DROUGHT AND CLIMATE SERVICES IN ARIZONA

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1. INTRODUCTION

Drought is endemic to Arizona. Between 1895 and 2004, Arizona experienced 11 major drought events, with each event recording a PDSI ≤ -2 for at least 6 consecutive months (Goodrich and Ellis, 2006). Three extended dry periods, 1896-1904, 1947-1964, and 1996-2004 account for 67 percent of all months in drought, as defined by at least 3 consecutive months recording a PDSI ≤ -2 (Goodrich and Ellis, 2006). The most recent drought, which has affected Colorado River Basin water supplies and forest ecosystems throughout the state, led Arizona's Governor to issue an executive order to create the state's first drought plan. During the driest years of the recent drought, 2001-2004, the demand for climate services related to drought increased rapidly. Since then, the state's drought monitoring technical committee, state and federal agencies, state climatologist, university initiatives, and others have stepped up efforts to provide timely drought and hydroclimatic information, web-based decision support, education and outreach and other climate services.

This paper describes a suite of efforts to provide drought and climate services, as well as a philosophy regarding the challenges and benefits of developing climate services to meet the needs of diverse stakeholders in Arizona. The paper emphasizes the benefits of multi-agency, multi-stakeholder partnerships for developing effective climate services. The paper concludes with a brief discussion of stakeholder priorities for hydroclimate observations, services, and products to meet challenges related to drought and climate change.

2. ARIZONA'S CLIMATE CONTEXT

Arizona is located in the heart of the southwestern United States' drought corridor. The state is located between 31.2°-37.0° N. During the winter, Arizona is under the influence of the subtropical high, tucked between polar and subtropical jet streams, and in the shadow of coastal ranges that wring heavy precipitation out of the winter westerlies. In the summer, its location at the northern limit of the North American Monsoon ensures high interannual variability in summer precipitation. Most of the state has a pronounced bimodal precipitation peak, punctuated by a reliably rainless late spring or "pre-monsoon" season. Interannual precipitation variability is also strongly influenced by the El Niño-Southern Oscillation (Sheppard et al., 2002). As mentioned above, the state is prone to multi-year and multi-decade drought, as a result of long-term variations in Pacific Ocean circulation (Brown and Comrie, 2002; 2004), and, perhaps, Atlantic Ocean circulation (McCabe et al., 2004; McCabe and Palecki, 2006).

2. CLIMATE SERVICES

2.1 *What are climate services and who provides them?*

Operational services that are available to the public 24 hours a day, seven days a week (for example those provided by the U.S. National Weather Service) rest on a foundation of support activities. The range of activities supporting operational services includes: observations, data generation and quality control; modeling; basic and applied research; the generation of data products and experimental decision support tools; data visualization; product testing and evaluation and assessment of the users' decision-making context (in order to make the services useful and usable); customer service (in order to obtain and respond to user recommendations), and education and outreach (in order to build capacity for society to understand the utility of science-based products and services) (Figure 1). These activities require a wide array of skills, and perspectives and expertise. Initiatives to develop experimental climate services, such as the NOAA Regional Integrated Sciences and Assessments program (RISA; Pulwarty et al., 2009), advocate the use of interdisciplinary teams to understand the contextual basis necessary to provide regionally-specific climate decision support. Moreover, the success of such endeavors depends on incorporating the perspectives of information users (e.g., Hartmann et al., 2002; Jagtap et al., 2002) and decision makers across a wide spectrum of society.

Figure 1. Climate services activities. "OPS" refers to operations.

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Several compelling visions of integrated national climate services have been put forth by a variety of authors, agencies, and U.S. National Academy of Science panels (e.g., National Research Council, 2001; Miles et al., 2006; NIDIS, 2007). However well-defined these overarching plans are, they still leave the question of how a state, small country, or regional organization, lacking sustained and substantial funding, provides climate services to meet the growing needs of a society whose expectations have grown exponentially as inexpensive information technologies are made more available and affordable. In Arizona, with a few exceptions (mentioned below), climate services are provided by a loosely coordinated network of federal agencies, such as the National Weather Service, UDSA-NRCS, USGS, university programs (including the State Climate Office, Cooperative Extension, and the Climate Assessment for the Southwest [CLIMAS]), and non-governmental organizations.

2.2. *A Matter of Perspective: Why stakeholders matter*

As mentioned in section 2.1, successful climate services depend on incorporating user perspectives. Thousands of climate products are currently available on the internet. These range from data access and summaries of recent trends, to forecasts, to information that synthesizes forecasts and impact data in an effort to guide decisions. The vast majority of these products have been developed by scientists and operational personnel, usually based on the availability of data and knowledge (using econonmic terminology, the "supply side"; Sarewitz and Pielke, Jr., 2007), and an informed guess about what will be useful to stakeholders. The motive for developing these products is in alignment with stakeholder needs, but the details have not been researched through iterative conversation with potential users; thus, these products may be useful, in theory, but not usable. The process of developing an ever increasing number of products in such a manner has been described as "the loading dock phenomenon" (Cash et al., 2006).

In order to move beyond the loading dock, and make climate science products useful and usable to stakeholders, and used by them, information users and decision makers must be consulted (Feldman et al., 2008). Their perspectives about the utility of climate services are informed by the usefulness of the information, as well as a host of concerns that include institutional practices, geographic specificity, transparent communication of forecast skill or data accuracy, hardware preferences, and other factors. Garnering user perspectives in order to ensure the effectiveness of an organization's investment in developing climate services, requires time to understand user decision contexts, technical capabilities, and other factors.

2.3. *Establishing the Climate Services Relationship*

Developing useful hydro-meteorological services depends on building good relationships. This is a lot like building personal relationships, such as the steps from friendship to intimacy to marriage. The first step is informing the world that you are available. In the context of climate services, this is usually carried out by creating a website, making phone calls to establish institutional connections, and attending meetings within the user's community. The next step in the climate services world might be to hold a meeting with a potential services user, in order to learn about the user's needs on short and long timescales, and to express what kinds of hydro-meteorological services can be made available on short and long timescales; this is equivalent to going on a date. After several dates, the service provider and information user begin to understand each other's limitations and strengths.

At this stage, if resources are available, the parties can commit to working together – perhaps through a series of meetings, workshops, or pilot projects. Following a successful engagement that meets both user and service provider needs, the partners may propose a long-term collaboration, that requires all parties to contribute human or financial resources; this is equivalent to marriage. As with any successful marriage, the partners need room to grow, and to adapt to changing needs and pressures; in the hydroclimate services world, pressures may include an imminent drought or a forecast for a severe storm season, and needs may change due to new science results, new technologies, or new treaties or business opportunities.

In recent years, several studies have endeavored to define the characteristics of successful science-society relationships. Cash (2001) reports on the more than one century of experience in the U.S. Cooperative Extension service, and how the extension model, of embedding university employees in rural communities, has successfully faciliated the transfer of new science to rural stakeholders, in order to meet their needs for improved agricultural techniques. Lemos and Morehouse (2005) identify sustained repeat engagements, or iterative relationship building, as a cornerstone of developing successful experimental climate services. Katharine Jacobs, a water manager for over 20 years, has written a valuable guide to developing relationships between scientists and stakeholders (Jacobs, 2003). The guide is free and available from the University of Arizona at the following URL:
http://ag.arizona.edu/AZWATER/presentations/Connecting.Science.Decisionmaking.pdf

3. DROUGHT AND THE DEVELOPMENT OF CLIMATE SERVICES IN ARIZONA

3.1 *21st Century Drought in the Southwestern United States*

Arizona, like most U.S. states, developed a drought plan in response to a drought crisis that was impossible to overlook. Between September 2001 and August 2002, Arizona logged 12 consecutive months of below average statewide precipitation; statewide precipitation

was also below average during 12 out of the following 13 months (Figure 2). Drought impacts during 2002 included the 468,638 acre Rodeo-Chediski fire (at the time, the most widespread and severe fire in Arizona's history), reduction of rangeland cattle by ~50%, water shortages in rural communities, and the loss of 80% of endangered Sonoran pronghorn antelope herds (Bright and Hervert, 2005). Other characteristics of the drought included pronounced early snowmelt and sublimation of snowpack (Pagano et al., 2004), massive conifer forest mortality (Breshears et al., 2005), and dramatic decrease in streamflow and reservoir storage in the Colorado River Basin – a key source of water for Arizona's metropolitan areas and central agricultural districts (Woodhouse et al., 2006).

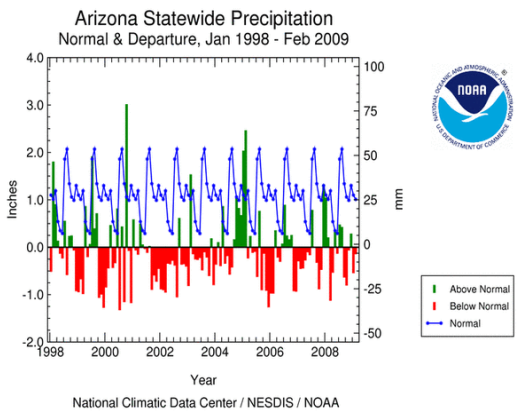

Figure 2. Arizona statewide precipitation, 1998-2009, expressed as departures from the long-term average. Below average values (red); above average values (green); average seasonal cycle of precipitation (blue). Data: NOAA National Climatic Data Center.

In March 2003, Arizona's incoming governor convened a drought task force (DTF), and entrusted the DTF to develop a drought plan in one year, with the following mission (Governor's Drought Task Force, 2004):

- Timely and reliable monitoring of drought and water supply conditions in the state and an assessment of potential impacts;
- An assessment of the vulnerability of key sectors, regions, and population groups in the state and potential actions to mitigate those impacts;
- Assisting stakeholders in preparing for and responding to drought impacts, including development of a statewide water conservation strategy and public awareness program.

The Arizona Drought Preparedness Plan (ADPP; Governor's Drought Task Force, 2004) calls for enhanced drought planning, especially in vulnerable rural areas and timely drought monitoring.

3.2 *Arizona's Drought Monitoring Technical Committee*

The primary vehicle for drought services is through Arizona drought monitoring technical committee (MTC), which is at the center of operational implementation of the ADPP. The MTC consists of representatives from state agencies (Arizona Department of Water Resources, Arizona Division of Emergency Management, Arizona State Lands Department), federal agencies (NOAA-National Weather Service, USGS-Water Resources Division, USDA-Natural Resources Conservation Service [NRCS]), private agencies (Salt River Project), and university programs (CLIMAS/University of Arizona, Office of the State Climatologist/Arizona State University, Arizona Meteorological Network [AZMET]). The committee has met monthly, since 2004, and has delivered drought status reports to the director of the Arizona Department of Water Resources and the citizens of Arizona. The reports evaluate drought status for large watersheds, (Figure 3) using a combination of precipitation, streamflow and reservoir data to evaluate drought severity (Garfin, 2006). In recent years, county-based Local Drought Impact Groups (LDIGs), and Native American nations on sovereign lands within Arizona, also advise the committee and contribute drought impact observations to the monthly drought status reports. The MTC recently decided to meet quarterly, but it produces short-term drought status updates each month.

The MTC also provides technical advice to an Interagency Coordinating Group (ICG) charged with advising the Governor on emergency declarations, funding needs, and improvements to the operational drought plan. The MTC and LDIG programs are overseen by the Statewide Drought Program, housed at the Arizona Department of Water Resources (ADWR).

3.3 *Drought Services for Arizona*

The monthly drought status reports and bi-annual technical advice to the ICG are only part of the drought-related climate services provided by the MTC and its members. Several products and services were developed to accompany the monthly drought status reports. For example, the National Weather Service forecast offices in Phoenix and Tucson provide web-based drought information, in order to meet needs expressed by stakeholders for data and information that cover smaller geographic regions and local weather stations. The USGS developed maps, keyed to the Arizona monthly drought status categories, that allow users to see watershed streamflow status for watersheds used in the monthly drought status reports. The State Climate Office and the USDA-NRCS also produce special supplemental drought information via their agency websites.

CLIMAS and Cooperative Extension, along with stakeholders in the Cochise County LDIG monitoring work group, have worked closely to develop a system for reporting and recording drought impacts. Drought

impact information, an under-reported form of data (Western Governors Association, 2004), are the

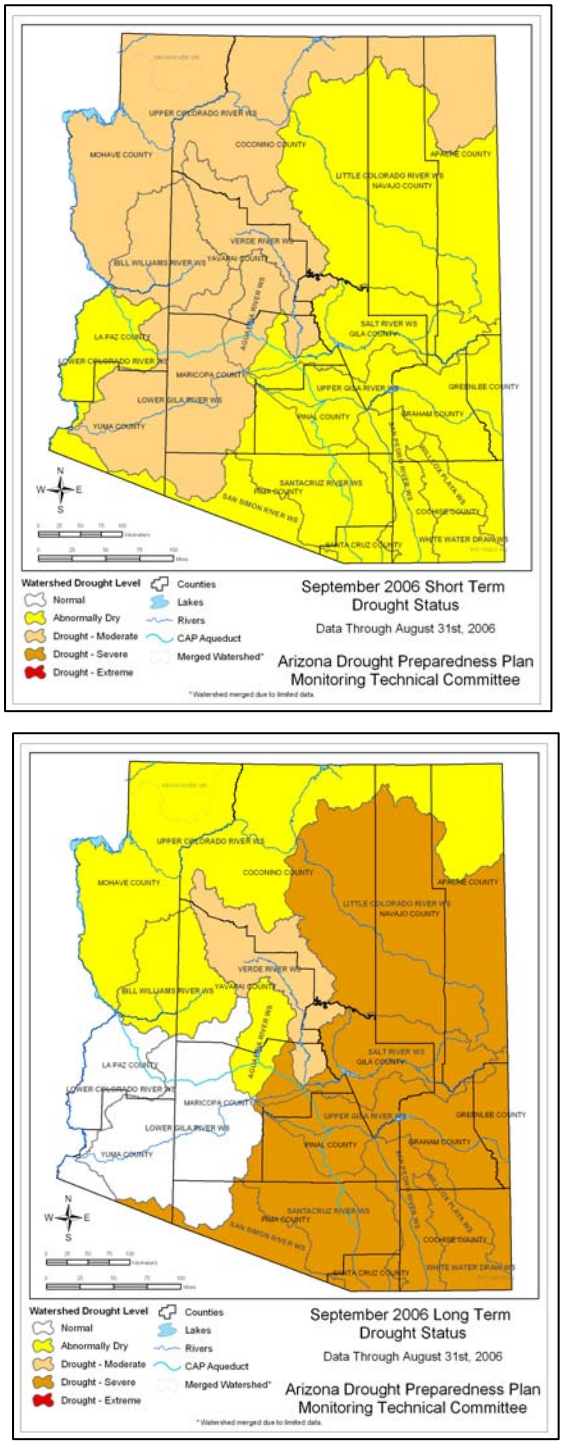

Figure 3. Examples of short-term (top) and long-term (bottom) Arizona monthly drought status maps (Arizona Drought Monitoring Technical Committee). Data are complete through August 31, 2006.

cornerstone in determining the relationships between drought status indicators and effects on the economy, water supplies, and ecosystems. After several iterations, the aforementioned partners decided to report impact status relative to previous conditions, with the option of specifying economic or other impact information. The list of impacts followed the model of the Colorado Drought Plan, and was tailored to Arizona stakeholder needs through successive refinements.

Based on the suggestions of the LDIG stakeholders, Arizona Cooperative Extension, in collaboration with the University of Arizona's Office of Arid Lands Studies (OALS) developed *AZ DroughtWatch* a web-based drought impact reporting system (Figure 4). A climate extension specialist, Michael Crimmins, is in charge of implementing *AZ DroughtWatch*, using a two-step process of (a) refining the operational process of impact observations with trained field scientists from state and federal agencies, and (b) building the capacity for a cadre of non-expert volunteer observers to report drought impacts. Impacts reported by LDIG professional and non-expert volunteers include the status of seeps, springs, and stock ponds; range impacts, ecological impacts (such as vegetation condition of indicator species, wildlife habitat, etc.); water table declines (including subsidence); soil conditions, and others. *AZ DroughtWatch* can only be as successful as the strength and commitment of the underlying partnerships between the MTC, volunteer observers, expert advisors, and the Statewide Drought Program. These partners can leverage resources, and combine efforts to expand and enhance the system. The *AZ DroughtWatch* website URL is http://azdroughtwatch.org/, and the site is also available through the U.S. Drought Portal (http://drought.gov).

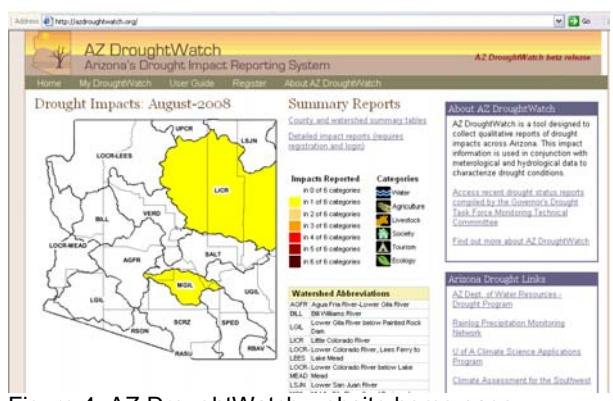

Figure 4. AZ DroughtWatch website home page http://azdroughtwatch.org.

3.4 *Expanding the Drought Services Enterprise*

Through further partnerships and engagement with an expanding network of stakeholders, Arizona institutions are developing a wider array drought-related climate services. Based on the highest priority request from Arizona's water management stakeholders, the Arizona Hydrologic Information System (AHIS), is an attempt to provide a consolidated hydrometeorological data infrastructure for the state. The project, a partnership of

the three state universities through the Arizona Water Institute, involves gathering water-related metadata and data in a single place, and conveying these data through a map-based web interface. AHIS components integrate a groundwater monitoring database and data display system, with National Weather Service station data, USGS streamflow gage data, and other drought decision support tools. As the AHIS moves from experimental to operational capability, the developers will review its functionality with stakeholders, to ensure usefulness and usability.

A separate effort by Cooperative Extension and the NSF Science and Technology Center for Sustainability of semi-Arid Hydrology and Riparian Areas at the University of Arizona (SAHRA) helped catalyze a citizens' precipitation monitoring network. These partners developed an online system called RAINLOG (www.rainlog.org), to garner precipitation and drought observations. RAINLOG partners distribute plastic rain gauges to willing participants; the participants can transmit their precipitation totals and remarks daily through a user-friendly web interface. RAINLOG software calculates simple statistics (e.g., cumulative precipitation) and displays precipitation totals and statistics through a map interface (http://www.rainlog.org). Funding for the project has been provided by SAHRA, Cooperative Extension, and the Salt River Project. Several television stations have co-sponsored the website through the enthusiastic participation by their broadcast meteorologists.

MTC members, CLIMAS and Cooperative Extension at the University of Arizona, have partnered with another NOAA RISA, the Carolinas Integrated Sciences and Assessments (CISA) to import its Dynamic Drought Index Tool (DDIT; Carbone et al., 2008) to Arizona. The DDIT software allows users to visualize many different drought indicators, such as streamflow, precipitation, and drought indices, for many different user-defined spatial and temporal scales. The project partners have tested the DDIT with potential users in Arizona, and are in the final stages of incorporating their suggestions to make the DDIT useful and usable for Arizona stakeholders. This partnership process leverages the successful efforts of CISA to avoid the start-up costs and lengthy process of software development and debugging – highlighting another way in which partnership is a fundamental aspect of developing successful climate services. The fact that the DDIT was already a functional and tangible decision support tool for another part of the United States, made it easier to gain endorsements from Arizona stakeholders for bringing the DDIT to Arizona and implementing it within a central data access infrastructure, such as AHIS or http://drought.gov.

3.5 *The Role of Process and Interaction in Arizona Climate Services*

It is important to acknowledge that providing climate services is not just a matter of developing web-based tools and technologies. Personal interactions, meetings, briefings, workshops, and trainings are an essential facet of providing effective climate services. Cultural norms in rural and Native American communities make face-to-face interactions an important part of developing the trust necessary to foster the use of climate services. Moreover, workshops are a particularly effective means of building capacity to use new data and technologies, and to connect stakeholders from different sectors, in order to improve drought preparedness efforts.

Arizona Cooperative Extension (ACE) and CLIMAS have conducted dozens of workshops with county LDIGs, and with sector-based professional organizations, such as the Society for Range Management (Crimmins et al., 2007) and the Arizona Riparian Council. ACE and CLIMAS also convene quarterly online drought videobriefings, using a system that allows participants to connect, for free, from their office computers (Figure 5). Videobriefing partners have included MTC members, such as the National Weather Service and USDA-NRCS, in addition to university scientists and the NOAA Colorado Basin River Forecast Center. (For information about the videobriefings, see: http://cals.arizona.edu/climate/ws/breeze.htm).

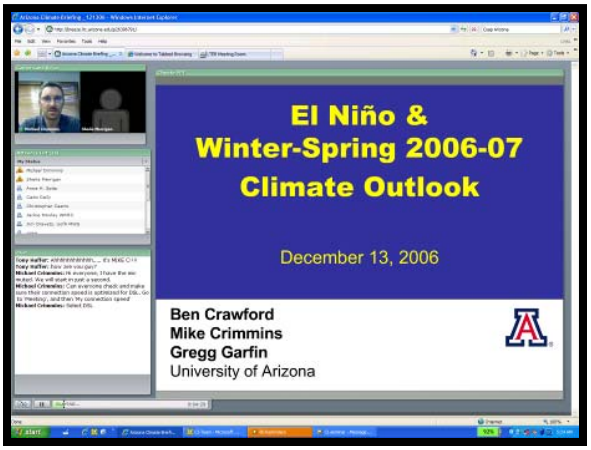

Figure 5. Screenshot of a videobriefing presentation. Upper left corner shows live image of presenter. Lower left is "chat box" in which participants can type questions and have them answered immediately. Main part of screen shows a Powerpoint presentation given by the briefing organizers.

Finally, the MTC and other members of the Arizona climate services community have developed partnerships with print and television journalists in the state. With each broadcast or newspaper article, these journalists can reach tens of thousands of citizens – which is essential for raising awareness of hydrometeorological hazards and improving drought preparedness. SAHRA and CLIMAS, in collaboration with MTC members and other institutions, have convened occasional media briefings to convey the latest information on drought, hydroclimatic hazards, and cutting-edge developments in science (http://www.sahra.arizona.edu/kt/media/). The MTC has also developed a policy of engaging newspaper editors,

in order to streamline the flow of information to newspaper audiences when drought conditions are worsening. As drought and climate change have become almost interchangeable in conversations about the future, CLIMAS and ACE have held climate change training workshops with members of the media. Accurate reporting is essential to reduce public confusion and gain trust for implementing actions necessary to improve preparedness and reduce vulnerabilities.

4. USER NEEDS AND PRIORITIES

From the kinds of stakeholder engagement activities mentioned above, especially through workshops targeted to land and water managers, the Arizona climate services community has learned about the major drought and climate change concerns and data needs of stakeholders in the state. As mentioned earlier, consolidated and easy-to-understand data access is an essential need. Because drought, ecosystem changes, and sustainability of water supplies are the major concerns of stakeholders facing a warming climate, decision-makers need simple, easy to use, online tools that allow access to hydrometeorological information, as well as societal data such as population growth trends (Garfin et al., 2008). Other high priority needs include for improved monitoring of consumptive water uses, such as agriculture, and improved hydrometeorological monitoring at high elevations, where snowpack declines are a major concern (Garfin et al., 2008). Summer rainfall is an important contributor to total annual precipitation in Arizona (Sheppard et al., 2002); thus, stakeholders, especially near the Arizona-Mexico border (Coles et al., 2009), consistently request improved summer rainfall forecasts and estimates of the effectiveness of summer storms to recharge groundwater supplies. The Arizona climate services community has come to learn that decision-makers do not necessarily expect a single deterministic answer from models, forecasts, and decision tools; rather these stakeholders rely on the guidance given by drought- and hydrometeorological service online products a point of departure to discuss options for planning and taking action (sensu Nelson, et al., 2001). This kind of "discussion support" will be increasingly demand in the array of services requested by stakeholders.

5. HOW DO WE KNOW IF WE'VE BEEN SUCCESSFUL?

…The best measures of the value of climate services depend, once more, on the users of the services. Are the users satisfied with the services provided? Do they use the services, and do they apply hydrometeorological information and knowledge to their decisions? The National Research Council evaluated ways in which the effectiveness of the U.S. Climate Change Science Program could be judged (National Research Council, 2005). They set forth metrics for process (e.g., Does the program have an adequate peer-review process?), inputs (e.g., Are there sufficient resources?), outputs (e.g., Are research results communicated to the appropriate range of stakeholders?), outcomes (Have institutions and human capacity been created that can better address a range of problems and issues?), and impacts (Has the program benefitted society in terms of enhancing economic vitality…protecting life and property, and reducing vulnerability...?). These metrics provide a valuable framework. Additional metrics for climate services have been suggested by Miles et al. (2006). These include, the degree to which well-functioning collaborations have been established, the quality and relevance of decision support services and tools to stakeholders, and evidence of the impact of the services on regional planning and decision making (Miles et al., 2006). Arizona's climate services community has not yet evaluated its efforts.

6. CONCLUSIONS

…Arizona has developed a combination of formal and ad hoc climate services to respond to and prepare for drought. The hub of these services is the Arizona Drought Monitoring Technical Committee, its member organizations, and the Statewide Drought Program. However, services provided by "the hub" have been substantially augmented and expanded through partnerships with universities and member agencies. Services include drought reports, data provision and access, and decision support tools, as well as processes, such as workshops, trainings, and briefings. Central to the success of these efforts is engagement and partnership with the users of climate services, who will ultimately be the best judges of the success of these services.

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