Chapter 16

Climate Change and U.S.-Mexico Border Communities

COORDINATING LEAD AUTHOR

Margaret Wilder (University of Arizona)

LEAD AUTHORS

Gregg Garfin (University of Arizona), Paul Ganster (Institute for Regional Studies of the Californias, San Diego State University), Hallie Eakin (Arizona State University), Patricia Romero-Lankao (NCAR), Francisco Lara-Valencia (Arizona State University), Alfonso A. Cortez-Lara (Colegio de la Frontera Norte), Stephen Mumme (Colorado State University), Carolina Neri (National Autonomous University of Mexico), Francisco Muñoz-Arriola (Scripps Institution of Oceanography)

REVIEW EDITOR

Robert G. Varady (University of Arizona)

Executive Summary

This chapter examines climate-related vulnerability in the western portion of the U.S.-Mexico border region from the Pacific coast of California–Baja California to El Paso–Ciudad Juárez, focusing primarily on border counties in the United States and municipalities in Mexico. Beginning with a brief overview of projected climate changes for the region, the chapter analyzes the demographic, socioeconomic, institutional, and other drivers of climate-related vulnerability, and the potential impacts of climate change across multiple sectors (e.g., water, agriculture and ranching, and biodiverse ecosystems). The border region has higher poverty, water insecurity, substandard housing,

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Chapter citation: Wilder, M., G. Garfin, P. Ganster, H. Eakin, P. Romero-Lankao, F. Lara-Valencia, A. A. Cortez-Lara, S. Mumme, C. Neri, and F. Muñoz-Arriola. 2013. "Climate Change and U.S.-Mexico Border Communities." In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 340–384. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

and lack of urban planning relative to the rest of the United States, and multiple socioeconomic asymmetries exist between the U.S. and Mexico sides of the border. These asymmetries create challenges for governance, planning, effective communication of climate-related risks, and design of adaptation strategies. Although they represent an important part of the picture, a comprehensive assessment of regional adaptation strategies was not within the scope of the chapter.

The chapter highlights the following key findings relating to climate change and socioeconomic and cultural diversity, water, wetlands ecosystems, and institutions and governance.

- Climate change exposes the populations in the border region to uneven impacts, due to their cultural and institutional diversity and uneven economic development. (high confidence)
- Climate change exposes sensitive wetland ecosystems, which are hotspots of border region biodiversity, to impacts such as reduced precipitation and extended drought. (high confidence)
- Projected climate changes will put additional pressure on severely stressed water systems and may exacerbate existing vulnerabilities relating to water supply and water quality. Cascading effects of additional stress on water systems include: challenges to energy infrastructure, agriculture, food security, and traditional farming and ranching cultures prevalent in the border region. (medium-high confidence)
- Building adaptive capacity to climate change generally benefits from efforts to cooperate and collaborate to resolve trans-border environmental problems, yet asymmetries in information collection, the definition and scope of problems, and language create challenges to effective cooperation and collaboration. (medium-high confidence)
- Institutional asymmetries, including distinctions in governance approaches—centralized (Mexico) versus decentralized (United States)—and institutional fragmentation and complexity, make the task of collaboration daunting, and reduce the potential adaptive capacity in the region. (medium-high confidence)

16.1 Introduction

While the U.S.-Mexico border has been called a "third country" and has been identified as a distinct region (Anzaldúa 1987), the challenges it faces are due in large measure to its high degree of *integration* into global processes of economic and environmental change. The border region is characterized by a so-called "double exposure" (Leichenko and O'Brien 2008)—meaning that environmental change in the region is driven by accelerated processes of global economic integration (such as foreign-owned industries and international migration) coupled with intensive climate change. It is critical to understand the drivers of climate-related vulnerability and capacities for adaptation in the region in the context of the region's distinct history and contemporary challenges, shared climate regime, transboundary watersheds and airsheds, and interdependent economies and cultures.

This chapter defines the border region and how observed climate trends since 1961 and projected climate change conditions have affected or are likely to affect the region. Next, the chapter provides a framework to understand climate-related vulnerability, adaptive capacity, and adaptation, and examines the major drivers (forces) that lead to vulnerability and the evidence of sectoral impacts of climate change resulting in vulnerability in the border region.

There are three important caveats as to the scope and analysis of this study. First, consistent with the risk-based vulnerability framework suggested by the National Climate Assessment, this discussion assesses the sensitivity, exposure, and capacity for response for a given population or sector. The evidence for this analysis is based on qualitative and (to a lesser extent) quantitative studies in specific contexts within the border region. With regard to the climatology, vulnerability, consequences, and impacts, there are no comprehensive studies that encompass the western portion of the U.S.-Mexico border. The highlighted vulnerabilities presented in the executive summary are those that are sustained by strong evidence from multiple contexts within the region. In most cases (especially drawing on qualitative studies), while the evidence of a vulnerability, impact, or consequence may be strong, it is often not sufficiently calibrated to assess degrees of exposure or sensitivity (of populations or sectors) to a climate risk. Thus, to a large extent, there is an imperfect fit between the kind of evidence available and the requirement to assess precisely the relative exposure and sensitivity. Second, for the purposes of this report, this chapter analyzes and highlights those areas of vulnerability (e.g., urban, agriculture, socioeconomic) judged to be of paramount importance and for which there is robust evidence, while excluding other important regional vulnerabilities (such as health and livelihoods). Third, this chapter focuses on assessing *key vulnerabilities*. It is not within the scope of this chapter to fully represent the adaptation activities—ongoing or planned—that may aid in reducing these vulnerabilities, but some are discussed here. (See also Chapter 18 for a general overview of solutions and choices for responding to climate change in ways that reduce risks and support sustainable development.) Throughout this chapter, four callout boxes present evidence of successful trans-border cooperation or collaboration. Collaboration is a significant component for strengthening the region's adaptive capacity and for building resilience.

16.2 Definition of the Border Region

The analysis here focuses on the U.S.-Mexico border—delimited for the purposes of this chapter to the western portion of the border from San Diego-Tijuana on the Pacific coast to the Paso del Norte area[i] of the Rio Grande—which has been identified as a distinct region that serves as the interface between Mexico and the western United States (Ganster and Lorey 2008) (Figure 16.1). The western portion of the border region corresponds to the definition used in the National Climate Assessment (NCA) for the Southwest region, which includes among the U.S. border states only California, Arizona, and New Mexico (and excludes Texas, which is part of the NCA's Middle West region). Nevertheless, this analysis incorporates the Paso del Norte corridor due to its key importance in the New Mexico portion of the border region.

Figure 16.1 Western portion of the U.S.-Mexico border region. Source: EPA (2011).

Most of the border's population is concentrated along the international boundary in fourteen city pairs (eight of them in the western portion)[ii] that constitute binational urban systems. Rural population is scarce except for the irrigated areas of the Colorado River and the Imperial-Mexicali valleys.

The border region can be defined in a number of ways (Ganster and Lorey 2008; Varady and Ward 2009). These include the six Mexican and four U.S. border states, the region of shared culture and language bisected by the border, the watersheds and subbasins along the boundary, the 62-mile zone (100 kilometers) on each side of international line as defined by the La Paz Agreement between Mexico and the United States, or by the administrative boundaries of the U.S. counties and the Mexican municipalities (*municipos*) that abut the international boundary. This chapter covers three U.S. states (California, Arizona, and New Mexico), the El Paso corridor, and three Mexican states (Baja California, Sonora, and Chihuahua). For present purposes, the latter category—border counties and municipios—is most important in terms of societal vulnerability to climate change, given the border population concentration in major urban areas. While the focus is on the region that includes the counties and municipalities along the border, data from these local administrative units are supplemented with state-level data.

16.3 Border Region Climate Variability, Climate Change, and Impacts

The border region considered here is characterized by high aridity and high temperatures. Typically, about half of the eastern part of the region's precipitation falls in the summer months, associated with the North American monsoon, while the majority of annual precipitation in the Californias falls between November and March. The region is subject to both significant inter-annual and multi-decadal variability in precipitation.[iii] This variability, associated with ENSO, has driven droughts and floods and challenged hydrological planning in the region.[iv] Further challenging this understanding is a paucity of data, particularly on the high-altitude mountainous regions in northern Mexico. Differences in the availability of high-quality and continuous meteorological and hydrological records spanning long periods of time, and relatively poor data sharing complicate understanding of the border region's climate. The scarcity of such data makes it difficult to verify climate model projections at fine spatial scales.

Also, reconciling differences in projected changes in temperature, based on global climate model (GCM) studies conducted separately by U.S. and Mexican scientists (Table 16.1),[v] is complicated by the fact that (1) they use different sets of models from the IPCC Fourth Assessment archive; (2) they use different methods of downscaling output from coarse spatial scale models to finer regional spatial scales;[vi] (3) in some cases they do not use the same greenhouse gas (GHG) emissions scenarios; (4) they average future projections for different spans of years; and (5) they use different spans of years for providing a measure of average historical climate. High quality data are essential for statistically downscaling GCM output. Thus, issues with meteorological observations add to several other sources of uncertainty (see discussion in Chapters 2 and 19).

Table 16.1 Summary of projected changes in selected climate parameters

Projected Change	**Direction of Change**	**Border Subregion Affected**	**Confidence**
Average annual temperature	Increasing	Throughout the border region; lowest magnitude of increase is near the coast; greatest is Arizona-Sonora border or New Mexico-Chihuahua border	High
Average summer temperature	Increasing	Throughout the border region; greatest increases in the Sonoran Desert border region	High
Average winter temperature	Increasing	Throughout the border region; greatest increases in the Sonoran Desert border region	High
Average annual maximum temperature	Increasing	Throughout the border region; greatest increases in the eastern Chihuahuan Desert; only estimated south of the border	Medium-High
Average annual minimum temperature	Increasing	Throughout the border region; greatest increases in the Sonoran Desert; only estimated south of the border	Medium-High

Table 16.1 Summary of projected changes in selected climate parameters (Continued)

Projected Change	Direction of Change	Border Subregion Affected	Confidence
Length of freeze-free season	Increasing	Throughout the border region; only estimated north of the border	Medium-High
Annual number of days with maximum temperatures > 100°F	Increasing	Throughout the border region; greatest increases in the central Sonoran Desert border and in northwest Chihuahua	Medium-High
Heat wave duration	Increasing	Throughout the border region	High
Cooling degree days	Increasing	Throughout the border region	High
Cold episodes	Decreasing	Throughout the border region	Medium-High
Annual precipitation	Decreasing	Greatest decreases along the coast and parts of the Arizona-Sonora border	Medium-High
Winter precipitation	Decreasing	Greatest and most consistent decreases (over time) are projected for the Arizona-Sonora border, into the western Chihuahuan Desert	Medium-Low
Spring precipitation	Decreasing	Occurs along the length of the border, from CA coast to NM-TX border (based on studies that only examine the U.S. side of the border)	Medium-High
Summer precipitation	Decreasing	Mid-century decreases are greatest for the Sonoran Desert border region	Medium-Low
Drought	Increasing	Throughout the border region; increasing markedly during the second half of the twenty-first century	High
Colorado River streamflows	Decreasing	Measured at Lees Ferry, AZ	High

Note: See Chapters 2 and 19 for a discussion of how confidence levels are assessed.

Temperature

Overall, climate models show trends of increasing temperatures for the border region; this result is robust throughout the course of the twenty-first century, regardless of which combinations of models, downscaling method, and emissions scenario were used (Tables 16.1 and 16.2 and IPCC 2007b).[vii] For the border region, average annual temperatures are projected to increase on the order of 2°F to 6°F (1°C to 3.5°C) during the mid-century time frame (around 2041–2070, according to the high-emissions scenario), with the greatest increases inland (see Chapter 6, Figure 6.1 and Magaña, Zermeño, and Neri 2012). The magnitude of temperature increases is greatest during the summer, as high as 6°F to 7°F (3°C -4°C) during the mid-century, with areas of especially high increases concentrated in the western Sonoran Desert (Montero and Pérez-López 2010) and the northern Chihuahuan Desert (see Chapter 6, Figures 6.1 and 6.8).[viii]

Associated with the maximum and minimum temperature projections are an array of projections for derived parameters and temperature extremes (Table 16.1). Some key derived and extreme temperature projections include large projected increases in cooling degree days in Southern California and Arizona (up to 100 degree days, using a 65°F (18°C) baseline; see Chapter 6), large increases in the annual number of days with maximum temperatures greater than 100°F (38°C), including increases of more than 30 to 35 days in the central Arizona and northwest Chihuahua border regions (see Chapter 6 and Figure 16.2), increased heat wave magnitude (but with more humidity, therefore having a larger impact on nighttime minimum temperatures; see Chapter 7),[ix] and diminished[x] frequency of cold episodes (see Chapter 7).

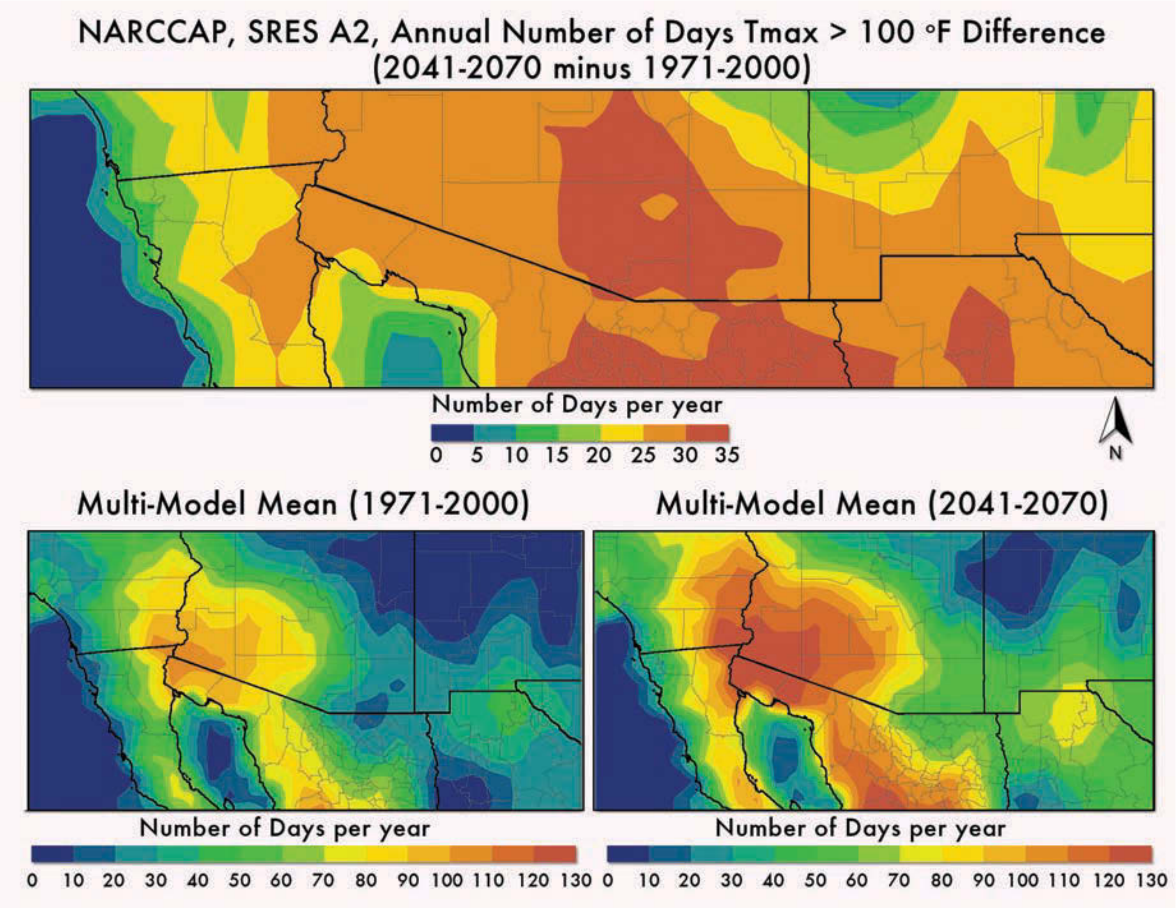

Figure 16.2 Change in the number of days with a maximum temperature greater than 100°F (38°C). The top map shows the change between the NARCCAP (Mearns et al. 2009) multi-model average for 1971–2000 (lower left) and the average for 2041–2070 (lower right). Map generated by Laura Stevens.

Table 16.2 Projected mean annual temperature increases (in °F) in comparison to 1971–2000 along the U.S.-Mexico border, from the California coast to the New Mexico-Texas border

Period	Higher Emissions (SRES A2) Projected Temperature	Lower Emissions (SRES B1) Projected Temperature
2021–2050	2–3°	2–3°
2041–2070	4–5°	3–4°
2070–2099	7–8°	4–5°

Note: Based on studies that only examine the U.S. side of the border

Source: Kunkel (2011).

Table 16.3 Mean temperatures for 1961–1990 (in °F) and projected changes under the high-emissions scenario for 2061–2090, averaged for the Mexican border states

State	1961–1990			2061–2090		
	Winter	Summer	Annual	Winter	Summer	Annual
Baja California	56.2°	83°	69.3°	+5.2°	+5°	+5.2°
Sonora	54.6°	82°	68.2°	+5.9°	+6.5°	+6.4°
Chihuahua	48.1°	76.8°	62.8°	+5°	+4.9°	+5.1°

Source: Montero and Pérez-López (2010).

Precipitation

Future precipitation in the border region, as projected by climate models, is dominated by a continued high degree of annual precipitation variability, indicating that the region will remain susceptible to anomalously wet spells and also remain vulnerable to drought (see Chapters 6 and 7). Precipitation projections have generally low to medium-low confidence, due to variability over shorter periods and the lack of firm consensus among GCM simulations. Nevertheless, spring precipitation is projected to decrease in all but one of sixteen models, exacerbating dryness in the border region's driest season and probably aggravating the dryness that initiates the summer period. Areas that are already prone to little precipitation are expected to see longer runs of days with little or no precipitation.

There is greater confidence in projections of decreased annual precipitation as one moves south. Statistically downscaled studies by Mexican scientists (under the high-emissions scenario) confidently project border region annual precipitation decreases of more than 20% by mid-century, with the largest seasonal decreases projected for winter in the Arizona-Sonora border region (Montero and Pérez-López 2010; Magaña, Zermeño, and Neri 2012).[xi]

Drought

Seager and colleagues (2007) project (under high-emissions SRES A1b) increased drought for a region that encompasses the border region.[xii] Their projections have been confirmed in subsequent studies (e.g., Seager et al., 2009), and independently by Magaña, Zermeño, and Neri (2012).[xiii] Cayan and others (2010) describe a tendency for intensified dryness in hydrological measures in the Southwest from downscaled climate model projections. In the first half of the twenty-first century, Magaña, Zermeño, and Neri's (2012) drought projections exhibit high interannual and multidecadal variability, characteristic of the region.[xiv] Dominguez, Cañon, and Valdes (2010) note that La Niña episodes, which are associated with drought in the border region, may become warmer and drier in the future.

We find that the results of these studies, in conjunction with the temperature and precipitation projections of Montero and Pérez-López (2010) and projections for the U.S. side of the border (summarized in Chapter 6), provide a compelling case for an increased likelihood of drought, with ramifications for northern Mexico water supplies (Magaña, Zermeño, and Neri 2012) and probably for groundwater recharge (e.g., Serrat-Capdevila et al. 2007; Earman and Dettinger 2011; Scott et al. 2012).[xv] Moreover, these assessments are consistent with projections of streamflow for trans-border rivers, such as the Colorado River and Rio Grande (known as the Río Bravo in Mexico, and hereafter Rio Grande), which show decreasing streamflow, lower flow extremes during drought, and potential water resource deficits greater than those previously observed (see Chapters 6 and 7; Hurd and Coonrod 2007; Reclamation 2011).

16.4 Understanding Vulnerability, Risk, and Adaptive Capacity in the Border Region

Definitions and concepts

Vulnerability to climate variability and climate change is the experience (by an individual, household, ecosystem, community, state, country, or other entity) of negative outcomes due to climate stresses and shocks (Leichenko and O'Brien 2008). Experts have approached vulnerability in two distinct but related ways. One approach centers on the underlying political and socioeconomic structures, institutions, and conditions that affect vulnerability, including asymmetries in power and resource distribution (e.g., Adger 2006; Eakin and Luers 2006; Lahsen et al. 2010; Ribot 2010; Sánchez-Rodriguez and Mumme 2010). Vulnerability may be reduced through poverty alleviation and development strategies in developing countries with persistent inequalities (Seto, Sánchez-Rodriguez, and Fragkias 2010). A second approach centers on developing systematic measures of climate-related *risk* in a system, calibrated by exposure and sensitivity (of actors at multiple scales, including households and neighborhoods to cities, states or countries) and the coping (or adaptive) capacity to deal with it (Yohe and Tol 2002; NRC 2010; Moss 2011). Adaptive capacity is the ability (of a household, community, or other unit of organization) to reduce its vulnerability to climate-related risks through coping strategies such as application of social, technical, or financial resources (Yohe and Tol 2002; NRC 2010). Consistent with the NCA framework, the analysis presented here uses the second, risk-based approach, but draws on both types of approaches to provide evidence for its conclusions.

This analysis uses the IPCC definition that "vulnerability is a function of character, magnitude and rate of climate change to which a system is exposed, as well as the system's sensitivity and adaptive capacity" (IPCC 2007a, 6). Risk embodies the likelihood of harm plus the consequences; thus the consequences of a harm occurring are embedded within the concept of vulnerability. Vulnerability to a climate-related risk is mediated by *sensitivity* (for example, by the degree of dependence on resources and activities that are impacted by climate change and non-climate parameters), by *exposure* (for example, the probability of experiencing change in non-climatic and climatic factors), and by *capacity* to cope or to adapt (for example, the demographic, socioeconomic, institutional and technological characteristics that enable response to stress). In general, where resources for coping are relatively abundant, vulnerability is relatively low; but where resources for coping effectively are lacking, vulnerability is typically high. This definition characterizes vulnerability both in terms of stressors and the stressed. Stressors here are regarded as the interactions of economic and cultural globalization, demographic change, and climate change. The vulnerability of the stressed border region includes both the specific attributes of the place and population that transform those stressors into specific risks that threaten the quality of life and the capacities to effectively cope with such stressors. Capacity can be considered a function of assets—financial, material, natural, human, political and social—as well as knowledge, perception of risk, and willingness to act (Grothman and Patt 2005; Moser and Sattherwaite 2010).

The primary determinants and outcomes of vulnerability can vary across scales (from local to international). Vulnerability is ultimately a nested phenomenon in which the impacts and adaptive actions taken at one scale can have ramifications for the whole system (Adger et al. 2009; Eakin and Wehbe 2009). Institutions (the rules, norms and regulations that govern the distribution of resources and their management) are instrumental in mediating risks. Effective cross-scalar governance is thus a critical element of addressing vulnerability (Adger, Arnell and Tompkins 2005), particularly in the border region where trans-border collaboration at multiple governance scales is critical. Trans-border collaboration among formal government agencies and informal governance stakeholders may help reduce regional vulnerability through a shared understanding of the priority vulnerabilities, shared data, and cooperative means of reducing these vulnerabilities (Wilder et al. 2010).[xvi] While non-collaboration has led to less than optimal outcomes in the past (see Box 16.1 for a case study on collaboration and non-collaboration), collaboration may help to reduce regional climate-related vulnerability and to promote appropriate adaptive strategies for the border region (see Box 16.2 for an example on the Colorado River Joint Cooperative Process in the Colorado River delta).

Collaboration takes place at multiple scales in the border region, ranging from formal intergovernmental collaborative agreements (such as the U.S.-Mexico Transboundary Aquifer Assessment Program) to informal networks of local water managers working with the climate research community to develop regional adaptive strategies (such as the Climate Assessment for the Southwest Program in Arizona and New Mexico).

Box 16.1

Case Study 1: Why Is Trans-border Collaboration Important?

Transboundary cooperation to address the impacts of climate variability and climate change is essential to promoting the best outcomes and to building regional adaptive capacity on both sides of the border. Despite formal agreements between the United States and Mexico to cooperate to resolve key transboundary environmental problems (e.g., La Paz Agreement; Minute 306), there are recent important examples where lack of cooperation has led to suboptimal (e.g., win-lose rather than win-win) outcomes:

- In 2002, Mexico invoked its privilege to declare conditions of "extraordinary drought" on the Rio Grande and withheld delivery of irrigation water to Texas farmers, causing millions of dollars in losses.
- When the United States extended the security fence at the border between Nogales, Arizona, and Nogales, Sonora, it was done without reference to local hydrological conditions and without input from officials on the Mexico side. Floodwaters in 2008 became impounded behind the fence on the Nogales, Sonora side of the border, causing millions of pesos worth of damage in Sonora.
- The lining of the All-American Canal (AAC) was completed in 2008, under formal protest and after legal challenges by Mexican and U.S. groups. The change resulted in increased water for households in San Diego County and decreased water for farmers in Baja California. Farmers in the irrigation district of Mexicali had used groundwater recharged by seepage flows from the earthen-lined canals for over sixty years, and concrete-lining of the AAC stopped groundwater recharge and therefore reduced groundwater availability.

Despite these examples of non-collaboration, the trend toward transboundary collaboration has been strong over the last twenty-five years and examples of successful collaboration to reduce environmental vulnerability abound:

- **Emergency Response.** The Border Area Fire Council (BAFC) provides collaborative emergency fire services on both sides of the California-Baja California border. The BAFC was formed during the 1996 fire season to facilitate cross-border assistance for wildfire suppression (GNEB 2008). Operating under a mutual assistance agreement that is updated periodically, BAFC has improved communications across the border, held many joint training exercises, implemented fire safety campaigns on both sides of the border, coordinated development and maintenance of fire breaks along the border, and jointly conducted prescribed burns along the border. BAFC operates in a number of natural protected areas in the region and has improved awareness and protection of biodiversity. It includes more than thirty federal, state, and local organizations representing fire protection, law enforcement, elected officials, the health sector, natural resource managers, and others from both sides of the border. Examples of BAFC's efforts include assistance in the fall of 2007 when sixty

Box 16.1 (Continued)

Baja California firefighters crossed the border to help with the San Diego County firestorm. Previously in June 2006, ten engines and crews from the California Department of Forestry and Fire Protection had crossed into Baja California to support Mexican fire authorities for six days with a fire that burned 5,200 acres.

- **Scientist-Stakeholder Research.** The Climate Assessment for the Southwest (CLIMAS) at the University of Arizona is a NOAA Regional Integrated Science Assessment program, focused on Arizona and New Mexico. The program brings together scientists and researchers from many disciplines in the natural and social sciences with citizen groups and decision makers to develop a better fit between climate science products (such as forecasts and projections) and the resource managers (such as water or forest managers) and decision makers who use the data. Since 2005, CLIMAS has actively worked with partners at the Colegio de Sonora, Universidad de Sonora, and other Mexican institutions of higher learning to build regional adaptive capacity in the border region via the bilingual Border Climate Summary, workshops with stakeholders and researchers, webinars, and fieldwork focused on identifying common understandings of regional vulnerability and appropriate adaptive strategies. Other funding partners who have collaborated in these projects include the Inter-American Institute for Global Change Research and NOAA's Sectoral Applications Research Program.
- **Trans-border Data Sharing.** The U.S.-Mexico Transboundary Aquifer Assessment Program (TAAP), authorized by U.S. federal law and supported institutionally and financially by both the U.S. and Mexico, is a successful binational program focused on the assessment of shared aquifers. Although the United States did not appropriate funds for TAAP in fiscal year 2011/2012, during this period the Mexican government began funding assessment activities on its side of the border. TAAP is implemented by the U.S. Geological Survey and the state water resources research institutes of Arizona, New Mexico, and Texas, with collaboration from Mexican federal, state, and local counterparts, as well as IBWC and CILA. Two central aims of TAAP include the scientific assessment of shared groundwater resources; and development of dual adaptive-management strategies through expanded binational information flows and data exchange (Wilder et al. 2010; Megdal and Scott 2011). Mutually defined priorities for Arizona's and Sonora's common Santa Cruz and San Pedro aquifers, for example, are meeting human and ecosystem water requirements in the context of growth and climate change (Scott et al. 2012). TAAP is a model of successful trans-border cooperation in data sharing and assessment that supports water-management decision-making in both countries and enhances the adaptive capacity of the region in the face of climate change.

Key drivers of border vulnerability

Growth trends, urban development patterns, socioeconomic factors, and institutions and governance mechanisms can be drivers of border region vulnerability.

CONTEXT-SHAPING VULNERABILITY. Today, rapid growth and uneven economic development are two major contributors to climate-related vulnerability. Institutional asymmetry and governance fragmentation on both sides of the transboundary region create challenges for reducing vulnerability and for trans-border cooperation. Multiple characteristics define the border region, including high rates of poverty in a landscape of uneven economic development; diverse ethnic identities; environmental, social, economic, and cultural interdependency; and rapid growth and urbanization relative to both U.S. and Mexico averages.

Box 16.2

Case Study 2: Colorado River Joint Cooperative Process

Trans-border collaboration is playing a significant role in addressing environmental challenges in the Colorado River delta. The Colorado River Joint Cooperative Process (CRJCP) formed under the auspices of the International Boundary and Waters Commission (IBWC) and its Mexican counterpart (Comisión Internacional de Límites y Agua, CILA) in 2008 to develop "binational processes for meeting municipal, agricultural, and environmental needs" in the delta (Zamora-Arroyo and Flessa 2009). The CRJCP includes government agencies, NGOs, and water stakeholders from both countries. The CRJCP has a difficult task ahead, given that excess flows from the United States are likely to be eliminated in the near future, operational losses are likely to decrease, groundwater supplies will be reduced, and agricultural return flows are likely to decrease as water moves from agriculture to the cities (Zamora-Arroyo and Flessa 2009). The supply of municipal effluent is likely to increase, however, although it may be captured for urban use rather than for ecological flows. A new treaty Minute (Minute 319) adopted on November 20, 2012 establishes a new commitment by the U.S. and Mexico to cooperate around water and ecological needs in the region. The CRJCP is a collaborative model for other trans-border areas and issues. Although it ultimately received formal federal approval in both the United States and Mexico, the CRJCP originated from an informal coalition of local stakeholders that led ultimately to the formal collaborative process.

HISTORY. Tribal peoples occupied the border region for many thousands of years before the arrival of Spanish, Mexicans, and then Americans to the area (see also Chapter 17).[xvii] Today there are twenty-three Native nations on the U.S. side in the border region, and about eight indigenous groups on the Mexican side (Starks, McCormack, and Cornell 2011); some of these peoples (such as the Kumeyaay, the Cocopah/Cúcapa, the Yaquis, and the Tohono O'odham) continue to have strong trans-border ties. They manage diverse lands and water and economic resources in the border region. Spanish colonizers in the sixteenth century expropriated significant land and resources, and mestizos, whose land use practices combined Indian and Hispanic traditions, settled in the border and created many of the current border towns. English-speaking colonizers of the United States introduced their beliefs of commercial capitalism and the frontier vision to land use and resource practices in the nineteenth century. The successive arrival of farmers, workers, investors, migrants, and bureaucrats has continually transformed the border over the last 100 years and created one of the most dynamic and diverse sociocultural landscapes in the world. The diversity of the border region's population—including differences in languages used at home and access to technology—challenges effective communication about climate-related risk.

CONTEMPORARY TRENDS. Currently, most of the U.S.-Mexico border population is concentrated in fourteen fast-growing, paired, adjacent cities with a common history, strong interactions, and shared problems (CDWR 2009). Eight of these binational pairs are on the western end of the border in the area included in this chapter (see Figure 16.3). In 2002, there were approximately 1 million (legal) border crossings daily by residents in the border's twin cities to work, shop, attend classes, visit family, and participate in other activities (GAO 2003); the number of crossings declined to half a million by 2010. Mexican border towns are part of a very centralized national political system, suffer from limited fiscal resources, and lack a tradition of urban planning. Across the border, U.S. towns have had greater political autonomy, are part of a strong and stable national economy, and have broadly applied land use planning and supplied basic infrastructure and services to their residents. Thus, the "twin cities" along the U.S.-Mexico border are places of encounter but also of intense political, social, and physical contrasts.

The per capita income within the U.S. border counties is only about 85% of the U.S. per capita income. If wealthy San Diego County is excluded, the GDP per capita of the border region is only about 64% of the national level (2007 data). In 2006, if the twenty-four U.S. counties along the border were aggregated as the fifty-first state, they would rank 40th in per capita income, 5th in unemployment, 2nd in tuberculosis, 7th in adult diabetes, 50th in insurance coverage for children and adults, and 50th in high school completion—all characteristic of regions of poverty (Soden 2006; and www.bordercounties.org). In the 2010 U.S. Census, Arizona and New Mexico were tied for the fourth-highest poverty level in the United States.

DEMOGRAPHIC DRIVERS. The binational border region from San Diego-Tijuana to Paso del Norte is demographically dynamic, growing much faster than the average of either nation (Figure 16.4).

Since 1970, the U.S. side of the border region has attracted huge flows of domestic migrants—mostly non-Hispanics, seeking a Southwestern "sunbelt" lifestyle (and climate), retirement, or job opportunities—and international immigrants—mostly from Mexico and Central America, seeking jobs and economic opportunities. Between 1983 and 2005, the population almost doubled (from 6.9 million people to over 13 million). Since the economic recession began in 2007–2008, however, growth rates have declined in border states, except Texas (Cave 2009; Frey 2011).[xviii] Growth rates have also declined in many border counties. For example, growth slowed in the counties bordering Sonora, from a rate of 5.3% between 2000 and 2005 to 1.6% between 2007 and 2008 (Mwaniki-Lyman, Pavlakovich-Kochi, and Christopherson, n.d.).

Population projections for the region (reported in USEPA's 2006 *State of the Border Region*) estimate that the region's population will grow to between 16 million and 25 million people by 2030, an increase of 46% (based on the medium scenario analyzed). Declining growth rates since the onset of recession in 2008 may represent slower than projected regional growth.

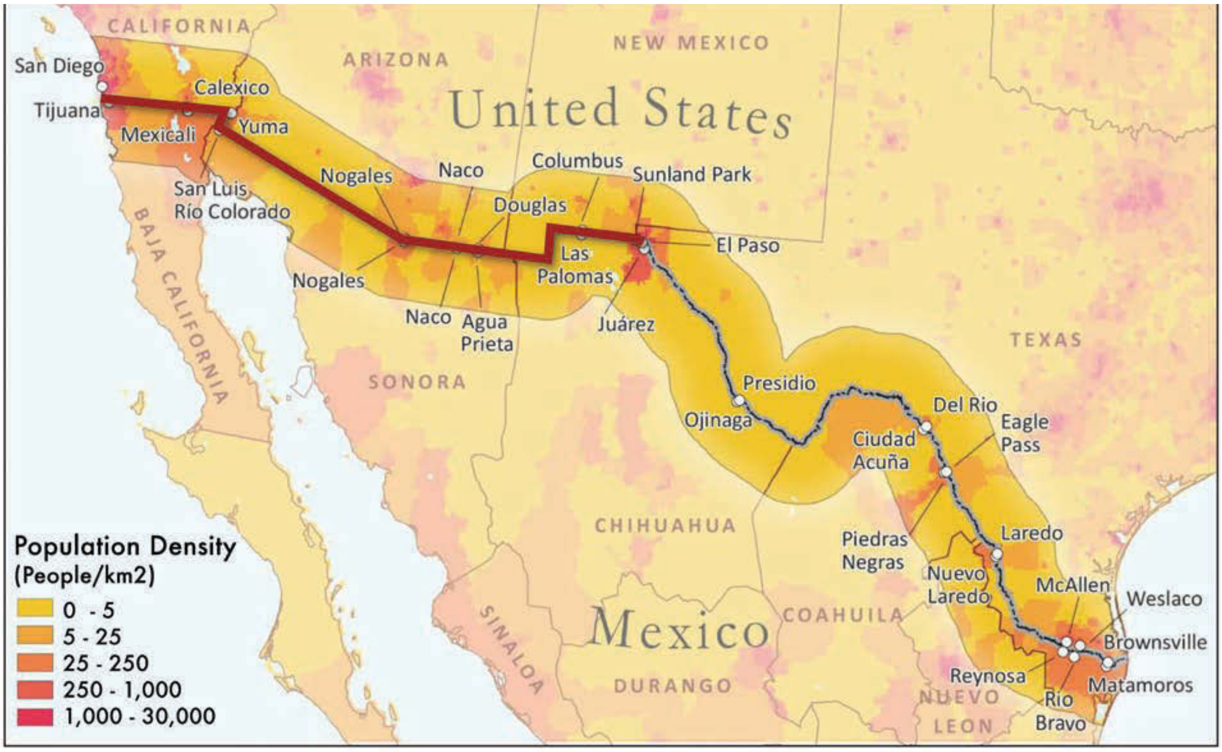

Figure 16.3 Population density in U.S.-Mexico border region. Population density shading refers to the areas on either side of the border, and not the borderline. Reproduced from EPA (2011).

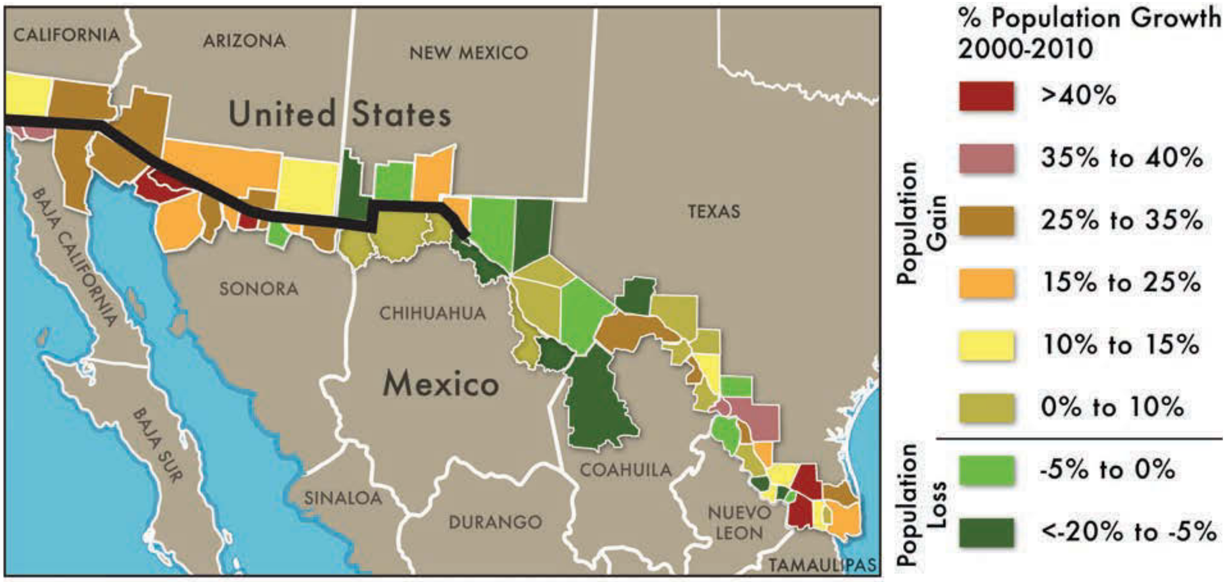

Figure 16.4 Population growth in the western portion of the U.S.-Mexico border region (2000–2010). Adapted from Good Neighbor Environmental Board 14th Report (GNEB 2011). Source: U.S. Census Bureau and Instituto Nacional de Estadistica y Geografia (INEGI).

Ninety percent of the border population resides in cities and the remaining 10% live in smaller tribal and indigenous communities or in rural areas. Over 40% of the region's population resides in California and Baja California, which are home to the major border cities of San Diego, Tijuana, and Mexicali (EPA 2011). Most population growth in the next few decades will occur in mid-size and large urban centers, intensifying border urbanization and metropolization (Lara et al. 2012). Especially on the Mexican side, the pace of urban growth will be highest in the large border cities and municipalities: the proportion of population living in urban Mexican centers with more than 500,000 people is predicted to rise to 58.1% in 2030, from about 44.6% in 2005 (CONAPO 2007). Already, cities like Ciudad Juárez, Chihuahua, and El Paso, Texas, are practically "fused" or continuous across the border and are merging with adjacent cities and towns forming trans-border metropolitan corridors.

This analysis indicates that in the future, exposure to climatic stress will not only increase with population growth, particularly in urban areas, but sensitivity may also increase through water-food-energy dependent growth trajectories that will be sensitive to climatic disturbance. Sustainable growth will be critical for adaptation.

Socioeconomic drivers

Multiple studies have identified the border as a region of high social vulnerability due to intersecting processes of rapid growth, domestic and international migration, economic intensification and globalization, and intensive climate change (Liverman and Merideth 2002; Austin et al. 2004; Varady and Morehouse, 2004; Hurd et al. 2006; Ray et al. 2007; Collins 2010; Jepson 2012; Wilder et al. 2010; Wilder et al. 2012). Climate impacts are not uniformly distributed across populations and space but instead affect specific vulnerable populations and places (Romero-Lankao et al. 2012).

Ethnicity is a significant factor in sensitivity and exposure to climate-related risk (Verchick 2008; Morello-Frosch et al. 2009). Hispanics are the largest ethnic group in the border region and in 2008 were 42.2% of the population of the U.S. border counties in the study area; if San Diego with its large non-Hispanic population is excluded, then the U.S. border region is 55.7% Hispanic.[ixx] In California, for example, Latino and African-American communities were found to be more vulnerable to heat exposure and heat stress than the state population as a whole (Morello-Frosch et al. 2009). Research in the South and in the Southwest United States documents a higher climate vulnerability among Latino and African-American populations due to relatively low incomes, substandard housing, structure of employment (e,g, outdoor laborers in landscaping and construction), lack of affordability of utility costs, and lack of transportation (Vásquez-León, West, and Finan 2003; Verchick 2008; Morello-Frosch et al. 2009). Minority communities have a greater exposure to the urban heat island effect and suffer more health problems due to poorer air quality and concentration of industrial uses in the areas where they live (Harlan et al. 2008; Ruddell et al. 2010).

The diverse cultural meanings and practices associated with resource allocation and management traditions (Sayre 2002; Sheridan 2010) are also likely to affect adaptation. For example, the water resources in the Rio Grande Valley, which bisects New Mexico, are challenged by multiple sector claims and increasing demand associated with population growth. These water resources must also serve the traditions and economic needs of Native American tribes and pueblos, and flow through traditional *acequias*—canals—the lifeblood of four-hundred-year-old Hispanic communities (Hurd and Coonrod 2007; Perramond 2012).

In general, climate change research has paid limited attention to socioeconomic vulnerability and adaptation in human communities. This analysis indicates that in the future an increasingly diverse population will be exposed to climatic stress (e.g., floods, storms, hurricanes [in coastal areas], heat waves, and drought) with implications for the languages and technologies used to communicate about climate risks and hazards that affect the region (Vásquez-León, West, and Finan 2003; Morello-Frosch et al. 2009; Wilder et al. 2012). In addition, development initiatives (such as infrastructure, sewerage networks, and improved housing) to address uneven development are critical to future adaptation.

Urbanization, infrastructure, and economy

Regional impacts associated with the climate changes described in Table 16.1 increase the stresses on urban infrastructure (such as energy for cooling) and water (to meet both consumptive and nonconsumptive demands for energy generation), exacerbate air pollution, create public health challenges associated with heat waves, and cause increased demand for urban green spaces. These concepts are explored further in Chapter 13.

Urban vulnerability is structured not only by demographic change, but rather occurs in multiple sectors, including the built environment and urban economy (Romero-Lankao and Qin 2011), especially with the increasing urbanization of poverty (Sánchez-Rodriguez 2008). Three processes of urban change at the city level have relevance for understanding and managing risks from climate variability and climate change generally and in the border region. First, cities have expanded into areas that are prone to droughts, heat waves, wildfires, and floods (Collins, Grineski, and Romo Aguilar 2009; Moser and Sattherwaite 2010; Seto, Sánchez-Rodriguez, and Fragkias 2010). Second, large sections of the urban population along the U.S.-Mexico border live in unplanned communities in "informal" housing, lacking the health and safety standards needed to respond to hazards, and with no insurance (Collins, Grineski, and Romo Aguilar 2009; Wilder et al. 2012). Third, characteristics of the built environment (such as the heat island effect, high levels of atmospheric pollutants, impervious surfaces, and inadequate drainage systems) can amplify the impacts of high temperatures, storms and other hazards associated with climate change (Wilbanks et al. 2007; Romero-Lankao and Qin 2011). While the urban infrastructure of many urban areas on the U.S. side of the border needs major upgrades to prepare for likely climate change impacts (Field et al. 2007), many Mexican cities have the additional burden of overcoming development deficits. Among these deficits are inadequate all-weather roads, lack of paved roads, poor water treatment (lack of water treatment plants or treatment plants with insufficient capacity for drinking water and sewage); decaying water infrastructure, and institutional constraints such as lack of financing from taxes, uncoordinated planning, and competition among agencies for agendas and resources.

Even at the neighborhood scale, certain characteristics of the built environment can amplify risks. For instance, studies showed variations in vegetation and land-use patterns across Phoenix produce an uneven temperature distribution that was correlated with neighborhood socioeconomic characteristics. In other words, affluent areas were less densely settled, had lower mean temperatures, and thus had lower vulnerability to heat stress, while low-income areas had more rental housing, greater prevalence of multi-generational families sharing a household, and a higher prevalence of non-English language speakers (Harlan et al. 2008). These findings point to the need for climate hazards and risks to be communicated to the public in a way that respects the diversity of media, technology, and languages in used in the region. In the long run, these problems could be reduced through improved urban development and investment in marginalized areas.

INFRASTRUCTURE. Dense urban areas in the border region contain substantial populations who are vulnerable to natural disasters linked to climate change because they live in substandard housing in floodplains or on steep slopes or in housing located in areas on the urban periphery that are susceptible to wildfires (GNEB 2008). Tijuana and Nogales, two border cities experiencing rapid population growth, have received an influx of immigrants seeking employment in the maquiladora industry. Many settle in informal (unplanned) colonias (border-region residential communities that are economically distressed and usually underserved by infrastructure) with unsuitable topography, characterized by steep slopes and canyons. With few measures to control erosion, extreme rain events and the prevalent topography lead to runoff and floods during extreme conditions (Cavazos and Rivas 2004; Lara and Díaz-Montemayor 2010).

Border cities are also underserved by water and wastewater infrastructure as well as other urban infrastructure such as paved streets and lighting (Lemos et al. 2002; Jepson 2012). In 2007, for example, the Border Environment Cooperation Commission estimated that there was nearly $1 billion in unmet investment in water and wastewater infrastructure in the border region (BECC 2007). An estimated 98,600 households in the United States and Mexico border region lacked safe drinking water, and an estimated 690,700 homes lacked adequate wastewater collection and treatment services (EPA 2011). Thus, on both sides of the border, large numbers of residents do not have safe potable water piped into their homes and lack proper sewage collection and treatment services (GNEB 2008).

Informal colonias from Tijuana to Nogales to Juárez often are off-the-grid for water, sanitation, and electricity and rely on purchased water from trucks at relatively higher cost than municipal tap water (Cavazos and Rivas 2004; Collins 2010; Wilder et al. 2012). Water-scarce states like Sonora have water rationing in major cities—including the capital, Hermosillo, and its largest border city, Nogales—based on a system known in Spanish as *tandeo*. Basic infrastructure is limited in the informal colonias, and construction on unsafe hillsides in floodplains leads to increased risk to human residents from severe flooding when it rains. Flooding of unpaved roads may disrupt water-truck deliveries for households not on the municipal grid.

ECONOMY. The border is a region of dynamic growth in both industry and employment. The region is of critical value to the global economy and both countries' national economies due to its production of agriculture and manufactured goods. Its economic significance therefore enhances its exposure to climatic stress. Its integration into the global economy means that climate stresses have potential impacts beyond local borders because of the potential of disrupted trade. The economy of the border is highly integrated through manufactured and agricultural trade, export-oriented production and labor, and markets that include cross-border manufacturing clusters in aerospace, electronics, medical devices, automotive products, and other sectors.

Mexico's maquiladora industry experienced declines due to the 2001–2002 recession and the period that followed. Maquiladoras are duty-free, foreign-owned assembly plants responsible for nearly half of Mexico's exports in 2006 (GAO 2003; Robertson 2009). At their peak in 2000, they employed over 1 million people, of which 78% (839,200) were from the five major border cities of Tijuana, Mexicali, and Juárez (and Matamoros and Reynosa in the eastern border region) (GAO 2003).[xx] After 2006, Mexico no longer tracked maquiladora exports separately from its other exports.[xxi]

Cities on the U.S. side of the border have benefited from the substantial flow of trade created by maquiladoras, with more than 500,000 jobs added to the U.S. border region between 1990 and 2006, in services, retail trade, finance, and transportation. While maquiladoras drive higher employment in Mexican border cities, Cañas et al. (2011) found that Texas border cities experienced the highest maquiladora-related employment increases, with El Paso providing the third-most maquiladora-related jobs of all border cities (after McAllen and Reynosa). By comparison, California and Arizona border cities experienced a smaller benefit. Asian production inputs have displaced U.S. suppliers, whose share dropped from 90% in 2000 to 50% in 2006, notably affecting Tijuana maquiladoras and San Diego suppliers. Maquila employment declined as a result of the 2001–2002 recession and global low-wage competition from southeast Asia. By 2006, maquiladoras employed over 750,000 people in border cities (Cañas and Gilmer 2009). Other forms of integration are trade and capital flows.[xxii]

This analysis indicates that urban areas in the border region are vulnerable based on exposure to climate stressors. Urban infrastructure is sensitive to flooding (and related erosion) and drought, and urban-based economic activities of both regional and global consequence may be sensitive to impacts caused by climate stressors (such as water scarcity or water shortage). Urban areas could be set on a more sustainable development path through urban and economic development strategies such as extending water and sanitation networks and improving their efficiency; improving flood and erosion control; promoting water conservation at the household (e.g., rainwater harvesting) and municipal (e.g., expanded water treatment and reuse) levels; improving substandard or inappropriately-sited housing; and extending urban green spaces in low-income areas.

Institutional and governance drivers

Institutional asymmetry and fragmentation—meaning differences in governance frameworks and lack of cohesion and coordination among multiple government agencies and actors on the two sides of the border—create potential vulnerabilities in managing transborder environmental resources. Water management is used here as a lens into institutions and environmental governance in the region. Governance refers to "the set of regulatory processes, mechanisms, and organizations through which political actors influence environmental actions and outcomes" (Lemos and Agrawal 2006, 298). The term encompasses both government and non-government actors, including communities, businesses, and non-governmental organizations. On the U.S. side of the border, water governance is decentralized; on the Mexican side, despite decentralization initiatives codified into national and state laws since 1992, it remains highly centralized (Pineda Pablos 2006; Mumme 2008; Scott and Banister 2008; Wilder 2010; Varady, Salmón Castillo, and Eden forthcoming). U.S. border cities and counties are embedded in systems of water rights and water administration dominated by the four border states—Texas, New Mexico, Arizona, and California—subject to applicable international treaties, interstate river compacts, an assortment of federal laws affecting water development, water quality, and ecological values, and contracts with federal agencies with water-related jurisdictions. Water providers range widely in size, from small local utilities up to giant municipal water providers like the Metropolitan Water District of Southern California and the San Diego Water Authority. Farther east, agencies include El Paso Water Utilities and local municipal water authorities. In irrigation, management ranges from the sprawling Imperial and Coachella irrigation districts, which have Colorado River water entitlements that dwarf those of Nevada and Utah combined, to lesser ones like New Mexico's Mimbres Valley Irrigation Company and Arizona's Upper San Pedro Water District. On the Mexican side of the border, states and municipios as well as irrigation districts are governed by Mexico's National Water Law through the National Water Commission (CONAGUA). The western Mexican border states (Baja California, Sonora, and Chihuahua) each have a state-level water agency that partners with CONAGUA and local water utilities (*organismos operadores*), while irrigation districts remain under the direct oversight of CONAGUA or, in the case of large irrigation districts, are administered by an irrigation district authority with CONAGUA oversight. At the international level, the allocation and management of riparian surface water is governed by several treaties and their amendments and extensions.[xxiii]

The inherent differences between these decentralized and centralized systems of water governance complicate binational cooperation and water planning at the border. Political and administrative decisions on managing scarcities and climatic variation are often achieved more readily in Mexico than in the United States owing to centralized planning in that country.[xxiv] Institutional fragmentation and complexity mark water resource management on the U.S. side, in particular (Mumme 2000; Milman and Scott 2010; Wilder et al. 2012). The treaties and international institutions for coordinating water also have limitations for the management of climate variability. The International Boundary and Water Commission (IBWC) has a limited mandate for coordinating binational activities in times of prolonged drought and lacks basin-wide advisory bodies to assist it as it deals with national, state, and local authorities (Mumme 1986). The IBWC also lacks clear jurisdiction for managing groundwater extraction of groundwater in the border zone (Scott, Dall'erba, and Díaz-Caravantes 2010).

These recognized policy challenges provide a strong rationale for the development of binational watershed partnerships and less formal arrangements aimed at supporting the ecological health of watersheds and water conservation in the border region. Partnerships like the Tijuana Watershed Task Force, the Upper San Pedro River Partnership, and the Santa Cruz River Aquifer Assessment all point in the direction of sustainable initiatives that need be supported and strengthened. Recent IBWC-based efforts have extended the treaty regimes on the Rio Grande and the Colorado River to better address conservation and long-term water supply planning. Programs include an innovative

Water Conservation Investment Fund established at the North American Development Bank (NADB) in 2003 and the 2010 establishment of the binational Consultative Council for the Colorado River to consider shortage challenges of an international nature (Mumme et al. 2009). These arrangements comprise adaptive strategies that help the border region address known shortcomings in current water governance and add to regional resilience (Wilder et al. 2010).

Vulnerability may be reduced and regional resilience increased through flexible and dynamic governance institutions and increased trans-border collaboration at the federal, state, and local scales to share information and data, respond to changing needs and conditions, and resolve transboundary water and other environmental issues via consultative or collaborative processes (see Box 16.3). In addition, a better integration of scientific and technological progress (such as climate variability/climate change monitoring and forecasts or irrigation and water distribution techniques) into planning and operations would help agencies and other governance actors be more responsive to climate change.

Box 16.3

Case Study 3: Reducing Cross-Border Emissions: California-Baja California Cooperation on Greenhouse Gas Emission

As a signatory to the Kyoto Protocol, Mexico initiated greenhouse gas (GHG) inventories, began a voluntary reduction program, and developed GHG management plans as part of a broad national approach characterized by public-private partnerships.[xxxvii] Baja California was one of the first Mexican states to develop a GHG inventory, in March 2010, through cooperation with the Center for Climate Strategies, U.S. Environmental Protection Agency (EPA), and the Border Environment Cooperation Commission (Chacon Anaya et al. 2010). In the absence of national programs, California took the initiative with AB 32, the Global Warming Solutions Act of 2006, which called for reducing by 2020 California's GHG emissions to levels of 1990.

As the two states have moved forward with GHG inventories and the planning process for climate plans, California and Baja California officials have exchanged information and methodologies. This was facilitated by the active involvement of EPA and the Border Environment Cooperation Commission, along with the Environmental Roundtable of the Border Governors Conference. At a local level, the San Diego Association of Governments (SANDAG) has facilitated transborder information exchange on climate change issues and data with counterparts in Baja California. This was accomplished through binational information meetings, including "Binational Seminar: Challenges and Opportunities for Crossborder Climate Change Collaboration" (2009) and "Binational Event: Crossborder Climate Change Strategies" (2010).[xxxviii] The SANDAG efforts have successfully placed GHG and climate change as topics on the planning agenda for local and state authorities in the California-Baja California border region. The Border 2020 binational environmental program will reinforce these regional transboundary efforts by focusing on reducing GHG and on actions to help border communities become more resilient to the effects of climate change. [xxxix]

Drivers of biophysical changes and their impacts

The border region is particularly rich in species and ecosystem diversity. The Good Neighbor Environmental Board (GNEB 2006) reports that the fragile ecosystems of the border region are under threat from drought, invasive species, and urban sprawl. Socioeconomic factors are related to biodiversity loss, in that population growth may drive higher resource use, leading to higher vulnerability to climate change. Biodiversity loss has many potential negative impacts, such as encouraging the encroachment of invasive species, decreasing water-retention capacities, and resulting in fewer locations that can be used as recreational areas or that can sequester carbon dioxide. (See Chapter 8 for more discussion of the benefits of ecosystem processes and biodiversity.)

The ecological features of the border region vary widely. About a dozen transboundary rivers provide water to cities, tribes, and farms in the two countries, including two major rivers, the Colorado River and the Rio Grande, and many smaller sources—such as the Tijuana and New rivers in California and Baja California, the Santa Cruz and San Pedro rivers in southern Arizona and northern Sonora, the Hueco Bolsón and the Mesilla-Conejo-Medanos in the Paso del Norte region, and the Mimbres-Los Muertos aquifer and drainage system in New Mexico. Major desert ecosystems include the Mojave (Imperial Valley, California), Sonoran (southern Arizona and Sonora), and Chihuahuan (eastern Arizona and western New Mexico) Deserts (GNEB 2006; EPA 2011). Features include fertile desert estuaries on the Baja California and Sonora coasts; chaparral-covered coastal plains and oak savannahs in California; deserts of cactus, creosote, mesquite, palo verde, and sagebrush across parts of Arizona and New Mexico, mixed with pine and oak forests in higher mountain elevations; and hilly areas of grasses and mesquite moving eastward into Texas. Coastal zones at the eastern and western ends of the border contain important marine and freshwater habitat (Liverman et al. 1999; Varady et al. 2001; GNEB 2006). As an example, Figure 16.5 indicates the vast ecological resources in protected designations within the Arizona-Sonora portion of the border region.

Within the entire U.S.-Mexico border region (including the eastern portion of the region outside the scope of this chapter), there are over 6,500 animal and plant species (EPA 2011).[xxv] On the Mexican side, 235 species found in the border region are classified in a risk category. Of these, 85 are considered endangered under Mexico law. In the United States, 148 species found in border counties are listed as endangered under the U.S. Endangered Species Act (EPA 2011, 15).

The border fence erected and extended by the United States Department of Homeland Security to prevent undocumented immigration has had extremely negative effects on wildlife, including endangered species, whose habitats and ranges lie in the transboundary region (López-Hoffman, Varady, and Balvanera 2009; Segee and Córdova 2009; Sierra Club 2010).[xxvi] The fence deters virtually all wildlife crossings, cutting animals and reptiles off from sources of water, food, and access to habitat and to potential mates.

Wetlands are a critical source of biodiversity and losses of wetlands may be irreversible, limiting or prohibiting future efforts at restoration (Beibighauser 2007). At-risk estuaries include the Tijuana River and the Rio Grande, including the adjacent Laguna Madre coastal lagoon (Liverman et al. 1999). The Rio Grande is also home to endangered silvery minnows in the last remnant of their historical habitat and to flocks of migrating cranes and geese who gather in vast numbers to rest and refuge in riparian *bosques*

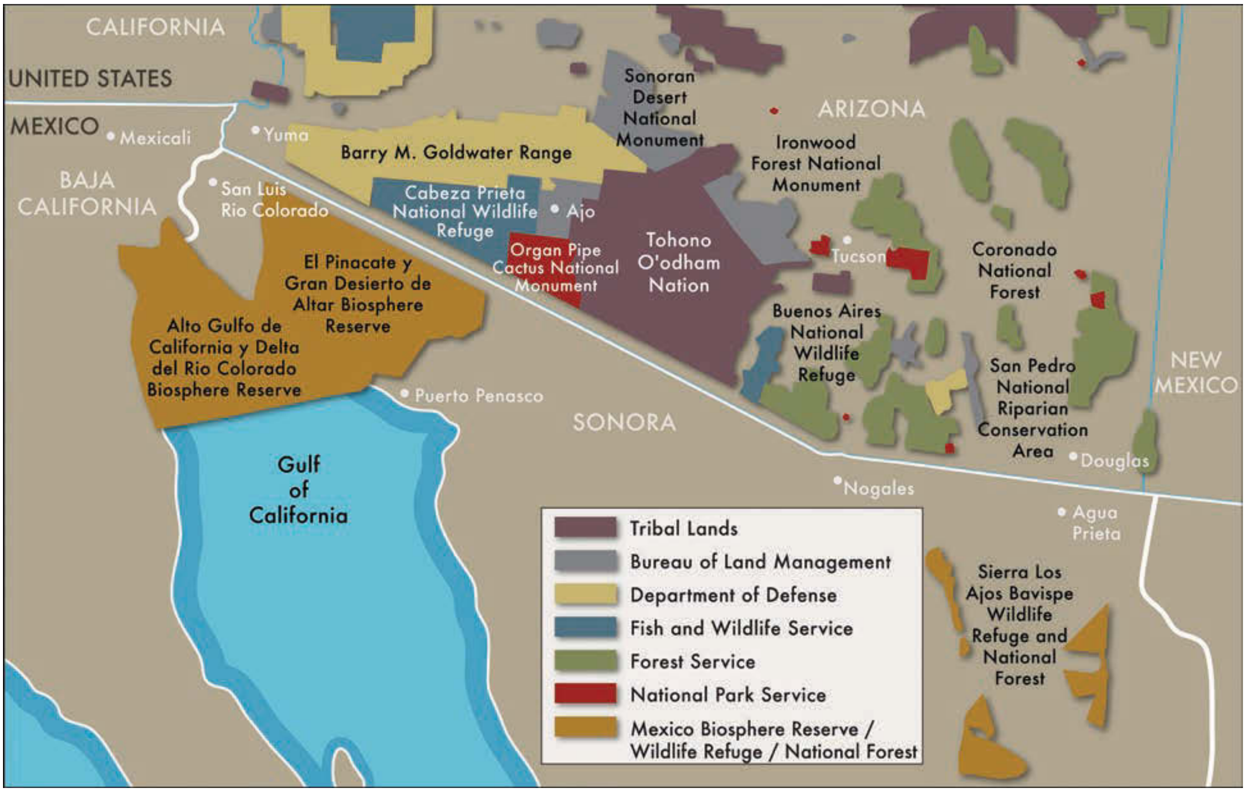

Figure 16.5 Protected areas in western portion of U.S.-Mexico border region. Source: Laird-Benner and Ingram (2011) reprinted with permission from Taylor & Francis.

(woodlands) (Hurd and Coonrod 2008). Native fish, neotropical songbirds, and migratory waterfowl, including threatened and endangered species, have all declined precipitously in recent decades (Lacewell et al. 2010).

The Colorado River delta is a significant border ecosystem that is most at risk from increasing regional water stress. Lacking a dedicated source of water to maintain ecological flows, several wetlands of high resource value are threatened, including the Ciénega de Santa Clara (see case study below) (Glenn et al. 1992; Glenn et al. 1996; Liverman et al. 1999; Pitt and Luecke 2000; Varady et al. 2001; Zamora-Arroyo and Flessa 2009). Two principal vulnerabilities associated with the Lower Colorado River and delta are (1) the lack of dedicated ecological flows to sustain critical wetlands and bird habitat in the delta; and (2) the over-allocation of Colorado River water and over-reliance of the seven U.S. basin states and Sonora and Baja California on its water as a principal source of supply.[xxvii] This latter issue is addressed in the water sector analysis below; the discussion here is on the Colorado River delta ecosystem.

Likely effects of the climate changes described in Table 16.1 are primarily associated with increasing temperatures, declining precipitation and streamflows, and increasing extreme events (i.e., droughts). Expected effects include: constraints on available water supply to major cities reliant on Colorado River water (MacDonald 2010; Woodhouse et al. 2010); increased urban-agriculture competition over water; constraints on meeting increasing regional water-energy demand; and threats to ecosystems of high resource value, including endangered species habitat (Pitt and Luecke 2000; Zamora-Arroyo and Flessa 2009).

The Colorado River delta has been called "one of the most important estuaries in the world" (Zamora-Arroyo and Flessa 2009, 23) and is the largest remaining wetland system in southwestern North America. Although it originally comprised 2 million acres (800,000 hectares) of wetlands habitat, it has shrunk to only 10% of its original size since 99% of the water has been diverted (Zamora-Arroyo and Flessa 2009). These wetland areas are critical stopovers on the Pacific migratory flyway and significant breeding and wintering habitat for 371 bird species (400,000 migratory waterbirds), including endangered species such as the Yuma Clapper Rail (listed in both the United States and Mexico). Both the Andrade Mesa and Ciénega de Santa Clara wetlands in the delta are experiencing water scarcity due to increased demand and changes in water management. The wetlands rely on system inefficiencies (water not used by agriculture or cities), amounting to less than 1% of its original sources (Pitt and Luecke 2000; Zamora-Arroyo and Flessa 2009). These "accidental" sources are now threatened as water managers increase efficiency; for example, the 2008 concrete-lining of the All-American Canal may cut off seepage that has been important in sustaining the Andrade Mesa wetlands.[xxviii]

A Colorado River Joint Cooperative Research Process involving key binational government agencies, non-governmental organizations, and water users has a goal of finding dedicated sources to meet minimum flows required to sustain these critical wetlands (Zamora-Arroyo and Flessa 2009) (see also Box 16.2). The best options to ensure the survival of the delta are agricultural return flows, municipal effluent, and acquisition of new water rights (Zamora-Arroyo and Flessa 2009).

Biodiverse and environmentally significant border ecosystems are exposed to urban encroachment, increasing scarcity of water, and habitat threats, as well as habitat fragmentation and land-use change caused by the U.S. border fence. Endangered species habitat and wetlands systems are sensitive to the increasing scarcity of water to sustain critical habitats. Institutional trans-border collaborations in critical wetlands areas such as the Ciénega de Santa Clara and the Tijuana Estuary (see Box 16.4) are developing adaptive strategies that may add to the sustainability of these areas and will help confront the impacts of future climate change.

16.5 Sectoral Analysis of Border Vulnerability

Water supply and sectoral vulnerability

Climate change in the Southwest will place additional burdens on an already-stressed water system (see Chapter 10). As a general rule across North America, the shift will be from wet to wetter, in wetter areas, and from dry to drier, in arid regions like the border (see Chapter 6). Severely over-drafted aquifers and those aquifers affected by saltwater intrusion are already a challenge for the region (see, for example, Figures 16.6 and 16.7 for northern Mexico). Regional impacts associated with these changes are anticipated to include: a decreased water supply in storage reservoirs for urban use and irrigation, especially in the Colorado system; higher summer temperatures leading to stresses on

Box 16.4

Case Study 4: Collaboration to Protect the Tijuana Estuary

The Tijuana River Estuary is the largest and one of the last remaining large tidal wetlands on the Pacific Coast (Roullard 2005, plates 31-36; Ganster 2010). The 2,500-acre (1,012-hectare) Tijuana River National Estuarine Research Reserve (TRNERR) is situated on the international boundary at the endpoint of the 1,750-square-mile (4,532 square kilometer) binational Tijuana River Watershed. One-third of the watershed is in the United States and the remaining area in Mexico, and includes much of the rapidly urbanizing areas of Tijuana and Tecate. The estuary's diverse contiguous beach, dune, salt marsh, riparian, and upland habitats are home to many rare and endangered species of plants and animals. The estuary is vulnerable to human impacts and the effects of climate change that include sea-level rise, altered precipitation patterns and sedimentation rates, and invasion of exotic species. The likely effects of climate change also pose significant challenges to the viability of past habitat restoration efforts in the estuary (see, for example, Zedler 2001).

In order to make this system more resilient to both watershed and coastal stressors, the Tijuana River Valley Recovery Team was convened in 2008.[xl] This effort brings together over thirty regulatory, funding, and administrative agencies with the scientific community, environmental groups, and other stakeholders. The Recovery Team has produced a "roadmap" that addresses broad ecosystem goals and identifies actions that can facilitate adaptation to climate change, such as controlling cross-border flows of sediment and trash, improving hydrology, changing land use, and restoring habitat (Tijuana River Valley Recovery Team 2012). The plan identifies broad zones of the Tijuana River estuary area that will serve different functions. These include (1) transitional areas designed to accommodate habitat shifts associated with rising sea level, (2) private lands that should be acquired and restored to habitats that can dynamically respond to changing conditions, and (3) lands that will remain in agricultural or recreational use and are protected inundation. The roadmap also specifically calls for the impacts of climate change to be assessed at more precise spatial scales and shorter time scales so that management practices can effectively respond to evolving climate conditions.

energy provision during peak demand; extended and more severe drought periods; and higher evapotranspiration rates (Table 16.1). As Udall (2011, 12) notes, "The past century is no longer a guide to water management" (see also Planning Techniques and Stationarity section, Chapter 10). The principal watersheds in the region are of particular significance to the sustainability of ecosystems and human activities.

The two major transboundary rivers in the border region—the Colorado River and the Rio Grande—are systems where conflicts over water are prevalent (see Chapter 10, Box 10.1). Both the United States and Mexico have aging water infrastructures with a voluminous backlog of needs that are very expensive to fix. As described throughout the present work, water is connected to many other sectors, including energy, transportation, human health, ecosystems, and agriculture. Higher projected temperatures will affect water quality; surface water temperatures are expected to increase, in turn impacting the organisms and species (including humans) that depend on these resources,

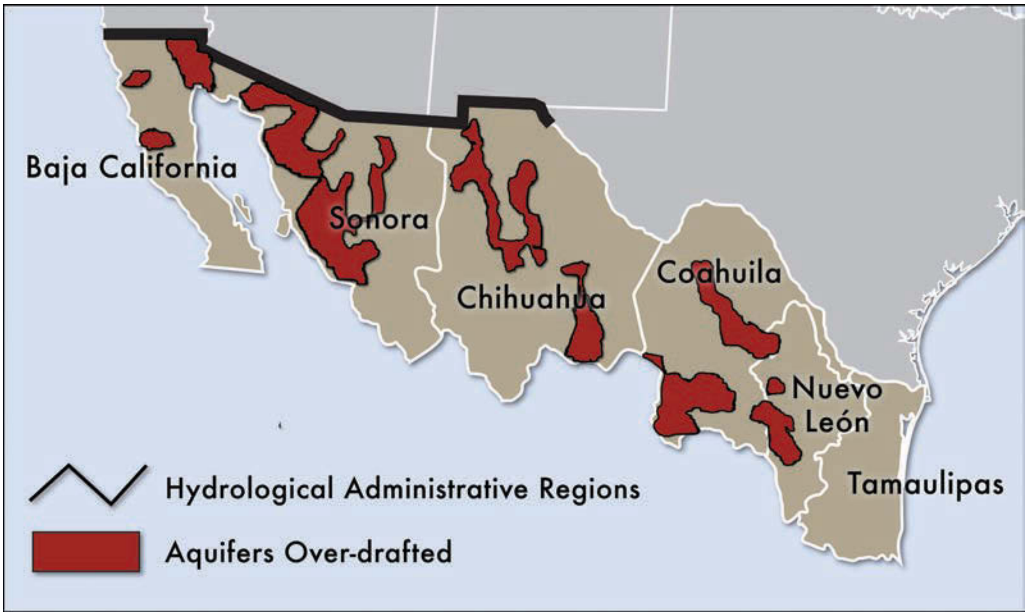

Figure 16.6 Over-drafted aquifers in Mexico. Note the concentration of these in northeast Baja California, along the coast of Sonora, and in the Rio Grande/Río Bravo watershed. Source: CONAGUA (2011, chap. 2, 34).

while groundwater quality in coastal aquifers may be affected by sea-level rise that leads to saltwater intrusion (see Chapter 9, Section 9). Chronic salt accumulation in soils associated with hot and arid climates can produce agricultural losses and places additional restrictions on regional agricultural water management.[ixxx] Scientific research on groundwater is lacking in comparison to knowledge on surface water resources, and the lack is particularly pronounced on the Mexican side (Moreno 2006; Scott, Dall'erba, and Díaz-Caravantes 2010; Granados-Olivas et al. 2012). Also, the effects of climate variability and change on water quality are virtually unexplored territory.

There are almost no natural impoundments of any substantial size in the border region. However, there are a number of man-made reservoirs, most of which are fed by the Colorado River or Rio Grande (examples are the Imperial and Morelos Dams on the Colorado River and the Leasburg and American Dams in the border region on the Rio Grande), and so are replenished by water derived primarily from winter snowpack in distant mountains. Upper Rio Grande flows in particular rely primarily on snowpack (Lacewell et al. 2010). Smaller border-crossing rivers like the Santa Cruz and the San Pedro get their most substantial flows from summer precipitation, and somewhat less from winter storms and local snowpack in high elevation "sky island" mountain ranges. The New River in the Mexicali-Imperial Valley region receives its flow from treated wastewater and agricultural drains. Numerous small reservoirs in the border region capture rainfall and many also store imported water from the major river systems. Of San Diego's twenty-five reservoirs, many import water from the Colorado River and from the California Water Project in Northern California. Coastal Baja California has

Figure 16.7 Areas in the border region of Mexico affected by saltwater intrusion or saline soil. Note the concentration of these problems in the irrigation districts of northeastern Baja California and along the coast of Sonora, as well as in the Juarez Valley. Source: CONAGUA (2011, chap. 2, 35).

two reservoirs that capture runoff and store water pumped over the mountains from the Colorado River to serve Tijuana, Playas de Rosarito, and Tecate.

Agriculture uses the largest share of water (about 80% of total supply) (McDonald 2010; CONAGUA 2011). The next largest use is municipal/urban, followed by industrial and thermoelectric. Figure 16.8 shows water use in the border states in Mexico.

The eight-year period from 2000 to 2007 was "a period of unprecedented dryness in the Colorado River basin when compared to the roughly 100-year historical record" (CDWR 2009, 21). Modeling by the U.S. Bureau of Reclamation shows that shortages due to drought become "increasingly likely" (CDWR 2009, 21) in the future as water demands increase. Cayan and others (2010, 21271) call the recent drought the "most extreme in over a century." The Colorado system of reservoirs is one of the region's "most important buffers against drought" (MacDonald 2010, 21259). During the early twenty-first century drought, storage levels have "declined precipitously" and could potentially fall below operable levels (MacDonald 2010, 21259). Impacts of the recent drought include: emergency restrictions on outdoor water use (for Tucson and San Diego); reductions in urban water service delivery (e.g., Metropolitan Water District of Southern California in 2009); agricultural revenue losses (documented at $308 million in California statewide); impacts to hydro-generated electricity; and forest loss due to wildfires and spread of bark beetle destruction (MacDonald 2010; see also Chapter 8).

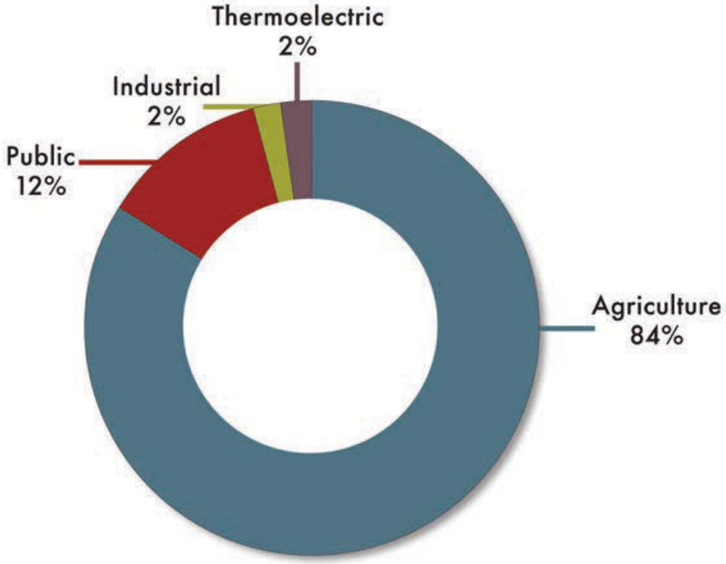

Figure 16.8 Water use in Mexico's border region (includes Region 1, Peninsula Baja California; Region II, Northwest; and Region VI, Rio Bravo). Adapted from CONAGUA (2011, annexes, 128-129, 133).

RIO GRANDE WATERSHED. The Rio Grande has its headwaters in the San Juan Mountains of southern Colorado, flows through New Mexico, forms the international boundary between the United States and Mexico (Figure 16.9), and terminates in the Gulf of Mexico. Its watershed is divided roughly equally between the United States and Mexico. The Upper Rio Grande is defined as the headwaters area in Colorado downstream to Fort Quitman, Texas (about 60 miles downstream from El Paso). The Lower Rio Grande, from Fort Quitman to the Gulf, takes in the river's largest tributaries, including the Pecos River and Devil's River in Texas and the Río Conchos, Río Salado, and Río San Juan in Mexico (CDWR 2009). The Upper Rio Grande system has two large storage reservoirs, Elephant Butte and Caballo Reservoirs, as well as smaller dams.[xxx] Overall, about half of the basin's 19 million acre-feet (MAF) of storage is in Mexico and the other half in the United States (CDWR 2009). A 1938 interstate compact divides the waters of the Upper Rio Grande among Colorado, New Mexico, and Texas. Two treaties between the United States and Mexico govern allocation of water from the river's international reach. Above Fort Quitman, the United States is required annually to deliver 60,000 acre-feet of Rio Grande water at Ciudad Juárez, in accordance with the Convention of 1906.

Significant shared groundwater resources that are critical supply sources for cities in this area include the Hueco Bolson and Mesilla Bolson aquifers in the El Paso–Ciudad Juárez region which are shared among New Mexico, Texas, and Mexico. Overdraft and salinity challenges are major issues for both sides of the border in this region (see Figures 16.6 and 16.7). Groundwater levels and quality have declined precipitously in the most important aquifer, the Hueco Bolson, since 1940 (Granados-Olivas et al. 2012). The water supply for the Upper Rio Grande Basin is fully allocated. Its system of engineered storage and delivery requires precipitation "at the right time, right place, over time, and with adequate quantity" in order to function properly (Lacewell et al. 2010, 105). Changes in the timing and amount of rainfall accompanied by an increase in temperature puts the system in a vulnerable situation (Lacewell et al. 2010).

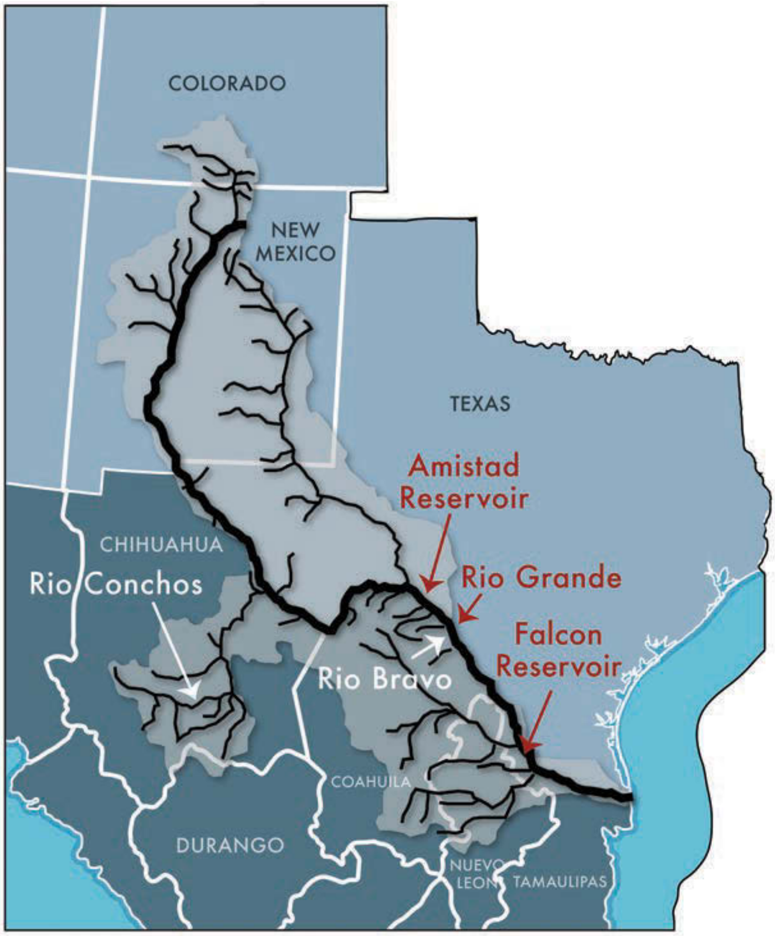

Figure 16.9 Rio Grande Basin.
Source: Lacewell et al. (2010).

The Rio Grande and its associated aquifers are the principal and often only water source for cities and farms from southern Colorado through New Mexico and into far west Texas (Hurd and Coonrod 2007). The vulnerability that these water users face in light of potential climatic and hydrologic changes is indicated not only by their dependence on a sole source of supply but by the oversubscribed claims to and exhaustive use of this source (Hurd et al. 2006; Hurd and Coonrod 2007). Using a hydro-economic model developed for the Upper Rio Grande, Hurd and Coonrod (2007, 2008) identified the following significant vulnerabilities for New Mexico based on a “middle severity” future climate change scenario:

- A reduction in long-run average water supply leading to a 2% reduction by 2030 and 18% by 2080, with the reduction affecting agriculture in 2030 and both agriculture and urban areas in 2080;
- Increases in water prices, as demand exceeds supply due to population growth and projected climate change;
- A concomitant shift in consumptive use by urban areas at the expense of agriculture;

- Secondary economic effects resulting from reduced consumptive use by agriculture, including significant economic losses from reservoir recreation and from job losses in the agriculture sector. For example, the 2030 middle scenario estimates a total economic loss of $8.4 million associated with a 3.5% reduction in agricultural water use, mostly in direct losses to agriculture ($7.1 million). By 2080, total economic losses associated with a 22.5% reduction in water use results in a loss of $61.7 million (based on year 2000 dollars).
- Worrisome impacts on natural ecosystems, in particular on the endangered silvery minnow habitat that lacks dedicated sources with the minimal flows needed to sustain it;
- Increased flooding (this is anticipated but not accounted for by the authors);
- Negative impacts on water quality;
- Negative impacts on native Hispanic communities who are likely to be among the first farmers to experience pressure to transfer water from their acequia systems to cities (see also Perramond 2012).

In the Paso del Norte binational area, key water resource vulnerabilities include:

- The lack of trans-border "data fusion" among governmental agencies;
- Higher evapotranspiration rates associated with increasing irrigation needs under projected climate changes;
- Increasing salinity of groundwater used for agriculture and drinking water (Hurd et al. 2006).

This analysis of water sector vulnerability indicates increasing risk exposure for agriculture, local economies, and ecosystems resulting in potentially serious impacts, including reduced natural water supplies; increased urban-agriculture competition; potentially negative impacts for off-the-grid users, including informal colonias and high-value riparian areas that lack a dedicated source of water. The water-energy infrastructure, especially during summer peak demand and during extended drought periods, will be sensitive to climate change. Traditional farming and ranching cultures may be increasingly exposed to climate-change impacts, resulting in reductions in their production. Finally, fundamental ecosystem changes may ensue, including reductions in soil moisture and increased pest infestations and disease.

Agriculture and ranching

Agriculture and ranching account for a small share of the border region's gross domestic product (GDP). Yet farmers and ranchers are the primary managers of most of the region's water and land resources. In the border region, agriculture accounts for approximately 80% of water consumption. About 74% of Arizona's land and 85% of New Mexico's land is used for farming and ranching (USDA n.d.). Agriculture and ranching in the border region will increasingly have to compete with cities for water. Agriculture and ranching also play an important cultural and political role in the regional identity and traditions, and agricultural ecosystems are significant. Thus climate change-related impacts on the Southwest landscape will most likely have significant impacts on the

Southwest's agricultural sectors. Changes in water availability, vegetation cover, carbon dioxide levels, and frequency of extreme events like floods and drought will impact crop and forage production, increasing costs for both producers and consumers.

The border region contains three major irrigated agriculture areas: Imperial Valley-Coachella (California), Yuma–San Luis Río Colorado–Mexicali (Arizona–Sonora–Baja California), and the Rio Grande Valley (New Mexico/Texas/Chihuahua). Agriculture consumes about 86% of total water resources in the Mexicali Valley (CONAGUA 2008). The Irrigation District 014, Colorado River, encompasses the Mexicali and San Luis Río Colorado valleys and provides water to about 2,500 agricultural operations over an irrigated area of 204,000 hectares (about 455,000 acres). This is one of the most productive agriculture districts in northern Mexico, sustained mainly by water from the Colorado River.[xxxi] Wheat, cotton, and alfalfa are the most important among fifty registered crops. An important secondary water source is a transboundary aquifer (which is recharged by the Colorado River) shared by the United States and Mexico.

Climate change impacts on regional agriculture and livestock in the Mexicali Valley are directly linked to production and productivity reductions. According to the Programa Estatal de Acción ante el Cambio Climático—Baja California (PEAC-BC)[xxxii], during the last three decades, changes in local and regional climate conditions have been and will be impacting agriculture. Preliminary PEAC-BC findings indicate that changing climate conditions will: drastically reduce the quantity and quality of available water; change the distribution and population dynamics of pest infestations and predator species; and cause changes in crop pollinators. A preliminary review suggests that major spring-summer season crops like cotton may be impacted by the more intensive and increased July−August rainfall period by staining the cotton fiber and reducing the quality for international market grades. Fall-winter crops such as wheat may be negatively affected in both yields and quality of grain protein produced because warming will reduce winter chill hours required for optimal results. The expected higher evaporative-transpiration rates will require increased application of irrigation water per acre, resulting in reduced production. Acreage devoted to alfalfa may decline. This, in turn, will affect the regional livestock sector, which will need to obtain more expensive alfalfa from distant suppliers (Cortez-Lara 2011).

In Arizona, agricultural use of irrigated water accounts for about 70% of water use and about 80% of the state's Colorado River allocations. Groundwater aquifers supply roughly half of total agricultural supply in Arizona, and the Colorado River and its tributaries supply the other half (Owen 2008). Agriculture in New Mexico uses almost 78% of the state's water supply (Owen 2008). Farm size and type of farm may be important indicators of the relative vulnerability of agricultural operations to climate or other stresses and factors (Hoppe, Banker, and MacDonald 2010).

In New Mexico, agriculture comprises a $1.7 billion annual industry, around three-quarters of it from livestock. Major crops include forage crops, onion, pecans, and wheat. In Arizona, agriculture is approximately a $2.4 billion annual industry, with over one-third in livestock (Owen 2008). Major crops include forage crops, cotton, lettuce, and wheat. Farmers may opt to alter their crop mix or invest in more water efficient systems as an adaptation strategy.

Cattle ranching in the Southwest relies on rainfed pastures and browse, which are sensitive to precipitation decreases as well as seasonality of precipitation[xxxiii]. Thus, drought is the most significant concern in some areas (Coles and Scott 2009). The yields of cattle (both in numbers of head and weight) will be reduced with declines in average precipitation (Owen 2008). Higher temperatures suppress cattle appetite, but warmer temperatures bode well for winter survival rates (Owen 2008). Small ranching operations are most vulnerable to drought, especially when combined with volatile cattle prices and pressure from urban land markets to subdivide the land (Eakin and Conley 2002).

Farmers with access to groundwater-supplied irrigation prefer dryness so they can control levels of water applied to crops (Vásquez-León, West, and Finan 2003; Coles and Scott 2009). The high cost of electricity for groundwater pumping is a major factor for irrigators (Wilder and Whiteford 2006; Coles and Scott 2009) because both energy and water needs increase with temperature (Garfin, Crimmins, and Jacobs 2007; Scott and Pasqualetti 2010). However, a study in southeast Arizona found that farmers and ranchers made limited use of climate information, preferring to continue customary practices and lacking confidence in linking their livelihoods to seasonal climate forecasts (Coles and Scott 2009). This study, like that of Eakin and Conley (2002), found small operations had less adaptive capacity than larger ones, indicating that scale of operation is a key factor shaping how vulnerability is experienced in the agricultural sector.

On the eastern edge of the area considered in this chapter, Rio Grande waters are impounded in Elephant Butte and Caballo Reservoirs for irrigation of 135,000 acres of land along approximately 200 miles of valley, including land in El Paso County, Texas. Crops include cotton, pecans, dairy, vegetables, and grapes in southern New Mexico and El Paso (Lacewell et al. 2010). Cattle and livestock are also a significant part of the economy.

This analysis indicates that farming and ranching in the border region are exposed to risks from climate change, and are especially sensitive to changes in seasonality and timing of these changes. Adaptation has a vital role in promoting sustainability of these livelihoods and traditional ways of life. Increasing the adaptive capacity of the agriculture and ranching sector to reduce livelihood risks will enhance the sustainability of these sectors. The current and future challenges in this field in relation to water availability must be addressed though a perspective that includes the conjunctive use of surface and groundwater (i.e., coordinated management of these resources to improve efficiency), technological improvement in irrigation, and sustainable crops. Additional discussion on potential impacts from climate change and climate variability on the agricultural sector can be found in Chapter 11.

Wildfire

Wildfires pose a considerable risk to border communities and to communities throughout the Southwest alike. Wildfires in the contiguous Western states in the United States increased by more than 300% from the 1970s to 2005 (Corringham, Westerling, and Morehouse 2008) and are extremely costly in terms of human life, loss of structures, forest mortality, habitat destruction, and direct fire suppression costs.[xxxiv] The years 2006 and 2008 were the worst on record for wildfire activity in the United States (Grissino-Mayer 2010). In California, the two largest wildfires on record and eleven of the twenty largest recorded fires occurred in the past decade (MacDonald 2010). The fire season of 2011 was "record-setting" in Arizona and New Mexico, and the southern border region (southeastern New Mexico and southeastern Arizona) was hardest-hit in each state.[xxxv]

Climatic factors including higher average temperatures since the 1970s and extensive droughts have contributed to conditions for increased wildfire, as have land-use changes and fire-suppression strategies (Williams et al. 2010). The seasonality of temperature and precipitation changes is especially critical; higher temperatures, earlier spring warming, and decreased surface water contribute to an increase in wildfires (MacDonald 2010). Drought-related bark beetle damage has had devastating effects on Southwest forests. Overall, Williams and colleagues (2010) estimate that approximately 2.7% of Southwestern forest and woodland area experienced substantial mortality due to wildfires from 1984 to 2006, and approximately 7.6% experienced mortality due to bark beetles or wildfire during this period.

Wildfire and land-use management play a large role in controlling the outbreak of wildfires, and climate information should be an important aspect of the planning process. Expected climatic changes will alter future forest productivity, disturbance regimes, and species ranges throughout the Southwest (Williams et al. 2010). Peak fire-suppression periods vary from region to region, with important implications for decision making around wildfire (Corringham, Westerling, and Morehouse 2008; Westerling et al. 2011).

While fire managers in the Southwest United States are integrating short-term weather and climate information into their planning, long-term forecasts are less utilized due to a perceived lack of reliability (Corringham, Westerling, and Morehouse 2008). Trans-border emergency response to wildfires is another critical element of effective management. Events such as wildfires "do not respect administrative boundaries" (GNEB 2008, 2). Trans-border communication-sharing and response systems (as appropriate) can add to regional resilience and improve forest sustainability.

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Endnotes

i The Paso del Norte area includes the Ciudad Juárez municipality in Chihuahua, El Paso County in Texas, and Doña Ana County in New Mexico.

ii Among the paired cities in the western portion of the border region are: San Diego, California-Tijuana, Baja California Norte; Calexico, California-Mexicali, Baja California Norte; Yuma, Arizona-San Luis Río Colorado, Sonora; Nogales, Arizona-Nogales, Sonora; Naco, Arizona-Naco, Sonora; Douglas, Arizona-Agua Prieta, Sonora; Columbus, Texas-Las Palomas, Chihuahua; El Paso, Texas-Ciudad Juárez, Chihuahua.

iii For further discussion of interannual and multidecadal precipitation variability on the U.S. side of the border, see Chapter 4; for Mexico, see Diaz-Castro et al. 2002; Higgins and Shi 2001; Higgins, Chen, and Douglas 1999; Méndez and Magaña 2010; and Seager et al. 2009.

iv For further discussion of ENSO (El Niño-Southern Oscillation), droughts, floods and hydrological planning on the U.S. side of the border, see Chapters 4 and 5 and Garfin, Crimmins, and Jacobs 2007; for Mexico, see Magaña and Conde 2000; Brito-Castillo et al. 2002; Brito-Castillo et al. 2003; Pavia, Graef, and Reyes 2006; Gochis, Brito-Castillo, and Shuttleworth 2007; Ray et al. 2007; Seager et al. 2009; Stahle et al. 2009; and Méndez and Magaña 2010.

v These studies include Hurd and Coonrod 2007; Dominguez, Cañon, and Valdes 2010; Montero Martinez et al. 2010; Gutzler and Robbins 2011; Kunkel 2011; Reclamation 2011; Magaña, Zermeño, and Neri 2012; Scott et al. 2012; and Chapter 6 of this report.

vi For a discussion of downscaling methods, see Chapter 6, Section 6 of this document.

vii One notable aspect of mean temperature projections for the border region and for western North America more generally is that temperatures are projected to increase over the course of the century, regardless of the emissions scenario.

viii Consistent with these estimates are statistically downscaled projections of increased maximum and minimum temperatures in summer and winter, with the highest minimum temperature increases in the western Sonoran Desert and the highest maximum temperature increases in the northern Chihuahuan Desert. One set of statistically downscaled estimates of temperature changes for the north of the border region (high- and low-emission scenario models) are summarized in Table 16.2 and another set of statistically downscaled estimates for Mexican border states in the region (SRES A2) in are summarized in Table 16.3.

ix Garcia-Cueto, Tejeda-Martinez, and Jáuregui-Ostos (2010) note that, in the historic record for the border city of Mexicali, Baja California Norte, the duration and intensity of heat waves have increased for all summer months, there are 2.3 times more heat waves now than in the decade of the 1970s, and that the high-emissions SRES A2 projections show that for the 2020s, 2050s, and 2080s, heat waves could increase (relative to 1961–1990), by 2.1, 3.6, and 5.1 times, respectively.

x A special consideration for the western part of the border region in the wintertime could be that the circulation may change so that there will be fewer cyclones and more anticyclones (Favre and Gershunov 2009) resulting in (a) less frequent precipitation (this is well corroborated by several studies and in many models) and also in (b) more frequent cold spells. The second result is less certain, studied only in one model—CNRM-CM3 by Favre and Gershunov (2009), in which Mexican data were explicitly considered. Some recent results from Pierce et al. (2012), based on several models, suggest that the magnitude of cold outbreaks in January (see Pierce et al. 2012, Figure 6) will not likely diminish in California. This signal should probably extend south of the border some into Baja California (see Chapter 7).

xi Although across the border region winter precipitation is perhaps less substantial than summer precipitation, it is during this season that major dams store water that is used in the onset of the agricultural activities in the spring and summer months. Baja California, with its winter-dominated Mediterranean annual cycle of precipitation, is projected to have the highest percent of precipitation decreases among the Mexican states in the U.S.-Mexico border region (Montero Martinez et al. 2010).

xii The projections of Seager and colleagues (2007) are based on GCM analyses of precipitation minus evaporation, from an ensemble of GCMs used in the IPCC Fourth Assessment Report. They note that projected changes in atmospheric circulation, which promote atmospheric stability and poleward expansion of the Hadley Cell, are factors that contribute to projected temperature-driven increases in evaporation and greater aridity.

xiii Magaña, Zermeño, and Neri (2012), using statistically downscaled data from an ensemble of GCMs that use the high-emissions scenario, show large decreases in 24-month Standardized Precipitation Index (a measure of drought) and soil moisture during the second half of the twenty-first century in northwestern Mexico. Similarly, Gutzler and Robbins (2011), using statistically downscaled data from an ensemble of GCMs (SRES A1b) show large increases in the Palmer Drought Severity Index in the northern part of the border region; they note that "the projected trend toward warmer temperatures inhibits recovery from droughts caused by decade-scale precipitation deficits."

xiv Seager et al. (2009) note that this strong natural variability may obscure the development of increasing aridity that is occurring as the result of increasing temperatures and evaporation.

xv See the Executive Summary above for confidence statements pertaining to this summary.

xvi When effective, collaborative networks may become "communities of practice" that pursue new "adaptive pathways"—intentionally adaptive operations or strategies responsive to climatic change—in their respective institutions (Wilder et al. 2010). For a general discussion of the integral role of collaboration (e.g., trust, social learning, iterative interactions, common definitions of challenges)—not related to the border region, see Cash et al. 2003 and Pelling et al. 2008. Relating these aspects of collaboration to scientist-decision maker networks with the goal of co-production of science and policy, see Lemos and Morehouse 2005.

xvii For a concise history of the border region, see Ganster and Lorey 2008.

xviii The Wall Street Journal Online reported that 37% of net new jobs created in the U.S. since the economic recovery began were created in Texas (http://online.wsj.com/article/SB10001424052702304259304576375480710070472.html). Texas leads the nation in minimum-wage jobs (at 9.5 % of total workforce) (CNNMoney, http://money.cnn.com/2011/08/12/news/economy/perry_texas_jobs/index.htm).

ixx Source: U.S. Census Bureau FactFinder, http://factfinder.census.gov/servlet/DTGeoSearchByListServlet?ds_name=PEP_2008_EST&_lang=en&_ts=286892460001.

xx For example, Tijuana, with a population of about 1.2 million, is heavily dependent on maquiladoras with over 600 plants (2002 data, GAO 2003) and is closely tied to the U.S. market.

xxi Robertson (2009) notes that November 1, 2006, the Mexican government formally integrated the firms in the maquiladora industry into the PITEX program (Programas de Importación Temporal para Producir Artículos de Exportación), thus ending the practice of separating maquiladora trade from other manufacturing trade statistics. Beyond this date, statistics specific to maquiladora export are unavailable.

xxii Much of U.S.-Mexico trade occurs between border states. For example, 62% of U.S. exports to Mexico originated in Texas, California, Arizona, and New Mexico; of this, 70% was destined for Mexican border states (GAO 2003). The total actual value of merchandise trade (exports and imports to and from the U.S. and Mexico) in 2008 was $367 billion—a 266% increase since 1994 (EPA 2011). Official data show that the four U.S. border states originated 58.8% of U.S. exports to Mexico (88.8 billion dollars), which is more than twice their 24% share of U.S. GDP (Bureau of Economic Analysis, Trade Stats Express). Retail sales contribute to GDP and economic interdependence at the border. Residents from Tijuana make 1.5 million trips per month into the San Diego area, mainly to shop. In El Paso, Juárez residents account for more than 20% of retail sales (GAO 2003). Cross-border tourism creates positive economic impacts in Arizona-Sonora (Pavlakovich-Kochi and Charney 2008) including jobs, retail sales, and tourism. Tijuana, El Paso, and Nogales, Arizona are all significant ports-of-entry for Mexican agricultural produce.

xxiii Three treaties are of particular importance: the 1906 Water Convention on the Rio Grande River, the 1944 Water Treaty allocating water on the Colorado and Rio Grande Rivers, and the 1970 Boundary Treaty. The International Boundary and Water Commission (IBWC), established in its modern form by the 1944 Water Treaty, oversees implementation of these treaties and is charged with settling all disputes related to these agreements.

xxiv Mexico has begun to decentralize and delegate some authority for water resources to regional watershed councils and the Mexican states. See Ley de Aguas Nacionales y su Reglamento. 1992 rev. Mexico, D.F.: Comisión Nacional de Aguas. Available at: http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/Ley_de_Aguas_Nacionales_baja.pdf; OECD. 2003. Environmental Performance Reviews: Mexico. Paris: Organization for Economic Cooperation and Development, p. 20.

xxv On the Mexico side of the region, inventories have documented the presence of 4,052 plant species; 454 species of invertebrates; 44 species of amphibians (mostly crustaceans); 184 species of reptiles; 1,467 species of birds; and 175 species of mammals (EPA 2011, based on Kolef et al. 2007).

xxvi The Sierra Club's "Wild Versus Wall" video (http://arizona.sierraclub.org/conservation/border/borderfilm.asp) illustrates the negative impacts on wildlife of the border fence.

xxvii The Colorado River has its headwaters in the Rocky Mountains and passes through nine states in two countries, and through the tribal homelands of the Cocopah tribe in the U.S. and the Cúcapa in Sonora. Waters of the Colorado River were allocated in the 1944 Treaty, based on a high-flow year (1922). Under the treaty, the water is shared among seven U.S. basin states (California, Arizona, Nevada, Colorado, Wyoming, and New Mexico) and Mexico is guaranteed 1.5 million acre-feet annually. From its distribution point at the Imperial Dam in Yuma, Arizona, the Colorado River winds to the west and empties into the delta before a trickle (in some years) reaches the Gulf of California. The total watershed of the Colorado is 244,000 square miles. The Colorado River system supports nearly 30 M people along its 1,400 mile (2,250 kilometer) length, 120 miles of which are in Mexico. It irrigates 3.7 million acres of farmland, including 500,000 in Mexico. Major cities in the border region drawing on the Colorado for urban uses include San Diego, San Luis Río Colorado, and Mexicali. Major agricultural areas reliant on surface water from the Colorado include Imperial and Coachella Valleys, and San Luis Río Colorado and Mexicali irrigation districts. All told, more than twenty U.S. Native American tribes have rights to Colorado River water.

xxviii No data are yet available on the impacts of AAC concrete-lining; however, experts have visually observed decreased flows (personal communication, 1/2012, A. Cortez-Lara).

ixxx MacDonald (2010) notes in the U.S. West today these losses are already on the order of $2.5 billon/year.

xxx In addition, the upper Rio Grande receives a trans-basin diversion from Reclamation's San Juan-Chama project (on the Upper Colorado River) of about 94,000 acre-feet annually.

xxxi The 2011-2012 agricultural programs for the Mexicali Valley and San Luis Río Colorado, after the reduced area due to the 2010 earthquake, are authorized to grow 72, 697 hectares of wheat, 32,064 hectares of cotton, and 27,251 hectares of alfalfa (SAGARPA, Delegación Estatal en Baja California, 2011).

xxxii In late 2008 the Secretary of the Environment of the State Government of Baja California formed the PEAC-BC, an interdisciplinary research team that includes research institutes and universities of the region such as the UABC, CICESE, and COLEF. Their aims were to assess current and potential impacts of climate change in Baja California as well as to propose mitigation actions. For more information see http://peac-bc.cicese.mx.

xxxiii The quantity of summer rain can be a major determinant of the number of head produced, but rain that is too heavy can waterlog pastures and wash out roads used to transport cattle to market

(Coles and Scott 2009). Other weather and climate-related sources of vulnerability identified include heavy rains, winds, hail, lightning, and frosts (Coles and Scott 2009).

xxxiv The annual cost of wildland fire suppression in California alone now typically exceeds $200 million (MacDonald 2010). Three simultaneous wildfires in San Diego County in October 2003 and another in October 2007 resulted in 25 deaths, destroyed a total of 3,700 homes, and scorched over 1,850 square miles (3,000 square kilometers) (Grissino-Mayer 2010).

xxxv Approximately 1.1 million acres burned in New Mexico in 2011, more than 4.5 times the state's average of around 242,000 acres. In Arizona, slightly more than 1 million acres burned, more than 5.5 times the state average of about 182,000 acres). Dry conditions desiccated soils and live fuel sources (e.g., grasses, shrubs, and trees) by the spring and a hard February freeze killed many plants and contributed to the fuel build-up (Southwest Climate Outlook, Oct. 25, 2011).

xxxvi The Colorado River Water Delta Trust has identified a minimum base flow need of 63 mcm (51,000 acre-feet). The Trust has acquired 1.7 mcm (1,367 acre-feet), based on a successful collaboration between NGOs and the state of Baja California in securing treated effluent from Mexicali for environmental flows to the Rio Hardy (Zamora-Arroyo and Flessa 2009).

xxxvii http://www.geimexico.org/english.html provides an overview of Mexican efforts.

xxxviii See http://www.sandag.org/index.asp?projectid=235&fuseaction=projects.detail.

ixl U.S. EPA, "Draft Border 2020 Document – for public comment – September 5, 2011," lines 126-153.

xl See http://www.tjriverteam.org.