Climatic Change (2007) 85:323–341
DOI 10.1007/s10584-007-9302-z

Climate, water management, and policy in the San Pedro Basin: results of a survey of Mexican stakeholders near the U.S.–Mexico border

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Received: 27 April 2004 / Accepted: 10 May 2007 / Published online: 31 August 2007

Abstract This paper reviews regional climate knowledge and vulnerability in the northern Mexico San Pedro River Basin, with a focus on water quality, quantity, and management issues on the Mexican side of the border. A discussion based on the available literature is supplemented by a survey assessing concerns about water and the quality and usability of climate and hydrologic information available to water managers and communities. The surveys indicate that the central concern for urban residents is the lack of reliable potable water due to frequent service breakdowns–with climate change and variability, specifically drought and high temperatures, as contributing factors. Water managers desire appropriate meteorological and hydrologic information to improve planning strategies, but access to this information remains limited. Considerable disagreement exists about who should pay for previously free or low-cost water and wastewater treatment. Urban users have little incentive to conserve because of the present flat, low rate and frustration with service. In rural areas, while a majority of ranchers recognize that variable climate and water loss could increasingly jeopardize their lifestyle, they seldom use meteorological information in planning or modify their water consumption. Climate vulnerability also includes potential for serious environmental health issues due to the presence of heavy metals and organic contaminants in the San Pedro.

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1 Introduction: project overview

The 2000-mile U.S.–Mexico border region, an area characterized by rapid population growth associated with economic development, exists in a physical setting that is exceptionally precarious—"chronically water-short, financially resource-poor, and subject to highly variable precipitation" (Varady 1998, p. 65). As Díaz and Morehouse have noted, "Resolution of competing demands in contexts of water scarcity... demands consideration of historical patterns of water use against the potential for radical changes in water availability arising from decadal and longer-term climatic variations" (Díaz and Morehouse 2003, p.4). At the same time, access to information about climate change and variability, and the impacts on water management, varies enormously on both sides of the border. Differing social, economic, and political conditions produce vastly different perspectives on the role of climate in water management, potentially leaving some populations less prepared for the future (Browning-Aiken and Morehouse 2006). Water, particularly its management and conservation, has become a matter of strategic national security to Mexico (Fox 2001). Water security, meaning "sufficient water of sufficient quality to protect the health, safety, welfare, and productive capacity of a population in both the short and long term," has become the goal not only of national governments, but of transboundary basins along the border (Whiteford and Melville 2003, p. vii). In this context, assessment of the impacts of climate variability and change on existing water service and water quality conditions becomes essential.

This study of water managers, municipal domestic water users, and rural *ejidal* water users in the Mexican portion of the Upper San Pedro River Basin (see Fig. 1) complements studies on climate sensitivity, vulnerability perceptions, and climate information use in the Arizona portion of the San Pedro Basin conducted by the Climate Assessment for the Southwest (CLIMAS) project (Carter and Morehouse 2003; Carter et al. 2000; Finan and West 2000). This study also adds to an earlier water survey conducted in the Mexican and U.S. portions of the basin by the Udall Center for Studies in Public Policy (Moote and Gutiérrez 2001). Similar data from a water manager survey completed by the Arizona Department of Water Resources in 2003 (ADWR 2003) in the U.S. portion of the watershed is also used in this paper for a comparison of management issues.

This paper begins with a review of regional climate knowledge and demonstrates the importance of basin water managers' and users' understanding the complex nature of climate variability and change in both short- and long-term planning. The Water issues section summarizes the water issues challenging existing water management in the Mexican (upstream) portion of the basin. The Survey of water managers and urban and rural users in Mexico section describes the sample design and methodology, along with the context in which the surveys were administered. In the Findings and discussion section, the results of the surveys are presented for urban and rural groups, and the findings are discussed in terms of eight thematic observations about water users' and managers' perceptions about the vulnerability of the population to water management and service problems. These observations highlight the urban residents' belief that water service problems are due more to management practices and to a reluctance to change the status quo than to lack of access to climate information. However, lack of access to resources, specifically finances and technology, do increase residents' vulnerability to climate variability and managers' capacity to address flaws in the current water system. We conclude with a series of recommendations addressing the current problems in decentralized water management and suggest that rural and urban communities would benefit from a capacity-building effort that promotes open and transparent dialogues about water service costs and the relationship between climate change and effective water management.

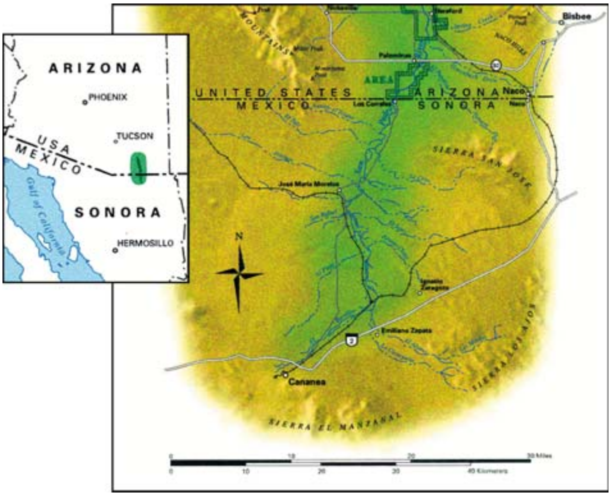

Fig. 1 Upper San Pedro Basin: survey area below US–Mexico border

2 Regional climate knowledge and vulnerability: a literature summary

Regional climate knowledge is important for establishing a shared basis of knowledge among regional stakeholders and participants in dialogues about water and climate at the watershed scale. These include scientists working with communities, planners, decision-makers and residents, in their attempts to use and interpret scientific information. Establishing shared knowledge is often difficult in the Upper San Pedro Basin, due in part to the context of significant variability and uncertainty—both scientific and climatic. Stakeholders in the border region speak frequently of monsoons and drought because their impacts on daily life are dramatic. However, interest in these phenomena can be channeled into decision-making, provided that stakeholders understand the links between historical climate information, climate predictions, and impacts on their decisions (Ray et al. 2007, p.26). Furthermore, research characterizing climatic conditions in the San Pedro basin and their potential impacts on basin residents' vulnerability suggests that water users and managers will face serious challenges in obtaining a secure potable water supply in the near future.

2.1 Climate variability

Semi-arid to arid conditions, a paucity of surface water sources, and highly variable climate conditions on seasonal, annual, and interannual time scales characterize and pose challenges to human and natural systems along the U.S.–Mexico border. The border area of the Upper San Pedro River Basin lies squarely in the monsoon region (Comrie 2003). Annual precipitation in the Upper San Pedro Basin ranges from around 300 mm in the lower and northern portions of the basin to over 750 mm in the Huachuca Mountains. Approximately 65% of this typically occurs during the July through September monsoon season from high intensity air mass convective thunderstorms. Roughly 30% comes from less intense winter frontal systems. Potential evapotranspiration is estimated at more than ten times annual rainfall at lower elevations in the basin (Goodrich et al. 1998). Interannual climate variability is also high with a demonstrated linkage to the El Niño-Southern Oscillation (Woolhiser et al. 1993). Summer monsoon precipitation may equal or exceed winter precipitation; however, the high temperatures generate high rates of evapotranspiration that in turn reduce the amount of water available (Garfin et al. 2007; Sheppard et al. 2002). Winter precipitation, by contrast, occurs over broader areas, usually falling more gently and persisting over a longer period of time. As is the case with summer precipitation, the amount of precipitation received over the course of the winter can vary substantially from year to year or even decade to decade.

El Niño and La Niña conditions in the tropical Pacific Ocean influence winter-season precipitation in Mexico and the U.S. Southwest (Sheppard et al. 2002). Broadly speaking, El Niño tends, with some degree of predictability, to produce wetter than normal winters. La Niña conditions tend to produce, with a higher degree of predictability, drier than normal winters (visit the Western Regional Climate Center web site, http://www.wrcc.dri.edu/enso/octmar02.gif, for graphical depictions of the degree of predictability of winter precipitation associated with El Niño and La Niña). Scientific understanding of seasonal to longer-scale predictability of summer (North American Monsoon) and fall (tropical storm) climatic conditions, as well as non-ENSO years, is somewhat less well developed, and forecasts are correspondingly weaker in skill and accuracy. Knowledge about the drivers influencing climatic variability and change is an important contribution to successful dialogues on water and climate at the watershed scale (Díaz and Morehouse 2003; Garfin et al. 2007; Jacobs et al. 2005a, b; Lemos and Morehouse 2005). These dialogues require that water stakeholders understand attributes of climate forecasts, such as the skill and reliability of forecasts at this spatial scale, in order to use them appropriately.

2.2 Climate impacts

Understanding the impacts of climate is equally important and requires research into the nature, extent, and severity of the climate-related stresses affecting ecosystems, households, communities, livelihoods, and economic sectors (Eakin 2006). In the Upper San Pedro Basin of Sonora, Mexico, improving the availability of and capacity to use a wider array of scientific knowledge about climate impacts is essential to managing water supplies in the context of growth in demand, changes in demand patterns, and challenges posed by persistent water quality and water delivery problems.

As Comrie (2003) has noted, climate does not stop at the border. The challenge for areas such as the Upper San Pedro River Basin is designing and communicating such information on a transboundary scale in ways that are useful, usable, and comprehensible to those who need the information. This challenge is heightened along the U.S.–Mexico border by significant disparities in the quantity, quality, and types of climate and hydrologic information that are available, as well as the number and location of data collection devices such as weather stations and stream gauges.

In a local area where annual precipitation averages about 593 mm and the historical low has dropped to an annual minimum of 58.8 mm (figures, provided by Cecilia Condé, are for Cananea, 1949–1999), flexible strategies are required to achieve balance between supply and demand. Currently, because no system of explicitly transboundary climate information exists, local residents on the Sonoran side of the border, as well as those on the U.S. side, rely to a large extent on information produced and disseminated in the United States.

2.3 Climatic change

Climatic change poses its own dilemmas for water management in the Upper San Pedro watershed, both in terms of what changes might occur and how well models actually represent current climate conditions in the region (Liverman 1998, pp.14–15). An assessment of potential future climate conditions in the U.S. Southwest notes that, “According to model scenarios, the slight warming trend observed in the last 100 years is projected to continue into the next century, with the greatest warming to occur during winter. These climate models depict temperatures rising approximately 2° to 3°C... by 2030 and between 4 and 7°C... by 2090” (Sprigg and Hinckley 2000, p.3). Sprigg and Hinckley also state that “this trend would increase pressures on the region’s already limited water supplies” (Ibid.). Climate change research also indicates the possibility of a rise in the frequency and intensity of extreme storm events due to climatic change.

Model results are not, however, necessarily consonant with each other. Sprigg and Hinckley go on to note that, “Future climate scenarios also depict rainfall increases up to 5 mm/day. . . during winter by the year 2090. This additional rainfall would alter the region’s ecosystems [and]...would likely increase the number of floods, accelerate rates of soil erosion and present greater risk to property and life” (Sprigg and Hinckley 2000, p.3). Model scenarios show that a rise in the frequency of El Niño events could contribute to increases in winter precipitation in the region. In contradiction to the assessment of the impacts of temperature rise, Sprigg and Hinckley note that increases in precipitation could increase vegetation growth, enhance water supplies, and “improve the carrying capacity of the land for agriculture, ranching, and wildlife,” although the timing and extent of the increases in rainfall will play a key role in determining the degree to which human and natural systems are affected (Ibid.). At a broader regional level, projections by Magaña and Condé suggest that Mexico may see either no change or a decrease in summer precipitation, and an increase in winter precipitation of 10–20% (Magaña and Conde 2003, p.21). Tree ring and paleoclimatic studies indicate that past atmospheric and ocean circulation have changed abruptly and that extended droughts occurred frequently in the greater Southwest (Sheppard et al. 2002). While the past is not necessarily a predictor of the future, knowledge of conditions occurring even in the deep past widen the imaginable range of future conditions under which decisions may have to be made.

As indicated by the above, contradictions remain with regard to projecting climate change for the U.S. Southwest and northern Mexico. Further, the North American monsoon is not included in general circulation models (GCMs), nor are factors that reflect either the possibility of abrupt change in circulation patterns or of potential increase in extreme events (Liverman and Bales 1998, pp.25–26). However, work is underway to develop regional-scale models that represent the area more accurately. These models will nest into the larger GCMs, thus allowing each to provide input to the other. In the meantime, substantial progress may be achieved by developing and communicating information about past climatic conditions and forecasts that operate at seasonal to interannual time scales. Processes such as the Dialogues on Water and Climate (see Acknowledgements) provide indispensable mechanisms for enhancing decision-making capacity and for stimulating assessment of the potential impacts of long-term climate change on the area and its human and natural systems.

3 Water issues

Quantity The Upper San Pedro Basin was selected for study for its potential to allow assessment of water quantity and quality issues on a scale more amenable to regional resource management. For the basin as a whole, most of the water demand has been for mining, municipal and domestic use, and irrigated agriculture. Recent research suggests that riparian vegetation also requires a large portion of the water budget (http://www.usppartnership.com/documents/USPP%20article%20III.pdf; Scott et al. 2006). Currently the basin’s water supply is considered to be in deficit, with annual withdrawals exceeding recharge by approximately 6 to 12 million cubic meters. Increased production of copper from extensive ore reserves in Mexico limits groundwater availability for municipal and agricultural uses in that region and compromises water conservation efforts. Pumping in Sonora between Naco and Cananea in 1986 was estimated at 11.28 million cubic meters, but 48 wells were drilled between 1986 and 1994 to increase water for mining operations, building up the pumping capacity to 40.2 million cubic meters (Arias 2000, p.210).

Quality In addition to the potential for water scarcity associated with over-extraction and climate variability, groundwater and surface water contamination also affect the quality of potable water supplies near the source of the San Pedro. Inadequate (in Naco) or nonexistent (in Cananea) wastewater-treatment plants contribute to uncontrolled discharge of residual waters into the river. Unlined landfills introduce a variety of known and unknown substances that infiltrate into the aquifer. Moreover, copper mines produce industrial waste that contaminates groundwater supplies via unlined and occasionally overflowing tailings dams (Moreno 1991, p.7; Jamail and Ullery 1979, pp.37–45; Zavala 1987, p.5).

4 Survey of water managers and urban and rural users in Mexico

4.1 Methodology

Sample design Three surveys were constructed by a team of U.S. and Mexican anthropologists, geographers, and an arid land specialist to obtain a clear picture of water and climate information and technology needs in the Mexican portion of the basin. A team of Mexican interviewers trained by the Udall Center administered 564 water and climate surveys in the Mexican portion of the Upper San Pedro River Basin. For the municipal domestic water users survey, the city of Cananea, Sonora, was divided into 11 sections based on population density statistics from the Mexican Instituto Nacional de Estadistica, Geografía e Informática (INEGI). From these sections, 400 respondents were randomly selected on a percentage basis according to population density. For the water manager survey, three water managers were interviewed from COAPAES (Comisión de Agua Potable y Alcantarillado del Estado de Sonora) and OOMPAS (the Organisimo Operador Municipal del Agua Potable y Ancantrillado de Sonora) in Cananea and Naco and one from the regional office of the Comisión Nacional del Agua (CNA). Three managers of bottled water companies in Cananea were also interviewed. For the rural water users survey, 157 surveys were taken in four *ejidos* located along the Mexican portion of the San Pedro River: Emiliano Zapata, Ignacio Zaragoza, José Maria Morelos, and Cuauhetemoc.

Interviews Face-to-face survey interviews (564) were conducted in Cananea and basin rural communities or *ejidos* by a Mexican team during a time of water crisis when service breakdowns had been frequent. In addition, summer heat and periodic drought had increased the demand for water in the basin as a whole. There was a strong public interest in the surveys and a sense of frustration among water users in regards to their experiences without a safe and steady supply of water.

The interview protocol was divided into five sections: personal data, water service and use over the last five years, impacts of climate change and variability on water use, access and use of information on climate and aquifer conditions, evaluation of the seriousness of community water problems and responsibility for water management, and how water costs should be paid. Rural surveys also looked at the relationship between crop and cattle selection and water use.

The separate water manager protocol also included five sections covering work background, the impacts of climate change and variability on water management strategies, access to climate and hydrologic information, community access to climate information, water supply, distribution, and infrastructure, and policy issues.

4.2 Results

4.2.1 Urban users

While urban residents perceive little impact from drought in the past 10 years, over 40% perceive a high degree of water service interruptions (one or two times per week) (Fig. 2). Water quality is perceived as a serious issue in Cananea, with over 70% of households rating water quality over the past six months in the worst two categories. The frequency of water quality problems is also a serious issue, with nearly 60% of households selecting the problem as an everyday occurrence.

Perceived water vulnerability Researchers created a cross-cutting index (Fig. 3) to represent "perceived water system vulnerability." The index incorporated 36 variables (all ordinal data) grouped as follows: 18 questions assess perceptions of climate vulnerability and impact, including 10 questions on the perception of frequency of different extreme climatic events over the past 10 years, and eight questions assess the perception of frequency of domestic water service difficulties directly tied to climatic conditions over the past 10 years. Two questions gauge perceptions of water quality, while 16 questions ask respondents to rate the seriousness of community-wide water issues. All 36 questions produced ordinal data on a scale of one to five, with five representing the worst situation (perceived frequency of climatic shocks, worst water quality ranking, most serious community water problems), and one representing the best scenario or least perceived impact. The graph presents the percentage of households grouped according to response. The "general perceived water system vulnerability" (top bar) is a composite index including more than the five variables presented (a total of 36 variables, reliability coefficient .7515). The index suggests that respondents' overall perception of water system vulnerability is relatively homogenous, with 79% of urban households scoring three out of five on the general index. The average score, however, results from offsetting trends: While urban residents perceive less risk associated with certain variables (such as climate related risk to the water system), there is a high-risk perception to other factors (such as quality concerns). The index was created to compare general perceived vulnerability to other variables such as residence within Cananea, age, education level and gender using factor analysis of variance. Of these variables, there is a statistically significant effect on mean score according to residence, with the lowest mean score in barrio El Dorado (43.6 out of 100), a higher income neighborhood, and the highest score in Mesa Sur (53.9), a less well-off neighborhood.

It is important to take a closer look at the disaggregated variables making up the general index and to observe the variability in response to particular issues. Five of these variables are presented in Fig. 3. While urban residents perceive little impact from drought in the past 10 years, 56% perceive a high degree of water service interruptions (one or two times per

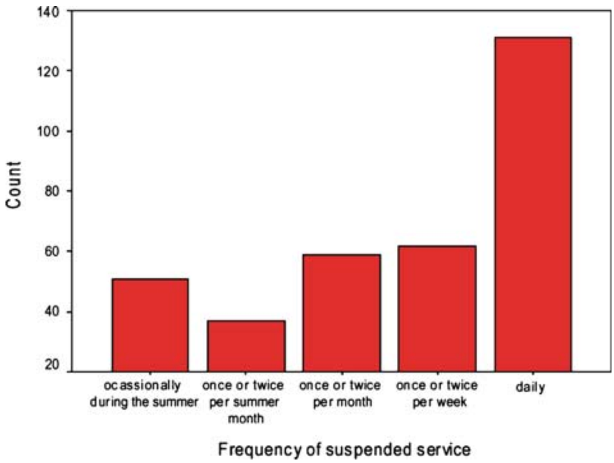

Fig. 2 Urban household perceptions of frequency in water disruptions over the past five years

week or more, 190 households, Fig. 2). Water quality appears to be perceived as a serious issue in Cananea, with over 70% of households rating water quality over the past six months in the worst two categories (Fig. 3). The frequency of water quality problems is also a serious issue, with nearly 40% of households (130 households) selecting the problem as an everyday occurrence.

As an interpretive tool by which to understand the perceptions of rural and urban water users surveyed, the index is not an objective attempt to quantify or qualify actual water system vulnerability. To do so is beyond the scope of this study (see Gleick 2002; Sullivan et al. 2003; and Finan et al. 2002 for discussion). Nor is the index meant to demonstrate that our study area is more of a "hot spot" than surrounding areas. As a measure of perceptions, the score does two things: it permits researchers to compare a composite of several responses from a single respondent to independent variables such as age, gender, and geographic location; and secondly, the range and distribution of household perceptions provides a picture of variability across the population with respect to water system vulnerability.

4.2.2 Urban water managers

Five of the seven water managers interviewed had lived in the San Pedro Basin all their lives, one for 30 years, and represent long-term knowledge. Two managers were in

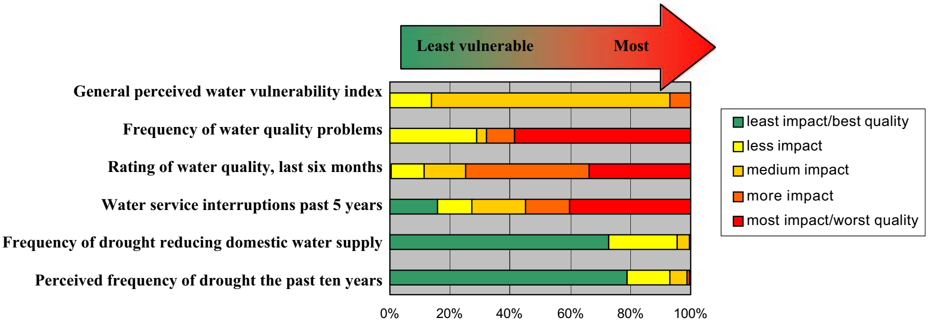

Fig. 3 Distribution of households along perceived water vulnerability index

municipal water institutions and represented legal, planning and technical expertise in water systems. The manager from the state-run institution (COAPAES) worked in technical administration, water system maintenance and budgeting. Most municipal administrators and planners had government training and/or university training in engineering. Private bottling companies were run by female administrators who may or may not have training in water purification and some business education. Most managers had worked in their present position for three to five years. These managers identified numerous challenges to the capacity for water management, along with a need for improved climate and weather information, which have been integrated directly into the Findings and discussion section, below. Overall, the desire for specific improvements in climate information by water managers is notable in comparison to the low perception of climate-related risk among urban water users.

4.2.3 Rural water users

For 157 rural water users in four *ejidos* within the San Pedro watershed, the average profile was a male cattle rancher over the age of 40 who had spent his life in an *ejido* under collective land tenure. Ranch respondents also lived and worked temporarily at other locations from time to time, probably to pursue other income sources from town jobs or family work. Only 14% of people raised crops. Livestock raising, on the other hand, was more prominent: 74 of 157 respondents (47%) owned livestock. At least one third of rural respondents neither cultivated crops nor raised livestock, which may stem from the fact that these respondents are pensioners, commute to Cananea for work, or derive income from alternative economies.

Most of the rural respondents had experienced lower water supply level due to drought from three to ten times or more in the last decade. However, about 40% had never experienced a drought severe or long lasting enough that obliged them to seek other water supply sources or that increased water demand (see Table 1). Sixty percent had never experienced well contamination due to heavy rainfall or had problems with electric pumps

Table 1 Water quality and drought among rural respondents

Percent (%) of respondents	Indication/Action
Drought and water quality	
40	Indicate they have never experienced severe *drought*
15.8	Consider *drought* to be the “most serious” water issue
60	Indicate they have never experienced well *contamination* due to heavy rainfall
15.8	Complain of water *contamination* problems
60	Indicate they have never had problems with electric pumps due to high temperatures
33.6	Complain of *mechanical* water service problems
40–50	Increased water demand due to high temperatures, storms, or frozen pipes
In the face of contamination	
30	Would buy bottled water
19	Would seek purified water elsewhere (neighbor, water store)
4	Would add chlorine to contaminated water
8	Would boil contaminated water
5	Would complain to local water authorities

due to high temperatures. About 40 to 50% had experienced increased water demand due to high temperatures, electrical storms or strong winds that affected their electric pumps, and frozen water pipes. They also had not had access to information regarding these weather and climate conditions.

Most did not normally use hydrologic information or weather forecasts, but if they did, the radio and television were their information sources. If they did use meteorological forecasts, summer would be the most useful time for planning livestock care or planting crops. Several ranchers mentioned that weather forecasts from Mexico City were not helpful for local planning, and that more realistic or accurate information was needed at least one week in advance. *Ejidal* cattle ranchers generally trucked in water during drought, and, rather than raise their own forage, brought it in by truck also.

Regarding water use, rural respondents all used a communal pump for their animals, with an occasional water tank. Domestic water use came from the same source. Monthly water bills were either 25 or 100 pesos, with the charges based on electricity use rather than water use. Very few of the respondents irrigated their crops; or if they did, they were more likely to depend upon rain.

The most frequent complaint about community water problems was the lack of sufficient water pressure, with some mentioning that their electric pumps were cut off if they did not pay their bills. Ranchers believed that the responsibility for water management lay with the municipal government and the *ejidal* community. *Ejido* ranchers generally had a water committee that established a water budget through membership allotments. If they experienced problems with the water supply due to drought, they were most likely to store water for domestic use and generally reduce their water use. They were very unlikely to reduce water for any crops, but this may have been because they were mainly ranchers. If their water were contaminated, they were very likely to buy purified water. When the *ejidal* ranchers were asked to looked into the future to the year 2025, they generally expressed concerns about there not being sufficient water to continue ranching. Some even thought the *ejidos* would be abandoned and ranchers would immigrate to the U.S.

5 Findings and discussion

A complex web of factors determines the vulnerability of water systems and communities to climate change and variability. Water system size and condition, volume of water sources, type of water system management, degree of reliance on groundwater, population and industrial growth, and access to funding for repairs and renovation are all factors implicated in water system vulnerability. However, with Finan et al. (2002, p.300), we agree that vulnerability is “as much about households and society as about climate variability. Whereas climatic events provide the context for understanding vulnerability, the concept itself is essentially a socioeconomic or ecological one.” In this sense, the degree of vulnerability of a water system and the community that depends on it is related directly to the severity of the exposure and the potential recovery rate, and inversely to the community’s capacity to overcome the impacts or adapt to severe climatic events. At the same time, a community’s capacity to adapt is in large part determined by their access to resources, political, economic, technological, and social (see Eakin 2006). This is especially the case in the Mexican portion of the basin, where municipal and rural *ejidal* governments are struggling with the transition from centralized management of water resources to neoliberal local water management.

Many of the survey results point much more strongly toward vulnerability associated with lack of basic water infrastructure, water quality concerns, and institutional issues than they do toward climatic vulnerability. However, given the high baseline level of water vulnerability, climatic variability and change have the potential to intensify the effects of already-existing problems. The observations below provide insight into the multiplicity of challenges faced by Mexican stakeholders in the Upper San Pedro River Basin, and into how climate information might be successfully integrated into decision-making at scales ranging from households to the entire upper basin.

Observation #1. ***Water managers' and water users' access to resources—specifically finances, technology, and local management capacity—plays a critical role in determining water system vulnerability.***

Resident perceptions of water Concerns about quality and service interruptions suggest that system problems are highly related to a lack of access to finances and technology at both the management and user levels. Local management capacity to effectively maintain clean water service depends on access to monitoring, detection, repair, treatment and personnel resources—resources that Cananea's water managers do not readily have as they confront rapid population growth. As one manager noted, "With population growth at about 4% per year, people will suffer a water scarcity, and effects will be extreme if people don't conserve water." At the domestic level, water users are clearly concerned with issues of quality and consistent supply, but they are not willing to allocate scarce resources to storing water or filtering devices. The amount spent by residents on bottled water, however, suggests that the issue may be more a lack of affordable filtration or storage technology, information, or knowledge about options, as opposed to lack of willingness to designate personal resources. Since the survey, researchers have also noticed an increased use of rooftop storage devices.

Link between resources and effective management The COAPAES administrator identified funding for infrastructure repairs as the greatest challenge in providing equitable and dependable water service to Cananea. From his perspective, climate extremes and population growth over the next 20 years will only increase problems for water management, because the administrator complained that, "the aquifer level is 20 m lower than it was in 1984."

Water use and management in Cananea Water use and management in Cananea reflect an on-going concern with water supply from the aquifer, problems with infrastructure as indicated above, and the potential impact of climate changes, particularly drought, on water service. In the last 15 years, the number of water connections increased, residential and industrial use increased, while agricultural use of water remained the same. To deal with the increased water demand, COAPAES has installed more efficient pumps and increased the number of pumps and reserve tanks. But, according to the administrator, "drought diminishes the supply, and water users are not paying their bills, which do not cover the cost of water service or repairs."

Among urban survey respondents, the frequency and severity of service disruptions are related to place of residence in Cananea, which may demonstrate links between service and relative poverty or isolation. When asked how often water service has been suspended in the past five years, 40.2% of urban respondents answered "daily." Close to 70% of respondents did not think drought affected their water supply, changed their water use behavior, or resulted in mandated water restrictions.

The relationship between water system vulnerability and access to finances and technology can also be explored with respect to rural water users around Cananea. Most of the rural respondents had experienced lower water supply levels due to drought three to 10 times or more in the past 10 years. However, about 40% had never experienced drought severe or long-lasting enough to oblige them to seek other water supply sources, or enough to see demand increase.

Observation # 2. ***Urban and rural water users recognize that water service problems, particularly those associated with water quality, can impact regional health, but, not surprisingly, tend to associate these problems with water management rather than climate variability***.

To examine potential relationships between climate and health among urban domestic water users, we looked at the frequency and types of climate problems associated with water supply over a decade; access to and use of climate and weather information; the relationships between water consumption and climate events over a decade; household evaluation of water quality, including degree of seriousness and frequency of problems; and perceptions of climate change impacts on ground and surface water.

We found no indications of links between climate problems/events or access to climate and weather information on the one hand, and water quality concerns on the other. However, problems with drinking water quality occurred every day according to 57.9% of urban domestic water users, and 67.9% considered contaminated drinking water “the most serious community water issue.” Of the urban population, 33.3% mentioned dirty water, possibly from sediments or unidentified matter, and 8% associated gastrointestinal illness with contaminated water (Table 2).

The capacity of households to adapt to problems in water quality depends partly upon the availability of other water resources and upon the household’s capacity to buy water filtering systems or purified bottled water. From our sample, 88.2% said they were “very likely” to purchased bottled water. Households generally do not have water filters: 89% said they currently did not use one, but 51% expected to buy one within the next five years.

While our study does not identify community health problems related to water quality, Cananea residents apparently perceive that the quality of their water supply is problematic and that buying bottled water, even though the COAPAES water manager claims Cananea’s bottled water is not really purified, is the preferred solution. This is consistent with the Moote and Gutierrez survey in which 70% of a sample of 195 Cananea residents had heard of water-related illnesses, such as diarrhea, parasites or hepatitis, in the community (Moote and Gutierrez 2001, p.8).

Among rural water users only 15.8% complained of water contamination problems and 15.8% considered drought the most serious water issue. One-third complained of service breakdowns relating to mechanical pumping problems. If faced with water contamination, 30% said they would buy bottled water, and 19% said they would seek purified water from another source, which could be either a neighbor or a bottled water store (see Table 1).

Observation #3. ***Water users do not believe that lack of access to reliable information about climate and aquifer conditions contributes to the vulnerability of their water system or to poor access to reliable potable water service.***

Although 50.7% of urban domestic water users consulted the media for weather or climate information on a daily basis, 82.9% claimed that media information did not really

Table 2 Water quality and service among urban respondents

Percent (%) of respondents	Indication of water quality
33.8	Found water quality "very bad."
41.2	Found water quality "tolerable but a matter of concern."
57.9	Indicated *daily* water quality problems.
67.9	Consider *drinking water contamination* "the most serious community water issue."
67.4	Consider *contamination in arroyos and rivers* to be a "serious" issue.
22.6	Consider presence of *heavy metals* in community water as a "moderately serious" issue.
24.7	Consider presence of *heavy metals* in community water as "the most serious" water issue.
33.6	Mention problems with water quality, frequently from *sediments* in pipes.
14	Complain of *inadequate water pressure* in pipes.
8	Associate contaminated water with experiences of *gastrointestinal illness.*

warn them about extreme events, and 76.4% said weather and climate information did not help them prepare for potentially dangerous impacts. When asked about the impact of extreme weather events on their water supply or service, 70% stated that drought had never affected their supply over the past 10 years.

From these findings, we may conclude that weather forecasts are not very helpful in household planning for extreme events, and that urban domestic users' perception is that drought has not been a factor in water supply in the last 10 years. Instead, urban domestic water users made recommendations aimed at helping households to cope better with water and climate stresses (see Table 3). This combination reinforces the idea that a complex web of factors determines a community's assessment of its vulnerability to climate change/ variability and to water supply.

Of rural water users, 88% said they did not normally use either meteorological reports or news about surface water conditions. For those who do use weather forecasts, this information was most useful during the summer to 69% of them. However, rural users commented that "more dependable" current weather or climate information sources delivered at least a week in advance would be valuable in planning water use.

Observation #4. ***Urban and rural water users do not currently modify their water consumption in response to climate variability or change.***

Ninety-eight percent of Cananea residents observed that climate changes had occurred during their residence in the basin, and 94% noted changes in rivers or arroyos. However, they apparently did not connect climate changes with water supply or surface water flow. Most of the urban respondents stated they had never experienced drought or flooding in the last decade, although according to climatologists the southwestern United States and northern Sonora may have begun a period of long-term drier conditions characteristic of past climatic patterns (Sheppard et al. 2002; Merideth 2001).

Rural water users were actually split in their perceptions of drought impacts; half observed that drought lowered their water supply and forced them to seek other sources six to nine times in the last decade, while the other half said they had never encountered problems. This difference might have to do with either microclimate conditions or proximity to the San Pedro River and thus to surface or near-surface water. In any case, 89% of rural respondents raised

Table 3 Urban water users' recommendations

Percent (%) of respondents	Recommendation
16	Apply existing laws
9	Better educate water users in community
9	Institute punishments for water users who do not pay
9	Invest money in the water system for repair and renovation
8	Install domestic water meters
5	Increase water system efficiency
4	Change current local water managers

cattle, at an average of 15 cattle per cattleman, but when faced with water shortage, they either trucked or piped in water rather than decrease herd size.

Observation #5. ***Water managers do modify their management strategies in response to climate variability or weather stresses.***

Climate and weather problems that caused management problems in the 10 years preceding the study include seven to eight years of drought, intense rains in 1994–1995, and freezing temperatures in 1996 and 1998. The COAPAES administrator had little confidence in the Mexican weather service, so he watched the U.S. weather channel for ten-day predictions on temperature, wind velocity and direction. Only the CNA regional director coordinates programs and strategies with federal and state agencies and uses mathematical models to interpret impacts of severe events on water systems for the northwest.

More accurate climate and weather information would help the administrators plan effectively in terms of pump use and potential for repairs, especially temperature data from May to July and wind velocity October to December. The Cananea COAPAES manager and the regional CNA manager both used meteorological forecasts to prevent or prepare for emergency situations. From their perspective, for most effective water planning, drought information is required five months in advance and information about heavy rains two to three months in advance. In comparison, in a recent water provider questionnaire administered by the Arizona Department of Water Resources in the Sierra Vista subbasin, all municipal and private water companies and water improvement districts pointed to drought as the most important water issue they faced. They regarded as most helpful in preparing for future droughts their capacity to charge higher fees for higher volume during droughts and the community's participation in a drought-triggered water conservation program (ADWR 2003).

Observation #6. ***Few urban or rural households have water storage capacity to meet their water demands under drought conditions.***

To determine how urban and rural households manage water, we asked them to identify their greatest demands for water. There is no metering to determine actual level of use. We also asked them who was currently responsible for their water service, how use was regulated, and what household adaptations were made to problems with water quality or water service cutoffs.

As might be expected, the greatest demand for water among urban households (see Table 4) was for personal consumption for drinking and cooking (93%), for bathing and toilet (67%), and washing and cleaning (59%). Few households (9%) had rooftop storage units, but 52% were considering buying them. Regarding other forms of water storage, 98% had none and 95% were not considering buying them.

Urban water service in the preceding five years was suspended once or twice a summer for 18% of households, once or twice a month for 14%, once or twice a week for 25, and 5% on a daily basis, but only 7% reported that their service had never been cut. The adaptation strategy most frequently chosen to cope with water cutoffs was to store water (85%). Purchasing bottled water was chosen by 88%, while 30% were willing to use less water. From the urban households, 71% had had to use one of these adaptation strategies.

Rural water users were reluctant to discuss their storage capacity and pumping information, but 19% indicated they had at least one well with an average well depth between 90 and 180 m and an average depth to water between 40 and 60 m. Only five rural respondents said they had a cattle tank or reservoir.

Observation #7. ***Urban water users are unwilling to pay increased tariffs or taxes for water, although some are willing to pay graduated (metered) water bills rather than a flat rate. Few rural water users pay for water, including electricity for pumping.***

Currently urban water users pay a flat rate of about 63 pesos (US$5.64) a month for water service. No one in the survey was willing to pay more for water or pay higher taxes in order to improve the community water supply. However, 47% were willing to participate in a combination of three activities to improve water supply: 1) voluntarily practice water conservation, 2) participate in community discussions about water use, and 3) pay for water by amount of use (metered). In terms of financing repairs to the current water system, 73% said they were unwilling to pay an increase.

Rural users paid between 20 to 100 pesos a month for water, although 31% did not pay for water at all. Only 11% of rural users had electric water pumps, for which they paid a monthly rate, usually about 100 pesos (US$9).

6 Conclusions and recommendations

Today, the role played by climate in vulnerability to water scarcity and quality problems in the Sonoran portion of the Upper San Pedro River Basin is relatively minor. By far the most pressing problems are related to the area's very considerable infrastructural and institutional

Table 4 Urban household water demand

Percent (%) of respondents	Indication
Demand types	
93	Personal consumption demand
67	Bathing and toilet demand
59	Washing and cleaning demand
Changes in demand	
57	Households show decreased consumption
Storage	
9	Currently have rooftop storage units
52	Consider buying rooftop storage units
98	Currently have no other type of storage
95	Currently do not consider buying any other type of storage

shortcomings. However, given growth in water demand and the finiteness of the region's water resources, climatic stress has high potential to exacerbate the stresses affecting human and natural systems alike. To summarize the conclusions, we have considered each sector separately:

6.1 Urban water resource management challenges

The San Pedro Basin surveys indicate that in the urban setting, the central concern is the lack of reliable potable water service due to the breakdown of infrastructure. Climatic impacts, specifically drought and high temperatures, exacerbate the underlying sensitivity and vulnerability of the region to water scarcity. While implementation of a new decentralized approach to water management in Mexico might increase basin participation and responsibility for more efficient water use, lack of sufficient funding remains a serious challenge to implementing any efficient management practices. There is considerable disagreement as to who should pay for water and wastewater treatment, especially since these services have previously been free or available at low cost.

At the same time, water managers would prefer having access to climate, weather, and hydrologic information to improve planning strategies, but access to this information is limited. Likewise, water managers and the surveyors noted that urban water users have little incentive to conserve water, both because of the low flat rate and their frustration with the existing water service system. They also noted that the community does not have sufficient information or understanding regarding the relationship between climate and water use and that community education about climate and the "culture of water" is definitely needed. When asked about the future water supply (looking forward to the year 2012), Cananea's managers said the water would run out if current trends continued. CNA predicted a possible water crisis under current trends, as is presently evidenced by interruption of surface (river) flow and the concurrent destruction of native vegetation.

6.2 Rural water issues

The rural surveys suggest that while ranchers recognize their lifestyle is in jeopardy because of climate changes and potential basin water loss, they are generally not using either climate or weather information in their planning. When faced with lack of water for their livestock, their strategy is to bring in water from other locations. However, the *ejidal* ranchers do have a system to manage their water allocation, and they have the general support of the CNA, probably with the help of the Cananea mine, in terms of access to well water. As with urban users, their costs for water are very low. The surveys also indicate that the challenge to basin residents, managers, scientists, and state and municipal officials is to inform, educate and convince people that changes in the provision of water services may require changes in the tariff system and that an efficient and reliable water system requires better water planning, including addressing vulnerability to climate variability and conservation.

6.3 Recommendations

The San Pedro surveys and the Dialogue on Water and Climate process may be regarded as strategies to generate information, raise awareness of the relationship between climate and water, and gather support and acceptance for the fact that change is necessary to obtain a level of water service that is efficient, equitable, and sustainable in the basin. They provide the necessary groundwork for potential binational cooperation on coordinated basin management. The following recommendations reflect the concerns and issues uncovered by the survey.

Decreasing vulnerability to water scarcity must begin with improving water infrastructure, including replacement of aged pipes and other equipment, installation of new infrastructure where needed, introduction of better water metering, and efficient water pricing structure and fee payment tracking. Equally critical is construction of water treatment facilities to assure safe water supplies for potable uses and economic development. Decreasing vulnerability to water scarcity also requires concerted effort to improve housing, education, and livelihoods for the poorer population segments.

Developing local institutional, organizational, and cultural capacity to manage water supplies at the local level is also a critical need. The Dialogues on Water and Climate can assist this process by establishing forums where community members may enhance their understanding of the links between water, climate, and vulnerability; and participate in educational activities that build knowledge about water policies, policy options, infrastructure needs and issues, water quality issues, and many other topics.

Specifically with regard to practical uses of climate information, the design and construction of infrastructure and institutional mechanisms requires that the best available scientific information about climate and hydrology be used. An enhanced monitoring system should be established in strategic locations in order to develop sufficient time series data where short, discontinuous, or no time series data currently exist. Concurrently, networks should be developed to communicate information about climate, water resource conditions, water infrastructure conditions, changes in laws, institutions, policies and practices, and about trends in water demand, conservation strategies, etc. The information should be tailored to broadly defined user groups, to meet specific needs with regard to the nature of the information presented, the time period covered, and how/when the information is transmitted. Further, research should be undertaken to develop and disseminate specifically *transboundary* climate information to border stakeholders. This research should be designed to integrate basin stakeholders into both the research and dissemination processes.

Acknowledgments This study was initiated in 2002 under the auspices of the Dialogue on Water and Climate (DWC), an international project aimed at better understanding the link between water resources and climate variability. The project received additional funding in 2003 under a NOAA/OGP grant to examine in greater depth the use of climate-information products by stakeholders in the upper San Pedro Basin. The Udall Center and CLIMAS, both located at the University of Arizona, and the USDA's Southwest Watershed Research Center collaborated with San Pedro Basin water stakeholders in an effort to address specific hydrologic and climate research needs and to build the capacity of water management partnerships or task forces to coordinate transboundary water management. We also wish to thank the interview team members for their hard work: Francisco Delgado of the School of Renewable Natural Resources, University of Arizona; Arturo Rodriguez and Felix Villaseñor of the Asociación Regional Ambiental Sonora-Arizona, Cananea, Sonora; and Mireya Cons, with the Instituto Nacional de Estadística Geografía e Informática, in Hermosillo, Sonora.

References

Arias HM (2000) International groundwaters: the Upper San Pedro River Basin case. Nat Resour J 40 (2):199–222

Arizona Department of Water Resources (ADWR) (2003) Rural water resources study, water provider questionnaires. Cochise County, Arizona

Browning-Aiken A, Morehouse B (2006) Managing water resources in semi-arid ecosystems along the U.S.–Mexico border: regional responses to climate changes. Paper presented to the Association for Borderlands Studies. April 21, 2006. Phoenix, Arizona

Carter RH, BJ Morehouse (2003) Climate and urban water providers in Arizona: an analysis of vulnerability perceptions and climate information use. Climate Assessment for the Southwest (CLIMAS) Report Series CL 1-03. Tucson, Arizona

Carter RH, Tschakert P, Morehouse BJ (2000) Assessing the sensitivity of the Southwest's urban water sector to climate variability: case studies in Arizona. Climate Assessment for the Southwest (CLIMAS) Report Series CL 1-00. Tucson, Arizona

Comrie AC (2003) Climate doesn't stop at the border: U.S.–Mexico climatic regions and causes of variability. In: Díaz HF, Morehouse BJ (eds) Climate and water: transboundary challenges in the Americas. Kluwer Academic Publishers, Dordrecht

Díaz HF, Morehouse BJ (eds) (2003) Climate and water: transboundary challenges in the Americas. Kluwer Academic Publishers, Dordrecht

Eakin HC (2006) Weathering risk in rural Mexico: climatic, institutional, and economic change. University of Arizona Press, Tucson, AZ

Finan TJ, West CT (eds), (2000) An Assessment of Climate Vulnerability in the Middle San Pedro River. Climate Assessment for the Southwest (CLIMAS) Report Series CL-00. Tucson, Arizona

Finan TJ, West CT, Austin D et al (2002). Processes of adaptation to climate variability: a case study from the U.S. Southwest. Clim Res 21:299–310

Fox V, Pres. (2001) Programa nacional hidráulico, 2001–2006. Mexican National Water Commission (Comisión Nacional del Agua). Mexico City

Garfin G, Crimmins MA, Jacobs KL (2007) Drought, climate variability, and implications for water supply and management. In: Colby BG, Jacobs KL (eds) Arizona water policy: management innovations in an urbanizing, arid region. Resources for the Future, Washington, D.C., pp 61–78

Gleick P (2002) The world's water: 2002–2003. In: The biennial report on freshwater resources. Island Press, Washington

Goodrich, DC, A Chehbouni, B Goff et al (1998) An overview of the 1997 activities of the Semi-Arid Land-Surface Atmosphere (SALSA) Program http://www.tucson.ars.ag.gov/salsa/archive/publications/ams_preprints/goodrich1.pdf

Jacobs K, Garfin G, Lenart M (2005a) More than Just Talk... Connecting Science and Decision making. Environment 47(9):6–21 Nov2005

Jacobs KL, Garfin GM, Morehouse BJ (2005b) Climate science and drought planning: the Arizona experience. J Am Water Resour Assoc 41:437–445

Jamail MH, Ullery SJ (1979) Pollution of the San Pedro River. International water use relations along the Sonoran Desert borderlands. Tucson: Arid Lands Resource Information Paper No. 14

Lemos MC, Morehouse BJ (2005) The co-production of science and policy in integrated climate assessments. Glob Environ Change Part A 15(1):57–68

Liverman DM (1998) Southwest regional overview. In: Climate variability and change in the Southwest: impacts, information needs, and issues for policymaking. Final report of the Southwest Regional Climate Change Symposium and Workshop. Tucson, Arizona, pp 13–19

Liverman DM, Bales RC (1998) Future climate of the Southwest. In: Climate variability and change in the Southwest: impacts, information needs, and issues for policymaking. Final report of the Southwest Regional Climate Change Symposium and Workshop. Tucson, Arizona, pp 26–27.

Magaña VO, Conde C (2003) Climate variability and climate change, and their impacts on freshwater resources in the border region: a case study for Sonora, Mexico. In: Díaz HF, Morehouse BJ (eds) Climate and water: transboundary challenges in the Americas. Kluwer Academic Publishers, Dordrecht, pp 373–392

Merideth R (2001) A primer on climatic variability and change in the Southwest. Udall Center for Studies in Public Policy and Institute for the Study of Planet Earth, Tuscon, Arizona

Moote A, Gutiérrez M (2001) Views from the Upper San Pedro River Basin: local perceptions of water issues. University of Arizona Udall Center for Studies in Public Policy, Tucson, Arizona

Moreno, JLVázquez (1991) El futuro de la problemática ambiental en Cananea y Nacozari. Paper presented at XVI Simposio de Historía y Antropología de Sonora. Instituto de Investigaciones Históricas, Universidad de Sonora, Hermosillo, Sonora, Feb. 23

Ray AJ, Garfin GM, Wilder M et al (2007) Applications of monsoon research: opportunities to inform decisionmaking and reduce regional vulnerability. J Climate 20(9):1608–1627 May 2007

Scott RL, Goodrich D, Levick L et al (2006) Determining the riparian groundwater use within the San Pedro Riparian National Conservation Area and the Sierra Vista subwatershed, Arizona. In: Leenhouts JM, Stromberg JC, and Scott RL, (eds) Hydrologic requirements and consumptive groundwater use by riparian vegetation along the San Pedro River, Arizona: U.S. Geological Survey Scientific Investigations Report. 2005–5163, pp 107–139

Sheppard PR, Comrie AC, Packin GD et al (2002) The climate of the U.S. Southwest. Clim Res 21:219–238

Sprigg WA, Hinckley T (2000) Preparing for a changing climate: the potential consequences of climate variability and change. Report of the Southwest Regional Assessment Group for the U.S. Global Change Research Program. September. Institute for the Study of Planet Earth, University of Arizona, Tucson, AZ

Sullivan CA, Meigh JR, Giacomello AM et al (2003) The water poverty index: development and application at the community scale. Nat Resour Forum 27:189–199

Varady RG (1998) U.S.–Mexico border workshop report. In: Climate variability and change in the Southwest: impacts, information needs, and issues for policymaking, Final report of the Southwest Regional Climate Change Symposium and Workshop. Tucson, Arizona. Tucson, AZ: Udall Center for Studies in Public Policy, pp 65–67

Whiteford S, Melville R (2003) Foreword. In: Whiteford S, Melville R (eds) Protecting a sacred gift: water and climate change in Mexico. Center for U.S.–Mexico Studies, San Diego, pp 1–28

Woolhiser DA, Keefer TO, Redmond KT (1993) Southern Oscillation effects on daily precipitation in the southwestern United States. Water Resour Res 29(4):1287–1295

Zavala EV (1987) Minera de Canaea, SEDUE, y el medio ambiente. Comunicobre Feb. (62):5