


Moving Forward from Vulnerability to Adaptation:
Climate Change, Drought, and Water Demand in the Urbanizing Southwestern United States and Northern Mexico

Avanzando desde la Vulnerabilidad hacia la Adaptación:
El Cambio Climático, la Sequía, y la Demanda del Agua en Áreas Urbanas del Suroeste de los EEUU y el Norte de México


CASEBOOK **Ambos Nogales • Puerto Peñasco • Tucson • Hermosillo**

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

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In collaboration with

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Moving Forward from Vulnerability to Adaptation
Avanzando desde la Vulnerabilidad hacia la Adaptación

Contents

Preface

The case studies in this book of urban water resources vulnerability and climate change in the U.S.-Mexico border region were prepared by a binational team of researchers led by Margaret Wilder (University of Arizona, UA), Gregg Garfin (UA), Nicolás Pineda (Colegio de Sonora), Robert Varady (UA), and Christopher Scott (UA). The studies represent three years of collaborative work involving multiple U.S. and Mexican institutions. The UA's Udall Center for Studies in Public Policy coordinated the research, while primary funding came from the National Oceanic and Atmospheric Administration's Sectoral Applications Research Program (NOAA-SARP). Additional research support was received through the Inter-American Institute for Global Change Research (IAI) and NOAA's Climate Assessment for the Southwest (CLIMAS) program (based at the UA's Institute of the Environment).

This volume's publication is supported by the newly emerging International Consortium for Adaptation in Drylands (ICAD), and in part through funding that ICAD receives from the National Science Foundation. ICAD was formed in late 2010 to bring together the assets and expertise of a group of researchers at the Universidad Nacional Autónoma de México (UNAM) and the University of Arizona in order to address the common problems that confront their respective nations in dealing with the management of their shared drylands. The growing pressures of climate change, population growth and resulting landscape transformation, played out against a background of water scarcity, present a set of challenges that must be overcome if these lands are to continue to provide essential services in the future. ICAD takes an interdisciplinary approach to ecosystem services that are either shared across the border of the two nations or paired in the dryland landscape.

The ICAD initiative is led by Dr. Joaquin Ruiz, dean of the UA College of Science and executive dean of the Colleges of Arts, Letters, and Science, and by Dr. Carlos Gay, director of the Climate Change Research Program at UNAM.

The authors of this casebook gratefully acknowledge ICAD, Dr. Joaquin Ruiz, the UA College of Science, and Dr. Carlos Gay for their support of the publication of this volume.

CHAPTER 1

INTRODUCTION

Moving Forward from Vulnerability to Adaptation: Theory, Methodology, and Context

By Margaret Wilder, Robert G. Varady, and Gregg M. Garfin

The Arizona-Sonora region along the U.S.-Mexico border has been called "the front line of ongoing climate change" (Harrison 2009). Due to its rapid growth, industrialization, and climate characteristics, it is recognized as a highly vulnerable region in terms of socioeconomic and climate characteristics (Liverman and Merideth 2002; Ray et al. 2007; Wilder et al. 2010). Ensuring future water supply is the region's highest priority challenge. Climate change projections for reduced precipitation and severe drought in this "already water-scarce region" are expected to cause "troublesome consequences for the southwest United States and Mexico" (Seager and Vecchi 2010:21277).

From 2008 to 2011, a binational team of researchers led by the University of Arizona and El Colegio de Sonora worked closely with decision-makers, water managers, and disaster relief planners (i.e., stakeholders) to conduct linked urban water vulnerability assessments of four urban climate change "hotspots" in the Arizona-Sonora region, as part of the NOAA/SARP project, *Moving Forward from Vulnerability to Adaptation: Climate Change, Drought, and Water Demand in the Urbanizing Southwestern United States and Northern Mexico*. The case studies were conducted by the research team using linked questions and methodologies to assess near- and long-term (5 to 20+ year) climate-related vulnerability and adaptive capacity of the water sectors in four urban areas in the region: Tucson, Ariz.; Nogales, Ariz./Nogales, Son.; Hermosillo, Son.; and Puerto Peñasco, Son. Research support was provided by the National Oceanic and Atmsopheric Administration's Sectoral Applications Research Program (SARP), NOAA's Climate Assessment for the Southwest (CLIMAS) Program; and the Inter-American Institute's Global Change Research Human Dimensions program (IAI).[1]

The rapidity of growth in Arizona and Sonora increases the vulnerability of urban water users to climatic changes due to such factors as aging or inadequate water-delivery infrastructure, over-allocation of water resources within the region, and location of poor neighborhoods in flood-prone areas or other areas at risk. Since 1980, the urban populations within our study region have exploded: Tucson has grown by 53 percent; Hermosillo by 116 percent; and Nogales, Son., by 189 percent. With Arizona remaining one of the United States's fastest growing states, and Sonoran cities growing at twice the national Mexican average over the last decade, water demand over the next 20 years is projected to double. Another sector vulnerable to climate – agriculture – continues to be an important

1 National Oceanic and Atmospheric Administration Sectoral Applications Research Program (NOAA-SARP) grant NA080AR4310704; NOAA's Climate Assessment for the Southwest (CLIMAS) Program grant NAG16GP2578; and Inter-American Institute's Global Change Research Human Dimensions program (IAI) grant SG-HD-#005, supported by the National Science Foundation grant GEO-0642841.

part of the regional economy and consumes approximately 70 to 80 percent of available water in the Arizona-Sonora region (Arizona Town Hall 2004; CNA 2008).

Research Questions

The *Moving Forward* project responds to four central research questions:

- How is urban water sector vulnerability defined in the four urban sites in the study region?
- What is the institutional capacity of this transboundary region to develop adaptive strategies for future water management, at a 5 to 20+ year horizon?
- How can the capacity of water managers and preparedness planners to use climate science and information to improve long-range and "adaptive" decision-making best be institutionalized?
- How can climate science best be integrated into planning processes to enhance the resilience of urban border communities to climatic and water-resources uncertainties?

To respond to these questions, we planned **three major outputs** from the study:

1. **Case studies of climate-related water sector vulnerability** in the four urban areas (Tucson, Ambos Nogales, Hermosillo, and Puerto Peñasco) based on analysis of identified vulnerability indicators, including biophysical, demographic, socioeconomic, and institutional characteristics;
2. Production of a quarterly **binational climate summary** (in Spanish and English) focused on dissemination of value-added, timely, and regionally focused climate information based on a principle of co-production of regional climate knowledge by policymakers and the scientific community;
3. A series of **stakeholder workshops** focused on identifying priority vulnerability areas and improving the fit between climate information needs of stakeholders and the climate information produced by the scientific community in the binational region.

Overview of Study Area: Four Urban Climate Change Hotspots

For these studies, we identified four major growth "hotspots": Tucson; Ambos Nogales (referring to Nogales, Ariz., and its 'twin' city, Nogales, Son.); Hermosillo, Sonora's state capital; and Puerto Peñasco, on the Gulf of California coast (see Figure 1-1). Climate is the key unifying factor in our selection of these sites—we have intentionally selected urban areas within monsoon-driven climate regimes.

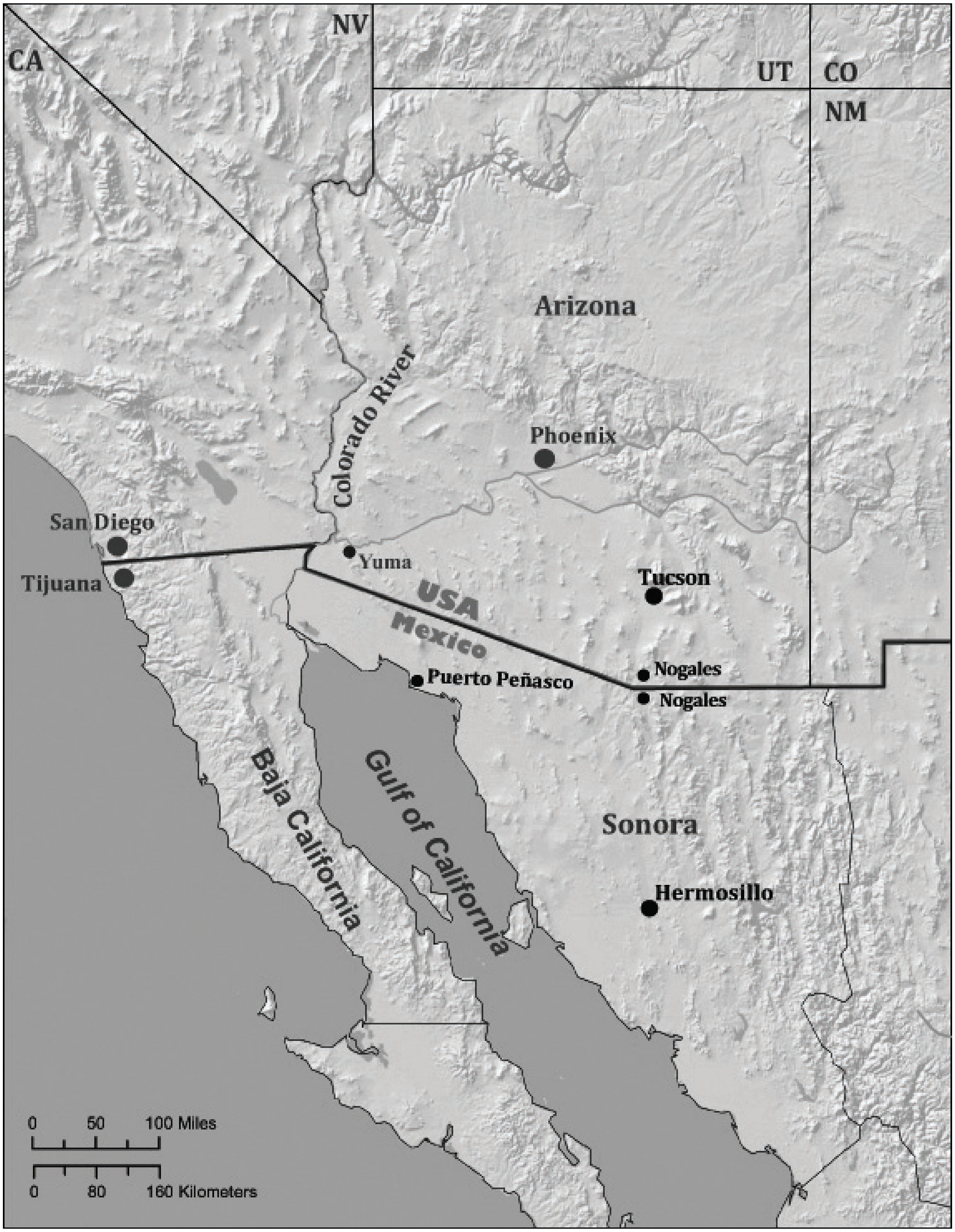

Figure 1-1. U.S.-Mexico border area and study sites (in black): Tucson, Ariz.; Nogales, Ariz./Nogales, Son.; Hermosillo, Son.; and Puerto Peñasco, Son. Source: Zack Guido, CLIMAS Project, University of Arizona.

These sites also encapsulate the most critical issues facing this region: changing urban water supply and demand in high-growth border-region cities; urban-rural interface and urban/agricultural water use tradeoffs; and the expanding phenomenon of resident-tourism driven growth that has transboundary economic drivers. ("Resident tourism" refers to the North American vacation house industry resulting in new subdivisions and commercial tourism development on the Sonoran coast.) Our study area includes the Colorado River system to the west of our main study area to the extent that its water is integral to current and future water-supply planning for the Tucson area; however, we did not include an extensive study of that basin within the scope of this project, given its distinct climate, water-resources profile, and demographic challenges. (The CLIMAS program does have ongoing climate and sustainability projects within the Lower Colorado River and Delta region.)

Theoretical Framework: Vulnerability and Adaptation

Vulnerability is produced by "on-the-ground" inequalities and political-economic conditions, rather than "falling from the sky" (Ribot 2010:49), and is conditioned by socioeconomic, institutional, and political, as well as environmental factors, including climate (Adger 2006). Uneven development is also a hallmark of relatively high vulnerability (Romero-Lankao and Borbor-Cordova forthcoming). Figure 1-2 identifies how biophysical and social processes interact with one another to create vulnerability to climate change.

In keeping with Kelly and Adger (2000), we define "vulnerability" as "the ability or inability of individuals and social groups to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being." "Adaptive capacity" refers to the ability of a given region to anticipate, respond dynamically to, and/or plan for projected changes associated with climate change. "Resilience" refers to a human-environment system's ability to "bounce back" by developing social networks and institutions capable of adaptation and learning to respond more sustainably to climate change (Tompkins and Adger 2004).

The uneven development evident in the border region poses challenges for developing adaptations in the Arizona-Sonora region. Climate impacts are not uniformly distributed across populations and space, but instead are closely-related with specific vulnerable populations and places (Romero-Lankao and Borbor-Cordova forthcoming). In the United States, studies have documented higher vulnerability among Latino and African-American populations, for example, due to factors such as low average incomes and lack of affordability of energy for cooling and heating in periods of extreme temperatures; outdoor employment; and lack of green spaces (Morello-Frosch 2009; Verchick 2008; Harlan 2006).

At the same time, effective cross-border collaboration can enhance the border region's adaptive capacity through developing shared understandings of regional vulnerabilities and working co-operatively to address them (Wilder et al. 2010). Shared information and data are particularly important. Integration of climate information into decision-making processes can help reduce social and climate vulnerability within the identified region and build community resiliency (IPCC 2007; Kelly and Adger 2000). Thus, the assessment of an area's social vulnerability and institutional capacity to respond to crises are points of beginning for research that may lead to increased community resilience (Ray et al. 2007).

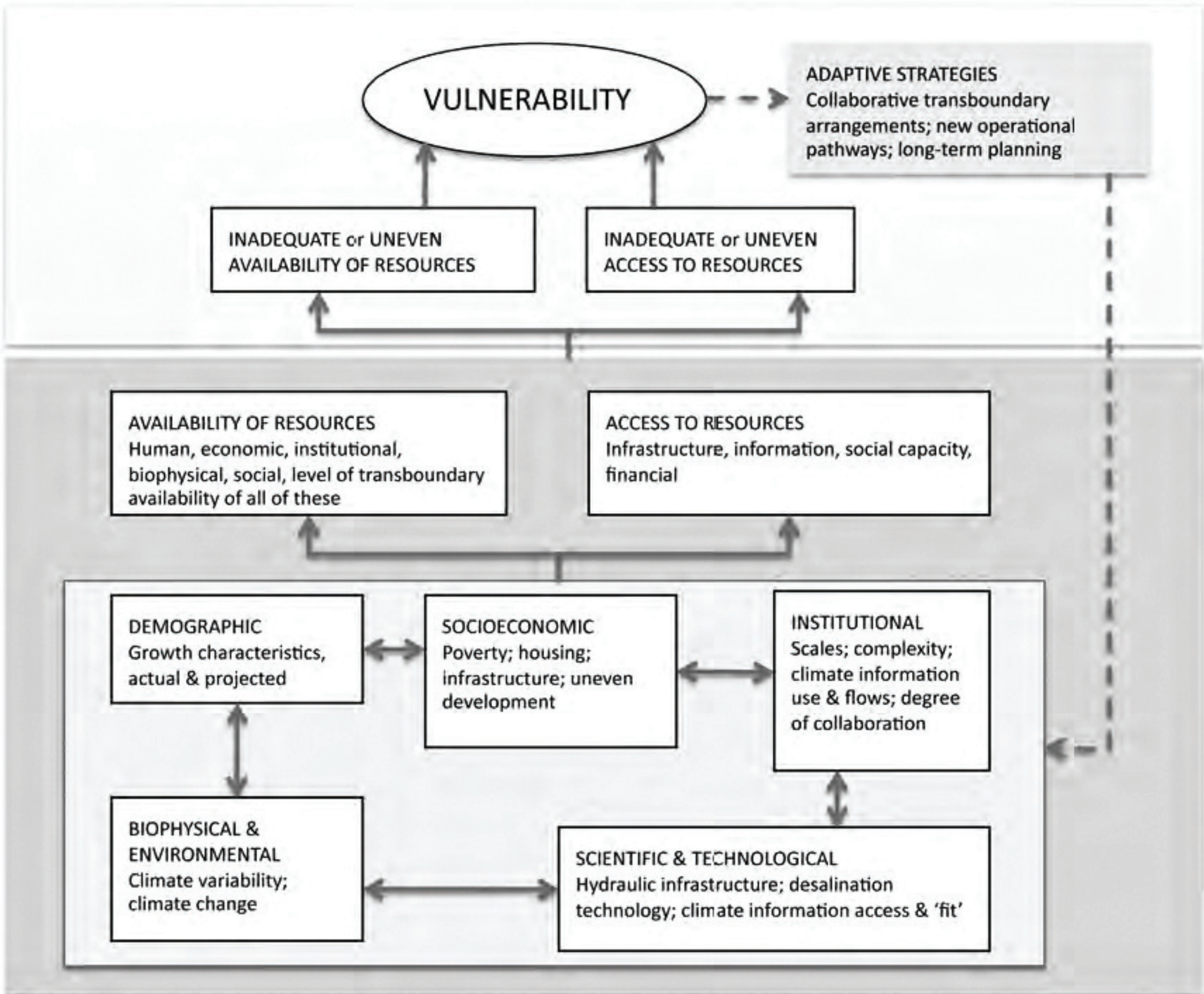

Figure 1-2. Theoretical Framework of the Processes Driving Vulnerability. Scaled analysis including global, binational, regional, and local drivers acting over the short term (shock) or long term (chronic). Adapted from Misselhorn 2005.

These key concepts need to be operationalized for assessment purposes. Thus, these case studies are integrated through their reliance on a common framework for assessing regional vulnerability. Our research framework (see Figure 1-2, adapted from Misselhorn 2005) is based on assessment of five indicators of regional vulnerability: demographic, socioeconomic, biophysical/environmental, scientific and technological, and institutional vulnerability. Each case study utilizes these five indicators to assess urban water vulnerability. At the same time, we use urban plans, transboundary collaboration, information-sharing and alternative conservation strategies as evidence of adaptive capacity. In Table 1-1, the major vulnerabilities and adaptation activities of each study site are summarized.

Table 1-1. Summary of Preliminary Findings.

RESEARCH SITES	PRIORITY VULNERABILITY THEMES IDENTIFIED	ADAPTATION ACTIVITIES (initiated, ongoing, or in planning stage)
Ambos Nogales, Ariz./Son.	Fragmented, complex transboundary water management across Ambos Nogales Inadequate access to drinking water and sanitation in poor Nogales, Sonora neighborhoods; and staggered water service (tandeo) across municipality Inadequate infrastructure for flood management in Nogales, Sonora	Collaboration on wastewater treatment and groundwater assessment via IBWC/CILA and state/local water management organizations Systematic research on water vulnerability at neighborhood level; community mobilization on key vulnerabilities in water access; alternative strategies being tested (e.g., compost toilets) Developing flood management and warning systems (municipal water authority, OOMAPAS, USGS & IMIP)
Puerto Peñasco, Son.	Aquifers exhausted and cannot support projected future growth of tourism/hotel industry Fragile estuaries in Upper Gulf with endangered species need protection from both over-fishing and tourism expansion	Municipal desalination plant in feasibility study to serve Puerto Peñasco and tourism industry Active NGO (Center for Protection of Deserts and Oceans, CEDO) working with local fishermen and businesses to put protections in place
Tucson, Ariz.	Reliance on sole-source supply from over-allocated and water-stressed Colorado River Drought-prone and high-growth area	Long-term water supply/climate scenario planning by Tucson Water Conservation promotion at household scale and recharge/re-use at municipal scale
Hermosillo, Son.	Water rationing (tandeo) across Hermosillo due to low water supply, use patterns, & infrastructure losses Regional and urban-rural competition for water	Arizona-Sonora have joint binational desalination planning underway for new desalination plant in Puerto Peñasco Sonora Integrated System (Sonora SI) plans major water transfers from commercial irrigation districts in the south of Sonora to Hermosillo and other cities

Overview of Climate Variability and Climate Change Forecasts and Impacts in Region

The U.S.–Mexico border region is a textbook case of "double exposure" (Leichenko and O'Brien 2008) to climatic and globalization processes (Liverman and Merideth 2002; Ray et al. 2007) as a vulnerable area undergoing urbanization, industrialization, and agricultural intensification. As mentioned above, the region has been called "the front line of ongoing climate change" (Harrison 2009). Global climate models for the region project severe precipitation decreases and temperature increases. Regional climate change is expected to lead to a 2 to 3° C increase in annual temperature and a 5 to 15 percent decrease in annual precipitation by 2080-99, in comparison with a 1980-99 base period, based on 21 global climate models (GCMs), using an A1B greenhouse gas emissions scenario (IPCC 2007). All models agree on the increase in annual temperature and more than 75 percent of models agree on the decrease in annual precipitation.

Moreover, Diffenbaugh et al. (2008) identify northern Mexico, and the Mexico-Arizona border region as persistent climate change hotspots; they note that these regions are sensitive to changes in winter and summer season precipitation variability, during the 21st century.

Anticipated probable impacts include longer, more extreme droughts, higher water and energy demand, decreased inflows to rivers and streams, and increased urban–agricultural conflict over water (IPCC 2007; Seager et al. 2007). Drought impacts on water supply are expected to become more severe (Cayan et al. 2010; Seager and Vecchi, 2010; Seager et al. 2007). If anticipated reductions in precipitation come to pass, aggravated by increased evapotranspiration due to increased temperatures, as projected, "they will lead to reduced surface moisture and river flows and stress water resources in an already water-scarce region with troublesome consequences for the southwest United States and Mexico" (Seager and Vecchi 2010:21277).

Summers during the observed early 21st century drought were remarkably warm, a feature also evident in many simulated droughts of the 21st century. These severe future droughts are aggravated by enhanced, globally warmed temperatures that reduce spring snowpack and late spring and summer soil moisture. As the climate continues to warm and soil moisture deficits accumulate beyond historical levels, the model simulations suggest that sustaining water supplies in parts of the Southwest will be a challenge (Cayan et al. 2010).

Institutional Framework and Stakeholder Engagement

The Arizona-Sonora region has a complex and fragmented set of water management institutions that can pose challenges for the development of adaptive strategies for urban areas in the study region. At the same time, the Arizona-Sonora region is the site of dynamic multi-stakeholder collaborations involving government agencies, non-governmental organizations, and civil society groups. Effective collaboration is key to adaptive water governance and may help coordinate responses by the diversity of water managers while helping develop common understandings of climate-related vulnerability in the water sector. These factors, we argue, potentially add to regional resilience (Wilder et al. 2010).

Recent research has increasingly shed light on the importance of understanding how society interacts with climate and how social stakeholders utilize (or fail to utilize) climate information (Jacobs et al. 2005). Adaptive capacity is a dynamic process based on social learning between and within institutions, rather than a static condition or set of attributes and outcomes (Wilder et al. 2010; Pahl-Wostl 2007; Pelling et al. 2008). Shared social learning in a transboundary setting refers to the development of common conceptual understandings of climate challenges and regional vulnerability integrated over multiple institutional scales, from individuals and local agencies to state, federal, and binational actors and authorities. The mere existence of climate information is not enough—stakeholders require tailored climate information that suits institutional needs and specific contexts for making decisions, as well as information available at multiple spatio-temporal scales (Wilder et al. 2010; Ray et al. 2007; Browning et al. 2007; Bales et al. 2004; Rayner et al. 2005; Jacobs et al. 2005; Feldman et al. 2008). In fact Feldman et al. (2008), quoting a 2008 National Research Council report, note "greater weight was given [by decision-makers] to 'creating conditions that foster the appropriate use of information' rather than to the information itself." Lowrey et al. (2009) also found that interactions between scientists, information providers and water managers helped improve managers' perceptions of risk, as well as scientists' understanding of parameters critical to management operations; the combination of such exchanges and the combined expertise of scientists and decision-makers, generated a co-production of knowledge in ways that fostered use of climate information, outlooks, and projections to adapt to changing climate conditions and increase water supply reliability.[2]

A more sophisticated and integrated use of climate information clearly resides in the adeptness of the science-stakeholder interaction. Thus, this project has responded to the needs identified in the studies discussed here by developing vulnerability assessments and site-specific studies for four urban areas unified by their location within the monsoon climate region. Through sustained collaboration and communication with regional stakeholders—including urban water managers and preparedness planners—this research was intended to move the science-stakeholder interaction forward toward a new plateau focused on assessing social and climate-related vulnerability in the context of future water supply planning at a long-term perspective. Central to this research was the development and delivery of a binational climate outlook product and the facilitation of institutional innovations to enhance access and use of climate information appropriate to specific contexts.

2 The Feldman et al. 2008 citation (CCSP 5.3, chapter 4) and CCSP 5.3 chapter 3 have abundant lessons, examples, and information germane to the co-production of knowledge between scientists and decision-makers.

Study Methodology

The binational research team on this project consisted of over twenty individuals in 8 institutions with consistent involvement from key policy making agencies involved in water management in the region.[3] The research team utilized a variety of research methods to assess urban vulnerability and adaptive capacity, including 60 fieldwork site visits, 84 stakeholder interviews, four online and on-site surveys of stakeholders, three focus groups, and participant observation at ten meetings from 2008 to 2010 (Table 1-2).

Table 1-2. Study Methodology.

RESEARCH METHOD	FREQUENCY
Fieldwork visits	60
Stakeholder interviews	84
Online and on-site (at workshops) stakeholder surveys	4
Focus groups	3
Participant observation at meetings	10
Stakeholder workshops (350 attendees)	5

In addition, the research team sponsored five major stakeholder workshops with the objective of identifying priority vulnerabilities and assessing the institutional capacity for meeting the climate challenges relating to the urban water sector at a 5 to 20+ year horizon (Table 1-3).

Finally, a major project output includes the quarterly bilingual Border Climate Summary/Resumen del Clima de la Frontera, now in its 10th edition.

Table 1-3. Stakeholder Workshops.

WORKSHOP	LOCATION	DATE	ATTENDANCE
NOAA-SARP/CLIMAS/IAI "Moving Forward" Project Launch	Tucson, Arizona	Sept. 26, 2008	50
Water and Climate Workshop	Hermosillo, Sonora	Nov. 8, 2008	60
Information Flows and Climate Diagnostics for the U.S.-Mexico Border Region	Jiutepec, Morelos	July 9, 2009	50
Water and Climate Workshop and Research Team meeting	Puerto Peñasco, Sonora	October 2-3, 2009	75
Water and Climate Workshop	Hermosillo, Sonora	May 10, 2010	60

3 University of Arizona (Tucson) and El Colegio de Sonora (Hermosillo) were the lead academic institutions in this collaborative study. In addition, researchers from the National Center for Atmospheric Research (NCAR) (Boulder CO), National Oceanic and Atmospheric Administration (NOAA), and the IRI (Columbia University, New York) also participated in the U.S. In Mexico, other key research institutions were the Instituto Mexicano de Tecnologia del Agua (IMTA, the research arm of Mexico's National Water Commission), the Universidad de Sonora (Hermosillo), CIBNOR (Guaymas, Sonora), CICESE (Ensenada and La Paz, Baja CA). Key government agencies that participated consistently in the workshops and assisted with research included Servicio Meteorologico Nacional (National Weather Service), National Water Commission, CEA, OOMAPAS, Tucson Water, Arizona Dept of Water Resources, among others.

Introducción en español

Este documento es un documento de trabajo y es uno de una serie de cuatro estudios vinculados que abordan la cuestión de la vulnerabilidad del agua en los lugares urbanos de la frontera de los EEUU y México. Como parte del proyecto NOAA/SARP, Avanzando desde la Vulnerabilidad hacia la Adaptación: El Cambio Climático, la Sequía, y la Demanda del Agua en Áreas Urbanas del Suroeste de los EEUU y el Norte de México. Los estudios de los casos se llevaron a cabo por un equipo de investigación con unas cuestiones y metodologías vinculadas para evaluar la vulnerabilidad relacionada con el clima a corto y largo plazo y la capacidad de adaptación de los sectores del agua en cuatro zonas urbanas de la región de Sonora y Arizona, incluyendo: Nogales, Arizona; Nogales, Sonora; Hermosillo, Sonora; y Puerto Peñasco, Sonora (Figura 1-1, página5).

La región de Sonora-Arizona en la frontera de México y Estados Unidos ha sido llamada "la primera línea de la batalla contra el cambio climático" (Harrison 2009). Debido a su rápido crecimiento, la industrialización y las características del clima, es reconocido como una región de alta vulnerabilidad en cuanto de sus características socioeconómicas y del clima (Wilder et al. 2010; Ray et al, 2007; Liverman y Merideth 2002). La garantía del suministro de agua en el futuro es la prioridad más difícil de la región. Proyecciones del cambio climático se espera la disminución de las precipitaciones y la sequía severa en esta región que ya tiene un problema con la "escasez de agua" van a causar "consecuencias molestas para el suroeste de los Estados Unidos y México" (Seager y Vecchi 2010:21277).

De 2008 a 2011, un equipo binacional de investigadores de la Universidad de Arizona y El Colegio de Sonora trabajó estrechamente con los encargados de tomar decisiones, los gestores del agua, y los planificadores de socorro (por ejemplo, las partes interesadas) para llevar a cabo evaluaciones de la vulnerabilidad de agua en cuatro lugares urbanos que son "puntos calientes" con respecto al cambio climático en la región Sonora-Arizona. El estudio se centra en el nexo entre el clima y el agua en los próximos cinco o veinte años. En nuestra investigación, el término *la vulnerabilidad* se refiere a la producción "en el terreno" de las desigualdades y las condiciones políticas económicas (Ribot 2010:49) y está condicionada por factores socioeconómicos, institucionales y políticos, así como el medio ambiente y las condiciones climáticas (Adger 2000). La capacidad de adaptación se refiere a la capacidad de una región a anticipar, responder dinámicamente a, y / o planear para los cambios esperados y asociados al cambio climático. Por último, *la resistencia* se refiere a la capacidad de un sistema humano y medio ambiental a "recuperarse," y desarrollar redes sociales e instituciones capaces de adaptarse y responder de manera más sostenible al cambio climático (Tompkins y Adger 2004).

El desarrollo económico desigual y la asimetría entre los procesos de instituciones diferentes son los factores más influyentes con respeto a la vulnerabilidad en la región fronteriza. Al mismo tiempo, la colaboración transfronteriza efectiva puede mejorar la capacidad de adaptación de la región fronteriza a través de una comprensión compartida de las vulnerabilidades regionales y también una cooperación en hacerles frente (Wilder et al. 2010). La información compartida y los datos son particularmente importantes. La integración de la información climática en la toma de decisiones puede ayudar a reducir la vulnerabilidad social y climática en la región y construir la resistencia de la comunidad (IPCC 2007; Kelly y Adger 2000; Finan et al. 2002; Vásquez-León et al. 2003).

Sin embargo, estos conceptos deben ponerse en práctica para propósitos de evaluación. Por lo tanto, estos estudios de casos se comparten un marco común para la evaluación de la vulnerabilidad regional. Nuestro marco de investigación (adaptado de Misselhorn 2005) (véase la Figura 1-2 en página 7) está basada en la evaluación de los cinco indicadores de vulnerabilidad en la región: demográficos, socioeconómicos, biofísicos, científicos y tecnológicos, e institucionales. Cada estudio de caso en esta serie de borradores utiliza estos cinco indicadores para evaluar la vulnerabilidad del agua urbana. Al mismo tiempo, usamos los planes urbanísticos, la colaboración transfronteriza, el intercambio de información y estrategias alternativas de conservación como prueba de la capacidad de adaptación. En el cuadro de resumen a continuación (Cuadro 1-4), las vulnerabilidades principales y las actividades de adaptación más usadas de cada área del estudio se están detalladas.

Preguntas de investigación

Cuatro cuestiones principales guían estos estudios:

- ¿Cómo se define la vulnerabilidad urbana del sector del agua en los cuatro sitios urbanos en la región del estudio?
- ¿Cómo es la capacidad institucional de esta región transfronteriza al desarrollar estrategias de adaptación para la gestión de agua en el futuro, en un horizonte de 5 a 20+ años?
- ¿Cómo puede ser institucionalizado en una manera mejor la capacidad de los administradores del agua y los planificadores de la preparación a utilizar la ciencia del clima y la información? ¿Y como pueden hacerlo en una manera que se va a mejorar la capacidad de tomar de decisiones para adaptar?
- ¿Cómo puede ser mejorada la resistencia de las comunidades urbanas de la frontera a las condiciones climáticas y a las incertidumbres de los recursos hídricos a través de la integración de la ciencia del clima en los procesos de planificación?

Metodología del estudio

Un equipo de investigación binacional de más de veinte personas de ocho instituciones trabajó en este estudio y constantemente colaboraron con agencias políticas claves en la gestión del agua en la región. El equipo de investigación utilizó una variedad de métodos de investigación para evaluar la vulnerabilidad urbana y la capacidad de adaptación, incluyendo 60 visitas al campo, 84 entrevistas con las partes interesadas, cuatro encuestas en el internet y en el campo con las partes interesadas, tres grupos de discusión y observación de participantes en diez reuniones. Además, el equipo de investigación patrocinó 5 talleres con las partes interesadas (en Tucson, Hermosillo (2), Puerto Peñasco, y Jiutepec, Morelos con una asistencia de 350 en total. Por último, una salida importante del proyecto incluye la publicación bilingüe de la trimestral Binacional Climate Summary / Resumen del Clima de la Frontera, ahora en su 10ª edición. Las conclusiones preliminares sobre la vulnerabilidad del agua relacionada con el clima urbano se resumen en la tabla de abajo.

Cuadro 1-4, español. Resumen de las conclusiones preliminares.

SITIO DE INVESTIGACIÓN	TEMAS DE VULNERABILIDAD IDENTIFICADAS	ACTIVIDADES DE ADAPTACIÓN (iniciado, en curso o en fase de planificación)
Ambos Nogales, Ariz./Son.	Una gestión de aguas transfronterizas fragmentada y compleja El acceso inadecuado al agua potable y saneamiento en los barrios pobres de Nogales ,Sonora Una infraestructura inadecuada para la gestión de alimentación	Colaboración en el tratamiento de las aguas residuales y la evaluación de las aguas subterráneas a través de CILA y organismos estatales y locales de gestión del agua. Investigación sistemática sobre la vulnerabilidad del agua a escala de barrio; la movilización de la comunidad sobre las vulnerabilidades clave en el acceso al agua; las estrategias alternativas que se están probando (por ejemplo, letrinas de composta) El desarrollo de la gestión de inundaciones y sistemas de alerta (la autoridad municipal del agua, OOMAPAS, USGS y IMIP)
Puerto Peñasco, Son.	Acuíferos agotados y no puede soportar el crecimiento proyectado del futuro de la industria hotelera/ turismo Estuarios frágiles en el alto Golfo que tiene especies en peligro de extinción que se tiene que proteger tanto de la pesca excesiva y la expansión del turismo	Desalinización municipal en el estudio de viabilidad para servir PEN y la industria del turismo Unas ONGs que son activas (Centro para la Protección de los Desiertos y Océanos, CEDO) y trabajan con los pescadores locales y las empresas para protejer en lugar
Tucson, Ariz.	Una dependencia en una sola fuente de suministro—el Rio Colorado—que es uno de los ríos mas más asignados y escasez de agua Una región propensa a la sequía y el alto crecimiento (todos los sitios)	La planificación de escenarios del suministro del agua/clima a largo plazo hecho por Tucson Water La promoción de la conservación de la promoción a la escala familiar y de recarga / re-uso a la escala municipal
Hermosillo, Son.	Un tandeo en HMO debido a un suministro de agua baja, los patrones de uso, y las pérdidas de infraestructura La competición regional y urbano-rural para el agua	AZ-SON han planeado conjuntamente la construcción próxima de la planta de desalación binacional en Puerto Peñasco Sistema Integrado de Sonora (SONORA SI) se planea transferencias de agua de los distritos de riego comerciales en el sur de Sonora a Hermosillo y otras ciudades

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CHAPTER 2

AMBOS NOGALES

www.nogales-mexico.com

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Urban Water Vulnerability and Institutional Challenges in Ambos Nogales

By Margaret Wilder, Jeremy Slack, Robert G. Varady, Christopher A. Scott, Andrea Prichard, Barbara Morehouse, Emily McGovern, Oscar Lai, and Rachel Beaty

A. Introduction

Ambos Nogales (or "both" Nogales) refers to the twin cities located at the Arizona-Sonora border. The two cities share many resources and have a long history of cultural and economic interdependence (Ganster and Lorey 2008; Pavlakovich-Kochi et al. 2004; Varady and Morehouse 2004). Historically, strong railroad and truck transport ties helped to develop this highly integrated urban, binational zone. Today, however, uneven development marked by asymmetrical growth is Ambos Nogales' most salient characteristic, making the moniker "twin cities" an evident misnomer.

Nogales, Arizona, had a 2010 population of 20,837, surrounded primarily by cattle ranches and low-density retirement communities. In Santa Cruz County, where Nogales, Ariz. is located, about 25 percent of the 2009 population had an income below poverty level, making it one of the poorest counties in the state (U.S. Census Bureau 2009). The median annual household income in Santa Cruz County ($34,378) is about one-third less than the statewide median ($49,214) (U.S. Census Bureau 2010). Nearly 19 percent of households qualify for food stamps (compared with almost 11 percent nationwide (U.S. Census Bureau 2010). Most residents and businesses of this city have access to water and sanitation hook-ups and have had since the mid-1940s. Two-thirds (63 percent) of the water services in Nogales, Ariz., go to single family or apartment residents, and one-quarter (24 percent) is delivered to commercial users (de Kok 2004). Nogales, Sonora, is a burgeoning city about ten times as large as its U.S. counterpart, with an official 2010 population of 220,292 (INEGI 2010) and an unofficial total estimated at perhaps up to 300,000 or 350,000 (Austin et al. 2006). Unlike is neighbor, 85 percent of Nogales, Son., households are connected to the municipal water network, but only 39 percent have piped water 24 hours a day (http://www.municipiodenogales.org/castellano/naturaleza/ecologia.htm, viewed on April 9, 2011). The other 15 percent—households in Nogales' informal neighborhoods (called *colonias)*—purchases water from water trucks (*pipas*) and stores it in rooftop tanks (Ingram et al. 1995; Varady and Mack 1995). Thousands live in substandard housing situated precariously atop the city's rolling hillsides in colonias traversed by interior networks of unpaved roads. Erosion and floods due to extreme storm events prove especially detrimental by limiting or cutting-off access to these neighborhoods altogether—a key example of vulnerability due to climate factors.

Shared climate and transboundary water resources, in particular the Santa Cruz River watershed, also contribute to the interdependency of Ambos Nogales. The entire region is semi-arid and susceptible to drought (Morehouse 2000; SAGARPA 2004). Average annual precipitation is about 480 mm and can vary considerably from year to year (municipiodenogales.com; Morehouse 2000). A complex and fragmented set of government agencies—local, state, federal, and binational—manage the region's water resources. Our adaptation research in Ambos Nogales focuses on uneven development, fragmented water management, and water-related vulnerability issues.

Research Questions

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

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

Study Methodology

In Ambos Nogales, we utilized a variety of research methods to assess urban vulnerability and adaptive capacity, including 24 fieldwork site visits, 45 stakeholder interviews, three focus groups, and participant observation at four meetings and in multiple ride-alongs with water delivery trucks. In addition, decision-makers, water managers, and disaster relief officials with responsibilities in Ambos Nogales were invited to participate in online and on-site vulnerability and adaptation surveys, and to attend the five stakeholder workshops for the overarching project, *Moving Forward from Vulnerability to Adaptation.* Interviews and survey data were used to identify priority vulnerability areas and adaptation plans as well as to develop a detailed understanding of climate information use and flows within organizations. Focus groups were held with colonia leaders to understand how climate-related factors intersect with water vulnerability in these areas. Participant observation provided opportunities to gather multiple and diverse perspectives on key vulnerability themes and to understand the architecture of water service provision, particularly in the colonias. Using these methods, we were able to identify key areas of climate-related vulnerability in the water sector in Ambos Nogales.

B. Background: The Transboundary Ambos Nogales Region

Ambos Nogales is located in the semi-arid Sonoran Desert ecosystem at an elevation of 1,125 meters (3,690 feet), in a narrow valley that stretches about 25 kilometers from north to south and 0.8 kilometers in width. Nogales, Son., especially, is dominated by populated hills to the west and east. The Santa Cruz River has its headwaters in the San Rafael Valley, Ariz. The river flows southward through Sonora and returns north into Arizona five miles east of Nogales, Ariz. (see Figure 2-5; ADWR 1999; Sprouse and Villalba 2004). When the Santa Cruz River flows, it pursues the downward gradient into Arizona then continues northward until it merges with the Gila River, which eventually joins the Colorado River at Yuma, Ariz., and in turn re-enters Mexico and the Sea of Cortez. The Nogales Wash, a small tributary of the Santa Cruz, runs south-to-north and bisects the valley floor (Varady et al. 1992).

Demographic and Socioeconomic context

Nogales, Ariz., is located approximately 65 miles south of Tucson in Santa Cruz County, adjacent to the Arizona-Sonora border. The United States acquired the town as part of the Gadsden Purchase in 1853 in order to facilitate the construction of a transcontinental railroad. The railroad was completed in 1882, but Nogales, Ariz., was not incorporated as a city until 1898. Nogales, Son.—also founded in conjunction with the railroad—was officially founded in 1884 (Tinker Salas 2001).

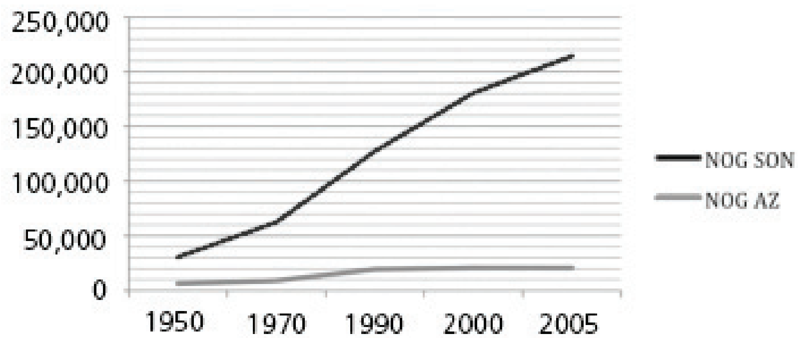


Figure 2-1. Population change, Ambos Nogales, 1950-2005. Source: Adapted from Ganster and Lorey, 2008 (Table 6.2), based on U.S. Census and INEGI data.

The population of the entire U.S.-Mexico border is expected to grow by 64 percent between 2000-2020 (USEPA 2003). During these same years, the population of Nogales, Ariz., is expected to grow by 67 percent, while Nogales Son., is expected to increase by 84 percent. According to one study, if these trends continue, by 2030 the population of the Arizona-Sonora border area may possibly even double (Norman et al. 2009). Nogales, Son., has been steadily growing, but the population of the city of Nogales, Ariz., has slightly declined (although Santa Cruz County as a whole grew by nearly 24 percent from 2000-2010).

Nogales, Arizona

The population of the city of Nogales, Ariz., increased by 239 percent from 6,153 in 1970 to 20,878 in 2000 (U.S. Census Bureau). In spite of long-term growth projections, since then, the population has declined slightly to a population of 20,837 in 2010 (U.S. Census Bureau 2009; see also Ganster and Lorey 2008).

Since its founding, Nogales, Ariz., has served as a crucial transshipment point for goods entering the United States from Mexico, with an economy based on border-related industries and the presence of Mexican visitors and other tourists. According to a study by for the Arizona Office of Tourism, an estimated 24 million Mexican nationals visited Arizona between July 1, 2007 and June 30, 2008, with 47 percent of these visitors from Nogales, Son. (Pavlakovich-Kochi and Charney 2008). The study estimates 23,400 hourly and salaried jobs in Arizona were directly attributable to Mexican visitors and approximately 15 percent (or 3,466) of these jobs were in Santa Cruz County. Moreover, Mexican expenditures in 2008 accounted for nearly 50 percent of the County's taxable sales (Pavlakovich-Kochi and Charney 2008). Several factors have contributed to a vast decrease in retail business in Nogales, Ariz., since 2008, including the U.S. economic crisis, Mexican peso devaluation, boycott in opposition to Arizona Senate Bill 1070, tightened border enforcement, and long waits at the downtown and Mariposa ports-of-entry (Wagner 2010).

The shipment of Mexican produce into the United States is another significant driver of the Nogales, Ariz., economy, as Mexican produce-filled trucks are obliged to transfer their shipments to warehouses on the U.S. side of the border. Nogales, Ariz., depends heavily on the retail tax derived from this commercial and produce-shipping industry. The Mariposa Land Port of Entry (LPOE) at Nogales is the third most traversed LPOE in the United States. In 2008, it registered approximately 2 million crossings, including 303,000 commercial trucks (Gibson 2009), of which one-third transported produce of 40 different varieties, worth $2 billion, representing between 50 and 60 percent of all winter produce entering the United States annually (www.nogalesport.com). Ten percent of the total produce entering the United States in 2008 crossed through the Mariposa LPOE (Kraushaar 2009). Another $5.5 billion in non-produce goods, such as canned or processed fruits, crossed the border into the United States.

As of 1994, Nogales, Ariz., was included in the Santa Cruz Active Management Area (SCAMA) under the Arizona Groundwater Management Act, with the goal of achieving safe yield (e.g., where withdrawals do not exceed recharge) and to prevent long-term declines in the groundwater table. Water consumption in the city of Nogales and other communities is drawn from groundwater sources (see detailed discussion below). The average annual groundwater production of the Santa Cruz River (SCR) basin is 51,500-55,300 acre-feet, according to an Arizona Department of Water Resources (ADWR) study, with over half going to sustain the SCR watershed (Santa Cruz County Comprehensive Plan 2004). Effluent from the joint wastewater treatment plant at Rio Rico (the Nogales International Wastewater Treatment Plant, NIWTP), north of Nogales, sustains dense vegetation tracts that grew from 6,200 acres in 1954 to 8,600 acres in 1995 due to the influx of effluent. However, this effluent is a variable source that could diminish or become subject to use in Mexico rather than on the U.S. side in the future (Prichard et al. 2010; Sprouse 2005).

The Santa Cruz River watershed is the most important environmental feature in the Upper Santa Cruz valley. The river supports native deciduous riparian vegetation (e.g., cottonwood gallery forests, alder, sycamore, and willow) and large numbers of bird species. The Santa Cruz County Comprehensive Plan update of 2004 states the goal of preserving it as a "Living River" ecosystem, and notes that the "river, its tributaries and watershed are at risk unless strong protective measures are implemented and enforced" (Santa Cruz County 2004).

Nogales, Sonora

The size and rate of population growth in Nogales, Sonora, has outstripped its neighbor on the Arizona side since the post-war period, a pattern common all along the U.S.-Mexico border (Ganster and Lorey 2008). Since 1970, the municipality of Nogales, Son., has increased from the official census figure of 53,494 to about 194,000 in 2005, which represents a 262 percent increase over the period, compared with only half that rate of growth in Nogales, Ariz., (Ganster and Lorey 2008, Table 6.2). The 2010 census count is 220,292 (INEGI 2010). In the past, there has been a widespread consensus that the census undercounts the actual population. Other estimates place Nogales, Son.'s population at as much as 300,000 or 350,000 (Austin et al. 2006; Sprouse 2005).[1] The undercount has implications

1 The official undercount of Nogales, Son.'s population can be attributed to a number of factors, including: the presence of a transient population that continually crosses the international border; rapid growth of informal colonias; the construction of semi-permanent residences to house migrants attempting entry into the United States; and finally, the return of deported migrants by the U.S. Customs and Border Protection's Tucson Sector. Some people seek to establish residency in the city in order to obtain legal tourist entry. It is much easier to receive a tourist (LASER) visa as a border resident so that one does not have to engage in the risky process of illegal entry. A stable history of local economic employment is necessary for a LASER visa.

for provision of water and other infrastructural needs. Because the allocation of Mexican federal funding is based on population estimates, the undercounting of the population noted above means that Nogales, Son., may receive a smaller budget than warranted.

While Nogales, Son., does have upper and middle class neighborhoods, the shape of its urban growth in recent decades has increased the city's vulnerability. Multiple land-invasion communities, known as informal colonias, have stepped in to address the shortage of housing for thousands of workers that are drawn to Nogales, Son., by the *maquiladora* (assembly plant) industry, as well as for potential migrants to the United States.[2] Downtown Nogales, the oldest part of the city, is pressed against the international border, and the colonias generally decrease in age and affluence as they get farther away from the downtown area (see Figure 2-2).[3] The city has expanded to the southwest and southeast, though steep topography on the eastern edge of town has limited expansion there. In addition, there has been a continual expansion up the hillsides. Settlements in these higher elevations generally lack services, including water, sewerage and paved roads, because it has been expensive and logistically difficult to construct infrastructure along the steep slopes. Lack of access to water hook-ups creates precarious access to a secure water supply for many colonia dwellers, as we detail in Appendix 2-A. Public health is negatively affected by exposure of children and others to running water strewn with sewage, garbage, and occasionally industrial discharges (Ingram et al. 1994; Lara-Valencia 2010).

Since the 1965 creation of Mexico's Border Industrialization Program allowing for maquiladoras in the border region, Nogales has been at the forefront of Sonora's industrialization by opening Mexico's first such assembly plan. As of 2006, 95 maquiladoras operated in the city, employing 32,535 people (INEGI 2006). Sixty-five of these factories were concentrated in seven Nogales industrial parks. Six of Sonora's top 50 businesses are located in Nogales. However, since 2000, border-region maquiladora employment has decreased due to competition from lower-wage countries like China and Malaysia (Hawkins 2006; Contreras 2006). In 2008 alone, Mexico's maquiladora industry lost over 50,000 jobs across the border region (Hennigan 2009).

Nogales, Son., is also a retail center for Arizonan and Sonoran shoppers. However, stern warnings by the U.S. State Department since 2007 regarding increases in border violence caused by territorial fights between warring drug cartels, has decimated tourism and shopping by U.S. visitors to the region, leading to a 70 percent decrease in retail business in Nogales, Son. (Alvarado 2010).

2 Informal urbanization has allowed residents who lack credit to become homeowners. Payment plans negotiated by colonia leaders (known as líderes) involve long processes that lack uniformity. Residents are generally allowed to pay off both the land and the services over an extended period of time. This makes selling land to squatters unprofitable for landowners who pressure the municipal government to provide them with a land swap. This also reduces the city's short-term urban development costs in that it allows the city to avoid any investment in infrastructure prior to the arrival of new residents. Infrastructure is usually provided based on a resident-government funds match (Peña 2005; Ward 1999).

3 The map does not show population density and is therefore slightly misleading as to the severity of the urban impact in the corresponding areas (Nogales, Ariz., is far less dense than Sonora for example). However, it does demonstrate the general trend of urban growth as extending south as well as east and west.

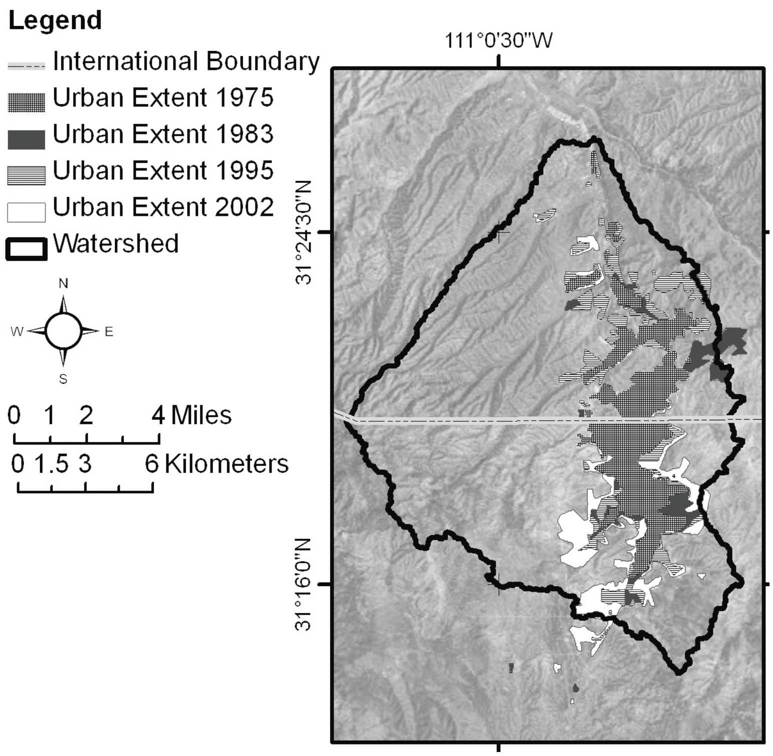


Figure 2-2. Urban footprint of Ambos Nogales, from 1975-2002. Source: Modified from original color map by Laura Norman.

C. Climate Variability, Climate Change, and Impacts

Climate Variability

Ambos Nogales receives 17.2 inches of rainfall annually (437 mm) (based on analysis of data from Western Regional Climate Center). Over 60 percent of precipitation normally falls during the summer monsoon (July-September), with the remainder falling as light *equipata* rains in the winter months (December-February) (Varady and Morehouse 2004). Average temperature is 61.4° F (16.3° C), ranging from a January average of 64.3° F/27.3° F (17.9° C/-2.6° C) to a July average of 94.1° F/63.9° F (34.5° C/17.7° C) (based on analysis of data from Western Regional Climate Center). Record extreme temperatures were a high of 112° F (44.5° C) in June 1990 and a low of -4.0° F (-20.0° C) in December 1978 (www.municipiodenogales.org/castellano/clima/clima.htm, confirmed by Western Regional Climate Center data). Semi-arid environments exhibit high intra-annual and inter-annual variability. The "combination of unpredictability, steep hillsides, and human-induced changes" make Ambos Nogales prone to the effects of floods, especially flashfloods (Varady and Morehouse 2004; see also Liverman et al. 1999).

Summer downpours can overwhelm the washes and water channels where there is no vegetation or thick soil to absorb the precipitation. Many roads in Ambos Nogales lie in washes and water channels where rainwater collects and eventually drains into the river basin. Consequently, storm events often result in dangerous flooding that impedes transportation of goods and people, and cause property damage and loss of life (Varady and Morehouse 2004).

Figures 2-3a and 2-3b. Damage is evident on unpaved roads in a Nogales, Son., colonia after heavy rain (1/28/2010). Source: Photos by Jeremy Slack.

Rapid urbanization has made flooding both more likely and more pronounced as many people have constructed homes on hillsides, leveling and de-vegetating land in the process. New developments in Ambos Nogales—both residential and industrial—have led to accelerated erosion and the movement of sediments into the valley bases and city centers. Rainfall that was previously absorbed and stored as groundwater in the riparian, vegetation-rich areas now is lost to urban drainage systems. Nogales, Son., remains especially vulnerable to flooding due to an inadequate drainage system. Recent flooding episodes in 1997, 2004, 2007, and 2008 have inflicted heavy costs for Ambos Nogales; the 2008 flood reportedly caused approximately $1 million in damage. In 2008, the Comisión Nacional de Agua (CONAGUA), with the support of the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADBank), collaborated to construct 3 filtration dams in Nogales, Son.'s most flood-prone areas. Currently, the USGS is collaborating with the municipality of Nogales, Son., to develop a flash-flood warning system (Norman 2010).

The tendency of the region to experience extremely high summer temperatures and cold winter lows creates vulnerability and exposure, since the majority of households in Nogales, Son., lack any kind of central heating or cooling system. In the informal colonias, substandard housing is uninsulated, sometimes made of cardboard or other found materials, and offers little to no protection against extreme temperatures. Forty-six percent of high poverty households in a survey conducted in 19 Nogales colonias use wood-burning cookstoves for heating, cooking, or both, exposing them to the danger of household fires and fumes (Austin et al. 2008).

Due to frequent droughts, Ambos Nogales' residents and industries often struggle to cope with water scarcity. Prolonged dry periods also pose threats to groundwater resources, leading to the depletion of already shallow aquifers (Varady and Morehouse 2004). Emergence of the informal housing sector has significantly impacted such municipal services as sewage, water, and electricity. Sewage and water resources are barely accessible to the city's majority; only 85 percent of Nogales, Son.'s residents have access to piped water (INEGI 2005). Questions surround the quality of these services. Nogales residents hooked up to the water network receive water for an average of about 12 hours per day, on a staggered basis (a system known as tandeo), based on official figures from Nogales, Son.'s Organismo Operador Municipal de Agua Potable Alcantarillado y Saneamiento (OOMAPAS) (see

Figure 2-4). In interviews, some residents reported receiving water fewer hours per day on average. This is partly due to the outdated infrastructure. Built in 1949, the original water delivery system is still largely in place today, and it lacks necessary equipment and technology to address Nogales' unique hydrological and topographical characteristics (Varady and Morehouse 2004).

Figure 2-4. The schedule for *tandeo,* or staggered water service, in Nogales, Son. The legend at right shows variable hours of service across the city, from 3-hours to 6- and 12-hours to 24 hours. Source: OOMAPAS 2008, courtesy of Arturo Pedraza Martínez, 2008. Proyecto de eficiencia física, operación hidráulica y electromecánica, para la ciudad de Nogales, Son. (Watergy 2008).

Climate Change

Regional climate change is expected to lead to a 2 to 3° C increase in annual temperature and a 5 to 15 percent decrease in annual precipitation by 2080-99, in comparison with a 1980-99 base period, based on 21 global climate models (GCMs), using an A1B greenhouse gas emissions scenario (IPCC 2007). All models agree on the increase in annual temperature and more than 75 percent of models agree on the decrease in annual precipitation. Seasonal nuances in the projections are significant for the region. The highest confidence in projections for the region are for the winter and spring seasons; projections from 15 GCMs show high confidence in a 20 percent decrease in winter precipitation and a 40 percent decrease in spring precipitation during the 2080-99 period, using an A2 greenhouse gas emissions scenario (Karl et al. 2009). There is less agreement among GCMs regarding summer and fall precipitation; some GCMs, with good reproduction of summer monsoon precipitation characteristics for the historic period, indicate a possible increase in summer precipitation for the region, during most of the 21st century (Chris Castro, personal communication). Summer temperatures are projected to increase more than winter temperatures, with regional projections of a 3-4° C increase in the 2080-99 period (IPCC 2007). The El Niño-Southern Oscillation is an important factor contributing to interannual variability in regional precipitation. Two GCMs that best capture seasonal precipitation and temperature of the region indicate that future aridity in the region will increase dramatically during La Niña episodes; this has important implications for surface flows and groundwater recharge, as well as for regional water demand, as the already reliably dry La Niña winters are projected to be warmer and even drier than at present (Dominguez et al. 2010). Higher temperatures will accelerate evapotranspiration rates; combined with decreasing rainfall, projected impacts for the region include more severe and prolonged droughts. Higher temperatures will also increase the frequency of extremely hot days; projections from 15 GCMs using the A2 greenhouse gas emissions scenario project that a day so hot that it is currently experienced once every 20 years would occur every other year by the 2080-99 time period (Karl et al. 2009). The projected trend toward less rainfall and more drought, combined with a projected population increase of 67 percent in Nogales, Ariz., and 84 percent in Nogales, Son., is likely to lead to calls for more inter-basin transfers, urban-agricultural competition over water, and higher vulnerability for marginalized neighborhoods or sectors.

Water Quality and Health Issues

Water quality is a major concern for Nogales, Son., residents. Households lacking sewer connections use latrines or open pits for disposal of human waste, creating a one of the “most significant environmental hazards” (Austin and Trujillo 2010; Varady and Mack 1995; Sprouse et al. 1996). A 2009 study by the Arizona Department of Environmental Quality reports that four toxins are found in Nogales, Son.’s water in quantities that exceed acceptable standards, including E. coli, ammonia, chlorine, and dissolved copper (Prichard et al. 2010). Maquiladoras historically generated runoff contaminated with industrial pollutants, although in recent years better regulation has led to improved compliance with environmental standards. Many informal colonias lack adequate and clean sanitation (e.g., both toilet facilities and sewerage systems). At least one new government (INFONAVIT) affordable housing subdivision completed in 2009 has visible mold forming on ceilings and walls (see discussion in Section G).

Water and Sewerage Coverage

Domestic water-supply coverage is universal in Nogales, Ariz., but falls short of that goal in the much-larger Nogales, Son. On the Arizona side, the water utility system extends coverage to 100 percent of its population (City of Nogales 2002). Statewide, 39.6 percent of water is treated in Sonora, slightly below the national average of 40.2 percent (CONAGUA 2009, Table 3.11). The municipality of Nogales reports that, “optimistically,” 75 percent of residences are hooked up to the sewage drainage system (http://www.municipiodenogales.org/castellano/ecologia.htm). Fewer than 20 percent of residents in some parts of the municipality received either piped water or had a sewer connection, according to a 1999 study, the most recent year these data are reported (Sudalla et al. 1999; Austin and Trujillo 2010). In Nogales, Son., only about 40 percent of the population receives water 24 hours a day; 36 percent receive water for shorter periods per day (http://www.municipiodenogales.org/castellano/ecologia.htm; Morehouse 2000); and just 85 percent of city households receive potable water (http://www.municipiodenogales.org/castellano/ecologia.htm). In 2000, it was estimated that between 74,400 and 128,000 people receive their water either through illegal connections or water truck deliveries (Liverman 2000; Morehouse 2000). The state water commission, COAPAES, estimated there are 3,000 illegal taps into the system (Liverman 2000; Morehouse 2000). In per-capita water use, Nogales, Son., ranked third among Mexican border cities in 1996, the most recent year for which these data are available (ITESM 1999). The infrastructure in colonias that do have water hook-ups is aging and deteriorated. Overall, the combination of breakage and porosity of old pipes, poor maintenance, and infiltration of contaminants into water-supply lines has posed continuing public-health problems (Varady and Mack 1995).

D. Urban Water Infrastructure

Ambos Nogales is served by three principal sources of water (see Figure 2-5): (1) Surface water and wells drilled into aquifers under the Santa Cruz River, provide 30 percent of total water supply; (2) Nogales Wash Aquifer, whose primary input is sewerage and (leaky) potable water pipes, as well as industrial runoff, supplies 13 percent of total supply; and (3) Los Alisos aquifer, south of Nogales, Son. in the Rio Magdalena watershed, provides 40 percent of total supply (Prichard et al. 2010; Watergy 2008).

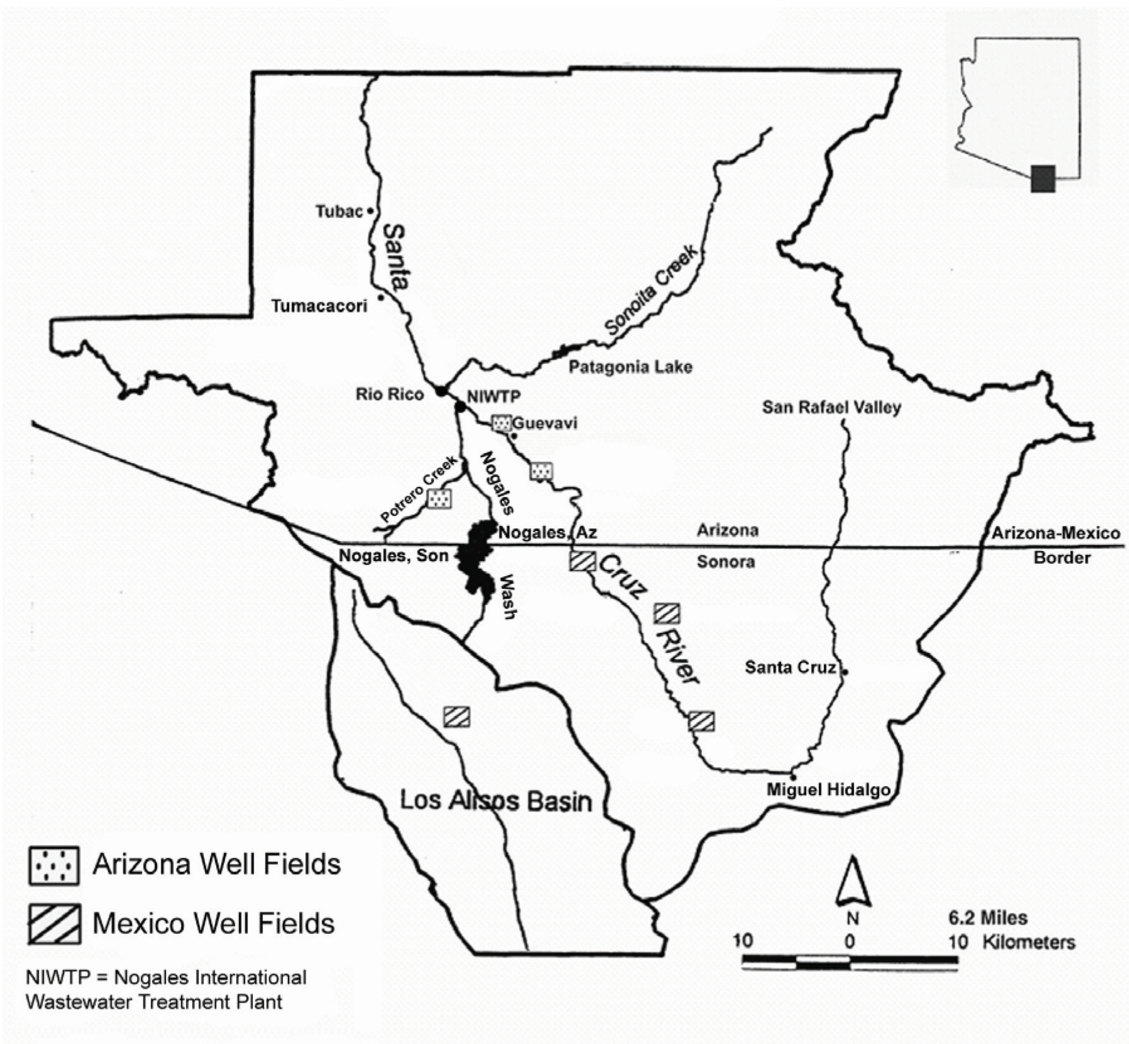


Figure 2-5. Regional water resources, Ambos Nogales. Source: Sprouse 2005.

Each city in Ambos Nogales currently draws about 50 percent of its water from the Santa Cruz River aquifer. Nogales, Son.'s well fields are located upstream from Arizona's well fields. As a result, water and wastewater management policies in Nogales, Son., determine the volume of water entering Arizona, because pumping water from the aquifer in Sonora reduces the surface and sub-surface flows into Arizona (Sprouse 2005). The Potrero Creek well field, located to the northwest, is the other main source of groundwater for Nogales, Ariz. Increased population and economic growth along both sides of the border has increased municipal water use, straining the small, isolated aquifers along the Santa Cruz River and Potrero Creek (ADWR 1999).

Wastewater Treatment

The shared wastewater treatment facility for Ambos Nogales creates a significant inter-dependency for the two cities (Scott et al. 2008).[4] Mexico has an agreement with the United States to treat wastewater from Nogales, Son. at the Nogales International Wastewater Treatment Plant (NIWTP), located north of the international border in Rio Rico, Ariz. The U.S. section of the International Boundary Water Commission (IBWC) operates and maintains the NIWTP. Given that Nogales, Son., is roughly ten times as populous as Nogales, Ariz., two-thirds of the wastewater treated at NIWTP is generated in Sonora and the plant is over-capacity. Sprouse et al. (2004) provide evidence that the joint NIWTP is mutually beneficial to Ambos Nogales.[5] Since Nogales, Son., currently sends all of its collected wastewater across the border to the NIWTP, there is growing concern about NIWTP's ability to keep up with the growing population demands for treated water. It is important to note that urban growth has generally outstripped the pace of all these projects. The Los Alisos treatment facility was scheduled for completion in January 2012. The government has subsidized major subdivision developments near the proposed facility site (see below for detailed discussion of sewage treatment for these new subdivisions).

E. Proposed Water Infrastructure Improvements

A number of infrastructure improvements in the planning or implementation stages have the potential to reduce regional vulnerability and add to adaptive capacity. These projects, largely funded by the Border Environment Infrastructure Program (BEIF), U.S. EPA, SEMARNAT, and NADBank, focus on both sewage treatment and management, and increased access to potable water.

4 Efforts to decentralize water resources management in Mexico are creating new issues for these treaties, since, all water issues were previously managed by federal entities, therefore the terms of contracts were written by federal authorities. Upon decentralizing control of water, the local and state authorities are now faced with the challenge of administering federal treaties.

5 NIWTP treats approximately 15.5 million gallons/day; 80 percent of this water comes from Mexico (IBWC). The plant has multiple benefits for both of the cities and their states. First, by treating wastewater, it significantly reduces groundwater contamination. Second, for Sonora, it has been financially beneficial because they can send their wastes downstream and get it treated at a reduced price instead of building their own plant and paying to have their wastes pumped there. Third, the effluent discharge is an important source of groundwater recharge for the Santa Cruz River aquifer. Fourth, it supports a lush riparian corridor along the Santa Cruz River, north of the plant. The treatment plant was recently upgraded and is now able to remove nitrogen compounds—which had apparently harmed the Santa Cruz River's fish and wildlife—from the discharged effluent.

Wastewater

- NIWTP upgrade: Concerns about *aguas negras* (untreated sewage water, contamination of the Nogales Wash and other binational waterways led to the upgrade of the NIWTP; the construction began in March of 2007 and ended by October 2009) (SEA 2009).
- IOI project: The International Outfall Interceptor (IOI) rehabilitation project, which has yet to be funded, plans to renovate the sewer system in Nogales, Ariz.'s "Old Nogales"—the area of the city closest to the border.
- Nogales, Son., system improvements: Another project is underway in Nogales, Son., which will reconstruct and relocate the main subcollectors, thereby reducing raw sewage spills.
- New wastewater treatment plant at Los Alisos: This plan involves the construction of a new wastewater and conveyance treatment facility at Los Alisos (SEA 2009; Scott et al. 2008). At completion (projected for January 2012), the plant will have the capacity to treat 40 percent of sewage waters in Nogales, Son. (Prichard et al. 2010). At present, Los Alisos serves as a primary groundwater pumping site for Nogales, Son. The proposed project will update these pumping facilities and provide sewage treatment to an estimated 34,560 residents in six colonias that currently lack sewage treatment altogether (EPA 2009).
- Sonora SI: Sonora SI stands for "Sonora Integrated System" (Sonora Sistema Integral). The plan is being promoted by Governor Guillermo Padrés as a way of resolving water challenges statewide, at a total projected cost of 11 billion pesos. The project involves upgrades to existing infrastructure, construction of new aqueducts and storage dams, and a desalination plant to improve and extend water services, especially to the cities (Padilla 2010). To date, the plan has met with strong resistance from the Yaqui indigenous communities and the large irrigation districts in southern Sonora, concerned about potential impacts on irrigation water concessions.

Increased Access to Potable Water

- Acuaférico: After nearly 15 years of controversy and continued debate, the Acuaférico project has almost been completed. It creates a distribution ring around the city of Nogales, Son., intended to improve water services provision (Varady and Morehouse 2004).
- Colosio Distribution Expansion: Another project exists that will purportedly create new towers and provide more potable water to the southwestern half of Nogales, Son. (EPA 2009). This project, called the Colonia Luis Donaldo Colosio Drinking Water Distribution Expansion, would cover almost all the residents living in the following neighborhoods: Colonia Flores Magón, Los Torres, Las Primaveras, Jardines de la Montana, El Rastro and Colosio.

Concerns abound that a small portion of residents living at the highest points of Nogales, Son., in Colonia Colosio will not be able to use gravity feeds like other homes to get their potable water, and that they will need to get their water pumped to them separately, rather than using the gravity feed like the rest of the homes.

F. Water Governance, Institutions and Management

Water resource planning along the U.S.-Mexican border has historically proven challenging. The border region represents an intersection of varying levels of local, state, and federal power and responsibilities. Lack of adequate financial resources and insufficient government commitment on both sides to resolve water and environment issues in Ambos Nogales hamper effective management.

Budget cuts have reduced management resources for important management agencies like the EPA's (binational) Border 2012 and the ADWR. Because Ambos Nogales shares an aquifer (Milman and Scott 2010), water and wastewater management requires binational cooperation and coordination. The success of this binational cooperation depends on the following: a clear articulation of the relevant scientific information to decision-makers; a high level of local participation; the financial and technical support of binational environmental organizations; and, effective governmental policy that provides the legal framework for efficient resource management.

Arizona

In the United States, the federal government defers to the individual states to manage their water resources. However, the federal government retains jurisdiction over inter-state commerce, international agreements, and public land management (Cox 1982; Heinmiller 2007; Sax et al. 2000). Consequently, water management activities involve a diverse set of actors, activities, and policies, all of which are designed and enacted at varying scales (Milman and Scott 2010). In the Ambos Nogales region, water management activities are carried out at various governmental levels. Figure 2-6 shows the major U.S. institutions working in the region. This complex network of authority and decision-making reduces the competence, capacity, and compatibility of the United States to effectively manage transboundary groundwater in the Upper Santa Cruz River Basin (USCRB) (Milman and Scott 2010).

ADWR

Created in 1980, the Arizona Department of Water Resources (ADWR) was meant to ensure dependable long-term water supplies for Arizona's growing communities. The ADWR administers state water laws except for those related to water quality, explores methods of augmenting water supplies to meet future demands, and works to develop public policies promoting conservation and equitable water distribution. It oversees the state's use of both surface and groundwater resources and negotiates with external political entities to protect and increase Arizona's water supply.

SCAMA

Arizona's areas of heavy groundwater use are divided into five active management areas (AMAs). Each AMA develops and implements its own phased management plans that reflect the evolution of the groundwater code and goals. Nogales, Ariz., falls within the Santa Cruz Active Management Area (SCAMA), a 716-square mile area along a 45-mile reach of the river, created in 1994. Nogales, Son., is the major city within the SCAMA, one of multiple urban management areas where well withdrawals are regulated by the state Groundwater Management Act. The Arizona Groundwater Management Act, adopted in 1980, has a goal of achieving "safe yield"—where extractions equal recharge—in the major urban areas. Municipal water consumption accounts for the majority of the water demand increase within the SCAMA, while both industrial and agricultural demands have remained stable. Agricultural water demands have remained stable and promise to remain so in the future because legally no new irrigated land can be brought into production within an AMA. The region faces further pressure to develop in the north as Green Valley, Ariz., continues to expand toward SCAMA's northern boundary. This continued population growth and increased border traffic will increase the demand for water and challenge AMA goals further; SCAMA will need to acquire additional water supplies and develop new, innovative management tools in order to maintain its safe yield status (ADWR 1999, Third Management Plan for SCAMA). SCAMA utilized various levels of public input to help craft its Third Management Plan. The Groundwater User Advisory Council is a five member governor-appointed board that advises on issues related to water management within the AMA; it is intended to represent the area's groundwater users. The SCAMA also receives input from stakeholders at public meetings before a plan is adopted.

At the 2010 completion of the Third Management Plan, ADWR was undergoing major restructuring and downsizing, in part responding to "small government" political ideology emanating largely from the state's electoral base in Maricopa County. In 2011, Fourth Management Plans were to have been passed with implementation begun; however, "assessment reports" updating information on water balances were the only updates made to the AMA Third Management Plans. With ADWR's drastically cut budget, the SCAMA office was closed, with significant loss of human resource capacity (most functions were centralized in the ADWR Phoenix headquarters), institutional memory, and above all, community contacts and stakeholder engagement that had given earlier initiatives a higher degree of adaptive capacity. This erosion, indeed an abrupt setback, of institutional capacity for water management in Nogales, Arizona poses major challenges for water resources vulnerability on the Arizona side, and by extension, for state-to-state cross-border collaboration on adaptive water management.

Citizens' groups

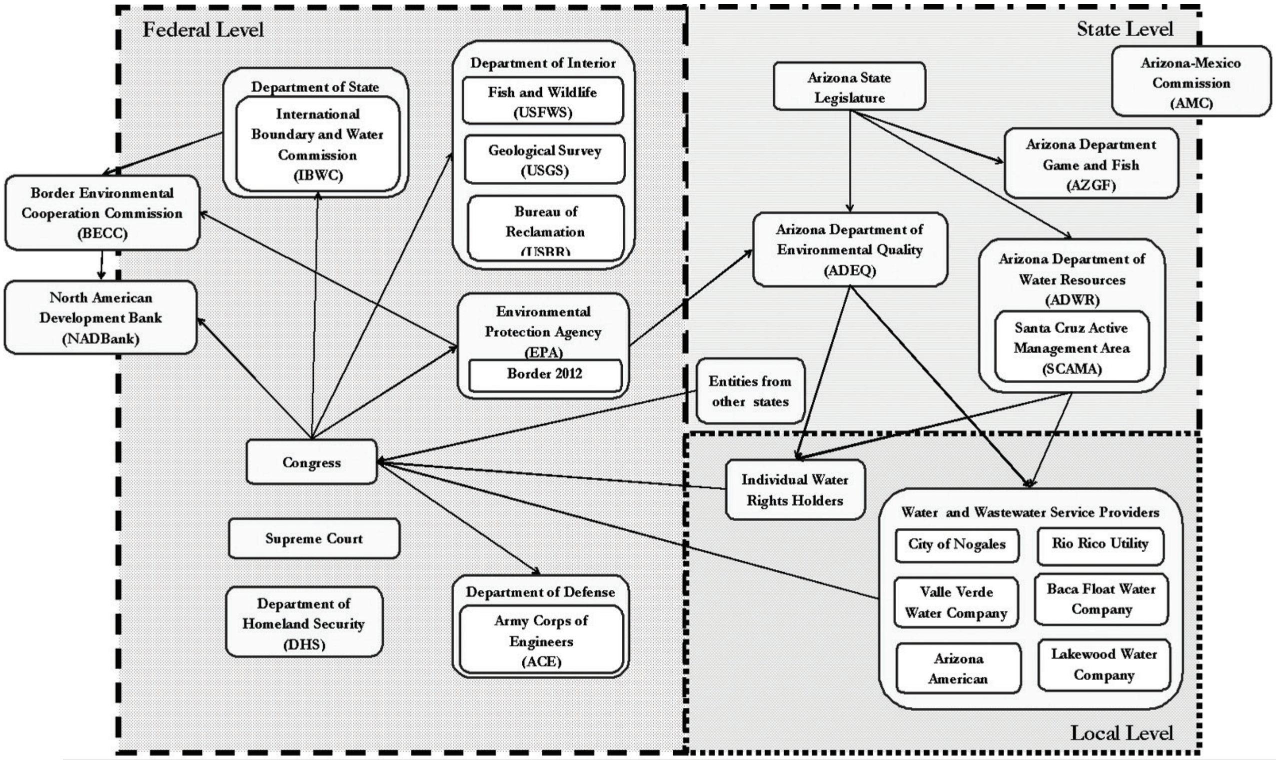
Individual residents have also led initiatives to create local organizations that address binational water issues (Ingram et. al. 1995). Friends of the Santa Cruz River (FOSCR) is one non-profit group that has been very active in the region, directly involving itself in the planning and execution of water monitoring, conservation, and advocacy within the border region. Formed in 1991, FOSCR aims to "protect and enhance the flow and water quality of the Santa Cruz River." FOSCR's volunteers collaborate with landowners, government agencies, and other citizen and community groups to keep the river's banks clean and green, and its environment bountiful for both wildlife and people to enjoy (FOSCR 2008). A major FOSCR accomplishment was the development of the Santa Cruz Riparian Vegetation Mapping Project, which indexes vegetation type and density along the Upper Santa Cruz corridor. FOSCR was instrumental in getting ADWR to create the SCAMA, bringing attention to the Santa Cruz River's unique water issues. Previously, the region was under the Tucson AMA's jurisdiction.

Sonora

Like Arizona, Sonora has a complex water management structure. Figure 2-7 shows the Mexican institutional environment for transboundary groundwater management in the Upper Santa Cruz River Basin.

CONAGUA and federal water reforms

In 1992, Mexico's decentralization reforms were introduced via new national water legislation (Ley de Aguas Nacionales) to address the over-drafting of aquifers, increased contamination of water sources, and increase in population and water demands (Wilder 2010; Castro 1995). However, despite the decentralization impulse in the 1992 and later 2004 reforms, water management in Mexico remains highly centralized. The national water commission (CONAGUA) was created in 1989 and continues to play the most central role in regional water management (Wilder 2010; Scott and Banister 2008). Decentralization did not result in reallocation of taxing or revenue-generating authority, and most municipalities lack the financial and technical resources effectively to operate municipal water systems with full authority (Pineda 2006). Short (three-year) electoral terms for municipal offices guarantee a high rate of turnover and do not promote long-term planning (Pineda 2006). While the Law of the Nation's Water's 2004 amendments strengthening watershed management through the promotion of



Entity	Synthesis of Mandate and Activities
BECC	Certify proposed environmental infrastructure projects and provide technical assistance to entities seeking to develop such projects in the border region.
NADBank	Assist BECC in arranging financing for certified projects through loans and grants.
Department of State	Conduct foreign policy. Grant 'Presidential Permits' for infrastructure crossing the border.
IBWC	Ensure compliance with the1944 treaty, negotiate treaty amendments, maintain hydrologic monitoring stations, manage joint infrastructure, and communicate information across the border.
EPA	Ensure pollution control and prevention by enforcing environmental legislation, develop water quality standards, and implement water conservation and pollution abatement programs.
Border 2012	Assist in environmental planning for the border region and finance related projects.
Supreme Court	Provide appeal mechanism for the regulation of water use that impacts interstate and foreign commerce.
USFWS	Protect endangered species
USGS	Conduct hydro-geological investigations, monitor surface water flow, maintain water availability data.
USBR	Conduct collaborative (inter-agency) water supply studies, fund infrastructure development.
ACE	Approve stream crossings (bridges and culverts) and conduct flood studies.
DHS	Monitor border crossing including through drainage culverts.
AMC	Provide a forum for advocacy and information sharing.
AZGF	Protect endangered species.
ADEQ	Develop, monitor and ensure compliance with pollution control measures including setting water quality standards, permitting discharge, reuse, and recharge activities.
ADWR	Conduct state-wide water resources planning, administer water rights, undertake hydrologic investigations and monitoring, permit water-related activities, and provide technical assistance to water users.
SCAMA	Develop management plans to achieve AMA goals, administer groundwater rights, monitor water use, and enforce conservation requirements.
WRRC	Implement the state's component of the Transboundary Aquifer Assessment Program, provide research and policy support for water resources planning and management in general.

Figure 2-6. U.S. institutional environment for transboundary groundwater management in the USCRB.
Source: Milman and Scott 2010, Figure 2.

river basin councils are promising, the enforcing regulations for the 2004 "sustainability" revisions were never adopted and the sustainability agenda of the national water policy reforms appears to have stalled (Wilder 2010).

OOMAPAS and CEASONORA

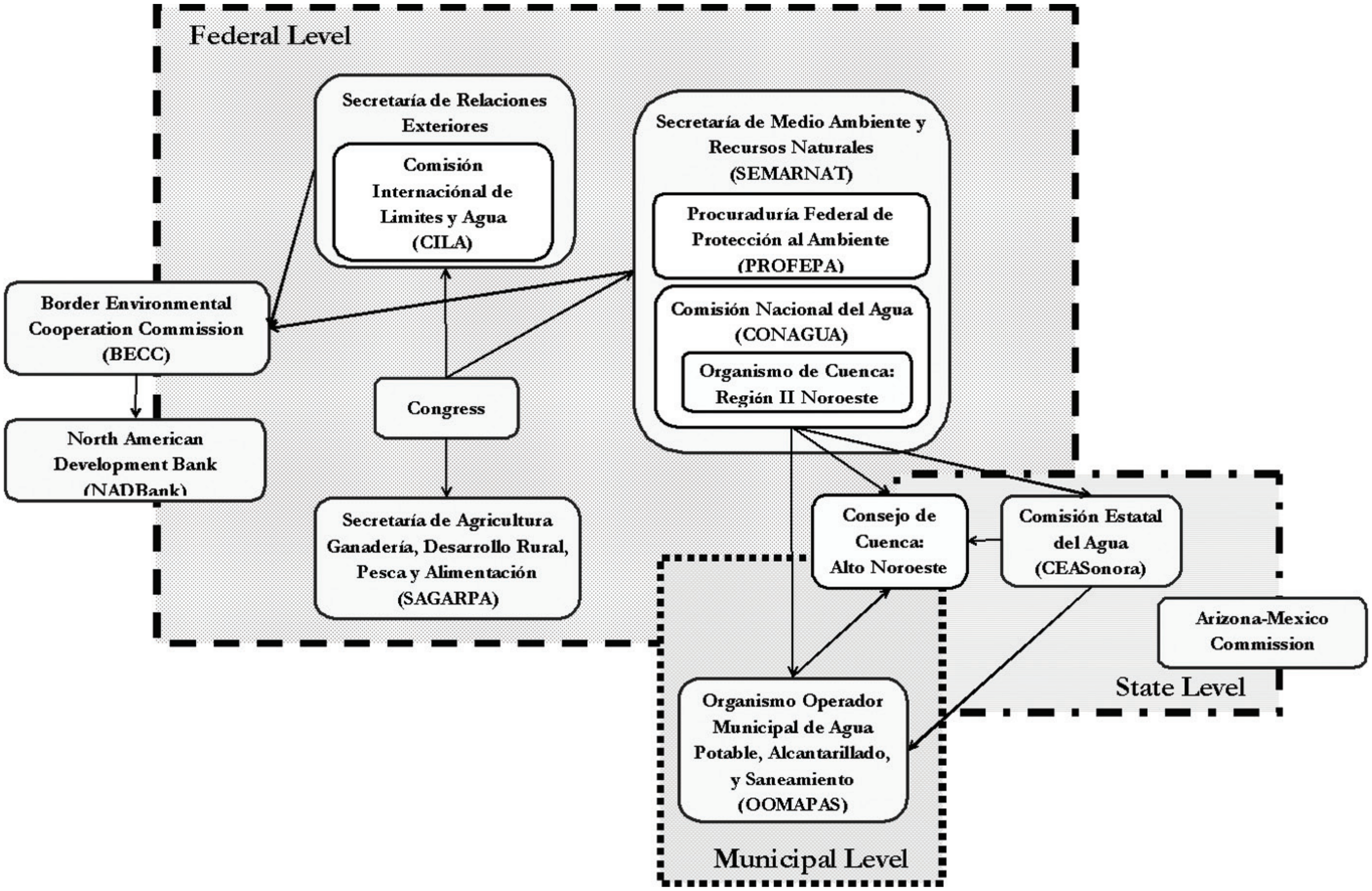
Mexico faces the same transboundary water challenges as the United States due to overlapping jurisdictions. Decentralization has further complicated issues by leading to ambiguity of authority amongst water management agencies. In June 2005, the ownership and responsibility of the Nogales, Son.'s Organismo Operador Municipal de Agua Potable Alcantarillado y Saneamiento (OOMAPAS) was transferred to the municipality proper. However, because OOMAPAS lacks the financial, technical and legal capacity to effectively manage the water system alone, it has come to rely heavily on CONAGUA support. Presently, CONAGUA remains responsible for conducting technical studies and administering water permits (Milman and Scott 2010). Both CONAGUA and OOMAPAS work under the auspices of the Comisión Estatal del Agua de Sonora (CEASONORA), the state apparatus charged with supporting water supply related programs and administering federal funds to municipalized water and sanitation services (Milman and Scott 2010).

Binational institutions

Created in 1944, the International Boundary and Water Commission (IBWC) and its Mexican counterpart, the Comisión Internacional de Límites y Agua (CILA) were meant to implement international boundary agreements and administer water treaties between the United States and Mexico. Because both were created as a means of enforcing treaty requirements, neither commission is fully equipped to deal with the border's contemporary water management issues. The effectiveness of IBWC/CILA is limited by lack of clarity in the treaty itself (for example, the treaty fails to define "extraordinary drought," nor does it explicitly deal with groundwater, Scott et al. 2008). Transboundary water scholar Stephen Mumme has argued that IBWC/CILA have not adequately responded to the drought conditions along the Rio Grande River, the promotion of transboundary water conservation campaigns and strategies, and the integration of stakeholders into their decision-making processes (Mumme 2008). However, in recent years, the IBWC/CILA has taken a more proactive environmental role, engaging with the scientific community and stakeholders at collaborative workshops and working toward environmentally sustainable solutions.

BECC and NADBank

In 1994, the U.S. and Mexico created two new binational organizations as part of the Environmental Side Agreement to NAFTA--Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADBank). Both binational organizations promote the sustainable development of the border region through water and wastewater infrastructure. BECC is charged with overseeing and certifying the development of the border's water, wastewater, and air quality improvement projects, and NADBank assists with assembling financing for their construction. BECC requires that all projects be locally controlled and sustained by user fees. Both organizations require public involvement in the project development processes, thereby increasing project transparency (Carter and Ortolano 2000). Because of BECC's efforts, new groups and spaces for debate have emerged, allowing for the exchange of ideas and improved access to data and funding sources (Lemos and Luna 1999).



Entity	Synthesis of Mandate and Activities
CILA	Ensure compliance with the1944 treaty, negotiate treaty amendments, maintain hydrologic monitoring stations, manage joint infrastructure, and communicate information across the border.
PROFEPA	Ensure pollution control and prevention by enforcing environmental (and water) quality standards.
CONAGUA	Administer and safeguard the nation's waters by establishing national water policies, develop standards and regulatory requirements, encourage water use efficiency, and support municipalities in the provision of water and wastewater services.
Organismo de Cuenca Región II Noroeste	Develop regional water plans, determine water availability, administer water concessions and discharge permits, and coordinate public and private sector activities.
Consejo de Cuenca	Assist in communication and coordination between government entities, water users, and other interests, especially with respect to defining and prioritizing specific actions in the basin.
SAGARPA	Coordinate water use policies and activities related to agriculture and rural development.
CEASonora	Coordinate water-related programs and resources transferred to the state from the federal government, establish planning standards and regulations regarding the use and supply of water, conduct studies, assess, assist and provide technical and financial support to municipal water, sewerage, sanitation providers and provide those services in conjunction with municipalities when requested.
OOMAPAS	Provide water, sewerage and wastewater treatment services within the municipality, conduct long-range planning activities, construct and operate infrastructure, and regulate connections to services.

Figure 2-7. Mexican institutional environment for transboundary groundwater management in the USCRB. Source: Milman and Scott 2010, Figure 3.

G. Urban Water Vulnerability and Adaptive Capacity in Ambos Nogales

In this section, we summarize key findings about priority vulnerability areas and discuss adaptive capacity by returning to the four questions we posed for each of the linked case studies.

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

This study has documented three major characteristics of climate-related urban water vulnerability in Ambos Nogales: (1) uneven transboundary development; (2) asymmetrical institutional and governance structures; and (3) high socio-economic vulnerability.

Uneven development

Slow demographic growth, higher per capita average income, and a higher municipal budget in Nogales, Ariz., contrast with rapid growth, high poverty levels, and a relatively modest municipal budget in Nogales, Son. While middle and upper-class housing with adequate water and sewer connections, and household heating/cooling systems dominate in Nogales, Ariz., informal and largely unplanned neighborhoods are a salient characteristic of the urban landscape in Nogales, Son. Many informal neighborhoods lack connections to municipal water and sewer networks, leading to a higher incidence of water-related public health concerns in Nogales, Son. Extreme storm events and drought conditions frequently affect Ambos Nogales; however, the two cities have distinct infrastructural arrangements to confront climate challenges.

Asymmetrical institutions and governance

Water management in Ambos Nogales is characterized by a fragmented, complex set of responsible institutions that in some areas manifest jurisdictional overlap or gaps in responsibility (Good Neighbor Environmental Board 2005). While both kinds of arrangements have merit, the number and complexity of water (and related land) management agencies involved in the region makes it difficult to coordinate responses and plans. ADWR's budget is severely menaced and Border 2012 and BECC have always been vastly underfunded. The priority of climate-related work in Arizona is very small, and this lack of commitment is even more pronounced for the transboundary area. Conservative political trends in the U.S. Congress are likely to reduce the impact of these organizations even more. At a geopolitical level, U.S.-Mexico relations overall have an impact on the prospects of good cross-border cooperation. Environmental progress can be diminished or held hostage to other conflictual policy areas, such as immigration. In the U.S., municipal water management is decentralized and supported by water tariffs; in Mexico, municipal water management is centralized and inadequately supported by water tariffs. Ambos Nogales are subject to the binational water management institutions responsible for transboundary waters (e.g., IBWC/CILA); both benefit from binational institutions established to promote infrastructure development (e.g., BECC and NADBank) and binational processes dedicated to promoting environmental protection (e.g., Border 2012/Frontera 2012). In Sonora, the Sonora SI Plan has been advanced as a future water supply program for the state, but it has already met with serious resistance and created protests in the politically powerful southern irrigation districts. At the same time, Sonora SI will require very high levels of government and private investment, and its funding sources are not fully identified yet. In Arizona, at the state level, there is little commitment to long-term water planning. The planning done at the statewide level is carried out by the Central Arizona Project, and cities like Tucson and its water utility Tucson

Water, are showing positive leadership by engaging in 50-year water and climate scenario planning and water-energy planning.

High socioeconomic vulnerability

As we document here and in more detail in Appendix A, there is a high proportion of the Nogales, Son., population living in vulnerable conditions in informal colonias. It is important to note that this vulnerability is in itself reflective of transboundary processes such as the growth of the maquiladora sector that drives job growth in Nogales, Son.; transboundary commerce, trade, and shipping; and transboundary migration and cultural processes. Substandard housing and unpaved roads in these areas lead to climate-related impacts. Monsoon seasonal rains and high temperatures lead to high humidity, with potential for public health hazards (e.g., mold growth in Fracc. La Mesa).

Climate factors differentially affect households and colonias with water hook-ups and those without. High temperatures increase demand on the municipal water system, resulting in low pressure and less water available in system. Water scarcity delays water truck services and creates water insecurity in colonias. Water trucks are a critical safety valve for those with no or limited water service. Paradoxically, those with limited water service via hook-up have the highest vulnerability, due to weaker ties to weak social networks with the water truck drivers. Strong social networks contribute to adaptive capacity for colonias.

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

Despite the fragmentation and complexity of water management in Ambos Nogales, we have argued elsewhere (Wilder et al. 2010) that transboundary processes can strengthen adaptive capacity in a transboundary context. From the coordinated response of Arizona and Sonora firefighters (*bomberos*) who work together to put out major fires to the City of Nogales, Ariz., general plan that explicitly calls for coordination of water planning with its counterpart agency in Nogales, Son., there is deep commitment to transboundary cooperation in the region. Two observations are salient here:

- **Boundary organizations that link a network of actors and agencies play a key role in developing and sustaining adaptive capacity in Ambos Nogales.** While it is often not within the formal mandate of a government agency to work cooperatively across the border, a boundary organization can witness a need and facilitate a collaborative transboundary process, thereby playing a pivotal role. The Friends of the Santa Cruz River (FOSCR) in Nogales and Santa Cruz County, Ariz., and the Municipal Research and Planning Institute (IMIP) in Nogales, Ariz., are excellent examples of boundary organizations that achieve results. FOSCR has played a role in negotiation and implementation of the NIWTP upgrade; the development of the Santa Cruz Riparian Vegetation Maps; incorporation of Santa Cruz County as an active management area; and development of the Santa Cruz County Comprehensive Plan (interview with FOSCR representative, April 8, 2010). IMIP is a quasi-municipal body with autonomous authority to conduct research and planning to promote sound urban growth and a sustainable environment via democratic governance (interview with IMIP representative, April 16, 2010). An IMIP representative noted in an interview that, "often times the municipality is bogged down with the day-to-day management of the city," but that "IMIP and university researchers are more focused on sustainability and long-term vision and planning" (interview with IMIP employee, April 9, 2010). IMIP has advanced an agenda—begun under the previous mayoral administration—involving neighborhood associations and *miercoles ciudadano* (citizens'

Wednesdays), as well as promoting development of AVES (Association of Neighborhood Associations) and agency advisory boards (for example, to OOMAPAS, the water utility) in decision-making about water and environment issues and in resolving civic problems. IMIP actively collaborates on numerous urban improvement projects with local and transboundary organizations, including Colegio de la Frontera Norte, University of Arizona and Arizona State University, USGS, IBWC/CILA, and the Municipio of Nogales.

- **Cross-border collaboration is most effective when each side in a transboundary setting defines a common problem or area of vulnerability and thus has a vested self-interest in using resources to achieve a goal or positive outcome.** Three examples of this kind of collaboration are salient. First, the transboundary collaboration over the last decade to develop and implement an upgrade plan for the joint wastewater treatment plant (NIWTP). Second, collaborations involving university researchers and local government agencies to pilot alternative conservation techniques in informal colonias in Nogales, Son., including composting toilets; efficient stoves; and water harvesting systems (Austin et al. 2008; Austin and Trujillo 2010). Third, a dynamic project involving multiple actors and agencies to develop a flash-flood warning system for Nogales, Son. Table 2-1 below indicates the scales of organizations that came together for this purpose.

Table 2-1. Flash-Flood Forecasting Project Collaboration and Actors. Source: Norman 2010.

Scale	Nogales/Son./Mexico	Nogales/Ariz./USA
Binational	CILA	IBWC
Federal	CONAGUA	USGS; USDA
State	CEA	UA; ADEQ-OBEP
Local/Municipal	IMIP; OOMAPAS; Protección Civil municipal	N/A

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

Some studies have shown a lack of interest in climate and climate science by water managers in the United States, Mexico, and elsewhere. For example, Rayner et al. (2005) found, based on three case studies in distinct U.S. regions, that water managers typically did not incorporate short-term climate forecasts into hydrologic plans due to a lack of confidence in such forecasts. On the other hand, this attitude appears to be changing. There is a growing concern about climate change and potential impacts on future water supply and a desire for information to adapt water management strategies. For example, Jacobs et al. (2009) report a high degree of interest among Arizona water managers in using climate information, and a desire for improved monitoring, prediction, and engineering, among other findings. Our findings in Ambos Nogales are consistent with the assessment that water managers are increasingly keen to incorporate climate information into water plans and desire appropriate, accurate, timely, and specific climate forecasts and products.

These findings underscore the need (1) to promote the significance of "climatic thinking" (in years and decades, not seasons and months) and (2) to work with water managers and other stakeholders to develop new operational pathways that explicitly link climate analyses to future water supply planning. For example, the City of Nogales, Ariz., general plan makes no reference at all to climate, despite a concern about future water supply and potential scarcity. While the United States has steadfastly refused to be party to the international Kyoto protocol for carbon emissions reductions, Mexico has assumed a high-profile role for planning to respond to climate change, hosting a 2010 follow-up (to Copenhagen) international summit. For example, Mexico requires all states to develop a State Climate Action Plan (Plan Estatal de Acción Climática). The national weather and climate agency (SMN) recently established a Regional Climate Science Center in Ciudad Obregón, Son., to provide regionally-specific climate information statewide. In interviews, we found limited use of climate information or climate science by water managers or other stakeholders. One IMIP employee indicated that they routinely receive historic weather information by date, current weather conditions, and forecasts up to three months in advance from the NOAA station at the Nogales, Ariz., airport (interview, IMIP employee, April 9, 2010). They would like to have: climate information related to urban development (such as floods and the effectiveness of dams) to guide development of future projects; more information on potential flood zones and suspended particles; and more consistent monitoring of relative humidity, wind direction, wind velocity, temperature, and precipitation. For stormwater management planning, IMIP needs hydrological models and more rain gauges, as well as automated precipitation monitoring systems.

How can climate science best be integrated into planning processes to enhance the resilience of Ambos Nogales to climatic and water-resources uncertainties?

Our results indicate that agencies and stakeholders in Ambos Nogales are mobilized around numerous water-related challenges, including the flash-flood early warning system, water for the ecosystem; improved access to potable water and sanitation; public health concerns; stormwater management; improved wastewater capacity; and appropriate use of effluent. As elsewhere in the Arizona-Sonora region (see Browning et al. 2007 study in the San Pedro region), however, these water problems are not defined or explicitly recognized as relating to *climate*. As climate change exacerbates many of the water-related vulnerabilities, and as the Mexican and U.S. governments mobilize efforts toward adaptation, it is important that these related environmental challenges be understood as related to climate variability and climate change.

Table 2-2 summarizes the demographic, socioeconomic, institutional, and biophysical vulnerability of the water sector in Ambos Nogales. In addition, Appendix 2-A provides a detailed study of water security and vulnerability in informal colonias in Nogales, Son.

Table 2-2. Summary of Urban Water Vulnerability Indicators, Ambos Nogales.

Types of Vulnerability	Indicators	Nogales, Ariz.	Nogales, Son.
Demographic and Socioeconomic	Growth characteristics (actual and projected); Poverty and inequality levels Housing and infrastructure Uneven development	Slow, declining growth pattern Medium-high average income and municipal budget Solid, middle-class housing stock and planned subdivisions; ranching	Rapid, accelerated growth pattern High poverty level Unplanned informal colonias w substandard hillside housing; lack of infrastructure
Biophysical and Climatic	Climate variability and climate change	Extreme storm events and monsoon Sustained drought Good warning system in place for flash floods; good infrastructure Extreme summer high temperatures and relatively cold winter low temperatures with good access to cooling and heating	Extreme storm events and monsoon Sustained drought Flash flooding of unpaved roads through much of municipality; flood warning system under development Extreme summer high temperatures and relatively cold winter low temperatures. with inadequate cooling and heating
Institutional	Scales of interaction Complexity of arrangements Degree of transboundary collaboration Climate information use and flows	Fragmented network of transboundary management institutions Climate information use limited Shared wastewater treatment plant w Nogales, Son., inadequate for growing demand on MX side Closure of SCAMA office increases vulnerability	Fragmented network of transboundary management institutions Climate information use limited and flows uneven Shared wastewater plant w Nogales, Ariz., over-capacity
Scientific and Technological	Hydraulic infrastructure Climate information adequacy and fit; Reliance on desalination technology to provide limitless supply Use of alternative conservation strategies	NIWTP expansion and IOI upgrade Climate information use limited and could be improved N/A Sta. Cruz County comprehensive plan highlights urban conservation elements	New diversion structures being installed to divert floodwaters; Sonora SI plans Climate information available is inadequate to growing need and need better 'fit'; use of climate info. not operationalized N/A Small pilot programs on alternative strategies (e.g., cookstoves; compost toilets)
Environmental	Reliable access to clean water and sanitation Presence of climate-related health issues Ecosystem health and impacts	Water and sanitation access Is full-coverage (100%) N/A Effluent from treatment plant helps sustain riparian habitats on Santa Cruz R.	Incomplete residential hook-ups to water and sanitation; high presence of substandard Contaminated water causes public health issues; some toxins in water exceed standards Historical problems with water contamination from maquila industries, but recent improvements

H. Implications for Policy and Planning

The study indicates that climate-related water vulnerability in Ambos Nogales is due to a complex mix of drivers. The major vulnerabilities we have identified are uneven development, asymmetrical institutions and governance, and socioeconomic vulnerability in specific sectors of the region. Facing future climate change over a 5 to 20+ year horizon, Ambos Nogales will have to find new adaptive strategies. The implications of these findings for improved adaptive management of water include the following:

- The **interdependency and local cooperation** that have been a standard in Ambos Nogales over the last 50 years provide a useful platform for enhanced cooperation to address water sector vulnerability in the context of future climate change;
- By developing and utilizing **common definitions of vulnerability and prioritizing areas in which each city has a self-interest**, Ambos Nogales will be in a better position to mobilize multiple actors and resources around the defined vulnerability;
- Climate variability and climate change are and will continue to be key drivers of urban water vulnerability, and thus need to have a **higher profile** in water management planning and operational strategies;
- By working closely with university researchers (Universidad de Sonora; Colegio de la Frontera; University of Arizona; Arizona State University) and government agencies (SMN and NOAA; CONAGUA; new Regional Climate Science Center), decision-makers in Ambos Nogales can better define the climate information and climate products they need to drive policy in particular areas; and participate in evaluative efforts so that the scientific community receives necessary input and feedback for a **better 'fit' between science and society** with respect to climate science;
- At the international level, climate change policy recommendations for "developing" countries suggest **mainstreaming adaptive strategies into development** policy. Thus, improving the efficiency of existing water delivery infrastructure, extending the water and sewer networks, improving wastewater treatment and regulation, and involving affected communities in decision-making, all would be expected to build adaptive capacity in the region.

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Acronyms

ADWR—Arizona Department of Water Resources
AMA—Active Management Area
BECC—Border Environment Cooperation Commission
BEIF—Border Environment Infrastructure Program
CEASONORA—Comision Estatal del Agua de Sonora (Sonora Water Commission)
CEDO—Center for Protection of Deserts and Oceans
CILA—Comision Internacional de Limites y Agua
CLIMAS—Climate Assessment for the Southwest
COAPAES—Comisión de Agua Potable y Al Cantarillado del Estado de Sonora (State of Sonora's Water and Wastewater Commission)
CONAGUA—Comisión Nacional del Agua
EA—Environmental Assessment
EPC—Environmental and Planning Committee
FOSCR—Friends of the Santa Cruz River
GUAC—Groundwater User Advisory Council
IAI—Inter-American Institute Global Change Research Human Dimensions program
IBWC—International Boundary and Water Commission
INEGI—Instituto Nacional de Estadísticas Geografía Informatíca(National Institute of Geographic Information System)
INFONAVIT—Instituto Fondo Nacional de la Vivienda para los Trabajadores (Institute for the National Housing Fund for Workers)
IOI—International Outfall Interceptor
IPCC—Intergovernmental Panel on Climate Change
ITESM—Instituto Tecnológico y de Estudios Superiores de Monterrey (Institute of Technology and Higher Education of Monterrey)
LPOE—Mariposa Land Port of Entry
NADBank—North American Development Bank
NAFTA—North American Free Trade Agreement
NIWTP—Nogales International Water Treatment Plant
NOAA-SARP—National Oceanic and Atmospheric Administration's Sectoral Applications Research Program
OOMAPAS—Organismo Operador Municipal de Agua Potable Alcantarillado y Saneamiento (Municipal Operating Agency for Wastewater and Sanitation)
POV—Privately Owned Vehicles
SAGARPA—Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentacíon (Secretary of Agriculture, Livestock, Rural Development, Fishing, and Food Goods)
SEA—Supplemental Environmental Assessment
SCAMA—Santa Cruz Active Management Area
SEMARNAT—Secretaría de Medio Ambiente y Recursos Naturales (Secretary of Environment and Natural Resources)
SONORA SI—Sonora Integrated System
USCRB—Upper Santa Cruz River Basin
US EPA—United States Environmental Protection Agency
USGS—United States Geological Survey

APPENDIX 2-A. Special Sub-Case Study on Water Security in Informal Colonias

We draw on a variety of different methodological approaches in answering questions about water security (defined as stable and reliable access to drinking and household water) in each of four *colonias* included in the Ambos Nogales study. We document the physical characteristics of each colonia and provide detailed notes on the in-depth interviews conducted with key informants (local leaders, government officials etc). We also provide documentation on three focus groups held and the participant observation activities conducted via multiple "ride-along" observations with municipal and private water trucks. In terms of background and context, the study draws information from archival work and oral histories, detailing the history of each community and the political contexts that have informed the distribution of services, such as water services and title-issuing.

The four colonias were selected for inclusion in the study based on each colonia's age, provision of services, access to legal titles, and topography. In addition, an important factor was knowledge of the area and existing contacts among community leaders in each site. Three are informal colonias, founded by organized land invasions, and the fourth is a government subsidized housing subdivision (*fraccionamiento)*.

Table 2-A1 below provides a summary of findings relating to this part of the study. Our principal finding challenged the accepted wisdom that a major development goal should be universal municipal water service coverage. Paradoxically, we found that the strength of a household's social ties to the water truck drivers was a more important indicator of accessibility to water. Given that Nogales is on staggered water service (*tandeo*), even households connected to the grid usually have limited access to water.

Table 2-A1. Summary of Water Accessibility in Informal Colonias of Ambos Nogales.

Colonia/Year Founded/ Location/Type	Socio-Economic Level	Residential Hook-up	Access to household water	Strength of Social Network (with *pipa*)	Legal status	Topography	Vulnerability
Flores Magón/ Torres/1996/ West	Low	No	Private pipas; Municipal trucks at discount	Strong	Founded by organized land invasion; now a semi-formal settlement; some residents being issued formal titles	Relatively flat, but has roads built in arroyos so highly susceptible to flooding and erosion	MEDIUM
Colinas del Sol/ 1998/East	Low	No	Municipal trucks at discount	Strong			MEDIUM

Los Encinos/Los Tapiros/1986/ West Central	Medium	Yes/Limited Hours	Majority have tap water; limited hours due to rationing; rely on pipas to supplement water needs	Weak			HIGH
Fraccionamiento de La Mesa/2009/Far South	Medium	Yes	100%	Very weak	Government launched and subsidized		LOW

Col. Flores Magón/Los Torres

Located on the west side of Nogales, Sonora, this neighborhood was founded in 1996 by an organized land invasion. There have been several recent expansions—one in 2002 and another in 2007—that resulted in an eviction of many individuals and families by state and local police and relocation by government authorities nearby (Slack 2008). This created a semi-formal settlement with government housing[1] at the edge of the informal settlement. Topographically the area is relatively flat, although low lying areas and roads located in arroyos are prone to flooding and highly susceptible to erosion (see Figures 5a and 5b). The winter and summer rains cause damage to the dirt roads and lead to decreased vehicle access. The many roads entering the colonia make it so that rarely is the erosion bad enough to sever access completely (focus group discussion, 2010**.** Local sources of groundwater exist but the quality of the water provided has yet to be assessed (Slack 2008)**.** It is still illegal to drill private wells, although there are several informal wells in the community.

Some of the lots in Los Torres are beginning to be issued formal titles, but the majority lack formal titles. While there is considerable debate about the cost to formalize these titles, negotiations appear to be moving forward. As mentioned, there are several different areas within these colonias that were established at different times, either through organized expansion/invasion efforts, or though gradual expansions of one or two families homesteading along the urban area's outskirts. The Confederacion de Trabajadores Mexicanos (Mexican Workers' Federation, CTM) has a long history of supporting local activists in their struggle for land access, but in recent years, political changes from the PRI political party to the PAN political party have made CTM support less influential.

While sanitation services have been installed, homes remain disconnected to these services. Everyone receives water via trucks called *pipas* and either uses pit-latrines or septic tanks. In focus group interviews, residents stated that they always buy from the same *pipero*. These social networks are extremely important for assuring access to water during times of scarcity. In order to assure that the truck driver will deliver water when everyone needs it, one must develop a social relationship when there is less demand and more access to water. Once the relationship is established, people can expect their truck drivers to be open to giving them lines of credit for water when cash is not readily

1 The housing was built under the state led "Pie de Casa" program, that provides the material to build a small basic house – bathroom, kitchen, living/sleep room.

at hand. Thus, the strength of a household's social networks—as reflected in a sustained purchasing relationship with a water truck driver—helps mitigate the socio-economic vulnerability of many residents in the area.

Col. Colinas del Sol

Founded by organized invasion in 1998, Colinas del Sol is Nogales, Sonora's highest neighborhood, altitudinally. Much controversy surrounded the decision to establish this colonia, and it is most likely the result of a deal with the land owner who wanted to increase his land value. By working with residents searching for a place to live, land owners can turn worthless land plots into residential neighborhoods by convincing individuals to set up a squatter settlement. This default re-zoning is standard practice for increasing the value of a piece of land. The municipal government often will give the landowner another piece of land around the city to compensate them for the loss of property, even though the title-holder may continue to collect rents from the squatter settlement (Ward 1999). Sometimes these efforts can be mutually beneficial for both residents and landowners, but often there is a great deal of exploitation involved whereupon the new residents must fight to gain access to basic services, while the land owner enjoys significant profits. Once the occupation occurs landowners typically lose control of the group and negotiation over the price per lot becomes contentious. This happened in Los Torres as well as Colinas del Sol, with varying degrees of support from the landowner.

The majority of the colonia has been regularized and people hold official land titles. While no water provisions exist, a filling station was constructed in 2008, allowing pipas to fill up and distribute water more efficiently to colonia residents. Beforehand, those pipas servicing the community had to journey down to the Torreon Pumping station, the second closest well. This newer station, the first local one of its kind, actually pumps water from a well near Col. Colosio. Although the presence of informal wells within the colonia suggests the existence of ground water a meter underground, these wells fail to provide a sufficient and secure water source. Since the filling stations' establishment, Colinas del Sol residents have enjoyed increased the access to water.

While there have been promises of extending water services in the coming year to underserviced areas, Colinas del Sol's location makes this practically impossible. The colonia is actually located within a different watershed, making the treatment of its water all the more challenging. Waste would have to be pumped uphill in order to join the rest of the sewage that is feed into the Nogales International Waste Water Treatment Plant (NIWTP) in Rio Rico, Arizona. However, plans for a new wastewater treatment plant have been approved, which will allow for greater sewage services in these types of hard-to-access colonias. All of the forthcoming water projects note that there are areas that simply will not receive services based on their altitude. It is unclear from these reports exactly how many homes would be excluded, but based on our understanding of urban growth it becomes more difficult for these hotspots of vulnerability to gain access to services after new colonias have been establish that are easier and less-expensive to provide services to.

Col. Los Encinos/Los Tapiros

Founded in 1985, Los Tapiros was Nogales, Sonora's first land invasion, while Los Encinos, essentially an extension of Los Tapiros, was the city's second land invasion, founded in 1989. Unlike Los Tapiros, Los Encinos enjoyed government support at its inception thus the existence of formalized roads and land plots. Los Encinos residents also got hooked up to regularized services faster than their Los Tapiros counterparts.

Both colonias are more centrally located within the urban periphery as the growing city has engulfed it over the past few decades.

Parts of Los Encinos and Los Tapiros fall into the category of what we have termed “hotspots” for vulnerability. They are higher than the nearest water tank servicing the colonia, and therefore even though the colonia officially has services, there are areas where the reality is different. While water and sanitation services exist, water provisions are only available for specific time periods within the day—usually from approximately 5 a.m. to 6 a.m; however, sometimes services will be available at times when people are not expecting it, or it will not come at all. Drought and monsoon events affect water services, both limiting the time when water is available and influencing the quality of water received. Heavy rains prompt sediments to enter the water system, making people’s tap water brownish. Residents must also buy water from trucks if they are unable to collect enough water during the one hour time frame. Furthermore, for those residents located in the neighborhood’s higher areas, the water may be accessible for ten minutes in the day or not at all. These residents must rely on pipas rather than the municipality for their water supply. Because many residents are technically in violation for not paying water bills, discord exists between residents and water managers. Threats have been posed to cut off sewage services; however no one has yet to report losing this service.

The extent to which people rely upon pipas depends on the season. For example, during the summer when water needs across the city rise and water supplies actually decrease, people generally become more reliant on pipas. One reason for this is that with less water comes less water pressure, thus residents located in higher climes become less likely to receive piped water. Drought events prove especially distressful for those limited-services areas such as Los Encinos and Los Tapiros, as neither community is accustomed to relying heavily on pipas for their water supply. Compared to residents in Colinas del Sol and Flores Magón, Los Encinos and Los Tapiros residents lack the solid social relationships with pipa truck drivers and are generally not used to waiting for water deliveries. This limited security generated from partial water service might actually have the effect of increasing vulnerability for some residents. Residents who participated in our focus group interviews and in-depth, semi-structured interviews stated that each year their water service worsens as more homes connect to the grid. In fact, some of our key informants ironically claimed they had better water service before they were legalized because they were stealing it from a secure pipeline nearby.

Although Los Encinos was constructed several years after Los Tapiros, it enjoys quicker access to services due to favorable treatment by the municipal government. Moreover, the quality of housing is much better here as residents had more time to build homes out of cinderblocks instead of scrap wood and metal. And yet, while they have more secure services and better edifices, the quality of the water they receive can decline with heavy rains as municipal water supplies might get contaminated, making them arguably more vulnerable than their Los Tapiros counterparts.

Fracc. La Mesa

The whole neighborhood, a government initiative at providing subdivision housing for maquila workers and their families, was officially founded in 2009. Located on the city’s extreme southern end, 21 kilometers south of the border, this formal government housing project enjoys complete services; however it is still considered vulnerable to municipal failures. As part of the INFONAVIT program, people must sign up to participate through their employer, usually a maquiladora. Workers are assigned a level of housing based on how much they have paid into social security. They do not get to look at the property before agreeing to pay a percentage of their paycheck towards the housing unit. Furthermore, they are not able to select the location of their home.

La Mesa residents live about 20 minutes from the city center by car and almost an hour by bus. No formal schools exist for children living within the fraccionamiento, however two housing units have been converted into part-time primary schools. Many residents complain about the quality of housing, and are lamentably unable to alter the physical characteristics themselves. After experiencing their first rainy season in La Mesa, one family's home already reported having dark green mold collecting around their home's light fixtures and the corner seams of their rooms. Some of individuals have relocated to an informal colonia where they have more control over their living spaces and more proximity to the city center.

A sewage treatment plant exists for La Mesa; however, it has insufficient capacity for all of the subdivision's households (estimated at 5,000). The surplus effluent from La Mesa will be directed to the treatment plant (specificially, the Planta de Tratamiento de Aguas Residuales; OOMAPAS official, interview with authors). Furthermore, because it is too expensive to pump waste uphill, connecting La Mesa to NIWTP-bound sewage lines, residents have to wait for a new plant to be built in order to receive proper sewage treatment.

Even more troubling is the fact that La Mesa is located several hundred yards from the Los Alisos pumping station, one of the two major sources of water for the whole city. The public health risks potentially posed by La Mesa's black water are significant. Since the area has only recently been urbanized, many trees and vegetation more generally have been cleared. Furthermore, a channel was dug on the south side of La Mesa as a means of diverting rainwater, however, the sandy soil already shows signs of intense erosion, and the fence delineating the park area is already falling into the man-made arroyo.

Table 2-A2. Architecture of Water Truck (Pipa) Service.

MUNICIPAL 7 trucks, 5 in service	CAPACITY 2@ 1,500 l. 1@2,500 l. 3@8,000 l. 1@2000 l.	PRICES 50 % discount for households with coupon; sometimes free
OOMAPAS Municipal water utility	Service no longer provided	Used to provide dust-control for unpaved roads & service to people who paid bill but didn't get tap water
PRIVATE TRUCKS	Fill 200 l drum Fill 1, 100 l rooftop tank Each "Pipada" size-dependent	$14 pesos $70 pesos $220 pesos each

Conclusions

Water insecurity is closely related to climate factors in the colonias. Overall, we conclude that households and colonias with water hook-ups and those lacking network connections are impacted differently by climate factors. Climate variability as manifested by extreme high (or low) temperatures create particular vulnerabilities for people living in substandard, uninsulated houses and no central cooling (or heating) system. High electrical energy costs exert downward pressure on use of fans (for hot weather) or space heaters (for cold weather); such appliances can in any case present a danger in households if they are not monitored or young children are resident. High temperatures increase the demand on the urban water network, resulting in low pressure, and less water available overall in the system. Monsoon seasonal rains coupled with high temperatures (July-Sept.) lead to high humidity, with the potential to give rise to public health hazards (as witnessed in the mold growth in new government subdivision, Fracc. La Mesa).

Table 2-A3. Conclusions: Climate Factors and Water Insecurity in Nogales, Son., Colonias.

High temperatures increase demand on water system, resulting in low pressure and less water available in system
Monsoon seasonal rains and high temperatures lead to high humidity, with potential for public health hazards (e.g., mold growth in Fracc. La Mesa)
Water scarcity delays water truck services and creates water insecurity in colonias
Climate factors differentially affect households/colonias with water hook-ups and those without
Water trucks are a critical safety valve for those with no or limited water service
Paradoxically, those with limited water service via hook-up have highest vulnerability, due to weaker ties to piperos (weak social networks). Strong social networks contribute to adaptive capacity for colonias.

For households and colonias not connected to the water grid, strong social ties form with particular water truck companies and their drivers, forming in the best case a strong social network. We found that strong social ties lead to more reliable and higher priority water delivery service than do weak social ties. If a truck is running low on water and can only serve a limited number of households, the driver will give priority to households where he has strong social ties. The same is true if unpaved roads are difficult to navigate after heavy rains or flooding. The households and colonias that are connected to the grid are less likely to have strong social ties with water truck drivers, as they only intermittently need their services. When the municipal water service is unreliable (due to low pressure) or unavailable (due to the tandeo), these households are less likely to be able to buy water from a truck, especially under the scarcity conditions described above. Paradoxically, those with limited water service via hook-up have highest vulnerability, due to weaker ties to piperos (weak social networks). Strong social networks contribute to adaptive capacity for colonias.

CHAPTER 3

PUERTO PEÑASCO

Photo by Jamie McEvoy.
Members of Cooperativa Única de Mujeres, a local oyster cooperative, sort through trays of oysters in the coastal mudflats of Morúa Estuary (Estero Morúa). Oyster farming has become an important livelihood for many families and there are now seven oyster farms near Puerto Peñasco. Morúa Estuary is a fragile ecosystem that supports a diverse population of marine and terrestrial life, including endangered fish and bird species. Estuaries are threatened by coastal development, such as the 20-story condominium development in the background and the proposed construction of a marina to facilitate a nautical "staircase" that would harbor large yachts and cruise ships throughout the Gulf of California. Photo by Jamie McEvoy, November 9, 2008.

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Water and Urban Development: Coastal Vulnerability in Puerto Peñasco

By Margaret Wilder, Jamie McEvoy, Gregg M. Garfin, Rachel Beaty, and Emily McGovern

A. Introduction

A burgeoning coastal resort town, Puerto Peñasco[1] in Sonora, Mexico, hugs the Gulf of California. Located four and a half hours from Tucson and Phoenix, Arizona, and Hermosillo, Sonora, by car, Puerto Peñasco is a favorite destination for landlocked Sonorans and Arizonans, university students, and retired winter visitors. Puerto Peñasco has attracted large numbers of North Americans who build second homes in luxury subdivisions that wind along the coast. Puerto Peñasco has a number of environmentally distinctive surroundings, including two estuaries—the Morua and La Pinta Estuaries—and a national biosphere reserve that provides habitat for hundreds of plant and animal species. The biodiversity of the Gulf of California and pristine beauty of its waters caused it to be called the "aquarium of the world" by oceanographer Jacques Cousteau (Kamp 2005). Due to actual and anticipated increases in population associated with Puerto Peñasco's tourism-centered economic strategy, many endangered species and their habitats are under stress, with implications for the human populations that depend on the coastal estuaries for livelihood and employment. Climate factors exacerbate water vulnerability in Puerto Peñasco. High summer temperatures and low average annual precipitation (~4 inches, or 10.16 cm) create high evapotranspiration rates, especially during the summer monsoon season. Groundwater aquifers have been stretched to their limit. Municipal water managers are searching for new, sustainable water sources. Many hotels and resorts have already installed their own desalination plants as a means of generating more water for their businesses and municipal planners have looked to such alternative technologies as a model. Two desalination plants—one a municipal plant, one a binational plant (for Arizona and Sonora)—are in the planning stages. Identifying and securing sufficient water supply to sustain Puerto Peñasco's urban growth as a tourism destination while limiting severe damage to its fragile environmental resources is a major challenge facing the region.

This case study of urban water vulnerability and climate variability and change is based on our research in Puerto Peñasco from 2008-2011. The study identifies priority vulnerabilities related to water and climate and assesses the adaptive capacity of water-management and emergency-preparedness institutions to address future water supply challenges. We discuss desalination as the region's principal adaptive strategy, allowing for increased population growth, while also examining the potential impacts, both direct and indirect, of such technologies. We take into account the different vulnerabilities that already exist within the municipality and the environment of the Upper Gulf of California coast, along with potential future increases in each of these.

1 Puerto Peñasco generally refers to both the city and the municipality. Ninety-eight percent of the municipality's population is concentrated in the city.

Research Questions

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

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

Study Methodology

In Puerto Peñasco, we utilized a variety of research methods to assess urban vulnerability and adaptive capacity. The research team made 15 fieldwork trips and conducted about 30 in-person, semi-structured interviews, including multiple interviews with the local, state-level, and national water managers, disaster relief planners, and non-governmental organizations. Among the agencies and organizations interviewed were representatives of the Organismo Operador Municipal de Agua Potable Alcantarillado y Saneamiento (the Municipal Operating Agency for Wastewater and Sanitation, OOMAPAS), Protección Civil, desalination project coordinators and engineers, developers, *ejido* residents, *colonia* residents, and staff from the Center for the Study of Deserts and Oceans (CEDO). We sponsored a daylong stakeholder workshop in Puerto Peñasco on October 2, 2009, attended by about 80 decisionmakers, water managers, and disaster relief officials from Puerto Peñasco and other cities in Sonora.

B. Background: The Puerto Peñasco Region

In 1927 fishermen established the region's first permanent fishing camps in what would later become the municipality of Puerto Peñasco (often called "Rocky Point," the English translation, by Arizonans). In an effort to open up trade routes, government authorities authorized the construction of a railroad between Mexicali, in Baja California, and Puerto Peñasco in 1937. Many of the railroad workers and their families settled in Puerto Peñasco (Munro Palacio 2007). Migrant agricultural laborers also began to pass through Puerto Peñasco on their way to harvest fields in Mexicali and in the United States as part of the Bracero Program in the 1940s. Small shops and guesthouses were established to accommodate the new arrivals. In 1942 the highway between Arizona and Puerto Peñasco was completed. Remarkably, this was the first highway to be built in the state of Sonora (see Figure 3-1). This highway was important for attracting tourism to Puerto Peñasco, connecting trade routes and facilitating transportation between Baja California, other parts of northwestern Mexico, and the southwestern United States.

With rumors that Japanese submarines had been sighted in the Gulf of California in 1939, the U.S. government was eager to work with Mexican authorities to develop better transportation routes to protect the region from a foreign invasion in the Gulf (Munro Palacio 2007). The first airport in Puerto Peñasco was built in 1942 for a meeting between Presidents Franklin D. Roosevelt and Lázaro Cárdenas to discuss national security issues. Though the presidential meeting never took place in Puerto Peñasco, the infrastructure improvements in the region made it an attractive place for other visitors – including sport fishermen who started coming to the region in 1944 in search of sailfish and marlin (Munro Palacio 2007).

With abundant shrimp and fish populations, commercial fisherman also moved to Puerto Peñasco. But by the 1980s, unsustainable fishing practices and reduced flows of freshwater into the Upper Gulf were negatively impacting populations of many commercially important marine species (see discussion below). In 1987, the El Niño Southern Oscillation (ENSO) caused the ocean water in the Gulf to warm and many of the prized commercial fishing species either died or moved to deeper, colder water. Largely as a result, businesses were forced to close and hundreds of people left Puerto Peñasco in search of new livelihood opportunities (Munro Palacio 2007). This provides an early example of how climate variability can affect social and economic stability in the region.

After the fishing bust in the 1980s, a tourism boom began in the 1990s. The passing of the North American Free Trade Agreement (NAFTA) in 1994 encouraged American investors to build condominiums and resorts along the expansive sandy beaches of Puerto Peñasco. But as evidenced by the recent economic downturn, the second-home and tourist industry is susceptible to exogenous shocks.

Contemporary Puerto Peñasco is located outside the Upper Gulf of California and Colorado River Delta Biosphere Reserve's southeastern border and the Pinacate y Gran Desierto de Altar Biosphere Reserve's southwestern border, both of which were established in 1993 (Figure 3-1). Puerto Peñasco lies approximately 100 km (62 mi) south of the U.S.-Mexico border and 543 km (337 mi) northwest of the Hermosillo, Sonora's capital.

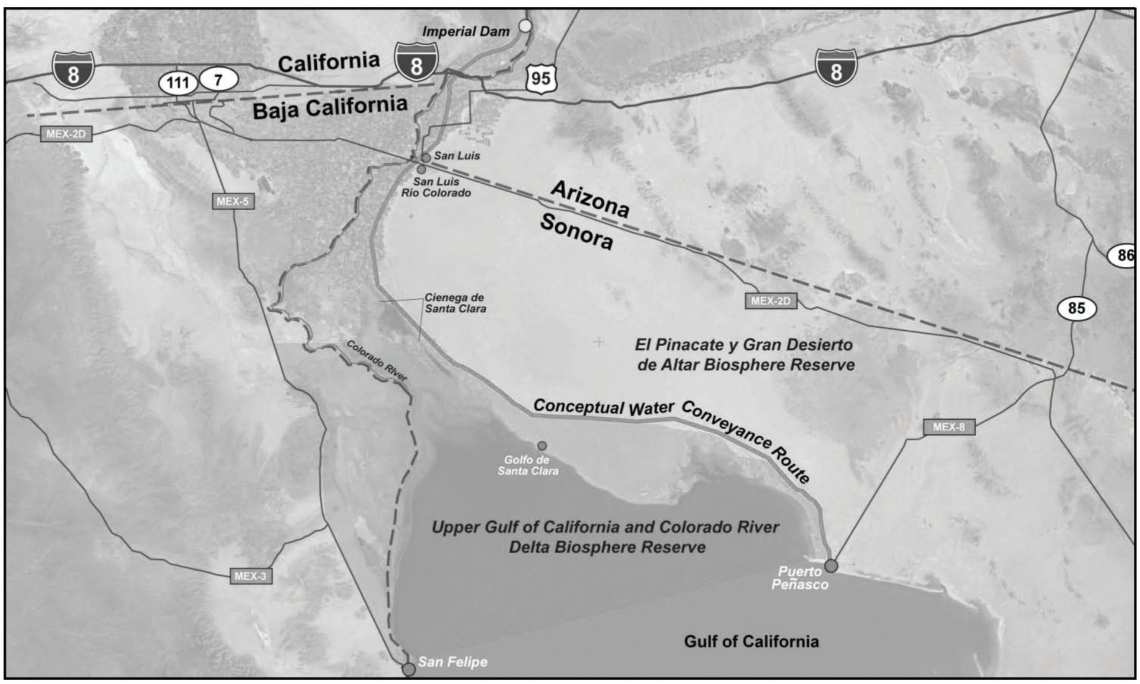

Figure 3-1. Puerto Peñasco Region. Source: HDR 2009:ES-4.

Demographic and Socioeconomic Context

The border region is one of the fastest-growing areas in both Mexico and the United States. Sonora has experienced above-average population growth rates due to urbanization trends in Mexico and the effects of NAFTA on industrialization of the border region (Wilder et al. 2010; Ray et al. 2007). While experiencing similar growth trends as the rest of the border region, based on industrialization, Puerto Peñasco's increasing population has been driven by the expansion of the tourist industry. In the last decade, the population has grown rapidly due to both the increasing number of tourists and U.S. investors—second-home buyers and hotel owners—and the increasing number of Mexican nationals who have migrated to Puerto Peñasco in the hopes of securing employment in the growing tourist sector (Comité de Planeación Municipal 2007). From 1970 to 2000 the population grew from 12,436 residents to over 31,157—a 260.8 percent increase. Between 2000 and 2010, the population of this once quiet fishing village increased by 46 percent, from 31,157 to 57,342 inhabitants (INEGI 2010).

In addition to the permanent residents, the number of tourists swells the actual population at any given time and creates additional demands on the municipality's infrastructure and water supply. More than a million tourists visit Puerto Peñasco each year (Association of Puerto Peñasco Developers). Part of its appeal involves its low costs relative to California or Baja California (Norte and Sur) coastal destinations (USTDA 2008). Puerto Peñasco visitors spend an estimated average of $50USD daily, as compared to $96USD in Rosarito, Baja California, and $450USD in Los Cabos, Baja California Sur. March, April, and May are the peak tourism months, with a smaller peak in October; most visitors are from Phoenix (24 percent), Mexicali (11 percent), and Tucson (10 percent) (H. Ayuntamiento 2007). As of 2005, the municipality had 10,924 rentable guest rooms, including hotel rooms (30 percent of total) and time-share vacation homes and condominiums (70 percent). RVs are also an important part of the tourist industry; 11 different trailer parks exist with a total of 1,626 spaces. The restaurant and bar industry has also increased due to tourism growth (H. Ayuntamiento 2007). Even with recent investments in the tourist sector, the economic indicators for Puerto Peñasco remain at or below the state level because most jobs offer below-average salaries.[2] Tourism contributes significantly to the local economy, accounting for 42.3 percent of Puerto Peñasco's economy (Secretaria de Economía 2003). The higher paid jobs in the real estate sector contribute another 25.6 percent to the economy. Puerto Peñasco accounts for 2.94 percent of the state's total tourism industry and 18.58 percent of the state's total real estate industry (Secretaria de Economia 2003).

Fishing continues to be the other important economic sector in Puerto Peñasco, accounting for 9.7 percent of the city's economic activity (Secretaria de Economia 2003). The municipality's 12 seafood-packing plants generate more than 3,000 tons of seafood annually, most of which is exported to Arizona and California (USTDA 2008; H. Ayuntamiento 2007). The principal export is shrimp. With over 125 large fishing boats and 300 smaller fishing boats, Puerto Peñasco is the primary seafood producer in Sonora, selling to both domestic and international markets (H. Ayuntamiento 2007) and making up 10.3 percent of the total Sonoran fishing economy (Secretaria de Economia 2003). The industry provides over 1,300 jobs and offers some of the best salaries in the region.[3]

2 The average per capita income of 28,400 pesos ($2,185USD) in Puerto Peñasco is significantly lower than the state's per capita average of 45,600 pesos ($3,508USD). The most highly paid jobs are in the real estate sector, with per capita incomes of 60,100 pesos ($4,624USD), but there are fewer opportunities in this sector. Salaries in the tourist industry of 27,700 pesos ($2,131USD) are below the municipal average. A study on competitiveness and sustainability by IMCO (n.d) suggests that incorporating principles of sustainable development would provide greater benefits for local residents. These imply incorporating local knowledge and skills and recruiting local residents for higher paying jobs as guides, chefs, and artisans, for which salaries can average more than $15,000USD/year. This contrasts with the conventional model of development, which typically brings in outsiders and foreigners to assume the more prestigious and higher-paying jobs, while employing local residents for lower-paying jobs such as housekeeping, gardening, and bellmen with average salaries of less than $7,800USD/year.

3 Jobs in the fishing industry have an average per capita salary of 34,200 pesos ($2,631USD).

Puerto Peñasco is especially vulnerable to the vicissitudes of the U.S. economy, given the high interdependence of the local economy with that of the southwestern United States. Since 2008, the global recession has had devastating impacts on Puerto Peñasco's development, leading to some local black humor that Puerto Peñasco should be nicknamed "Muerto Peñasco" (dead Peñasco). The downturn in Puerto Peñasco's economy has created economic vulnerability for local residents dependent upon employment in local tourism industry.

Future Growth

The most recent planning documents indicate that construction trends are likely to accelerate in the future. However, the extent to which the recent recession has impacted these plans remains unknown. Mexico's tourism and sustainable development plan indicates Puerto Peñasco is targeted to be one of Mexico's 32 major resort destinations. Municipal officials estimate that the population could more than double to 98,000 habitants by 2030 (H. Ayuntamiento 2007). As of 2005, a number of development projects were either being built or were in the process of being authorized. These proposed projects were expected to add 26,002 rentable guest rooms. An additional 22,839 rooms were to be authorized, pending completion of the sales permits. Two other major construction projects—the Mayan Palace and Sandy Beach Resort—were expected to add another 105,554 rooms (H. Ayuntamiento 2007).

To facilitate this anticipated growth, the municipality and federal government have made, or plan to make, significant investments in infrastructure. For example, the *Carretera Costera*, is a recently completed coastal highway that connects Puerto Peñasco with San Luis Río Colorado.

Figure 3-2. The new Carretera Costera (coastal highway). Source: Photo by Jamie McEvoy.

Regional developers hope that this direct route will increase domestic tourism from Mexicali, as well as bring in more international visitors from the San Diego area. The Carretera Costera will ultimately extend south to the resort town of Guaymas, for a total of 600 km (373 mi) of new roads. Another planned transportation corridor known as the Corredor CANAMEX (Canada-Mexico Highway) is an integrated highway that would run through North America, connecting tourist destinations and industrial regions in western Canada, the United States, and Mexico with the goal of stimulating economic growth and investment in the region (CANAMEX 2010). A newly upgraded international airport opened in Puerto Peñasco in November 2009, bringing in flights, and potential visitors, from other Mexican states and the United States.

Two "mega-projects" have been planned that, if constructed, will affect the ecosystem of the entire region. In both cases, little progress has been made on the projects in recent years and therefore their future status is unclear. The first is a proposal to build a nautical route, or series of connected ports, throughout the Gulf to facilitate visits by yachts, sailboats, and cruise lines. The project, known as Escalera Náutica del Mar de Cortés y Riviera Maya (referred to in English as "The Sea of Cortez Project"), is being promoted by the federal government and is overseen by the National Fund for Tourism Development (Fondo Nacional de Fomento al Turismo or FONATUR), which was responsible for large-scale tourist developments in Cancún, Ixtapa and Huatulco (Escalera Náutica 2001). Planning for the Escalera Náutica project in the Gulf of California began in 2001 under former President Vicente Fox, who saw tourism as "the passport to modernity" (Escalera Náutica 2001). The plan gained the support of state authorities in Sinaloa, Sonora, Baja California Sur, and Baja California and became a focal point for tourist development in the nation. The plan promotes the construction of 29 new marinas within a one-day travel distance to facilitate the access of more than 60,000 cruise ships and boats throughout the Gulf. In addition to the dredging and marine infrastructure needed for each new marina, each locality where a marina is built would likely see the construction of major tourist infrastructure inland, including hotels and golf courses (IMCO n.d.). The planned development will also include a new road between Mexicali and San Felipe and construction and renovations of airports throughout the region (WWF 2004). This could spur additional new tourist development, including an anticipated 900 km (559 miles) of tourist development along the Sonora coastline (Escalera Náutica 2001). While the construction of the Escalera Náutica network of projects may provide new job opportunities, infrastructure improvements, and economic growth, it is important to consider the environmental impacts of this project, as well as the impacts on traditional fishing livelihoods (IMCO, executive summary, n.d.) (see discussion below).

The second proposed mega-project for the region is the construction of the Liberty Cove development in Puerto Libertad, south of Puerto Peñasco, billed by its promoters as the "largest resort in North America." Puerto Libertad is already the site of a major natural gas operation on land that was converted from a mangrove estuary. The new coastal highway has been extended through most of the Liberty Cove proposed area. Owned by Rockingham Management Assets, LLD, the development would transform a 187-square kilometer (72-square mile) area (an area 3.5 times as large as Manhattan) into a complex of residential subdivisions, hotels, condominiums, golf courses, an equestrian center, and a Formula One racetrack. However, for the moment, environmental concerns and tight financing may have put both mega-projects on hold (interview with environmental NGO representative, April, 2008).

Environment

The Gulf of California has 244 islands and inlets and multiple protected areas totaling 1.8 million hectares (4.5 million acres) (UNESCO data, Kamp 2005). The Gulf ecosystem is considered "exceptional" for its 181 bird species (90 endemic) and 695 plant species (28 endemic); it has 39 percent of the world's marine mammal species and one-third of the world's cetacean species (Kamp 2005). Overall, 70 species are fished here. While fishing is an important economic and livelihood contributor, a major environmental concern is the significant bycatch of the endangered vaquita porpoise in both shark and shrimp fishing gear (Kamp 2005).

Puerto Peñasco is a significant area of biodiversity in both its land area and local estuaries, such as La Pinta, Morúa, and Bahía San Jorge. Given the development profile described above, these fragile estuaries are especially vulnerable due to three stressors: 1) fishing stresses (both over-fishing and endangerment of species due to bycatch); 2) reduced inflow of freshwater from use and diversion of inland surface water; and 3) coastal development (i.e., impacts of municipal discharge into the estuaries) (Calderón-Aguilera and Flessa 2009). In addition, two large-scale desalination plants that are in the planning stages (see discussion below) have potentially serious environmental implications for the fragile estuaries, due to the difficulties of disposing of briny discharge (NRC 2008). These estuaries provide important environmental services such as habitat for threatened and endangered fish and bird species, filtering out pollutants, and protecting shorelines (Calderón-Aguilera and Flessa 2009). Environmental vulnerabilities are discussed here and summarized in Table 3-1 below.

Puerto Peñasco borders two ecological reserves: the Upper Gulf of California and Colorado River Delta Biosphere Reserve and the Pinacate y Gran Desierto de Altar Biosphere Reserve. Both reserves are part of the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Network of Biosphere Reserves under the Man and Biosphere Program, which seeks to conserve and promote the rational use of natural resources through sustainable development principles (UNESCO 2010). Established in 1993, the Reserves protect over 3 million acres of open water and shoreline and 155,399 hectares (384,000 acres) of a unique inland desert ecosystem. In addition, 250,096 hectares (618,000 acres) of wetlands are protected under the United Nations Ramsar Wetland Convention (Campoy Favela 2001).

The area provides habitat for several threatened and endangered species, including two endemic marine species – totoaba (*Totoaba macdonaldi*) and the vaquita (*Phocoena sinus*), a species of harbor porpoise, which is now “the most endangered cetacean in the world” (Calderón-Aguilera and Flessa 2009:162). The vaquita is at risk of extinction because it is a common bycatch of the shrimp fishing industry. A number of threatened and endangered birds are also found in this area, including the Yuma clapper rail (*Rallus longirostris yumanensis*), the California black rail (*Laterallus jamaicensis coturniculus*), the least tern (*Sterna antillarum*), the reddish egret (*Egretta rufescens*), the southwest willow fly-catcher (*Empidonax traillii extimus*), and the yellow-billed cuckoo (*Coccyzus americanus occidentalis*) (Zamora-Arroyo et al. 2005).

Commercially important marine species are also in decline due to unsustainable fishing practices (particularly ocean bottom trawling) and reduced flows of freshwater from the Colorado River (Calderón-Aguilera and Flessa 2009). Although these two human-induced causes are the most responsible, El Niño may also play a role in species decline., For example, a history of Peñasco reports that, in 1987, the El Niño Southern Oscillation (ENSO) caused the ocean water in the Gulf to warm and many of the prized commercial fishing species either died or move to deeper, colder water, leading to negative results for the local economy (Munro Palacio 2007). Climate variability also affects the recruitment rates and natural mortality of marine species (Vásquez-León 2002). Most notably for the fishing industry, there has been a decline in catches of blue shrimp (*Litopenaeus stylirostris*) and brown shrimp (*Farfantepenaues californiensis*). In the Upper Gulf, shrimp catches have decreased from an average season catch of 500 tons in the 1980s to less than 300 tons at present (Calderón-Aguilera and Flessa 2009). Fish populations of gulf corvina (*Cynoscion othonopterus*) and totoaba (*Totoaba macdonaldi*) are also declining (Calderón-Aguilera and Flessa 2009), as are populations of the black murex snail (*Hexaplex nigritus*) and rock scallop (*Spondylus calcifer*) (Cudney-Bueno et al. 2009). A University of Arizona research project—PANGAS (Spanish acronym for Small-scale

Fisheries in the Northern Gulf—Environment and Society)—collaborates with local fishermen and other regional researchers and NGO's (including CEDO, see sidebar below) to promote sustainable small-scale fishing and marine conservation in the Upper Gulf.[4]

In sum, rapid tourist and urban development, increasing water demands and seawater desalination in and around Puerto Peñasco, along with climate change, will have important consequences for the fishing industry and the ecosystems that support it.

Environmental Vulnerabilities

1. Located near the boundary of two important ecological reserves.
2. Ecosystem provides habitat to hundreds of species of birds, plants, and commercially important marine animals – many of which are endemic species.
3. Fragile estuary ecosystems are threatened by coastal development (especially proposed mega-projects), urban runoff, dredging to construct marinas, brine discharge from desalination plants, reduced inflows of freshwater, and unsustainable fishing practices (particularly ocean-bottom trawling).
4. High climate variability in year-to-year climate is characteristic of arid regions.
5. Variability of precipitation patterns related to El Niño-Southern Oscillation contributes primarily to fall and winter precipitation variability, which can produce some ferociously wet winters.
6. Climate change will exacerbate conditions of marginal precipitation and reduce the effectiveness of groundwater recharge due to increased evaporation.
7. Increasing demands for scarce water supplies.

Table 3-1. Summary of Environmental Vulnerabilities around Puerto Peñasco.

The environmental impacts of urban and tourist development are also a concern in the region—particularly the mega-projects Escalera Náutica and the proposed Liberty Cove development in Puerto Libertad. Environmental NGOs, like Pro Esteros, fear that the project "will compromise a unique desert and coastal ecosystem" and have called for more in-depth environmental reviews (Thompson 2003). The fishing industry is directly threatened by plans to dredge estuaries in order to develop marinas and tourist developments (Guido 2006). Other environmental concerns include increased demand for scarce water resources, increased wastewater and solid waste, and land use changes that result in more impermeable surfaces and disrupt habitat (such as the construction of hotels, parking lots and roadways).

In addition to these mega-projects, local authorities in Puerto Peñasco are feeling pressure to authorize and support the development of infrastructure, hotels and condominium projects that would impact the sensitive marine reefs, wetlands and the estuaries of La Pinta, Morúa, and Bahía

4 A short video describing the goals and research of PANGAS can be viewed on the project's website at: http://www.pangas.arizona.edu/en/researchers

San Jorge (Guido 2005). These new developments are encroaching upon the Federal Maritime Land Zone (Zona Federal Maritimo Terrestre), which preserves 20 meters (66 feet) from the water's edge of coastal land as public land where development should not be allowed to occur. These developments threaten a protected species of scallop—the rock scallop—and the least tern.

Despite these negative impacts, the local government is strongly supporting such development—as indicated by the increasing number of permits approved for the construction of new hotels in the last decade. As reported by Guido (2005), the local government has authorized all proposed projects and local agencies willingly provide the necessary paperwork to affirm water availability and approve land use changes.[5] To address the concerns of water availability for future growth, the municipality is seriously considering two separate plans for the construction of a desalination plant to meet increased water demands; a separate planning process is underway to study the feasibility of a binational desalination plant (see discussion below).

30 YEARS PROTECTING THE UPPER GULF:
CENTER FOR THE STUDY OF DESERTS AND OCEANS

An important local environmental NGO in Puerto Peñasco is the Intercultural Center for the Study of Deserts and Oceans (Centro Intercultural de Estudios de Desiertos y Océanos, CEDO). CEDO was established in 1980 and promotes environmental research, education, and conservation in the Northern Gulf of California (CEDO 2010). Its main conservation efforts involve working with local fisherman and divers to promote more sustainable fishing practices, co-management and monitoring of commercial and non-commercial marine resources, and establishment of cooperative management practices to ensure the sustainable harvest of marine resources. CEDO has also participated in a study on the endangered vaquita and encourages fisherman to use alternative fishing methods that do not rely on gillnets, which can easily ensnare and kill the small vaquita (Dalton 2010). In addition to work on sustainable fisheries, CEDO also promotes the sustainable management of coastal wetlands by working to conserve public and private land, using legal tools to promote conservation and develop alternative economic options that protect livelihoods. CEDO works with a group of local women to support the operation of an oyster cooperative that uses sustainable aquaculture techniques to raise and harvest oysters and promotes eco-tourist activities such as kayaking and birdwatching tours (CEDO 2010; see also photo at beginning of this chapter).

C. Climate Variability, Climate Change, and Impacts

Climate Variability

Located in an arid desert region, Puerto Peñasco experiences high temperature extremes in the summer months (July-September), ranging between 30°C (86°F) and 43°C (109°F). These high temperatures can create dangerous heat wave conditions. Average annual precipitation is only 93.7 mm (3.7 in) due to Puerto Peñasco's location in the rain shadow of mountains on northern Mexico's Baja California peninsula. Puerto Peñasco experiences substantial seasonality in precipitation, due to its location on the northwest fringe of the North American Monsoon (NAM)6 circulation pattern. July and August are the wettest months, wherein precipitation is delivered through torrential convective

5 Again, while the development in the tourism industry has undoubtedly been affected by the recent global recession, we do not know to what extent.

6 The NAM precipitation pattern results in highly variable intraseasonal, interannual, and interdecadal precipitation patterns contributing to frequent and intense floods and droughts (Hallack-Alegria and Wallace 2007; Magaña and Conde 2000; Comrie and Glenn 1998).

thunderstorms; however, little precipitation occurs during the rest of the year. The greatest rates of evaporation occur from May to September, with an average monthly evaporation rate of 210 mm (8.27 in). In contrast, the coolest months, December, January, and February, have temperatures reaching below 11°C (51.8°F); during these cooler months, the region experiences an average of 10 to 30 days in which minimum temperatures are below freezing (USTDA 2008; H. Ayuntamiento 2007).

Flooding occurs during the summer monsoon season, especially in Puerto Peñasco's wetlands and estuaries. Flooding river water often mixes with tidewater, leading to a more expansive area of inundation. Unfortunately, current development patterns and plans fail to take these sensitive estuary and wetland areas into account (H. Ayuntamiento 2007). In January 2010, unusually heavy rains and strong winds, brought on by a tropical storm, flooded and destroyed city infrastructure in the colonias (neighborhoods) of San Rafael and Nuevo Peñasco. Protección Civil reported that 15 houses lost their roofs, 15 houses were completely razed, and 42 electrical cables were cut or knocked down. Two hundred and forty residents had to seek refuge at one of the two established shelters in the city (the gymnasium and the fire station). In addition to this example of winter flooding, initiated by an El Niño-generated tropical storm, there is evidence for increasing intensity of summer monsoon precipitation (Cavazos et al. 2008). Cavazos and her colleagues report increases in intensity of summer and warm season precipitation, due to an increased contribution of tropical storm moisture. In a further study of trends in intense precipitation, Arriaga-Ramírez and Cavazos confirmed these trends for northwest Mexico, during 1960-1997, for June-October (Arriaga-Ramírez and Cavazos 2010). These recent studies expand upon results noted in a recent U.S. Climate Change Science Program synthesis and assessment product on climate change extremes (Kunkel et al. 2008), which also characterized rainfall in northwest Mexico, as becoming "more erratic with a tendency towards high intensity rainfall events, a shorter monsoon, and shorter wet spells."

Nevertheless, Puerto Peñasco itself is not especially prone to such natural disasters because of its location. Baja's extensive mountain ranges and the two nearby large islands (Tiburón and Angel de la Guarda) located in the Gulf form natural barriers and usually protect the municipality from such extreme weather events. However, it is important to note that cyclones can develop in the Gulf of California, typically beginning in the latter part of July. From 1951 to 2003, 14 tropical cyclones have affected Puerto Peñasco; since 2003, no cyclones have passed near Peñasco (pers. comm., Luís Farfán, CICESE. La Paz, Baja California Sur, Mexico). According to a municipal study, the municipality has an estimated 0.05 percent chance of being hit by a hurricane (used interchangeably with the term "cyclone") and a 0.10 percent of being struck by tropical storms (H. Ayuntamiento 2007).

Like the rest of the Arizona-Sonora border region, from 1996 to 2006 Puerto Peñasco was in an extended drought. Less water has not translated into less water usage; along with population growth has come an increase in consumption. Groundwater aquifers are being overused to the extent that other surrounding aquifers are also being overexploited. Such overdrafting of aquifers can result in a saline intrusion and land subsidence. Municipality officials are finding it increasingly difficult to guarantee residents with a reliable and secure water supply. Furthermore, with lower water tables more electricity is needed to pump water, thus increasing pumping costs. Farmers in the few *ejidos* (communal farms) north of the city of Puerto Peñasco have found that the increased cost of groundwater pumping, along with reduced agricultural credit availability, have made farming in the region increasingly financially prohibitive. The ejidos have drastically declined in population and are now all but devoid of people (interviews with *ejidatarios*, April 23, 2009).

Climate Change

Regional climate change is expected to lead to a 2 to 3° C increase in annual temperature and a 5 to 15 percent decrease in annual precipitation by 2080-99, in comparison with a 1980-99 base period, based on 21 global climate models (GCMs), using an A1B greenhouse gas emissions scenario (IPCC 2007). All models agree on the increase in annual temperature and more than 75 percent of models agree on the decrease in annual precipitation. Higher temperatures will accelerate evapotranspiration rates; combined with decreasing rainfall, projected impacts for the region include more severe and prolonged droughts. It is expected that this northwest region of Mexico will experience increased temperatures, increased evaporation, increased variability of rainfall, and longer dry spells (Seager et al. 2007; Díaz-Caravantes and Wilder n.d). Regional models predict that surface temperatures may increase by as much as 2° C (3.6° F) (Magaña and Conde 2000). While precipitation projections remain uncertain, there will most likely be an increase in rainfall variability. Extreme weather events including floods, droughts, and heat waves are expected to become more intense and frequent. The El Niño-Southern Oscillation is an important factor contributing to interannual variability in regional precipitation. Two GCMs that best capture seasonal precipitation and temperature of the region indicate that future aridity in the region will increase dramatically during La Niña episodes; this has important implications for surface flows and groundwater recharge, as well as for regional water demand, as the already reliably dry La Niña winters are projected to be warmer and even drier than at present (Dominguez et al. 2010).

D. Urban Water Infrastructure

Located within the Sonoyta River watershed, Puerto Peñasco is part of the Comisión Nacional del Agua's (CONAGUA) Hydrologic Region 8 and it is one of four municipalities in the Sonoyta-Peñasco aquifer.[7] Puerto Peñasco obtains its water supply from 11 deep wells, ranging from 58 m (280 ft) to 200 m (656 ft) in depth; however, only eight of the 11 wells are operational.[8] Each well field pumps out approximately 360 liters of water per second (lps). According to CONAGUA, overdrafting of the aquifers occurred as early as 1978. Such overdrafting has led to increased threat of saline intrusion and land subsidence.

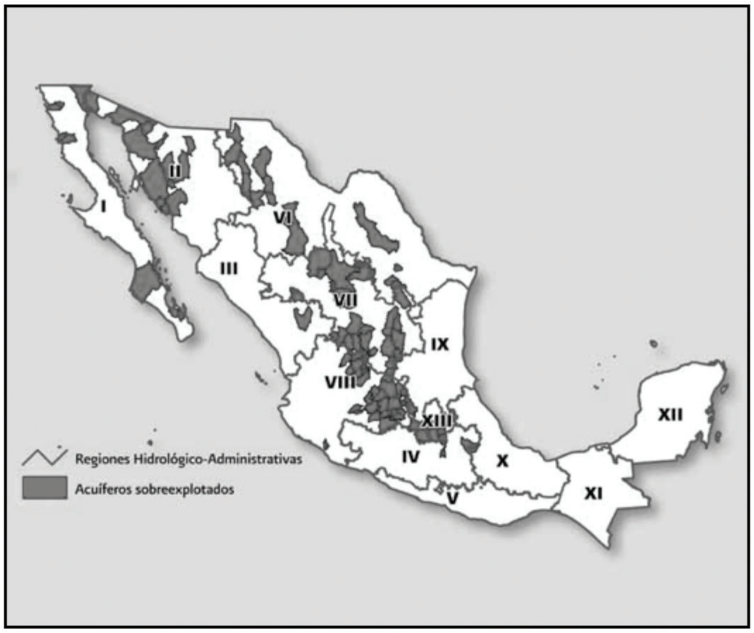

Figure 3-3. Overdrafted aquifers in Mexico, showing the northwest coastal area as one of most severely exploited in the country. Source: CONAGUA 2008, Estadisticas del Agua Mexicana: 44.

The allocation of water from the Sonoyta-Peñasco aquifer is divided as follows: 40 percent is used in agriculture; 37 percent is used in urban centers; 6 percent goes to fisheries; and the other 17 percent goes to unspecified uses (CONAGUA 2005). According to the 2005 CONAGUA report, no new wells should be drilled due to the still-current overdrafting issues and the persistent deficit in the water balance (i.e., extractions are greater than recharge). Instead, the state water agency, Comisión Estatal del Agua (CEA), has called for new water sources and conservation measures to be explored as a means of supporting the region's new population growth.

7 The four municipalities are: Puerto Peñasco, Plutarco Elías Calles, Caborca and Altar.

8 These wells are located just outside the boundaries of the ejidos Ortiz Garza (23 km/14.4 mi from the city of Puerto Peñasco) and John F. Kennedy (about 45 km/28 mi from the city).

Figure 3-4. Saltwater intrusion in Mexico. The coastal area of Sonora, including the Sonoyta-Peñasco aquifer, is one of the severely affected areas. Source: CONAGUA 2008.,Estadísticas del Agua Mexicana: 45.

Water and Sewerage Coverage

Puerto Peñasco's water supply system is 40 years old and composed of 90 m (30 ft) diameter pipes that extend for 71 km (44 mi). It is estimated that the municipality loses approximately 60 percent of its water due to the age of the system's infrastructure and the lack of investment;[9] limited maintenance is provided and system upgrades are rare due to the high cost (CEA n.d.). A total of 14,422 registered water users are connected to the municipal water supply system (USTDA 2008; H. Ayuntamiento 2007). According to the 2000 Mexican Census, 91 percent of Puerto Peñasco households have water, meaning Puerto Peñasco has better coverage than both the entire state of Sonora (88 percent) and the Mexican nation as a whole (89 percent) (H. Ayuntamiento 2007). Ninety-three percent of the registered water users are charged a fixed fee for services; unlike farmers who are directly affected by the electricity costs implicit to pumping water from lower water tables, residents' water prices remain stable. The remaining users, seven percent, are connected to water meters and thus are charged based on a tiered-fee system (USTDA 2008) (see Table 3-2).

Table 3-2. Types of Water Users and Fee System. Source: USTDA 2008:15.

Type of water user	Users charged a fixed fee	Fee based on water metered
Domestic	11,763	659
Commercial	844	248
Industrial	15	81
Tourism related	758	54
Totals	13,380	1,042

9 A 2008 project called for the replacement of the municipality's main pipeline (called Sectorizar Informe Hydraulica). The project was supposed to address these leaks in the deteriorating distribution network, but has only been carried out.in two areas (ejido San Rafael and ejido Nuevo Peñasco).

A lower percentage of households in Puerto Peñasco have a connection to the sewage system, 69 percent relative to 78 percent nationally (H. Ayuntamiento 2007). Of those connected in Puerto Peñasco, about 85 percent are domestic, 10 percent commercial, and the remainder tourism or commercial uses. The 240 liters per second (lps) of sewage collected is directed into one of the two wastewater treatment facilities in the area (USTDA 2008). The Mayan Palace, a private tourist resort, operates one of these systems—an oxidant pond—and accepts and treats only the effluent generated by its own resort. A group of tourism businesses runs the second plant, using a sludge system. Golf courses and green spaces receive the treated effluent from both facilities and use it for irrigation (USTDA 2008; H. Ayuntamiento 2007).

There is a clear link between demands on infrastructure and the growing tourism economy, especially in terms of water supply. More tourists will invariably mean an increase in water demands. According to municipality officials, the tourist sector uses approximately 599 liters per day per capita and 320 liters per day per room (H. Ayuntamiento 2007). In addition to a hotel, resorts often build a golf course, which uses an average of 30 lps (or 9 million liters annually) for irrigation purposes. Currently, all of the residual and treated water from the treatment facilities is siphoned off and used to irrigate resort golf courses (CEA n.d.).

E. Water Institutions and Management

Since the introduction of Mexico's 1992 water reforms and their 2004 update, the responsibility for managing water has shifted from the federal level to the state or municipal level. However, Mexico's decentralization strategy has not been fully implemented to extend to taxation authority and cost recovery (Wilder 2010; Scott and Banister 2008). A significant limitation is that municipal authorities lack adequate financial and technical resources (Pineda 2002). For example, the local water management agency, OOMAPAS, manages and operates Puerto Peñasco's potable water service and sewerage network. OOMAPAS-Peñasco has a significant degree of non-collection of water fees owed to the agency; moreover, the trend is moving in the wrong direction, with proportionately less fees collected as the population has increased (Table 3-3).

Table 3-3. Cost Recovery for Water Service Provision in Puerto Peñasco. Source: USTDA 2008:15.

Year	Water/wastewater charges (million pesos)	Amount collected (million pesos)	Percent of total collected	Percent uncollected
2003	28.6	21.7	76	24
2004	31	25.3	82	18
2005	35	28.4	81	19
2006	45	35.6	79	21

OOMAPAS—as managed by the previous municipal administration of Puerto Peñasco (2006-2009)—emphasized five programs to improve water management in the municipality (interview with water agency personnel, April 24, 2009). However, with changes in administration since 2009, it remains unclear which of these programs will be continued, discontinued, or re-vamped. The five programs focus on: education, conservation, legal and economic incentives, and investment in physical infrastructure.[10] One of these programs, begun in 2008, promotes water meter installation. Initially, as in many Latin American cities, metering was met with resistance by colonia residents. Metering is a significant improvement that water utilities believe is necessary to allow accountability for precise volumetric measurement of consumption. People who had grown accustomed to fixed rates for their water typically feared that metering would increase their monthly water bill. Some residents have destroyed the meters or have collected petitions to have meters removed. At present, only four colonias have meters. Despite its unpopularity, OOMAPAS still hopes to expand the network of meters.[11] OOMAPAS bundles the water supply and wastewater management services into a single customer bill based on the total volume of water used. In addition to collecting payment, OOMPAPAS has introduced a new, tiered scheme for metered water users, wherein different sectors are charged at different levels.[12]

Another program undertaken by the previous administration was a water-sectorization project (Sectorizar Informe Hidraulica). One of the municipality's greatest challenges has been maintaining adequate water pressure so that water reaches the city's center. Sixty percent of water was being lost in the system. The sectorization program was initiated by the CEA with the goal of equalizing the distribution of the city's water pressure, allowing all areas to enjoy the same amount of pressure. In 2007, the city spent 49 million pesos ($3.8 million USD) to install 18.5 km (11.5 mi) of 76 cm (30 in) PVC pipe and a large water tower with 8,000 m^3 of storage capacity. A year later, the city's main water line was replaced with PVC piping. Since the repairs, the city's water pressure has jumped from 270lps to 550 lps (interview, municipal water manager, April 9, 2010).[13]

10 Two water conservation education programs were developed by OOMAPAS-Peñasco. The first program, "Cuidado del Agua" ("Caring for the Water") is a program based in primary, secondary, and post-secondary schools. Youth in this program are trained to become "inspectors" who keep an eye out for misuse of water in their colonia. As "inspectors," students can report incidences of water misuse to OOMAPAS and then the agency can follow up with any necessary legal action. The second program is "OOMAPAS en tu Colonia." ("OOMAPAS in your Neighborhood")—a program meant specifically for adults. In this program, OOMAPAS employees go to various colonias and conduct home-visits. Adults learn how OOMAPAS operates and how they, as citizens, can help conserve water. A third program assumes a more regulatory approach, imposing fines for the misuse of water, such as overwatering landscaping; using water to clean sidewalks or patios; using too much water to wash a car; or not fixing a leak within the specified time period. Residents are typically given three warnings before receiving a fine of 700 pesos ($54USD).

11 Associated with the metering program, OOMAPAS has changed the tariff rates to encourage water conservation. OOMAPAS tries to assure residents that metering will actually work in their favor because residents were previously charged a flat rate for using 0 to 20 m^3. The average water bill for a two-month period in a non-metered flat-rate household was 370-390 pesos ($29-30USD). But the new tariff system allows residents to pay for smaller blocks of water beginning with a minimal charge for 0 to10 m^3. According to OOMAPAS, most metered residents use less than 10 m^3 and now pay only 45-70 pesos ($3.50-5.40USD) for a two-month period.

12 Domestic metered households pay $45 pesos ($3.50USD) for 1 to10 m^3, plus 5 pesos ($0.39USD) for each additional cubic meter from 11 to 20 m^3. Commercial metered users pay 98 pesos ($7.60USD) for 1 to10 m^3, plus 10 pesos ($0.78USD) for each additional cubic meter from 11 to 20 m^3. The metered tourist industries have a minimum quantity of 20 m^3 and pay 279 pesos ($22USD) for 0 to 20 m^3. They pay an additional 11 pesos ($0.85USD) for the next additional 21-30 m^3.

13 However, large amounts of sand have been sucked into the piping from the intake wells and remain present in the distribution system. Increased water pressure had caused this sand to enter household plumbing systems and even clog some pipes. To address the sand issue, city officials have since constructed a supply tank where pumped water accumulates before being distributed through the pipe network; this allows the water to settle and for the particulates to collect on the bottom where they will eventually be scraped out prior to water distribution. Thus far, the sectorization program has only been carried out in two areas (ejido San Rafael and ejido Nuevo Peñasco). OOMAPAS personnel indicated that the new administration will make sure that this program is carried out in the remaining 10 sectors (interview, municipal water manager, April 9, 2010).

F. Water Demand and Proposed Water Infrastructure Improvements

The state water agency (CEA) and the municipality have estimated Puerto Peñasco's present and future water demand (Table 3-4).[14]

Table 3-4. Current and Future Water Demand, Puerto Peñasco. Source: Comisión Estatal del Agua (CEA n.d.).

PERIOD	POPULATION	DEMAND Liters per second (lps) per day
Current	45,000	314
Projected	98,000	784
Percent change	117	166

Due to the severe situation of overdraft in area aquifers, it is not possible for the municipality to simply drill more wells and extract more groundwater to meet the growing water demands. Instead, these demands will have to be met by alternative management strategies that focus on supply side and/or demand side management.

The water infrastructure and management priorities for Puerto Peñasco include: repairing leaks and replacing deteriorating pipes, expanding the water conservation education programs, improving the administrative procedures to ensure collection of water bills from all users, adopting policies for regulating further development along the coast and estuaries, studying the possibility of installing an automated water supply system using Supervisory Control and Data Acquisition System (SCADA) to improve efficiency, and determining the feasibility of building a desalination plant to augment water supplies (USTDA 2008; H. Ayuntamiento 2007). Developing desalination technology is the most salient of these options, due, in part, to interest in both Arizona and Sonora in locating a binational plant in Puerto Peñasco.

Desalination

Twenty-two small-scale, privately owned desalination plants have already been built to provide water for individual hotels and condominiums at Puerto Peñasco's Mayan Palace and Las Conchas developments. However, two recent proposals to build larger-scale, publicly funded desalination plants to augment the public water supply have gained considerable attention in the last few years. The first is a local plan to provide a sustainable source of water for the municipality; the second is a binational plan that could meet the water needs of both Sonora and Arizona, and potentially other parts of the southwestern United States, such as California or Nevada (Table 3-5).

14 The current population of over 45,000 inhabitants uses 3,000 liters per person per day. The average total demand is 313.5 lps; the tourist sector accounts for 90 lps of this demand. The current water system can supply 430 lps. Before the major project to replace the main pipeline (Sectorizar Informe Hidraulica) was started in 2008, 60 percent of the water is lost due to leaks in the deteriorating distribution network. The city receives a water flow of 270 lps (CEA n.d.). The municipio estimated the water demand for 2030 based on a projected population of 98,000 inhabitants using 300 liters per person per day. Planners expect tourist demand to increase significantly to 343 lps (over three times the current rate of 90 lps) and total demand to average 785 lps.

Table 3-5. Desalination Plant Plans in Puerto Peñasco, 2011.

	Municipal Desalination Plan	Binational Desalination Plan	
		Arizona-Sonora Project	**Regional Project**
Year begun	2008	2009	2009
Intended use	Produce enough water to meet city's needs and support growing tourist sector	Produce enough water to benefit Arizona and Sonora	Produce enough water to benefit California and Nevada, in addition to Arizona and Sonora
Capacity	1,000 lps in phase 1	4,694 lps	46,936 lps
Estimated cost	$35 million (USD)	$567 million USD + $119 million/year in operating costs	$4.3-4.4 billion USD + $1.0 billion/year in operating costs
Funding source	Inter-American Development Bank (IADB) and the Export-Import Bank of the United States (Ex-Im Bank)	Inter-American Development Bank (IADB), the Export-Import Bank of the United States (Ex-Im Bank), and the North American Development Bank (NADBank)	Inter-American Development Bank (IADB), the Export-Import Bank of the United States (Ex-Im Bank), and the North American Development Bank (NADBank)
Status	Initial feasibility study completed. Municipality considering a second feasibility study to compare the costs of desalination brackish water instead of seawater. EIS underway.	Feasibility study completed	Feasibility study completed.

Municipal Plan

In February 2008, the municipality of Puerto Peñasco contracted with the U.S. Trade and Development Agency (USTDA) to conduct a study to determine the feasibility of building a desalination plant near the city. The municipality is interested in pursuing a desalination plant to meet the water needs of the city, as well as to support the growing tourist sector in the region. The former municipal mayor, Heriberto Rentería Sánchez, is "'convinced' that seawater desalination is the only option for this desert community at this point in time" (USTDA 2008:20). Alejandro Zepeda Munro, Puerto Peñasco's mayor since October 2009, agrees with this assessment (stakeholder workshop, October 2, 2009).

The original plan for the municipal plant called for the construction of the "the largest desalination plant in Latin America" (interview with former desalination coordinators, November 10, 2008). This plan called for a multi-phased construction of the plant, with the first phase producing 1,000 lps. Producing this quantity of water would require a significant supply of energy, which could potentially be supplied by building a 50 megawatt concentrated solar energy facility. To manage the saltwater concentrate, the long-term goal of the municipal plan was to completely capture all of the saltwater concentrate with the intention of using the briny discharge to grow salt-resistant (halophyte) plants for commercial sale. However, for the first phase of the project, it would be more likely for a saltwater dispersal system to be implemented (e.g., dispersion of the briny discharge in tiny concentrations into the Gulf), and saltwater concentrate recapture would be delayed until the second phase. The USTDA (2008) report determined that there is potential funding for this $35 million USD project from both the Inter-American Development Bank (IADB) and the Export-Import Bank of the United States (Ex-Im Bank).

BINATIONAL DESALINATION PLANT: KEY CHALLENGES

- Environmental—location outside protected areas; management of briny discharge
- Energy use—strict Mexican federal regulation of imported energy; issues relating to co-location of nuclear energy and desalination plants; increasing price of energy in the future
- Financial—equity of access related to affordability of desalted water; identifying and securing investment capital
- Legal and Institutional—increased reliance on non-local sources of water; distribution issues; shared ownership and management of infrastructure

Source: Interview, CAP official, March 24, 2010

However, it is difficult to gauge the degree to which these plans are advancing in reality. With the change in administration in 2009, the plan for the municipal plant appears to be at a standstill and progress on the feasibility and environmental impact studies have been significantly slowed. After firing the previous administration's engineers and desalination coordinators, the current administration has not designated new leaders for the project. As of this writing, no new plans have been announced with regard to the future of the desalination project. OOMAPAS officials have indicated that the municipality is considering conducting a new feasibility study that would assess the costs of using brackish groundwater—as opposed to seawater—as the source water for the desalination plant. This new study could take up to three years to complete. One official noted that, with the constant turnover in management, it's "like taking steps backward—it's very hard to move forward" (interview, local water manager, Feb. 15, 2010). OOMAPAS officials also mentioned their concern about how much the desalted water would cost, observing that "hotels already think the price of water is too high" (interview, local water manager, April 9, 2010).

Binational Plan

The Central Arizona Project (CAP) and the Salt River Project (SRP) recently funded a feasibility study for locating a binational desalination plant in Puerto Peñasco (HDR 2009).[15] The study compared the costs of two different scales of desalination. The first was a model of a smaller-scale Arizona-Sonora project, which could provide 120,000 acre-feet per year (AFY) (4,694 lps) of desalinated water from the Gulf of California in Puerto Peñasco (see Table 6, above). The water would travel 270 km (168 mi) and via pipeline to the Imperial Dam, just outside Yuma, Arizona. The total cost for the smaller-scale project is estimated to be $2,727USD/AF (HDR 2009:9). The study also considered a larger-scale regional project that could take advantage of economies of scale and produce 1.2 million AFY

15 Past plans for desalination in Puerto Peñasco. The idea of using desalination technology to provide potentially endless supplies of freshwater to the region is not new. In 1965, U.S. President Lyndon B. Johnson and Mexican President Gustavo Díaz Ordaz signed an agreement to explore the feasibility of a joint U.S.-Mexico nuclear powered desalination and energy production facility. A U.S.-Mexico International Atomic Energy Agency study (UMIAEA 1968) concluded that, "large dual purpose plants using nuclear energy are technically feasible means of providing power and fresh water to the [northeastern Mexico and southwestern U.S.] area studied. Additionally, the economic forecasts for these plants appear to be sufficiently attractive to merit further consideration" (p. v). With the help of Interior Secretary Stewart Udall, Nogales businessman John McChesney, researchers at the University of Arizona, and Sonoran officials, a pilot project producing 6,000 to 8,000 gallons of desalinated water per day was built (Munro Palacio 2007). However, during this same time period, the quality of the Colorado River water that Mexico received was degrading significantly. Increased agricultural use and rapid economic development in the United States, along with a prolonged drought, caused the salinity levels of the water delivered to Mexico to increase. This resulted in a dispute between the United States and Mexico in the 1960s, which strained the relationship, particularly in regards to collaboration on water resources projects between the two countries, and the desalination project was abandoned.

(46,936 lps) to be pumped to Imperial Dam via canal for $1,183USD/AF (less than half the cost of the smaller-scale project). This larger project could provide enough water to augment supplies in California and Nevada, in addition to Arizona and Sonora. As indicated in the report, "Desalinated water conveyed to Imperial Dam will displace Colorado River water that can then be exchanged for users in Arizona, and possibly the other basin states, which would then divert the additional Colorado River water through their existing, expanded, or new infrastructure" (HDR 2009:7).

Arizona water managers are not the only ones considering the option of partnering with Mexico to build a binational desalination plant. In a report commissioned by the seven Colorado River Basin states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming), the states considered 12 different long-term augmentation strategies (Colorado River Water Consultants 2008). Among these was the construction of an ocean-water desalination plant in California, Baja California, or the Gulf of California. The freshwater produced by the plant would "be used in California or Mexico in place of water otherwise diverted from the Colorado River, thereby adding to the available supply in the Colorado River and avoiding the costs of long-distance diversion" (p. 10). In May of 2010, water managers from the nine U.S.-Mexico border states gathered in San Diego, California to discuss binational desalination (WEF 2010). In 2005, Nevada was charging forward with plans to build a desalination plant in San Diego and/or Tijuana in exchange for their Colorado River water to serve the city of Las Vegas (Southwest Nevada Water Authority 2009, accessed 4/6/2011 at http://www.snwa.com/assets/ pdf/wr_instate_presentation.pdf). However, current Southern Nevada Water Authority (SNWA) administrators have taken a more negative view of desalination based on anticipated high costs and the unreliable nature of Colorado River flows.

From a geopolitical standpoint, a binational desalination plant would make the U.S. southwest more dependent upon friendly and collaborative relations between the United States and Mexico. Overall, we have argued elsewhere (Wilder et al. 2010) that the proposed binational desalination plant has low potential for contributing to regional adaptive capacity (see sidebar, above).

Desalination may be the preferred water augmentation alternative in Sonora and Arizona because it is less politically divisive than other options, such as rural-to-urban or inter-basin transfers, strict conservation measures, or limiting future growth. For example, during a stakeholder workshop in Hermosillo, Sonora, Mexican federal water managers emphasized that a major statewide water infrastructure plan, known as "Sonora SI" would promote efficiency, water reuse and desalination so that agriculture would not lose a single drop of water. Similarly, Kohlhoff and Roberts (2007) have argued that rural-to-urban transfers in Arizona will be more politically difficult than many policy experts have suggested. Instead, in the long term, Arizona may need to partner with either Sonora or California to build a desalination plant along the coastline in exchange for an equivalent portion of that state's Colorado River water. Although both Californian and Mexican coasts provide opportunities for desalination, California is less likely to be interested in cooperating with Arizona because protecting its coastal views and property values are priorities for California. Environmental regulations are more daunting and complex in California. Any desalination plants that are permitted to be built on the California coast will likely be used to serve California's own growing water demands. Building a desalination plant in Mexico is the most "promising and farsighted" augmentation strategy for Arizona (Kohlhoff and Roberts 2007: 276).

Despite these challenges, the USTDA (2008) report determined that potential funding exists for the project through the Inter-American Development Bank (IADB) and the Export-Import Bank of the

IS DESALINATION AN ADAPTIVE STRATEGY?

Following Pelling et al. (2008), our theoretical framework for assessing the adaptive capacity of desalination is based on whether or not this technology facilitates social learning and the development of social networks. Adaptive capacity is a dynamic process based on social learning between and within institutions, rather than a static condition or set of attributes and outcomes (Pahl-Wostl 2007; Pelling et al. 2008). Given that the proposal to build a desalination plant in Puerto Peñasco has binational implications, it is important to evaluate the project and associated adaptive capacity in this transboundary context. This includes shared learning over multiple institutional scales, from individuals and local agencies to state, federal, and binational actors. Using a process-based understanding of adaptive capacity, we employ three indicators: (a) dynamic, structured opportunities for social learning, (b) emergence of formal and informal networks, and (c) potential for development of adaptive pathways.

When subjected to this analysis, desalination does not rank high on our measures of adaptive capacity. While it is technologically feasible to meet the region's growing water needs with desalination, it does not require a sustainable change in water users' behavior under climate change. In fact, desalination, if not coupled with conservation measures, enables a "business-as-usual" water culture—averse to social learning—and discourages sustainable water use.

The environmental consequences of the proposed desalination plant are largely unknown. There is concern about the impact of the brine, or concentrated saltwater waste, which is a by-product of the desalination process. There are currently no laws that regulate how a desalination plant operates in Mexico (López-Pérez 2009). Also, it is unclear where the energy to run the plant would come from. It is likely to be a carbon intensive process that will contribute to further greenhouse gas emissions.

Those in favor of the desalination project argue that augmenting existing groundwater sources would reduce pressures on the already overdrawn aquifers and potentially allow them to recover to nearer equilibrium levels. However, proponents of the project also perceive desalinated seawater as a "limitless" resource that would enable further growth. This additional growth is likely to negatively impact the fragile estuaries and fisheries of the Gulf of California. Furthermore, if the binational component of the project is implemented, it is likely that an aqueduct would be built through the Pinacate and Gran Desierto de Altar Biosphere Reserve. Moreover, because Arizona and Nevada would continue to use their full Colorado River allotments *plus* desalinated supply, it is unlikely that any net gains to the aquifers or to Colorado River allocations would be achieved.

In summary, we conclude that desalination, as an augmentation strategy, has a low adaptive capacity. When assessed against the indicators of social learning, network development, and creation of adaptive pathways, we find that the desalination proposal does not involve structured opportunities for social learning or changes in institutional culture or policy priorities. Data-sharing would be in the context of formal contract-based exchanges, rather than more permeable, fluid, relational kinds of knowledge exchanges such as those identified by Cash et al. (2003). New communities of practice are not anticipated to emerge from desalination strategies and binational relationships will be straitjacketed within a bounded legal framework. The desalination strategies are not only unlikely to add to adaptive capacity, they could lead to more of the entrenched, legalistic relations that have sometimes hampered cooperative, binational water management in the past. Absent a conservation strategy, these strategies enable a status-quo water culture that views desalted seawater as a limitless substitute for freshwater. Ironically, increased U.S.-Mexico interdependence may ensue under the proposed desalination strategies, requiring improved cooperation between the U.S. and Mexico, yet these strategies do little to foster better communication and enhanced collaboration, and therefore could actually increase vulnerability.

Source: Excerpted from Wilder et al. (2010).

United States (Ex-Im Bank). NADBank may be an additional source of financing. NADBank's Jorge Garcés stated that while NADBank had not yet received any formal proposals for the binational desalination plant, they remain interested and opened to binational proposals. He reiterated the NADBank's willingness to provide funding. Like Sanchez and Munro, the NADBank sees desalination as an "important part of meeting future water needs" (Garcés 2010).

While the need for Puerto Peñasco to augment its water supply is urgent, Arizona water managers have long-term plans in place, at a high confidence level, based on rural-to-urban transfers, reuse and recharge, storage capacity, desalination of brackish groundwater, and conservation. As one CAP official stated, "Realistically, we don't need the water yet – we especially don't need a big project for awhile" (interview, March 24, 2010). Adding binational desalination to the CAP's water portfolio isn't likely to happen for at least another 20 to 30 years. However, the official observed that given the complexities of a binational arrangement, Arizona "needs to be thinking about it now."

G. Urban Water Vulnerability and Adaptive Capacity

In this section, we summarize key findings about priority vulnerability areas and discuss adaptive capacity by returning to the four questions we posed for each of the linked case studies.

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

This study has documented three major characteristics of urban water vulnerability in Puerto Peñasco: 1) environmental vulnerability in the Gulf of California; 2) lack of sufficient existing water sources to meet current and projected water demand; and 3) challenges associated with desalination, including costs and affordability, and management of briny discharge.

During a stakeholder workshop with water managers and decision-makers at the local, state, and national levels in Puerto Peñasco, participants indicated on a survey that their perception of the greatest vulnerabilities in the water sector in the face of climate change included both physical and social elements of vulnerability. Given a list of 11 potential sources of water-sector vulnerability in Puerto Peñasco, the top three indicated were: overdrafting of aquifers (57 percent), lack of long-term (5-20 year horizon) water management and planning (56 percent), and urban growth (45 percent). Water sector vulnerabilities included: water scarcity, diminishing surface water levels and low dam levels, overdrawn aquifers, extreme events (especially droughts and heavy rains), desertification, and sea level rise. Social factors seen as contributing to vulnerability within the water sector included: increasing water demands, overuse or misuse of water resources, golf courses (which are a major water user in Puerto Peñasco), limited ability to evaluate damage and needs during extreme meteorological events, deteriorating or sub-optimal water infrastructure, limited ability to capture rain and run-off during extreme precipitation events, and limited understanding of the vulnerabilities by decision-makers. Additional social factors that participants identified were data needs, information management, and science-stakeholder communication. They noted a need for high quality climate information, but also a lack of baseline data, along with a need for more climate information and better networks for data and information exchange.

Table 3-6. Summary of Urban Water Vulnerability Indicators, Puerto Peñasco.

Types of Vulnerability	Indicators	Puerto Peñasco
Demographic and socioeconomic	Growth characteristics (actual and projected)	Rapid growth due to increased development in the tourist industry (e.g., hotel, resort, and beach home, and golf course construction) Growth also experienced as result of migration, people looking for job opportunities in the tourism sector
	Poverty and inequality levels	High cost of water (for farmers and residents) due to the amount of energy spent on pumping water from local wells
	Infrastructure	Lower than average salaries relative to the rest of Sonora Major new infrastructure (e.g., coastal highway and airport) promote increased tourism and development
Biophysical and climatic	Climate variability and climate change	Hot and arid climate, dry winters, torrential summer rains Increase in intensity of torrential summer rains, due to increased contribution of tropical cyclone precipitation North American Monsoon highly variable, intra-seasonally, intra-annually, and intra-decadally Prone to extended droughts Wetlands and estuaries prone to flooding especially during and after monsoon events
Institutional and governance	Characteristics of municipal water management	Political appointment of water agency key personnel and lack of civil service Short electoral cycles and lack of civil service limits consistent, long-term water supply planning High level of unaccounted for water (unpaid water fees) OOMAPAS unable to recover costs of its services Binational element introduces complex, transboundary institutional arrangements

Scientific and technological	Hydraulic infrastructure	Plans to construct municipal and binational desalination plants 40 year old water supply system and prevalence of leaks resulting in a 60 percent loss of all piped water Only 69 percent of municipio residents connected to waste water system Existence of smaller desalination plants owned by individual tourist establishments/hotels Struggle to maintain adequate water pressure so that water reaches city center
	Climatic information adequacy and fit	Lack of baseline data Need for high-quality climate info and better communication networks to distribute data/info Need for better weather monitoring and forecasting systems so can avoid weather-related catastrophes
	Use of alternative conservation strategies	Insufficient amount of planning and discussions regarding adaptive water management; potential reliance on desalination technology to provide limitless supply should the construction of such plants happen
Environmental	Reliable access to clean water and sanitation	Only 69 percent of municipio residents connected to waste water system; compared to 91 percent of population which are connected to water system Water scarcity further aggravated by increased development of tourist industry
	Ecosystem health and impacts	Puerto Peñasco borders on two UNESCO-designated national protected areas with high biodiversity in plant and marine mammal species Impacts on endangered species (e.g., vaquita) due to significant by-catch problem in commercial shark and shrimp fishing Dredging of ocean floor can threatening protected species Severe depletion of groundwater aquifers leads to perceived need for municipal desalination plant, with potential impacts on fragile estuaries due to briny discharge Saline intrusion problem due to overdrafted aquifers Indirect impacts of more growth on estuaries and biosphere reserves

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

The principal adaptive strategy planned to address insufficient water supply to meet current and projected demand is focused on desalination strategies. Lack of sufficient water supply is the result of over-drafting of groundwater aquifers (common not just in Puerto Peñasco but along the entire coast of Sonora) coupled with increasing demand due to urban growth and tourism development. Climate variability, including both prolonged droughts and highly-variable precipitation (and storm events), creates management challenges for local water managers. In Puerto Peñasco, future water supply planning is focused on providing a sustainable source of water via municipal and a binational desalination plants. Desalination has had a difficult history at times in Sonora, such as when a major desalination plant planned for Hermosillo was canceled by the incoming state governor in 2002. With relatively weak municipal institutional strength (e.g., lack of fiscal and technical resources), Puerto Peñasco will need to turn outward to CONAGUA, CEA, and to binational collaborators (as evidenced by their relationship with USTDA) to develop sufficient capacity to meet the future demands. With respect to desalination, while it has many apparent positive benefits, we have argued that in itself it does not so much represent potential adaptive capacity as it represents doing "business as usual" (Wilder et al. 2010). As recognized by the regional water authority in southern Nevada, desalination is not a panacea to resolve water-related vulnerability. Puerto Peñasco may need to call on additional institutional and technological resources from outside the municipality to provide assistance with such tasks as doing desalination well, in a way that protects the local environment and local social and economic interests, and also with identifying diversifying strategies to meet long-term water needs.

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

The results from a non-probabilistic survey questionnaire that our research team asked workshop participants (October 2, 2009 in Peñasco) to complete shed light on the climate information needs of Puerto Peñasco water managers and disaster relief planners.[16]

- Sources of Climate Information. The most commonly used source of information for making

16 Questionnaires asked the following questions, with responses listed: Which of the following sources of information do you use to make forecasts, understand historic water and climate conditions, and water and hydrology information: SMN = 67 percent, Conagua = 54 percent, NOAA 46 percent, TV, radio and newspapers = 44 percent (n= 48). For Puerto Peñasco and other regions along the coast, what type of water and climate information is most useful? (select 3 from a list of 16 options): top 4 responses: temperature by season (55 percent), groundwater level (51 percent), seasonal climate forecasts (51 percent), and rainfall by season (43 percent) (n~48). What type of climate change information would be most useful for helping to create plans for the next 20 to 50 years? (select from a list of 18) top 3 responses: water and energy (67 percent), groundwater levels (63 percent), sea level rise (56 percent) (n = 48). Which of the following topics would you be most interested in collaborating on in terms of climate change and planning for future sustainability? Answers: urban water supply, energy and desalination (37 percent), risk management training/capacity for droughts, storms, floods, and heat waves (19 percent), and regional agriculture and water supply (17 percent) (n=47).

forecasts, understanding historic water and climate conditions, and obtaining water and hydrology information are the Mexican National Weather Service (Servicio Meteorológico Nacional, SMN), the National Water Commission (Comisión Nacional del Agua, CNA), the National Oceanic and Atmospheric Administration (NOAA), and television, radio and newspapers.

- Most Useful Weather and Climate Information. Respondents indicated that the top four (of 16) most useful water and climate information for planning in Puerto Peñasco and other coastal regions were: temperature by season (55 percent), groundwater level (51 percent), seasonal climate forecasts (51 percent), and rainfall by season (43 percent).

- Most Useful Climate Change Information for Long-Term Planning (20-50 years). Respondents highlighted water and energy (67 percent), groundwater levels (63 percent), and sea level rise (56 percent), as the types of climate change information that would be most useful for helping to create long-term plans at the 20-50 year horizon.

- Identifying Priorities for Future Collaborative Research. Respondents expressed interest in potential future collaborative research in the following areas: urban water supply, energy and desalination (37 percent), risk management training/capacity for droughts, storms, floods, and heat waves (19 percent), and regional agriculture and water supply (17 percent).

  Discussion during the stakeholder workshop regarding climate information and data needs underscored the need for financial investments to improve the weather monitoring and forecasting systems. While it was noted that more data on historic climate are needed, it was also recognized that the variability of temperature and precipitation patterns will be affected by climate change, making the historic record perhaps less useful. Managers noted the need to know what the 10 year oscillations might be expected under conditions of climate change.

  Managers also highlighted the need to be able translate information to the public. For example, it was noted that scientific organizations such as NOAA and NASA have the resources to predict exactly where the runoff will go and can determine how much precipitation a storm may produce. If this information is available and arrives in time, then it could be used to prevent weather-related catastrophes. Managers stated that most natural disasters are predicted ahead of time, but emergency preparedness planners have to be well equipped with information and be informed; and even then, not all harm and damage can be prevented.

- Qualitative Comments on Stakeholder Concerns for Climate Variability and Urban Water Vulnerability. In addition to identifying and prioritizing climate information needs, we asked participants at the workshop to discuss the high-priority vulnerabilities relating to the future urban water supply. One participant surmised that the greatest challenges facing the water sector in the next 5 to 10 years will not be technical, but social. Many participants agreed that the greatest challenges are related to the management of scarce resources including transferring water between sectors and watersheds, as well as between the United States and Mexico, sharing and negotiating over scarce resources, increasing demands for water, and a lack of funding for management and infrastructure improvements.

A recurring theme at the workshop was the need to focus on demand management and cultivate a "*cultura del agua"* (water culture) or "*cultura del desierto"* (desert culture). Some suggested tools to facilitate this social change included: expanding legal and institutional arrangements to encourage the efficient use of water, full collection of payment for services in order to incentivize water efficiency, fines for wasting water, educational programs, and investments for improving the efficiency of water infrastructure and reducing leaks.

The greatest concerns expressed by water managers included: managing water under conditions of non-stationarity (e.g., non-linear change, associated with a range of uncertainty regarding future climate change and impacts); extreme events, damage to infrastructure during extreme events; the need to introduce flexible planning measures into their agencies' planning and decision-making processes; and lack of communication between scientists, water mangers and policymakers, as well as between different agencies and levels of government. For example, water managers from CNA lamented that it took three years for politicians to listen to their suggestion to increase water tariffs. Additionally, an animated discussion revolved around the lack of communication between water managers, civil protection services, and residents of the coastal community of Guaymas when a near-hurricane strength storm made landfall with residents claiming they had received little or no warning about the devastating strength of tropical storm Jimena.

The top priorities, as identified by water managers and decision-makers during the stakeholder workshop in Puerto Peñasco, for managing variability and climate change in an adaptive manner in the next 5-10 years include: investing in infrastructure and diversifying the sources of water (e.g., groundwater protection, improve rainwater filtration and rainwater harvesting, wastewater reuse, desalination, improved efficiency, and greater storage); increasing water user education and developing a "cultura del desierto"; expanding the coverage of meteorological stations; and improving the collection and dissemination of climate information.

COMMENTS BY STAKEHOLDERS, PUERTO PEÑASCO WORKSHOP, OCTOBER 2, 2009

"Why worry about climate change when we already have problems with water management as it is? We need to make plans to improve our current water management." –Water manager, Sonora

"Depoliticize decision-making within water management agencies and professionalize the water management agency in order to change the planning horizon. Rather than thinking about what will benefit them in their three-year period [corresponding to mayoral terms], managers need to be thinking about long term investments." –Water manager, Sonora

"We need to consider the voices and actions of key stakeholders—namely agriculturalists, who use over 80 percent of the total available water. This would necessitate the development (or re-development) of institutional mechanisms for allowing a broader participation of agriculturalists in the decision-making processes, along with the implementation of institutional, market and regulatory mechanisms to induce more efficient water use in agriculture." –University researcher, Sonora

"We need better communication between water managers and decision-makers. For example, in order to raise the water tariffs, it took three years for CNA to be heard by politicians. Water managers, scientists and decision-makers have to work together and communicate. Additionally, there is a need for greater participation by all stakeholders in the planning process." –Water manager, Sonora

"Right now we have a good opportunity in water governance with a flexibility that will be important, for the state and federal levels to plan together for the coming years, to defend proposals and see how to invest resources. We need to move away from (only) planning, which is at times very self-critical and slows down the process, very politicized. But there are plans that are moving forward on consumptive human use, irrigation support to become more efficient, and…institutional support, too." –Climatologist, Sonora

- Stakeholder Perspectives on Desalination as an Adaptive Strategy to Reduce Urban Water Vulnerability. During the stakeholder workshop, a significant emphasis was placed on the need to consider new technologies, including desalination, and both large and small-scale technologies to capture precipitation during extreme weather events. It was suggested by a national SMN representative that with enhanced capacity to capture and store stormwater runoff, water managers could shift their view of extreme precipitation events from a "disaster" to an "opportunity."

  Of 38 stakeholders who responded to a question on our online questionnaire regarding the appropriateness of desalination as an adaptive strategy, a total of 66 percent (42 percent strongly agree and 24 percent agree) agreed that desalination is an appropriate and "adaptive" strategy for confronting the water availability challenges of this region. In addition, 51 percent agreed or strongly agreed that their city will very likely receive desalinated water in the near future to meet needs, while 40 percent disagreed or strongly disagreed with this statement

  One of the most salient points raised in the desalination discussion was that major infrastructure improvements would have to occur before the construction of a multi-million dollar desalination plant, in order to ensure that the expensively manufactured water would not be wasted in a leaky network. Furthermore, metering and payment for services would need to be expanded so that users would be incentivized to save water. Therefore, it was widely agreed that an emphasis on efficiency improvements is a necessary precursor to the implementation of desalination technology, and that desalination should be complementary to other demand management strategies, including conservation, institutional changes, and market mechanisms. This sentiment was also reflected in the survey, in which 42 percent (n=31 for question) of respondents strongly agreed and 23 percent agreed that desalination is just one of many options available for future water management (while 19 percent disagreed and 10 percent strongly disagreed with this statement).

  Desalination, as presented by its proponents, would have three benefits for the local municipality. First, it would allow the city to overcome the natural water scarcity that has posed a limit to continued urban growth (USTDA 2008). The former municipal desalination planning coordinator noted that once a desalination plant is built, many of the fears that investors have will be relieved. With the uncertainty of water provision resolved, the region could open up 400 kilometers of coastline for development. As Smith (2009) observes, desalination allows regions to "have limitless development 'cake' and eat it too." Second, given the abundance of saltwater, desalination has come to be viewed as a nearly "drought-proof" water resource (Kohlhoff and Roberts 2007:276; see also "Tapping the Oceans" 2008; National Research Council 2008). Third, the new source of water could take pressure off already overdrawn aquifers, allowing them to recover to near-equilibrium levels.

  Some of the concerns that were raised about a move toward water supply augmentation via desalination at the stakeholder workshop in Puerto Peñasco include: the high energy demand of desalination and the increased contribution to greenhouse gas production, the water-energy nexus, disposal of the salt concentrate discharge, the high cost of the construction and operation of the project and the burden of increased water costs for users, sea level rise and effects on new coastal infrastructure related to desalination, and the location of the plant intake and discharge being near the biosphere reserve.

At least two issues related to desalination were not adequately addressed in interviews, presentations or stakeholder workshops. First, there was no discussion of the environmental risks posed by the chemical waste associated with the desalination process, including iron chloride as an anticoagulant, hypochlorite as an oxidant, sulfuric acid to equilibrate the ph-level for the membranes, sodium bisulphate, an anti-scalant, and calcium carbonate. Second, there was little recognition of the growth inducement potential and related environmental impacts. In arid regions where scarce water resources have limited urban growth, the introduction of “limitless” desalinated water is likely to encourage urban growth, which is associated with a range of environmental impacts including increased air and water pollution, habitat fragmentation, coastal development, saline intrusion into agriculture, and loss of biodiversity (Smith 2009; Sax et al. 2006; Cooley et al. 2006; Johnson 2001). At the Border Governors Binational Desalination Conference in San Diego in 2010, water managers noted that their job is to find a way to provide water to meet demands. The task of managing demand and making decisions about the level and type of development that produces that demand is the responsibility of other governmental agencies.

H. Implications for Policy and Planning

In sum, the major challenges and vulnerabilities in the water sector include: 1) the politicized management of the water agencies, where three year terms inhibit long-term planning; 2) lack of payment for water services; 3) lack of coordination and communication between different levels of government and scientists and decision-makers; 4) the need to improve current water management regardless of future concerns about climate change; 5) the role of desalination as an augmentation strategy; 6) the natural scarcity of water the arid region, for which climate change will only increase the challenges of the management of this scarce resource; 7) disagreement over how to manage the resource as it is; 8) a need to understand the context of water management and climate change – including both the climate variability and the social vulnerability; and 9) the importance of the role of planning for a more adaptive water management in the future. Other details of vulnerabilities are documented in Table 3-6, above.

Policy improvements suggested by workshop participants in Puerto Peñasco include: the need to promote watershed-scale management, protect aquifers, develop new laws for wastewater treatment and expand wastewater reuse, develop laws for rainwater harvesting in new developments, and improve the planning process in order to integrate land-use planning with water resource management. Building the institutional capacity to identify climate information and product needs and to use them appropriately will help make long-term water supply planning more sustainable. The expansion of climate science use in planning for urban water needs in Puerto Peñasco and in influencing future decisions about the desirability and design of desalination plants could make a critical difference to environmentally-sound management of natural and marine resources and species in the Upper Gulf of California.

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Acronyms

AF—Año fiscal (fiscal year)
AFY—Acre-feet per year
AZRise—Arizona Research Institute for Solar Energy
CAP—Central Arizona Project
CEA—Comision Estatal del Agua (State Water Commission)
CEDO—Center for Protection of Deserts and Oceans (Centro Intercultural de Estudios de Desiertos y Océanos)
CONAGUA—Comisión Nacional del Agua
Ex-Im Bank—Export-Import Bank of the United States
FONATUR—Fondo Nacional de Fomento del Turismo (National Fund for Tourism Promotion)
GDP-Gross Domestic Product
H. Ayuntamiento—Honorable Ayuntamiento
IMCO—Mexican Institute for Competitiveness
IADB—Inter-American Development Bank
INEGI—Instituto Nacional de Estadística y Geografía
MAB—Man and Biosphere Program
NADB—North American Development Bank
NAFTA—North American Free Trade Agreement
NAM—North American Monsoon
NASA—National Aeronautics and Space Administration
NGO—Non-Governmental Organizations
NOAA—National Oceanic and Atmospheric Administration
OECD—Organization for Economic Cooperation and Development
OOMAPAS—Organismo Operador Municipal de Agua Potable Alcantarillado y Saneamiento (Municipal Operating Agency for Wastewater and Sanitation)
RV—Recreational Vehicle
SCADA—Supervisory Control and Data Acquisition system
SMN—Servicio Meteorológico Nacional (National Meteorological Service)
SONORA SI—Sonora Integrated System
SRP—Salt River Project
UMIAEA—U.S.-Mexico-International Atomic Energy Agency
UN-United Nations
UNESCO—United Nations Educational, Scientific and Cultural Organization
USD—United States' Dollar
USTDA—U.S. Trade and Development Agency
WEF—Water Environment Federation
WWF—World Wildlife Fund

CHAPTER 4

TUCSON

Tucson cityscape, istock photo

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

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

A. Introduction

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

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

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

Research Questions

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

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

Methods

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

B. Background: The Tucson Region

Historical Overview of Water in the Tucson Region

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

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

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

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

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

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

Demographic and Economic Factors

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

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

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

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

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

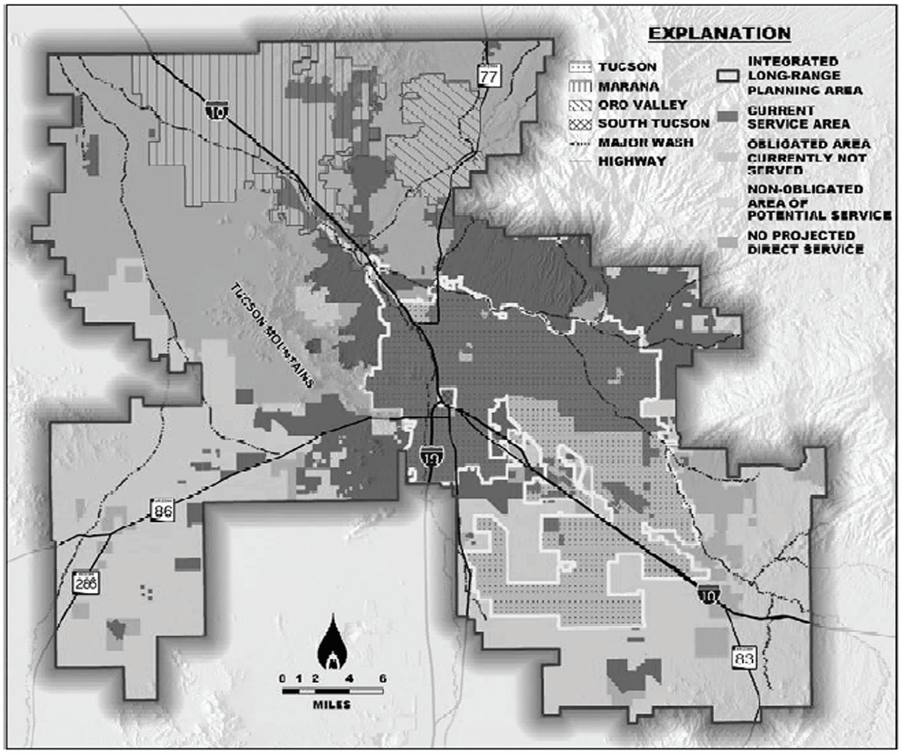

Figure 4-1. Tucson Water long-range planning area, obligated service area, and potential service area. Source: Tucson Water 2008, Figure ES-1.

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

Climate Variability

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

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

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

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

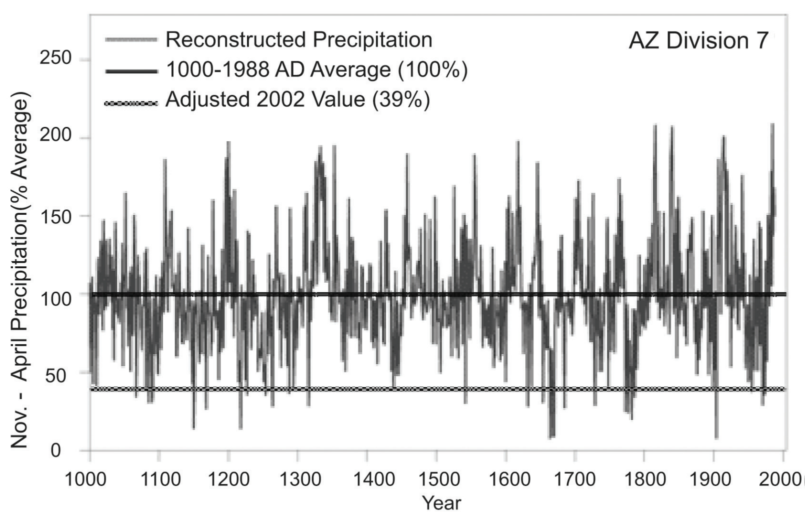

Figure 4-2. Single-Year Reconstruction for AD 1000-1988 (% Average). Source: Tucson/Pima County Oversight Committee 2009a:4.

Climate Change

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

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

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

D. Water Governance, Institutions and Management

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

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

E. Urban Water Infrastructure

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

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

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

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

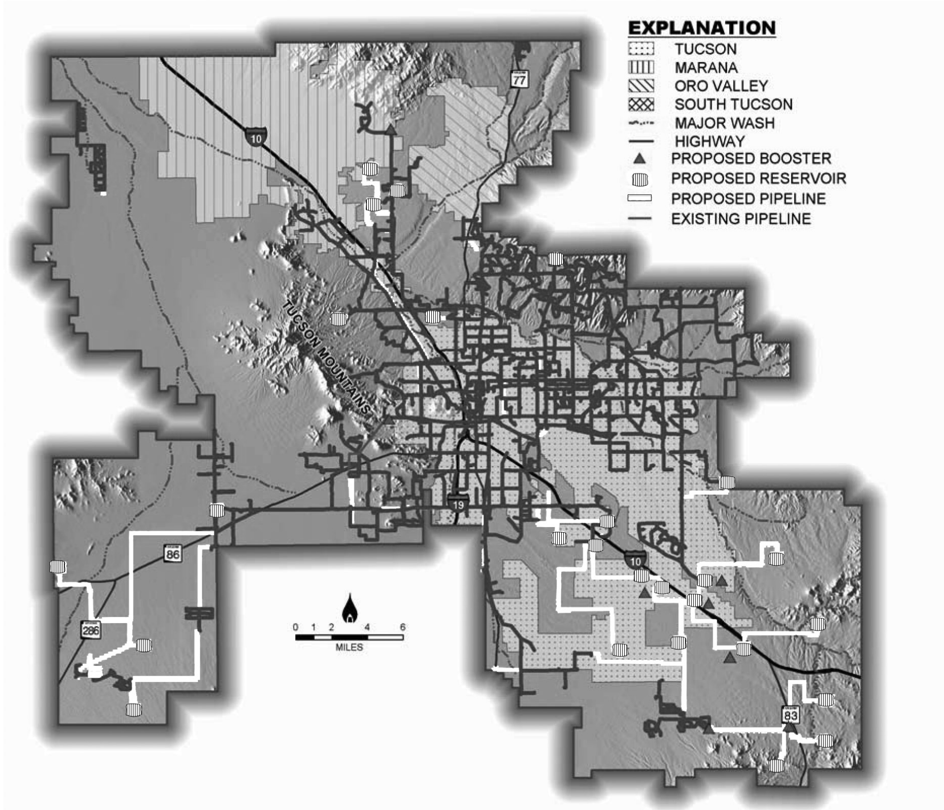

Figure 4-3. Potential Expansion of Tucson Water's Potable System Through 2050
Source: Tucson Water 2004, Chapter 5.

Tucson Water plans to continue expansion of the city's potable water delivery system over the next 20 years (Figure 4-3, light grey lines). The system-expansion costs will average about $20 million annually through 2030. This annual rate of capital expenditure will only cover incremental costs for system expansions and does not include other costs required to maintain or replace existing infrastructure or to bring additional renewable water supplies into use (Tucson Water 2004:4-10).

The Pima County RWRD, together with a number of community partners (the City of Tucson, the Town of Oro Valley, and others), has also created a master plan to allow RWRD to meet environmental regulatory requirements regarding ammonia and nitrate. When the ROMP plan is completed, the Ina Road facility will be upgraded and expanded to treat 50 million gallons per day (mgd). The Roger Road plant will be decommissioned after a new 32 mgd water reclamation facility is built adjacent to the existing plant. Preliminary 2006 estimates for this project were $536 million. However, the ROMP will ultimately cost more once additional needs and requirements are identified and inflation and debt service are factored into project costs. RWRD will be asking for increases in sewer rates and sewer connection fees. These rate increases are paid by those individuals who receive sewer service, developers, and any others who connect new plumbing fixtures that discharge into the sewer system (see http://www.pima.gov/wwm/programs/ROMP/).

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

F. Water Use Trends and Changing Demand

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

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

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

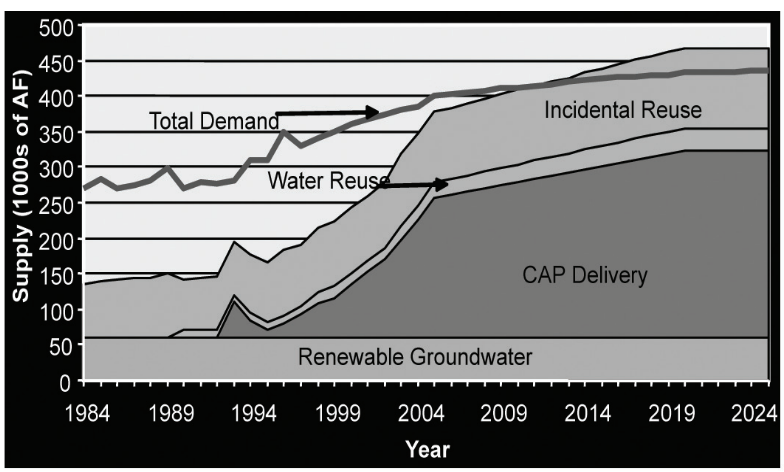

Figure 4-4. Historic and projected water demand in the Tucson Active Management Area. Source: Based on data from City of Tucson, 2004.

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

G. Urban Water Vulnerability in Tucson

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

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

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

Socioeconomic Vulnerability and Resource Dependency

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

In turn, Adger defines social resilience as:

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

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

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

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

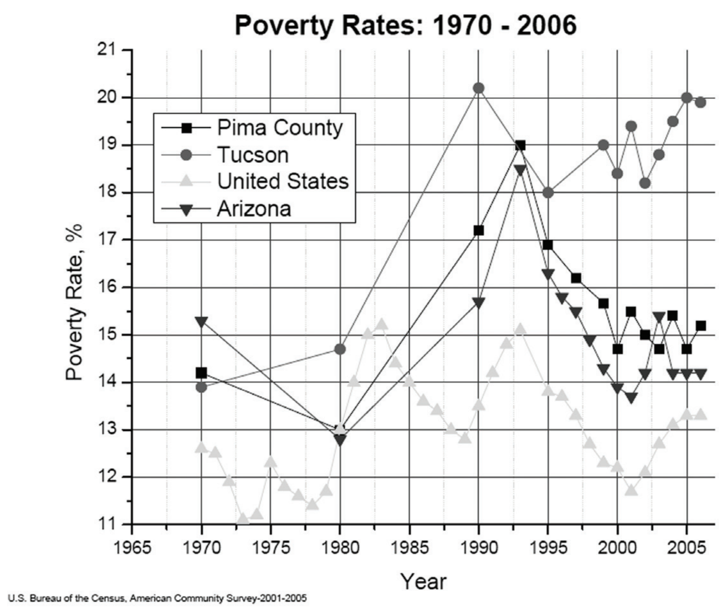

Figure 4-5. Poverty rates, 1970-2006. Source: U.S. Census Bureau, American Community Survey, 2001-2005.

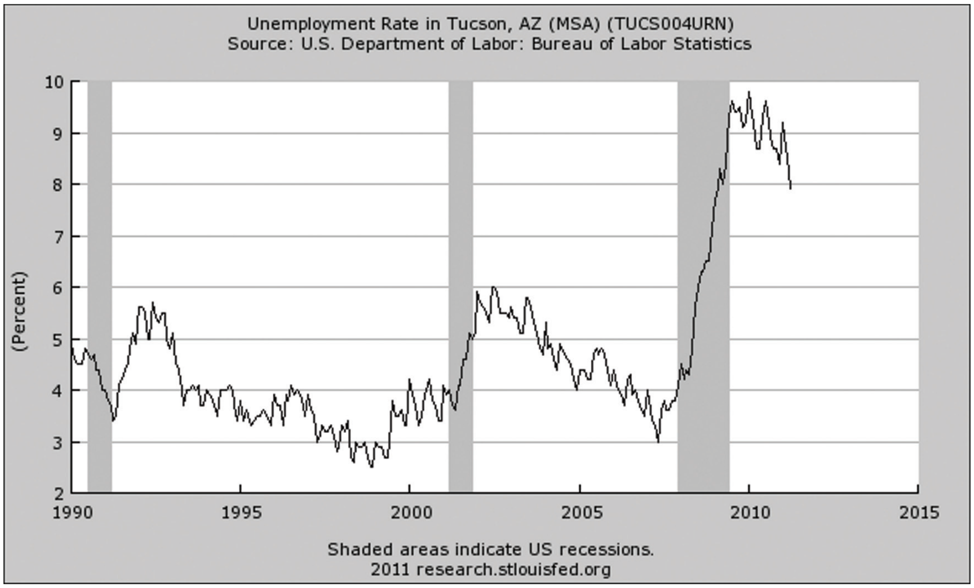

Figure 4-6. Tucson unemployment rate, 1990-2011. Source: http://research.stlouisfed.org, based on U.S. Bureau of Labor Statistics data.

Infrastructure Vulnerability

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

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

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

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

Water Supply and Resource Dependency

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

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

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

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

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

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

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

WATER BANKING

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

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

Helen Ingram notes that:

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

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

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

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

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

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

Institutional Vulnerability

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

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

H. Adaptation and Adaptive Capacity

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

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

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

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

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

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

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

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

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

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

Outcomes of Scenario Planning for the Clearwater Program

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

1. What is the public's threshold for paying for discretionary water-quality improvements to the Clearwater blend?
2. Will the public accept the use of the Hayden-Udall Treatment Plant for direct treatment of Colorado River water?

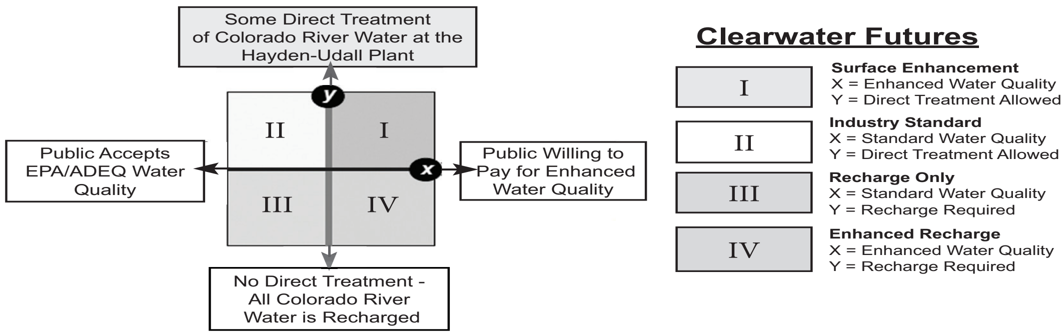

Figure 4-7. Tucson Water Scenario Planning Process. Source: Tucson Water 2004:6-5.

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

- The Drought Impact Monitoring Program created by ADWR with the University of Arizona Cooperative Extension is working to get agencies and individuals interested in drought impact monitoring, mainly by promoting the use of Arizona Drought Watch qualitative reports of drought impacts across Arizona. This "impact information will be used in conjunction with meteorological and hydrological data to characterize drought conditions, and perhaps more importantly, to help determine the environmental, social and economic impacts of drought." (citation?) In addition, ADWR assembled a Conservation Toolkit to "assist communities and water providers in the design and implementation of comprehensive, customized and proven conservation strategies. These tools provide residents, businesses and the agricultural community with information on sector-specific water-efficient measures" (ADWR 2009).
- Water reuse as a hedge against water sector vulnerability. In addition to renewable groundwater and CAP deliveries, water reuse (reclaimed effluent) represents the third source of water to meet Tucson's demands, as shown in Figure 4 above. Currently, the City of Tucson distributes 15,750 acre-feet of effluent, largely to institutional users such as golf courses, schools, public parks, etc. A small fraction is made available to residential users in three Tucson neighborhoods adjoining the reclaimed water distribution lines. A share of effluent is released to the (otherwise dry) Santa Cruz River, where it supports important habitat. Only fifty percent of this release counts toward water banking credit under the provision that only certified facilities with strictly controlled conditions for recharge receive full credit, i.e., in the Santa Cruz, the uncredited balance is considered to be "cut to the aquifer." The combined total effluent use meets on average nine percent of Tucson's water demand. However, with projected growth, effluent available to the City of Tucson is projected to grow to a 62,000 acre-feet annual entitlement by 2030 (Tucson Water 2004).

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

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

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

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

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

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

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

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

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

I. Summary of Urban Water Vulnerability and Adaptive Capacity

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

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

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

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

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

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

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

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

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

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

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

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

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

J. Implications for Policy and Planning

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

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

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

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

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

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

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Acronyms

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

CHAPTER 5

HERMOSILLO

photo by Nicolás Pineda-Pablos

Vista del Cerro de la Campana desde el Boulevard y el canal embovedado del Río Sonora, desde el lado poniente. Entre los edificios se aprecia la silueta de la catedral.

View of the Cerro de la Campana (an Hermosillo landmark) from the boulevard and the lined canal of the Sonora River, from the west. Among the landscape of buildings can be seen the towers of the main cathedral.

Hermosillo, ciudad sin agua para crecer. Vulnerabilidad hídrica y retos frente al cambio climático

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Resumen / Abstract

Español/ Hermosillo, Sonora representa un caso ilustrativo de crecimiento urbano en un contexto de baja disponibilidad o disminución de agua, misma que tiende a agravarse por el cambio climático, además enfrenta retos importantes de vulnerabilidad social sin resolución. Este estudio analiza las dimensiones geográficas, hidro-climatológicas, sociales e institucionales de la expansión de Hermosillo en el pasado, presente y futuro. El cambio y la variabilidad climática aumentan las posibilidades de una crisis de acceso y distribución equitativa del agua en la ciudad. La capacidad institucional para abordar la vulnerabilidad es incipiente y, como en gran parte de México, hay grandes expectativas de que la infraestructura resuelva la crisis. Sin embargo, los conflictos urbano-rurales por la tierra y el agua, la vulnerabilidad social extrema de ciertos grupos sociales, la diversa capacidad adaptativa producto de la desigualdad socioeconómica, y la rápida rotación del personal profesional responsable de la prestación de servicios, planificación y respuesta a emergencias se combinan para presentar un continuo desafío para la seguridad hídrica en Hermosillo.

English/ Hermosillo, Sonora represents an illustrative case of urban growth in the context of fixed or declining water resources availability, exacerbated by climate change, and with important but unresolved challenges of social vulnerability. This study reviews the geographical, hydro-climatological, social and institutional dimensions of Hermosillo's expansion – past, present, and future. Climate change and variability accentuate a growing crisis of water access and equitable distribution for the city. Institutional capacity to address vulnerability is nascent and, as in much of Mexico, there are heightened expectations that infrastructure solutions will resolve the crisis. However, urban-rural conflicts over land and water, extreme social vulnerability of certain social groups, varying adaptation capacity resulting from socio-economic disparity, and rapid turnover of professional staff responsible for service provision, planning and emergency response – all combine to present continued challenges for water security in Hermosillo.

A. Introducción al estudio

La ciudad de Hermosillo está ubicada en una región semiárida en el estado de Sonora. En la primera década del siglo XXI, la ciudad cuenta con 715,000 habitantes (INEGI 2011), una tasa de crecimiento anual de 2.5 por ciento, muy superior a la tasa estatal de 1.8por ciento (que incluye a Hermosillo) y a la nacional de 1.4 por ciento, y se ha convertido en uno de los centros económicos más importantes del Noroeste de México. Si se toman en cuenta las inversiones públicas y privadas que se están haciendo en la ciudad, todo parece augurar que ese crecimiento no sólo se va a sostener sino que incluso pudiera incrementarse.

Estos datos se vuelven preocupantes cuando se contrastan con la baja disponibilidad de agua para la ciudad (Scott and Pineda 2011). Hay diversas señales que muestran que el agua disponible para la ciudad ha estado disminuyendo en términos relativos y, lo que es peor, en términos absolutos. En 1998, la ciudad vio secarse la presa que le suministraba de líquido; posteriormente los pozos de agua del oriente de la ciudad se han estado abatiendo y durante esta década los administradores del agua han enfrentado serias dificultades para mantener el suministro de agua durante los meses del estío veraniego. Esto sólo se ha logrado por medio del sistema de racionamiento conocido como tandeo.

Preguntas de investigación

Con este telón de fondo, planteamos las siguientes preguntas incorporadas en el proyecto de investigación apoyado por la NOAA, *Moving Forward*:

- ¿Cómo se define la vulnerabilidad urbana del sector agua en Hermosillo?
- ¿Cuál es la capacidad institucional de Hermosillo para desarrollar estrategias de adaptación para la gestión del agua en un horizonte de 5 a 20+ años?
- ¿Cómo puede ser institucionalizada en Hermosillo la capacidad de los administradores del agua y los planificadores de la preparación a utilizar la ciencia del clima y la información? ¿Y cómo pueden hacerlo de manera que se mejore la capacidad de tomar de decisiones para adaptar?
- ¿De qué manera la resiliencia de los recursos hídricos en Hermosillo ante las condiciones climáticas (incluyendo la incertidumbre) puede ser mejorada a través de la integración de la ciencia e información climática en los procesos de planificación?

Metodología del estudio

Este estudio es resultado del trabajo colectivo de un equipo binacional de investigadores coordinado por Robert Varady y Margaret Wilder (proyectos NOAA SARP y CLIMAS), y de Christopher Scott (proyecto IAI) de la Universidad de Arizona (ver sección de Introducción al Proyecto, arriba). El estudio de caso de la ciudad de Hermosillo fue coordinado por Nicolás Pineda del El Colegio de Sonora. Además participaron investigadores que aparecen como coautores incluso otros investigadores y algunos funcionarios de entidades gubernamentales. En general, este estudio es resultado de un largo proceso de observación directa, recopilación de información publicada, consultas, entrevistas y seguimiento de prensa sobre la gestión del agua en Hermosillo. Los métodos de investigación utlizados para el análisis de la vulnerabilidad del manejo del agua ante la variabilidad climática y el cambio climático fueron: revisión de literatura y análisis de contenido de los reportes e información publicada por el organismo de agua, Agua de Hermosillo, seguimiento de indicadores y datos publicados por la Comisión Estatal del Agua de Sonora y la Comisión Nacional del Agua, seguimiento cotidiano de notas de prensa relacionadas con la operación de las obras de infraestructura, así como pláticas, consultas personales y participación conjunta con las autoridades hidráulicas locales en los talleres realizados los días: 8 de noviembre de 2008 en Hermosillo, Sonora; 22 de julio de 2009 en Jiutepec, Morelos; 2 de octubre de 2009 en Puerto Peñasco, Sonora; 7 de mayo de 2010 en Hermosillo, Sonora y 1 de marzo de 2011 en Los Cabos, Baja California Sur. Además, para la realización de este estudio de caso, el coordinador realizó un panel de discusión el 17 de noviembre de 2010 para intercambiar puntos de vista sobre la situación del agua en Hermosillo; en este panel participaron representantes de Agua de Hermosillo, la Comisión Estatal del Agua de Sonora, la Comisión Nacional del Agua y expertos de la sociedad civil y académicos estudiosos del tema.

Hay que aclarar que los temas que abarca este estudio son bastante amplios y no se cubren en su totalidad con la información aquí presentada. Quedan por lo tanto muchas lagunas de información y aspectos que pueden ser materia de estudios posteriores con un mayor nivel de profundidad. Por otra parte, no se excluye que existan carencias de información o que la información disponible no siempre sea sistemática, confiable o congruente entre sí.

En general, este trabajo busca reunir la información disponible con la finalidad de presentar una síntesis e identificar áreas de vulnerabilidad relacionadas con el manejo del agua y la variabilidad climática en Hermosillo.

El marco teórico conceptual de este estudio gira en torno a la vulnerabilidad climática urbana y las estrategias de adaptación (Wilder et al. 2010). La vulnerabilidad es definida como la disponibilidad insuficiente de recursos socioeconómicos para enfrentar la amenaza de un clima más caliente y árido o bien un acceso desigual o diferenciado a los medios para hacerle frente al clima más caliente y árido (vea la Introducción al Proyecto, arriba, para mayor detalle).

B. Antecedentes: Hermosillo y la modesta cuenca del Río Sonora

La ciudad de Hermosillo se ubica en la parte media de la cuenca del río Sonora (Figura 5-1) a una elevación de 210 metros sobre el nivel del mar. La ciudad fue fundada como presidio militar en el año 1700 y su ubicación obedece a que ese era el último lugar con agua superficial disponible de manera permanente desde el cual se podía vigilar y combatir a los indios Seris rebeldes en esa época (Molina Molina 1983).

En el siglo XVIII, el misionero jesuita Juan Nentuig, en su descripción geográfica de la región, registraba que las aguas de los ríos Sonora y su afluente el San Miguel riegan las tierras y viñas de Pitic (antiguo nombre de Hermosillo) y ahí se acababa su corto caudal; sólo en los años de lluvias copiosas, las aguas llegaban hasta los siete cerritos ya que todo se pierde en los arenales y no llega una sola gota al mar (Nentuig 1977).

En 1865, el Capitán Guillet del ejército francés describe así el río Sonora:

> El río Sonora corre de noroeste a suroeste, irrigando Arizpe, Ures y Hermosillo y se pierde en la arena antes de llegar al mar. Recibe a la derecha el río San Miguel, torrente insignificante durante casi todo el año. El Sonora es un río muy encajonado en la parte superior de su curso, se ensancha considerablemente al desembocar en la planicie de Ures [y] en Hermosillo tiene más de 400 m. de ancho; pero a partir de Ures sus aguas se pierden poco a poco en la arena y

> no conserva sino pocas gotas al llegar a Hermosillo, a no ser en época de grandes lluvias. Esto dura solo unos días y desde septiembre el río retoma sus proporciones normales. (Larios Gaxiola 2010)

El río Sonora nace al norte del estado de Sonora en el municipio de Cananea y tiene una amplia cuenca de 21,200 km^2 (Cotler, Garrido, Mondragón, and Diaz 2007). La ciudad divide a la cuenca del río Sonora en dos, la parte alta y la baja. Hacia el oriente y el norte de la ciudad de Hermosillo, el río Sonora recibe como tributarios a los ríos San Miguel y Zanjón. Es una corriente criptorréica porque su escurrimiento desaparece en el acuífero de la Costa de Hermosillo en la parte baja de la cuenca y normalmente no llega al mar (Tamayo 2009:287).

El río Sonora es de régimen intermitente pues al final del período de estiaje deja de escurrir superficialmente. El gasto máximo instantáneo registrado es de 955 m3/seg y el mínimo es 0.0 durante el período de estiaje cuando el cauce de la corriente se seca. El volumen medio anual escurrido es de 98.7 Mm^3, con un máximo de 270.6 Mm^3/año y un mínimo de 16.6 Mm^3/año. El volumen anual escurrido muestra una alta variabilidad con un coeficiente de variación de 0.57 (CONAGUA 2009:10).

Un dato interesante es que el volumen medio anual escurrido equivale al consumo total de la ciudad de Hermosillo en el año 2009. Es decir que la sola ciudad es capaz de consumir el escurrimiento superficial promedio anual y excluir al resto de los consumidores de agua de la cuenca.

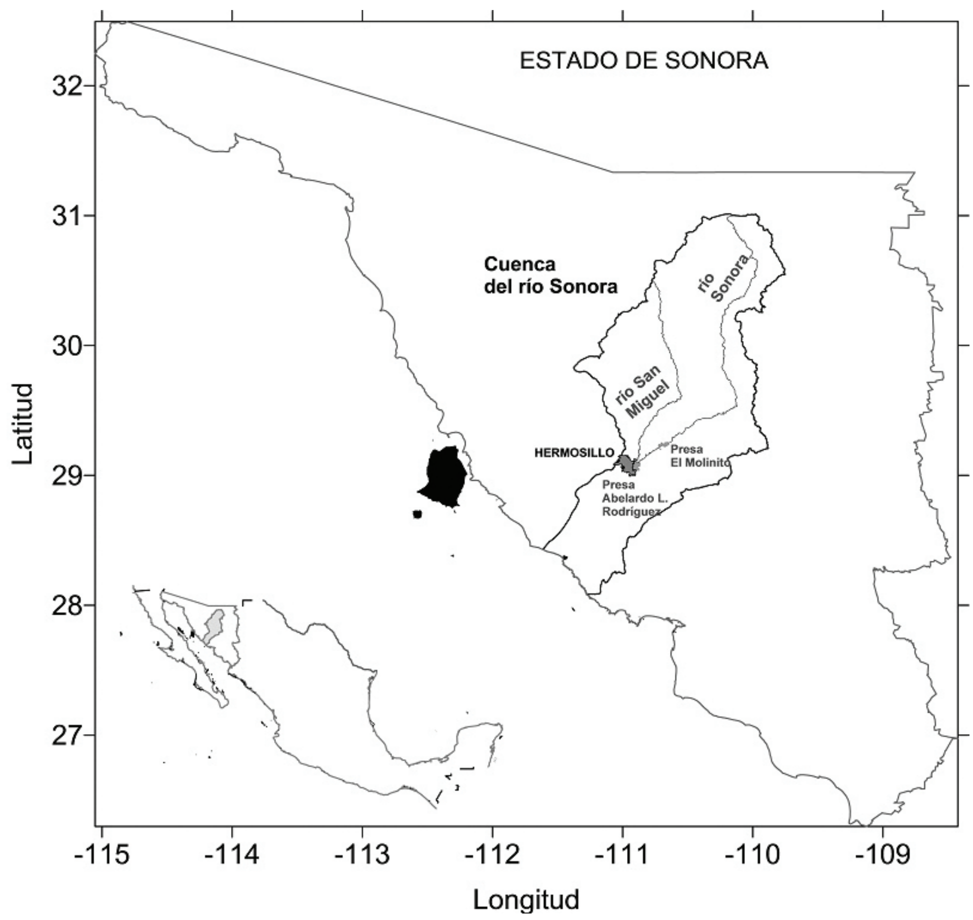

Figura 5-1. Localización de la cuenca del río Sonora y de la ciudad de Hermosillo. Fuente: Mapa elaborado por Luis Brito 2010.

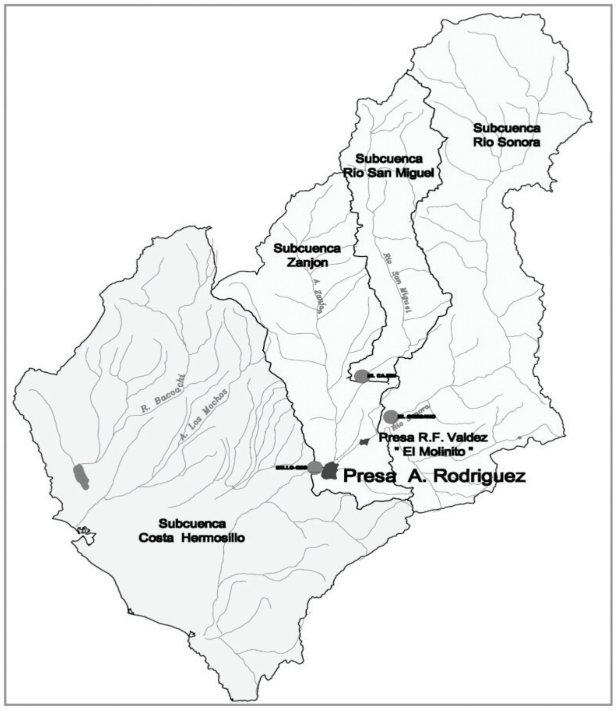

Figura 5-2. División de la cuenca alta y baja del río Sonora-Hermosillo. Fuente: Lucas Oroz 2010. Foro "Va a haber agua el próximo verano." El Colegio de Sonora 17 nov. 2011, Hermosillo, Son.

En la estación climatológica de la Presa Abelardo L. Rodríguez se registra una precipitación media anual de 273 mm y una temperatura media anual de 24.2°C (CONAGUA 2009:9). Sin embargo, en la parte alta de la cuenca el promedio histórico de precipitación ha sido de 401 mm por año durante el período de 1968 a 2010.

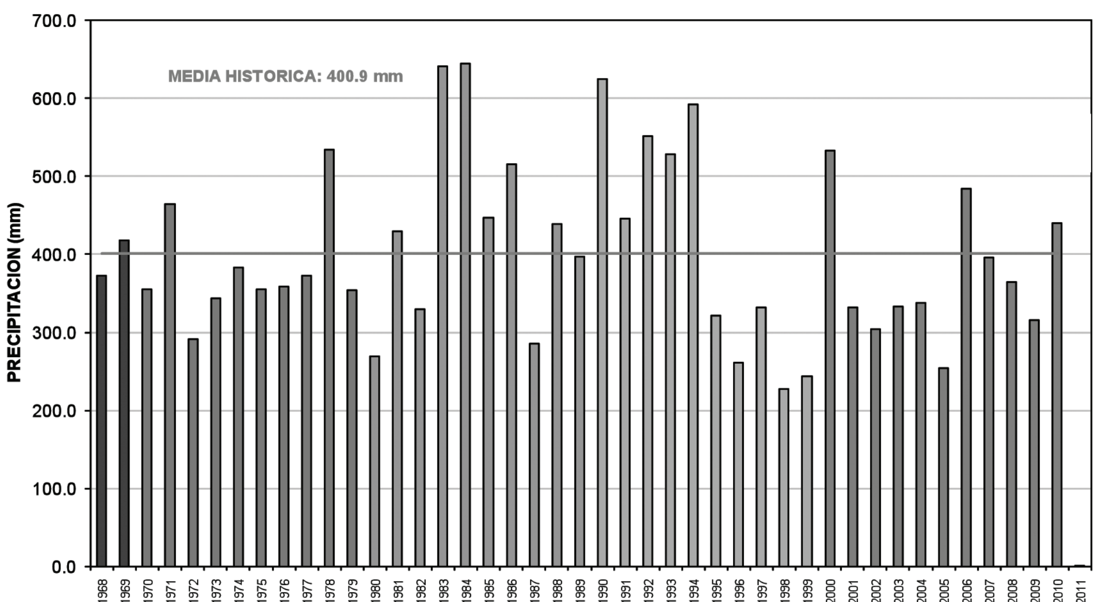

Figura 5-3. Precipitación en la parte alta de la cuenca del Río Sonora hasta 2010. Fuente: Organismo de Cuenca del Noroeste, CONAGUA 2011.

Por otra parte, en la parte baja de la cuenca, que corresponde a la parte más árida y donde se ubica el distrito de riego (con agua subterránea) de la Costa de Hermosillo, el promedio histórico de precipitación es de sólo 230 mm por año.

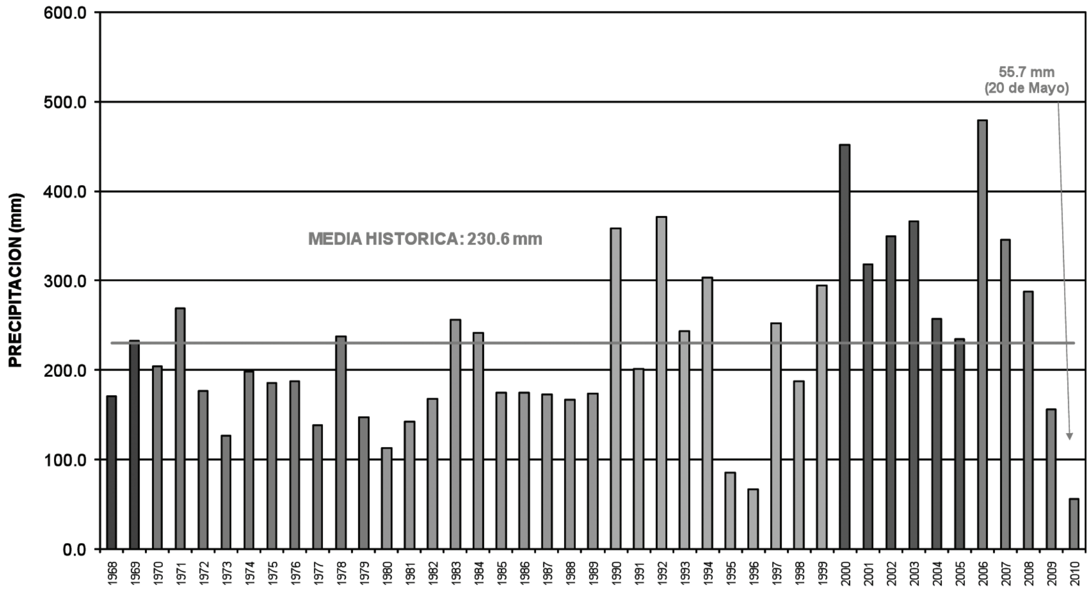

Figura 5-4. Precipitación histórica de la cuenca baja del río Sonora. Fuente: Organismo de Cuenca del Noroeste, CONAGUA 2011.

Analizando el comportamiento de las precipitaciones durante los últimos cincuenta años, se observa la ocurrencia de períodos de humedad y de sequía. Con base en el índice estandarizado de precipitación (SPI por sus siglas en inglés, ver Figura 5-5) se pueden observar distintos periodos de sequías prolongadas propias de una región árida. El periodo de sequía más reciente se presentó a mediados de la década de los noventa y duró aproximadamente hasta el año 2010.

Considerando las distintas cantidades de lluvia a lo largo de la cuenca y la disponibilidad de agua que ésta tiene, donde el promedio de escurrimiento superficial corresponde aproximadamente al consumo total de la ciudad de Hermosillo en el año 2009, la pregunta es si el manejo adecuado de la cuenca podrá sostener el crecimiento previsto para la ciudad sin eliminar los otros usos agrícolas e industriales. Más aún, sabiendo que las previsiones futuras no pueden hacerse en base a promedios, sino que se deben de tomar en cuenta los períodos de sequía, ¿cómo puede adaptarse y planearse el consumo urbano de agua en caso de que, de acuerdo con los escenarios de cambio climático, hubiera una sequía de mayores proporciones que las padecidas en años anteriores?¿Hasta qué grado el desarrollo urbano y económico de Hermosillo puede sustentarse en el volumen de agua almacenado en los acuíferos?

La población de Hermosillo y sus alrededores se ha beneficiado significativamente del río Sonora. Sin embargo, esto se ha hecho a base de grandes costos y pérdidas para el medio ambiente. Según lo plantean Postel y Richter, los ríos en su estado natural llevan a cabo una miríada de funciones tales como purificar el agua, moderar las inundaciones y las sequías, y mantener el hábitat de peces, pájaros y la vida silvestre. Desde una perspectiva estrictamente humana, los ríos sanos desarrollan numerosos "servicios ecológicos": absorben contaminantes, descomponen los desechos y limpian y purifican el agua. Los ríos, humedales y otros ecosistemas de agua dulce constituyen la "infraestructura natural" que sustenta la economía. Los ríos hacen esto de manera gratuita. Sin embargo, en menos de un siglo, las sociedades han alterado los ríos de manera que ya no desarrollan de manera adecuada muchas de los servicios ecológicos de los que dependen las sociedades humanas. El control de los ríos para la explotación económica está trayendo más daños que beneficios. No obstante, la mayoría del daño no se reconoce ni se evalúa y queda fuera de las ecuaciones de costo beneficio. El reto para el siglo XXI, es mejorar el equilibrio entre las demandas humanas y las necesidades de agua del mismo río. Para enfrentar este reto, se requiere un nuevo enfoque para valuar y manejar los servicios que prestan los ríos (Postel and Richter 2003:2-4).

C. Variabilidad climática, cambio climático y sus impactos en Hermosillo

En verano, el clima de la región noroeste de México se rige por el fenómeno conocido como el Monzón de América del Norte. Este fenómeno incluye al Noroeste de México y al Suroeste de los Estados Unidos y se refiere a la alternancia de las estaciones de lluvia y secas, cada una con un patrón distinto en la dirección de los vientos prevalecientes (Gochis 2009). Mientras que en invierno, algunos frentes fríos llegan a producir lluvias y nevadas en las partes altas del estado. El mecanismo modulador de las lluvias de invierno es el conocido fenómeno El Niño, que resulta en una tendencia a mayores lluvias invernales, mientras que La Niña lleva a disminución de la precipitación invernal. No es claro qué modula las lluvias de verano. Aparentemente, El Niño no tiene gran influencia sobre las tormentas del Monzón de América del Norte, por lo que la predecibilidad del clima en esta región es baja (INE-U.S.EPA 2004).

En el caso de Sonora, las lluvias estacionales exhiben una marcada variabilidad interanual, por lo que en ciertos años las lluvias pueden alcanzar los 600 mm en un año mientras que en otros difícilmente alcanzan los 200 mm. La gráfica del análisis del SPI (ver Figura 5-5) muestra la importancia de la variación decadal (o por décadas) en los períodos de humedad y de sequía. Con base en estos antecedentes, se espera que en el futuro continuará la alternancia de períodos de humedad y de sequía al menos similares a los que se han experimentado en el pasado.

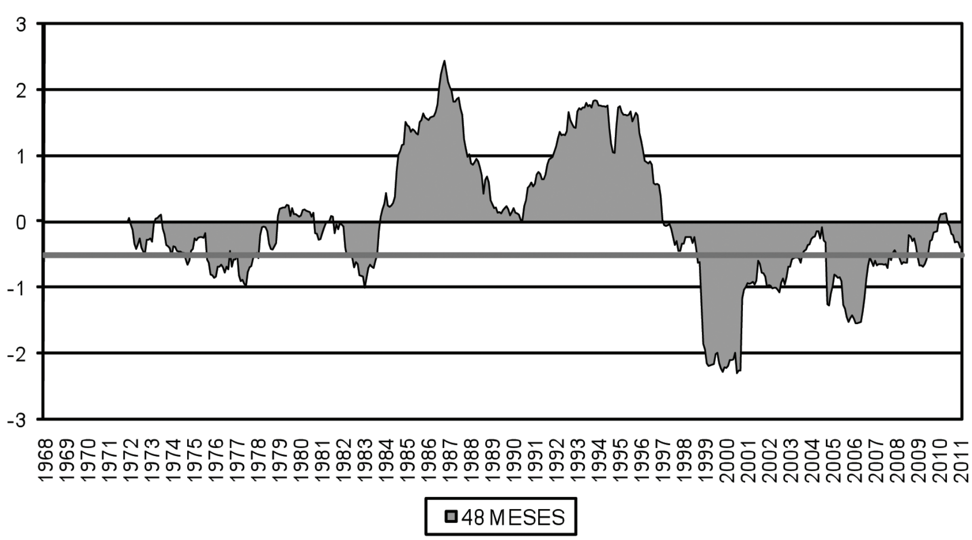

Figura 5-5. Índice Estandarizado de Precipitación (SPI, por sus siglas en inglés): períodos de humedad y sequía en la cuenca del río Sonora. Fuente: Organismo de Cuenca del Noroeste, CONAGUA 2011.

Por otra parte, los escenarios de cambio climático elaborados por el IPCC (2007) señalan que en esta región habrá un incremento significativo de la temperatura promedio y que hacia fines del siglo XXI podría incrementarse hasta 4° C. De acuerdo con elescenario A1B, hay una alta probabilidad de que la precipitación promedio se reduzca hasta en un 15por ciento. En resumen, el clima de la región podrá ser más caliente y más seco (IPCC 2007) (ver Figura 5-6). Sin embargo, se deben considerar los resultados de otros escenarios para la región, los cuales indican que la precipitación podría incrementarse dependiendo del comportamiento del Monzón y los ciclones en el Pacífico Oriental, en estos casos es muy probable que la tendencia sea hacia un aumento de las precipitaciones extremas asociadas a estos fenómenos (Cavazos et al. 2008).

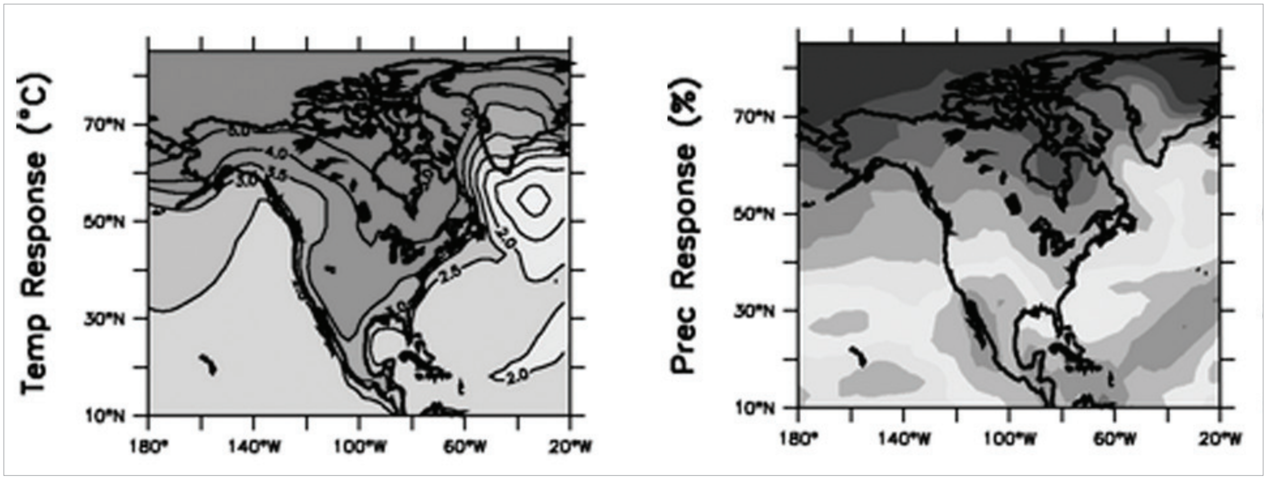

Figura 5-6. Escenarios del cambio de temperatura y precipitación hacia fines del siglo XXI en América del Norte, escenario A1B. Fuente: IPCC 2007, 4th Assessment: Working Group I, Chapter 11, Regional Projections.

De acuerdo a estos estudios científicos, hay un alto grado de probabilidad de que las temperaturas promedio de Hermosillo se incrementarán entre 1.5 y 2° C para mediados de este siglo y que habrá un descenso relativo en la precipitación. Más que el incremento de la temperatura, es importante considerar la variabilidad de la precipitación (láminas e intensidades pluviales esperadas durante el monzón de verano versus en invierno cuando hay una mayor recarga en los acuíferos) y los posibles cambios en las temperaturas extremas. De esta manera, si el promedio anual de la temperatura de Hermosillo es de 25.1° C, con temperaturas mínimas promedio de 3.5° C en el mes de diciembre y temperaturas máximas promedio de 45° C (Gobierno Municipal de Hermosillo 2006), se puede esperar que en unfuturo cercano las temperaturas promedio, mínimas y máximas de Hermosillo se elevarán en la misma proporción.

La Figura 5-7 muestra el comportamiento de las temperaturas máximas y mínimas durante el año 2008 de acuerdo a la estación meteorológica de la CONAGUA ubicada centro de la ciudad de Hermosillo, mismo que indica el fenómeno de isla de calor. Dicha gráfica muestra la evolución y los registros de las temperaturas máximas (color rojo) que alcanzaron 45° C los días 2 y 29 de junio de ese año. La gráfica también muestra el comportamiento de las temperaturas mínimas (color azul) y se aprecia que la temperatura mínima más extrema se registró de 4° C el 19 de enero. Por otra parte, las líneas en color verde representan los días en que hubo precipitaciones, con excepción de la precipitación más extrema de 72 mm registrada el 7 de julio (en la gráfica solamente aparecen los primeros 50 mm).

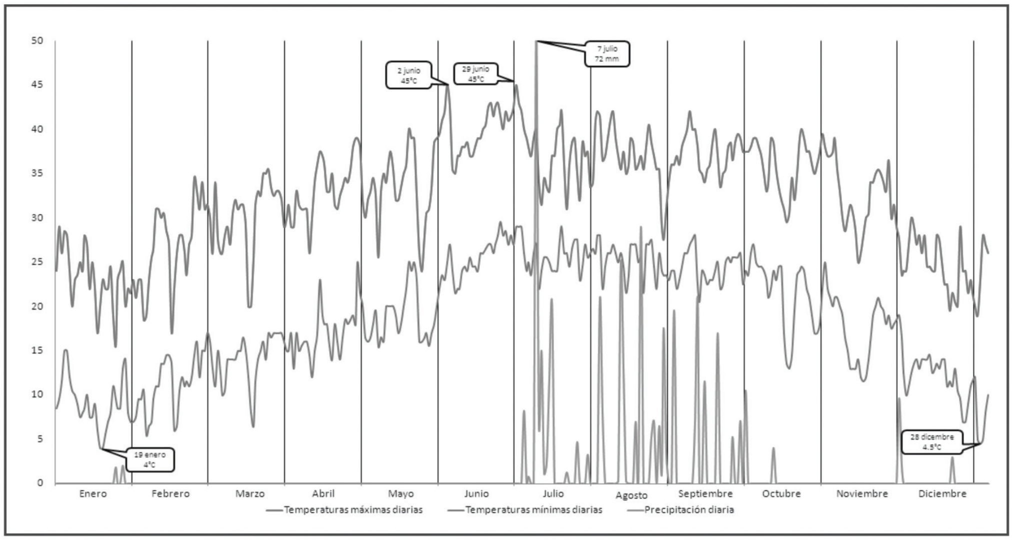

Figura 5-7. Temperaturas máximas y mínimas, y la precipitación en el año 2008. Fuente: Datos del Observatorio Meteorológico ID. 76160 (Hermosillo) de la CONAGUA.

La Figura 5-8, por su parte, muestra el comportamiento de la temperatura del 29 de junio, uno de los días más calurosos del año 2008 de acuerdo a la información proporcionada por la estación meteorológica de la CEA, ubicada en la azotea del edificio de esa misma institución en el centro de la ciudad de Hermosillo, a tres cuadras del Palacio de Gobierno. Ahí se registra la evolución de la temperatura por períodos de 20 minutos y se aprecia que la temperatura más baja se registró a las 6:00 a.m. y fue de 28.4° C. A partir de esa hora, el ascenso de la temperatura es constante hasta alcanzar el pico máximo a las 4:10 p.m. cuando se alcanza un registro de 43.5° C. A partir de esa hora la temperatura desciende casi hasta los 35° C a la media noche.

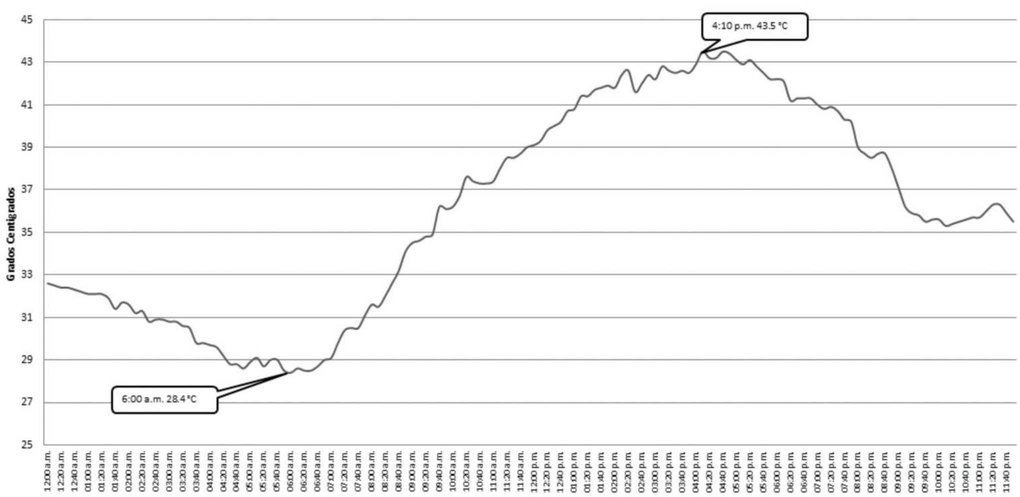

Figura 5-8. Comportamiento de la temperatura el día 29 de junio de 2008. Fuente: Estación meteorológica de la Comisión Estatal del Agua de Sonora.

De acuerdo a la base de datos de la CONAGUA, en el período de 1961 a 2008 la temperatura más alta registrada en Hermosillo fue de 47.5° C alcanzada el 23 de junio de 1998. Mientras que las temperaturas más bajas se registraron los días 5 y 7 de enero de 1971 y fueron de -3.0° C (Barrón 2009), siendo la oscilación máxima de las temperaturas de 50° C.

Tomando en cuenta las previsiones de los escenarios de cambio climático, aún considerando la incertidumbre, la temperatura promedio de Hermosillo podría incrementarse a 27° C para mediados de este siglo XXI. Asi mismo, asumiendo el mismo grado de incertidumbre, las temperaturas máximas extremas del verano podrían incrementarse hasta 49° C. Sin embargo, si se considera que la variabilidad (o en términos del coeficiente de variación) también está cambiando, hay una alta probabilidad de que las temperaturas máximas lleguen incluso más allá de los 49° C.

Entre los indicios de incremento en los días de calor que se han estado percibiendo en Hermosillo, está que en los últimos años se han estado rompiendo las marcas que se tenían establecidos en los registros históricos de temperaturas que lleva la CONAGUA. Así por ejemplo, el 16 de marzo de 2007 el termómetro de Hermosillo alcanzó la marca de 41.5° C, cuando anteriormente la marca era que dicho nivel de temperatura no se alcanzaba sino hasta a partir del 21 de marzo de acuerdo al registro establecido en 2004. Por otra parte, el 27 de octubre de 2008 el termómetro alcanzó una temperatura de 40.5° C con lo cual se rompió la marca que estaba establecida de que la fecha más tardía para esta temperatura era el 20 de octubre. Así, en Hermosillo se puede alcanzar una temperatura igual o mayor a los 40° C durante 226 de los 365 días del año (Barrón 2009).

Cuadro 5-1. Registros de temperaturas extremas en Hermosillo 1965-2008. Fuente: Barrón 2009.

	Marca anterior	**Nueva marca**
Fecha más temprana en que se alcanzan los 40°C	21 marzo (2004)	16 marzo (2007)
Fecha más tardía en que se alcanzan los 40°C	20 octubre (1995)	27 octubre (2008)
Fecha más temprana en que se alcanzan los 45°C	01 junio (1969)	11 mayo (1996)
Fecha más tardía en que se alcanzan los 45°C	09 septiembre (1969)	21 septiembre (1982)

Sobre estos datos hay que señalar por un lado que la base de datos históricos de temperaturas abarca un período demasiado corto para poder establecer sus parámetros y, por lo tanto, puede ser normal que se sigan rompiendo marcas. Además, estas nuevas marcas pueden deberse también al efecto conocido como “islas urbanas de calor” que resulta del crecimiento de la mancha urbana, del aumento de la superficie pavimentada y del mayor uso del cemento en las construcciones (Gartland 2008). Sin embargo, los datos presentados no dejan de ser un indicador que hay que tomar en cuenta en la planeación urbana y las medidas de adaptación al cambio climático que deberán adoptarse.

Con respecto a las tendencias en las temperaturas máximas y mínimas, los estudios realizados por Brito-Castillo, Crimmins y Diaz C. (2010:82) señalan que en el desierto de Sonora a inicios de 1900 las heladas severas ocurrían cada dos a tres años. Esta frecuencia se redujo durante el siglo XX a tal punto que a fines de siglo las heladas ocurren cada dos décadas o más, con lo que se incrementó la temporada libre de heladas y disminuyeron los días con temperaturas inferiores a 0° C. Por otro lado, las temperaturas máximas se están incrementando a un ritmo más acelerado que las temperaturas mínimas, provocando que a partir de 1970 la tendencia en la oscilación térmica diurna, esto es la temperatura máxima menos la temperatura mínima en el día, sea positiva. No está claro todavía de qué manera ha contribuido el incremento de los gases de invernadero a este calentamiento regional pero se sugiere que los cambios en el uso del suelo, así como la degradación provocada por el sobrepastoreo, que reduce la cubierta vegetal y disminuye la transpiración, hacen que la temperatura del suelo se eleve y se incremente el flujo de calor sensible en relación con el flujo de calor latente, lo que promueve el calentamiento de las temperaturas máximas e incrementa la oscilación térmica diurna (Gutiérrez-Ruacho et al. 2010).

En resumen, el clima de Hermosillo se define como de cálido-seco a desértico, con temperaturas altas en verano que superan los 45° C. Los períodos alternados de sequía y humedad van a continuar y probablemente, debido a la mayor variabilidad climática, en el futuro cercano se van a acentuar más los períodos de sequía y van a presentarse más días con altas temperaturas. Estas previsiones llevan a preguntar sobre las medidas que deben de tomarse, los cambios que deben de hacerse y la adaptación que debe de realizarse en general en la planeación urbana y en particular en la gestión del agua.

D. Población, instituciones e infraestructura hidráulica

A fin de revisar la vulnerabilidad y deficiencia de la ciudad en cuestión de infraestructura hidráulica, haremos un breve repaso de la evolución de la población, las principales obras hidráulicas y las instituciones encargadas de la gestión del agua durante el período de 1948 a 2010.

El crecimiento de la población de Hermosillo ha ido aparejado a la construcción de infraestructura hidráulica y la creación de instituciones que han impulsado el desarrollo de la ciudad. Su evolución se puede dividir en tres grandes períodos que son: el tiempo del pueblo sencillo, la ciudad de la presa Abelardo Rodríguez y la metropolización de la ciudad de Hermosillo.

El impulso urbano de la presa Abelardo L. Rodríguez 1948-1998

El gran despegue urbano de Hermosillo vino con dos innovaciones en materia de recursos hídricos: una la construcción de la presa Abelardo L. Rodríguez concluida en 1948 y otra la introducción de las bombas eléctricas que permitieron la extracción de agua del subsuelo a mayor profundidad tanto en la ciudad como en la Costa de Hermosillo.

La presa ubicada justo al oriente de la ciudad, tenía una cortina de 1,440 metros de longitud, con una elevación de 27.60 metros. La longitud del vertedor de demasías es de 300 metros y la capacidad original de almacenamiento era de 250 millones de metros cúbicos (Sobarzo 1949). El proyecto inicial contempló el desarrollo agropecuario e industrial de la región. Éste incluyó la irrigación de 10,000 hectáreas de cultivo, así como el suministro de agua a la ciudad a través de pozos localizados aguas debajo de la cortina de la presa (Del Castillo Alarcón 1994:71).

Con base en esta nueva infraestructura, la capacidad instalada para el suministro de agua a la ciudad se elevó considerablemente y se abrieron nuevos horizontes de crecimiento y desarrollo. En esa época el servicio de agua potable era operado por la Junta Federal de Agua que era controlada por la Secretaría de Recursos Hidráulicos, una dependencia del gobierno federal. El panorama se veía muy alentador y parecía que se había superado definitivamente la barrera de la limitación hídrica. La ciudad, impulsada por las inversiones del gobierno y por la creciente ola de servicios, creció a un ritmo inusitado pasando de 43 mil habitantes en 1950, a 95 mil en 1960 y a 176 mil en 1970.

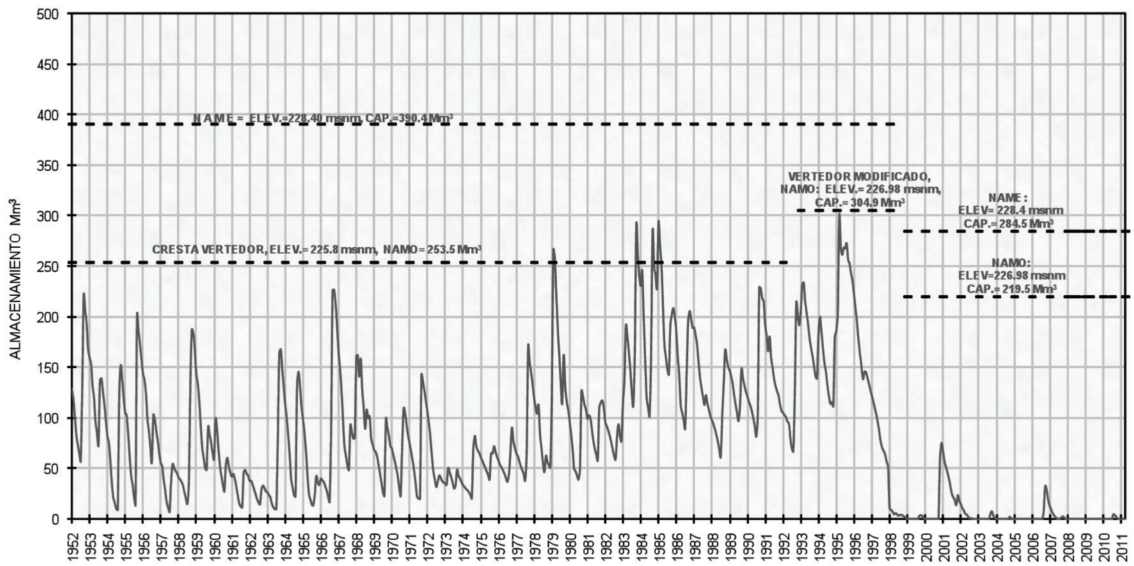

Figura 5-9. Almacenamiento de la presa Abelardo L. Rodríguez. Fuente: Comisión Nacional del Agua, Organismo de Cuenca del Noroeste, gráfica proporcionada por José Arturo López Ibarra, abril 2011.

Para los años setenta, a fin de satisfacer la creciente demanda urbana de agua, el agua de la presa dejó de destinarse al riego agrícola y de huertas y comenzó a utilizarse para el abasto de agua a la ciudad. Un problema que se enfrentó para este cambio de uso fue el agua del embalse de la presa era contaminado por las granjas de puercos, los corrales de engorda de ganado, los desechos industriales y las descargas de aguas residuales de colonias aledañas que se desechaban en la presa. Para resolver esta problemática, además de tratar de controlar las actividades contaminantes, se construyeron tres plantas potabilizadoras de agua. La primera entró en operación en 1981 con una capacidad de 300 Lps; la segunda potabilizadora entró en operación en 1982 con una capacidad similar (Del Castillo Alarcón 1994:72-75). Más adelante se construiría una tercera planta. Los años ochenta fueron de lluvias abundantes, la presa estaba llena y se le agregaron refuerzos para aumentar su capacidad y al menos en un año el agua volvió a correr por el río, impidiendo el tráfico entre Villa de Seris y el centro de la ciudad. A fin de reducir la amenaza de inundaciones, el gobierno del estado construyó un canal revestido desde el vertedor de la presa Abelardo L. Rodríguez a lo largo del lecho del río hasta el poniente de la ciudad que permitía manejar y controlar los derrames de agua.

En 1980, el gobierno federal transfiere la responsabilidad del servicio de agua potable al gobierno del estado. De este modo, deja de operar la Junta de Agua y se crea primeramente el Sistema Estatal de Agua Potable que en 1984 se convierte en la Comisión Estatal de Agua Potable y Alcantarillado (COAPAES). De este modo, el servicio pasa a ser administrado por la administración estatal y comienza a ser parte de la agenda pública local.

El marcado crecimiento de la ciudad hizo que en 1986 se iniciara la construcción de 11 pozos profundos en el área conocida como La Victoria para la extracción de 1000 lps. Para 1987, la extracción se incrementó a 3,650 lps al entrar en operación los pozos de La Sauceda.

En 1989, a nivel federal, se crea la Comisión Nacional del Agua (CONAGUA) que, de manera centralizada, administra las presas y comienza en 1992 la transferencia de los distritos de riego a los usuarios. En Hermosillo este organismo federal opera por medio de una gerencia regional que posteriormente será denominada "Organismo de Cuenca del Noroeste".

En 1990, la ciudad tenía 406,417 habitantes. Para contener las avenidas del río Sonora y aumentar la seguridad de la ciudad, en ese año, se construyó, a 26 kilómetros al oriente, la Presa El Molinito, llamada oficialmente Rodolfo Félix Valdés. Su capacidad inicial es de 150 Mm^3. Ésta es una presa con basamento permeable en la que gran parte de su agua se infiltra al subsuelo y por lo tanto no sirve para almacenar agua. Su función es únicamente controlar las grandes avenidas y proteger a la ciudad (Contreras 2008).

En 1992 el servicio de agua potable de la ciudad consumió 94.9 millones de metros cúbicos de agua y en 1995 se llegaron a consumir 95.9 Mm^3 (CONAGUA 1994; CONAGUA 1997), que es el máximo consumo de agua que ha tenido la ciudad hasta 2010.

En la Costa de Hermosillo, en 1993 se crea la Asociación de Usuarios a fin de administrar el distrito de riego número 51 que le corresponde (Moreno Vázquez 2006:360; AUDR051). En esos mismos años, se incrementa considerablemente la agricultura aguas arriba del río San Miguel, en el Noreste y Norte de Hermosillo. Para el ciclo 1995-96 la superficie de siembra programada era de alrededor de 10 mil hectáreas, destacando los cultivos de vid de mesa, trigo, rye grass, granos forrajeros, hortalizas, naranja y nogal. Así, a los 577 pozos para uso agrícola ubicados aguas arriba, se le suman los 498 pozos de la Costa de Hermosillo y los 70 pozos de El Sahuaral ubicados aguas abajo, el total de pozos existentes en el área es de 1145 significando una extracción global aproximada de 740 Mm^3 en ese ciclo (Moreno Vázquez 2006:363-364).

Para principios de la década del 2000, de acuerdo a estudios oficiales reportados por Moreno (2006), se aprecia que los cuatro acuíferos que circundan la ciudad (Zanjón, Sonora, San Miguel y La Costa) tenían una recarga anual agregada estimada en 446 Mm^3 anuales, mientras que el volumen concesionado agregado era de 690 Mm^3. Hay entonces un déficit de 244 Mm^3 que estaban sobre-concesionados. Esta sobre explotación está fuertemente ligada con el suministro y régimen de tarifas de energía eléctrica (Scott and Pasqualetti 2010) y se acentúa aún más con el exceso de extracciones reales que se tiene en todos los acuíferos, excepto en el río Sonora en donde aparentemente no se extraía todo el volumen concesionado.

Cuadro 5-2. Recarga y extracción en acuíferos de la cuenca del río Sonora (Mm³). Fuente: Elaborada por Moreno 2006:395, con base en Diario Oficial de la Federación 2003, Acuerdo por el que se dan a conocer los límites de 188 acuíferos de los Estados Unidos Mexicanos, los resultados de los estudios realizados para determinar su disponibilidad media anual de agua y sus planos de localización, México, 31 enero 2003.

Acuífero	Recarga	Volumen concesionado	Volumen de extracción (según estudios)	Déficit
Río Zanjón	77	90	109	-13
Río Sonora	67	115	57	-49
Río San Miguel	52	54	57	-1
Costa de Hermosillo	250	431	430	-181
Total	446	690	654	-244

Hay que señalar que éstos eran años de lluvias por arriba del promedio y todavía en 1994 se tuvo que desfogar agua de la presa Abelardo L. Rodríguez, a través del canal del vado del río, a fin de prevenir posibles avenidas debido a las lluvias. Sin embargo, esta situación cambiaría a partir de mediados de la década cuando comenzó un período de sequía en el que los anteriores volúmenes de extracción y de consumo empezaron a dar señales de abatimiento y crisis.

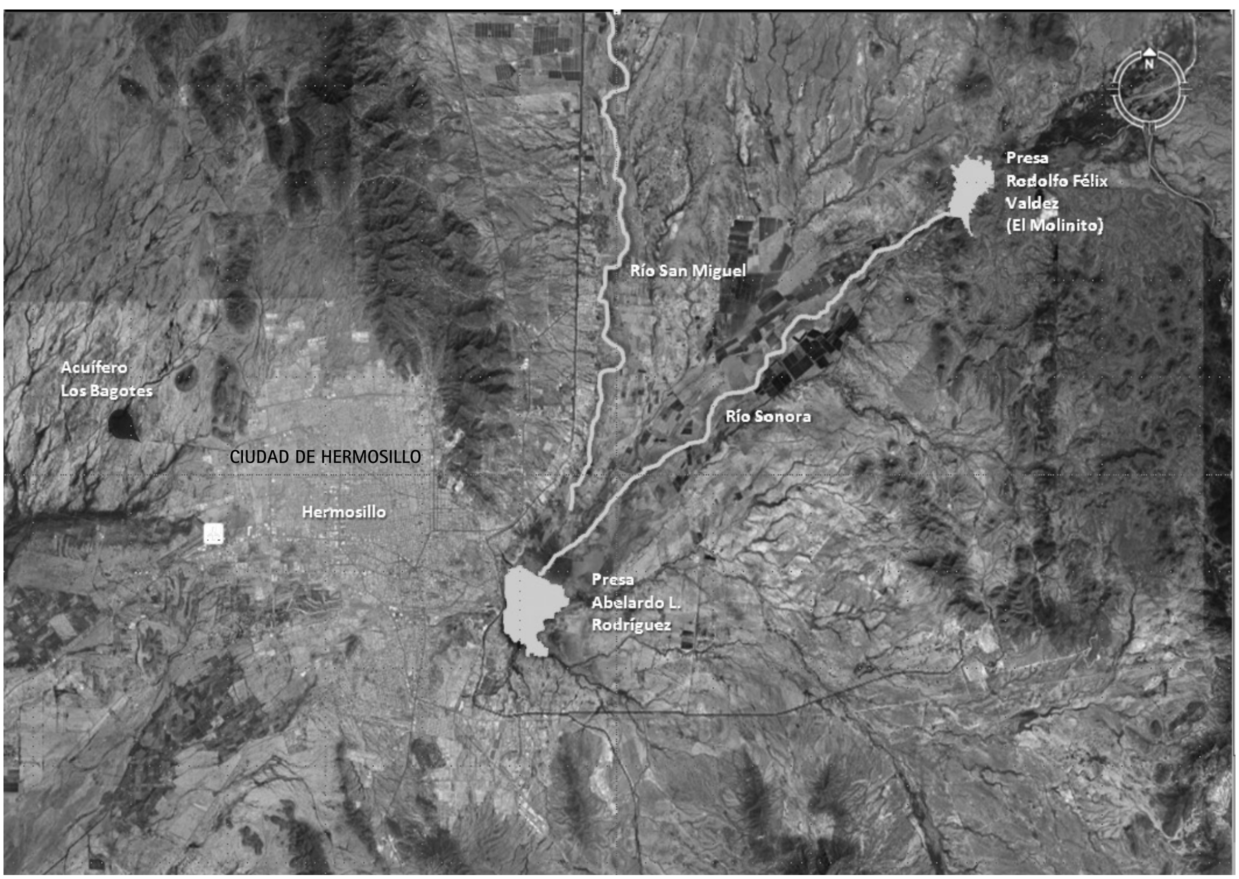

Figura 5-10. Sistema de abasto de agua de la ciudad de Hermosillo. Fuente: Elaboración propia con base en datos de Google Earth 2011.

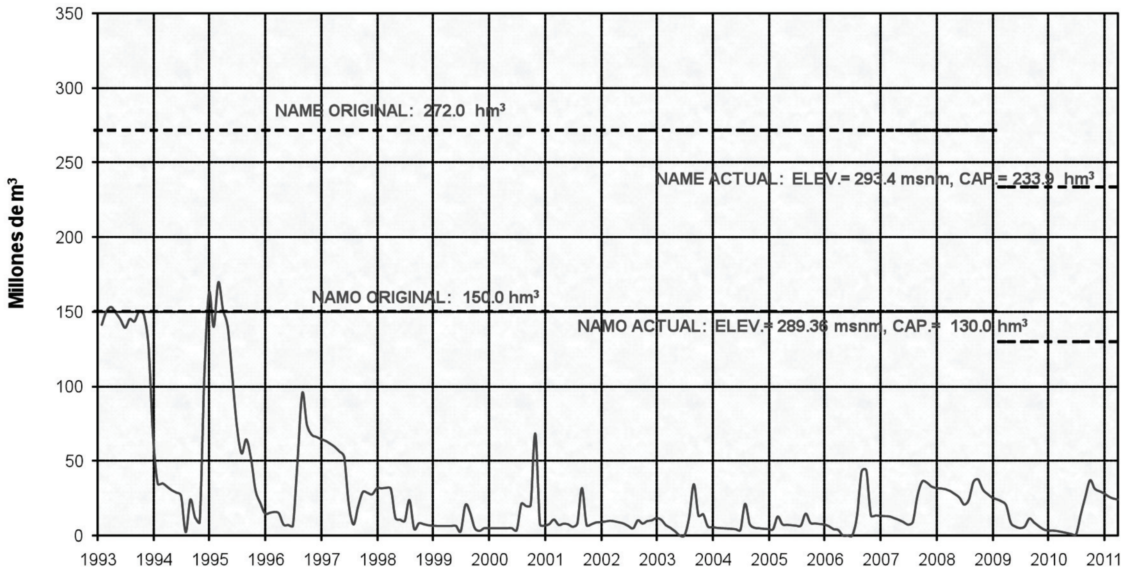

Figura 5-11. Almacenamiento de la presa El Molinito. Fuente: Comisión Nacional del Agua, Organismo de Cuenca del Noroeste, gráfica proporcionada por José Arturo López Ibarra, abril 2011.

Para la década de 2000 se reconoce que la problemática de la Costa de Hermosillo incluye que hay extracciones que exceden tres veces el volumen de la recarga natural promedio, se hacen extracciones mayores al volumen concesionado, hay avance en la intrusión salina y un esquema de subsidios que estimula un patrón inadecuado de cultivos con rentabilidad negativa (Comisión Nacional del Agua 2004). Por otra parte, el Plan Director, a fin de afrontar la problemática de este distrito de riego 041, propone "elevar la eficiencia en el uso y manejo del agua de riego, recuperando volúmenes de agua que en principio se destinarán al equilibrio entre el valor de las concesiones de agua en el acuífero respecto de la disponibilidad de agua". Asimismo, otra opción que plantea es destinar volumen recuperado al uso público urbano de la ciudad de Hermosillo, mediante convenios entre el organismo operador y particulares propietarios de derechos de agua en el distrito para el financiamiento de obras y acciones para la tecnificación del riego y reconversión de la explotación agrícola (CONAGUA 2007).

De este modo, en general en el período de 1948 a 1998, la gestión del agua estuvo dominada por la orientación a la oferta y el aumento de las fuentes de suministro y por una política fragmentada y diferenciada de los usos urbanos y agrícolas. Las instituciones encargadas del recurso (la Secretaría de Recursos Hidráulicos, la Junta Federal de Agua Potable y la Comisión de Agua Potable y Alcantarillado del Estado de Sonora) se dedicaron a construir grandes obras de infraestructura y a promover el crecimiento y la rentabilidad de las actividades económicas privadas. El recurso agua es manejado bajo los supuestos implícitos de que es abundante de manera permanente y los niveles de consumo y extracción se ajustan a la alza. En la mayoría de los casos los costos de infraestructura son cubiertos con recursos fiscales y no se traslada a los usuarios la señal de escasez ni de que el servicio tiene altos costos.

El vertiginoso crecimiento de la ciudad impulsó un aumento aún mayor de la demanda de agua de la ciudad y de su entorno. Junto con la ciudad, se intensificaron la agricultura y el riego con agua de los acuíferos tanto al poniente de la ciudad en la Costa de Hermosillo en la parte baja de la cuenca, como al oriente y al norte de la ciudad en la parte alta de la cuenca. Este crecimiento regional conjunto de las demandas urbana y agrícola del agua pronto alcanzó la disponibilidad que ofrece la modesta cuenca del río Sonora y rompió el equilibrio hidrológico. En esta carrera de crecimiento hizo crisis en la segunda mitad de la década de los noventa cuando la cuenca comenzó a dar señales de "escasez", aunque en este caso se trata de una escasez socialmente construida.

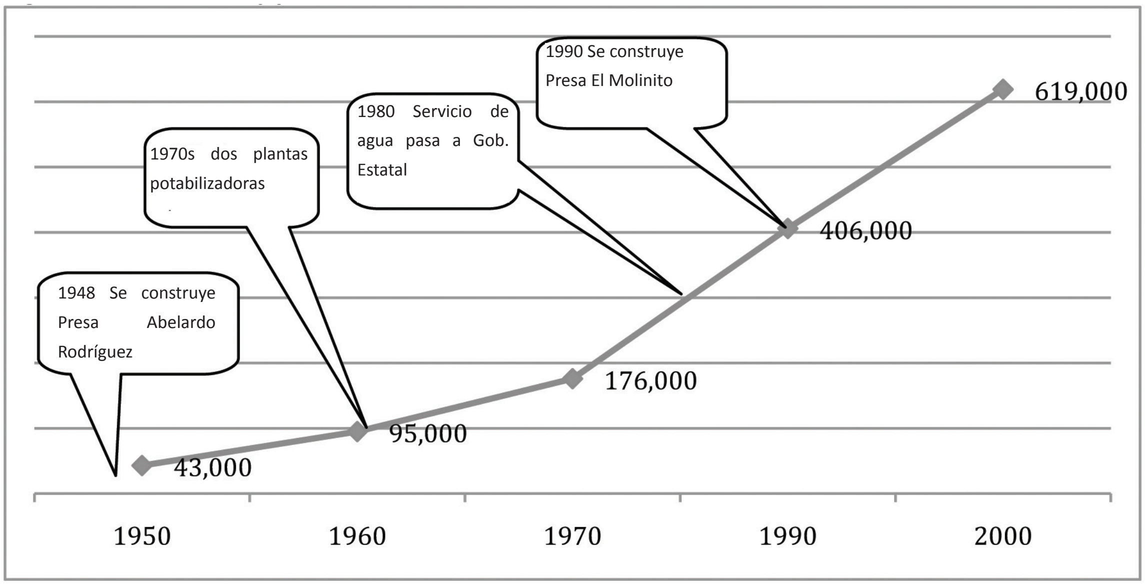

Figura 5-12. Población y política hidráulica en Hermosillo 1948-2000. Fuente: Elaboración propia de los autores.

En los años 2010 y 2011, en materia de infraestructura hidráulica, la ciudad de Hermosillo tiene dos vulnerabilidades importantes. La primera es la obsoleta red de distribución de agua de la ciudad, que, por su deterioro, es la causa de que se pierdan cantidades considerables de agua. Por lo tanto, se requiere una rehabilitación general que le permita elevar los niveles de eficiencia y recuperar volúmenes importantes del agua que se pierde por las fugas y las malas conexiones. Esta rehabilitación se ha venido postergando al menos desde mediados de la década de los noventa y sólo se hacen reparaciones de emergencia o parciales.

La segunda gran vulnerabilidad es la carencia de tratamiento de las aguas residuales y la no existencia de la reutilización de las aguas tratadas. Este proyecto ha encontrado obstáculos y se ha venido postergando desde 1995. En el año 2011 se licitó nuevamente la construcción de una planta de tratamiento de aguas residuales de la ciudad que permitirá tratar y reutilizar una parte sustantiva del agua residual de la ciudad.

E. Demanda de agua y proyectos de mejora

La crisis del abasto y proyectos hidráulicos 1994-2010

Hacia mediados de la década de los noventa, la disponibilidad de agua comenzó a disminuir y las autoridades hidráulicas se dieron cuenta de que la ciudad se acercaba aceleradamente a los límites de la capacidad instalada de suministro de agua. En esos años comenzó una sequía que, aunada al aumento de las extracciones agrícolas y el consumo urbano de agua, dieron origen al descenso de los almacenamientos de las presas El Molinito y Abelardo L. Rodríguez.

Para subsanar la amenaza de escasez, se emprendieron diversas obras hidráulicas. A principios de la década, se abrieron nuevos pozos en el ejido la Victoria que luego tuvieron que ser cerrados debido a que contenían flúor y zinc. En 1994, la COAPAES construyó una galería filtrante para extraer la corriente de agua del subsuelo pero que no produjo el resultado esperado y sólo funcionó dos o tres años.

Un proyecto más ambicioso que implicaba traer agua de otra cuenca fue la construcción de un acueducto de 144 kilómetros para traer agua de la Presa El Novillo sobre el río Yaqui, el principal río del estado. A fines de 1995, el gobierno del estado inició el proceso de licitación para que una empresa construyera el acueducto para traer agua del río Yaqui a 144 kilómetros de Hermosillo, pero el proceso se canceló en abril de 1996 sin explicar las razones y no se llevó a cabo el proyecto (Pineda Pablos 2007).

En 1999 se comenzó a promover el proyecto de construir una planta desaladora de agua de mar en Bahía Kino. El proyecto enfrentó la oposición de los agricultores de la Costa, así como la del alcalde de la ciudad y tuvo que cancelarse en octubre de 2001. Para detener el proyecto de construir una planta desaladora, que aparentemente no era financieramente viable, el gobierno municipal, basándose en disposiciones constitucionales que dicen que el servicio debe de ser municipal, reclama la operación del servicio. De este modo, en noviembre de 2001, el gobierno del estado transfiere al gobierno municipal la operación del servicio. Para atender esta responsabilidad, el gobierno municipal crea el organismo conocido como Agua de Hermosillo que inicia formalmente operaciones en febrero de 2002 (Pineda Pablos 2007).

En los años 2004 y 2005, a fin de adquirir nuevas fuentes de suministro de agua, el gobierno municipal comenzó una estrategia de compra de derechos de agua de uso agrícola. Primeramente, en 2004 compró el agua de los pozos conocidos como Las Malvinas ubicados en la región del río San Miguel. El convenio fue por veinte años y los pozos aportan 250 Lps que equivalen a 7.5 Mm^3 anuales. Posteriormente en 2005 concretó con los agricultores de la Costa de Hermosillo la compra de derechos por 40 Mm^3, de los cuales 26 se destinarían al uso urbano y el resto se cancelarían para recuperación del acuífero (Del Río Sánchez 2005). Es hasta esta estrategia que se logra agregar nuevas fuentes de suministro y aliviar, así sea parcialmente, la demanda de agua de la ciudad.

En el año 2008 se completa los 13 kilómetros que faltaban para concluir el acueducto de la presa El Molinito que había sido iniciado doce años antes. Este acueducto tiene una longitud total de 28.3 kilómetros de la presa a las plantas potabilizadoras con un diámetro de 48 pulgadas (1.22 metros), para abastecer 1.1 metros cúbicos de agua por segundo. La inversión total fue de 121 millones de pesos que fueron aportados conjuntamente por los gobiernos federal, estatal y municipal (Contreras 2008). Esta cuantiosa inversión, sin embargo, no aporta una nueva fuente de agua a la ciudad sino que simplemente adelanta o anticipa el agua que, de no ser extraída por los pozos intermedios, de todos modos llegaría por la corriente del subsuelo a la ciudad. Esta obra sirvió para solventar el abasto de los veranos de 2008 y 2009.

SONORA SI y el Acueducto Independencia

En el año 2010, el nuevo gobierno del Estado lanzó un amplio programa hidráulico para todo el estado conocido como Sonora SI (Gobierno del Estado de Sonora, 2010). Este programa incluye, como uno de sus proyectos principales, la construcción de un acueducto de la presa El Novillo a la ciudad de Hermosillo al cual se le bautiza como “Acueducto Independencia” y se prevé que tenga un diámetro de 48 pulgadas en una longitud de 152 kilómetros, para conducir 2,380 Lps y una dotación anual de 75 Mm3 a la ciudad de Hermosillo. La inversión que se estima es de 3,680 millones de pesos (Comisión Estatal del Agua y Servicios de Consultoría y Asesoría para Evaluación de Proyectos, 2010)

A fin de realizar esta obra, se adquirieron derechos de agua del río Yaqui de los pueblos de Huásabas y Granados por 52 Mm3 que el 27 de julio de 2010 fueron registrados a nombre de la Comisión Estatal del Agua. El 28 de julio, se convocó la licitación para seleccionar a la empresa constructora que se haría cargo de la obra misma que, el 6 de octubre de 2010, fue asignada al consorcio Empresas Mineras del Desierto. La construcción de la obra inició formalmente el 8 de diciembre de 2010.

Esta obra ha enfrentado la oposición de diversos actores del Valle del Yaqui entre los que están usuarios del Distrito de Riego del Valle del Yaqui 041, el grupo denominado “Movimiento Ciudadano por el Agua” y autoridades tradicionales de la Tribu Yaqui. Estos actores han emprendido diversas acciones entre las que están marchas y desplegados en la prensa, así como un proceso judicial en contra de la construcción y operación del acueducto Independencia.

La obra está programada para concluirse e iniciar operaciones en el verano de 2012. Se considera que, si se realiza, esta obra impulsará fuertemente el crecimiento de la ciudad de Hermosillo.

El postergado proyecto de una planta de tratamiento de aguas residuales

Un aspecto crítico de la infraestructura hidráulica de la ciudad de Hermosillo es el tratamiento de sus aguas residuales y su posible reutilización para aliviar la demanda de agua de la ciudad. Desde cuando menos 1985, las aguas residuales fueron asignadas y han estado siendo aprovechadas para riego agrícola en los ejidos La Manga, Villa de Seris y La Yesca en cultivos como de forrajes. En 1994 se contrató la construcción de una planta de tratamiento con la Empresa Tecnología e Ingeniería Avanzada (filial del grupo Protexa) de Monterrey que, por problemas financieros derivados de la crisis económica que tuvo México en 1995, suspendió la construcción y operación en diciembre de 1997. Posteriormente se hizo un plan para construir pequeñas plantas de tratamiento que liberaran 120 litro por segundo de agua tratada por intercambio de aguas residuales. El proyecto contemplaba construir cuando menos diez plantas en diversos puntos estratégicos de la ciudad. Este programa arrancó en octubre de 1999 con una planta ubicada dentro de los campos deportivos de la Universidad de Sonora, cercana a varios restaurantes y casas residenciales ubicadas en las colonias Valle Verde, Valle Escondido y Los Arcos. Los vecinos de estas colonias se inconformaron y pararon la obra manteniendo un plantón por espacio de varios meses. Esto provocó la cancelación de este programa y no se construyó el resto de las plantas. De este modo, la ciudad ha continuado desechando las aguas residuales al poniente de la ciudad sin ningún tipo de tratamiento. En 2010 el gobierno municipal concursó nuevamente la construcción de una planta de tratamiento ubicada en el poniente de la ciudad y está planeada para concluirse antes de septiembre 2012.

Cuadro 5-3. Proyectos emprendidos para aumentar el suministro de agua a Hermosillo. Fuente: Elaboración de los autores.

Año	**Proyecto**	**Resultado**
1994	Batería de pozos en ejido La Victoria	Se cancelaron porque el agua contenía flúor
1996	Galería filtrante	No funcionó
1996	Acueducto hacia presa El Molinito	No se concluyó entonces por conflictos sociales y el alto costo de construcción
1995-1996	Acueducto de la Presa El Novillo a Hermosillo	Cancelado por el gobierno del Estado
1999-2001	Construcción de planta desaladora en Bahía Kino	Suspendida al ser vetada por el alcalde de Hermosillo
2004	Compra de agua de pozos de Las Malvinas	Aporta 7.5 millones de M^3 al año.
2005	Compra de derechos de agua de la Costa de Hermosillo	Acuerdo en junio 2005 para iniciar extracción en 2006. Aporta 26 millones de M^3 al año.
2008	Acueducto de Presa El Molinito a Hermosillo	Se construyó
2010	Acueducto desde el Novillo y Planta Tratadora de Aguas Residuales para Hermosillo	Acueducto se licitó y se inició la construcción en diciembre de 2010. PTAR se licitó en 2011

En resumen, el período de 1994 a 2010 puede ser caracterizado como un período de crisis en el que se seca la presa, se abaten los pozos y se declara una sequía y una escasez de agua. Para resolver la demanda apremiante del crecimiento urbano, se emprenden una serie de obras de infraestructura, la mayoría de las cuales resultan fallidas o no se llevan a cabo. De este modo, la gestión urbana del agua se ve obligada a recurrir a la administración de la demanda y a tratar de controlar y reducir los consumos urbanos de agua.

El consumo y pérdidas de agua de 1995 a 2009

Al llegar al límite de la disponibilidad de agua proporcionada por la presa Abelardo L. Rodríguez, la del Molinito y por los acuíferos que la rodean, la ciudad de Hermosillo se debate en un doble reto. Por un lado tiene urgencia y necesidad de impulsar el crecimiento económico, lo cual implica mantener y acelerar el crecimiento de la población y la actividad económica, ampliar el mercado local e incluso competir con otras ciudades globales que no cuentan con dicha limitación. Por otro lado, debe de ajustarse a la realidad que su entorno semiárido le impone, reducir al mínimo sus fugas y pérdidas de agua, tratar y reusar las aguas residuales e imponer niveles más racionales de los consumos domésticos, institucionales e industriales por medio de la medición volumétrica, una estructura tarifaria adecuada y una efectiva estrategia de cobranza.

Si la ciudad ha continuado su crecimiento, ha sido con base en la disminución de los consumos y en las adiciones de nuevas fuentes de suministro provenientes de la compra de derechos de agua agrícola (Scott and Pineda 2011). A finales de la década de los noventa, a fin de afrontar la urgencia de abastecer de agua para el crecimiento de la ciudad, además de emprender obras de infraestructura que buscaban aumentar el suministro, el organismo de agua se vio obligado a buscar maneras de reducir el consumo. En el verano de 1998, se inicia el racionamiento del agua y se establecen horarios para el suministro del líquido a la red, conocidos como “tandeo”. El suministro de agua a la red deja de ser continuo las 24 horas del día y se restringe a un horario determinado. Al mismo tiempo, se comienza a dividir la red de distribución en “sectores hidrométricos” que permiten un mayor control de las presiones y de las pérdidas de agua. El proyecto es dividir la red de suministro en 115 sectores hidrométricos.

Cuadro 5-4. Proyectos emprendidos para reducir el consumo de agua a Hermosillo. Fuente: Elaboración de los autores.

Año	Proyecto	Problema
1998	Se inicia el racionamiento que suministra agua de acuerdo a un horario, durante los veranos.	Se restringe a 16 y a 12 horas el suministro de agua.
1999	Se inicia la sectorización de la red	Se proyecta dividir la red en 110 sectores hidrométricos.
1998-2000	Promoción de instalación de tinacos y de dispositivos domésticos de ahorro de agua (como regaderas y sanitarios)	Sin micro-medición resulta muy difícil que el consumidor pague los costos de ahorro
Permanente	Reducción de fugas y rehabilitación de la red	Falta de, o inadecuados recursos financieros de inversión
Desde 1998	Programa de cultura del agua en escuelas y publicidad	Largo periodo (de años a décadas) de impacto en menor consumo

Por otra parte, a partir de 1996 el organismo de agua inicia un programa de “cultura del agua” con el objetivo de sensibilizar a los estudiantes de educación preescolar, primaria, secundaria, preparatoria y padres de familia, en el uso adecuado del agua dentro de la campaña denominada “Cuidar el agua … tarea de todos”. En una etapa posterior el programa se orienta al público en general e incluye además la promoción del uso de dispositivos ahorradores de agua en regaderas y sanitarios. Como parte de estas campañas entre septiembre de 2002 y junio de 2003 se visitaron 85 escuelas y se instruyó a 13,877 niños a través de pláticas y videos. A este programa se le atribuyó el descenso del consumo de agua de 470 a 375 lhd. en el período de 1996 a 2002. Aunque desde otro punto de vista, este descenso puede atribuirse más bien al programa de racionamiento iniciado desde 1998 (Eakin et al. 2007).

Al analizar los consumos urbanos de agua durante el período de 1995 a 2009, se aprecian dos etapas con comportamientos diferentes. En la primera etapa, los volúmenes de agua suministrada se redujeron progresivamente. Los datos publicados por el organismo operador en diferentes años muestran que, después de los 95.9 Mm^3 suministrados en 1995, el volumen de agua suministrado se redujo hasta 68.6 Mm^3 en 2005. Sin embargo, en la segunda etapa, a partir de 2005, año cuando se adquirieron nuevas fuentes de uso agrícola, el volumen de agua producido ha repuntado y se ha elevado nuevamente. De este modo, en 2009 se reporta que se produjeron 106 Mm^3.

Para ponderar este crecimiento del abasto de agua, hace falta que consideremos el consumo por habitante. En este aspecto, sin embargo, nos encontramos con la situación de que hay varias cifras publicadas sobre la población urbana de Hermosillo para los mismos años. Por un lado, están las cifras oficiales del Consejo Nacional de Población (CONAPO) que se muestran en una columna del Figura 15 y por otro lado tenemos las estimaciones demográficas del mismo organismo de agua que generalmente tienden a ser más elevados que las cifras oficiales. En ambos casos, se aprecia que el consumo per cápita disminuyó de 1995 a 2005 y repunta a partir de ese año y mantiene su crecimiento cuando menos hasta el 2009. De acuerdo a los datos del organismo, el promedio de lhd consumidos en Hermosillo se redujo de 462 en 1995 a 243 en 2005 y repuntó hasta 338 en 2009.

Cuadro 5-5. Suministro de agua en Hermosillo 1995-2009. Fuentes: Para los años 1995-1999: Comisión Nacional del Agua, Situación del Subsector Agua Potable y Alcantarillado, México, D.F., años respectivos. Para los años 2005 y 2009, el documento "Indicadores de gestión 2005-2009" publicado en: http://www.aguadehermosillo.gob.mx/inicio/, consultados en febrero 2009 y en abril 2010**.**

Año	**Millones de M^3 de agua producida**	**Habitantes atendidos según AGUAH**	**Litros/hab/día**	**Población según CONAPO**
1995	95.9	569,579	462	558,141
1999	77.7	651,450	327	626,765
2005	68.6	772,962	243	721,516
2009	106.0	858,122	338	779,073

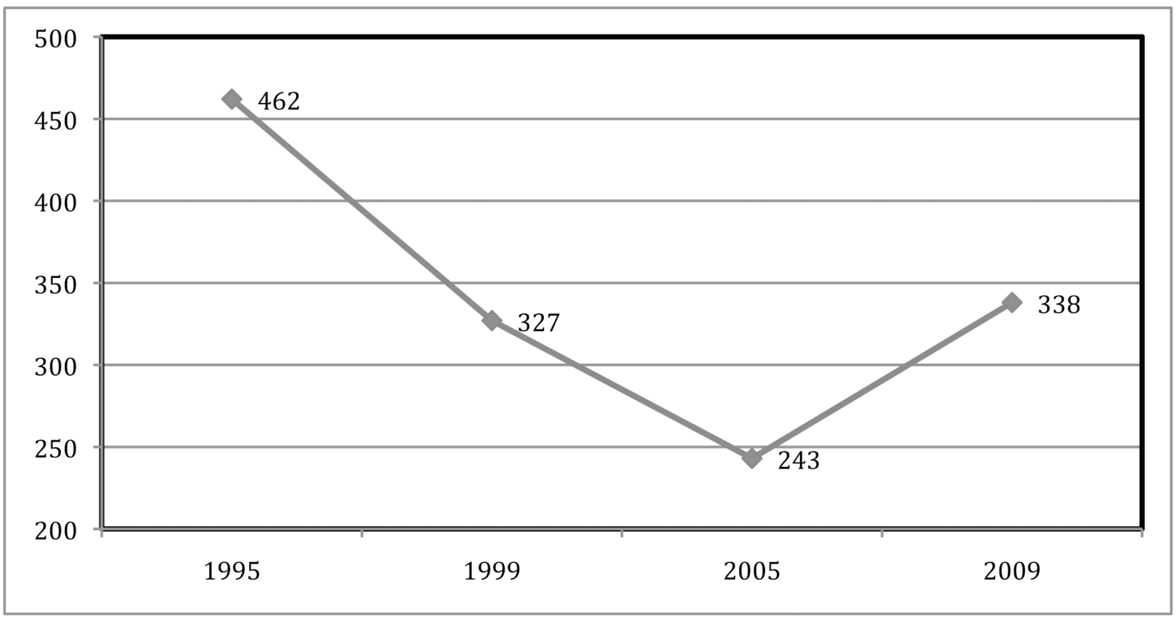

Figura 5-13. Consumo diario per cápita en Hermosillo 1995-2009 (litros por habitante por día). Fuente: Elaboración por los autores.

No obstante, si tomamos como base de cálculo la población publicada por CONAPO, el consumo por habitante en 2009 resulta ser de 373 litros por habitante por día (Lhp), es decir hay una diferencia de 35 litros según la cifra de población que se utilice. Existe entonces la posibilidad de que las cifras de población estimadas por el organismo estén infladas con el fin de reducir la tasa de consumo per cápita.

A fines de 2009, debido a la baja disponibilidad que ofrecía la presa de El Molinito y el abatimiento de diversos pozos, el nuevo gobierno local emprendió nuevamente el racionamiento del suministro de agua. A partir del 1 de diciembre de 2009 se estableció primeramente un horario de las 22:00 a las 5:00 horas, es decir, 16 horas de servicios y ocho sin servicio. Posteriormente, a principios de 2010, el horario del servicio se redujo a ocho horas al día, repartido en tres horarios: matutino, de 5:00 a 13:00 horas; vespertino, de 14:00 a 22:00 horas; y mixto, alternando los dos horarios en algunas colonias (Gandara Magaña 2010:21). Al mismo tiempo, la mayoría de los hogares que no lo habían hecho anteriormente comenzaron a instalar tinacos de agua en las azoteas a fin de contar con agua durante los horarios sin servicio en la red. De esta manera se ha establecido como norma general el contar con un depósito o tinaco de agua de modo que las familias puedan mantener la disponibilidad doméstica de agua durante todo el día. Tomando en cuenta estos cambios de conducta de los hogares, puede considerarse que la medida del racionamiento ha dejado de ser efectiva como instrumento para modificar los patrones de consumo doméstico. De hecho, la principal utilidad del racionamiento es que evita que la red de tuberías deje de perder agua por fugas durante el horario en que se suspende el flujo.

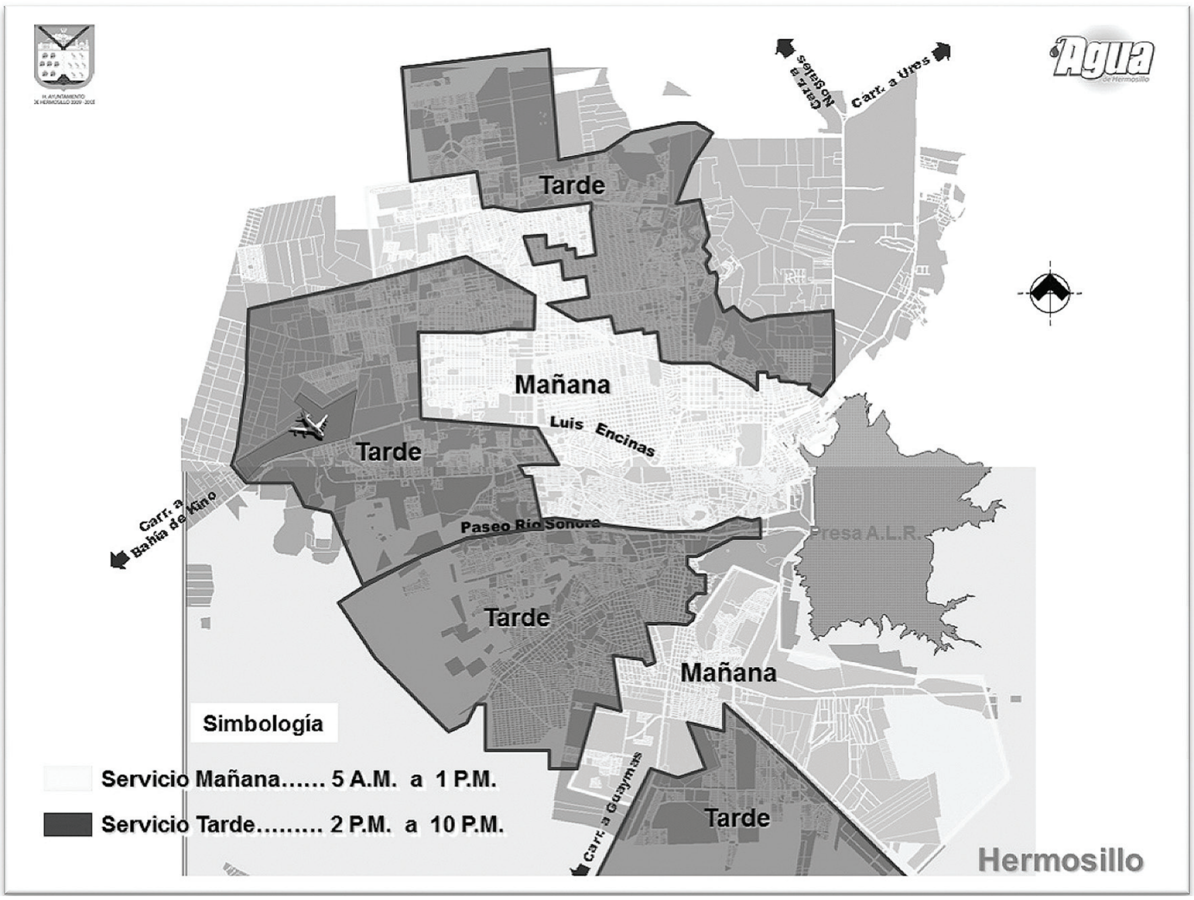

Figura 5-14. Tandeo del servicio de agua en la ciudad de Hermosillo en 2010. Fuente: Agua de Hermosillo, febrero 2010.

Un efecto no deseado del racionamiento o "tandeo", es que ha provocado el deterioro de las tuberías y el incremento paulatino de fugas de agua en la red. Por ello, el organismo ha tenido que poner en práctica un agresivo programa de reparación de fugas. En el año 2010, Agua de Hermosillo tenía un total de 146 trabajadores destinados a la reparación de fugas organizados por cuadrillas distribuidas en dos zonas geográficas y en tres turnos de trabajo. Además, se destinaban a esta misma tarea también 32 vehículos y 27 máquinas, así como 31 personas más que desarrollan actividades de asistencia. En 2010, alcalde reportó que se atendía un promedio mensual de 1,970 fugas (Gandara Magaña 2010:22-23). Esto significa que se atiende un promedio de 65 fugas diarias. Lo grave de la situación es que este problema no se está resolviendo sino que, mientras exista el racionamiento, se mantiene y tiende a agravarse.

En lo que respecta a la construcción de sectores hidrométricos, para septiembre de 2010, se reporta que se estaban operando 92 de los 115 sectores proyectados. Sin embargo, esta sectorización de la red no está siendo aprovechada para reducir las pérdidas de fluido y sólo se utiliza para regular la presión y realizar los tandeos. Para la realización de este estudio, se solicitó al organismo los datos de los suministros y consumos por toma en los sectores y, debido a la falta de medición completa de las tomas, sólo se proporcionaron estimaciones incompletas de algunos sectores. Hasta donde se cuenta información, no lleva a cabo el monitoreo por sectores de las eficiencias físicas de la red.

Está claro que la red pierde una cantidad significativa de agua la cual hace que se incremente el promedio de consumo por habitante. Para analizarla comencemos primeramente por la proporción o porcentaje de "agua contabilizada", es decir el agua que se factura y se contabiliza como parte del suministro del organismo de acuerdo los indicadores publicados por la CONAGUA. Según esta fuente, el agua facturada por el organismo fue de 64 por ciento en 2001, 49 por ciento en 2005, 62 por ciento en 2006, 47 por ciento en 2007 y 56 por ciento en 2008. Puede verse entonces que no hay una clara tendencia, sino un comportamiento que asemeja una línea quebrada. Por otra parte, la cantidad de agua cobrada con respecto a la facturada, que se conoce como "eficiencia comercial", fue de 79 por ciento en 2005 y en los tres años posteriores se ha mantenido en torno al 73 por ciento. Ésta es la proporción de agua que efectivamente mide, factura y cobra Agua de Hermosillo. La parte restante, puede considerarse como "no contabilizada" y que no contribuye ni a su autosuficiencia y sí para aumentar la cantidad de agua que el organismo extrae de la cuenca. De modo que en términos prácticos, el agua no contabilizada puede considerarse como pérdida de agua.

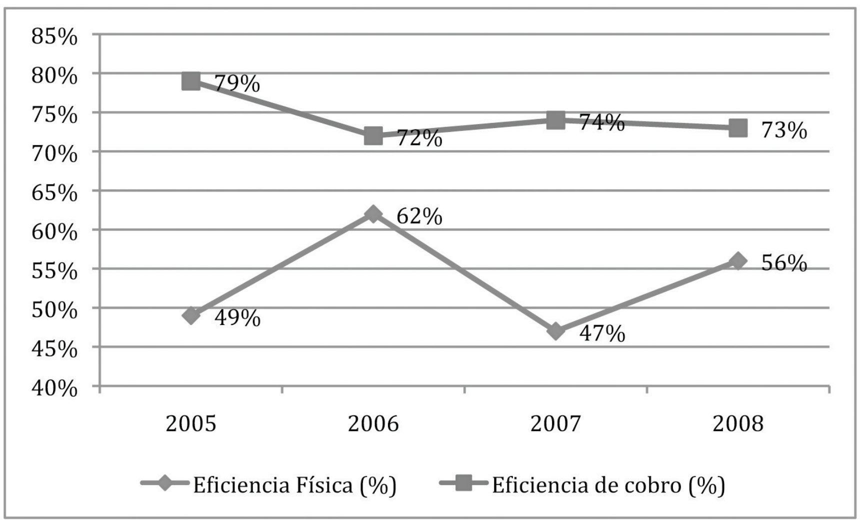

Figura 5-15. Eficiencias física y comercial de acuerdo a la CONAGUA. Fuente: Elaborada por Alejandro Salazar y América Lutz con base en datos de la CONAGUA, Situación del subsector Agua Potable, Alcantarillado y Saneamiento, ediciones 2005 2006 2007 y 2008.

Por otra parte, el director del organismo, al ser interpelado sobre el volumen y proporción de las pérdidas, ha argumentado que no se trata propiamente de pérdidas o fugas de la red, sino de los consumos de las instituciones públicas que, por disposición del artículo 115 constitucional, no pueden ser cobrados sino que se otorgan gratuitamente. El cuadro 6 muestra el desglose que el entonces director del organismo hizo del agua contabilizada y no contabilizada de la ciudad para el año 2009. De acuerdo a esta información, se factura el 59.2 por ciento del agua producida y el 48.2 por ciento restante se suministra de manera gratuita (es decir sin medir, ni cobrar), a instituciones gubernamentales, escuelas, parques y jardines de la ciudad, a las invasiones, a ejidos o poblaciones rurales. De acuerdo a este reporte, las pérdidas de la red sólo son el 6.6 por ciento estimado de tomas clandestinas, el 3.4 por ciento de los usuarios en baja por impago, el 6.8 por ciento de fugas domiciliarias no medidas y el 17.8 por ciento que se pierde o fuga en la red.

Cuadro 5-6. Análisis del agua contabilizada y no contabilizada de Hermosillo. Fuente: Información presentada por el Ing. José Luis Jardines, Director de Agua de Hermosillo, al Ayuntamiento de Hermosillo el 3 de febrero de 2010.

	Suministro de agua	**Tipo info**	**Volumen Mm³**	**Proporción**
1.1	Volumen facturado a usuarios domésticos	Dato	46.304	49.1 %
1.2	Volumen facturado a comercios e industrias	Dato	7.215	7.7 %
1.3	Volumen facturado a escuelas, gobierno e instituciones no lucrativas	Dato	2.311	2.5 %
1	***Subtotal contabilizado***		**55.83**	**59.2 %**
2.1	Agua a bienes del dominio público (gobierno)	Estimado	0.268	0.3 %
2.2	Escuelas (excedente no facturado)	Estimado	0.460	0.5 %
2.3	Riego de Parques y Jardines	Dato	2.569	2.7 %
2.4	Agua entregada a invasiones por medio de “pipas”	Estimado	0.730	0.8 %
2.5	Transferencia a poblaciones rurales	Dato	1.892	2.0 %
2.6	Tomas clandestinas	Estimado	6.216	6.6 %
2.7	Volumen a usuarios en baja por impago (autoconexión)	Estimado	3.162	3.4 %
2.8	Pérdidas estimadas intradomiciliarias (sin medición)	Estimado	6.421	6.8 %
2.9	Pérdidas estimadas en la red	Estimado	16.742	17.8 %
2	Subtotal no contabilizado		38.46	40.8 %
3	Total volumen producido 2009 (1 + 2)		94.29	100 %

En total podemos entonces dividir el agua no contabilizada en dos tipos: la que se da gratuitamente a instituciones públicas que se estimó en 6.3 por ciento en 2009 y el 34.6 por ciento que se pierde ya sea en la red, por robos de agua, excesos de consumos no medidos. De cualquier modo, la pérdida de agua es considerable y asciende a cuando menos la tercera parte del agua suministrada. Además, hay que señalar que el total de agua producida reportado no corresponde al publicado para ese año por el mismo Agua de Hermosillo. Para el 2009, la página Web de Agua de Hermosillo reportó un total de 106 Mm^3 de agua producidos (ver Figura 15). Existe entonces un discrepancia entre ambos datos que hace falta explicar y que, quizá, pudiera también ser abonada al agua perdida o no contabilizada.

Un dato preocupante es del de los nuevos permisos de conexión a la red que continúa expidiendo el organismo para nuevos fraccionamiento y construcciones. En el año 2010, se expidieron 14 nuevos permisos de “factibilidad” y se renovaron 20. En conjunto estos nuevos permisos significan el compromiso de suministrar 640 Lps adicionales para un total de 6,638 viviendas (Gandara Magaña 2010:24). En estos permisos se denota el conflicto de intereses y la verdadera prioridad del gobierno local ya que entre la alternativa de impulsar el crecimiento urbano, favorecer a la industria de la

Las fallas de padrón, la medición y la cobranza

El diagnóstico que la empresa Bal Ondeo (www.bal-ondeo.com.mx) hizo de la gestión comercial de Agua de Hermosillo a principios de 2011 reporta que el organismo operador ha caído en un círculo vicioso en el que: la falta de recursos causa la carencia de inversiones necesarias para mejorar el servicio, esto provoca un servicio deficiente, el mal servicio a su vez hace que los usuarios no paguen el servicio y esto propicia la falta de recursos. Si no se logra romper este círculo vicioso, aunque se consigan grandes apoyos y se hagan grandes obras siempre vamos a estar en crisis.

Entre los problemas detectados por el estudio de Bal Ondeo está, por ejemplo, que no hay un padrón confiable y se encontró que hay fraccionamientos y casas que tienen servicio, pero no han sido incorporados al padrón. Existen domicilios que tienen medidor pero no se les toma la lectura porque no aparecen en las rutas de los encargados. A fin de cuentas hay 40% de usuarios a los que, aunque tengan medidor, se les cobra con base en estimaciones.

Hay además muchas diferencias en las cargas de trabajo y en los criterios que aplican los contratistas privados que realizan la lectura de los medidores y a quienes también les debiera de tocar detectar conexiones ilegales y realizar los cortes por falta de pago.

Existen muchas tomas de agua de grandes consumidores en los que la toma está registrada como de media pulgada y cuyo consumo hace sospechar la existencia de alguna toma adicional no registrada. Otros grandes consumidores tienen toma directa y no se les mide.

De acuerdo a este estudio, queda claro que hace falta que se ponga orden en el padrón de usuarios y en las políticas comerciales de Agua de Hermosillo. Para ello, a partir del verano de 2011, se contrató a Bal Ondeo, la misma empresa que hizo el estudio, para que se haga cargo del área comercial del organismo operador.

construcción y la creación de empleos adquiriendo compromisos que quizá no pueda cumplir o negar dichos permisos y moderar o controlar el crecimiento urbano, siempre escoge lo primero.

¿Cuáles son entonces las principales vulnerabilidades del consumo y la demanda de agua en Hermosillo? Las principales vulnerabilidades en este respecto son, primero, las deficiencias del padrón de usuarios y la medición tanto a nivel de los sectores hidrométricos como a nivel agregado. En varios momentos se ha intentado dar el brinco hacia la medición total del consumo de las tomas de agua, pero no se ha alcanzado la meta. En el año 2011, con la contratación de una empresa privada para que se encargue del área comercial, se está anunciando nuevamente un avance substancial en la medición del consumo doméstico. Por otra parte, una segunda vulnerabilidad es la morosidad o de los usuarios y problemas de la cobranza. La ausencia de sanciones y consecuencias para quienes no pagan a tiempo su servicio hacen que el organismo esté subsidiando a muchos usuarios que no son necesariamente los más pobres ni los más necesitados. Los problemas de la cobranza incluyen, además, el consumo de agua de una gran cantidad de instituciones públicas a las que, por disposición del artículo 115 constitucional, se les suministra el agua de manera gratuita. De hecho, la falta de medición y de cobro del agua a las instituciones públicas pone desorden en toda la política de manejo eficiente del agua y ha sido un lastre para la buena administración del organismo.

Escenarios futuros de crecimiento y demanda

El crecimiento de México en el siglo XXI será principalmente urbano, siendo las ciudades del norte las de mayor crecimiento en el país (Pineda y Salazar 2009). De acuerdo con CONAPO (2006), se espera que Hermosillo tenga un crecimiento poblacional de 1.5 por ciento anual entre 2010 y 2030. Así, la población de Hermosillo crecería de 717 mil habitantes en 2010 a 966 mil en 2030.

Cuadro 5-7. Proyección del consumo del agua hacia 2030. Fuente: Elaboración de Alejandro Salazar con base en CONAPO (2006).

Año	2010	2015	2020	2025	2030
Población	717,711	788,044	853,534	913,751	966,821
PIB per cápita	117,652	131819	147691	165475	185401
Consumo de agua per cápita	187	189	196	203	212
Consumo total de agua en Hermosillo (Millones de m^3) sin pérdidas	49	54	61	68	75
Consumo total de agua en Hermosillo (Millones de m^3) con pérdidas (ineficiencias)	104	116	130	144	159

El PIB per cápita de Hermosillo en 2008 fue estimado en 112,421 pesos o 9,309 dólares (Banamex 2009). No se tienen datos sobre el PIB municipal en México, sin embargo, considerando que la ciudad de Hermosillo concentra una parte importante del PIB estatal, podemos darnos una idea de cuál ha sido el crecimiento económico de la ciudad echando un vistazo a los datos estatales: entre 1993 y 2006 se observó un crecimiento promedio del PIB en Sonora del 3.9 por ciento, mientras que el crecimiento del PIB per cápita fue de 2.3 por ciento anual (INEGI 2011). Bajo el supuesto de que en el futuro el crecimiento del PIB per cápita seguirá la tendencia estatal de los últimos años entonces se esperaría que hacia el año 2030 el PIB per cápita de Hermosillo sea de 185,401 pesos, 58 por ciento más que la estimación para 2010.

Según Agua de Hermosillo en 2008 se produjeron un total de 100 Mm^3. Sin embargo, la eficiencia física fue del 50 por ciento, lo que significa que solamente 50 Mm^3 fueron consumidos por los hogares. Esto implica un consumo per cápita efectivo de 150 metros cúbicos per cápita o bien 200 Lhp.

Considerando una elasticidad ingreso de la demanda de agua de 0.28 (Dalhuisen et al. 2003), se llevaron a cabo proyecciones del consumo de agua hasta 2030. Si se mantienen los precios del agua en sus niveles actuales, se esperaría que el consumo per cápita crezca de 187 Lhp al día en 2010 a 212 litros en 2030. Aun cuando el crecimiento del consumo de agua per cápita sólo se elevaría en 13 por ciento, el crecimiento poblacional provocaría que el consumo total de la ciudad se elevará de 49 a 75 Mm^3, un crecimiento de más del 50 por ciento. Además, de mantenerse los niveles de eficiencia física tan bajos (en 2007 fue de 47 por ciento) los requerimientos de extracción de agua para la ciudad se incrementarían de 106 Mm^3 estimados para 2009 a 159 Mm^3 en 2030.

En suma, el desarrollo de la infraestructura de Hermosillo ha aliviado la crisis del agua, al menos temporalmente, sin embargo, no se ha enfrentado de forma adecuada los retos actuales y futuros. Conflictos urbanos-rurales por la tierra y el agua, la vulnerabilidad social, la capacidad variable de adaptación resultado de la disparidad socioeconómica, y la rápida rotación del personal de las agencias representan desafíos para la seguridad hídrica en Hermosillo.

F. Vulnerabilidad hídrica urbana y capacidad adaptativa en Hermosillo

Vulnerabilidad social

La ciudad de Hermosillo es vulnerable a las altas temperaturas, la escasez de agua y a la variabilidad climática. Pero esta vulnerabilidad no es uniforme e igual para todos sus habitantes. El grado de vulnerabilidad de los hogares está determinado por el tipo de vivienda en que habitan y por los medios de que disponen (Castro 2007). Desde este punto de vista, la población más vulnerable es la que habita en viviendas precarias que carecen de los medios para mitigar el calor o para evitar las deshidrataciones, golpes de calor, diarreas e incluso la muerte. Asimismo, dentro de los grupos en pobreza patrimonial, la población más vulnerable son los niños, las personas de la tercera edad y las mujeres que permanecen la mayor parte del tiempo en dichas viviendas y que no cuentan con los medios adecuados para guarecerse de las altas temperaturas y la radiación solar, principalmente en los días de marzo a octubre en que pueden darse temperaturas de 40° C o superiores. En Hermosillo, esta vulnerabilidad social al clima caluroso coincide en buena medida con la población marginada.

¿Cuánta agua va a demandar Hermosillo en el año 2030?

En cuestión de gestión del agua, pueden plantearse entonces dos escenarios para el año 2030. En ambos escenarios la población de la ciudad se estará acercando entonces al millón de habitantes y se mantiene el dinamismo de las actividades productivas y el nivel de vida de la población como constantes. Sin embargo, en un primer escenario la ciudad demanda sólo 75 millones de metros cúbicos. Esto se logra con base la planeación y manejo integrado de la cuenca, con un inventario y regulación de las extracciones y una adecuada distribución de derechos entre los usos urbanos y los usos agrícolas; así como estableciendo, mediante inversiones estratégicas en infraestructura de la red y el establecimiento de reglas, incentivos, medición, cobros y sanciones adecuados, niveles aceptables de control y eficiencia física del agua. En este caso se provee un servicio medido, pero confiable y suficiente para las necesidades.

En el otro escenario la demanda urbana de agua se eleva a 159 Mm^3. En este caso, se mantienen las pérdidas de agua en la red, la falta de medición y las deficiencias en la facturación y cobranza del servicio. Sin embargo, el servicio no es confiable y está sujeto a suspensiones y cortes inesperados. Además, en este escenario el suministro se mantiene gracias a la inversión de grandes recursos fiscales y subsidios que dejaron de utilizarse en otras áreas y proyectos de desarrollo.

El primero es el escenario del orden y del desarrollo. El segundo es el del desorden, la mala administración, la ineficiencia y el dispendio.

Según el CONEVAL (2007), de los 701,838 personas que habitaban en el municipio de Hermosillo en 2005, el 31.1 por ciento no contaba con ingreso suficiente para cubrir sus necesidades de vivienda, vestido, calzado y transporte, es decir estaban en situación de pobreza de patrimonio. Entre éstos, el 9.5 por ciento no era capaz de cubrir sus necesidades de educación y salud y se encontraban por lo tanto en pobreza de capacidades. El grupo más extremo es el 4.9 por ciento cuyo ingreso no era suficiente ni siquiera para cubrir sus necesidades de alimentación.

Por otra parte, según estudios de CONAPO, en 2005, de la población de 701,828 habitantes estimados en ese año, el 6.9 por ciento vivía en viviendas con piso de tierra, el 2.3 por ciento carecía de servicio de agua entubada y el 1.1 por ciento no contaba con energía eléctrica en la vivienda. Considerando el porcentaje de viviendas con piso de tierra, hay 48,500 hermosillenses que habitan en viviendas precarias y que son vulnerables a los efectos del clima. A esto hay que agregar a la población ocupada cuyo ingreso es menor a dos salarios mínimos y que asciende a 23.8 por ciento de la población ocupada (CONAPO 2006). Si este porcentaje lo trasladamos a toda la población, tenemos entonces que 166,700 hermosillenses pueden ser ubicados como debajo de la línea de pobreza.

Cuadro 5-8. Población marginada de Hermosillo en 2005. Fuente: CONAPO 2006. Nota: Éstos son los últimos datos de marginación disponibles hasta 2011.

Población total	701,838
por ciento de población ocupada con ingreso de hasta 2 salarios mínimos	23.8
por ciento de ocupantes de viviendas con piso de tierra	6.9
por ciento de ocupantes en viviendas sin agua entubada	2.3
por ciento de ocupantes en viviendas sin energía eléctrica	1.1

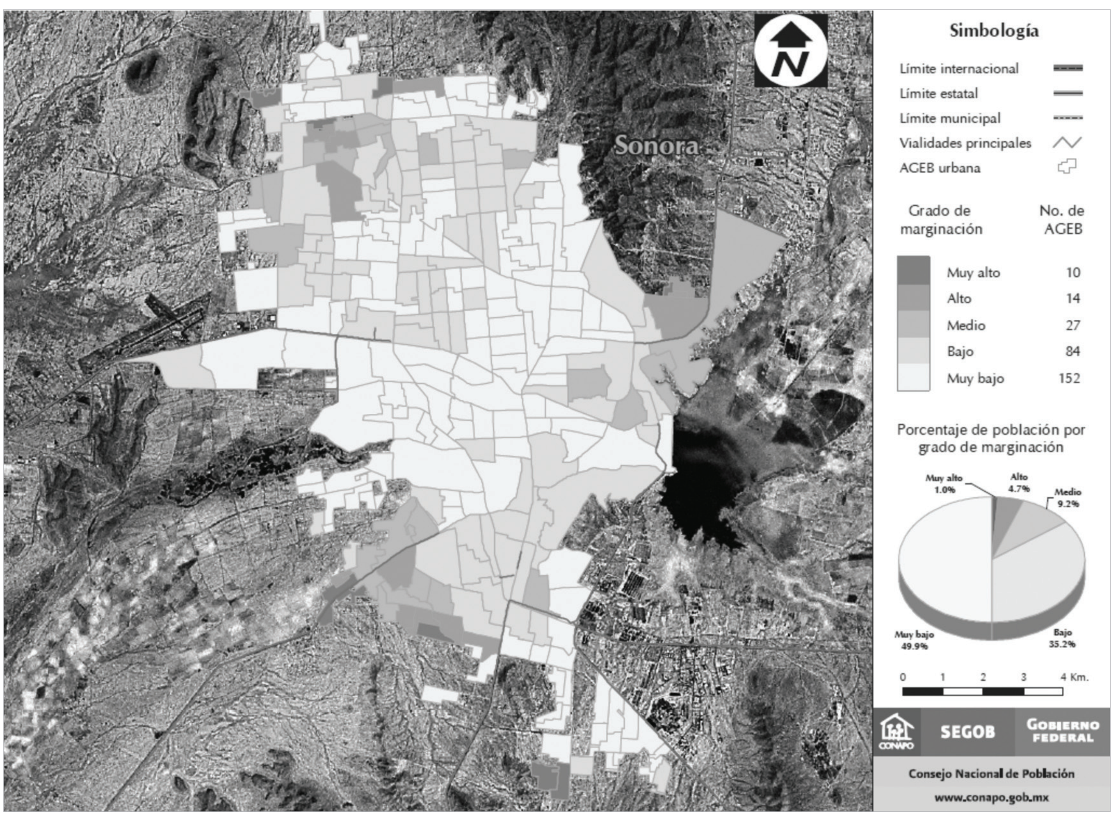

Figura 5-16. Mapa de la marginalidad en Hermosillo. Fuente: CONAPO 2006.

Una buena parte de esta población, quizá la más marginada, se ubica en los asentamientos irregulares conocidos como "invasiones" que se ubican en la periferia de la ciudad. Éstos consisten en un conjunto de familias que se asienta en un lote baldío sin contar con título de propiedad, sin que los lotes hayan sido fraccionados y urbanizados y sin contar con los servicios de agua, energía eléctrica o drenaje.

Para posesionarse del terreno, estas familias construyen viviendas con material precario como tablas y postes de madera, láminas de cartón, anuncios publicitarios y material de desecho.

De acuerdo a datos proporcionados por el gobierno municipal, en el año 2004, en Hermosillo había 36 asentamientos irregulares que no contaban con servicio de suministro de agua entubada[1]. Se calculaba que en estos asentamientos habitaban 2,500 familias, que a una tasa de 4 miembros por familia, equivale aproximadamente a un total de 10,000 habitantes.

Figura 5-17. Asentamiento irregular en Hermosillo. Fuente: Fotografía propia.

A fin de suplir la deficiencia de agua, el gobierno municipal les abastece de agua por medio de carros cisternas, localmente conocidos como "pipas". Estos carros cisternas transportan agua a estos asentamientos dos veces por semana y la depositan en los tinacos, pilas o depósitos que las familias tienen dispuestos para este fin. El servicio es gratuito y se paga con fondos fiscales del ayuntamiento. La calidad del agua es verificada por el Departamento de Sanidad y Limpia del gobierno municipal y supuestamente está destinada exclusivamente para consumo humano. De acuerdo a los datos proporcionados por el gobierno municipal en el período de julio de 2003 a junio de 2004 se distribuyó un promedio mensual de 11,629 Mm^3 de agua con un costo para el gobierno local de 303,403 pesos mensuales (Gobierno Municipal Hermosillo 2003-2006 2004). Con base en estos datos, se puede estimar que cada familia de estos asentamientos recibe un promedio de 4.7 metros cúbicos al mes con un costo mensual promedio de 121 pesos por familia, lo que equivale aproximadamente a 155 lhd.

1 Los lugares atendidos eran los siguientes: Altares IV Etapa, Ejido 23 de Octubre (km 36), Ladrilleras de Buchard, Predio Villa Ensueño (Ejido Nueva Ilusión), Hermosa Provincia, López Mateos, San José de las Minitas, Predio Los Pinoles, Cocheras Nuevo Amanecer, Jesús Vega (Ladrilleras III Etapa), Alborada, Camaroneras, Chaparral, Mirador, Luis Donaldo Colosio, Predio Las Cuevas, Piedras Negras, Lo que siembras cosecharas (Dispensario), Hoyo Taurian, Manuel Villa, Solidaridad IV Etapa, Beltrones, Armando López Nogales, Milenio 2000, Lomas del Progreso (Insurgentes III Etapa), Miguel Valencia II Etapa, Laura Alicia Frías de López Nogales, Miguel Valencia, Lomas del Paraíso, Lomas del Norte, Cocheras (Unión de Porcicultores), Ladrilleras 5 de febrero, Ladrilleras Unión del Norte, Ejido San Pedro el Saucito, Ejido El Tronconal, y Relleno Sanitario.

Cuadro 5-9. Abasto de agua a población sin agua entubada (julio 2003-junio 2004). Fuente: Gobierno Municipal Hermosillo 2003-2006 2004.

Mes/año	Abasto agua (M^3)	Costo (pesos)	Familias	Población aprox.	M^3/fam /mes	Lhd aprox	Costo/fam /mes
jul-2003	12,421	$360,026	2,500	10,000	5.0	166	$144
ago-2003	12,897	$331,387	2,500	10,000	5.2	172	$133
sep-2003	12,366	$352,082	2,500	10,000	4.9	165	$141
oct-2003	13,489	$341,666	2,500	10,000	5.4	180	$137
nov-2003	11,686	$239,666	2,500	10,000	4.7	156	$96
dic-2003	8,932	$308,666	2,500	10,000	3.6	119	$123
ene-2004	8,607	$200,566	2,500	10,000	3.4	115	$80
feb-2004	8,163	$185,964	2,500	10,000	3.3	109	$74
mar-2004	11,395	$287,026	2,500	10,000	4.6	152	$115
abr-2004	11,510	$290,661	2,500	10,000	4.6	153	$116
may-2004	13,585	$355,565	2,500	10,000	5.4	181	$142
jun-2004	14,497	$387,565	2,500	10,000	5.8	193	$155
Promedio	11,629	$303,403			4.7	155	$121

Figura 5-18. Calle de un asentamiento irregular en Hermosillo.
Fuente: Fotografía del equipo de investigación 2011.

Como puede observarse estas familias no sólo reciben menos agua que el resto de la población, sino que la reciben de manera irregular, más insegura y menos confiable. Si a esto, agregamos la falta de electricidad y la frecuencia de materiales, como láminas y cartón negro, que no ayudan a protegerse de los rayos solares, tenemos entonces el cuadro propicio para una mayor recurrencia de deshidrataciones, diarreas e incluso la muerte por insolación de menores de edad y ancianos o de cualquier persona expuesta a estas condiciones durante los meses de verano en donde las temperaturas suben con frecuencia arriba de los 40°C durante varias horas al día.

Vulnerabilidad del sector rural peri-urbano

Otro sector vulnerable de la ciudad de Hermosillo es la población de los ejidos del área rural y semirural ubicados en la zona peri-urbana. La sequía de los años noventa disparó la competencia entre los usuarios urbanos y agrícolas, principalmente de los ejidos próximos a la ciudad. En estas áreas rurales que rodean a la ciudad de Hermosillo hay 16 ejidos que comprenden una extensión aproximada de 32,000 hectáreas con alrededor de 1,000 ejidatarios o propietarios de derechos de propiedad ejidal. Estos ejidos fueron creados en la década de 1930 (con la excepción del San Miguel, que fue creado en 1987). Las principales actividades productivas de estos ejidos son agricultura irrigada y ganadería en pequeña escala. Estos ejidos, que solían cultivar trigo en el ciclo otoño-invierno y maíz y fríjol en el ciclo primavera-verano, en los últimos años han cambiado su patrón de cultivo hacía pastura para alimentar su ganado. El principal destino de los becerros que crían los ejidatarios son los mercados de engorda de Estados Unidos. En promedio cada ejidatario tiene 11 cabezas de ganado. Asimismo, en promedio, cada ejidatario tiene cinco hectáreas de tierra agrícola irrigada. Debido a las estrategias de abastecimiento de agua de la ciudad, muchos ejidos han perdido su agua de uso agrícola y han tenido que abandonar esta actividad. Para complementar sus ingresos, muchas familias de ejidatarios tienen que trabajar fuera del campo como albañiles u obreros en las localidades vecinas o en la ciudad de Hermosillo. A este ingreso familiar tienen que contribuir muchos de los miembros del hogar (Jambry et al. 1997).

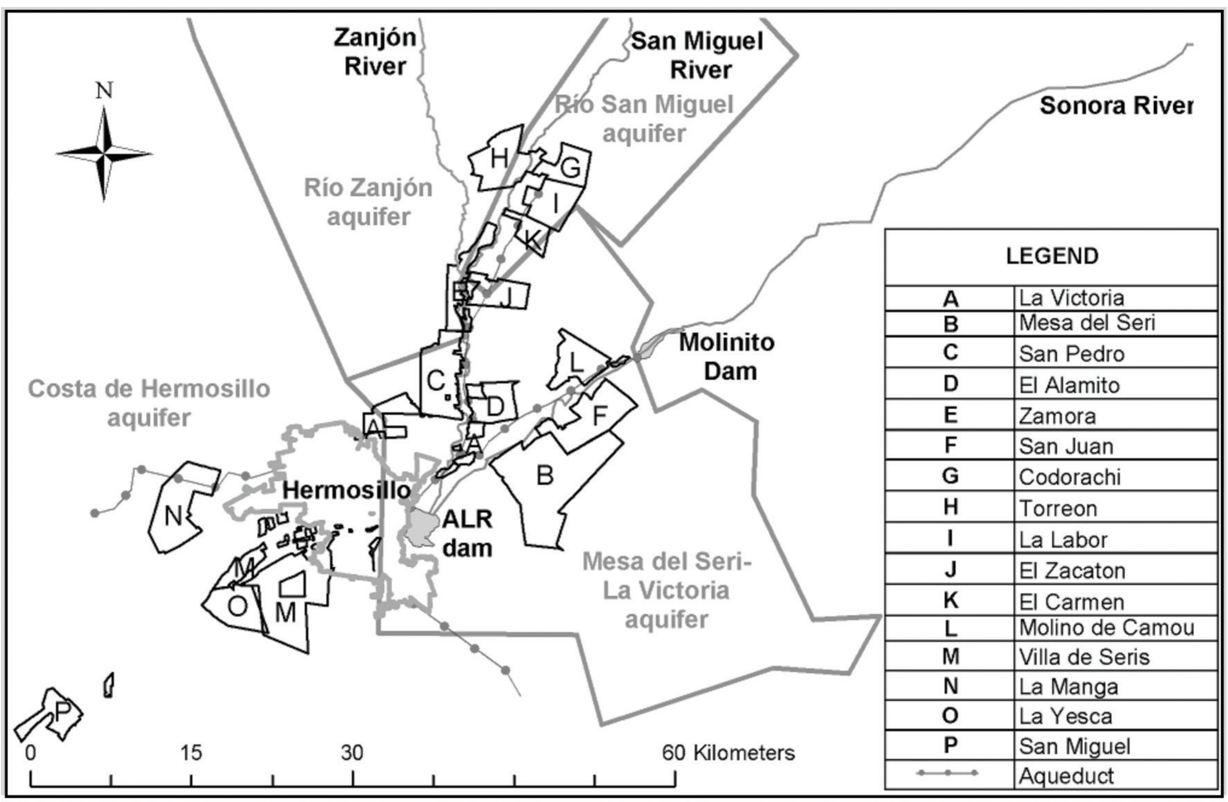

Figura 5-19. Ejidos periurbanos de Hermosillo. Fuente: Diaz-Caravantes and Sánchez-Flores 2010.

Todos estos 16 ejidos fueron perjudicados en algún grado por las estrategias de abastecimiento de agua de la ciudad de Hermosillo.

Utilizando los métodos de percepción remota en combinación con la visita y observación directa, se pueden observar importantes cambios de uso y cobertura de suelo ocurriendo en toda la zona peri-urbana, los cuales se ejemplifican en los casos del ejido La Victoria y el ejido Molino de Camou.

¿Cómo afecta el crecimiento de Hermosillo a los ejidos que la rodean?

Los ejidos La Victoria, Mesa del Seri, San Pedro, y El Alamito fueron perjudicados por la batería de pozos que se perforaron en sus linderos para abastecer a Hermosillo y que les redujo el acceso de agua para riego. De estos ejidos, la Victoria ha reportado además problemas de calidad de agua debido al alto índice de sales

El ejido San Juan fue afectado por el acueducto el Molinito. Antes de la existencia de este acueducto, el agua de la presa El Molinito se soltaba en distintas épocas del año y permitía que los pozos del ejido se recargaran. Sin embargo, ahora que el agua de la presa El Molinito se envía a la ciudad a través de un acueducto, los ejidatarios han visto disminuido su acceso al agua para uso agrícola (Diaz-Caravantes y Sánchez-Flores 2010).

Los ejidos Codórachi, El Torreón, La Labor, y El Carmen fueron afectados en 2006 por la compra del agua de los pozos ubicados en la zona llamada Las Malvinas en la subcuenca del Río San Miguel para abastecer de 250 lps a la ciudad a través de un acueducto de 17 kilómetros (Aguah, 2007). Estos ejidos fueron perjudicados porque ahora sus pozos agrícolas tienen que competir con los pozos de la ciudad.

El ejido Molino de Camou fue perjudicado en 1998 cuando, debido a la política de darle prioridad al agua para la ciudad, sus cultivos fueron limitados de dos ciclos agrícolas a solo uno. Sin embargo, en 2007, el ejido Molino de Camou fue capaz de negociar con la empresa administradora del agua, Agua de Hermosillo y Conagua el mejoramiento de su sistema de irrigación e incrementar su volumen de extracción de 1.4 a 2.1 Mm^3.

Finalmente, los ejidos de La Manga, Villa de Seris y La Peaña, ubicados río abajo al poniente de la ciudad, desde 1996 sólo tienen acceso a las aguas residuales de la ciudad. Por ello, han visto limitadas sus opciones de siembra al cultivo de forrajes y, a pesar de que la cantidad de agua se ha ido incrementando, es de muy mala calidad (Scott & Pineda Pablos, 2011).

En la Victoria debido a la escasez de agua en sus pozos agrícolas, por la cercanía de pozos urbanos, muchos ejidatarios han parado definitiva o parcialmente la actividad agrícola en su parcela. La información obtenida mediante percepción remota confirma esta drástica disminución en los últimos casi 20 años. Lo mismo sucede con muchos ejidos y agricultores privados ubicados en el área peri-urbana. De hecho, el uso del suelo agrícola disminuyó en el área peri-urbana del 19.1por ciento en 1987 a 6.8por ciento en el 2007 en el área periurbana de Hermosillo.

Vulnerabilidad institucional

La vulnerabilidad de la ciudad de Hermosillo a la variabilidad climática también está determinada por las instituciones encargadas de la política hidráulica. Si las instituciones son capaces de recopilar y ordenar la información, planear y fijarse metas y alcanzarlas, entonces estamos hablando de que hay instituciones capaces de proponer y dirigir las políticas de adaptación a la variabilidad climática. Pero si las instituciones no cuentan con la estabilidad necesaria para la toma de decisiones y sostener políticas de cambio estructural, entonces estamos frente a un caso de vulnerabilidad institucional (Wilder et al. 2010; Barkin and Klooster 2006). A fin de presentar la debilidad institucional de la política hidráulica en Hermosillo, se presentan cuatro aspectos críticos: la ausencia de planeación, la falta de continuidad en la dirección, la debilidad de la participación social y la fragilidad financiera.

Primeramente, no se cuenta con un ente u organismo que lleve a cabo la planeación integral de la cuenca del río Sonora de manera real y operativa. Aunque la Ley de Aguas Nacionales de (art. 13) prevé la creación de consejos de cuenca como una instancia en la que se coordinen la CONAGUA, las autoridades locales y los diferentes tipos de usuarios del recurso con el objeto de "formular y ejecutar programas y acciones para la mejor administración de las agua, el desarrollo de la infraestructura hidráulica y de los servicios respectivos y la preservación de los recursos de la cuenca", En el caso de la cuenca del río Sonora, es un consejo inexistente.

No hay un consejo de cuenca propio del río Sonora, sino que está agrupado junto con las cuencas del río Concepción y del río Sonoyta en lo que se denomina Consejo de Cuencas del Alto Noroeste, instalado el 19 de marzo de 1999. Esta integración de cuencas parece sugerir que la cuenca del río Sonora, a pesar de que alberga a la ciudad más poblada e importante del estado, no requiere de un consejo propio o sus asuntos no son lo suficientemente relevantes para ameritar un consejo exclusivo para esta cuenca. Por otra parte, a lo largo de más de diez años, sus reuniones y agenda de trabajo han evitado de manera sistemática abordar los problemas más relevantes de esta cuenca y se ha dedicado solamente a encargar estudios y crear comisiones que nada resuelven. Su desempeño revela además la incapacidad de la CONAGUA, como su principal agente promotor, para impulsar acciones coordinadas y concertadas con los usuarios y un aparente déficit de representatividad en su integración. A fin de cuentas, lo que se infiere es una falta de voluntad política para impulsar una verdadera instancia local de deliberación y toma de decisiones para la cuenca del río Sonora (Sánchez Meza 2008:43).

Como segundo elemento de la vulnerabilidad institucional local está la falta de estabilidad institucional y de una dirección continua en la gestión urbana del agua en Hermosillo. Esta falta de estabilidad y de una política continua se pone de manifiesto con la rotación frecuente de los directores del organismo y en sus frecuentes cambios de política y de proyectos de infraestructura. Se aprecia que mientras más frecuente es el cambio de directores, más se afectan las políticas de desempeño y más deficiente es el desempeño de los organismos. De 1992 a 2010, el organismo de agua potable de Hermosillo no sólo ha cambiado varias veces su marco institucional legal y su razón social, sino que además ha tenido en esos 18 años 10 directores generals.[2] O sea que los directores han tenido una duración promedio de 1.8 años. De manera similar, la junta de gobierno que toma las decisiones estratégicas del organismo operador, que es presidida por el presidente municipal, cambia su composición al menos cada tres años, cuando se renueva el ayuntamiento. La consecuencia de esta rotación frecuente de directivos y de integrantes de la junta de gobierno y de directivos del organismo es la ausencia de planes y programas de mediano y largo plazo que propicien el desarrollo y avance de la capacidad institucional del organismo y en cambio favorece la prevalencia de medidas y acciones cortoplacistas que generalmente atienden más a las coyunturas político-electorales más que la prestación de un servicio de calidad.

Como tercer elemento de vulnerabilidad local está el hecho de que la participación social en la toma de decisiones estratégicas del organismo es débil y restringida. Esta participación se da principalmente a través de un consejo consultivo ciudadano, creado desde 1993 (Güereña de la Llata 2004). No existe un reglamento que defina cómo deben de nombrarse sus integrantes. Desde su inicio, sin embargo, el

2 Los diez directores del organismo de agua potable de Hermosillo de 1992 a 2010 son los siguientes: Ing. Mario Yeomans Martínez, Ing. Humberto Valdez R. Sánchez, Sr. Juan R. Heguertty Urrea, Ing. Fco J. Hernández Armenta, Ing. Carlos Daniel Fernández, Arq. Enrique Flores López, Ing. Virgilio López Soto, Ing. Jorge Amaya Acedo, Cp. Enrique A. Martínez Preciado, y Ing. José Luis Jardines Moreno.

consejo ha estado dominado por representantes de la iniciativa privada. El representante de la Unión de Usuarios que era tal vez el más "popular" de los miembros, renunció al mismo y prefirió continuar como observador. De acuerdo a la Ley Estatal de Aguas (Gobierno del Estado de Sonora 2006), este consejo sólo tiene la función de opinar, recomendar y proponer sobre la gestión del organismo. En la práctica su grado de participación y actuación ha variado de acuerdo con las ideas y criterios del presidente municipal en turno. Así ha habido períodos de gobierno, como el de 2003-2006 en el que estuvo bastante activo y otros como el de 2006-2009 en el que su participación y actuación decayó bastante. En el año 2009, el nuevo presidente municipal redujo el número de sus miembros e introdujo la modalidad de un nuevo consejo técnico que lo asesorara en la conducción del organismo. A fin de tener una mayor legitimidad y gobernabilidad, hace falta construir una participación social más amplia y permanente que participe en la planeación hidráulica de la ciudad y en la gestión de la cuenca.

Por último, está la capacidad financiera del organismo Agua de Hermosillo. De acuerdo a la calificadora de riesgo Fitch México (2011), Agua de Hermosillo tiene una calificación crediticia de "BBB". Esto significa que su calidad crediticia es adecuada pero "cambios en las circunstancias o condiciones económicas pueden afectar su capacidad de pago oportuno". En esta misma evaluación del desempeño de organismos de agua, los organismos de Mexicali, Tijuana, Monterrey y Torreón están calificados con "A" y el organismo de León está calificado con "AA". Entre los factores positivos de Agua de Hermosillo están que tiene una favorable estructura y perfil de vencimiento de la deuda bancaria; que tiene buenos niveles de cobertura de servicios y que cuenta con el respaldo financiero del Municipio de Hermosillo (calificado con A+). Por otra parte, entre sus limitantes se señalan los déficits recurrentes, el bajo nivel de cobertura en el tratamiento de aguas residuales, los débiles indicadores de eficiencia física y global, los altos requerimientos de inversión en infraestructura, la dependencia de aportaciones federales, estatales y municipales y los frecuentes cambios en los directivos del organismo.

Vulnerabilidad y capacidad adaptativa en Hermosillo

Una vez revisados los datos e información disponibles más relevantes de la cuenca del río Sonora, así como sobre los consumos que hacen la ciudad y los usos agrícolas cercanos, podemos responder a las preguntas planteadas al principio de este trabajo de la siguiente manera:

¿Cómo se define la vulnerabilidad urbana del sector agua en Hermosillo?

La vulnerabilidad del sector agua de Hermosillo se define por la sobreasignación (o concesión excesiva) de derechos de agua, la sobreexplotación o utilización excesiva de las dotaciones, la desecación de la presa Abelardo L. Rodríguez y el agotamiento de los cuerpos superficiales de agua, el abatimiento de los pozos de agua subterránea y la escasez relativa "socialmente construida" de agua limpia. Esta escasez es socialmente construida porque no es provocada por la naturaleza sino por el crecimiento urbano y el uso dispendioso y desordenado del recurso.

Esta vulnerabilidad se hace más evidente si se toma en cuenta la probabilidad de contar con más días calurosos y sequías más intensas en los años venideros como efecto del cambio y la variabilidad climática.

Si se mantienen los patrones de consumo de la última década del siglo XX y la primera del XXI, la ciudad no cuenta entonces con agua suficiente para sostener el crecimiento urbano alcanzado y alentar el crecimiento en el futuro.

¿Cuál es la capacidad institucional de Hermosillo para desarrollar estrategias de adaptación para la gestión del agua en un horizonte de 5 a 20+ años?

No hay capacidad institucional para ordenar y planear los usos y extracciones de agua para hacer frente a la reducción de la disponibilidad de agua a mediano plazo. No existen actualmente las instituciones que pongan orden y establezcan el equilibrio entre el uso agrícola y el uso urbano, reduzcan de manera efectiva las pérdidas e impulsen niveles aceptables de eficiencia y equidad.

Las dos instituciones que pudieran ser estratégicas en la adopción de medidas de adaptación son el Consejo de Cuenca y el organismo operador no cuentan con capacidad suficiente o no son funcionales para estos propósitos.

El Consejo de Cuenca del Alto Noroeste y la Comisión de Cuenca del Río Sonora, que pudieran ser instancia de concertación y desarrollar estrategias y planes de adaptación, no tienen facultades suficientes. Estas instancias de participación y concertación no son operativas y su funcionamiento es meramente simbólico.

Por otra parte, ni organismo operador ni el gobierno municipal local han sido capaces de planear los usos urbanos de agua a mediano y corto plazo. Su principal impedimento es la brevedad de sus administraciones y la rotación de los directivos que no permite elaborar y poner en práctica planes y programas sostenidos más allá de su horizonte de gobierno de tres años. De hecho, el marco institucional actual favorece más bien la toma de decisiones de corto plazo orientadas a fines político-electorales.

Tal vez por ello, la respuesta que se ha venido impulsando hasta ahora no es la de planear de una manera más sustentable y equilibrada los usos agrícolas y el consumo urbano, sino la búsqueda de nuevas fuentes de suministro más lejanas y más costosas. A pesar de su alto costo financiero, se considera más viable la construcción de grandes obras de ingeniería que la planeación, la reducción de las asignaciones, el control de las extracciones y la modificación de los usos y conductas de los consumidores.

¿Cómo puede ser institucionalizada en Hermosillo la capacidad de los administradores del agua y los planificadores de la preparación a utilizar la ciencia del clima y la información? ¿Y cómo pueden hacerlo de manera que se mejore la capacidad de tomar de decisiones para adaptar?

Para institucionalizar la capacidad adaptativa de la gestión del agua en Hermosillo, se propone crear instancias institucionales de concertación y toma de decisiones para la planeación y las medidas de ajuste que sean necesarias en el ordenamiento de la cuenca y el crecimiento de la ciudad.

Entre las principales medidas tendentes a crear e impulsar estas instancias de planeación, se identifican las siguientes cinco líneas de actividad:

- <u>Convertir al Consejo Consultivo en una instancia de deliberación y planeación.</u> Esto es: Impulsar la creación y desarrollo de una instancia de planeación del abasto y consumo urbanos de agua a mediano y largo plazo dentro del organismo operador de agua de la ciudad. Esta instancia pudiera ser el consejo consultivo de Agua de Hermosillo el cual, de manera coordinada con el Instituto Municipal de Planeación del Gobierno local, si su presidencia deja de recaer en el presidente municipal y sus miembros son seleccionados con criterios técnicos y ciudadanos por períodos ajenos a los calendarios político-electorales, de manera que tenga una mayor capacidad de planeación y sus decisiones se orienten a la adopción de medidas de mediano y largo plazo.

- Hacer operativo el Consejo de Cuenca del Río Sonora. Estos es: Crear un órgano de deliberación y concertación donde concurran los usuarios del agua de la cuenca y las autoridades hidráulicas a fin tomar las decisiones y medidas para le gestión sustentable del recurso a mediano y largo plazo. Este órgano puede ser un Consejo de Cuenca del Río Sonora que está previsto que desarrolle estas funciones.
- Crear un sistema de información útil, continuo, sistemático y accesible sobre los usos del agua tanto en la cuenca como en la ciudad. Este sistema de información debe estar orientado a la toma de decisiones informada, la planeación y la evaluación de los usos del agua y de las instancias reguladoras del recurso.
- Profesionalizar al organismo operador Agua de Hermosillo. Esto implica en primer lugar que la designación de su director general no se haga por el presidente municipal cada tres años de manera libre y reservada, sino en base a concurso, por una comisión técnica y por períodos más largos que los tres años que duran actualmente los gobiernos municipales. Este tipo de administración en base a desempeño se deberá de replicar en los mandos medios del organismo de modo que se alcance la profesionalización de la gestión urbana del agua. Además, la gestión de los directores generales y de área deberá de ser evaluada periódicamente por instancias técnicas, independientes y externas con base en indicadores previamente establecidos.
- Impulsar la participación ciudadana en la gestión del agua. Esto implica impulsar canales diversos para la participación informada de los medios, los analistas, académicos y ciudadanos interesados en la gestión urbana sustentable del agua en Hermosillo.

¿De qué manera la resiliencia de los recursos hídricos en Hermosillo ante las condiciones climáticas (incluyendo la incertidumbre) puede ser mejorada a través de la integración de la ciencia e información climática en los procesos de planificación?

La resiliencia o capacidad de respuesta y recuperación del medio ambiente de la ciudad de Hermosillo está estrechamente vinculada al desarrollo urbano ordenado de la ciudad. Si se logra moderar y regular el crecimiento, se podrá apoyar y mejorar la resiliencia y la adopción de medidas adecuadas para un desarrollo sustentable más armónico con el medio ambiente y las incertidumbres del cambio climático.

En el esquema de "desarrollo" orientado al aumento de la oferta, los sectores más vulnerables y afectados por la "escasez relativa" son la población pobre y los ejidos periurbanos. Entre la población pobre destaca aquella que carece de las viviendas y del equipo de acondicionamiento adecuados para mitigar el calor y que estimada como la cuarta parte de la población. Esta población habita particularmente en los asentamientos informales, llamados "invasiones", que frecuentemente carecen del servicio de agua corriente y viven en viviendas precarias. El otro grupo vulnerable es el sector rural y semirural que rodea la ciudad en los ejidos periurbanos, cuyas actividades agropecuarias se han visto afectadas por la reducción de su acceso al agua o porque se ha visto obligado a utilizar las aguas residuales no tratadas.

En una mirada general a la gestión del agua y los retos que enfrenta la ciudad de Hermosillo, se puede resumir en los siguientes puntos:

- Ha habido una sobreasignación (concesión excesiva) y una extracción excesiva de derechos tanto de aguas superficiales como subterráneas en los acuíferos que rodean a la ciudad de Hermosillo. Esta sobreasignación se agrava con la proclividad de los concesionarios a extraer más agua de la que tienen concesionada.
- Esta sobreasignación y la excesiva extracción de aguas superficiales aparentemente responden al período de abundancia relativa de aguas de los ochenta y principios de los noventa, pero es motivo de severa crisis en los períodos de sequía y disminución de las lluvias y los escurrimientos de agua.
- La sobreasignación y la excesiva extracción de aguas subterráneas aparentemente responden a conductas individuales de maximización de beneficios que afectan directamente el comportamiento conjunto de los usuarios y produce a mediano plazo el encarecimiento de los costos de extracción y el agotamiento de los acuíferos.
- La sobreasignación y sobrexplotación del agua de la cuenca en torno a Hermosillo afectan directamente y reduce la disponibilidad de agua para la ciudad de Hermosillo.
- La gestión del agua en la ciudad de Hermosillo ha estado orientada principalmente a la construcción de obras de infraestructura de gran ingeniería que aumentan el abasto de agua. Ha sido una gestión orientada a la oferta.

Por otra parte, la gestión del agua en la ciudad de Hermosillo ha descuidado el control de las pérdidas en la red y la administración del consumo (o demanda) por medio de los sectores hidrométricos, la medición, el cobro en base a volúmenes de agua consumidos y la sanción a los que no pagan el servicio.

Los sectores más afectados y vulnerables a la escasez relativa de agua son la población de menores ingresos, sobre todo aquella que carece del servicio, y la población que vive en los ejidos periurbanos que han visto seriamente afectados su acceso al agua, sus actividades agropecuarias y sus modos de vida.

Esta situación se agrava por la ausencia de instituciones que puedan llevar a cabo la planeación y gestión integral de la cuenca y de los consumos urbanos de agua. El Consejo de Cuenca del Alto Noroeste no ha funcionado en lo que respecta a la planeación y diagnóstico de los usos del agua en la cuenca del río Sonora. Igualmente tanto la Junta de Gobierno como el Consejo Consultivo de Agua de Hermosillo están severamente limitados por sus períodos de tres años y por sus facultades legales limitadas.

A fin de ordenar y ajustar la gestión de las extracciones y usos del agua en la cuenca se requiere la gestión integral de la cuenca. Esto implica primeramente hacer un inventario y priorizar los usos agrícolas, urbanos e industriales de agua. Esta gestión deberá además de articularse con la gestión ambiental de la cuenca y su capacidad de sustentación de la vida silvestre como el mantenimiento de los servicios ambientales y recreativos que provee el río Sonora. Además, para alcanzar la gobernabilidad del sector hídrico se debe fomentar la participación efectiva de toda la sociedad,

G. Implicaciones para la planeación y el diseño de políticas públicas

Español/ La concurrencia de los procesos físicos (de los recursos hidráulicos) y de los institucionales en Hermosillo, presentados y analizados en este estudio de caso, aportan bastantes elementos para tratar de contestar las preguntas planteadas al principio (véase la Introducción). Primero, la vulnerabilidad urbana del sector agua en Hermosillo es de origen tanto social como hidroclimático. Aunque la infraestructura urbana puede aliviar temporalmente el estallamiento de una crisis grave, el manejo adaptativo continua siendo un objetivo lejano. Segundo y derivado de lo anterior, la capacidad institucional de Hermosillo para desarrollar estrategias de adaptación para la gestión del agua en un horizonte de 5 a 20 o más años está aún en pañales en cuanto que las autoridades y los ciudadanos están conscientes de los retos y están adoptando medidas adaptativas; sin embargo la puesta en práctica de programas efectivos de adaptación va a requerir un decidido y sostenido compromiso público e institucional. Tercero, los flujos de información científica sobre el clima constituyen una herramienta poderosa, pero todavía subdesarrollada, para enfrentar la variabilidad hidroclimática. Esto se aprecia en la sección titulada "Vulnerabilidad y capacidad adaptativa en Hermosillo." Finalmente, la resiliencia, como la capacidad para responder de manera flexible a los impactos y a los disparadores internos y externos de crisis, actualmente depende de soluciones de infraestructura. Pero, a fin de mejorar la planeación y los resultados a largo plazo, hace falta que se desarrollen mecanismos para la construcción de capacidades, el aprendizaje social y la respuesta adaptativa.

English/ The confluence of physical (water resources) and institutional processes in Hermosillo presented and analyzed in this case study permit greater insight on the questions posed at the outset (see Introducción, above). First, urban water sector vulnerability in Hermosillo is both social and hydroclimatic in origin. Infrastructure development may have temporarily alleviated overt crisis but adaptive management remains an elusive goal. Second and following the observation just made, Hermosillo's institutional capacity to develop adaptation strategies for water development over the next 5 to 20+ years is nascent in the sense that authorities and citizens are acutely aware of the challenges and are grappling with adaptive responses; however, their implementation in effective adaptation programs will required sustained institutional and public commitment. Third, climate science information flows present a powerful, but as yet underdeveloped, tool to address hydroclimatic variability. This is commented on in the previous section titled "Vulnerabilidad y capacidad adaptativa en Hermosillo." Finally, resilience as the ability to respond flexibly to shocks and internal as well as external triggers of crisis currently relies heavily on infrastructure solutions. Capacity building, social learning, and adaptive response mechanisms must be developed to accompany investments in infrastructure in order to improve planning and enhance social outcomes over the long term.

Cuadro 5-10. Resumen de indicadores de vulnerabilidad hídrica urbana.

Tipos de vulnerabilidad	Indicadores	Hermosillo
Demográfica y socioeconómica	Características del crecimiento (actual y proyectado) Niveles de pobreza y desigualdad Vivienda e infraestructura Desarrollo desigual	Patrón de crecimiento rápido y acelerado Alto nivel de pobreza (24por ciento) Asentamientos informales (no planeados) con viviendas precarias, sin infraestructura ni servicios
Biofísica y climática	Variabilidad climática y cambio climático	Altas temperaturas Períodos largos de verano Sequías periódicas Posibilidad de chubascos y tormentas tropicales intensas con inundaciones
Institucional y de gobernanza	Instituciones locales de planeación Gestión integral Conocimiento y transparencia informativa Participación social	Ausencia de planeación efectiva Carencia de instituciones planeadoras Falta de instrumentos para la gestión integral Desvinculación de gestión hídrica e información climática Información dispersa y sin diagnóstico Canales precarios de participación social
Científica y tecnológica	Infraestructura hidráulica Información climática adecuada Utilización de estrategias alternativas de ahorro y conservación	Red de distribución deteriorada y con altos índices de pérdida de agua Sectores hidrométricos subutilizados Bajo nivel (10por ciento) de tratamiento de aguas residuales. Planta proyectada en proceso. Dependencia (actual y futura) de transferencias de agua de otra cuenca Uso limitado de información climática y su vinculación con la disponibilidad de agua en la cuenca Utilización de tandeo, tinacos y dispositivos ahorradores de agua.
Del medio ambiente	Acceso confiable a agua potable y al saneamiento Presencia de enfermedades relacionadas con el clima Salud e impactos en el medio ambiente (ecosistema)	Sectores significativos de población sin servicio de agua entubada y sin conexión al drenaje, sobre todo en asentamientos irregulares (invasiones) Enfermedades gastrointestinales, deshidratación y golpes de calor. Deterioro e impacto ambiental en los usos del suelo en la periferia urbana.

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Acrónimos

AGUAH - Agua de Hermosillo

AUDRI51 - Asociación de Usuarios del Distrito de Riego número 51

CEA - Comisión Estatal del Agua

COAPAES - Comisión de Agua Potable y Alcantarillado del Estado de Sonora

CONAGUA -Comisión Nacional del Agua

CONAPO -Consejo Nacional de Población

CONEVAL - Consejo Nacional de Evaluación de la Política Social

INEGI - Instituto Nacional de Estadística, Geografía e Informática

IPCC - Panel Intergubernamental sobre el Cambio Climático (Intergovernmental Panel on Climate Change)

SPI - Índice Estandarizado de Precipitación (Standarized Precipitation Index)

Abreviaturas

°C, grados centígrados

Km, kilómetros

Lhd, litros por habitante por día=

Lps, litros por segundo

Mm3, millones de metros cúbicos

m3, metros cúbicos

mm, milímetro

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