years. Long-term risk of drought is more enduring because if water providers do not prepare adequately for future demands or climate conditions, they will not be able to compensate quickly, resulting in longer periods of water shortages that deplete reservoir reserves and cannot be overcome with demand management policies. The water managers in this study have a longer history of using climate outlooks for annual operating decisions than of using climate projections for long-term planning. From their perspective, the likelihood of a single year deviating from the historic average in the short-term can be relatively well-defined whereas significant uncertainty exists regarding the degree to which the climate may vary from the average in the future.

Use of Climate Information, Outlooks and Projections in Annual Operating Decision Before 2002

NOAA climate scientists within WWA began interacting with water managers in the Colorado Front Range in 1997(Table 4),, providing forecasts of the El Niño event with meetings and informational packets. At that time, water providers were looking at historic gauge records of streamflows in their water supply basins to get an idea of the potential variability of their annual water supplies. Several providers regularly looked at the U.S. Drought Monitor, monitored U.S. Geological Survey streamflow gauges, and used winter and spring/summer streamflow forecasts from the NRCS and the CBRFC (Table 4).

Use of Climate Information, Outlooks and Projections in Long-term Planning Before 2002

For long-term planning, most water providers relied on the design basis for which the greatest amount of reliable data existed by assuming that future water supply variability would be like the historic record of streamflows. Prior to the 1990s, only two of the water providers (Denver and Northern Water) actively investigating use of paleo-reconstructed streamflows (Table 4), which provide information on the range of natural variability of drought in the past that were longer or more severe than any experienced in the 100+ years of the historic record. Between water years 1997 and 2000, water supplies were average or above average (McKee et al. 1999; Colorado Division of Water Resources 1997-2000), and WWA found that most water managers did not look at seasonal climate outlooks or climate change projections, instead they used historic streamflows and current water supply/snowpack data to assess their annual vulnerability to drought (Lewis 2003).

Use of Climate Information, Outlooks, and Projections in Annual Operating Decisions After 2002

Beginning in 2002, all six water providers indicated that they increased their use of climate information, outlooks, and projections in both annual operations and long-term planning decisions relative to the time period before the drought. To calculate annual water demand, these water managers previously used historic data on water use per capita, accounting for any new or anticipated development. However, because at least 50% of municipal annual water use is for outdoor lawn irrigation (Mayer et al. 1999), several providers have attempted to account for the impact of climate on water demand. Beginning in or after 2002, all six water managers started looking at seasonal climate outlooks issued monthly by NOAA/CPC and regional experimental seasonal guidance products from WWA to qualitatively anticipate above average summer demand. Summer demand information is especially important during years of below average snowpack and/or below average streamflow projections. These water managers also look at seasonal climate outlooks to anticipate times of low water supply, but this is only a qualitative use and they do not input any climate forecast information into models.

The four reasons given by the six study participants for not using climate outlooks quantitatively are consistent with previous studies (Callahan et al. 1999; Carter & Morehouse 2003; Gamble et al. 2003; Hartmann et al. 2002; Pagano et al. 2001, 2002; Rayner et al. 2005; Steinemann 2006). First, climate outlooks do not provide information on the appropriate scale. Climate outlooks are for climate divisions, not river basins or watersheds, which is the scale water managers use for streamflow forecasts. Second, climate outlooks provide information about temperature and precipitation, not streamflows. As of 2009, these water managers are not using water system operational models that can convert temperature and precipitation into streamflows. Operational water system models are typically constructed to use streamflow data and would need to be modified to bring in temperature and precipitation data, adequately correlate these data to historic streamflow data and reliably project future streamflow. Third, verification information about climate outlooks does not meet their needs. Many water managers do not understand skill scores or know the difference between skill and accuracy[9] (Table 6). Finally, water managers take the consistent above average temperature and EC ("equal chances") precipitation forecasts for the Intermountain West Region[10] (Livezey & Timofeyeva 2008) to mean there are no forecasted anomalies. Despite these limitations, water managers look at and discuss seasonal outlook, and incorporate them into "mental models," which combine objective evidence of current snowpack and streamflow conditions with a subjective assessment of their systems' reliability (Table 4).

Use of Climate Information, Outlooks and Projections in Long-term Planning After 2002

Most providers are planning ahead to 2030 and/or 2050 (Table 4). Such long-term planning involves ensuring system reliability as the water demand and population grow, which traditionally means acquiring additional water supplies. The amount of new water supplies needed is based on how much water demand and population are anticipated to grow. Cities like Aurora and Colorado Springs that have a lot of physical room to expand would need to acquire

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[9] *Accuracy* is the degree to which the forecast corresponds to what actually happened, and *skill* is the degree to which the forecast did better than a reference forecast (i.e. climatology) (Wilks 1995).

[10] According to the Forecast Evaluation Tool, a precipitation forecast was only made 1/4 to 1/3 of time for the winter (snow fall) months (http://fet.hwr.arizona.edu/ForecastEvaluationTool/).

more water than providers in Denver and Westminster that are physically blocked from expanding by the surrounding suburbs. Northern Water, while not physically expanding, will need to acquire more water to supply cities that are continuing grow. Assuming continued population growth, the annual water demand of all the water providers in this study will continue to increase in the next 20–40 years (Table 4).

All six water providers use supply reliability models to evaluate historic water supplies against future demands and ensure a reliable water supply under a range of climate conditions (Table 4). These models project future water demands onto the instrumental record of streamflows and reservoir storage, which includes the range of climate variability from the recent past. All the water managers in this study are interested in using paleo-reconstructed streamflows created from tree-rings to increase the range of climate variability in their long-term models because these reconstructions include longer and more severe droughts than indicated by the instrumental record (Woodhouse & Lukas 2006). Since 2002, all six providers have expressed an interest in integrate paleo-reconstructions of streamflows into their planning. Several providers already have or are trying to incorporate paleo-reconstructed streamflows into their models, but this has proved difficult due to differing timescales: the reconstructed streamflows are for annual flows and the models require weekly or monthly values (Table 4).

Before and After the 2002 Drought

Interest in and understanding of climate by water managers has increased through the study period (Table 4). Beginning in 1998 and continuing through the study period, the water managers in this study have attended many workshops and meetings co-organized by NOAA and

WWA. These workshops had two purposes: 1) to both educate water managers on topics such as seasonal forecasting, climate variability and change, paleo reconstructions of streamflows, forecast verification, and climate change modeling, and 2) to improve climate scientists' understanding of water system operations decision making as part of a process to identify opportunities for new climate information to meet the needs of water managers (Figure 1). Most of these workshops occurred after the 2002 drought in parallel with a renewed interest in the WATF. During the 2002 drought WWA conducted "rapid-response" efforts to inform and educate water managers including regularly updating summaries of current climate information and outlooks. These summaries were distributed as information sheets at stakeholder meetings such as the WATF and discussions within conference calls.

With their improved climate literacy, water managers in the Front Range of Colorado have started to use climate information, outlooks and projections in new ways as well as to fund research to develop more useful climate products (Figure 1).. Boulder, Denver, Northern and Westminster now incorporate tree ring reconstructed streamflows into long-term supply reliability models in order to extend the range of historic climate variability. In Boulder, formal drought plans use climate related variables like snowpack and projected reservoir storage to "trigger" different stages of drought and associated water use restrictions. This approach allows water managers to ensure that demand will not exceed supply if water shortages are expected (Table 4). Water managers also want to understand the skill of forecasts, including seasonal climate outlooks, streamflow forecasts, and long-term climate change projections. To do this they need to understand both forecast methodology and verification techniques. In February

2008, WWA co-hosted a workshop about streamflow forecast verification with NWS and NRCS to meet this need by regional water managers.

For long-term planning, providers are beginning to pay close attention to climate change projections and are trying to incorporate them into long-term supply reliability models. Since 2006, both Aurora Water and Denver Water have hired climate change scientists to specifically address this issue. Boulder has worked with two private companies, Stratus Consulting and AMEC, to complete a study of the potential effects of climate change on its water supplies that was partially funded by NOAA. Water managers in Colorado are working together to use climate information in water supply planning. Collaboration among water providers on water supply planning and climate is unprecedented in Colorado. Since 2007, a project funded by WWA, AMEC, and four Front Range cities (Aurora, Boulder, Colorado Springs, and Denver) are developing a model that uses climate variables to find analogue years of streamflows and to create ensemble forecasts of management variables like reservoir storage. In 2008, Boulder completed a climate change study that used climate change projections to assess the long-term variability of Boulder's water supplies. Also in 2008, water managers from six providers (Aurora, Boulder, Fort Collins, Colorado Springs, Denver, and Northern) began funding the Joint Front Range Climate Change Vulnerability Study on the impact of climate change on the water resources in Colorado. This study will use downscaled projections of changes in temperature and precipitation from GCMs in regional hydrologic models (Table 4).

Two-way Flow of Information Between Decision Makers and Climate Information Providers

Throughout the study period as interactions with climate information providers has helped improve climate literacy among water managers (Figure 1), we have seen how the water managers have also informed climate sciences on needs for additional research. The water managers in this study have specific needs for climate information, outlooks and projections, and they had insightful suggestions about different or additional information needs. The bottom half of Table 5 shows specific types of climate outlooks, projections and streamflow forecasts that water managers would like to that are currently not available or not skillful enough. Table 6 contains specific ideas for climate education, data and services that water managers would like the climate science community to provide. These results are consistent with a recent federal interagency perspective on climate change and water resource management (Brekke et al 2009).

Water managers have an interest in climate information and a better understanding of climate systems than the average public due to the nature of their work. An increased understanding of the availability and utility of climate information and natural variability will help water managers comprehend and use climate information as well as place anomalous years in a historical perspective. For annual operating decisions, water managers would like streamflow forecasts for the South Platte and Arkansas Rivers similar to what is available for the Colorado River. They need a better understanding of the connections among snowpack, soil moisture, other climate variables like temperature, and streamflows and recommend research in these areas which would enable more accurate and possibly earlier streamflow forecasts. Also needed are more skillful spring and summer streamflow forecasts and precipitation outlooks at lead times in the fall in order to give water managers an earlier assessment of water availability for the following year and allow them to plan for water use restrictions if necessary.

For long-term planning, water managers want to learn more about the difference between natural variability and climate change projections, especially as climate change projections translate into streamflows. They want to know how climate change may affect the timing and volume of streamflows and water rights administration in the future. In addition to education efforts, a research priority should be to quantify the relationship among weather variables (snowpack, soil moisture, temperature, and precipitation) and streamflow in order to increase the accuracy of seasonal streamflow forecasts. The Natural Resources Conservation Service in Utah has already begun this kind of research (Julander & Perkins 2004), and water managers are willing to fund the installation of new soil moisture sensors. Finally, the water managers in this study supported increased monitoring of precipitation by expanding the SNOTEL observation network because a more accurate understanding of current climate will lead to a better understanding of possible changes that are occurring and are projected to occur.

CONCLUSION

Water managers in the Colorado Front Range use a variety of climate information, outlooks and projections in annual operating decisions and long-term plans. In general, the water managers in this study use climate information quantitatively in annual operating decisions and long-term decision models, use seasonal climate outlooks qualitatively in annual operating decisions, and are beginning to use climate change projections to assess future vulnerability to drought. They look at seasonal climate outlooks and climate change projections, but for the most part they do not use them quantitatively due to inadequate skill, spatial and temporal scales, or lack of variables (i.e. monthly streamflows) that they need for input to their models. Throughout the study period, we observed an increased interest in climate information, outlooks and projections as the water managers improved their climate literacy. Water managers are now able to articulate the specific kinds of climate information, outlooks and projections they need in order to increase their ability to quantitatively use these climate products in their annual operations and long-term decision models. Thus, climate professionals have a better understanding of the factors affecting management of water systems and the types of climate information that may be useful in supporting water manager decision-making.

We attribute this increased interest in climate and a desire to improve one's climate literacy to an elevated in perception of risk that occurred as a result of the severe drought in 2002. 2002 appears to be a focusing event (Birkland 1998; Pulwarty et al. 2005) where water managers' perception of risk shifted as they realized that their water supply systems may not be reliable if they only plan for droughts in the historic record. This experience increased wate r managers' anxiety over a possible future where water shortages may occur with a different pattern or frequency than they did in the past. Thereafter they sought out new climate information and education leading to improved climate literacy and increased use of climate products. Despite concerns with climate outlooks and projections, water managers across the Front Range of Colorado want to learn how they can increase their use of climate outlooks and projections to make their systems more reliable in the face of possible changing climate variability.

The interactions between WWA and water managers before and throughout this critical time of shifting perceptions helped foster these changes. Scientists and climate information providers helped elevate water managers' perception of risk by increasing climate education efforts through workshops, meetings, and publications specifically developed for water resource decision makers. Improved climate literacy enabled water managers to understand the benefits of using climate information and forecasts in annual and long-term decisions. Another outcome was an improved understanding by climate specialists of the operational factors affecting water managers' decisions such as water rights limitations, sensitivity to seasonal aspects of precipitation, and the need for translation of temperature and precipitation data into streamflow data. Our study confirms the value of the co-production of knowledge (Lemos and Morehouse 2005) that results in climate science informing but not prescribing decision making, and decision-making informing climate science but not prescribing research priorities. Climate information providers, like the Western Water Assessment and other RISA programs, should continue and increase these partnership education and outreach efforts. Through regular communication, we can help water mangers increase their understanding of climate systems, how forecasts are made, and the current limitation of seasonal and longer forecasts. Regular communication will also improve the understanding climate information providers have of water system operations and the type and format of climate information of use to water managers. Armed with that information, water managers and climate professionals will be better suited to combine their technical expertise on water supply and management with climate information, outlooks and projections to adapt to a changing climate and increase the reliability of their water availability and manage demand now and in the future.

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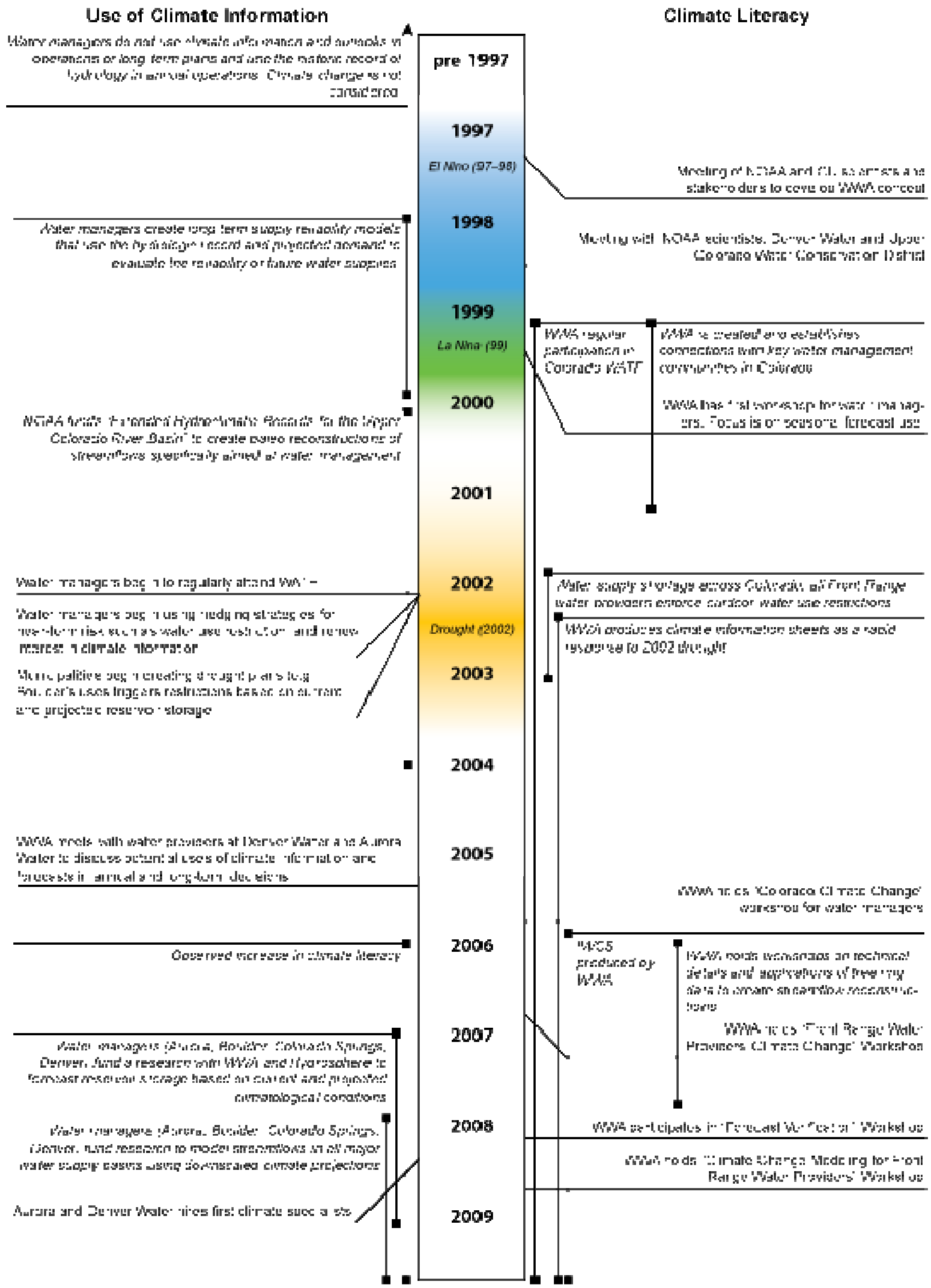

Figure 1. Time line showing how significant climatological events and interactions with WWA helped increase water managers' perception of risk, climate literacy and use of climate information and forecasts.

Table 1. Table of water providers, population, annual supply, % of total CO population (personal communication with water managers throughout the study period).

Provider	**Population served**	**% of Colorado population (2003)**	**Annual availability/system yield (acre-feet)**	**Reservoir storage capacity (acre-feet)**	**Annual demand (acre-feet)**	**Ratio of storage: demand**
Aurora	289,325	6.4%	77,900	156,000	40,186	3.9:1
Boulder	93,051	2.0%	24,000	26,000	24,000	1:1
Colorado Springs	370,448	8.1%	119,000	243,000	80,000	3:1
Denver	1,100,000	24.2%	345,000	673,000	285,000	2.4:1
Northern[a]	750,000	14.4%	312,200	808,700	232,000	3.5:1
Westminster	104,642	2.3%	30,000	22,500	22,000	1:1
	sum	**57.5%**				

[a] Northern Water's service area includes Boulder and Northern Water's population served number is inclusive of the same population number served by Boulder. However, the % of Colorado population shown for Northern does not include Boulder.

Table 2. Communication between researchers and study participants during the study period (workshops, interviews, meetings, etc.), includes only agencies and their staff participating in this study.

Date	Type of communication: Title	Water management agencies participating	Number of participants	Areas of expertise of participants
August 27, 2004	*Presentation:* Science-Policy Assessments for Water Resource Managers	Northern Water	~7	annual water supply modeling and annual operations and public relations
January 21, 2005	*Meeting:* Denver Water and WWA Informational Meeting	Denver Water	7	annual operations and long-term planning management, demand projections/management, long-term water supply projections, annual water supply modeling
February/March 2005	*Questionnaire on the* Experimental Southwest Climate outlooks	Denver Water, Northern Water	3	annual water supply modeling, long-term planning and modeling
August 25, 2005	*Meeting:* WWA Demand and Conservation Pre-Meeting with Aurora Water	Aurora Water	1	demand management/conservation
September 8, 2005	*Meeting:* Aurora Water Demand Meeting	Aurora Water	5	annual operations and long-term planning management, public relations, horticulture, demand management/conservation, irrigation,
November 22, 2005	*Meeting:* Denver Water Climate Change Scoping meeting	Denver Water	2	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling
December 1, 2005	*Workshop:* Colorado Climate Workshop	Aurora Water, Boulder, Colorado Springs Utilities, Denver Water, Northern Water, Westminster	12	annual operations and long-term planning management, annual water supply modeling, demand management/conservation, long-term planning and modeling
February 9, 2006	*Interview*	Denver Water	2	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling

February 24, 2006	*Interview*	Northern Water	2	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling
March 3, 2006	*Interview*	Westminster	4	annual water supply modeling and operations, long-term planning and modeling, demand management/conservation,
June 31, 2006	*Interview*	Boulder	1 (consultant)	consultant on planning for annual operations and long-term decisions
November 17, 2006	*Workshop:* Front Range Water Provider Climate Change Workshop	Aurora Water, Boulder, Colorado Springs Utilities, Denver Water, Northern Water	7+	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling
September 17, 2007	*Interview*	Aurora Water	9	annual operations and long-term planning management, annual operations and water accounting, demand management/conservation, planning for climate variability, water reuse
October 15, 2007	*Interview*	Colorado Springs Utilities	2	annual operations and long-term planning management, long-term planning and modeling
February 1, 2008	*Workshop:* Climate Change Modeling for Front Range Water Providers	Aurora Water, Boulder, Colorado Springs Utilities, Denver Water, Northern Water	10	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling
February 19, 2008	*Workshop:* Forecast Verification	Aurora Water, Denver Water, Northern Water, Westminster	9	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling, conservation
December 2008/January 2009	*Email exchanges:* Follow-up questions from interviews regarding use of climate information before 1997 and between 1997-2002	Aurora Water, Boulder, Colorado Springs Utilities, Denver Water, Northern Water, Westminster	6	annual operations and long-term planning management, annual water supply modeling, long-term planning and modeling

Table 3. Public documents from each city that the researchers reviewed for information about annual and long-term decision processes.

Aurora

Aurora Water (2007). Water Management Plan, Aurora, CO. Accessed 6 Sep 2007. www.aurora.gov

Rocky Mountain News article from 6/18/04 regarding exchanges of Colorado River Basin water with Eagle Park Reservoir Co., accessed from http://www.rockymountainnews.com/drmn/local/article/0,1299,DRMN_15_2972709,00.html

City council meeting minutes (2-7-05)

City council meeting minutes (8-8-05)

Bureau of Reclamation document asking for comments on the scope of an EA regarding use of excess capapcity in Fry-Ark Project (Sept. 2003)

Bureau of Rec. Scoping Report regarding use of excess capacity in Fry-Ark Project (March 2004)

USBR Great Plains NEPA report website: http://www.usbr.gov/gp/nepa/quarterly.cfm#ecao accessed 8/24/05

Aurora Utilities press release, (March 21, 2005)

Denver Water "Waterwire" article on Chatfield Reservoir accessed 8/9/04

City council meeting minutes (3-21-05)

IGA document (May 2004) and Water Chat article from 5/25/04 accessed 7/29/04 from http://www.waterchat.com/News/State/04/Q2/state_040528-03.htm

City council meeting minutes (4-25-05)

Agenda for a city council study session on 8-8-05

Boulder

http://www3.ci.boulder.co.us/publicworks/depts/utilities/water_supply/where.htm444444 accessed 8/6/04

Drought Plan vol 1 and 2, 2003

Colorado Springs

"March 1st IGA (IGA 2-04.pdf) and Colorado Springs Utilities news release from Feb. 10, 2004 accessed 9/9/05 at http://www.csu.org/about/news/news/release3798.html

C. Springs Utilities Southern Delivery System Fact Sheet (Jan 2004)

Southern Delivery System EIS newsletter from USBR (Sept. 2004)

www.sdseis.com , accessed 9/13/05

IGA document regarding IGA with City of Aurora, City of Pueblo, Board of Water Works of Pueblo, Southeastern CO WCD, City of Fountain, and Colorado Springs Utilities(May 2004)

Water Chat article from 5/25/04 accessed 7/29/04 from http://www.waterchat.com/News/State/04/Q2/state_040528-03.htm

Denver

Moffat Final Purpose and Need Statement (April 2004)

DW's Water Watch Report of 11/27/06

Denver Water 2002 Integrated Resource Plan (Feb 2002).

Drought Response Plan (June 2004)

http://www.water.denver.co.gov/waterwire/wwframe.html accessed 8/9/04

Northern

http://www.ncwcd.org/datareports/snowpack/snowstations.pdf

Vincent E (1999). Streamflow forecast model using weighted snowpack averages. MS Thesis, ENSHMG, Grenoble, France

Brazil, et. al. 2005. Frasier River extended streamflow prediction system. ASCE

http://www.ncwcd.org/datareports/WIR.asp, accessed 22 February 2006

http://www.ncwcd.org/datareports/snowpack.asp, accessed 22 February 2006

http://www.ncwcd.org/ims/ims_weather_form.asp, accessed 22 February 2006

Waternews, April 2005

Annual Carryover Program rules, August 2004 Accessed on 5/17/07 at: http://www.ncwcd.org/news_information/web_news/LatestNews/ACP.pdf

http://www.ncwcd.org/project_features/power.asp, accessed 2/23/06

http://www.ncwcd.org/hot_topic/rentalwater.asp accessed 2/22/06

http://www.ncwcd.org/datareports/westflow.aspaccessed 2/22/06

http://www.ncwcd.org/news_information/web_news/LatestNews/RPP%20-%20finaldraft.pdf, accessed when 5/16/07

Windy Gap Firming Project fact sheet from December 2004, accessed at www.ncwcd.org

http://www.ncwcd.org/project_features/wgp_firming.asp, accessed 8/16/05

WGFP Alternative Plan Executive Summary (February 2003)

USBR WGFP Project Update (Dec. 2004)

From http://www.ncwcd.org/project&features/wgp_firming.asp, accessed 7/20/04

"NISP NEWS" newsletter vol. 2, no. 1, March 2004, accessed at www.ncwcd.org

NISP Phase II Alternative Evaluation (Jan 2004)

NISP Scoping Report (March 2005)

HWY 287 meeting handout, NCWCD, CDOT and USACE (March 2005)

Woodcock SJ, Thiemann M, Brazil LE, Vincent E, Pineda A (2006). Fraser River extended streamflow prediction system for the Windy Gap Project. Zimbelman D, Loehlein WC (eds) Operating reservoirs in changing conditions. Proc Operations Management Conference, Environmental and Water Resources Institute (EWRI) of ASCE, Sacramento, CA

Westminster

Lang, JL (2003) unpublished graduate term paper. Westminster water use restrictions 2003: An evaluation of the intelligence decision process. Environmental Studies, University of Colorado, Boulder, CO.

http://www.ci.westminster.co.us/res/env/waterquality/Default.htm, accessed 2/27/2006

Table 4. Synthesis of information gained from interviews and informal communication with water managers in this study between 2004-2009.

How did you use climate information before 1997 El Nino and between 1997 and the 2002 drought?	*AW (Aurora Water), B (City of Boulder Water Utility), CSU (Colorado Springs Utilities), DW (Denver Water), NW (Northern Water), WWR (City of Westminster Water Resource and Treatment Division)*
When did your organization begin to use the historic gauge streamflow record in your long-term planning models or decisions?	All providers have been using historic streamflow records for as long as they can remember to make subjective decisions about annual and long-term water supplies. More recently, as they have developed models of water rights and water supply systems, they use the stream gauge record in a more quantitative way.
When did your organization begin learning about paleo reconstructions of streamflows, and when did you attempt to incorporate that information into long-term planning decisions?	All providers had looked at paleo reconstructions before 2002, largely because of outreach efforts by local NOAA researchers (Woodhouse). Two providers began to look at paleo reconstructions before Woodhouse's efforts in the 60s/70s/80s (DW, NW). Four are using them in long-term models as of 2009 (B, DW, NW, WWR). The remaining two (AW, CSU) plan to use them in future long-term plans.
When did your organization begin to attend the Water Availability Task Force?	Water providers have fuzzy memories of when they or someone else at their organization began attending WATF, but they all recalled a new or renewed interest during and since the 2002 drought.
When did your organization first begin to look at and use seasonal climate outlooks, the drought monitor, etc	None of the water managers use these products in a quantitative way in their decisions, but they all look at these products for subjective assessments of drought, annual water supplies, and demand. Half began looking at these since 2002 (AW, CSU, NW), one between 1997 and 2002 (B), and two before 1997 (W-80s, DW-mid90s).
When do you recall first learning about Western Water Assessment and/or interacting with us?	Water managers are fuzzy about their first encounters with WWA, but the majority of them are sure it was after 2002 (B says late 1990s).
What annual projections does your organization make?	
Sources of spring runoff or annual streamflows.	Use streamflow forecasts from NRCS/CBRFC and monitor streamflows using own gauges or USGS. DW and NW also make their own projections. DW and WWR also look at NW's projections.
Projections of reservoir storage each year, including estimating the time when your storage reservoirs will fill.	Use streamflow forecasts, water rights, SWE and current reservoir storage to get a qualitative idea. DW and CSU use models that give a more accurate estimate of reservoir storage. Others use data and experience to make projections.
Calculation of annual demand each year and how is it calculated?	Mostly based on average per capita water use, increased when there is new development. WWR calculates future annual water demand based

	on observed water use for land use types. CSU and DW use a model that accounts for temp and precip. NW's projections are based on water availability because their water is supplemental.
Other data sources?	All look at NOAA/CPC seasonal climate outlooks, WWA experimental seasonal forecast guidance and/or medium range precip forecasts, but only use qualitatively. Most read IWCS and/or attend WATF to get more information.
What are your annual operations & planning for these?	
Reservoir and tunnel operations for water supply	All own and operate reservoirs. All operate multiple reservoirs and use transbasin water. AW, CSU, and NW use water from/operate Reclamation trans-mountain projects. B gets their transbasin water from NW and WWR gets transbasin water from DW.
Reservoir operations for hydroelectric power	B, DW and NW produce hydropower from their reservoirs and it is a secondary use of the water. Water is never released just for hydropower. CSU produces hydro-power locally when water is delivered to treatment plants from local and terminal storage reservoirs.
Reservoir releases for endangered species, senior water rights, contracts, exchanges, leases, etc.	All must operate for senior water rights: AW and CSU have a lot of exchanges, WWR has a few. NW, B and WWR have to use bypass flows for senior water users. DW has contracts to provide untreated water to several entities including WWR. DW has endangered species requirements on the Colorado River.
Determining necessity of drought-year operations, including restrictions.	All except NW have drought plans with triggers that use streamflow forecasts, snowpack, reservoir storage and/or projected reservoir storage, to determine necessity of drought restrictions.
What are your long-term projections and plans?	All except B are in the process of acquiring more water or more storage space for water. Several are expanding reuse operations.
How much more water do you expect to need for build out? When do you estimate you will reach build out?	Range of times until build-out. DW, B and WWR are closer. AW and CSU are still growing. NW is only growing because the cities are growing. Most cites plan for 2030, 2050 or both. DW, B, and WWR have a better idea of the specific amounts of water they will need at build-out.
Long-term projections for future annual water demand for treated water, future annual supply availability, and the firm yield of reservoirs based on future supplies.	Projections for demands come from anticipated growth, usually from a Land Use Plan created by a different department with limited or no input from water resources. Projections for supplies: DW, CSU, WWR and B have models that use past hydrology to determine supply reliability under future demands.

Information sources for these projections.	Demand projections from land use plans, supply projections from hydrologic record, internal demand-side mgmt. and conservation planners, and water rights administration
Evaluation of the reliability of future water supply options	Most use hydrologic record and make sure they will be reliable in a 50's drought or at least able to meet necessary demands with the use of restrictions. B uses sophisticated reliability standards, saying how often different types of drought restrictions will be necessary.
Use of tree-ring reconstructions of past streamflows to determine water supply reliability under different drought scenarios	All have looked into it and would like to use it. Their models cannot use data directly because they need weekly or monthly, not annual flows. Water providers are actively pursuing this because they feel more comfortable using reconstructions of the long-term past than uncertain projections of the future to determine if their water supplies will be reliable.
Recommendations on how climate forecasts & other products could be improved so you could use them?	
ANNUAL OPERATIONS	Streamflow forecasts for the South Platte and Arkansas Rivers similar to what is available for the Colorado River. Better understanding of the connection between snowpack, soil moisture and streamflows to get more accurate streamflow forecasts; more skillful precip outlooks earlier (forecasts for winter precip in the fall; accurate April 1 snowpack in fall; leading to earlier streamflow forecasts); use of additional variables in streamflow and reservoir forecasts (like Hydrosphere forecasting project for water utilities). For demand, better understanding of relationship between climate variables and demand, then they could use seasonal climate outlooks to know if they will have different than average demand.
LONG-TERM PLANNING	A better understanding between climate variables (snowpack, temp, soil moisture, etc) and streamflows and demand. Relationship of climate variables and forest conditions. Climate change scenarios turned into hydrologic scenarios (like Joint Front Range Climate Change Vulnerability Project). How climate change will affect water rights and timing of streamflows, as well as volume. A better understanding about natural variability vs. climate change projections. More data on precip (expand SNOTEL network; improve SNODAS).

582

Table 5. Information used quantitatively (top two sections) and information not used quantitatively (bottom two sections) by water managers in both annual and long-term decisions.

ANNUAL	**Information**	**Source**	**How used quantitatively**	**Providers using this**
	current snowpack/ SWE from SNOTEL	NRCS	annual water availability: reservoir storage projections	all
	current streamflows	USGS and own gauges	annual water availability: reservoir storage projections & daily reservoir operations	all
	streamflow projections	NWS/CBRFC and NRCS	annual water availability: reservoir storage projections & daily reservoir operations	all, NW also makes own projections
	instrumental record of hydrology	USGS & own reconstructed natural flows	annual water availability: comparing inter-annual variability of supplies	all
LONG-TERM				
	paleo reconstructions of streamflow	NOAA/WWA	long-term supply reliability models: supply projections	all are experimenting with this
	instrumental record of hydrology	USGS & own reconstructed natural flows	long-term supply reliability models: supply projections	all
	historic temp and precip	NOAA/NCDC	long-term supply reliability models: demand projections	CSU and DW
ANNUAL	**Information**	**Source**	**Why NOT used quantitatively**	
	seasonal climate outlooks (summer temp & precip) in the winter	NOAA/CPC & WWA	not skillful enough	
	seasonal streamflow forecasts in the fall based on climate outlooks	NRCS & NWS/CBRFC	not available	
	fall forecasts of winter precip	NOAA/CPC and WWA	not skillful enough	
LONG-TERM				
	climate change scenarios converted into streamflows	IPCC-various GCMs	do not have hydrology models of all basins	
	historic streamflow data expressed as exceedence probabilities		not available	

Table 6. Water managers' expressed needs for climate data and education, which would help increase their climate literacy.

Availability and utility of climate information and natural variability:	**Climate forecast methodology and skill:**
• Effect of climate patterns (e.g. ENSO) on regional weather • Regional trends in temperature, precipitation, and streamflows; compare anomalous years to natural variability • Reoccurrence interval of single- and multi-year droughts and other extremes • Regional variability in historic streamflows among river basins (exceedence probabilities); reliability of current or future water rights	• Underlying assumptions and uncertainties of forecast models • Sources of forecast and data error • Verification methods, including hind casting • Types of verification (resolution/sharpness vs. reliability) • Skill vs. accuracy • Regional patterns of skill

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Appendix: General interview questions

How did you use climate information before 1997 El Niño and between 1997 and 2002?

- When did your organization begin to use the historic gauge streamflow record in your long-term planning models or decisions?
- When did your organization begin learning about paleo reconstructions of streamflows, and when did you attempt to incorporate that information into long-term planning decisions?
- When did your organization begin to attend the Water Availability Task Force?
- When did your organization first begin to look at seasonal climate outlooks, the drought monitor, etc.? If you use these in your decision-making, when first start doing so?
- When do you recall first learning about Western Water Assessment or interacting with us?

What annual projections does your organization make?

- Sources of spring runoff or annual streamflows. Do you generate these in house (if so, how) or get this information from NRCS, State Engineer's office, or another source?
- Projections of reservoir storage each year, including estimating the time when your storage reservoirs will fill.
- Calculation of annual demand each year (if so, how and inputs), or is annual demand a constant, and if so how was it arrived at?
- Other data sources? (e.g. Attend the Colorado Water Availability Task Force meetings regularly or look at the presentations posted on the website; Read the monthly Intermountain West Climate Summary that WWA creates.)

What are your annual operations & planning for these?

- Reservoir and tunnel operations for water supply
- Reservoir operations for hydroelectric power
- Reservoir releases for endangered species, senior water rights, contracts, exchanges, leases, etc.
- Determining necessity of drought-year operations, including restrictions. Definition of a drought (i.e. supplies or projected supplies corresponding to drought stages)? What are your drought triggers?

What are your long-term projections and plans?

- How much more water do you expect to need for build out? When do you estimate you will reach build out?
- Long-term projections for future annual water demand for treated water, future annual supply availability, and the firm yield of reservoirs based on future supplies.
- Information sources for these projections.
- How do you evaluate the reliability of future water supply options? (e.g. compare water demand in the future to climate conditions during the 50's drought.)
- Have you considered using tree-ring reconstructions of past streamflows to determine your water supply reliability under different drought scenarios?

Do you have any recommendations on how climate outlooks and other products could be improved so you could use them in annual operations and long-term planning

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