

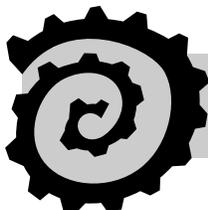
# **Climate and Urban Water Providers in Arizona**

**An Analysis of Vulnerability  
Perceptions and Climate  
Information Use**



**Rebecca H. Carter and  
Barbara J. Morehouse**

**CLIMAS Report Series CL1-03**



**CLIMAS**

Climate Assessment for the Southwest

THE UNIVERSITY OF ARIZONA • Institute for the Study of Planet Earth



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## Abstract

Among the many stressors affecting urban water supply and demand in the U.S. Southwest is climatic variability, particularly prolonged drought. At shorter time scales, weather events such as floods, high winds, unusually hot weather, and electrical storms may also affect water production and delivery systems. At the same time, climatic variability is but one of a number of factors affecting urban water management in the region. Research into the sensitivity and vulnerability of urban water systems in Arizona reveals that managers are more concerned about factors such as population growth projections, economic trends, and revenue flows. Reliance on groundwater resources in many cases obscures recognition of any direct impact of precipitation on water supply. Some systems rely on multiple water sources and/or interconnections with other providers to address the risk that they may at some point not be able to serve customers' needs. In other cases, water providers, especially many who rely on fossil groundwater that receives little recharge, do not perceive any link between climate and risk to their water supply. Given the low level of perceived climate risk among many providers interviewed for this study, it would seem unlikely that climate information would be needed. However, pockets of sensitivity and vulnerability to climatic impacts do exist in the four study areas covered in this study. Findings indicate that efforts to provide climate information may best be directed toward these particular providers. Whether the strong perceptions of invulnerability held by water managers hold up under a severe sustained drought remains to be tested.

## 1. Introduction

### 1.1. Project Overview

The Southwest is one of the most rapidly growing areas of the United States and also one of the most arid. Water managers must balance the needs of exponentially expanding populations with the physical reality of limited water supplies. Weather- and climate-related events, such as unusually hot weather, prolonged drought, or flood events, frequently place additional stress to urban systems. One way that water managers may prepare for and cope with such events is through expanding their use of climate information and forecasts. However, the climate research community lacks sufficient knowledge about the use of information by local water managers, exactly which types of weather and climate events managers find most difficult to contend with, and what their specific information needs are. Water managers, on the other hand, may have limited knowledge of what products are available, where to access them, and how to apply them to their decision-making processes.

This analysis seeks to answer some of these questions. It provides insight into the ways that climate- and weather-related factors affect urban water systems in the southwestern United States and whether and how water providers use climate information in coping with weather- and climate-related events and situations. The research identifies factors that affect the perceived and reported adaptability and vulnerability of water systems to climatic fluctuations and links these issues to key organizational factors within each water system.

The study also includes a summary of providers' reported current level of use of climatic forecasting products, as well as comments and suggestions from the water providers regarding potential improvements to the relevance and clarity of forecasts.

The study reflects several hypotheses that were generated through a background literature review and preliminary interviews and tested through the survey process. These hypotheses included:

- Given that the study areas include some of the driest and hottest locations in the United States, drought and high temperatures cause the most significant strains of water systems in southern Arizona.
- Smaller water systems serving fewer people are more sensitive to climatic variations than larger systems, due to a lack of capital to install buffers such a storage space and additional/deeper wells.
- The rate of population growth plays a critical role in determining how vulnerable a system is to climatic variability. However, the exact nature of this role is uncertain, since smaller, stable systems may not have the capital to put in buffers against climatic disruptions, but systems in fast-growing areas might not be able to keep up with growth.
- Systems relying on only one water source are more vulnerable to drought due to less redundancy in their water supplies and less flexibility in their sys-

tems. Hence, the greater the number of water sources a system can access, the less vulnerable to climatic fluctuations it is.

- Water systems dependent exclusively on ground-water resources are essentially invulnerable to short-term climatic variability, but are at risk from long-term climate shifts towards drier weather.

The study revealed that a complex web of factors determine the resilience of systems, including water system size, number of water sources, degree of reliance on groundwater, and rate of population growth; but that previously unconsidered features, such as the availability of backup systems for pumps, depth to water table, and type of water system management also play important roles. This report will show that while some providers are adept at coping with the types of climatic situations that they currently encounter, their potential resiliency in the face of unusual climatic conditions may be less robust than they anticipate. Although there was a lack of clear correlation between self-assessed vulnerability and natural or human-created factors, water providers may not be as well buffered against climatic extremes as they may think, particularly once water supplies are stretched thinner by population growth. When examining individual water systems, we were often able to delineate variables that determine that system's vulnerability or resiliency. Systems that were highly vulnerable tended to have one or more of the following factors:

- Only one water source, which could be at risk due to contamination or overdraft,
- An organizational structure that made it difficult to obtain sufficient funds for infrastructure maintenance and improvement,
- Location in rapidly growing areas where power systems and other infrastructure were already stressed by demand,
- Location in newly developed areas that had not yet developed adequate infrastructure.

On the other hand, systems that demonstrate resiliency had one or more of these characteristics:

- Plan for possible future events, rather than relying solely on actual past events,

- Have several layers of redundancy in their systems,
- Have detailed drought and flood mitigation plans,
- Have backup systems.

The findings reinforce the importance of examining water systems as unique entities, and the need for system managers to be thoroughly involved in any future efforts to better buffer systems against climatic variability. A more detailed discussion of the hypotheses and the study findings is presented in the Results section.

### 1.2. Climate Assessment for the Southwest Project

The Climate Assessment for the Southwest (CLIMAS) Project at the University of Arizona is an integrated assessment of the impacts of climatic variability in the southwestern United States. The project draws upon the expertise of an interdisciplinary team of hydrologists, climatologists and social scientists to holistically examine the physical, economic, and social ramifications of potential climate change. Funded by a grant from the National Oceanic and Atmospheric Administration's Office of Global Programs, the project seeks to provide decision makers and stakeholders with better access to and understanding of climate forecasting products, and also to provide those who produce climate predictions with insight into the types and forms of information most useful to users.

More information about the CLIMAS Urban Water Study, and the place of this report within it, may be found on our website, <http://www.ispe.arizona.edu/climas/research/>.

### 1.3. Regional Climate Assessments

This study provides an example of the importance of taking a regional approach to the study of climate impacts. It is at the regional and local levels that climate actually affects people, and thus the impacts of global and hemispheric weather and climate phenomena can best be studied at this level. By undertaking a more in-depth investigation of a smaller area, regional assessments provide opportunities for comparing and contrasting results between locations and sectors, thereby increasing the overall knowledge base and ensuring that measures enacted to mitigate the effects of climatic variability are appropriate at the community level. A regional approach also allows assessment of the impacts of climate change to effectively integrate stakeholders.

Specific constraints, concerns, and challenges faced by water providers, and ways that forecasting products can be designed to increase the efficiency and resiliency of individual water systems, can best be understood at the regional level. One of the primary challenges of water system management is ensuring that the physical realities of water supply and demand are effectively integrated within a region's unique environmental, social, and legal milieu.

## 2. Background

A large and growing body of literature exists regarding climate impacts on water resources, as evidenced by the online bibliography maintained by the Pacific Institute (<http://www.pacinst.org/global.html#bib>). Much of the literature reflects the fact that research on the impacts of climate on water resources has been directed toward determining the effects of long-term climate change. Due to limited ability to downscale the results produced by general circulation models, efforts to identify the impacts of climate change at regional or finer scales of resolution have not achieved desired levels of accuracy. However, consensus has formed around the notion that arid and semiarid areas could be among the most seriously affected by anticipated climatic changes and 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 in these regions (IPCC 1995). Regardless of what any future climate change may bring, CLIMAS takes a "no regrets" stance toward understanding how water providers deal with current levels of climatic variability and in assessing what repeats of past climatic extremes might mean to water resources and systems with both present and projected populations, in order to better anticipate, prepare for and manage climate-related disruptions to water systems.

The Intergovernmental Panel on Climate Change (IPCC) suggested that a focus on natural climate variability and impacts at regional and local scales would enable researchers and decision makers to find ways to effectively address climate-induced disparities between water supply and demand in a context-specific manner (IPCC 1995). The ultimate goal of these efforts is to enable water managers to achieve standard performance criteria (reliability, safe yield, probable maximum flood level, resilience and robustness) under a va-

riety of climatic conditions. According to the IPCC, *sensitivity* analysis and *vulnerability* analysis, combined with focused *institutional* analysis, are useful methods for contextualizing the impacts of natural climatic variability and of greenhouse gas-induced climate change (IPCC 1995). The CLIMAS Urban Water Study is investigating these three facets of urban water in the Southwest.

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" (1995:5). A previous CLIMAS report (Carter et al. 2000) examined the sensitivity of urban water systems in five Arizona locations by investigating the past and potential future impacts of the worst 1-, 5-, and 10-year droughts in the historical record in the case study areas that are further examined in this report. The current study also includes questions about the sensitivity of water systems that attempt to determine the degree to which specific systems respond to weather and climate. An institutional analysis of Arizona water laws and policies provided a contextual framework for understanding climate impacts on urban water resources and summarized the legal framework within which water managers must work when coping with climate impacts (Carter and Morehouse 2001).

The current vulnerability analysis of urban water systems thus constitutes the third component of study. The Panel defines *vulnerability* as "the extent to which climate change may damage or harm a system" (IPCC 1995:5). This theme is reflected throughout the present study, with questions targeted toward determining the vulnerability of water systems in order to examine the extent to which weather and climate may impede their capacity to function (O'Connor et al. 1999). Vulnerability analyses have contributed substantially to enhanced understanding of the human dimensions of climate variability and change (see, e.g., Liverman 1999), and the present study is intended to make similar contributions. Vulnerability analyses have also aided in the development of methodologies for effectively combining social science and natural science research through integrated assessments, including the CLIMAS project (see, e.g., Parson 1995, Easterling 1997, Schneider 1997, and Rotmans and Dowlatabadi 1998).

Because the extent of vulnerability depends not only on the sensitivity of water systems to normal climatic

fluctuations, but also on their ability to cope with the new climatic conditions, evaluation of adaptability is essential as well; therefore, many of the questions asked of water providers in this study are intended to assess this factor. *Adaptability* is defined as the capacity of a system to adjust to specified actual or projected conditions (IPCC 1995). Questions in the present study designed to elicit information about the adaptability of water systems focus on how practices, processes, or structures could be adjusted to respond to past climatic fluctuations or a changing future climate.

The present report is to some extent modeled after a similar study that O'Connor et al. (1999) carried out with water managers in Pennsylvania's Susquehanna River Basin. The report provided an important source for contextualizing the Arizona findings through comparing and contrasting survey results with those of a region of the United States that is much more humid and has a greater abundance of surface water sources. As discussed in greater detail in the Research Methods section of this report, this study replicates many of the questions asked in the Susquehanna survey in order to facilitate comparison across the two regions. Several of the same issues are considered by both the present study and the Susquehanna study, and some findings are similar; for instance, in neither case do smaller water systems appear to be more vulnerable to climatic factors than larger ones. However, a comparison of the two studies reveals important differences as well. For one, many of the water providers in the Susquehanna study were in the process of shifting from surface water to greater groundwater use in an effort to meet stricter Safe Drinking Water Act requirements; this process was found to also reduce vulnerability to weather and climatic fluctuations. In contrast, many water providers in southeastern and central Arizona are taking the opposite approach of shifting from reliance on groundwater to greater use of surface water. In an effort to reduce vulnerability to weather and climate, this strategy is seen as a mechanism for preserving groundwater resources until they are needed to address long-term drought stresses.

Likewise, a survey of water resource managers in the Pacific Northwest's Columbia River Basin (Miles et al. 2000), which was designed to identify perceptions of climate change, climate impacts on water resource operations, and use of climate information, provided additional insights useful to the present study. The results of that study revealed considerable potential for conflicts among competing users such as irrigation, hydro-

power, municipal, navigational, recreational, environmental, and commercial interests. A relative lack of reservoir storage capacity was identified as a contributing factor to the various vulnerabilities articulated by the respondents. The authors found that management inertia and the lack of a centralized authority to coordinate all water resource uses impeded capacity to adapt to drought and to optimize water distribution. The report emphasized the importance of understanding the patterns and consequences of natural regional climate variability as a foundation for developing sufficient response capacity for responding to future climatic changes, which is identical to the philosophy underlying the CLIMAS vulnerability analysis.

This type of analysis is particularly important in the rapidly growing arid and semiarid areas of the Southwest, where rainfall and temperatures in any given year are rarely "average," and climatic extremes are common occurrences. A review of the current state of knowledge about climate and climate processes in the Southwest (Sheppard et al. 1999) provided important background information about climate variability in the study areas. Frederick stressed the need to take large seasonal and annual variations into account when analyzing climate impacts on water resources in the United States, noting, "The highest levels of use and the lowest prices are often found in the more arid areas of the country" (Frederick 1995:17). Reflecting on research on U.S. river basins regarding the ratio of water storage to average annual water supply required to maintain safe yield (roughly defined as a sustainable balance between inflow/recharge and outflow/withdrawals), Frederick warns, "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 1995:17). Given some of the study areas' increasing reliance on Colorado River supplies to meet the needs of their burgeoning populations, and their location in highly variable climatic regions, a better understanding of the current and potential impacts of climate on water resources in arid areas such as the U.S. Southwest constitutes a key research area.

Given the reliance of the Phoenix and Tucson metropolitan areas on Colorado River water, the work of Nash and Gleick (1993), which focuses on the sensitivity of water flows and supply in the Colorado River Basin to climate variability, provided valuable background information. Likewise, Gleick and Chalecki's (1999) report on the impacts of climate change on water re-

sources in the Colorado and Sacramento-San Joaquin River Basins was informative. A report by Henderson and Lord (1995) details the results of a gaming exercise designed to evaluate alternative institutional options available to water managers to cope with drought conditions as severe as those that occurred from approximately 1579 to 1600 throughout the Colorado River Basin, providing insights into how water managers might respond to the stresses of water shortages. Among the findings pertinent to the present study, the player representing Arizona was successful in reducing the state's demand for consumptive use of Central Arizona Project (CAP) water delivered from the Colorado River by 20 percent, while at the same time essentially eliminating drought-related water shortages. This was accomplished through interstate water marketing and banking and selection of intrastate water management rules (such as subsidizing CAP water use and enforcing safe-yield policies).

Imbalance between renewable supplies and demand pose marked challenges to water managers in the Southwest. Maddock and Hines (1995) observed that rapid growth occurred in urban water use in the Southwest between 1965 and 1990. During this time, public supply withdrawals and per capita consumption grew at about double the national rate. The authors noted that this rate of growth accelerated into the early 1990s, although per capita consumption may have begun leveling off in some urban areas. Further, they observed that even before taking climate variability into account, predictions have indicated that Las Vegas, Nevada would consume its entire Colorado River entitlement in less than 15 years. Careful conservation and full use of its Colorado River entitlement notwithstanding, Las Vegas may see water supply deficits after the year 2025. Denver's water supply is likewise anticipated to be insufficient to meet demand by the year 2020 (Riebsame 1997).

Specific to the urban water case studies examined in this report, the Third Management Plans published by the Arizona Department of Water Resources (ADWR) for the Phoenix, Tucson, and Santa Cruz Active Management Areas (AMAs) were indispensable (ADWR 1999a, 1999b, 1999c), as was a hydrographic survey report issued by the department for gaining a basic understanding of water resources in the Sierra Vista area (ADWR 1991). The Third Management Plans, in particular, provided a wealth of information about the nature of water resource management in each area, in terms of both supply and demand, and listed

the water companies within the AMA boundaries by size and location.

The CLIMAS Urban Water Study was further informed by an array of sources. A significant addition to the climate and water resources literature was made through research carried out under the U.S. National Climate Assessment, which was mandated by Congress. Under the "Global Change Research Act of 1990" (PL 101-606), the U.S. Global Change Research Project analyzed the effects of global change on natural and human made systems and formulated trend projections for the next 25 to 100 years. The *Journal of the American Water Resources Association* published two special issues devoted to research on the interactions among climate, hydrology and water resource management (Vol. 35, No. 6, December 1999 and Vol. 36, No. 2, April 2000; see also Gleick 2000).

Work by Lins and Stakiv (1998), which examines issues surrounding the management of water resources in the context of broad-scale climate change, provided a foundation for thinking about the impacts of natural climate variability in local settings. Miller's analysis (1997) of the impacts of both natural climate variability and longer-term climate change on water in the western United States and Revelle and Waggoner's work (1983) on anthropogenically induced climate change on western water supplies provided a more regional focus for understanding the interactions between climate, water resources, and society.

It is in this context that climate impacts of urban water resources in Arizona must be considered. Yet although the United States, including the Southwest, is now predominantly urban, relatively few studies of the impacts of climatic conditions on water resources have been done on urban water systems, particularly with regard to climate impacts on water demand (Boland 1997). The CLIMAS Urban Water Study aims to help fill that gap.

### 3. Research Methods

This report combined a written survey with a detailed interview protocol to develop an in-depth assessment of climate impacts and climate information use among urban water providers in four areas of Arizona. Using a combination of structured and semi-structured approaches allowed us to acquire important information about water providers' *perceptions*. Perceptions are im-

portant because, as this report will demonstrate, water managers tend to combine personal, subjective assessments of a situation and potential risks with more objective types of evidence. While many of the questions in the survey asked about verifiable, objective factors (the number and proportion of water sources, etc.), several of the key questions asked water providers to recall their responses to past events and to project what their responses might be to possible future conditions. Answers to these types of questions were tempered by the amount of experience the interviewee had in managing the water system, their level and type of education in water management, the political and economic context of their water system, and their individual awareness of and interest in climate-related issues.

In the spring of 1999, we mailed surveys to 54 of the 59 large water providers in four areas of southern Arizona, as identified by ADWR. (Those not interviewed included institutional or military water providers.) We received 28 responses, and follow-up interviews with the 22 providers who were willing and able to meet were conducted over the summer of the same year. An example of the survey is included in Appendix A; a sample set of interview questions may be found in Appendix B.

Table 1 gives a breakdown of the numbers of water providers surveyed and interviewed in each study area. This sample of water providers allowed us to examine a wide variety of water systems with differing water sources, population sizes, types of demand, and organizational structures.

Based on CLIMAS's previous research endeavors and a similar study of the Susquehanna River Basin in the U.S. mid-Atlantic region (O'Connor et al. 1999), our questionnaire and personal interview questions were designed to address the general hypotheses listed in the Introduction and to address the following specific climate-related impacts on water systems: a) drought and high temperatures would place the most significant strains on normal water delivery in Southeastern Arizona; b) smaller systems would be more sensitive to climatic variation due to a lack of capital to install buffers against drought and high temperatures, such as greater storage space and deeper or additional wells; c) population growth is an important determinant in the ability of water systems to cope with

climatic variability; d) systems with multiple water sources may be expected to have greater redundancy and hence flexibility in coping with climate-related stress; and e) systems dependent on surface water were expected to be vulnerable to short-term climatic fluctuations, but systems that relied solely on groundwater reserves would be less able to cope with longer-term droughts.

Our aim was to expand our understanding of the *sensitivity*, *adaptability*, and *vulnerability* of urban water systems in the U.S. Southwest (IPCC 1995). Sensitivity-related questions attempt to determine the degree to which the specific system responds to weather and climate; those seeking information about the adaptability of water systems focus on how practices, processes, or structures might be adjusted to respond to past climatic fluctuations or a changing future climate; and vulnerability-related questions examine the extent to which weather and climate may impede a water system's capacity to function (O'Connor et al. 1999).

### 3.1. Questionnaire

A four-page questionnaire was constructed and mailed to all water providers classified as "large" by ADWR, meaning that they serve over 250 acre-feet (about 81 million gallons) of water per year. A sample of the survey may be found in Appendix A. The survey responses provide basic information regarding the size of the population served, water resources utilized, infrastructure, and the job title and number of years in their current position of the person responding to the survey. Parts of the survey were modeled after the Susquehanna River Basin study conducted by researchers at Pennsylvania State University (O'Connor et al. 1999), particularly those questions that asked respondents to rate the likelihood that they would be

**Table 1.** Written Survey Return Rates and Interviews Conducted.

Location	Surveys Mailed	Surveys Returned	Return Rate	Interviews
Phoenix AMA	30	13	43%	11
Tucson AMA	16	10	63%	7
Santa Cruz AMA	4	3	75%	3
Sierra Vista	4	2	50%	1
TOTAL	54	28	52%	22

affected by various climactic events in the next five years (Question 4) and to report the frequency with which they had suffered problems related to weather and climate in the past decade (Question 5). The Susquehanna group constructed this and other survey questions after extensive individual interviews and focus group sessions with water managers in central Pennsylvania. This gave them ample opportunity to test the effectiveness of such questions and heightened our confidence in using a similar approach for our research.

The survey results were recorded using the Microsoft Access relational database program; this program was also used to perform queries and analysis of the data. Where appropriate, Microsoft Excel was used to graph numerical responses.

### 3.2. Personal Interviews

Interviews were requested from most respondents who returned surveys. Efforts were made to assure representation of the spectrum of water supply sources, system sizes and organizations, and broad geographical coverage of service areas within the study sites. A sample of the interview questions is located in Appendix B.

The interview was presented as a follow-up to the survey questions, and respondents were asked to meet with the interviewer for approximately one hour. The interviews were a combination of structured and more open-ended questions. The same questions were asked of each respondent, using the same wording. Some questions were added to later interviews to cover themes that had surfaced repeatedly in earlier interviews. Although efforts were made to cover all survey topics at some point in the interview, several of the meetings became more free-flowing discussions of related issues that the providers believed relevant to the discussion. Thus not all questions were asked in the order indicated; instead, responses were sometimes rearranged during write-up to more closely conform to the interview format and to facilitate the analysis. These interview techniques allowed the researcher to obtain a sufficiently standardized set of responses to allow for comparisons among and identify key variables between systems, while at the same time allowing respondents to provide examples and explanations of factors that were unique to their water systems.

The interview questions are divided into sections covering internal policies and institutions; knowledge of climate and hydrologic variability in the past, present

and future; relevant policies and institutions; and climate information use and needs.

Because the personal interviews were conducted in a semi-structured format, respondents were free to answer these questions in any way they saw fit, and the range of answers made quantifying the responses somewhat difficult. In some cases, providers volunteered information that they were not specifically asked about. Subsequent analysis of the data revealed instances where several providers had mentioned similar concerns or observations, and thus these issues emerged as concepts meriting analysis. However, since these findings were *not* uncovered by systematically questioning all providers specifically about them, we were unable to draw any firm conclusions as to whether or not these factors affect regional water systems generally. Many providers brought up issues that they believed to be important not only to their system, but to other systems as well, and indicated how widespread they think these issues are. This document occasionally uses terms such as “a few” or “many” or “several” providers to report such information, which does not otherwise fit neatly into our analytical framework.

### 3.3 Confidentiality

As would be expected regarding a scarce resource in a rapidly growing area, water is a contentious issue in central and southeastern Arizona. Access to ample and secure water supplies to a large extent determines development and investment patterns in this region. Water providers must negotiate between their present customers' needs and the potential for future growth, as well as navigate through a complex web of local, state, and federal regulations dictating water quality and quantity standards. In order to assure that water providers would be as candid as possible, the cover letter that accompanied the mailed survey included a statement saying that providers would not be individually identified, and that the results of the survey would only be presented in aggregate form. Providers were also assured before the interviews that their confidentiality would be maintained. Although analyzing the relative vulnerability of water systems according to their location or other distinguishing characteristics might have provided interesting results, it would have violated the confidentiality agreement, and could have raised issues that are beyond the scope of the CLIMAS study. Therefore, while verbatim quotations from the surveys and interviews have been used, information that could reveal the identity of individual providers and water systems has been omitted from this analysis.

## 4. The Research Context

### 4.1. Geographical Context

Figure 1 illustrates the geographical areas considered in this report. The four areas investigated share a generally warm and dry climate, with a bimodal distribution of winter and summer rains. However, the locations differ in terms of both natural features, such as elevation, average temperatures and seasonal rainfall amounts, and human-related features such as population size, growth rates, number of water resources utilized, and primary economic activities. Each area also has a unique water supply and demand profile, along with varying institutional arrangements, which highlight the importance of taking a regional approach to understanding the potential impacts of climate change. Three of the study areas (Tucson, Santa Cruz, and Sierra Vista) are located in the southeastern part of the state, while the fourth, Phoenix, is more centrally located.

Table 2 summarizes the spectrum of water providers in each of the study areas. Large water providers are those who serve over 250 acre-feet (about 81 million gallons per year). This group included systems that serve the vast majority of the population of each area; indeed, small providers served less than 5 percent of the residents of any study area. Only large providers were included in this study. Specific information about numbers and types of providers surveyed and interviewed for this study is included in the Research Methods section.

The urban centers of Phoenix, Tucson, and Nogales lie within Active Management Areas (AMAs)—designated by ADWR in 1980 as locations in need of more stringent groundwater use regulation to combat rapid declines in their aquifers. As such, these areas must work toward the goal of “safe yield,” in which groundwater withdrawals do not exceed the amount replenished to the aquifer on an annual basis.

Although some urban water supplies are used for industrial purposes in the urban areas of Arizona, most systems are heavily dedicated to serving the area’s rapidly growing population. As Table 3 illustrates, 26 of the 28 respondents indicated that more than half of

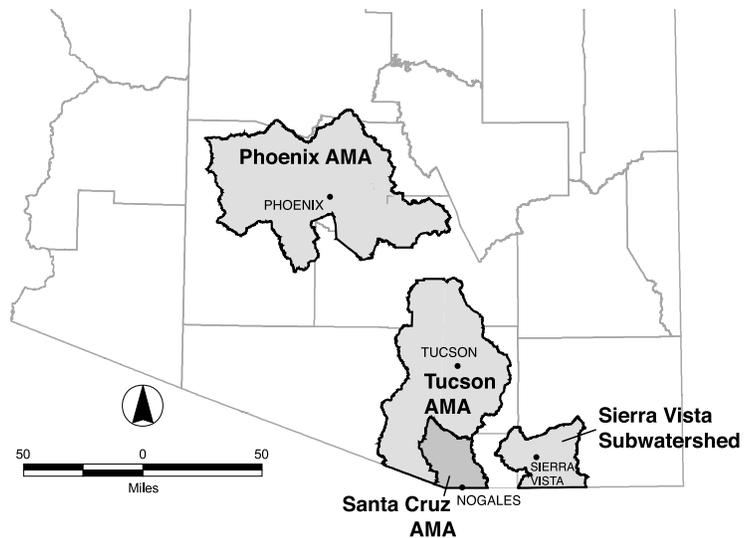


Figure 1. CLIMAS Urban Water Providers Study Areas.

Table 2. Summary of Water Providers.

Location	Total Providers	Small Providers	Large Providers
Phoenix AMA	147	115	32
Tucson AMA	151	127	19
Santa Cruz AMA	14	10	4
Sierra Vista	7	3	4
TOTAL	319	255	59

the water they supply goes to municipal/residential users and 7 indicated that a full 100 percent of their users are in this category.

The four study areas comprise different mixes of water supplies and types of demand. The next section will highlight the salient features and issues in each area.

#### *Phoenix Active Management Area*

The Phoenix and Tucson AMAs were chosen because they include the largest water systems in the state, and also encompass the fastest-growing urban water use areas. Phoenix is the capital of Arizona and its most economically important area. It is also the largest population center, with more than twice the population of the Tucson AMA.

The Phoenix AMA is made up of communities of various sizes and divergent interests, along with extensive agricultural areas and several Indian reservations. Municipal water needs accounted for 49 percent of total

**Table 3.** Number and Percentage of Users in Different Water Sectors.

	<b>Industrial</b>	<b>Municipal/ Residential</b>	<b>Other*</b>
0 percent of users	9	0	20
1-10 percent of users	9	0	4
11-49 percent of users	8	2	2
50-99 percent of users	2	19	0
100 percent of users	0	7	0

\*Other types of users include commercial, lost and unaccounted for, agriculture, urban irrigation, government, and construction.

water demand in 1995; this figure is expected to rise to 61 percent by 2025 (ADWR 1999a). There are a total of 147 water providers regulated under the Department of Water Resources' municipal conservation program. Of those, 32 large municipal providers serve 82 percent of total demand in the Phoenix AMA, while large untreated providers<sup>1</sup> meet 17 percent of demand. Small municipal providers account for 1 percent of total demand. In this AMA, large providers serve 98 percent of the population, while small providers serve 1 percent, and 1 percent is served by unregulated wells. The large providers consist of 12 municipal providers, which serve 93 percent of the population, and 18 private providers, serving 6 percent of the municipal population. The municipal providers have an average gallons per capita per day (gpcd) rate of 230, while the rate for private providers is 312 gpcd.

In addition to having the largest population of the study areas considered, the Phoenix AMA is endowed with the widest variety of water resources available for use. Some Phoenix AMA providers are able to utilize up to four different water sources: groundwater, surface water via the Salt River Project (SRP) system, Colorado River water delivered through the Central Arizona Project (CAP) canal, and substantial amounts of treated effluent.

Water management is a contentious issue in the AMA. Some areas are experiencing rapidly dropping water tables, while other locations are waterlogged due to recharge efforts or being located down gradient from return flows. Although some areas of the AMA have access to up to four different water sources, including SRP and CAP supplies, other areas are logistically un-

likely to ever access these resources, and thus must rely solely on groundwater and effluent supplies. Access to SRP and CAP water is determined primarily by location within the AMA, and also by a provider's ability to build the treatment plants necessary to utilize these water sources. Although long-standing rights determine the basic allotments of these water sources, there is some room for negotiation for greater or lesser amounts of water based on population growth and the expansion of treatment and recharge facilities.

Private and municipal water systems differ in their access to water resources. Most private providers serve only groundwater, with a mere 11 percent of this sector's total water supplies coming from surface water. Municipal providers, on the other hand, usually have access to several different water sources. Some large municipal water companies that make up the urban core of the Phoenix AMA have access to all four water sources. For example, the City of Phoenix is the largest municipal water provider, meeting the water demand of 45 percent of the AMA's population, and has access to groundwater, SRP and CAP supplies, and effluent. Renewable supplies (non-groundwater sources such as effluent and river water, i.e. SRP and CAP) account for 93 percent of the City of Phoenix's water supplies (ADWR 1999a).

The value of a more fine-grained study of individual water providers is highlighted by the fact that 30 percent of the water providers in the Phoenix AMA utilize only groundwater, and 23 percent employ groundwater and one other water source. These providers may have more in common with water providers in the other three study areas, where the vast majority of providers have access only to groundwater, than with other providers in the Phoenix AMA. This was the case with 8 out of 10 water providers in the Tucson AMA, and all providers in the Santa Cruz AMA and in the Sierra Vista area.

#### *Tucson Active Management Area*

The Tucson AMA, which encompasses the second largest metropolitan area of the state, presents quite a different water supply and demand profile. Municipal water demand accounted for 66 percent of total demand in 1995 and is expected to comprise 80 percent of demand by 2025 (ADWR 1999b). Of the 151 total water providers in the AMA, 127 are small municipal providers; however, these small providers meet only 4

percent of total demand. Of the 19 large providers, 5 are municipal providers, 11 are privately owned water companies, and 3 are institutional providers (which were not included in the present study). Large providers meet the water needs of 96 percent of the AMA's population. Unlike the Phoenix AMA, which has several large municipal providers, the Tucson AMA is dominated by Tucson Water, the municipal provider for the City of Tucson, which serves 76 percent of total water demand. Municipal providers as a whole serve 92 percent of the AMA's population, while large private water companies serve 6 percent of the population. Gallons per capita per day rates in the Tucson AMA tend to be lower than those in the Phoenix AMA, with the average for both municipal and private water companies being around 172 gpcd (ADWR 1999b).

Tucson was long the largest city in the United States to subsist solely on groundwater, but this situation has changed. CAP water, the only surface water available, is scheduled to supply 63 percent of the area by 2025, initially through groundwater recharge<sup>2</sup> and eventually through direct use. Full use of these additional water supplies is necessary to meet the demands of the area's rapidly growing population. The city's direct use of CAP water is expected to expand as treatment plants are built in the coming decades. However, as in the Phoenix AMA, different areas within the AMA face contrary water management challenges. Water tables are rising in the northwestern portion of the AMA, and falling in the southern regions, due to the northwest trending topography; thus the northwest benefits from recharge being undertaken in areas to the south. At the same time, the northwestern area has far easier access to CAP supplies due to its proximity to the CAP Canal than do other areas such as the south and southeast, where rapid population growth is already underway.

#### *Santa Cruz Active Management Area*

The Santa Cruz AMA, where the cities of Nogales, Tubac, and Rio Rico are located, was chosen in part because its location along the U.S.-Mexico border encompasses important international water issues (Morehouse et al. 2000) and also because its hydrological structure and water supply situation differ significantly from the other study areas. This AMA is dependent on effluent that is generated in Mexico but is treated in the United States at the Nogales International Wastewater Treatment Plant. The population of Santa Cruz County was estimated to be 39,590 in

2001 (U.S. Census bureau 2002), making it by far the least populous of the areas studied. It is also the least wealthy area studied, with a median household income for Santa Cruz County of \$29,710, compared with \$40,558 for Arizona as a whole and \$45,358 for Maricopa County, where Phoenix is located (U.S. Census Bureau 2002). This has implications for its ability to build and maintain infrastructure that could be crucial in coping with increased climatic variability. The Santa Cruz AMA has 4 large water providers, 3 of which are private water companies, and 10 small providers. The average rate is 189 gpcd, although the rate varies considerably among providers.

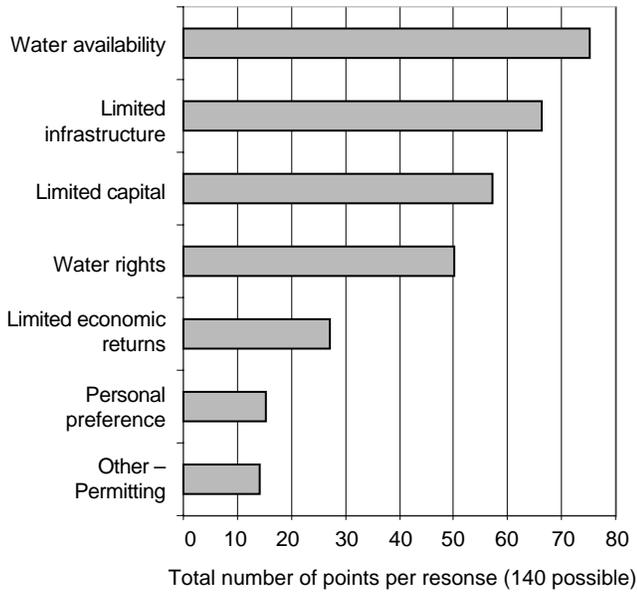
#### *Sierra Vista Subwatershed*

The fourth study site, the city of Sierra Vista, is located near an important and endangered riparian area, the San Pedro River. The human population of the area is expanding rapidly, but this location is not subject to the same stringent level of regulation as are the AMAs of Phoenix, Tucson, and Santa Cruz. A group known as the San Pedro Partnership currently handles water management in the San Pedro watershed, where Sierra Vista is located. The group's goal is to establish an alternative management structure in order to avoid being declared an Active Management Area. ADWR is very much involved in this process.

Sierra Vista is adjacent to a major military installation, Fort Huachuca Army Base, which also has substantial water needs that are unlikely to decrease over the next several decades. In addition to the military base, there are four main water providers, the largest of which has 6,400 customers. The Sierra Vista area also has hundreds of private wells operated by widely dispersed homeowners throughout the area. While the water use of these individual well owners falls below the level that would subject them to ADWR regulation, the impact of such large numbers of small wells upon the aquifer is not fully understood.

## **4.2. Water, Population Growth, and Climate in the Southwest**

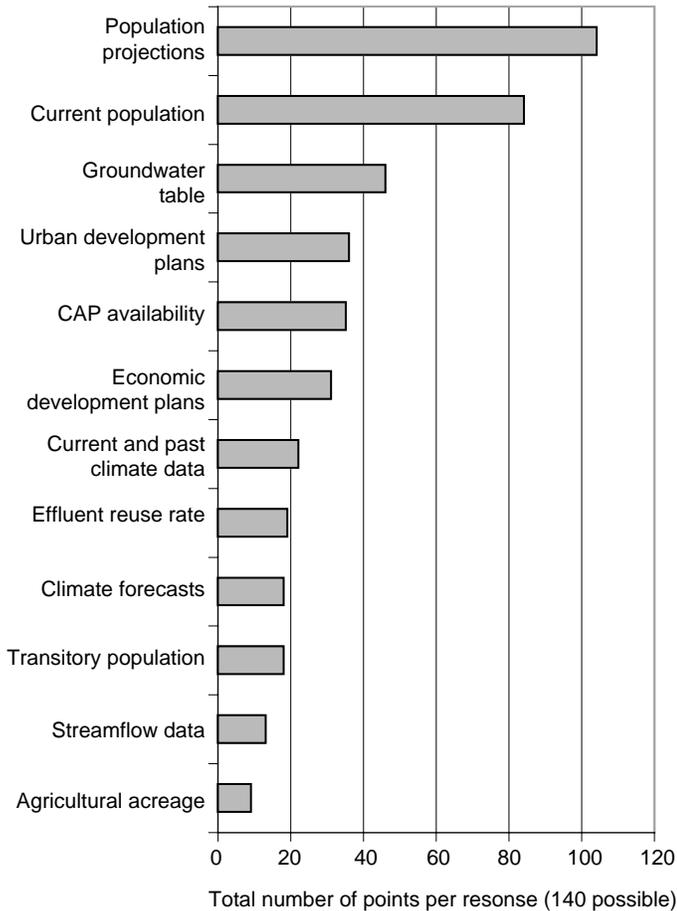
According to the survey responses, water availability and population growth are the overriding natural and social factors in water management in the Southwest. Water managers were given a list of possible factors that determine water supply and demand budgets and that limit the number of customers served. In each case, they were asked to select the five most important and rate them from 1 to 5, with 1 being the most important. The numbers along the x-axis in Figures 2 and



**Figure 2.** Factors Limiting Number of Customers Served.

3 indicate the total number of points awarded to each possible response. If single factor had garnered 5 points from each of the 28 survey respondents, the total would have been 140 points.

As Figure 2 shows, water availability ranked as the most important factor in determining the number of customers that a water system could serve. Water is limited in the study areas not only by relative aridity, but also by regulations and policies (discussed in greater detail in a later section of this report). Groundwater pumping is regulated in the Phoenix, Tucson, and Nogales urban areas due to the fact that they are located in legislatively defined AMAs. Surface water is available in some areas of Phoenix via the CAP canal, which delivers Colorado River water, and through the SRP system, which brings water from the Salt and Verde Rivers. Colorado River water is also delivered to Tucson via the CAP canal. (Surface water is not available to Nogales or Sierra Vista.) However, water managers are allotted set amounts of surface water via these delivery systems and must negotiate to purchase additional amounts if demand exceeds supply.



**Figure 3.** Factors Determining Water Supply and Demand Budgets.

As indicated in Figure 3, population projections are by far the most significant determinant of most water providers' supply and demand budgets.<sup>3</sup> Most water providers interviewed said that they assume that both water supply and per capita water use will stay the same; thus population projections multiplied by usage rates is the primary factor they consider when budgeting and in planning for infrastructure and capital improvement projects. As one provider noted, "We don't really do long-term planning; we just update things based on usage rates."

Water budgeting is closely interwoven with, and in some cases indistinguishable from, fiscal budgeting. As one provider said, "We do financial budgets annually and estimate demand only for financial reasons, not really anything having to do with supply." When asked to describe what they would consider the ideal climatic conditions from a water management standpoint, some managers indicated cool, wet weather that would keep demand low and supply high; but several others said that they preferred hot, dry weather because high demand ensures a robust revenue stream. A preference for predictable and fairly moderate weather, with no sudden extremes, was mentioned repeatedly.

Groundwater levels ranked as the third most important factor in determining water budgets, indicating

that many water providers are aware of the condition of their aquifers and reflecting the focus of current sustainable water-use initiatives in the state. Urban and economic development plans were also relatively important determinants. CAP availability ranked fifth overall, but was the third most important factor in the Phoenix AMA, probably due to the area's greater reliance on this water resource. It is likely that SRP water availability would have proven to be important in the Phoenix AMA if this option had been listed, although no providers included them in the category of "other." Current and past climate data, climate forecasts, streamflow predictions, transitory population, the effluent reuse rate, and changes in agricultural acreage were ranked as relatively unimportant. The relative unimportance of climatic data or forecasts was borne out by the interview results: none of the water providers interviewed employed a staff person specifically responsible for climate or forecast analysis.

Another way of examining the results of this question is to combine the factors that can be clearly linked to climatic factors, including CAP availability, groundwater level, climate data and forecasts, and streamflow data, and compare them to the sum of the factors that are more human-related, such as population projections, current population, urban development plans, economic development plans, effluent reuse rate, transitory population, and changes in agricultural acreage. The aggregate number of points for climatically linked factors is 134, while the human-related figure would be 301. After dividing by the total number of possible points in each category, a resultant ratio of .19 for climatically linked factors versus .31 for human-related variables can be created. This ratio supports the conclusion that human-related water supply factors are considered more important than natural supply factors by water providers as a whole.

#### 4.3. Policy and Political Context

Urban water managers in the Southwest operate within a complex web of international, federal, state, county, and municipal laws and policies. The policy analysis of the CLIMAS Urban Water Study (Carter and Morehouse 2001) addresses these issues in greater detail. Although the present study included only a few questions that explicitly focused upon policy issues, water managers mentioned them repeatedly in many different contexts. This illustrates the importance of considering the policy context in understanding the vulnerability of urban water systems to climatic variability.

Interviewees were asked, "What changes in laws, policies and procedures would you consider most useful in enabling your organization to better deal with climate stresses on your system?" Only 13 of the 21 water providers asked this question had any specific answers, but those who did respond revealed interesting perspectives.

Two responses dealt specifically with the complex web of policy and economic issues that hinder the ability of water providers to cope with drought. One provider said that ADWR's groundwater management requirements for dealing with drought need greater flexibility. Another provider noted the lack of more localized information regarding the likely impacts of drought on their area: "DWR hasn't shown us any data about how long or serious a drought we could endure before there were problems. DWR doesn't seem to have accurate or adequate information about our situation here..." Water quality issues related to the EPA's recent tightening of Safe Drinking Water Act (SDWA) requirements were also mentioned by four providers as management issues likely to become more problematic in times of climatic stress, and as populations continue to expand. It has long been assumed that if drought conditions decreased surface water availability, groundwater reserves could be called upon to make up for any shortages. However, regardless of climatic conditions, groundwater contamination due to arsenic, nitrates, fluoride and heavy metals is a problem in some areas. If groundwater quality does not meet new SDWA requirements, as is particularly likely during drought periods, severe supply problems could result. One provider suggested that the Arizona Department of Environmental Quality should modify their water quality requirements during drought periods.

In addition to ADWR regulation of water systems within the AMAs, the governing body of the municipality where the system is located regulates municipal water providers in Arizona. Non-municipal water services, on the other hand, are governed by the Arizona Corporation Commission (ACC), as provided in the Arizona State Constitution (Arizona Revised Statutes 40). The ACC has as its first priority regulating the rates charged by these providers and limits the ability of water providers to pass on the costs of water conservation to consumers, or to raise rates to encourage conservation. In our interviews, few providers mentioned the ACC as being problematic, and one even commented on how much the ACC has improved over the past few years. However, when asked whether rationing water or raising water rates were potential

means of encouraging water conservation in drought situations, private providers frequently noted that ACC regulations would make those actions impossible. One provider noted that, “It would be helpful to have the legal ability to cut back on the water pressure when we need to, and also to be allowed to pass on the cost of any additional water we’d have to bring in to cope with drought.” Municipal providers would have more flexibility in raising prices in times of water scarcity to encourage conservation. Some providers said that this option was included in or being considered for their drought plan, but none reported having actually enacted higher rates based on climatic factors.

## 5. Results

### 5.1 Most Disruptive Types of Weather and Climate

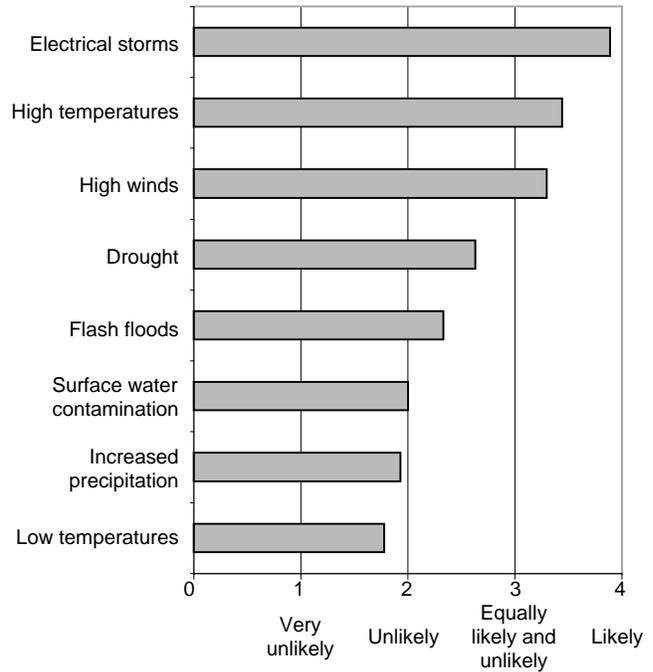
It might seem that in a region with limited water supplies and a rapidly growing population, drought and similar long-term climatic changes could be the most severe threat to the effective functioning of urban water systems. Thus we hypothesized that:

Given that the study areas include some of the driest and hottest locations in the United States, drought and high temperatures cause the most significant strains of water systems in southern Arizona.

To test this hypothesis, we used survey and interview questions to examine how vulnerable overall water systems are to weather- and climate-related disruptions, and to identify which types of climate or weather-related occurrences are most disruptive. Our findings, however, did not wholly support this hypothesis.

In general, water managers believe themselves to be relatively impervious to climate-related impacts in the near term. Providers cited myriad other factors as being more important to the management of the water systems, including population growth, the actions of state agencies, decisions made by town councils, customers, and stockholders, and regulations. Despite the general lack of concern about climate impacts and the relatively low level of concern about weather-related impacts, however, all providers were able to cite examples of ways such factors did indeed affect the operations of their systems, as this section will discuss.

Figure 4 shows the results of a survey question that asked respondents to rate on a scale of one to five the



**Figure 4.** Likelihood of Climate-related Impacts Within the Next Five Years (Average of 27 responses).

likelihood that the daily operations of their water system would suffer climate-related impacts within the next five years, with one being “very unlikely” and five being “very likely.”<sup>4</sup> The results of this question disprove one of our hypotheses, that drought and high temperatures would be the most significant disruptions to water systems. Instead, electrical storms were considered more likely to cause disruptions than were high temperatures; high winds ranked third, above drought.

Table 4 provides more detail about managers’ expectations of future weather and climate-related disruptions by examining the distribution of high and low responses to the previous survey question. Respondents clearly expect greater disruptions due to shorter-term weather-related factors, such as electrical storms and high winds that can disable pumps, than they do from swings in natural climate variability, such as drought or extended periods of increased precipitation. All respondents indicated that capacity to cope with drought stress is built into their systems. However, analysis of our findings suggests the importance of distinguishing between the amount of water *available for use* (i.e. stored in an aquifer) and the portion of that water that can *actually be delivered*. Even systems with ample supplies of water, but that lack the secure infrastructure to deliver that water on a consistent basis, may face short-term difficulties that would appear to be similar to those of systems actually lacking sufficient water supplies.

Table 5 illustrates the distribution of answers to survey question 6, which asked water providers about the specific problems that their systems have encountered in the past<sup>5</sup>. Respondents were asked to circle the number from 1 to 5 that corresponded with the number of times their system had been affected, with 1 indicating “never,” and 5 meaning “10 or more times per decade.”

The interviews provided greater specificity into climate and weather impacts on water systems. For example, respondents said during interviews that delayed or scanty summer rains may have a much more significant impact on water systems than dry winters, despite the fact that winter rains and mountain snows are far more important in hydrologic terms for replenishing aquifers and ensuring adequate stream flows (see Sheppard et al. 2000). Notably, drought was considered a fairly likely consequence by respondents in Sierra Vista and the Santa Cruz AMA, reflecting the more climate-sensitive nature of the aquifers in these areas. Impacts from extremely low temperatures were also viewed as more likely in Santa Cruz AMA.

#### *Electrical Storms and High Winds*

It is not surprising that electrical storms and high winds were identified as the most significant sources of weather-related disruptions; these conditions may be an almost daily occurrence during the early July through late August monsoon period, and may also occur in conjunction with storms at other times of the year. Although the monsoon season may account for up to one-half of an area’s total annual rainfall in just two months, local convective activity gener-

**Table 4.** Distribution of High and Low Responses for the Likelihood of Climate-related Impacts Within the Next Five Years.

Climatic Condition	Number of “very unlikely” (1) responses	Number of “very likely” (5) responses
Electrical Storms	1	8
Extremely high temperatures	4	5
High winds	3	5
Drought	7	1
Flash floods	12	3
Surface water contamination	10*	0
Increased precipitation	11	0
Extremely low temperatures	12	5

\*Ten of the 28 providers actually use some form of surface water, including CAP, SRP, or other surface water.

**Table 5.** Vulnerability of Water Systems to Extreme Weather and Climate Events in the Past 10 Years.

Weather/Climate Condition	Number of “never” (1) responses	Number of “10 or more times per decade” (5) responses
Drought lowered water supply	16	0
Drought necessitated another water source	22	0
Drought increased demand	2	1
Floods increased turbidity in surface water system	19*	1*
Floods damaged or contaminated wells	21	0
High temperatures overloaded electrical pumping systems	8	4
High temperatures caused higher demand, strained supply	8	4
Electrical storms caused power outages, affected pumping	0	9
High winds caused power outages, affected pumping	4	4

\* Surface water is actually used in 10 of the systems surveyed.

ates a “hit or miss” pattern, producing up to several inches of rainfall in localized areas over a span of under an hour, while leaving adjacent areas dry (Sheppard et al. 2000). Lightning occurs not only during the monsoon season, but also notably before the rains actually begin. As with rainfall, lightning displays considerable temporal and spatial variability across the region.

As water providers explained in the interviews, lightning strikes can lead to power outages that affect water delivery and can disable wells through direct hits to the pumps. No water providers reported that they are “never” affected by electrical storms, while nine providers said they were impacted 10 or more times per decade. Many providers noted that they are taking steps to better cope with electrical storms that knock out the electrical lines crucial to running their pumps, such as installing generators and other types of backup power systems. High winds can also damage power lines and lead to electrical disruptions, which can affect plants that treat CAP and SRP water supplies. One provider also noted that high winds raise water demand by increasing the evapotranspiration rate.

Water providers were asked during interviews to discuss some of the most extreme climatic/hydrologic events that their water service has experienced, what the major impact of each event was, and how their water system coped with it. As one provider noted, “Lightning strikes can take out our booster systems, and so can high winds. That type of weather is primarily monsoon related.” A particular type of monsoon-related phenomena, microbursts<sup>6</sup>, was cited as one provider’s “worst nightmare” in terms of disrupting the water system.

Most providers who cited electrical outages said that it takes an average of two to six hours to restore power, depending on the nature of the problem and how rapidly they are able to dispatch repair people. The length of time that pumping could be disrupted before customers would notice varied from immediately, for minimally-buffered systems with no gravity-fed storage and little ability to reroute water between wells or draw on backup power sources, to several days (or never) for providers who could effectively shunt water between different parts of their system or quickly switch to backup generators. Interestingly, preparation for potential computer problems caused by the Y2K “Millennium Bug” was cited in several cases as spurring water providers to install backup generators on their pumps, which can now be used to compensate for lightning

strikes or electrical overloads. As one provider noted, “As our demand goes up, sometimes our reservoirs can’t keep up. It’s better now because we’ve got natural gas backup generators, which we added in preparation for Y2K.” Another provider said, “We’ve had our pumps hit before, but thanks to Y2K preparedness, we’ve now got enough generators to cover that kind of problem. So the outages we do have are generally pretty short-term.”

### *High Temperatures*

High temperatures ranked as the second most prevalent response to survey question 4 regarding anticipated climate-related impacts. The number of respondents who believed these conditions either very likely or very unlikely to occur was relatively evenly distributed, as Table 4 shows. High temperatures can increase demand enough to strain water supplies and overload electrical pumping systems, and thus inhibit providers’ ability to meet peak water needs during times of heavy demand. According to the responses to survey question 6, high temperatures that increase demand enough to strain water supplies were reported to “never” occur in eight systems, while four providers said that this occurred 10 or more times per decade (see Table 5). High temperatures leading to overloaded electrical systems already stressed by demand for power to run cooling systems “never” occurred in eight systems, while four reported this type of situation 10 or more times per decade. In the interviews, providers noted that peak demand times usually occur in May and June, when temperatures are high and the monsoon rains have not yet begun.

### *Flooding*

Flooding can occur in the Southwest as a result of short-duration, highly localized and sometimes torrential summer monsoon storms; after longer-lasting, more widespread storms that occur due to offshore tropical storm activity in the Gulf of California and Pacific; or during the winter, particularly in El Niño years. Monsoon-related flash floods ranked as a far less significant concern in survey question 4, indicating that systems can normally handle the usually localized and short-term effects. However, two interview respondents noted that flooding during monsoon season is likely to cause water lines to break or water mains to become exposed, while another reported that two heavy monsoon storms had strained their sewer system’s ability to run at three times normal capacity. Adverse consequences of increased surface water runoff, such as damage to or contamination of wells, or in-

creased turbidity, were infrequently noted. Two interviewees, however, did cite flooding as the cause of the most severe climatic events to affect their systems. Long periods of increased precipitation, another type of flooding-related disruptive weather listed in question 4, were considered unlikely to cause problems in most study areas (see Pagano et al. 1999).

### *Drought*

It is surprising to find that in a region characterized by low rainfall and rapid population growth, and following two of the driest winters in history, drought ranked only as the fourth most likely climate-related impact. The weight given to this response varied significantly between and within study areas; those with shallow aquifers and no alternative water sources rated the impacts of this condition far higher than did those with deeper aquifers and/or multiple water sources. For the purposes of this study, drought was not specifically defined for water providers; instead, the responses to drought-related questions reflect providers' perceptions of what constitutes drought and how often it occurs.

Although winter rains and mountain snowfall are more important to reservoir and aquifer recharge, drought conditions and high temperatures that extend beyond the normally dry April-to-June period are of greater immediate concern to water system managers. Much of the increase in demand as the weather warms is related to landscape watering and similar outdoor water uses, which decreased markedly after the summer rains start. Delayed or scanty monsoon rains can significantly increase demand; indeed, several providers mentioned this as being their "worst nightmare." As illustrated in Table 5, only two providers reported that increased demand due to drought is "never" a problem, while one reported this happening 10 or more times per decade. As one provider responded when asked about the most extreme hydrologic/climatic conditions his system had been forced to cope with, "Hot and dry summer conditions caused a situation...where our pumps couldn't keep up with demand. It was a situation where the monsoon started six weeks late, and it was really hot. Evaporative coolers were what was making the difference—they really use a lot of water when you get enough of them going at once." Another provider commented on the impacts of delayed monsoon rains: "There have been a couple of times in the pre-monsoon season, when it's been very hot and dry, when we've asked people not to wash their cars, not washed the city fleet, and had (the city bus service) not wash their buses; but it's been the kind of thing where

we do that for a week, and then the monsoons come. As soon as the monsoons come, our demand really drops." Although many providers do currently have the capacity to pump sufficient groundwater to compensate for higher demand and less surface water, maintaining this level of redundancy in a system despite significant population growth is considered a major challenge. Providers who depend solely on groundwater and are in areas with more climatically-sensitive, shallower aquifers would feel the impacts of both a short-term delay in monsoon rains and more protracted drought sooner.

A few water systems serve primarily winter visitors, the "snowbirds" that come to Arizona each winter to escape from colder climates. Those systems reported that their annual peak demand occurs in the winter and noted fewer problems with meeting water needs due to less steep increases in demand. However, the manager of one such system said that summer demand does not fall as much as the population decline would suggest, because many winter residents leave their irrigation timers set at the same rate year-round.

### *Low Temperatures and Long Periods of Increased Precipitation*

Providers evidenced little concern with the types of weather- and climate-related situations that are likely to occur during the winter months. Low temperatures and long periods of increased precipitation, as are more likely to occur during El Niño years, were considered unlikely to cause problems. Flooding in general, as previously discussed, ranked low in the responses to question 6. Even in years when winter rainfall is scanty, demand is also far lower during the cooler times of the year, so water providers may not perceive winter droughts as problematic. Freezing of pipes was noted to be a problem by only one water provider, who is located in an area that is colder in the wintertime relative to the other study areas.

Interview data from providers whose water supplies are derived from shallow, hydrologically-responsive aquifers showed that these groundwater-dependent systems are quite vulnerable to both short-term and long-term droughts. Other groundwater-dependent systems, in contrast, reported rising water tables and problems with water logging due to their physical location down gradient from groundwater flows and due to the effects of proactive recharge activities. These findings affirm that it is inappropriate to lump all groundwater systems into a single category of either more or less vulnerable

to climate impacts. Rather, it is necessary to view these systems in terms of a set of complex, interactive variables—such as characteristics of aquifer deposits, aquifer depth, hydrologic connectivity of the groundwater system to surface events/conditions, and degree and nature of dependency on this source for different uses (as well as the criticality of those uses; that is, to what extent is reduction or elimination of this type of water use feasible?). Given that much of the analysis of water supply and demand budgets is produced at the AMA or watershed level, fine-scale variability can be glossed over, masking micro-scale climatic vulnerabilities among water providers and consumers. These vulnerabilities may be exacerbated by lack of infrastructure to allow ready access to alternative water sources in times of drought stress.

### 5.2 Size DOESN'T Matter

Despite only including water systems classified by ADWR as “large” (those that serve over 250 acre-feet of water per year), the study sample encompassed a wide range of system sizes, serving from 485 to 206,000 customers, with the median number of customers being 2,800. We hypothesized that:

Smaller water systems serving fewer people are more sensitive to climatic variations than larger systems, due to a lack of capital to install buffers such as a storage space and additional/deeper wells.

In order to understand the importance of size independently from the rate at which a water system must grow to accommodate an expanding population, we compared the size of water systems (defined here as number of connections) with the total number of weather and climate impacts experienced over the most recent 10-year period. Table 6 shows the aggregate of the number of times providers were affected by the conditions listed in Table 5, along with system size (in terms of number of connections).

As the table illustrates, size alone does not appear to be a major factor in determining a system’s sensitivity to climatic fluctuations. The systems that reported the highest average number of disruptions are those in the 10,001-50,000 range, while that those with 1,000-1,500 connections report the fewest disruptions. Although the number of systems surveyed is not large enough for these results to be statistically conclusive, these findings suggest that larger, more complex systems may actually be more vulnerable to weather- and

**Table 6.** Number of Weather and Climate Impacts Over the Past 10 Years Based on Water System Size.

Number of connections	Number of systems	Total number of weather and climate impacts over past 10 years
<1,000	4	17
1,000-1,500	4	11
1,501-3,000	5	19
3,001-10,000	5	18
10,001-50,000	3	27
>50,000	5	19

climate-related problems than smaller systems. As described in greater detail later in this report, smaller systems are not more likely to have difficulty getting the funding required to build and maintain adequate infrastructure; nor are they less likely to engage in planning for extreme climatic events such as prolonged drought or floods. It is also worth noting that there was no obvious correlation between number of weather- and climate- related impacts and location within the study areas.

### 5.3 Population Growth

Given the importance of population growth on water demand, we hypothesized that

The rate of population growth is an important influence on system vulnerability to climate variability and change. However, the exact nature of this role is uncertain, since smaller, stable systems may not have the capital to put in buffers against climatic disruptions, but systems in fast-growing areas might not be able to keep up with growth.

This hypothesis was supported by our findings. There can be little doubt that population growth is the dominant focus in regional water planning, as Figure 3 showed. Although water supplies may be adequate at present, the additional pressure that larger populations will put on those supplies should be a vital consideration in coping with future climatic variability. Respondents believe that growth in much of the region will continue at a rapid pace into the foreseeable future, with overall expectations of 3 and 10 percent growth over the next 20 years. Several providers antici-

pated that their population would double by 2025, particularly in the rapidly growing suburbs of the Phoenix metropolitan area. Most providers interviewed did not expect their areas to reach their full population potential, or *build-out*, for another 20 years. One provider noted, “We’ve issued about 10,000 building permits per year for the past five years. Our secure water supply is one of the reasons that companies are eager to locate here.” Another provider said, “Our increases in demand are all based on growth. To get an idea of how fast it’s growing, look at new building permits: in 1994, 2,500 were issued; for 1996, it was 3,600; in 1998, it was 4,200.” Another provider noted that the population of his city had grown from 12,000 residents in 1980 to 90,000 in 1999.

Negative effects of unrestrained growth, including insufficient fees charged to developers to cover additional infrastructure, as well as environmental impacts upon endangered species, were mentioned as problems in some areas, and believed by some to be significant enough factors to redirect rapid growth to other areas.

Most of the growth in Arizona is in the form of new subdivisions, which can range from a few dozen to several hundred homes constructed within a limited time frame. One provider’s comments reflected the general trend: “All of the new growth is in subdivisions. Some of those subdivisions have limits on the amount of grass you can have; most homeowners’ associations call for desert landscaping. They’ve also got parks and open spaces that use some water.” Although xeriscaping<sup>7</sup> is popular in many areas (particularly the Tucson AMA), and is required by some subdivision plans, high water use turf lawns are still being installed in some areas. Private golf courses are a significant water-use feature

in some subdivisions (although others are discouraging them) and swimming pools are increasingly prevalent as well.

In order to evaluate exactly how growth is changing water sources and systems, survey respondents were asked about current trends and expected future changes in six different water demand and supply categories. The results are shown in Table 7.

All 28 respondents report that they are currently experiencing an increase in the number of service connections; only 1 of 27 anticipated a decrease in service connections in the future. Given the ban on increased irrigated agriculture within the three AMAs included in the survey, it is not surprising that only 1 of 17 respondents indicated an increase in agricultural demand. Current conditions and anticipation of the future of industrial, municipal, and residential demand trends show no such declines.

One would expect that increasing populations reliant on groundwater resources would be drawing down water table levels, and this is the case in 15 of the 28 water systems queried. However, 10 systems indicated rising water table levels, most likely due to greater use of surface water and increased recharge efforts, often incorporating greater use of effluent. Seven systems anticipated that these actions would lead to increases in the water table level in their areas the future, while 14 anticipated decreases. Fewer respondents answered questions about surface water trends, probably due to the lack of surface water sources within many service areas. Only one of seven respondents saw surface water flows currently increasing, while four saw decreases and two saw no change. One respondent indicated anticipating surface water increases in the future, perhaps

**Table 7.** Trends in Water Use and Water Availability.

	Trends to date			Future Changes		
	Increase	Decrease	No Change	Increase	Decrease	No Change
Number of service connections	28	0		26	1	
Water use in agriculture	1	16		1	16	
Municipal/Residential water use	27	0		25	1	
Industrial water use	0	17		19	0	
Groundwater table	10	15	1	7	14	1
Steamflow	1	4	2	1	3	1

as further rights are secured; three anticipated decreases, and one expected no change.

Providers were asked, “Given the current population projections for your area, what impact could extreme climate conditions have on your company 10 or 20 years from now? What’s your worst nightmare?” A more specific question about an area’s growth rate and pattern (subdivisions, in-fill, industry) was added to the interview protocol after several providers mentioned this topic as important.

The comments of one provider incorporate the wider realm of growth-related conflicting interests in managing under drought conditions and illustrate the fact that the rate and type of growth an area is experiencing have bearing on a water system’s ability to cope with climatic variability:

Responses to drought between municipalities (as in deciding when a drought is occurring and what should be done about it) are heavily dependent on several factors such as groundwater quality, the particular mix of water sources, etc. This makes regional planning and responding in a unified way difficult, because there are always local pressures not to declare a drought. Every water provider wants to be the last to admit that they are having problems. There are times when it’s really important to present a unified response, but it’s difficult to do. The media seize on every statement we make. It’s all tied to development; the residential development will come regardless, but for commercial and industrial users, each town tries to woo them, and water supply and management plays a role in their decisions.

Only one of the 15 providers interviewed who reported having a CAP allocation was currently using its full supply. Nine providers were using a portion of their allotments, while five had not yet started to use their allotments. Providers who had not yet started using their CAP allotments or were not yet using their full portion said that the lack of infrastructure, such as canals, pipes, and treatment plants, was the major hindrance. A few of those who are utilizing at least part of their allotment had the treatment plants in operation to provide the water to customers through direct delivery, but many more reported recharging their CAP water to replace mined groundwater, rather than using it directly. Providers in this category generally expect to

construct more treatment plants to treat CAP water for direct delivery, particularly in the Phoenix AMA. As one provider put it, “We’re not currently using our entire allotment because the treatment plant can’t yet handle the whole allotment. With our development rate, we will eventually need the whole allotment. The population of (our service area) was about 8,000 in 1985; now it’s 100,000, and we expect to reach 250,000 eventually.”

Increased utilization of their portions of Arizona’s CAP supply is the major way that many water providers intend to keep pace with population growth. Most providers with unused CAP allotments intend to meet increasing consumer demands through greater use of this resource, and some mentioned that they could buy larger allotments if and when they need them. However, this projected reliance on Colorado River water could become problematic if a severe basin-wide drought combined with population pressures were to cause Arizona to have its CAP allocation significantly reduced or totally suspended, as could occur under existing law if there was insufficient water in the river to first meet the needs of Mexico, California, Nevada and non-CAP senior rights holders in Arizona. Shorter-term disruptions to the CAP system could also occur if extensive infrastructure repairs were needed. A few providers mentioned concerns about the reliability of the CAP supply. One noted that disruptions to either the canal itself or to the electrical infrastructure necessary for pumping CAP water to Phoenix and Tucson that lasted longer than a month would result in a serious water shortage. Another mentioned what he termed “toxic terrorism,” the potential for deliberate contamination of water supplies that might be possible in many areas along the largely open-access canal. A situation of this sort could have far-reaching consequences, particularly if such contamination spread throughout the CAP system.

Providers who currently utilize only groundwater express little concern about overexploiting this water resource. Most of these providers have made arrangements to recharge their CAP allocations and hence are recording rising water tables. The majority of providers are also currently recharging effluent supplies or plan to do so in the near future. Providers in areas without CAP allocations have the impression that groundwater reserves are sufficient to handle the expanded population: “I’m not worried about it at all, because we’ve got enough water and nothing is going to happen to it. It’s all up to the economy, when and whether those homes

get built, but there won't be any problem no matter what." However, some providers did express significant levels of concern: "I expect that the situation will become more precarious due to declining water quality in the aquifer. We've got very good water quality now, with no contamination problems, but in 20 years, I don't know. Even if there's not much population growth in this area, [a nearby municipality] is growing like crazy, and it could still affect us."

In contrast to the lack of concern regarding water supplies, some providers did express difficulties in ensuring that infrastructure was able to expand as rapidly as population growth: "Based on our planning, no major problems are expected under normal conditions. A lack of infrastructure could become a problem, but our resources look like they'll be more than adequate to keep up with growth. It does seem like we're always playing catch-up to keep up with our 3 to 4 percent growth rate, and that's expected to continue. We expect build-out by 2010 or 2020." Another provider noted, "We're trying not to raise our rates, but it's tough with all the new subdivisions going in. We've got an 8 to 10 percent growth rate..."

If these providers are struggling to keep pace with simply meeting the needs of their populations under normal climatic conditions, it is unlikely that additional storage and precautions against changing climatic conditions are being taken. Although some providers did express concern about this, few believed that they were justified in raising rates or asking municipal governments for additional funds to further extend their safety margins.

Other providers were more sanguine about growth issues. They acknowledged that although growth is indeed a major change occurring within their systems, developers are required to ensure that adequate infrastructure is built. As one provider summarized, "Developers are required to be 100 percent self-sufficient, and much of the infrastructure needed will be coming in before the actual developments, which should put us way over-capacity for quite some time." Developers are also mandated to comply with ADWR's 100-year assured supply rules, which at least in theory should limit construction to areas considered to have adequate water supplies. (For a critique of the Assured Water Supply program, see Carter and Morehouse 2001).

Both large and small providers expect greater consolidation of water systems over the next 20 to 25 years, as

municipal boundaries expand to encompass what are now smaller, outlying suburbs. Thus some smaller water providers expect to be subsumed within larger ones, and some larger systems expect to expand their service areas by taking over smaller systems. These trends warrant monitoring, both to assess the nature of and extent to which vulnerability to climatic events may change, and to identify how this may alter the nature and extent of climate information needs.

The Groundwater Code dictates that AMAs should achieve safe-yield (water withdrawals not greater than replenishment) by 2025, and thus the issue of growth is likely to become increasingly salient as the deadline approaches. For the non-AMA areas of the state, this date can serve as a convenient marker for estimating and anticipating potential impacts of development on water supply and demand, particularly as high growth rates are anticipated to continue in many of these areas. Changes in the patterns in types and volumes of demand, in interaction with climatic variability, constitute potentially important sources of stress on both human and natural systems. Working with providers, other community decision makers, and climate service entities over the next several decades to monitor changes in climate information needs—as these needs change in response to the nature and intensity of multiple stressors—could prove vital in averting adverse impacts on vulnerable natural and human systems.

#### 5.4 Water Sources, Delivery, and Distribution

Initial conversations with water management officials and water providers indicated that having access to a variety of water sources and the ability to easily shift delivery between sources is an important buffer against climatic variability. Providers with access to more than one water source spoke of the "level of redundancy" in their delivery systems as a key means of ensuring that if conditions such as long-term drought affected one surface water supply, they could mitigate adverse effects by utilizing more groundwater or other surface water sources. These findings support our hypothesis that

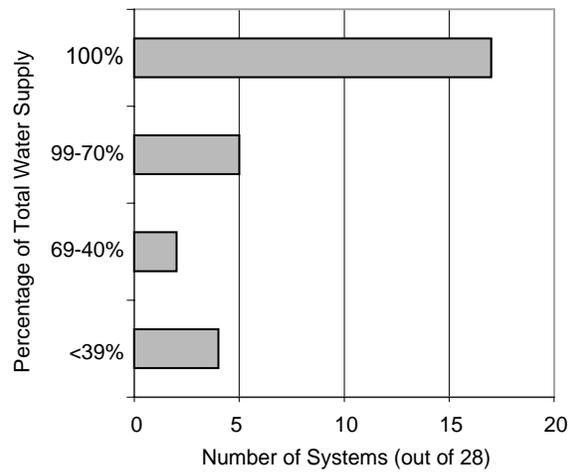
Systems relying on only one water source are more vulnerable to drought due to less redundancy in their water supplies and less flexibility in their systems. Hence, the greater the number of water sources a system can access, the less vulnerable to climatic fluctuations it is.

Water providers who have access to multiple water supplies believe that this is a formidable buffer against

drought-related decreases in water supplies. Some of the providers who exhibited the highest degree of confidence in their water supplies were those who had access to surface water from both CAP and SRP sources. As one very large (>100,000 customers) provider noted, “We have the ability to switch between CAP and groundwater, or SRP and groundwater, if we need to...It’s possible that there could be a shortage on either the Colorado or the Salt/Verde, but the odds of both occurring at once are pretty slim.” Other multiple-source providers echoed the belief that while drought might affect one river system or the other, the odds of both the Colorado River Basin and the Salt/Verde system experiencing severe drought at the same time are virtually nonexistent. However, analysis of tree-ring records by Meko et al. (1995) contradicts this assumption. This study found evidence of a severe drought from 1566–1585 that extended throughout the entire western United States, significantly reducing flows on both river systems for 19 years. Likewise, the current drought, while not yet of the magnitude of the 1500s drought, has extended across both the Upper and Lower Colorado River Basins, including the Salt-Verde River system.

While shifting between water sources may be a useful strategy in coping with water supply disruptions, it is not an option available to the majority of providers in the study areas. As Figure 5 indicates, of the 28 respondents, only 11 reported using other water sources in addition to groundwater, and thus have other water sources available. Looking to the future, 9 additional providers expect to acquire the use of sources beyond naturally recharged groundwater.

Of the 11 respondents who have access to water sources beyond groundwater, the two primary alternative sources are CAP water (available in parts of the Phoenix and Tucson areas) and Salt River Project water, available only in certain portions of the Phoenix AMA. Of the systems having access to one or both of these water sources, CAP water supplies ranged from 10 to 50 percent of total water use in individual service areas, while SRP water ranged from 8 to 60 percent of total supply. Most providers anticipated eventually using a mix of CAP, SRP, and effluent supplies to fulfill 2 to 95 percent of their water demand. In at least two cases, making a substantial shift to CAP water may be interpreted as a strategy to cope with water shortages identified in the Third Management Plan for the Phoenix AMA (ADWR 1999a). Only one provider anticipates increasing use of SRP water.



**Figure 5.** Percentage of Water Supplied by Groundwater.

Perhaps the most surprising finding to come out of this question is the low rate of anticipated future use of effluent. At present, effluent is used by five providers, with proportion of total supply ranging from 1 to 10 percent, and neither the percentage of total supply nor number of systems using effluent are expected to increase dramatically in the near future. In part, this may be because the survey question asked about plans for the next five years, and construction of separate effluent delivery systems can take a long time. However, given the current high use of water for non-potable purposes (such as landscaping, artificial lakes, and golf courses), a more rapid and thorough incorporation of effluent into provider water budgets might have been expected.

In order to ascertain the vulnerability of water systems with more or fewer water sources, each system’s number of water sources was compared with the total number of drought-related disruptions reported; then the number of drought-related disruptions was divided by the number of systems in each “number of water sources” category. Table 8 displays the results.

As Table 8 illustrates, although systems with only one water source did report that drought conditions had affected their systems in various ways over the past 10 years slightly more often than systems with multiple water sources, the correlation is not clear. The one system with five water sources reported only slightly fewer drought impacts than average, while the five systems with four water sources reported more drought effects than systems with only two water sources.

Some small systems that utilize only groundwater also report that they can easily cope with both frequent causes of disruptions such as lightning strikes and high

**Table 8.** Number of Water Sources, Systems and Drought Impacts.

Number of water sources	Number of systems	Number of drought impacts over past 10 years
1	16	5.6
2	5	3
3	0	n/a
4	5	3.8
5	1	5

wind, as well as with less frequent occurrences such as severe drought. As the manager of one of the smallest systems interviewed noted, “Even if the wind blew all those power poles down, we have natural gas backup for our pumps. We’ve also got two wells and could run with just one if something happened to the other one. We’ve also got storage tanks. In 15 years, there’s never been a situation where customers would have noticed any problems.”

#### *Sustainability and Reliability of Groundwater vs Surface Water Use*

Most water providers intend to ensure long-term sustainability of water supplies in the face of rapid urban development and population growth by increasing their ability to shift between water sources, from reliance on groundwater to more readily renewable sources such as CAP, SRP, and effluent. Interestingly, the exact opposite strategy was identified in the survey of providers in the Susquehanna River Basin: providers were shifting to groundwater to enhance their resilience to climatic stresses (O’Connor et al. 1999). In some respects, the Arizona providers’ shift to renewable surface water supplies should reduce the area’s vulnerability to long-term drought by ensuring that adequate groundwater remains in reserve for use if surface water becomes unavailable.

In urban water management in the Southwest, groundwater is viewed as fail-safe insurance against drought-induced water shortages that more readily affect surface water resources. However, groundwater in the region is not considered to be an entirely renewable water source. Researchers believe that much of the water in subterranean aquifers in the Southwest was deposited during prehistoric periods when conditions were much wetter than those currently found in the re-

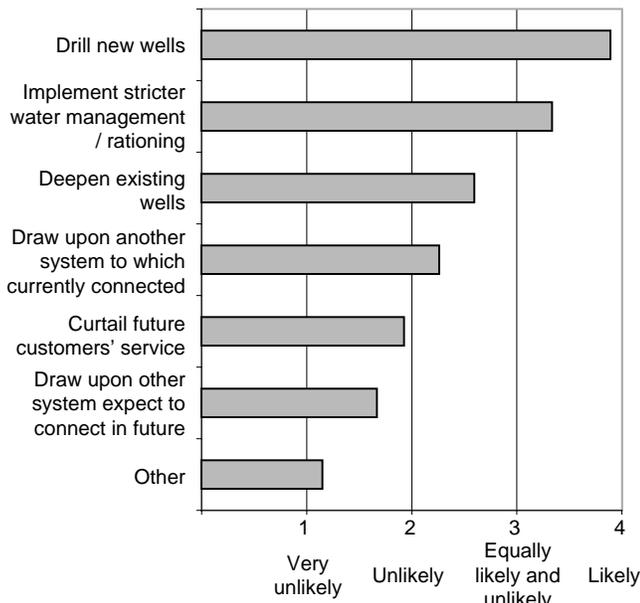
gion. Depending on the geology, local climatic conditions and rate of use of groundwater reserves, the portion of groundwater that is replenished annually may be only a fraction of the water withdrawn to meet human needs. Strategies and infrastructure for moving available supplies to areas of critical need during a sustained drought, or other interruption in supplies, may fail if these systems have not been adequately maintained.

In recognition of the ultimately unsustainable nature of reliance on groundwater reserves to meet the demands of rapidly expanding populations, the Arizona Department of Water Resources has mandated that water systems within its Active Management Areas balance groundwater withdrawals with the best hydrological estimates of annual recharge amounts. However, these standards are based on assumptions of a stable climate with precipitation levels and water supplies similar to those that have occurred over the past 100 or so years of record keeping, despite the fact that the longer-term climate record suggests that the 1980s through the early 1990s (when most population growth occurred) was actually one of the wettest periods on record (Western Regional Climate Center 2002). There is little evidence that providers seriously believe that water supplies may be subject to decreases from long-term dry spells or through contamination (due to either naturally-occurring concentrations of contaminants that increase as water tables drop, or through runoff from agricultural, industrial and municipal activities). However, in this arid region, warmer, drier weather generates significant increases in evapotranspiration as well as in water demand for outdoor irrigation, cooling, and water-oriented recreational activities. According to Boland, “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 1997:158).

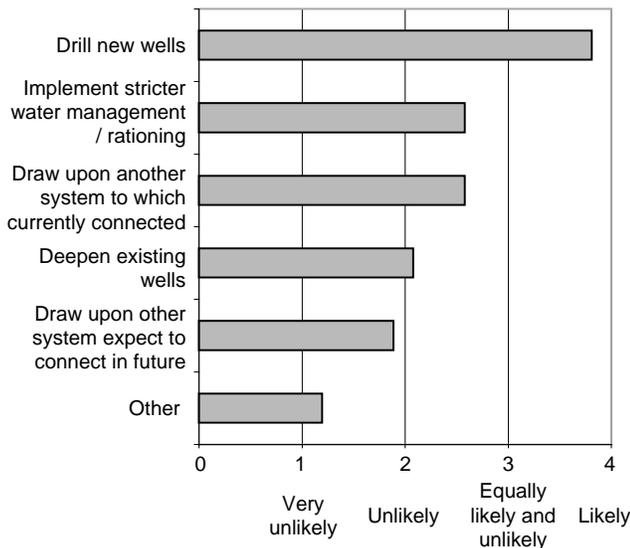
Water providers were asked what type of actions they would expect to take in the event of a longer-term decrease in water supplies, or in response to contamination of water supplies. Respondents were given seven possible responses (including “other”) to a long-term overall decrease in water supplies, as could occur with either a long-term drought or actual climate change. Providers were asked to rate the likelihood of their employing each of these solutions on a scale of 1 (very unlikely) to 5 (very likely). The total points for each re-

sponse were then added together and divided by 27 to find the average. The results are presented in Figure 6.

The responses to question 7 can be grouped into those that would rely more heavily on the aquifer (drill new wells, deepen existing wells, draw upon another system to which currently connected, draw upon another system you expect to be connected in the future) and those that would decrease human impacts on water resources (implement stricter water management/rationing, curtail future customers' service). According to respondents, their most likely response to an overall



**Figure 6.** Likely Responses to Long-term Decrease in Water Supplies (Average of 27 responses).



**Figure 7.** Likely Responses to Contamination of Water Sources (Average of 27 responses).

long-term decrease in water supplies would be to drill new wells; the third most likely response would be to deepen existing wells.

Although measures that draw more heavily on groundwater supplies are among the most likely to be taken, their utility in coping with long-term climate change is dubious. Each of these remedies seeks to mitigate the impacts of falling water tables and reduced surface flows by simply exploiting water resources more heavily than has been done in the past. Drilling new wells, deepening existing wells, and drawing on the water resources of other areas are limited solutions to simply not having adequate water resources to support the current consumption levels of expanding populations, particularly in times of prolonged climate stress.

Strategies to decrease human impacts on water sources, such as implementing water restrictions and curtailing future customers' service, provide more sustainable ways of coping with water scarcity. However, these remedies may be politically unpopular (particularly among growth-minded development interests) and may also conflict with existing regulations. Under current Arizona Corporation Commission (ACC) regulations, private water providers cannot refuse water service to anyone requesting it within their service boundaries. Thus even if a water provider knows that adding more customers will increase its overall demand more than the supply can support, they must continue to provide connections. As one provider put it, "The ACC says that we have to provide water to anyone within our service area who wants it. There will come some sort of breaking point where our demand outstrips what we can provide, and I don't know what will happen then." Similar constraints limit the flexibility of municipal water providers.

*Expected Responses to Contamination of Water Supplies*  
 Similar responses were given to a question that asked water providers to identify measures they might employ if faced with contamination of their water sources (with the exception that curtailing future customers' service was not offered as an option). Using a tabulating procedure identical to the one outlined for the previous question, the results for this question are presented in Figure 7.

Responses to this question were quite similar to those for the previous one, with the exception that drawing upon another system ranked higher than deepening

existing wells. As previously mentioned, in some areas water quality could become a greater concern in times of climate stress. While drilling new wells or deepening existing wells might provide some short-term relief, the utility of these responses would be limited if contamination were widespread. Drawing upon other systems could offer some relief, but if the contamination occurred during a time of water scarcity, this might not prove a viable solution.

*Ability to Deliver Groundwater*

Another aspect of providers' ability to use groundwater reserves in the event of severe sustained drought is the capacity of their wells to remain effective despite falling water tables and diminishing supplies. Therefore, providers were asked specific questions about well depth, depth to water and average well flow, which may all influence how severely water systems might be affected by fluctuating precipitation amounts. Systems with shallow wells, and particularly those drawing on shallow aquifers, would be more immediately affected than those with deeper wells and aquifers. Respondents were asked to indicate the minimum and maximum depth of their wells and the average depth to water. As Figure 8 shows, there is considerable range in providers' access to groundwater resources.

These results indicate that the vast majority of systems have maximum well depths deeper than 500 feet, much deeper than the average depth of water. This indicates that these systems would be well equipped to respond to water table declines, although they might have to deal with issues such as decreasing water quality and increasing pumping costs as aquifers are drawn down, and might eventually reach a point where groundwater pumping is no longer feasible.

Reducing well flow has been cited as a way that water providers might cope with decreasing water resources. Providers who start with higher flow rates may be better able to endure reductions than those who have low flow rates to begin with. The average well flow for the respondents was 816 gallons per minute, with a range extending from a low of 175 gallons per minute to a high of 2,100 gallons per minute (Figure 9).

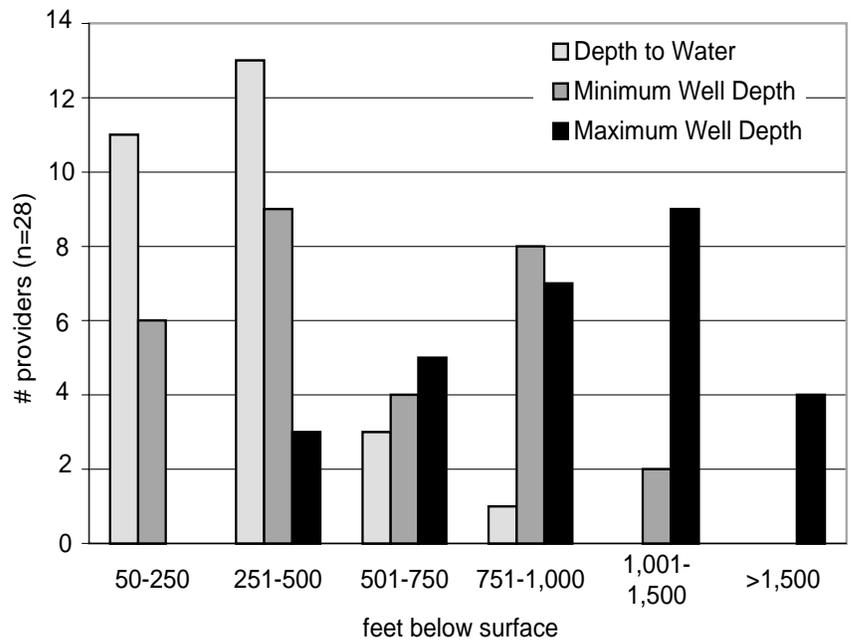


Figure 8. Depth to Water, Minimum and Maximum Well Depths.

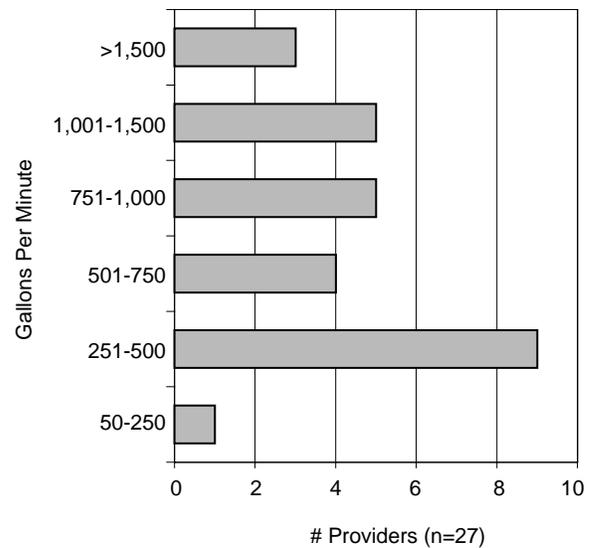


Figure 9. Average Well Flow.

*Current and Future Service Capacity*

In order to assess the current and future service capacity of urban water systems in the study areas, providers were asked about infrastructure such as the number of wells and pumps, and the amount of reservoir capacity and miles of pipeline. These could be key determinants in how water systems cope with weather- and climate-related problems, and help determine whether shifting to groundwater supplies to cope with decreased amounts of surface water is indeed a feasible strategy. For example, redundant well capacity means that some wells can be shut down if need be without depriving customers of water; and high storage capacity allows

systems to better cope with peak demand times and shortages. Therefore providers were asked about their system's infrastructure.

The results of these questions revealed a wide range of responses, such that it was impossible to ascertain by this factor alone which systems have adequate capacity to manage their water resources in periods of drought and unusually hot weather, or whether water managers could respond to forecasts that indicate that high water use and low supply situations may be imminent. However, responses regarding plans to expand infrastructure in the future did reveal that most systems see this as a way of increasing their resilience to climatic variability and keeping ahead of population growth.

Looking to the future, most respondents indicated that they plan to increase the number of wells they operate, with 5 being the highest number of new wells planned. One provider intends to take 15 wells off line. Similar trends were noted in the number of pumps. As might be expected, the greatest number of new wells and pumps are, for the most part, planned by the providers located within the more rapidly growing residential areas of the Phoenix and Tucson AMAs.

With regard to plans for future reservoirs and reservoir capacity, 22 of 28 respondents indicated expansion, ranging from one to eight new units. Likewise, the anticipated future reservoir capacity was expected to rise, ranging from 90,000 gallons to 275 million gallons, computing to an average of 20 million gallons and a median of 5 million gallons. The variance in this case may be attributed to the high number of smaller systems included in the survey. Nineteen respondents indicated that they expected the number of miles of pipeline to increase, a revealing indication of the extent to which urban sprawl persists in the region.

*Connections with Other Water Systems*

To examine other possible means water providers might employ to cope with disruptions to their water systems, providers were asked whether they are a) connected to a neighboring community; b) have an agreement to purchase water; c) are in the process of connecting with a neighboring community; d) neither, but are considering an agreement to buy water in emergencies; or e) not connected to any other water systems. Ten of the 28 survey respondents indicated that they are not connected to any other water systems and have no immediate plans to connect (Figure 10). Six out of the 28 indicated that they are connected to a neighbor-

ing community. Four respondents already had an agreement to purchase water. Another four respondents indicated that had an agreement to purchase water *and* were connected to another system. Only one provider indicated being in the process of connecting with another community, while three said they were considering an agreement to buy water in emergencies.

This question was pursued further during the interview process; providers were asked about the nature of their connections and how often they used them, or why they had not chosen to build interconnections with other water systems. Of the providers who had connections to neighboring communities, most said that the connections were only used in true emergencies. About half said that the connection had been used only once or twice to their knowledge, while the other half said that such connections had never been used. Some Phoenix AMA water providers are connected to other systems because of agreements to share treatment plants; several mentioned plans to make more such connections as the AMA's shift from groundwater to surface water continues.

Opinions about the value of interconnections for emergency purposes varied; as one provider noted, "Anytime I can get an interconnection, I'll take it, because it adds an extra layer of buffering, and it's good insurance for both water services." Another provider expanded upon this: "It's stipulated that they're only to be used in the event of an equipment failure or some other short-term problem, not for when they can't

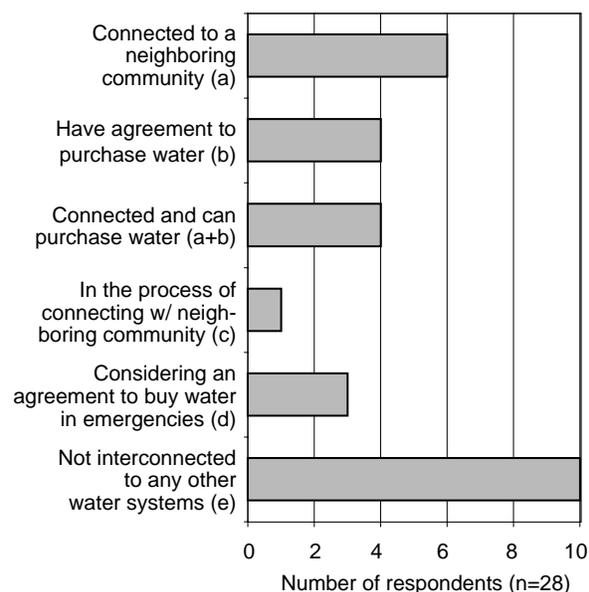


Figure 10. Connections to Other Water Systems.

meet their demand. We feel like if they're going to be in the water business, they need to be able to take care of their system. It's also stipulated that others using our system can't adversely affect our customers." These responses indicate that relying on interconnections would not be an effective way of dealing with long-term drought. Other providers brought up concerns about possible water quality issues associated with using interconnections and potential problems with corrosion of pipes when switching between groundwater and surface water.

Thus the ability to access multiple water resources appears to be an important, but neither infallible nor essential, means by which urban water systems in the Southwest may decrease their vulnerability to climate-related decreases in water supplies.

**5.5 Short-term Service vs. Long-term Sustainability**

Another hypothesis relating to the importance of time scales on multiple levels in water planning was also supported by our findings:

Water systems dependent exclusively on groundwater resources are essentially invulnerable to short-term climatic variability, but are at risk from long-term climate shifts towards drier weather.

Time is a crucial element in terms of both planning and population growth in the Southwest. We explored the groundwater/surface water relationship in the previous section. However, this hypothesis caused us to consider the importance of multiple time scales in two additional ways: 1) planning horizons; and 2) long-term climate-related vs short-term weather-related disruptions to urban water systems.

*Planning Horizons*

The means by which water managers plan for the operations of their water systems and infrastructural needs is important in coping with potentially increased climatic variability, water scarcity, and population growth. Understanding the time frames that water providers use in planning and budgeting for water supplies and infrastructure has implications for how quickly water providers might adapt to long-term climate shifts; for example a provider who plans only three years in advance might more easily incorporate new assumptions about water supplies and demand than one who plans decades ahead, although longer-

term planning could include more realistic assessments of the sustainable use of water resources.

To assess this factor, providers were queried regarding the perspective from which they engage in planning for their operations, and the results are shown in Table 9. Most providers said they take a middle of the road approach to planning based on actual past events versus possible future events, although many lean more toward planning based on possible future events. This indicates that water system managers do not rely heavily on what the recent conditions have been like, and that they plan in a way that would seem to be more proactive in dealing with the possibility of different climatic conditions.

Another survey question asked respondents to indicate whether or not they had ever found it necessary to re-evaluate their water budgets and, if so, why. Of the 23 individuals who answered the question, 10 indicated that they had found it necessary to reevaluate their water budget, often due to unexpected climatic conditions. Reasons for reevaluation ranged from needing to address shortfalls in levels of reservoir storage, changes in water demand forecasts, and lower-than-average rainfall and recharge.

Providers were also asked to indicate the time horizon associated with water budgeting for their operations, and the results are presented in Table 10. The 24 individuals who responded to this question indicated planning time horizons ranging from 2 to 100 years, with the longer time frames being punctuated by interim planning as well. As Table 11 indicates, when planning capital improvements, most respondents say they plan from 1 to 5 years in advance, although a few use much longer planning horizons.

The ability to secure funding for capital improvements necessary to cope with long-term climate shifts could become an important part of allowing water systems to cope with such changes, as well as in keeping ahead of rapid population growth. In response to a question about efforts to fund capital improvements, repairs, or

**Table 9.** Estimating Budgetary Needs Based on Past and Future Events.

Scale of 1 to 5 *	1	2	3	4	5
No. providers with this response	1	0	14	8	3

\*1 being always planning on actual past events, 5 being planning ahead for possible future events.

**Table 10.** Number of Years Providers Plan Ahead for Water Budget (Supply and Demand).

	1-5 years	5-10 years	11-20 years	21-50 years	Over 51 years
No. Providers	11	7	3	2	3

Note: 24 providers answered this question, but some gave their answers in ranges of years, indicating multiple planning time frames; the endpoints of the ranges of years were counted as separate responses.

**Table 11.** Number of Years Providers Plan Ahead for Capital Improvement Projects.

	1-5 years	5-10 years	11-20 years	21-50 years	Over 51 years
No. Providers	19	6	1	2	0

Note: 26 providers answered this question, but some gave their answers in ranges of years, indicating multiple planning time frames; the endpoints of the ranges of years were counted as separate responses.

expansion over the past five years, only 4 of 27 providers reported that they had not sought such funding, and only 3 of 22 were unsuccessful in their efforts. Thus, inaccessible funding would probably not be a prohibitive issue in adapting to different climatic conditions.

## 6. Implications

### 6.1 Low Concern About Climate-related Disruptions

The relatively low level of concern among water system managers about increased climatic variability contrasts sharply with another study of the CLIMAS project, an assessment of the same four study areas of the sensitivity of urban water sources to droughts of different duration (Carter et al. 2000). That study compared 1995 and projected 2025 annual water supplies and demand with the driest historic 1-, 5- and 10-year periods for each study area and for the subwatershed of the middle San Pedro River in Arizona. The study found that if similarly dry climatic conditions were to occur with the 1995 populations for these areas, the results could be significant, particularly for the longer-term droughts. If droughts of this severity were to occur with the projected 2025 populations, the consequences could be worse. For example, the Phoenix AMA expects to rely on groundwater overdraft to meet 24 percent of its annual water needs in 2025. However, if a decade-long drought of an intensity equal to the one from 1946–1955 were to recur, the AMA might need to mine as much as 39 percent of its water supply annually, leading to an additional four million acre feet of groundwater overdraft over 10 years (assuming that no additional water resources become available, and that no new conservation measures are implemented to reduce per capita water use). Even during a severe one-year drought, the AMA could end up mining 44 per-

cent more groundwater to compensate for shortages in surface water and CAP supplies, and to meet additional water demand (again assuming no new water supplies or additional conservation measures).

Potential reasons for the underassessment of vulnerability on the part of water managers are three-fold. First, the depletion of groundwater resources may only be seen as problematic when it causes severe problems such as subsidence, declines in water quality, and/or much higher pumping costs. Long-term aquifer depletion is occurring in some of the study sites and was reported by some providers; however, as noted earlier, other areas are currently experiencing rising water tables as they shift towards greater use of surface water for both direct use and recharge.

A second reason for a lack of concern about climatic factors may be that the decades of the 1980s and the early 1990s were some of the wettest on record in our study areas. During the period of 1980 through 1994, rainfall amounts averaged 17.73 inches, 26 percent wetter than the long-term median of 14.11 inches (Western Regional Climate Center 2002). Even the few water managers who have been at their jobs for more than 20 years, since the late 1970s, may not realize that the recent past has been unusually wet, or be aware of the severity of past droughts. Although the most recent five years have averaged 10 percent below the median amount, this scarcely compares with the driest five continuous years on record, from 1952–56, when rainfall amounts averaged 18 percent below the median and when a single year's total rainfall was 46 percent below the median. The 1950s drought had a devastating effect on dry land agriculture and ranching in the Southwest, although the impact on urban areas was minimal. However, given the significant amount

of urban growth that has occurred since the 1950s, if a similar drought were to occur today, the toll on urban water systems could be severe and would likely result in intensive negotiation between “wet water” and “paper water” rights holders.

A third reason for the apparent underassessment of vulnerability to drought is that many (particularly smaller) water providers tend to plan only for the more immediate future, from 1 to 10 years in advance. Interview data indicates that the only planning that some providers regularly undertake is annual fiscal planning. These providers deal with water supply and demand issues only as their systems require repairs or new subdivisions necessitate expansion. The additional stress that substantially higher populations in the region will have on water resources, or the fact that a long-term shift towards a drier climate is possible, may thus not be entirely appreciated. Even if smaller providers are aware of these potential problems, they may not have the resources or the latitude to plan for such events. One of the strongest messages generated by the interviews was that climate-related problems were secondary to the day-to-day challenges of managing a water service.

Whether the current drought will prompt greater interest in incorporating climate information into water management operations remains to be seen. Efforts to increase awareness among providers and regulators with regard to the track records of existing climate forecasts and scientific advances in climate and hydrological forecasting are both needed to address these issues. Such efforts will require time and persistence, particularly with regard to building ongoing, long-term relationships between scientists, climate services entities, and water managers and regulators.

### **6.2 High Provider Confidence in Their Systems**

The high degree of confidence expressed by providers in the capacity of their systems to withstand sustained climatic stress remains untested, since no severe decadal-scale drought has occurred since the 1950s, and the effects of that drought were relatively minimal in urban areas.<sup>8</sup> However, very rapid urban growth and development have occurred since the 1950s, increasing the likelihood that in the next decadal-scale severe drought at least some urban water systems will be substantially affected. While the impacts of such a drought would certainly be unevenly distributed in terms of severity, geographical extent, and length of time, we believe that all providers would benefit from a more cautious assessment of the resilience of their water systems.

The results of the provider survey further suggest that there is a generalized, if unstated, belief among water managers in the relative stability of the region's climate. Climate variability may be recognized, but only within a restricted distribution on either side of the statistical mean. Yet previous studies have demonstrated that the Southwest is in fact characterized by a quite high degree of variability (see, e.g., Sheppard et al. 2002). Research on the potential impacts of climatic change on the Southwest reinforces the need to think more broadly in assessing the capacity of water systems to hold up under climatic stress. As Miller (1997:1) observed, “The available evidence suggests that global warming may lead to substantial changes in mean annual streamflows, the seasonal distribution of flows, and the probabilities of extreme high or low flow conditions...Rapid population growth, increasing environmental concerns, and resulting changes in the character of water demands have led to increased competition for water even under normal flow conditions. These same changes contribute to increased vulnerability to hydrologic extremes.”

The lack of concern among most providers regarding potential threats of climate-related problems to their systems does not reflect this perspective, nor does it reflect the CLIMAS findings that urban water systems would be heavily impacted by long-term drought (Carter et al. 2000). The results of our survey indicate that providers rely significantly on heuristics in managing their water systems (see Nicholls 1999). A key question is whether their confidence in their systems' insensitivity to climatic variability is warranted. In a few cases, this may be true: all of the providers we interviewed had what they considered to be solid contingency plans for many other climatic problems they might encounter. Even in these cases, however, the actual effectiveness of the plans remains untested. Should a severe extended drought emerge that creates region-wide water shortages, it would be advisable to undertake economic and institutional analyses of the extent to which these plans worked as expected, of changing perceptions about the potential extent of climate impacts, and of changes in recognized climate information needs.

### **6.3 High Variability Among Water Systems and Locations**

As was discussed in the introduction to this report, each of the four study areas has a unique water demand and supply profile. Each area also appears to be heading in its own direction in terms of future water

use. Further, the Phoenix, Tucson, and Santa Cruz AMAs and the Sierra Vista subwatershed each exhibit a unique culture of water, an avenue of inquiry that should be pursued in future studies.

#### *Phoenix AMA*

An aerial view of the Phoenix AMA reveals not only a high percentage of single family homes with swimming pools and green lawns, but also a considerable number of water-intensive features such as human-made lakes and golf course developments. Indeed, the City of Tempe now boasts of its Town Lake in its economic development and tourism promotions. Adding to these water demands, the continued spread of urban growth in the greater Phoenix area consumes land every year that was formerly devoted to agriculture; yet agriculture persists and is not anticipated to disappear in the near future (ADWR 1999a). Water logging in some portions of the Phoenix AMA appears to contradict the message of the Department of Water Resources about the need to conserve and to use water wisely rather than profligately. By contrast, other provider areas within the AMA are already expressing concern about the sufficiency of water to meet demand. Such unevenness across the AMA illustrates the complexity associated with mapping climate vulnerability in that area, but does not diminish the need to think more broadly about the implications of climatic stress for water resource management. Water managers and regulators need to address more fully and directly the potential impacts of a range of climatic conditions so as to decrease vulnerabilities and increase resilience through an array of measures focused on adaptation strategies in anticipation of future events and enhancement of coping capacity when climatic stresses actually occur.

#### *Tucson AMA*

Portions of the Tucson AMA stand in stark contrast to the profile of the Phoenix AMA depicted above. Although there are golf courses and swimming pools, xeriscaping is more readily apparent in this area, particularly in new subdivisions where landscaping rules apply. Yet even here a spectrum of vulnerability exists, although no system is as heavily buffered by multiple water sources as some of the Phoenix-area systems. In part, this is due to the fact that Tucson is at the end of the CAP system and would likely feel the effects of a shortage of CAP water before providers in Phoenix would. Further, Tucson lacks any alternative source analogous to the SRP in Phoenix. Thus, groundwater and effluent are the only two fallback sources currently

available. As in Phoenix, some providers are distant from the CAP canal and are unlikely to ever be connected to that source of supply. Most of these providers currently participate in a CAP-based groundwater replenishment program that is designed to offset the non-renewable water that they pump; however, the recharge areas are typically not located nearby and no infrastructure currently exists to move the water from the area of replenishment to the area of potential need. Such geographical and infrastructural constraints, as well as the institutional constraints mentioned earlier in this report, increase the potential vulnerability of these providers. An explicit dialogue within the AMA regarding potential climatic implications for water management is essential to enhancing the resilience, adaptation, and coping capacity of local providers.

#### *Santa Cruz AMA*

The landscape of Nogales, the largest city in the Santa Cruz AMA, tends toward smaller yards, minimal use of water-intensive landscaping, and less water use overall. In contrast, the town of Rio Rico is promoting itself as a golf resort, with consequent higher water use. Providers in Nogales may be somewhat more cognizant of the potential for climatic conditions to pose challenges to water management. Because much of the city's water is currently supplied from shallow aquifers that are highly responsive to variability in precipitation, even short-term weather events are readily reflected in water supply. Furthermore, the city's location on the U.S.-Mexico border, and its adjacency to a much larger sister city across the border (Nogales, Sonora has a population of more than 200,000) makes water management an international affair, particularly during times of drought or flood (see, e.g., Ingram et al. 1995, Morehouse et al. 2000). Here, convincing water providers to broaden their perception of possible climatic stresses affecting both sides of the border may be the greatest need. Also important is persuading providers to think beyond the confines of the current climate to consider possible scenarios based on concepts of climate non-stationarity and longer-term climatic change in the transboundary region.

#### *Sierra Vista*

The Sierra Vista area includes a medium-sized city and several nearby small towns. The area is characterized by a widely dispersed settlement pattern. While most people live in single-family subdivisions, and most of the homes are now xeriscaped, a significant number live on larger plots of land. These "ranchette" developments are extending outward at an ever-increasing dis-

tance from the population centers of Sierra Vista, Huachuca City, Palominas, and Nicksville. Many of these residents have their own wells. While no single well draws a large amount of water, the fact that there are so many of them has been cited as a significant factor associated with generalized decreases in the local water table (Glennon and Maddock 1994). Cones of depression have formed where groundwater pumping has been most intensive, and these cones are now converging to produce a more widespread drop in the water table. Projections indicate that the population will continue to grow rapidly, aggravating the imbalance between renewable supply and demand, even under current “normal” conditions. Effluent management has been identified as the one alternative the area currently possesses to address the situation, and projects are underway to maximize the capture and reuse of this resource. However, changes in climatic conditions over periods of several years, decades, or even longer have the potential to stress water operations in the area, and to pose serious threat to the nearby and highly valued San Pedro National Riparian Conservation Area. Ensuring the long-term viability of the river and its habitat, while allowing for continued urban growth, requires that climate information be taken more fully into account in both planning and routine operations. Interest exists in using such information. This opportunity needs to be actively pursued, especially with regard to development of information and forecasts scaled to the local level.<sup>9</sup>

#### **6.4 Current Use of and Interest in Climate Information**

As this report illustrates, the number and types of climate-related stresses that providers said they had faced varies considerably. Many providers mentioned the weeks or months leading up to the monsoon season as stressful, while others recalled flooding incidents that occurred in the 1980s and 1990s. However, no provider in any of our study areas has yet been forced to deal with a severe, long-term drought. The impacts of current drought conditions, which intensified after we had completed our survey, on urban water systems remain to be assessed. Given that most providers have managed to cope with climatic variability without great difficulty in the past, and have for the most part done so without benefit of climate forecasts or related information, it is little wonder that few automatically recognize the value of such information. As previously discussed, providers believe that they have enough “solid” information in the form of population projections and demand, as well as past supply conditions, to

make their water management decisions, without attempting to use forecasting tools. Providers regularly situate their decision making within a complex arena of sometimes conflicting and contentious policies and institutions, and emphasize the fact that they must negotiate between local, state, and federal water management entities and their customers. These types of challenges greatly overshadow any concerns regarding potential climate impacts.

Few providers used longer-term climate information for planning purposes. Instead, current population and expected growth are the primary criteria. It is not surprising that data of this nature would seem much more reliable than uncertain climate forecasts, due in part, no doubt, to water managers’ lack of knowledge of forecasting products and how to use them. Undoubtedly, the planning cycles and organizational structure of the individual operations play a significant role in the prioritizing of what is important to consider in planning and budgeting activities. However, recent interest in initiating drought planning (see, e.g., Governor’s Water Management Commission 2001; Slivka and McKinnon 2002) may prompt providers to develop a more open mind toward using climate forecasts and other such information.

Interview information reveals that water providers are not seriously considering the possibility of reduced water supplies and that few providers are even concerned about the outcome of ongoing litigation over Indian water rights. Yet some of these water rights cases, including the current adjudication of all rights to waters of the Gila watershed, have the potential to reallocate considerable portions of the existing water supply. It is not inconceivable that, under climatic stress, providers would need to negotiate with specific tribes to purchase water to cover unmet demand.

Another factor in the lack of interest in using climate forecasts (or other climate information) is the need to maintain an adequate revenue stream. Revenues are needed not only to sustain operations but also to address infrastructure repairs and expansion. For most providers, such considerations override consideration of long-term sustainability goals, such as those reflected in the safe-yield provisions of the Arizona Groundwater Management Act. By assuming that water supply is a constant, and that demand will increase in a linear fashion along with population, water providers simplify their planning process considerably. Regulatory changes that have the effect of encouraging

or requiring greater consideration of climate variability in calculating prices charged to customers, revenue streams, infrastructure requirements, and contingency planning needs may be required to change ways of doing business in the water management sector.

Indeed, while the effects of a severe long-term drought on water supplies and consequently on water systems could be dramatic, so too could the impacts of an extended wet, cool period. In an informal discussion outside the survey process, one provider noted that the anomalously wet summer of 1999 had reduced revenues more than the utility would have preferred. Extending such concerns over longer periods suggests that the unpopular and difficult step of raising water rates might be required in the absence of contingency plans that could buffer against wide oscillations in revenue streams. Under such scenarios, providers might not have sufficient funds to sustain operations and infrastructure. For private water companies, raising enough revenue to sustain themselves as viable businesses could prove challenging, especially given the ACC's historically conservative attitude toward allowing rate hikes. As suggested by interviewees, the future is likely to be one where water companies are increasingly consolidated under the ownership of large corporations. Water company stocks will be more extensively traded on stock exchanges, and water itself is likely to be traded on commodity markets. Trading in climate derivatives, already underway, may be expected to grow in importance. Under these conditions, it is very likely that climate information will become an increasingly important adjunct to planning and decision-making. Those providers who wish to remain in business and to effectively compete would do well to enhance their use of climate information now, in preparation for the future.

### 6.5 Strategies for Enhancing the Use of Climate Information

Recognizing that the different study areas have varying water supply and demand issues, as well as multiple types of water resources, climate information ideally should be tailored to address the diversity of needs. This will not always be possible, but the differences in information needs should be taken into account when issuing climate information to the different providers.

To make climate forecasting relevant and useful to water providers, several steps should be taken. Most importantly, the forecasts and other information need to be reasonably easy for providers to interpret, and providers should be trained in how to use the information

most effectively. While several providers expressed an interest in learning more about climate forecasts and how to use them in planning and decision making, none said that they had sufficient time or inclination to undertake such learning on their own. As a corollary to this recommendation, the information must be easily accessible to providers and issued at the times the providers most need that particular information.

As emphasized by several of the providers surveyed, forecasts and other such information need to be backed up with data attesting to their accuracy over time. Until recently, assessment of forecast accuracy ("skill level") was sparse to nonexistent. Current CLIMAS research activities designed to fill this gap are an important contribution to addressing this need (see, e.g., Hartmann et al. 2002). Findings of the survey discussed in this report reveal that, to assure user acceptance, the forecast evaluations need to be supplemented by a "test period" in which providers test the accuracy and utility of the forecasts themselves, before their use can become a regular factor in their planning and decision-making activities. This finding echoes the results of Pagano et al. (1999), in which water and emergency response managers were found to express confidence in the 1997–1998 El Niño forecasts when the forecasts accorded with their own in-house information or their past experience. Such reliance on heuristics is typical (see Nicholls 1999), but may be one of the more difficult hurdles to clear in efforts to effectively communicate climate information to stakeholders such as water managers.

## 7. Conclusions

As the population and competition for water resources increases, water providers and decision makers will face new and more intense challenges. Vulnerability to climatic conditions already exists among some water providers and even more are likely to be affected, particularly if a severe sustained drought should recur or if the frequency of severe events, such as electrical storms, increases. A few urban water systems are well buffered against climate stresses by having access to multiple water sources, including both groundwater and surface water resources, but many are not. Recognition among providers of their own potential vulnerability, however, is low. High confidence in existing buffering capacity contributes to this mind set. Other contributing factors include insufficient understanding of how climate interacts, or could potentially interact, with existing

structural and institutional arrangements to produce or exacerbate systemic vulnerability. The lack of recognition may also be related to excessive reliance on personal experience, outdated professional knowledge, or simple lack of imagination about possible futures.

Overcoming these perceptual barriers is no easy task. However, strategies do exist for enhancing capacity to understand vulnerabilities and develop greater resilience to climatic impacts.

On the research side, continuation of research in regionally relevant climatology and hydrology is essential, as is integrated climate impacts assessment work designed to improve knowledge about climate processes and impacts of particular salience to the Southwest. Advances in capability to downscale climate forecasts would be especially useful. Likewise, outreach activities, which facilitate the two-way flow of information between researchers and the public, are crucial to ensuring the relevance of research results to stakeholder needs and to formulating research agendas. Continued work on improving the theoretical and methodological foundations for generating and diffusing new knowledge is essential for broadening the array of questions that can productively be answered by science.

Effective communication of climate information is equally important. To be useful to water providers, the information must be provided at the appropriate temporal and spatial scale(s) for the specific area in question and must be provided at the time that particular information is needed. The scales and timing of information will vary, depending on factors such as whether the information is to be used for long-term planning, operational decision making, or other reasons. Knowing what information is needed, at what scales, and at what time—and in what format—requires ongoing interactions with stakeholders. Likewise, ensuring that the information is effectively used requires well-designed educational efforts that fill gaps in providers' understanding of climate processes, the basics of forecasting, and interpretation of information. Simplifying access to information and ensuring that providers know, at any given time, where such information may be found is equally important, because today there are myriad climate information sources from which to choose. Being certain that providers know which information to use for specific purposes is essential to building their confidence in the quality, reliability, and utility of that information. Indeed, enhancing stakeholder confidence in climate information and

forecast products may be one of the more serious challenges to maximizing resilience and coping capacity in the face of serious climatic stresses we are likely to eventually face.

## Endnotes

<sup>1</sup> Untreated water providers deliver water not treated to drinking water standards to industrial users such as golf courses, parks, etc.

<sup>2</sup> Groundwater recharge in this context involves filling retention basins with CAP water and allowing it to infiltrate the aquifer, where it is naturally filtered and mixed with fossil groundwater. The water is then pumped back out for delivery to customers.

<sup>3</sup> All responses to each factor were added together based on a score ranging from 5 for most important to 1 for least important, regardless of whether the respondent had strictly complied with the instructions to the question by choosing only the five most important factors; some respondents ranked less than five choices, and some more than five. No provider rated any one factor higher than five.

<sup>4</sup> This question was taken verbatim (with permission of the authors) from the Susquehanna River Basin Integrated Assessment discussed in the Background section. To produce Figure 4, the numerical responses from the 27 respondents who answered the question were added together. The average score was derived by dividing this number by 135, the total that would have been achieved if all respondents had chosen 5 (very likely). Two respondents chose answer 6, meaning “don't know,” for two of the questions; these responses were changed to a 3, so as not to skew the totals. Thus, the fact that electrical storms have the highest numerical score indicates that providers view this as the most important factor, awarding it more 5-point responses and fewer 1-point responses.

<sup>5</sup> This question was also modeled after a similar question asked and tested by the Susquehanna assessment, although minor alterations were made to make the question more appropriate to conditions in the CLIMAS study areas.

<sup>6</sup> Sudden, intense, and highly localized weather activity that can generate torrential rains, numerous lightning strikes, and winds of up to 70 mph.

<sup>7</sup> Xeriscaping is the use of low-water use vegetation and inorganic groundcover such as gravel for landscaping.

<sup>8</sup> The most severe drought in recent history is the 1950s drought, lasting from 1947–1956. During this time frame, approximately 74 percent of the mean average rainfall of 14.33 inches fell each year. The effects of this drought were widespread and severe, with heavy losses in both ranching and crops. Despite having less technologically advanced water management systems, urban areas generally coped fairly well. If such a drought were to occur today, however, the effects could be quite severe in urban areas. Such a drought scenario was tested against population projections for 2025 in each of the study areas in the CLIMAS Sensitivity Analysis (Carter et al. 2000). The results were a 10 to 15 percent increase in groundwater overdraft. If such a drought were widespread and long-term enough to affect CAP allotments, and in the absence of effective water conservation and demand management, the Phoenix AMA would be forced to rely on nonrenewable groundwater supplies to meet 59 percent of its total water needs (in contrast to the normal expected overdraft of 24 percent). In the Tucson AMA, 75 percent of its water needs would have to be met using nonrenewable groundwater resources (up from the projected normal overdraft of 15 percent of total supplies).

<sup>9</sup> We recognize that scientific capacity to downscale forecasts to the local level is quite limited; however, continued dialogue with water managers may produce products that contribute substantially to decision making under conditions of climatic variability and change.

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- 6) On average, in what ways has your current system been vulnerable to extreme weather and climate events in the past ten years? For each of the items below, indicate how many times in a typical decade that your system has suffered some form of difficulty due to the types of events listed below.

		Never	1-2 times per decade	3-5 times per decade	6-9 times per decade	10 or more times per decade
A	Drought conditions lowered the supply of water in the system beyond normal seasonal levels	1	2	3	4	5
B	Drought conditions forced us to seek another water source	1	2	3	4	5
C	Drought conditions led to significant increased demand on our system	1	2	3	4	5
D	Floods increased turbidity in our surface water system	1	2	3	4	5
E	Floods led to damaged or contaminated wells	1	2	3	4	5
F	Extremely high temperatures overloaded electrical circuits and knocked out pumping systems	1	2	3	4	5
G	Extremely high temperatures have increased demand enough to strain our water supply	1	2	3	4	5
H	Electrical storms have led to power outages that affect our ability to pump water to our customers	1	2	3	4	5
I	Heavy winds have led to power outages that affect our ability to pump water to our customers	1	2	3	4	5
J	Other _____ _____	1	2	3	4	5

- 7) If your water source became unstable due to **long-term overall decrease in water supplies**, which of the following solutions would you employ?

		Very unlikely				Very likely
A	Draw upon another system to which you are currently connected	1	2	3	4	5
B	Draw upon another system that you expect to be connected to in the future	1	2	3	4	5
C	Implement a stricter water management plan (rationing)	1	2	3	4	5
D	Curtail future customers' service	1	2	3	4	5
E	Deepen existing wells	1	2	3	4	5
F	Drill new wells	1	2	3	4	5
G	Other _____ _____	1	2	3	4	5

8) If your water source became unstable due to **contamination**, which of the following solutions would you be likely to employ?

		Very unlikely				Very likely
A	Draw upon another system to which you are currently connected	1	2	3	4	5
B	Draw upon another system that you expect to be connected to in the future	1	2	3	4	5
C	Implement a stricter water management plan (rationing)	1	2	3	4	5
D	Deepen existing wells	1	2	3	4	5
E	Drill new wells	1	2	3	4	5
F	Other _____ _____	1	2	3	4	5

9) What sort of infrastructure does your water company possess?

Do you intend to expand or decrease this infrastructure within the **next five years**?

	<u>current</u>	<u>expected future</u>
• Number of wells:	_____	_____
• Number of pumps:	_____	_____
• Number of reservoirs:	_____	_____
Storage capacity:	_____	_____
• Miles of pipes:	_____	_____
• Miles of canals:	_____	_____

10) Which factors are most important in limiting the number of customers that you can serve? Please identify the **five most important** and rate them from 1 to 5, with 1 being the most important:

- |  |   |
|--|---|
| _____ Water rights                           | _____ Limited access to capital for expansion |
| _____ Water availability                     | _____ Limited economic returns                |
| _____ Competition with other water providers | _____ Limited infrastructure                  |
| _____ Personal preference                    | _____ Market saturation                       |
| (small company atmosphere, etc.)             | _____ Other (please specify) _____            |

11) Which factors are most important when developing your water budget (supply & demand)?

Please identify the **five most important** and rate them from 1 to 5, with 1 being the most important:

- |  |                                     |                                     |
|--|-------------------------------------|-------------------------------------|
| _____ Current population                                   | _____ Groundwater table             | _____ Agricultural acreage          |
| _____ Population projections                               | _____ CAP availability              | _____ Urban development plans       |
| _____ Transitory population<br>(tourists, snowbirds, etc.) | _____ Effluent reuse rate           | _____ Economic development<br>plans |
| _____ Streamflow data                                      | _____ Current and past climate data | _____ Other: _____                  |
|  | _____ Climate forecasts             |                                     |

12) How far in the future do you plan your water budget (supply & demand)? \_\_\_\_\_ years

13) Have you ever had to reevaluate your water budget? \_\_\_\_\_ yes \_\_\_\_\_ no  
 If yes, why?

14) To date, have you identified any trends in water use and water availability within your service area?  
 Do you foresee any additional changes for the future? Please indicate an increase (I) or decrease (D):

	<u>Trends to date</u>		<u>Future changes</u>	
• Number of service connections	I	D	I	D
• Water use in agriculture	I	D	I	D
• Municipal/residential water use	I	D	I	D
• Industrial water use	I	D	I	D
• Groundwater table	I	D	I	D
• Streamflow	I	D	I	D
• Other (please specify)	I	D	I	D

15) When preparing capital improvement projects, how many years in the future do you typically plan ahead?  
 \_\_\_\_\_ years

16) To estimate budgetary needs, some individuals prefer to look ahead and consider all possible difficulties of what could happen to their system, while others look back at the events that actually affected their system. On the scale below, please estimate how your system estimates its future improvement needs.

Always plan based on <u>actual</u> past events					Always plan ahead for <u>possible</u> future events
1	2	3	4	5	

17) Have you acquired or attempted to acquire funds to pay for major capital improvements, repairs, or expansion in the **last five years**?  
 Yes No

If yes, was your attempt successful?

18) In the course of your duties, how often do you consult:

- Weather forecasts (current to two weeks into the future) \_\_\_\_\_
- Climate forecasts (more than two weeks into the future) \_\_\_\_\_
- Hydrologic forecasts \_\_\_\_\_

*Thank you for your information!*

## Appendix B: Interview Questions

Interview with \_\_\_\_\_  
 Name of Water Service \_\_\_\_\_

### A. Internal Policies and Institutions

I'd like to start out by asking you a few basic questions about your operation here:

A1. How many employees does your water company have?

Are any of those people involved with climatology or hydrology?

A2. How is your service structured?

Under normal conditions, who makes decisions for your company?

A3. What type of pricing structure do you use now?

A4. What might cause your company to change its pricing structure? (for example, in case of an extended drought...)

What's the development rate and pattern around here?

A5. Have you ever had to ration water to customers?

A6. What is your gpcd rate? Are you being asked to reduce it?

A7. When will CAP use get underway on a widespread basis?

A8. What are your current recharge plans? Future plans?

### B. Climate and Hydrologic Variability - Past, Present & Future

B1. You had noted on the survey that drought, high temperatures, and electrical storms have caused problems to your system in the past. What were some of the most extreme climatic/hydrologic events that your company has had to deal with? Examples?

B2. What was the major impact of each? How did you cope?

How long could an outage go on before customers would notice?

B3. What information was available to warn you that this event was going to occur, and about how severe it might be? Where did you obtain this information?

B4. Were you able to prepare for those conditions? How?

B5. Given the current population projections for your area, what impact could extreme climate conditions have on your company in 10, 20 years from now?

What's your worst nightmare?

B6. What types of climatic and hydrologic conditions are most advantageous to your water company? How frequently do these conditions occur?

### C. External Policies & Institutions

C1. I see that you have interconnects to provide water to smaller systems during emergencies...have you had to use these often?

Do you negotiate with any other water users or water managers regarding the acquisition, allocation, and distribution of water resources? Who and how? Under what conditions? Please explain.

C2. Who else do you interact with? (for example, oversight committees, agencies, public interest groups, political entities, etc.)

Does this change during times of climate stress? How?

C3. Will any of the pending Indian water claims affect you?

C4. Do you or does anyone from your operation serve on any committee or board as a water provider?

C5. What changes in laws, policies, and procedures would you consider most useful in enabling your organization to better deal with climate stresses on your system?

### D. Forecasting Information and Needs

D1. When do you do your annual planning?

D2. How often do you do longer-term planning?

D3. Do you use any climate/hydrological information and forecasts in planning (for example, history of temperatures and precipitation for this area)? What types of information and forecasts? On what time scale and over what geographical extent?

D4. Are you satisfied with the information you use? Advantages? Disadvantages?

D5. What are the biggest gaps in your current information? What information do you need most that you don't have?

D6. If there was a "one-stop shopping center" for climate/hydrologic information, would you use it? How would you prefer to access it (internet, fax, radio, personal visit, etc)?

D7. Would improved information about climate and hydrology influence public understanding about water availability in your community? How might it help?

D8. Would using improved climate/hydrologic information change the development process in your community? How?

D9. Where do you see your water company in the year 2025?