Moving Forward from Vulnerability to Adaptation:

Climate Change, Drought, and Water Demand in the Urbanizing Southwestern United States and Northern Mexico

Avanzando desde la Vulnerabilidad hacia la Adaptación:

El Cambio Climático, la Sequía, y la Demanda del Agua en Áreas Urbanas del Suroeste de los EEUU y el Norte de México

Edited by Margaret Wilder, Christopher A. Scott, Nicolás Pineda-Pablos, Robert G. Varady, and Gregg M. Garfin

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CHAPTER 4

TUCSON

Tucson cityscape, istock photo

Resilience and Adaptive Water Management in the Context of Urban Growth and Climate Change Vulnerability in Tucson, Arizona

By Anne Browning-Aiken, Christopher A. Scott, Emily McGovern, Oscar Lai, and Delphine Clavreul

A. Introduction

Tucson is located in the semi-arid northern reaches of the Sonoran Desert in southeastern Arizona, with mountains on each side – the Santa Catalinas to the north, the Rincons to the east, the Tucson Mountains to the west, and the Santa Ritas to the south. Most of the population of the greater Tucson area lives between these mountain ranges in the Santa Cruz River Valley. In addition to climatic factors, population growth, and increasing municipal and industrial demand are the most important drivers of water supply in Arizona today (AWI 2008:16) and this is true for Tucson as well. The valley's dry desert air and winter sunshine make it a popular health and winter resort destination, and the city provides high-tech services such as health care facilities for the region, an optics research center, the University of Arizona, and industrial production focused on the defense sector. Urban Tucson and much of surrounding Pima County depend largely on the Colorado River, plus groundwater, for meeting their water needs. With the knowledge that eight times more water per year potentially evaporates than is supplied by rain, Tucson residents have supported a decreasing per capita water consumption rate despite population growth since the 1970s, but a recent city and county study revealed that:

> To achieve sustainability goals, changes to the existing infrastructure must begin by improving the efficiency and flexibility of the existing built environment, including roads, parks, public services, water, wastewater and stormwater systems. In addition to considering the location and form of growth, integrated planning also needs to consider the efficient allocation, distribution and use of all available water resources including stormwater, effluent, reclaimed and potable water (Tucson/ Pima County Oversight Committee 2009b:20).

Adaptive water resources management (i.e., a flexible approach to planning in response to climatic and growth uncertainties) in water-scarce regions facing climate variability and economic growth requires innovative approaches to the complex and interlinked requirements of water law, public opinion, ecosystem services, and water quality. This case study of adaptive management of urban water and climate variability is based on research in Tucson from 2008-2011. The study examines the nature of population growth and other challenges to adaptive water resources management, including ambiguity in policy and institutional direction from elected officials and state agencies, needs for integrated service provision, the need for more comprehensive regional planning, regulatory and legal constraints, infrastructure costs, and mixed consumer preferences about water reuse. In addition, the study offers evidence of recent advances in promoting water reuse through the application of incentives, trading, water banking, and other market mechanisms.

Research Questions

Four major questions guided the Tucson case study, based on the research questions for the overarching *Moving Forward* project:

- How is urban water sector vulnerability defined in Tucson and what are the key indicators?
- What is Tucson's institutional capacity to develop adaptive strategies for future water management, at a 5 to 20+ year horizon?
- How can a greater capacity of water managers and preparedness planners to use climate science and information to improve long-range and "adaptive" decision-making best be institutionalized?
- How can climate science best be integrated into the planning process to enhance the resilience of Tucson to climatic and water-resources uncertainties?

Methods

This case study employed institutional analysis to assess the level of urban vulnerability to climate change, interviews with 24 water planners, managers and providers in Pima County, and urban water and wastewater user surveys to analyze current and potential uses of treated wastewater as a part of regional planning efforts in Tucson and the Santa Cruz River Valley, within the broader context of Arizona's burgeoning "Sun Corridor" (including Prescott, Phoenix, Tucson, and Nogales, Arizona). The research also entailed attendance at agency meetings and a review of city, county, regional and state planning documents.

B. Background: The Tucson Region

Historical Overview of Water in the Tucson Region

Surface water diversion in the Tucson Basin began as early as 650 A.D., as the prehistoric Hohokam settled along the river we now know as the Santa Cruz and grew crops. The Hohokam's network of canals was used to divert river flows to irrigate crops. Intensive farming along the river by the Hohokam peaked between 900 and 1300 A.D., but was still practiced by the Tohono O'odham when Father Eusebio Kino visited the area in 1694 (Betancourt 2004; Logan 2002). Many different cultures have lived near the Santa Cruz River: Native Americans, Spanish, Mexicans, and later settlers from the United States and its territories. Tucson was founded in 1776. By the early 1880s, Tucsonans could no longer rely on surface-water flows from the Santa Cruz River to satisfy their increasing need for water for crops, milling operations, livestock, recreational lakes, and mining (Tucson Water 2004). By the 1940s, pumping finally caused the water table in the area to drop so low that the river began to flow only during floods (Logan 2002).

Various water-courses transect the area, although flow is now either non-existent or ephemeral, with the exception of Sabino Creek, which receives both snowmelt and rain initiating at relatively high elevations. According to Gelt et al. (1999:1), the groundwater table in the Tucson area was once much higher, and was sufficient to feed into the Santa Cruz River. Today, surface flows occur during years with heavy summer or winter precipitation, but overall scarcity and variability of flow has made surface water an unreliable and largely impractical water supply for a large population (Gelt et al. 1999:4). Further, "year-to-year variation of precipitation in the Tucson Basin is quite substantial" (Gelt et al. 1999:3).

Eventually, the city and county, along with other major Arizona population centers, had to face up to growing groundwater depletion. Since the 1960s, the Tucson population increased to the extent that established well fields did not provide enough water, so the city began purchasing farms in the Avra Valley to the west in order to gain access to their wells. Ultimately, 27,000 acres of farmland were retired. Meanwhile, the city "also was buying water companies and their wells throughout the city limits" (Gelt et al. 1999:9). As Gelt et al. report:

> When a new area was annexed, the city would offer to buy the water company…. Controlled growth advocates on the Tucson City Council soon found an opportunity to press for change by dealing with the pressures facing the Tucson Water Department. The distribution system was expanded rapidly in the early 1970s to keep up with growth…. During the 1980s, the city increased its water conservation efforts, partly in response to the requirements of Arizona's new Groundwater Management Act (Gelt et al. 1999:9).

By 1989, Tucson's service area population had grown to about 570,000, and the region's only available renewable water resources were Colorado River water, available through the Central Arizona Project (CAP) canal (which ended in Tucson), and effluent. Tucson Water, the city's water provider, began direct deliveries of treated Colorado River water to portions of its service area in 1992, but the pH level of the new source water reacted with old water mains in the potable distribution system and in customer plumbing. As a result of public outcry, direct delivery of Colorado River water was then shut down. In response to this dilemma, the Tucson Water developed the Central Avra Valley Storage and Recovery Project (CAVSARP), a large recharge and recovery facility on west of the city in the Avra Valley, to provide a blend of native ground water and Colorado River water. By 2001, Tucson Water began deliveries of this blended water.

However, the City of Tucson Mayor and Council and the Pima County Board of Supervisors knew this would not be a sufficient supply for future growth, so in 2008 they initiated a multi-year study of water and wastewater infrastructure, supply, and planning issues to assure a sustainable community water source. The study culminated in 2010 with an action plan from the oversight committee that set forth more integrated water and land planning (Tucson/Pima County Oversight Committee 2010). As part of this new planning approach, Tucson Water and the county developed a Regional Optimization Master Plan (known as ROMP) to match the "needs for recharge, environmental restoration, and public amenities such as parks, golf courses and ball fields" and looked at potential ways to increase use of treated wastewater (Tucson/Pima County Oversight Committee 2010:9). These and other recent developments in water management strategies will be examined more closely in the remainder of this report, especially sections E and H.

Demographic and Economic Factors

The Southwest's rapid economic growth and expanding population, including internal migration from elsewhere in the United States, are driving steep increases in the demand for water. Rapid growth is resulting in demand for water that exceeds traditional supplies in this water-scarce region. Tucson, situated in Pima County, is part of the rapidly growing megapolitan "Sun Corridor," which spans the central part of Arizona from Flagstaff southward to Phoenix, then to Tucson and southward to Nogales at the U.S.-Mexico border.

Arizona. Arizona was one of the fastest growing states in the country prior to the onset of the nationwide economic recession in 2008, with population growth taking place mostly in its towns and cities. Southern Arizona, including along the border with Mexico, has experienced particularly accelerated growth. According to the U.S. Census Bureau, Arizona was the second fastest growing state after Utah in 2008, up 2.3 percent over the previous year (U.S. Census Bureau 2008). Although the recent economic downturn has slowed growth across the state, this trend is likely to be temporary. Pima County. Pima County was projected in a 2004 Tucson Water planning assessment to increase from 843,746 people in 2000 to about 1.5 million by 2030 and 1.9 million by 2050 (2004; see also Scott et al. 2011:3). With the ongoing economic recession, as of 2011, overall population growth in Pima County has slowed, although over the long term, like the state as a whole, the county's population is still expected to continue growing (Pima Association of Governments 2011:4). The 2010 U.S. Census reported Pima County's population at 980,000, having grown by 16.2 percent since 2000 (http://www.census.gov/popfinder/; http://www.pagnet.org/RegionalData/Population/tabid/104/ Default.aspx).

Tucson and the Tucson Water service area. The 2010 U.S. Census reported Tucson's population at 520,000, having grown by 6.9 percent since 2000 (http://www.census.gov/popfinder/). Arizona Department of Water Resources (ADWR) reported that Tucson's population of municipal water users grew 43.9 percent from 1991 (662,000) to 2008 (953,000) (as tallied in Cohen 2011:14). In translating its population projections into projected demand for water, the 2004 Tucson Water Plan indicates that, "annual total demand is projected to grow from 128,521 acre-feet in 2000 to 253,000 acre-feet in 2050. The slower increase in water demand from 2030 to 2050 reflects the shift in population growth to areas outside of Tucson Water's projected service area" (2004:3-4). To provide a more regional perspective, the Tucson Water planning assessment includes population projections through 2050 for all of Pima County and the Long-Range Planning Area (entire area of Figure 4-1), as well as Tucson Water's current (area with darkest shading) and projected/obligated service area (hatchmarked area to the south and east, encompassed by white outline). In addition to the projected growth in Pima County, the Long-Range Planning Area population is projected to grow from 779,684 in 2000 to about 1.4 million in 2030 and 1.5 million by 2050. A significant amount of future growth in Pima County is thus projected to occur outside of the current service area.

The population forecast used by Tucson Water in 2008 indicated that population in its service area was expected to increase to 1,275,023 residents by 2050 (Tucson Water 2008). According to Tucson Water, the population in their service area "continues to increase but at a slower rate than what was originally projected" in their 2000-2050 water plan; "[n]onetheless, the increasing number of people will create a growing need for water" (Tucson Water 2008:2-3 to 2-4).

It is important to note that the population growth seen since the early 1990s has in fact not resulted in a proportionate increase in water demand; a recent study of municipal water use throughout the Colorado River basin, including Arizona, indicated that per capita water deliveries have gone down for basin cities as a whole, and down 13 percent in Tucson between 1991 and 2005 (Cohen 2011:16). This idea is followed up on in section F.

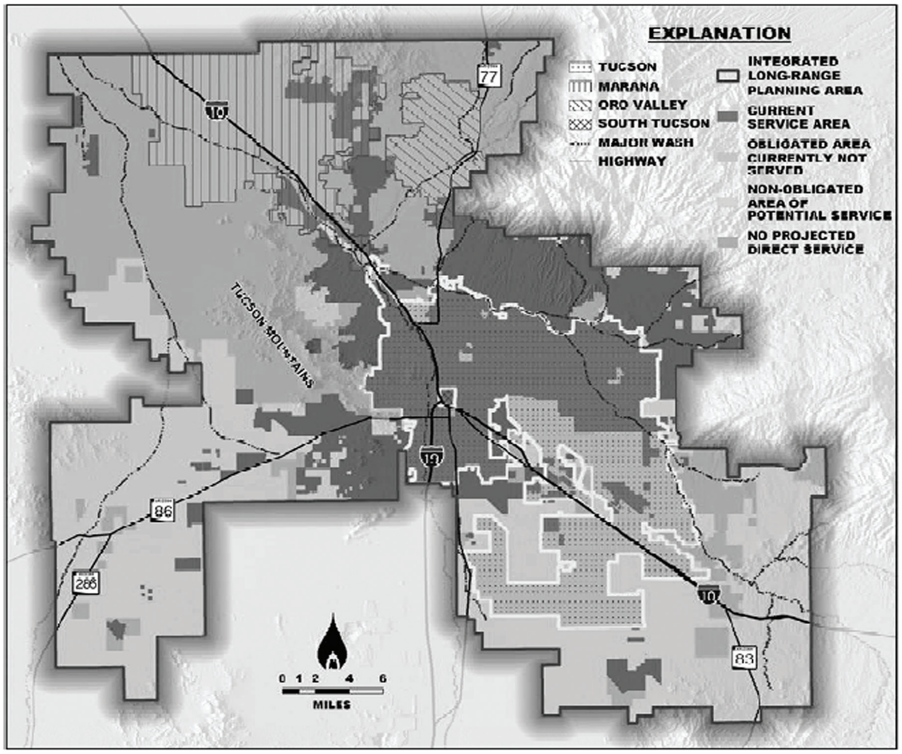

Figure 4-1. Tucson Water long-range planning area, obligated service area, and potential service area. Source: Tucson Water 2008, Figure ES-1.

C. Climate Variability, Climate Change, and Impacts: Sustained Drought

Climate Variability

Tucson receives 12.0 inches of rainfall annually (305 mm) (based on National Climatic Data Center data). Over 50 percent of precipitation normally falls during the summer monsoon (July-September), with the remainder primarily occurring in October-March. April-June are the driest months. Average maximum and minimum temperatures are 82.2° F (27.9° C) and 54.6° F (12.6° C) respectively. Record extreme temperatures were a high of 117° F (47.2° C) in June 1990 and a low of 16° F (-8.9° C) in December 1974.

According to the report, Water in the Tucson Area: Seeking Sustainability, “[A]bout 10,000 years ago, before the climate began to get warmer and drier, much more moisture reached the [Tucson] basin than does today. Water isotope studies show that much of the water now stored underground fell as rain during these ancient times” (Gelt et al. 1999:1). Gelt et al. describe substantial year-to-year variation in precipitation in the Tucson Basin, often affected by global phenomena such as El Niño and La Niña (1999:3). These two phenomena affect both the distribution and magnitude of precipitation in the basin, with “winter precipitation in 1992/93 and 1997/98 … as much as 55 percent higher than the winter average”(Gelt et al. 1999:3).

Tucson has summer high temperatures in the upper 90s with peaks above 110° F. The built environment (pavement, roofs, and energy use) has resulted in an urban heat island, by which Tucson is warming by 1° C (1.8° F) every 15 years, significantly more quickly (0.04° C per year faster) than surrounding non-urban areas (Scott et al. 2009:1). The urban heat island effect is most pronounced during the pre-monsoon period (February through May). High temperatures and low relative humidity contribute to very high water loss through evapotranspiration of native and non-native vegetation.

In this study, we identified drought as a particularly important aspect of the Tucson urban area's experience of climate variability and change. The Arizona Drought Plan (ADWR 2009) provides evidence (see Figure 4-2) of recurring periods of drought followed by wet periods. Arizona's state drought plan defines drought in part based on duration – drought is a "sustained, natural reduction" (Tucson/Pima County Oversight Committee 2009a:3) that the Tucson/Pima County Oversight Committee notes "can extend for a single season or last for several years. Our current drought has lasted for about ten years and we have no indications of when this drought will end. … June 14, 2009, the *Arizona Daily Star* in an article about the summer monsoon, noted that the average June to September rainfall is an average 6.06 inches, but that in 1989 and 2004 the monsoon rainfalls were 2.40 and 2.43 inches respectively, or 40 percent of the norm" (Tucson/Pima County Oversight Committee 2009b:3).

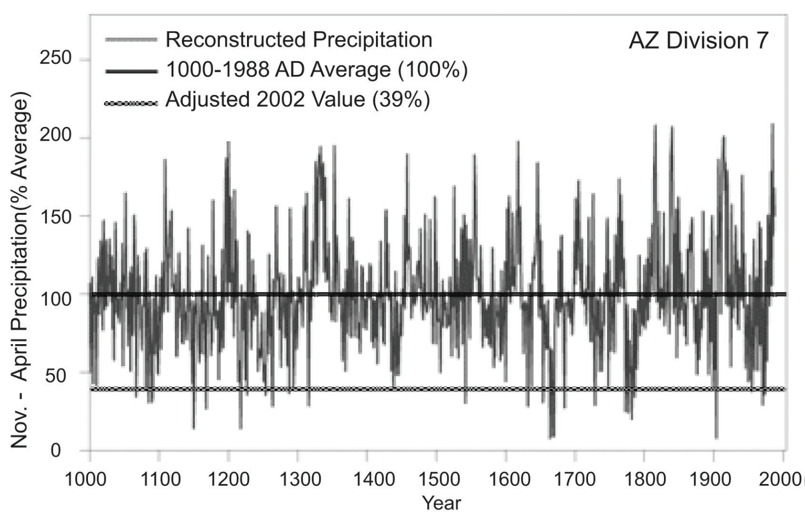

Figure 4-2. Single-Year Reconstruction for AD 1000-1988 (% Average). Source: Tucson/Pima County Oversight Committee 2009a:4.

Climate Change

Regional climate change is expected to lead to a 2 to 3° C increase in annual temperature and a 5 to 15 percent decrease in annual precipitation by 2080-99, in comparison with a 1980-99 base period, based on 21 global climate models (GCMs), using an A1B greenhouse gas emissions scenario (IPCC 2007). All models agree on the increase in annual temperature and more than 75 percent of models agree on the decrease in annual precipitation. Seasonal nuances in the projections are significant for the region. The highest confidence in projections for the region are for the winter and spring seasons;

projections from 15 GCMs show high confidence in a 20 percent decrease in winter precipitation and a 40 percent decrease in spring precipitation during the 2080-99 period, using an A2 greenhouse gas emissions scenario (Karl et al. 2009). There is less agreement among GCMs regarding summer and fall precipitation; some GCMs, with good reproduction of summer monsoon precipitation characteristics for the historic period, indicate a possible increase in summer precipitation for the region, during most of the 21st century (Christopher Castro, personal communication). Summer temperatures are projected to increase more than winter temperatures, with regional projections of a 3-4° C increase in the 2080-99 period (IPCC 2007). The El Niño-Southern Oscillation is an important factor contributing to interannual variability in regional precipitation. Two GCMs that best capture seasonal precipitation and temperature of the region indicate that future aridity in the region will increase dramatically during La Niña episodes; this has important implications for surface flows and groundwater recharge, as well as for regional water demand, as the already reliably dry La Niña winters are projected to be warmer and even drier than at present (Dominguez et al. 2010). Higher temperatures will accelerate evapotranspiration rates; combined with decreasing rainfall, projected impacts for the region include more severe and prolonged droughts. Higher temperatures will also increase the frequency of extremely hot days; projections from 15 GCMs using the A2 greenhouse gas emissions scenario project that a day so hot that it is currently experienced once every 20 years would occur every other year by the 2080-99 time period (Karl et al. 2009).

The projected trend toward higher temperatures, more variable rainfall, and extended drought both within the Tucson Basin and the larger Colorado River Basin from which surface water supplies are delivered to Tucson via the CAP (Bark et al. 2011), combined with projected population increases, has already prompted consideration of "next bucket" water supplies. Additional inter-basin transfers are less likely than are agricultural-urban water transfers (via water rights purchases and fallowing farmland) or desalination of brackish groundwater. As described in this report, there is growing attention to rainwater harvesting, grey-water use, and effluent as future water supply options. It is expected that continued conservation will take place; however, expanding population and other water demands will surpass the gains achieved by conservation alone.

D. Water Governance, Institutions and Management

City and county water governance are carried out chiefly by the Tucson Active Management Area (AMA), Tucson Water (the city's municipal water utility), and the Pima County Regional Wastewater Reclamation Department (RWRD). Metro Water, Oro Valley Water, the Flowing Wells Irrigation District, and a number of smaller water utilities also serve the Tucson metropolitan area (TREO n.d.). Traditionally, Tucson Water and the other smaller water providers mentioned above make plans and decisions in response to the Arizona Department of Water Resources (ADWR), but the state budget for ADWR has been cut to such an extent that the state-level organization's activities are mainly to issue well permits and promote the state Assured Water Supply (AWS) Program. The AWS program protects and preserves limited groundwater supplies within Arizona's five Active Management Areas (AMAs), including the Tucson AMA. The goal of the AWS is to reach safe yield, defined as "the long-term balancing of groundwater withdrawals with the amount of water naturally and artificially recharged to Active Management Area aquifers" by 2050 (ADWR Office of Assured and Adequate Water Supply Program, n.d.). (Outside the AMAs, the Adequate Water Supply Program, while not as protective as the Assured Water Supply Program, acts as a consumer advisory program, ensuring that potential real estate buyers are informed about any water supply limitations.)

Water providers and the county RWRD adhere to regulations concerning water quality from the Arizona Department of Environmental Quality (ADEQ) and the federal Environmental Protection Agency (EPA). However, the Tucson/Pima County Water and Wastewater Action Plan also proposed increased collaboration with "partners on environmental restoration and water planning" (Tucson/Pima County Oversight Committee 2010). In fact, Tucson Water and RWRD are attempting to work together on a plan to increase the use of treated wastewater throughout Tucson and Pima County, but since wastewater has previously been under the purview of Pima County and water provision under the purview of the City of Tucson, collaboration has so far been tentative.

E. Urban Water Infrastructure

Tucson's urban water is provided by multiple companies. Tucson Water is the city's municipal water utility, providing 77 percent of the potable water supplies in the greater Tucson Metropolitan area, drawing mainly from groundwater and surface water supplies. (Again, Metro Water, which provides water service primarily in the northwest metropolitan Tucson area, Oro Valley Water, the Flowing Wells Irrigation District, and a number of smaller water utilities also serve the metropolitan area, TREO n.d.)

In 2008, the City of Tucson Mayor and Council and the Pima County Board of Supervisors initiated their multi-year study of water and wastewater infrastructure, supply and planning issues (see also the discussion of this study in section B, above). The ultimate goal of this effort was "to assure a sustainable community water source given continuing pressure on water supply caused by population growth" (Tucson/Pima County 2009b). The initial focus of the study was to identify and agree on basic facts related to the condition and capacity of water, wastewater, and reclaimed water infrastructure, and the ability of the infrastructure to accommodate existing and future populations within the city and county service areas.

In their report on comprehensive integrated planning, released in 2010, the 12-member Oversight Committee (appointed by the Tucson Mayor and Council and Pima County Board of Supervisors) indicated a need for improvements to infrastructure including water delivery, wastewater, and stormwater systems as part of their joint sustainability goals (Tucson/Pima County Oversight Committee 2009b:20).

The primary areas for expansion of infrastructure are projected to be in the south, southwest, and southeast portions of the Long-Range Planning Area (see Figure 4-1, above, and Figure 4-3). These are the areas where Tucson Water anticipates providing direct service in the future. Other water providers will be responsible for meeting their own future demands. However, depending on future agreements, their water resources may be treated and delivered to their respective service areas through Tucson Water's potable system (Tucson Water 2004:5-8).

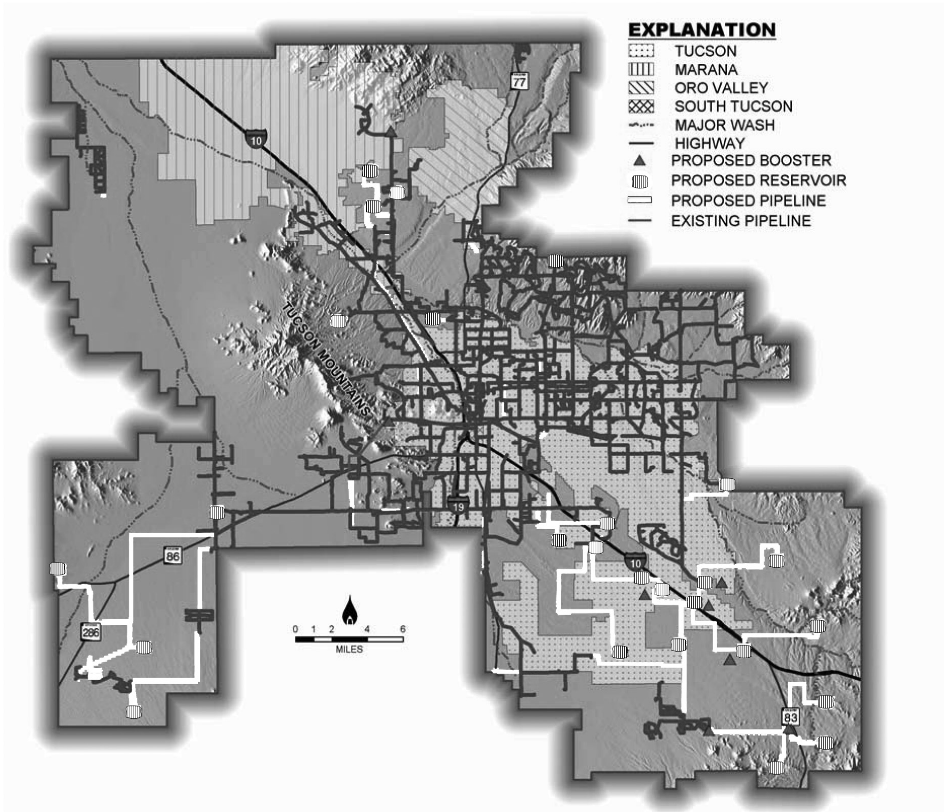

Figure 4-3. Potential Expansion of Tucson Water's Potable System Through 2050
Source: Tucson Water 2004, Chapter 5.

Tucson Water plans to continue expansion of the city's potable water delivery system over the next 20 years (Figure 4-3, light grey lines). The system-expansion costs will average about $20 million annually through 2030. This annual rate of capital expenditure will only cover incremental costs for system expansions and does not include other costs required to maintain or replace existing infrastructure or to bring additional renewable water supplies into use (Tucson Water 2004:4-10).
The Pima County RWRD, together with a number of community partners (the City of Tucson, the Town of Oro Valley, and others), has also created a master plan to allow RWRD to meet environmental regulatory requirements regarding ammonia and nitrate. When the ROMP plan is completed, the Ina Road facility will be upgraded and expanded to treat 50 million gallons per day (mgd). The Roger Road plant will be decommissioned after a new 32 mgd water reclamation facility is built adjacent to the existing plant. Preliminary 2006 estimates for this project were $536 million. However, the ROMP will ultimately cost more once additional needs and requirements are identified and inflation and debt service are factored into project costs. RWRD will be asking for increases in sewer rates and sewer connection fees. These rate increases are paid by those individuals who receive sewer service, developers, and any others who connect new plumbing fixtures that discharge into the sewer system (see http://www.pima.gov/wwm/programs/ROMP/).

For all infrastructure projects, one possible source of financing is the Arizona Water Infrastructure Finance Authority (WIFA), which is authorized to finance the construction, rehabilitation and/or improvement of drinking water, wastewater, wastewater reclamation, and other water quality facilities/projects. Generally, WIFA offers borrowers below-market interest on loans for 100 percent of eligible project costs (http://www.azwifa.gov/).

F. Water Use Trends and Changing Demand

As noted above, a recent study of municipal water use throughout the Colorado River Basin, indicated that *per capita* water deliveries have gone down 13 percent in Tucson between 1991 and 2005 (Cohen 2011:16). While total water demand in the region as a whole has increased since the early 1990s, "[t]hese decreases represent more than a million acre-feet of reduced demand [in the Colorado River Basin] each year relative to what demand would have been had water delivery rates remained constant" (Cohen 2011:3). Nonetheless, the Tucson Water Plan projects annual total demand to grow from 128,521 acre-feet in 2000 to 253,000 acre-feet in 2050. There is a slower projected increase in water demand from 2030 to 2050 reflecting the shift in population growth to areas outside of Tucson Water's projected service area (see Figure 4-1 and section B, above).

Almost half of Tucson Water's annual customer demand at present is met through use of CAP water, and this percentage is projected to increase over the next several years (Tucson/Pima County Oversight Committee 2009b). Tucson Water projected as of 2004 that at least eight percent of total future water demand will be met with reclaimed water and the remaining 92 percent using potable-quality water (Tucson Water 2004).

Almost half of Tucson Water's annual customer demand at present is met through use of Central Arizona Project (CAP) water, and this percentage is projected to increase over the next several years (Tucson/Pima County Oversight Committee 2009b, and see Figure 4-4). The conjunctive use of groundwater and CAP water supplies provides a great deal of resiliency for the Tucson Water supply system during times of local drought, particularly through the operation of the Clearwater Resource Recovery Facility, a recharge and recovery system to the west in the Avra Valley.

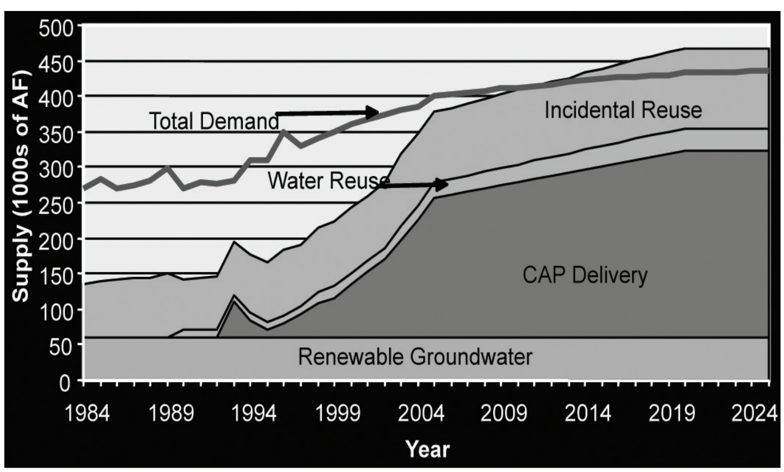

Figure 4-4. Historic and projected water demand in the Tucson Active Management Area. Source: Based on data from City of Tucson, 2004.

However, a 2011 study by CLIMAS (Climate Assessment for the Southwest, based at the University of Arizona) entitled "Patterns and Causes of Southwest Drought Variability" suggests that Tucson's reliance on CAP water, which originates in the Colorado River, may be less secure than expected. Next, this reliance is explored as one aspect of urban water vulnerability in Tucson.

G. Urban Water Vulnerability in Tucson

The Tucson region's heightened potential for drought associated with climate change and variability is central to its vulnerability. A crucial characteristic of drought is the set of negative impacts associated with a sustained reduction in precipitation. Arizona defines drought as having "negative impacts to the environment and human activities" (Tucson/Pima County Oversight Committee 2009a:3). The Joint City/County Water and Wastewater Study highlights "potential risks and tolls to Tucson and Pima County, to the environment and wildlife, to agriculture, to municipal water supplies, and tourism that could result from sustained drought and water shortages" (Tucson/Pima County Oversight Committee 2009a:3-4). However, their studies have not yet determined the degree of risk and the vulnerabilities that arise from these risks.

Understanding the urban context is critical to analyzing of the role of water planning and management in confronting urban vulnerability through resiliency to natural hazards and climate variability. There are three tasks in defining the resiliency of an urban area: 1) to identify any inherent property or specific conditions existing in the urban area that would affect its resiliency, 2) to identify the nature and degree to which an urban system experiences a stress or hazard, and 3) to assess the relative sensitivity or ability of the urban system to adapt to the stress or hazard (Romero-Lankao and Tribbia 2009; Manuel-Navarette et al. 2007; Ionescu et al. 2008; Adger 2006).

We focus on four critical areas of vulnerability to climate variability and climate change in Tucson: 1) socioeconomic vulnerability and resource dependency, 2) infrastructure vulnerability, 3) water supply and resource dependency, and 4) institutional vulnerability.

Socioeconomic Vulnerability and Resource Dependency

Vulnerability can be expressed in terms of resource dependency – in this case, dependence on a scarce supply of water. Resource dependency is defined as an element of individual vulnerability, and consists of reliance on a narrow range of resources, leading to social and economic stress within a livelihood system (Adger and Kelly 1999). Resource dependency relates to communities and individuals whose social order, livelihood and stability are a direct function of their resource production and localized economy (Machlis et al. 1990; Adger 1999). Resource dependency in the context of the present study can be characterized as dependence on the structure and diversity of income, social stability and resilience, which we define as "the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organise and the capacity for adaptation to emerging circumstances" (Adger 2006; Carpenter et al. 2001; Berkes et al. 2003; Folke 2006).

In turn, Adger defines social resilience as:

> the ability of communities to withstand external shocks to their social infrastructure. This is particularly apposite for resource-dependent communities where they are subject to external stresses and shocks, both in the form of environmental variability (such as agricultural pests or the impacts of climatic extremes), as well as in the form of social, economic and political upheaval (associated with the variability of world markets for primary commodities, or with rapid changes in property laws or state interventions) (Adger 2000:361).

While the existence and implications of resource dependency can be observed by examining variability in income sources, migration, and other social variables associated with stability and resilience, the focus in this case study is on Tucson's reliance on climate-dependent resources.

As indicated above, climate variability and extended drought contribute to Tucson's vulnerability to reductions in urban water availability. In addition, while poverty rates in Tucson are not directly correlated with urban vulnerability to water or climate challenges, the fact that Tucson has a considerably higher poverty rate than the U.S. or Arizona averages could impact the ability of residential water users to pay for increases in rates for water or wastewater treatment and services. Likewise, it may be more difficult for water managers and water companies to acquire funding from taxes for infrastructure investments given lower incomes in Tucson, even using the WIFA (described above in section E).

As of 2005, Tucson's poverty rate was 20 percent (see Figure 4-5); that rate is 5.3 percentage points higher than the Pima County rate, 5.8 points over the statewide rate, and 6.6 points over the national rate. As of April, 2001, Tucson's unemployment rate was 9.7 percent (in comparison, Albuquerque's rate was 6.6 percent, Phoenix's was at 10.2 percent, and Las Vegas was 13.2 percent) (Bureau of Labor Statistics 2011, http://www.bls.gov/lau/lacilg09.htm). Figure 4-6 shows how drastically the unemployment rate in Tucson has risen since 2008. If we consider poverty rates and unemployment in Tucson as indicators of socioeconomic vulnerability, the picture suggests that Tucson residents are in a vulnerable state due to the current economic downturn and therefore not in a good position to pay increased prices for water.

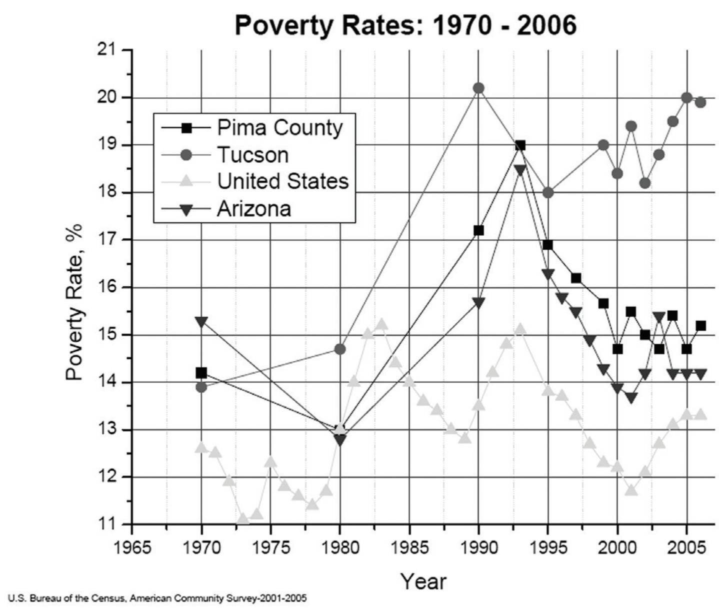

Figure 4-5. Poverty rates, 1970-2006. Source: U.S. Census Bureau, American Community Survey, 2001-2005.

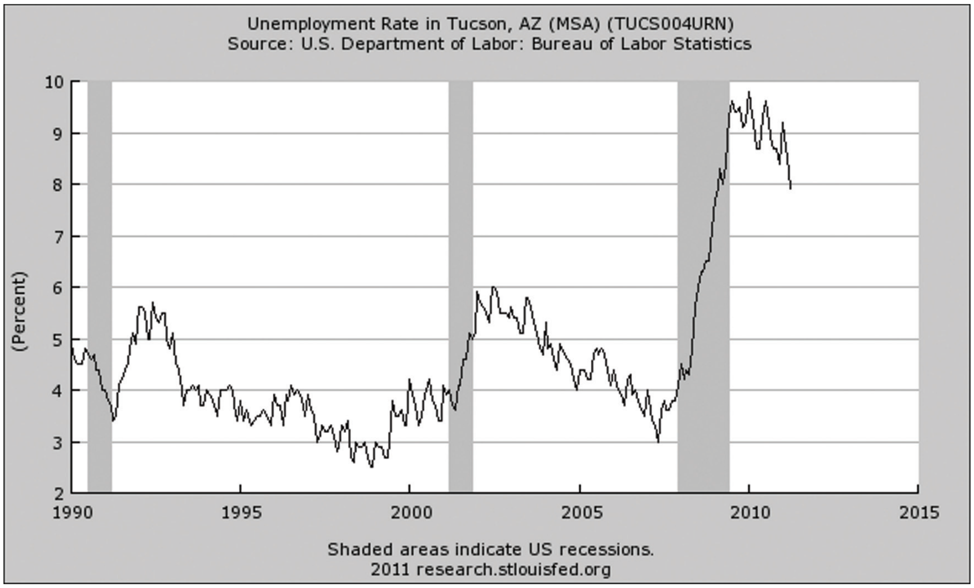

Figure 4-6. Tucson unemployment rate, 1990-2011. Source: http://research.stlouisfed.org, based on U.S. Bureau of Labor Statistics data.

Infrastructure Vulnerability

The current state of water and wastewater infrastructure, described above, is evidence of Tucson's vulnerability to climate variability and change. The City/County Water and Wastewater Study, without providing specific numbers or costs, identified a number of maintenance issues:

> Aging wells in the central well field are in need of refitting or reconstruction. Reservoirs are aging, and some are in need of complete refurbishing. Storage capacity in reservoirs will need to be increased over time as the Utility's customer base increases. Isolated systems require new wells, equipment, or piping to meet demand or to provide redundancy for system reliability. The current valve exercise program is not robust enough to keep up with system needs. The Utility's corrosion control program is not able to meet all system needs. A need for a more formal and fully-funded program is needed for the evaluation of transmission mains (the larger diameter pipes in the system). A need for a fully-functional and comprehensive method for evaluating any critical system component over 20 years of age (Tucson/Pima County Oversight Committee 2009b:Chapter 1).

There have also been improvements. As a result of the introduction of Colorado River water into Tucson's system in 1992, Tucson Water began an accelerated replacement program for its water mains. Tucson Water's service area covers more than 300 square miles and contains more than 4,200 miles of distribution and transmission mains. Nearly 220 miles of galvanized steel or unlined cast iron mains were identified and prioritized for replacement or rehabilitation by 2006 (Basefsky 2006).

The spatial distribution of supply and demand, variable seasonal demand (particularly for landscaping), and elevation change across the Tucson Basin mean that infrastructure for water and wastewater is energy-intensive. This heightens a physical vulnerability of water with uncertainty in energy supply, pricing, and emissions regulations. Additionally, ageing infrastructure is a particular challenge given that much of the current distribution system was built several generations ago and is nearly the end of its design life. Finally, the centralization of wastewater recovery and treatment (with large capital investments in Pima County's Roger Rd. and Ina Rd. facilities) will obviate opportunities for decentralized wastewater reclamation.

Water Supply and Resource Dependency

Social factors also affect water use practices among the public. Although golf courses and swimming pools exist in the Tucson AMA, low water use landscaping (xeriscaping) is more readily apparent in this area compared to Phoenix, particularly in new subdivisions where water-conserving landscaping rules apply. Yet vulnerability still exists in the Tucson AMA because the city is at the end of the CAP system. It would likely feel the effects of a shortage of CAP water and lacks any alternative source analogous to the Salt River Project in Phoenix. Thus, groundwater and effluent are the only two fallback sources currently available (Carter and Morehouse 2003:30).

Colorado River flows and the availability of CAP supplies are a principal concern in Tucson's efforts to manage a climate-resilient water portfolio. Each year, the Bureau of Reclamation is charged by the Secretary of the Interior to declare the Colorado River water supply availability conditions ("normal, surplus, or shortage") for the Lower Basin States including Arizona. Regulations and operational procedures exist for normal and surplus availability; however, shortage is managed on the basis of interim guidelines. Because Lakes Mead and Powell form the principal storage reservoirs on the Colorado River, the interim guidelines are an effort to coordinate their operations. If Lake Mead levels drop below 1,075 feet (from "normal conditions" to "shortage"), Arizona must accommodate a 350,000 acre-feet reduction; at 1,025 feet, this would be reduced to 480,000 acre-feet (U.S. Bureau of Reclamation 2007; Pearthree 2009).

The implications of declared water shortage for Tucson are reductions in the banking of excess supply (current deliveries minus contracted volumes). This does not include the recharge of municipal water contracts but would affect the ability to secure water for the Central Arizona Groundwater Replenishment District (CAGRD). Agricultural contracts would be reduced next in the order of priority. Finally, municipal, industrial, and Native American water allotments would be affected. Tucson and Phoenix have informally exchanged their approaches to sharing reductions across the southern Arizona growth corridor (Buschatzke 2009).

According to Sharon Megdal, director of the University of Arizona's Water Resources Research Center, Tucson's supply portfolio is less than certain due to the unknown identity and cost of future water supplies:

> The confidence factor directly relates to the implementation of the Assured Water Supply Rules. The uncertainty reflects the complicated nature of current-day water supply portfolios, where arrangements are not in place today to meet all of the demands of current platted developments, let alone future developments. Water is physically present to meet demands, but all of the water required to replenish groundwater pumping by members of the Central Arizona Groundwater Replenishment District (CAGRD) has not been identified. The CAGRD has been a key enabling mechanism for those in the Tucson AMA desiring an AWS Designation or Certificate. But associated with the CAGRD are significant uncertainties due to the assumption that the CAGRD will find the water supplies needed for replenishment rather than a guarantee based on water supplies under contract for the full 100 years (Megdal 2006:25).[1]

As noted earlier in this case study, most of the Colorado River water that is delivered to Tucson is put into recharge basins in Avra Valley at the Clearwater Resource Recovery Facility. The water sinks

1 Assured Water Supply Rules "establish that new municipal growth must utilize renewable water supplies. The Rules do provide flexibility; they do allow new growth to be served with groundwater, should sufficient groundwater be available for pumping, but most groundwater use must be replenished with other water supplies, such as Central Arizona Project (CAP) water or effluent" (Megdal 2006: 1).

WATER BANKING

The Arizona Water Bank Authority (AWBA), created by the Arizona Legislature in 1986, is a water management strategy to increase the reliability of CAP deliveries during potential CAP shortages or canal outages:

> Under the AWBA, up to 400,000 acre-feet of Arizona's unused CAP allocation can be diverted and stored underground for recovery during times of shortage. The AWBA has stored this "firming" water at recharge facilities in the TAMA [Tucson Active Management Area] on behalf of Tucson Water and other CAP subcontractors in the region. This water can then be recovered (pumped) during shortage periods. However, AWBA is dependent on the availability during shortage periods, and continuing legislation to permit storage beyond 2016 (City of Tucson and Pima County Consolidated Drought Management Plan Technical Paper 2009:6).

Helen Ingram notes that:

> "While such banking actions reduce groundwater overdraft for about fifteen years, the aquifer depletion problem escalates after that because of population growth, resistance to conservation regulations, exempt wells, drought, and dwindling surface water supplies continue unabated. Further, recharge credits are allowed to over pumpers even if recharged waters occur in other, disconnected aquifers" (Ingram n.d.).

into the earth and blends with the native groundwater in the aquifer. The blend is then recovered by a number of wells and treated before delivery to Tucson Water customers. The use of this blended water reduces Tucson's reliance on groundwater and has allowed a number of wells to be shut off, reducing but not eliminating over-pumping.

A 2011 regional drought and climate variability study by CLIMAS (Climate Assessment for the Southwest, based at the University of Arizona) entitled "Patterns and Causes of Southwest Drought Variability" indicates that the risks of drought and water shortage in the Colorado River basin may still be high:

> the frequency, severity and duration of decadal megadroughts are influenced by variations in both the North Atlantic and tropical Pacific sea surface temperature. … State-of-the-art climate models (like those used by the IPCC [Intergovernmental Panel on Climate Change]) likely underestimate future drought risk. … Current reconstructions of "worst possible drought" for the Colorado River are, in fact, underestimates of the severity and duration of drought that has occurred, and that could occur in the Colorado River Basin (Overpeck et al. 2011).

The findings of the study by CLIMAS suggest that Tucson's reliance on CAP water, which originates in the Colorado River, may be less secure than expected. Of the 7.5 million acre-feet of Colorado River water available to the lower basin states of California, Arizona and Nevada, Arizona's 1.5 million acre-foot CAP water supply has the most junior priority (Colorado River Basin Project Act of 1968). Section 301(b) of the Act provides for Arizona to curtail use of its CAP entitlement to assure water availability to satisfy uses in California and water rights in Arizona and Nevada which have higher priority under the Act than the Central Arizona Project if Colorado River water supplies are below normal.

Further, once a "Stage 1" drought response has been declared for Tucson Water's service area, progression through Stages 2, 3 and 4 will be declared based on either threats to Tucson Water's Colorado River supplies or on local system indicators that signal negative impacts to the utility's groundwater supplies (Tucson/Pima County 2009:8).

Institutional Vulnerability

In a recent survey (Browning et al. 2011 in press), Tucson water planners, managers and providers expressed strong concerns about water planning and management during periods of prolonged drought or climate change. The CAP allotment from the Colorado River, declining groundwater, and the need to maintain or replenish water supplies were the top three concerns, but the full set of responses suggests that these actors are considering a number of linked issues, also including: refurbishment of existing infrastructure, equitable distribution, lack of access to funding or technology, water rights and the larger institutional framework of water management, a basic uncertainty about the length of the current drought, and the need for regional scale water data. Water planners and managers expressed a fairly clear consensus on the legal and regulatory problems they faced, especially at the state level: citing a "lack of real authority for ADWR exists to require implementation of water conservation measures, despite the state Drought Plan;" a "lack of enforcement for water violations, e.g. well drilling within AMAs"; and "a hydrological disconnect between ADWR and the development community, which operates the pumps while staying within existing laws" (Browning et al. 2011 in press). Similarly, several managers and planners noted that "the regulatory system was not designed to get us to sustainability; safe yield within the AMAs and lack of regulation outside them prevent that" (Browning et al. 2011 in press). Several also blamed the existence of prior appropriation for the current dispute between agricultural and municipal water demands over retiring agricultural water rights in favor of municipal water expansion. At least one respondent pointed out that "ADWR is influenced by lobbyists and citizens groups, but the legislative rules can be changed in times of drought" (Browning et al. 2011 in press). In addition to these regulatory and institutional flaws, everyone recognized that the Colorado River Basin Compact or "the Law of the River" determines how much CAP water is available for Arizona, but that extended drought could dramatically decrease that allotment. Several managers admitted that although CAP water is a potentially uncertain resource, it is being used to offset groundwater pumping in the state.

The planners and managers identified other pressures centered on financial concerns, population and housing growth, and common pool resource v. property rights arguments. Financial issues have to do mainly with cost or budgetary concerns for water managers and the issue that water companies' low cost billing structure ensures that consumers have no real incentive to decrease water use. Several respondents suggested that water companies should create rate structures that reflect other use values. Water managers also pointed out that increased energy costs are incurred for injection wells and for drilling and pumping using deeper wells when the aquifer drops. The growth issue is framed in terms of challenging the carrying capacity of the regional water system, yet managers are quick to recognize that this is a complex issue when considering increased use of treated wastewater and real implementation of water conservation measures. The private property rights or sense of entitlement conflicts with the perspective that water is a regional common pool resource for which everyone has the obligation of "responsible use." Water managers hear the sentiment from consumers that, since they pay their fair share, they should be able to do whatever they like with their water.

H. Adaptation and Adaptive Capacity

The other side of the vulnerability coin is adaptive capacity, which involves the "ability [of individuals] to cope with or adapt to external stresses placed upon their livelihoods and well-being" (Adger and Kelly 1999). Institutionally, adaptation is based on the ability of organizations to incorporate new information in decision-making, particularly with regard to uncertainties that are inherent, and potentially increasing, in physical and social processes (Pahl-Wostl et al. 2007), sometimes identified as adaptive management. Implicit here is the notion that vulnerability is tied to differential impacts of lack of availability of or access to resources (i.e., assets), to notions held by individuals and groups regarding their respective entitlements to the resource, and to the capacity of an urban center to adapt and maintain livelihoods. Also implicit to adaptive capacity is the concept of social learning, "a defining feature of adaptive management" that occurs through participation in planning, impact assessment, and sustainable management activities (Berkes 2009:1696; Holling 1978; Kumler and Lemos 2008; Muro and Jeffrey 2008; Pahl-Wostl and Harre 2004; Pahl-Wostl et al. 2007; and Tabara and Pahl-Wostl 2007). In short, our analysis of adaptive capacity focuses on social and institutional factors of urban water planning, management and provision that influence the area's relative exposure, impact, and capacity to respond effectively to threats or hazards.

Adaptive management or planning, according to the Intergovernmental Panel on Climate Change *Climate Change 2007: Synthesis Report: Summary for Policy Makers*, refers to "programs to manage or reduce adverse impacts related to weather and climate change and variability. The Committee believes that the issues of conservation, drought preparedness, and use of reclaimed water fall under this category" (IPCC 2007). In what follows, we assess several current areas of activity and opportunity for advancing adaptation and adaptive capacity in the Tucson Basin. These include regional planning for drought, the use of effluent, the important consideration of energy use, water conservation, and several specific multiparty efforts.

- <u>Regional drought planning</u>. The City of Tucson and Pima County attempted to improve governance practices, including access to resources, and regional planning in their 2009 water study (Tucson/Pima County Oversight Committee 2009b). However, they found that the actual consolidation of City and County drought management plans was not desirable because as a water provider, Tucson has different drought planning requirements than the County. The City's drought management plan relies heavily on CAP water, which necessitates monitoring and establishing measures to respond to changing conditions that impact the Colorado River, not only local conditions.

  At the same time, Pima County is not a water provider and is thus not required to develop a Drought Preparedness Plan under the statute. Nevertheless, the County Board of Supervisors adopted a drought preparedness plan in 2006, and in 2009, "the City [began] working with a 26-member Climate Change Committee to consider how climate change may increase the per capita use of water, how this increased use will be linked to preserving human health and welfare, the need to shift water for purposes of meeting local food and energy needs, and how potential future shortages in water availability can be handled to reduce social, economic, and environmental consequences for the community" (Tucson/Pima County Oversight Committee 2009b).

  Because of the level of uncertainty the Committee faced, an adaptive, flexible, and regularly updated scenario planning approach was needed to prepare the community for drought. The City of Tucson's climate change committee members represent a balanced range of interests, including non-profit, academic, and private sectors (see http://cms3.tucsonaz.gov/ocsd#TopOfPage).

A recent study interviewing water managers and planners along Arizona's Sun Corridor, including Tucson, noted the need for regional scale planning in order to achieve economies of scale in water services (Hill et al. 2008). Cost-effective water use appears feasible to achieve primarily on a regional scale (Hill et al. 2008). Intergovernmental agreements, such as the 1979/2000 agreement between Tucson and Pima County over water and wastewater operations, have thus far been a tool for cooperative planning (Browning-Aiken et al. 2011 in press:20).

- The Pima County Drought Impact Group monitors and collects information on drought impacts. Drought outreach activities and the development of county drought preparedness and response measures are longer-term goals for the group. The Pima County Drought Impact Group in its 2009 Annual Report indicated that, generally, "long-term drought conditions are much worse than they have been in recent years. Since April, seven watersheds dropped one category and two dropped two categories. During the water year, precipitation was below 70 percent of average for most of the state. While the reservoir system is in good shape, the groundwater aquifers are not as quick to recharge, so this dry year has been especially hard on those water resources" (ADWR 2009).

  The group further noted that all water providers are to construct drought and conservation programs, but that ADWR, in their review of these plans, indicated that "many small water providers may lack the training and/or resources necessary to develop a good water planning document. It is also evident that water providers need assistance in securing emergency supplies and preparing for potential water shortage conditions" (ADWR 2009).

- City/County Water and Wastewater Committee. The City/County Water and Wastewater Oversight Committee prepared a technical paper on Consolidated Drought Management and a Primer on Drought and Drought Preparedness. The technical paper points to two major actors in its drought management: the Pima County Local Drought Impact Group (see above) and Tucson Water, which looks closely for drought indicators in annual Colorado River flows. Their drought response measures focus on "public education and awareness campaigns, visible leadership, and reducing non-essential uses in the early drought response stages with progressive restrictions, fines and curtailment in the more severe drought response stages" (Tucson/Pima County Oversight Committee 2009a). With Tucson Water, the Committee views creating different scenarios as a means of adapting to current and future vulnerabilities. The City of Tucson also submits an Annual Drought Monitoring Report, which looks at supply and demand. (Tucson, City of 2009). With the conclusion of the first two phases of this study, the Pima Association of Governments (PAG) has been asked to convene a third phase with wider stakeholder involvement to develop a regional dialogue about establishing a sustainable water future for the entire region.

- The Tucson Water Drought Plan includes four drought response stages based upon local drought conditions, declaration of drought on the ADWR website, and severe or sustained drought on the Colorado River Watershed as monitored by the U.S. Drought Monitor. The Tucson Water Plan 2000-2050 uses scenario planning as a tool to weigh alternatives for increasing use of treated wastewater (water reuse), as the example below demonstrates (Figure 4-7).

Outcomes of Scenario Planning for the Clearwater Program

The Clearwater Program was developed to maximize Tucson Water's use of its Central Arizona Project allocation by blending Colorado River water with native ground water. As shown on Figure 6-3, four futures were developed based on the following critical uncertainties:

1. What is the public's threshold for paying for discretionary water-quality improvements to the Clearwater blend?

2. Will the public accept the use of the Hayden-Udall Treatment Plant for direct treatment of Colorado River water?

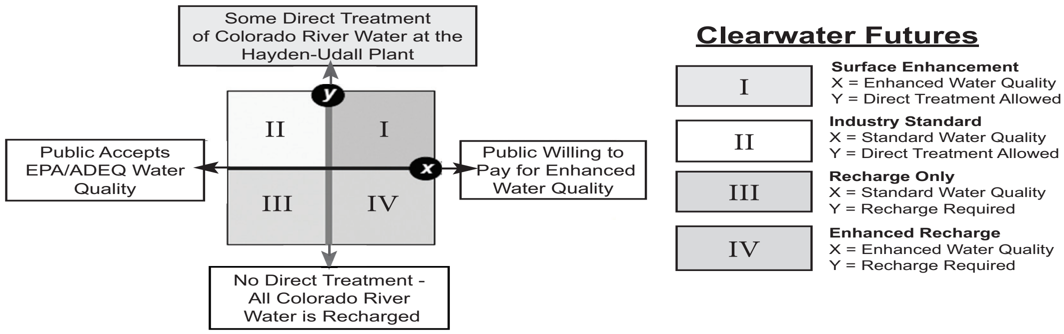

Figure 4-7. Tucson Water Scenario Planning Process. Source: Tucson Water 2004:6-5.

Developing alternative scenarios allows planners and managers to identify uncertainties and explore consequences of decisions before making them, which is a form of adaptive planning.

- The Drought Impact Monitoring Program created by ADWR with the University of Arizona Cooperative Extension is working to get agencies and individuals interested in drought impact monitoring, mainly by promoting the use of Arizona Drought Watch qualitative reports of drought impacts across Arizona. This "impact information will be used in conjunction with meteorological and hydrological data to characterize drought conditions, and perhaps more importantly, to help determine the environmental, social and economic impacts of drought." (citation?) In addition, ADWR assembled a Conservation Toolkit to "assist communities and water providers in the design and implementation of comprehensive, customized and proven conservation strategies. These tools provide residents, businesses and the agricultural community with information on sector-specific water-efficient measures" (ADWR 2009).

- Water reuse as a hedge against water sector vulnerability. In addition to renewable groundwater and CAP deliveries, water reuse (reclaimed effluent) represents the third source of water to meet Tucson's demands, as shown in Figure 4 above. Currently, the City of Tucson distributes 15,750 acre-feet of effluent, largely to institutional users such as golf courses, schools, public parks, etc. A small fraction is made available to residential users in three Tucson neighborhoods adjoining the reclaimed water distribution lines. A share of effluent is released to the (otherwise dry) Santa Cruz River, where it supports important habitat. Only fifty percent of this release counts toward water banking credit under the provision that only certified facilities with strictly controlled conditions for recharge receive full credit, i.e., in the Santa Cruz, the uncredited balance is considered to be "cut to the aquifer." The combined total effluent use meets on average nine percent of Tucson's water demand. However, with projected growth, effluent available to the City of Tucson is projected to grow to a 62,000 acre-feet annual entitlement by 2030 (Tucson Water 2004).

For new real estate developments in Tucson and Pima County, it has proven easier to build a dual system for water supply and water reuse from the outset (as the Phoenix-based management company Global Water has learned in its work there). This consideration becomes a key factor when the costs of infrastructure are considered and when decisions by one AMA contradict decisions by another in regard to use of groundwater. The concept of total water management ("highest and best use for recycled water" and "the right source for the right use") (Hill et al. 2008:9) requires large scale planning that can address local needs and assets. At the same time, Tucson Water and the Pima County Regional Wastewater Reclamation Department staff have set a goal "to improve communication and coordination between the two agencies, cooperatively pursue and develop a joint constructed recharge project for City and County effluent being discharged to the Santa Cruz River, finalize the Conservation Effluent Pool and Intergovernmental Agreement Amendments, and finalize the location of a wastewater reclamation facility in the Southeast Area"(Tucson/Pima County 2007:2). This kind of regional cooperation might offset some of Tucson's institutional vulnerability to climate variability and change.

While effluent clearly represents an important resource, it may require extra management attention due to public concerns over safety. Further, its availability is directly related to the primary sources of supply. In other words, shortages in Colorado River water, groundwater pumping restrictions, and other factors that affect the supply and use of potable water directly or indirectly, including for example grey-water use, will have an impact on the wastewater available to be reclaimed and reused. It appears very likely that highly treated effluent will form part of the city's long-term aquifer recharge and recovery plans. Public opinion, indicated through community questionnaires, is not uniformly opposed to this prospect. 48 percent of Tucsonans polled consider groundwater recharge an acceptable use of reclaimed water with an additional 22 percent unsure, and 29 percent opposed (Ormerod et al. 2009).

- <u>Regional Optimization Master Plan.</u> The Regional Optimization Master Plan (ROMP) was created by the Pima County Regional Wastewater Reclamation Department (RWRD) and local partners to meet environmental regulatory requirements regarding ammonia and nitrate. When the plan is completed, the Ina Road facility will be upgraded and expanded to treat 50 mgd. The Roger Road plant will be decommissioned after a new 32 million gallons per day (mgd) water reclamation facility is built adjacent to the existing plant. RWRD will be asking for increases in sewer rates and sewer connection fees. These rate increases are paid by those individuals who receive sewer service, developers, and any others who connect new plumbing fixtures that discharge into the sewer system (see http://www.pima.gov/wwm/programs/ROMP/).
- <u>Effluent Master Plan.</u> In addition to the ROMP, Tucson Water has been developing an effluent master plan that looks at effluent entitlements for 2010, assesses the current amount of effluent available, and estimates the amount that will be available upon completion of the ROMP infrastructure improvements. With a view to prolonged drought and the potential for decreased supplies from CAP, their plan acknowledges the importance of increased use of treated effluent, including indirect potable recharge or "highly purified recycled water" as a means of offsetting groundwater pumping. They acknowledge the need for public education about and acceptance of this effluent management planning document; and, for this reason, they are framing water reuse as a conservation strategy. In order to address the complex driving forces for increasing effluent reuse and future uncertainties regarding potable regulatory standards, Tucson Water has begun building a series of

planning scenarios that revolve around choices regarding reclaiming or treating water and indirect recharge. While the scenarios demonstrate that Tucson Water is searching for ways of adding to the area's water portfolio, more public input is needed for the scenario planning process to be truly valid. Also, the City of Tucson and Pima County have agreed to work together, but the County's role in the scenario development appears to be absent.

- The role of energy use. The energy intensity and reliance of Tucson's water supply have been assessed by Scott and Pasqualetti (2010), Scott et al. (2007), and Hoover and Scott (2009). All three water sources – CAP, groundwater, and reclaimed water – require significant amounts of electricity that is largely met through fossil-fuel generation. The shares shift constantly, but fossil fuels account for all of CAP's energy and most of the energy for Tucson Electric Power and Trico, the electrical utilities that supply power to Tucson Water and Pima County Wastewater. As a result, Tucson's short-term adaptation to climate change coupled with growing demand have longer-term negative implications for climate change mitigation as a result of the contribution of energy for water to increased emissions. In short, adaptive water planning might better take into account the energy component of water use and reuse when determining the best mix of resources and strategies.
- Conservation. Significant uncertainties remain with respect to the water conservation behavior of the public, particularly as the perception of vulnerability remains high. Tucson's success in reducing gallons per capita per day has resulted in the "hardening of demand," i.e., fewer opportunities for conservation. This is accentuated by the perception that water saved through conservation has allowed for new growth to occur. And future conservation through increased household level use of grey water may in effect compete with reclaimed water (this water would otherwise return to wastewater treatment plants to be reclaimed and reused). However, the social learning represented by grey-water and rainwater-harvesting movements across Tucson are an important instance of adaptive response to water scarcity and prolonged drought.
- The Pima County Sustainability Action Plan includes optimizing the use of water resources with rights held in the county, including groundwater, surface rights, and effluent for natural resource protection. This plan has a goal to reduce county water use by 15 percent by 2025.
- Tucson Climate Change Advisory Committee is developing a Climate Change Mitigation and Adaptation Plan that includes recommendations to achieve the City's greenhouse gas reduction commitments under the Mayor's Climate Protection Agreement (signed by the Tucson mayor and council in 2006) along with strategies and action steps needed to prepare for both the direct and indirect effects of climate change on the City's infrastructure and operations, as well as its ecological, economic, and social capital (see http://cms3.tucsonaz.gov/ocsd#TopOfPage).
- Integrated Drought-Management/Climate-Variability Preparedness Program. Initiated in October, 2010, this program represents an effort to anticipate and plan for future shortages in Colorado River supplies and possible increases in the costs of energy. The mission of its team from Tucson Water, the City of Tucson, ADWR, CAP, and the University of Arizona is to: "Coordinate integrated climate-variability planning within the Utility to expand the organization's adaptive capacity to address climate-change uncertainty and to minimize and mitigate plausible impacts to Utility functions" (Tucson Water Department 2010). The program aims to investigate a host of climate-related challenges, including mitigating future CAP shortages, understanding potential seasonal and long-term climate-related impacts on water demand, potential water-quality changes, severe weather, etc. It also questions the role that climate

change projections might have on water customers' willingness to conserve, how this might in turn reduce future water supply costs, and what near- to mid-term actions might be taken to "maximize resource flexibility and adaptability in the future" (Tucson Water Department 2010).

- The Governor's Blue Ribbon Panel on Water Sustainability began meeting in 2010 to address water concerns in light of continued drought. The panel meetings, which drew in a large number of interested stakeholders, has been organized by ADWR, ADEQ and the Arizona Corporation Commission into working groups with leaders selected by the trio in agreement with the groups themselves. The Panel's focus is on advancing water reuse and recycling. According to the director of ADEQ, Ben Grumbles: "The future of Arizona's water is about reducing, reclaiming, and reusing. By reducing water waste and inefficiency and by reclaiming and recycling water, we can save more and waste less, stretching our supplies further at a time when climate change, drought, ground water mining and development strain and drain our exhaustible resource. The Blue Ribbon Panel experts, however, knew that legal, regulatory, scientific, and social/cultural barriers often stand in the way of progress. For example, we recognized the public would need more time and credible information before it would trust the experts on the safety of reused wastewater, particularly with all the news and concern over pharmaceuticals. We also recognized the need for an infrastructure strategy if we were going to get serious about the use of purple pipe, dual plumbing, gray water reuse, and stormwater recycling. The continuing goal is to find the sweet spot, the right mix of law, science, and policy to get results and earn public support for smart growth and water sustainability in Arizona communities" (pers. comm., January 18, 2012).

- Central Arizona Project ADD Water. According to the CAP website: "In response to its 2006 Strategic Plan, CAP created Project Acquisition, Development and Delivery (ADD) Water in 2007 in an effort to establish a collaborative process to determine when new supplies need to be acquired and what entities get those supplies. Since this idea was much larger than the issues the CAP addressed the Central Arizona Water Conservation District (CAGRD) was established to work with CAP in order to provide water to those customers who did not have access to CAP water. The CAGRD would find water in order to assure a customer (frequently a developer) that he/she would have a 100-year assured supply. In January of 2008, CAP created the ADD Water Project Team that included three CAP Board members, representatives from a variety of external stakeholder perspectives and CAP staff to refine, finalize, adopt and implement the Stakeholder Participation Plan. The Project Team will accurately report the results and recommendations from stakeholder meetings to constituents, stakeholders and the CAP Board. The Stakeholder Process began on May 21, 2008 and is expected to conclude in 2010" (http://www.cap-az.com).

  ADD Water represents an effort to find further water for water entities that would be willing to pay for it in order to fulfill the Assured Water Supply mandate. It is innovative in that it is linked to CAGRD's efforts to help stakeholders with their water banking issues and potentially enlarges the role of CAP in providing water to Arizona water providers. At this point ADD Water is directed toward the central part of Arizona, but CAP also delivers water to Tucson, so it is not clear if Tucson might become involved in this process as well. Some might question whether this is really an example of adaptive management.

I. Summary of Urban Water Vulnerability and Adaptive Capacity

In this section, we summarize key findings about priority vulnerability areas and discuss adaptive capacity by returning to the four questions we posed for each of the linked case studies, including Tucson. Overall, the key elements of the Tucson case study are: 1) reliance on sole-source supply from the over-allocated and water-stressed Colorado River, 2) drought-prone and high-growth areas, which constrain Tucson's adaptation activities, 3) long-term water supply/climate scenario planning by Tucson Water and its partners, and 4) conservation promotion at the household scale and recharge/reuse at the municipal scale.

How is urban water sector vulnerability defined in Tucson and what are the key indicators?

For example, how do Tucson water managers and planners perceive "climate change and variability" in operational terms? This study has documented four major types of urban water vulnerability in Tucson: 1) socioeconomic vulnerability and resource dependency, 2) infrastructure vulnerability, 3) water supply and resource dependency, and 4) institutional vulnerability. In order to compare the Tucson case study with other case studies from the *Moving Forward* project, Tucson's vulnerabilities can be further articulated using the theoretical framework described in the project introduction (chapter 1) to identify demographic and socioeconomic, biophysical and climatic, institutional and governance, scientific and technological, and environmental indicators.

What is the institutional capacity of this transboundary region to develop adaptive strategies for future water management, at a 5 to 20+ year horizon?

For example, what are current adaptations that water planners and managers are using to address potential water shortages and increased demand (e.g., changes in decision-making, public outreach and comment, modification of infrastructure, preparedness, emergency plan scenarios)? In addition, does adaptive management for extended drought or climate change generally include building a capacity for learning and adapting locally among water managers and planners?

Institutional capacity for adaptive water management is high at the city (Tucson) and utility (Tucson Water) levels. This is the case despite major retrenchment of state-level support for agencies such as the Arizona Department of Water Resources, which arguably would be better placed to address regional and statewide water and related climate challenges. Much of the science input for decision-making comes from the University of Arizona.

Tucson Water does not see its water supply as a transboundary challenge (at least in U.S.-Mexico terms) although it is acutely aware of interstate issues on the Colorado River. Nevertheless, Tucson Water staff members have participated in U.S.-Mexico climate and water adaptation workshops conducted by the research team with support from NOAA's Sectoral Applications Research Program (SARP) and the Inter-American Institute for Global Change Research (IAI).

Table 4-1. Summary of Urban Water Vulnerability Indicators, Tucson.

Types of Vulnerability	Indicators	Tucson
Demographic and socioeconomic	For example: Growth characteristics (actual and projected)	Rapid growth of population, expected to nearly double in the coming decades, places immense pressure on water resources and greatly heightens vulnerability of sections of the Tucson populace.
	Poverty and inequality levels	Tucson consistently ranks below Pima County, Arizona state, and national averages for poverty rate, income, and educational attainment.
Biophysical and climatic	Climate variability and climate change	Climate change and variability (variously referred to as "extended drought") has important implications for Tucson's CAP-dependent water supply. Heat island physical processes and social adaptation (vegetation and cooling) are important wildcards in Tucson's response to climate change and variability.
Institutional and governance	Characteristics of water management	City of Tucson and Pima County disjuncture in terms of management of water and wastewater, respectively, heightens challenges for adaptive management. Additionally, cross-jurisdictional claims to water resources and infrastructure (eg., Marana) raise the need for regionalized institutional strategies. Indirect potable reuse plans in Tucson raise important governance questions.
Scientific and technological	Hydraulic infrastructure	Heavy reliance on infrastructure for water and wastewater supply (CAP aqueduct, electricity grid, Regional Operations Master Plan – ROMP wastewater plants) is offset, somewhat counter-intuitively, by strong focus on conservation, growing adoption of rainwater harvesting, and recognition of ecosystem services. In addition to large infrastructure and community- and residential-level innovation with water harvesting and graywater use, several other considerations are important, especially water reuse infrastructure (to produce reclaimed water of quality fit for different end uses, spatial distribution of treatment plants, etc.).
	Climatic information adequacy and fit	Adequate, good fit.
	Use of alternative conservation strategies	Low per capita water demand, relatively high conservation commitment and adoption, at least when compared to other Southwest U.S. communities.
Environmental	Reliable access to clean water and sanitation	Relatively high; however, environmental justice issues associated with ecosystem services in poor neighborhoods will remain an important environmental challenge in Tucson.
	Ecosystem health and impacts	Effluent for nature defacto policy can be problematic unless preserved through protected water rights or regulatory controls.

How can the capacity of water managers and preparedness planners to use climate science and information to improve long-range and "adaptive" decision-making best be institutionalized?

For example, what further policy and institutional measures/strategies are needed to overcome urban vulnerability to decreasing water supply? The Mayor and Council in Tucson have effectively drawn a "line in the sand" by fixing the obligated service area (see Figure 4-1). This was not initially see in a positive light by the utility, given that it was perceived to fix (i.e., limit) future revenues. However, considering future water supply variability, i.e., as resulting from extended drought and Lower Colorado River water shortage sharing agreements, this will come to be seen as providential.

How can climate science best be integrated into planning processes to enhance Tucson's resilience to climatic and water-resources uncertainties?

As indicated, the University of Arizona provides much of the climate science used for planning in Southern Arizona. However, a unique feature of Tucson Water's approach to enhance resilience and address climatic and water-resources uncertainties is the application of scenario planning (see Figure 4-7). In an allied project supported by the National Science Foundation's Resilient and Sustainable Infrastructures (RESIN) program, members of the research team are currently involved in conducting scenario planning, together with Tucson Water and Pima County Wastewater, to address uncertainties in water supply, demand, and public acceptability of water reuse and other future alternatives.

J. Implications for Policy and Planning

Two broad themes need to be highlighted here. First, resilience and adaptive water management in high-growth and water-scarce regions such as Tucson must be considered not solely in relation to physical processes such as climate change and hydrological variability. In addition, the very process of (short- and medium-term) adaptation can expose future (long-term) vulnerabilities. That is, water supply sufficiency, efficiency and conservation without caps on service expansion, and alternative practices such as rainwater harvesting and grey-water use that add to water demand without substituting existing, conventional supplies may all contribute to increased aggregate water demand over the long-term. How this will be sustained over average conditions is difficult enough a proposition; determining how to adaptively address vulnerabilities that derive from supply variability (hydroclimatic and institutional in origin) and uncertain growth and demand is the water and climate challenge of our time.

The second theme relates back to collaboration. As we have emphasized elsewhere in this paper, policy and planning in the Tucson area would benefit from a closer working relationship between the City and the County. The City/County Water and Wastewater Infrastructure and Supply Study has already demonstrated the benefits of collaboration, even if the two have different responsibilities for water and effluent planning. The science-policy model pioneered in Tucson offers an excellent example of social and institutional learning (Wilder et al. 2010). This must be extended through increased public outreach and inreach, i.e., particularly citizens' involvement in planning, as well as creating and sustaining programs that bring the very real challenges (hydroclimatic, environmental, and social) of water management to the public. Ultimately, this will translate into modified consumption patterns, as well as economic and political pressure that currently drive the expansion of supply, "next bucket" mindset.

We concur with the City/County Water and Wastewater Committee's recommendations that strategies, ordinances, programs, and funding considerations by Mayor and Council and Board of Supervisors should place adaptive planning as a principal goal ("the continued coordination of drought response actions for the region and an adaptive management approach"), and build on the current reclaimed, drought planning, and conservation efforts of the City and County (Tucson/Pima County Oversight Committee 2009b).

From this follows a series of recommendations that we simply synthesize here:

- Underscore the Governor's Blue Ribbon Panel's efforts to increase water reclamation and recycling. This will need to identify specific public engagement and regulatory strategies to support infrastructure and technological options.
- Promote regional planning that marshals multiple jurisdictions, infrastructure, and planning initiatives for integrated water and wastewater management. Addressing the common challenges faced in urbanizing southern Arizona must address equity and efficiency, given the context of increasing population growth and the prospect of prolonged drought.
- Conduct a media campaign that demonstrates the challenges urban areas face in planning and managing water supplies and provide televised townhall-like opportunities to discuss potential solutions.
- Continue Tucson's leadership among arid and semi-arid regions facing long-term drought by encouraging the use of water conservation techniques such as more efficient plumbing fixtures and reduced outdoor landscape watering requirements through the use of tax discounts and rebates. Similarly, promote rainwater harvesting and grey-water for outdoor watering.
- Increase the use of treated wastewater for non-potable uses such as toilets in order to decrease the demand for potable water.

The effectiveness of Tucson's innovative planning, conservation and technology adoption, and public participation to strengthen resilience to climate change, variability, and water scarcity will be significantly hampered if growth is not effectively regulated. Further research is required on the policy options and implications of growth, particularly with respect to water resources in Tucson and more generally across the case studies considered in this project.

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Acronyms

AMA—Active Management Area
ADD Water—Acquisition, Development and Delivery of new Water supplies project
ADEQ—Arizona Department of Water Quality
ADWR—Arizona Department of Water Resources
AWBA—Arizona Water Banking Authority
AWI—Arizona Water Institute
AWS—assured water supply
CAP—Central Arizona Project
CAGRD—Central Arizona Groundwater Replenishment District
CAVSARP—Central Avra Valley Storage and Recovery Project
CLIMAS—Climate Assessment for the Southwest
EPA—U.S. Environment Protection Agency
GCM—global climate model
IAI—Inter-American Institute for Global Change Research
IPCC—Intergovernmental Panel on Climate Change
MCPA—Mayor’s Climate Protection Agreement
RESIN—National Science Foundation’s Resilient and Sustainable Infrastructiores Program
ROMP—Regional Optimization Master Plan, Tucson/Pima County
RWRD—Pima County Regional Wastewater Reclamation Department
TAMA—Tucson Active Management Area
TREO—Tucson Regional Economic Opportunities, Inc.
WIFA—Arizona Water Infrastructure Finance Authority