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

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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...
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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). The undercount has implications

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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. 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). 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).

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2 Informal urbanization has allowed residents who lack credit to become homeowners. Payment plans negotiated by colonia leaders (known as lideres) 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.
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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).
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 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).

![Regional water resources, Ambos Nogales](image-url)

*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). 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. 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 (BEIP), U.S. EPA, SEMARNAT, and NADBank, focus on both sewage treatment and management, and increased access to potable water.

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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.
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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 the 1944 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.

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**Figure 2-6. U.S. institutional environment for transboundary groundwater management in the USCRB.**

Source: Milman and Scott 2010, Figure 2.
Moving Forward from Vulnerability to Adaptation

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).
### Synthesis of Mandate and Activities

<table>
<thead>
<tr>
<th>Entity</th>
<th>Synthesis of Mandate and Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CILA</td>
<td>Ensure compliance with the 1944 treaty, negotiate treaty amendments, maintain hydrologic monitoring stations, manage joint infrastructure, and communicate information across the border.</td>
</tr>
<tr>
<td>PROFEPAL</td>
<td>Ensure pollution control and prevention by enforcing environmental (and water) quality standards.</td>
</tr>
<tr>
<td>CONAGUAL</td>
<td>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.</td>
</tr>
<tr>
<td>Organismo de Cuenca Región II Noroeste</td>
<td>Develop regional water plans, determine water availability, administer water concessions and discharge permits, and coordinate public and private sector activities.</td>
</tr>
<tr>
<td>Consejo de Cuenca</td>
<td>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.</td>
</tr>
<tr>
<td>SAGARPA</td>
<td>Coordinate water use policies and activities related to agriculture and rural development.</td>
</tr>
<tr>
<td>CEASONORA</td>
<td>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.</td>
</tr>
<tr>
<td>OOMAPAS</td>
<td>Provide water, sewerage and wastewater treatment services within the municipality, conduct long-range planning activities, construct and operate infrastructure, and regulate connections to services.</td>
</tr>
</tbody>
</table>

**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’
Moving Forward from Vulnerability to Adaptation

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. 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.

<table>
<thead>
<tr>
<th>Types of Vulnerability</th>
<th>Indicators</th>
<th>Nogales, Ariz.</th>
<th>Nogales, Son.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic and Socioeconomic</td>
<td>Growth characteristics (actual and projected); Poverty and inequality levels; Housing and infrastructure Uneven development</td>
<td>Slow, declining growth pattern; Medium-high average income and municipal budget; Solid, middle-class housing stock and planned subdivisions; ranching</td>
<td>Rapid, accelerated growth pattern; High poverty level; Unplanned informal colonias w substandard hillside housing; lack of infrastructure</td>
</tr>
<tr>
<td>Biophysical and Climatic</td>
<td>Climate variability and climate change</td>
<td>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</td>
<td>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</td>
</tr>
<tr>
<td>Institutional</td>
<td>Scales of interaction; Complexity of arrangements; Degree of transboundary collaboration; Climate information use and flows</td>
<td>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</td>
<td>Fragmented network of transboundary management institutions; Climate information use limited and flows uneven; Shared wastewater plant w Nogales, Ariz., over-capacity</td>
</tr>
<tr>
<td>Scientific and Technological</td>
<td>Hydraulic infrastructure; Climate information adequacy and fit; Reliance on desalination technology to provide limitless supply; Use of alternative conservation strategies</td>
<td>NIWTP expansion and IOI upgrade; Climate information use limited and could be improved; N/A; Sta. Cruz County comprehensive plan highlights urban conservation elements</td>
<td>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)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Reliable access to clean water and sanitation; Presence of climate-related health issues; Ecosystem health and impacts</td>
<td>Water and sanitation access is full-coverage (100%); N/A; Effluent from treatment plant helps sustain riparian habitats on Santa Cruz R.</td>
<td>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</td>
</tr>
</tbody>
</table>
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.
References


U.S. Environmental Protection Agency. (2003). Environmental Pollution and Disease: Links between Exposure and Health Outcomes.


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 Alimentación (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.

<table>
<thead>
<tr>
<th>Colonia/Year Founded/Location/Type</th>
<th>Socio-Economic Level</th>
<th>Residential Hook-up</th>
<th>Access to household water</th>
<th>Strength of Social Network (with pipa)</th>
<th>Legal status</th>
<th>Topography</th>
<th>Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flores Magón/Torres/1996/West</td>
<td>Low</td>
<td>No</td>
<td>Private pipas; Municipal trucks at discount</td>
<td>Strong</td>
<td>Founded by organized land invasion; now a semi-formal settlement; some residents being issued formal titles</td>
<td>Relatively flat, but has roads built in arroyos so highly susceptible to flooding and erosion</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Colinas del Sol/1998/East</td>
<td>Low</td>
<td>No</td>
<td>Municipal trucks at discount</td>
<td>Strong</td>
<td></td>
<td></td>
<td>MEDIUM</td>
</tr>
</tbody>
</table>
Los Encinos/Los Tapiros/1986/West Central

| 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

| 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 available.

\(^1\) 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.
Moving Forward from Vulnerability to Adaptation

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 fed 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 (specifically, 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.

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


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>
<thead>
<tr>
<th>Table 2-A3. Conclusions: Climate Factors and Water Insecurity in Nogales, Son., Colonias.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High temperatures increase demand on water system, resulting in low pressure and less water available in system</td>
</tr>
<tr>
<td>Monsoon seasonal rains and high temperatures lead to high humidity, with potential for public health hazards (e.g., mold growth in Fracc. La Mesa)</td>
</tr>
<tr>
<td>Water scarcity delays water truck services and creates water insecurity in colonias</td>
</tr>
<tr>
<td>Climate factors differentially affect households/colonias with water hook-ups and those without</td>
</tr>
<tr>
<td>Water trucks are a critical safety valve for those with no or limited water service</td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

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.