A Primer on Drought and Drought Preparedness

Oversight Committee
Joint City/County Water and Wastewater Study

July 2009

Introduction

The Oversight Committee discussed the "City of Tucson and Pima County Consolidated Draft Management Plan Technical Paper" at its March 19, 2009 meeting. The technical paper provided detailed information on the city's and county's drought mitigation plan, how they are similar and how they are by necessity different. Some members requested basic information on the definition of and mechanics of drought, to serve as preamble to the Committee's final report for Phase 2.

This document is a primer on drought and drought preparedness. The primer emphasizes that drought is best understood (1) as a natural, recurring event that causes harm to people and environments and (2) by how well we prepare ourselves to anticipate droughts, reduce our vulnerabilities to drought in advance of the event, and endure the events as they occur.

(This primer does not include impacts of climate change on temperatures and drought. A June 17, 2009 Arizona Daily Star article[1] on a White House report[2] quotes Jonathan Overpeck from the University of Arizona as saying the "Southwest, especially Arizona, 'is going to be hit as hard, or harder, than any other part of the United States.'" According to the Daily Star article, the White House report observes that "Decreased precipitation and increased temperatures, exacerbated by other man-made changes such as the heat-island effect in our cities, will bring more drought, wildfires, invasive species, pest-borne diseases, and flooding." According to Overpeck, "Everything, absolutely everything, points to less water, and substantially less water, unless we get climate change under control.")

The ABCs of Drought

We best begin to understand drought with an appreciation of how complex the phenomenon is. For example, in a glossary on the website of CLIMAS (Climate Assessment for the Southwest) at the University of Arizona, there is the following statement about drought: **"There is no definitive definition of drought based on measurable processes**…"[3] (emphasis added)

The National Drought Monitoring Center amplifies on this point:

> "Research by Donald A. Wilhite, director of the National Drought Mitigation Center, and Michael H. Glantz, of the National Center for Atmospheric Research, in the early 1980s uncovered more than **150 published definitions of drought**. The definitions reflect differences in regions, needs, and disciplinary approaches." [4](Emphasis added)

The difficulty with pinning down a definition of drought can be highlighted in part by comparing Hawaii and Arizona. In Hawaii, with an average annual rainfall of 70 inches, as of May 26, 2009, 99.8% by area of the Hawaiian Islands were in drought, with 56.4% in the category of **Abnormally Dry**, 20.2 % the

Drought – Moderate and 23.2% in the **Drought – Severe** categories.[5] In Arizona, with an average annual rainfall of 12 inches, in May 2009, "All watersheds are observing some type of drought, with **abnormally dry conditions** present across the northern and western parts of the state and **moderate drought conditions** across southeast Arizona."[6] So, drought can and does occur everywhere on earth, while its particulars –climate, amount of precipitation, flora and fauna, patterns of human use and settlement, and vulnerabilities to drought– will be unique to place and time.

Despite the differences in particulars, however, there are four elements central to an understanding of drought, regardless of where it is occurring. The State of Arizona's drought plan uses a definition of drought, on a very general level that is common to all definitions:

> "Drought, in this context is defined as a sustained, natural reduction in precipitation that results in negative impacts to the environment and human activities.[7]"

- **Reduced precipitation**

Drought does not mean arid. In Southern Arizona, we already live in an arid environment. In the Sonoran Desert, under normal or even "wet" conditions, water is a scarce commodity. Droughts start with reductions in precipitation from the normal rainfall for an area. Whatever the climate, a reduction in precipitation starts the drought process, whether the reduction is from Arizona's average of 12 inches annually or Hawaii's average of 70 inches annually. In its June 14, 2009 edition, the Arizona Daily Star published some statistics on the least rainfall during our monsoon rainy season. The average June to September rainfall is 6.06 total inches, but in 1924 there was only 1.59 inches (26% of the norm), while in 1989 and 2004, the monsoon rainfalls were 2.40 inches and 2.43 inches respectively (40% of the norm).[8]

- **A natural event**

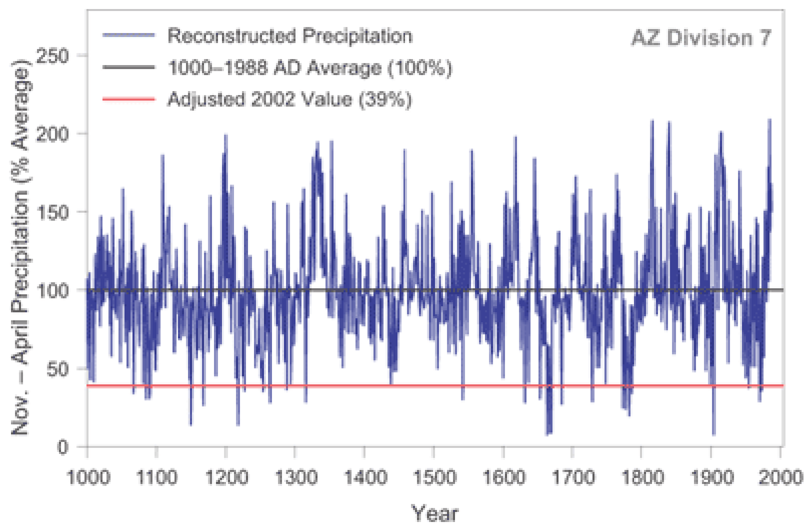
Many consider drought to be a rare and random event. In fact, as Arizona's definition points out, drought is a **"natural"** reduction in precipitation. Drought is a natural, recurring event in our arid climate.

The Arizona "Drought Preparedness Plan" makes the following observation:

> "Reconstructions of Arizona climate division winter (November-April) precipitation show extensive dry periods in some or all parts of Arizona during virtually every century in the last 1000 years, with notable year droughts in the mid-1200s, late 1500s, mid-to-late 1600s, mid-1700s, late 1800s, early 1900s, and mid-20th century." [9]

Exhibit 1 presents a graph showing trends cited by the state's drought plan documents. [10]It is important to note that Exhibit 1 shows the recurring pattern of drought; it also demonstrates that droughts end, followed by periods of wet weather permitting some measure of recovery.

Exhibit 1 Single-Year Reconstruction for AD 1000-1988 (% Average)



- **A sustained event**

Arizona's definition of drought includes duration as a quality; it is a "**sustained**, natural reduction," that the state's drought plan notes "can extend for a single season or last for several years." Our current draft has lasted for about ten years and we have no indications of when this drought will end. (Recent research on droughts in Africa unearthed evidence of droughts lasting a century or more.)

- **An event that results in negative impacts**

A crucial, perhaps the central, characteristic of drought is the negative impacts associated with a sustained reduction in precipitation. Arizona's definition of refers to "negative impacts to the environment and human activities**.**

Two headlines from early in 2006 hint at what such negative impacts could be:

> January 12, 2006, Arizona Republic, "State's water supply at risk as drought lingers"
> March 3, 2006, USA Today, "Drought taking potentially disastrous toll on Arizona."

These two articles, and others like them, identify potential risks and tolls to farming, to the environment and wildlife, to agriculture, to municipal water supplies, and tourism that could result from sustained drought and water shortages. [11]

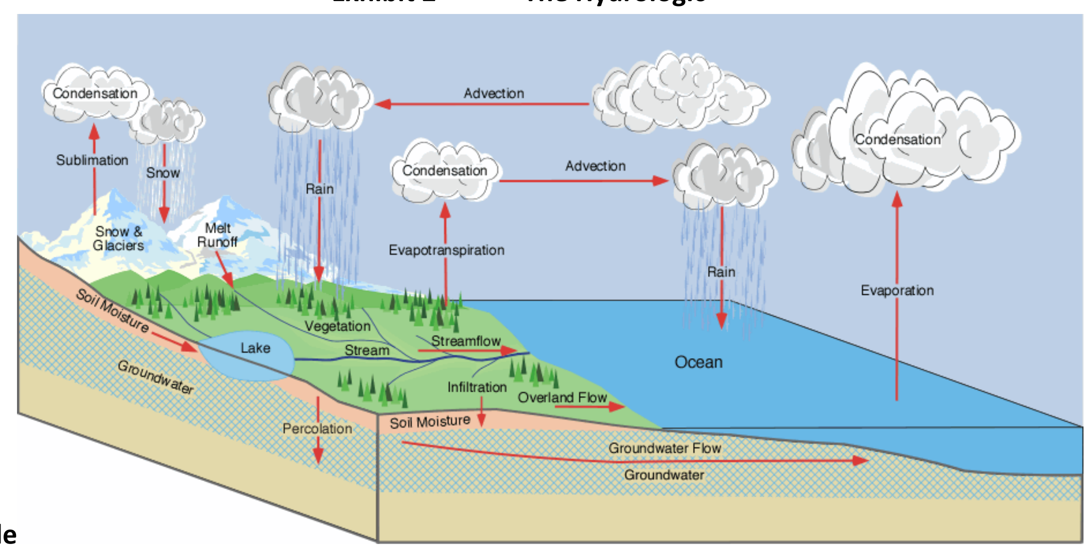
Rainfall levels in 2007 and 2008, subsequent to these articles, returned to more normal levels, obviating the risks and tolls described in the articles. The higher rainfall levels did not end the drought, but highlight another drought fact to remember: even during a drought, precipitation varies from higher to lower levels, modifying, but not eliminating the need for drought monitoring, management and mitigation.

The Hydrologic Cycle and Four Types of Drought

Experts distinguish between four types of drought: meteorological, agricultural, hydrologic, and socio-economic. Drought and the types of drought are products of the hydrologic cycle, as explained below.

The hydrologic cycle refers to the **movement of water** between various **natural storage reservoirs**, as depicted in Exhibit 2 below. [12]

Exhibit 2 The Hydrologic Cycle



The following simplified summary of the hydrologic cycle characterizes the movement of water. [13]

> "The hydrologic cycle begins with the evaporation of water from the surface of the ocean. As moist air is lifted, it cools and water vapor condenses to form clouds. Moisture is transported around the globe until it returns to the surface as precipitation. Once the water reaches the

ground, one of two processes may occur; 1) some of the water may evaporate back into the atmosphere or 2) the water may penetrate the surface and become groundwater. Groundwater either seeps its way into the oceans, rivers, and streams, or is released back into the atmosphere through transpiration. The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again."

The three major natural storage reservoirs are:

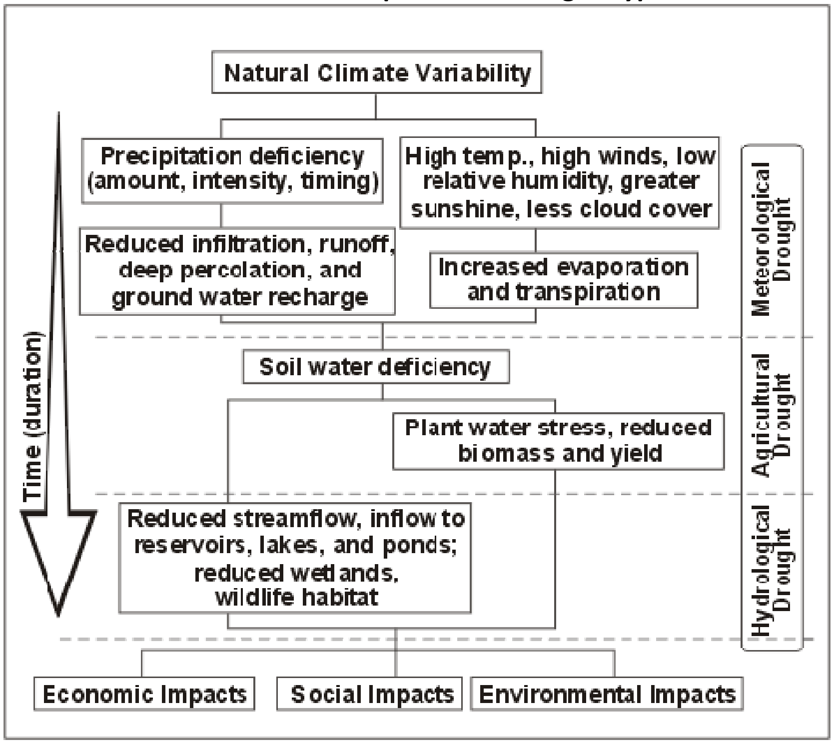
- the oceans (salt water), which contain 97.5% of the earth's water;
- the land, which is freshwater in ice caps and glaciers, surface water, groundwater, and soil moisture, which constitutes 2.4% of the earth's water; and
- the atmosphere, also freshwater, which constitutes.001% of the earth's water.

The land's freshwater reservoirs, currently a remarkably small percentage of water in the hydrologic cycle, are the major sources of our use and are impacted during the cycles of drought.[14] For example, three-quarters of evaporation falls as precipitation back into the oceans. Of the remaining 26% that falls on the land, the majority returns to the atmosphere through evaporation and evapotranspiration. Furthermore, 68.7% of the earth's freshwater is stored in ice caps and glaciers.[15] All told, groundwater, surface water, and soil moisture account for only 0.695% of water at the earth's surface.

The four types of drought are related to different uses of water that can be negatively impacted by drought and the natural storage reservoirs upon which they depend.. For example, the Arizona Drought Preparedness Plan recognizes the following uses (sectors) to which our freshwater supplies can be put: Irrigated Agriculture; Municipal and Industrial Water Users; Energy Production; Public Health; Wildlife; Environmental Health and Watershed Management; Livestock; Commerce and Recreation; and Tourism.

As Exhibit 3 shows, drought types typically sequence, from meteorological through socio-economic drought.[16] .

Exhibit 3 Sequence of Drought Types



Meteorological Drought

Meteorological (or climatological) drought refers to reductions in precipitation or increases in dryness relative to a specific region. Meteorological measurements are considered the first indicators of drought. Meteorological drought can begin to have impacts on environmental health and watershed management and on livestock and wildlife. For example, the Arizona Republic article of January 12, 2006 noted that (1) "Poor range conditions could tighten grazing allotments, squeezing ranchers who have yet to recover from earlier dry years" and (2) "Forests are losing moisture rapidly, creating ideal conditions for fire. Some experts are already predicting one of the worst seasons in years, fearing a lethal combination of drying trees and dried-out grass and shrubs."

As we move from meteorological drought, we begin to pay more attention to the negative impacts of drought on human activity.

Agricultural Drought

Agricultural drought occurs when precipitation shortages and increased rates of evapotranspiration cause a soil moisture deficit, with the result that there is not enough soil moisture to meet the needs of crops typically grown in a region. Agriculture and ranching are usually the first economic sectors to be negatively impacted by drought.

Hydrological Drought

Hydrological droughts occur when precipitation (including snow fall) deficits last long enough and are steep enough to negatively impact surface water and groundwater supplies. Hydrological droughts are typically measured in terms of stream flow, lake or reservoir levels, and groundwater levels. Hydrological drought will impose negative impacts on irrigated agriculture and municipal/industrial water supplies, among other sectors. A September 26, 2003 Arizona Republic article was titled “Lack of rain forces SRP to tap wells,” followed by a September 13, 2004 Arizona Republic article titled “Drought, SRP rationing spur aggressive plans,” which states that “Underscoring the seriousness of a drought that has persisted for nearly a decade, Salt River Project voted Monday to ration its dwindling water supply for an unprecedented third year.”

There is usually a time lag between the onset of reduced precipitation and negative impacts on surface water and groundwater. Typically, these water supplies lag in their positive reaction to the end of drought.

Socio-Economic Drought

Socioeconomic drought occurs when physical water shortage starts to affect people, individually and collectively. Or, in more abstract terms, most socioeconomic definitions of drought associate it with the supply and demand of an economic good. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

Levels of Drought Intensity

In the first instance, drought is a reduction in precipitation relative to average precipitation for a region. Droughts can vary by their severity and resultant impacts, measured by the degree to which dryness diverges from the norm. The National Drought Monitoring Center recognizes five stages of drought, from least to most severe, with examples of associated impacts.[17]

Table 1 Drought Severity and Possible Impacts

Category	Description	Possible Impacts
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures; fire risk above average. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered.
D1	Moderate Drought	Some damage to crops, pastures; fire risk high; streams, reservoirs, or wells low, some water shortages developing or imminent, voluntary water use restrictions requested
D2	Severe Drought	Crop or pasture losses likely; fire risk very high; water shortages common; water restrictions imposed
D3	Extreme Drought	Major crop/pasture losses; extreme fire danger; widespread water shortages or restrictions
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; exceptional fire risk; shortages of water in reservoirs, streams, and wells, creating water emergencies

A Complex Process

Drought clearly is a complex process. The following quote from the Arizona Drought Preparedness Plan nicely summarizes the preceding discussion and simplifies the complex interactions between sectors (i.e., agriculture, municipal and industrial users, the environment and wildlife, energy production, or commerce, recreation and tourism):

> "Each sector has differing vulnerabilities to the impacts of drought. Within each sector, vulnerability to drought may vary regionally. A sector's vulnerability to drought is generally a function of the reliability of the available water supply, availability of replacement or backup water supplies, and the degree of impact that occurs from a reduction in supply. For example, an irrigated farm may experience different impacts than a neighboring ranch operation experiencing the same drought. The farm may have the option of drilling a well to replace some or all of the reduced supply to save a portion of the crop. The ranch may not have the option of developing groundwater and may have to reduce the herd size or sell off the stock entirely. Furthermore, different types of drought (e.g. meteorological, agricultural, hydrologic, and socioeconomic) can trigger different impact to the sectors at different times. For example,

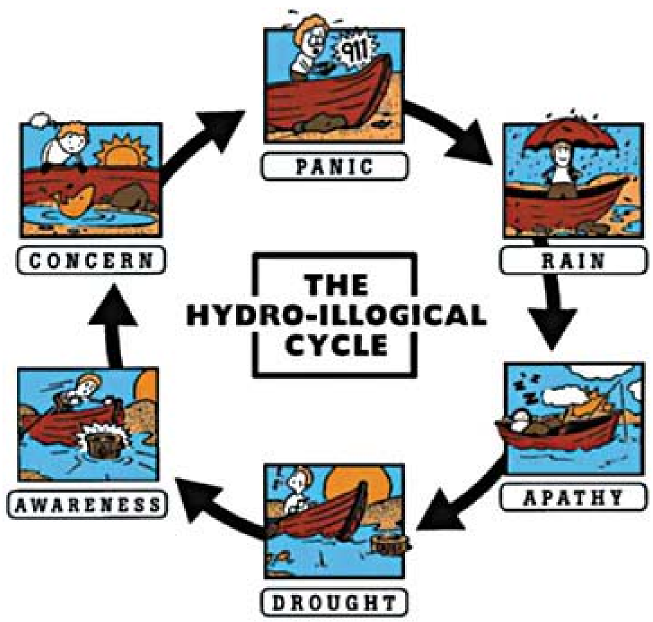
> municipal water providers may experience increased water demands during a meteorological drought because lack of precipitation causes customers to water their lawns more frequently. If a drought deepens, the same water provider may experience a hydrologic drought if a reduction in water supply (e.g. reduced reservoir storage) occurs. Finally, in an extended drought, the water provider may endure a socioeconomic drought, if the revenue of the entity is reduced due to decreased water deliveries or sales."[18]

Given this complexity of sectors and vulnerabilities, what can we do about drought?

Breaking the Hydro-Illogical Cycle: Being Prepared for Drought

In a play on words, the National Drought Mitigation Center (NDMC), School of Natural Resources at the University of Nebraska, Lincoln coined the phrase "hydro-illogical cycle" and created the graphic in Exhibit 4 below to characterize it. (Pima County's Drought Management Plan includes this graphic.)

Exhibit 4 The Hydro-Illogical Cycle



NDMC explains the essence of the hydro-illogical cycle on its website by reference to the following quote from I.R. Tannehill, *Drought: Its Causes and Effects*, Princeton University Press, Princeton, New Jersey, 1947:

> "We welcome the first clear day after a rainy spell. Rainless days continue for a time and we are pleased to have a long spell of such fine weather. It keeps on and we are a little worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather

> contributes as much to the drought as the last, but no one knows how serious it will be until the last dry day is gone and the rains have come again."[19]

The cycle can start with rain, or wet weather, which leads to apathy about drought, which will be followed by a drought that leads to awareness, concern and then panic – until it starts raining again and the cycle starts all over again. Once one accepts that droughts are natural and recurrent, the hydro-illogical cycle makes no sense as a long term policy.

One breaks the hydro-illogical cycle, obviously enough, with planning and preparedness. Despite the historical recurrence of droughts throughout the world and the U.S., many of which were severe, drought planning and preparedness, at least on the state level, is a relatively recent innovation.[20] Arizona's statewide plan, which is described later in this primer, was adopted in 2004.

Drought planning and preparedness consists of risk assessment, monitoring, and crisis management/risk management.[21]

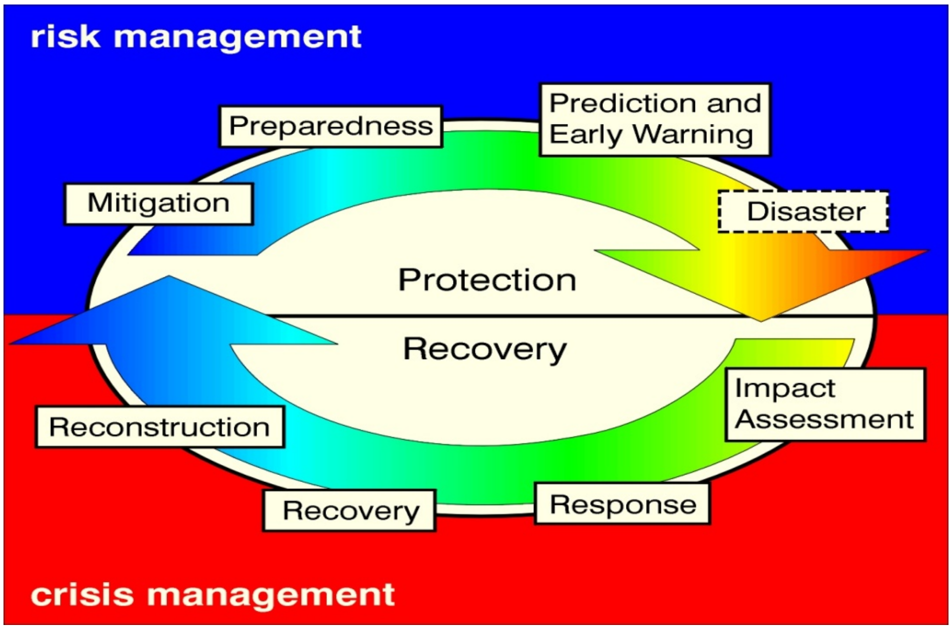
Risk Assessment: "Drought risk is based on a combination of the frequency, severity, and spatial extent of drought (the physical nature of drought) and the degree to which a population or activity is vulnerable to the effects of drought. The degree of a region's vulnerability depends on the environmental and social characteristics of the region and is measured by their ability to anticipate, cope with, resist, and recover from drought.

"Society's vulnerability to drought is determined by a wide range of factors, both physical and social, such as demographic trends and geographic characteristics. People and activities will be affected in different ways by different hazards (see, for example, a comparison of droughts, floods, and hurricanes). Understanding and reducing these vulnerabilities is essential in preparing for and dealing with drought."

Monitoring: The second major component of preparedness is monitoring of "the physical nature of drought" in light of the vulnerabilities determined in the risk assessment. Monitoring involves measurement of indices of drought and determination of triggers that relate indices to threat and response.

Crisis Management/Risk Management: Preparedness finally entails an interactive process of risk management and crisis management as shown in Exhibit 5 below.[22]

Exhibit 5 Risk Management and Crisis Management in Drought Planning



➢ **Response, or crisis management**, the reactive posture, is a community being prepared to initiate procedures that help it endure and recover as quickly as possible from a drought, once it is started. Crisis management depends upon aggressive and continuous monitoring of conditions that indicate a drought is imminent, has begun, and is over.

➢ **Mitigation, or risk management**, the "proactive" approach, is taking actions before the onset of drought that minimize the community's long-term vulnerabilities to negative impacts, an approach of changing water use to enhance the community's drought tolerance. Conservation in advance of drought is a risk management approach.

Ultimately, crisis management and risk management, recovery and protection, should work together. Droughts will not stop occurring, but we can learn from each drought, enhancing our ability to recover, strengthening our ability to provide protection against vulnerability, and thereby enhancing once again our ability to recover when drought returns.

Getting Specific about Drought in Arizona and Pima County

Arizona's statewide drought preparedness plan was adopted in 2004. The following information provides a very brief overview of the plan.

Drought Assessment for Arizona

The Plan made the following assessment of drought in Arizona, as of 2004:[23]

> "Arizona has been affected by drought conditions during **most of the last decade**. It is not known at this time whether the drought conditions will abate in the short term, or **whether this is a multi-decade drought** sequence as has occurred in the past. However, it is absolutely clear that this is **not the last drought** that will affect the state. The **economic and environmental impacts** of drought continue to increase as the population of the state increases. Recent **climatic and water supply conditions on the Colorado River** have initiated shortage-planning discussions because the last five years of drought in the **Colorado River Basin** has depleted water levels in Lake Mead and Lake Powell to the lowest level since the dams were built. Although in general Arizona has a reliable water supply, drought conditions in some **rural parts of Arizona have had devastating personal and economic impacts**. In addition, due to the Central Arizona Project's low priority on the Colorado River system, there is **cause for some concern about potential supply availability** in the case of a long-term drought that affects both the Colorado and the Salt-Verde system. Arizona has made huge investments in importing and storing water supplies for the major metropolitan areas, and those investments have significantly **buffered the state from impacts** during the current drought. However, there is a **need for further preparedness in case conditions worsen**." (emphasis added to highlight key elements in the understanding and preparedness for drought)

Goals of the Arizona Drought Preparedness Plan

The Plan establishes three goals for the state:

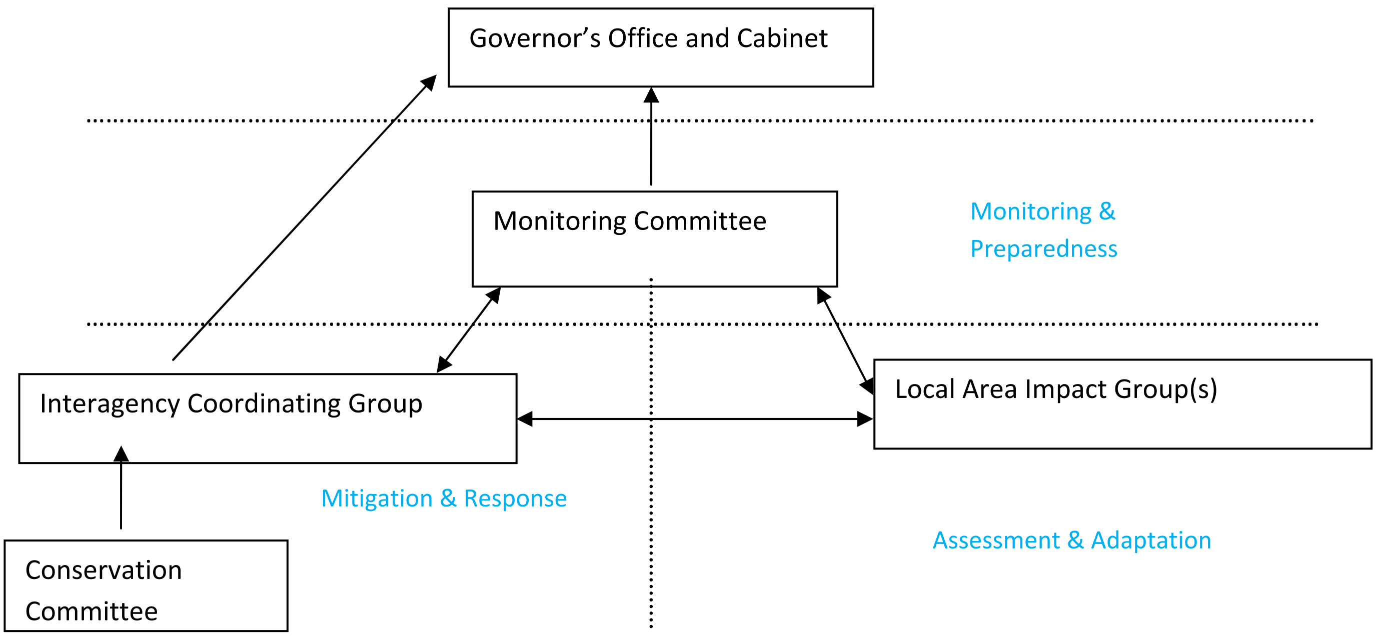
1. Identify the impacts of drought to the various sectors of water uses;
2. Define the sources of drought vulnerability for water use sectors and outline monitoring programs to alert water users and resource managers of the onset and severity of drought events; and
3. Prepare drought response options and drought mitigation strategies to reduce the impact of drought to water users in Arizona.

Plan Structure and Responsibilities in the Drought Preparedness Plan

The Plan establishes the following structure and division of labor for implementing drought preparedness (Exhibit 6).

- The Monitoring Committee is responsible for monitoring and preparedness;
- An Interagency Coordinating Committee is responsible for mitigation and response, and a Conservation Committee reports to the coordinating group; and,
- Local Area Impact Assessment Groups are responsible for assessment and adaptation.

Exhibit 6 Arizona Drought Preparedness Structure



Drought Monitoring: Indicators, Triggers, Declarations, and Drought Levels in the Drought Preparedness Plan

Drought in Arizona is monitored and assessed by the Monitoring Technical Subcommittee. Some critical components in the drought monitoring process are:

Indicators: "Variables to describe drought conditions that will cause stress to a system's water supplies (examples – precipitation, stream flow, groundwater, reservoir levels, soil moisture)."

Triggers: "Specific values of the indictor that initiate and terminate each drought status level, and suggested management responses."

Short-term Drought: "Measured by the departure of precipitation or another drought indicator from average conditions on a time-scale from one to several seasons. Typically related to soil moisture and vegetation stress." (Meteorological drought)

Long-term Drought: "When sustained precipitation deficits over time periods of one to several years affect surface and subsurface water supplies." (Hydrologic drought)

Going into drought: "For each of the drought categories (short- and long-term), the individual indicators in a climate division must reach or pass a certain prescribed threshold for two consecutive months."

Coming out of drought: "For each of the drought categories (short- and long-term), the individual indicators in a climate division must reach or be lower than a certain prescribed threshold for four consecutive months."
Exhibit 7 below identifies the drought categories, possible impacts, and indicator triggers for four levels of drought.

Exhibit 7 Overview of Arizona Drought Categories, Impacts, and Trigger Percentiles

Category	Description	Possible Impacts	Indicator Percentiles
0	Normal Conditions		>40.00
1	Abnormally Dry	Measurable reduction in precipitation, stress to seasonal grasses, stock pond storage somewhat reduced	25.01-40.00
2	Moderate Drought	Noticeable reduction in precipitation, some vegetation stress, stock pond storage reduced, reduced streamflows, lower than average reservoir levels	15.01–25.00
3	Severe Drought	Long-term reduction in precipitation, low snowpack, reduction in reservoir levels, vegetation stress affecting trees and shrubs, habitat and pasture degradation	5.01 - 15.00
4	Extreme Drought	Multi-year precipitation deficits (including snowpack), significant reduction in reservoir levels, measurable reduction in groundwater levels, near-record low streamflows, substantial stress on trees and significant rangeland degradation, diminished wildlife populations	<5.00

Community Water Systems

A community water system is defined in Arizona state statute as "a public water system that serves at least fifteen service connections used by year-round residents." Arizona's drought preparedness plan requires that all community water systems submit an annual water use report, a system water plan, and a drought preparedness plan. The state plan starts with the realization that community water systems will have different water supply portfolios and, therefore, requires that each system submit plans tailored to its specific circumstances.

Current Drought Status in Arizona[24]

Drought status, both short-term and long-term drought, is monitored and declared for each of the fifteen watersheds in Arizona. Pima County includes:

- The Santa Cruz River water shed, coterminous with the Tucson Active Management Area, includes eastern Pima County, within which the Tucson Water service lies, and portions of Santa Cruz and Pinal counties;

- The San Simon River water shed, which includes the Avra Valley and Altar Valley and a portion of the Tohono O'odham Nation; and,
- The Lower Gila River water shed, which includes the Tohono O'odham Nation and far western Pima County.

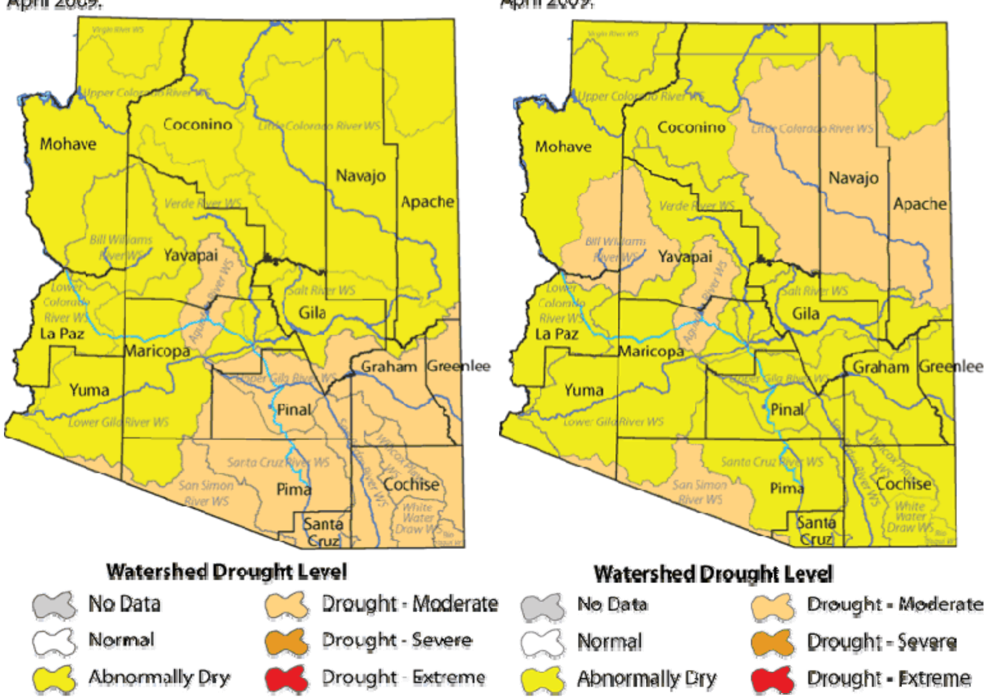
Exhibits 8 and 9 reproduce graphics from the May 2009 Southwest Drought Status Report that show drought status for April 2009 in Arizona and in Pima County.

Figures 4a and 4b in Exhibit 8 below reproduce drought status maps for Arizona for April 2009, as published in CLIMAS. Figure 4a monitors short-term or meteorological drought conditions. Figure 4b monitors long-term drought or hydrological drought.

Exhibit 8 Drought Status Maps for Arizona, April 2009

Figure 4a. Arizona short-term drought status for April 2009.

Figure 4b. Arizona long-term drought status for April 2009.



Because of the importance of the Colorado River as an Arizona water supply, drought in the Colorado River Basin is an important indicator of hydrologic drought conditions in the state. Reservoir levels in Lake Mead and Lake Powell are important indictor measurements of basin drought conditions. Exhibit 9 reproduces Figure 6 from the May 2009 report shows Arizona reservoir levels, as a percent of capacity, for April 2009. The figure shows that the level in Lake Powell was slightly better than last year, but substantially below either the maximum capacity or the average capacity. For Lake Mead, the level in April 2009 was lower than one year ago and also substantially lower than maximum and average capacity.

Exhibit 9 Reservoir Levels in Arizona, April 2009

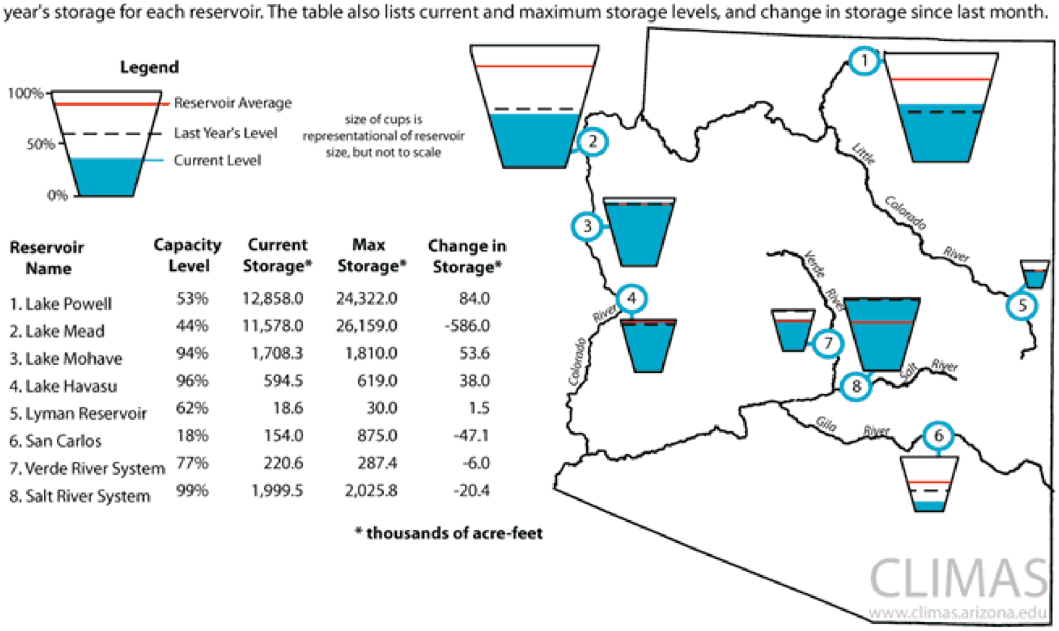


Figure 6. Arizona reservoir levels for April 2009 as a percent of capacity. The map depicts the average level and last year's storage for each reservoir. The table also lists current and maximum storage levels, and change in storage since last month.

Reservoir Name	Capacity Level	Current Storage*	Max Storage*	Change in Storage*
1. Lake Powell	53%	12,858.0	24,322.0	84.0
2. Lake Mead	44%	11,578.0	26,159.0	-586.0
3. Lake Mohave	94%	1,708.3	1,810.0	53.6
4. Lake Havasu	96%	594.5	619.0	38.0
5. Lyman Reservoir	62%	18.6	30.0	1.5
6. San Carlos	18%	154.0	875.0	-47.1
7. Verde River System	77%	220.6	287.4	-6.0
8. Salt River System	99%	1,999.5	2,025.8	-20.4

* thousands of acre-feet

Conclusion

In their white paper on Consolidate Drought Management and in their response to committee concerns, staff used the Arizona Drought Management definition of drought: "Drought, in this context, is defined as a sustained, natural reduction in precipitation that results in negative impacts to the environment and human activities." This is a common, accurate, and complete definition of drought, but it is also a terse, bare-bones definition. Behind, and underneath the terseness lies a richer layer of detail, emphasis, and complexity. This primer hopes to present a larger discussion of drought, in the hopes that readers of the staff white paper will more completely understand what staff is telling us. Phase II report

END NOTES

[1] Tom Beal, "State in the 'bull's-eye' for change," Arizona Daily Star, June 17, 2009
[2] "Global Climate Change Impacts in the United States," at "www.globalchange.goiv/usimpacts"
[3] CLIMAS, at "http://www.CLIMAS.arizona.edu/forecasts/glossary.html
[4] "Defining Drought: Overview," at "http://drought.unl.edu/whatis/define.htm"
[5] Hawaii Drought Monitor at "http://hawaii.gov.dlnr/drought/
[6] Climate Assessment for the Southwest (CLIMAS) at "http://www.climas.arizona.edu"
[7] Arizona Drought Preparedness Plan at http://www.azwater.gov/dwr/Drought/ADPPlan.html
[8] Arizona Daily Star, "Debunking those monsoon myths," June 14, 2009
[9] ibid
[10] "http://www.climas.arizona.edu/research/paleoclimate/product/AZ7/reconstruction.html"
[11] The risks and "potentially disastrous toll" of drought can be steep indeed. For example, Australia reports on a drought between 1963 and 1968 in which "The last two years saw a 40 per cent drop in wheat harvest, a loss of 20 million sheep, and a decrease in farm income of $300-500 million."(Living with Drought at "http://www.bom.gov.au/climate/drought/livedrought.shtml"
[12] "The Hydrologic Cycle," The Encyclopedia of Earth, at http://www.eoearth.org/Hydrologic_cycle
[13] Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign: (http://ww2010.atmos.uiuc.edu/(Gh)/home.rxml)
[14] There are a fair number of ocean water desalination plants in operation around the world and continuing research is underway to find methods that make the technology more accessible and cost effective. Tucson Water has participated in on-going studies such as the Central Arizona Salinity Study and the Multi State Study.
[15] United States Geologic Survey, at http://ga.water.usgs.gov/edu/watercycleice.html
[16] "http://drought.unl.edu/whatis/concept.htm"
[17] " http://drought.unl.edu/dm/archive/99/classify.htm"
[18] Arizona Drought Preparedness Plan at http://www.azwater.gov/dwr/Drought/ADPPlan.html
[19] http://drought.unl.edu/plan/cycle.htm
[20] The NDMC website reports that no states had drought plans during the 1976-1977 drought and only three states had plans in 1982. As of October 2006, however, thirty-seven states had drought plans and only nine states had no plans.
[21] The following information is excerpted from Understanding Your Risk and Impacts: Drought Impacts and Vulnerability ," at http://drought.unl.edu/risk/impactvulnerability.htm
[22] See The U.S. Experience in Drought Management: Breaking the Hydro-illogical Cycle, at "*drought.unl.edu/risk/impactvulnerability.htm"*
[23] Arizona Drought Preparedness Plan at http://www.azwater.gov/dwr/Drought/ADPPlan.html
[24] Information in this sections was excerpted from CLIMAS at "http://www.climas.arizona.edu/forecasts/swconditions.html"