Chapter 4

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Chapter 4

Challenge Theme 2. Assuring Water Availability and Quality in the 21st Century

By James Callegary, Jeff Langman, Jim Leenhouts, and Peter Martin

Along the United States–Mexican border, the health of communities, economies, and ecosystems is inextricably intertwined with the availability and quality of water, but effective water management in the Borderlands is complicated. Water users compete for resources, and their needs are increasing. Managers are faced with issues such as finding a balance between agriculture and rapidly growing cities or maintaining public supplies while ensuring sufficient resources for aquatic ecosystems. In addition to human factors, the dry climate of the Borderlands, as compared to more temperate regions, also increases the challenge of balancing water supplies between humans and ecosystems. Warmer, drier, and more variable conditions across the southwestern United States—the projected results of climate change (Seager and others, 2007)—would further stress water supplies.

International Boundary and Water Commission water control structures on the United States–Mexican border

Adding to the complexity of water availability, resource managers must address and attempt to balance the complicated interweaving of interstate compacts, international treaties, Native American water rights, and the water needs of ecosystems and endangered species. Rivers and aquifers cross both state and international boundaries and are shared between Mexican and United States communities. The few major rivers of the Borderlands are either currently under adjudication (with thousands of legal claims that are taking decades to sort out and have no end in sight) or their waters were divided up decades ago by international treaties and domestic laws.

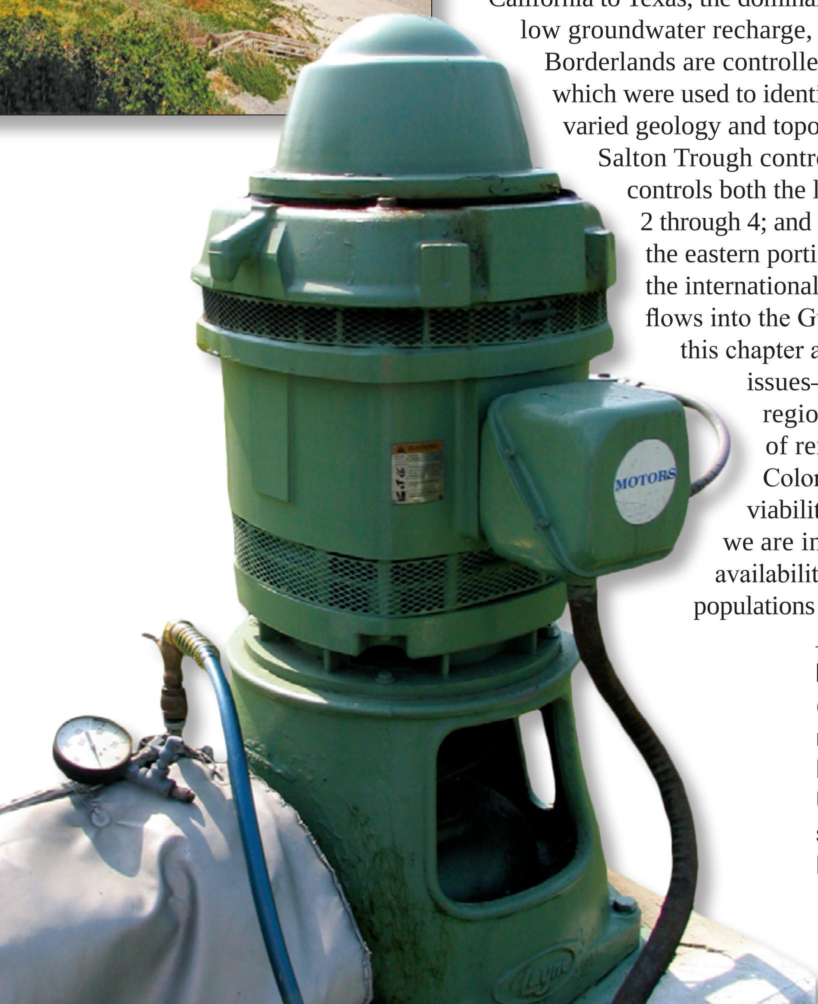
Water quality also contributes to the issues facing water resource managers. Population increases and the growth of urban areas in the last fifty years not only have caused increased water use but also have dramatically increased contamination of water supplies. One source of contamination is increased flooding. As cities grow, so does the presence of impermeable surfaces such as streets, parking lots, and buildings. Water from these surfaces can contain high levels of contaminants from automobile and industrial sources (Mahler and van Metre, 2011). Because water cannot permeate these surfaces, it runs off into lakes (Wilson and others, 2006) and into stream channels where it can adversely affect aquatic and riparian life and infiltrate bed sediment, sometimes reaching groundwater and bringing contamination along with it.

National Park Service staff at Amistad National Recreation Area, Texas

Unfortunately, knowledge of the availability, sustainability, quality, and interaction of surface waters and groundwaters is limited or nonexistent in some areas of the Borderlands. Many border communities use groundwater at rates that are unsustainable. Increased withdrawals exceed aquifer replenishment by rain and snowfall (Arizona Department of Water Resources, 2012), and water tables have dropped in many locations, drying up rivers and requiring farmers and cities to redrill and deepen their wells. As a result, there is a sense of urgency in the Borderlands as communities struggle to find and secure the adequate supplies of good quality water needed to sustain future generations.

To address these challenges and provide science for possible solutions, the U.S. Geological Survey (USGS) has been working to identify contaminated water and its potential effects on ecosystems and people, help communities find additional supplies, and monitor river flow to provide timely flood warnings and to ensure the United States meets its treaty obligations (Asquith and Heitmuller, 2008; Norman and others, 2010b; Jagucki and others, 2011; Tillman and others, 2011). The USGS establishes connections with and provides scientific and technical information to cities, counties, States, and Federal agencies such as the National Weather Service, the Bureau of Reclamation, the U.S. Environmental Protection Agency, and the U.S. Department of Homeland Security to aid them in their work in mitigating flood hazards and providing clean, sustainable water for the communities they serve. The USGS negotiates agreements and works with partners in Mexico to study shared water supplies and water quality so that both countries can make informed collaborative decisions about management of water resources. The Transboundary Aquifer Assessment Program (TAAP) is an example of just such a collaborative international effort (U.S. Congress, 2006). Enacted by Congress in 2006, TAAP is a partnership of the USGS and the Water Resources Research Institutes in Texas, New Mexico, and Arizona. The scientists working on TAAP collaborate with Federal, State, and local entities on both sides of the border, including the International Boundary and Water Commission, universities, and nongovernmental organizations, to answer the questions identified by water managers as being of critical importance to the use and understanding of aquifers shared by the United States and Mexico (Megdal and Scott, 2011). Topics of concern include the need to understand the structure of critical transboundary aquifers and the distribution of sediments within them, the need to understand how urbanization affects recharge to aquifers, and the need for new and improved computer models of water flow and contaminant transport on both sides of the border. The USGS is currently addressing all of these questions. The TAAP program participates in the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Internationally Shared Aquifer Resource Management Initiative, which aids and supports member groups by improving understanding of the scientific, institutional, environmental, socioeconomic, and legal issues associated with transboundary aquifers worldwide. As an example of USGS efforts to address the complex interaction among people, animals, ecosystems, water, and pollution across the border, the USGS Border Environmental Health Initiative (BEHI; *http://borderhealth.cr.usgs.gov*) has been working with United States and Mexican agencies to assess aquatic ecosystems for contaminants present in treated effluent discharged into rivers and streams (Norman and others, 2010a) and with public health officials to develop, collect, and serve to the public and public health officials data of particular relevance, such as location and rates of infectious disease (Norman and others, 2012). Multidisciplinary teams of BEHI scientists are working to assess the effect on humans and aquatic ecosystems of pharmaceuticals and personal care products present in treated effluent discharged into Borderlands rivers and streams. The TAAP and BEHI efforts are but two of many examples of water-focused projects that demonstrate the expertise of the USGS and the substantial contribution it makes to improving the health and well-being of people and communities along the United States–Mexican border.

water



Status of Resources

The Borderlands region is characterized by a large diversity of natural environments, ranging from coastal basins to deserts, and of human populations, ranging from dense urban complexes to sparsely populated rural areas. Yet the scarcity of water unifies them all. From California to Texas, the dominant climate is semiarid to arid characterized by low precipitation, low groundwater recharge, and frequent drought conditions. Water resources in the Borderlands are controlled by physiographic, geologic, and hydrologic characteristics, which were used to identify the eight subareas used in this report (see chapter 2): the varied geology and topography of the coastal plains, the Peninsular Ranges, and the Salton Trough control water resources in subarea 1; Basin and Range geology controls both the location of rivers and the geometry of aquifers in subareas 2 through 4; and the Rio Grande and its tributaries dominate the hydrology in the eastern portion of the Borderlands. In subareas 5 through 8, the river forms the international border in Texas from El Paso to Brownsville and ultimately flows into the Gulf of Mexico. Although the Borderlands are described in this chapter as multiple subareas—each with its own specific hydrologic issues—water is a limiting resource throughout the entire border region. In fact, consumptive use ranges from about 35 percent of renewable supplies in California to 103 percent in the Lower Colorado, indicating an ongoing deficit (fig. 4–1). To ensure the viability and sustainability of people and the environment to which we are inextricably linked, improved knowledge of the quality and availability of water resources in the Borderlands (fig. 4–2) is needed as populations continue to increase along the border.

Figure 4–1 (facing page). Average consumptive water use compared with renewable water supply for water resources regions in the western United States. The Lower Colorado and Rio Grande water resources regions are the only regions in the United States that consume 40 percent or more of their renewable supply. Over half of the U.S. regions use 10 percent or less. Modified from Anderson and Woosley (2005).

EXPLANATION

1 **Subareas of the border region**

1 Pacific Basins–Salton Trough
2 Colorado River–Gulf of California
3 Mexican Highlands
4 San Basilio–Mimbres
5 Rio Grande West—Elephant Butte Reservoir to Rio Conchos
6 Rio Grande Central—Rio Conchos to Amistad Reservoir
7 Rio Grande East—below Amistad Reservoir to Falcon Reservoir
8 Lower Rio Grande Valley

Consumptive use as a percentage of renewable supply

0 – 10
10 – 40
40–100
Greater than 100

Volume, in billion gallons per day

3.8 — 1995 consumptive use
5.4 — Renewable water supply

International boundary

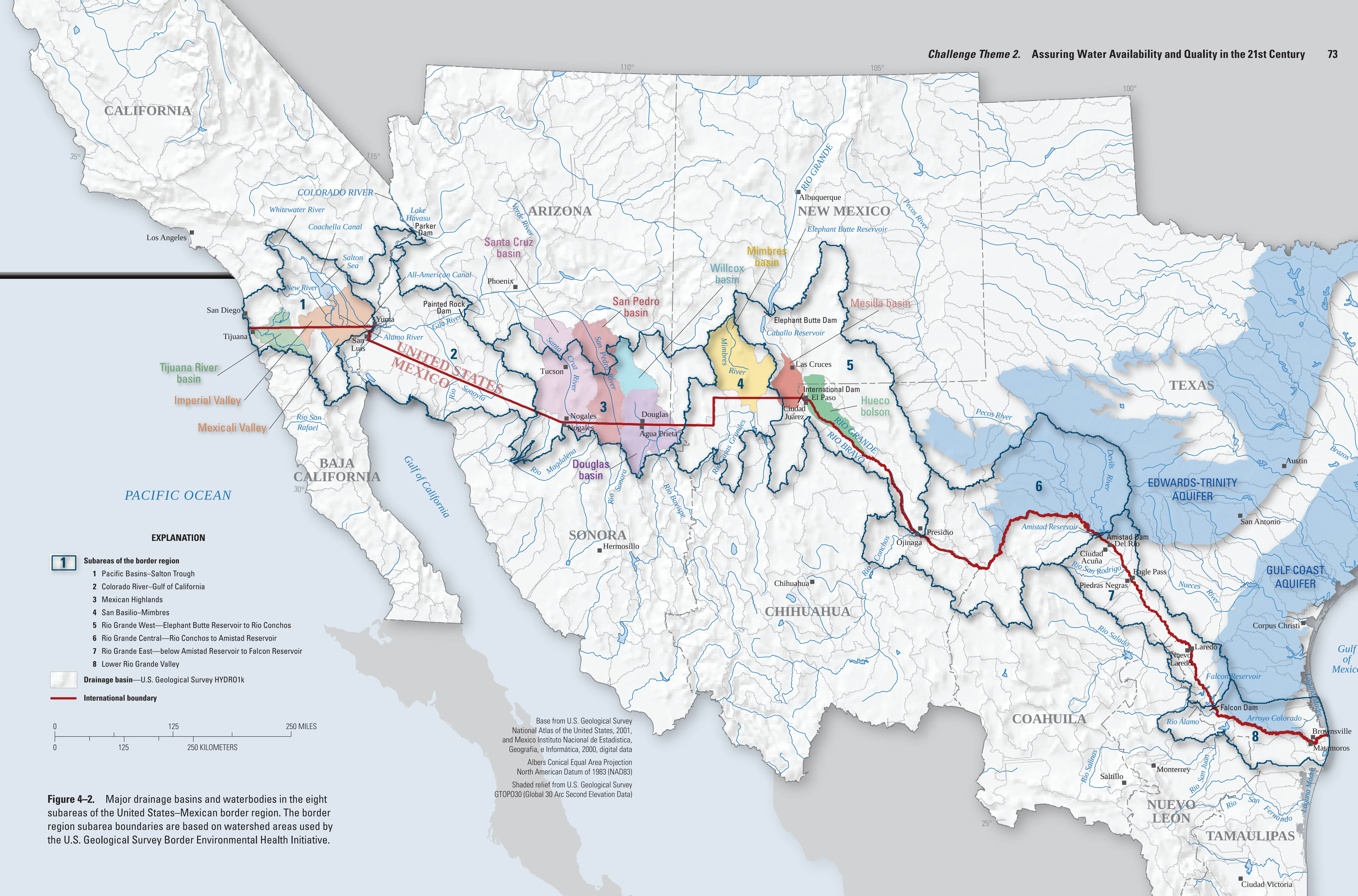


Figure 4–2. Major drainage basins and waterbodies in the eight subareas of the United States–Mexican border region. The border region subarea boundaries are based on watershed areas used by the U.S. Geological Survey Border Environmental Health Initiative.

Subarea 1. Pacific Basins and Salton Trough

The Pacific Basins–Salton Trough subarea (subarea 1; fig. 4–2) includes the coastal basins encompassing San Diego and Tijuana and the desert basins of the Imperial and Mexicali Valleys in the Salton Trough. Local water resources are limited because precipitation is low, and much of the water used in this subarea is imported. A large portion of the area's water resources comes from the Colorado River, which provides substantial irrigation to agricultural lands in California, Arizona, and Mexico. The San Diego–Tijuana metropolitan area is one of the most heavily populated areas along the border (combined population of more than 4 million). Groundwater supply is limited in the coastal area, and the most productive aquifers are Quaternary alluvial deposits that are generally less than 46 meters (m) (150 feet [ft]) thick (Izbicki, 1985). The Tijuana River basin crosses the international border, with about 72 percent of the basin in Mexico and 28 percent in the United States. Groundwater quality in the Tijuana River basin is poor because of excessive groundwater mining that occurred from the 1950s through the 1970s—when more groundwater is pumped than recharged in coastal aquifer systems, saltwater intrudes into the groundwater supply area.


Imperial Dam, Colorado River

The lowest part of the Salton Trough is the Salton Sea, which was accidentally filled by a canal levee break in 1905. It currently receives surface-water inflow from the New and Alamo Rivers originating in Mexico (fig. 4–2) and agricultural runoff from land in the United States. Numerous studies have documented elevated levels of pesticides in the water and sediments carried by these water sources (Eccles, 1979; Setmire, 1984; Schroeder and others, 1988; Setmire and others, 1990; Michel and Schroeder, 1994; Crepeau and others, 2002; Leblanc and others, 2004 a, b; Orlando and others, 2008). Because of the contamination, groundwater is unsuitable for domestic and irrigation uses without treatment. The valley's agricultural productivity relies on imported Colorado River water, which recharges groundwater through irrigation and seepage from canals that carry the water from the river to the agricultural areas (Loeltz and others, 1975).


Salton Sea


Tijuana River Reservoir

A salt-encrusted tree
in the Salton Sea

Palo Verde Diversion Dam, Colorado River

Parker Dam, Colorado River

Subareas 2, 3, and 4. Colorado River and Gulf of California, Mexican Highlands, and San Basilio and Mimbres

The Colorado River–Gulf of California, Mexican Highlands, and San Basilio–Mimbres subareas (subareas 2, 3, 4; fig 4–2) are within the Basin and Range physiographic province (Anderson, 1995). Surface-water resources in these subareas have either been completely allocated through legal compacts and water-right agreements or are the subject of a decades-long legal process (adjudication) to decide water rights (Arizona Department of Water Resources, 2007). The Colorado River, the largest river in this area, has a median annual flow of over 9 billion cubic meters (m^3) (about 7.3 million acre-feet [acre-ft]) as measured from 1935 to 2008 below Lake Havasu and Parker Dam (U.S. Geological Survey, 2009). A total of about 1.9 billion m^3 (1.5 million acre-ft) are appropriated for flow across the international boundary into Mexico (Arizona Department of Water Resources, 2008), and more than 1.7 billion m^3 (1.4 million acre-ft) are diverted into the Central Arizona Project, along with additional diversions to the All-American Canal, which diverts water to the Salton Trough. So much flow is diverted from the Colorado River that, in years without a flood, water from the river almost never reaches the Gulf of California (Cohen and Henges-Jeck, 2001).

New Waddell Dam, part of the Central Arizona Project

Most of the available surface-water and groundwater resources in the area are the result of episodic recharge from spring snowmelt and summer thunderstorms or of effluent from wastewater treatment plants. Much of the precipitation and runoff, however, comes from monsoon thunderstorms, rapid snowmelt, or hurricanes, which can have large negative effects on human populations and riparian and aquatic ecosystems. Though these events contribute to the available water supply, flooding and mobilization of sediments can quickly alter the shape and size of rivers and stream channels and can transport contaminants to downstream lakes, reservoirs, and ecosystems and into vulnerable aquifers.

In many locations within these three subareas, groundwater mining has caused water tables in the aquifers to decline. Some aquifers are becoming more saline because of intrusion of deeper, salty groundwater into pumped aquifers. Arizona and New Mexico groundwater resources are estimated to be depleted annually by about 3.1 billion m^3 (2.5 million acre-ft) and 1.6 billion m^3 (1.3 million acre-ft), respectively, resulting from combined municipal, industrial, and agricultural usage (Wilson and others, 2003). Evapotranspiration is also a substantial factor in water budgets for this arid and semiarid region.

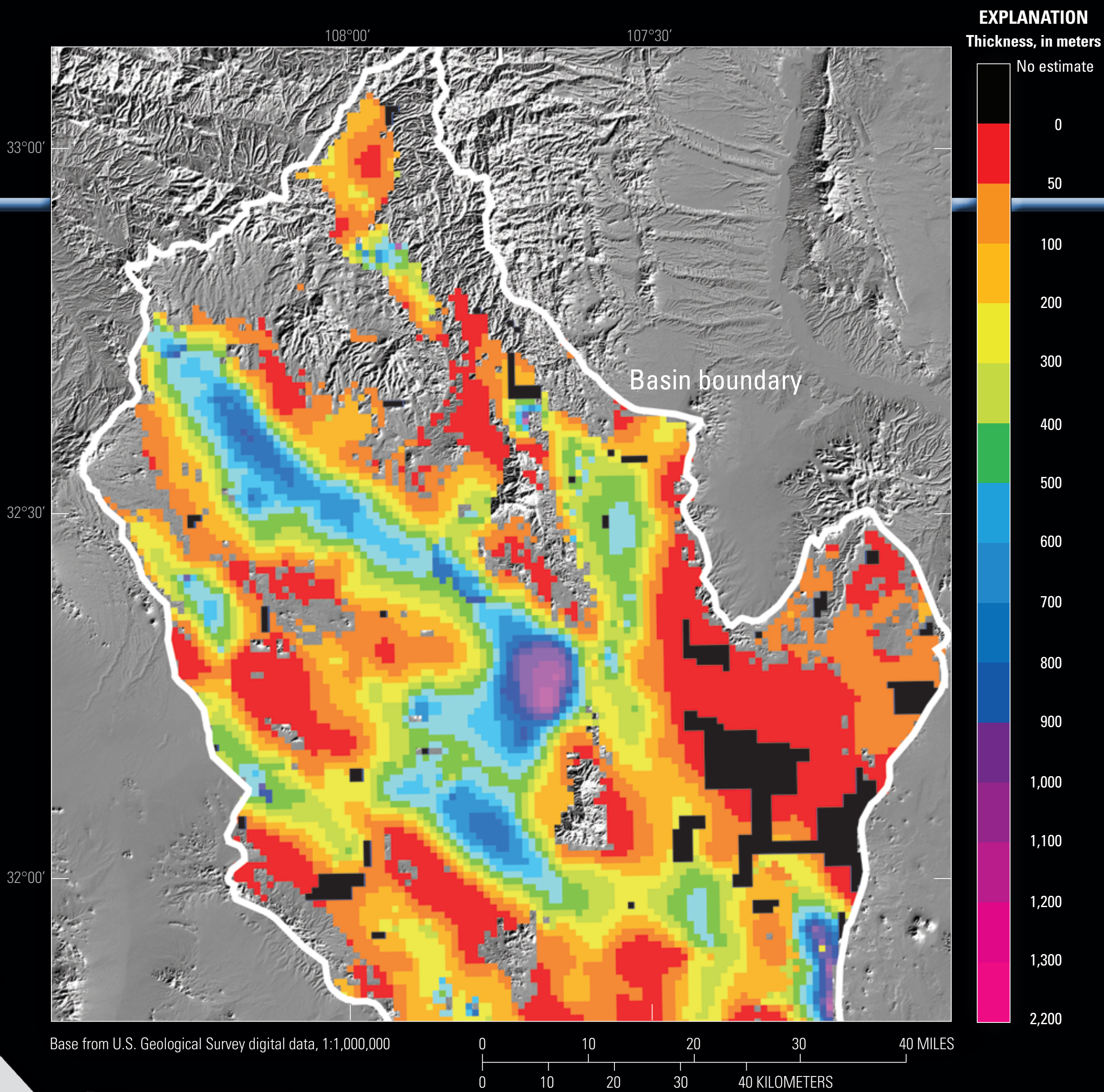
Aside from the Colorado River, the major drainage systems are the San Pedro, Bavispe, Santa Cruz, Gila, and Mimbres Rivers, though each has at least one ephemeral or intermittent section along its course. The major aquifers are found within alluvial deposits of the Colorado, Willcox, Douglas, San Pedro, Santa Cruz, Gila, and Mimbres basins. These aquifers contain substantial volumes of water in storage, but annual recharge is low, so groundwater in this region is largely a nonrenewable resource. Before water-resource development, the Santa Cruz, San Pedro, and Gila Rivers had sustained flow for most of the year in some reaches. Groundwater pumping and surface-water diversions and impoundments for agricultural and municipal uses, however, have substantially decreased water levels and have captured groundwater that once flowed to streams and rivers (see special section on capture maps, p. 84) (Hoffmann and Leake, 2005; Thomas and Pool, 2006; Webb and others, 2007). As a result, rivers such as the Santa Cruz have become almost entirely dependent on effluents for their water supply for most of the year, and the change in source water has created substantial negative effects on water quality (Cordy and others, 2000).

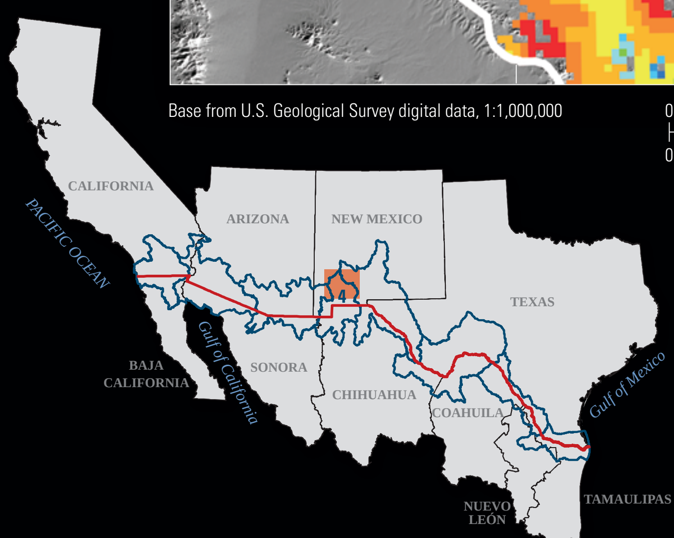
Portion of the Colorado River Aqueduct in southern California

. . . facing the challenge

Estimation of Aquifer Thickness in the Mimbres Groundwater Basin, New Mexico, Using Gravity

Groundwater is a principal supply for domestic, industrial, and agricultural water in the Mimbres basin in southwestern New Mexico. Substantial groundwater withdrawals since the 1930s have resulted in water-table declines of as much as 40 m (130 ft), causing land subsidence, fissuring, and abandonment of some agricultural land. To better manage water resources in this area, it is critical to understand the quantity and movement of groundwater in the local aquifers. Partnering with the New Mexico Office of the State Engineer, the USGS set out to determine the shallow geologic structure of the Mimbres basin and to identify possible locations of other nearby productive aquifer systems. Previous studies indicated that the geologic structure of the basin is characterized by north- and northwest-trending subbasins, but the locations and depths of the subbasins were unknown. Sedimentation has filled and obscured the boundaries of these subbasins and formed potentially productive aquifers of varied thickness. As part of this study, the shape and depth of the subbasins were estimated from variations in the Earth's gravity from one place to another. Differences in the density and thickness of sediment versus bedrock in these subbasins cause variations in gravity that are large enough to be measured. Analysis of the gravity data allowed for the separation of the regional gravity field from the gravity signal of the alluvium (sediment) filling the subbasins. The data were used to estimate the locations and depths of the subbasins and to compute the thickness of the alluvium. The thickness estimates were compared with exploratory drill-hole information, other geophysical data, and geologic mapping to check the accuracy of the gravity analysis. The resulting map of alluvium thicknesses indicated the existence of large areas of thin alluvium within the subbasins and suggested that there were no additional large, untapped aquifers in the area. The lack of additional groundwater for domestic, industrial, and agricultural demands highlighted the need to conserve current resources for future uses. For more information, see Heywood (2002).





Estimated thickness of alluvial deposits in the Mimbres basin derived from gravity analysis. Modified from Heywood (2002).

Rio Grande near Santana Mesa

Subareas 5, 6, 7, and 8. Rio Grande and Lower Rio Grande Valley—Elephant Butte Reservoir to the Gulf of Mexico

The four subareas along the Rio Grande (subareas 5, 6, 7, 8; fig. 4–2) are located within three physiographic provinces—Basin and Range, Great Plains, and Coastal Plain (fig. 2–2, poster) (Fenneman, 1931; U.S. Geological Survey, 2003)—but are united by the Rio Grande. In these subareas, the river is the international boundary between Texas in the United States and Chihuahua, Coahuila, Nuevo León, and Tamaulipas in Mexico. The Rio Grande drains portions of the Chihuahuan Desert in southern New Mexico, northern Chihuahua, most of Coahuila, western Nuevo León, and southwestern Texas, as well as the subtropical lower Rio Grande valley of southern Texas and northern Tamaulipas. Mean annual flow was about 800 million m^3 (650,000 acre-ft) for the period 1961–2006 below Caballo Dam about 161 kilometers (100 miles) north of El Paso, Texas (U.S. Geological Survey, 2009). The primary tributaries are the Pecos River, Devils River, Rio Conchos, Rio San Rodrigo, Rio Salado, Rio Álamo, and Rio San Juan. Major aquifers are the Mesilla basin and Hueco bolson aquifers near El Paso, Tex., the Edwards-Trinity aquifer in south-central Texas, and the Gulf Coast aquifer in southeastern Texas. The Rio Grande has been described as a river that has been disconnected in the middle. Between Fort Quitman and Presidio, Tex., the river is intermittent, but near Presidio, the Rio Conchos, which drains 68,376 square kilometers (26,400 square miles) of the Sierra Madre Occidental of Mexico, provides substantial inflow that can contribute as much as 75 percent of the downstream flow of the Rio Grande. The river then flows between Big Bend National Park and adjacent protected areas in Mexico. Near its discharge to the Gulf of Mexico, flow in the Rio Grande is typically small, ranging from 0 to 25 m^3 (0 to 872 cubic feet [ft^3]) per second from 1934 to 2008 (International Boundary and Water Commission, 2009), and flow may disappear prior to reaching the Gulf of Mexico.

Pecos River Bridge
(tallest bridge in Texas)

Pecos River

Amistad Reservoir

Elephant Butte Reservoir

The portion of the Rio Grande in the Borderlands is highly regulated by four major reservoirs: Elephant Butte and Caballo Reservoirs in southern New Mexico and Amistad and Falcon Reservoirs along the Texas border with Mexico. These reservoirs were constructed for water storage and flood control and provide a continuous source of water for irrigation that accounts for about 80 percent of surface-water use of Rio Grande waters on the United States side (Texas Natural Resource Conservation Commission, 1996). The 1906 Convention for Equitable Distribution of the Waters of the Rio Grande requires that the United States deliver about 77 million m^3 (60,000 acre-ft) of irrigation water annually to Mexico as measured at El Paso–Ciudad Juárez by way of the International Dam (Meuller, 1975). Diversions carry water to crops in the floodplain of the river, and numerous drainage ditches return agricultural runoff to the river, which has increased salinity.

Critical Issues

Growing human populations and natural climate variability are straining the water resources of the Borderlands. The 1944 Treaty for Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande serves as the principal reference for boundary water questions between the United States and Mexico, but this treaty may not adequately address issues arising from the growing border population and increased competition for water resources (Southwest Center for Environmental Research and Policy, 2002). In Mexico, surface waters and groundwaters are considered a national resource and are federally regulated (Comisión Nacional del Agua, 2008). In the United States, regulation of the major rivers of the Borderlands, such as the Colorado River and the Rio Grande, has been decided by Supreme Court decisions, multistate compacts, and Congressional acts along with the international obligations described above. Groundwater resources, however, are not regulated by treaty between the United States and Mexico and, to varying degrees in the individual U.S. States, are less regulated than surface water.

Primary competing interests for available water resources include agricultural, industrial, municipal, and recreational uses. A number of animal and plant species on both sides of the border, many of them imperiled, also depend on an adequate supply of good-quality water (Fernandez and others, 2009; U.S Fish and Wildlife Service, 2011). Currently, a large share of water used for domestic and municipal supplies in the Borderlands is drawn from groundwater (Ward, 2003) at rates that often exceed the natural recharge of aquifers. Water tables have lowered as a result, which has caused land subsidence in a number of areas such as the Mimbres basin, the Imperial and Mexicali Valleys, and the Willcox and Douglas basins of southern Arizona (Arizona Land Subsidence Group, 2007). Subsidence and related earth fissuring can damage infrastructure such as pipelines, canals, and roads. In aquifers pumped for agricultural, industrial, and municipal use, especially in the Mesilla basin and Hueco bolson, the salinity of aquifer water is increasing because deeper, more saline groundwater is intruding into the water supply (Witcher and others, 2004). Groundwater depletion throughout the Borderlands has caused several municipalities to pursue other water resources such as interbasin groundwater transfers, reallocation of traditionally agricultural supplies, and addition of surface-water supplies to meet municipal usage demands for drinking water and industrial use water. For example, while the City of Tucson uses Colorado River water delivered through the Central Arizona Project, it has also purchased agricultural land in a neighboring basin to supplement its groundwater resources and add to the city's water supply. This change in the distribution of water supplies can complicate the existing issues of increasing endangered species and habitat requirements, water-rights claims, adjudication proceedings, and other legal issues.

Earth fissure in Cochise County, Arizona

Population growth and associated commercial growth in the Borderlands not only increase demand for available water supplies but also increase the possibility of contamination and degradation of water quality. The Tijuana River, for example, is one of the region's largest contributors of chemical and microbial contamination to the Pacific Ocean (Gersberg and others, 2004). In large agricultural areas such as the Mexicali and Imperial Valleys and the Rio Grande valley, pesticides and fertilizers degrade surface-water resources. Several streams in the Santa Cruz, San Pedro, Douglas, and Willcox basins of Arizona are designated as impaired because of *Escherichia coli* and nitrate exceedances (Arizona Department of Environmental Quality, 2008). In addition, there are widespread occurrences of metals and arsenic contamination in southern Arizona due in part to industry, current and historic mining, and natural ore deposits (Arizona Department of Environmental Quality, 2008; Arizona Department of Water Resources, 2009 a, b). Improper disposal of industrial chemicals, landfill leachate, leaking underground storage tanks, and infiltration from septic tanks have affected groundwater quality in municipal areas. Nearly 40 percent of wells in southern New Mexico have been found to be contaminated from a variety of human sources (Ward, 2003). In addition to contaminants, such as nitrates, pesticides, metals, and fecal bacteria, there is growing concern over pharmaceutical products that are commonly found in treated sewage and have been detected in the Rio Grande and many other river systems and aquifers in the Borderlands (Barnes and others, 2008; Focazio and others, 2008). Many compounds associated with these products are endocrine disrupters and possible carcinogens. Such organic contaminants have not been studied until recently, but published work to date indicates that they may be much more widespread than previously thought (Barnes and others, 2002; Barnes and others, 2008).

Tijuana River, Tijuana, Baja California

Increasing demands for surface-water and groundwater supplies and the increasing threat of contamination have led water-resource managers to consider alternative water resources. Some communities and government entities have implemented or are examining desalination of deeper saline groundwater to supplement their freshwater supplies. A joint project of El Paso Water Utilities and Fort Bliss created the world's largest inland desalination facility, which produces 104 million liters (27.5 million gallons) of fresh water daily when running at full capacity. The facility turns brackish water from a formation underlying the freshwater zone within the Hueco bolson into a new freshwater source that supplements groundwater withdrawals from the Mesilla basin and Hueco bolson and surface water diversions from the Rio Grande. In addition, the diversion of the brackish water diminishes the upward intrusion of saltwater into the existing freshwater supply (El Paso Water Utilities, 2008). Though desalination plants augment freshwater supplies, they create new waste streams (concentrate) that must be disposed of properly to minimize any potential negative effect on the environment. El Paso Water Utilities uses deep wells to inject concentrate into receiving waters that have total dissolved solids concentrations that are greater than the concentrate. The interaction between vertically stacked aquifers, however, is generally not well understood, and withdrawals or injections into deeper aquifers have the potential to affect overlying and underlying aquifers.

Given the current stresses on water resources and the growing population in the Borderlands, resource planning requires timely and accurate science. The current stresses will only intensify with increased population and the predicted increase in drought and alteration of precipitation patterns that may occur with climate change (see chapter 10).

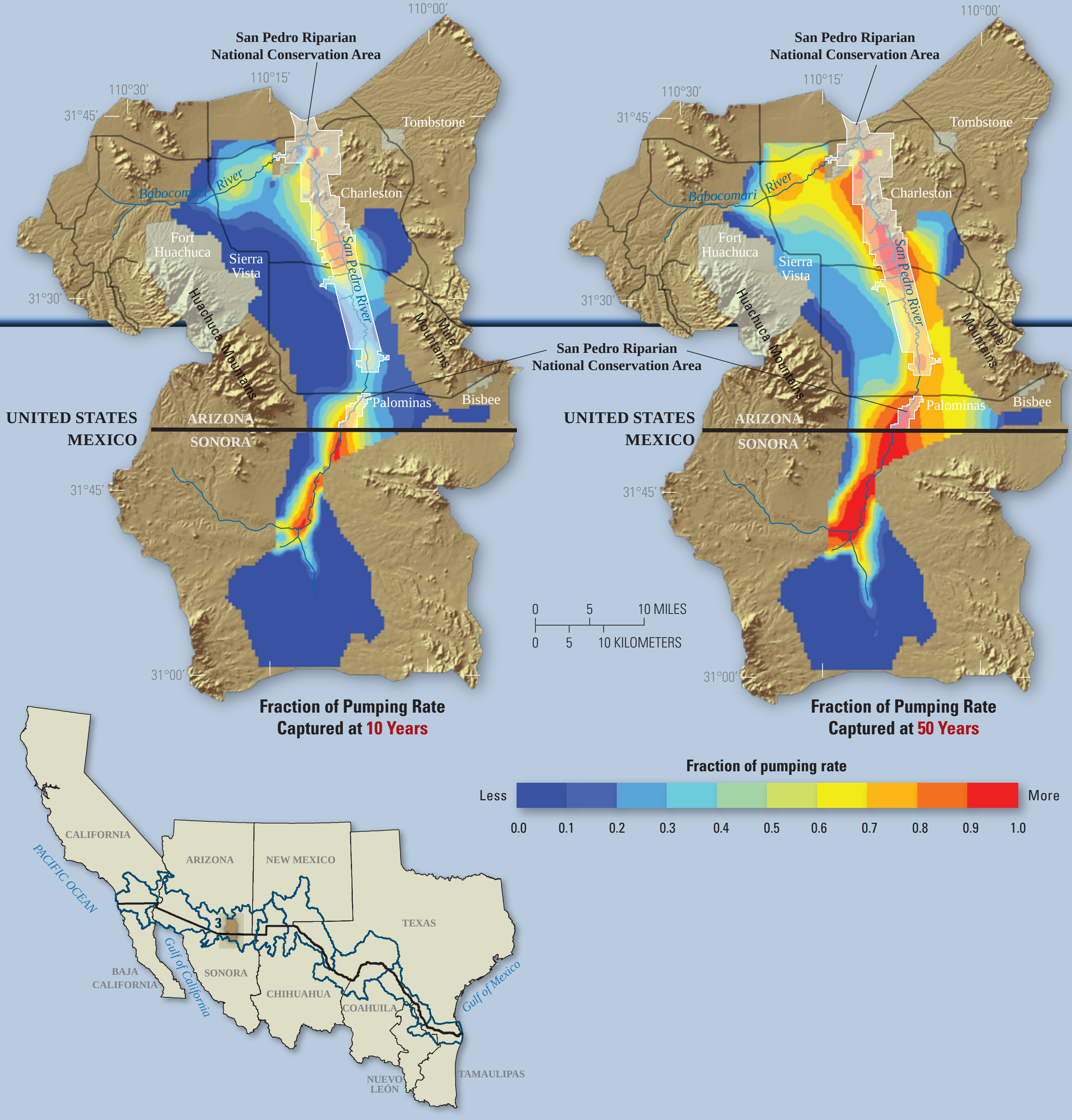
Yuma Desalting Plant, Yuma, Arizona

. . . facing the challenge

Capture Maps Help Water Managers Understand the Effects of Groundwater Pumping on Streams, Springs, and Riparian Vegetation

In many parts of the United States–Mexican border region, surface-water supplies are limited or nonexistent, so groundwater is an essential resource for human water needs. Groundwater discharging from aquifers also is critical for maintaining natural streams, springs, and riparian vegetation. Groundwater pumping removes water from storage in the aquifer, but with time, the effects of pumping spread to greater distances and can reduce groundwater discharge to natural features. The timing of these effects is dependent on aquifer properties and on the proximity of pumping locations to streams, springs, wetlands, and riparian vegetation. Extraordinary efforts have been carried out to better understand how groundwater pumping and artificial recharge by humans might affect the availability of groundwater to sustain streams, springs, and riparian vegetation. One of those efforts has been the development of a groundwater flow model simulating flow in the upper San Pedro basin of Arizona and Sonora that simulates movement of water from areas of natural replenishment (recharge) to areas of discharge. The model also can be used to understand the timing of the effects of pumping and artificial recharge on groundwater discharge to the San Pedro River in Arizona and Sonora and its congressionally protected riparian ecosystem, the San Pedro Riparian National Conservation Area.

By running the model sequentially with a pumping well in a different location in each simulation, "capture maps" were constructed to illustrate effects on the river, springs, and vegetation for any pumping location. In the example capture maps shown, effects are given in terms of a fraction of the pumping rate, ranging from no effect (a fraction of 0.0, or 0 percent, in darkest blue) to an effect on resources equal to the total pumping rate (a fraction of 1.0, or 100 percent, in red). The maps show the greatest effects of pumping near to the river, and comparison of the two maps shows that effects progress with time for most locations. The maps also can be used in the reverse sense to understand the timing of enhanced water availability to streams and vegetation by artificial recharge. Recharge in red areas would enhance water availability much more quickly than recharge in blue areas. For more information, see Leake and others (2008).



Capture maps showing computed change in streamflow, riparian evapotranspiration, and springflow after 10 years (left) and 50 years (right) of continuous pumping or recharge in the upper San Pedro basin in Arizona and Sonora. The color at any location represents the fraction of the pumping/recharge rate by a well at that location that can be directly accounted for as a reduction/increase in availability of groundwater (respectively) for streams, springs, and riparian vegetation. Modified from Leake and others (2008).

USGS Capabilities

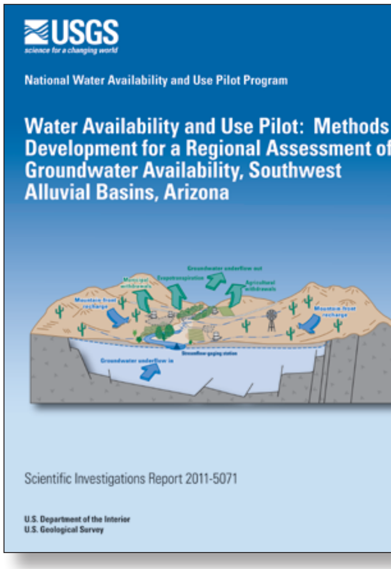
A clear understanding of the quantity and quality of water along the United States–Mexican border is critical if it is to be used to support a thriving economy, intact ecosystems, and a growing, healthy population. Additional research and a combination of new and traditional tools are needed to fill gaps in our understanding of how these sectors act and interact with regard to water. By using existing approaches, developing new techniques and tools, and bringing together scientists from diverse disciplines such as ecology, geology, geography, social science, and hydrology, the USGS is prepared to address the complex questions presented by the interactions of people, land, ecosystems, climate, and water along the United States–Mexican border. The capabilities of the USGS (table 4–1) allow us to monitor, characterize, and model hydrologic processes and thus assess water supplies and water quality and address water-resource issues in the Borderlands. In recent years, our ability to monitor and store data has improved tremendously. We can follow trends in groundwater levels, river flow, and water quality with greater resolution and in more places than ever before with greater accuracy and precision. Scientists with the USGS now monitor, via satellites, changes in land use, land cover, and water storage in river basins at a space and time resolution heretofore impossible. We can see underground in three dimensions using a variety of geophysical tools and can thus understand the shapes and boundaries of aquifers and the distribution of geologic materials within them. With newly developed regression equations, we can now predict flow in ungaged basins. We can then take the data generated by these monitoring techniques and combine them in multi-parameter models to understand and predict how land-use change, topography, population growth, changes in agricultural practices, urban expansion, and climate change affect flow in rivers, groundwater levels, and sediment and contaminant movement.

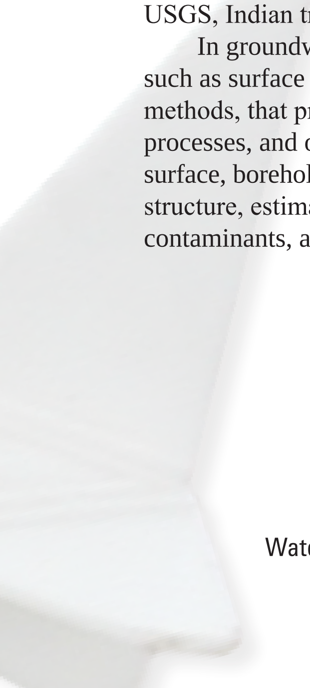
U.S. Geological Survey employee collecting a water quality sample in response to Hurricane Irene, August 2010.

The USGS Water Resources National Research Program (*http://water.usgs.gov/nrp/*) develops new methods, theories, and techniques to understand, anticipate, and solve water-resource problems. Scientists with the USGS work closely with colleagues in other Federal agencies, State water agencies, and State Water Resource Research Institutes to help plan, facilitate, and conduct research to aid in the resolution of State and regional water problems. We are also building strong relationships with scientists and agencies in Mexico. Through formal partnerships, the entire suite of USGS capabilities can be called on to assist land- and water-resource managers at all levels of government. Below are some examples of USGS programs that provide unique resources to help address complex hydrologic problems.

The USGS operates and maintains approximately 7,500 streamgages as part of the National Streamflow Information Program and the Cooperative Water Program, which provide long-term, accurate, unbiased, and permanently archived streamflow data (*http://waterdata.usgs.gov/nwis*) to meet the needs of diverse users (Norris, 2001). Streamflow data are not only essential in assessing water availability, but are also a critical component of the flash flood and debris-flow warning system provided by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration. Some of the oldest gages in the national network are especially relevant to the United States–Mexican border region; for example, the Rio Grande gages at Embudo, N. Mex., and below Elephant Butte Dam have records dating back to 1889 and 1917, respectively. These long-term records are essential if we are to understand and predict flood frequency, monitor climate change, and assist the U.S. Army Corps of Engineers as well as city and State governments in assessing infrastructure needs and zoning requirements for floodplain and disaster management. The majority of gages are funded through partnerships involving the USGS, Indian tribes, and Federal, State, and local agencies with a need for streamflow data.

In groundwater studies, the USGS is at the forefront of devising new techniques and tools, such as surface and borehole geophysical applications and chemical and isotopic age-dating methods, that provide detailed understanding of flow paths, water-rock interactions, recharge processes, and other aquifer characteristics. Current USGS research is focused on integrating surface, borehole, and airborne geophysical data analyses in order to image subsurface geologic structure, estimate physical properties that control fluid flow and contaminant transport, detect contaminants, and monitor hydrologic and remediation processes.





Water quality sampler used by the U.S. Geological Survey

Table 4–1. U.S. Geological Survey Water Resources capabilities for examining hydrologic systems.

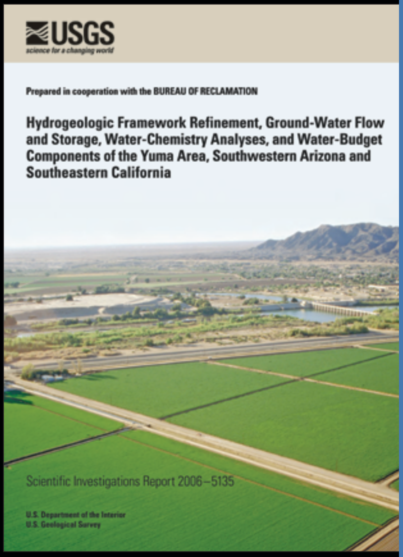
Discipline	Capabilities
Water Chemistry—Assess natural and contaminant chemicals in water and sediment, and study fundamental chemical and biochemical processes that affect the movement of organic and inorganic solutes in aquatic systems.	Organics in aquatic systems Carbon cycling Isotope hydrology and paleohydrology Trace elements and radionuclides Weathering and watershed processes Transport and biogeochemical reactions Gases in aquatic systems
Groundwater Hydrology—Understand the processes that control movement and availability of subsurface water; its transport of dissolved substances, microbes, particulate, and other fluid phases; and its interactions with the geological environment.	Development and application of quantitative groundwater models Groundwater resource assessments Groundwater–surface water–atmospheric interactions Unsaturated-zone hydrology Fractured-rock hydrology Groundwater in geologic processes Geophysical investigation of subsurface processes
Surface-Water Hydrology—Quantify, understand, and model the physical processes that control the distribution and quality of the Nation's surface-water resources.	National stream gaging network Flow and transport in rivers Watershed modeling Estuarine hydrodynamics Climate variability and surface-water hydrology Statistical analysis of floods and droughts
Hydrogeologic Framework Modeling	Geologic mapping Three-dimensional modeling Geophysical data integration Hydrostratigraphy
Geomorphology and Sediment Transport—Understand stream-channel morphology and erosional processes that govern the source, mobility, and deposition of sediment.	Sediment transport dynamics Changes in river channels over time Channel morphology and sediment transport Flow and sediment mechanics
Ecology—Investigate the ecological and biogeochemical processes that affect the quality of water in aquatic systems.	Microbiology Aquatic ecology Climate and ecology Biogeochemistry

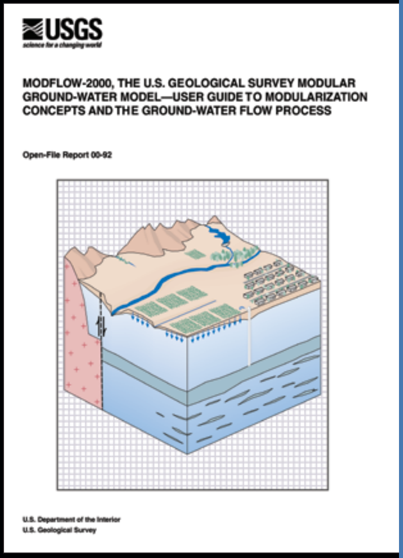
The state-of-the-art National Water Quality Laboratory (NWQL) analyzes water, sediment, soil, and plant and animal tissue for constituents such as heavy metals, pesticides, polychlorinated biphenyls (PCBs), and flame retardants, as well as components of pharmaceutical and personal-care products such as hormones, barbiturates, antimicrobial compounds, and anti-epileptics. The NWQL provides high-quality, reproducible water-quality data to the Nation, readily accessible on the Internet (*http://nwql.usgs.gov/*). The laboratory specializes in trace- and ultratrace-level analyses and the identification and quantification of benthic invertebrates. These analytical facilities and their leading-edge capabilities, especially for research on emerging contaminants, are ideal for the characterization of a wide range of contaminant sources and allow the USGS to conduct research on topics such as the effects of sewage treatment and disposal on groundwater and surface-water quality along the border. Other specialized laboratories around the country expand and deepen USGS investigative capabilities: the Chlorofluorocarbon Laboratory in Reston, Virginia, can date young waters through chlorofluorocarbon, sulfur hexafluoride, and tritium-helium methods; the Wisconsin mercury laboratory is pioneering the detection of highly toxic methylmercury at ultratrace levels; and the Stable Isotope Laboratories, also in Reston, use isotope ratio techniques to identify sources of waters, flow paths in aquifers, and the migration of contaminants.

Computer models allow us to conduct hydrologic experiments that would be too costly or lengthy to carry out any other way. Computer models can incorporate all measured and monitored information collected in rivers and aquifers and couple it with the best mathematical and theoretical understanding of the manner in which the physics, chemistry, and biology of a system fit together and interact. By comparing the output of computer models to measured data, calibrated models give us an idea of how well we understand the complex interplay among processes such as pumping or contaminant movement in rivers and aquifers. The USGS has built extensive modeling capabilities through the development of hydrologic software such as GCLAS (constituent loading in surface waters), HYDROTHERM (multi-phase groundwater and heat transport), PHAST (flow, solute transport, and geochemical reactions), PHREEQC (geochemical analyses), and MODFLOW, many of which have become industry standards.[1] For instance, MODFLOW is the mostly widely used groundwater-modeling software in the world. State and local governments, groundwater scientists, and engineers in the private sector often need predictive computer models to make informed decisions on hydrologic resources. Models are developed by the USGS for use in the public interest and the advancement of science, and their developers are continually improving the capabilities of the models to better simulate physical, chemical, and microbial processes.

It is expected that water challenges along the United States–Mexican border will continue into the foreseeable future. With population increases, urbanization, and the growing effects of climate change, there will continue to be issues of water sufficiency and contamination in this arid region. The USGS will continue to fulfill its role by providing the scientific and technical information needed to support communities, decisionmakers, and resource managers in their efforts to ensure a sufficient supply of good-quality water for the people and ecosystems of the Borderlands.

References cited in this chapter are listed in chapter 12.





[1] GCLAS, Graphical Constituent Loading Analysis System; PHAST, combination of PHREEQC and HST3D; MODFLOW, modular three-dimensional finite-difference groundwater flow model.

. . . facing the challenge

The Use of Semipermeable Membrane Devices To Assess Organic Compounds in the Rio Grande from Presidio to Brownsville, Texas

Population growth and agricultural and industrial development along the Rio Grande, particularly along the part of the river that forms the international boundary between Texas and Mexico, have altered the water quality and flow of the river. Urban and agricultural runoff and wastewater discharges from industrial and municipal facilities are potential sources of toxic organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides including DDT (dichlorodiphenyltrichloroethane) and chlordane that were banned earlier in the United States than in Mexico. The USGS has used semipermeable membrane devices (SPMDs; Alvarez, 2010) as long-term contaminant-accumulating samplers to detect concentrations of hydrophobic organic compounds in the lower reach of the Rio Grande. Traditional monitoring of PAHs, PCBs, and pesticides typically emphasizes the collection and analysis of riverbed sediments and the tissues of aquatic organisms because many of these compounds stick to sediment surfaces and move into the fat of people and other organisms. Traditional water-sampling methods generally involve a single grab or a representative composite sample that is taken during a few seconds or minutes. The short duration of traditional water-sampling methods and the small volumes of water collected decrease the probability that hydrophobic contaminants can be detected if they are present at low or variable levels. An SPMD typically consists of a lipid film membrane with a high surface-area-to-volume ratio and is similar to a biological membrane such as a fish gill. The SPMDs were deployed in the Rio Grande in 1997 for about 30 days at six locations between Presidio and Brownsville, Tex. Seven organochlorine pesticides, including DDT and its daughter product DDE (dichlorodiphenyldichloroethylene), were detected in these SPMDs. All organochlorine pesticides detected were banned or restricted from use in the United States by the U.S. Environmental Protection Agency in the 1970s or 1980s and by Mexico in the late 1990s. Frequent detections of these compounds demonstrated their persistence in the aquatic environment and the continuing need to monitor for legacy contaminants that might remain in the environment for decades after release or that might be less regulated in certain countries.

U.S. Geological Survey employees prepare a semipermeable membrane device (SPMD) for deployment (top and bottom right). The membrane, housed in a deployment capsule (above), is similar to biological membranes and thus can simulate the bioaccumulation of organic compounds in water and sediment.