Assessing the Sensitivity of the Southwest's Urban Water Sector to Climate Variability

Case Studies in Arizona

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CLIMAS Report Series

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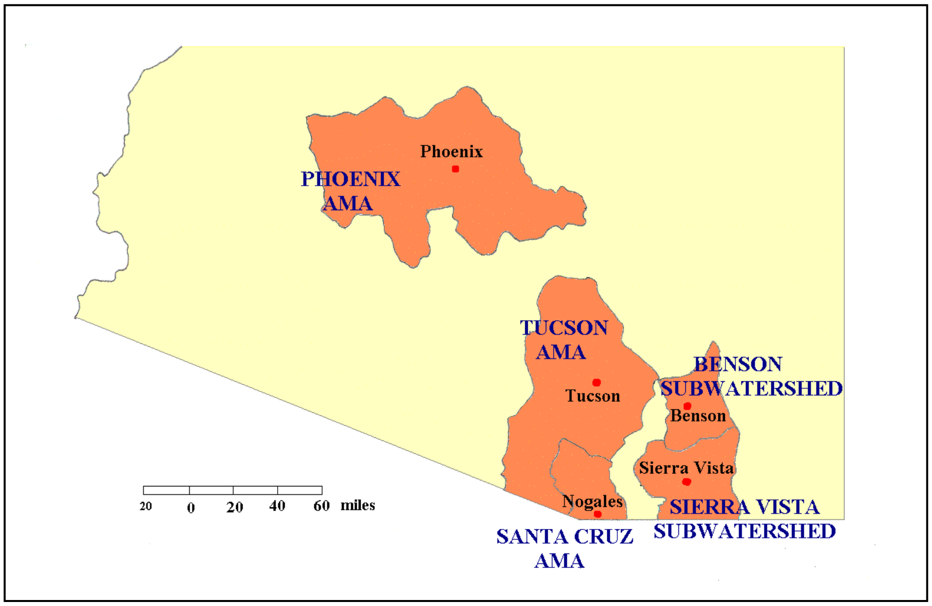

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Table of Contents

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Executive Summary

Conventional wisdom often views the urban water sector as being among the more sensitive sectors in the arid U.S. Southwest. To test this assumption, the Climate Assessment Project for the Southwest (CLIMAS), funded by the National Oceanic and Atmospheric Administration (NOAA), analyzed the water budgets of five Arizona cities to determine how severe the impacts would be from the deepest one-, five-, and ten-year droughts on record. Case study sites for the analysis included the Phoenix Active Management Area, Tucson Active Management Area, Santa Cruz Active Management Area, and the Benson and Sierra Vista subwatersheds of the San Pedro River.

The Active Management Areas (AMAs) studied include three of five geographical areas in Arizona where more stringent groundwater management is mandated under the 1980 Arizona Groundwater Management Act. In each of the three areas, even under assumptions of continuation of something approaching "average" climate conditions, issues persist regarding the possibility of achieving safe-yield (i.e., renewable supply and demand are in balance) by the year 2025, as articulated in the Act.

As is abundantly clear from both paleo and historical records, the Southwest is characterized by a very high degree of climatic variability over seasonal, annual, and longer time scales. The Urban Water Sensitivity Analysis represents an effort to assess how climatic variability, as evidenced in the data for each study site, affects the water supply/demand budgets for each area.

Profile of Study Sites

The water sector in the Phoenix AMA is characterized by availability of both surface water (including Colorado River water delivered via the Central Arizona Project) and groundwater resources, although access to surface water is not universal within the AMA. By far the largest population center in the state and the state's capital, the Phoenix area continues to be one of the fastest growing urban areas in the country. Here serious water conservation efforts are notably lacking, even in the context of a relatively arid environment and continued high population and economic growth. The Tucson AMA encompasses the second-largest population concentration in the state. In contrast to the Phoenix AMA, however, Tucson has a more limited number of water sources. The AMA remains reliant on groundwater, although much of the area is making the transition to blending recharged CAP water with groundwater. Supplies have been further augmented by construction of a treated-effluent delivery system, which delivers water for many turf-based uses such as golf courses. The Santa Cruz AMA encompasses an area with a relatively low population, but is located directly on the U.S.-Mexico border. Nogales is the major urban area. Directly across the border from Nogales, Arizona is Nogales, Sonora, a rapidly growing city ten times the size of its Arizona counterpart. The two cities share a common watershed, and thus water management decisions and strategies developed in the Santa Cruz AMA, downstream from the Mexican portion of the watershed, inevitably requires consideration of Mexican decisions and actions.

The two subwatersheds of the San Pedro River offer a contrasting perspective, for neither is designated as an AMA, nor is seen likely to be so designated in the near future. The Benson subwatershed has a relatively small population, currently some 10,000 people. Based on current growth rates, the CLIMAS Urban Water Study team estimates that the population may reach

18,861 by the year 2025. While far from qualifying as a major urban area, the subwatershed was included in this analysis as part of a broader community ethnographic study of climate impacts being carried out under the CLIMAS research umbrella. The Sierra Vista subwatershed, on the other hand, provides an excellent example of a rapidly growing and developing area that is dependent upon groundwater. This area currently has a population of some 50,000 people and is anticipated to have between 76,000 and 87,000 residents by the year 2025. The area must cope with pressures generated by multiple demands for water as well as with values associated with preservation of an internationally renowned protected area, the San Pedro Riparian National Conservation Area which is managed by the U.S. Bureau of Land Management (BLM).

Summary of Analysis Assumptions

A number of assumptions provided a framework for containing the sensitivity analysis within manageable bounds. A few of the key assumptions are summarized here; a detailed discussion of the assumptions appears in Section 2 of the working paper.

A critical assumption involved use of precipitation data, which are available for the time period of roughly 1900 to present. The most extreme one-, five-, and ten-year droughts were derived from data available for the Climate Division in which each study area was located (see table below). For all areas except the Santa Cruz AMA, the data used covered the winter half-year period, based on research indicating that, although typically lower in total quantity, winter precipitation generally contributes more to overall water supply and aquifer recharge than does summer half-year precipitation. This is largely a function of temperature and general intensity of precipitation, wherein summer conditions favor higher evapotranspiration rates and storms of greater intensity but shorter duration, leading to high runoff rates, but low recharge rates. For the Santa Cruz AMA, the entire yearly record was used to identify the historically worst drought periods. This decision was based on evidence that key aquifer resources in the AMA are relatively small and are rapidly responsive to precipitation events. The ADWR water budget for this AMA is unique in providing a water supply range, rather than a single number, based on the tendency of this water source to rapidly deplete and refill, in response to the combination of climatic conditions and demand.

Mean Precipitation and Most Severe 1-, 5-, and 10-Year Droughts in Historical Record

Climate Division	Mean Annual Precipitation	Mean Period Precipitation	Driest One-Year Period	Driest Five-Year Period	Driest Ten-Year Period
East Central *Phoenix AMA* Winter Precip. (Nov.-Apr.)	19.00”	10.21”	1904 1.18” 11.57% of mean	1900-1904 28.42” total 5.6”/yr. avg. 55.7% of mean	1946-1955 74.66” total 7.47”/yr. avg. 73.16% of mean
Southeast *Tucson AMA; Benson and Sierra Vista Subwatersheds* Winter Precip. (Nov.-Apr.)	14.33”	5.18”	1904 0.6” 11.58% of mean	1900-1904 14.73” total 2.95”/yr. avg. 56.95% of mean	1947-1956 38.27” total 3.83”/yr. avg. 73.94% of mean
Southeast *(Santa Cruz AMA)* (Ann. Precip.)	14.33”	14.33”	1948 7.94” 55.4% of mean	1900-1904 49.9” total 9.98”/yr. avg. 69.64% of mean	1948-1957 115.8” total 11.58”/yr. avg. 80.8% of mean

Demographic data used for the analysis of the AMAs were derived from the numbers provided by each AMA in its Third Management Plan. For the AMAs, population figures for 1995 and 2025 were used. For the Sierra Vista and Benson subwatersheds, data availability issues resulted in the use of figures for 1990 and 2025. Due to the fact that the population is growing more rapidly than projected by the Arizona Department of Economic Security (DES), additional calculations were made to identify, based on current growth rates rather than DES projections, what the population levels are likely to actually be in 2025. The year 2025 was selected for analysis because this is the year the Groundwater Management Act specifies that the AMAs are expected, though not mandated, to have achieved safe-yield. Although this provision does not apply to the Benson and Sierra Vista subwatersheds, it provides a consistent framework for analysis.

In all cases, a linear relationship between precipitation and surface water availability and between precipitation and groundwater recharge levels was assumed. For the Phoenix and Tucson AMAs, the five- and ten-year drought scenarios included a variant whereby Colorado River water was eliminated from the supply side of the water budget. While the Colorado River system includes storage to meet Lower Basin demands for four years, Arizona's Central Arizona Project is the junior right holder, and therefore is first in line to experience reductions in supply should sufficient water not be available to meet senior right-holders' demands. Thus, it is not outside the realm of possibility that, under severe sustained drought, part or all of the supply may not be available to the AMAs. The decision to cut off all CAP flows for the entire five- and ten-year period allowed for analysis of worst-case scenarios in these study areas.

On the demand side, all five study areas feature considerable water use by the agricultural sector, and in each area shifting from agricultural to municipal and industrial water use constitutes a key assumption in assuring the capacity to continue supplying new demands. For this reason, the analyses for each area included an alternative whereby agriculture was eliminated as a strategy to enhance supply needed to meet municipal and industrial demand during the drought periods. Further, for the Santa Cruz AMA, scenario analysis included a variant in which the effluent flows received from Mexico were eliminated. In this case, the 2/3 portion of effluent that Mexico legally owns currently constitutes a significant source of recharge to the Santa Cruz AMA aquifer, and also serves as the major source of support for a rich riparian area downstream from the Nogales International Wastewater Treatment Plant. The Mexican effluent is currently counted in the supply column of the AMA's water budget.

With regard to drought impacts on demand, an assumption was made that the droughts would persist throughout the year; thus, water shortages in the winter half-year would not be made up by unusually wet summer half-year conditions. Based on this assumption, demand was altered in the municipal sector (primarily due to assumed increases in outdoor water use), and in the agricultural, and riparian demand sectors to reflect proportionally greater water use relative to baseline conditions. Offsets to demand were calculated based on assumed changes in incidental groundwater recharge generated by the increase in water pumped but not consumed.

It is likely that extended drought, of five or ten years' duration or longer, would result in imposition of progressively more stringent conservation requirements in the study areas. However, the effectiveness of alternative conservation measures in terms of maintaining a reasonable balance between renewable supply and demand was not included in this analysis. The choice not to include conservation alternatives in the drought scenarios was based on an overriding interest in identifying climate impacts on existing patterns of supply and demand. The work carried out here, however, does provide a solid framework for water managers and regulators to initiate sensitivity analyses that take conservation alternatives into account.

Results of Sensitivity Analysis

The results of the sensitivity analysis indicate that droughts of the magnitude recorded in the instrumental record for each study area would have a significant impact, in terms of groundwater mining, on that community's capacity to pursue "business as usual." The impacts of the drought scenarios on each AMA and the two subwatersheds in the Upper San Pedro basin are summarized below. Note that the "eliminate CAP" assumption was not included in the one-year scenarios for the Phoenix and Tucson AMAs because it was not considered likely that a one-year drought would result in any cut-off in availability of this source of supply.

Sensitivity of the Phoenix AMA to the Drought Scenarios
In the Phoenix AMA, even assuming average climate, the overdraft between renewable supply and demand is projected to amount to 24 percent of total demand by the year 2025.

Under the **one-year drought scenario**, reduction in precipitation is very pronounced, producing significant imbalances between renewable supply and demand:
- ♦ Drought, but full availability of CAP water: groundwater overdraft reaches 68 percent
- ♦ Drought and elimination of agriculture: groundwater overdraft reaches 43 percent
- ♦ Drought and 1995 supply, 2025 demand: demand outstrips renewable supply by 79 percent

Under the **five-year drought scenario**, percentages are somewhat lower, but impacts over the entire period in actual acre-feet are substantial:
- ♦ Drought plus full availability of CAP water: groundwater overdraft is 47 percent of total demand
- ♦ Drought, but zero CAP water available: groundwater overdraft rises to 67 percent
- ♦ Elimination of agriculture, but full CAP supply: a mere 6 percent overdraft occurs
- ♦ Elimination of both CAP and agriculture: overdraft reaches 42 percent
- ♦ Drought and 1995 supply: overdraft amounts to 59 percent

The **ten-year drought scenario** produces the following outcomes, which are similar to those derived for the five-year scenario:
- ♦ Drought plus full availability of CAP water: groundwater overdraft is 39 percent of total demand
- ♦ Drought, but zero CAP water available: groundwater overdraft rises to 59 percent
- ♦ Elimination of agriculture, but full CAP supply: an 8 percent surplus occurs
- ♦ Elimination of both CAP and agriculture: overdraft reaches 27 percent
- ♦ Drought and 1995 supply: overdraft amounts to 52 percent

Sensitivity of the Tucson AMA to the Drought Scenarios
In the Tucson AMA, assuming average climate, the overdraft between renewable supply and demand is projected to amount to 15 percent of total demand by the year 2025.

Under the **one-year drought scenario**, drought produces less-severe impacts in the Tucson AMA than in the Phoenix AMA:

- ♦ Drought, but full availability of CAP water: groundwater overdraft reaches 36 percent
- ♦ Drought and elimination of agriculture: overdraft is reduced to 23 percent
- ♦ Drought and 1995 supply, 2025 demand: demand outstrips renewable supply by 95 percent

Under the **five-year drought scenario**, percentages are somewhat lower, but overall impact on groundwater mining is significant:
- ♦ Drought plus full availability of CAP water: groundwater overdraft is 28 percent of total demand
- ♦ Drought, but zero CAP water available: groundwater overdraft rises to 78 percent
- ♦ Elimination of agriculture, but full CAP supply: overdraft drops to 14 percent

- ♦ Elimination of both CAP and agriculture: overdraft reaches 74 percent
- ♦ Drought and 1995 supply: overdraft amounts to fully 87 percent of total demand

The **ten-year drought scenario** produces conditions similar to those calculated for the five-year scenario:

- ♦ Drought plus full availability of CAP water: groundwater overdraft reaches 25 percent of total demand
- ♦ Drought, but zero CAP water available: groundwater overdraft rises to 75 percent
- ♦ Elimination of agriculture, but full CAP supply: overdraft drops to 11 percent
- ♦ Elimination of both CAP and agriculture: overdraft reaches 71 percent
- ♦ Drought and 1995 supply: overdraft amounts to 84 percent

Sensitivity of the Santa Cruz AMA to the Drought Scenarios

The Santa Cruz AMA, based on calculation of average annual supply available, within the 10th and 90th percentile, may be expected to show a 20 percent imbalance between renewable supply and demand by the year 2025. Note, however, that the high variability of water supply in the AMA is such that full balance or even some surplus may be anticipated in some seasons and/or years.

Under **the one-year drought scenario**, impacts on the AMA water budget may be expected to approximate the following:

- ♦ Drought: groundwater overdraft reaches 40 percent
- ♦ Drought and elimination of 2/3 Mexican share of effluent: overdraft rises to 68 percent
- ♦ Drought and elimination of agriculture: groundwater overdraft amounts to 30 percent of total demand
- ♦ Drought, no agriculture, loss of 2/3 Mexican effluent: overdraft reaches 62 percent
- ♦ Drought and 1995 supply, 2025 demand: overdraft amounts to 48 percent

With 1995 levels of supply and **five-year drought conditions**:

- ♦ Drought: groundwater overdraft is 35 percent of total demand
- ♦ Drought and elimination of 2/3 Mexican share of effluent: overdraft rises to 62 percent
- ♦ Drought and elimination of agriculture: groundwater overdraft amounts to 24 percent of total demand
- ♦ Drought, no agriculture, loss of 2/3 Mexican effluent: overdraft reaches 56 percent
- ♦ Drought and 1995 supply, 2025 demand: overdraft amounts to 42 percent

Under the **ten-year drought scenario**:

- ♦ Drought: groundwater overdraft is 32 percent of demand
- ♦ Drought and elimination of 2/3 Mexican share of effluent: overdraft reaches to 59 percent
- ♦ Drought and elimination of agriculture: groundwater overdraft is 20 percent of total demand
- ♦ Drought, no agriculture, loss of 2/3 Mexican effluent: overdraft rises to 52 percent
- ♦ Drought and 1995 supply, 2025 demand: overdraft amounts to 38 percent

As illustrated in the results summarized below, elimination of agriculture goes a long way toward reducing imbalances between renewable supply and demand. However, in the absence of considerable incentives or disincentives, it is unlikely that full elimination of agricultural demand would occur. In the Phoenix AMA, and to a lesser extent in the Tucson AMA, Indian agriculture influences the contours of supply and demand. Tribal sovereignty, and legal agreements between the tribes and federal and state governmental entities constitute intervening factors that complicate the picture. However, loss of external sources (CAP flows for the Phoenix and Tucson AMAs, Mexican effluent for the Santa Cruz AMA) would clearly pose the greatest challenges for managing water resources, and would require the greatest conservation efforts to redress.

Sensitivity of the Benson Subwatershed to the Drought Scenarios

Unlike the other study areas, agriculture in the Benson subwatershed is expected to persist as the primary demand sector for water. Under the scenarios developed for this sensitivity analysis, elimination of agriculture actually increases groundwater mining, due to the loss of return flows that could be counted as inputs to overall supply. The percentages reported below represent the DES projections for the year 2025, and the “population high” estimates calculated on the basis of the higher growth rates of recent years. Assuming average climate conditions, groundwater overdraft is projected to amount to 31 percent of total supply under the DES population scenario and 31 percent of total supply under the “population high” scenario.

Based on 2025 population projections, the deepest **one-year drought** on record produces the following impacts:

- ♦ Drought: groundwater mining reaches 78 percent of total demand under both population scenarios
- ♦ Drought and elimination of agriculture: groundwater mining increases to 84 percent of total demand

The **five-year drought scenario** results in a less-severe impact on groundwater proportionally, but the total impact in acre-feet is substantial:

- ♦ Drought: groundwater overdraft reaches 56 percent of total demand
- ♦ Drought plus elimination of agriculture: groundwater overdraft amounts to 49 to 50 percent of total demand

The **ten-year scenario** is similar to that of the five-year scenario, but with a somewhat smaller impact on groundwater:

- ♦ Drought: groundwater overdraft amounts to 43 to 44 percent of total demand
- ♦ Drought and elimination of agriculture: overdraft increases slightly to between 38 and 40 percent of demand

Sensitivity of the Sierra Vista Subwatershed to the Drought Scenarios

Calculations indicate that, assuming average climate conditions, groundwater mining accounts for 25 percent of total demand. Under the 2025 DES and “population high” demand assumptions, groundwater mining rises to 32 percent and 35 percent, respectively, of demand. As drought does not vary the groundwater impact by more than two percent, the percentages are reported below as a range, with the lower number reflecting DES population growth projections, and the higher number reflecting the larger demand generated by the higher population estimate. As in the Benson subwatershed, elimination of agriculture would actually increase groundwater mining.

The historic **one-year drought** produces the following impacts, based on 2025 population:

- ♦ Drought: groundwater mining reaches 76 percent of total demand under both population scenarios
- ♦ Drought and elimination of agriculture: groundwater mining decreases to 82 percent of total demand

The **five-year drought scenario** produces a less-severe impact on groundwater proportionally, although the total impact in acre-feet is substantial:

- ♦ Drought: groundwater overdraft reaches 56 to 57 percent of total demand

- ♦ Drought plus elimination of agriculture: groundwater overdraft amounts to 59 to 61 percent of total demand

The **ten-year scenario** is similar to that of the five-year scenario, but with a somewhat smaller impact on groundwater:

- ♦ Drought: groundwater overdraft amounts to 47 to 49 percent of total demand
- ♦ Drought and elimination of agriculture: overdraft increases slightly to between 50 and 52 percent of demand

Implications

A common theme among the five study areas is the large impact that agricultural activities have on local water budgets. While elimination of some or all agricultural activity would contribute substantially to redressing supply and demand imbalances, simplistic assumptions that conversion of agricultural lands to urban uses "solves" local water problems are overly optimistic. In all study areas, a key challenge is to eliminate or minimize the mining of non-renewable groundwater resources under conditions of wide climate variability. Under sustained drought, water table declines, potential tapping of lower-quality water, and land subsidence may be amplified. The costs of addressing such problems could be quite large. Further, in some areas, such as the San Pedro Riparian National Conservation Area and the Santa Cruz River riparian area, deep extended drought could seriously compromise or even destroy valued landscapes and ecosystems. Protecting such areas would require a considerable level of compromise among competing water users.

Phoenix AMA. In the Phoenix AMA, the capacity to draw upon multiple sources of surface water, as well as groundwater, water banked under the Arizona Water Banking Authority, and (potentially) large amounts of effluent, provides an important buffer to drought. However, there are significant localized differences within the AMA. Each of the 31 large, and nearly 80 small, water providers has a unique portfolio of water supply sources and customer base, as well as a more or less complex web of arrangements regarding treatment and recharge facilities.

Longer-term, relatively severe droughts have potential to cause considerable problems in some areas, particularly those where groundwater pumping is the sole source of water. The lack of a conservation mentality in the AMA, as evidenced by the large amounts of lush landscaping, artificial bodies of water, and extensive golf facilities, is likely to impede conservation efforts under any but the worst drought conditions. Further, assumptions about the extent of conversion from farmland to municipal land and water use may be overly optimistic. The continuation of substantial agricultural activity is especially likely on tribal reservation lands adjacent to the metroplex.

Tucson AMA. Unlike the situation in the Phoenix AMA, changes in water management in the Tucson AMA promise a decrease in the rate of groundwater overdraft anticipated in the near future. Use of CAP water is expected to account for most of this progress toward achieving safe-yield. Agriculture constitutes only a small proportion of overall water demand in the AMA, indeed smaller than in any of the other study areas, and is expected to continue declining over the next several decades. While the demise of agriculture in the AMA could probably be expedited if compensation were sufficient to meet farmers' expectations, temporary transfer of water to municipal uses, as a drought relief strategy, would require institutional and infrastructural changes that might not be easily accomplished. Still, even if agriculture were eliminated and aquifer overdraft cut by half, withdrawals would continue to exceed renewable supplies under the drought scenarios used in this study.

Reliance on CAP supplies will contribute to water resource security under normal or minimally stressful climatic conditions, but the lack of other substantial supplies aside from fossil groundwater and effluent poses a challenge to management if severe sustained drought throughout the Colorado River Basin produced a sustained cutoff in CAP supplies. As in the case of the Phoenix AMA, water banking provides a buffer, but the system remains untested in terms of institutional and infrastructural capacity to draw upon this water in times of climatic stress. Also like the Phoenix AMA, differences among water providers in terms of their access to CAP supplies or to other alternatives under drought conditions suggest that climatic impacts will be unevenly experienced across the AMA.

Santa Cruz AMA. The Santa Cruz AMA has several major areas of significant climatic sensitivity. One involves the high degree of interaction between climate and water supply. To address this issue, development of impoundments and of additional groundwater resources is currently underway. It remains to be seen, however, whether the effects of deep, sustained drought would be sufficiently countered by reliance on the newer sources.

A second, potential area of sensitivity involves the continued availability of effluent flows from Nogales, Sonora. Minute 272 of the International Boundary and Water Commission (IBWC) stipulates that Mexico owns its share of the effluent treated at the Nogales International Wastewater Treatment Plant on the Arizona side of the border. However, the Santa Cruz AMA includes the effluent in the supply column of its water budget. Whether, under conditions of severe extended drought and continued large rates of increase in demand, Mexico would reclaim its effluent remains an open question, and one that cannot be ignored. A third issue relates to well-drilling in the alluvium of the Santa Cruz River. Although no such drilling is currently contemplated by Mexican water managers, under conditions of sustained drought such drilling might be revisited. The drilling of additional wells in the Santa Cruz River on the Mexican side of the border, with consequent increase in capture of subflows, would likely decrease the amount of water that reaches Nogales, Arizona, particularly under drought conditions.

Benson Subwatershed. The Benson subwatershed analysis reveals that this area would be significantly affected by both short- and longer-term drought conditions. Because the major user in the subwatershed is agriculture, any changes that either directly or indirectly affect this sector may be expected to produce discernible impacts on water supply, demand and groundwater balance. By contrast, increases in municipal demand, based on population growth projections, are not expected to result in significant impacts on the local renewable supply-demand balance.

The most significant drought impacts on the subwatershed are likely to be increased groundwater pumping, particularly for agriculture that might otherwise rely on surface water rights, and an almost threefold increase in groundwater overdraft during the worst conditions. As would likely be the case for all the study areas, increased groundwater pumping could be expected to generate higher water costs to consumers. The potential increase in both groundwater demand and pumping costs during drought conditions is likely to be of particular concern due to the crop mix currently farmed in the area, which consists predominantly of high-water-use alfalfa and pasturage. Ultimately, the specific economic situation of the individual farmers will determine their resilience to the combination of climatic and economic pressures involved.

Drought would raise the possibility of increasing conflicts over surface water access, including access for in-stream uses and Indian water rights. Given the current structure of institutional arrangements, it must be assumed that competition over surface water under drought conditions will favor agriculturalists, who own senior water rights. Even though the scenarios used in this analysis include situations where agriculture is eliminated, the more likely scenario is that agriculture would continue, but under a more conservation-oriented approach that includes improved irrigation efficiency and planting of crops requiring less water. Retired farmland would probably not be transformed into riparian habitat; rather, a transition to recreational vehicle parks, ranchettes, and other such uses could be expected.

Sierra Vista Subwatershed. In comparison with the analysis of the Benson subwatershed, interactions between changes in population size and climatic variation are expected to constitute the critical factors affecting future water supply and demand in the Sierra Vista area. Agriculture is fairly limited in this area, and is not expected to have a pronounced impact on the water budget of the area by the year 2025.

Highly localized groundwater extraction in the Fort Huachuca/Sierra Vista area has increased over the past two decades, and is not likely to abate in the next two decades. Increases in groundwater mining in the Fort Huachuca/Sierra Vista area are particularly worrisome, for a cone of depression in the area has been deepening since the 1960s. The water table has been declining relatively rapidly, and the cone has now coalesced with another cone of depression located in the Palominas/Hereford area, nearer the San Pedro River and in an area of intensive agricultural irrigation. Further, continued growth in demand, and consequent water table declines, poses a potential threat to small domestic wells. The situation also poses a threat, based on growing scientific evidence, that the expansion of the cone of depression is already beginning to intercept and divert paths of groundwater flow that would otherwise reach the River either directly or via the river's main tributary, the Babocomari River.

Drought impacts in the subwatershed may be expected to be substantial, though highly localized. The sector that is most sensitive to such impacts is clearly the San Pedro Riparian National Conservation Area. Although irrigated agriculture in the subwatershed relies exclusively on groundwater, the cones of depression in the area intercept subflows to the river, thereby also affecting water needs of the riparian vegetation. Indeed, drought impacts might be even more severe than indicated by the subwatershed-level results, in that the availability of surface water might have been be overestimated in this analysis. The decline would likely exacerbate the existing trend of declining summer baseflow in the river, causing further negative impacts on the riparian ecosystem. It is also important to note that elimination of agriculture under drought stress would still result in a 58 percent increase in groundwater overdraft relative to 1990 baseline conditions.

Recommendations

- Water resource managers and regulators should consider making greater use of historical and paleoclimate information, as well as of seasonal and longer-lead climate forecasts.
- Water managers should formulate their water budgets and water management strategies based on a range of climatic and hydrologic conditions, rather than assuming climate stationarity.
- Sensitivity analyses should be carried out by the Arizona Department of Water Resources for each of the state's urban areas, using ADWR hydrologic models.
- To assure equity among water providers and consumers, water managers and regulators should examine the results of climate sensitivity analyses within the context of their specific communities and water resource structures.
- Analyses of alternative approaches to water conservation should consider climate variability.
- An analysis should be conducted of the impacts of institutional factors on capacity to respond effectively to climate variability.
- Sensitivity analyses conducted in the Sierra Vista subwatershed and the Santa Cruz AMA should be extended across the international boundary.
- Explicit analysis of the interaction of climatic impacts and urban water management practices on existing, highly valued natural landscapes and ecosystems should be carried out.

Table of Contents

Assessing the Sensitivity of the Southwest's Urban Water Sector To Climate Variability

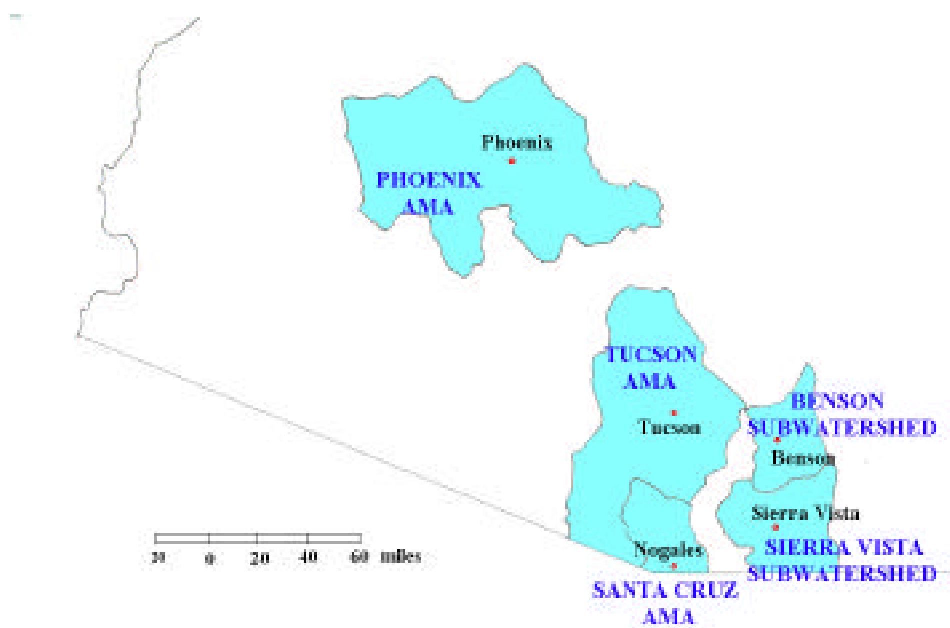
I. Introduction

The purpose of this analysis is to examine the impacts of climatic fluctuation and population growth on water supply and demand on five water management areas in southern Arizona, and to highlight the distinct sensitivities that each of these areas is likely to experience under different climatic scenarios. In doing so, we hope to provide insight that will be useful to water managers regarding the role of climatic variability in evaluating water supply and demand. Greater understanding of the role played by climate variability may spur closer examination of the utility of current climate forecasts and perhaps encourage water managers to further integrate additional forecast information in planning annual and longer-term water use.

In order to examine the disparate impact of climatic variability on a variety of water management areas, we have chosen five sites that vary in population size, type of water demand, and in water sources available. The study areas are depicted in Figure 1. Four of these areas (the Tucson AMA, the Santa Cruz AMA, the Benson subwatershed, and the Sierra Vista subwatershed) are located in southeastern Arizona, while the fifth site, the Phoenix AMA, is in the central part of the state.

Study Areas for the Water Sensitivity Analysis, Southern Arizona

Fig. 1



The Study Areas

The Phoenix and the Tucson AMAs were chosen because they include the two largest cities in the state, and because both are growing rapidly in a context of potentially limited water supply. The Santa Cruz AMA was chosen because it is located on the U.S.-Mexico border, and thus incorporates important international water issues; the community also presents several interesting contrasts to the water supply and demand contexts of the Phoenix and Tucson AMAs.

Sierra Vista, the only truly urban area within the Sierra Vista subwatershed, is located near the San Pedro River, which has been identified as one of the most important riparian areas in the United States (American Rivers 1999). Adjacent to the community is a large U.S. Army base. The community and the base are currently under pressure to consider the impacts of its groundwater withdrawal on the viability of the riparian ecosystem. The area uses large amounts of groundwater, yet is not subject to the level of stringent regulation imposed on Phoenix, Tucson, and Nogales, which were declared Active Management Areas by the Arizona Department of Water Resources in 1980. Sierra Vista is a rapidly growing community. Climate variability, when added to the pressures of urban activity and ecosystem needs, has the potential to significantly intensify existing pressures.

The Town of Benson constitutes the major population center in the middle San Pedro River, downstream from Sierra Vista and the protected riparian area along the San Pedro River. With a total population throughout the entire watershed of only about 6,000 people, the area does not qualify as significantly urban. However the area was the focus of community case study of climate vulnerability, and thus provides insight into how climate might affect water resources the context of a small community undergoing rapid development arising from tourism and increases in winter residents.

Methodological Considerations

The methodology used in this sensitivity analysis considers a number of key factors in determining the impacts of climatic variability on each area by using historic droughts as extreme parameters. Factors considered include the seasonality of precipitation, the number and types of water sources available, the structure of water demand among municipal, agricultural, industrial and riparian sectors, and variations in demand based on population size versus renewable water supplies.

The degree to which a location's water supply and demand is susceptible to climatic variability at both current and projected future population levels could be expected to lead to different conflicts over water in each location. For example, in times of water scarcity in Benson, reductions in surface flow would likely cause conflicts among surface flow users, who, according to the data available, are primarily agricultural and riparian interests. In Sierra Vista, on the other hand, the primary dispute during a drought would more likely be between municipal users and protectors of riparian habitat.

II. Literature Review

Much of the research into climate impacts on water resources has been directed toward determining the effects of long-term climate change. Limitations in ability to downscale the results produced by general circulation models (GCMs) has constrained efforts to identify the impacts of climate change at regional or final scales of resolution, but consensus has formed around the notion that arid and semi-arid areas could be among the most seriously affected. Further, it has been suggested that relatively small changes in temperature and precipitation, combined with non-linear effects on evapotranspiration processes and soil moisture conditions, could result in relatively large changes in runoff, especially in arid and semi-arid regions (IPCC 1996). For example, one study found that a 2°C increase in temperature and a 5 percent decrease in precipitation would pose challenges to managers of surface water in the Trinity, Colorado, and Rio Grande basins of the United States (Schmandt and Ward 1993, cited in IPCC 1996).

Recognizing the high degree of reliance on groundwater in areas featuring limited availability of surface water and dry climates, the Intergovernmental Panel on Climate Change (IPCC) noted that few direct studies had been done of the impacts of global warming on groundwater recharge. Yet "A shorter recharge season may result from increased temperatures and evaporation in spring and autumn" (1996, p. 336). The implications of such changes for Arizona could be significant, for groundwater provides about half of the water supplies of the state, and the Colorado River now constitutes the largest single source of renewable water supplies for the rapidly growing urban areas in the central portion of the state.

While global warming has been the focus of much of the research pertinent to the CLIMAS urban water study, understanding natural climate variability also holds promise for improving water resource management. By focusing on natural climate variability and its implications at regional and local scales, researchers and decision makers may find ways to effectively address, in a context-specific manner, climatically induced imbalances between water supply and demand (IPCC 1996). Such an approach would also facilitate assessment of the extent to which water managers can achieve standard performance criteria (reliability, safe yield, probable maximum flood level, resilience and robustness) under different climatic conditions. The panel identified sensitivity analysis and vulnerability analysis, combined with focused institutional analysis, as being useful for contextualizing the impacts of natural climatic variability and of greenhouse gas-induced climate change (IPCC 1996).[1]

Even in an age of extensive water engineering, drought remains a significant source of stress to both human and natural systems. To address the problem of drought and its impacts throughout the United States, Congress enacted legislation in 1998 to create a national Drought Commission. The Commission is charged with ensuring development of proactive drought response plans throughout the country. Yet drought eludes easy definition, for any definition must reflect local cultural, social, economic, and physiographic characteristics (IPCC 1996). Additionally, understanding of the processes producing climate variability—including extended drought condition—remains incomplete, as does thorough knowledge of the processes by which drought affects human and natural systems.

Frederick (1995) noted that addressing concerns about water adequacy in the United States is constrained by the fact that annual statistics for precipitation and runoff are insufficient for determining available supplies and identifying potential problems. He stressed the need to take large seasonal and annual variations into account, noting that "the highest levels of use and the lowest prices are often found in the more arid areas of the country" (Frederick 1995, p. 17). Research on U.S. river basins has suggested that safe yield (roughly defined as a balance between inflow and withdrawals) is at maximum level when the ratio of storage to average annual renewable supply ranges between 1.6 and 4.6. "By this criterion, the point of negative returns may already have been reached in three major basins--the Lower Colorado, the Upper Colorado, and the Rio Grande. . . " (Frederick 1995, p. 17).

[1] The IPCC defines sensitivity as the "degree to which a system will respond to a change in climatic conditions, for example the extent of change in ecosystem composition, resulting from a given change in precipitation or temperature" (1996, p. 5). Vulnerability is "the extent to which climate change may damage or harm a system" (IPCC 1996, p. 5). Because the extent of vulnerability depends not only on the sensitivity of the system but also its ability to cope with the new climatic conditions, evaluation of the system’s adaptability is essential as well. Adaptability is defined as the capacity of a system to adjust to specified actual or projected conditions (IPCC 1996, p. 5).

Drought clearly exacerbates such conditions, and can result in significant social and economic impacts. For example, in California the drought of 1976-77 was estimated to have resulted in losses exceeding $2.6 billion, while the 1987-92 drought produced losses of more than $3 billion (Gleick and Nash 1991). Both of these droughts were associated with the same La Niña-spawned zonal atmospheric flows that brought very dry conditions to Arizona.

Many of the studies investigating the impact of climate on water resources in Arizona have focused on surface water conditions in the Colorado River. For example, Revelle and Waggoner (1983) found that warmer air temperatures and a slight decrease in precipitation would probably result in a severe reduction in the quantity and quality of Colorado River water. Based on multiple regression analysis of mean annual flows at Lees Ferry for the period 1931 to 1976, the authors noted that ". . .variations in precipitation were reflected almost linearly in variations in runoff" (p. 431). In their analysis of climate change impacts on the Colorado River, Stockton and Boggess (1979) found that 2°C rise in temperature and a 10 percent decrease in precipitation and produced a 44 percent decrease in runoff. This, they observed, was very close to the 40 percent reduction in runoff calculated by Revelle and Waggoner (1983). By contrast, Nash and Gleick (1991), using the same temperature and precipitation numbers and including an 8 percent rise in potential evapotranspiration, calculated that a 20 percent decrease in runoff would result. They also noted the existence of a linear relationship between increases or decreases in annual precipitation and increases or decreases in mean annual runoff. Exceptions began to occur only when precipitation increased by 20 percent or more (in which case runoff increased at a more rapid rate), or when precipitation increased by 10 percent, but no change in temperature or evapotranspiration occurred (in this case, runoff also increased). The authors noted that "Overall, seasonal changes in runoff patterns are likely to be greater than annual changes and may be a more sensitive indicator of climate change" (p. 239). Based on evaluation of these studies and other factors, the CLIMAS urban water sensitivity analysis assumed linearity between precipitation and runoff for all study sites.

The potential for a total cutoff of Arizona's CAP allotment (1.5 maf) was also an important point of consideration in designing the sensitivity analysis presented here, particularly since Arizona's CAP water right is junior to the other rights in the Lower Colorado Basin. In a 1993 study, Nash and Gleick found that a 10 percent decrease in Colorado River flow translated into a 20 to 30 percent reduction in storage and power generation and an increase in salinity. Analyzing the best-case scenario of climate changed impacts on scheduled water deliveries specified by law and Bureau of Reclamation operating procedures, they found that even a 20 percent increase in runoff, combined with warmer temperatures, would translate into Arizona receiving only 97 percent of its full CAP allotment. Under the worst-case scenario, the CAP would receive no water at all (Nash and Gleick 1993). This latter scenario was adapted for use in the worst-case scenario developed for the CLIMAS urban water study.

Among the most extensive of these studies was the Severe Sustained Drought project carried out by a multidisciplinary team under the auspices of the Powell Consortium (Powell Consortium 1995). The analysis was based on the most severe drought that could be identified from existing instrumental and tree-ring records. This drought occurred between 1579 and 1598. The twenty-year average flow over these twenty years was only 10.95 maf, which was 2.55 maf below the 13.5 maf identified as the long-term reconstructed flow of the Colorado River. Such a reduction, should it occur today, would require stringent and aggressive measures to equitable apportionment of supplies among the various rights holders, including the Central Arizona Project and its urban constituents. This sort of impact is reflected in the findings of Harding, Sangoyomi and Payton (1995), who compared the severe sustained drought of the 1500s with a comparably long streamflow record (October 1938 through September 1975) representing normal mean flow conditions. They found that the Upper Basin states of Utah, Wyoming, Colorado, New Mexico, and northern Arizona would be strongly affected by the drought, and that Arizona and Nevada would experience shortages of delivery. Water deliveries to the CAP would be reduced to 450,000 af, from its regular allotment of 1.5 maf.

As noted above, some of the most rapid growth in the United States is occurring in the West and Southwest, areas where water resources are already stressed. The U.S. Office of Technology Assessment recognized in 1993 that problems with meeting growing demand for water already existed and were likely to increase in San Diego, Los Angeles, Las Vegas, Reno, Denver, El Paso, and San Antonio (cited in Lins and Stakhiv 1998). Even under static climate conditions, California, the Great Basin, Lower Colorado, Upper Colorado, and Rio Grande regions have the highest ratios of consumptive use to average renewable supply. Of relevance for the CLIMAS urban water study, even under normal conditions, all but the northeastern corner of Arizona the ratio of consumption relative to renewable water supply is greater than 100 (Lins and Stakhiv 1998).

Imbalance between renewable supplies and demand continue to challenge water managers in the Southwest. Maddock and Hines (1995) observed that rapid growth occurred in urban water use between 1965 and 1990. During this time, public supply withdrawals and per capita consumption grew at about double the national rate. This rate of growth accelerated into the early 1990s, although per capita consumption may have begun leveling off in some urban areas. Even before taking climate variability into account, predictions indicate that Las Vegas, one of the fastest growing cities in the United States, will consume its entire Colorado River entitlement in less than 15 years. Even with careful conservation and full use of its Colorado River entitlement, the city is anticipated to see water supply deficits after the year 2025. Denver's water supply is anticipated to be insufficient to meet demand even earlier, by the year 2020 (Riebsame 1997).

Although the nation—and the Southwest—are now largely urban, relatively few studies of the impacts of climatic conditions on water resources have focused on urban water systems, particularly with regard to impacts on urban water demand (Boland 1997). Yet warmer, drier weather increases evapostranspiration as well as increased water demand for outdoor irrigation, cooling, and water-oriented recreational activities. Indeed, "If supply facilities and water management policies continue to be based on an assumption of stationary climate, [warmer and drier] climate. . .would lead to increased probability and severity of water shortages in the affected urban area" (Boland 1997, p. 158).

A recent American Water Resources Association Specialty Conference on the "Potential Consequences of Climate Variability and Change to Water Resources in the United States" featured a number of papers that may contribute to filling the gap in studies on climate impacts on urban water systems. O'Connor et al. (1999), for example, provided results of a survey of water providers in the U.S. Susquehanna Basin. Findings of this study revealed that the size of operation is only weakly related, if at all, to vulnerability in the region's water systems and that vulnerability is not at all related to the number of different water systems available to the provider. Systems using surface water were found to be more vulnerable to climate impacts than those on groundwater, but systems using both sources were even more vulnerable than those using one or the other exclusively.

Earlier, Woodard and Horn (1988) studied the effects of climate on urban water demand in Phoenix and Tucson, Arizona. They found that demand was more sensitive to climate conditions in Tucson than it was in Phoenix, and that the key variable was decision making on summertime outdoor irrigation. A comparison of water usage rates with precipitation patterns revealed that Tucson residents were much more likely than Phoenix residents to take amount and timing of rainfall into account when deciding whether or not to water their outdoor vegetation. Phoenix residents were more likely to rely on automated irrigation systems, which operate according to preprogrammed schedules rather than to weather events. Subsequent analysis by the Tucson AMA indicates that summer water use levels closely track evapotranspiration rates (ADWR 1999b).

Because of the perverse relationship between climate effects on water supply and water use, "the overall impact may be more severe than the magnitude of the climate change alone would suggest" (Boland 1997, p. 158). Options for coping with such stresses involve supply augmentation (often requiring infrastructural enhancements requiring long lead times) and/or demand management. According to Boland, ". . .all available water use forecasting techniques, from the simplest to the most complex, assume stationary climate. Many assume stationary weather: that is, zero climate variability" (p. 158). Further, ". . .it is not clear that socially and politically feasible demand management strategies will be sufficient to address climate-induced water shortages" (p. 159). In analyzing climate impacts on water resource management, Boland noted that it is important to keep in mind that urban water use patterns may change substantially over time, requiring that decisions be made in a context of considerable uncertainty about future patterns.

Reflecting on the implications of climate variability for European urban and industrial water systems, Kaczmarek and Kindler (1989) observed that while natural systems behave in stochastic ways, water resource planners and managers assume climate stationarity, even though they recognize that this approach has been insufficient. The authors observed that changes in variance, skewness, and persistence may be more important in managing urban water resources than differences in mean values. They noted that a "long-term" drought in the United Kingdom and elsewhere in Europe is one that lasts from three to five years, and is one of the major factors taken into account when planning and developing water systems. Any attempt to take climate variability more explicitly into account in that region would cause significant escalation in system costs, and thus pose a considerable disincentive to changing existing design practices. The authors noted, by contrast, that U.S. water resource systems are more robust, due in part to recognition of the variability of climate over seasonal to decadal time scales.

Indeed, in the United States, other factors such as population trends, land use practices, institutional considerations, and values attached to different kinds of water use are seen to influence water resource planning much more strongly than climate (Frederick and Major 1977; see also Schwarz and Dillard 1990). For example, overall water demand in Boston dropped from 310 mgd in 1988 to 242 mgd in 1992, due to an increase in the price of water. A further 10 percent reduction in demand, anticipated by the year 2020 (and which even includes projected population growth), is also an influential factor (Lins and Stakhiv 1998).

Lins and Stakhiv (1998) found that Boston would actually benefit from climate changes projected by most scenarios, with progressive decadal increases in safe yield amounting to 12 to 15 percent; however, population growth would negate these gains. In fact, increased demand could produce "far more water supply shortfalls and far greater drawdown in the primary storage reservoir" than would be likely to occur as a result of climate change alone" (p. 1261). The conclusion in this case was that incorporation of climate change into long-range planning appeared to be far less important for the city's water system than continued emphasis on strategies designed to reduce water demand.

A Tacoma case study (also reported in Lins and Stakhiv 1998) demonstrated that climate change was anticipated to produce increased annual streamflow in the lower basin of the Green River, due to an increase in precipitation primarily in the winter months. Excluding demand growth, increased in-stream flows, and flooding, climate change was expected to have little effect on either system performance or revenues. When an 80 percent growth in demand by 2050 was projected, however, pressures on the system and on instream flows were expected to stimulate a need for appropriate adaptation strategies. Nevertheless, the authors noted, "Given the small climatic effect relative to population growth, the adaptive measures implemented to cope with [demand growth] will, in all likelihood, also handle [climatic impacts]" (Lins and Stakhiv 1998 p. 1262). The authors reported in the same article that, for the Rio Grande River, an assumed 1°C rise in temperature would produce a 10 percent increase in rainfall, and a shift toward earlier snowmelt. As in Boston and Tacoma, the results indicated that such changes would pose less significant stresses on water resources than population growth and shifts in the patterns of water demand.

Notably, Lins and Stakhiv (1998) cast a skeptical eye on the efficacy of sensitivity analyses that have focused on the impact of climate change on water resources. In their view,

> "In practice . . . water management is a process of continual adaptation using existing or new management options, which is exactly how management has responded to variable climatic conditions during this century. This single weakness renders nearly all of the published studies seriously incomplete and potentially misleading from the standpoint of the consequences for 'water resources'" (1998, p. 1260).

However, they also noted that, "Unquestionably, the management of water resources could be significantly enhanced by improving understanding of climatic variability at monthly to seasonal, and interannual to decadal time scales (through such mechanisms as El Niño/Southern Oscillation and Pacific Decadal Oscillation, for example). Better understanding of long-term trends in climate, particularly precipitation, would also be valuable for infrastructure enhancement and protection (1998, p. 1264). Further, although most assessments indicate that climate change would have limited impact on most water systems, and that most systems have sufficient management capacity to cope with likely impacts, the authors emphasized that

> ". . .water resources managers must develop their management systems in a context that assumes a wide range of climatic conditions. Plans that assume that future climate will repeat past climate are destined to perform poorly in comparison with plans that recognize the potential for significant and persistent departures from historically 'normal' conditions" (p. 1264).

The CLIMAS sensitivity analysis avoids some of the pitfalls noted by Lins and Stakhiv by employing scenarios that take into account future growth in demand, climatic conditions outside the parameters of water decision making but not outside the realm of reasonable expectation of recurrence, and certain adaptation strategies.

In sumamry, the sensitivity analysis reported here builds upon a growing body of research aimed at understanding the relationships between physical climate processes and human impacts and responses (e.g., IPCC 1996, Rayner and Malone 1998). Human impacts of climate variability has, for example, been well documented in the vulnerability assessment work of Liverman (e.g., 1994). Sensitivity analyses of the Colorado River (Nash and Gleick, 1993) and of the San Pedro River by Conde, Liverman and Magaña (1997) are reflected in the methodologies used to calculate climate impacts on water supplies in the study reported here. Reports produced by the Arizona Department of Water Resources (ADWR 1991, 1996, 1998a, 1998b) also provided a wealth of information about water supply and demand in each of the localities studied. A hydrologic study by the San Pedro Interdisciplinary Study Team (Hydrographic Survey Report, 1991) and a study of climate and water demand in Phoenix and Tucson conducted by Woodard and Horn (1988) provided further methodological foundations.

Materials on the specific areas studied provided important insights into local conditions and context. For example, a wealth of information exists on the interdependence in water supply and demand between Nogales, Arizona and Nogales, Sonora (see Ingram et al. 1995, Morehouse and de Kok 1996, and Sprouse, et al.1996. A study by Snyder, Williams and Gempko (1997) was useful in determining the details of riparian water use in the San Pedro.

III. Methodology

A. Data Sources

Climate Data

Winter Precipitation

The first task of this analysis was to assemble one-, five-, and ten-year precipitation scenarios that encompassed historic maximum dry conditions in the southwest at each time scale. The analysis uses winter (November – April) rather than annual precipitation for Phoenix, Tucson, Sierra Vista and Benson. According to Sheppard et al (1999), while up to 60 percent of the southwest's annual rainfall comes during the summer monsoon season, under typical climate conditions little, if any, of this amount reaches the aquifer or is stored in reservoirs for later use. Although some summer storms may be large enough to result in actual flows in the normally dry riverbeds of the region, the vast majority of the precipitation is lost to evapotranspiration. Exceptions might occur in unusually wet summer/six month seasons such as that of 1999; however, it is generally not the case that summer precipitation will contribute significantly to water supplies. The highly localized nature of the monsoon rains further diminishes the potential of summer precipitation as a reliable source for augmenting urban water supplies.

This general assumption notwithstanding, we are aware of the important role that intense summer monsoons in the Upper San Pedro Valley can play for recharge. According to Pool (personal communication, 09/23/99), one- to two-year variations in base flows in the San Pedro River at Charleston depend to a great extent on runoff from summer precipitation that recharges the alluvium near the stream. However, the majority of the winter-dry years chosen for this analysis were also relatively dry during the summer. The only two exceptions were August 1954 and 1955 when the Charleston gage recorded several days with high (<2,000 cfs) discharge (USGS/WRD Arizona District at http://wwwdaztcn.wr.usgs.gov).

The unique hydrological and climatological conditions of the Santa Cruz require use of total precipitation amounts for the entire year, rather than only winter precipitation figures for this specific study location. This exception was made in recognition of certain features of the Santa Cruz AMA that are not present in the other study areas (see ADWR 1999c). For one, the aquifer of the Santa Cruz AMA is both smaller in capacity and considerably shallower than is the case in the other study areas. This creates a great deal more surface water/groundwater interaction, and means that the aquifer can be both depleted and replenished within a matter of months, rather than over the longer time scales involved in the deeper aquifers of the other study areas. While summer rains are not believed to result in significant recharge in the other areas due to high evaporation rates and the localized nature of the storms, in the Santa Cruz AMA the monsoons are more widespread, frequent and heavier. In fact, the summer rains are actually seen to be more reliable than is winter precipitation, and have a more pronounced effect on water table levels. The Santa Cruz AMA is currently developing a groundwater model that will allow greater understanding of recharge rates and other hydrological processes within the AMA (Nagle 1999). The figures used in this analysis were the best available during the autumn of 1999, when this analysis was constructed. Newer figures could result in different conclusions than those drawn here.

Precipitation Records

Data from the Western Regional Climate Center's website (http://www.wrcc.dri.edu/) proved useful for identifying precipitation trends over the period of record for each location. The U.S.A. Divisional Climate Data Plots provide the actual winter or annual precipitation amounts for each climate division for the period 1890 to the present, along with the long-term average precipitation amount for this time period. Climate divisions were deemed a more appropriate scale than more localized measurements, because data at this level eliminates much of the microclimatic variation between locations. Additionally, this level of measurement better reflects the impacts of widespread winter storms that often cover the entire area and affect regional water supply systems such as reservoirs, rivers and aquifers. Finally, it should be noted that elevation has an important effect on precipitation levels and groundwater recharge. The study areas' wide range of elevations, from approximately 1,000 ft to 4,600 ft, is well captured in the two climate divisions (Central East and Southeast) on which this analysis is based.

Climate Divisions of Arizona
(Modified from WRCC)

Fig. 2

1	Northwest
2	Northeast
3	North Central
4	**East Central**
5	Southwest
6	South Central
7	**Southeast**

The East Central Division was used to obtain data for the Phoenix AMA (the city's average elevation is 1,082 feet) while the Southeast Division was used for the Tucson (average elevation 2,437 feet), Nogales (3,857 feet), Benson (3,576 feet), and Sierra Vista (4,600 feet). The seven climate divisions for Arizona are depicted in Figure 2. Mean precipitation records are summarized in Table 1. It is important to note that the winter precipitation in the Tucson AMA, and in Benson and Sierra Vista, varies from the winter average precipitation amount of 5.18 inches indicated for the entire climate division. Since the climate division also includes data from higher mountain elevations, it is not surprising that all four locations are, on average, drier than the mean winter precipitation value of 5.18 inches might suggest. However, the amount of inter-annual variation between sites varies by approximately the same proportion across the region. Similar findings were noted for Nogales, based on annual precipitation records.

An attempt to correlate and verify these precipitation records with historic streamflow data was only partially successful. For the San Pedro River, the earliest data available are for March 1904 (USGS/WRD Arizona District, http://wwwdaztcn.wr.usgs.gov). For the Santa Cruz River, regular records start only in 1936. Thus, a direct comparison for both the driest winter (Nov 1903 to April 1904) and the driest five-year period (1900 to 1904) on record was not possible. However, a comparison between precipitation records from the driest ten-year period (1947 to 1956) and available streamflow data for the same period of time reveal a strong correlation. Combining the streamflow data for the San Pedro and the Santa Cruz Rivers during this ten-year drought period results in 42,930 af/year (71.45 percent of the long-term mean) (USGS/WRD Arizona District, http://wwwdaztcn.wr.usgs.gov). This closely reflects the proportion of winter precipitation actually received during the same time period when compared with the long-term mean (74 percent) calculated for the Southeast Climate Division. While a direct comparison for the other drought periods was not feasible, a similar strong correlation might be assumed.

Table 1: Summary of Climatic Variation in Project Locations

Climate Division	Mean Annual Precipitation	Mean Period Precipitation	Driest One-Year Period	Driest Five-Year Period	Driest Ten-Year Period
East Central (Phoenix AMA) **Winter Precipitation (Nov – April)**	19.00 inches	10.21 inches	1904 1.18 inches 11.57 percent of mean	1900-1904 28.42 inches total 5.68 inches/year 55.7 percent of mean	1946-1955 74.66 inches total 7.47 inches/year 73.16 percent of mean
Southeast (Tucson AMA, Benson Subwatershed, Sierra Vista Subwatershed) **Winter Precipitation (Nov – April)**	14.33 inches	5.18 inches	1904 0.6 inches 11.58 percent of mean	1900 – 1904 14.73 inches total 2.95 inches/year 56.95 percent of mean	1947 – 1956 38.27 inches total 3.83 inches/year 73.94 percent of mean
Southeast (Santa Cruz AMA) **Annual Precipitation**	14.33 inches	14.33 inches	1948 7.94 inches 55.4 percent of mean	1900-1904 49.9 inches total 9.98 inches/year 69.64 percent of mean	1948-1957 115.83 inches total 11.58 inches/year 80.8 percent of mean

The data were utilized in the following manner:

- ♦ Mean winter precipitation was used for the Phoenix AMA, the Tucson AMA, and the Sierra Vista and Benson subwatersheds as a baseline for comparison. Annual precipitation was used for the Santa Cruz AMA. The baseline amounts were multiplied by five and ten, respectively, in order to enable comparison between the five- and ten-year scenarios.
- ♦ The minimum one-year winter precipitation was identified for the two climate divisions in order to provide parameters for the driest winter conditions experienced during the period of historic record for the Phoenix AMA, the Tucson AMA, and the Sierra Vista and Benson subwatersheds. For both the East Central Division and the Southeast Division, 1904 was identified as the year with the lowest winter precipitation in records. 1904 is also the first year that was recorded as a cold phase/La Niña year (see http://www.publicaffairs.noaa.gov/lanina.html).
- ♦ The minimum one-year annual precipitation amount for the Southeast Climate Division (used for the Santa Cruz AMA calculations) occurred in 1948.
- ♦ The lowest consecutive winter precipitation amounts for a five-year period were identified to determine the most severe short-term drought in record. For both climate divisions, encompassing Phoenix, Tucson, Sierra Vista and Benson, this period lasted form 1900 to 1904. Comparable cold phase/La Niña information for this five-year drought period is not

available; 1904, the last year of this period, constitutes the first entry in the La Niña records while the four prior years are missing (see http://www.publicaffairs.noaa.gov/lanina.html).

- For the Santa Cruz AMA, the lowest consecutive annual precipitation amounts for a five-year period occurred from 1900-1904.
- The ten-year period with the lowest consecutive winter precipitation amounts was identified in order to determine the most severe extended drought on record for the Phoenix and Tucson AMAs, and the Sierra Vista and Benson subwatersheds. The driest ten consecutive winters on record were 1947-1956 for Tucson, Sierra Vista and Benson in the Southeast Climate Division and 1946-1955 for Phoenix in the East Central Climate Division. However, some years within this ten-year period show close to normal precipitation amounts, which is also reflected in alternating cold (La Niña) and warm (El Niño) episodes during this time frame (see http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.html).
- The driest consecutive ten years on record were identified as 1948-1957 for the Santa Cruz AMA, in the Southeast Climate Division.

Demographic Data

The second step in this analysis was to gather demographic data for the year 2025. The intention was to examine possible effects of population growth on water supply and demand, both under average and extreme precipitation scenarios. Population projections were obtained from the Arizona Department of Economic Security website, (http://www.de.state.az.us/links/economic/webpage/popweb/subco97.html.) The Arizona Department of Water Resources uses these same projections in planning for each community's future water needs. For the three study areas that lie within Active Management Areas, ADWR's calculations of future water supply and demand are contained in the Third Management Plans for Phoenix and Tucson, and the draft Third Management Plan for the Santa Cruz AMA. These projections form the basis for analysis of these areas.

DES population projections were also used for Benson and Sierra Vista subwatersheds. However, for some communities within these two units, including the city of Benson, DES estimates for 1998, also obtained through the Department's website, proved already higher than the 2025 projections. Therefore, an alternative population scenario was created (POP High). It is based on 1990-1998 population growth rates for all the communities in the two subwatersheds. The 1990 numbers were derived from Lord et al. (1991). The two different projection results are shown in Table 2. Similar problems with regard to population forecasts were not noted in the AMA areas.

Table 2: Population Projections for Study Areas

Location	Population Baseline	Population 2025 (DES)	Population 2025 (High)
Phoenix AMA	2,549,931 (1995)	4,482,876	-
Tucson AMA	768,000 (1995)	1,266,500	-
Santa Cruz AMA	32,975 (1995)	57,675	-
Benson Subwatershed	9,870 (1990)	14,176	18,861
Sierra Vista Subwatershed	49,085 (1990)	76,607	87,052

Water Supply and Demand Data

Three of the study areas, Phoenix, Tucson and Nogales, lie within Active Management Areas (AMAs) established by the Groundwater Management Act of 1980 and administered by the Arizona Department of Water Resources (ADWR). Each AMA office is charged with working toward better management of water supplies and slowing groundwater depletion in its area. The baseline 2025 supply and demand projections for these three areas were derived from each AMA's water budget, included in its management plan. Management plans are issued by ADWR at five to ten year intervals, beginning in 1985.

For the Tucson and the Phoenix AMAs, the numbers were derived from the final versions of the respective Third Management Plans. These management plans cover the period from 2000-2010, and include projections out to 2025. Data from the draft Third Management Plan were used for the Santa Cruz AMA. The Santa Cruz Draft Third Management Plan offers ranges of totals for various supply categories based upon the amount of natural variation present. For most categories of supply, including mountain front recharge and minor tributary flow and underflow figures, the midpoint of the range was used in our water budgets. For main channel and major tributary natural flow, the long-term median figure of 14,283 af, included in the draft TMP on p. 2.-12, was used, due to the fact that this more precise measure based on stream flow existed for this category of recharge. For the effluent amount, the totals included in Appendix 11B of the draft TMP were used, because this provided the breakdown between effluent supplies generated in Arizona and those generated in Sonora. The appendix offered two figures, one for the current use rate and one a conserving rate based on expected improvements to the effluent collection and distribution system. The conserving rate was used, because these improvements have already been planned and budgeted for, and thus it seems likely that they will actually take place by 2025. Baseline figures for 1995 are included in all cases for comparison purposes.

For the Benson and Sierra Vista subwatersheds, the baseline supply and demand figures were derived form the *Hydrographic Survey Report for the San Pedro River Watershed*, published 1991 by the Arizona Department of Water Resources. Baseline figures for the two subwatersheds are located in the first column of Appendices 4 and 5. In order to make these figures comparable to those from the AMAs, water withdrawals had to be computed on the basis of recharge factors. The recharge factor derived for municipal uses was 0.1, which constitutes an acceptable average between the value of 0.05 presented in the ADWR management plans and 0.35 used in an ADWR draft report for the Sierra Vista subwatershed. The recharge factor derived for agricultural uses was 0.34 for the Benson subwatershed and 0.285 for the Sierra Vista subwatershed, based on differential irrigation efficiency. These values were approximated by using EPA and USGS standards. Domestic water withdrawals were calculated by using a recharge factor of 0.275, approximated after ADWR and USGS figures. Water withdrawals for industrial use were directly derived from the ADWR *Hydrographic Survey Report*.

Furthermore, total surface water supply was computed by subtracting surface water outflow from inflow. It was assumed that most of the outflow could be attributed to streamflow related to intense summer precipitation, water that, in any case, would not be available for human use. In addition, 14,584 af of surface water that were unaccounted for in the available data for the Benson subwatershed were not included in the supply numbers.

Finally, the original demand figures for Benson and Sierra Vista had to be disaggregated according to the source of water. Agricultural surface water use for the Benson subwatershed was derived from the *Hydrographic Survey Report*. Surface water used by riparian vegetation was assumed to amount to 25 percent in both subwatersheds (approximated after Snyder, Williams and Gempko 1997).

While the information in the Management Plans for the Phoenix, Tucson and Nogales AMAs does provide some disaggregation of water sources used to meet demand, it was not in a form that could be directly recalculated for each scenario.

B. Scenario Construction

Supply Side Calculations

The renewable sources considered in the supply calculations for this analysis include surface water, natural groundwater recharge, Central Arizona Project (CAP) deliveries, and effluent supplies. It should be noted that not all of these sources of water are used in each location; rather, each area relies on a unique combination of supplies to satisfy the needs of its community. The analysis shows that reliance on greater or lesser proportions of each supply contributes to a location's overall sensitivity to climatic fluctuations (see the Analysis of Climate-Induced Changes in Supply section).

This approach seeks to identify fluctuations in renewable water supplies, with the assumption that any shortfalls will be met by groundwater overdraft. This is currently the case, to a greater or lesser extent, under mean annual conditions in all study areas. New water supplies are being developed in some cases, notably through the addition of CAP supplies in the Tucson AMA, the lining of surface water distribution canals and expansion of reservoirs in the Phoenix AMA, and greater effluent use in most areas. However, when combined with the expected population increases, overdraft conditions are expected to continue in all study areas (see ADWR 1999a, 1999b, 1999c). The amount of groundwater overdraft required during the various scenarios tested can be taken as a measure of the level of sustainability of each area's use of its water resources, both during normal climatic conditions and during extreme events, at one-year, five-year and ten-year time scales. Renewable water supplies are disaggregated from non-renewable groundwater use throughout the analysis.

The supply calculations made in this analysis allow for a rough estimate of the impact of climatic variations on water supply. For the purposes of this analysis, under the assumption that drought constitutes a greater climatic stress on urban water systems than unusually high rainfall, only drier than normal conditions are used. Several simplifications of the conditions tested were made. For example, the analysis does not take into account variations in temperature nor the time lag between rainfall events and actual groundwater recharge.

Surface Water

Following Nash and Gleick's hydrologic model (1991) on the impact of climatic changes on streamflow in the Colorado River basin, a linear relationship between precipitation and surface water availability was assumed. For the Phoenix, Tucson, Sierra Vista and Benson portions of this analysis, winter precipitation is considered the primary factor for the amount of surface water available for use. Although most of the rivers in the Southwest experience highest streamflow during the summer rains, this surface water is usually not available due to rapid runoff and/or high evaporation (Sheppard et al, 1999). Thus, percent deviations in winter precipitation were proportionally translated into changes in surface water supplies. For instance, a reduction of 30 percent in winter precipitation compared to the long-term mean was assumed to result in 30 percent less surface water supply.[2] Similar methodology was used with annual precipitation deviations from the median in the Santa Cruz AMA for the reasons discussed in the Climate Data section of this report.

To verify the skill of the linear-relation approach, we compared the calculated percentage reductions in surface water supply with actual surface water records for periods of interest at the gaging stations at Charleston (San Pedro River) and at Buena Vista (Santa Cruz River). These data are available at the USGS/WRD Arizona District at http://wwwdaztcn.wr.usgs.gov. For the ten-year drought, the only period of interest in which both precipitation data and streamflow data

[2] Changes in temperature that have a negative impact on snow pack accumulation and snow water equivalent were not factored into this analysis, nor has the possibility of earlier snowmelt. These are areas requiring additional research.

were available, there was a deviation of no more than 2.55 percent, which we consider to be within an acceptable range. This negligible difference confirms that, although there exist non-linear relationships between precipitation and streamflow due to variable rainfall intensities and antecedent rainfall conditions (Pool 1999), the approach taken is well-suited for the overall purpose of this analysis.

Since rainfall and flow patterns in the Southwest are highly localized and variable, the reliance on climate divisions instead of local weather/climate stations proved very useful. By using a wider geographic region, it was possible to take into account precipitation that occurred in more distant locations but still had an impact on local surface water availability.

The most significant surface water source utilized in the Phoenix and Tucson AMAs is Colorado River water via the CAP canal. This resource is discussed in a separate section. Other important surface water sources used in the study areas are the Salt, Verde and Gila Rivers, which supply Phoenix AMA, and the San Pedro, which contributes to supply in Benson and Sierra Vista. The Santa Cruz River system supplies only a small amount of surface water to the Santa Cruz AMA, but it is a significant source of groundwater recharge for both the Santa Cruz and Tucson AMAs.

Natural Groundwater Recharge

Natural groundwater recharge occurs in all study areas, either in the form of streamflow infiltration or mountain front recharge or both. It forms a large proportion of the renewable supply in every location but the Phoenix AMA, where its importance is overshadowed—at the AMA level, though not necessarily in specific local areas—by renewable water sources. The same linear relationship assumed between surface water and winter precipitation is also assumed for natural groundwater recharge. Winter storms in much of Arizona are generally more widespread, less intense and likely to last several hours or days, and thus have much greater recharge potential than highly localized, intense and brief summer storms where most precipitation is lost to evaporation. In fact, Sheppard et al (1999) report that while winter precipitation (between November and March) provides an average of only thirty percent of the total annual rainfall in the region, this amount is far more important to the total recharge amount.

Although in reality recharge amounts are extremely variable depending on a multitude of factors including temperature and the duration, severity and frequency of precipitation, the simplified assumption of a linear relationship was used for the purposes of this preliminary analysis. Variations in mountain front recharge rates, which are closely linked to topography, altitude, geology, vegetation, and particular snow pack conditions and have important effects on local hydrology, are also beyond the scope of this analysis. As in the case of surface water supply, percent deviations in winter precipitation were proportionally translated into changes in naturally recharged groundwater. Accordingly, a reduction of 30 percent in precipitation, for example, was assumed to result in 30 percent less natural recharge.

The same type of linear reduction was derived from the annual precipitation records in the Santa Cruz AMA. Annual records rather than winter precipitation data were used due to the greater degree of surface water / groundwater interaction and the increased importance of summer rains in this area.

A more sophisticated approach for calculating recharge has been proposed by Anderson, Freethy and Tucci in their Regional Aquifer-System Analysis (USGS, 1992). In this study, a logarithmic function was developed, relating annual precipitation over a watershed to average-annual recharge. A direct comparison between the recharge numbers calculated in this analysis and numbers produced by using the USGS approach was not feasible, primarily because of differences in the units of analysis (watersheds versus climate divisions, precipitation in acre-feet versus precipitation in inches). Also, the USGS study defines an arbitrary threshold value of 8 inches of precipitation/year (roughly 2,000 af/year of mountain front recharge) below which the water budget in insensitive to this type of recharge. In contrast, in this analysis recharge is assumed to occur no matter how little precipitation is received over the unit of analysis because recharge amounts are calculated in proportion to precipitation. It can be noted, however, that overall water supply under drought conditions, at least in the two subwatersheds in the Upper San Pedro River Basin, would be 25 to 40 percent smaller if this 2,000 af/year threshold value were taken into account.

Direct Use of Effluent

Effluent, which is treated water discharged from wastewater treatment plants, is unusual in that it is expected to increase with population growth, as opposed to other water sources that are currently being exploited to the extent of their natural limits. It was assumed that larger municipal populations would use more water, thereby also increasing the amount discharged to wastewater treatment plants. ADWR's 2025 projections for effluent use were used in the AMA areas. In the Benson and Sierra Vista subwatersheds, the amount of effluent available was adjusted in proportion to growing population numbers. Although effluent supplies are currently a relatively minor portion of the water supply, by 2025 the situation is expected to change dramatically in the Phoenix and Tucson AMAs and to increase to a lesser extent in the other study areas.

Effluent supplies are a particularly important factor in the Santa Cruz AMA. Approximately 16,188 af of the AMA's water supply is generated by waste water discharged from the Nogales International Wastewater Treatment Plant (NIWTP); this amount is expected to increase to 19,549 af by 2025. Of the 1995 total, 11,169 af was generated in Nogales, Sonora, while 5,019 af was generated in municipal areas on the Arizona side of the border. The riparian corridor along the Santa Cruz River is dependent on this discharge, and incidental recharge of this water source is important in replenishing the aquifer. Because of the unique nature of the Santa Cruz AMA's hydrology and water supply, an additional scenario involving a reduction in effluent supplies and associated recharge was constructed for this area. This water source is expected to expand in the coming years as population growth and expansion of the sewage conveyance system on the Mexican side of the border results in an increased waste stream to be treated at the NIWTP. At present, wastewater from Mexico constitutes about two-thirds of the effluent discharged by the treatment plant. It is conceivable that a treatment plant could be constructed in Mexico to service Nogales, Sonora, or that Mexico may develop the capacity to utilize its wastewater. Under Minute 227 of the International Boundary and Water Commission Agreement between the United States and Mexico, Mexico may use a part or all of the Nogales, Sonora sewage in its own territory whenever it desires to do so. The impacts of such an action are analyzed in the "Reduced NIWTP" scenario. While this turn of events might seem particularly probable during a severe sustained drought, when efforts to maximize supply would be heightened, ADWR officials in the Santa Cruz Active Management Area believe this to be unlikely (Nagle 1999). The consensus is that Sonora will continue to send the same volume of water to the NIWTP, but build its own facilities to treat additional wastewater generated by the expanding population.

It is also possible that groundwater pumping could increase south of the border, as Sonora moves towards greater utilization of water supplies in the Los Alisos aquifer. Increased pumping south of the border would affect the amount of groundwater flowing into the aquifer of the Santa Cruz AMA, which could, in turn, affect the amount of underflow to the Tucson AMA. However, quantifying a specific set of circumstances including the amount and location of pumping is beyond the scope of this analysis. These issues are discussed more fully in the Implications section of this document.

Central Arizona Project (CAP) Water

One supply factor that merits special consideration for the Phoenix and Tucson AMAs is the state's water rights to Colorado River water. Under normal conditions Arizona is entitled to a total of 2.8 maf of Colorado River water; half of this amount, 1.4 maf, is designated as Central Arizona Project (CAP) water[3]. The distinction is important, for the CAP allotment is legally defined as a water right that is junior to all other Lower Basin rights defined under the Colorado River Compact. As Sax et al (1991: 703) note, the Colorado River was significantly over-allotted in the original Colorado River compact; the 16.4 maf flow at Less Ferry that the Colorado Compact allocations were based upon was later found to be the highest flow in 500 years (MacDonnell et al 1995). Tree ring records indicate that flows vary from 4.4 maf to over 22 maf, with the average being about 13.5 maf (Meko, Stockton and Boggess 1995; Tarboton 1995). Clearly climatic variability has already impacted allocation of this resource. An increase in the degree of natural variation in rainfall and temperature could push high and low flows to new extremes. The implications of the CAP canal's junior standing of this right become very apparent when the existing doctrine of prior appropriation (first in time, first in right) is combined with extended drought in the upper Colorado Basin. In a case such as this, it is entirely possible that Arizona could receive no CAP water at all.

A cutoff in CAP water could be particularly problematic for the Tucson AMA in the future, when both reliance on CAP supplies and population pressure are greater. By 2025, the AMA is expected to meet nearly half of its water needs with CAP water, and will continue to have no other substantial supply sources except for groundwater.

Adding to the Tucson AMA's sensitivity to climate impacts is political resistance to allowing direct delivery of CAP water for municipal use within the City of Tucson water service area. Until recently, city policies required CAP water to be recharged to the aquifer and withdrawn at a later date, after it has presumably undergone filtering and mixing with groundwater. Yet, situations such as the dry 1999 winter, which was influenced by La Niña conditions, prompted warnings that water use must be cut by 10 percent to ensure stability of deliveries (*Arizona Daily Star, May 3, 1999).* Direct delivery of CAP water to homes is clearly one of the most readily available alternatives to cope with stresses to the local water system. The November 1999 election produced a turning point in local institutional arrangements when voters approved a ballot measure to relax the restrictions on management of CAP water supplies. Local water providers remain sensitive to customer resistance to receiving CAP water, however. One provider continues to emphasize maximizing recharge and initiating delivery of a blend of CAP and groundwater to customers.

As described below, separate scenarios have been developed to gauge the sensitivity of the urban water systems in the two AMAs, based on availability and non-availability of CAP water. In contrast to the situation in the state's two largest metropolitan areas, water providers within the Santa Cruz AMA sold off their CAP allotments to other Arizona water users, due to the economic unfeasibility of extending the CAP canal into their service areas. The Santa Cruz AMA must therefore look to other sources to meet its water demands. This is also the case for the Benson and Sierra Vista areas.

The contrast between the two alternatives for handling CAP supplies in the Phoenix and Tucson AMAs allows for evaluation of the impact of the CAP-related water rights framework, under basin-wide drought conditions, on the water budgets of these two urban areas. In the first alternative, the total projected amount of CAP water is included in the renewable supply calculations. The reason for this is that, in the event that a severe drought occurs in (and is restricted to) the Lower Colorado River Basin, Arizona would likely receive its full CAP allocation, since more than 95 percent of the Colorado's flow is generated in the Upper Basin. In the second alternative, all CAP supplies are eliminated from the water budgets for the five-year

[3] As per Section 301 (b) of the Colorado River Basin Project Act.

and ten-year drought scenarios. Here, the underlying rationale is that, if a severe sustained drought were to affect both the Upper and Lower Basins more or less simultaneously (as has been identified in the paleo record by Meko, Stockton and Boggess 1995 for the period 1566-1585), Arizona could lose its 1.4 maf CAP allotment to senior right holders (California, Nevada, non-CAP Arizona, and Mexico) in the Lower Basin. The non-CAP situation was not included in the one-year drought scenario because it is unlikely that such a situation would develop during even the most severe short-term drought because an aggregate of nearly four years of the Colorado's cumulative flow is stored in Lake Mead and Lake Powell (MacDonnell et al 1995). The no-CAP situation is included in the five-year scenario based on an assumption that, although five years would probably not be sufficient to cause a cessation of CAP water availability, the situation could arise if the drought were embedded in a longer, basin-wide period of drier than normal conditions.

It is important to note that, under 1995 population figures, the Colorado River System still contains a bit of "wiggle room" in the allocation of supplies, due to under-utilization by other rights holders. Thus, California has regularly continued to use more than its allotment and Arizona has succeeded in instituting the Arizona Water Bank, the purpose of which is to store "excess" water (i.e. unused Arizona entitlements to Colorado River water) through 2016 (AWBA 1998). By 2030, it is anticipated that development of the capacity of the Upper Basin states to use their full allotments, and growth in demand in Arizona arising from population growth, will result in the disappearance of "surplus" flows. After this time, the only "surplus" likely to be available on the Colorado River will be water produced under unusually wet climatic conditions, such as occurred in 1983. With Colorado River supplies stretched to their limits, relatively smaller climatic fluctuations could be expected to have more severe consequences, and fewer "wet water" options will be available to alleviate the impacts.

Demand Side Calculations

It is assumed that changes in demographic and climatic conditions would not only affect water supply but also water demand. Once the calculations were completed to illustrate the impact of population growth and drought periods on water supply, the demand side of the water budget equation was addressed. For this part of the sensitivity analysis, various parameters were used to capture user adaptations in the municipal, agricultural, and industrial sector as well as altered demands of riparian vegetation. Offsets to demand, including incidental recharge, intentional groundwater recharge, remediation water, and the ADWR-mandated cut to the aquifer and Assured Water Supply replenishment obligation, were included where appropriate to arrive at a net consumption figure for each scenario. Each of these categories will be further explained below.

For the Phoenix AMA, the Tucson AMA and the Santa Cruz AMA, these adjustments were first made to a constructed average hot, dry year. These results are shown in appendix for each location. Based on the results, demand figures for the other scenarios were calculated by establishing the relationship between reduction in supply and increase in demand, and then adjusting proportionally to reflect the severity of the driest historic one, five and ten year periods. The results of these calculations are included in Appendix 1 for the Phoenix AMA, Appendix 2 for the Tucson AMA and Appendix 3 for the Santa Cruz AMA.

For the two subwatersheds in the Upper San Pedro River Basin, adjustments were made for the municipal, the agricultural, and the riparian demand sector. Unlike in the AMAs, changes on the demand side were based on actual historic precipitation records for the one-, five-, and ten-year scenarios rather than proportional adjustments from one constructed average hot, dry year. This was possible because of the way the data are structured in the reference material available.

The results for each scenario are listed under “Water Demand” in Appendix 4 for Benson and Appendix 5 for Sierra Vista.

Again, basic demand information was taken from 1995 baseline figures in the water budgets of the Third Management Plans for the Phoenix AMA and the Tucson AMA and from the draft Third Management Plan for the Santa Cruz AMA. For Sierra Vista and Benson, basic use numbers were derived from the *Hydrographic Survey Report for the San Pedro River Watershed* (1991).

Municipal Demand

In determining annualized impacts of the drought scenarios on demand in the study areas, it was assumed that the summer monsoon season would be relatively dry, as was generally the case for the drought years on which the scenarios were based. As discussed below, drier summer monsoon conditions have implications for overall water demand, with outdoor water use constituting the important variable. It is recognized, but not addressed, in this analysis that a very wet monsoon season can occur in the midst of a dry period, as occurred during summer 1999, which was sandwiched between two very dry La Niña winters.

In the AMA study areas, municipal demand projections for 2025 were taken from the management plans of each respective area. Increases in expected population for Benson and Sierra Vista according to the projections for the year 2025 (DES and Population High Scenarios) were translated proportionally into increases in municipal demand. For the Sierra Vista and Benson subwatersheds, a 20 percent higher population size was assumed to result in 20 percent higher municipal water demands. In order to simplify the calculations and guard against making unprovable assumptions, possible changes in per-capita use such as conservation measures were not taken into account in any of the study areas; thus the 1995 gallons per capita per day (gpcd) rate was also applied to 2025.

In calculating climate-induced changes to municipal demands, a study by Woodard and Horn (1988) provided many useful insights. In their analysis of urban water use in the Phoenix AMA and Tucson metropolitan areas, they note that fluctuations in the gpcd rate are largely due to increased outdoor water use during hot, dry periods; indoor water use remains relatively constant regardless of climatic conditions. They also found that frequency of rainfall is a much more important factor in determining water use than either intensity or duration of rainfall. Based on these assumptions, Woodard and Horn calculated that the municipal gpcd rate increases by 11.4 gallons during hot, dry years in the Tucson AMA.

To assess the validity of this rate of variation in gpcd use in the other urban areas, precipitation probability statistics for each location were derived from the climate records database set up by the Western Regional Climate Center. Variation in gpcd rate between locations was at its greatest during the summer monsoon season, roughly early July through early September. Outdoor water use (the portion of water use most affected by climatic variability) is also high at this time, although not as great as during the pre-monsoon months of May and June. Using Woodard and Horn’s 11.4 gpcd increase as a baseline for increased summer watering given the level of rainfall probability in the Tucson AMA, gpcd rates for the other locations were adjusted accordingly.

Woodard and Horn derived the baseline figure of 11.4 gpcd variance in Tucson in response to climatic variations from a sampling of years that they characterized as hot and dry; this figure does not reflect variations caused by the precise degree of heat or drought. In the CLIMAS sensitivity analysis it was assumed that such a sampling of hot, dry years would reflect the normal range of hotness and dryness, within one standard deviation of the norm. For all study areas, this basic degree of variation was applied across all scenarios. Note, however, that the calculation does not precisely reflect the variations in severity between one-, five-, and ten-year droughts.

Rainfall is roughly ten percent less likely in the Phoenix AMA during monsoon season than it is in the Tucson AMA. Therefore we assumed that the Phoenix residents would not count on rainfall to water outdoor landscaping to the same extent as the Tucson AMA residents, and relatively high watering would continue throughout the year, with less variation during periods of climatic extremes than is seen in the Tucson AMA. Therefore, we calculated that 7.1 gpcd of water use in the Phoenix AMA is subject to climatic influence, and increased per capita water consumption by this amount.

For Santa Cruz AMA, gpcd rates for 1985-1998 for the water provider areas of the City of Nogales, Rio Rico Utilities, Valle Verde Water Company, and Citizens-Tubac were examined. After reviewing climate records for this time period, 1993 was taken as a year with normal precipitation and thus a normal gpcd rate, and 1997 as a year with drier-than-normal conditions and an elevated gpcd rate. The difference between gpcd rates for each area were calculated, and resulted in an increase of 5 gallons per capita, or 2.7 percent, between normal and dry years. Thus 2.7 percent was added to municipal demand in the drought scenarios.

For the two subwatersheds in the Upper San Pedro, mean per-capita water use numbers for the two urban areas were derived from a study of water resources and efficient management in the San Pedro Basin written by Lord et al. (1991). Additional information was obtained from the Bella Vista Water Company, the largest provider in the Sierra Vista area. Benson Municipal Water declared itself unable to provide insightful facts due to a pending lawsuit. Probabilities of monsoon rainfall, a useful indicator for the outdoor watering behavior of urban residents, were derived from the climate records database from the Western Regional Climate Center.

Mean per-capita use in Sierra Vista amounts to 150gpcd (1990), with approximately 100 gpcd indoor use over the entire year and 90-103gpcd outdoor use between April and September. Based on a 20-47 percent chance of rain in a one-day period during the monsoon season, which is slightly higher than in Tucson AMA, an average of additional 10 gpcd of annual water use during a dry period is calculated for the entire subwatershed. The 10 gpcd represent a proportional adjustment to the 11.4 gpcd used for the Tucson AMA given the higher probability of rain in the Sierra Vista area. This increase of 10 gpcd can be translated into a 7 percent increase in municipal water use.

For Benson, an increase of 5gpcd (3 percent) municipal water use was calculated for dry periods. Despite the fact that the probability of rainfall in a one-day period during the summer months is slightly lower than in the Sierra Vista area (17-35 percent), changes in municipal water use are not as pronounced. This might be explained by the fact that outdoor water use, especially gardens and watered lawns, in the Benson area is not as significant as in the urbanized area of Sierra Vista. As indicated by the Bella Vista Water Company in Sierra Vista, outdoor water use for July 1997, the month with the highest water use, amounted to 136gpcd. Even though there were no directly comparable values available for Benson, the numbers in Lord et al. (1991) suggest a maximum outdoor water use of 69gpcd for the driest season (April – June).

Table 3: Gallons per Capita per Day (gpcd)

Location	Percent Variation	Average annual gpcd rate	Average annual gpcd rate under hot, dry conditions
Phoenix AMA	3	238	245
Tucson AMA	7	172	183.4
Santa Cruz AMA	2.7	185	190
Benson	3	168	173
Sierra Vista	7	150	160

Agricultural Demand

Based on ADWR estimates for the Phoenix AMA, Tucson AMA and Santa Cruz AMAs (ADWR Third Management Plans, 1998), and for the Sierra Vista and the Benson subwatershed (*Hydrographic Survey Report for the San Pedro River Watershed*, 1991), variations in annual precipitation and temperature were translated into changing water requirements for irrigated crops. It is assumed that more irrigation water has to be withdrawn when overall precipitation decreases to compensate for higher evapotranspiration rates and greater use of water by plants.

The nature of agriculture within the three AMA study areas varies, and the particular characteristics of water demand in each location were taken into account. In the Phoenix AMA, the predominant crops are cotton, alfalfa, wheat and barley. Vegetables, citrus, potatoes and melons are also important (ADWR 1999a: 3-6). In the Tucson AMA, cotton rotated with winter wheat or barley is the most important crop. Pecan crops are important in some southern areas of the AMA, while grain sorghum, alfalfa, pasture grasses and vegetables are also grown (ADWR 1999b: 3-3). Agriculture in the Santa Cruz AMA, on the other hand, consists primarily of cattle ranching on open range land, with forage crops such as winter wheat, alfalfa, Bermuda grass, sorghum, native pasture, and fescue being the major crops. Vegetables and grapes are also grown.

Calculations of water use during the drought scenarios were based on changes in evapotranspiration rates. In all instances, the number of acres under irrigation, whether row crops in the Phoenix AMA or pastureland in the Santa Cruz AMA, is unlikely to change under short-term drought conditions (Fish 1999, personal communication). While it is probable that during longer-term dry periods farmers might fallow some crop or range lands, assumptions regarding the precise nature of such changes are beyond the scope of this analysis.

In the AMA study areas, evapotranspiration rates included in ADWR information covering 1985-1995 were used to adjust consumptive use rates. For example, with regard to the Tucson AMA, the Western Regional Climate Center data revealed that 1988 was a year with 24 percent less than average precipitation and showed a corresponding evapotranspiration rate of 78.24 inches. In 1989, rainfall was 39 percent lower than normal, and the evapotranspiration rate was 85.93 inches. Since one standard deviation represents the outer limits of normal climatic variation, the evapotranspiration rate for that climatic condition (82.09 inches) was applied to all scenarios. This evapotranspiration rate is 6.4 percent higher than the ten-year average evapotranspiration rate of 77.15 inches. Therefore, it can be assumed that if the consumptive use rate of crops in the Tucson AMA is normally 3.6 acre feet per acre, the consumptive use rate during a year with one-third less rainfall would be 6.4 percent higher, or 3.83 af/acre. This standardized rate of increase was used for each drought scenario at each time scale.

Corresponding information was available for the Phoenix AMA, and the same type of calculations were made. The change in evapotranspiration rate between normal and a standardized hot, dry year was 3.7 percent. This resulted in a new consumptive use rate of 3.94 af/acre for the dry period, in contrast to the baseline rate of 3.8 af/acre. For the Santa Cruz AMA, evapotranspiration rates were not available, so consumptive use per acre was estimated. The evapotranspiration rates for Tucson AMA rates were combined with the consumptive uses rates for the Santa Cruz AMA to give the new consumptive use rate of 2.86 af/acre during the dry period. This is a 6.4 percent variation on either side of the normal evapotranspiration rate. This rate was applied to each drought scenario.

Based on the type of information available, a slightly different methodology had to be used for the two subwatersheds in the Upper San Pedro River Basin. Agricultural demands are linked to the total water requirement of irrigated crops which is a function of annual precipitation and water availability. Unlike in other scenarios where winter precipitation from the Southeast Climate Division was used, this component of demand required annual rainfall data from the available local weather/climate stations in order to capture highly variable and localized rainfall and its direct impact on crop requirements. Technically, annual precipitation was converted into effective precipitation[4] and the difference between a certain threshold value specified. The actual amount received was then accounted for through increased/decreased crop consumptive use requirements[5].

The values used for the Sierra Vista subwatershed are as follows: crop consumptive use requirements of 2.59af/acre and effective precipitation of 0.78af/acre. This results in an average total water requirement of 3.37af/acre for an irrigated acreage of 2,181 in 1990. The most dominant crops are pasture crops, accounting for 54 percent of all irrigated crops in the subwatershed (HSR, 1991). The next major crop type is alfalfa (17 percent), followed by grapes (11 percent) and turf (10 percent).

The numbers used for the Benson subwatershed are slightly higher. Crop consumptive use requirements amount to 2.78af/acre while effective precipitation remains at 0.78af/acre. Higher crop consumptive use requirements might occur with a different crop mix and/or less efficient irrigation techniques. A total average water requirement of 3.56af/acre is used for an irrigated area of 5,330 acres. Pasture crops are the most dominant crop type in this subwatershed, with all pasture crops amounting to 53 percent of the crops grown in 1990 (HSR, 1991). The next major crop type is alfalfa (29 percent), followed by small grains (11 percent).

Table 4: Consumptive Use per Acre Calculations

Location	Average consumptive use/acre	Average consumptive use/acre under standardized dry conditions
Phoenix AMA	3.80	3.94
Tucson AMA	3.60	3.83
Santa Cruz AMA	2.70	2.86
Benson	3.56	3.67
Sierra Vista	3.37	3.49

Changes in Agricultural Demand

In reviewing the ADWR projections for water demand under current use conditions, it was noted that these projections assume reductions in agricultural activity for the Tucson AMA and Santa Cruz AMA, along with a very slight increase in Phoenix AMA. Substantial municipal growth and moderate industrial growth are expected in all three AMA areas. A review of the Tucson Second Management Plan (ADWR 1991) revealed that the reduction in agricultural water demand due to decreased agricultural activity was a key assumption in this plan; however, reductions did not take place as expected. With this in mind, a scenario was constructed in which agricultural water demand does not change, but is maintained at current levels, in conjunction with the expected level of population growth.

Within the Phoenix AMA, agricultural activity is expected expand very slightly through 2025 as compared to 1995. While some non-Indian agricultural water use in the Phoenix AMA will be transferred to municipal interests, increases in Indian farming will more than offset any overall reduction. This shift is primarily due to recent settlements of previously conflicted Indian water rights claims. Although the potential exists for Indian tribes to sell or lease some of their water rights to municipal interests, the mechanisms for doing so are not clearly established, and

[4] ADWR defines effective precipitation as the portion of annual precipitation falling on cropped acreage during the growing season that provides some of the water consumptively used by the crop.
[5] Consumptive use is the amount of water actually used by the plant and therefore no longer available in the water supply (ADWR).

some settlement agreements place restrictions on water marketing. In any event, it is likely that such arrangements would require lengthy negotiation, and perhaps litigation.

In order to test the other extreme of the agricultural decline question, another scenario was constructed in which agriculture was eliminated. Although unlikely in areas where agriculture is a major component of the local economy, such as Benson, Nogales and Phoenix, this scenario is less far-fetched in Tucson or Sierra Vista, where municipal interests are exploring the potential of water transfers and sales. While agriculture would probably not be totally eliminated in any of our study areas, cutting the agricultural component of total water demand allows us to see how this most extreme case would impact water supplies for other needs.

Industrial Demand

Some types of industry are likely to be affected by climatic variability, while others are not. The management plans for the Phoenix, Tucson and Santa Cruz AMAs provided breakdowns of the amount of water used by different types of industry for each area. Industrial turf facilities (such as golf courses), for example, would need to change their water use according to climatic conditions. Turf was therefore subjected to the same calculations as crops were to determine the effect of higher or lower evapotranspiration rates on water use. Dairies constitute a small percentage of water use in Phoenix AMA and Tucson AMA, and none at all in the Santa Cruz AMA. There is a tiny amount of feedlot water use in Phoenix AMA. These amounts were altered by the same percentage as agricultural crops were; they would be likely to show some variation in demand, but it is unclear how great it would be. Mining, on the other hand, is far more sensitive to fluctuations in the world market price for metals than to climatic variation, so it was not altered. Sand and gravel facilities were not expected to change water use according to climatic conditions. Nor were electricity production facilities, since, as the Tucson AMA Third Management Plan notes, increasing amounts of power are purchased from outside producers. These producers are more likely to be called upon to meet additional demands during climatic fluctuations than local electricity producers would be.

No changes were assumed for industrial uses in the two subwatersheds of the Upper San Pedro. Not only do these local industries account for a very small percentage of overall water uses (1 percent), their water demands are also very unlikely to be affected by climatic changes. Therefore, changes in industrial demands were emitted from the detailed scenario descriptions.

Water Use by Riparian Vegetation

Riparian vegetation is also assumed to react to climatic variations and resulting changes on the supply side. To calculate the impact of increased precipitation on water requirements for riparian areas within the AMAs and along the Upper San Pedro, the same respective approaches as for agricultural demands were used. It is assumed that more water has to be withdrawn from groundwater sources when overall precipitation falls below a specific threshold.

Thus, for the Phoenix, Tucson and Santa Cruz AMAs, evapotranspiration for riparian use was altered 3.7 percent, 6.4 percent and 6.4 percent respectively. It should be noted that riparian water use is far more significant in the Santa Cruz AMA, due to its much larger riparian habitat along the Santa Cruz River. The flowing water and lush vegetation along this stretch of the river is supported by the outflow of the Nogales International Wastewater Treatment Plant.

The riparian area along the Santa Cruz River in the Tucson AMA is much smaller. Although the Phoenix AMA riparian figure is much larger, it is a much smaller proportion of total water use than that of the Santa Cruz AMA. Most of the riparian vegetation in the Phoenix AMA is supported by effluent discharge from the 92nd Street Wastewater Treatment Plant.

According to ADWR figures (*Hydrographic Survey Report for the San Pedro River Watershed*, 1991), average effective precipitation over riparian areas along the Upper San Pedro amounts to 0.42af/acre for both hydrologic units. However, riparian consumptive use requirements are higher in the Benson than in the Sierra Vista subwatershed (2.86af/acre versus 2.46af/acre). Since riparian vegetation relies on both summer and winter precipitation, annual amounts of rainfall, derived from the Southeast Climate Division data set, were used for adjustments during dry periods in Benson and Sierra Vista. Based on actual amounts of rain translated into effective precipitation over riparian areas, total water requirements are calculated for 5,874 acres in the Sierra Vista subwatershed and 6,180 acres in the Benson subwatershed. For this part of the analysis, USGS conversion factors proved very helpful (1 inch of rain = 27,200 gallons per acre = 0.083504af/acre). They are accessible at http://water.usgs.go/watuse/wuconv.html

Offsets to Demand

Offsets to demand appear in the tables as reductions to total water demand. This category includes water that contributes to recharge totals; without it, the amount of natural recharge would be significantly lower. Rather than treating these offsets as an additional supply category, we subtracted the respective amounts from total demand (the San Pedro subwatersheds) or from the specific demand categories (in the AMAs) to obtain total net water consumption. Offsets to demand include incidental recharge in all study areas. Also included are ADWR-mandated AWS replenishment obligation and the cut to the aquifer, both of which were intended to help compensate for groundwater overdraft in the Phoenix and Tucson AMAs. Remediation water is a category unique to the Tucson AMA.

Incidental Groundwater Recharge

Incidental groundwater recharge, which is primarily the amount of water that is applied to but not consumed by crops and turf areas - and thus seeps back into the water table - constitutes a fairly large component of groundwater recharge in each of the study areas. Determining precisely how large a proportion of water demand is actually consumed is an inexact science, and subject to several confounding factors; this figure is subject to change as further research results become available.[6] While recharge volumes may change from year to year depending on how much groundwater pumping is required due to climatic and other factors, the rate of recharge remains constant (Phoenix AMA Draft TMP, p. 11-2). Therefore, for the Phoenix, Tucson and Santa Cruz AMAs, incidental recharge was recalculated using the recharge factors supplied by ADWR for each water use sector based on the calculated increases in demand for each climatic scenario. Recharge factors used for the AMAs are as shown in Table 5. For the two subwatersheds in the Upper San Pedro River Basin, incidental recharge represents the difference between water use as presented in the *Hydrographic Survey Report* and the water demand numbers calculated on the basis of the recharge factors listed under the section on water supply and demand data.

Table 5: 2025 Incidental Recharge Recalculation Factors

(Current Use Scenario)

Location	Municipal	Urban Irrigation	Non-Indian Agriculture	Indian Agriculture	Industrial	Effluent
Phoenix	.04	.24	.26	.24	.04-.12 (a)	.90
Tucson	.04	n/a	.16	.20	0-.12	.90
Santa Cruz	.04	n/a	.34	n/a	.05	.90

[6] It should also be noted that the quality of incidental recharge, once it has leached through pesticide- and fertilizer-laden farmland, has proven unacceptable in the past.

Offsets to Demand

Net natural recharge
In a given year, the volume of water that naturally recharges the groundwater supply minus natural depletions. Components include stream channel infiltration, mountain front recharge, groundwater inflow, groundwater outflow, and evapotranspiration. Counts toward safe yield. (explained in another section – delete?)

Incidental recharge
Originates as groundwater or surface water that percolates to the water table after it has been used for human activity; counts toward safe yield

Cut to aquifer: The volume of water stored under the UWS program as a permanent allocation to the aquifer and thus not recoverable. This water is counted as a contribution to safe yield.

Assured Water Supply (AWS) Allowable Groundwater Mining: This allowance of mined groundwater was intended to assist water providers in the transition from groundwater to renewable water supply use; it is also intended to provide a secure water supply in years when there is a shortage of CAP water.

Remediation Water: This category is composed of poor quality groundwater water used in an incentive program designed to facilitate the remediation of contaminated groundwater; thus the withdrawal of this water supply is counted as a renewable water supply rather than added to the Tucson AMA's overdraft figures.

Note Regarding CAP Recharge
Recharge of CAP water that is ordinarily part of the AMA's allotment does not constitute any addition to the AMA's water supply beyond the original credit as a renewable surface water supply.

Sources: Arizona Department of Water Resources, Phoenix and Tucson Third Management Plans (Phoenix, Arizona, 1999).

IV. Analysis

A. Changes in Supply

The overall goal in constructing the supply scenarios presented here was to identify key variables affecting water supply under various scenarios. In light of the various mixes of water resources available, differences in economic activities important in each area, and due to the variety of information available for analysis, the scenarios were tailored to the unique features of each study area.

All scenarios present two baseline cases: 1995 and 2025 for the Phoenix, Tucson and Santa Cruz AMAs, and 1990 and 2025 for the Benson and Sierra Vista subwatershed. The 1995 supply figures and projections for water supply in 2025 for the Phoenix and Tucson Active Management Areas (AMAs) are based on water supply numbers found in the Third Management Plan (TMP) for each area. For the Santa Cruz Active Management Area, equivalent information was obtained from the area's Draft Third Management Plan (DTMP). The 2025 scenarios for the Benson and the Sierra Vista Subwatershed are based on water supply numbers found in the *Hydrographic Survey Report for the San Pedro River Watershed* (1991), and on DES population projections. Alternative growth projections were also extrapolated from recent growth rates (Pop High), which have been slightly higher than the actual DES 2025 projections.

Although the respective tables in the Appendices show figures for all scenarios, it is important to note that not all of these scenarios include changes in water supply figures. Some scenarios, such as those involving changes in agricultural water use, only reflect changes in water demand factors; others, such as the combinations of 1995 supply and 2025 demand, are only relevant when their combined effects on groundwater use are the focus of analysis. In the interests of clarity and brevity, only scenarios that involve change in water supply factors are discussed and graphed in this section. A brief description of the scenarios is included at the beginning of each study area section.

Phoenix AMA Scenarios

The Phoenix AMA, with a mean annual rainfall of 8.22 inches, is the most arid of the study areas. Average winter precipitation over the entire the East Central Climate Division, however, is 10.21 inches. The latter average was used as the baseline precipitation amount for this study area because the higher elevations in this climate division are an important source of water for the AMA. Further, the AMA's heavy reliance on surface water, accounting for about half of its total water supply under average conditions, suggests considerable sensitivity in the AMA to climatic fluctuation.

The Phoenix AMA is characterized by a wider array of water sources than is the case in the other study areas. In addition to effluent and natural groundwater recharge, which are present in all study areas, the AMA relies heavily on both surface water and CAP deliveries for direct use. This array of different water supply sources may provide the AMA with greater flexibility in switching between water sources to increase overall efficiency and reduce costs. However, the system is not as malleable as it might seem at first glance. Large areas of the AMA are currently beyond the reach of infrastructure required for CAP use; others have rapidly dwindling or contaminated groundwater supplies; still others lie beyond the boundaries of the Salt River Project (SRP) and/or CAP service areas, and thus have limited access to surface water supplies (ADWR 1999a). Improved climate forecasting holds potential to facilitate decision making with regard to the management of water supplies, including efforts aimed at reducing groundwater overdraft. The Salt River Project, the valley's largest water and electricity provider, already integrates climate forecasting into its annual water management processes, and incorporates climate information into decisions such as whether—and how much—additional CAP water should be purchased to supplement projected supplies. This issue will be discussed further in the Implications section.

For the Phoenix AMA, the supply change scenarios graphed at the one-, five- and ten-year time scales are as follows:

- TMP 1995 baseline (for comparative purposes)

- TMP 2025 baseline

- TMP 2025 baseline + drought: 2025 baseline supplies combined with the anticipated affects of one-, five- and ten-year reductions in precipitation in the East Central Climate Division, with CAP supplies held to the ADWR baseline projections

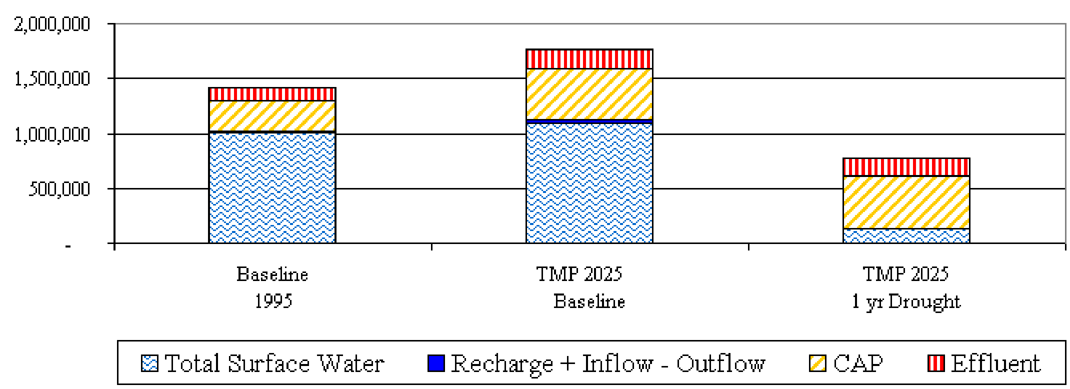
- TMP 2025 baseline + drought and with CAP for the one-year scenario; for the five- and ten-year scenarios, elimination of CAP supply

<u>One Year Scenarios</u>

The results of the one-year scenario calculations are illustrated in Figure 3, below.

Changes in Renewable Supply during One-Year Periods, Phoenix AMA, 1995 and 2025 (acre-feet/year)

Fig. 3



The TMP baseline water budget for the Phoenix AMA, which assumes normal climatic conditions, projects an increase in total water supply of 20 percent between the 1995 and 2025 baseline scenarios (ADWR 1999a). This increase is due primarily to greatly expanded CAP use, both for direct deliveries and through intentional recharge, as the AMA shifts from its reliance on groundwater toward greater use of renewable supplies in its efforts to reach safe-yield. Availability of other surface water is also expected to increase by approximately 8 percent, due to the lining of water delivery and irrigation canals. Incidental recharge (directly related to increased water use) should increase by 1.5 percent, as detailed in the Demand section of this analysis.

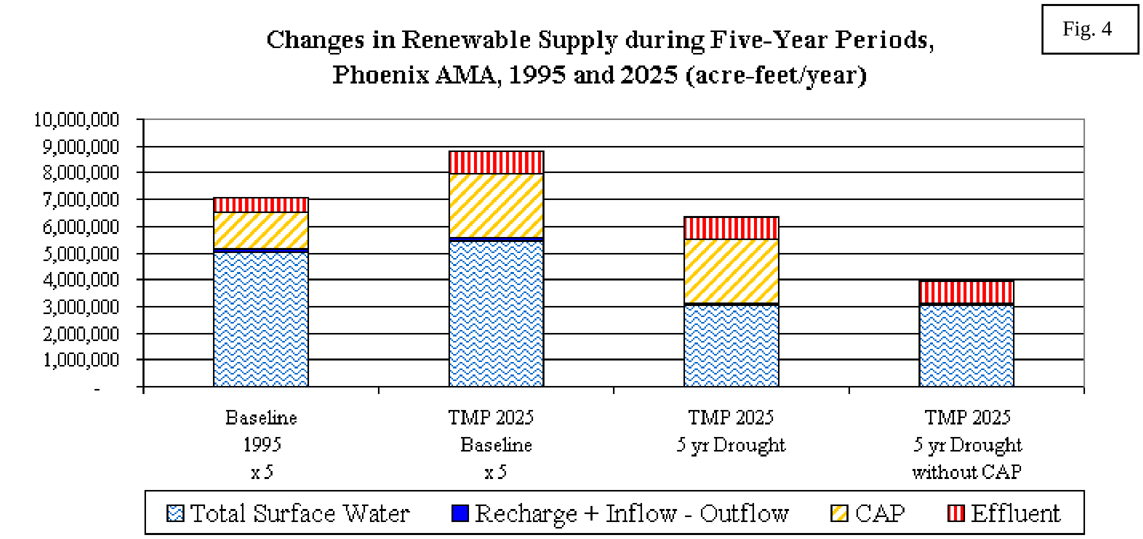
The drought scenario used in the analysis reflects the proportional decrease in precipitation experienced during the driest winter on record, 1904. In this year, only 11.5 percent of the normal amount of precipitation fell. Based on this decrease, surface water availability was reduced to 11.5 percent of the norm, as was natural groundwater recharge. CAP flows were maintained, under the assumption that existing storage in Lake Mead and Lake Powell would compensate for any potential decrease in flows on the Colorado River. Effluent was also assumed to continue being available at the same level.

When drought was figured into the TMP water budget projections for the year 2025, (see the Methodology section for calculation details), the calculations produced a 56 percent reduction in new renewable supplies for the one-year period. Because surface water is stored in a fairly extensive system of reservoirs within the AMA, however, actual impacts over a one-year dry spell would likely not be as severe as this proportion would suggest (see the Demand section of this analysis). Rather, the actual impact of such a drought on water supplies would depend on reservoir levels prior to the dry period.

Five Year Scenarios

The driest five successive winters in the East Central Climate Division occurred between 1900 and 1904. The mean winter precipitation during this period was 5.68 inches, or 56 percent of the normal amount. In analyzing the potential impacts of a 56 percent reduction in precipitation over a five-year period, baseline amounts indicated in the TMP were multiplied by five to allow for comparison; the results for our scenarios are shown in Figure 4.

Fig. 4

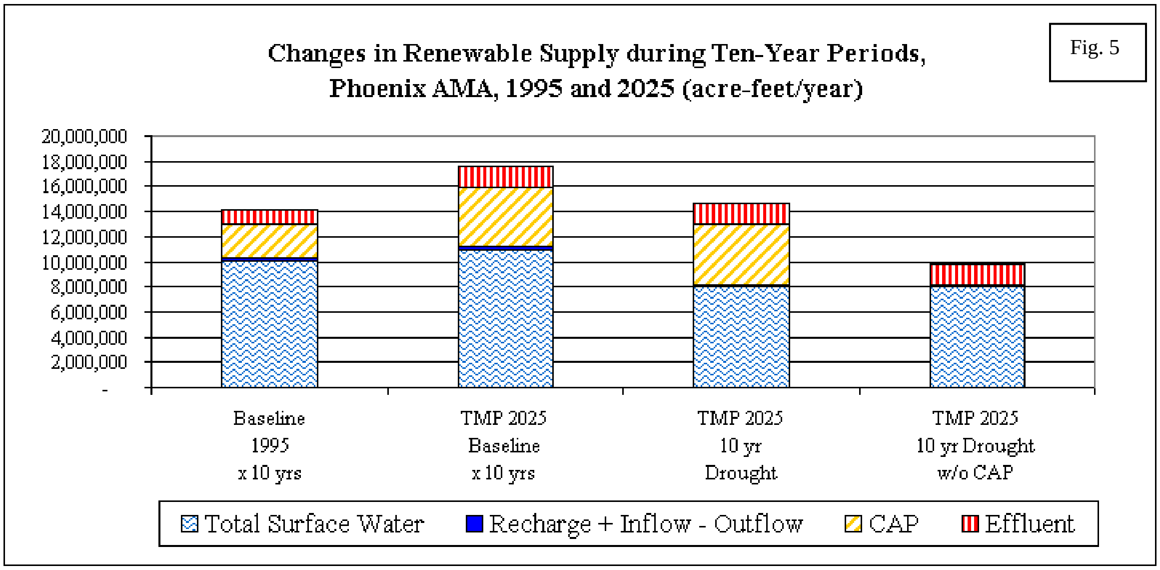


When the five-year drought conditions of 56 percent of mean annual rainfall are applied to the 2025 TMP baseline amount (as described for the one-year drought discussed above), the result is a 28 percent reduction in renewable water supplies.

A further variable was added to the five-year drought scenarios: the elimination of CAP supplies for both direct use and various types of recharge programs. This variable is based on an assumption that extended drought conditions would prevail throughout the Colorado Basin (see the Methodology section). As previously noted, Arizona's CAP allotment has the lowest priority, and would be met only after California, Nevada and non-CAP Arizona received their full allocations. Although it is debatable whether a five-year drought would cause Arizona to loose its CAP allotment at current population levels, this situation would be more likely by 2025 when population and demand growth are expected to result in full utilization of available Colorado River water, even under normal conditions. The combination of 44 percent less precipitation plus the elimination of CAP supplies, which make up over 27 percent of the Phoenix AMA's total renewable water supply, resulted in a reduction of 55 percent below the baseline. Note that, when interpreting this result, an isolated five-year drought within a longer normal or above-average rainfall period would have less severe consequences than if it were to occur after several years of drier than average conditions. For this analysis, we assume normal precipitation conditions prior to the drought.

Ten Year Scenarios

The driest ten-year period in the East Central Climate Division occurred between 1946 and 1955. During that period, mean precipitation amount was 7.47 inches, which is equal to 73 percent of the normal mean. Again, baseline amounts used in these scenarios were multiplied by ten to allow comparison. Results of the calculations are illustrated in Figure 5.



The ten-year scenarios show the same general pattern as one- and five-year scenarios, although the results appear more moderate due to less dry climatic conditions. However, it is important to keep in mind that the cumulative effects of a decade-long drought could actually be more severe than a shorter-term drought of greater intensity due to greater cumulative depletion of aquifers and reservoirs. It must also be kept in mind that extended drought conditions would undoubtedly trigger more stringent conservation rules and, in the case of a decade-long drought, could prompt changes in policies and priorities regarding allocation of available supplies.

Results of the analysis indicate that, when precipitation is reduced to 73 percent of the TMP baseline level, 83 percent of expected renewable supplies is available. The elimination of CAP supplies reduces this figure to only 56 percent of total renewable supplies.

Tucson AMA Scenarios

Average winter precipitation in the Southeast Climate Division, which encompasses the Tucson AMA, is 5.18 inches. Although this is only half of the amount of winter precipitation that the East Central Climate Division receives, it should be noted that this climate division encompasses some extremely arid areas to the west of the Tucson AMA.

The Tucson AMA differs from the Phoenix AMA, as well as some other study areas, in that it does not rely on any natural surface water supplies. At the time that this report was written, Tucson was relying on groundwater reserves to meet virtually all of its water demand. Of that amount, only 25 percent is recharged annually. ADWR estimates that there are 12 million acre-feet of useable water above the 1,000 foot below surface level limit decreed by assured water supply rules (ADWR 1999b). Based on this estimate, current water use patterns, and normal climatic conditions, if Tucson continued to rely completely on groundwater, it has been estimated that readily accessible supplies would be used up within 56 years. At 2025 population projection levels, the accessible supplies would last for 43 years (ADWR 1999b).[1] The Tucson AMA water budget does not include direct municipal use of CAP supplies. Rather, except for direct delivery of CAP water to agriculture, CAP water is allocated to recharge and recovery. The plan assumes that Tucson Water (the largest municipal water provider in the AMA) will recharge sufficient water to meet 80 percent of potable municipal water demand starting in 2005; for other water providers in the AMA, the amount is 75 percent (ADWR 1999b, p. 11-19).

For the Tucson AMA, the supply change scenarios for the one-, five- and ten-year time scales are as follows:

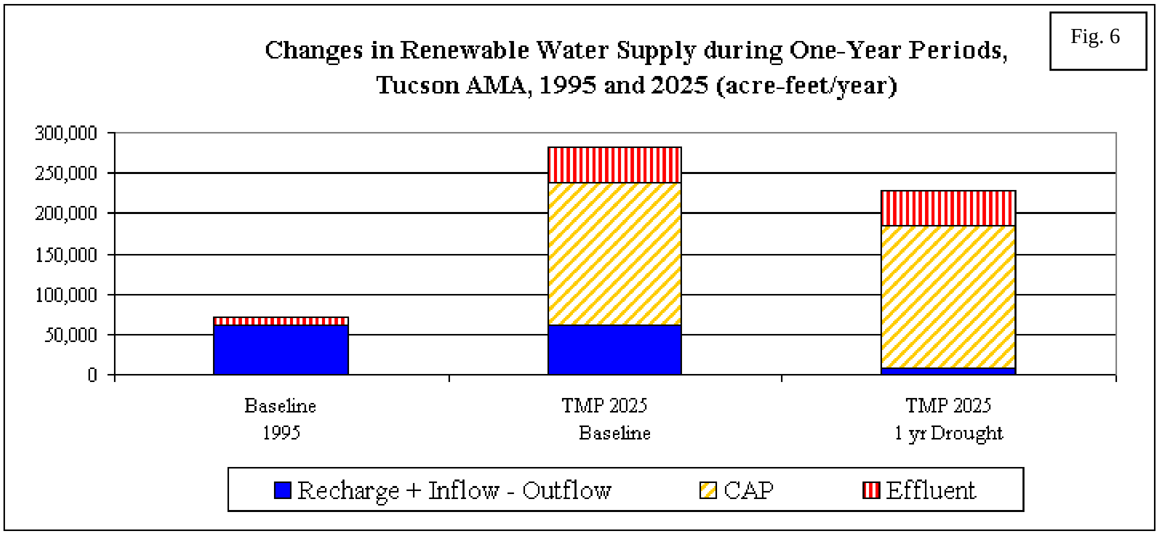
- TMP 1995 baseline (for comparative purposes)
- TMP 2025 baseline
- TMP 2025 baseline + drought: 2025 baseline supplies combined with the anticipated affects of one-, five- and ten-year reductions in precipitation in the Southeast Climate Division, with CAP supplies held to the ADWR baseline projections
- TMP 2025 baseline + drought without CAP: for the five- and ten-year scenarios, CAP supplies are eliminated from water supply calculations

<u>One-Year Scenarios</u>

The lowest recorded winter precipitation for this climate division was 0.6 inches, or 11.5 percent of the norm, during the winter of 1903-1904. As per the methodology section, the 88 percent reduction in precipitation was assumed to reduce natural recharge accordingly, while effluent supplies remained unchanged. Calculations for one-year scenarios are shown in Figure 6, below.

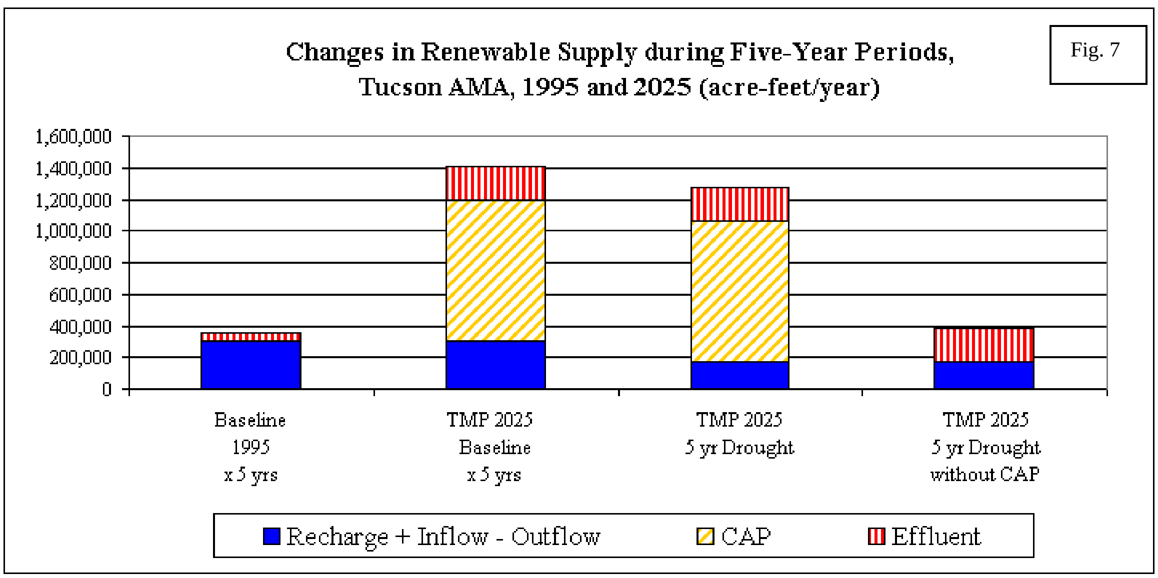
Renewable water supplies under normal climate conditions are projected to more than double between 1995 to 2025, from 71,200 af to 281,400 af, due to the addition of CAP supplies and expanded use of effluent. Even in the drought scenario, with only 11.5 percent of natural groundwater recharge occurring, renewable supplies would still more than triple the 1995 baseline amount. However, when viewed from the perspective of 2025 projections, drought does have significant effects: total renewable supplies decrease to 81 percent of the amount projected.

[1] Tucson voters blocked the direct use of CAP water for municipal purposes in 1995 due to water quality problems linked to the delivery system; however, in November 1999 the initiative prohibiting CAP use was overturned.



Five-Year Scenarios

The driest five consecutive winters on record in the Southeast Climate Division occurred between 1900 and 1904. During that period, winter precipitation averaged only 57 percent of the mean. Calculated reductions in supply are shown in Figure 7.

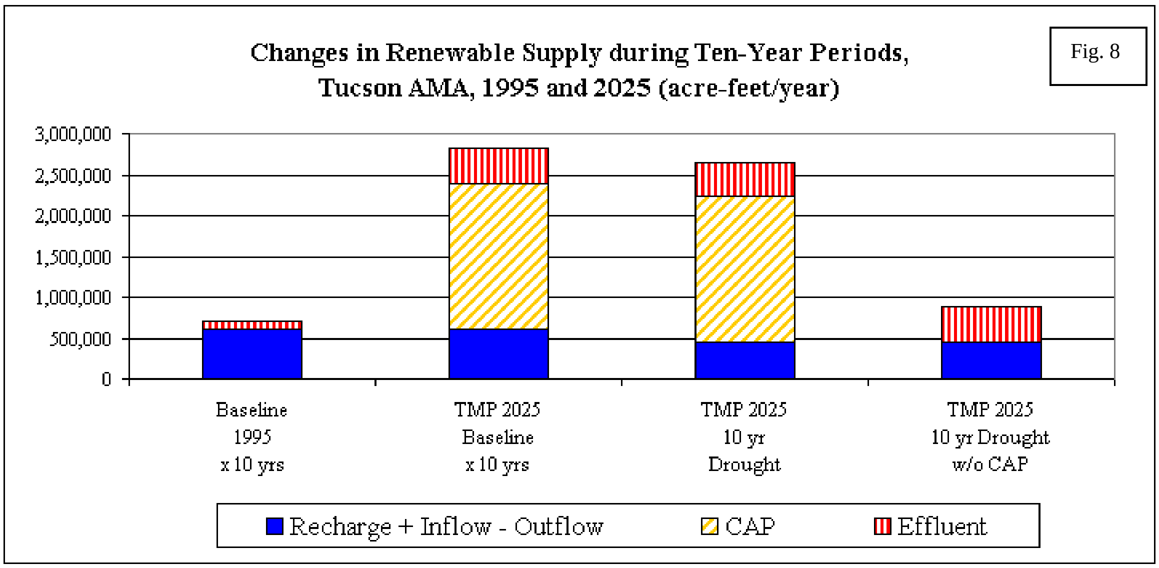


For ease of comparison, the 2025 baseline amount under normal climate conditions, multiplied by five years, results in a cumulative supply of 1,407,000 af. Reductions to this amount during a drought of the magnitude described above would result in a 9 percent reduction in total renewable supplies, to 1,276,128 af. Further reducing this amount by eliminating CAP supplies would result in only 27 percent, or 386,628 af, of the average water supply being available.

Ten-Year Scenarios

The driest ten consecutive winters in the Southeast Climate Division occurred from 1947-1956, during which 74 percent of the normal amount of precipitation fell. Water supply impacts are shown in Figure 8. This scenario resulted in a pattern of findings similar to the one- and five-year scenarios, although the impacts were less severe due to the less severe drought. As was the case with the Phoenix AMA, the cumulative effects of a long-term drought may well be more severe than that of a more extreme drought of shorter duration. It is also important to note that during an entire decade of drought, adaptations and a reorganization of policies and priorities would likely take place. Potential institutional responses are discussed below in the "Implications" section. Results of the ten-year supply calculations are shown in Figure 8.

The 2025 baseline scenario under normal climate conditions was multiplied by 10, producing a cumulative total renewable water supply of 2,814,000 af. Application of the ten-year drought, based on 74 percent of normal winter precipitation being available, reduced supplies by 6 percent, to 2,655,555 af. Totally eliminating CAP supplies for this time period decreased availability of renewable water by more than two-thirds, to 876,555 af.



Santa Cruz Scenarios

The same basic methodology for adjusting water supply figures was used in the Santa Cruz AMA, with a few notable exceptions. Water sources in the Santa Cruz AMA are limited to a small amount of surface water, considerable natural groundwater recharge, and substantial effluent supplies, most of with are recharged into the aquifer rather than directly used. The Santa Cruz AMA does not have access to CAP supplies and has no plans to build the infrastructure necessary to utilize its allotment.[2]

Another important difference in calculation of the one-, five-, and ten-year droughts for the Santa Cruz AMA is that, rather than using winter precipitation records, annual records. This change in methodology was made in order to take into account key differences in hydrologic features between the Santa Cruz AMA and the other study areas. Specifically, interaction between groundwater and surface water is far more important in the Santa Cruz AMA than in

[2] The AMA's allotment has been sold to the City of Scottsdale.

other study areas, due to the nature of the area's geohydrology. As noted in the AMA's DTMP, shallower aquifer conditions in a key pumping area of the AMA cause the water table to be much quite responsive to short-term climatic fluctuations (ADWR 1999c). Thus, while winter precipitation is assumed to be the primary source of aquifer recharge in most areas of the region,[3] even relatively brief precipitation events throughout the year can quickly recharge the local water supply. Notably, the summer monsoon may produce more rain in the Santa Cruz AMA than in the other study areas. Although the precipitation data reported at the climate division level are lower than those for the local area, the proportional change between normal and drought conditions remains substantially the same. This factor, combined with the fact that localized data are available only from 1914 forward—thus missing important dry periods near the start of the century—drove the decision to use the climate division data.

Yet another factor that distinguishes the Santa Cruz AMA from the other study areas is the fact that an important portion of its water supply actually originates as effluent flowing across the border from Nogales, Sonora. As discussed in the Methodology section, much of the Santa Cruz AMA's water supply comes from effluent generated by the Nogales International Wastewater Treatment Plant (NIWTP), which treats wastewater produced by both cities. Of the projected 19,549 af average annual output, approximately two-thirds of this water supply, or 13,600 af, is generated by Nogales, Sonora, while the remaining one-third comes from sources within the Santa Cruz AMA. To test possible impacts of the elimination of the Sonoran portion of this supply due to increased treatment capacity south of the border, the scenarios used in this analysis include alternatives in which effluent recharged in the AMA is reduced by the two-thirds portion which Mexico can legally reclaim.

Basic supply information for the Santa Cruz Active Management Area was found in the Draft Third Management Plan (DTMP) for that area (ADWR 1999c). Unlike the Third Management Plans for the Phoenix and Tucson AMAs, fhe DTMP does not project any substantial changes in water supply between 1995 and 2025. Further, the DTMP includes ranges of maximum and minimum amounts for most water supply categories, including effluent recharge from the NIWTP. According to ADWR calculations, renewable water supplies in the AMA are expected to range from 33,900 af to 137,500 af annually. For most water supply categories, the average of the low and high range numbers was used in this analysis. However, for the recharge category "main channel and major tributary natural flow," the figure used was the long-term median flow of 14,283 af per year shown in Figure 2-9 of the DTMP (ADWR 1999c).

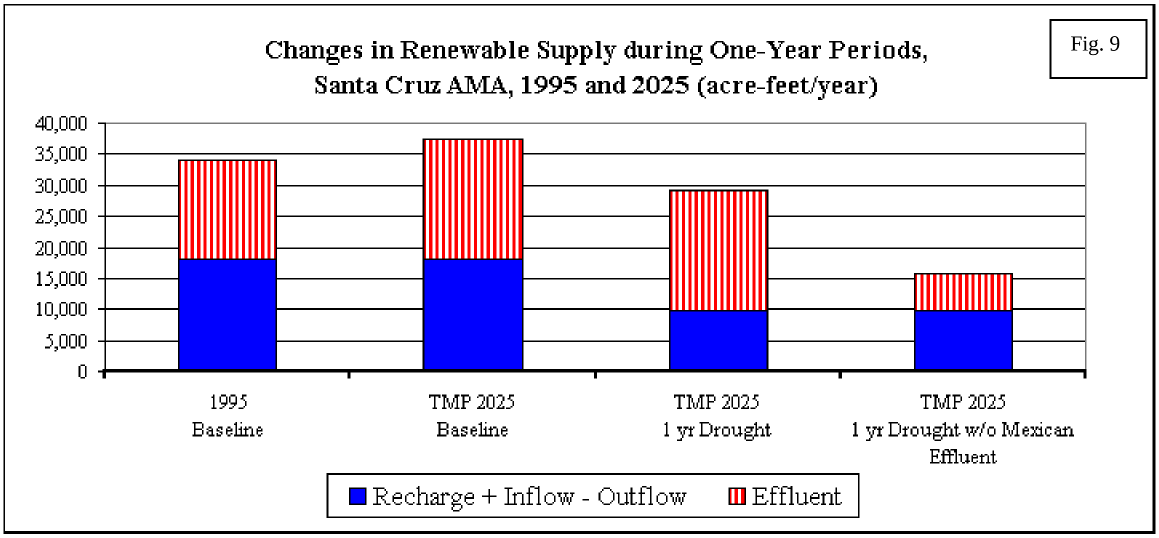
For the Santa Cruz AMA, the supply change scenarios graphed at the one-, five- and ten-year time scales are as follows:

- TMP 1995 baseline (for comparative purposes)
- TMP 2025 baseline
- TMP 2025 baseline + drought: 2025 baseline supplies combined with the anticipated affects of one-, five- and ten-year reductions in precipitation in the Southeast Climate Division, with NIWTP supplies held to the ADWR baseline projections
- TMP 2025 baseline + drought without Mexican effluent: for all scenarios, NIWTP supplies are reduced by two-thirds (the Mexican portion of total effluent) from water supply calculations

[3] Summer temperatures increase evaporation rates substantially; thus, even though more rain may fall in the summer, a smaller proportion is available as renewable water supplies.

One-Year Scenarios

As per the methodology section, the 45 percent reduction in precipitation noted during the driest year on record, 1948, was assumed to reduce natural recharge linearly; recharged effluent was assumed to remain constant. Amounts of underflow entering the AMA, as well as outflow leaving the AMA, were reduced proportionally. Calculations for the one-year scenarios are show in Figure 9.

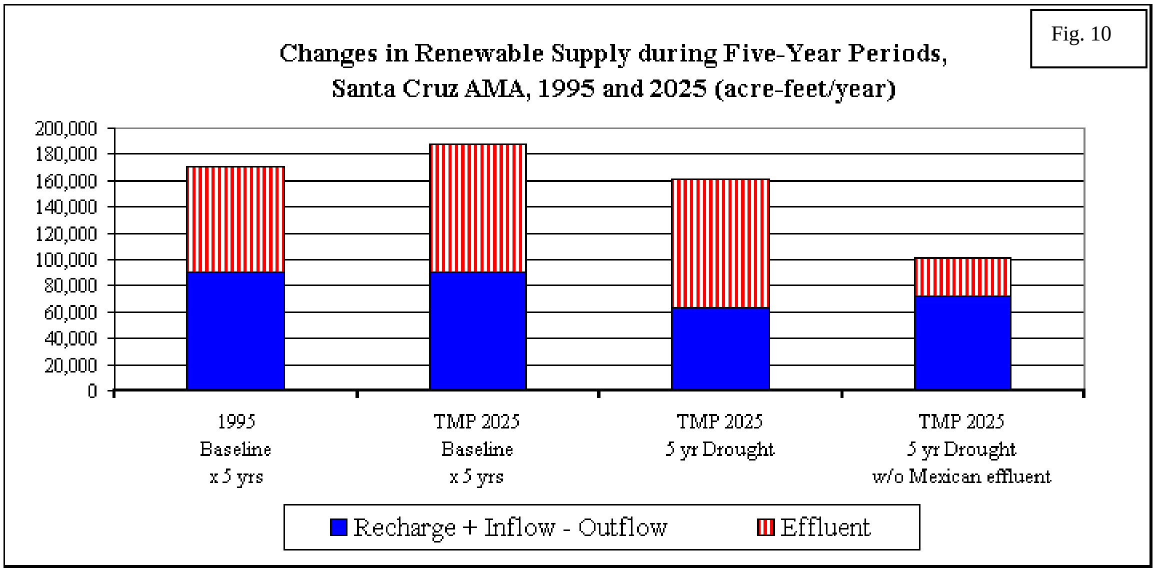


Under average climatic conditions, the Santa Cruz AMA has 34,171 af of renewable water supplies annually. By 2025, this amount is expected to increase to 37,532 af, due to the recharge of greater amounts of effluent generated by the NIWTP. Applying the one-year minimum winter precipitation conditions to this scenario decreased 2025 renewable water supplies to 79 percent of the normal amount, or 29,688 af. The elimination of the Sonoran portion of NIWTP discharge, on top of the drought-caused reductions, produced a situation in which only 43 percent, or 16,088 af, of renewable supplies would be available. A reduction of this magnitude could have serious consequences for the AMA, even over only a one-year drought period because, unlike the Phoenix and Tucson AMAs, there is little storage capacity available to buffer the effects of such a large reduction. Given that Santa Cruz AMA has few other options for supply (i.e., no access to CAP and questionable access to other water sources), the impacts of loss of NIWTP water would likely require strict enforcement of water conservation rules.

Five-Year Scenarios

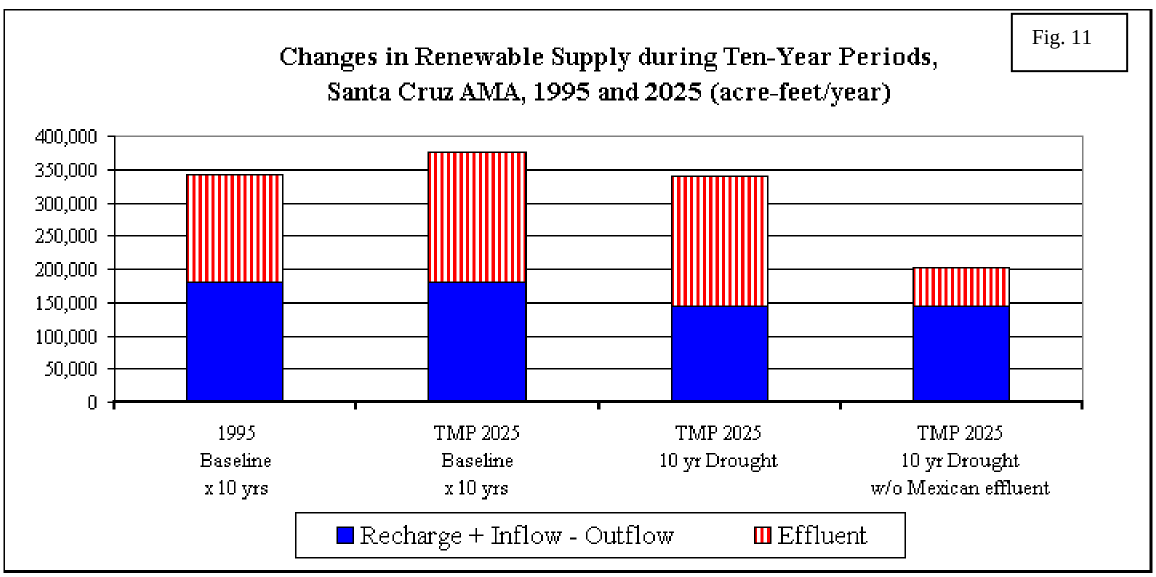
In the Southeastern Climate Division, the driest five consecutive years on record occurred between 1900 and 1904. During that period, precipitation averaged only 70 percent of the mean, or an average 9.98 inches per year over the five-year period. For purposes of this analysis, natural recharge, inflow, and outflow were reduced by this same proportion. Figure 10 illustrates the results of the calculations.

When the 2025 baseline amount is multiplied by 5, the result is 187,660 af of renewable water supplies over a five year period under normal climate conditions. If only 70 percent of normal precipitation occurred during this period, 161,585 af, or 86 percent, of the baseline supply amount would by available. Without the Mexican portion of NIWTP supplies, renewable supplies would plummet to 50 percent of the norm; only 93,585 af of renewable water would be available. Again, the AMA would be faced with serious management choices under such conditions.



Ten-Year Scenarios

The driest ten consecutive years in the Southeast Climate Division occurred from 1948-1957, during which 81 percent of the normal amount of precipitation fell. This scenario resulted in a similar pattern of findings as those identified in the one- and five-year scenarios (as Figure 11 illustrates), although the impacts were less severe due to the less-intense nature of the drought. However, the cumulative effects of a long-term drought may well be farther-reaching than those of a more extreme drought of shorter duration. It is also important to note that, during an entire decade of drought, more fundamental changes in policies and priorities would likely take place. Potential institutional responses of the Santa Cruz AMA are further discussed in the "Implications" section.



The DTMP baseline amount under normal climate conditions, multiplied by 10 amounts to 375,320 af. Even under a ten-year drought of equivalent magnitude to the worst on record for the area would produce a full 90 percent, or 339,354 af of normal renewable supplies. Reducing NIWTP supplies by two thirds, however, would decrease renewable supplies to only 54 percent, or 203,354 af of renewable supplies available over the ten-year time frame.

Benson Subwatershed Scenarios

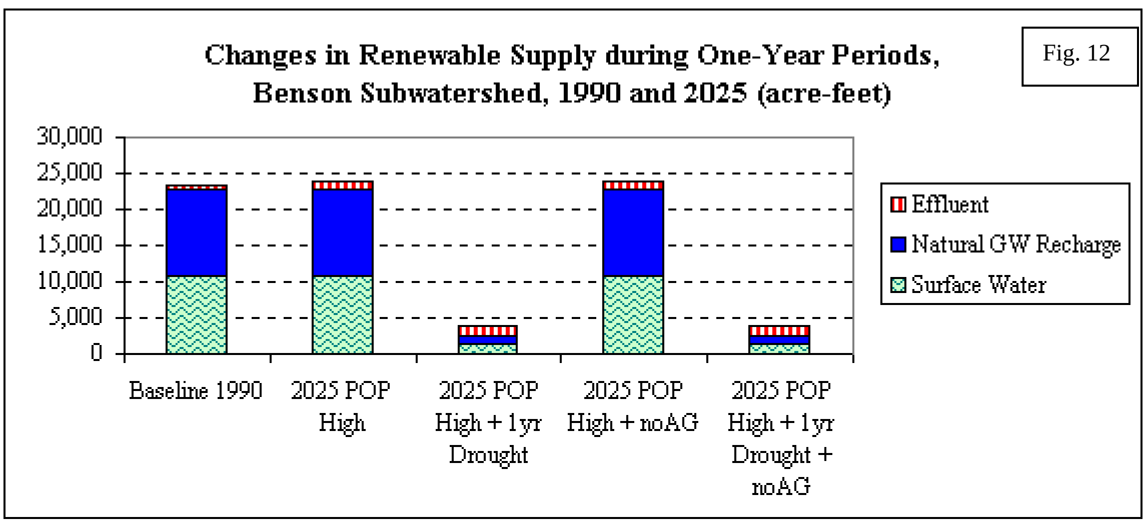
For the Benson subwatershed, the supply change scenarios for 2025 and at the one-, five- and ten-year time scales are as follows:

- population growth only: increased population size (DES and Pop High)
- drought: increased population (DES and Pop High) size combined with the historic minimum in winter precipitation in the Southeast Climate Division
- elimination of agriculture: increased population size (DES and Pop High) and elimination of agriculture; increased population size (DES and Pop High) combined with the historic minimum in winter precipitation and elimination of agriculture. Since this scenario does not have any impact on water supply, it will not be discussed in this section. For reasons of consistency, however, it is included in the graphs.

For reasons of simplicity and improved comparability, only the scenarios with the higher population projections (Pop High) are depicted in the graphs below. Detailed figures for every supply scenario in each study location are shown in the respective tables of Appendix 4.

One-Year Scenarios

Results of the analysis of the one-year scenarios for the Benson subwatershed are provided in Figure 12.



Population Growth Only

A scenario with unchanged climatic conditions but higher population size would increase the amount of effluent available by 44 to 91 percent, based on the number of people projected for the subwatershed for the year 2025. Since all the other supply categories would remain the same, supply under this scenario might increase by only 1.1 to 2.4 percent (263 to 547 af) relative to the 23,146 af available under the 1990 baseline conditions.

Drought

Significantly greater changes could be expected under the "worst-case" scenario, using both the historic minimum precipitation of 1904 and the two population projections for 2025. Compared to an average winter precipitation of 5.18 inches, the Southwest Climate Region received only 0.6 inches between November of 1903 and April of 1904. Assuming a linear relationship between winter precipitation and water supply, this represents an 88 percent decline in natural groundwater recharge as well as total surface water available. Combined with a slight increase in effluent water, identical to the one in the growth-only scenario, total water supply can be expected to be as low as 3,370 or 3,654 af. This represents a decrease of 84 to 85 percent (19,492 to 19,776 af) compared to the 23,146 af of water available in the 1990 baseline year.

Elimination of Agriculture

The hypothetical elimination of agriculture does not result in any changes on the supply side. The numbers calculated for the three supply categories are identical with those under the two 2025 scenarios. Thus, under the population growth-only scenario, total supply would increase by roughly 2 percent, due to an increase in effluent. Under the drought scenario, on the other hand, a sharp decline (85 percent) can be expected.

<u>Five-Year Scenarios</u>

Results of the analysis of the five-year scenarios for the Benson subwatershed appear in Figure 13, below.

Population Growth Only

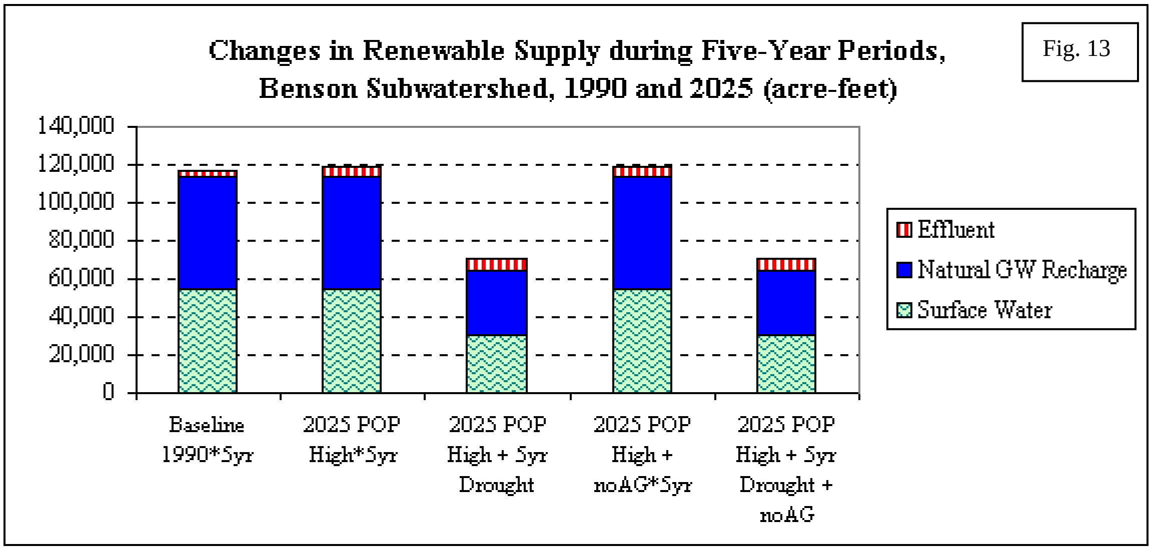
The scenarios with increased population size are based on the one-year conditions replicated over the duration of five years. Therefore, they result in the same percentage change as the latter ones, meaning an overall increase of supply between 1.1 and 2.4 percent compared to the baseline conditions multiplied by five. Again, the increase is due to higher amounts of effluent generated by growth in municipal demand.

Drought

The scenarios including climate-induced changes on the supply side (population increase and drought) differ from the one-year cases. Since the worst five year winter drought in the Southeast Climate Division has a six-month precipitation mean that is higher than that of the one-year historic minimum (2.946 inches compared to 0.6 inches), the percentage decrease of available supply in the Benson subwatershed is less marked. Under these scenarios, a 42 percent decline could be translated into roughly 70,000 af of total water supply, which is approximately 50,000 af less than under baseline conditions. Surface water may be expected to decrease by 23,492 af and natural groundwater recharge by 25,331af. However, compared to the one-year scenarios, this decline is not as pronounced. As a result, overall supply under five-year drought scenarios seems less stressed than during a one-year worst drought event.

Elimination of Agriculture

The hypothetical elimination of agriculture does not result in any changes on the supply side compared to the other 2025 scenarios. Assuming population growth only and comparing the numbers with the 1990 baseline conditions, overall supply is expected to increase due to a slightly higher amount of effluent available. This increase would be at the same rate as under the one-year scenarios (2 percent). Changes during conditions with reduced precipitation are more significant. As in the other 2025 drought scenario, where agriculture is included, total water supply will decline by 42 percent, barely reaching 70,000 af.

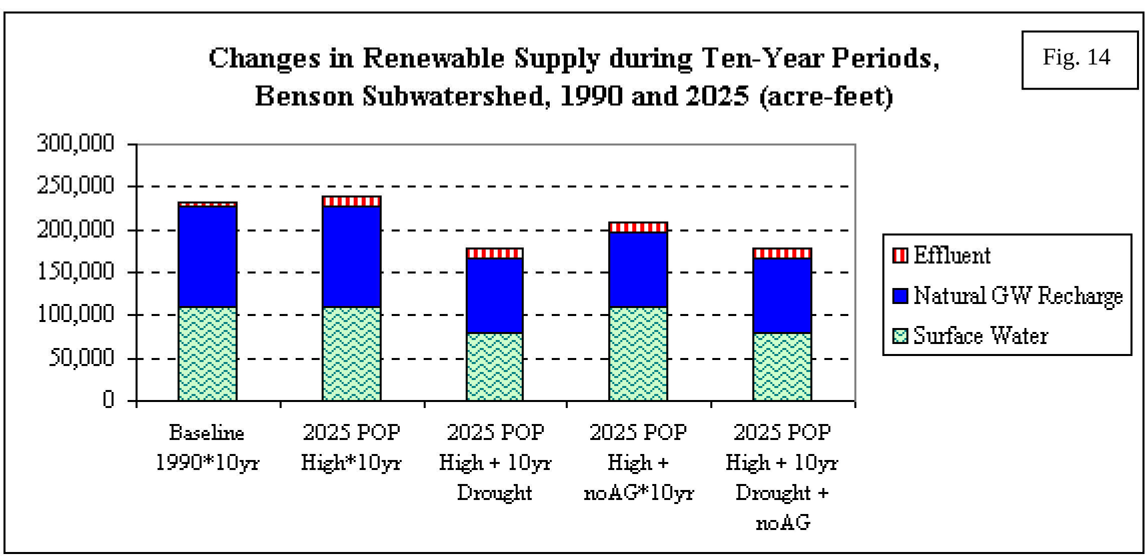


Ten-Year Scenarios

Results of the analysis of the ten-year scenarios for the Benson subwatershed appear in Figure 14.

Population Growth Only

As in the five-year scenarios, the increase in population condition represents an extension of the one-year case over a period of ten years. Consequently, overall supply can be expected to increase by 1.1 to 2.4 percent, resulting in up to 5,470 af more water than in the 1990 baseline conditions. Again, these gains are due to increased availability of effluent.



Drought

As in the other drought scenarios described above, a decrease in water supply has to be expected, but compared with the one- and five-year drought scenarios, the ten-year conditions are the least extreme. Based on the six-month mean of the 1947-1956 drought (3.83 inches), supply may be expected to decrease by only 25 percent. Under these conditions, overall water supply would amount to roughly 175,000 af compared to the 231,460 af available in the baseline case, extended over ten years. Reductions in both surface water and natural groundwater recharge amount to 26 percent of average supply.

Elimination of Agriculture

As above, no changes in supply are expected to occur under the elimination of agricultural scenario. Under the no-drought condition, total supply would increase slightly, and at the same rate (2 percent compared to the 1990 baseline condition), as under the one- and five-year scenarios. Assuming a ten-year drought situation, a 25 percent decline in water supply could be expected. Although the amount available (roughly 180,000 af) represents the lowest amount of supply in the subwatershed of the various scenarios employed, the rate of decrease is clearly less pronounced than under the five- and particularly the one-year drought conditions. Again, this fact is linked to the relatively higher average precipitation occurring over the long-term dry conditions than during short-term drought events.

Sierra Vista Subwatershed Scenarios

For the Sierra Vista subwatershed, the supply change scenarios for 2025, at the one-, five- and ten-year time scales, are as follows:

- population growth only: increased population size (DES and Pop High)

- drought: increased population (DES and Pop High) size combined with the historic minimum in winter precipitation in the Southeast Climate Division

- elimination of agriculture: increased population size (DES and Pop High) and elimination of agriculture; increased population size (DES and Pop High) combined with the historic minimum in winter precipitation and elimination of agriculture. Since this scenario does not have any impact on water supply, it will not be discussed in this section. For reasons of consistency, however, it is included in the graphs.

For reasons of simplicity and improved comparability, only the scenarios with the higher population projections (Pop High) are depicted in the graphs below. Detailed figures for every supply scenario in each study location are shown in the respective tables of Appendix 5.

One-Year Scenarios

Results of the analysis of the one-year scenarios appear in Figure 15, below.

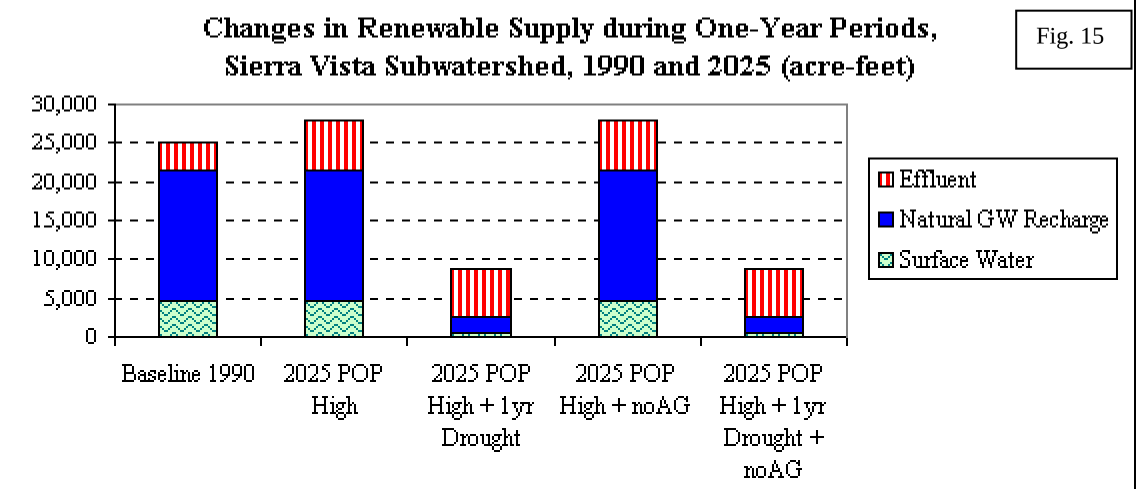
Population Growth Only

As in the Benson subwatershed, gains in water supply under increased population conditions for the year 2025 will be due to an increase in the amount of effluent available. A population growth of almost 40,000 would be expected to produce nearly 3,000 af more treated effluent that can be reused for various purposes. Overall, water supply is assumed to increase by 8 to 11 percent, relative to the 1990 baseline year.

Drought

Calculation of drought impacts under the one-year scenario, indicates that losses due to reduced winter precipitation during the historic worst case drought (1904) could amount to roughly 19,000 af (68 to 70 percent) of average supply. Although reductions in surface water and natural groundwater recharge are almost as high as in the Benson subwatershed (88 percent), total losses are slightly lower. This difference can be explained by the more significant gains in supply expected from an increase in effluent flows. Nevertheless, the decrease in water supply is considerable. Compared to the baseline conditions, the reduction amounts to roughly one third of the original amount available.

Fig. 15



Elimination of Agriculture

As in the Benson subwatershed, the elimination of agriculture scenarios reveals the same changes as the other 2025 scenarios. Assuming average precipitation conditions, total supply would be expected to increase by 8 to 11 percent when compared to 1990 baseline conditions. This increase can be explained by a higher amount of effluent expected to be generated as a result of higher population numbers.

When winter precipitation is reduced by 88 percent compared to the long-term average, total water supply is reduced substantially. Specifically, an 88 percent reduction in surface water and natural groundwater recharge was calculated to reduce the total amount of water available in the Sierra Vista subwatershed to less than 10,000af, roughly one-third of the average supply.

<u>Five-Year Scenarios</u>

Results of calculations based on the five-year scenarios for the Sierra Vista subwatershed appear in Figure 16, below.

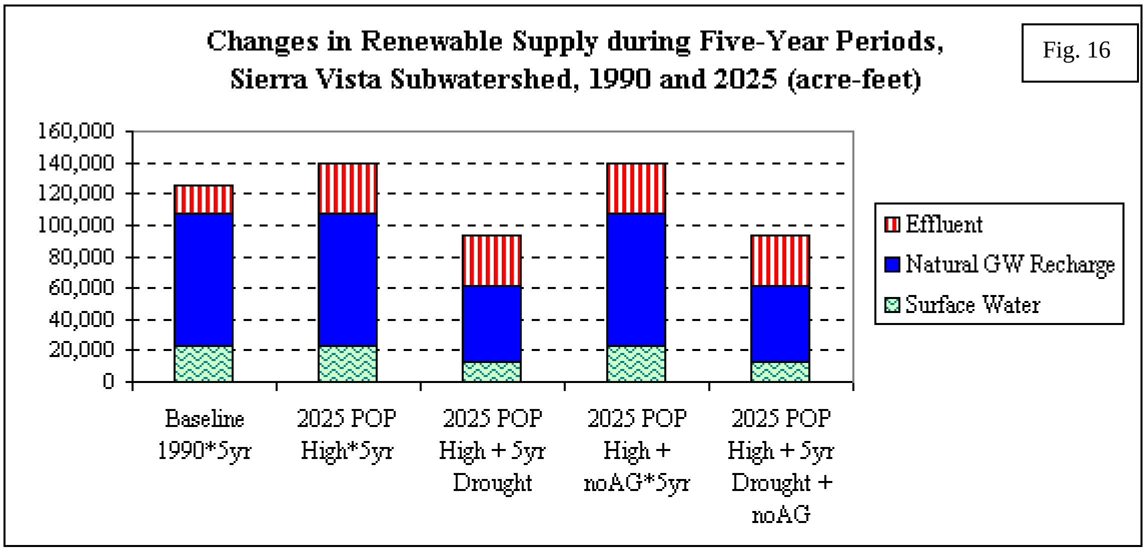
Population Growth Only

The same 8 to 11 percent increase in water supply as in the one-year scenarios can be expected for the five-year scenarios with increased population size. The total amount of available water will be roughly 137,000 af compared to 125,120 af during the five-year baseline period.

Again, these gains may be attributed to increased availability of effluent (as much as 14,000 af more).

Drought

The decreases calculated for the five-year drought scenarios are similar to the ones in the Benson subwatershed. Overall, a decrease in supply of 46,000 af may be anticipated (30 to 32 percent), relative to the 2025 no-drought condition. These calculations are based on the winter precipitation conditions that existed during the 1900-1904 drought. Again, losses in surface water and natural groundwater recharge were calculated to approach 43 percent (9,831af and 36,316af respectively), roughly half of the deficit anticipated during the one-year drought scenarios.



Elimination of Agriculture

Under the population growth-only scenarios, overall supply would increase at the same rate as under the one-year scenarios (8 to 11 percent). As in the one-year situation, overall supply would still be higher than under the 1990 baseline year, a fact that has to be attributed to increased population size and increased generation of effluent.

Changes during a five-year drought period are more significant, yet less pronounced than under the one-year scenarios. Total water supply is expected to decrease by 30 percent, leaving the subwatershed with less than 100,000 af of renewable supplies. Compared with the 68 to 70 percent reduction in supply calculated for the corresponding one-year drought scenario, the five-year decrease is not as large. Again, this is due to the fact that reductions in surface water and natural groundwater recharge are not as pronounced under the medium-term drought used here as under the one-year drought scenarios.

<u>Ten-Year Scenarios (Fig.17):</u>

Population Growth Only

The increase in population conditions, extended over a period of ten years, results in an overall gain of water supply of 8 to 11 percent, resulting from additional effluent flows. The additional amounts of effluent available under the various scenarios amount to 20,185 af and 27,846 af under the two population projections (DES and Pop High) used.

Drought

The reduced winter precipitation under the ten-year drought scenarios was calculated to result in 11,894 af less surface water and 43,937 af less natural groundwater recharge. As in the other locations, this represents a decline of 26 percent compared to the extended baseline conditions. Overall, water supply would decrease from 250,240 af (baseline multiplied by ten years) to approximately 220,000 af, or by 20 percent.

Elimination of Agriculture

As under the one- and five-year no-drought scenarios, the numbers calculated are identical to the 2025 scenarios, with agriculture. An 8 to 11 percent increase in supply can be assumed, relative to extended 1990 baseline conditions.

Under the drought scenarios, where additional reductions would have to be expected due to lower average winter precipitation, total supply would decrease by 18 to 20 percent compared to the extended 1990 baseline conditions. Although the amount available (roughly 220,000 af) represents the lowest amount of supply in the subwatershed under the various scenarios employed, the rate of decrease is clearly less pronounced than under the five- and particularly the one-year drought scenario. Again, this condition is linked to the relatively higher average precipitation during long-term dry conditions examined here than during the one-year drought.

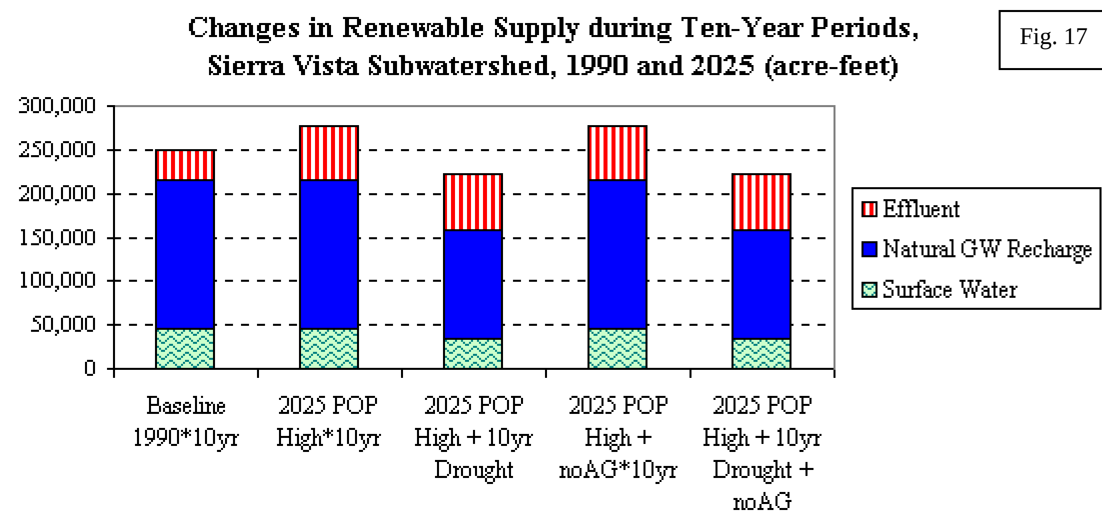


Fig. 17

B. Changes in Demand

Changes on the demand side for all locations for each scenario and time frame were calculated using the parameters specified in the Methodology section. In parallel with the assumptions used in calculating changes in supply, all demand scenarios for the year 2025 included projected population increase. The data were then overlaid with the historic one-, five-, and ten-year drought conditions, as well as with a hypothetical scenario under which all irrigated agriculture is eliminated from the respective unit of analysis. For the Phoenix, Tucson and Santa Cruz AMAs, a further scenario was used, which combined 1995 agricultural water use with 2025 projected demands for all other sectors. This scenario was included in order to assess the potential impacts that might occur under drought conditions if the changes in agricultural demand anticipated by ADWR did not occur.

The scenarios described and graphed below represent a combination of these various assumptions. As was the case in the Supply section, only the scenarios reflecting actual changes in water demand are included in the graphs. Detailed spreadsheets are provided in Appendices 1-3 for the AMAs and in Appendices 4 and 5 for the two subwatersheds in the San Pedro River basin.

A further set of calculations relevant to this section involves offsets to demand, graphed as return flow. These include naturally occurring factors such as incidental recharge, as well as policy-created water supplies, including the AWS replenishment obligation, the cut to the aquifer, and remediation water (see the Methodology section). Unlike incidental recharge, these other components of return flow were held constant in all scenarios.

The most significant of the return flow factors, and the only one considered in this analysis to be sensitive to climatic factors, is incidental recharge. As water demand increases, so too does the total amount of water that is not absorbed by human, animal or plant uses. This water, as runoff, eventually contributes to recharging the aquifer.

In this analysis, the same proportion of total water demand counted as incidental recharge in the Third Management Plans for the AMAs is applied to the increased water demand in the drought scenarios. This results in slightly higher incidental recharge amounts in the drought scenarios, and a radical reduction in incidental recharge in the "no agriculture" scenarios.[5] For the two subwatersheds in the San Pedro River basin, incidental recharge was calculated on the basis of water use numbers published in the *Hydrographic Survey Report* (ADWR 1991). Additional agricultural water demand in the drought scenarios is assumed to be lost to evapotranspiration, thereby leaving incidental recharge unchanged. In all cases, incidental recharge is treated as an offset to total demand. Where appropriate, incidental recharge, the AWS replenishment obligation, the cut to the aquifer and remediation water are subtracted from total demand to produce net total water consumption. Thus, the amounts discussed in the text refer to net water consumed, rather than total water demand. The graphs show total net water consumption and an additional bar line representing return flow.

Projections for a near doubling of population in the AMAs by 2025 will inevitably generate increases in water demand even under normal climate conditions, although the relationship is less than one-to-one. Proportional increase in water demand by sector is discussed for each study area below. Generally speaking, demand is not sensitive to climatic variability to the same degree as is renewable supply availability, although patterns indicating certain levels of increased demand do show up during dry period. Thus, as discussed in more detail below, we assumed that drought would generate some increase in demand.

Further, the Third Management Plans for the Phoenix and Tucson AMAs and the Draft Third Management Plan for the Santa Cruz AMA include scenarios projecting demand based on existing patterns and on reductions in demand based on enhanced conservation. Because our

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[5] Approximately one-third of the water applied to agricultural crops is assumed to return to the aquifer.

analysis seeks to identify a worst-case scenario that focuses on the impacts of climate, rather than on the steps that humans may take to conserve water, we used the current use rates as a baseline for our calculations.

Disaggregation of demand data by economic sector for each study area provides insight into the similarities and differences between the areas. As the calculations reveal, in each study area, some sectors are more sensitive to climatic fluctuations than others. Thus the components of demand in a particular area can have serious bearing on how vulnerable that location might be to more extreme climatic conditions.

Phoenix AMA Scenarios

For the Phoenix AMA, the net water consumption change scenarios at the one-, five- and ten-year time scales include:

- TMP 1995 baseline (for comparative purposes)
- TMP 2025 baseline
- TMP 2025 baseline + drought: baseline net water consumption is combined with anticipated increases in demand and consequent increases in return flows via incidental recharge
- 2025 demand + 1995 agriculture + drought: projections for municipal, industrial and riparian demands for 2025 are combined with 1995 agricultural demand figures and drought impacts
- 2025 demand + no agriculture + drought: projections for municipal, industrial and riparian demands for 2025 are combined with the total elimination of agricultural water demand and the calculated impact of drought

One Year Scenarios

Results of the demand calculations for a one-year drought are shown in Figure 18, below.

TMP 2025 Baseline and Drought

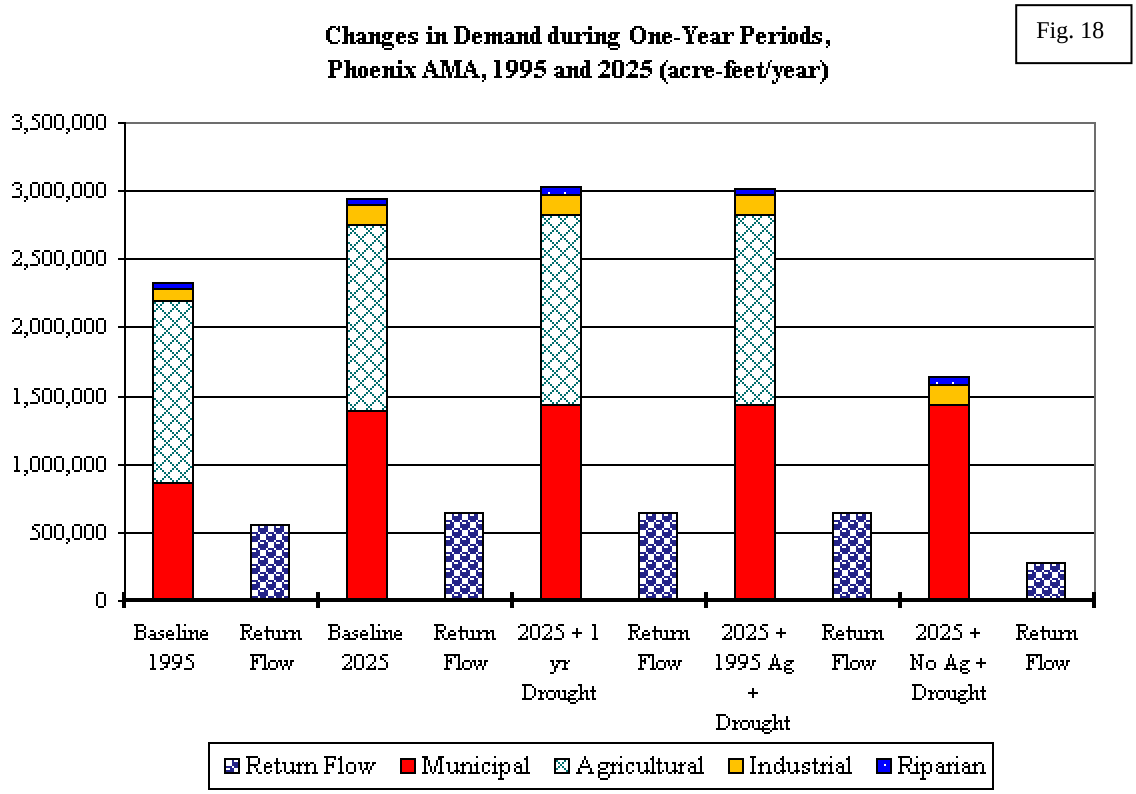
Net water consumption in the Phoenix AMA under normal climate conditions is expected to increase from 1,773,002 af, based on a 1995 population of 2,549,931, to 2,303,805 af, based on a 2025 population of 4,482,876. Thus, while population is expected to grow by 43 percent, overall water consumption is anticipated to increase by only about 23 percent. Viewed by water use sector, municipal water demand is expected to expand by 38 percent, from 869,962 af in 1995 to 1,395,725 af in 2025, and industrial demand by 39 percent, from 83,088 af to 137,628 af.

Agricultural water use is also projected to expand slightly, from 1,333,885 af to 1,360,743 af, or 2 percent, between 1995 and 2025. While ADWR expects urbanization of agricultural land to continue in the AMA, agricultural activity by Indian groups is expected to expand significantly, thus increasing total demand in this sector. Specifically, according to the Phoenix AMA Third Management Plan (ADWR 1999a, p. 11-7), non-Indian agriculture is expected to fall from 161,797 acres in 1995 to 133,114 acres by 2025, while Indian agriculture is projected to more than double from 37,956 acres to 93,575 acres by 2025. Improved irrigation efficiency is expected to occur in both Indian and non-Indian agriculture, thus mitigating the impacts on total water demand.

In calculating the impact of population growth on return flows for the one-year scenario, the portion of water returned to the aquifer via incidental groundwater recharge was assumed to increase by 1.6 percent (from 556,735 af to 564,684 af). The cut to the aquifer was assumed to increase from 5,197 af to 21,615 af. These calculations produce a total return flow to 638,291 af for average climate conditions, which is an increase of 13.5 percent compared to the 1995 baseline.

A drought equal in the intensity to that of the driest winter in the Southeast Climate Division, that of 1903-1904, would produce only 11.5 percent of mean precipitation. The effect of this decrease, when applied to baseline demand, resulted in an increase in net annual water consumption of 3.3 percent of 2,382,124 af. Return flow rose to 647,248 af, based on anticipation of higher incidental recharge.

Fig. 18



Maintain Agriculture at 1995 Level

If agriculture remained at 1995 levels in the Phoenix AMA through 2025 under normal climate conditions, there would be an insignificant impact on the water projections. Net water consumption would decrease to 2,290,171 af, which is only 0.6 percent less than the demand projected in the Phoenix AMA TMP. Return flows would also remain virtually unchanged. Application of the minimum one-year precipitation criterion would increase net water consumption to 2,380,985 af. This amounts to 3.3 percent more than the baseline amount.

Eliminate Agriculture

The total elimination of agricultural water demand from the Phoenix AMA's 2025 water budget, which is based on normal climate conditions, resulted in a 43 percent drop in net water consumption for the year under the drought scenario (a decrease from 2,382,124 af to 1,349,764 af). A 37 percent decrease in incidental recharge reduced overall return flow from 647,248 af to 284,527 af. This large decrease testifies to the significance of agriculture in overall water demand patterns in the Phoenix AMA: in 1995 agriculture accounted for 56 percent of the AMA's water demand. By 2025 this proportion is expected to decrease to 45 percent of the total, while municipal use is anticipated to rise from 38 percent of total 1995 demand to 48 percent of total 2025 demand. Even at 45 percent of total demand, however, agriculture will still play a more significant role in the local economy of the Phoenix AMA than it will in either of the other two AMA study areas. It should be noted that the total elimination of agriculture in the Phoenix AMA is extremely unlikely, and that the shift from non-Indian to Indian agriculture is expected to continue.

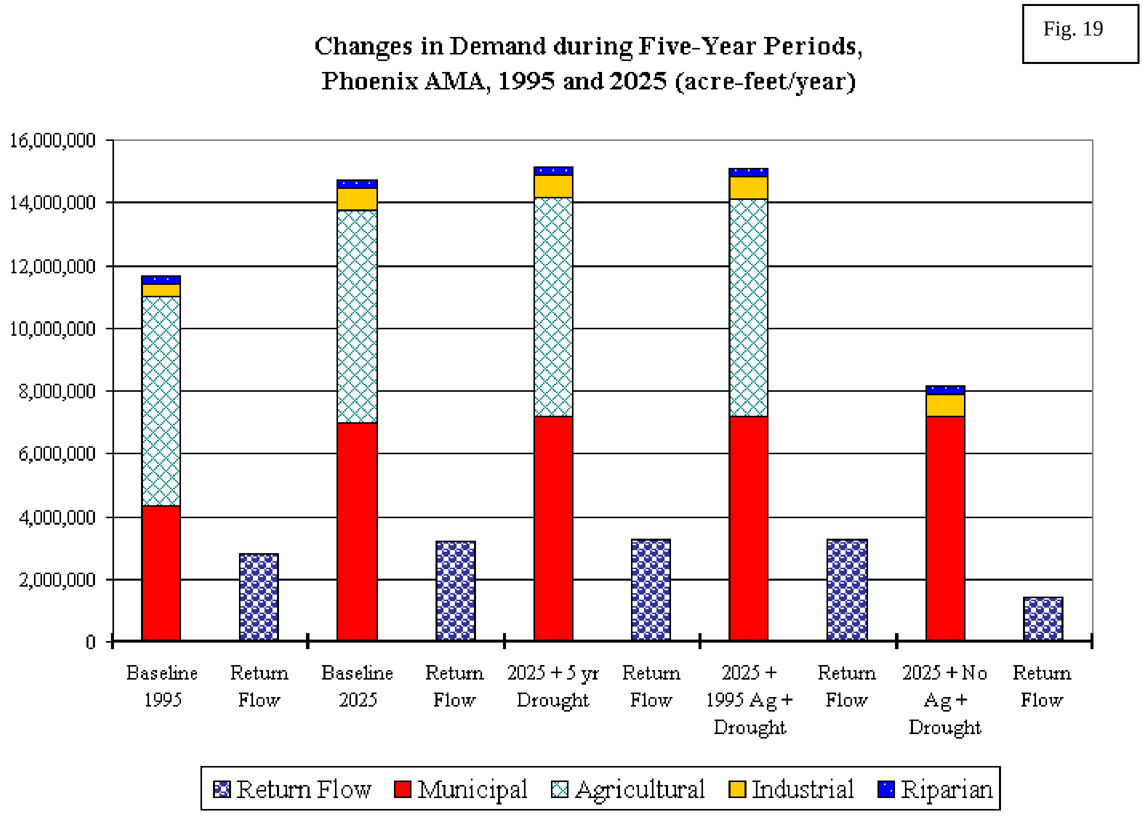
Five-Year Scenarios

Calculations of demand variability for the five-year drought scenario are presented in Figure 19.

TMP 2025 Baseline and Drought

To facilitate comparison, the Phoenix AMA TMP's figure for total one-year water demand in the year 2025 (which assumes average climatic conditions) was multiplied by 5. This produced a five-year demand level of 11,519,025 af. The worst five-year drought produced 44 percent less precipitation in the Climate Division. This decrease, calculated against the baseline five-year demand total, produced a 3.3 percent increase in net consumption (11,910,620 af). Changes calculated for return flow rates, between average and drought conditions, were similar to those noted for the one-year scenarios.

Fig. 19



Maintain Agriculture at 1995 Level

Maintaining agriculture at 1995 levels in the Phoenix AMA under either normal climate or drought conditions produces negligible impacts on net water consumption in the AMA, since the expected increase in water demand for this sector is only 134,290 af, or 2 percent, over the entire period. Net consumption over all sectors may be expected to increase to 11,384,735 af under normal climate conditions, and an additional 4 percent to 11,851,407 af under drought conditions.

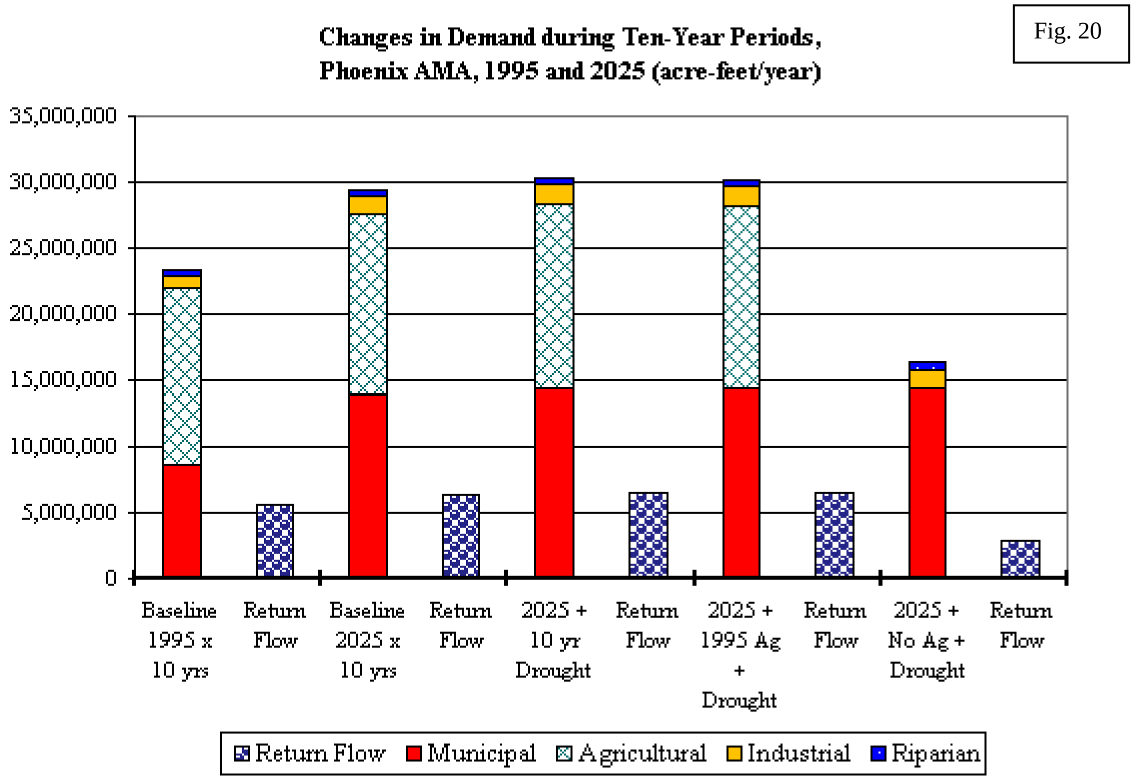
Eliminate Agriculture

The elimination of agriculture from the Phoenix AMA over a five year period, under normal climate conditions would cut net water consumption nearly in half, from 11,519,025 af to 6,484,276 af. If the previously described drought were to occur within this time frame, net consumption could be expected to increase to 6,748,819 af (4 percent) over the 2025 baseline amount. At the same time, return flows could decrease from 3,191,455 af to 1,422,634 af (a decrease of 55 percent), due to a substantial reduction in incidental recharge.

Ten-Year Scenarios

Figure 20 illustrates changes in demand in the Phoenix AMA for the ten-year drought scenarios.

Fig. 20



TMP 2025 Baseline and Drought

Multiplying baseline TMP annual water demand by ten years, assuming normal climate conditions, produces a total demand of 23,038,050 af. As in the above scenarios, it was assumed that conditions similar to the driest ten winters on record could be expect to increase net water consumption by 3.3 percent (23,821,241 af), if agricultural demand were maintained at the 2025 level indicated in the TMP. Total return flows would increase from 3,191,455 af under average climatic conditions to 3,236,240 af under drought circumstances.

Maintain Agriculture at 1995 Level

Keeping agriculture at 1995 levels and assuming normal climate conditions, net water consumption for the ten-year period would produce a demand of 22,769,470 af. Allowing for the drought-induced increase in demand, notably due to a higher evapotranspiration rate, increases net consumption to 23,702,814 af could be expected for the decade. Incidental recharge would increase to 2,757,300 af. These are inconsequential differences relative to the TMP baseline ten-year results.

Eliminate Agriculture

Elimination of agricultural water demand for a decade under normal climate conditions could result in a reduction of 10,069,498 af, or 44 percent, in water consumption over the course of the decade. Return flows would decrease by 43 percent, from 3,236,240 af to 1,422,634 af, due to less incidental recharge. Net water consumption would amount to 13,497,638 af, which is 3.3 percent more than under normal climatic conditions, but still 41 percent less than under baseline demand circumstances.

Tucson AMA Scenarios

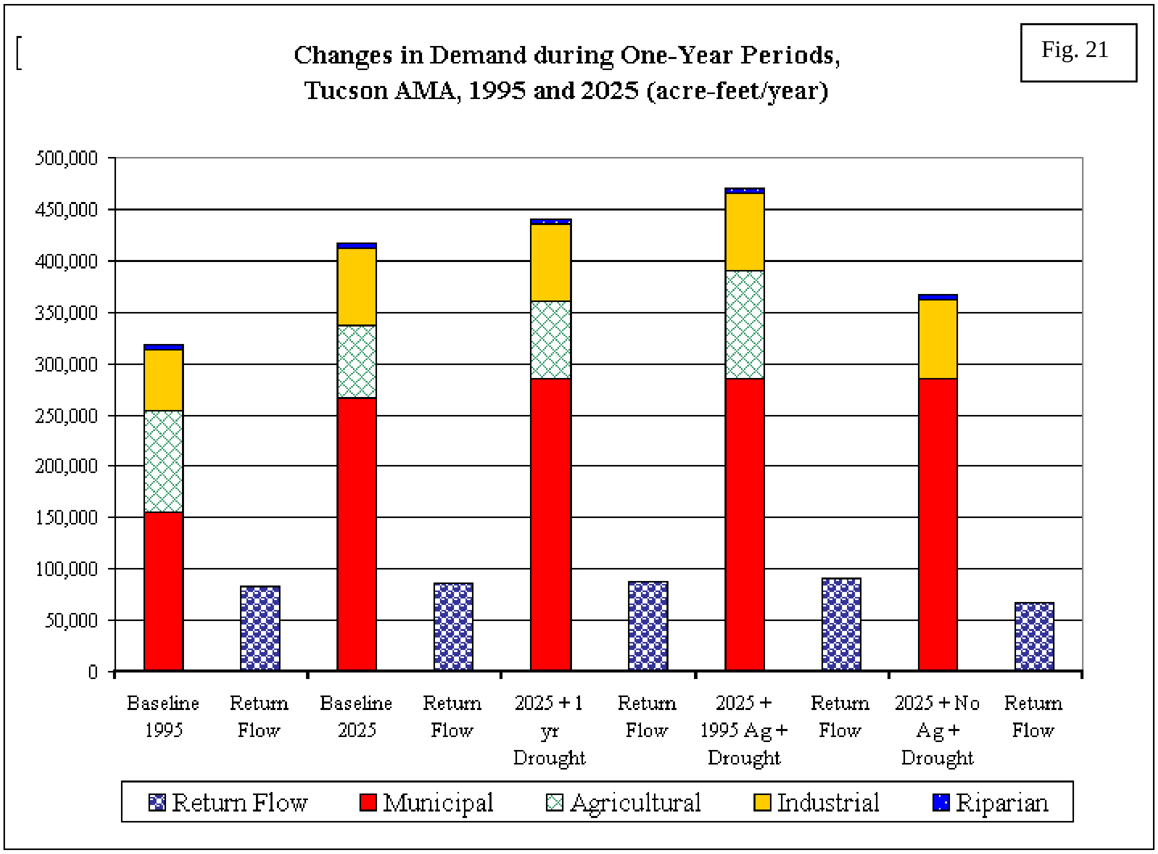
For the Tucson AMA, the net water consumption change scenarios for the one-, five- and ten-year time scales are as follows:

- TMP 1995 baseline (for comparative purposes)
- TMP 2025 baseline
- TMP 2025 baseline + drought: baseline net water consumption is combined with anticipated increases in demand and consequent increases in return flows via incidental recharge
- 2025 demand + 1995 agriculture + drought: projections for municipal, industrial and riparian demands for 2025 are combined with 1995 agricultural demand figures and drought impacts
- 2025 demand + no agriculture + drought: projections for municipal, industrial and riparian demands for 2025 are combined with the total elimination of agricultural water demand and the calculated impact of drought

The water budget for the Tucson AMA includes remediated groundwater as part of the "return flow" category. This type of water is not shown in the water budgets of the other study areas. Remediated groundwater is poor quality groundwater used to facilitate the clean up of contaminated groundwater. State law requires that this amount be accounted for as surface water in determining compliance with conservation requirements. Up to 65,000 af withdrawn within all AMAs may be considered consistent with the management goal for AWS purposes (Stitzer 1999). If this water supply were not counted, industrial demand for groundwater would appear higher.

One Year Scenarios

Calculations for the one-year scenarios for the Tucson AMA are shown in Figure 21.



TMP 2025 Baseline and Drought

Population in the Tucson AMA is projected to grow from 768,000 in 1995 to 1,266,500 by 2025. This 40 percent population increase is expected to increase net water consumption under normal climate conditions by approximately 29 percent, from 235,100 af to 330,900 af under ADWR's TMP current use projections. Under normal climate conditions, municipal demand of 155,500 af currently makes up 50 percent of the AMA's total water use; as shown in the Third Management Plan for the Tucson AMA (ADWR 1999b), this proportion is expected to increase to 65 percent of the total, or 267,100 af, by 2025. Agricultural water use is projected to decline from 98,000 af to 70,000 af by 2025, meaning that agricultural water demand would drop from 31 percent of current water supplies to only 17 percent. As is the case in the Phoenix AMA, non-Indian agriculture is expected to decline while Indian agriculture expands. The industrial water use sector consumes 60,200 af, or 19 percent of the total at present, and is expected to increase proportionally to 75,900 af by 2025. Riparian demand is fairly insignificant in the Tucson AMA, accounting for only 3,700 af, or 1 percent, of the AMA's water supply in 1995. This amount is not expected to increase in the future. Interestingly, incidental groundwater recharge, which offsets total demand figures, is expected to be slashed from 82,300 af to 33,300 af due to decreased agricultural acreage and improved irrigation efficiency. However, total return flow is expected to increase from 82,300 af to 85,800 af, a difference of 4 percent. The amount counted as remediation water is projected to grow from 0 af in 1995 to 6,500 af by 2025, while implementation of the cut to the aquifer provisions will increase this demand offset from 0 af to 46,000 af by 2025.

Combining the baseline water budget with the most severe one-year drought (in 1904), when only 11.5 percent of the normal amount of precipitation fell, produces an increase in net water consumption of 7 percent, to 353,124 af. Total return flow increases by less than 2 percent, to 436,510 af.

Maintain Agriculture

A chief assumption of the Second Management Plan of the Tucson AMA (1991) was that agricultural water demand would decline, allowing municipal and other interests to utilize former agricultural water rights. The expected decrease, however, has not been as large as expected. The current analysis, therefore, includes a scenario in which agriculture is maintained at 1995 levels throughout the management period to 2025. Maintaining agriculture at 98,000 af instead of the projected 29 percent reduction to 70,000 af, in combination with 2025 population figures, produces interesting results for the Tucson AMA. Net water consumption, under normal climate conditions reaches 354,420 af, which is 7 percent higher than baseline 2025 projections. This figure includes the impacts of 5 percent higher total return flows due to greater incidental recharge. Adding drought to this scenario increases total one-year demand to 379,826 af, which is 15 percent higher than baseline 2025 projections. Although Tucson could probably meet this level of demand for a short period of time, it would obviously have significant effects on the AMA's water management decision-making.

Eliminate Agriculture

A fairly prevalent idea in the Tucson AMA is that the decline of agriculture will make water sources available for municipal use. In keeping with the scenario described above, another scenario was constructed in which agriculture was completely eliminated. Doing so under normal climate conditions led to a net water consumption of 278,690 af, which is still 16 percent higher than the 1995 baseline figure, although it would reduce the 2025 baseline figure by 16 percent. While eliminating water demand for agricultural uses does reduce total consumption, the fact that incidental recharge, a key offset to demand, is reduced by 22,270 af diminishes the beneficial effect. Adding the one-year drought to this scenario increases net water consumption another 6 percent, to 298,216 af. Thus it could be said that even if agriculture were eliminated and all available water were to be reallocated to municipal and industrial uses, population growth and its accompanying water demand would still outpace current water demand, which includes agriculture.

Five-Year Scenarios

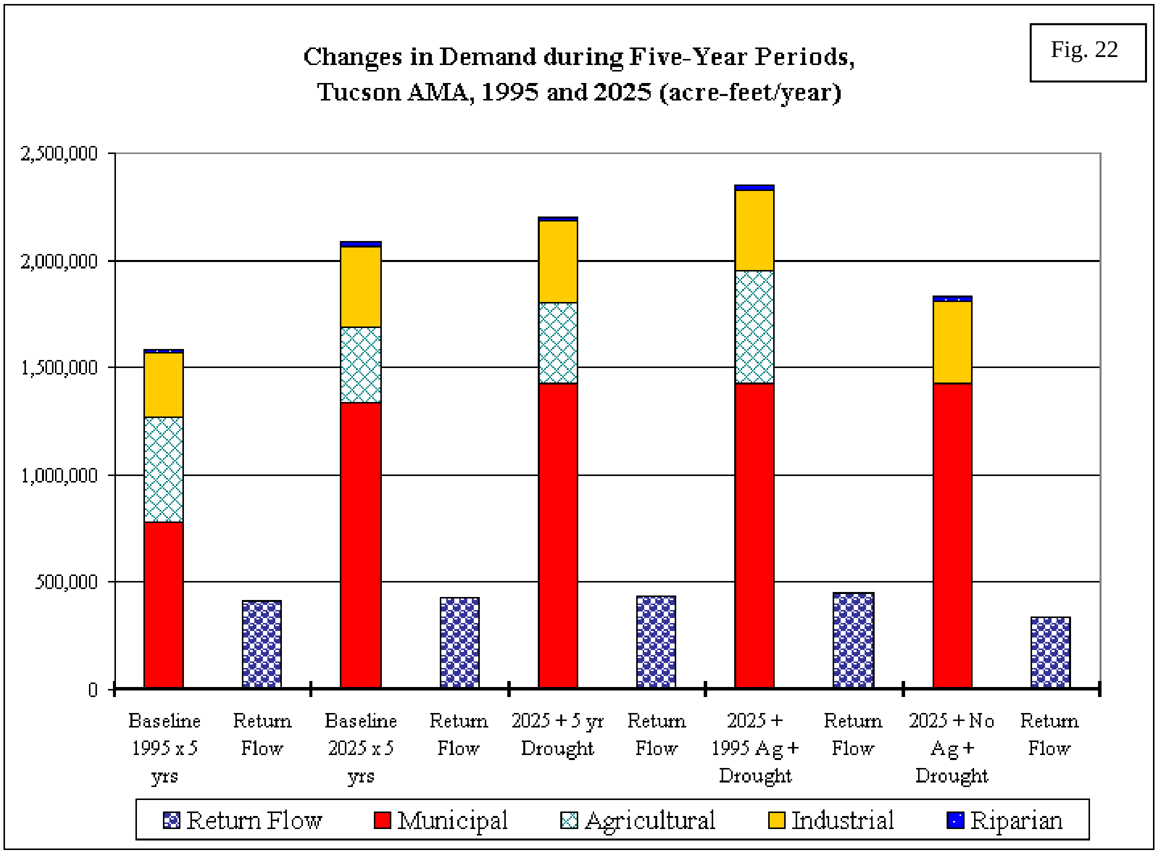
Demand changes based on the five-year drought scenario are illustrated in Figure 22.

TMP 2025 Baseline and Drought

Multiplying the Tucson AMA's TMP 2025 demand projections by five years and assuming normal climate conditions produces a total water demand of 1,654,500 af. Total return flow is 429,000 af. Adding the five-year drought scenario results in a 7 percent increase in net water consumption (1,765,621 af), while increasing the incidental recharge portion of the return flow by just over 4 percent to 174,010 af.

Maintain Agriculture at 1995 Level

When agriculture is maintained at 1995 levels under normal climate conditions for five years, combined with 2025 municipal and industrial demand levels, net water consumption equals 1,771,600 af, while incidental recharge amounts to 189,400 af. The five-year drought increases net water consumption to 1,898,631 af, or approximately 15 percent over the 2025 baseline.



Eliminate Agriculture

The elimination of agriculture in the Tucson AMA over a five-year period under normal climate conditions would result in a net water consumption of 1,395,500 af, which is 16 percent lower than the baseline TMP amount. Return flow would be 338,000 af. Calculation of the impact of the five-year drought increases return flow to 340,050 af; a net water consumption of 1,491,081 af would result. This is a reduction of 10 percent from the baseline TMP amount for drought conditions.

Ten-Year Scenarios

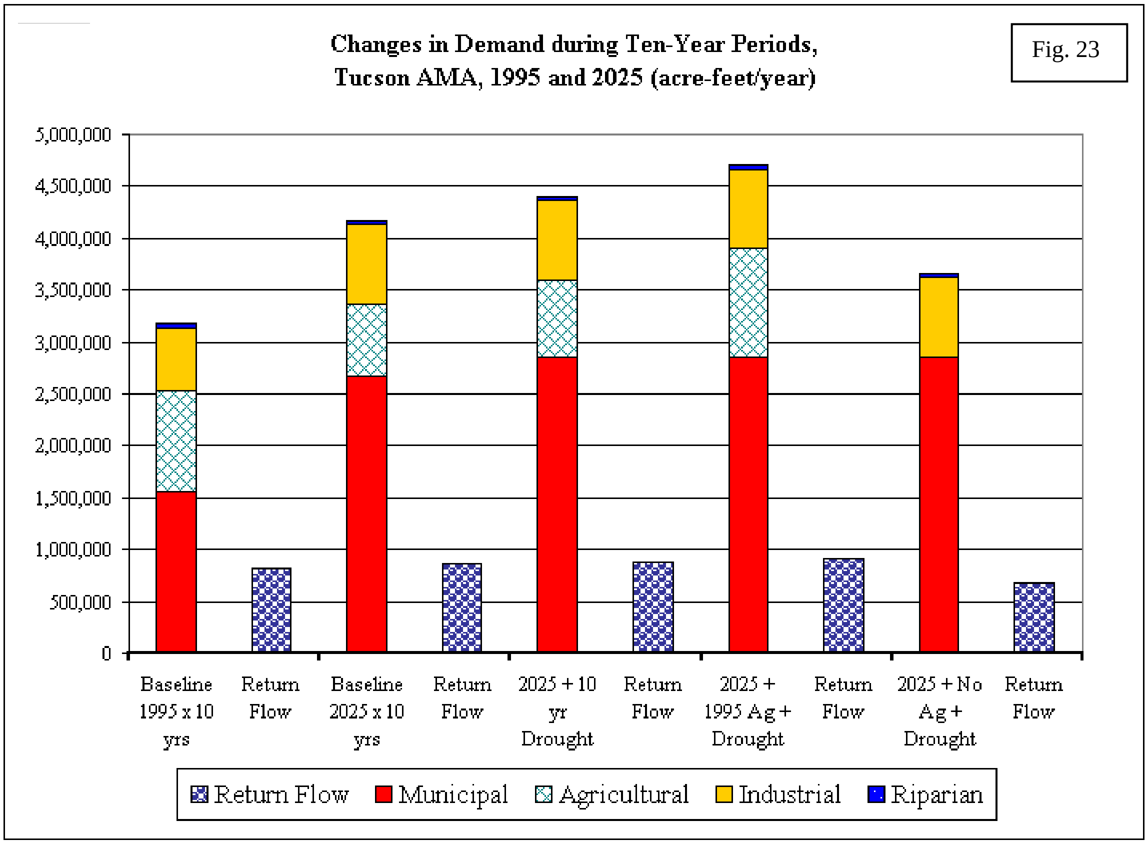
Figure 23 depicts the calculations for the ten-year drought scenario for the Tucson AMA.

TMP 2025 Baseline and Drought

Applying a ten-year time frame to 2025 net water consumption projections under normal climate conditions produces a baseline demand of 3,309,000 af. The ten-year maximum historic drought, wherein precipitation amounted to 74 percent of average, would result in a 7 percent increase in net water consumption. This works out to 3,531,242 af when total demand is combined with return flows of 873,020 af.

Maintain Agriculture at 1995 Level

This scenario, when spread over a decadal time period and under an assumption of normal climate conditions, results in a total water demand of 3,544,200 af. The addition of the drought pushes demand up to 3,798,262 af, a 15 percent increase over the ten-year baseline. Net consumption would total 489,262 af due to the cumulative effects of the extended drought.



Eliminate Agriculture

At this time scale, under normal climate conditions the elimination of agriculture would result in a ten-year net water consumption of 2,791,000 af, compared to 3,309,000 af for the baseline case. Return flows would be decreased 31 percent, from 858,000 af to 676,000 af. Factoring in the ten-year drought increases net total consumption by an additional 6 percent, to 2,982,162 af, which includes an offset of 680,100 af in return flow.

Santa Cruz AMA Scenarios

For the Santa Cruz AMA, the net water consumption change scenarios graphed at the one-, five- and ten-year time scales are as follows:

- TMP 1995 baseline (for comparative purposes)

- TMP 2025 baseline

- TMP 2025 baseline + drought: baseline net water consumption is combined with anticipated increases in demand and consequent increases in return flows via incidental recharge

- 2025 demand + 1995 agriculture + drought: projections for municipal, industrial and riparian demands for 2025 are combined with 1995 agricultural demand figures and drought impacts

- 2025 demand + no agriculture + drought: projections for municipal, industrial and riparian demands for 2025 are combined with the total elimination of agricultural water demand and the calculated impact of drought

<u>One-Year Scenarios</u>

Figure 24 illustrates changes to water demand and consumption for the one-year scenarios.

DTMP 2025 Baseline and Drought

Comparison of the 1995 DTMP water budget to the projections for the Santa Cruz AMA in 2025 indicates an increase in net water consumption of 13 percent over the thirty-year period. This might seem like a surprisingly low increase in net water consumption considering that the population of the AMA is expected to expand by 57 percent, from 32,975 to 57,675 people; indeed, municipal water demand is expected to nearly double between 1995 and 2025. However, municipal demand is a relatively small component of the Santa Cruz AMA's net water consumption, accounting for only 15 percent of total net water consumed in 1995 and a projected 24 percent by 2025. Based on comparisons between gallons per capita per day (gpcd) rates in different water service areas of the AMA in average and hot, dry years, overall municipal demand appears to fluctuate by approximately 2.7 percent in response to climatic conditions. One-year drought conditions would thus increase municipal demand to 11,708 af.

Agricultural water use, on the other hand, is expected to decline from 11,300 af to 10,300 af, or by 9 percent, under normal climate conditions, as cropped acreage decreases.[6] Increased consumptive water use by crops during one-year drought conditions could increase this amount to 10,959 af. Industrial water use in the Santa Cruz AMA is a relatively minor factor both in the present-day and future water budgets. This sector currently accounts for only 3 percent, or 1,300 af, of net water consumption. This sector is projected to require 5 percent, or 2,400 af of water supplies by 2025, of which 3,708 af would return to the aquifer as incidental recharge. A one-year drought could increase industrial demand by 96 af, to 2,496 af, with incidental recharge from this sector increasing to 3,945 af.

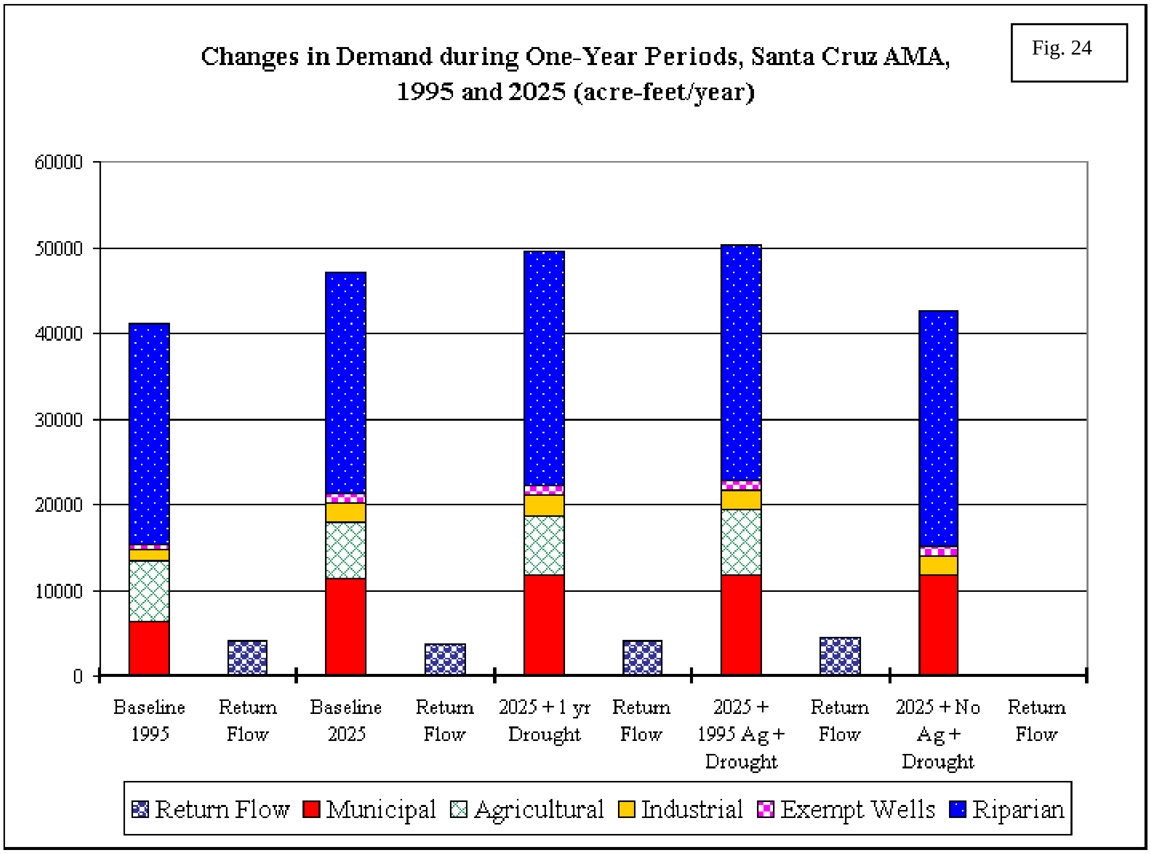
Riparian vegetation is a more significant water user in the Santa Cruz AMA than in the other AMAs. In both 1995 and 2025 riparian demand accounted for 25,800 af, or between 55 and 62 percent, of net water consumption. One-year drought conditions were calculated to increase riparian water demand to 27,451 af.

Note that while the scenarios tested for the Santa Cruz AMA include one involving the loss of NIWTP discharge, this is a supply variable that would not be expected to have a significant impact on net water consumption.

Maintain Agriculture at 1995 Level

Without the 9 percent decline in agricultural water use projected to occur between 1995 and 2025, and assuming normal climate conditions, agricultural water demand would remain at 11,300 af through 2025. Net water consumption for 2025 under normal climate conditions would be 47,712 af, or one percent higher than the DTMP baseline projections indicate; incidental recharge from this sector would be 4,068 af. A one-year drought would increase agricultural water demand by 6 percent, to 12,023 af, with incidental recharge rising to 4,328 af, and net water consumption expanding by 8 percent, to 50,909 af.

[6] Unlike the Phoenix and Tucson AMAs, there are no water rights allocated towards irrigating Indian land in the Santa Cruz AMA.



Eliminate Agriculture

The elimination of agriculture in the Santa Cruz AMA would result in significantly lower water demand even under normal climate conditions, since in 1995 agriculture accounted for about one-fourth of all water demand. Net water consumption could decline to 40,480 af, 86 percent of the average during normal climatic conditions. This would, in turn, decrease total return flows to 120 af (an amount too small to be visible on the graph). Net water consumption would rise to 42,610 af, or 91 percent of the norm, with only 125 af of total return flow, during the one-year drought.

Five-Year Scenarios

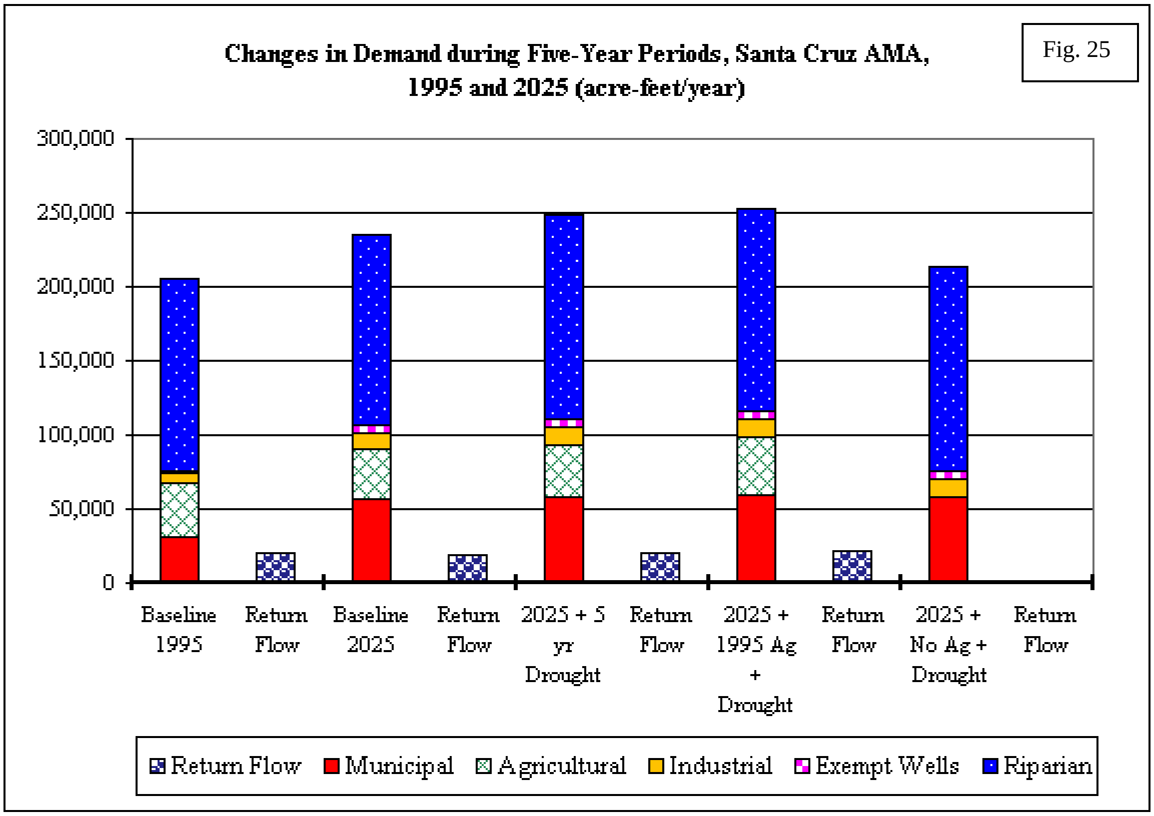
Demand changes arising from the five-year drought scenario are presented in Figure 25.

DTMP 2025 Baseline

Multiplying the DTMP baseline amounts calculated by ADWR for 2025 (which assumed normal climatic conditions) by five results in a net water consumption of 235,360 af, and total return flows of 19,140 af. Adding the five-year drought conditions to the calculation results in a total water demand of 248,120 af, and total return flows of 20,51 af, an increase of approximately 5 percent.

Maintain Agriculture at 1995 Level

Under normal climatic conditions, if agriculture did not decline as expected during the five-year period, net water consumption would equal 238,560 af, with 20,940 af of incidental recharge. If the five-year drought occurred as well, the resultant increase in net water consumption would be 251,525 af, or 6 percent higher, while incidental recharge would expand to 22,266 af.



Eliminate Agriculture

If agriculture were eliminated over the five-year time frame, assuming normal climatic conditions, net water consumption would decrease to 202,400 af, or 86 percent of the baseline five-year figure of 235,360 af, while return flows would decrease to 600 af. Drought conditions would increase this amount by 5 percent, to 213,051 af, with incidental recharge of 624 af.

<u>Ten-Year Scenarios</u>

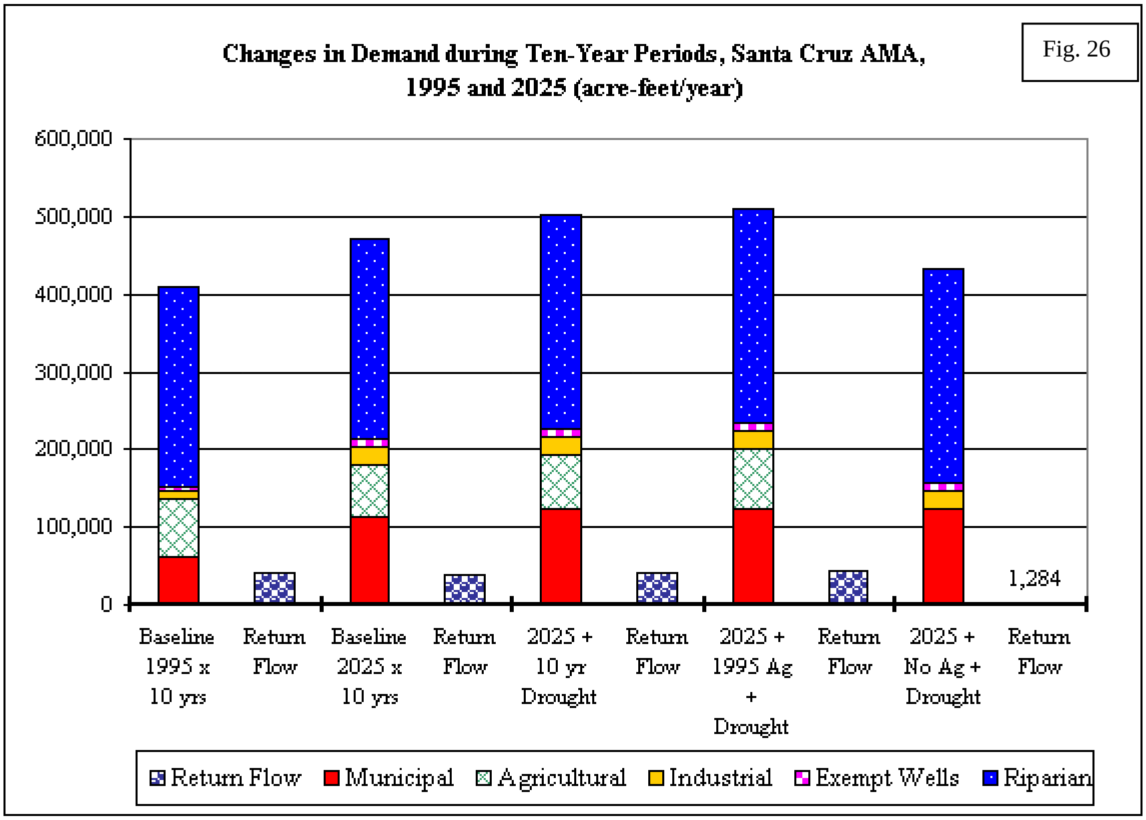
Figure 26 illustrates the demand calculations for the ten-year scenarios.

DTMP 2025 Baseline

Ten years of 2025 baseline conditions with normal climate equates to a net water consumption of 470,720 af, including 38,280 af of offsets to demand through return flow. A drought at the severity of the driest ten years on record would increase net consumption by 5 percent, to 496,241 af, while also increasing return flows to 40,701 af.

Maintain Agriculture at 1995 Level

Under normal climatic conditions, maintaining agriculture at 1995 levels for a decade would require a total of 477,120 af of water, after a return flow of 41,880 af is counted. Doing so under drought conditions would necessitate 503,050 af of net water consumption.



Eliminate Agriculture

Eliminating agriculture for ten years would reduce total demand to 404,800 af of water under normal climatic conditions; total return flow would amount to 1,200 af. Drought conditions would increase this amount to 426,102 af, with incidental recharge rising to 1,248 af.

Benson Subwatershed Scenarios

In the Benson subwatershed, agriculture represents the single largest water demand category. In the 1990 baseline year, 21,569 acre-feet or nearly 50 percent of total water demand was withdrawn by irrigated agriculture. Over an area of 5,330 acres, pasture crops are the most dominant crop type in this subwatershed, with total pasture crops amounting to 53 percent of the crops grown in 1990 (HSR, 1991). The second most extensively grown crop is alfalfa (29 percent), followed by small grains (11 percent).

The second largest water consumer category is the riparian vegetation along the San Pedro River, accounting for 41 percent of total water demand. Municipal demand in the 1990 baseline year accounted for only 3 percent.

The demand scenarios for the Benson subwatershed for the year 2025, including one-, five, and ten-year periods, are the same as used for the supply side calculations (refer to Appendix 4). The scenarios are as follows:

- population growth only: increased population size (DES and Pop High)

- drought: increased population (DES and Pop High) size combined with the historic minimum in winter precipitation in the Southeast Climate Division

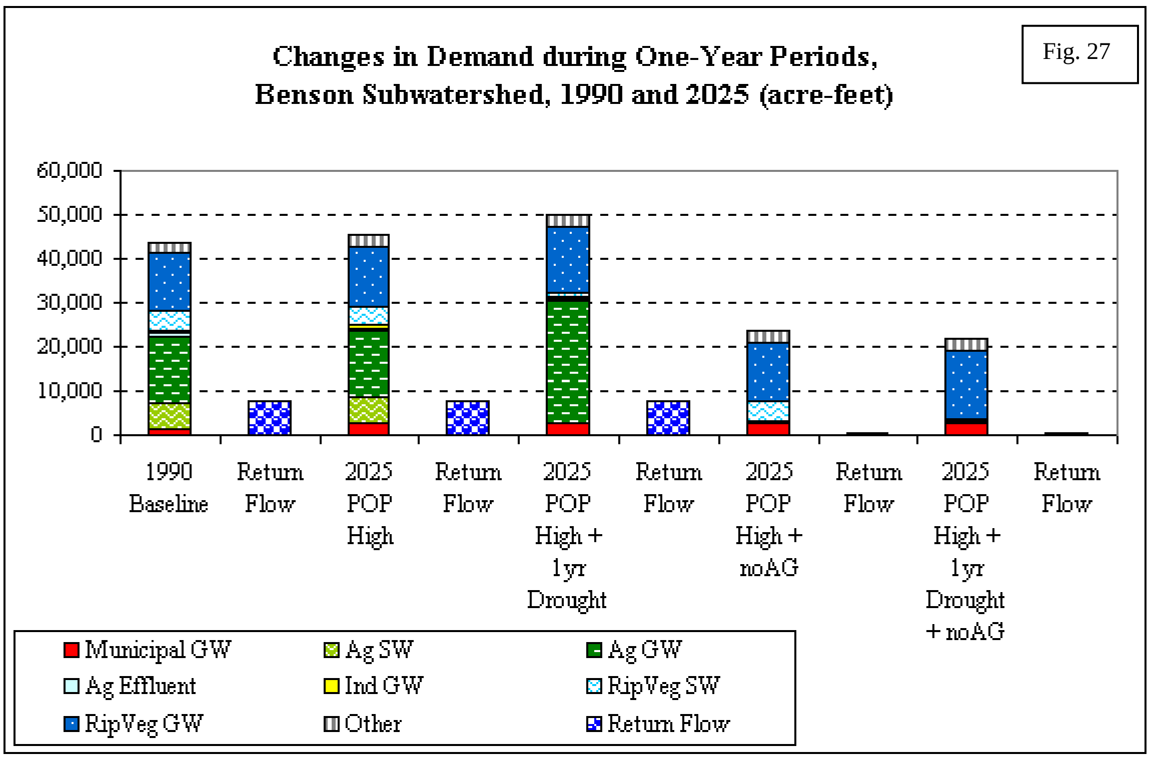
- elimination of agriculture: increased population size (DES and Pop High) and elimination of agriculture; increased population size (DES and Pop High) combined with the historic minimum in winter precipitation and elimination of agriculture.

One-Year Scenarios

The results of the analysis of the one-year drought scenarios appear in Figure 27, below.

Population Growth Only

Under the scenarios assuming population growth only, overall demand is expected to grow due to higher municipal water use. However, since municipal water consumption amounts to less than 4 percent in this subwatershed, the increase in demand for the year 2025 is expected to be fairly moderate, even though municipal water demand might almost double. While municipal water use will change from 1,425af to a possible maximum of 2,723af under the Pop High scenario (an increase of 91 percent), total water demand will only increase by 2 to 4 percent. Compared to the other four study locations, this is by far the smallest increase in demand that can be expected for the year 2025. Incidental recharge, an offset to total water demand, remains at the 1990 baseline level (7,675af). Subtracting this amount from the total demand under the population growth scenario yields 36,705 af of total net water consumption. Compared to the 1990 conditions, this represents the same increase (2 to 4 percent) as derived for total demand.



Drought

Combining population increase with the historic minimum precipitation, produces more significant impacts. In this case, total demand would increase by 13 to 15 percent compared to the 1990 baseline scenario. Municipal demands are assumed to expand at a rate only slightly higher (3 percent) than under the previous scenario. Compared with the other four locations, this represents the lowest increase in acre-feet, and can be explained by patterns of fairly limited outdoor water use in the Benson subwatershed.

Clearly, the most significant increase (81 percent) occurs with regard to demand for agricultural groundwater (from 15,263 af to 27,613 af). This large increase can be explained by the fact that large reductions in surface water supply would occur due to the drought; therefore, no surface water would be available to satisfy increasing crop requirements. All irrigation water would have to be pumped from the aquifer, with the exception of 600 af of effluent. Although agricultural water demands increase, incidental recharge is assumed to remain unchanged (7,675 af) as a result of higher plant needs, including evapotranspiration. Thus, total net water consumption would amount to roughly 42,000 af or 17 percent more than under 1990 baseline conditions.

At the same time, water needs for riparian vegetation are expected to rise, putting additional pressure on groundwater resources. Groundwater demand by riparian vegetation is anticipated to increase by 14 percent (from 13,260af to 15,102af). Although the available amount of surface water is split between channel evaporation and riparian needs, instead of being diverted for irrigation purposes, not enough surface water would be available to satisfy demands of shallow rooted plants along the San Pedro River. Depending on the drought resistance of the various riparian plants, it may be assumed that most of these plants would become dormant or die off, thereby reducing the total water demand by riparian vegetation. Overall, water demand will increase by roughly 6,000af. Given the lack of surface water, it is safe to assume that this additional amount would have to be drawn from groundwater resources.

Elimination of Agriculture

Under the elimination of agriculture scenarios, total demand would be reduced to approximately half of the baseline amount. Assuming normal climate conditions and an increase in population, overall demand would drop roughly to between 23,000 af and 24,000 af, compared to the baseline 43,495 af demand for 1990.

Combining population increase and drought conditions, the total demand under the elimination of agriculture scenario would be even lower. Again, this is based on the assumption that the majority of the surface water-dependent riparian vegetation would become dormant or die off. Generally, this significant decrease in water demand can be explained by the fact that agriculture in the Benson subwatershed accounts for 50 percent of total water use under baseline conditions. Indeed, a hypothetical elimination of the major water user in the area would result in the lowest water demand among the five study locations.

At the same time, however, return flows (incidental recharge) would decrease as well. Since the amount of water used for agriculture and incidental recharge are directly linked, the elimination of agriculture under this hypothetical scenario would be noticed in an immediate decline in this type of recharge. In the Benson subwatershed, agricultural return flows are fairly substantial, accounting for 93 percent of all return flows. Thus, a total elimination of irrigation would result in 93 percent or 7,117af less incidental groundwater recharge. As a result, the difference between total net water consumption and total water demand is fairly small (558af).

Five-Year Scenarios

The results of the analysis for the five-year drought scenarios are depicted in Figure 28, below.

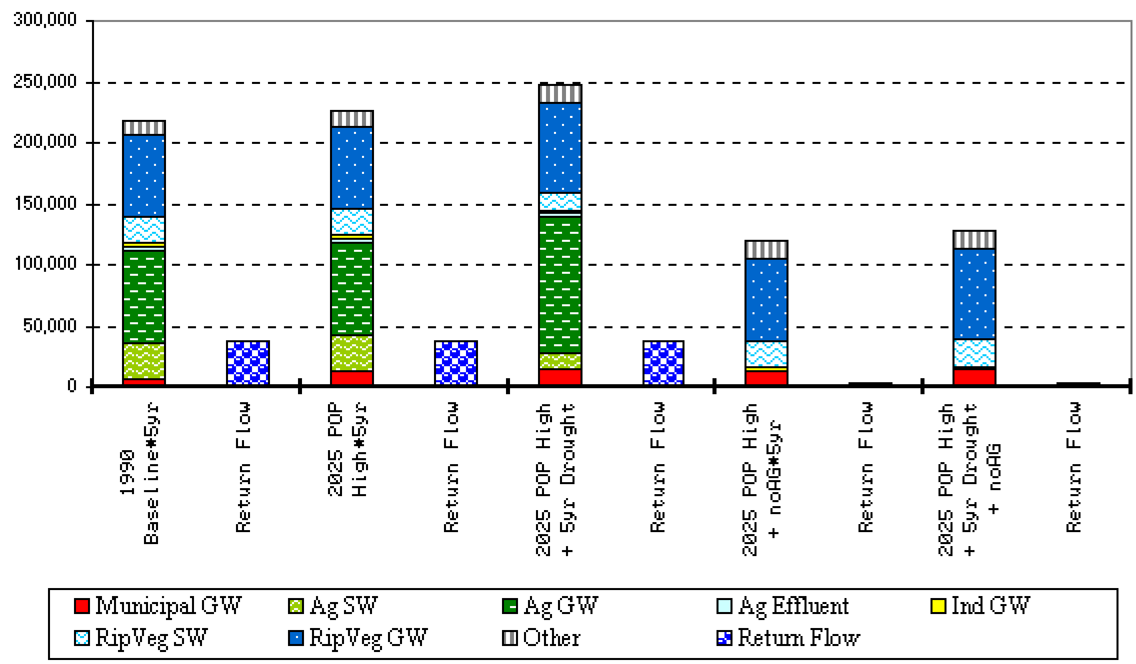
Population Growth Only

Under this scenario, demand is again expected to increase due to higher municipal water use. Since the population growth scenarios represent a simple extension of the one-year scenarios, the same percent increase in demand (2 to 4 percent compared to the baseline conditions, multiplied by five) was calculated. In actual numbers, this increase would amount to

4,425 to 9,225 af under the two population projections (DES and Pop High), respectively. Incidental recharge is assumed to remain unchanged (38,375af), resulting in a total net water consumption of roughly 185,000af.

Changes in Demand during Five-Year Periods, Benson Subwatershed, 1990 and 2025 (acre-feet)

Fig. 28



Drought

As in the corresponding one-year scenario, demand is anticipated to rise under drought conditions. However, since the five-year drought documented for the Southeast Climate Division was not as extreme as the worst single year event, the increases in water demand are somewhat more moderate. All in all, increase in demand may be expected to amount to 12 to 14 percent compared to the baseline conditions extended over five years.

Only a slight increase is anticipated for the municipal sector (3-4 percent). As before, the highest increase would occur in the agricultural sector (19 percent) with emphasis on groundwater use (46 percent). Although some surface water can be expected to be available for irrigation diversion (13,594 af, or roughly half of the amount required under baseline conditions), irrigation farmers would still have to increase their groundwater pumping by an additional 35,326 af in order to meet higher crop demands. As shown in the section on water budgets, this additional demand would add considerably to groundwater overdraft. As in the one-year scenarios, return flows from agriculture (incidental recharge) is assumed to remain constant (38,375af), resulting in total net water consumption of roughly 205,000 af or 14 percent more than under 1990 conditions.

Moreover, the groundwater needs of riparian vegetation would increase as well. Unlike in the one-year drought scenarios, roughly half of the shallow rooted plants that depend on surface water might be expected to survive a five-year drought period. This assumption holds true as long as available San Pedro River water is equally split between riparian vegetation and irrigated agriculture, as assumed in this analysis. The relatively large increase in groundwater demand (8,556 af or 13 percent) is attributable to the assumption that, during a five-year period, the composition of the riparian vegetation might shift to an increased number of deeper-rooting plants such as mesquite. Total water demand by riparian vegetation, however, is assumed to remain the same.

Elimination of Agriculture

As in the one-year scenarios, the hypothetical elimination of agriculture in the Benson subwatershed would considerably reduce total water demands. A net decrease of 108,000 af, and 120,000 af, can be expected under the population growth-only scenario and the drought scenario, respectively. Compared to the extended baseline conditions, this would represent an overall decrease of roughly 40 percent. This large decline in water use can be anticipated despite the fact that, at the same time, municipal as well as riparian levels of consumption are expected to increase.

This is particularly true for the scenario where population increase, drought, and the elimination of agriculture are combined. While the increase in municipal demand is expected to be fairly small (3 to 4 percent), riparian vegetation will consume roughly 10 percent more water. This increase can be attributed to the availability of enough surface water to sustain shallow-rooted plants at the baseline rate and the expectation that overall plant requirements would increase due reduced effective precipitation. It was assumed, in this analysis, that the additional amount of water required would be met by groundwater.

Ten-Year Scenarios

The impacts on water demand of the worst ten-year drought in the historical record for this Climate Division are depicted in Figure 29, below.

Population Growth Only

As in the five-year scenarios, increases in municipal demand are calculated by simply multiplying the one-year numbers by ten years. The growth rate is retained at 2 to 4 percent, relative the baseline conditions. In actual numbers, by the year 2025 the population in the Benson subwatershed would consume 6,220 to 12,980 additional acre-feet. This increase, compared to the other four study locations, seems rather small. Incidental recharge will amount to 76,750 af and total net water consumption to approximately 370,000 af.

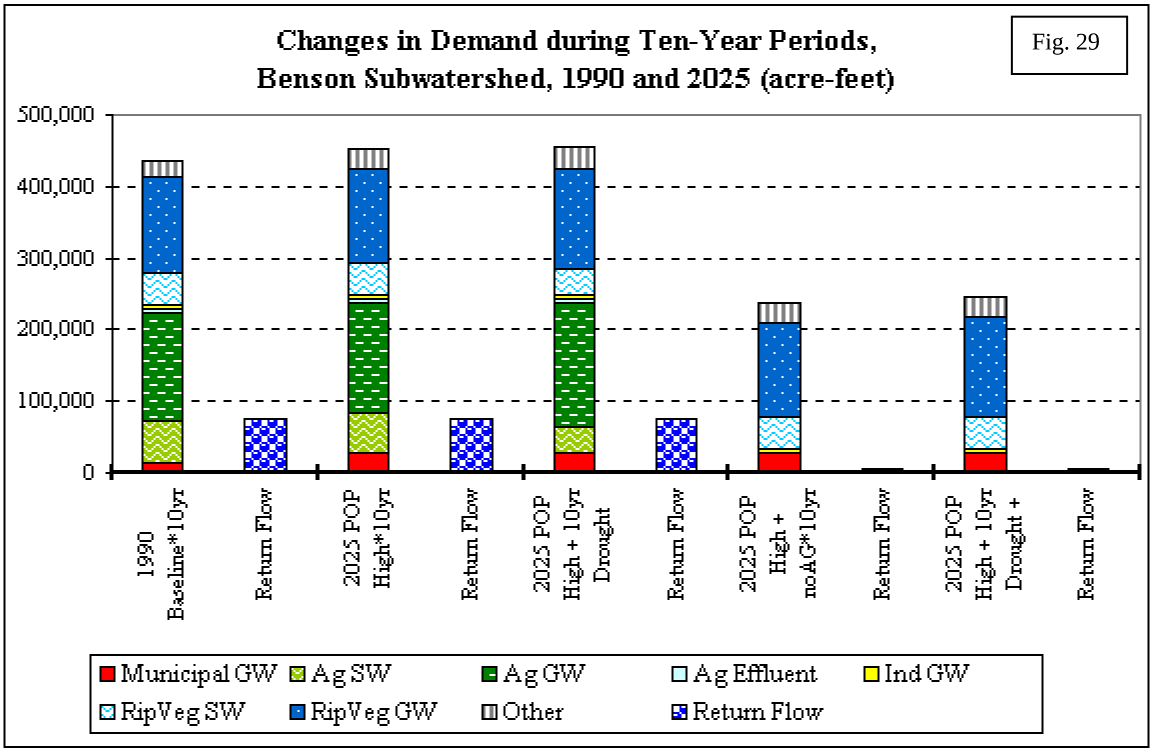
Drought

The increases in demand that could be anticipated for the ten-year drought scenarios are only slightly higher than the ones under the five-year scenario. While somewhat higher consumption can be expected for the municipal sector, primarily due to increased outdoor water use (3 to 4 percent), no changes are assumed to occur in the total water needs for agriculture and riparian vegetation. Based on the methodology used for making adjustments to agricultural and riparian to account for reduced rainfall, the expected mean precipitation recorded for the 1950s drought would still be above the effective precipitation threshold.

Nevertheless, not enough surface water is expected to be available to satisfy both agricultural and riparian surface water needs as specified in the extended baseline conditions. Thus, additional groundwater would have to be pumped in compensation (20,700 af for irrigated agriculture and 7,669 af for riparian vegetation along the San Pedro River). As in the five-year scenarios, a shift toward deeper-rooted plants along the riparian corridor may be anticipated.

Elimination of Agriculture

Again, overall water demand is expected to drop when agriculture in the subwatershed is eliminated. Gains under this hypothetical scenario would amount to roughly 215,000 af (45 to 48 percent) if only a population increase is assumed. Under drought conditions, potential gains would be slightly lower (approximately 210,000af), given that some of the riparian vegetation might shift to more pronounced reliance on groundwater. As under the one- and five-year scenarios, incidental recharge is expected to decrease significantly, allowing only for 5,580 af in return flows to groundwater reserves.



Sierra Vista Subwatershed Scenarios

In the Sierra Vista subwatershed, the largest water consumer category in 1990 was the riparian vegetation along the San Pedro River (39 percent of total demand), followed by municipal use (30 percent). Unlike in the Benson subwatershed, agricultural water demand is fairly small (17 percent). Although the overall irrigated acreage is also smaller than in the Benson area (2,181.2 acres in 1990), the proportion of the most dominant crop type, pasture crops, is roughly the same: 54 percent of all crops are irrigated, compared with 53 percent in the Benson subwatershed (ADWR, 1991). The next major crop type is alfalfa (17 percent), followed by grapes (11 percent), and turf (10 percent).

For the Sierra Vista subwatershed, the one-, five-, and ten-year demand scenarios for 2025 are the same as those used for the supply side calculations (refer to Appendix 5). They can be grouped as follows:

- population growth only: increased population size (DES and Pop High)

- drought: increased population (DES and Pop High) size combined with the historic minimum in winter precipitation in the Southeast Climate Division

- elimination of agriculture: increased population size (DES and Pop High) and elimination of agriculture; increased population size (DES and Pop High) combined with the historic minimum in winter precipitation and elimination of agriculture.

<u>One-Year Scenarios</u>

Results of the analysis of the one-year drought scenarios are depicted in Figure 30, below.

Population Growth Only

Compared to the Benson subwatershed, increases in demand in the Sierra Vista subwatershed are expected to be more significant due to the clearly higher population numbers. While the 2025 population projections for the former range between 14,176 and 18,861 total residents, those for the latter are assumed to be almost 6 times as high. Since changes in population size are proportionally translated into municipal water demand, an increase of 56 to 77 percent in residential and commercial water consumption is expected. In actual numbers, municipal demand would amount to roughly 17,000 to 19,500 af compared to a demand level of 11,000 af in the 1990 baseline year. Overall, demands in this part of the San Pedro River basin are expected to reach almost 47,000 af under the higher population projection scenario. This represents a maximum increase of 27 percent in demand relative to the baseline amount. Unlike the Benson case, where total changes in demand amounted to only 2 to 4 percent, this increase is far more substantial.

At the same time, agricultural return flows to groundwater (incidental recharge) are less important than in the Benson subwatershed. Due to more limited needs for irrigated agriculture, this type of recharge would amount to only 1,755 af in the Sierra Vista subwatershed, compared with the 7,117 af of return flows calculated for the Benson area. Therefore, the difference between total water demand and total net water consumption (total incidental recharge) in the Sierra Vista area is significantly smaller (2,591af).

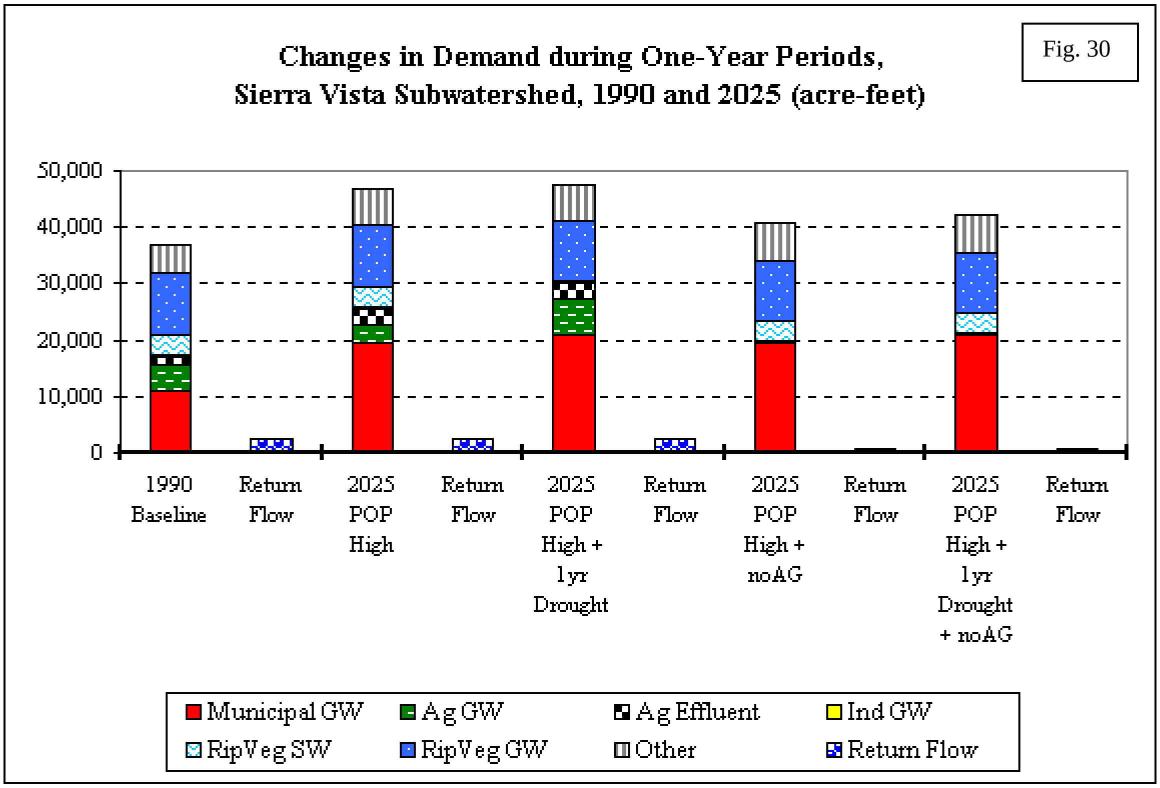
Drought

Combining population growth and historic drought conditions revealed some interesting patterns. Although total demand is barely higher than in the population growth-only scenarios (less than 1 percent), significant shifts can be noticed within the demand categories.

As expected, municipal demand will increase, primarily because of higher outdoor demands. The increase, at 7 percent, is clearly higher than that calculated for the Benson subwatershed (3 percent). Under these conditions, municipal water needs would exceed 20,000 af, an amount almost twice as large as demand in the baseline year.

Nevertheless, compared to increases in agricultural demands, the changes in the municipal sector are relatively small. Since irrigated agriculture in the Sierra Vista subwatershed relies primarily on aquifer resources, increased crop requirements would have to be met by increased groundwater pumping. It can be expected that more than twice the 2025 baseline amount (+109 percent) would have to be pumped to maintain irrigated crops. In actual numbers, this represents a change from 3,516 af to 6,627 af. Agricultural return flows were assumed to remain at the 1990 baseline level (2,591 af).

Groundwater demand by riparian vegetation is expected to remain unchanged, since the actual effective precipitation necessary to satisfy plant demands would stay within the defined threshold value. However, given the very limited amount of surface water available under the historic drought condition, it has to be assumed that no surface water could be obtained from the river. As a consequence, all shallow rooted plants would be expected to become dormant or, if not drought resistant, eventually die off. In either case, overall water demand in this category would be reduced to roughly 75 percent of the baseline amount (10,838 af versus 14,450 af).



Elimination of Agriculture

Since agricultural demands account for less than 20 percent in this part of the San Pedro River basin, the elimination of irrigation water use would not yield results as dramatic as in the Benson subwatershed. Total water demand is expected to decline, on average, from roughly 45,000 af to 36,000 af. This 20 percent decrease is fairly small compared to the 50 percent reduction assumed for the Benson area. In fact, total demands would still be higher than those reported for the 1990 baseline year. This situation holds for both the no-drought and the drought scenarios.

With the elimination of agriculture, incidental recharge would be reduced, leaving only 836 af of return flow to groundwater. Since irrigation water demands in the Sierra Vista subwatershed are smaller, the reduction of incidental recharge under this scenario would amount to only 67 percent, compared to 93 percent in the Benson case.

Five-Year Scenarios

Results of the analysis of the impacts of the ten-year drought scenarios are illustrated in Figure 31, below.

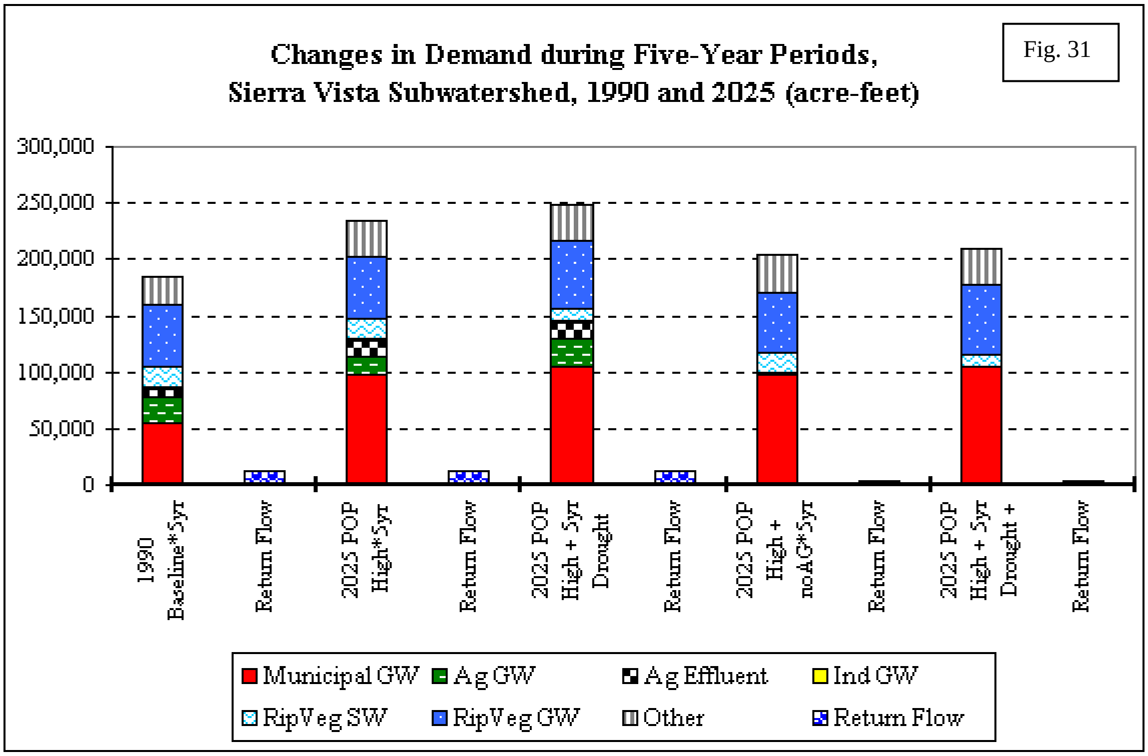
Population Growth Only

As in the other population-only scenarios, one-year municipal demand numbers were extended over a period of five years. Consequently, under baseline conditions, the percent increase in total demand remains unchanged (20 to 27 percent). In terms of changes in sectoral demand, municipal water consumption is expected to increase by 56 to 77 percent compared to the baseline. Incidental recharge is assumed to remain at the 1990 level (12,955 af), resulting in roughly 220,000 af of total net water consumption.

Drought

Under the five-year drought and 2025 Pop High scenario, total demand is anticipated to increase from 184,805 af to almost 250,000 af. This represents an increase of 34 percent compared to 1990, but only a change of 6 percent when compared to the 2025 average climate and Pop High scenario. Clearly, the large increase in the former case is due to the projected population growth and the related increase in municipal demand rather than to increased water needs related to the impact of drier conditions.

In terms of demand change per category, both municipal and agricultural groundwater needs would be expected to rise, with increases amounting to 7 and 55 percent, respectively. In other words, roughly 7,000 additional af of water would be needed to satisfy residential and commercial demands, as well as another approximately 8,000 additional af to meet crop needs. Incidental recharge amount remains the same as under the 1990 and 2025 population growth conditions (12,955af).



While total riparian water demand is assumed to remain unchanged, a shift toward more drought tolerant/deeper rooted plants is expected to occur during these five years of unusually dry conditions. Since agriculture in this part of the basin does not rely on surface water at all, there is no direct competition between irrigated crops and riparian vegetation, although there is interception of subflow by irrigation wells. Instead, competition occurs primarily between riparian vegetation and municipal pumping from well fields located west of the river. All available water in the river is split between channel evaporation and roughly 60 percent of the surface water dependent riparian plants. Deeper-rooted plants, such as mesquite, are assumed to rely primarily on groundwater, thereby increasing groundwater extraction by 14 percent compared to baseline conditions.

It should be noted, however, that the analysis was based on basin-wide numbers rather than on site-specific levels of water demand. Thus, the effects of groundwater withdrawals in the Fort Huachuca/Sierra Vista area that, according to Pool and Coes (1999), have resulted in a cone of depression with the highest rates of water-level decline in the regional aquifer (0.5 to more than 1 foot/year) could not be taken into account. Another factor that is not reflected in the basin-wide calculations is the interception and diversion of groundwater flows that, in the absence of current high pumping rates in the Fort Huachuca/Sierra Vista area, would discharge to the river. While the portion of the San Pedro currently most affected by this interception and diversion of underground flows is downstream of the Charleston gage (in the northernmost portion of the subwatershed), continued groundwater pumping and the expansion of the cone of depression will eventually also affect portions of the river south of the gage (Pool and Coes, 1999). Accordingly, the 10,344 af of San Pedro surface water, which in this analysis have been calculated to be available to the more shallow-rooted plants in the riparian channel, might be overestimated. This amount might not reach the alluvial aquifer that underlies the river channel and, subsequently, might not discharge to the stream as anticipated.

Elimination of Agriculture

As in the one-year scenarios, total demand for the year 2025 is expected to exceed the 1990 numbers, even with total elimination of agriculture. The increase in population growth and related municipal demand are primarily responsible for these high demand numbers in the Sierra Vista subwatershed, both under drought and no-drought conditions. Total water consumption under this hypothetical scenario is assumed to amount to roughly 200,000 af, which represents a net decrease of approximately 40,000 af of demand calculated in the 2025 population growth-only scenario.

With the elimination of agriculture, incidental recharge would drop from 12,955 af to 4,180 af. As under the one-year scenario, this decline is relatively small compared to that calculated for the Benson subwatershed, where total agricultural water demands are substantially higher. As a result, the difference between total water demand and total net water consumption amounts to only 2 percent.

<u>Ten-Year Scenarios</u>:

Results of the analysis of the impacts of the ten-year drought scenarios are illustrated in Figure 32, below.

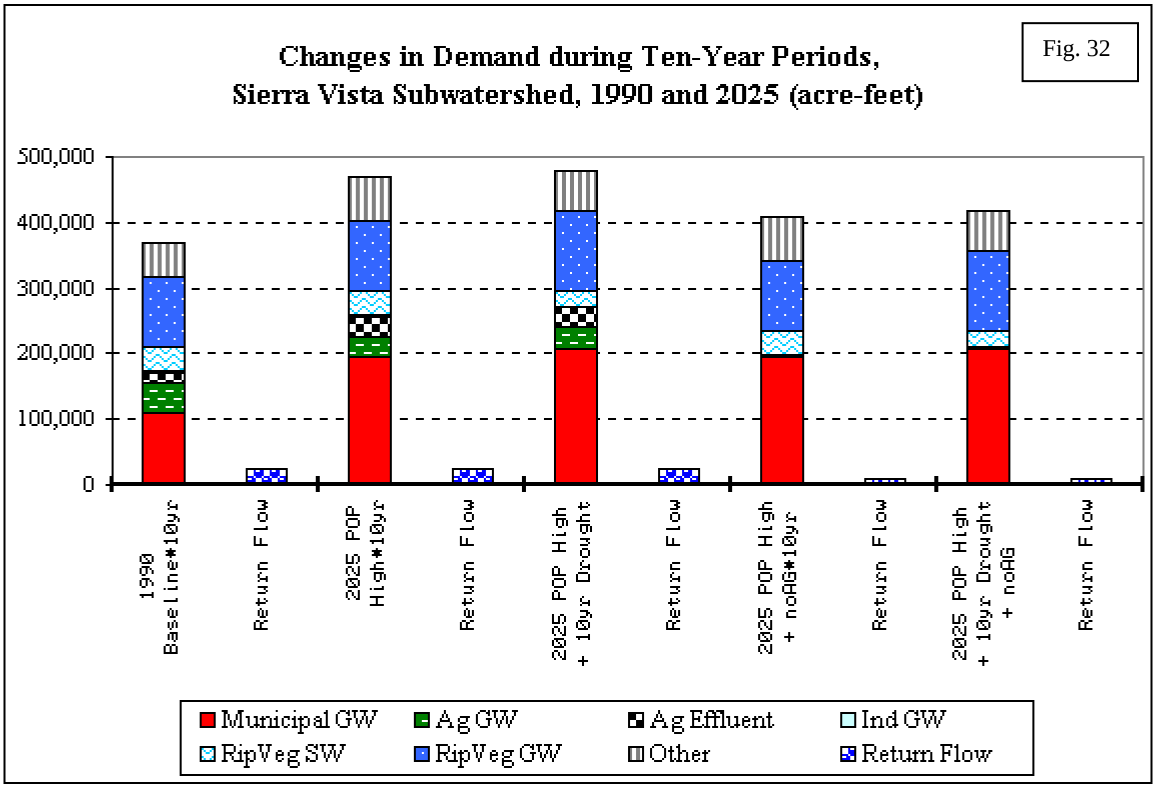
Population Growth Only

The ten-year scenarios repeat the trends described for the one- and five-year population growth-only scenarios. In the ten-year scenarios, the percent increase in total demand was calculated to range between 20 and 27 percent. In terms of sectoral demand increase, municipal water consumption could be expected to increase by 56 to 77 percent compared to the baseline number. Incidental recharge, when multiplied by ten, is identical to the 1990 numbers (25,910 af).

Drought

Under the ten-year scenarios, demand is anticipated to increase by a maximum of 31 percent relative to the 1990 baseline year. Compared with the 2025 population growth-only scenario, this increase amounts to only 3 percent. Total demand would range between 469,000 af and 454,000 af.

Municipal demands are assumed to grow at the same rate as under the five-year drought scenarios (a 7 percent increase) when compared to the 2025 baseline conditions. Unlike in the five-year scenarios, no changes are expected for total agricultural demands. This is due to the fact that the effective precipitation during this ten-year drought period stays within the critical threshold for crop water requirements. Return flows to groundwater remain unchanged as well at 25,910 af. In terms of riparian vegetation, not enough surface water would be available to satisfy needs of surface water-dependent plants. Thus, as it is also the case in the Benson subwatershed both for the five- and ten-year drought scenarios, a shift toward more groundwater-dependent, deeper-rooted plants is assumed.



Elimination of Agriculture

As in the one- and five-year scenarios, high increases in population size and municipal demand are responsible for the results showing that, by the year 2025, total demand would exceed the 1990 baseline number (assuming that agriculture was entirely eliminated). This hypothetical scenario holds true for both the drought and no-drought conditions. The rate of exceedance would range between 6 and 14 percent. Compared with the other 2025 scenarios, however, the elimination of agriculture results in a decrease of total demand that ranges between 10 and 13 percent. As in the other scenarios, the elimination of agriculture is expected to result in a significant decrease in incidental recharge. Compared to the scenarios that include agricultural irrigation, only 8,360af could be considered return flow to groundwater. Given this small amount of return flow, total net water consumption nearly equals total water demand.

C. Changes in Groundwater Balance (Groundwater Impact)

The final part of our sensitivity analysis consisted of calculating groundwater impacts for the five locations under the various 2025 scenarios. Groundwater impact is defined as total groundwater recharge (including incidental recharge, the AWS replenishment obligation and the cut to the aquifer) minus total groundwater withdrawals minus groundwater outflow (where relevant). Groundwater overdraft reflects the amount of groundwater that is not replaced by recharge under normal circumstances, and is therefore unsustainably mined. Another way of depicting groundwater impact, as illustrated in the graphs in this section, is to subtract total net water consumption (as well as unused effluent and unused surface water, where relevant) from total water supply. The detailed groundwater impact calculations for the Phoenix AMA, the Tucson AMA, and the Santa Cruz AMA are presented in Appendices 1, 2, and 3. The spreadsheets for the Benson and Sierra Vista subwatersheds are included in Appendices 4 and 5.

For the purposes of this analysis, it is assumed that deficits between water supply and increased consumption would be met through greater groundwater mining. This assumption recognizes that increasing surface supply is not likely to be undertaken under short-term drought conditions. Further, no adjustments are made for potential conservation savings, because the amount of savings achieved would depend on the nature and effectiveness of the specific conservation measures employed. Such decisions involve formulation and/or application of regulations, policies and procedures beyond the scope of this analysis.

In making our calculations, both the variations in natural recharge due to increased or decreased precipitation and the added effects of changes in human demand on the water balance were explored. The scenarios analyzed here represent combinations of the supply and net consumption changes discussed in the Supply and Demand sections of this report, plus the addition, for the AMA study areas, of 1995 supply figures and 2025 consumption projections under both normal climatic and drought conditions.

Phoenix AMA

For the Phoenix AMA, the groundwater impact scenarios analyzed and graphed for the one-, five- and ten-year time scales are as follows:

- TMP 1995 baseline renewable supply and net consumption
- TMP 2025 baseline renewable supply and net consumption
- TMP 2025 baseline renewable supply and net consumption + drought
- TMP 2025 baseline renewable supply and net consumption + drought – CAP (five- and ten-year scenarios only)
- 2025 renewable supply + 1995 agricultural demand
- 2025 renewable supply + 1995 agricultural demand + drought
- 2025 renewable supply + 1995 agricultural demand + drought – CAP (five- and ten-year scenarios only)
- 2025 renewable supply + no agricultural demand

- 2025 renewable supply + no agricultural demand + drought

- 2025 renewable supply + no agricultural demand + drought – CAP (five- and ten-year scenarios only)

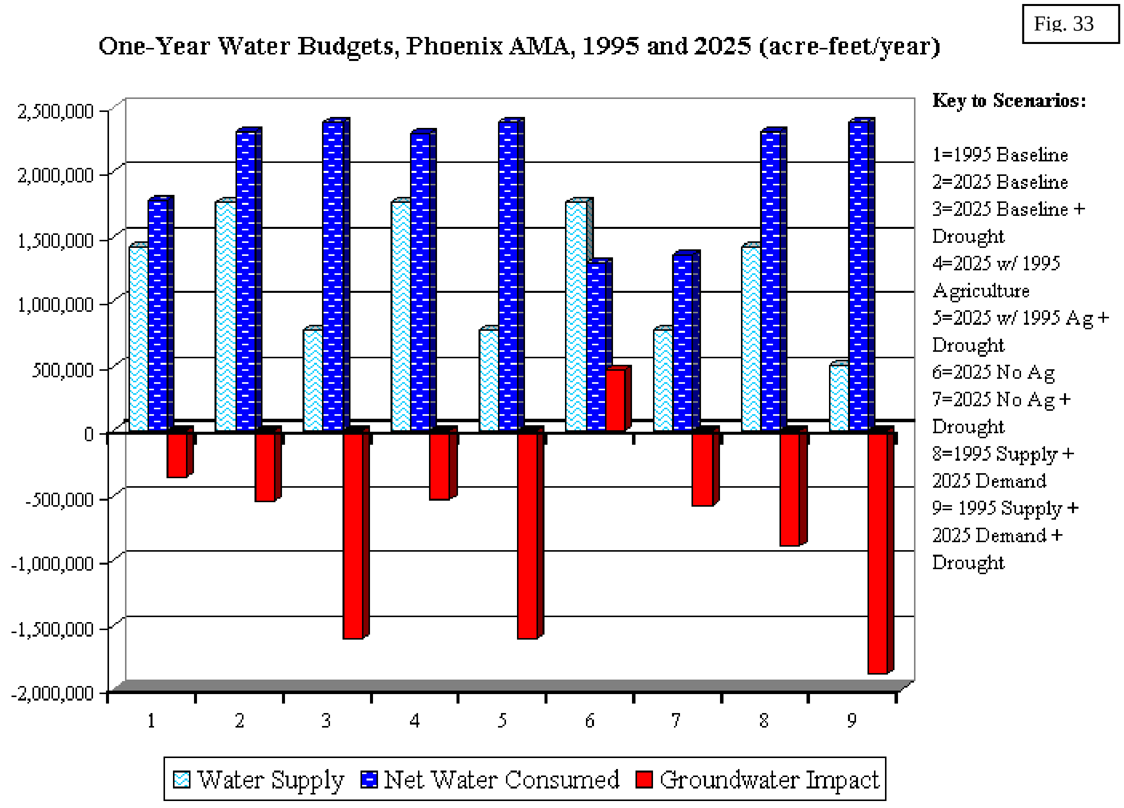
- 1995 renewable supply and 2025 net consumption

- 1995 renewable supply and 2025 net consumption + drought

One Year Scenarios

Impacts on water budgets of the one-year scenarios for the Phoenix AMA are illustrated in Figure 33.

Fig. 33



TMP 2025 Baseline and Drought (Scenarios 1, 2 & 3)

Despite the language of the GWMA, current projections indicate that safe-yield will not be achieved by 2025 (see ADWR 1999a). In fact, substantial population growth and few new renewable supply sources can be expected to increase the imbalance between renewable supply and demand by an additional one-third, or 183,235 af above 1995 baseline overdraft conditions.

The 1995 TMP baseline figures show groundwater overdraft at 360,019 af over the amount that is recharged into the aquifer annually. This means that in 1995, Phoenix relied on unsustainable groundwater mining to meet 20 percent of its annual needs. By 2025, the annual overdraft is expected to be 543,254 af, or 24 percent of Phoenix's annual supply even under the TMP Baseline scenario, and assuming normal climate conditions.

If a drought of the magnitude of the 1903-1904 event, where only 11.5 percent of the normal amount of precipitation fell, were to recur in conjunction with expected 2025 population size, the effects could be substantial. In this case, and assuming agricultural activity at the level specified in the Phoenix AMA's TMP for 2025, Phoenix would be forced to rely on groundwater overdraft for 1,609,614 af of its water supply. Under these conditions, less than one-third of its demand could be met with renewable supplies.

Maintain Agriculture at 1995 Level (Scenarios 4 & 5)

If agriculture were maintained at the 1995 level (rather than increasing slightly as anticipated for 2025 in the TMP), the total aquifer overdraft would be 13,634 af less than in the baseline condition. The addition of drought conditions would increase the overdraft by an additional 1,078,855 af, for a total overdraft of 1,608,475 af. Although these numbers constitute only small percentages of the total overdraft situation on a one-year basis, the five- and ten-year scenarios discussed below reveal more significant cumulative effects of this slight increase in overdraft.

Eliminate Agriculture (Scenarios 6 & 7)

The elimination of agriculture from the Phoenix AMA would eliminate overdraft during years with normal winter precipitation amounts. In fact, a 36 percent, or 463,696 af surplus of renewable water supplies were calculated to occur. However, under the one-year drought scenario, a 43 percent deficit in renewable water supplies was determined to occur. Based on these calculations, ad assuming no significant conservation efforts, the Phoenix AMA would have to mine 577,254 af of groundwater. This suggests that even the elimination of the largest water-using sector in the Phoenix AMA would not bring the city into sustainable use of its existing water supplies for one-year periods under severe drought conditions. This is slightly more than the amount of overdraft that would be required under normal climatic conditions, or to maintain agriculture at 1995 levels scenarios.

1995 Supply with 2025 Demand (Scenarios 8 & 9)

Although expanding net water consumption is expected to be offset in part by more efficient utilization of renewable water supplies, these supply changes are based on human actions rather than changes to the natural hydrological system. In the interest of further exploring the changing dimensions of groundwater overdraft, two additional groundwater impact scenarios were created. In the first, 1995 supply was compared to 2025 normal demand. The result was a deficit in renewable supplies of 890,822 af, meaning that nearly 40 percent of the AMA's water needs would have to be met through overdraft. In the second, the impacts of the one-year drought were calculated against the 1995 supply figures and the 2025 net consumption numbers. The result indicates that a renewable supply deficit of 1,878,814 af would occur, meaning that only 21 percent of the Phoenix AMA's water needs could be met without resorting to overdrafting the aquifer.

<u>Five-Year Scenarios</u>

Figure 34 depicts the water budgets under the five-year scenarios for the Phoenix AMA.

TMP 2025 Baseline and Drought (Scenarios 1, 2, 3 & 4)

Groundwater withdrawal levels for 2025 (including agriculture specified in the TMP for the year 2025) were multiplied by five to reflect a five-year period. The result was a total groundwater overdraft of 2,716,270 af for the period. Under this level of demand and consequent overdraft, the Phoenix AMA must rely on overdraft for 24 percent of its water supply even during normal climatic conditions. A five-year drought reducing mean winter precipitation by 44 percent would deplete renewable supplies and increase demand such that an overdraft of 5,582,716 af would result, even if CAP supplies were retained. If CAP supplies were cut off for the entire five-year period (the worst-case five-year scenario), groundwater overdraft would rise to 7,985,206 af.

Maintain Agriculture at 1995 Level (Scenarios 5, 6 & 7)

Maintaining agriculture at the 1995 level would make little difference in the Phoenix AMA. If this were the case, a slightly lower 23 percent, or 2,581,980 af of groundwater, would have to be mined to meet demand under normal climatic conditions. A five-year drought of the magnitude experienced from 1900-1904, with CAP supplies available, would produce an overdraft of 5,523,502 af, or 47 percent of the total water supply. Without the CAP contribution, Phoenix's demand would exceed its renewable supply by 8,188,967 af for the five-year period, a figure roughly triple the baseline overdraft amount.

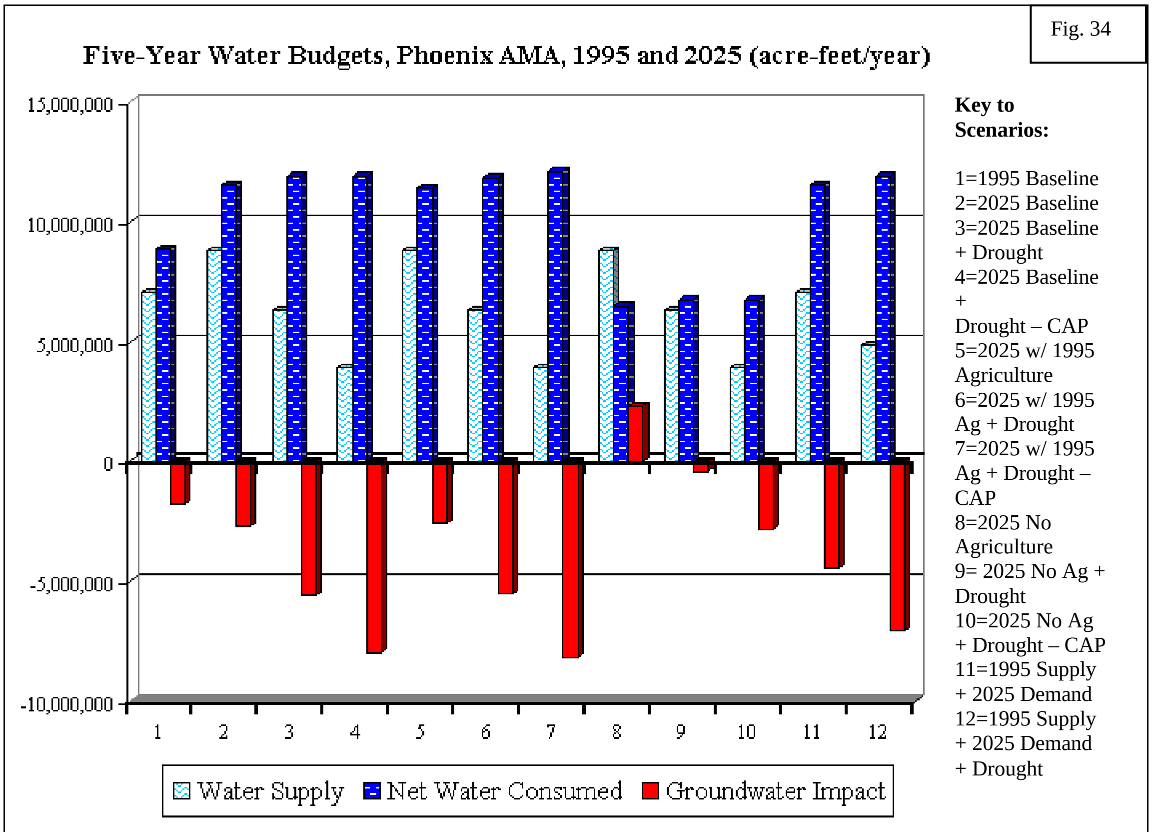


Fig. 34

Eliminate Agriculture (Scenarios 8, 9 & 10)

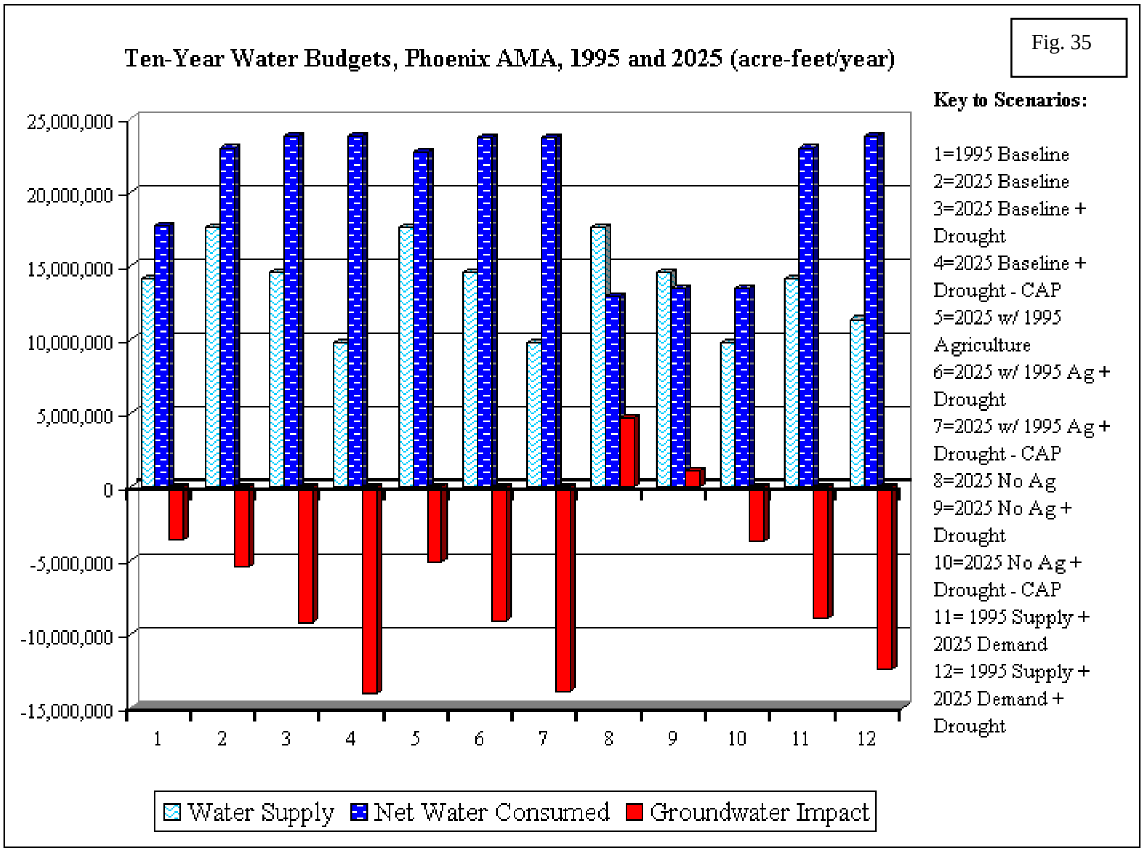
The elimination of agriculture would resolve Phoenix's overdraft problem during years with normal climatic conditions. The 36 percent excess renewable supply margin mentioned in the one-year baseline scenario equates, before accounting for drought conditions, to total renewable water supplies of 8,802,755 af for the five-year period. Net water consumption totals 6,484,276 af, which yields a surplus of 2,318,479 af. Under the five-year drought scenario, however, even with CAP water, supplies would not be sufficient to meet demand. In this case, without enhanced conservation activities, Phoenix would exceed its renewable supplies by 420,915 af, a 6 percent overdraft. Without CAP supplies, the overdraft amount rises sharply to 2,823,405 af, or 42 percent.

1995 Supply with 2025 Demand (Scenarios 11 & 12)

In this scenario, it is assumed that renewable supplies (including CAP water) remain at 1995 levels, but demand rises to the levels determined for the year 2025. The result a 39 percent deficit in renewable supplies. In this case, and in the absence of conservation measures, the Phoenix AMA would see an overdraft of 4,454,110 af. If 2025 demand were to occur with 1995 water supplies under five-year drought conditions, the Phoenix AMA would have to overdraft its supplies by 7,059,967 af, or 59 percent, to meet its water needs.

Ten-Year Scenarios

Calculations for the ten-year scenarios are presented in Figure 35.



TMP 2025 Baseline and Drought (Scenarios 1, 2, 3 & 4)

Examination of the longer-range impacts on the water budget of the Phoenix AMA reveals patterns of overdraft similar to those found for the shorter time frames. These patterns are of less proportional severity but greater cumulative impact. For comparison purposes, and assuming 2025 levels of agricultural activity and normal climate conditions, the TMP scenario multiplied by ten would create an overdraft of 24 percent of the renewable supply, or 5,432,540 af over a ten-year period. The historically worst ten-year drought scenario, when applied to this baseline water budget, results in 9,214,601 af of overdraft (39 percent of total demand). If CAP supplies were eliminated, net water consumption would exceed supply by 59 percent, or 14,019,581 af for the ten-year period.

Maintain Agriculture at 1995 Level (Scenarios 5, 6 & 7)

Maintaining agriculture at 1995 levels under normal climate conditions for the decade, but assuming 2025 population levels would result in a cumulative overdraft of 5,163,960 af. Application of the drought conditions, assuming continued full availability of CAP supplies, brings the overdraft to 9,096,175 af, or 38 percent of total water needs. The loss of CAP supplies would mean that demand would exceed supply by 59 percent, or 13,901,155 af.

Eliminate Agriculture (Scenarios 8, 9 & 10)

Over ten years, under normal climate conditions, elimination of agriculture in the Phoenix AMA would lead to a surplus in renewable water supplies of 4,636,958 af. If the ten-year drought were to occur under these conditions, and CAP supplies were maintained, there would still be a surplus of 8 percent, or 1,109,001 af. However, if CAP supplies were lost during the ten-year drought period, a deficit of 3,695,979 af would occur in the water budget.

1995 Supply with 2025 Demand (Scenarios 11 & 12)

The scenario combining 1995 supply with 2025 demand, under normal climate conditions, would result in a 27 percent deficit of renewable supply over the decade. Combining these figures with ten-year drought conditions would produce 8,908,220 af of groundwater overdraft (39 of the AMA's water needs).

Tucson AMA

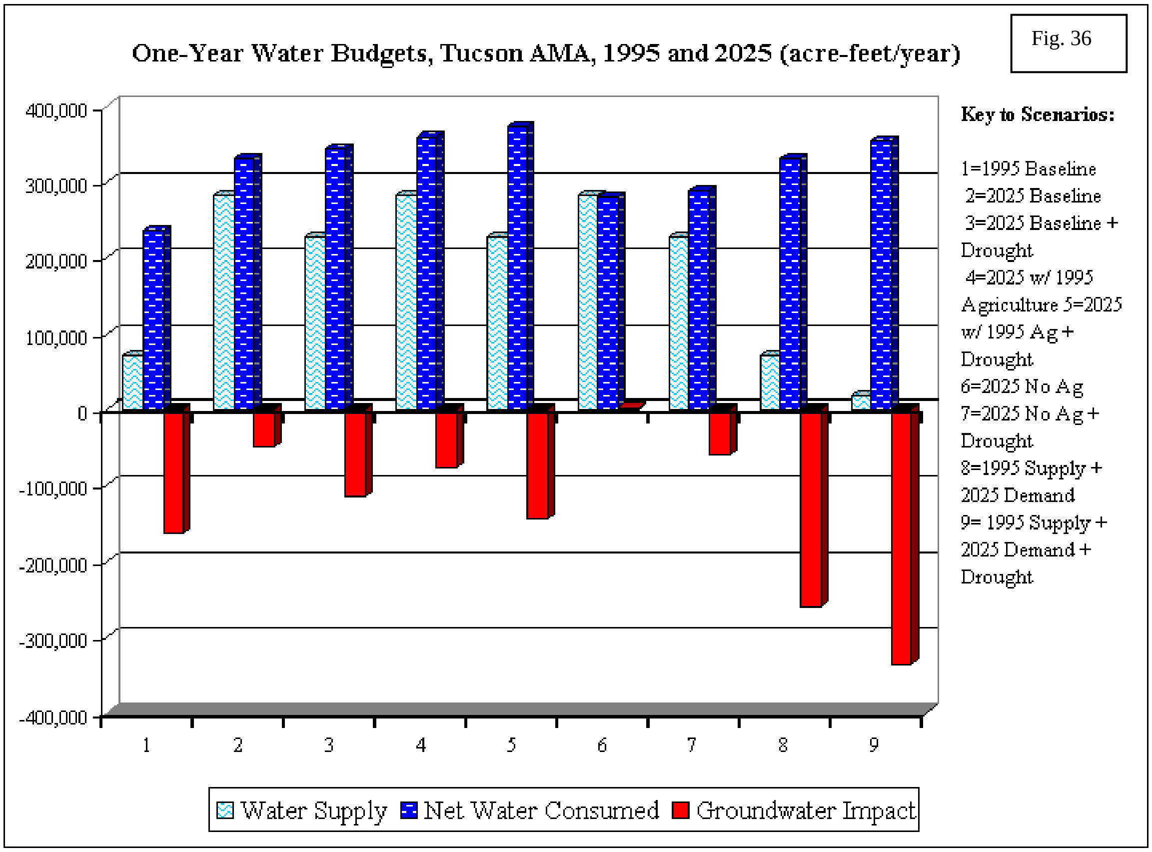
For the Tucson AMA, the groundwater impact scenarios discussed below include:

- TMP 1995 baseline renewable supply and net consumption
- TMP 2025 baseline renewable supply and net consumption
- TMP 2025 baseline renewable supply and net consumption + drought
- TMP 2025 baseline renewable supply and net consumption + drought – CAP (five- and ten-year scenarios only)
- 2025 renewable supply + 1995 agricultural demand
- 2025 renewable supply + 1995 agricultural demand + drought
- 2025 renewable supply + 1995 agricultural demand + drought – CAP (five- and ten-year scenarios only)
- 2025 renewable supply + no agricultural demand
- 2025 renewable supply + no agricultural demand + drought
- 2025 renewable supply + no agricultural demand + drought – CAP (five- and ten-year scenarios only)
- 1995 renewable supply and 2025 net consumption

- 1995 renewable supply and 2025 net consumption + drought

<u>One-Year Scenarios</u>

Figure 36 shows the impacts of the one-year scenarios for the Tucson AMA.



TMP 2025 Baseline (Scenarios 1,2 & 3)

The 1995 water budget for the Tucson AMA reveals that the area is currently meeting 70 percent of its demand with groundwater overdraft under normal climate conditions. With the projected 2025 decline in agriculture in the AMA and the addition of CAP supplies, the 1995 overdraft of 163,900 af per year is expected to decline to 49,500 af annually by 2025. However, this still means that net water consumption will exceed renewable supply in the Tucson AMA by 15 percent. A one-year drought with winter precipitation conditions similar to those of 1903-1904, when 11.5 percent of the normal amount of precipitation fell, would increase overdraft to 125,490 af, meaning that 36 percent of demand would have to be met by non-renewable supplies.

Maintain Agriculture at 1995 Level (Scenarios 4 & 5)

If agriculture remained at 1995 levels through 2025, the overdraft amount would rise by an additional 6 percent over the baseline amount under normal climate conditions, to 73,020 af of overdraft annually. The one-year drought scenario brings this deficit to 152,192 af, which means that 40 percent of total demand would have to be met by non-renewable supplies.

Eliminate Agriculture (Scenarios 6 & 7)

Under baseline climate conditions, total elimination of agricultural water demand in the Tucson AMA results in a surplus of 2,710 af (1 percent, of the net water consumption). However, a drought with conditions similar to the historically driest winter would result in a deficit in renewable supplies of 70,582 af, or 24 percent.

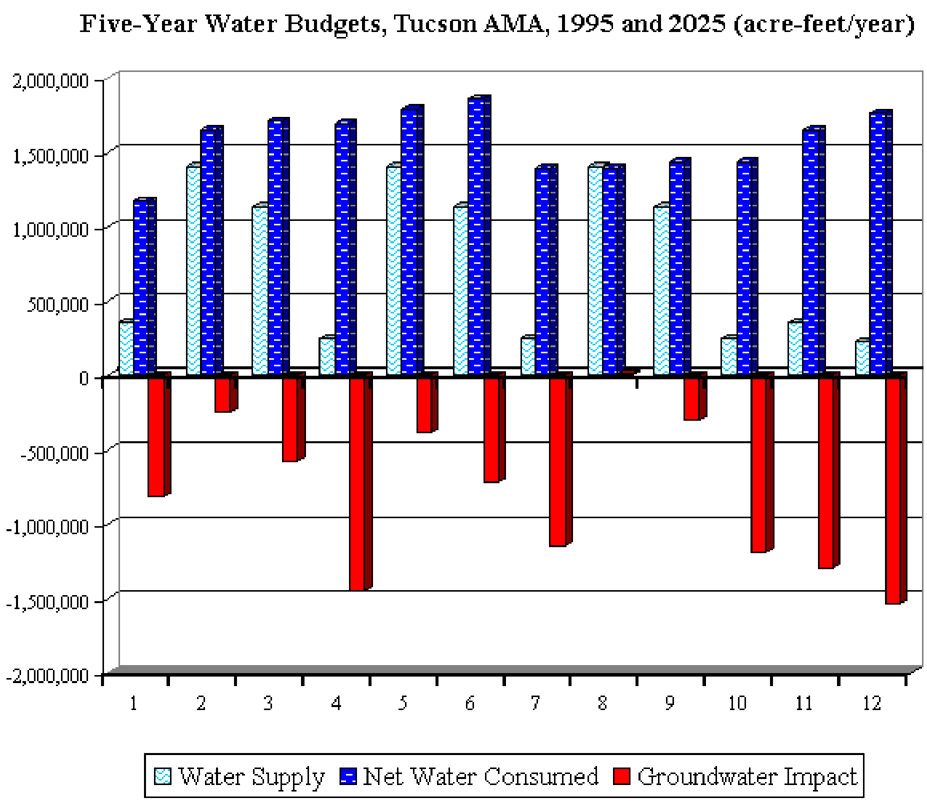
1995 Supplies with 2025 Demand (Scenarios 8 & 9)

Combining 1995 supplies with 2025 net water consumption, the AMA would only be able to meet 22 percent of its annual demand with renewable supplies. This scenario essentially depicts what the AMA's groundwater balance would be if CAP supplies were not utilized, since this water source was not used in the AMA during 1995. Adding drought conditions creates an astounding 95 percent deficit, meaning that the AMA would have to overdraft 335,690 af of groundwater per year over the course of the drought.

<u>Five-Year Scenarios</u>

The five-year water budgets are illustrated in Figure 37.

Fig. 37



Key to Scenarios:

1=1995 Baseline
2=2025 Baseline
3=2025 Baseline + Drought
4=2025 Baseline + Drought – CAP
5=2025 w/ 1995 Agriculture
6=2025 w/ 1995 Ag + Drought
7=2025 w/ 1995 Ag + Drought – CAP
8=2025 No Agriculture
9= 2025 No Ag + Drought
10=2025 No Ag + Drought – CAP
11=1995 Supply + 2025 Demand
12=1995 Supply + 2025 Demand + Drought

TMP 2025 Baseline (Scenarios 1, 2, 3 & 4)

For comparison purposes and using the AMA's assumptions for agriculture, the baseline 2025 overdraft is projected to be 247,500 af, or 15 percent of total demand under normal climate conditions. This is a proportional decrease from the 1995 baseline overdraft figure of 70 percent of total demand met by non-renewable supplies. Adding the five-year drought conditions to the calculations increases this figure to 489,493 af, meaning that 28 percent of total demand would have to be met by groundwater overdraft. If the situation were worsened by the elimination of CAP supplies, the deficit would jump to 1,374,847 af, which is to say that 78 percent of the AMA's water needs would have to be met with non-renewable supplies.

Maintain Agriculture at 1995 Level (Scenarios 5, 6 & 7)

If agriculture does not decline as ADWR anticipates will occur by 2025, overdraft in the AMA over a five-year period (assuming normal climate conditions) can be expected to reach 364,600 af, exceeding supply by 21 percent. With the five-year drought factored in and CAP supplies maintained, this amount increases to 622,503 af, or 33 percent of demand. If the drought were widespread and severe enough to cause a suspension of Arizona's CAP allotment, 80 percent, or 1,512,003 af, of the AMA's water demand would have to be met with non-renewable supplies over the five-year period.

Eliminate Agriculture (Scenarios 8, 9 & 10)

The elimination of agriculture in the Tucson AMA eliminates the need for groundwater overdraft; in fact, a cumulative surplus of 11,500 af could be expected to result over a five-year period under normal climate conditions. Conditions like those of the historically worst five-year drought would produce 14,953 af of groundwater overdraft. If exacerbated by the loss of CAP supplies, the Tucson AMA could find itself needing to pump 1,104,453 af of non-renewable groundwater over this period, fully 74 percent of the AMA's demand.

1995 Supply with 2025 Demand (Scenarios 11 & 12)

Combining 1995 supplies (i.e., no CAP water) with 2025 net consumption figures results in a deficit of renewable supplies of 1,298,500 af, or 78 percent of the total water needed. Adding drought conditions of the magnitude experienced in the historic five-year drought results in a deficit amount of 87 percent, or 1,540,493 af.

<u>Ten-Year Scenarios</u>

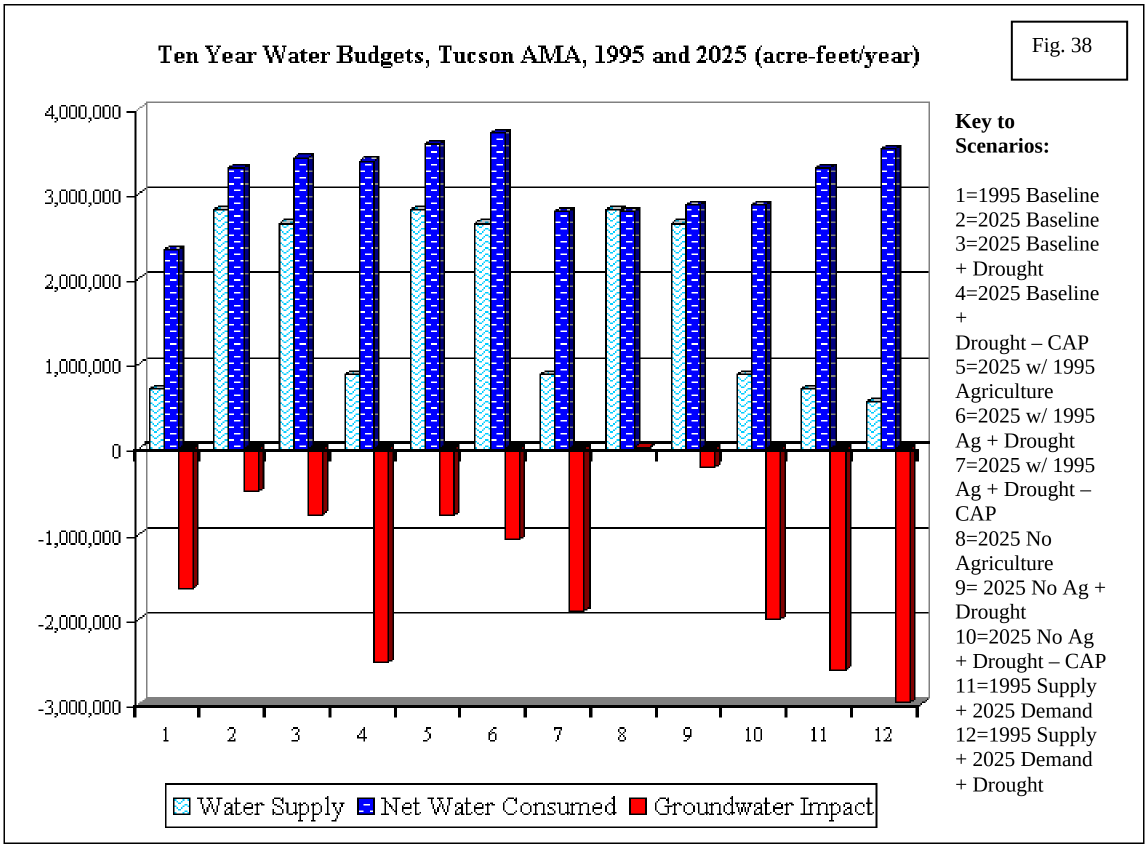
Figure 38 below depicts the results of the ten-year scenario calculations.

TMP 2025 Baseline (Scenarios 1, 2,3 & 4)

Under normal climate conditions and assuming agriculture at the level specified by the TMP for 2025, the cumulative amount of groundwater overdraft is expected to reach 495,000 af over a ten-year period. The inclusion of supply and demand adjustments to reflect the driest historic ten-year period increases the overdraft to 875,687 af, or 25 percent more than that available from renewable sources. If CAP supplies were suspended for this entire time period, the result would be a cumulative overdraft of 2,604,395 af, which means that the AMA, in the absence of effective conservation activities, would have to meet 75 percent of its demand through the use of non-renewable supplies.

Maintain Agriculture at 1995 Level (Scenarios 5, 6 & 7)

If agriculture were maintained at 1995 levels over a ten-year period, the result would be 730,200 af of overdraft under normal climate conditions. With the application of drought conditions, overdraft expands to 1,142,707 af (a 30 percent imbalance between renewable supply and deman). Eliminating CAP supplies increases the disparity between renewable supplies and net consumption to 69 percent, or 1,914,445 af.



Eliminate Agriculture (Scenarios 8, 9 & 10)

Shifting all water supplies away from meeting agricultural demand would eliminate the Tucson AMA's groundwater overdraft situation. Indeed, under normal climatic conditions, a ten-year total of 23,000 af of surplus renewable water supplies would result. By contrast, drought conditions could be expected to cause a deficit of 326,607 af, meaning that non-renewable supplies would have to meet 11 percent of the AMA's net consumption. Without CAP supplies, net consumption would outpace renewable supply by 2,105,607 af of cumulative overdraft over the ten-year period; thus, non-renewable supplies would have to meet 71 percent of the AMA's total water needs.

1995 Supplies with 2025 Demand (Scenarios 11 & 12)

Combining 1995 supplies with 2025 net consumption predictions results in a ten-year overdraft of 2,597,000 af. If the historic ten-year drought were to occur under these conditions, it would result in the AMA only being able to meet 16 percent of its annual needs with renewable supplies. Overdraft totals could reach 2,977,687 af for the decade.

Santa Cruz AMA

For the Santa Cruz AMA, the groundwater impact scenarios graphed at the one-, five- and ten-year time scales are as follows:

- TMP 1995 baseline renewable supply and net consumption

- TMP 2025 baseline renewable supply and net consumption

- TMP 2025 baseline renewable supply and net consumption + drought

- TMP 2025 baseline renewable supply and net consumption + drought – Mexican effluent

- 2025 renewable supply + 1995 agricultural demand

- 2025 renewable supply + 1995 agricultural demand + drought

- 2025 renewable supply + 1995 agricultural demand + drought – Mexican effluent

- 2025 renewable supply + no agricultural demand

- 2025 renewable supply + no agricultural demand + drought

- 2025 renewable supply + no agricultural demand + drought – Mexican effluent

- 1995 renewable supply and 2025 net consumption

- 1995 renewable supply and 2025 net consumption + drought

One Year Scenarios

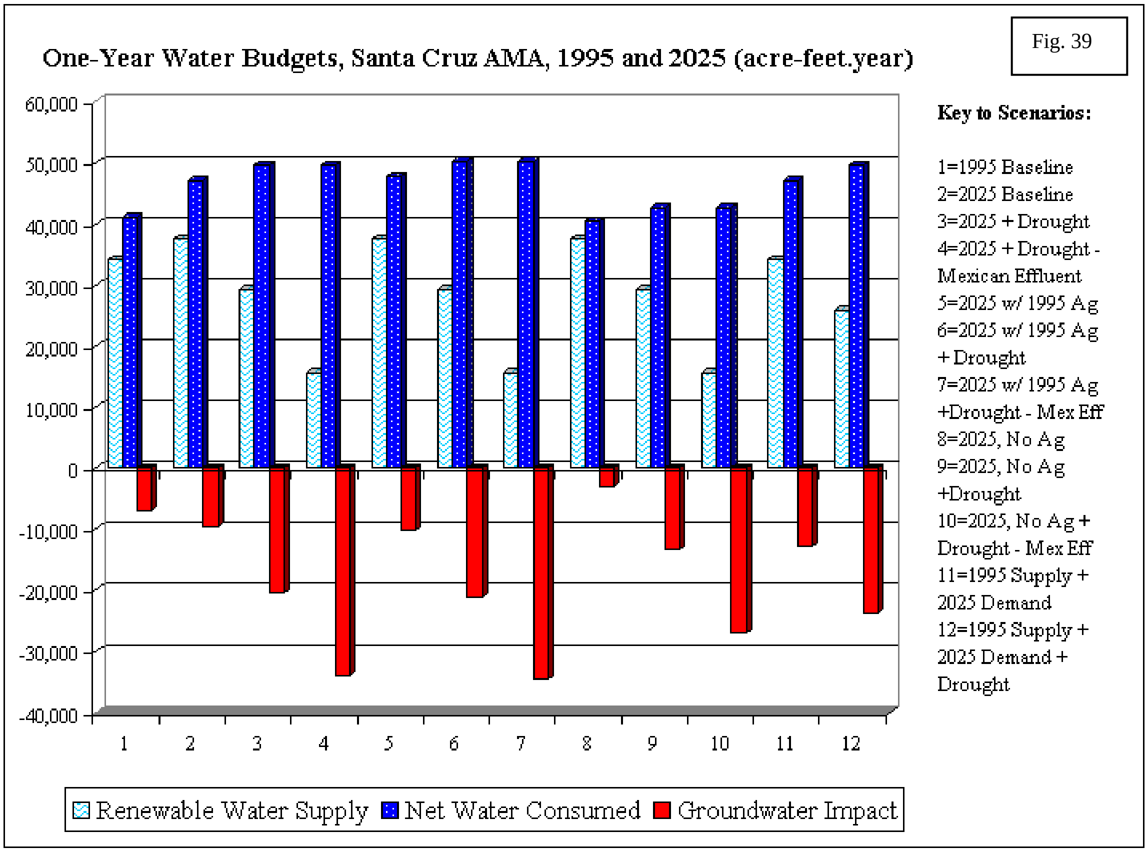
Figure 39 illustrates the results of the calculations for the one-year scenarios for the Santa Cruz AMA.

TMP 2025 Baseline (Scenarios 1, 2, 3 & 4)

The Santa Cruz AMA is unique among the study areas in that it does not have vast reserves of groundwater to rely on during dry periods, a situation that is likely to become more problematic as population pressure further increases demand. On the other hand, the shallower aquifer also has the capacity to more quickly recharge given favorable climatic conditions. Despite the fact that most of the AMA's water demand is met through groundwater pumping, natural and incidental recharge may fully replenish the aquifer each year. Once all storage capacity in the AMA's aquifer is filled, the remaining groundwater exits the AMA, flowing northward and becoming input to the Tucson AMA. Much of the renewable supply comes from effluent generated by the treatment of sewage from Nogales, Sonora, a city whose population is growing extremely rapidly. This portion of the water supply could either expand if additional capacity is added to the NIWTP, or decrease if some or all of the Mexican-generated effluent is retained on the Mexican side of the border. For these reasons, maintaining adequate groundwater supplies through conservation and greater use of renewable supplies is more of a short-term issue in the Santa Cruz AMA.

Projections of supply and demand for 2025 found in the SCAMA draft Third Management Plan (ADWR 1999c) suggest that predicting demand may be more certain than estimating supply, precisely because of climatic variability. Estimates of total annual renewable supply range from 33,600 af to more than quadruple that amount, to 135,500 af. Net water consumption, on the other hand, is projected to increase by 13 percent, from 41,067 af to 47,072 af. This results in a range of possible groundwater impacts that range from a deficit of 13,472 af to a surplus of 87,428 af. Using the calculations described in the Methodology section results in a projected 2025 average water supply figure of 37,532 af. When combined with a projected 2025 demand of 47,072 af, the result is an annual deficit of 9,540 af. Thus the AMA could have to rely on groundwater mining for 20 percent of its supply in 2025, as opposed to the 17 percent calculated for 1995. During one-year drought conditions, this amount increases to 40 percent of the total water supply, or a 19,936 af deficit in renewable supplies.

The situation changes dramatically if NIWTP effluent is eliminated as a water source, particularly if this occurred in combination with drought. In this case, the AMA would require 33,536 af of groundwater to meet the deficit; renewable supplies would be sufficient to meet only 32 percent of demand.



Maintain Agriculture at 1995 Levels (Scenarios 5, 6 & 7)

The same pattern of surplus and deficits appears in this scenario as in the baseline cases, although since demand would be higher than projected for 2025 and supply would stay the same, the deficits are more severe. Under normal climatic conditions, supply would exceed demand by 10,180 af, or 21 percent. Under drought conditions, the AMA would have to rely on groundwater overdraft to meet 20,617 af, or 41 percent, of its total demand. Drought combined with the loss of NIWTP discharge has even more significant impacts in this scenario than in the previous one: demand would exceed supply by 34,217 af, meaning that the AMA would need to overdraft to meet 68 percent of its demand.

Eliminate Agriculture (Scenarios 8, 9 & 10)

The elimination of agriculture in the Santa, Cruz AMA reduces the margin of demand over supply to 2,948 af, meaning that nonrenewable supplies would be required to meet only 7 percent of total demand under normal climate conditions. Drought increases the deficit to 12,922 af, which is 30 percent greater than renewable supply. Although the loss of NIWTP discharge has slightly less severe consequences under this scenario than the previous ones, it would still cause a deficit in renewable water supplies of 26,5522 af; 62 percent of total demand would be unmet by renewable water supplies.

1995 Supply with 2025 Demand (Scenarios 11 & 12)

Combining 1995 supply with 2025 demand results in a renewable supply deficit of 8,439 af, meaning that 20 percent of the AMA's water needs would have to be met through overdraft. Adding drought conditions to this scenario produces an overdraft of 21,173 af, or 45 percent of total supply.

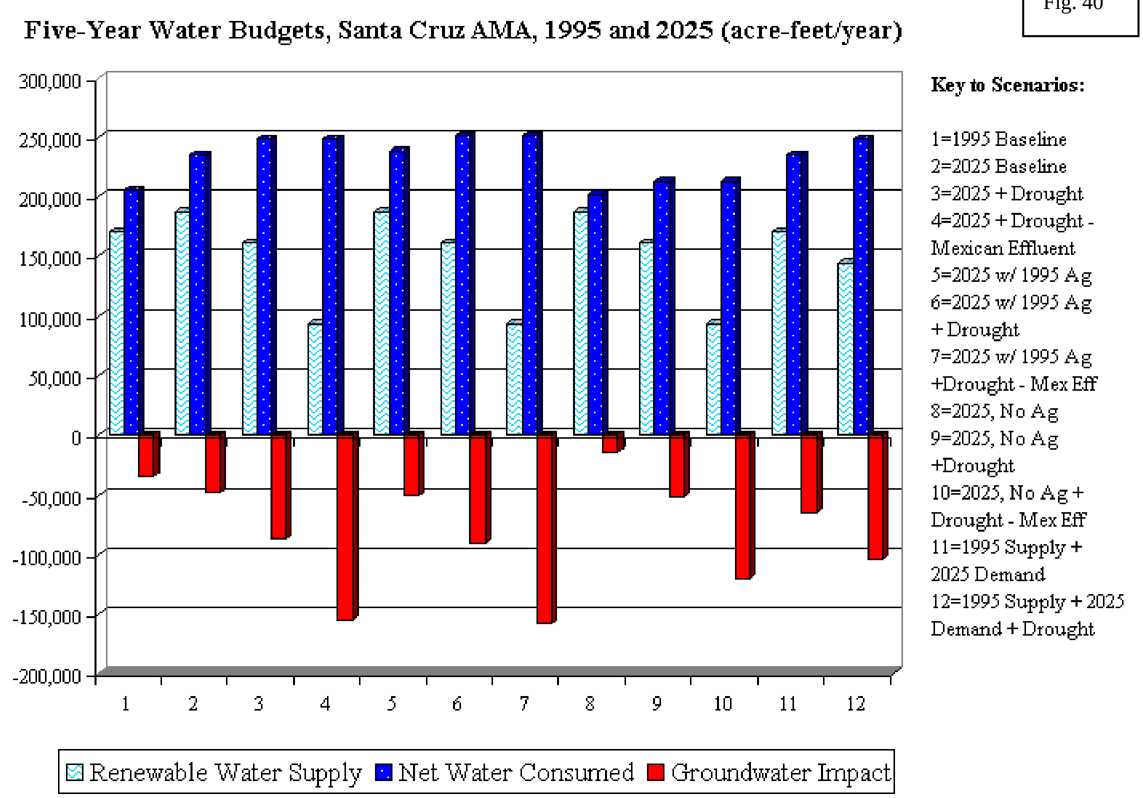
<u>Five-Year Scenarios</u>

Figure 40 illustrates the results of the five-year groundwater impact scenarios.

TMP 2025 Baseline (Scenarios 1, 2, 3 & 4)

Five years of TMP baseline conditions result in a total water deficit of 47,700 af, meaning that, as in the one-year scenarios, 20 percent more water is demanded than is available from renewable sources under normal climate conditions. Since the historic five-year drought was less severe than the driest single winter on record, the amount of groundwater overdraft required would be equal to 35 percent of total demand (as opposed to a 40 percent under the one-year drought conditions). Loss of NIWTP discharge leads to net consumption exceeding supply by 154,536 af, or 62 percent. In comparison, a 68 percent deficit occurs under the one-year scenario.

Fig. 40



Maintain Agriculture at 1995 Level (Scenarios 5, 6 & 7)

Even without the projected reduction in agriculture, the Santa Cruz AMA would experience the same pattern of changes as under the TMP projections. The deficit under normal climate conditions would be 21 percent, or 50,900 af. The maximum historic five-year drought would increase this amount by an additional 15 percent, to 89,941 af. The loss of NIWTP discharge would result in a deficit of 157,941 af, meaning that only 37 percent of the renewable supplies necessary to meet demand would be available.

Eliminate Agriculture (Scenarios 8, 9 & 10)

Elimination of this important sector of water use over a five-year time period would result in a water renewable deficit of 14,740 af under normal climate conditions (7 percent). Drought conditions would increase the deficit to 51,466 af. Loss of NIWTP supplies creates a deficit of 119,466 af, meaning that only 56 percent of the renewable supplies necessary to meet demand would be available.

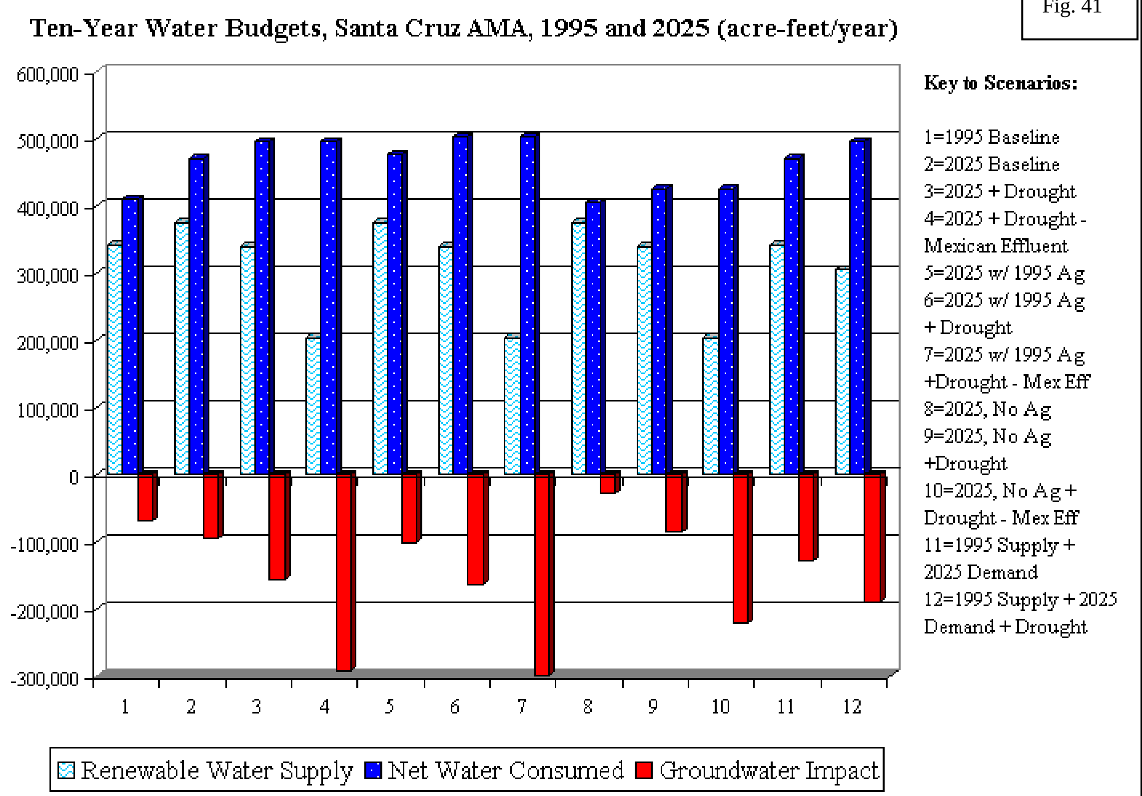
1995 Supply with 2025 Demand (Scenarios 11 & 12)

If 2025 demand was to occur with 1995 renewable supplies, the result would be a five-year overdraft of 42,196 af. Under drought conditions, the overdraft increases to 90,580 af.

Ten-Year Scenarios

Results of the ten-year groundwater impact calculations are shown in Figure 41.

Fig. 41



TMP 2025 Baseline (Scenarios 1, 2, 3 & 4)

As has been the case with the other AMA locations analyzed, the impacts of ten-year drought are less severe on a per year basis, but may have greater cumulative impacts on the AMA. In the Santa Cruz AMA, a ten-year drought results in 32 percent less renewable water supply than is necessary to meet demand. The deficit calculated in this scenario is 156,887 af, which is close to the AMA's total estimated storage capacity of 156,000 af. Without NIWTP supplies, the deficit created balloons to 292,887 af, which means that demand exceeds supply by

59 percent. Clearly augmentation measures would have to be taken much earlier in the Santa Cruz AMA, since the limits to total possible overdraft appear to be much lower than those in the other AMA areas.

Maintain Agriculture (Scenarios 5, 6 & 7)

The maintenance of agriculture at 1995 levels over a ten-year time period would result in 101,800 af less renewable supply than net water consumption under normal climate conditions; drought conditions would increase this deficit margin to 163,696 af, or 33 percent of demand. Without NIWTP supplies, the deficit would reach a cumulative 299,696 af (a 60 percent overdraft). This figure is nearly twice the amount of storage capacity the AMA is estimated to contain.

Eliminate Agriculture (Scenarios 8, 9 & 10)

If, even under normal climate conditions, agriculture were to cease in the Santa Cruz AMA for ten years, imbalance between water supply and demand would amount to a deficit of 29,480 af, (7 percent). Drought conditions would increase the deficit to 20 percent. Elimination of NIWTP supplies, combined with the drought, produces a deficit of 222,748 af, or 52 percent.

1995 Supply with 2025 Demand (Scenarios 11 & 12)

If 1995 water supply were combined with 2025 water demand, the result would be a deficit of 84,392 af, or 20 percent, over the ten-year period. Adding drought to this scenario results in a deficit of 164,976 af, again exceeding the total groundwater storage capacity in the AMA.

Benson Subwatershed

The groundwater impact scenarios for the Benson are the same as used for the supply and demand side calculations (refer to Appendix 4). They can be grouped as follows:

- population growth only: increased population size (DES and Pop High)
- drought: increased population (DES and Pop High) size combined with the historic minimum in winter precipitation in the Southeast Climate Division
- elimination of agriculture: increased population size (DES and Pop High) and elimination of agriculture; increased population size (DES and Pop High) combined with the historic minimum in winter precipitation and elimination of agriculture.

One Year Scenarios

Under the 1990 baseline condition, 12,674 af of the total demand is met by mined groundwater, causing an overall deficit or overdraft of 29 percent. Under the various 2025 scenarios, groundwater overdraft emerged as highest under the worst condition assumed, the historic winter minimum precipitation of 1904 (38,661af). The percentage of total demand met by mined groundwater was highest drought (84 percent) when agriculture was eliminated in combination with. The results are shown in Figure 42.

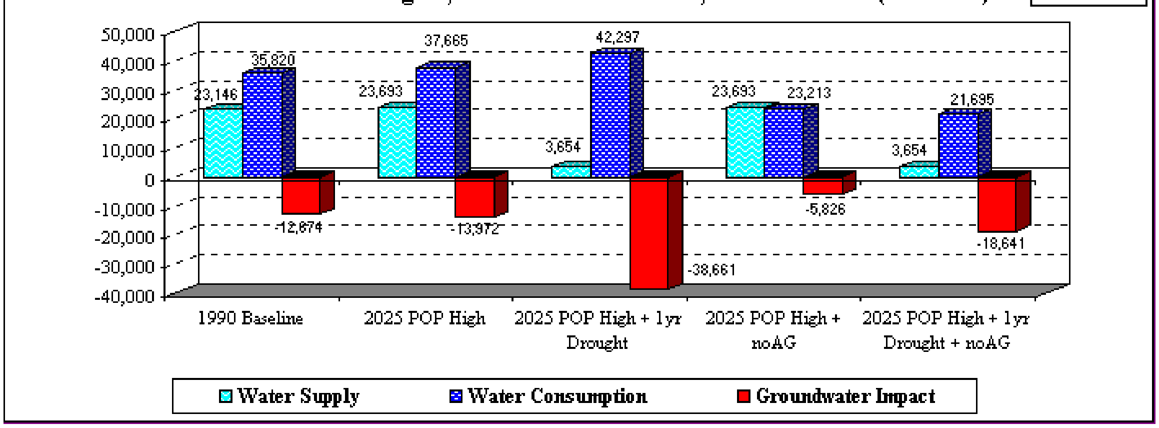
Population Growth Only

Assuming only population growth for the year 2025, the increase in groundwater overdraft is barely noticeable (1-2 percent). Compared to the other study locations, this is attributable to the relatively low increase in population growth anticipated for the Benson subwatershed; as a result, increases in municipal water demand are expected to be very moderate. Even under the Pop High scenario, only 18,861 people are expected to be living in this area by the year 2025. Although this represents a doubling of residents compared to the 9,870 reported for the 1990 baseline year, the projections in the other four study locations are 3 to 238 times higher (the extremes are the Santa Cruz AMA and the Phoenix AMA).

Drought

Under the one-year drought scenario, the groundwater overdraft tripled compared to the baseline year, amounting to a total of 38,661 af assuming the Pop High condition. It should be noted that these 38,661 af, which exacerbate the local water balance situation, are the result of sharply reduced overall water supply as well as relatively large increases in agricultural demands.

Fig. 42



Elimination of Agriculture

This hypothetical scenario, under which all current irrigated agriculture in the Benson subwatershed is abandoned, would still result in a negative groundwater balance. Intuitively, one would expect a surplus in groundwater once the main consumer, irrigated agriculture, is eliminated from the area. However, the elimination of agriculture would also result in less incidental recharge, thereby keeping net total water consumption at a high level. Moreover, the second largest consumer of non-renewable groundwater is riparian vegetation, which is assumed to remain unchanged.

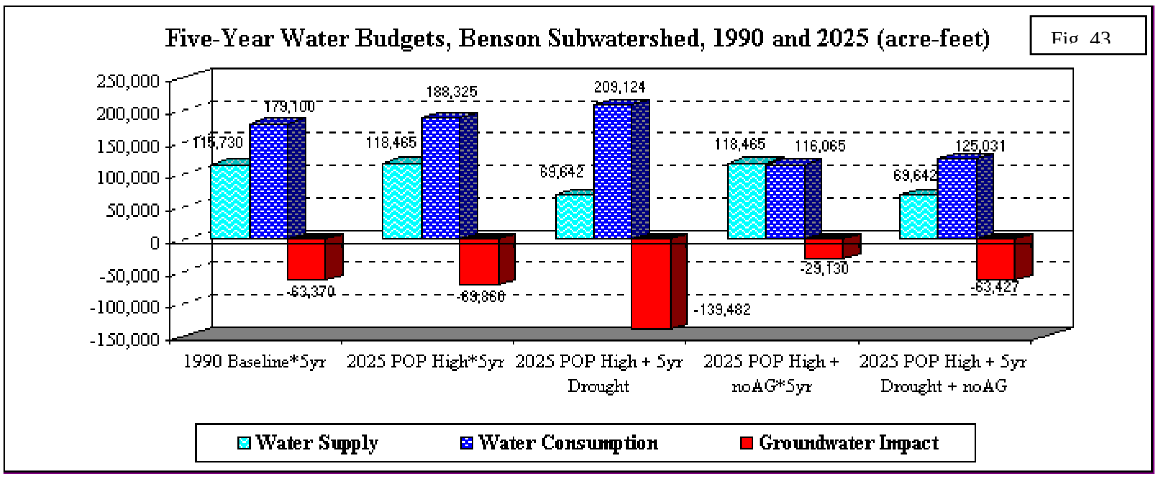
Based on the calculations, groundwater overdraft would amount to almost 6,000 af under the no-drought scenario, and would triple to nearly 19,000af under the drought scenario. Although these numbers are considerably lower than those under the corresponding scenarios where agriculture is maintained, they remain negative. In terms of percentage of total demand met by mined groundwater, the results range from a 24 percent deficit under the first scenario to an 84 percent deficit under the drought conditions.

It should be noted, however, that other sources of water supply, namely effluent and surface water that are used for irrigation purposes under baseline conditions, would no longer be used at the full rate. Under the one-year scenarios, effluent surplus would amount to 600 af, the amount used to irrigate fields around the wastewater treatment plant in Benson. While no surface water surplus would be available under drought conditions, under normal climate conditions, surface water surplus would reach half of the available amount. Without any alternative usage in the subwatershed, this surplus would be lost, either in the form of evaporation or as outflow. Although such potential consumption of unused effluent and surface water is not included in this analysis, it can be assumed that if appropriate institutional arrangements were made, these additional amounts of supply could be used to counterbalance the groundwater overdraft at least to some degree.

Five-Year Scenarios (Fig. 43)

Population Growth Only

The same moderate increase in the extent of groundwater overdraft as described under the one-year scenarios applies under the five-year conditions. Due to the comparatively low population size projected for the year 2025 and the resulting limited increases in municipal demand, total demand that is met by mined groundwater will only increase by 1 to 2 percent.



Drought

As expected, groundwater overdraft is most significant under the assumed drought scenarios. While total demand met by mined groundwater would almost reach 140,000 af, the increase compared to the baseline year amounts to only 56 percent, which is not quite as dramatic as the change expected under the one-year drought situation (78 percent). Since the average precipitation during this historic five-year period of 1900-1904 was not as low as the one-year winter minimum of 1904, comparatively more surface water would be available under similar conditions assumed for the year 2025. Hence, parts of the agricultural and riparian demands could be satisfied by the available surface water without exacerbating the use of non-renewable groundwater resources.

Elimination of Agriculture

As in the one-year scenarios, no positive groundwater impact is expected to occur under this hypothetical scenario. Under the population growth-only conditions, the groundwater deficit would amount to almost 30,000 af, roughly half of the amount reported for the 1990 baseline year. Assuming a five-year drought at the same time, the deficit would more than double. Under this scenario, groundwater overdraft is expected to reach the dimensions of the 1990 baseline year, despite the fact that irrigated agriculture would not be pumping water from the regional aquifer.

Again, surplus effluent and surface water no longer used for irrigation was not taken into account for this analysis. Under the five-year scenarios, this surplus would amount to 3,000 af of effluent and 5,000 to 28,500 af of surface water. Given certain technical and institutional arrangements, this surplus water could be used to substitute for groundwater, thereby reducing groundwater mining.

Ten-Year Scenarios (Fig. 44)

Population Growth Only

Again, a slight increase in groundwater mining can be expected under the ten-year scenarios. As under the one- and five-year conditions, the increase amounts to only 1 to 2 percent, explained by the comparably low population size as well as the relatively small municipal demand expected for the year 2025.

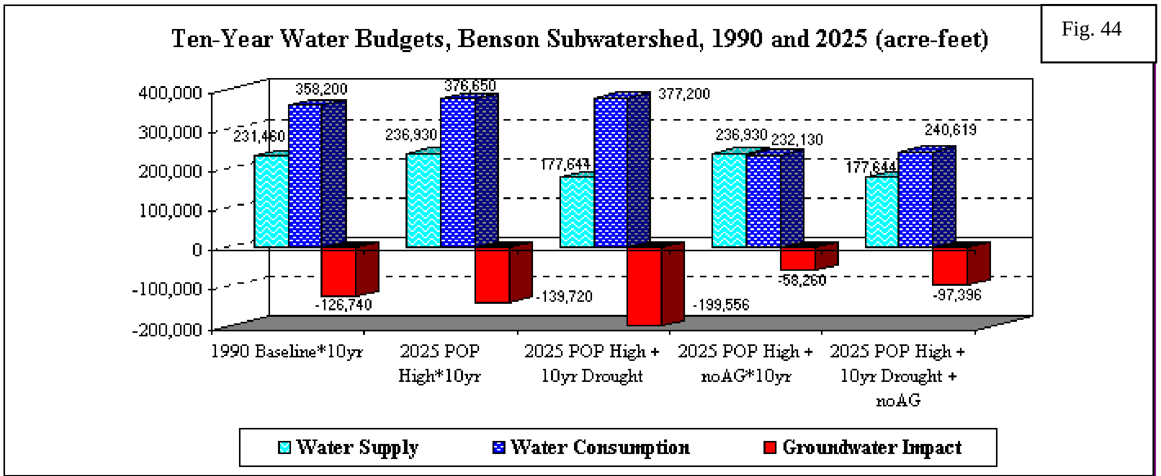


Fig. 44

Drought

As anticipated, groundwater overdraft, if compared to all other ten-year scenarios, would be highest under the extended drought conditions. It is expected to amount to nearly 200,000 af. However, the percentage increase is smaller than that calculated for the one-and five-year periods. Here, 43 to 44 percent of the entire demand would be met by groundwater mining, whereas the percentage was as high as 56 and 78 under the two other scenarios respectively.

Although the 1950s drought, on which this hypothetical scenario is based, was the most historically severe drought period on record in the Southwest, the average winter precipitation was higher than during both the single most severe case and the five-year worst-case period. Following the methodology used for this analysis, relatively more water can be assumed to be available during a ten-year drought period. The difference in the supply-consumption ratio during the various drought scenarios, illustrated in Figures 42-44, explains the comparatively lower groundwater overdraft under the ten-year drought scenarios.

This lower number notwithstanding, groundwater overdraft is expected to be substantial and, given longer-term socio-political, ecological, and economic implications not taken into consideration in this analysis, should be taken very seriously.

Elimination of Agriculture

As under the one- and five-year scenarios, no positive groundwater balance would be achieved even if all irrigated agriculture in the subwatershed were eliminated. Groundwater mining would continue to occur both under the population growth-only and the drought scenario, although at dimensions less significant than under the other scenarios employed. Deficits would range between roughly 60,000 af and slightly less than 100,000 af. Total demand that would have to be met by mined groundwater would amount to 24 to 40 percent.

Sierra Vista Subwatershed Scenarios

The groundwater impact calculations for the Sierra Vista subwatershed are the same as those used for the supply and demand side calculations (refer to Appendix 5). They can be grouped as follows:

- population growth only: increased population size (DES and Pop High)

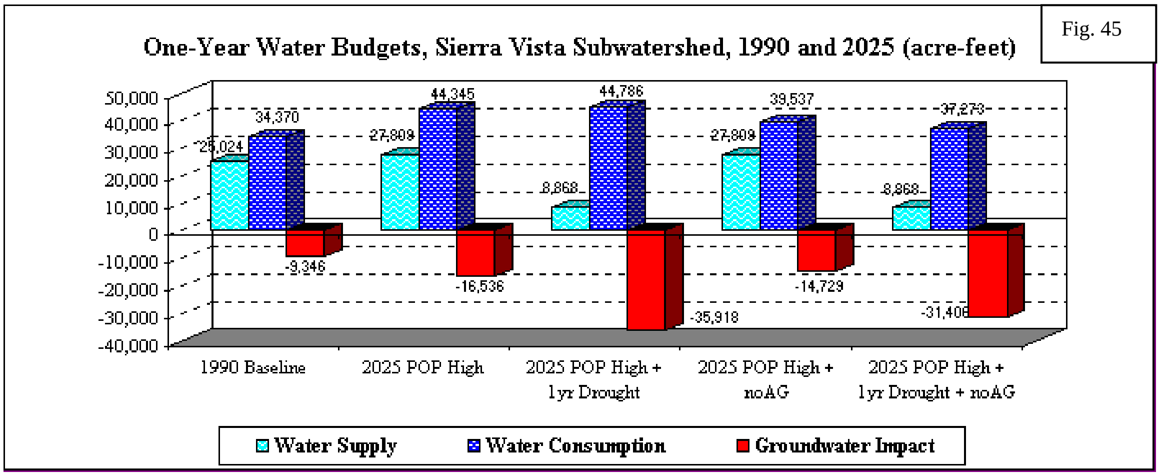
- drought: increased population (DES and Pop High) size combined with the historic minimum in winter precipitation in the Southeast Climate Division

- elimination of agriculture: increased population size (DES and Pop High) and elimination of agriculture; increased population size (DES and Pop High) combined with the historic minimum in winter precipitation and elimination of agriculture.

One-Year Scenarios (Fig. 45)

Under the 1990 baseline condition, 9,346 af of the total demand are met by mined groundwater, causing an overall deficit, or overdraft, of 25 percent. This is slightly lower than in the Benson subwatershed. Changes in the extent of total net water consumption met by groundwater mined for the year 2025 are expected to range between 21 and 76 percent. As in the Benson case, the elimination of agriculture scenario would not result in a positive groundwater balance.

Fig. 45



Population Growth Only

The Sierra Vista subwatershed is projected to reach a population of 76,607 to 87,052 by the year 2025. Since municipal demands, relying exclusively on groundwater, are expected to reflect this growth rate, groundwater overdraft would increase as well. According to the analysis, 35 percent of the total demand is anticipated to be met by mined groundwater.

Note, however, that since this percent change refers to the subwatershed as a whole, it masks the effects of groundwater mining that are expected to occur in the Fort Huachuca/Sierra

Vista area. Currently, the rates of water-level decline in this area are greater than anywhere else in the regional aquifer (Pool and Coes, 1999). Factoring in a population increase of up to 40,000 residents by the year 2025, primarily in this area, localized groundwater mining is expected to rise considerably.

Drought

Under the historic winter minimum precipitation scenario, groundwater mining can be expected to worsen. Almost 36,000 af of non-renewable groundwater (76 percent of total demand) would be needed to satisfy growing demands under conditions of limited supply and lack of effective conservation efforts. Compared to the 1990 baseline conditions, this would represent an almost fourfold increase.

Elimination of Agriculture

A hypothetical elimination of the remaining agriculture in the subwatershed would not prevent groundwater mining from occurring. Even under the most favorable conditions of average precipitation, 34 to 36 percent of the entire water consumption would have to be met by non-renewable groundwater (13,000 af to 15,000 af). Under the one-year drought scenario, this amount would rise to more than 30,000 af (82 percent).

Under both the population growth-only scenarios and the combined population growth and drought scenarios, the groundwater deficit would be expected to be slightly smaller than when full agricultural demand is included. These relatively moderate gains are not surprising given the limited role agriculture plays in the subwatershed. During the 1990 baseline conditions, only 17 percent of the total demand can be attributed to irrigation needs. The main consumers are municipal users and the riparian vegetation along the San Pedro River. Under the 2025 baseline case, the share of agricultural demand is expected to be even smaller, with irrigation needs expected to drop to roughly 13 percent. At the same time municipal demands are expected to rise to more than 40 percent, making this sector the most important single consumer category in the subwatershed. Thus, it is comprehensible that the elimination of 13 percent of the total demand would not result in any truly notable impact on the groundwater balance.

It should be noted, however, that, as in the Benson subwatershed, surplus water – water that, under baseline conditions, would be used by agriculture – is not accounted for in this analysis. In the Sierra Vista case, 2,641 to 3,001 af of effluent could be considered surplus, assuming elimination of all agriculture. It could be hypothesized that by the year 2025 this surplus effluent would be made available to other user categories in substitution for precious groundwater resources. It should be noted that the city of Sierra Vista has already started to seriously pursue effluent recovery as a way of balancing their water budget. By considerably reducing the costs for getting this renewable supply to potential users, this effort could play a crucial role in counterbalancing groundwater overdraft.

<u>Five-Year Scenarios (Fig. 46):</u>

Population Growth Only

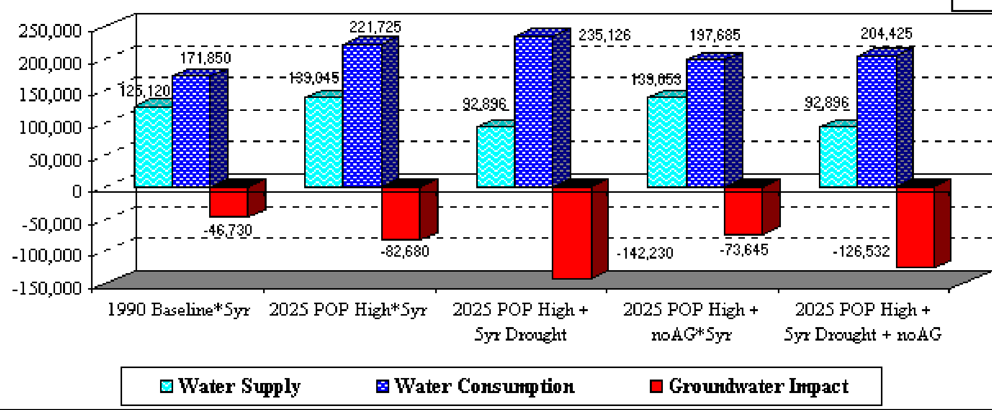
The same 21 percent increase in groundwater overdraft assumed in the one-year scenario can be expected for an extended five-year 2025 baseline situation. This relatively higher increase compared to the Benson subwatershed can be attributed to the nearly five-fold increase in population size projected for the year 2025. Overall, more than 80,000 af or 35 percent of the total net water consumption would have to be met by non-renewable groundwater. Again, rates of groundwater mining are expected to be highest in the Fort Huachuca/Sierra Vista area, contributing to expansion of the cone of depression beneath the city.

Drought

As in the other study locations, basin-wide groundwater mining is expected to be highest under the drought scenarios. However, the percent of total net water consumption met by non-renewable water resources would not be as high as under the single-year drought events. In the Sierra Vista subwatershed, the total deficit would amount to slightly more than 140,000 af or 57 percent of total consumption. Unlike the one-year drought period, riparian vegetation is anticipated to draw more than half of its water needed from the San Pedro River, without extensively affecting the pressure on groundwater.

It should be noted however, that, in reality, groundwater supplies could be significantly affected given the cone of depression in the Sierra Vista/Fort Huachuca area. As discussed by Pool and Coes (1999), groundwater withdrawals in this area have already intercepted and have diverted groundwater path flows in the northern part of the subwatershed (north of Charleston). With continued pressure on the aquifer, these activities are likely to affect the central and southern part of the watershed as well. By reducing base flow to the stream, this interception/diversion of groundwater flow poses a threat to the surface water supply used by riparian vegetation. During five-year drought periods, a shift to deeper-rooted riparian plants (phreatophytes) might be hypothesized, resulting in even greater pressure on the aquifer. Moreover, increased groundwater withdrawals by phreatophytes might generate increased recharge along the streambed, thereby reducing surface flow and runoff, primarily during the summer months (Pool and Coes, 1999). This would further reduce the availability of water supply for more shallow-rooted plants.

Five-Year Water Budgets, Sierra Vista Subwatershed, 1990 and 2025 (acre-feet) Fig. 46



Elimination of Agriculture

As in the one-year scenarios, no significantly positive impact can be expected from a hypothetical elimination of irrigated agriculture in the Sierra Vista study location. Roughly 70,000 to 127,000 af of groundwater would have to be mined to satisfy primarily municipal and riparian demands, even without any irrigation consumption. These two numbers, or 36 and 61 percent of the entire demand, apply for the no-drought and drought condition scenarios respectively.

Again, although groundwater overdraft appears as less pronounced than under the corresponding scenarios that include agriculture, the groundwater balance remains negative. In short, municipal demands are too high to be offset even by a total elimination of irrigated agriculture. Absent effective conservation efforts, only reasonable usage of surplus effluent, in this case 13,000 af to 15,000 af, could counterbalance this trend. On the other hand, increased groundwater withdrawals in the vicinity of Fort Huachuca/Sierra Vista and the continued expansion of the already-existing cone of depression could offset the gains achieved through efficient use of surplus effluent. According to Pool and Coes (1999), intercepted and diverted groundwater flows will increasingly affect discharge in the form of base flow to streams and groundwater underflow. This could result in increased groundwater use by riparian vegetation, especially during periods of longer-term droughts. Under these conditions a shift toward deeper-rooted plants might have to be expected. Stromberg, Richter and Tiller (1996) argue that a sequential "desertification" of the riparian flora along the San Pedro River occurs when depth to groundwater declines below roughly 4 m, resulting in a loss of cottonwood and willow stands while mesquite stands expand.

Ten-Year Scenarios (Fig. 47)

Population Growth Only

The percentage rate of total net water consumption met by mined groundwater under the ten-year scenarios is identical to the ones calculated for the one- and five-year conditions (32 to 35 percent). Compared to the Benson subwatershed, this relatively large percentage can be explained by the larger population and related increase municipal demand expected for the year 2025.

Drought

Under the ten-year drought scenario, the total water deficit is anticipated to exceed 200,000 af. Compared to the other drought scenarios at one- and five-year time frames, however, the percentage of total consumption that would have to be met by non-renewable groundwater is lower (47 to 49 percent). This is due to the fact that average winter precipitation during the 1950s drought, the basis for this scenario, was not as low as under the shorter-term drought conditions. As a result, water supply would not be as severely impacted. Nevertheless, almost half of the total net water consumption in the Sierra Vista subwatershed would need to come from mined groundwater. This certainly constitutes a significant amount and should be given appropriate attention.

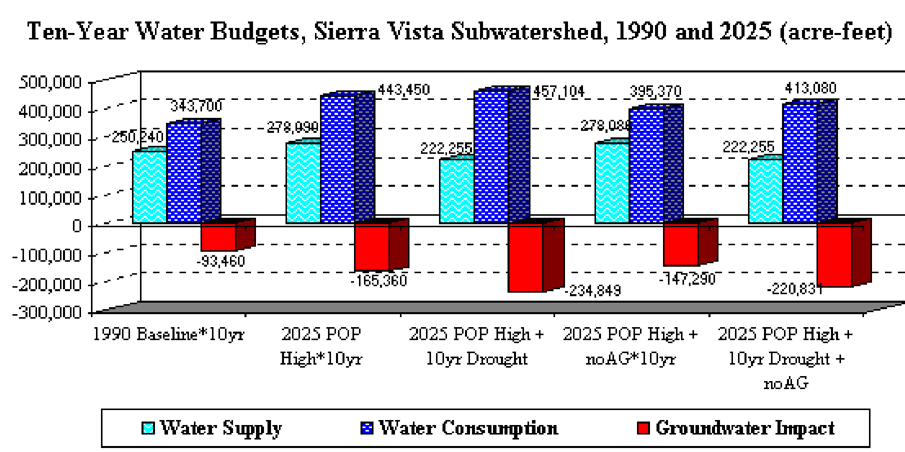


Fig. 47

Elimination of Agriculture

As in the one- and five-year scenarios, the elimination of irrigated agriculture in the Sierra Vista subwatershed would not be sufficient to offset the groundwater deficit, which would be caused primarily by high municipal demands. Under both the assumed no-drought and the drought conditions, groundwater mined would be substantial, ranging between 150,000 and 222,000 af, or 37 % to 53% of total net water consumption, respectively.

For the same reasons discussed under the one- and five-year scenarios, the extent of the actual groundwater overdraft could vary depending on the usage of surplus effluent as well as the expansion of the existing cone of depression around Sierra Vista/Fort Huachuca. Between 26,000 af and 30,000 af of unused effluent would be available for alternative usage, thereby reducing the heavy reliance on non-renewable groundwater resources. On the other hand, the expanding cone of depression could increasingly intercept and divert base flow (Pool and Coes, 1999). The diversion and interception of groundwater flows could reduce the amount of surface water that, according to this analysis, is available to riparian vegetation. As a result, riparian plants might be forced to depend more extensively on groundwater, which is expected to offset the gains achieved through efficient effluent use.

V. Implications

The foregoing sensitivity analysis points out the hazards of continuing to rely on "normal" climate conditions when managing urban water resources, and when making decisions about growth and development in and around urban areas. A common theme among all five study areas is the large impact on water budgets generated by agricultural activities. While elimination of some or all agricultural activities would go a considerable distance toward redressing supply and demand imbalances, simplistic assumptions that the conversion of agricultural lands to urban uses "solves" local water problems are overly optimistic. In all of the study areas, a key challenge is to eliminate or minimize the mining of non-renewable groundwater resources under conditions of wide climate variability. Under sustained drought conditions, existing threats such as significant enlargement of cones of depression in the aquifers, water table declines and possible tapping of lower-quality water as wells are drilled ever deeper, and land subsidence caused by compaction of de-watered lands, may become amplified. For example, well productivity has been demonstrated to decline in the Tucson and Santa Cruz AMAs as depth to water increases (Stitzer 1999).

The costs of addressing such problems, and perhaps of recompensing for damages, may strain local finances, lead to significant increases in consumers' water bills, and generate increasingly stringent water conservation regulations. In the Tucson and Santa Cruz AMAs, and along the San Pedro River, deep, extended drought conditions could seriously compromise or even destroy valued riparian ecosystems. Protecting these riparian areas would require a considerable amount of compromise on the part of competing water users.

The specific implications of deep, extended drought in combination with population growth and/or elimination of agriculture for each of the study areas are discussed below.

<u>Phoenix AMA</u>

As noted in the Groundwater Impacts section, the Phoenix AMA's currently relatively modest groundwater overdraft will expand by approximately one-third, or 183,235 af, by 2025 if current population and demand projections are realized. The crux of the problem lies in the fact that net water consumption is projected to expand approximately 30 percent, while supplies will only increase by 25 percent.

The situation becomes considerably more worrisome when the potential effects of drought are added to the equation. The Phoenix AMA's reliance on surface water under normal conditions would seem to make this area more subject to climatic fluctuations in the short term. However, the AMA's access to multiple sources of water and lower proportion of groundwater mining relative to the Tucson AMA could also argue for greater sustainability over the long run, as well as more flexibility in coping with short-term climatic anomalies.

If a winter similar to that of 1903-1904 were to recur under the population pressure expected by 2025, resulting in a 44 percent decrease in supply and a 3 percent increase in demand, the AMA as a whole could probably cope by drawing down reservoir levels and increasing groundwater pumping. Higher energy costs for pumping and conveyance would likely result. If the drought were confined to a one-year period, it seems rather unlikely that the full cost would be immediately or directly passed on to consumers. Under such conditions, the Phoenix AMA could request that municipal water users conserve water by taking shorter showers, watering landscaping less, not washing their cars, etc. During the similarly serious drought periods in southern California, for example, programs to fine homeowners and businesses caught wasting water were implemented with some success.

The cumulative impacts of a more moderate but longer-term drought could precipitate a wider array of unforeseen consequences. While it might be possible to support an overdraft of one-and-a-half million acre feet or more (as our calculations indicate would be necessary) under a severe drought lasting a year or two, a series of dry years in a row could have more serious impacts.

Increased depth to groundwater and greater possibility of subsidence are among the more tangible physical effects of longer-term droughts. The longer a severe drought extends, the more necessary it might be for the Phoenix AMA to enact policy measures to decrease water demand and increase available supplies. Such a situation could impact water managers, providers and consumers through several different channels. If a deep five-year drought were to occur, changes could include increased incentives for low water use landscaping, plumbing fixtures and water-conserving home appliances, such as clothes washers and dishwashers. Water pricing structures might also be adjusted to discourage non-essential water use. For example, the average cost of enough water for a family of four to meet its basic needs might not be significantly increased, but the additional volumes of water exceeding a specified baseline amount could cost substantially more. It may be expected that a significant rise in price would lead at least some consumers to decrease the amount water-intensive outdoor landscaping they maintain.

A ten-year drought has even greater potential to produce less easily reversible changes in land use and water use by different sectors. Lakes and turf facilities such as parks and golf courses could be particularly vulnerable if longer-term droughts led to reprioritization of needs. The lush green landscaping and numerous pools found in the Phoenix AMA could come under heavy pressure if strict conservation measures were implemented.

Another factor affecting water demand is the rate at which farmland is converted to municipal uses. Generally speaking, the only new agricultural acreage being brought into production in the AMA is on Indian reservations, for reasons; otherwise, agricultural acreage is decreasing steadily in the AMA. The impact that urbanization will have on agricultural water demand is likely to depend on how water that would otherwise have been directed to crops is used. The density level of new developments is another key factor. While factors such as the price of crops and government subsidies are likely to have a greater impact on farmers' decisions about whether to continue farming or sell out than are climate or availability of water per se, severe sustained drought is likely to increase tensions between agriculture and other sectors in the AMA.

A severe drought lasting a decade or longer might lead to subsidization programs that would discourage farmers from planting crops during dry years, thus alleviating some of the stress in the AMA's water budget. Under such conditions, mechanisms allowing municipal water providers to lease or purchase unused agricultural water rights would probably be pursued. It is possible that if the climate changed to generally drier conditions over the long term, the demise of non-Indian agriculture would be hastened in the Phoenix AMA. This trend could be further hastened by anticipated growth in the AMA's population and consequent expansion into the remaining agricultural areas.

As the Eliminate Agriculture cases illustrate, even if all agricultural water use is instead dedicated towards meeting municipal and industrial needs, substantial deficits remain. However, there is a limit to the extent that agricultural water allotments could be switched to municipal uses, since (among other reasons) agriculture in the AMA increasingly takes place on Indian lands through water rights that have restrictions on their use and exchange. Pending litigation over Indian water rights represents an additional unresolved issue with the potential to affect water supply in the Phoenix AMA. Tribes have already sued for and won the right to water from the Salt River (Checcio and Colby 1993). Much of the watershed that supplies the Gila River is currently in the process of adjudication, and rights are being claimed by several Colorado River tribes to that source as well. The decisions rendered in these cases are sure to have major impacts on water management in the state, and are likely to be felt strongly in the Phoenix AMA. Chief among the institutional considerations affecting Indian water rights in the state is the 1963

Supreme Court decision in Arizona v. California.[6] This decision states that, under the Federal Reserve Rights through which Indian reservations were created, Indians have the right to sufficient water to irrigate all "practicably irrigable acreage" on the reservations. Although the reservations in the Phoenix AMA are far from demanding that much water, increases in Indian water use are expected to continue to increase for this reason.

A further aspect of agricultural water use is that all farmers in the Phoenix AMA are increasingly being urged to accept subsidized CAP water for irrigation, rather than using their groundwater pumping rights, in an effort to conserve groundwater resources in the AMA. This trend is likely to continue, as the costs associated with getting farmers to use CAP are generally considered money well spent in terms of preserving groundwater reserves for future generations and emergency use (Frank 1999).

It should be noted that actions are currently being taken to further protect the Phoenix AMA from water shortages in times of drought. The Arizona Water Banking Association plans to store as much water as possible over the next twenty years as insurance against drought (AWBA 1998). Although it is unlikely that new surface reservoir space will be constructed within the AMA, it is possible that existing storage capacity could be expanded through raising dam heights, as recently happened with San Carlos and Roosevelt dams.

Despite these efforts, a drought that affected both the Upper and Lower Colorado River basins simultaneously could have impacts beyond what water managers and infrastructure can currently protect against. This would be particularly true if such a drought continued for a sufficient length of time to significantly deplete the Colorado River reservoir system, where Lakes Mead and Powell have the capacity to store approximately four years of the river's flow. If this were the case, and the demands of more senior rights holders such as California and Nevada preempted fulfillment of Arizona's more junior CAP allocation, the effects could be very significant. Much of the agriculture in the Phoenix AMA depends on heavily subsidized CAP water. If this supply were suspended, it is unlikely that farmers could invest in the infrastructure and obtain the rights necessary to tap into other surface water sources. They would probably rely more on groundwater pumping, since the infrastructure to do so is already in place in many areas. In this case, farmers who currently use a mix of CAP and/or SRP water and groundwater would be able to shift to using groundwater exclusively (Frank 1999). Farmers reliant exclusively on CAP supplies, however, might experience greater difficulties related to intensive groundwater pumping. Subsidence associated with rapidly expanding cones of depression could become a serious threat to the overlying land. Further, deeper pumping would necessitate greater electricity use, perhaps coinciding with escalating residential and commercial power demands. If such a drought went on long enough to significantly deplete the aquifer, reallocation of water resources across sectors could become not just more economically efficient, but essential.

While the foregoing analysis does show that the AMA as a whole has a considerable amount of flexibility in coping with drought, it is important to note that some areas of the AMA would be more severely affected than others in the event of a serious protracted drought. Each of the 31 large and nearly 80 small water providers has a unique portfolio of water resources, as well as a complex web of arrangements regarding treatment and recharge facilities that may be shared or act as back-ups for other water providers.

The water providers who have the greatest amount of redundancy in their systems, that is the highest number of water sources and greatest ease in switching between resources, would be best able to cope with drought. These include providers who have access to water via the Salt River Project, the CAP canal, and recharged effluent, in addition to groundwater pumping. Those providers who have access to neither SRP nor CAP and are not yet utilizing extensive effluent recharge, and thus must rely completely on groundwater, are apt to be more vulnerable to both drought and contamination of their water supply. Even more at risk are the few communities

[6] 373 U.S. at 600, 83 S.Ct. at 1498.

where groundwater is becoming scarce or is unavailable, and thus depend heavily on CAP supplies (Frank 1999). The CAP canal has the potential to suffer disruptions not only due to climatic factors, but also due to problems with the complex system of pumping facilities and reservoirs, or contamination.

Hydrology and patterns of water use also play a role in determining the sensitivity of different water providers to climatic factors. The Phoenix AMA is made up of seven major sub-basins, some of which have extensive groundwater reserves and some that are less well endowed. Some areas are heavily agricultural, and thus have high degrees of incidental recharge replenishing their aquifers, while others are more urbanized and thus have higher proportions of actual water consumption. For these reasons, parts of the AMA have actually experienced water logging due to rising water tables, while others have reached their growth limits due to lack of alternative water supplies, and are now longer able to secure the Certificates of Assured Water Supply necessary for new construction (Frank 1999).

Neither the State of Arizona nor the Arizona Department of Water Resources has a comprehensive drought management plan. Instead, such contingency plans are generally left to individual water providers, although they are required to meet basic supply reliability requirements. The Arizona Municipal Water Users' Association (AMWUA), which most of the large providers in the Phoenix AMA belong to, does have a drought management plan based on a tiered set of conditions and responses to various levels of drought. However, compliance is voluntary, and water providers note that it is difficult to enforce conservation requirements when nearby providers, due to differential access to water resources, are not facing drought conditions and thus not enforcing the same reduced water use standards.

Tucson AMA

Unlike the situation in the Phoenix AMA, changes in water management in the Tucson AMA are expected to decrease the rate of groundwater overdraft in the near future. Overdraft is projected to decline from its 1995 level of 70 percent of the AMA's water supply, down to only 15 percent by 2025. Use of CAP water will account for most of this progress toward achieving sustainability. Other measures aimed at replacing some of the overdraft in the aquifer, notably effluent use, are now becoming more widespread as well.

While renewable water supplies are expected to nearly quadruple during this period, the population is projected to increase by 40 percent. This rate of population growth is similar to Phoenix's 43 percent growth rate, although the actual additional numbers are much smaller: 498,500 additional people in Tucson AMA, as opposed to 1,932,947 in Phoenix. Even in the one-year drought conditions, the 36 percent of the AMA's water supply that would have to come from nonrenewable groundwater pumping is a vast improvement over the overdraft rate for 1995.

Agriculture is already a smaller component of water demand in the Tucson AMA than in any other study location, and its decline is expected to continue. As in the Phoenix AMA, farmers are increasingly being subsidized to use CAP water and preserve groundwater reserves for other uses and as an emergency supply. As the Maintain Agriculture cases illustrate, the overdraft situation would worsen by 23,520 af annually under one-year drought conditions if the sector does not diminish as expected. Basically, the decline of agriculture could be accelerated if the price cities were willing to pay for water increased in times of scarcity, meaning that they could lease water rights from farmers who agreed not to plant crops in years when droughts are predicted. This would require the creation of new institutional arrangements with additional flexibility to accommodate such short-term transfers of water rights. However, even if agriculture were completely eliminated and overdraft consequently cut in half, withdrawals would still exceed aquifer replenishment by 25 percent per year under drought conditions.

The Tucson AMA's increased reliance on CAP supplies will clearly help ease the overdraft situation; however, a long-term, widespread drought that caused these supplies to be eliminated would have impacts similar to those detailed in the Phoenix AMA "Implications" section. The Tucson AMA could be considered more vulnerable to drought due to the fact that it does not have access to the substantial surface water resources present in the Phoenix AMA. However, the AMA's natural recharge and smaller population base do compensate somewhat. Many of the same mechanisms for coping with droughts of different duration, assuming a significantly higher population, would be similar for the Tucson AMA as those described for Phoenix. However, a few unique characteristics of the Tucson AMA could have bearing on community acceptance of policy changes. Water users in the Tucson AMA seem to have become acclimated to controversial water issues over the past seven years, since the incidents and issues surrounding CAP deliveries first came to the fore. Distrust of professional water managers and providers remains, although this may be improving as residents become more aware that groundwater resources are limited. Long-time local residents also recall events such as the ouster of the mayor and council in the 1970s in response to an attempted water rate hike.

The most recent controversy over the use of CAP supplies culminated with Tucson voters' rejection of Proposition 200 in November 1999. Acceptance of the proposition would have imposed restrictions on the use of CAP water by dictating that it be pumped into dry streambeds and washes in an effort to replenish groundwater reserves. Rejection of the proposition paved the way for delivery of a blend of CAP water and groundwater to residential users. Widespread delivery is slated to begin in 2001. Construction is underway on an 11.5-mile pipeline that will carry water from recharge sites in nearby Avra Valley and allow pumping in the severely depleted central well field to be discontinued. This will greatly increase the portion of the City of Tucson's 139,000 af CAP allocation that is actually used from its 1999 level of 22,000 af to the 177,000 af AMA-wide amount projected for 2025.

Questions are also being raised about the wisdom of relying on CAP supplies since there is no guarantee that these supplies are secure, and use of Colorado River water has already decimated the once thriving Colorado River delta Gulf of California ecosystems. At the same time, Tucson has a visible activist community concerned with long-term sustainability issues including greater water conservation through use of residential gray water and effluent and low water use landscaping. Xeriscaping is already a part of the Tucson landscape, in contrast to the green lawns more common in Phoenix. Although generalizing about community attitudes is a risky proposition, it does seem that Tucson residents may be more willing to accept conservation measures on an individual basis, particularly if they were assured that sacrifices in water use could be evenly distributed over different sectors. More information about the potential impacts of climatic variability and greater awareness of the AMA's sensitivity to drought, such as this analysis aims to provide, could add impetus to water conservation and sustainable use measures.

Santa Cruz AMA

A quick glance at the preceding charts and graphs would seem to indicate that the long-term water situation in the Santa Cruz AMA is among the most secure of the five areas studied; indeed, it has the lowest percentage of normal overdraft of all study areas.[7] However, three factors contradict this conclusion. For one, the hydrology of the AMA is such that it does not possess the vast groundwater reserves of either the Phoenix or Tucson AMAs. The aquifer in the

[7] Although the method used in this analysis of taking the mid-point of the range for most water supplies, as described in the Methodology section, resulted in overdraft conditions in both baseline scenarios, it should be noted that in most years the Santa Cruz AMA does maintain its groundwater balance.

Santa Cruz AMA is more narrowly contained within deposits of bedrock, thus eliminating the sort of secure reserve supply that the other two AMA areas possess. Another factor limiting the Santa Cruz AMA's ability to cope with drought is that it does not have access to either significant surface water or CAP supplies. Thus if its shallow and confined aquifer is depleted during a severe sustained drought, the area has fewer options and less flexibility in securing additional water supplies.

The Santa Cruz AMA's relationship with Nogales, Sonora and other water users across the border is the third factor that may work against the area's long-term water security. The 1999 population of Nogales, Arizona was 21,360 and is expected to grow to 27,000 by 2018 (SEAGO 1999); Nogales, Sonora, on the other hand, had a 1999 population of 206,554, and is projected to swell to 344,988 by 2018 (CNA 1996). Effluent from both cities is treated at the Nogales International Wastewater Treatment Plant (NIWTP), downstream from Nogales, Arizona. The discharge from this facility forms a significant component of recharge for the Santa Cruz AMA, as the scenarios illustrate. Under current conditions and those projected into the future, the rapidly growing city south of the border will continue to provide increasing amounts of effluent discharge to the AMA.

However, effluent-related policy changes in Mexico, which the Santa Cruz AMA has little influence over, could affect this crucial water supply. The NIWTP was sited in Arizona with the intention of treating effluent from both cities because Arizona's "downhill" location made the plan more cost-effective. While it would be very expensive for the Mexican portion of the treated effluent to be pumped back into Mexico, the state of Sonora or the federal government could decide to build a treatment plant south of the border and retain its effluent. Although Nogales, Sonora does not seem to have any immediate plants to construct a plant, it has been suggested (Nagle 1999) that one will eventually be built on the Mexican side of the border. A long-term drought and increasing water scarcity could speed up this process. The volume of Mexican effluent sent to NIWTP is expected to continue to increase until such a facility is built; after such a time, additional effluent is expected to be retained in Mexico, while the portion sent to the NIWTP would be maintained at existing flow levels. The potential impact of climatic fluctuations on these plans remains to be seen, but does have the potential to alter them significantly.

Another factor to consider is that at present residents of Nogales, Sonora do, to some extent, obtain water supplies from their sister city by taking containers across the border to fill or clandestinely tapping into the Nogales, Arizona municipal water system through strategically placed pipes (COLEF 1992). It is difficult to quantify how significant this sharing of water resources across the border is at present, but the Colegio de la Frontera Norte estimated in 1992 that 3,000 such connections existed. If water supplies in Sonora were to become scarcer due to system failures or overload caused by extremely dry conditions, use of these connections is likely to increase, possibly to the extent that it would impact Nogales, Arizona.

It seems clear that greater stress on water supplies south of the border, either through increased population or due to climatic conditions, could easily affect the Santa Cruz AMA in unpredictable ways. Although few, if any, permanent changes are likely to be made during a severe one-year drought, the longer that drier-than-normal conditions lasted, the more likely it would be that major infrastructural changes would take place on one or both sides of the border. As the "No NIWTP" cases illustrate, loss of the discharge of the sewage treatment plant would have drastic impacts on the AMA's water supply, and on the highly valued riparian area downstream (see below). A further "wild card" in this assessment is the fact that any major change in Mexico, be it political, economic, or climatic, could very well send even more people to communities on the northern border, such as Nogales, Sonora.

Increased groundwater pumping south of the border could also affect the aquifer, since the AMA's most significant source of underflow, along the Nogales Wash, runs from south to north, cutting first through Nogales, Sonora and then through Nogales, Arizona before joining the

Santa Cruz River. To meet the explosive growth in demand for potable water for the burgeoning city on the Mexican side of the border, Nogales, Sonora draws upon the Los Alisos Basin south of the city. However, if the city were to increase its concentration of wells along the Nogales Wash, underflow into Nogales, Arizona would be reduced to the wells along that stretch of the wash. Although there is currently no indication that water managers on the Mexican side of the border have any immediate plans to drill new wells along the Santa Cruz River (Sprouse 1999), the additional stress of a severe sustained drought could prompt such decisions to be made.

The Santa Cruz AMA has a larger riparian area than either of the other two AMAs, and some members of the community place great value on preserving this habitat. The shallow aquifer and high level of groundwater / surface water interaction mean that the riparian area is quite sensitive to groundwater overdraft, and the effects of over-pumping in even a single year would be noticeable in the response of the vegetation lining the stream. A severe sustained drought could force serious choices between preserving the riparian area and providing sufficient water for agriculture, though the outcome remains unclear. Agriculture is expected to gradually decrease in the AMA, and generally drier conditions could speed this decline. The elimination of agriculture in most of the scenarios tested simply increases the surplus margin; however, the eradication of this water use sector would not be enough to compensate for the loss of NIWTP supplies.

While the water situation of the Santa Cruz AMA may be somewhat precarious at present, efforts are underway to improve the reliability of local water supplies. The AMA recently called for proposals for the construction of impoundment projects, which are particularly well suited to the climate and topography of the area. Since much of the total annual rainfall occurs in heavy rains that last only a short length of time, increasing the AMA's ability to capture the run-off from these events, rather than losing the extra water as it flows down the Santa Cruz River into the Tucson AMA, makes good sense. Efforts are also underway to locate new groundwater supplies in surrounding areas, and also to develop a new well field in the Guevavi Ranch area, northeast of the City of Nogales. Finally, the AMA is producing a sophisticated groundwater modeling program that will take into account the area's complex topography and unique conditions, thus allowing for better understanding of the hydrological system and better water management. The calculated outcomes of the scenarios described in this report are subject to revision pending more certain baseline supply and demand information produced by these models.

Benson Subwatershed

The results from the 2025 sensitivity analysis indicate that, at the basin level, the Benson subwatershed would be more severely affected by both short- and longer-term drought conditions than by changes in the size of its population. In this regard, the results from the Benson subwatershed differ significantly from those obtained for the Sierra Vista subwatershed. While the elimination of agriculture case reveals some interesting patterns, it is unlikely that agriculture will entirely disappear from the area in the time period covered in this analysis.

Implications of Population Growth

Because the major user category in the subwatershed is irrigated agriculture, any changes directly or indirectly related to this sector will result in clearly noticeable impacts on water supply, demand, and overall groundwater balance. Municipal demand, on the other hand, is not expected to increase in a way that would have a significant impact on either water supply or demand. Not even under the higher population projection assumed, where the 1990 population is anticipated to almost double by the year 2025, does municipal water use account for a significant percentage of mined groundwater (8 percent).

It should be noted, however, that recent development plans in the greater Benson area are not taken into account in this analysis. These plans include the opening of Kartchner Caverns, one of the largest living wet caves in the country, and development of facilities to accommodate anticipated increases in the number of tourists and winter residents. If indeed Kartchner Caverns were to become the second largest tourist attraction in the state of Arizona, as described in detail in the Draft report *"An Assessment of Climate Vulnerability in the Middle San Pedro River Valley"* (Austin et al., 1999), municipal water demand would certainly experience a significant increase.

<u>Implications of Drought</u>

The implications of drought conditions for the Benson subwatershed are manifold. The most significant changes that can be expected due to reduced water supply during drought years is increased groundwater pumping for irrigated agriculture, especially under the one- and five-year scenarios, as well as an almost threefold increase in groundwater overdraft under the worst historic conditions assumed.

Consequences of drought conditions for irrigated agriculture include higher pumping costs due to reduced surface water availability in the two irrigation canals of St. David and Pomerene. This is particularly true for surface water diversion during the winter growing season. During the summer months, on the other hand, farmers rely primarily on their private wells.

All three winter drought scenarios, covering periods of one, five, and ten years, would imply either total or partial shifts from surface to groundwater, assuming that irrigated acreage remained unchanged. At the same time, increases in crop water requirements are expected to put additional stress on groundwater resources. As described, up to 12,000 af of extra irrigation water (81 percent more than in the 1990 baseline year) would have to be pumped to satisfy crop demands during times of reduced effective precipitation, but increased evapotranspiration over irrigated land. This represents by far the largest growth in water demands that would have to be anticipated in the Benson area. It is largely because of these additional thousands of acre-feet of irrigation water needs that the groundwater overdraft is expected to almost triple under the one-year drought scenario.

The increase in both pumping demands and pumping costs during drier than normal years is especially worrisome because of the crop mix currently in place in the Benson area. In 1990, highly water-consumptive crops such as pasture and alfalfa constituted over 80 percent of all irrigated crops. Despite the fact that exactly these crops will cause the highest increase in water requirements, it is very unlikely that farmers would switch to less water consuming plants, at least not within a short period of time. Also, the reliance on low-efficiency irrigation systems, such as surface water use without pumpback, is expected to further increase water demands as well as pumping costs during drought years. In the end, it will be the specific economic situation of individual farmers that will determine whether or not they will be able to afford such additional pumping costs and whether or not their business will still be profitable under altered conditions.

Another serious impact of reduced supply concerns the riparian vegetation in the subwatershed. Theoretically, it has to be assumed that the most direct implications of such drier climate conditions would be a state of dormancy, a reduction in distribution, or a partial to complete die-off of shallow-rooted plants. Most likely, this will depend on the drought resistance of the species composition. As described by Snyder, Williams and Gemko (1997), cottonwood and willow are considered to be the first to be affected by reductions in surface water. Mesquite and tamarisk, on the other hand, are more flexible in terms of their water sources. They could become more widespread and, ultimately, contribute to the "desertification" (Stromberg, Tiller and Richter, 1996) of the riparian vegetation.

However, as explained in more detail in the Draft report *"An Assessment of Climate Vulnerability in the Middle San Pedro River Valley"* (Austin et al. 1999), the existing riparian vegetation between St. David and north of Pomerene is considered to be in such poor shape that the implications of drought conditions described above might no longer be applicable. In fact, this "desertification" might have already occurred. An observed shift toward less surface water-dependent plants could be the result of long-term extensive human use in the area exacerbated by sustained dry conditions over the last few years. Pool and Coes (1999) report a long-term trend of both decreasing wet season runoff and decreasing summer base flow at the Charleston stream gage[8]. Although the gage is located south of the Benson subwatershed, this reduced surface water supply, presumably related to increased seasonal use by phreatophythes and/or declines in summer precipitation relative to winter precipitation, might have been contributing to the deterioration of the riparian area north of St. David.

A third possible ramification of altered water supply and demand under drought conditions is related to increasing conflicts over surface water. These conflicts can be expected to occur between in-stream water uses and other demand sectors relying on water from the San Pedro River. According to the 1990 data available for the Benson subwatershed, irrigated agriculture seems to be in direct competition with surface water-dependent riparian vegetation. Since both user categories rely on roughly 25 percent surface water, a decline in precipitation and streamflow would be experienced immediately. The results from this analysis suggest that an extreme event, such as the driest ever recorded winter (1904), could cause irreconcilable conflict between the two user groups. In this case, the little amount of available surface water would probably be used by riparian vegetation before it could even reach the irrigation canals.

As argued above, however, the 1990 baseline numbers for overall water demand by riparian vegetation might no longer be representative. If indeed a shift toward deeper-rooted plants in this part of the San Pedro river basin has already occurred, increasing conflicts with other surface water users becomes a non-issue. It could be hypothesized that by the year 2025 the entire riparian vegetation in this zone will be irrevocably transformed.

These speculations notwithstanding, it has to be assumed that any type of conflict over surface water supply will also largely depend on political decisions, including those affecting prioritization of water rights – particularly the settlement of Indian claims to waters of the Gila River and its tributairies, including the San Pedro River. Given the current structure of water rights in the basin, agriculture seems more likely to be favored in times of water shortage. Both the irrigation canals of St. David and Pomerene enjoy senior water rights. In-stream uses, although recognized as a beneficial use under Arizona water law, are likely to be more vulnerable. Also, the northern part of the San Pedro River National Conservation Area, administered by the BLM, lies within the Benson subwatershed. The BLM holds federal reserved water rights that may or may not secure their claims to water in this area depending on the position of their water rights within the priority order of rights holders to that supply source. This issue, as well as unresolved Indian claims[9], could dramatically affect water supply and demand in the area.

In terms of municipal demands, drought conditions in the Benson area are not likely to constitute any significant impact. Although municipal water use in 2025 is expected to increase during drier than normal years, this increase by itself is not expected to cause pronounced problems of groundwater mining in the Benson area. Also, Benson's outdoor water use, the main

[8] Wet season runoff: >40,000acre-feet (before 1935), <10,000 acre-feet (early and mid 1990s). Summer base flow: 2.5-5.0 ft^3/s (before 1963), 1.0-4.0 ft^3/s (during 1963 through 1982), 0.4-3.3 ft^3/s (after 1982).

[9] Precise implications will not be known until the General adjudication of Gila river water rights, including Indian rights, is completed.

cause for rises in municipal water demands under drier conditions, is relatively low compared to that in the Sierra Vista area (the proportion of total summer water use is 35 percent in Benson versus 50 percent in Sierra Vista). Unless future development in the greater Benson area involves large private residences with extensive water-intensive landscaping that requires sustained watering during periods of drought, increases in demand during drought periods will play a fairly moderate role.

Implications of Elimination of Agriculture

Although this scenario is purely hypothetical and, unlike some of the other study locations, is highly improbable to occur in the Benson subwatershed in the near future, it reveals some interesting patterns. Since irrigated agriculture is the primary water consumer in the area, it is not surprising that its elimination would drastically reduce water demands, especially groundwater demands. Despite the fact that the absence of agricultural activity would result in significantly less incidental recharge as one of the main components of total water supply, it is expected to improve the overall water balance in the subwatershed. In other words, the elimination of agriculture would considerably reduce the extent of groundwater mining.

This promising scenario notwithstanding, it is probably more realistic to assume that agriculture in this part of the San Pedro river will continue, yet with decreased water needs. It can be hypothesized that irrigation farmers will switch to less-water consuming plants and/or to practices of improved irrigation efficiency, such as drip irrigation and laser leveling. And some farmers might indeed abandon agriculture.

It should be noted, however, that, in any case, surplus water resulting from a decline in agricultural uses would not necessarily be available to the hydrologic system. If irrigation, as it is assumed in this analysis, were indeed eliminated, the former agricultural land would probably be used for development. Unlike in the Sierra Vista subwatershed or in other subwatersheds in the northern part of the San Pedro River basin - where protected areas of riparian vegetation might replace or continue to replace former farmland - RV parks, campgrounds, ranchettes, and more residential areas seem to constitute the most probable alternative to irrigated agriculture in the greater Benson area. In this case, agricultural water use would simply be replaced by other user categories. Whether or not these other user categories will imply an increase or decrease of water use in this part of the San Pedro River basin should certainly be addressed in any future study.

Finally, it should be emphasized that climatic, demographic, and even economic variability does not occur in a vacuum. Other variables such as political and environmental changes will also influence supply and demand patterns. For the Benson subwatershed, conservation efforts, Indian water rights, and the Endangered Species Act [10] are likely to be the most important factors. However, climatic stress holds considerable potential to enhance the impact of these factors.

Sierra Vista Subwatershed

Compared to the Benson analysis, the results for the Sierra Vista area indicate that the interactions between changes in population size and climatic variation will constitute the most critical factors for future water supply and demand in the subwatershed. Irrigated agriculture, on the other hand, whose role is already fairly limited, is not expected to have a significant impact on the 2025 water balance.

[10] The Endangered Species Act, one of the strongest federal laws, has a significant influence on land-use decisions. Once listed species are identified and land is designated as critical habitat, future use and development on this particular piece of land can be restricted.

Unfortunately, the sub-basin wide data and analytical results tend to mask localized particularities, especially the highly localized groundwater extraction in the Fort Huachuca/Sierra Vista area during the last two decades. According to Liverman et al. (1997), the city of Sierra Vista grew by 44 percent between 1980 and 1990 and is expected to grow by another 50,000 people by 2025. Due to the smoothing effect of using basin-wide data, the actual implications of increasing municipal demand in the Fort Huachuca/Sierra Vista area combined with periods of significantly reduced precipitation might be even more severe than the results of this analysis suggest.

Implications of Population Growth

According to the projections used in this analysis, the population of the Sierra Vista subwatershed will grow by 56 to77 percent until the year 2025, increasing to 80,000 and 90,000 people over the next two and a half decades. While, in 1990, riparian vegetation was reported to consume the highest amount of water, the municipal sector is expected to become the primary user in this part of the San Pedro River basin. These municipal demands will then account for up to 42 percent of total water withdrawals, which is clearly more than the demand generated by riparian plants (31 percent) and irrigated agriculture (13 percent).

Unlike in the Benson subwatershed, municipal demand accounts, and will continue to account for, a significant proportion of groundwater overdraft. More than half of all groundwater mined will be attributed to the growing population and its expanding water needs. Total groundwater overdraft could be as high as 16,500 af, a significant increase (77 percent) relative to the baseline year. Efficient conservation measurements, including increased effluent generation and use, as well as implementation of intentional recharge initiatives, are expected to become crucial in offsetting this trend.

Increases in groundwater overdraft in this area of the San Pedro watershed are particularly worrisome because of a cone of depression that has been developing since the 1960s and 1970s under well fields in the Fort Huachuca/Sierra Vista area. Water levels in wells in this area declined at rates of 0.5 to more than 1 feet per year through 1998, which is faster than in most other wells tapping the regional aquifer (Pool and Coes, 1999). According to MacNish (1998), the deepest part of this cone of depression has coalesced with another cone of depression, located in the Palominas/Hereford area. While the first cone can be considered the result of extensive groundwater extraction for municipal and military purposes, the second cone developed due to irrigation pumping. Given the additional 27,000 to 38,000 residents projected for the year 2025, it can be assumed that this zone of depression will expand and/or deepen as a direct consequence of increasing municipal demands. This not only means higher pumping costs for municipal water suppliers and their clients, it also represents a threat to smaller domestic wells that, due to a declining water table, lose contact with the aquifer and, consequently, run dry.

In addition, there is growing scientific evidence that the expanding cone of depression in the Fort Huachuca/Sierra Vista area has already started to intercept and divert groundwater flow paths in the basin, thereby reducing flows that otherwise would have reached the San Pedro River or the Babocomari River, the San Pedro’s main tributary (MacNish, 1998; Pool and Coes, 1999). Available data suggest that the areas most affected by diverted groundwater flows are those north of the Charleston gaging station (Pool and Coes, 1999). However, as argued by the authors, continued groundwater pumping in the vicinity of Fort Huachuca/Sierra Vista and further expansion of the cone of depression will also undercut the flows that discharge upstream of the Charleston gaging station, thereby reducing base flow in the central part of the subwatershed.

Although there is no study that explicitly addresses the impact of the expanding cone of depression on the riparian area along the San Pedro, it may be assumed that reduced base flow in and groundwater underflow to the river - both a direct consequence of diverted groundwater flows - might alter the composition and the extent of the riparian zone. Most affected would be the San Pedro River National Conservation Area (SPRNCA), established by the US Congress in

1988 and administered by the Bureau of Land Management. This conservation area covers 47,668 acres along the river, the majority of which is located within the Sierra Vista subwatershed. Clearly, expected increases in municipal demand in this growing urban area would intensify the pressure on groundwater resources and, as a result, also on the surrounding ecosystem.

Although the SPRNCA enjoys Federal reserved surface water rights to protect the riparian vegetation and its habitat, these rights do not protect the conservation area from users with more senior water rights such as Fort Huachuca. Both BLM and Fort Huachuca have filed claims with the General Adjudication of Gila River water rights. As in the case of Benson and Indian claims, precise implications of future changes in supply and demand are unclear until the adjudication is completed.

Implications of Drought

Drought conditions are expected to considerably worsen groundwater mining in the subwatershed. Under the worst single-year scenario, groundwater overdraft is anticipated to be almost four times as large as under the 1990 conditions. Again, the actual impacts of reduced supply combined with increased demand are expected to be highly localized.

Unlike in the Benson subwatershed, the most significant changes can be expected for the municipal sector. Not only is overall municipal demand higher in the Sierra Vista subwatershed, so is the proportion of outdoor water use, which, in turn is directly related to the amount of precipitation received. Again, it will largely depend on institutional arrangements whether or not the subwatershed will be able to counterbalance increased water needs during both short- and longer-term drought periods.

The other user category directly affected by reductions in available supply is riparian vegetation. As in the Benson case, drier conditions would be expected to result in temporary dormancy, reduced distribution, or partial to complete die-off of riparian plants. Since irrigated agriculture in this part of the San Pedro basin depends exclusively on groundwater, riparian areas are not in direct competition with any other surface water users. However, as explained above, the cones of depression to the west of the San Pedro intercept groundwater flows to the river (MacNish, 1998; Pool and Coes, 1999), thereby also impacting water needs of riparian vegetation. Since this study relies on basin-wide numbers, and does not take into account localized hydrologic patterns, the implications of drought periods on riparian water needs might in fact be more severe than illustrated in this analysis. In other words, the availability of surface water for riparian vegetation during five- and ten-year droughts, which, according to this analysis, ranges between 2,070 and 2,420 af/year, might be overestimated. An expanding cone of depression and the increased interception of groundwater flows that would eventually would discharge to the river in the form of base flow might considerably reduce the amount of surface water that is actually available to the riparian vegetation.

Moreover, droughts at a magnitude used for this analysis are likely to exacerbate the trend of declining summer base flow as discussed by Pool and Coes (1999) and, as a direct result, the condition and extent of the riparian vegetation. According to the authors, the decline in summer base flow in the San Pedro River, measured at the Charleston gaging station and amounting to about 2.0 ft^3/s during 1936 through 1997, may be related to declines to summer precipitation relative to winter precipitation and/or increased seasonal groundwater water use by riparian plants. When looking at the combined effect of reduced wet season precipitation and base flow with winter drought conditions (such as those used in this analysis) and corresponding reductions in base flow, as depicted by Pool and Coes for the 1950s drought (1999), it may be assumed that the pressure on the riparian ecosystem would become even greater.

Agricultural water demands can be expected to increase when rainfall declines. However, this increase would be significantly smaller than in the Benson subwatershed where agriculture is clearly more significant. Moreover, it can be assumed that more high-efficiency irrigation techniques and a lower percentage of high water consuming crops would help to lessen additional water demands. Nevertheless, small-scale farmers might not have the necessary management strategies and/or the financial means to afford increasing pumping costs or water-saving devices and, therefore, could very well be more vulnerable to climatic variability.

Implications of Elimination of Agriculture

In contrast to the Benson subwatershed, where agriculture constitutes the most significant user category, irrigation plays a fairly moderate role in the Sierra Vista subwatershed. By the year 2025, only 13 percent of total water supply is anticipated to be used by agriculture. Thus, the hypothetical scenario under which all irrigated agriculture is eliminated from the unit of analysis will not result in any significant changes in this part of the San Pedro basin. Even if agriculture disappeared entirely from the area, groundwater overdraft would still be substantial (58 percent increase compared to the 1990 baseline year). Again, this can be attributed to the high municipal demand that is expected for the year 2025.

Ironically, the elimination of agriculture scenario is more likely to occur in this part of the basin than further downstream in the greater Benson area. A considerable extent of formerly agricultural land along the San Pedro has already been converted into the San Pedro River National Riparian Conservation Area. While there is no intention to expand this conservation area north of St. David, which might be considered part of the greater Benson area, plans may be emerging to incorporate the area south of the existing boundary of the BLM land and even on the other side of the international border in Mexico. The extension into Mexico would allow incorporation of the headwaters of the San Pedro River into the protected area. Currently, it is in the southern portion of the river where the large majority of irrigation in the subwatershed takes place. A replacement of agricultural lands by riparian vegetation is likely to transform water use patterns in this part of the watershed. An extension of this sensitivity analysis, in combination with an institutional analysis, to the headwaters will be needed to assess possible water use changes and their impact on an overall groundwater balance on the Mexican side of the San Pedro watershed.

VI. General Summary and Recommendations

The analysis presented in this working paper provides some parameters for thinking about the extent to which droughts of historically high magnitudes might affect water resource budgets in urban areas of Arizona. The analysis also reveals the high degree to which sensitivity to drought varies among the study sites. This variance among the study sites is largely due to local factors such as existing water use patterns, historical rainfall patterns, level of population growth expected, anticipated changes in water use among sectors over the next 25 years, and responsiveness of local water supplies to climatic conditions. Results indicate that the Santa Cruz AMA highly vulnerable even to short-term climatic variability. By contrast, the strongest impacts on the Tucson and Phoenix AMAs, and on the Sierra Vista subwatershed, are more apt to be experienced under longer-term conditions of deep drought. Sensitivity in the Benson subwatershed is the most sector-specific, with the significant climatic impacts likely to occur in its agricultural sector.

Although agriculture is a highly visible user of water resources, results of this analysis indicate that elimination of agriculture under conditions of deep drought cannot be expected to fully counter imbalances between supply and demand. In most cases, stringent conservation measures would also be required. Sustained severe drought conditions could generate particularly acute dissent among competing water users in areas where valued riparian areas exist—notably the San Pedro National Conservation Area and the Santa Cruz River riparian area downstream from the Nogales International Wastewater Treatment Plant .

The following recommendations suggest avenues for pursuing the work begun in this analysis and for identifying and addressing risks posed by the kinds of conditions the analysis uncovered.

- ♦ *Water resource managers and regulators should consider making greater use of historical and paleoclimate information, as well as of seasonal and longer-lead climate forecasts.* Abundant information continues to be amassed regarding past climates and climatic conditions. This information, however, remains largely untapped by the water resource management community. At the same time, climate forecasting has improved markedly in the area of predicting ENSO events, and intensive research continues on improving capability to forecast other major climatic processes such as the Southwestern Monsoon. Workshops should be offered to improve water managers' ability to incorporate information on past climatic conditions and impacts with seasonal and longer-term climate forecasts. Such training would enable water managers and regulators to interpret and productively use the wealth of available information.

- ♦ *Water managers should formulate their water budgets and water management strategies based on a range of climatic and hydrologic conditions, rather than assuming climate stationarity.* Some individual providers, and the Santa Cruz AMA, already recognize the need to include climate variability in their water budgeting and decision making activities. This should become standard practice.

- ♦ *Sensitivity analyses should be carried out by the Arizona Department of Water Resources, for each of the state's urban areas, using ADWR hydrologic models.* Running the drought scenarios through the ADWR models, which better reflect the complexity of hydrologic processes and demand patterns in specific geographical areas, would allow for a more sophisticated approach to calculating climate impacts. Because variation in evapotranspiration rates appear to have the greatest explanatory power with regard to variance in outdoor water demand, a model-based analysis would allow for a more finely tuned assessment of impacts due to climatic variability.

- *To assure equity among water providers and consumers, water managers and regulators should examine the results of climate sensitivity analyses within the context of their specific communities and water resource structures.* It is unlikely that climatically based risk would be shared equally by all urban water providers. Identification of those water providers in each urban area most vulnerable to climate impacts is essential, as is formulation of plans and policies to alleviate critical stresses on those systems. A survey of water providers is currently being carried out by CLIMAS. More such surveys remain to be done.

- *Analyses of alternative approaches to water conservation should consider climate variability.* In order to ascertain "worst-case" conditions, the present study assumed that no substantial conservation measures would be in force during the drought periods. However, it could prove quite useful to policy making and implementation under conditions of climatic stress to evaluate the effectiveness of different conservation strategies in reducing the impacts on non-renewable water resources. This would involve looking at trends in climate variability occurring over short and long time spans to evaluate the relative effectiveness of different demand-reduction approaches under various climatic conditions.

- *An analysis should be conducted of the impacts of institutional factors on water managers' ability to respond effectively to climate variability.* Such an analysis, which would focus on the role of statutes, rules, policies, and procedures in facilitating or constraining effective preparation for and/or response to climatic conditions, is a necessary precursor to improving the resilience of urban areas to climatic impacts. One such an analysis is currently being carried out by CLIMAS.

- *Sensitivity analyses conducted in the Sierra Vista subwatershed and the Santa Cruz AMA should be extended across the international boundary.* Hydrology does not stop at international boundaries. Both the Sierra Vista subwatershed and the Santa Cruz AMA are located downstream from important water users in Sonora, Mexico. The Santa Cruz River has its headwaters in Arizona, flows into Sonora, then turns northward again to Arizona, which makes the connections across the border even closer. Like surface water, subflows and groundwater formations are shared across the border, as are climatic conditions. These conditions alone argue in favor of extending this sensitivity analysis into the Mexican portion of the two subwatersheds. In the case of the Santa Cruz AMA, close economic ties and social interactions between Nogales, Arizona and Nogales, Sonora have important implications for patterns of water demand. Thus, transboundary analysis of climate impacts on water resources becomes even more important.

- *Explicit analysis of the interaction of climatic impacts and urban water management practices on existing, highly valued natural landscapes and ecosystems should be carried out.* The present study takes into account the importance of the riparian areas in the Santa Cruz AMA and on the San Pedro River. While not explicitly in the Tucson or Phoenix AMA water budgets, relatively small patches of riparian area and other natural landscapes are important to these areas as well. In the Tucson sub-basin of the Tucson AMA, for example, it is estimated that some 39,000 acre feet of water are diverted annually from valued riparian and aquatic ecosystems (Fonseca 2000). Localized water withdrawals, particularly in the context of climatic stress, pose a potentially serious threat to the viability of these areas.

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Appendices

Appendix 1: Phoenix AMA

1.1 One-Year Scenarios

1.2 Five-Year Scenarios

1.3 Ten-Year Scenarios

Appendix 2: Tucson AMA

2.1 One-Year Scenarios

2.2 Five-Year Scenarios

2.3 Ten-Year Scenarios

Appendix 3: Santa Cruz AMA

3.1 One-Year Scenarios

3.2 Five-Year Scenarios

3.3 Ten-Year Scenarios

Appendix 4: Benson Subwatershed

4.1 One-Year Scenarios

4.2 Five-Year Scenarios

4.3 Ten-Year Scenarios

Appendix 5: Sierra Vista Subwatershed

5.1 One-Year Scenarios

5.2 Five-Year Scenarios

5.3 Ten-Year Scenarios

Appendix 1: Phoenix AMA

1.1 One-Year Scenarios

1.2 Five-Year Scenarios

1.3 Ten-Year Scenarios

Appendix 1.1: Phoenix AMA 1995 and 2025 - One-Year Scenarios

Renewable Water Supply	Baseline 1995	TMP 2025 Baseline	TMP 2025 1 yr Drought	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag + 1 yr Drought	2025 No Agriculture	2025 No Ag + 1 yr Drought	Baseline 1995	1995 Baseline 1 yr Drought
Total Surface Water	1,004,593	1,093,214	126,485	1,093,214	126,485	1,093,214	126,485	1,004,593	116,231
Recharge + Inflow - Outflow	24,100	24,100	2,788	24,100	2,788	24,100	2,788	24,100	2,788
CAP	274,559	480,498	480,498	480,498	480,498	480,498	480,498	274,559	274,559
Effluent	109,731	162,739	162,739	162,739	162,739	162,739	162,739	109,731	109,731
Total Renewable Water Supply	1,412,983	1,760,551	772,510	1,760,551	772,510	1,760,551	772,510	1,412,983	503,310
Percentage of 2025 baseline amount	**80**	**100**	**44**	**100**	**44**	**100**	**44**	**80**	**29**

Water Demand	Baseline 1995	TMP 2025 Baseline	TMP 2025 1 yr Drought	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag + 1 yr Drought	2025 No Agriculture	2025 No Ag + 1 yr Drought	TMP 2025 Baseline	TMP 2025 1 yr Drought
Municipal	869,962	1,395,725	1,437,597	1,395,725	1,437,597	1,395,725	1,437,597	1,395,725	1,437,597
Agricultural	1,333,885	1,360,743	1,395,081	1,333,885	1,383,239	0	0	1,360,743	1,395,081
Industrial	83,088	137,628	145,445	137,628	145,379	137,628	145,445	137,628	145,445
Riparian	48,000	48,000	51,249	48,000	51,226	48,000	51,249	48,000	51,249
minus incidental recharge	-556,736	-564,684	-573,641	-551,460	-562,848	-210,891	-210,920	-564,684	-573,641
minus AWS replenishment obligation	0	-51,992	-51,992	-51,992	-51,992	-51,992	-51,992	-51,992	-51,992
minus cut to the aquifer	-5,197	-21,615	-21,615	-21,615	-21,615	-21,615	-21,615	-21,615	-21,615
total return flows	-561,933	-638,291	-647,248	-625,067	-636,455	-284,498	-284,527	-638,291	-647,248
Net Water Consumption	1,773,002	2,303,805	2,382,124	2,290,171	2,380,985	1,296,855	1,349,764	2,303,805	2,382,124
Percentage of 2025 baseline amount	**77**	**100**	**103**	**99**	**103**	**56**	**59**	**100**	**103**

Groundwater Impact	Baseline 1995	TMP 2025 Baseline	TMP 2025 1 yr Drought	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag + 1 yr Drought	2025 No Agriculture	2025 No Ag + 1 yr Drought	1995 Supply 2025 Demand	95 Sup, '25 Dem 1 yr Drought
Renewable Water Supply	1,412,983	1,760,551	772,510	1,760,551	772,510	1,760,551	772,510	1,412,983	503,310
Net Water Consumption	1,773,002	2,303,805	2,382,124	2,290,171	2,380,985	1,296,855	1,349,764	2,303,805	2,382,124
Groundwater Impact	-360,019	-543,254	-1,609,614	-529,620	-1,608,475	463,696	-577,254	-890,822	-1,878,814
% demand met by non-renewable supply	**20**	**24**	**68**	**23**	**68**	**-36**	**43**	**39**	**79**

Appendix 1.2: Phoenix AMA 1995 and 2025 - Five-Year Scenarios

Renewable Water Supply	Baseline 1995 x 5	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought	TMP 2025 5 yr Drought without CAP	2025 w/ 1995 Agriculture x 5	2025 w/ 1995 Ag 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought without CAP	2025 No Agriculture x 5	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought without CAP	Baseline 1995 x 5	1995 Baseline 5 yr Drought
Total Surface Water	5,022,965	5,466,070	3,044,601	3,044,601	5,466,070	3,044,601	3,044,601	5,466,070	3,044,601	3,044,601	5,022,965	2,860,579
Recharge + Inflow - Outflow	120,500	120,500	67,119	67,119	120,500	67,119	67,119	120,500	67,119	67,119	120,500	68,625
CAP	1,372,795	2,402,490	2,402,490	0	2,402,490	2,402,490	0	2,402,490	2,402,490	0	1,372,795	1,372,795
Effluent	548,655	813,695	813,695	813,695	813,695	813,695	813,695	813,695	813,695	813,695	548,655	548,655
Total Renewable Water Supply	7,064,915	8,802,755	6,327,904	3,925,414	8,802,755	6,327,904	3,925,414	8,802,755	6,327,904	3,925,414	7,064,915	4,850,653
Percentage of 2025 baseline supply	**80**	**100**	**72**	**45**	**100**	**72**	**45**	**100**	**72**	**45**	**80**	**55**

Water Demand	Baseline 1995 x 5	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought	TMP 2025 5 yr Drought without CAP	2025 w/ 1995 Agriculture x 5	2025 w/ 1995 Ag 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought without CAP	2025 No Agriculture x 5	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought without CAP	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought
Municipal	4,349,810	6,978,625	7,187,984	7,187,984	6,978,625	7,187,984	7,450,958	6,978,625	7,187,984	7,187,984	6,978,625	7,187,984
Agricultural	6,669,425	6,803,715	6,975,407	6,975,407	6,669,425	6,916,194	6,916,194	0	0	0	6,803,715	6,975,407
Industrial	415,440	688,140	727,226	727,226	688,140	727,226	727,226	688,140	727,226	727,226	688,140	727,226
Riparian	240,000	240,000	256,244	256,244	240,000	256,244	256,244	240,000	256,244	256,244	240,000	256,244
minus incidental recharge	-2,783,680	-2,823,420	-2,868,205	-2,868,205	-2,757,300	-2,814,240	-2,868,205	-1,054,454	-1,054,599	-1,054,599	-2,823,420	-2,868,205
minus AWS replenishment obligation	0	-259,960	-259,960	-259,960	-259,960	-259,960	-259,960	-259,960	-259,960	-259,960	-259,960	-259,960
minus cut to the aquifer	-25,985	-108,075	-108,075	-108,075	-108,075	-108,075	-108,075	-108,075	-108,075	-108,075	-108,075	-108,075
total return flows	-2,809,665	-3,191,455	-3,236,240	-3,236,240	-3,125,335	-3,182,275	-3,236,240	-1,422,489	-1,422,634	-1,422,634	-3,191,455	-3,236,240
Net Water Consumption	8,865,010	11,519,025	11,910,620	11,910,620	11,450,855	11,905,372	12,114,382	6,484,276	6,748,819	6,748,819	11,519,025	11,910,620
Percentage of 2025 baseline amount	**77**	**100**	**103**	**103**	**99**	**103**	**105**	**56**	**59**	**59**	**100**	**103**

Groundwater Impact	Baseline 1995 x 5	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought	TMP 2025 5 yr Drought without CAP	2025 w/ 1995 Agriculture x 5	2025 w/ 1995 Ag 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought without CAP	2025 No Agriculture x 5	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought without CAP	1995 Supply 2025 Demand	1995 Supply 2025 Demand 5 yr Drought
Renewable Water Supply	7,064,915	8,802,755	6,327,904	3,925,414	8,802,755	6,327,904	3,925,414	8,802,755	6,327,904	3,925,414	7,064,915	4,850,653
Net Water Consumption	8,865,010	11,519,025	11,910,620	11,910,620	11,450,855	11,905,372	12,114,382	6,484,276	6,748,819	6,748,819	11,519,025	11,910,620
Groundwater Impact	-1,800,095	-2,716,270	-5,582,716	-7,985,206	-2,648,100	-5,577,467	-8,188,967	2,318,479	-420,915	-2,823,405	-4,454,110	-7,059,967
% demand met by non-renewable sup	**20**	**24**	**47**	**67**	**23**	**47**	**68**	**-36**	**6**	**42**	**39**	**59**

Appendix 1.3: Phoenix AMA 1995 and 2025 - Ten-Year Scenarios

Renewable Water Supply	Baseline 1995 x 10	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought without CAP	2025 w/ 1995 Agriculture x 10	2025 w/ 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought without CAP	2025 No Agriculture x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought without CAP	Baseline 1995 x 10	1995 Baseline 10 yr Drought
Total Surface Water	10,045,930	10,932,140	7,997,954	7,997,954	10,932,140	7,997,954	7,997,954	10,932,140	7,997,954	7,997,954	10,045,930	7,349,602
Recharge + Inflow - Outflow	241,000	241,000	176,316	176,316	241,000	176,316	176,316	241,000	176,316	176,316	241,000	176,316
CAP	2,745,590	4,804,980	4,804,980	0	4,804,980	4,804,980	0	4,804,980	4,804,980	0	2,745,590	2,745,590
Effluent	1,097,310	1,627,390	1,627,390	1,627,390	1,627,390	1,627,390	1,627,390	1,627,390	1,627,390	1,627,390	1,097,310	1,097,310
Total Renewable Water Supply	14,129,830	17,605,510	14,606,639	9,801,659	17,605,510	14,606,639	9,801,659	17,605,510	14,606,639	9,801,659	14,129,830	11,368,818
Percentage of baseline supply	**80**	**100**	**83**	**56**	**100**	**83**	**56**	**100**	**83**	**56**	**80**	**65**

Water Demand	Baseline 1995 x 10	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought without CAP	2025 w/ 1995 Agriculture x 10	2025 w/ 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought without CAP	2025 No Agriculture x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought without CAP	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought
Municipal	8,699,620	13,957,250	14,375,968	14,375,968	13,957,250	14,375,968	14,375,968	13,957,250	14,375,968	14,375,968	13,957,250	14,375,968
Agricultural	13,338,850	13,607,430	13,950,814	13,950,814	13,338,850	13,832,387	13,832,387	0	0	0	13,607,430	13,950,814
Industrial	830,880	1,376,280	1,454,451	1,454,451	1,376,280	1,454,451	1,454,451	1,376,280	1,454,451	1,454,451	1,376,280	1,454,451
Riparian	480,000	480,000	512,488	512,488	480,000	512,488	512,488	480,000	512,488	512,488	480,000	512,488
minus incidental recharge	-5,567,360	-5,646,840	-5,736,410	-5,736,410	-5,646,840	-5,736,410	-5,736,410	-2,108,908	-2,109,198	-2,109,198	-5,646,840	-5,736,410
minus AWS replenishment obligation	0	-519,920	-519,920	-519,920	-519,920	-519,920	-519,920	-519,920	-519,920	-519,920	-519,920	-519,920
minus cut to the aquifer	-51,970	-216,150	-216,150	-216,150	-216,150	-216,150	-216,150	-216,150	-216,150	-216,150	-216,150	-216,150
total return flows	-5,619,330	-6,382,910	-6,472,480	-6,472,480	-6,382,910	-6,472,480	-6,472,480	-2,844,978	-2,845,268	-2,845,268	-6,382,910	-6,472,480
Net Water Consumption	17,730,020	23,038,050	23,821,241	23,821,241	22,769,470	23,702,814	23,702,814	12,968,552	13,497,638	13,497,638	23,038,050	23,821,241
Percentage of 2025 baseline amount	**77**	**100**	**103**	**103**	**99**	**103**	**103**	**56**	**59**	**59**	**100**	**103**

Groundwater Impact	Baseline 1995 x 10	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought without CAP	2025 w/ 1995 Agriculture x 10	2025 w/ 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought without CAP	2025 No Agriculture x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought without CAP	1995 Supply 2025 Demand	1995 Supply 2025 Demand 10 yr Drought
Water Supply	14,129,830	17,605,510	14,606,639	9,801,659	17,605,510	14,606,639	9,801,659	17,605,510	14,606,639	9,801,659	14,129,830	11,368,818
Net Water Consumption	17,730,020	23,038,050	23,821,241	23,821,241	22,769,470	23,702,814	23,702,814	12,968,552	13,497,638	13,497,638	23,038,050	23,821,241
Groundwater Impact	-3,600,190	-5,432,540	-9,214,601	-14,019,581	-5,163,960	-9,096,175	-13,901,155	4,636,958	1,109,001	-3,695,979	-8,908,220	-12,452,423
% demand met by non-renewable supply	**20**	**24**	**39**	**59**	**23**	**38**	**59**	**-36**	**-8**	**27**	**39**	**52**

Appendix 2: Tucson AMA

2.1 One-Year Scenarios

2.2 Five-Year Scenarios

2.3 Ten-Year Scenarios

Appendix 2.1: Tucson AMA 1995 and 2025 - One-Year Scenarios

Renewable Water Supply	Baseline 1995	TMP 2025 Baseline	TMP 2025 1 yr Drought	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag + 1 yr Drought	2025 No Agriculture	2025 No Ag + 1 yr Drought	Baseline 1995	1995 Baseline 1 yr Drought
Recharge + Inflow - Outflow	60,800	60,800	7,035	60,800	7,035	60,800	7,035	60,800	7,035
CAP	100	177,900	177,900	177,900	177,900	177,900	177,900	100	100
Effluent	10,300	42,700	42,700	42,700	42,700	42,700	42,700	10,300	10,300
Total Renewable Water Supply	71,200	281,400	227,635	281,400	227,635	281,400	227,635	71,200	17,435
Percentage of 2025 baseline amount	**25**	**100**	**81**	**100**	**81**	**100**	**81**	**25**	**6**

Water Demand	Baseline 1995	TMP 2025 Baseline	TMP 2025 1 yr Drought	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag + 1 yr Drought	2025 No Agriculture	2025 No Ag + 1 yr Drought	TMP 2025 Baseline	TMP 2025 1 yr Drought
Municipal	155,500	267,100	285,797	267,100	285,797	267,100	285,797	267,100	285,797
Agricultural	98,000	70,000	74,200	98,000	103,880	0	0	70,000	74,200
Industrial	60,200	75,900	76,507	75,900	76,507	75,900	76,507	75,900	76,507
Riparian	3,700	3,700	3,922	3,700	3,922	3,700	3,922	3,700	3,922
minus incidental recharge	-82,300	-33,300	-34,802	-37,780	-39,411	-15,510	-16,179	-33,300	-34,802
minus remediation water	0	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500	-6,500
minus cut to the aquifer	0	-46,000	-46,000	-46,000	-46,000	-46,000	-46,000	-46,000	-46,000
total return flow	-82,300	-85,800	-87,302	-90,280	-91,911	-68,010	-68,679	-85,800	-87,302
Net Water Consumption	235,100	330,900	353,124	354,420	378,195	278,690	297,547	330,900	353,124
Percentage of 2025 baseline amount	**71**	**100**	**107**	**107**	**114**	**84**	**90**	**100**	**107**

Groundwater Impact	Baseline 1995	TMP 2025 Baseline	TMP 2025 1 yr Drought	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag + 1 yr Drought	2025 No Agriculture	2025 No Ag + 1 yr Drought	1995 Supply 2025 Demand	95 Sup, '25 Dem 1 yr Drought
Renewable Water Supply	71,200	281,400	227,635	281,400	227,635	281,400	227,635	71,200	17,435
Net Water Consumption	235,100	330,900	353,124	354,420	378,195	278,690	297,547	330,900	353,124
Groundwater Impact	-163,900	-49,500	-125,490	-73,020	-150,561	2,710	-69,913	-259,700	-335,690
Percentage of supply non-renewable	**70**	**15**	**36**	**21**	**40**	**-1**	**23**	**78**	**95**

Appendix 2.2: Tucson AMA 1995 and 2025 - Five-Year Scenarios

Renewable Water Supply	Baseline 1995 x 5	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought	TMP 2025 5 yr Drought without CAP	2025 w/ 1995 Agriculture x 5	2025 w/ 1995 Ag 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought without CAP	2025 No Agriculture x 5	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought without CAP	Baseline 1995 x 5	1995 Baseline 5 yr Drought
Recharge + Inflow - Outflow	304,000	304,000	173,128	173,128	304,000	173,128	173,128	304,000	173,128	173,128	304,000	173,128
CAP	500	889,500	889,500	0	889,500	889,500	0	889,500	889,500	0	500	500
Effluent	51,500	213,500	213,500	213,500	213,500	213,500	213,500	213,500	213,500	213,500	51,500	51,500
Total Renewable Water Supply	356,000	1,407,000	1,276,128	386,628	1,407,000	1,276,128	386,628	1,407,000	1,276,128	386,628	356,000	225,128
Percentage of 2025 baseline supply	**25**	**100**	**91**	**27**	**100**	**91**	**27**	**100**	**91**	**27**	**25**	**63**

Water Demand	Baseline 1995 x 5	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought	TMP 2025 5 yr Drought without CAP	2025 w/ 1995 Agriculture x 5	2025 w/ 1995 Ag 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought without CAP	2025 No Agriculture x 5	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought without CAP	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought
Municipal	777,500	1,335,500	1,428,985	1,428,985	1,335,500	1,428,985	1,428,985	1,335,500	1,428,985	1,428,985	1,335,500	1,428,985
Agricultural	490,000	350,000	371,000	371,000	490,000	519,400	519,400	0	0	0	350,000	371,000
Industrial	301,000	379,500	382,536	382,536	379,500	382,536	382,536	379,500	382,536	382,536	379,500	382,536
Riparian	18,500	18,500	19,610	19,610	18,500	19,610	19,610	18,500	19,610	19,610	18,500	19,610
minus incidental recharge	-411,500	-166,500	-174,010	-174,010	-189,400	-197,575	-197,575	-75,500	-77,550	-77,550	-166,500	-174,010
minus remediation water	0	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500	-32,500
minus cut to the aquifer	0	-230,000	-230,000	-230,000	-230,000	-230,000	-230,000	-230,000	-230,000	-230,000	-230,000	-230,000
total return flow	-411,500	-429,000	-436,510	-436,510	-451,900	-460,075	-460,075	-338,000	-340,050	-340,050	-429,000	-436,510
Net Water Consumption	1,175,500	1,654,500	1,765,621	1,765,621	1,771,600	1,890,456	1,890,456	1,395,500	1,491,081	1,491,081	1,654,500	1,765,621
Percentage of 2025 baseline demand	**71**	**100**	**107**	**107**	**107**	**114**	**114**	**84**	**90**	**90**	**100**	**107**

Groundwater Impact	Baseline 1995 x 5	TMP 2025 Baseline x 5	TMP 2025 5 yr Drought	TMP 2025 5 yr Drought without CAP	2025 w/ 1995 Agriculture x 5	2025 w/ 1995 Ag 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought without CAP	2025 No Agriculture x 5	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought without CAP	1995 Supply 2025 Demand	1995 Supply 2025 Demand 5 yr Drought
Renewable Water Supply	356,000	1,407,000	1,276,128	386,628	1,407,000	1,276,128	386,628	1,407,000	1,276,128	386,628	356,000	225,128
Net Water Consumption	1,175,500	1,654,500	1,765,621	1,765,621	1,771,600	1,890,456	1,890,456	1,395,500	1,491,081	1,491,081	1,654,500	1,765,621
Groundwater Impact	-819,500	-247,500	-489,493	-1,378,993	-364,600	-614,328	-1,503,828	11,500	-214,953	-1,104,453	-1,298,500	-1,540,493
% demand met by non-renewable sup	**70**	**15**	**28**	**78**	**21**	**32**	**80**	**-1**	**14**	**74**	**78**	**87**

Appendix 2.3: Tucson AMA 1995 and 2025 - Ten-Year Scenarios

Renewable Water Supply	Baseline 1995 x 10	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought without CAP	2025 w/ 1995 Agriculture x 10	2025 w/ 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought without CAP	2025 No Agriculture x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought without CAP	Baseline 1995 x 10	1995 Baseline 10 yr Drought
Recharge + Inflow - Outflow	608,000	608,000	449,555	449,555	608,000	449,555	449,555	608,000	449,555	449,555	608,000	449,555
CAP	1,000	1,779,000	1,779,000	0	1,779,000	1,779,000	0	1,779,000	1,779,000	0	1,000	1,000
Effluent	103,000	427,000	427,000	427,000	427,000	427,000	427,000	427,000	427,000	427,000	103,000	103,000
Total Renewable Water Supply	712,000	2,814,000	2,655,555	876,555	2,814,000	2,655,555	876,555	2,814,000	2,655,555	876,555	712,000	553,555
Percentage of 2025 baseline supply	**25**	**100**	**94**	**31**	**100**	**94**	**31**	**100**	**94**	**31**	**129**	**78**

Water Demand	Baseline 1995 x 10	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought without CAP	2025 w/ 1995 Agriculture x 10	2025 w/ 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought without CAP	2025 No Agriculture x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought without CAP	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought
Municipal	1,555,000	2,671,000	2,857,970	2,857,970	2,671,000	2,857,970	2,857,970	2,671,000	2,857,970	2,857,970	2,671,000	2,857,970
Agricultural	980,000	700,000	742,000	700,000	980,000	1,038,800	1,038,800	0	0	0	700,000	742,000
Industrial	602,000	759,000	765,072	759,000	759,000	765,072	765,072	759,000	765,072	765,072	759,000	765,072
Riparian	37,000	37,000	39,220	37,000	37,000	39,220	39,220	37,000	39,220	39,220	37,000	39,220
minus incidental recharge	-823,000	-333,000	-348,020	-348,020	-377,800	-394,106	-394,106	-151,000	-155,100	-155,100	-333,000	-348,020
minus remediation water	0	-65,000	-65,000	-65,000	-65,000	-65,000	-65,000	-65,000	-65,000	-65,000	-65,000	-65,000
minus cut to the aquifer	0	-460,000	-460,000	-460,000	-460,000	-460,000	-460,000	-460,000	-460,000	-460,000	-460,000	-460,000
total return flow	-823,000	-858,000	-873,020	-873,020	-902,800	-919,106	-919,106	-676,000	-680,100	-680,100	-858,000	-873,020
Net Water Consumption	2,351,000	3,309,000	3,531,242	3,480,950	3,544,200	3,781,956	3,781,956	2,791,000	2,982,162	2,982,162	3,309,000	3,531,242
Percentage of 2025 baseline demand	**71**	**100**	**107**	**105**	**107**	**114**	**114**	**84**	**90**	**84**	**100**	**107**

Groundwater Impact

	Baseline 1995 x 10	TMP 2025 Baseline x 10	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought without CAP	2025 w/ 1995 Agriculture x 10	2025 w/ 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought without CAP	2025 No Agriculture x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought without CAP	1995 Supply 2025 Demand	1995 Supply 2025 Demand 10 yr Drought
Renewable Water Supply	712,000	2,814,000	2,655,555	876,555	2,814,000	2,655,555	876,555	2,814,000	2,655,555	876,555	712,000	553,555
Net Water Consumption	2,351,000	3,309,000	3,531,242	3,480,950	3,544,200	3,781,956	2,791,000	2,791,000	2,982,162	2,982,162	3,309,000	3,531,242
Groundwater Impact	-1,639,000	-495,000	-875,687	-2,604,395	-730,200	-1,126,401	-1,914,445	23,000	-326,607	-2,105,607	-2,597,000	-2,977,687
% demand met by non-renewable sup	**70**	**15**	**25**	**75**	**21**	**30**	**69**	**-1**	**11**	**71**	**78**	**84**

Appendix 3: Santa Cruz AMA

3.1 One-Year Scenarios

3.2 Five-Year Scenarios

3.3 Ten-Year Scenarios

Appendix 3.1: Santa Cruz AMA 1995 and 2025 - One-Year Scenarios

Renewable Water Supply	Baseline 1995	TMP 2025 Baseline	TMP 2025 + 1 yr Drought	TMP 2025 1 yr Drought 1/3 NIWWTP	TMP 2025 w/ 1995 Agriculture	TMP 2025 w/ 1995 Ag + 1 yr Drought	2025 w/ 1995 Ag + 1 yr Drought 1/3 NIWWTP	2025 No Agriculture	2025 No Ag + 1 yr Drought	2025 No Ag + 1 yr Drought 1/3 NIWWTP	Baseline 1995	1995 Baseline 1 yr Drought
Recharge												
Main Channel & Major Tributary	14,283	14,283	8,141	8,141	14,283	8,141	8,141	14,283	8,141	8,141	14,283	7,713
Total Effluent	16,188	19,549	19,549	5,949	19,549	19,549	5,949	19,549	19,549	5,949	16,188	16,188
Mountain Front & Minor Tributary	11,400	11,400	6,156	6,156	11,400	6,156	6,156	11,400	6,156	6,156	11,400	6,156
Underflow												
Santa Cruz River @ Mexico/US Bdr.	300	300	162	162	300	162	162	300	162	162	300	162
West of Nogales Mexico/US Border	700	700	378	378	700	378	378	700	378	378	700	378
Total Inflows	42,871	46,232	34,386	20,786	46,232	34,386	20,786	46,232	34,386	20,786	42,871	30,597
minus underflow leaving SCAMA	-8,700	-8,700	-4,698	-4,698	-8,700	-4,698	-4,698	-8,700	-4,698	-4,698	-8,700	-4,698
Potentially available renewable supply	34,171	37,532	29,688	16,088	37,532	29,688	16,088	37,532	29,688	16,088	34,171	25,899
Percentage of 2025 baseline available	**91**	**100**	**79**	**43**	**100**	**79**	**43**	**100**	**79**	**43**	**91**	**69**

Water Demand	Baseline 1995	TMP 2025 Baseline	TMP 2025 + 1 yr Drought	TMP 2025 1 yr Drought 1/3 NIWWTP	TMP 2025 w/ 1995 Agriculture	TMP 2025 w/ 1995 Ag + 1 yr Drought	2025 w/ 1995 Ag + 1 yr Drought 1/3 NIWWTP	2025 No Agriculture	2025 No Ag + 1 yr Drought	2025 No Ag + 1 yr Drought 1/3 NIWWTP	TMP 2025 Baseline	TMP 2025 + 1 yr Drought
Municipal	6,300	11,400	11,708	11,708	11,400	11,708	11,708	11,400	11,708	11,708	11,400	11,708
Agricultural	11,300	10,300	10,959	10,959	11,300	12,023	12,023	-	-	0	10,300	10,959
minus 36% incidental recharge	-4,068	-3,708	-3,945	-3,945	-4,068	-4,328	-4,328	0	0	0	-3,708	-3,945
Industrial	1,300	2,400	2,496	2,496	2,400	2,496	2,496	2,400	2,496	2496	2,400	2,496
minus 5% incidental recharge	-65	-120	-125	-125	-120	-125	-125	-120	-125	-124.8	-120	-125
Exempt Well Demand	500	1,000	1,080	1,080	1,000	1,080	1,080	1,000	1,080	1,080	1,000	1,080
Riparian	25,800	25,800	27,451	27,451	25,800	27,451	27,451	25,800	27,451	27,451	25,800	27,451
total return flow	-4,133	-3,828	-4,070	-4,070	-4,188	-4,453	-4,453	-120	-125	-125	-3,828	-4,070
Net Water Consumption	41,067	47,072	49,624	49,624	47,712	50,305	50,305	40,480	42,610	42,610	47,072	49,624
% of 2025 baseline amount	**87**	**100**	**105**	**105**	**101**	**107**	**107**	**86**	**91**	**91**	**100**	**105**

Groundwater Impact	Baseline 1995	TMP 2025 Baseline	TMP 2025 + 1 yr Drought	TMP 2025 1 yr Drought 1/3 NIWWTP	2025 w/ 1995 Agriculture	2025 w/ 1995 Ag +1yr Drought	2025 w/ 1995 Ag + 1 yr Drought 1/3 NIWWTP	2025 No Agriculture	2025 No Ag +1yr Drought	2025 No Ag + 1yr Drought 1/3 NIWWTP	1995 Sup 2025 Dem	1995 Supply 2025 Demand 1yr Drought
Renewable Water Supply	34,171	37,532	29,688	16,088	37,532	29,688	16,088	37,532	29,688	16,088	34,171	25,899
Net Water Consumption	41,067	47,072	49,624	49,624	47,712	50,305	50,305	40,480	42,610	42,610	47,072	49,624
Groundwater Impact	-6,896	-9,540	-19,936	-33,536	-10,180	-20,617	-34,217	-2,948	-12,922	-26,522	-12,901	-23,725
% demand met by non-renewable supp	**17**	**20**	**40**	**68**	**21**	**41**	**68**	**7**	**30**	**62**	**27**	**48**

Appendix 3.2: Santa Cruz AMA 1995 and 2025 - Five-Year Scenarios

Renewable Water Supply	1995 Baseline x 5 yrs	TMP 2025 Baseline x 5 yrs	TMP 2025 x 5 5 yr Drought	TMP 2025 x 5 5 yr Drought 1/3 NIWWTP	TMP 2025 x 5 w/ 1995 Agriculture	TMP 2025 x 5 1995 Ag + 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought 1/3 NIWWTP	TMP 2025 No Ag x 5 yrs	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought 1/3 NIWWTP	1995 Baseline x 5 yrs	1995 Baseline x 5 yrs
Recharge:												
Main Channel & Major Tributary	71,415	71,415	50,705	50,705	71,415	50,705	50,705	71,415	50,705	50,705	71,415	50,705
Main Channel Effluent	80,940	97,745	97,745	29,745	97,745	97,745	29,745	97,745	97,745	29,745	80,940	80,940
Mountain Front & Minor Tributary	57,000	57,000	40,470	40,470	57,000	40,470	40,470	57,000	40,470	40,470	57,000	40,470
Underflow		-										
Santa Cruz River @ Mexico/US Bdr.	1,500	1,500	1,065	1,065	1,500	1,065	1,065	1,500	1,065	1,065	1,500	1,065
West of Nogales Mexico/US Border	3,500	3,500	2,485	2,485	3,500	2,485	2,485	3,500	2,485	2,485	3,500	2,485
Total Inflows	214,355	231,160	192,470	124,470	231,160	192,470	124,470	231,160	192,470	124,470	214,355	175,665
minus underflow leaving SCAMA	-43,500	-43,500	-30,885	-30,885	-43,500	-30,885	-30,885	-43,500	-30,885	-30,885	-43,500	-30,885
Potentially available renewable supply	170,855	187,660	161,585	93,585	187,660	161,585	93,585	187,660	161,585	93,585	170,855	144,780
Percentage of 2025 baseline available	**91**	**100**	**86**	**50**	**100**	**86**	**50**	**100**	**86**	**50**	**91**	**77**

Water Demand	1995 Baseline x 5 yrs	TMP 2025 Baseline x 5 yrs	TMP 2025 x 5 5 yr Drought	TMP 2025 x 5 5 yr Drought 1/3 NIWWTP	TMP 2025 x 5 w/ 1995 Agriculture	TMP 2025 x 5 1995 Ag + 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought 1/3 NIWWTP	TMP 2025 No Ag x 5 yrs	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought 1/3 NIWWTP	TMP 2025 Baseline x 5 yrs	TMP 2025 5 yr Drought
Municipal	31,500	57,000	58,539	58,539	57,000	58,539	58,539	57,000	58,539	58,539	57,000	58,539
Agricultural	56,500	51,500	54,796	54,796	56,500	60,116	60,116	0	0	0	51,500	54,796
minus 36% incidental recharge	-20,340	-18,540	-19,727	-19,727	-20,340	-21,642	-21,642	0	0	0	-18,540	-19,727
Industrial	6,500	12,000	12,480	12,480	12,000	12,480	12,480	12,000	12,480	12,480	12,000	12,480
minus 5% incidental recharge	-325	-600	-624	-624	-600	-624	-624	-600	-624	-624	-600	-624
Exempt Well Demand	2,500	5,000	5,400	5,400	5,000	5,400	5,400	5,000	5,400	5,400	5,000	5,400
Riparian	129,000	129,000	137,256	137,256	129,000	137,256	137,256	129,000	137,256	137,256	129,000	137,256
total return flow	-20,665	-19,140	-20,351	-20,351	-20,940	-22,266	-22,266	-600	-624	-624	-19,140	-20,351
Net Water Consumption	205,335	235,360	248,120	248,120	238,560	251,525	251,525	202,400	213,051	213,051	235,360	248,120
Percentage of 2025 baseline amount	**87**	**100**	**105**	**105**	**101**	**107**	**107**	**86**	**91**	**91**	**100**	**105**

Groundwater Impact	1995 Baseline x 5 yrs	TMP 2025 Baseline x 5 yrs	TMP 2025 x 5 5 yr Drought	TMP 2025 x 5 5 yr Drought 1/3 NIWWTP	TMP 2025 x 5 w/ 1995 Agriculture	TMP 2025 x 5 1995 Ag + 5 yr Drought	2025 w/ 1995 Ag 5 yr Drought 1/3 NIWWTP	TMP 2025 No Ag x 5 yrs	2025 No Ag 5 yr Drought	2025 No Ag 5 yr Drought 1/3 NIWWTP	1995 Sup 2025 Dem 5 yrs	1995 Supply 2025 Demand 5 yr Drought
Renewable Water Supply	170,855	187,660	161,585	93,585	187,660	161,585	93,585	187,660	161,585	93,585	170,855	144,780
Net Water Consumption	205,335	235,360	248,120	248,120	238,560	251,525	251,525	202,400	213,051	213,051	235,360	248,120
Groundwater Impact	-34,480	-47,700	-86,536	-154,536	-50,900	-89,941	-157,941	-14,740	-51,466	-119,466	-64,505	-103,341
% demand met by non-renewable supp	**17**	**20**	**35**	**62**	**21**	**36**	**63**	**7**	**24**	**56**	**27**	**42**

Appendix 3.3: Santa Cruz AMA 1995 and 2025 - Ten-Year Scenarios

Renewable Water Supply	1995 Baseline x 10 yrs	TMP 2025 Baseline x 10 yrs	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought 1/3 NIWWTP	TMP 2025 w/ 1995 Ag	TMP 2025 x 5 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought 1/3 NIWWTP	TMP 2025 No Ag x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought 1/3 NIWWTP	1995 Baseline x 10 yrs	1995 10 yr Drought
Recharge:												
Main Channel & Major Tributary	142,830	142,830	114,264	114,264	142,830	114,264	114,264	142,830	114,264	114,264	142,830	114,264
Main Channel Effluent	161,880	195,490	195,490	59,490	195,490	195,490	59,490	195,490	195,490	59,490	161,880	161,880
Mountain Front & Minor Tributary	114,000	114,000	91,200	91,200	114,000	91,200	91,200	114,000	91,200	91,200	114,000	91,200
Underflow		-										
Santa Cruz River @ Mexico/US Bdr.	3,000	3,000	2,400	2,400	3,000	2,400	2,400	3,000	2,400	2,400	3,000	2,400
West of Nogales Mexico/US Border	7,000	7,000	5,600	5,600	7,000	5,600	5,600	7,000	5,600	5,600	7,000	5,600
Total Inflows	428,710	462,320	408,954	272,954	462,320	408,954	272,954	462,320	408,954	272,954	428,710	375,344
minus underflow leaving SCAMA	-87,000	-87,000	-69,600	-69,600	-87,000	-69,600	-69,600	-87,000	-69,600	-69,600	-87,000	-69,600
Potentially available renewable supply	341,710	375,320	339,354	203,354	375,320	339,354	203,354	375,320	339,354	203,354	341,710	305,744
Percentage of 2025 baseline available	**91**	**100**	**90**	**54**	**100**	**90**	**54**	**100**	**90**	**54**	**91**	**81**

Water Demand	1995 Baseline x 10 yrs	TMP 2025 Baseline x 10 yrs	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought 1/3 NIWWTP	TMP 2025 x 5 w/ 1995 Agriculture	TMP 2025 x 5 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought 1/3 NIWWTP	TMP 2025 No Ag x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought 1/3 NIWWTP	TMP 2025 Baseline x 10 yrs	TMP 2025 10 yr Drought
Municipal	63,000	114,000	117,078	117,078	114,000	117,078	117,078	114,000	117,078	117,078	114,000	117,078
Agricultural	113,000	103,000	109,592	109,592	113,000	120,232	120,232	0	0	0	103,000	109,592
minus 36% incidental recharge	-40,680	-37,080	-39,453	-39,453	-40,680	-43,284	-43,284	0	0	0	-37,080	-39,453
Industrial	13,000	24,000	24,960	24,960	24,000	24,960	24,960	24,000	24,960	24,960	24,000	24,960
minus 5% incidental recharge	-650	-1200	-1248	-1,248	-1200	-1248	-1,248	-1,200	-1,248	-1,248	-1200	-1248
Exempt Well Demand	5,000	10,000	10,800	10,800	10,000	10,800	10,800	10,000	10,800	10,800	10,000	10,800
Riparian	258,000	258,000	274,512	274,512	258,000	274,512	274,512	258,000	274,512	274,512	258,000	274,512
total return flow	-41,330	-38,280	-40,701	-40,701	-41,880	-44,532	-44,532	-1,200	-1,248	-1,248	-38,280	-40,701
Net Water Consumption	410,670	470,720	496,241	496,241	477,120	503,050	503,050	404,800	426,102	426,102	470,720	496,241
Percentage of 2025 baseline amount	**87**	**100**	**105**	**105**	**101**	**107**	**107**	**86**	**91**	**91**	**100**	**105**

Groundwater Impact	1995 Baseline x 10 yrs	TMP 2025 Baseline x 10 yrs	TMP 2025 10 yr Drought	TMP 2025 10 yr Drought 1/3 NIWWTP	TMP 2025 x 10 w/ 1995 Agriculture	TMP 2025 x 10 1995 Ag 10 yr Drought	2025 w/ 1995 Ag 10 yr Drought 1/3 NIWWTP	TMP 2025 No Ag x 10	2025 No Ag 10 yr Drought	2025 No Ag 10 yr Drought 1/3 NIWWTP	1995 Sup 2025 Dem x 10 yrs	1995 Sup 2025 Dem 10 yr Drought
Water Supply	341,710	375,320	339,354	203,354	375,320	339,354	203,354	375,320	339,354	203,354	341,710	305,744
Water Demand	410,670	470,720	496,241	496,241	477,120	503,050	503,050	404,800	426,102	426,102	470,720	496,241
Groundwater Impact	-68,960	-95,400	-156,887	-292,887	-101,800	-163,696	-299,696	-29,480	-86,748	-222,748	-129,010	-190,497
% demand met by non-renewable suppl	**17**	**20**	**32**	**59**	**21**	**33**	**60**	**7**	**20**	**52**	**27**	**38**

Appendix 4: Benson Subwatershed

4.1. One-Year Scenarios

4.2. Five-Year Scenarios

4.3. Ten-Year Scenarios

Appendix 4.1: Benson Subwatershed 1990 and 2025 - One-Year Scenarios

	Baseline 1990	Pop Proj DES Baseline (6)	Pop Proj High Baseline (7)	Pop. DES + Hist. Min. Precip (8)	Pop High + Hist. Min. Precip	Pop Proj DES No AG (9)	Pop Proj High No AG	Pop. DES + Hist Min Precip No AG	Pop High + Hist Min Precip No AG
Population	**9,870**	**14,176**	**18,861**	**14,176**	**18,861**	**14,176**	**18,861**	**14,176**	**18,861**
WATER SUPPLY									
Total Surface Water (Inflow-Outflow)	10,906	10,906	10,906	1,264	1,264	10,906	10,906	1,264	1,264
Natural Groundwater Recharge	11,760	11,760	11,760	1,363	1,363	11,760	11,760	1,363	1,363
Groundwater Outflow	-120	-120	-120	-120	-120	-120	-120	-120	-120
Total Groundwater	11,640	11,640	11,640	1,243	1,243	11,640	11,640	1,243	1,243
Effluent	600	863	1,147	863	1,147	863	1,147	863	1,147
Total Water Supply	**23,146**	**23,409**	**23,693**	**3,370**	**3,654**	**(10) 23,409**	**(10) 23,693**	**(11) 3,370**	**(11) 3,654**
Percentage of Baseline	100	100	100	14	15	100	100	14	15
WATER DEMAND									
Municipal Surface Water	0	0	0	0	0	0	0	0	0
Municipal Groundwater	1,425	2,047	2,723	2,108	2,805	2,047	2,723	2,108	2,805
Municipal Effluent	0	0	0	0	0	0	0	0	0
Total Municipal (1)	1,425	2,047	2,723	2,108	2,805	2,047	2,723	2,108	2,805
Agricultural Surface Water	5,706	5,706	5,706	0	0	0	0	0	0
Agricultural Groundwater	15,263	15,263	15,263	27,613	27,613	0	0	0	0
Agricultural Effluent	600	600	600	600	600	0	0	0	0
Total Agricultural (2)	21,569	21,569	21,569	28,213	28,213	0	0	0	0
Industrial Surface Water	0	0	0	0	0	0	0	0	0
Industrial Groundwater	542	542	542	542	542	542	542	542	542
Industrial Effluent	0	0	0	0	0	0	0	0	0
Total Industrial	542	542	542	542	542	542	542	542	542
Riparian Vegeation Surface Water	4,430	4,430	4,430	494	494	4,430	4,430	494	494
Riparian Vegeation Groundwater	13,260	13,260	13,260	15,102	15,102	13,260	13,260	15,102	15,102
Total Riparian Vegetation (3)	17,690	17,690	17,690	15,596	15,596	17,690	17,690	15,596	15,596
Other Surface Water	770	770	770	770	770	770	770	770	770
Other Groundwater	1,499	1,499	1,499	1,499	1,499	1,499	1,499	1,499	1,499
Other Effluent	0	263	547	263	547	263	547	263	547
Total Other (4)	2,269	2,532	2,816	2,532	2,816	2,532	2,816	2,532	2,816
Total Demand	**43,495**	**44,380**	**45,340**	**48,991**	**49,972**	**22,811**	**23,771**	**20,778**	**22,253**
Incidental Groundwater Recharge	-7,675	-7,675	-7,675	-7,675	-7,675	-558	-558	-558	-558
Total Net Consumption	**35,820**	**36,705**	**37,665**	**41,316**	**42,297**	**22,253**	**23,213**	**20,220**	**21,695**
Total Surface Water	10,906	10,906	10,906	1,264	1,264	5,200	5,200	1,264	1,264
Total Groundwater	31,989	32,611	33,287	46,864	47,561	17,348	18,024	19,251	20,442
Total Effluent	600	863	1,147	863	1,147	263	547	263	547
Total Demand	**43,495**	**44,380**	**45,340**	**48,991**	**49,972**	**22,811**	**23,771**	**20,778**	**22,253**
Percentage Change	0	0	0	10	10	-49	-48	-53	-51
Total Surplus/Deficit (5)	**-12,674**	**-13,296**	**-13,972**	**-37,964**	**-38,661**	**-5,150**	**-5,826**	**-17,450**	**-18,641**
Demand Met by GW Mining	**12,674**	**13,296**	**13,972**	**37,964**	**38,661**	**5,150**	**5,826**	**17,450**	**18,641**
Percentage met by Mined GW	29	30	31	78	78	22	24	84	84

Footnotes to Appendix 4.1: Benson Subwatershed - One-Year Scenarios

(1) Effects of a dry period on municipal use: Benson has a mean per-capita water use of 168gpcd (1990), with approximately 128 gpcd indoor water use over the entire year and 60-70 gpcd outdoor water use between April and September. Based on a 17-35% chance of rain during the monsoon season for Benson (WRCC) and Gary Woodard's numbers for increases in gpcd during hot and dry years (11.4gpcd), an average of additional 5gpcd of annual water demand was calculated for drought periods.

(2) Effects of a dry period on agricultural demands: based on ADWR estimates (HSR 1991), average total water requirements for crops amount to 3.56 af/acre (including 2.78 af/acre crop consumptive use requirements and 0.78 af/acre average effective precipitation). It can be assumed that more irrigation water has to be withdrawn when overall precipitation decreases. Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation, and the difference is accounted for through increased/decreased crop consumptive use requirement. Irrigated acreage amounts to 5,330 acres.

(3) Effects of a dry period on riparian vegetation: based on ADWR estimated (HSR 1991), riparian consumptive use requirements amount to 3.8 af/acre (including 2.86 af/acre riparian consumptive use requirements and 0.42 af/acre average effective precipitation). The extent of riparian vegetation amounts to 6,180 acres (adopted after HSR 1991). Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation. If less precipitation than 0.42 af/acre is available, additional water has to be withdrawn from the aquifer. However, if more water than the threshold value of 0.42 af/acre was available, the additional water remained unconsumed. Moreover, it is assumed that riparian vegetation relies to 25% on surface water

(4) Other water demands include channel evaporation, reservoirs, stockponds, and domestic wells.

(5) Groundwater impact: total groundwater supply minus total groundwater demand plus incidental groundwater recharge. Negative numbers indicate groundwater overdraft.

(6) Pop Proj DES: based on the 2025 projection projection provided by DES

(7) Pop Proj High: 2025 population projections extrapolated from estimated 1998 DES numbers. They tend to be higher than the actual DES projections for 2025.

(8) Hist. Min. Precip. Historic minimum winter precipitation for the South East Climate Division: 0.6 inches (1904)

(9) NoAG: hypothetical scenario assuming the elimination of all irrigated agriculture from the subwatershed

(10) Total supply includes 600af of unused effluent and 5,706af of unused surface water

(11) Total supply includes 600af of unused effluent

Appendix 4.2: Benson Subwatershed 1990 and 2025 - Five-Year Scenarios

	Baseline 1990*5yr	Pop DES* 5 years Baseline (6)	Pop High* 5 years Baseline (7)	Pop. DES + 5yr Hist Drought (8)	Pop High + 5yr Hist Drought	Pop Proj DES No AG*5yr (9)	Pop Proj High No AG*5yr	Pop. DES + 5yr Hist Drought No AG	Pop High + 5yr Hist Drought No AG
Population	**9,870**	**14,176**	**18,861**	**14,176**	**18,861**	**14,176**	**18,861**	**14,176**	**18,861**
WATER SUPPLY									
Total Surface Water (Inflow-Outflow)	54,530	54,530	54,530	31,038	31,038	54,530	54,530	31,038	31,038
Natural Groundwater Recharge	58,800	58,800	58,800	33,469	33,469	58,800	58,800	33,469	33,469
Groundwater Outflow	-600	-660	-600	-600	-600	-660	-600	-600	-600
Total Groundwater	58,200	58,200	58,200	32,869	32,869	58,200	58,200	32,869	32,869
Effluent	3,000	4,315	5,735	4,315	5,735	4,315	5,735	4,315	5,735
Total Water Supply	**115,730**	**117,045**	**118,465**	**68,222**	**69,642**	**(10) 117,045**	**(10) 118,465**	**(11) 68,222**	**(11) 69,642**
Percentage of Baseline	100	100	100	58	58	100	100	58	58
WATER DEMAND									
Municipal Surface Water	0	0	0	0	0	0	0	0	0
Municipal Groundwater	7,125	10,235	13,615	10,540	14,025	10,235	13,615	10,540	14,025
Municipal Effluent	0	0	0	0	0	0	0	0	0
Total Municipal (1)	7,125	10,235	13,615	10,540	14,025	10,235	13,615	10,540	14,025
Agricultural Surface Water	28,530	28,530	28,530	13,594	13,594	0	0	0	0
Agricultural Groundwater	76,315	76,315	76,315	111,641	111,641	0	0	0	0
Agricultural Effluent	3,000	3,000	3,000	3,000	3,000	0	0	0	0
Total Agricultural (2)	107,845	107,845	107,845	128,235	128,235	0	0	0	0
Industrial Surface Water	0	0	0	0	0	0	0	0	0
Industrial Groundwater	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710
Industrial Effluent	0	0	0	0	0	0	0	0	0
Total Industrial	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710
Riparian Vegeation Surface Water	22,150	22,150	22,150	13,594	13,594	22,150	22,150	22,150	22,150
Riparian Vegeation Groundwater	66,300	66,300	66,300	74,856	74,856	66,300	66,300	74,856	74,856
Total Riparian Vegetation (3)	88,450	88,450	88,450	88,450	88,450	88,450	88,450	97,006	97,006
Other Surface Water	3,850	3,850	3,850	3,850	3,850	3,850	3,850	3,850	3,850
Other Groundwater	7,495	7,495	7,495	7,495	7,495	7,495	7,495	7,495	7,495
Other Effluent	0	1,315	2,735	1,315	2,735	1,315	2,735	1,315	2,735
Total Other (4)	11,345	12,660	14,080	12,660	14,080	12,660	14,080	12,660	14,080
Total Demand	**217,475**	**221,900**	**226,700**	**242,595**	**247,499**	**114,055**	**118,855**	**122,916**	**127,821**
Incidental Groundwater Recharge	-38,375	-38,375	-38,375	-38,375	-38,375	-2,790	-2,790	-2,790	-2,790
Total Net Consumption	**179,100**	**183,525**	**188,325**	**204,220**	**209,124**	**111,265**	**116,065**	**120,126**	**125,031**
Total Surface Water	54,530	54,530	54,530	(12) 31,038	(12) 31,038	26,000	26,000	26,000	26,000
Total Groundwater	159,945	163,055	166,435	207,242	210,726	86,740	90,120	95,601	99,086
Total Effluent	3,000	4,315	5,735	4,315	5,735	1,315	2,735	1,315	2,735
Total Demand	**217,475**	**221,900**	**226,700**	**211,557**	**216,461**	**114,055**	**118,855**	**122,916**	**127,821**
Percentage Change	0	0	0	9	9	-48	-48	-45	-44
Total Surplus/Deficit (5)	**-63,370**	**-66,480**	**-69,860**	**-135,998**	**-139,482**	**-25,750**	**-29,130**	**-59,942**	**-63,427**
Demand Met by GW Mining	**63,370**	**66,480**	**69,860**	**135,998**	**139,482**	**25,750**	**29,130**	**59,942**	**63,427**
Percentage met by Mined GW	29	30	31	56	56	23	24	49	50

Footnotes to Appendix 4.2: Benson Subwatershed - Five-Year Scenarios

(1) Effects of a dry period on municipal use: Benson has a mean per-capita water use of 168gpcd (1990), with approximately 128 gpcd indoor water use over the entire year and 60-70 gpcd outdoor water use between April and September. Based on a 17-35% chance of rain during the monsoon season for Benson (WRCC) and Gary Woodard's numbers for increases in gpcd during hot and dry years (11.4gpcd), an average of additional 5gpcd of annual water demand was calculated for drought periods.

(2) Effects of a dry period on agricultural demands: based on ADWR estimates (HSR 1991), average total water requirements for crops amount to 3.56 af/acre (including 2.78 af/acre crop consumptive use requirements and 0.78 af/acre average effective precipitation). It can be assumed that more irrigation water has to be withdrawn when overall precipitation decreases. Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation, and the difference is accounted for through increased/decreased crop consumptive use requirement. Irrigated acreage amounts to 5,330 acres.

(3) Effects of a dry period on riparian vegetation: based on ADWR estimated (HSR 1991), riparian consumptive use requirements amount to 3.8 af/acre (including 2.86 af/acre riparian consumptive use requirements and 0.42 af/acre average effective precipitation). The extent of riparian vegetation amounts to 6,180 acres (adopted after HSR 1991). Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation. If less precipitation than 0.42 af/acre is available, additional water has to be withdrawn from the aquifer. However, if more water than the threshold value of 0.42 af/acre was available, the additional water remained unconsumed. Moreover, it is assumed that riparian vegetation relies to 25 % on surface water.

(4) Other water demands include channel evaporation, reservoirs, stockponds, and domestic wells.

(5) Groundwater impact: total groundwater supply minus total groundwater demand plus incidental groundwater recharge. Negative numbers indicate groundwater overdraft.

(6) Pop Proj DES: based on the 2025 projection projection provided by DES

(7) Pop Proj High: 2025 population projections extrapolated from estimated 1998 DES numbers. They tend to be higher than the actual DES projections for 2025.

(8) Hist. Min. Precip. Historic five-year minimum winter precipitation for the South East Climate Division: 14.73 inches (1900-1904), winter mean: 2.95 inches

(9) NoAG: hypothetical scenario assuming the elimination of all irrigated agriculture from the subwatershed

(10) Total supply includes 3,000af of unused effluent and 28,530af of unused surface water

(11) Total supply includes 3,000af of unused effluent and 5,038af of unused surface water

(12) Available surface water is split between channel evaporation (other SW) and the remaining amount equally between riparian vegetation and agriculture

Appendix 4.3: Benson Subwatershed 1990 and 2025 - Ten-Year Scenarios

	Baseline 1990*10yr	Pop DES* 10 years Baseline (6)	Pop High* 10 years Baseline (7)	Pop. High+ 10yr Hist Drought (8)	Pop. DES + 10yr Hist Drought	Pop Proj DES NoAG *10yr (9)	Pop Proj High No AG*10yr	Pop. DES + 10yr Hist Drought No AG	Pop High + 10yr Hist Drought No AG
Population	**9,870**	**14,176**	**18,861**	**14,176**	**18,861**	**14,176**	**18,861**	**14,176**	**18,861**
WATER SUPPLY									
Total Surface Water (Inflow-Outflow)	109,060	109,060	109,060	80,421	80,421	109,060	109,060	80,421	80,421
Natural Groundwater Recharge	117,600	117,600	117,600	86,953	86,953	117,600	117,600	86,953	86,953
Groundwater Outflow	-1,200	-1,200	-1,200	-1,200	1,200	-1,200	-1,200	-1,200	1,200
Total Groundwater	116,400	116,400	116,400	85,753	88,153	116,400	116,400	85,753	88,153
Effluent	6,000	8,630	11,470	8,630	11,470	8,630	11,470	8,630	11,470
Total Water Supply	**231,460**	**234,090**	**236,930**	**174,804**	**177,644**	**(10) 234,090**	**(10) 236,930**	**(11) 174,804**	**(11) 177,644**
Percentage of Baseline	100	100	100	75	75	100	100	75	75
WATER DEMAND									
Municipal Surface Water	0	0	0	0	0	0	0	0	0
Municipal Groundwater	14,250	20,470	27,230	21,080	28,050	20,470	27,230	21,080	28,050
Municipal Effluent	0	0	0	0	0	0	0	0	0
Total Municipal (1)	14,250	20,470	27,230	21,080	28,050	20,470	27,230	21,080	28,050
Agricultural Surface Water	57,060	57,060	57,060	36,360	36360	0	0	0	0
Agricultural Groundwater	152,630	152,630	152,630	173,330	173330	0	0	0	0
Agricultural Effluent	6,000	6,000	6,000	6,000	6,000	0	0	0	0
Total Agricultural (2)	215,690	215,690	215,690	215,690	215690	0	0	0	0
Industrial Surface Water	0	0	0	0	0	0	0	0	0
Industrial Groundwater	5,420	5,420	5,420	5,420	5,420	5,420	5,420	5,420	5,420
Industrial Effluent	0	0	0	0	0	0	0	0	0
Total Industrial	5,420	5,420	5,420	5,420	5,420	5,420	5,420	5,420	5,420
Riparian Vegeation Surface Water	44,300	44,300	44,300	36,361	36,361	44,300	44,300	44,300	44,300
Riparian Vegeation Groundwater	132,600	132,600	132,600	140,269	140,269	132,600	132,600	140,269	140,269
Total Riparian Vegetation (3)	176,900	176,900	176,900	176,900	176,900	176,900	176,900	184,569	184,569
Other Surface Water	7,700	7,700	7,700	7,700	7,700	7,700	7,700	7,700	7,700
Other Groundwater	14,990	14,990	14,990	14,990	14,990	14,990	14,990	14,990	14,990
Other Effluent	0	2,630	5,470	2,630	5,470	2,630	5,470	2,630	5,470
Total Other (4)	22,690	25,320	28,160	25,320	28,160	25,320	28,160	25,320	28,160
Total Demand	**434,950**	**443,800**	**453,400**	**444,140**	**453,950**	**228,110**	**237,710**	**236,389**	**246,199**
Incidental Groundwater Recharge	-76,750	-76,750	-76,750	-76,750	-76,750	-5,580	-5,580	-5,580	-5,580
Total Net Consumption	**358,200**	**367,050**	**376,650**	**367,390**	**377,200**	**222,530**	**232,130**	**230,809**	**240,619**
Total Surface Water	109,060	109,060	109,060	(12) 80,421	(12) 80,421	52,000	52,000	52,000	52,000
Total Groundwater	319,890	326,110	332,870	355,089	362,059	173,480	180,240	181,759	188,729
Total Effluent	6,000	8,630	11,470	8,630	11,470	2,630	5,470	2,630	5,470
Total Demand	**434,950**	**443,800**	**453,400**	**363,719**	**373,529**	**228,110**	**237,710**	**236,389**	**246,199**
Percentage Change	0	0	0	<1	<1	-49	-48	-47	-46
Total Surplus/Deficit (5)	**-126,740**	**-132,960**	**-139,720**	**-192,586**	**-199,556**	**-51,500**	**-58,260**	**-90,426**	**-97,396**
Demand Met by GW Mining	**126,740**	**132,960**	**139,720**	**192,586**	**199,556**	**51,500**	**58,260**	**90,426**	**97,396**
Percentage met by Mined GW	29	30	31	43	44	23	24	38	40

Footnotes to Appendix 4.3: Benson Subwatershed - Ten-Year Scenarios

(1) Effects of a dry period on municipal use: Benson has a mean per-capita water use of 168gpcd (1990), with approximately 128 gpcd indoor water use over the entire year and 60-70 gpcd outdoor water use between April and September. Based on a 17-35% chance of rain during the monsoon season for Benson (WRCC) and Gary Woodard's numbers for increases in gpcd during hot and dry years (11.4gpcd), an average of additional 5gpcd of annual water demand was calculated for drought periods.

(2) Effects of a dry period on agricultural demands: based on ADWR estimates (HSR 1991), average total water requirements for crops amount to 3.56 af/acre (including 2.78 af/acre crop consumptive use requirements and 0.78 af/acre average effective precipitation). It can be assumed that more irrigation water has to be withdrawn when overall precipitation decreases. Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation, and the difference is accounted for through increased/decreased crop consumptive use requirement. Irrigated acreage amounts to 5,330 acres.

(3) Effects of a dry period on riparian vegetation: based on ADWR estimated (HSR 1991), riparian consumptive use requirements amount to 3.8 af/acre (including 2.86 af/acre riparian consumptive use requirements and 0.42 af/acre average effective precipitation). The extent of riparian vegetation amounts to 6,180 acres (adopted after HSR 1991). Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation. If less precipitation than 0.42 af/acre is available, additional water has to be withdrawn from the aquifer. However, if more water than the threshold value of 0.42 af/acre was available, the additional water remained unconsumed. Moreover, it is assumed that riparian vegetation relies to 25 % on surface water.

(4) Other water demands include channel evaporation, reservoirs, stockponds, and domestic wells.

(5) Groundwater impact: total groundwater supply minus total groundwater demand plus incidental groundwater recharge. Negative numbers indicate groundwater overdraft.

(6) Pop Proj DES: based on the 2025 projection projection provided by DES

(7) Pop Proj High: 2025 population projections extrapolated from estimated 1998 DES numbers. They tend to be higher than the actual DES projections for 2025.

(8) Hist. Min. Precip. Historic ten-year minimum winter precipitation for the South East Climate Division: 38.27 inches (1947-1956), winter mean: 3.83 inches

(9) NoAG: hypothetical scenario assuming the elimination of all irrigated agriculture from the subwatershed

(10) Total supply includes 6,000af of unused effluent and 57,060af of unused surface water

(11) Total supply includes 6,000af of unused effluent and 28,421af of unused surface water

(12) Available surface water is split between channel evaporation (other SW) and the remaining amount equally between riparian vegetation and agriculture

Appendix 5: Sierra Vista Subwatershed

5.1. One-Year Scenarios

5.2. Five-Year Scenarios

5.3. Ten-Year Scenarios

Appendix 5.1: Sierra Vista Subwatershed 1990 and 2025 - One-Year Scenarios

	Baseline 1990	Pop Proj DES Baseline (6)	Pop Proj High Baseline (7)	Pop DES+ Hist. Min. Precip (8)	Pop High+ Hist. Min. Precip	Pop Proj DES NoAG (9)	Pop Proj High NoAG	Pop DES + Hist Min Precip NoAG	Pop High + Hist Min Precip NoAG
Population	**49,085**	**76,607**	**87,052**	**76,607**	**87,052**	**76,607**	**87,052**	**76,607**	**87,052**
WATER SUPPLY									
Total Surface Water (Inflow-Outflow)	4,564	4,564	4,564	529	529	4,564	4,564	529	529
Natural Groundwater Recharge	16,860	16,860	16,860	1,954	1,954	16,860	16,860	1,954	1,954
Groundwater Outflow	0	0	0	0	0	0	0	0	0
Total Groundwater	16,860	16,860	16,860	1,954	1,954	16,860	17,696	1,954	1,954
Effluent	3,600	5,619	6,385	5,619	6,385	5,619	6,385	5,619	6,385
Total Water Supply	**25,024**	**27,043**	**27,809**	**8,102**	**8,868**	**(10) 27,043**	**(11) 27,809**	**(10) 8,102**	**(11) 8,868**
Percentage Baseline	100	100	100	30	32	100	100	30	32
WATER DEMAND									
Municipal Surface Water	0	0	0	0	0	0	0	0	0
Municipal Groundwater	11,003	17,172	19,514	18,374	20,879	17,172	19,514	18,374	20,879
Municipal Effluent	0	0	0	0	0	0	0	0	0
Total Municipal (1)_	11,003	17,172	19,514	18,374	20,879	17,172	19,514	18,374	20,879
Agricultural Surface Water	0	0	0	0	0	0	0	0	0
Agricultural Groundwater	4,477	3,516	3,156	6,627	6,267	0	0	0	0
Agricultural Effluent	1,680	2,641	3,001	2,641	3,001	0	0	0	0
Total Agricultural (2)	6,157	6,157	6,157	9,268	9,268	0	0	0	0
Industrial Surface Water	2	2	2	2	2	2	2	2	2
Industrial Groundwater	225	225	225	225	225	225	225	225	225
Industrial Effluent	0	0	0	0	0	0	0	0	0
Total Industrial	227	227	227	227	227	227	227	227	227
Riparian Vegeation Surface Water	3,612	3,612	3,612	0	0	3,612	3,612	0	0
Riparian Vegeation Groundwater	10,838	10,838	10,838	10,838	10,838	10,838	10,838	10,838	10,838
Total Riparian Vegetation (3)	14,450	14,450	14,450	10,838	10,838	14,450	14,450	10,838	10,838
Other Surface Water	950	950	950	527	527	950	950	527	527
Other Groundwater	2,254	2,254	2,254	2,254	2,254	2,254	2,254	2,254	2,254
Other Effluent	1,920	2,978	3,384	2,978	3,384	2,978	3,384	2,978	3,384
Total Other (4)	5,124	6,182	6,588	5,759	6,165	6,182	6,588	5,759	6,165
Total Demand	**36,961**	**44,188**	**46,936**	**44,466**	**47,377**	**38,031**	**40,373**	**35,198**	**38,109**
Incidental Groundwater Recharge	-2,591	-2,591	-2,591	-2,591	-2,591	-836	-836	-836	-836
Total Net Consumption	**34,370**	**41,597**	**44,345**	**41,875**	**44,786**	**37,195**	**39,537**	**34,362**	**37,273**
Total Surface Water	4,564	4,564	4,564	529	529	4,564	4,564	529	529
Total Groundwater	28,797	34,005	35,987	38,318	40,463	30,489	32,425	31,691	34,196
Total Effluent (12)	3,600	5,619	6,385	5,619	6,385	2,978	3,384	2,978	3,384
Total Demand	**36,961**	**44,188**	**46,936**	**44,466**	**47,377**	**38,031**	**40,373**	**35,198**	**38,109**
Percentage Change	-	-	-	1	1	-14	-14	-20	-19
Total Surplus/Deficit (5)	**-9,346**	**-14,254**	**-16,536**	**-33,773**	**-35,918**	**-12,793**	**-14,729**	**-28,901**	**-31,406**
Demand Met by GW Mining	**9,346**	**14,254**	**16,536**	**33,773**	**35,918**	**12,793**	**14,729**	**28,901**	**31,406**
Percentage met by Mined GW	25	32	35	76	76	34	36	82	82

Footnotes to Appendix 5.1: Sierra Vista Subwatershed - One-Year Scenarios

(1) Effects of a dry period on municipal use: Sierra Vista has a mean per-capita water use of 150gpcd (1990), with approximately 100 gpcd indoor water use over the entire year and 90-103 gpcd outdoor water use between April and September. Based on a 20-47% chance of rain during the monsoon season for the subwatershed and Gary Woodard's numbers for increases in gpcd during hot and dry years (11.4gpcd), an average of additional 10gpcd of annual water demand was calculated for drought periods.

(2) Effects of a dry period on agricultural demands: based on ADWR estimates (HSR 1991), average total water requirements for crops amount to 3.37 af/acre (including 2.59 af/acre crop consumptive use requirements and 0.78 af/acre average effective precipitation). It can be assumed that more irrigation water has to be withdrawn when overall precipitation decreases. Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation, and the difference is accounted for through increased/decreased crop consumptive use requirement. Irrigated acreage amounts to 2,181 acres.

(3) Effects of a dry period on riparian vegetation: based on ADWR estimated (HSR 1991), riparian consumptive use requirements amount to 2.88 af/acre (including 2.46 af/acre riparian consumptive use requirements and 0.42 af/acre average effective precipitation). The extent of riparian vegetation amounts to 5,874 acres (adopted after HSR 1991). Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation. If less precipitation than 0.42 af/acre is available, additional water has to be withdrawn from the aquifer. However, if more water than the threshold value of 0.42 af/acre was available, the additional water remained unconsumed. Moreover, it is assumed that riparian vegetation relies to 25% on surface water.

(4) Other water demands include channel evaporation, reservoirs, stockponds, domestic wells, and fields and parade courts at the base in Fort Huachuca.

(5) Groundwater impact: total groundwater supply minus total groundwater demand plus incidental groundwater recharge. Negative numbers indicate groundwater overdraft.

(6) Pop Proj DES: based on the 2025 projection projection provided by DES

(7) Pop Proj High: 2025 population projections extrapolated from estimated 1998 DES numbers. They tend to be higher than the actual DES projections for 2025.

(8) Hist. Min. Precip. Historic minimum winter precipitation for the South East Climate Division: 0.6 inches (1904))

(9) NoAG: hypothetical scenario assuming the elimination of all irrigated agriculture from the subwatershed

(10) Total supply includes 2,641af of unused effluent and 5,706af of unused surface water

(11) Total supply includes 3,001af of unused effluent

(12) Under the 2025 scenarios, increased amount of effluent is proportionally split between agriculture and other uses.

Appendix 5.2: Sierra Vista Subwatershed 1990 and 2025 - Five-Year Scenarios

	Baseline 1990 *5years	Pop DES* 5 years Baseline (6)	Pop High* 5 years Baseline (7)	Pop DES+ 5 yr Hist Drought (8)	Pop High+ 5 yr Hist Drought	Pop Proj DES NoAG*5yr (9)	Pop Proj High NoAG*5yr	Pop DES + Hist Min Precip NoAG*5yr	Pop High + Hist Min Precip NoAG*5yr
Population		**76,607**	**87,052**	**76,607**	**87,052**	**76,607**	**87,052**	**76,607**	**87,052**
WATER SUPPLY									
Total Surface Water (Inflow-Outflow)	22,820	22,820	22,820	12,989	12,989	22,820	22,820	12,989	12,989
Natural Groundwater Recharge	84,300	84,300	84,300	47,984	47,984	84,300	84,300	47,984	47,984
Groundwater Outflow	0	0	0	0	0	0	0	0	0
Total Groundwater	84,300	84,300	84,300	47,984	47,984	84,300	88,480	47,984	47,984
Effluent	18,000	28,093	31,923	28,093	31,923	28,093	31,923	28,095	31,925
Total Water Supply	**125,120**	**135,213**	**139,053**	**89,066**	**92,896**	**(10) 135,213**	**(11) 139,053**	**(10) 89,066**	**(11) 92,896**
Percentage Baseline	100	100	100	68	70	100	100	68	70
WATER DEMAND	0								
Municipal Surface Water	0	0	0	0	0	0	0	0	0
Municipal Groundwater	55,015	85,862	97,570	91,870	104,395	85,860	97,570	91,870	104,395
Municipal Effluent	0	0	0	0	0	0	0	0	0
Total Municipal (1)	55,015	85,860	97,570	91,870	104,395	85,860	97,570	91,870	104,395
Agricultural Surface Water	0	0	0	0	0	0	0	0	0
Agricultural Groundwater	22,385	17,580	15,780	26,271	24,471	0	0	0	0
Agricultural Effluent	8,400	13,205	15,005	13,205	15,005	0	0	0	0
Total Agricultural (2)	30,785	30,785	30,785	39,476	39,476	0	0	0	0
Industrial Surface Water	10	10	10	10	10	10	10	10	10
Industrial Groundwater	1,125	1,125	1,125	1,125	1,125	1,125	1,125	1,125	1,125
Industrial Effluent	0	0	0	0	0	0	0	0	0
Total Industrial	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135
Riparian Vegeation Surface Water	18,060	18,060	18,060	10,344	10,344	18,060	18,060	10,344	10,344
Riparian Vegeation Groundwater	54,190	54,190	54,190	61,906	61,906	54,190	54,190	61,906	61,906
Total Riparian Vegetation (3)	72,250	72,250	72,250	72,250	72,250	72,250	72,250	72,250	72,250
Other Surface Water	4,750	4,750	4,750	2,635	2,635	4,750	4,750	2,635	2,635
Other Groundwater	11,270	11,270	11,270	11,270	11,270	11,270	11,270	11,270	11,270
Other Effluent	9,600	14,890	16,920	14,890	16,920	14,890	16,920	14,890	16,920
Total Other (4)	25,620	30,910	32,940	28,795	30,825	30,910	32,940	28,795	30,825
Total Demand	**184,805**	**220,940**	**234,680**	**233,526**	**248,081**	**190,155**	**201,865**	**194,060**	**208,605**
Incidental Groundwater Recharge	-12,955	-12,955	-12,955	-12,955	-12,955	-4,180	-4,180	-4,180	-4,180
Total Net Consumption	**171,850**	**207,985**	**221,725**	**220,571**	**235,126**	**185,975**	**197,685**	**189,880**	**204,425**
Total Surface Water	22,820	22,820	22,820	12,989	12,989	22,820	22,820	12,989	12,989
Total Groundwater	143,985	170,025	179,935	192,442	203,167	152,445	162,125	166,181	178,696
Total Effluent (12)	18,000	28,095	31,925	28,095	31,925	14,890	16,920	14,890	16,920
Total Demand	**184,805**	**220,940**	**234,680**	**233,526**	**248,081**	**190,155**	**201,865**	**194,060**	**208,605**
Percentage Change	-	-	-	6	6	-14	-14	-12	-11
Total Surplus/Deficit (5)	**-46,730**	**-71,270**	**-82,680**	**-131,505**	**-142,230**	**-63,965**	**-73,645**	**-114,017**	**-126,532**
Demand Met by GW Mining	**46,730**	**71,270**	**82,680**	**131,505**	**142,230**	**63,965**	**73,645**	**114,017**	**126,532**
Percentage met by Mined GW	25	32	35	56	57	34	36	59	61

Footnotes to Appendix 5.2: Sierra Vista Subwatershed - Five-Year Scenarios

(1) Effects of a dry period on municipal use: Sierra Vista has a mean per-capita water use of 150gpcd (1990), with approximately 100 gpcd indoor water use over the entire year and 90-103 gpcd outdoor water use between April and September. Based on a 20-47% chance of rain during the monsoon season for the subwatershed and Gary Woodard's numbers for increases in gpcd during hot and dry years (11.4gpcd), an average of additional 10gpcd of annual water demand was calculated for drought periods.

(2) Effects of a dry period on agricultural demands: based on ADWR estimates (HSR 1991), average total water requirements for crops amount to 3.37 af/acre (including 2.59 af/acre crop consumptive use requirements and 0.78 af/acre average effective precipitation). It can be assumed that more irrigation water has to be withdrawn when overall precipitation decreases. Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation, and the difference is accounted for through increased/decreased crop consumptive use requirement. Irrigated acreage amounts to 2,181 acres.

(3) Effects of a dry period on riparian vegetation: based on ADWR estimated (HSR 1991), riparian consumptive use requirements amount to 2.88 af/acre (including 2.46 af/acre riparian consumptive use requirements and 0.42 af/acre average effective precipitation). The extent of riparian vegetation amounts to 5,874 acres (adopted after HSR 1991). Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation. If less precipitation than 0.42 af/acre is available, additional water has to be withdrawn from the aquifer. However, if more water than the threshold value of 0.42 af/acre was available, the additional water remained unconsumed. Moreover, it is assumed that riparian vegetation relies to 25% on surface water.

(4) Other water demands include channel evaporation, reservoirs, stockponds, domestic wells, and fields and parade courts at the base in Fort Huachuca.

(5) Groundwater impact: total groundwater supply minus total groundwater demand plus incidental groundwater recharge. Negative numbers indicate groundwater overdraft.

(6) Pop Proj DES: based on the 2025 projection projection provided by DES

(7) Pop Proj High: 2025 population projections extrapolated from estimated 1998 DES numbers. They tend to be higher than the actual DES projections for 2025.

(8) Hist. Min. Precip. Historic five-year minimum winter precipitation for the South East Climate Division: 14.73 inches (1900-1904), winter mean: 2.95 inches

(9) NoAG: hypothetical scenario assuming the elimination of all irrigated agriculture from the subwatershed

(10) Total supply includes 13,205af of unused effluent and 5,706af of unused surface water

(11) Total supply includes 15,005af of unused effluent

(12) Under the 2025 scenarios, increased amount of effluent is proportionally split between agriculture and other uses.

Appendix 5.3: Sierra Vista Subwatershed 1990 and 2025 - Ten-Year Scenarios

	Baseline 1990 *10 years	Pop DES* 10years Baseline (6)	Pop High* 10years Baseline (7)	Pop DES+ 10 yr Hist. Drought (8)	Pop High+ 10 yr Hist. Drought	Pop Proj DES NoAG *10yr (9)	Pop Proj High NoAG*10yr	Pop DES + Hist Min Precip NoAG*10yr	Pop High + Hist Min Precip NoAG*10yr
Population	**49,085**	**76,607**	**87,052**	**76,607**	**87,052**	**76,607**	**87,052**	**76,607**	**87,052**
WATER SUPPLY									
Total Surface Water (Inflow-Outflow)	45,640	45,640	45,640	33,746	33,746	45,640	45,640	33,746	33,746
Natural Groundwater Recharge	168,600	168,600	168,600	124,663	124,663	168,600	168,600	124,663	124,663
Groundwater Outflow	0	0	0	0	0	0	0	0	0
Total Groundwater	168,600	168,600	168,600	124,663	124,663	168,600	176,960	124,663	124,663
Effluent	36,000	56,185	63,846	56,185	63,846	56,185	63,846	56,190	63,850
Total Water Supply	**250,240**	**270,425**	**278,086**	**214,594**	**222,255**	**(10) 270,425**	**(11) 278,086**	**(10) 214,594**	**(11) 222,255**
Percentage Baseline	100	100	100	80	82	100	100	80	82
WATER DEMAND	0								
Municipal Surface Water	0	0	0	0	0	0	0	0	0
Municipal Groundwater	110,030	171,720	195,140	183,741	208,794	171,720	195,140	183,740	208,790
Municipal Effluent	0	0	0	0	0	0	0	0	0
Total Municipal (1)	110,030	171,720	195,140	183,740	208,790	171,720	195,140	183,740	208,790
Agricultural Surface Water	0	0	0	0	0	0	0	0	0
Agricultural Groundwater	44,770	35,160	31,560	35,160	31,560	0	0	0	0
Agricultural Effluent	16,800	26,410	30,010	26,410	30,010	0	0	0	0
Total Agricultural (2)	61,570	61,570	61,570	61,570	61,570	0	0	0	0
Industrial Surface Water	20	20	20	20	20	20	20	20	20
Industrial Groundwater	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250
Industrial Effluent	0	0	0	0	0	0	0	0	0
Total Industrial	2,270	2,270	2,270	2,270	2,270	2,270	2,270	2,270	2,270
Riparian Vegeation Surface Water	36,120	36,120	36,120	24,226	24,226	36,120	36,120	24,226	24,226
Riparian Vegeation Groundwater	108,380	108,380	108,380	120,274	120,274	108,380	108,380	120,274	120,274
Total Riparian Vegetation (3)	144,500	144,500	144,500	144,500	144,500	144,500	144,500	144,500	144,500
Other Surface Water	9,500	9,500	9,500	9,500	9,500	9,500	9,500	9,500	9,500
Other Groundwater	22,540	22,540	22,540	22,540	22,540	22,540	22,540	22,540	22,540
Other Effluent	19,200	29,780	33,840	29,780	33,840	29,780	33,840	29,780	33,840
Total Other (4)	51,240	57,590	65,880	57,590	61,650	57,590	65,880	57,590	61,650
Total Demand	**369,610**	**441,880**	**469,360**	**453,901**	**483,014**	**380,310**	**403,730**	**392,330**	**421,440**
Incidental Groundwater Recharge	-25,910	-25,910	-25,910	-25,910	-25,910	-8,360	-8,360	-8,360	-8,360
Total Net Consumption	**343,700**	**415,970**	**443,450**	**427,991**	**457,104**	**371,950**	**395,370**	**383,970**	**413,080**
Total Surface Water	45,640	45,640	45,640	33,746	33,746	45,640	45,640	33,746	33,746
Total Groundwater	287,970	340,050	359,870	363,965	385,418	304,890	324,250	328,804	353,854
Total Effluent (12)	36,000	56,190	63,850	56,190	63,850	29,780	33,840	29,780	33,840
Total Demand	**369,610**	**441,880**	**469,360**	**453,901**	**483,014**	**380,310**	**403,730**	**392,330**	**421,440**
Percentage Change	-	-	-	3	3	-14	-14	-11	-10
Total Surplus/Deficit (5)	**-93,460**	**-142,540**	**-165,360**	**-213,397**	**-234,849**	**-127,930**	**-147,290**	**-195,781**	**-220,831**
Demand Met by GW Mining	**93,460**	**142,540**	**165,360**	**213,397**	**234,849**	**127,930**	**147,290**	**195,781**	**220,831**
Percentage met by Mined GW	25	32	35	47	49	34	36	50	52

Footnotes to Appendix 5.3: Sierra Vista Subwatershed - Ten-Year Scenarios

(1) Effects of a dry period on municipal use: Sierra Vista has a mean per-capita water use of 150gpcd (1990), with approximately 100 gpcd indoor water use over the entire year and 90-103 gpcd outdoor water use between April and September. Based on a 20-47% chance of rain during the monsoon season for the subwatershed and Gary Woodard's numbers for increases in gpcd during hot and dry years (11.4gpcd), an average of additional 10gpcd of annual water demand was calculated for drought periods.

(2) Effects of a dry period on agricultural demands: based on ADWR estimates (HSR 1991), average total water requirements for crops amount to 3.37 af/acre (including 2.59 af/acre crop consumptive use requirements and 0.78 af/acre average effective precipitation). It can be assumed that more irrigation water has to be withdrawn when overall precipitation decreases. Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation, and the difference is accounted for through increased/decreased crop consumptive use requirement. Irrigated acreage amounts to 2,181 acres.

(3) Effects of a dry period on riparian vegetation: based on ADWR estimated (HSR 1991), riparian consumptive use requirements amount to 2.88 af/acre (including 2.46 af/acre riparian consumptive use requirements and 0.42 af/acre average effective precipitation). The extent of riparian vegetation amounts to 5,874 acres (adopted after HSR 1991). Annual precipitation is translated into effective precipitation, using the USGS conversion factor of 0.083504 af/acre for 1 inch of precipitation. If less precipitation than 0.42 af/acre is available, additional water has to be withdrawn from the aquifer. However, if more water than the threshold value of 0.42 af/acre was available, the additional water remained unconsumed. Moreover, it is assumed that riparian vegetation relies to 25% on surface water.

(4) Other water demands include channel evaporation, reservoirs, stockponds, domestic wells, and fields and parade courts at the base in Fort Huachuca.

(5) Groundwater impact: total groundwater supply minus total groundwater demand plus incidental groundwater recharge. Negative numbers indicate groundwater overdraft.

(6) Pop Proj DES: based on the 2025 projection projection provided by DES

(7) Pop Proj High: 2025 population projections extrapolated from estimated 1998 DES numbers. They tend to be higher than the actual DES projections for 2025.

(8) Hist. Min. Precip. Historic ten-year minimum winter precipitation for the South East Climate Division: 38.27 inches (1947-1956), winter mean: 3.83 inches

(9) NoAG: hypothetical scenario assuming the elimination of all irrigated agriculture from the subwatershed

(10) Total supply includes 26,410af of unused effluent and 5,706af of unused surface water

(11) Total supply includes 30,010af of unused effluent

(12) Under the 2025 scenarios, increased amount of effluent is proportionally split between agriculture and other uses.