WWA

WESTERN WATER ASSESSMENT

Use of Climate Information in Municipal Drought Planning in Colorado

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Introduction

In Colorado as elsewhere, water supply systems and water supply managers are largely evaluated by their ability to withstand droughts. As growth pressures intensify municipal demands and as conservation-inspired water management reforms remove some of the slack from water systems, drought management becomes an increasingly difficult challenge. Additionally, there is some evidence to suggest that droughts may become more common as part of larger trends in climate (NAST 2000).

The recent drought in Colorado first emerged in 1999 but did not become severe until 2002. By April 1 of that year, Colorado's snowpack statewide was 53% of normal, the second lowest it had been on that date since 1968 (Doesken and Pielke 2002). By late July 2002 Colorado was at the center of an extensive regional drought (Doesken and Pielke 2002; NOAA et al. 2002). Drought conditions continued throughout Colorado and adjacent states in 2003 and 2004 (NOAA et al. undated). Despite a wet spring throughout much of the southwest in 2005, the concern over drought remains strong in many basins in the West.

Earlier research by the authors examined eight municipal water providers' responses to the 2002 drought. At the time most of the eight providers did not have written plans with clearly defined drought response measures; consequently the responses largely took the form of ad hoc emergency outdoor watering restrictions. We found that mandatory summer lawn watering restrictions were effective in reducing demand between 13% and 56% over the previous 2 years, depending on how savings were measured and the stringency of the restrictions (Kenney et al. 2004). Several other studies tracking drought in the West have reached similar conclusions regarding emergency conservation and landscape watering restrictions: for example, Shaw et al. (1992) found 36% summer savings in Los Angeles during the 1991 drought; Shaw and Maidment (1988) found 31% savings in Corpus Christi during the 1984 drought, and similarly, found 30 – 40% savings in the San Francisco Bay area during the 1976-1977 drought (CDWR 1991); Shaw and Maidment (1987, 1988) found voluntary restrictions to have no effect; and Shaw et al. (1992) found San Diego's voluntary program to yield summer savings of 27% compared to 36% from Los Angeles' mandatory program.

To complement our earlier analysis, this study revisits municipal drought planning in Colorado, this time focusing on the development/modification of written drought plans since the 2002 drought and how they draw upon climate data to define drought conditions. While we are interested in (and thus explore) the trend toward greater levels of municipal drought planning in Colorado, our primary focus is the extent to which these planning efforts take advantage of the suite of climate-related data and products available to water managers and other decision makers. This is a major research focus of the Western Water Assessment (WWA), a NOAA-sponsored initiative at the University of Colorado. This transition from studying actual experience with drought response measures to drought planning may seem to lack a chronological logic. Ideally planning should precede action but in reality often it does not. However, as one of our providers pointed out, even where some previous drought planning has taken place, actual experience with the response of a particular water system and community to drought conditions may cause drought plans to change or become better defined. From that provider's experience the response of city council and the community, both to the announcement of drought conditions and to use restrictions, greatly helped shape what finally went into its drought plan. Our expectation is that the 2002 drought was sufficiently severe to break the usual pattern of responding to crisis then returning to "business as usual" until the next disaster strikes without engaging in long-term planning efforts (see Wilhite and Svoboda 2000).

Drought Planning in Colorado: An Update

Drought plans provide clear guidelines on how best to manage water supply and demand during drought. They are intended to minimize the effects of water shortages on the public and provide a framework to prepare for and respond to drought (Palmer et al. 2002). Drought planning avoids a state of crisis management where water providers move from one disaster to the next without reducing their vulnerability. The practical value of a drought management plan is that it reduces the likelihood of either over- or under-reacting to a water supply emergency (AWWA 2002).

As a precursor to our more focused look at the use of climate information in drought planning, we assessed the general state of drought planning in Colorado. As expected, drought planning at the municipal level is becoming more common since the onset of drought conditions in the state (circa 1999). A 2000 Colorado Water Conservation Board (CWCB) survey found that 22% of the 67 municipal water providers in Colorado that produced 2,000 acre feet or more of treated water per year had a drought response plan at that time (CWCB 2000). In 2004, a follow-up study funded by the CWCB surveyed 241 Colorado municipal water providers, a much broader group than the 2000 survey that was compiled from the State Engineer's Office's water rights accounting database. This survey found that approximately half of those 241 municipal water providers had drought plans (Bouvette et al. 2004, fig. 12-2).

Our survey of Front Range water providers found that, as of the summer of 2004, 13 of 29 providers had a written drought plan, defined as "a document that describes an agreed upon process to assess periodically water supply conditions and the options for responding to emerging drought based on pre-defined deficiencies or triggers" (CWCB 2000:6). Sixteen providers did not have a drought plan as defined. Of those 16 four had water management/conservation plans as of the summer of 2004, and another one was in the process of developing a water conservation plan. The remaining 11 providers had no writ ten drought or water management/conservation plans though several rely on measures such as voluntary schedules or altered rate structures when drought occurs.

Despite the rapid increase in drought planning, many municipalities have not adopted plans. A Denver Post editorial chided local officials for failing to enact drought plans in greater numbers following the devastating drought of 2002: "Five years after the onset of the worst drought in Colorado's recorded history (perhaps even surpassing the dry 1930s), most Colorado communities still don't have water conservation plans, drought management programs or water supply master plans. What, me worry? It's jaw-dropping denial" (Denver Post 2004).

Section 37-60-126, C.R.S. requires state-approved water conservation plans for water providers with total customer demand of at least 2,000 acre feet who receive financial assistance from the CWCB or Colorado Water Resources and Power Development Authority. Unlike Texas, Georgia, Kentucky, and South Carolina, however, Colorado does not require that municipal providers have drought plans. In 2004 the state enacted section 37-60-126.5, C.R.S., directing the CWCB to develop programs to provide technical assistance to water providers who want (but are not required) to develop drought mitigation plans.

On May 25, 2005 the CWCB issued guidelines to review and evaluate drought mitigation plans (CWCB 2005). The guidelines provide that drought mitigation plans must consider and include, if appropriate, several elements: a drought task force, vulnerability assessment of the water supply system, drought response principals, objectives and priorities, authorities for declaring drought, triggers for drought-related actions, drought ordinances, lines of communication protocols and content, monitoring, emergency response needs and associated actions and programs, ongoing public education and awareness programs, and a link between drought mitigation and water supply and conservation planning. The CWCB has no immediate plans or money available to develop a model drought plan, however (May 17, 2005 email from Kathie Ann Lucki, CWCB).

Of course, simply having a "drought plan" does not necessarily mean it will be meaningful or effective in better managing water resources. As discussed later, we found significant variability in the scope and sophistication of those plans that do exist. This variability is a function of several factors, including the unique features of each system's physical and institutional environment, the way in which these factors influence drought vulnerability and the options for response, and the resources each municipality has to invest in drought planning.

We do not attempt to assess whether Colorado should expand its support of drought planning or if it should mandate drought planning among all water providers, nor do we propose a "model drought plan" that could potentially be the basis for a statewide program of this nature. Rather, we focus on the approaches these providers are already utilizing to learn more about opportunities to better assist with drought coping efforts. Specifically, our primary interest in this study is how drought planners use climate-related information, defined broadly to include monitoring data and forecasts pertaining to those weather and climate phenomena and the associated hydrologic parameters that influence how water systems are influenced by drought. A better understanding of how climate information is used in municipal drought planning can help researchers evaluate and improve dissemination of existing technical information, and can guide efforts to devise future climate products and services. Similarly, a better understanding of how climate information is currently applied in drought planning should be of immediate interest and use to the water management community as it offers the promise of an improved ability to withstand drought—a political and cultural imperative as much as an operational responsibility.

Drought Planning, Indicators and Triggers

The recent CWCB guidelines recommend that drought plans include triggers for drought-related actions but do not define the term. One definition of triggers is "the specific value of a drought indicator that activates a management response." Drought indicators have been defined as "any single observation or combination of observations that contribute to identifying the onset and/or continuation of a drought" (Palmer et al. 2002). Triggers can simplify decision-making (Fisher and Palmer 1997). Failing to define triggers can lead to government delay or inaction to avoid conflict (Hrezo et al. 1986).

Several authors have noted the difficulties in defining appropriate drought indicators and triggers (e.g., Steinemann 2003; Karl et al. 1987; Guttman et al. 1992). In part, this difficulty reflects the many different conceptualizations of drought. Wilhite and Glantz (1985), for example, have identified more than 150 drought definitions. An approach that is appropriate in one context is likely to be deficient in another. As Steinemann (2003: 1217) explains:

Indicators often lack spatial and temporal transferability, comparability among scales, and relevance to critical drought impacts. Triggers often lack statistical integrity, consistency among drought categories, and correspondence with desired management goals.

As articulated in the AWWA's Drought Management Handbook, "the choice of indicators will depend on the site-specific circumstances of the community's water system" (AWWA 2002: 10).

Several variables can potentially be used as drought indicators, including weather-based variables such as precipitation, and hydrologic/water management variables such as streamflow, soil moisture, and reservoir storage. To be useful as a trigger, indicator data normally must be converted to a measure that relates the observed value to some other value such as a percentage of total capacity (for reservoir storage), or standardized onto a scale based on another consideration, such as a recurrence interval. For example, Denver's triggers rely on predicted or actual July 1 reservoir storage levels as a percentage of total capacity (Denver Water 2004).

Variables are sometimes combined to form a drought index that may provide a more complete picture of drought than does any single indicator. The oldest and best-known drought indices such as the Palmer Drought Severity Index (PDSI) were primarily designed to serve the needs of agriculture, and thus, are primarily a function of trends in weather (namely precipitation and temperature) and soil moisture (Hayes 2005). Indices that, theoretically, are better suited to the needs of western municipalities include the Surface Water Supply Index (SWSI) which calculates basin-specific values using four inputs of relevance to snowmelt basins: snowpack, streamflow, precipitation, and reservoir storage (Hayes 2005).

Methodology

This study includes data from the following municipal water providers along Colorado's Front Range:

- The eight providers featured in the 2002 study (Kenney et al. 2004): Aurora, Boulder, Denver, Fort Collins, Lafayette, Louisville, Thornton, and Westminster;
- Twenty other major South Platte water providers described in the Metropolitan Water Supply Investigation (Hydrosphere Resource Consultants et al. 1999: Table 2);
- Pueblo and Colorado Springs from the neighboring Arkansas River Basin were also included due to their size.

A total of 30 Front Range municipal water providers were initially included in this study. These providers served roughly 2.95 million customers in 2004, 78% of the Front Range population and 63% of the state's population, based on the Colorado State Demography Office's 2004 population estimates. Cities that are contractually obligated to abide by Denver's drought rules (e.g., Arvada and Lakewood) were not included.

Much of the data compiled was obtained through informal email surveys. Between April and June 2004 we sent email inquiries to all thirty providers asking whether they had a drought plan defined as "a document that describes an agreed upon process to assess periodically water supply conditions and the options for responding to emerging drought based on pre-defined deficiencies or triggers" (CWCB 2000: 6). We received responses from 27 providers. We were able to answer our survey questions from information posted on the websites of two of the three providers that did not respond. The remaining city was dropped from the study, leaving a total of 29 providers in the study. Of those 29 providers:

- Thirteen had drought plans as defined above;
- Four had water management/conservation plans but not drought plans (see footnote 1 for definitions); and
- Twelve had neither a drought plan nor a water management/conservation plan, although one of the twelve had developed a draft water conservation plan after the study concluded.

We collected and reviewed the 13 drought plans. Eight of these plans explicitly include drought indicators and/or triggers in their plans. We sent follow-up questions to seven of these eight cities (one plan already identified the types of climate information/products used). We asked about the products they used, which agency(s) provided the information, how the information was obtained (web, mail, phone, etc), and whether the provider obtained any information from state Water Availability Task Force (a.k.a. drought task force) meetings. We did not receive a response to our follow-up questions from one provider.

Survey Results

Indicators used in the eight plans include but are not limited to current and projected reservoir storage, streamflow (current and projected), snowpack, weather (current and projected), demand, and Colorado-Big Thompson (CBT) allocations. Despite the availability of indices such as SWSI, only three of the providers in our study explicitly refer to them for drought planning purposes. Two others created their own indices that, in simplified terms, divide projected supply by projected demand. The resulting quotient is the trigger that determines drought severity and response. Tables 1 and 2 list the indicators used in the eight drought plans that we examined. For each provider we have identified indicators that are either explicitly listed in the provider's drought plan or were provided to the authors in response to our follow-up questions, and that appear to play a significant role in drought planning and management. Table 1 includes all indicators that rely on historical or current data, while Table 2 indicators rely on projections or forecasts. Climate-related indicators are shaded in each table.

Table 1. Indicators Based on Historical or Current Data

	Aurora	Boulder	Co. Spgs.	Denver	Erie	Longmont	Louisville	Thornton
Snowpack	X	X	X	X	X	X	X	X
Streamflow		X		X	X			
Weather	X		X	X	X			X
Drought Indices (SWSI,SPI,PDSI)	X	X						X
Reservoir Storage	X	X	X	X	X	X	X	X

Sources: Drought plans, personal communications with authors

Table 2. Indicators Based on Projections or Forecasts

	Aurora	Boulder	Co. Spgs	Denver	Erie	Longmont	Louisville	Thornton
Streamflow	X	X		X	X	X	X	X
Weather/Climate	X	X	X	X				X
Soil Moisture	X*							
Runoff	X			X	X		X	
Drought Indices (PDSI)	X							
Reservoir Storage	X	X		X			X	
Alternative Supply Availability	X							X
CBT/Windy Gap Shares		X			X	X	X	
Water Treatment Capability					X	X		

Sources: Drought plans, personal communications with authors

*Aurora consults the Soil Moisture Forecast posted on the Drought Monitor website at http://www.drought.unl.edu/dm/forecast.html

We assume all of the providers consider historic demand in determining appropriate drought responses. In addition some attempt to forecast demand. Three consider demand as affected by weather (drought) conditions. Table 3 summarizes the factors affecting demand as stated in the drought plans.

Table 3. Factors Impacting Demand

	Historical or Current (measured)						Projected (forecasted) - factors considered					Other
Provider	Actual Demand	Water Treatment Plant Flows	Historic Demand	Historic Demand with no restrictions	Demand considering current weather	Pupulation Adjusted Average Use	Normal Conditions	Assumes no additional resetrictions	Economic Growth	Weather Forecasts	Conservation Savings	Drought Responses of Other Local Providers/ Area
Aurora	X	X	X				X					
Boulder			X	X							X	
Co. Spgs.	X		X		X			X	X	X		
Denver	X		X		X	X						X
Erie		X	X							X		X
Longmont	X		X							X		
Louisville			X				X					
Thornton			X								X	

Sources: Drought plans

Table 4 describes the triggers used in the drought plans to identify different drought stages. Two of the providers do not explicitly define triggers but rather identify drought stages on a case-by-case basis. This table does not include a description of the actions to be taken in response to the triggers, which was beyond the scope of our study.

Table 4. Drought Triggers

City	Drought Triggers
Aurora	60% storage pre-runoff triggers adoption of drought stages
Boulder	Drought state determined by value of system-specific Projected Storage Index (projected storage/unrestrained demand)
Co. Springs	Drought stage detemined by how much projected demand exceeds expected yield
Denver	Drought stage deterined by actual or projected July 1 reservoir storage as % full
Erie	Case by case
Longmont	Drought stage determined by comparing reservoir storage to target levels and raw water supply availability as % of projected demand
Louisville	Drought stage determined by value of system-specific Water Supply Index (supply/demand)
Thornton	Case by case

Sources: Drought plans

Climate Information Used in Drought Planning

Water providers use a variety of climate information and products from several sources to define indicators and establish triggers. Almost all of the information is obtained from websites, though one provider receives its information via phone calls with the water commissioner and several rely in part on their own observing sites. Table 5 lists the types and sources of climate information used by the water providers. An “X” indicates that at least one water provider responding to the survey received that type of information from that source. Appendix A lists the reports by name and provides a URL, if available.

We also asked the providers whether they attend the state Water Availability Task Force (WATF) meetings or obtain information from these meetings.[3] Of the 5 that answered:

- One provider said it does not have a representative on the WATF, noting it has “never been invited.” It receives information about the task force meetings from Denver, however.
- Two do not receive much information from the WATF meetings.
- Two have representation/attendees at the WATF meetings.

Table 5. Type and Source of Climate Information

Source	Streamflow Reports	Streamflow Forecasts	Snowpack Reports	Weather Reports	Climate Forecasts	Drought Indices	Soil Moisture Report
Natural Resources Conservation Service (NRCS)		X	X		X (SWSI)		
CO Basin River Forecast Center		X					
National Operational Hydrologic Remote Sensing Center			X				
National Weather Service				X			
Colorado Climate Center				X			
US Geological Survey	X						
Colorado Division of Water Resources/State Engineer	X					X (SWSI)	
Norther Colorado Water Conservancy District	X	X	X				
Own records	X						
Own measurements	X		X				
Colorado Division of Water Resources/Water Commissioner via telephone		X	X				
NOAA Climate Diagnostics Center (Klaus Wolter)					X		
NOAA Climate Prediction Center (CPC)					X	X (PDSI, SPI)	
Private consultant		X			X		
Drought Monitor website (to access information from NRCS & CPC)		X				X (PDSI)	X
Colorado Water Conservation Board	Unknown *						

Used by Water Providers

* Survey respondent indicated he reviewed information on the Colorado Water Conservation Board website but did not specify the nature of the information.

Expanding Use of Climate Information

Identifying needed next steps regarding the use of climate information in municipal drought plans must be done on a case-by-case basis, as each water system is unique in a variety of physical and institutional ways, including the internal resources available to devote to drought monitoring and planning. Many researchers are advocating a greater use of long-term climate forecasts in these efforts (Buehrer 2003). Since it is easier for climatologists to model inflows from snowpack than from rain, the potential application of climate forecasts in drought plans is generally higher in the West and Northeast than elsewhere in the United States. A similar appreciation of the value of climate forecasts is articulated by Jacobs and Garfin (2004: 16) as part of Arizona's emerging drought planning:

[M]ost existing drought plans do not explicitly incorporate monitoring the drivers of climate, and developing capacity to project interannual to decadal scale climate conditions at the regional scale. Such information may enhance the ability to limit future drought impacts. Projections that the current negative phase of the PDO [Pacific Decadal Oscillation] may persist and enhance the possibility of dry conditions provide a focus for thinking about the possibility of sustained drought over timeframes of a decade or more for the Southwest.

This is not to suggest, however, that the trend toward the greater use of climate information in drought planning is limited to snowmelt systems. One study, for example, found that 19 of 22 Midwestern water utilities surveyed took preemptive actions based on NOAA drought forecasts of which they were aware (Changnon and Vonnahme 2003). However, the best opportunities appear to be in regions characterized by snowmelt-dominated water systems, and in regions subject to strong ENSO (El Nino Southern Oscillation) and, potentially, PDO climate signals.

The municipalities studied in this report generally fit this first criterion, but not the second. The ENSO signal in Colorado is generally considered to be weak (Clark et al. 2001). While one provider does consult El Nino forecasts, most of the rest make no mention of it. Boulder's drought plan explains: "To date, global factors (El Nino, Southern Oscillation, Pacific Decadal Oscillation, etc) basically have no predictive skill with respect to droughts in Boulder Creek or the Upper Colorado/CBT drainage area" (City of Boulder 2003, vol. 2: 35). This observation reflects a larger constraint on the use of climate tools in drought planning and management: the recurring concern over the accuracy of forecasts, especially long-term forecasts. Three of the providers in our study consider long-range forecasts (up to six months into the future) for general context or-- in the case of Denver Water, to get a rough idea whether its wet, average, or dry reservoir forecast scenario seems most likely-- rather than to directly calculate water supply. In terms of using forecasts, water managers are a very risk-averse community of users. Managers often pay more attention to forecasts as droughts worsens, but concerns over the accuracy of forecasts, combined with the disincentives for taking the risk of relying on forecasts and a lack of familiarity with the forecasts or how to use them, combine to provide a persistent obstacle to greater application (Buehrer 2003; Carter and Morehouse 2003). Carter and Morehouse recommend that to make climate forecasting more relevant and useful to urban water providers the information must be relatively easy to interpret, users should be trained in how to use the information effectively, the information must be easily accessible and available when providers most need it, and it should be provided at the appropriate temporal and spatial scale. Ongoing stakeholder interactions are necessary to understand stakeholder needs (Carter and Morehouse 2003).

A related area of activity involves a greater use of paleoclimate information as part of drought planning and management and water management in general. Denver is using multi-century tree-ring reconstructions of South Platte and Colorado River streamflows to help model the yield of their system under a broader range of conditions than those seen in the 90-year gaged record (Schmitzer 2005). In this case, Denver takes the annual flow values (1650-2002) reconstructed from the tree rings, then uses a "gage year-analog" method to derive a plausible daily hydrology for these years. Those daily flows are input into a water supply model to examine what level of demand could be met during the reconstructed drought events. The City of Boulder used tree ring data to reconstruct the likely hydrology for the Boulder Creek basin back to the early 1700's and appended it to recorded data that goes back to the early 1900's. This data feeds into Boulder's water system model and played a key role in determining the triggers in Boulder's drought plan. Boulder had been working on this effort as part of its drought planning process when in March 2002 it received the results showing droughts more severe than the 1950's had occurred several times in the 1700's and 1800's. Boulder's water manager thought at the time that these "theoretical" drought series were interesting, but never expected to see such a thing play out. Three months later we were deep into a "theoretical" drought year that exceeded everything in the series back until the early 1700's.

Summary and Conclusions

From this study it is apparent that municipal drought planning in Colorado has become more common since the onset of drought conditions in the state, increasing from 22% of larger municipal providers in 2000 to between 45% (this study) and 50% (CWCB study) in 2004. The providers in this study that have drought plans serve approximately 2.4 million Front Range customers out of a total Front Range population of about 3.8 million, based on 2004 population estimates by the Colorado State Demography office. The structure and detail of the plans differ considerably; clearly there is no "one accepted model" for drought planning in the region, though that could change if the state adopts a model municipal drought plan. Of the plans that include indicators and triggers, a variety of indicators are used, not surprising given the multi-faceted nature of the water systems studied. The triggers used are conceptually similar, relating reservoir storage or other measures of supply to projected demand.

The plans allow for considerable exercise of professional judgment in translating indicators to triggers to action. For example, triggers in one provider's plan may seem explicit, but past experience with watering restrictions indicates the water provider's governing board does not consider itself strictly bound by those triggers. As one water manager explained, professional judgment is necessary because a simplified trigger cannot capture all of the elements water managers may evaluate and weigh when projecting water supply. Many of these elements come solely from the manager's experience with the intricate interactions of facilities they manage and the unique characteristics of the watersheds supplying a particular water system. A detailed Decision Support System for an individual water system might come close, but would be prohibitively expensive for most utilities. This manager found it best to use the trigger to identify a potentially problematic water supply condition and then to evaluate any mitigating or exacerbating factors too difficult to incorporate into a simple triggering formula. A water manager's judgment may be the most valuable evaluator a utility has. Thus, while the triggers help inform and guide decision-making, they should not be viewed as deterministic.

Our primary interest in this study is how drought planners use climate-related information, defined broadly to include monitoring data and forecasts pertaining to weather and climate phenomena, and the associated hydrologic parameters that influence how water systems are influenced by drought. We found that planners use a diverse set of climate products, primarily obtained on the Internet, to define indicators and triggers. Despite the abundance of government provided data, two cities also obtain information from private consultants. Three out of eight providers studied look at standardized climate/water indices such as the Palmer Drought Severity or Surface Water Supply indices, though one water manager commented that he doesn't know how or if the standardized indices provide any predictive or forecast ability relative to drought triggers. Two other providers create their own, system-specific, indices, suggesting a need for indices at scales more appropriate for decision making. Long-term projections (beyond seasonal) are used sparingly, and only then for general context. Only one city consults ENSO forecasts, and Boulder explicitly rejects their use due to the weak signal. (Most make no mention of ENSO.) In at least two major cities (Boulder and Denver), paleo data are being used to inform thinking about long-term climate. Use of climate information to make municipal demand projections is limited and could be expanded. One provider noted that due to the interrelationship between agricultural and municipal supplies through the water rights framework and shared storage facilities, managers might want to consider climate impacts on agricultural demand as well.

Looking Ahead

Identifying options for the improved use of climate information as part of drought management will remain an ongoing challenge for the Western Water Assessment. This study highlights a few potential questions to focus additional thinking:

- Given that about half of Front Range municipal water providers currently have drought plans, are there potential benefits of and impediments to an expanded use of drought planning among Colorado Front Range municipalities?

- Given the considerable exercise of professional judgment by water providers, what are the appropriate mechanisms for balancing professional judgment with quantitative thresholds in managplay in providing information that facilitates the exercise of professional judgment?

- Given the variety of indicators (see Tables 1 and 2) and climate information sources (see Table 5) used, are the information demands of water managers being satisfied? How can WWA determine what information needs currently are not being satisfied? What can it do to help satisfy those needs? This is not a simple set of questions, and the answer is likely to have multiple parts and be subject to each particular supply and demand context.

- Given that only 3 out of 8 water providers consult standardized indices such as SWSI and PDSI, is there a need to devise new indices, perhaps at finer scales?

- Currently, the use of climate information appears to be almost exclusively for supply-side projections. Given the skill of seasonal forecasts, what is the potential for using climate information as part of demand projections, and can WWA help cities meet this potential?

- Given that there seems to be a perception among at least some providers that they will not receive information from state Water Availability Task Force meetings unless they are invited to attend, should greater efforts be made to disseminate information from these meetings to a broader set of municipalities?

- Despite the weak ENSO signal in the region, do opportunities exist to better utilize long-range climate forecasts as part of drought planning and response? Similarly, is there a role for an expanded use of paleo data in these efforts? Do other "signals" or indices exist that might have a stronger causation or correlation with drought? What is WWA's role in these efforts?

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Appendix

Streamflow reports

1. Colorado Division of Water Resources, Office of the State Engineer, Streamflow Data Retrieval, http://www.dwr.state.co.us/Hydrology/flow_search.asp
2. USGS, Daily Streamflow for Colorado, http://nwis.waterdata.usgs.gov/co/nwis/discharge
3. Northern Colorado Water Conservancy District, Snowpack and Streamflow Update Reports, http://www.ncwcd.org/datareports/snowpack.asp

Streamflow forecasts

1. Natural Resources Conservation Service Colorado Basin Monthly Outlook Reports, http://www.wcc.nrcs.usda.gov/cgibin/bor.pl
2. Northern Colorado Water Conservancy District, Snowpack and Streamflow Update Reports, http://www.ncwcd.org/datareports/snowpack.asp
3. National Weather Service Colorado Basin River Forecast Center, http://www.cbrfc.noaa.gov/ (Water Supply Outlooks)
4. Division 1 Water Commissioner (via telephone)

Snowpack

1. Division 1 Water Commissioner (via telephone)
2. NRCS Snow Precipitation Update, ftp://ftp.wcc.nrcs.usda.gov/data/snow/update/co.txt
3. NRCS Snowpack Reports, http://www.wcc.nrcs.usda.gov/cgibin/snow_rpt.pl?state=colorado
4. NRCS Snow Survey Program, http://www.co.nrcs.usda.gov/snow/
5. NRCS Snow Water Equivalent Data Table, http://www.wcc.nrcs.usda.gov/cgibin/state-site.pl?state=CO&report=waterequivtable
6. NRCS SNOTEL data, http://www.wcc.nrcs.usda.gov/snow/snotel-data.html
7. NRCS SNOTEL Weekly Snowpack and Drought Monitor Update Report, http://www.wcc.nrcs.usda.gov/water/drought/wdr.pl
8. Northern Colorado Water Conservancy District, Snowpack and Streamflow Update Reports, http://www.ncwcd.org/datareports/snowpack.asp
9. Northern Colorado Water Conservancy District (via telephone)
10. NWS National Operational Hydrologic Remote Sensing Center, http://www.nohrsc.nws.gov/ (comment of one provider: although mainly experimental, good graphics understandable by non-experts such as council members)

Weather Reports

1. National Weather Service Monthly Precipitation Totals, http://www.crh.noaa.gov/bou/coop/cooppcpn.php
2. Colorado Climate Center, Water Year Summaries, http://ulysses.atmos.colostate.edu/coloradowatersummaries.php

Weather/Seasonal/Long-Range Forecasts Forecasts

1. NOAA Climate Diagnostics Center (Klaus Wolter), Colorado (and Interior Southwest) forecasts, http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/index.html
2. NOAA NWS Climate Prediction Center, Seasonal outlooks, http://www.cpc.ncep.noaa.gov/products/predictions/90day/
3. John Henz, Hydro-Meteorological Services, long-range weather outlooks (private consultant)
4. Connely Baldwin, long-range weather outlooks (private consultant)
5. NWS, Climate Prediction Center, Seasonal Drought Outlook, http://www.cpc.ncep.noaa.gov/

Drought Indices

1. Palmer Drought Severity Index, http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif
2. Surface Water Supply Index, http://water.state.co.us/pubs/swsi.asp
3. Standard Precipitation Index, http://www.drought.unl.edu/monitor/currspi.htm

Other

1. National Drought Mitigation Center et al., Drought Monitor, http://www.drought.unl.edu/dm/index.html
2. Colorado Water Conservation Board, cwcb.state.co.us/