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Decision Making Under Uncertainty: Ranking of Multiple Stressors on Central Arizona Water Resources

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Approved by

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Abstract

This paper explores the value of multiple stressor analysis as a support for decision making under uncertainty associated with water management policy in the Central Arizona region of the southwestern United States. More specifically, this paper assesses the significance of each stressor in its relation with the vulnerability of water supply systems and generates a ranking of the stressors through a weight-of-evidence approach. Based on the causal links between stressors and their effects on water resources, the multiple stressors of Phoenix AMA are broadly placed in three categories: municipal, agricultural, and biophysical. My analysis shows that outdoor irrigation uses within the municipal category is the largest stressor on water resources. Ranked second is the loss of water due to rise in temperature and simultaneous reduction in precipitation due to global warming in the Colorado and Salt/Verde River basin, the largest supplier of surface water to the Phoenix AMA. This is closely followed by the stress on water resources resulting from inefficient agricultural practices. Indoor water use is ranked fourth among the stressors. The relatively low ranking of indoor water use is not surprising given the implementation of efficiency standards and innovation of technologies in plumbing fixtures. Higher residential water demand due to increased night time temperature in the urban area is a distant fifth. Analysis and ranking of multiple stressors in the water resources of Phoenix AMA reveals that outdoor water use and agriculture practices are comparably fertile targets for efficiency gains from technical and management perspectives.

Key words: multiple stressors, water management, sensitivity analysis, Arizona, decision making, uncertainty, vulnerability

Acknowledgments

About the Author

Netra is currently a Postdoctoral Research Associate at the Consortium for Science, Policy and Outcomes at Arizona State University. His work seeks to understand science policy interface to support climate-related decision making in the face of fundamental uncertainties. Other areas of Netra's academic research include sensitivity analysis of ecosystems to climate change; risks and vulnerability assessment; land-use land cover change; political ecology of land degradation; community based resource management; and sustainable agriculture. He recently completed his PhD in geography with a minor in demography from Penn State University. Prior to pursuing his academic degree, Netra worked in community development and natural resource management in Nepal. In the Third Assessment Report (TAR) of the Working Group II of the Intergovernmental Panel on Climate Change (IPCC), Netra was involved in the review and synthesis of literature for Chapter 5 "Ecosystems and Their Goods and Services." In the upcoming Fourth Assessment report of the IPCC, Netra is a contributing author on Chapter 5 "Food, Fibre, and Forest Products."

Decision Making Under Uncertainty: Ranking of Multiple Stressors on Central Arizona Water Resources

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I.   Introduction

Water resource management in the southwestern United States has become increasingly complex as pressures on existing supply continue to mount. Projected population growth, rising water demand for economic development, the need to preserve and enhance aquatic ecosystems, and a variable and changing climate are part of the complex dynamics that affect the regional hydrologic system (NRC, 2001). Nowhere is the complexity of water management more crucial than in the desert landscapes of central Arizona where limited water supply restricts the structural solutions to its management. The capacity of the region to successfully meet these interrelated challenges while managing its water resources in a sustainable manner will depend, in large part, on relevant knowledge gained through scientific research.

This discussion paper provides a sensitivity analysis of multiple factors (referred to as stressors) that influence water resources in the Phoenix Active Management Area (AMA), which includes the city of Phoenix, one of the fastest growing metropolitan areas in the country. Based on extensive literature review and secondary data from sources such as the Third Management Plan of the Arizona Department of Water Resources (TMP-ADWR, 1999) and Maricopa Association of Government (MAG), this paper investigates the effects of multiple factors that stress water resources at present, and, using available data, attempts to extend this analysis to 2025. More specifically, the paper aims to: a) identify and provide the scientific basis for study of multiple stressors on the water resources of Phoenix AMA; b) assess the significance of each stressor in its relation with the vulnerability of water systems; and c) generate a ranking of the stressors through a weight-of-evidence approach. The broader goal of this research project is to explore the value of multiple stressor analysis as a support for decision making under uncertainty in science policy and in water management.

II.   Background

a.   Phoenix AMA: biophysical context

The Phoenix AMA is one of the five AMAs mandated by the Groundwater Management Act of 1980 (i.e., the Groundwater code) to establish a long-term management goal for groundwater supplies (Connall, 1982)[1]. Each AMA has a statutory water management goal for limiting the overdraft of groundwater. The AMAs are responsible for exploring ways of augmenting water supplies to meet future needs, and work to develop public policies in order to promote sustainable use of water resources. The Phoenix AMA

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[1] Only four AMAs were created by the GMA in 1980. The fifth (Santa Cruz) was added later.

covers 5,646 square miles, consists of seven groundwater subbasins, and includes a large portion of Maricopa County and smaller sections of Pinal and Yavapai Counties (TMP-ADWR, 1999).

Located primarily in the subtropical desert, the climate of the Phoenix AMA is semiarid and is characterized by low precipitation, hot summers, and mild winters. The average daytime temperatures during the hottest month of July consistently hover between 100^0F and 110^0F, with little relief during the night when temperatures rarely fall below 80^0F. In the winter, daytime temperatures for January, the coolest month, are between 60^0F and 70^0F, and nighttime lows can sometimes fall below freezing (TMP-ADWR, 1999). Since the 1930s there has been an overall increase in the average temperature. While in the urban areas this trend may be attributed to the urban heat island (UHI) effect, this rise in temperature has also been observed in rural areas (Brazel et al., 2000). These higher temperatures result in greater water demands, increased evaporation from exposed water bodies, and increased evapotranspiration from plants.

Annual precipitation averages 7-8 inches across the Phoenix AMA, with higher elevations receiving more rainfall (TMP-ADWR, 1999). The rainfall is bimodal, with summer monsoon rains from July to mid-September, and winter rainfall from November through mid-April. From a hydrological point of view, winter rainfall is more important because of its longer duration, lower intensity, and wider coverage, and therefore reduced surface run-off, greater percolation, and higher groundwater recharge.

Rainfall is also characterized by a high degree of interannual variability due to El Niño-Southern Oscillation - ENSO (Andrade and Sellers, 1988; Kiladis and Diaz, 1989; Allen and Ingram, 2002; Hidalgo and Dracup, 2002; McPhee et al., 2004). In recent years several La Niña phases of ENSO has occurred with widespread droughts in the region (GDTF, 2004). Multidecadal fluctuations in ocean temperatures (e.g. AMO - Atlantic Multidecadal Oscillation and PDO - Pacific Decadal Oscillation) are also associated with persistent dry conditions in this region (Enfield et al., 2001). Together these two phenomena can bring extended periods of drought to the southwestern U. S. (McCabe et al., 2004), which can have significant implications for recharging water sources in Arizona. Tree-ring records of Colorado River stream flow show periods of extended drought years in the 1580s, the early 1620s to 1630s, the 1710s, the 1770s, and the 1870s (Hirschboeck and Meko, 2005). Drought years mean less snow pack in the watershed of the rivers and therefore reduced supply of surface water, leading in turn to compensatory increases in groundwater pumping.

b.   *Overview of water supply*

Approximately 2.3 million acre-feet[2] (af) of water is used annually in the Phoenix AMA, primarily from four major sources: 1) local rivers; 2) Colorado River water; 3)

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[2] Western United States water publications make use of the measure "acre-foot" rather than the more widespread metric equivalents for water volumes. Because all of the water demand and supply units are reported in acre-foot, unless mentioned specifically acre-foot will be the primary unit of measure followed in this paper. Note that one acre-foot equals 325,851 gallons.

groundwater; and 4) effluent. The Gila River along with four principle tributaries (the Salt, Verde, Agua Fria, and Hassayampa Rivers) form the primary sources of surface water[3] for the AMA. Based on historic data, average surface water availability from these rivers is a little over one million acre-feet (maf) annually. Of the 2.8 maf of Colorado River water to which Arizona is entitled, the Phoenix AMA receives less than 0.5 maf through the Central Arizona Project (CAP). An estimated 409,222 af of CAP water was delivered in 1995 by the Central Arizona Water Conservation District (CAWCD) in the Phoenix AMA (CAWCD, 1996). Groundwater withdrawal varies over time and is governed by the amount and timing of precipitation. In 1995, 946,052 af of groundwater was extracted in the AMA. The availability of effluent water continues to increase in Phoenix AMA, and was reported to be 286,000 af in 1995 (TMP-ADWR, 1999).

The Colorado River Compact (1922) apportioned water between the Upper (Wyoming, Utah, Colorado, and New Mexico) and Lower (California, Arizona and Nevada) Basin states, with each receiving 7.5 maf. In addition, the 1994 United States–Mexico treaty guaranteed an annual flow of not less than 1.5 maf to Mexico. These allocations were based on what was then an incorrectly estimated figure of average discharge of 18 maf (Christensen et al., 2004). Recent analysis, using three centuries of river discharge data, indicates an average annual flow of 13.5 maf with considerable annual variations, ranging from 4.4 maf to over 22 maf (Gelt, 1997). A tree-ring based assessment completed in 2005 estimated that during the period between 1521 and 1964, the mean annual flow at Lees Ferry was about 14.2 maf (Hirschboeck and Meko, 2005), indicating that the total legal entitlement to the river's water is greater than the average flow of the river.

3.   *Overview of water demand*
Excluding riparian ecosystems, there are three major water demand sectors in the Phoenix AMA: agricultural, municipal, and industrial. Table 1 shows the Phoenix AMA's water consumption for 1995 and projected demand for 2025 by sector. Overall demand is projected to rise from 2.3 maf in 1995 to over 2.9 maf in 2025, an increase of more than 20 percent, mostly due to rising municipal demand from projected population growth. According to the TMP-ADWR (1999), if the Phoenix AMA does not implement new efficiency policies, these projections will translate to approximately half a million acre-feet of excess groundwater extraction by 2025, thus compromising the AMA's goal of reaching "safe yield," or no net groundwater withdrawal.

Each Phoenix AMA demand sector has unique water use characteristics that may affect the AMA's ability to manage water in a sustainable manner (Holway, et al., 2006). The municipal sector comprises residential and nonresidential water uses (TMP-ADWR, 1999). Residential demand includes interior and exterior use at single and multifamily dwellings. Interior water use can vary according to the efficiency of appliances and

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[3] Refers to water from sources such as streams, canyons, natural channels, floodwater, wastewater, lake water, and recycled water.

water use practices of residents. Exterior water use is determined by the type of residential landscape, irrigation practice, and lot size. Non-residential use predominantly includes commercial and institutional water use. On average, about 67% of municipal water is used for the residential sector in the Phoenix area. The remaining 33% is used by public operations such as city parks, public schools, public colleges and universities, and everyday government operations. Water demand in the municipal sector is closely tied to population growth and may go up by 60% to nearly 1.4 million acre-feet in 2025 (TMP-ADWR, 1999). As shown in Table 1, the municipal sector is projected to become the largest consumer of the AMA's water, growing from 37% of total water use in 1995 to 47% in 2025.

Sector	Demand Characteristics	1995 (af)	2025 (af)
Municipal	- Residential, commercial and institutional uses - Irrigation for parks, & others	869,962	1,395,725
Agriculture	- Indian and Non-Indian demand for growing crops	1,333,885	1,360,743
Industrial	- Industrial, commercial and institutional uses	83,088	137,628
Riparian	- Riparian areas	48,000	48,000
Total water demand		**2,291,935**	**2,942,096**
Population projection		**(2,549,931)**	**(6,256,500)**

Table 1: Estimated water demand based on current use scenario by sector and population projection, Phoenix AMA, 1995-2025

Source: TMP-ADWR, 1999 (water demand) and MAG, 2003 (population projection prepared for Central Arizona Project)

Demand for irrigation water in agriculture is influenced primarily by four factors: the number of acres under crop, type of crop grown, irrigation efficiency, and government subsidies. As shown Table 1, agricultural water use is projected to remain at about 1.3 maf between now and 2025[4]. Loss of agricultural land to urbanization in principle leads to water being "saved" and available for other uses. However, housing trends show that housing density is increasing, leading in turn to higher per-acre water consumption. Therefore, saving water by switching from agriculture to housing development may turn out to be an urban myth.

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[4] TMP-ADWR (1999) projects that net acres under crop will increase by 10% in the by 2025 within the Indian communities.

Industrial water use includes sand and gravel facilities, power plants, dairy operations, and manufacturing facilities in the AMA. Industrial use comprises a small proportion of demand, but it is increasing steadily over time. Total industrial water use is projected to grow from 83,000 af in 1995 to about 138,000 af by 2025. Most importantly, the preponderance of industrial water demand is met through mining groundwater. This demand is projected to rise from 8% of the AMA's ground water use in 1995 to 11% by 2025 (TMP-ADWR, 1999).

Another important but under recognized component of demand is the need for minimal water required to maintain ecosystem functioning (NRC, 2001). Until now addressing the human dimensions of water use has been the major focus of water planners. Neglect of ecosystem needs over the years has led to a state of steady deterioration of the riparian environment (Morrison et al., 1996), and could potentially have significant adverse effect on the supply of water.

III.   Analysis of water resource stressors: scientific basis

A stressor is any biophysical, chemical, or anthropogenic factor (process) that can adversely affect water resources. Analysis of multiple stressors involves studying more than one stressor operating at the same time and within the same geographic context (WERF, 2004). It includes, but is not limited to, assessing the relationship between various factors that exert pressure on water resources and are assumed to be associated with increasing the vulnerability of water supply systems (Barrett, 1976).

Understanding the Phoenix AMA water supply vulnerability depends on establishing causal links between stressors and their effects on water resources. Such analysis is complicated by many factors (biophysical and anthropogenic) that operate, and can be assessed, at different temporal and spatial scales (Adams, 2005). For example, surface water availability can vary significantly from year to year, yet policy frameworks are often based on long term average flow. Given that about 30% of the Phoenix AMA water is derived from CAP, future decreases in water flow or increased upstream demand could provoke water rights disputes that challenge basic assumptions about supply. At a more macro level, uncertainty associated with the possible alteration of hydrological cycle due to the effects of global warming increases the complexity of stressor analysis at the local level. Other factors implicated in stressor analysis include growth in water use due to increasing population, changing water use patterns, prevalence of water inefficient technologies, and anthropogenic water pollution.

In light of these multiple variables, a practical approach would simply document and estimate how a variety of stressors of water resources, and identify mechanisms for mitigating the stress (Galloway et al., 2004). Ecologists such as Harwell and Gentile (2000) and others suggest a comparison of a "*baseline*" scenario with respect to a more desirable state of affairs. Using this concept I compare a baseline scenario with "*standard*" state to analyze the effects of stressors on ecosystems properties. Simply stated, this approach compares the human influenced environment (baseline) to that of a relatively undisturbed (standard) state. This paper defines the baseline scenario as the current water use pattern of all water-demanding sectors in the Phoenix AMA. The baseline scenario assumes that the level of water use efficiency among various sectors

through the year 2025 will remain at the current level established by the TMP-ADWR (1999)[5]. For example, the outdoor water use scenario in Phoenix AMA is projected to be 145 gallons of water/household/day for irrigation of lawns and gardens.

The standard state is developed from estimates of potential water savings through best practices of demand management as documented in reliable, published case studies. For example, the standard state for outdoor water is represented by adoption of efficient xeriscapic landscape that can reduce water use by as much as 76 percent. In this paper the baseline scenarios for all water-demanding sectors will be compared against the same sectors using documented best-practice approaches for improved water efficiency (standard state). In short, the baseline scenario defines the lower limit ("business as usual") and standard state defines the upper limit ("best practice") for various water management measures, *assuming no changes in the state of technology and policy*.

As I've stated earlier the scientific basis for the standard state is derived from suite of literatures of best practices of water use. The standard state is meant to serve as an example of a plausible demand management strategy, and not as a comprehensive analysis of any water management policy. It is in this premise that the standard state takes a "weight-of-evidence" measure to establish a reasonable basis for comparison with baseline scenario. The comparison between the baseline scenario and the standard state will allow for the quantification of differences in demand for water between the two cases. Although hypothetical, the quantitative information obtained by comparing these two different scenarios allows stressors to be ranked in terms of their relative impact on water supply and demand.

As indicated earlier, the Phoenix AMA is one of the fastest growing urban centers in the country. The growing population thus becomes one of the most important factors that directly or indirectly influence the outcomes of other stressors. Since 1950, the population of the Maricopa County (about 80% of the Phoenix AMA population) increased from 331,770 to over 3 million in 2005, more than an 8 fold increase. More importantly, the trajectory of population growth must be taken into account in order to anticipate future water demands of the AMA and to plan for it accordingly. The population projections for the Phoenix AMA for 1995, 2005, 2015, and 2025 are 2,530,000, 3,730,000, 5,006,000, and 6,256,500 respectively. While there are other projections available, this is the most commonly used figures in planning purposes. In this paper all estimates are based on this projection. It is to be noted here that the use of an alternative population projection model may result in different outcomes.

Based on the discussion of supply of water and the demands placed on its usage, the multiple stressors of the Phoenix AMA can be located within three categories: **a) municipal, b) agriculture, and c) biophysical**. Operating at various levels, these stressors can impact water resources in single, cumulative, or synergistic ways.

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[5] Water use by Indian communities within the Phoenix AMA is not managed by the Arizona Department of Water Resources (although included in the AMA water budget), and is therefore excluded from analysis in this paper. Also, Indian municipal water use is not subject to the AMA's conservation requirement so assumptions placed on stressor analysis may not be realistic.

IV.   Discussion of water resource stressors by category

A.   *Municipal category*

To best assess and compare existing municipal water consumption rates and potential savings due to increased water use efficiency (technological and managerial), this paper addresses *indoor residential water use* and *outdoor residential water use* separately Together they are not only the largest consumers of municipal water but also provide direct indicators of demand management, and are most affected by many water conservation programs.

i) Indoor water use: According to an empirical study for over 1,100 homes across 12 cities in North America and Canada, indoor water use averages 69.3 gallons per capita per day (gpcd). Indoor water use in Phoenix, which typically ranges from 60-80 gpcd, and averages 62 gpcd, accounts for 32% of residential water consumption in the Phoenix metropolitan area (Mayer and DeOreo, 1999a). Over 100 water efficient appliances are available in the market that can result in permanent indoor-use water savings if applied appropriately (Vickers, 2001). For example, the Massachusetts Water Resources Authority (MWRA) reduced system-wide water requirements in the Boston area by 25 percent during the 1990s. Similarly, since the early 1990s, New York City has saved more than 250 million gallons per day in water and sewer flows through water demand management activities such as a low-flow toilet rebate program.

To illustrate the importance of water efficient appliances for reducing indoor water use, this section focuses on four key indoor appliances –*flushing toilets, washing machines, showerheads*, and *faucets* (see Table 2). The comparison is based on the quantitative breakdown between appliances that are considered water inefficient but still in practice and those that meet water efficient standard as set by the 1992 Energy Policy Act of the federal government.

a) Flushing Toilet: On average a person uses about 18.5 gallons of water per day by flushing toilets (Heaney et al., 1999). This is the indoor appliance where most waste occurs through leaks and inefficient products. The 1992 Energy Policy Act requires that newly installed toilets not exceed 1.6 gallons per flush (gpf). As shown in Table 2, by upgrading to toilets that use only 1.6 gpf, the daily average toilet water use could be reduced by 9.5 gallon per person. Over the course of a year, a person could save 3,467 gallons of water. One of the public concerns with respect to toilets with lower volume per flush is that people would double or triple flush thereby defeating the objective of saving water. However, a study by Mayer and DeOreo (1999b) comparing ultra-low flush (ULF) and conventional toilets showed the same frequency of flushing for both, resulting in a water saving of over 60% in the ULF toilets.

b) Washing Machine: Washing machines account for 21.6% of residential indoor water use. A washing machine with a low water factor uses 30-35% less water per load than conventional machines (http://www.energystar.gov). By replacing water inefficient washing machines, on average, a person could potentially save as much as 1,643 gallons of water annually.

"Baseline" (BAS) vs. "Standard" (STD) case			Per person H_2O use (Daily)	Per person H_2O saving (Daily)
Flushing Toilets	BAS	3.5 gallon/flush * 5 flushes/person/day	17.5	-
	STD	1.6 gallon/flush * 5 flushes/person/day	8.0	9.5
Faucets	BAS	4.5 gallon/minute * 4 minute/person/day	18.0	-
	STD	2.0 gallon/minute * 4 minute/person/day	8.0	10.0
Showerheads	BAS	3.5 gallon/shower * 7.9 minute/shower * 0.9 shower/person/day	24.9	-
	STD	2.5 gallon/shower * 7.9 minute/shower * 0.9 shower/person/day	17.8	7.1
Washing machines	BAS	40 gallon/load * 0.30 load/person/day	12.0	-
	STD	25 gallon/load * 0.30 load/person/day	7.5	4.5
Total				31.1

Table 2:   Comparison of the Baseline (BAS) and Standard (STD) appliances/fixtures in outcome of water use per person per day in the Phoenix AMA

Note: Frequency of activities such as number of flushes per person per day and others are derived from the statistics used by the Arizona Department of Water Resources in its Third Management Plan

c) Showerheads: The installation of high efficiency showerheads is a relatively low cost way for individuals to save water. A significant amount of residential indoor water (16.7%) is used for taking showers. By replacing commonly used showerheads (3-4 gpm) with low-flow ones (2.5 gpm), a person would save 7 gallons of water per shower. This translates into a net saving of 2,591 gallons of water per person per year. In Seattle, Washington, over 330,000 low-flow showerheads were distributed to residential customers, saving close to 6 million gallons of water per day (Vickers, 2001).

d) Faucets: Faucets are important components of residential water use, accounting for 15.7 percent of total indoor water use. Ordinary kitchen and bathroom

faucets use up to 4-5 gallons of water per minute. By installing high efficiency (2.0 gallon per minute) yet inexpensive faucets a person can save up to 3,650 gallons of water per year.

The 1992 Energy Policy Act requires that water efficiency standard be applied to plumbing fixtures in all new and renovated housing after 1994. However, there are substantial numbers of houses built prior to 1994 in the Phoenix AMA that could have substandard plumbing fixtures resulting in inefficient use of water. Based on the population data prepared by the Maricopa Association of Governments for the Central Arizona Projects (2003), two separate scenarios of water use can be developed. The first scenario (Scenario A), assumes an incremental (logistic) adoption of water efficient appliances between 1995 and 2025. By the end of 2025 it is calculated that the projected population of the Phoenix AMA (6.2 million) will use 289,438 af of water (see Figure 1). The second scenario (Scenario B) assumes that during the same period 80% of the population of the base year (i.e., 1995) will not change their appliances, resulting in the net use of 378,268 af of water, a difference of 88,830 af, or 23 % (see Appendix A for detail calculations of scenarios).[6]

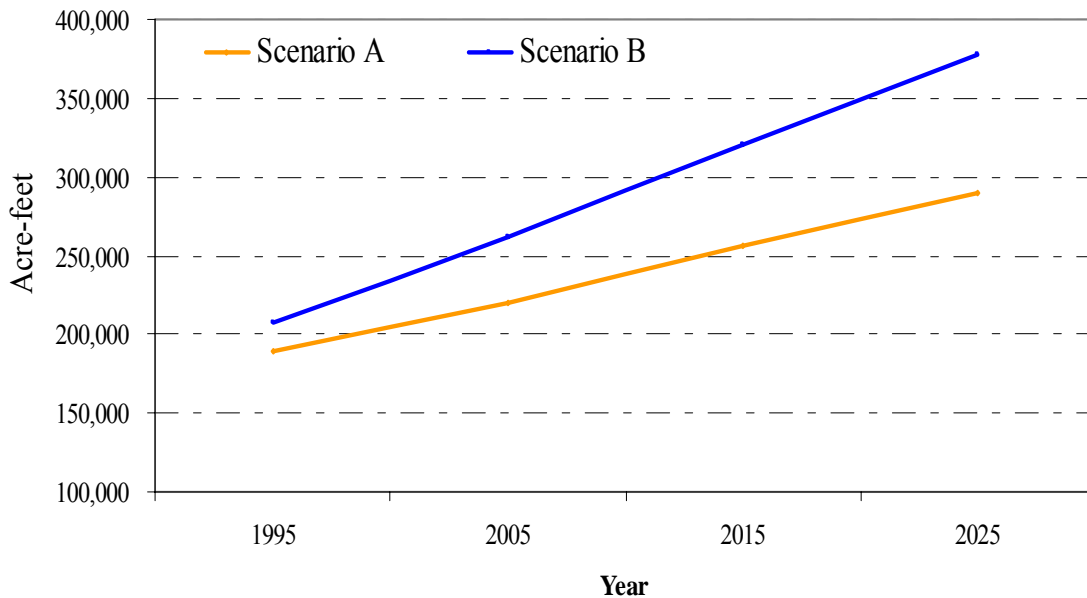Figure 1:   Indoor residential water use for single family residences in the
               Phoenix AMA, 1995-2025 – an illustration of two different
               scenarios

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[6] With continual advancement in efficiency in water appliances and fixtures, newer devices may have even better water use rates than those discussed here.

ii) ***Outdoor water use*:** Average outdoor water use for single family residents in Tempe, Phoenix, and Scottsdale accounts for 63% of their total water consumption, as shown in Table 3. A multiyear survey of 72 households in the Phoenix metropolitan area reveals that actual outdoor water use is highly variable, and depends only partly on the type of landscaping used (see Figure 2). Poor irrigation scheduling – watering too often, too long, and at the wrong time of day – is one of the factors leading to excess water use in outdoor gardening (Vickers, 2001). Knowing when and how much water is needed and adjusting irrigation schedules according to changing climatic conditions is critical to efficient water use and optimal plant health (Epstein, 2000). For the purpose of quantifying outdoor water use I have analyzed water efficiency standard using three general categories: a) management practices, b) hardware improvement, and c) landscape design.

Study City	1,000 gallons per household per year		
	Total	% Indoor	% Outdoor
Scottsdale/Tempe, AZ	185	33.5	66.5
Phoenix, AZ	172	41.3	58.7
Las Virgenes, CA	301	23.8	76.2
Lompoc, CA	103	61.1	38.9
San Diego, CA	150	37.2	62.8
Walnut, CA	209	36.1	63.9
Boulder, CO	134	42.8	57.2
Denver, CO	160	40.3	59.7
Seattle, WA	80	61.8	38.2
Eugene, OR	108	59.2	40.8
Tampa, FL	99	54.5	45.5
Waterloo, ON	70	77.7	22.3

Table 3:   Average indoor and outdoor water use for single family household across 12 cities (Heaney et al, 1999.

a) Management practices are referred to here as activities that involve caring for outdoor lawns and plants on the basis of available scientific knowledge. Efficient water management involves a range of activities including irrigation scheduling based on knowledge of plant water needs. A field study that compared outdoor water use patterns in two single family housing units (approximately the same size) planted with a mix of low water-use plants found a difference of 8.7 gallon/ft^2/month between gardens (or 218,000 gallons/year) (Martin, 2001).

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a) Water use by percent xeriscape in Phoenix AMA (n=38 residential landscape)

b) Water use by percent turf grass Phoenix AMA (n=33 residential landscape)

Figure 2:   Variations in water use for the period of 1999-2002 in randomly selected residential landscapes across cities in the Phoenix AMA.

Note: Average annual water use for the 38 residential landscapes was 17.62 gallons/ft2 for xeriscape landscape and 37.88 gallons/ft2 for turf landscape

Source: ADWR 2003.

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The common perception that application of more water translates into a better quality (growth) is not necessarily true (Beard, 1973; Kneebone et al., 1992). Under restricted irrigation (or deficit irrigation) plants may use significantly less water without experiencing any difference in vigor (Qian and Engelke, 1999; Kirda, 2002). This deficit irrigation strategy has been successfully applied in many agronomic, horticultural, and turf grass species. For example, studies on turf grass show that reducing irrigation by 20-40% below the recommended rate results in no reduction in quality or physiological condition (Fu et al., 2004; DaCosta and Huang, 2005). In fact, moderate deficit irrigation is associated with better quality (Fry and Huamn, 2004; Jordan et al., 2003). Acceptable turf quality in the fall for most of the turf species could be maintained with 40% less than normal application (DaCosta and Huang, 2005).

b) *Hardware improvement*: Most water-efficient hardware devices ensure that water is applied only when and where it is needed. As a move towards increasing outdoor water efficiency, increasing numbers of homeowners install automatic irrigation systems. Although automatic irrigation systems do offer the potential for more efficient use of water, research shows mixed results (Courtney, 1997). Most home owners do very little to adjust their irrigation schedule in response to seasonal changes in plant water requirements. Indeed, one study stuggests that automatic irrigation systems actually lead to increased water waste (Vickers, 2001).

Recent technological advances in evapotranspiration monitoring, rain sensors, soil moisture sensors, and similar devices can augment the efficiency of irrigation systems. For example, a large, interconnected information system can help reduce the excess use of water in outdoor lawns. The most well-known system is the California Irrigation Management System (CIMIS), which uses information generated at about 100 computerized weather stations throughout the state to help industrial, commercial, and residential property owners determine optimal timing and quantity of irrigation. CIMIS users reported an average of 13% savings in applied water.

c) *Landscape design:* Water-wise and natural landscape planning, design, and implementation are approaches that can be applied anywhere in the world (Vikers, 2001). There has been a shift in public policy towards promoting water-wise xeriscapic landscaping that takes into account water efficiency, native and adaptive plants, natural features, and climatic characteristics of the site (TMP-ADWR, 1999; Martin and Stabler, 2002). If designed and maintained properly, xeriscapes use less water than traditional landscapes with turf grass. Studies of residential properties that have been partially or fully converted to xeriscapic landscapes have for several years reported actual water savings of 20-50% (Nelson, 1994; Epstein, 2000), but savings could be higher. One of the most comprehensive studies of landscaping in southern Nevada shows water savings of 76% resulting from replacing turf grass with xeriscaped landscapes (Sovocol et al., 2006). According to Sovocol et al. (2006) annual total water consumption was reduced by approximately 96,000 gallons per household.

Single family residences designed and maintained according to water-wise principles in Austin, Texas, used an average of 43% less water than conventional landscapes. A survey of over 6,000 households reveals that drought tolerant turf grass species (e.g. Buffalo and Bermuda grass) use about 30% less water per landscape than most commonly used species such as St Augustine grass (DaCosta and Huang, 2005). In

the East Bay Municipal Utility District in Oakland, California, study of more than 1,000 single-family residences found that those with water conserving landscapes used 42% less water than those with traditional turf dominated landscape (U.S. Water News, 1993).

According to the TMP-ADWR (1999), a typical household unit consumes 145 gallons of water/day for outdoor irrigation. Based on the research on prevailing practices I have developed three separate scenarios of water use, shown in Figure 3. The first scenario (Scenario A) assumes that by 2025 all housing units in the Phoenix AMA will adopt xeriscapic landscaping with appropriate irrigation practices, thereby saving 76% of outdoor residential water (see Appendix A for detailed discussion of scenario). This would mean only 47,627 af of water will be used for outdoor irrigation by year 2025, a net saving of 290,353 af. Scenario B assumes partial conversion to xeriscapic landscape leaving some portion of outdoor lawn with turf. This practice is assumed to save 45%, i.e. 151,347 af of water by 2025. The final scenario (Scenario C) assumes that the residents of the Phoenix AMA would continue with turf dominated landscaping but would upgrade their irrigation hardware. This assumption would save 13% irrigation water, a saving of 44,240 af by 2025.
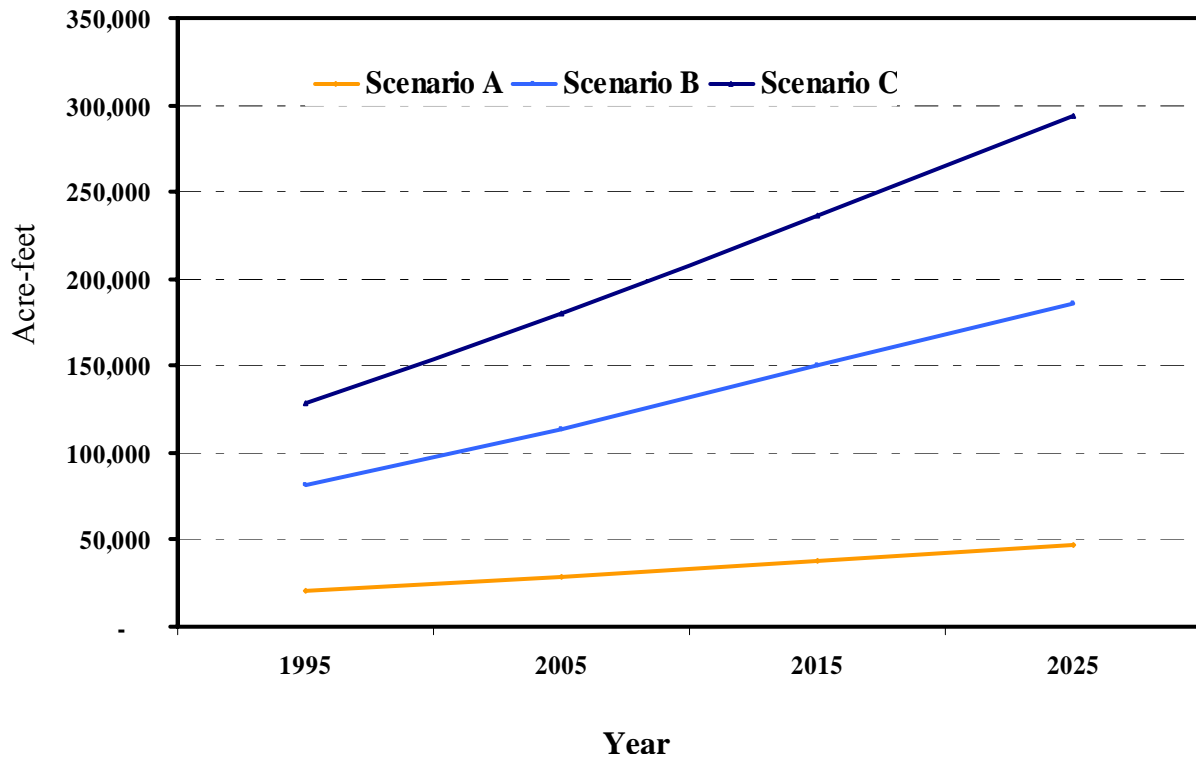

Figure 3:   Projection of outdoor irrigation water use for single family residences in the Phoenix AMA, 1995-2025 – an illustration of three different scenarios

2.   **Agriculture category**

Agricultural water use includes water supplied for irrigation of crops grown for human and animal consumption (TMP-ADWR, 1999). Although decreasing steadily from about 60% in 1985 to 42% in 2000, the agricultural sector still remains the largest consumer of water in the Phoenix AMA. Several factors determine the agricultural use of water including water rights, energy costs, market value of crops, and government subsidies. For example, cotton and wheat producers receive most federal subsidies, with the large cotton farms receiving the bulk (Ayer, 2003). Following Morrison et al. (1996), there are three principal ways by which agriculture water demand can be reduced: i) *irrigation efficiency improvement*, ii) *water efficient agronomic practices*, and iii) *crop adjustment and or retirement*.

        i) Improving irrigation efficiency: Although excess irrigation is justified for flushing the salts and chemicals from agricultural land, Morrison et al. (1996) show that water use in Arizona's agriculture is inefficient and wasteful (see Figure 4). The efficiency of irrigation water use is always less than 100% as some portion of the water applied to a field is unavailable to crops due to local climatic factors. Nevertheless, cost-effective reduction of on-farm water use can generally be achieved through improved irrigation technologies and efficient water management practices.
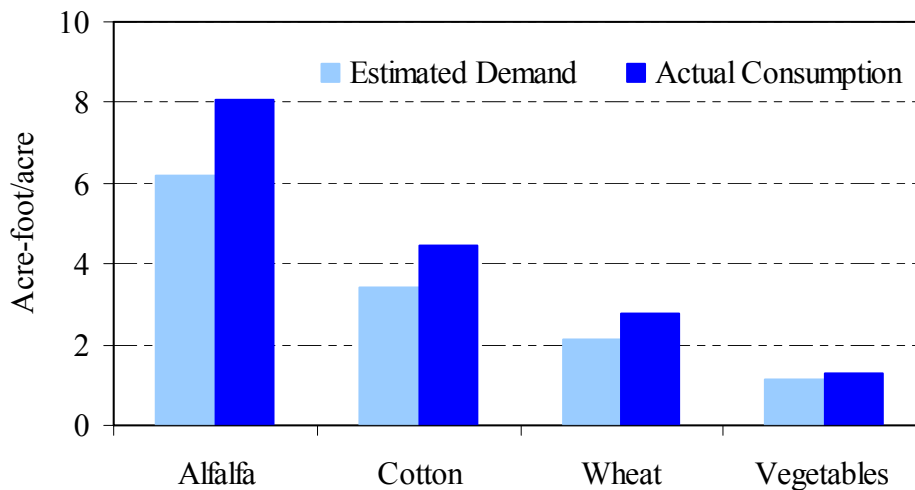
Figure 4:   Crop water demand based on years of research done in Phoenix and actual water supplied by farmers

        Approximately 90% of crop land in Arizona is watered by gravity or surface irrigation systems, the most inefficient practice of irrigating crops. Drip and sprinkler irrigation constitute only 1% and 9% of irrigated agriculture respectively (Postal, 1992), yet drip irrigation is considered to be appropriate in most of the crops grown in Arizona. According to Wilson et al. (1984), cotton farmers in the arid Southwest can reduce their water requirements by 30-50% if they switch to drip irrigation, while simultaneously

increasing cotton yield. A well known example of efficient irrigation is that of Arizona-based Sundance Farms, whose system combines drip irrigation lines placed 8-10 inches below the soil in every row of crops along with minimum tillage so the drip lines are undisturbed. Together, these measures can reduce irrigation water requirement for cotton by 50%, while often producing better yield (Murphy, 1995).

In the Phoenix AMA, agricultural water demand is categorized separately for Indian and non-Indian agricultural land. Of the total 199,753 acres of agricultural land cropped in 1995 in the Phoenix AMA, 161,797 acres was non-Indian cropped acres (TMP-ADWR, 1999). Approximately 50% of this land (80,898 acres) was under cotton in 1995. According to Erie et al. (1982), cotton requires 3.43 af of water per acre, which translate into 277,482 af of water for meeting irrigation demand for its cultivation. About 18.5% (29,932 acre) of 1995 non-Indian cropped acres was planted with alfalfa. Alfalfa requires 6.19 af of water per acre, translating to 185,281 af of water for its cultivation. Together, in 1995, cotton and alfalfa consumed 462,763 af of water in the Phoenix AMA. Based on the estimate of crop water requirements, farmers growing cotton and alfalfa waste approximately 25% of irrigated water due to the system's inefficiency (Morrison et al., 1996). If the prevailing inefficiency in water application (Erie et al., 1982) is reduced through optimum irrigation management, a net saving of 115,691 af can be achieved (see Appendix C for detailed calculation)

ii) Water efficient agronomic practices: The choice of crop accompanied by better cultivars is equally important for increasing water use efficiency in agriculture (Passioura, 2006; Stirzaker, 2003). Research shows that crops such as wheat and barley are more efficient with water when they are stressed (Oweis and Hachum, 2003). For example, wheat production can be maintained with 20-40% less water provided other management practices are in place. Agronomic practices such as the incorporation of organic materials in the soil, use of mulch, and tillage practices all contribute to water use efficiency (Zhang and Oweis, 1999). Approximately 17,798 acres of wheat was grown in the Phoenix AMA in 1995. Wheat requires 1.77 af of water per acre, translating 31,502 af of water for meeting irrigation needs (see Appendix C for detailed calculation).

iii) Adjusting cropping patterns: According to Morrison et al. (1996) farmers can reduce their water demand by more than 50% by switching from cotton and alfalfa to vegetables. Furthermore, as shown in Figure 5, switching to high value crops such as vegetables results in a net increase in crop revenue. For example, economic return to per unit water consumption is significantly greater in vegetables than in alfalfa and cotton. Estimated economic return from per acre-foot of water uptake by vegetables is $1,495 whereas for alfalfa it is $95. Replacing some low value yet water intensive crops may be a useful approach in the future. If the Phoenix AMA could afford to switch 20% of its annual cotton area to vegetables it would be able to save about 23,137 af of water annually. Likewise retiring 5% of alfalfa would yield an additional saving of 9,264 af of water per year. Therefore, by simply rearranging crop mix, the Phoenix AMA could potentially save as much as 32,401 af of water (see Appendix C for detailed calculation).

Like anywhere around the world, farmers generally try to maximize their net profit, and select crop and growing methods that help them do it. These decisions are influenced by subsidy policy, legal rights to water use, and other considerations discussed earlier. Thus, restructuring agricultural practices to minimize water application is a

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complex issue (Morrison et al., 1996). The discussion in this section is intended to shed light only on the potential for reduced agricultural water use, given a policy and economic environment that rewarded such reductions. By making irrigation more efficient, implementing water efficient agronomic practices, and adjusting cropping patterns, 198,818 af of water per year in Phoenix AMA could be saved.
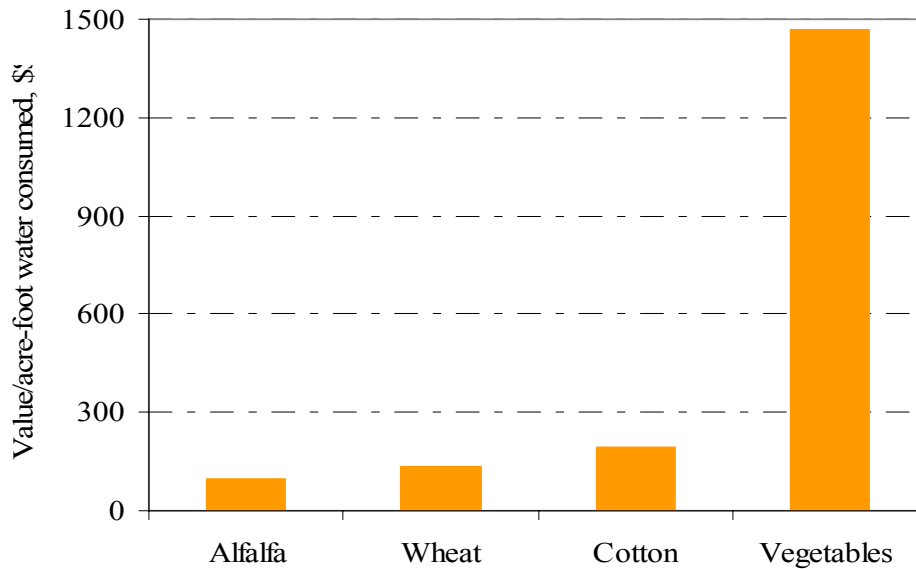

Figure 5:   Economic return per acre-foot of water consumed by crops

Source: Morrison et al., 1996

3.   Biophysical category

Increases in average nighttime temperatures, persistent droughts, and possible alteration of hydrological cycles are some of the biophysical stressors that can have direct effect on the supply and demand for water. For example, Urban Heat Island (UHI) effects may increase pan evaporation rates of swimming pools, requiring frequent refilling. Rising temperatures due to greenhouse effects may exacerbate the effects of UHI leading to further loss through evaporation. Climate change and variability may alter the hydrological cycle and reduce the supply of water into the system. These stressors on water supply create a different analytical challenge for understanding the future of water in the Phoenix AMA. Here I consider two biophysical stressors: i) urban heat island and ii) climate change due to global warming.

i) Urban Heat Island: With the documented gradual increase in average nighttime temperatures in Phoenix and surrounding areas due to urbanization, the impact of UHI on water demand has emerged as a significant concern (Guhathakurta and Gober, *forthcoming*). The phenomenon of UHI effect in the Phoenix metropolitan area has been studied since the middle of 1980s with research showing that in the last 50 years, average nighttime temperature in part of Phoenix metropolitan area has increased as much as

11.7^{0}F (Gelt, 2006; Cayan and Douglas, 1984; Balling and Brazel, 1986; Brazel et al., 2000; Stabler et al., 2005).

Given that thermoelectric power generation withdraws more water than any other water use (Golden et al., *forthcoming*), increases in nighttime temperatures would automatically result in increased water consumption. While the studies on the relationship between UHI, energy consumption, and water use are now beginning to surface (e.g. Guhathakurta and Gober *forthcoming*), quantitative assessment of household water demand are less studied. Significantly higher temperatures extending longer into the evening may increase residential water consumption. After accounting for other factors that lead to increased water use, Guhathakurta and Gober (*forthcoming*) show that a typical single family home in a census tract impacted by heat island effect consumes an additional 1,532 gallons of water a month (in summer) when compared to similar households not directly affected by UHI. During the five months of the summer period, the effects of UHI alone on water demand could be as much as 25,357 af by 2025 (provided all 2,078,675 single family units were affected by UHI)

Water loss through evaporation is a natural occurrence at any open water body (e.g. lakes, reservoirs, canals, and swimming pools) in the Sonoran Desert representing a major loss of water from the system. Higher nighttime temperatures would potentially increase evapotranspiration, thereby increasing water demand for plants, lawns, and swimming pools. It is estimated that open water bodies in the Phoenix area evaporate at about 6.2 acre-feet per year for each acre of surface area. Annual evaporation loss at the six Salt River Project (SRP) reservoirs on the Salt and Verde rivers often exceeds 100,000 AF (32.5 billion gallons) annually. Tempe Town Lake's evaporation is approximately 1,900 acre-feet per year (about 1.7 million gallons per day). Homes with pools have been shown to use more than twice the amount of exterior water than those without pools (Mayer and DeOreo, 1999a). In addition to greater water consumption, swimming pools in urban climates can experience even greater pan evaporation in the summer, necessitating frequent ''topping off.''

ii) Climate change due to global warming: In addition to the ongoing challenges discussed thus far, the problem of climate change due to buildup of greenhouse gases further complicates the issue of water resource management in the region. Among others, the expected impacts of climate with respect to water resources are higher evaporation, change in the regional patterns of rainfall, snowfall, and snow melts, and changes in the intensity, severity, and timing of major storms (Nash and Gleick, 1993). The instrumental record of climate shows that during the 20th century average temperature increased by 0.37 ^{0}C across the U.S., 0.56 ^{0}C across the western U.S., and 0.79 ^{0}C in the Colorado River Basin (CORB) area (Folland et al., 2001). In the CORB, winter temperatures increased more than summer temperatures and are most pronounced at medium to high elevations (Stewart et al., 2005). Shifts in seasonality of precipitation (Rajagopalan and Lall, 1995) and stream flows (Dettinger and Cayon, 1995, Stewart et al., 2005) have been observed across several regions of the western U.S. Studies also show long-term decreases in snowpack, and increasingly early snowmelt over the CORB (Cayan 1996; Hamlet et al., 2005; Mote et al., 2005). Since about 70% of the annual runoff into the CORB comes from the permanent snowpack of the Rocky Mountain and the remaining 30% comes from accumulated snow during the winter and

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spring melt (Christensen et al., 2004), the rise of winter temperature has been a cause of concern.

Several studies have examined the possible impacts of climate change on the Colorado River Basin and its subbasins using both empirical and General Circulation Models (GCMs). In general all studies predict an increase in temperature by the end of 21st century, the disagreement however, lies in the specific details of change in precipitation, impacts on seasons, and the range of temperature change. For example, Revelle and Waggoner (1983) used empirical models to assess the impact of hypothetical climate change in the CORB catchments. They concluded that a 4^{0}F change in temperature coupled with 10% decrease in precipitation would result in 24% decrease in river flow. Consistent with this study, Nash and Gleick (1991) also show that an increase of temperature by 2^{0}F and decrease of precipitation by 10% would reduce aggregate runoff by 20% in the CORB. Of the range of scenarios tested by Nash and Gleick (1993), the net impacts of climate change by 2025 would result in the reduction of runoff in the range of 8-20%.

As a part of the Accelerated Climate Prediction Initiative (ACPI), scholars have evaluated the impacts of climate change on water resources of the western United States. The climate change scenarios of projected "business as usual" (BAU) greenhouse gas emissions were simulated using the National Center for Atmospheric Research (NCAR)/Department of Energy (DOE) Parallel Climate Model (PCM). The BAU scenarios exhibited an average warming of up to 8^{0}F by the end of 21st century. Downscaling these scenarios to the CORB, Christensen et al. (2004) estimated a reduction of annual runoff by 14% in 2010-39, 18% in 2040-69, and 17% in 2070-98. Overall decrease in runoff can potentially strain the CORB system's ability to meet the competing demands driven by population growth, irrigation, environmental needs, and power generation (Barnett et al., 2004). This is especially true given the high sensitivity of the CORB due to over-allocation of water resources.

A sensitivity analysis to change in average temperature and annual flow of the Salt and Verde Rivers was tested using a suite of climate models by Ellis et al. (*in review*). They estimated the projected change in temperature and rainfall for the time slice of 2020 and 2050. Based on the projected output of the models, on average the region is expected to warm by 1.4^{0}C (2.5^{0}F) by 2020 with 8.77 mm drop in annual rainfall. The net implication of this is a reduction in the flow of Salt and Verde Rivers. For example, about 1.8^{0}F increase in temperature would results 6% decrease of runoff. Likewise, 10% decrease in precipitation would result in a 20% decrease in runoff. By 2050, the combined effects of 2.9^{0}C (5.4^{0}F) temperature change and 10% reduction in rainfall would results in a 37% decline in the flow of these rivers.

There is a large and unspecifiable degreee of uncertainty associated with these climate models. Based on the review of studies, for the purposes of this paper I select a mid-range decrease of 15% in the flow of Colorado and Salt/Verde Rivers due to the effects of climate change. The net effects of climate change on the reduction of surface water flow by 2025 would be in the range of 187,368 to 245,020 af, with average being 216,194 af. The climate change projections that drive the conclusions of most studies were generated using Global Circulation Models (GCMs). Because of their low resolution, GCMs are prone to creating large errors in the simulation of complex climatic

phenomenon that operate at regional and local levels (Shackley et al., 1998). Many fundamental hydrologic processes occur on spatial scales smaller than most climate models are able to resolve. We thus know much less about how the hydrologic cycle will change than we would like in order to make appropriate decisions about managing regional water systems. These uncertainties greatly complicate the planning for the future and have contributed to the ongoing debate over how to respond to the problem of climate change (Schneider and Kuntz-Duriseti, 2002).

While climate variability and change may contribute to the variations in the natural water cycle and cause stress on the water resources, the above discussions show that there are significant other issues which have more direct impacts on water resources (and vice versa). Indeed this paper demonstrates that local factors such as use of water inefficient technologies, practice of water demanding landscaping, land-use change, and the persistence of water-intensive agricultural practices are seen to influence water resource significantly.

V.   Ranking stressors and discussions

Using the results of the foregoing analyses, I have tabluated and ranked stressors according to two criteria: a) projected water lost due to system's inefficiency, and b) water lost due to biophysical impacts (stress) on the system. This analysis has required a number of assumptions based on the review of literature. In particular, many of the case studies and examples mentioned in this paper refer to areas that are decidedly different from the Phoenix AMA. This problem was further complicated by lack of data at the scale of the Phoenix AMA. However, I have sought to ensure that comparative studies are closely aligned with that of the Phoenix AMA in terms of biophysical and demographic characteristics.

Three other assumptions also embedded in the rankings. First, I used the population growth projection of the Maricopa Association of Governments (2003) which is basically a linear extension of historical growth trends. Obviously, such trends may or may not continue unabated into the future. Second, I do not try to account for technological change that could increase efficiencies. This assumption means that my standard state estimates are conservative, and that feasible savings on the demand side are likely to end up being higher. Finally, the projections used in the rankings assume no changes in water policies.

Table 4 illustrates the ranking of stressors based on additional water used from increased population and lost due to the system's inefficiency, as well as through biophysical stress. Following the discussion in the earlier section, the stressors are tabulated under the categories of municipal, agricultural, and biophysical. Expressed in acre-feet, Table 4 shows that largest stress on water resources occurs in outdoor landscaping under the municipal category. The significant loss of water due to rise in temperature and simultaneous reduction in precipitation due to global warming in the Colorado and Salt/Verde River basin, the largest supplier of surface water to the Phoenix AMA, ranks it as the second most important stressor. This is closely followed by the stress on water resources from inefficient agricultural use. Indoor water use is ranked fourth among the stressors discussed in this paper. This ranking is not surprising given

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that efficiency standards and innovation of technologies in saving water has focused on this sector. Water demand due to UHI ranked fifth, about 70% less than water lost through inefficiency in outdoor water use. This estimate is conservative because it only accounts for household demand, due to a lack of studies that take into account the effects of UHI in open water bodies in the Phoenix area. But even this information would not plausibly lift UHI out of last place.

	Stressors	Difference between baseline vs standard case by 2025
Projected water lost (af) due to inefficiency	**Municipal**	**328,180**
	Indoor water use	88,830
	Outdoor water use	239,350
	Agriculture	**198,818**
Water lost due to biophysical stress	**Biophysical**	**241,551**
	Additional demand due to UHI	25,357
	Reduction of surface water flow of Colorado and Salt/Verde Rivers due to the effects of climate change	216,194

Table 4: Ranking of stressors based on projected water lost due to inefficiency in water use and added stress due to biophysical changes, 2025

Conclusion

While water consumption patterns is clearly related to its supply, it is also determined by a host of other factors such as population growth, household use, landscaping preferences, availability and use of water-conserving technologies, and price. However, the impacts of these variables on decision making about water use are not well documented. This paper is an initial attempt to address this shortcoming by synthesizing existing literature on water resource management in the Central Arizona. This has been accomplished by ranking the multiple stressors so as to facilitate decision making in water management in Central Arizona. In so doing it has also identified gaps in current research portfolio and decision making.

An important revelation of this paper is that reduction in individual and system-wide water demand not only decreases stress on water resources but avoids unnecessary cost on water supply infrastructure and extends the ability of existing supplies to meet current and growing demands. More generally, the ranking suggests that outdoor water use and agriculture are comparably fertile targets for efficiency gains from technical and management perspectives. The scientific knowledge to develop more intelligent demand management methods, which are valuable for domestic and agricultural water use, are

some of the dimensions that this ranking offers in the pursuit for solutions by decision makers. The creation of water management policies reflecting the best practices are also critical for effective water resource management. While the question of what approaches and sectors are adoptable from a political and policy perspectives would be the subject of a different study, the ranking suggests that water use in outdoor irrigation and agricultural practices can be reduced substantially. Likewise, the literature review on climate change indicates that the loss of water is in the range of half of the available saving that could be achieved on the demand side and therefore suggests that adaptation to the impacts of climate change for Phoenix AMA is manageable.

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Appendix A

Demand management in indoor water use

Population of Phoenix AMA in 1995 as reported by the Maricopa Association of Government for the Central Arizona Project (MAG-CAP) (2003) was 2,549,931. For 2005, 2015, and 2025, the estimated projections are 3,730,000, 5,006,000, and 6,256,000 respectively. Difference in water use between two scenarios (Scenario A and Scenario B) is calculated based on the population of 1995 and the trajectory of population growth till 2025.

As discussed in the text, scenario A assumes that by 2025 all residents of the Phoenix AMA will have installed water efficient plumbing fixtures (as required by Energy Policy Act, 1992) to optimize their indoor water use. The pattern of adoption of water efficient plumbing fixtures by 2025 follows the S-shaped curve (or logistic curve), i.e. slow adoption in the beginning followed by acceleration and then eventual saturation. Although purely descriptive, the logistic model captures the temporal pattern of adoption across a range of technical innovation (Fisher and Pry, 1971). Scenario B assumes that significant portion of population will make no changes in their plumbing fixtures and continue to use excess water. It serves as useful benchmark for comparison of stressors in the Phoenix AMA's water resources.

Scenario A

1995: Assumptions

In 1995 approximately 20% of the Phoenix AMA's population (i.e. 509,986) will reside in new or remodeled houses which have installed water efficient plumbing fixtures following the standards set by the 1992 Energy Policy Act. On average, this population consumes 41.3 gallons of water/person/day (GPDP). The other 80% of the population (i.e. 2,039,945) will continue to live in houses that do not have water efficient plumbing fixtures. On average this population consumes 72.4 GPDP.

Calculation: 1995

509,986 * 41.3 = 21,062,930 gallons/day

2,039,945 * 72.4 =147,692,004 gallons/day

= 21,062,930 + 147,692,004 = 168,754,434 gallons/day

≡ **189,029 af/year**

2005: Assumptions

Total population of Phoenix AMA in 2005 is estimated to be 3,730,000, with a net growth of 1,180,069 between 1995 and 2005. It is assumed that this additional population lives in new or remodeled housing units and uses water efficient plumbing fixtures. Also, following the logistic adaptation curve, approximately one-third of the population (i.e. 2,039,945*0.33 = 673,182) that had not installed

water efficient plumbing fixtures and appliances recognize the benefits and have started to install them.

Calculation: 2005

(509,986 + 1,180,069 + 673,182) = 2,363,237 * 41.3 = 97,601,687 gallons/day.

1,366,763 * 72.4 = 98,953,642 gallons/day

$$\equiv \textbf{220,170 af/year}$$

2015: Assumptions

Total population of Phoenix AMA in 2015 is estimated to be 5,006,000, with a net growth of 2,456,069 between 1995 and 2015. The additional population is assumed to live in new or remodeled housing units that use water efficient plumbing fixtures. Also two-thirds of the 1995 population (i.e. 2,039,763 *0.67 = 1,366,763) that had not installed water efficient plumbing fixtures and appliances recognize the benefits and have started to install them.

Calculation: 2015

(509,986 + 2,456,069 + 1,366,763) = 4,332,818 * 41.3 = 178,945,383 gallons/day.

693,581 * 72.4 = 50,251,264 gallons/day

$$\equiv \textbf{256,693 af/year}$$

2025: Assumptions

Total population of Phoenix AMA in 2025 is estimated to be 6,256,000, with a net growth of 3,976,069 between 1995 and 2025. By now all the population living in the AMA will have installed the water efficient fixtures.

2025: Calculation

6,256,000 * 41.3 = 258,372,800 gallons/day.

$$\equiv \textbf{289,438 af/year}$$

Scenario B

1995: Assumption

The 1995 population of the Phoenix AMA does not install water efficient plumbing fixtures and continues to use an average of 72.4 GPDP of water.

1995: Calculation

2,549,931 * 72.4 = 184,615,004 gallons/day

$$\equiv \textbf{206,795 af/year}$$

2005: Assumption

Total population of Phoenix AMA in 2005 is estimated to be 3,730,000, with a net growth of 1,180,069 between 1995 and 2005. With the exception of this additional group, all others continue to use an average of 72.4 GPDP of water.

2005: Calculation

2,549,931 * 72.4 = 184,615,004 gallons/day

1,180,069 * 41.3 = 48,736,849 gallons/day

$\equiv$ **261,388 af/year**

2015: Assumption

Total population of Phoenix AMA in 2015 is estimated to be 5,006,000, with a net growth of 2,456,069 between 1995 and 2015. It is assumed that this population will use water efficient fixtures and uses only 41.3 GPDP of water but the other will continue to use on average of 72.4 GPDP.

2015: Calculation

2,456,069 * 41.3 = 105,565,650 gallons/day

2,549,931 * 72.4 = 184,615,004 gallons/day

$\equiv$ **320,418 af/year**

2025: Assumption

Total population of Phoenix AMA in 2025 is estimated to be 6,256,000, with a net growth of 3,976,069 between 1995 and 2025. It is assumed that this population will use the water efficient fixtures and use only 41.3 GPDP of water but the others will continue to use on average of 72.4 GPDP.

2025: Calculation

3,976,069 * 41.3 = 164,211,649 gallons/day

2,549,931 * 72.4 = 184,615,004 gallons/day

$\equiv$ **378,268 af/year**

Difference in water use (af) between two scenarios:

Year	Scenario A	Scenario B	Difference
1995	189,029	206,795	17,766
2005	220,170	261,388	41,218
2015	256,693	320,418	63,725
2025	289,438	378,268	88,830

Appendix B

Single family outdoor water use – calculation for scenarios A, B, and C

The scenarios of outdoor use reflect the three different water use patterns that have been assumed for outdoor landscape types. According to the data prepared for Central Arizona Project by the Maricopa Association of Government (MAG-CAP, 2003), total number of housing units in Phoenix AMA for 1995, 2005, 2015, and 2025 are estimated to be 1,075,500; 1,498,500; 1,971,500; and 2,445,500 respectively. The calculation of water consumption is based on the assumption that approximately 85% of the housing units in the Phoenix AMA are single family residential (SFR) unit (TMP-ADWR, 1999). On an average, a typical family living in a SFR unit in the Phoenix AMA consumes 145 gallons of water a day (TMP-ADWR, 1999). This amount is applied to irrigate residential landscape and does not include water for swimming pool and cooling. This consumption pattern has been developed to reflect water use projections during four different time periods (1995, 2005, 2015, and 2025) in each of the three scenarios. While there is a significant variation in the level of water efficiency, all three scenarios assumes some degree of water saving.

Scenario A

As discussed in the text, scenario A assumes that the entire single family housing units in the Phoenix AMA adopt xeriscapic landscape thereby saving 76% of outdoor water use. In other words, they use only 20.3 gallons/day or 14% of the 145 gallons of water a day. For the purpose of this paper scenario A is taken as a standard case.

Calculation for 1995:

Total single family housing units = 1,075,500 *0.85 = 914,175

Water applied to irrigate outdoor landscape = 914,175 * 20.3 = 18,557,753 gallons/day ≡ 20,787 af/year.   A net saving of **127,694 af.**

Calculation for 2005:

Total single family housing units = 1,498,500 *0.85 = 1,273,725

Water applied to irrigate outdoor landscape = 1,273,725 * 20.3 = 25,856,618 gallons/day ≡ 28,963 af/year. A net saving of **177,916 af**

Calculation for 2015:

Total single family housing units = 1,971,500 *0.85 = 1,675,775

Water applied to irrigate outdoor landscape = 1,675,775 * 20.3 = 34,018,233 gallons/day ≡ 38,105 af/year. A net saving of **234,016 af.**

Calculation for 2025:

Total single family housing units = 2,445,500 *0.85 = 2,078,675

Water applied to irrigate outdoor landscape = 2,078,675 * 20.3 = 42,197,103 gallons/day ≡ 47,267 af/year. A net saving of **290,356 af.**

Scenario B

Scenario B assumes partial conversion to xeriscapic landscape leaving some portion of outdoor lawn under turf. This practice is assumed to save 45% of outdoor irrigation water or would use only 55% of 145 gallons (i.e. 80 gallons/day).

Calculation for 1995:

Total single family housing units = 1,075,500 *0.85 = 914,175

Water applied to irrigate outdoor landscape = 914,175 * 80 = 731,340,000 gallons/day ≡ 81,921 af/year. A net saving of **66,560 af.**

Calculation for 2005:

Total single family housing units = 1,498,500 *0.85 = 1,273,725

Water applied to irrigate outdoor landscape = 1,273,725 * 80 = 1,018,980,000 gallons/day ≡ 114,140 af/year. A net saving of **92,739 af.**

Calculation for 2015:

Total single family housing units = 1,971,500 *0.85 = 1,675,775

Water applied to irrigate outdoor landscape = 1,675,775 * 80 = 134,062,000 gallons/day ≡ 150,169 af/year. A net saving of **122,012 af.**

Calculation for 2025:

Total single family housing units = 2,445,500 *0.85 = 2,078,675

Water applied to irrigate outdoor landscape = 2,078,675 * 80 = 42,197,103 gallons/day ≡ 186,273 af/year. A net saving of **152,347 af.**

Scenario C

Scenario C assumes that the residents of Phoenix AMA would continue with turf dominated landscape but are expected to upgrade their irrigation hardware. This practice is assumed to save only 13% of outdoor irrigation water or would use 126 gallons/day/housing unit.

Calculation for 1995:

Total single family housing units = 1,075,500 *0.85 = 914,175

Water applied to irrigate outdoor landscape = 914,175 * 126 = 115,186,050 gallons/day ≡ 129,025 af/year. A net saving of **19,456 af.**

Calculation for 2005:

Total single family housing units = 1,498,500 *0.85 = 1,273,725

Water applied to irrigate outdoor landscape = 1,273,725 * 126 = 160,489,550 gallons/day ≡ 179,771 af/year. A net saving of **27,108 af.**

Calculation for 2015:

Total single family housing unit = 1,971,500 *0.85 = 1,675,775

Water applied to irrigate outdoor landscape = 1,675,775 * 126 = 211,147,650 gallons/day ≡ 236,516 af/year. A net saving of **35,665 af.**

Calculation for 2025:

Total single family housing units = 2,445,500 *0.85 = 2,078,675

Water applied to irrigate outdoor landscape = 2,078,675 * 126 = 261,913,050 gallons/day ≡ 293,380 af/year. A net saving of **44,240 af.**

Appendix C

Increasing efficiency on agricultural water use

According to the TMP-ADWR (1999), net crop area under non-Indian agriculture in 1995 is estimated to be 161,797 acres. For 2005, 2015, and 2025 this is projected to be 155,184, 146,258, and 133,114 acres respectively. Approximately 50% of this land is assumed to be under cotton, 18.5% under alfalfa, and 11% under wheat. Research shows that in Arizona's climate an acre of cotton requires 3.43 af; an acre of alfalfa requires 6.19 af; and an acre of wheat needs 1.77 af of irrigation water. As discussed in the text, farmers growing cotton and alfalfa waste approximately 25% of irrigated water due to the system's inherent inefficiency (Morrison et al., 1996). Research also shows that 20-40% of irrigation water can also be reduced without any detrimental effects on crop yield (Zhang and Oweis, 1999). As discussed earlier, there are three principal ways by which better agriculture water demand management can be achieved: i) *improving irrigation efficiency*; ii) *water efficient agronomic practices*; and iii) *crop adjustment and or retirement*

i.   Improving irrigation efficiency

Approximately 25% of irrigation water that is applied in growing cotton and alfalfa can be saved by improving efficiency in irrigation while often simultaneously producing better yield. This water could potentially be saved through improved irrigation efficiency

ii.   Water efficient agronomic practices

This scenario assumes that approximately 20% of irrigation water in wheat can be potentially reduced without any reduction in yield.

iii.   Crop adjustment and or retirement

This scenario assumes some adjustments in cropping patterns including the practice of fallowing. This includes replacing 20% of existing cotton area with vegetables and retiring 5% of current alfalfa crop area completely (on average vegetables takes 2 af of water/acre of vegetable area).

Calculation for 1995:

Irrigation efficiency:

Total area under cotton is estimated as 80,899 acres (161,797 * 0.50 = 80,899).

Total water applied for cotton = 277,482 af (80,899 * 3.43 = 277,482).

Total area under alfalfa is estimated as 29,932 acres (161,797 * 0.185 = 29,932). Total amount of water applied for growing alfalfa is estimated as 185,282 af (29,932 * 6.19 = 185,282).

Net water saved by improving irrigation efficiency in cotton and alfalfa is 115,691 af [(277,482 + 185,282) * 0.25) = 115,691)].

Agronomic efficiency:

Total area under wheat is estimated as 17,798 acres (161,797 * 0.11 = 17,798).

Total amount of water applied for growing wheat as 31,502 af (17,798 * 1.77 = 31,502).

Net water saved in wheat through water efficient agronomic practices = 6,300 af. (31,502 * 0.2 = 6,300).

Crop adjustment and fallowing:

About 16,180 acres of cotton area can be substituted by vegetables (80,899 * 0.20 = 16,180).

This translates into a net reduction of irrigation demand for cotton by 23,137 af. [(16,180 * 3.43) – (16,180 * 2.0) = 23,137)].

About 1497 af of alfalfa area can be permanently retired (29,932 * 0.05 = 1497) which will reduce the demand for alfalfa irrigation by 9,264 af.

Total water saved from all three activities is calculated as: 115,691 + 6,300 + 23,137 + 9,264 = **154,392 af.**

Calculation for 2005

Irrigation efficiency:

Total area under cotton is estimated as 77,592 acres (155,184 * 0.50 = 77,592). Total water applied for cotton (77,592 * 3.43) = 266,141 af.

Total area under alfalfa is estimated as 28,709 acres (155,184 * 0.185 = 28,709) acres.

Total amount of water applied for growing alfalfa is estimated as 177,709 af (28,709 * 6.19 = 177,709).

Net water saved by improving irrigation efficiency in cotton and alfalfa is estimated as 110,962 af [(266,141 + 177,709) * 0.25) = 110,962].

Agronomic efficiency:

Total area under wheat is estimated as 17,070 acres (155,184 * 0.11 = 17,070). Total amount of water applied for growing wheat is estimated as 30,214 af (17,070 * 1.77 = 30,214).

Net water saved in wheat through water efficient agronomic practices is estimated as 6,043 af. (30,214* 0.2 = 6,043).

Crop adjustment and fallowing:

About 15,518 acres of cotton area can be substituted by vegetables (77,592 * 0.20 = 15,518).

This translates into a net reduction of irrigation demand for cotton by 22,191 af. [(15,518 * 3.43) – (15,518 * 2.0) = 23,191)].

About 1435 af of alfalfa area can be permanently retired (28,709 * 0.05 = 1435) which will reduce the demand for alfalfa irrigation by 8,885 af.

Total water saved from all three activities is calculated as: 110,962 + 6,043 + 22,191 + 8,885 = **148,081 af.**

Calculation for 2015

Irrigation efficiency:

Total area under cotton is estimated as 73,129 acres (146,258 * 0.50 = 73,129).

Total water applied for cotton is estimated as 250,832 af (73,129 * 3.43) = 250,832 af. Total area under alfalfa is estimated as 27,058 acres (146,258 * 0.185 = 27,058) acres.

Total amount of water applied for growing alfalfa is estimated as 167,487 af (27,058 * 6.19 = 167,487).

Net water saved by improving irrigation efficiency in cotton and alfalfa is estimated as 104,580 af [(250,832 + 167,487) * 0.25) = 104,580].

Agronomic efficiency:

Total area under wheat is estimated as 16,088 acres (146,258 * 0.11 = 16,088).

Total amount of water applied for growing wheat is estimated as 28,476 af (16,088 * 1.77 = 28,476).

Net water saved in wheat through water efficient agronomic practices is estimated as 5,695 af. (28,476 * 0.2 = 5,695).

Crop adjustment and fallowing:

About 14,626 acres of cotton area can be substituted by vegetables (73,129 * 0.20 = 14,626).

This translates into a net reduction of irrigation demand for cotton by 20,915 af. [(14,626 * 3.43) – (14,626 * 2.0) = 20,915].

About 1353 af of alfalfa area can be permanently retired (27,058 * 0.05 = 1,353) which will reduce the demand for alfalfa irrigation by 8,374 af.

Total water saved from all three activities is calculated as: 104,580 + 5,695 + 20,915 + 8,374 = **139,564 af.**

Calculation for 2025

Irrigation efficiency:

Total area under cotton is estimated as 66,557 acres (133,114 * 0.50 = 66,557).

Total water applied for cotton is estimated as 228,291 af (66,557 * 3.43 = 228,291) af. Total area under alfalfa is estimated to be 24,626 acres (133,114 * 0.185 = 24,626) acres.

Total amount of water applied for growing alfalfa is estimated as 152,435 af (24,626 * 6.19 = 152,435).

Net water saved by improving irrigation efficiency in cotton and alfalfa is estimated as 95,182 af [(228,291 + 152,435) * 0.25) = 95,182].

Agronomic efficiency:

Total area under wheat is estimated as 14,643 acres (133,114 * 0.11 = 14,643).

Total amount of water applied for growing wheat is estimated as 25,917 af (14,643 * 1.77 = 25,917).

Net water saved in wheat through water efficient agronomic practices is estimated as 5,183 af. (25,917 * 0.2 = 5,183).

Crop adjustment and fallowing:

About 13,311 acres of cotton area can be substituted by vegetables (66,557 * 0.20 = 13,311).

This translates into a net reduction of irrigation demand for cotton by 19,035 af. [(13,311* 3.43) – (13,311* 2.0) = 19,035].

About 1231 af of alfalfa area can be permanently retired (24,626 * 0.05 = 1231) which will reduce the demand for alfalfa irrigation by 7,622 af.

Total water saved from all three activities is calculated as: 95,182 + 5,183 + 19,035 + 7,622 = **127,022 af.**