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CLIMATE SCIENCE AND DROUGHT PLANNING: THE ARIZONA EXPERIENCE[1]

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ABSTRACT: In response to recent severe drought conditions throughout the state, Arizona recently developed its first drought plan. The Governor's Drought Task Force focused on limiting the economic and social impacts of future droughts through enhanced adaptation and mitigation efforts. The plan was designed to maximize the use of new, scientific breakthroughs in climate monitoring and prediction and in vulnerability assessment. The long term objective of the monitoring system is to allow for evaluation of conditions in multiple sectors and at multiple scales. Stakeholder engagement and decision support are key objectives in reducing Arizona's vulnerability in light of the potential for severe, sustained drought. The drivers of drought conditions in Arizona include the El Niño-Southern Oscillation, the Pacific Decadal Oscillation, and the Atlantic Multidecadal Oscillation.

(KEY TERMS: drought; climate variability/change; water resources; sustainability; water policy; risk assessment.)

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INTRODUCTION

Until recently, the major urban areas of Arizona, Phoenix, and Tucson were thought to be insulated from the impacts of drought because of past federal and state investments in multiple water supply sources. Thanks to dams and delivery infrastructure, the Colorado River today supplies about 39 percent of Arizona's water supply. On average, 90 percent of the annual streamflow of the Colorado is generated in the Upper Basin (above Lees Ferry, Arizona). Therefore, water supplies in Arizona are affected by drought impacts in Colorado, Wyoming, Utah, and New Mexico, in addition to more local conditions. Commonly, the climate conditions in the Upper Basin differ from those in the Lower Basin, but during regional scale events such as the current drought, the entire Colorado River watershed has been affected.

The Colorado River is among the most heavily regulated rivers in the world, affected by over 50 court decisions, state statutes, interstate compacts, and international treaties. The Colorado River Compact of 1922, which divided the Colorado River Basin into an Upper and Lower Basin, apportioned 7.5 million acre-feet (9.25 billion cubic meters) to each basin. The Upper Basin was required to restrict its use so that the flow of the river at Lees Ferry would not fall below an aggregate of 75 million acre-feet for any period of ten consecutive years. In addition, the Mexican Treaty of 1944 annually allocated 1.5 million acre-feet (1.85 billion cubic meters) of water to Mexico, to be increased in times of surplus to 1.7 million acre-feet (2.1 billion cubic meters), but also to be reduced proportionately during years of "extraordinary" drought. There are concerns about the reliability of these allocations because the long term average flow is roughly 13.5 million acre-feet (16.6 billion cubic meters), almost 20 percent lower than the total allocation of 16.5 million acre-feet (20.3 billion cubic meters). Drought planning in Arizona is in the context of ongoing interstate and international discussions about management of the Colorado River, including criteria for shortage sharing.

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Within Arizona, the Salt River Project provides 1 million acre-feet (1.2 billion cubic meters) of surface water per year to the Phoenix area under average conditions, and the Central Arizona Project, completed to its terminus in Tucson in 1992, has the capacity to provide approximately 1.5 million acre-feet (1.8 billion cubic meters) of Colorado River water to central Arizona. In addition, Arizona has made major investments in managing the ground water supplies in the Active Management Areas (AMAs) of the state (Phoenix, Tucson, Pinal, Prescott, and Santa Cruz). However, serious drought conditions over the past eight years have raised awareness of the need for a comprehensive state drought plan and concerns about dependability of urban water supplies during sustained drought. The most critical water supply concerns are in the rural parts of the state, where alternative water supplies are generally very limited and the economies are strongly affected by drought particularly in the grazing, recreation, and forestry-related sectors.

With the assistance of the National Drought Mitigation Center and some financial assistance from the U.S. Bureau of Reclamation, Arizona recently developed a drought plan that uses some lessons from other states while adding some new approaches that are unique.

Governor Janet Napolitano established the Governor's Drought Task Force by executive order on March 20, 2003. Customarily, drought response activities in Arizona have been handled within the Arizona Department of Emergency Management; however, recognizing the need for a more proactive approach to drought planning, the Governor directed the Arizona Department of Water Resources to provide leadership in this effort. The Drought Task Force itself was comprised of representatives of state agencies and elected officials, however all meetings were open to the public and stakeholder participation in the drought planning process was encouraged. An e-mail notification list of over 1,000 participants was developed, and meetings of the Drought Task Force were well attended. Work groups have been established to actively solicit input from municipal water providers, irrigated agriculture, environmental and resource management interests, tribal governments (there are 22 Indian reservations within Arizona), and the commerce, recreation, and tourism sector. In addition, the planning process was directly supported by public and private sector volunteers who supplied much needed expertise.

The Drought Task Force adopted its first drought plan before the end of 2004. However, the majority of the effort was focused on developing an ongoing, sustainable planning process. The importance of developing a highly adaptive process that involves continual improvement in monitoring of conditions throughout the state, along with programs intended to reduce the vulnerability of the most drought prone sectors, were the major thrusts of the planning effort (e.g., Wilhite *et al.,* 2000). It is hoped that the ongoing process will allow for continual improvement of predictive capacity as well as investments that limit the economic impact of future droughts.

The Drought Task Force planning process was designed to encourage the use of the latest scientific information, particularly climate data. In addition to the strong science focus, the process was designed to maximize stakeholder input over time. Stakeholders helped to shape the research, monitoring, and communication processes of the plan. The drought planning effort was highly integrated with planning and research efforts of the University of Arizona, which provided natural and social science expertise including the stakeholder driven research initiatives of the Climate Assessment for the Southwest (CLIMAS) project. The State Climatologist, located at Arizona State University, also played a key role in this process.

An issue that is raised on a regular basis within the work groups and by the public is concern about long term water supply availability in rapidly growing communities outside of the AMAs, including some significant urban areas like Flagstaff, where state regulation of ground water use is virtually nonexistent. Although growth issues are of central importance to the state's future, the short time horizon and the limited resources of the Drought Task Force necessitated shifting this issue to other venues to allow members to concentrate on completing the first phase of the drought plan.

BACKGROUND ON LONG TERM CLIMATE AND DROUGHT IN ARIZONA

Arizona's climate is characterized by arid to semiarid conditions, as it is situated at the intersection of the four major North American deserts. Arizona's primary vegetation is typical of the Sonoran Desert in the south and the Great Basin Desert in the north (Figure 1), and is far lusher than deserts centered in the subtropical latitudes (e.g., the Sahara). As is typical of most of the world's desert regions, Arizona's climate is strongly influenced by subtropical atmospheric circulation. However, the interplay of subtropical high pressure features with mid-latitude circulation, such as the polar and subtropical jet streams during the winter and with the North American monsoon circulation during summer, determines the season-to-season (intraseasonal) and year-to-year (interannual) variations in precipitation, sunshine, and temperature.

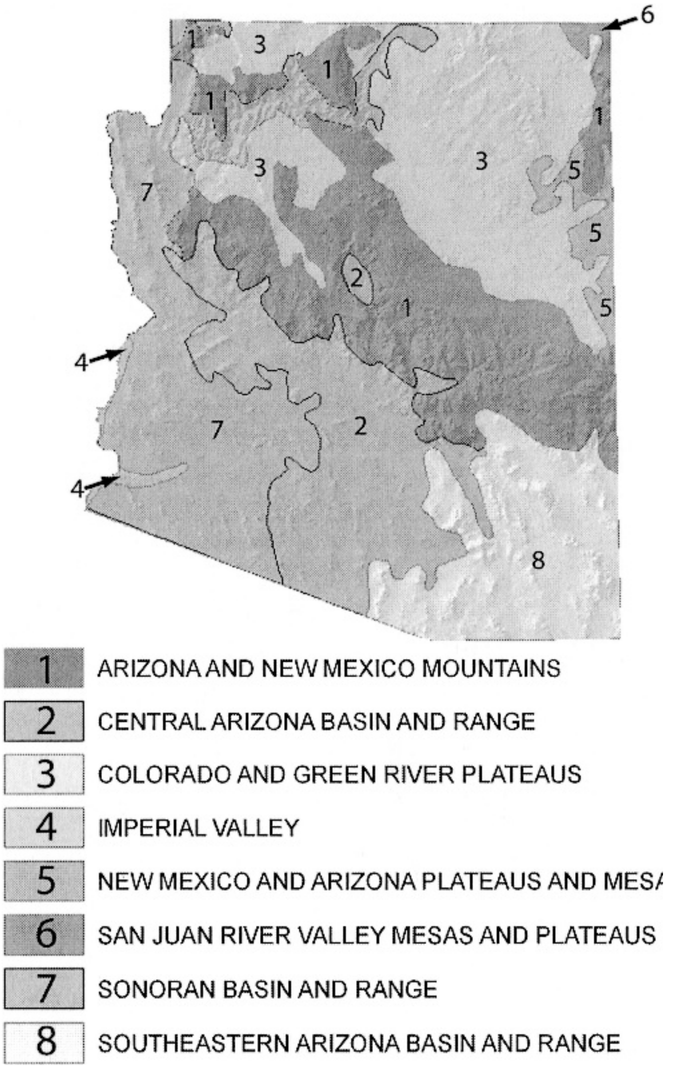

Figure 1. Major Land Resource Areas in Arizona and Topography. Map courtesy of University of Arizona Center for Applied Spatial Analysis. Original data: USGS.

Precipitation in Arizona is highly seasonal, with peaks during the winter (November to April) and summer (July to September). The summer precipitation peak is most pronounced in southeastern Arizona, and generally becomes more pronounced as one proceeds from west to east across the state. Winter precipitation is associated with widespread storms that are one to several days in duration and provide soaking rains at lower elevations and snowfall at higher elevations (Sheppard *et al.,* 2002). Winter precipitation is particularly important to Arizona water supply, as cooler winter temperatures attenuate evaporation in the soil and surface water bodies, and allow snowpack to persist until the spring. In contrast, summer precipitation is associated with convective thunderstorm activity accompanying the North American monsoon circulation; summer precipitation is typically of high intensity, short duration, and spatial heterogeneity (Adams and Comrie, 1997). Due to the high intensity of summer precipitation accompanied by maximum annual temperatures and high rates of evaporation, recharge to the soil column and water supplies is limited. Consequently, variations in winter precipitation are critical to understanding drought in Arizona.

In addition to strong seasonality, Arizona precipitation, like that of most of the world's desert regions, is characterized by a high degree of year-to-year (interannual) variation. One of the key factors influencing interannual precipitation variations in Arizona, particularly during winter, is the El Niño-Southern Oscillation (ENSO), a multi-season to multi-year variation in equatorial Pacific Ocean temperatures and associated atmospheric circulation (Kiladis and Diaz, 1989; Redmond and Koch, 1991; Cayan *et al.,* 1999; Sheppard *et al.,* 2002). The ENSO has varied considerably in frequency, intensity, and interval between its El Niño and La Niña phases over the historical and paleoclimate record (Allan *et al.,* 1996; Stahle *et al.,* 1998; Diaz *et al.,* 2001).

When ENSO is in its El Niño phase, Arizona frequently receives above average winter precipitation, due to an enhanced subtropical jet stream and increased low latitude moisture available to storms tracking across the Southwest. However, the El Niño wet Arizona winter connection is quite variable (Hoerling and Kumar, 2002), and although most of the wettest Arizona winters have occurred during the El Niño phase, there have been a considerable number of dry Arizona El Niño winters (Hereford *et al.,* 2002; McPhee *et al.,* 2004). When the El Niño phase is combined with the high phase of the North Pacific Oscillation, Arizona summer precipitation is frequently below average and the onset of the summer monsoon is delayed (Castro *et al.,* 2001). When ENSO is in its La Niña phase, Arizona winters are most frequently dry, and are reliably not wet, due to a more northern storm track and increased influence of subtropical high pressure. However, summer precipitation can be above average, with an early monsoon onset, when ENSO is in its La Niña phase (Castro *et al.,* 2001). Several Arizona droughts during the past two decades (e.g., 1989 to 1990, 1995 to 1996, and 1998 to 2001) have been initiated by La Niña conditions in the Pacific. Paleoclimate research indicates a strong connection between the historical frequency and intensity of the La Niña phase and multi-year drought in the Southwest (Cole *et al.,* 2003). The noted 1950s drought, which had exceedingly severe effects on New Mexico and the Southern Plains states (and to a lesser extent, Arizona), was embedded during a longer term 1940s to 1970s dry period in the Southwest, which in turn was associated with more frequent La Niñas and fewer and lower magnitude El Niños. A step change in Pacific Basin climate in 1976 to 1977 heralded two decades of wet conditions in the Southwest, associated with more frequent and higher magnitude El Niños (Ebbesmeyer *et al.,* 1991; Miller *et al.,* 1994).

Multi-decade time scale changes in the climate of both the Pacific and Atlantic Ocean basins are implicated in severe sustained drought in Arizona. In the North Pacific Ocean, a feature called the Pacific Decadal Oscillation (PDO) has been associated with the record of winter (November to March) precipitation variations in the western United States (Mantua *et al.,* 1997; Zhang *et al.,* 1997; McCabe and Dettinger, 1999; Sheppard *et al.,* 2002; Hereford *et al.,* 2002). Sea surface temperatures (SST) and western U.S. drought patterns since 1999 indicate the possibility that the PDO might have shifted to a phase favoring dry conditions in Arizona for perhaps the next 20 years (Gedalof and Smith, 2001; Hereford *et al.,* 2002). Across Arizona, 1999 through 2003 was one of the driest five-year periods of winter precipitation in the instrumental climate record (Figure 2). There is concern about an episode of PDO influenced prolonged drought in Arizona; such concerns are heightened by the fact that the long term predictability of winter precipitation in the Southwest is diminished during negative PDO phases (Gutzler *et al.,* 2002).

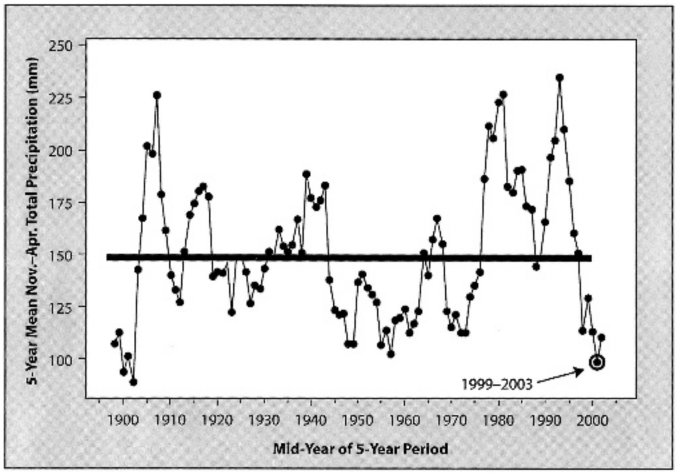

Figure 2. Arizona Statewide Five-Year Average Winter Half Year (November to April) Precipitation. The horizontal dark black line is the long term average five-year winter precipitation.

The multi-decadal behavior of the Atlantic Ocean is also associated with multi-decade dry conditions in the Southwest (Enfield *et al.,* 2001). The Atlantic Multidecadal Oscillation in conjunction with Pacific Ocean climate patterns, such as ENSO, appears to produce atmospheric circulation patterns conducive to enhanced La Niña like conditions in the Southwest (Enfield *et al.,* 2001; McCabe *et al.,* 2004).

The paleoclimate record of drought shows that the late 1500s is probably the drought of record in Arizona for the last 1,000 years (Ni *et al.,* 2002; Gray *et al.,* 2003). This drought has been tied to record low flows on the Colorado River (Meko *et al.,* 1995), native population collapse due to disease in Mexico (Acuna-Soto *et al.,* 2002), and widespread drought conditions across North America (Stahle *et al.,* 2000). The CLIMAS reconstructions of Arizona climate division winter (November to April) precipitation show extensive dry periods in some or all parts of Arizona during virtually every century in the last 1,000 years (Ni *et al.,* 2002), with notable multi-year droughts in the mid-1200s, late 1500s, mid-to-late 1600s, mid-1700s, late 1800s, early 1900s, and mid-20th Century. Most of the aforementioned winter dry periods were more severe, and many were more sustained than the Arizona drought of the last eight years. Taking into account the range of future possibilities demonstrated by the paleoclimate record is crucial to drought preparedness in the future.

PRELIMINARY APPROACH TO THE ARIZONA DROUGHT PLAN

Arizona's Drought Plan benefits from being set in this long term climate context, based in part on decades of tree-ring research in the Southwest and ecological work linking drought, fire, and large scale ecological change (Swetnam and Betancourt, 1998). The planning process has also benefited substantially from the experience of Montana, Georgia, Colorado, and New Mexico in particular. The Montana drought planning approach has inspired the concept of the "adaptive" drought plan, focused on a rigorous monthly monitoring and adaptive learning process that has now been in place for 12 years. The Georgia Drought Plan is a very sophisticated approach to establishing monitoring and trigger mechanisms (Steinemann, 2003). In the authors' opinion, Colorado has done an excellent job of documenting recent drought impacts (McKee *et al.,* 2000), and the recently revised New Mexico drought plan has an extremely well defined and specific set of mitigation and response actions (New Mexico Drought Task Force, 2003).

The Arizona Drought Plan acknowledges that drought affects not only different regions of the state differently, but also affects multiple sectors differently. To this end, the plan establishes trigger mechanisms that are related to the vulnerability of each sector and region rather than establishing statewide drought stages. This approach is imperative in a state that is so dependent on imported surface water supplies from the Colorado, with reservoirs that hold a multi-year water supply, and large ground water reserves. In contrast with portions of the state that have these long term, generally reliable water supplies, sectors such as grazing and recreation, dependent on timely precipitation, are likely to be in elevated drought status more commonly than the major urban areas. In these sectors, enhanced data collection will be required. In all sectors, monitoring focuses on current conditions as well as trends, and impacts associated with various levels of drought condition. It is recognized that the triggers selected for use also need to acknowledge and work in concert with the relatively complex institutional water management context, as well as responding to different sources of vulnerability and adaptation options for each sector.

Assessment of drought indices, monitoring techniques, and trigger points is essential to ensure their applicability in the Arizona context. This need is especially critical given the varied landscape types in Arizona's primary physiographic regions (basin and range, Mogollon Rim, Colorado Plateau) and the influence of local and regional elevation induced weather and climate patterns.

CONTRIBUTIONS IN THE USE OF SCIENCE AND MONITORING

The Arizona Drought Task Force Monitoring Technical Committee (MTC) was formed during the summer of 2003. The MTC consists of representatives from state agencies, including Arizona Department of Water Resources and Arizona Department of Emergency Management; federal agencies, including the National Oceanographic and Atmospheric Administration (NOAA) National Weather Service, the U.S. Geologic Survey (USGS) Water Resources Division, the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), and the U.S. Bureau of Reclamation; private agencies, including the Salt River Project; and universities, including CLIMAS at the University of Arizona and the State Climatology Office at Arizona State University. The MTC is faced with considerable technical and conceptual challenges in monitoring drought in Arizona, including the following: (1) accounting for extremely diverse topography and large elevation changes within relatively short distances; (2) the need to monitor multiple sources of surface water, including supplies imported from out of state; (3) major spatial gaps in climate and snow monitoring networks, especially at higher elevations, and spatial and temporal gaps in ground water and soil moisture monitoring networks; (4) the need to take into account institutional considerations and systems designed to buffer water supplies (i.e., water banking); and (5) addressing the multiple scales of drought that might affect well buffered urban and suburban core areas very differently than nearby outlying areas. Addressing these challenges requires not only state-of-the-art drought monitoring techniques and data, such as the use of integrated remotely sensed and ground based data products, but also state-of-the-art knowledge transfer techniques, in order to portray the complexity of spatial drought variations across Arizona at multiple time scales.

Given Governor Napolitano's short deadline for delivery of a completed drought plan and an operational drought monitoring process, the MTC developed a flexible approach to drought monitoring, with short, medium, and long term goals that employ various combinations of quantitative and subjective methods of drought monitoring. In order to meet short term goals of providing drought monitor reports to the Governor by summer 2004, the MTC adopted a model based on the U.S. Drought Monitor (USDM) process (Svoboda *et al.,* 2002). For these short term reports, the MTC used a combination of objective monitoring tools and data, such as state-of-the-art drought indices (e.g., McKee *et al.,* 1993, 1995), analyses of ground based precipitation, temperature, and snow data, surface and ground water supply status, remotely sensed vegetation condition, and various indices of annual to decadal scale ocean atmosphere circulation affecting the Southwest. Emulating the USDM process, the MTC plan includes soliciting local expertise in reporting conditions throughout Arizona. The MTC used subjective monitoring measures to the extent feasible, such as cooperative extension, USDA-NRCS, Arizona Game and Fish, and tribal reports on the conditions of topsoil, vegetation and forage, stock ponds, and wildlife habitat.

The MTC medium term drought monitoring strategy is to create an operational system to monitor drought on multiple time scales at a minimum spatial resolution of the NOAA climate divisions. The use of climate division data is expedient, although far from ideal, given that in Arizona the divisions cover very large and topographically diverse areas and given the local scales at which drought mitigation and response decisions must be made. Using geographic information system (GIS) based monitoring data allows analysis at multiple scales, as well as the ability to overlay a variety of jurisdictional boundaries for each sector as needed. The MTC will monitor drought at multiple time scales, taking into account short term variations of seasonal weather, accumulated moisture deficits and processes that respond on seasonal to annual time scales, and multi-season to multi-year hydroclimatic variations.

To implement an objective process, the MTC conducted statistical analyses to translate drought indicator data into drought response triggers (Steinemann, 2003). This process was originally developed for the Georgia Drought Management Plan for seasonal to interannual time scales. The process will allow the MTC to keep close tabs on a relatively small group of parameters for the purpose of triggering drought mitigation and response actions, while also monitoring a larger array of spatially-specific parameters less intensively. As with many other states' drought plans, the first step after a drought mitigation or response trigger has been "tripped" is to evaluate, using local scale and high spatial resolution data, the need for specific localities to take voluntary action (the Drought Task Force itself does not have regulatory authority). In addition to objective approaches to drought monitoring, the MTC is incorporating subjective monitoring measures such as quarterly district status reports provided by USDA-NRCS. CLIMAS is conducting a diagnostic study of the relationship between various drought indices and corresponding environmental and economic impacts. Results of the diagnostic study will help the MTC develop methods for incorporating subjective and sporadically reported nonhydroclimatic measures of drought.

The MTC plans to develop drought monitoring and drought status reporting at county and smaller spatial scales, using GIS to the extent feasible. This scale of reporting, which is necessary to account for Arizona's diverse topography and associated spatial data gaps, will require standard analyses of hydroclimatic data at individual locations and the use of new interpolated data products for which retrospective time series have been developed (e.g., Daly *et al.,* 1994, 2004; Molotch *et al.,* 2004a, 2004b). Such datasets are also required to create a baseline for incorporating the short term records of stations installed to overcome spatial gaps in existing data networks. In order to take advantage of extensive paleoclimate records of Arizona drought and precipitation variations (e.g., Meko *et al.,* 1995; Ni *et al.,* 2002), the MTC eventually intends to develop additional, complementary records of drought history, severity, and duration for drought monitoring. Further, because Arizona's climate responds to decade scale climate variability (e.g., Mantua *et al.,* 1997) in complex ways across the state (Brown and Comrie, 2002), the MTC plans to incorporate measures of decadal climate variability into future drought monitoring products.

CONTRIBUTIONS TO DECISION SUPPORT

Portraying drought status in a way that addresses urban/rural water supply disparities and drought vulnerabilities, while minimizing confusion among stakeholders, requires state-of-the-art knowledge transfer and creative communication techniques (Tufte, 1990). The MTC, in coordination with member agencies and with the proposed National Integrated Drought Information System (WGA, 2004), will conduct drought product usability studies (e.g., Nielsen and Mack, 1994; Hackos and Redish, 1998) to ensure that decision makers can understand and make the best use of the drought monitoring products and science being provided to them.

There are many ongoing studies within the three Arizona universities as well as within government agencies and stakeholder groups that are being used to identify and assess the components of vulnerability. The Arizona drought planning process focuses on defining the conditions that create vulnerability to drought and identifying and encouraging potential adaptive responses. The intent is to increase the effectiveness of drought planning and reduce long term costs related to emergencies. The process also focuses on building institutional relationships and operationalizing an adaptive approach that allows incorporation of new information over time. Previous work (see, for example, Gibbons *et al.,* 1994; Jasanoff and Wynne, 1998; Sarewitz *et al.,* 2000) shows that trust between stakeholders and those who generate the scientific information, and capacity building to interpret and evaluate such information (see, e.g., Nicholls 1999; Stern and Easterling 1999; Hartmann *et al.,* 2002), are integral components of a successful planning process (Jacobs and Morehouse, 2003). This work should assist decision makers in focusing on the adaptation and mitigation activities that are most effective in reducing vulnerability.

The Governor's Drought Task Force website (Governor's Drought Task Force, 2004) currently provides the public with information produced by the MTC, including current drought status, seasonal averaged weather projections and background data, as well as all of the drought-related presentations made at the Drought Task Force meetings and monthly climate summaries, initially produced by CLIMAS under its 2002 to 2003 END Insight (El Niño Drought Insight) Initiative. The monthly climate summaries, with interpretation to enhance their utility for Arizona and New Mexico, were supported by funds from the U.S. Bureau of Reclamation. The MTC site also provides guidelines for how to use the information provided. In addition, the Phoenix National Weather Service forecast office has developed a user friendly station level drought monitoring tool for Arizona (National Weather Service, 2004).

CONCLUSIONS

Lessons learned in other states have contributed significantly to the approach described here (Wilhite 2000a,b). Most existing drought plans do not explicitly incorporate monitoring the drivers of climate, such as atmosphere/ocean circulation at interannual to decadal time scales. The authors cite current limitations in climate science that preclude capacity to project interannual to decadal scale climate conditions at the regional scale as the primary reason for this exclusion (American Association of State Climatologists, 2001). However, appropriate use of such information, in the context of understanding regional and sectoral vulnerability to drought, may enhance the ability to limit future drought impacts. Projections that the current negative phase of the PDO may persist and enhance the probability of dry conditions provide a focus for thinking about the possibility of sustained drought over time frames of a decade or more for the Southwest. Understanding the long term historical context of drought through tree-ring records can provide valuable information about the possible range and intensity of drought. Looking to the future, there is a concern that future conditions will be exacerbated by human alterations to the climate system, as well as population growth. Among the many challenges to integration of climate information into drought planning are educating Task Force members and the public about the availability and use of forecast products and the skill and accuracy of predictions over time, space, and across water use sectors of the state.

Given the high degree of variability of Arizona's topography, climate, and hydrological conditions, and the importance of societal factors (economic, political, land use, livelihood, size of community, demographics, etc.), downscaling climate information whenever possible for local applications is essential. The Arizona drought planning process provides an opportunity for collaboration with the three state universities as well as with numerous stakeholders, agencies, and nongovernmental groups to develop and disseminate such information specifically for drought monitoring and response. Expectations are that the drought stage/trigger system will provide insights into sectoral vulnerability within each geographic area; however, participants will continue to face significant challenges in the process of creating a dynamic drought planning process. These challenges also offer important opportunities for exploring innovative ways to bridge the science/society gap.

First, building the capacity for decision making entities to understand drought related issues, interpret drought data, and implement their own analyses of vulnerability and mitigation measures is an essential component of the Arizona drought planning process. The emphasis on capacity building recognizes the politics of the state, where emphasis is on local control and empowerment. Through advocating local empowerment and acknowledging current drought planning efforts, the Arizona plan aims to recognize the strengths inherent in local knowledge about conditions, practices, and values, while at the same time providing a comprehensive statewide support structure to help communities and impacted sectors be better prepared for drought in the future. Sustaining this effort over the long term, however, will require focused effort and political will.

Second, the Arizona drought plan seeks to integrate science and public policy in ways that allow refinements to be made as expertise and experience grows. For this to occur, however, the planning process must have sufficient administrative support to be sustained even during relatively wet periods. A plan that is flexible enough to adjust to changing vulnerabilities and adaptive capacities within the state is equally essential. However, it is clear that supporting an "adaptive" approach to drought planning and preparedness is resource intensive, and it is not clear whether the necessary resources will be available over the long term.

Third, close interaction between scientists, decision makers and the public throughout the drought planning process and beyond is essential. Providing for adequate levels of public participation, especially for outlying communities in a state as large as Arizona, during the initial planning effort has been challenging due to the short time frame and limited resources available during the development of the drought plan. Use of web based information sharing and a large e-mail network has overcome some of the participation issues. Over the longer term, assuring continued close interactions requires development and maintenance of a system for exchange of information and ideas, and for allowing the kinds of iteration that are essential for establishing adaptive drought planning and management.

It is hoped that Arizona's approach to integration of a wide array of hydroclimatic information into the planning process and its emphasis on framing decision criteria in terms of vulnerability and adaptation will provide enhanced drought management approaches that may be useful to other states. Interaction among drought planners and iteration of drought plans based on shared experience and new knowledge offers opportunities for operationalizing adaptive management of drought and its impacts across the United States.

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