Chapter 6


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Chapter 6

Challenge Theme 4. People in the Borderlands

By Laura M. Norman, Rudy M. Shuster, and Jean W. Parcher

Introduction

The management of shared resources in the United States–Mexican border region requires cooperation from the people of both countries to assess and understand their relation to the environment. Society is dependent on the long-term healthy functioning of ecosystems and their ability to supply food and raw materials. Likewise, resources and services obtained from nature could be used efficiently within the society. A more equitable distribution of costs and benefits related to goods and services can lead to fewer tensions and a higher quality of life for all the people in the Borderlands. Urban development, background contamination from mineral ore deposits, irrigation, sewage effluent, and even global climate change all have the potential to alter the stability of the fragile systems in the Borderlands (Brady and others, 2001, 2002; Norman, 2007, 2010; Gu and others, 2008; Norman, Gray, and others, 2008; Norman, Hirsch, and Ward, 2008; Norman, Callegary, and others, 2010; Norman, Huth, and others, 2010; Norman, Levick, and others, 2010; Norman, Tallent-Halsell, and others, 2010; Norman, Villarreal, and others 2012). Social efficiency means that because resources should be

Downtown Yuma, Arizona

used where they are needed most, they should be distributed proportionally among human societies and individuals (Azar and others, 1996). Despite the critical role natural resources play in maintaining human and environmental health, current knowledge of the manner in which natural and human-caused forces interact to limit these resources—including their quality and quantity (such as through spatiotemporal changes in precipitation, evapotranspiration, pumping of groundwater, and release of contaminants)—is inadequate. The U.S. Geological Survey (USGS) is trying to understand the relation between changing landscapes, changing demographics, and a changing climate in the Borderlands while the environmental, economic, and societal issues continue to be intertwined between the two nations.

Providing scientific information to land management and public policy decisionmakers is at the heart of the USGS science strategy.

> By understanding the status of U.S. natural resources, how natural resources interrelate and change with time, and how resilient they are to future natural and human-caused threats, decisionmakers will be able to ensure the security of the Nation, the vitality of its economy, the health of its environment, *and the well-being of its citizens*. (U.S. Geological Survey, 2007, p. 1, emphasis added)

Specifically, the USGS provides unbiased, multidisciplinary science in the context of climate/global change, water, natural hazards, and human health risks so decisionmakers can assess the interrelations and effects of these issues on human populations. The climate research goals of the USGS are also outlined in the science strategy.

> The USGS will conduct research to advance the knowledge of processes that are crucial to predicting the future evolution of global climate and to understand the land, water, environmental, and *societal consequences* of changing climate. *** Studies of the probability and consequences of abrupt changes and thresholds will be used to clarify the nature of change and the effects on the environment and *society*. (U.S. Geological Survey, 2007, p. 16, emphasis added)

Combining the results of USGS natural and biological science with socioeconomic research fosters resilience in human communities and throughout the socioecological system.

The USGS science strategy uses the concept of complex and nonlinear relations to frame the interactions between social and ecological systems. For example, a wildlife preserve might be dependent upon a watershed that contains intense human development (cities, industrial centers, etc.). The human communities might be dependent on the ecological system within the wildlife preserve for ecosystem services such as drinking water purification or subsistence hunting for local populations. Climate change might result in increased precipitation within the watershed, which would lead to increased runoff bringing industrial pollutants into the ecological system. Native vegetation might adapt to the increased pollutants, and the wildlife might adapt to a new habitat. This relation is complex but with an obvious cause and effect; anticipating and managing these relations and the resulting effects to humans, however, is difficult. Nonlinear relations have disproportionate cause and effect relations and are inherently difficult to manage.

> Complex and nonlinear physical, chemical, and biological interactions are becoming an increasingly important focus for climate change assessments and basic research. *** but there is little insight into when biological thresholds will be crossed, much less on the implications for species, ecosystems, and the *services society expects from the environment*. (U.S. Geological Survey, 2007, p. 14, emphasis added)

The socioecological systems (SES) method describes the complex relations between humans and their environment. It hypothesizes that the well-being of the ecosystems and human communities are co-dependent and must be managed simultaneously; changes in one system might cause changes in the other. The SES approach acknowledges not only that humans and nature are both nested in the system, but also that humans react to nature and nature reacts to human actions as two complementary but distinct entities within the system (Berkes and Folke, 1998; Carpenter and Folke, 2006).

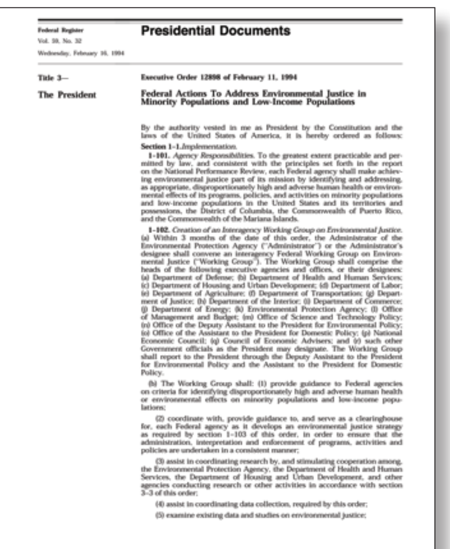
Cacti along a Central Arizona Project canal

Governance systems are a third external factor influencing the SES and must be accounted for.

> Institutions not only regulate the way humans relate to nature and how resources are used, both individually and collectively, but are at the core of the organizations (for example, governmental agencies dealing with Natural Resource Management) and governance systems (including public and private spheres). (de la Torre-Castro, 2009, p. 437).

One example of governance driving science in SES is Executive Order 12898, "Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations," issued in 1994 (U.S. President, 1994). The order mandated that each U.S. Federal agency make environmental justice part of its mission by focusing on how agency policies and actions affect the relation between human health and environment in low socioeconomic and high minority communities. The U.S. Environmental Protection Agency (EPA) defines environmental justice as

> …the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work. (U.S. Environmental Protection Agency, 2012a)



Federal Register
Vol. 59, No. 32
Wednesday, February 16, 1994

Presidential Documents

Title 3—

The President

Executive Order 12898 of February 11, 1994

Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1-1. *Implementation.*

1-101. *Agency Responsibilities.* To the greatest extent practicable and permitted by law, and consistent with the principles set forth in the report on the National Performance Review, each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions, the District of Columbia, the Commonwealth of Puerto Rico, and the Commonwealth of the Mariana Islands.

1-102. *Creation of an Interagency Working Group on Environmental Justice.* (a) Within 3 months of the date of this order, the Administrator of the Environmental Protection Agency ("Administrator") or the Administrator's designee shall convene an interagency Federal Working Group on Environmental Justice ("Working Group"). The Working Group shall comprise the heads of the following executive agencies and offices, or their designees: (a) Department of Defense; (b) Department of Health and Human Services; (c) Department of Housing and Urban Development; (d) Department of Labor; (e) Department of Agriculture; (f) Department of Transportation; (g) Department of Justice; (h) Department of the Interior; (i) Department of Commerce; (j) Department of Energy; (k) Environmental Protection Agency; (l) Office of Management and Budget; (m) Office of Science and Technology Policy; (n) Office of the Deputy Assistant to the President for Environmental Policy; (o) Office of the Assistant to the President for Domestic Policy; (p) National Economic Council; (q) Council of Economic Advisers; and (r) such other Government officials as the President may designate. The Working Group shall report to the President through the Deputy Assistant to the President for Environmental Policy and the Assistant to the President for Domestic Policy.

(b) The Working Group shall: (1) provide guidance to Federal agencies on criteria for identifying disproportionately high and adverse human health or environmental effects on minority populations and low-income populations;

(2) coordinate with, provide guidance to, and serve as a clearinghouse for, each Federal agency as it develops an environmental justice strategy as required by section 1-103 of this order, in order to ensure that the administration, interpretation and enforcement of programs, activities and policies are undertaken in a consistent manner;

(3) assist in coordinating research by, and stimulating cooperation among, the Environmental Protection Agency, the Department of Health and Human Services, the Department of Housing and Urban Development, and other agencies conducting research or other activities in accordance with section 3-3 of this order;

(4) assist in coordinating data collection, required by this order;

(5) examine existing data and studies on environmental justice;

Executive Order 12898

Children playing in a makeshift swimming pool at a colonia in Aqua Prieta, Sonora, Mexico, in 2004

Acknowledging the relations among the social and ecological systems is integral to successfully applying scientific information in resource management and governance (Pachauri and others, 2007; Resilience Alliance, 2007 a, b). The social system is a strong driver of change in ecological systems—increased human development pressure has pushed the limits of adaptability in ecological systems—but adaptability in ecological systems drives and limits change in social systems. The complexities of the SES have created problems and questions that are not confined to a single scientific discipline. Interdisciplinary research among social, behavioral, economic, and natural/biological scientists is necessary to solve these problems and develop new technologies to manage social and ecological systems within their limits of adaptability (National Academy of Sciences, 2005).

Human uses of natural resources, although required for civilization, might also lead to undesirable ecological consequences, which often create environmental justice issues in low socioeconomic and high minority communities at a disproportionately high rate in comparison to more affluent communities. According to Moda (2007), a large number of communities suffer from environmental justice issues in the United States portion of the Borderlands, where 25 percent or more of the population lacks native language proficiency, 25 percent or more of the population is foreign born, 25 percent or more of the population is minority, and (or) median annual income of the population is at or below 65 percent of the State median income. The distribution of environmental hazards (for example, contaminated drinking water, decreasing water yields, or susceptibility to flooding) has shown high frequency in low income, high minority communities along the border (Norman, Caldeira, and others, 2012). Rural communities along the border are also confronted with multiple environmental justice issues: illegal dumping of trash and (or) industrial waste, agricultural drainage, exposure to airborne dust and pesticides, inadequate water supplies, insufficient waste facilities, and degraded natural resources and ecosystems (Norman, Hirsch, and Ward, 2008; Norman, 2010). In addition, the World Health Organization has identified that these communities are more vulnerable and susceptible to local health effects of climate change (Patz and Balbus, 1996).

The United States–Mexican border region is an area where the SES and governance structures interact to create a complex natural resource and policy decisionmaking arena. In the United States, mandates such as the environmental justice Executive Order drive the need for scientific environmental information in a specific social context. The USGS is dedicated to providing scientific information to assist in this complex decisionmaking through projects that integrate social, behavioral, economic, and natural science analyses in the context of human and natural resource interactions. The international border separating the two countries, however, further complicates matters because differences in culture, language, priority, law, and policy interrupt management of an environment that spans the border. Science that crosses the border needs to be coordinated in order to understand the human drivers of undesirable consequences and forecast socioecological events. The sections that follow in this chapter showcase USGS capabilities and projects, both completed and ongoing, and list areas where more science is needed.

Inside a maquiladora in Mexico

maquiladora

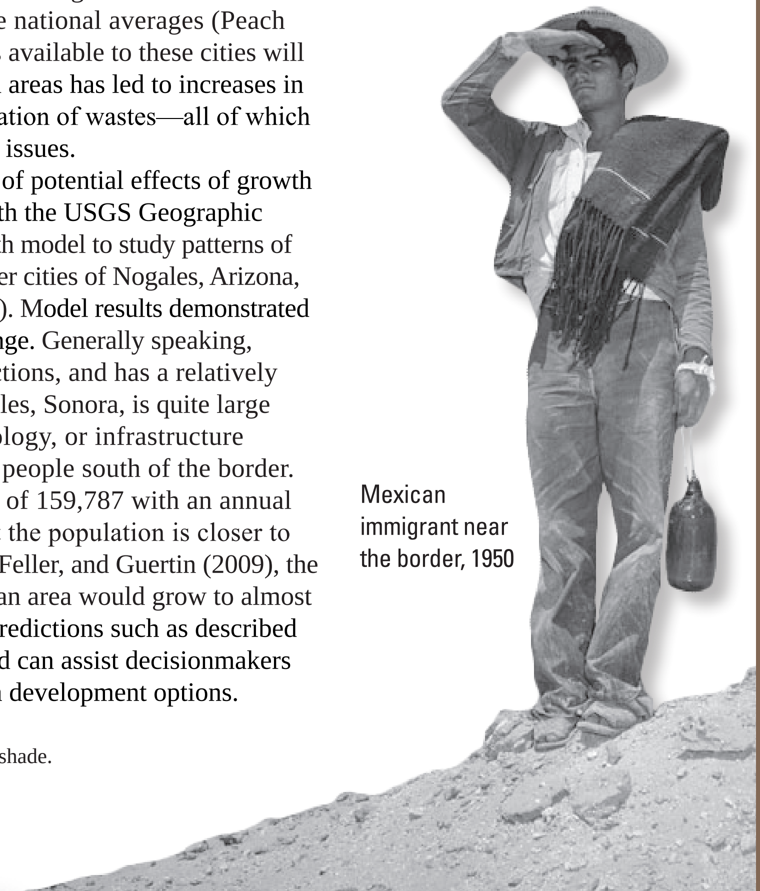
Population Growth

The populations on both sides of the border respond to ebbs and flows in social and economic change—largely dependent on current regulation. Policy reforms on both sides of the border greatly affect how and where human populations migrate and reside. Labor shortages in the United States brought about by World War II instigated reliance on Mexican workers. In response, the Bracero Program, in effect from 1942 through 1964, encouraged millions of Mexicans to work in the United States (Donelson and Esparza, 2007). During the 1960s, Mexico started two important programs: El Programa Nacional Fronterizo [the National Border Program] and the Border Industrialization Program (BIP). The purpose of the BIP was to aid the economic development of northern Mexico by attracting foreign assembly firms, called maquiladoras, to the border region (Garibay, 1977). Maquiladoras are factories that can be owned and operated by United States companies though they are located in Mexico. These factories import raw materials on a tax-free basis into Mexico for use in manufacturing and then export products back to United States markets. Maquiladoras often employ laborers from Mexico at what can be considered low wages compared to American standards. In addition, because they are located in Mexico, they do not necessarily have to conform to the strict building and processing codes required in the United States (Donelson and Esparza, 2007). The North American Free Trade Agreement (NAFTA) in 1994 was designed to foster greater trade between Canada, the United States, and Mexico through the elimination of taxes on goods shipped between these countries. The agreement created favorable economic conditions for the expansion of maquiladoras in border communities, thus creating incentives for individuals to migrate to the border cities. Low wages paid to Mexican workers and high productivity have attracted foreign investment and job creation at the border, which have contributed to the huge population expansion in arid areas that have diminishing and effectively irreplaceable water resources (Ingram and Varady, 1996; Norman, Donelson, and others, 2006).

Mexican workers at Mexicali, Baja California, waiting for legal employment in the United States, 1954

Laborers return to Mexico after working in the United States, 1954

Mexican laborers working in southern California as part of the Bracero Program, 1963



Mexican immigrant near the border, 1950

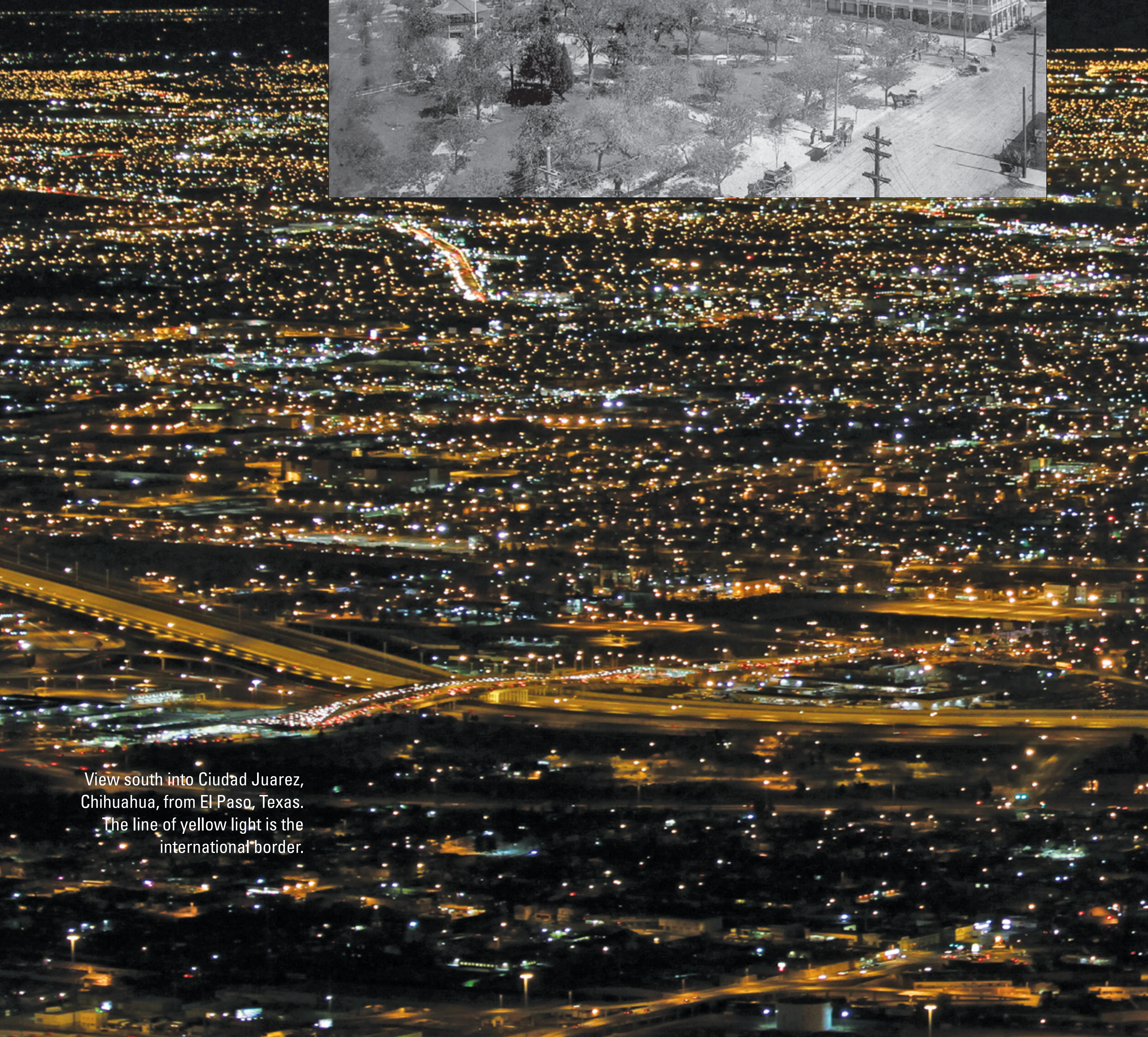
The demographic settlement pattern of the Borderlands follows the world trend toward increased urbanization (14 percent urban in 1900 rising to almost 50 percent urban in 1990), shifting the population from rural farms to integrated population centers (Douglas, 1994). Because of the binational heritage in the region, populations on both sides of the border are interconnected economically, politically, and socially, and 14 sister city pairs have developed as a result (Parcher, 2008). (Sister cities or twin cities are those communities where a city in one country borders a city in the other, creating a large urban area separated by political and administrative boundaries. For a list of sister cities in the Borderlands, see table 2–1.) Families and individuals from southern Mexico interested in improving their status migrate to these regions in search of employment. Migration is the primary factor for urban population growth at the border and is compounded by increasing birth rates. Population growth rates in both Mexican and United States sister cities are more than double the national averages (Peach and Williams, 2003), and if current trends continue, the resources available to these cities will quickly become overburdened. Rapid population growth in urban areas has led to increases in the demand for land and energy, traffic congestion, and the generation of wastes—all of which affect available resources and contribute to environmental justice issues.

Prediction of urban growth can help promote understanding of potential effects of growth on water resources, the economy, and the people. Researchers with the USGS Geographic Analysis and Monitoring Program used the SLEUTH[1] urban growth model to study patterns of growth and identify potential areas of future populations in the sister cities of Nogales, Arizona, and Nogales, Sonora (Mexico) (Norman, Feller, and Guertin, 2009). Model results demonstrated that the sister cities are undergoing very different processes of change. Generally speaking, Nogales, Ariz., is a small city, adhering to urban-planning restrictions, and has a relatively low household income for the State of Arizona. In contrast, Nogales, Sonora, is quite large and is growing without much restriction to slope, natural hydrology, or infrastructure capacity because it offers so much employment opportunity for people south of the border. Within Nogales, Sonora, the 2000 census recorded a population of 159,787 with an annual growth rate of 4.9 percent. In 2009, unofficial estimates suggest the population is closer to 300,000. Based on urban growth scenarios predicted by Norman, Feller, and Guertin (2009), the SLEUTH model predicted that by 2030 the Nogales, Sonora, urban area would grow to almost 3.5 times its size in 2002. Temporal urban mapping and growth predictions such as described here can be analyzed for patterns, rates, and trends in land use and can assist decisionmakers in evaluating the relative merits of the various land use and urban development options.

[1] SLEUTH—slope, land cover, exclusion, urbanization, transportation, and hillshade.

then

View of the Franklin Mountains and El Paso, Texas, in 1909



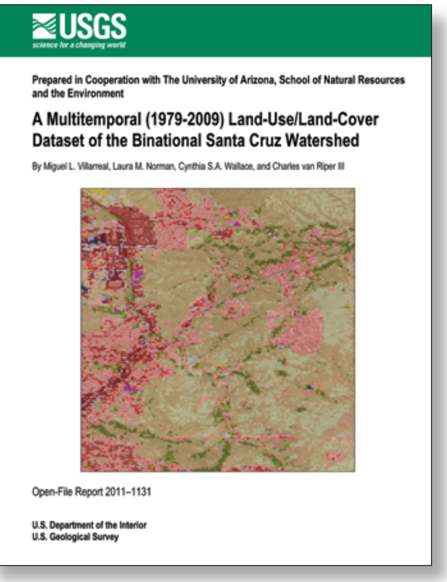
View south into Ciudad Juarez, Chihuahua, from El Paso, Texas. The line of yellow light is the international border.

now

View of the Franklin Mountains and El Paso, Texas, in 2012

El Paso, Texas

Land Use


USGS
science for a changing world

Prepared in Cooperation with The University of Arizona, School of Natural Resources and the Environment

A Multitemporal (1979-2009) Land-Use/Land-Cover Dataset of the Binational Santa Cruz Watershed

By Miguel L. Villarreal, Laura M. Norman, Cynthia S.A. Wallace, and Charles van Riper III

Open-File Report 2011–1131

U.S. Department of the Interior
U.S. Geological Survey

The study of land-use and land-cover (LULC) change is a science that describes human modification of the Earth's surface. Humans modify land to obtain food, energy, and natural resources and to pursue outdoor recreation, and these modifications cause changes in ecosystems and environmental processes at local, regional, and global scales. These changes encompass the greatest environmental concerns of human populations today, including climate change, biodiversity loss, resource management and planning, resource security, disaster planning, and the pollution of water, soils, and air.

Land use normally refers to human activities upon the landscape. Geographers monitor changes to the landscape by using standardized land-use categories. The term land cover refers to the character of the landscape surface—vegetative cover, water, or other earth materials. While land-use changes normally result from a shift in human activity, land-cover changes result from physical changes to the environment, which can be natural or human-induced. The process of urbanization has a considerable effect and influence on environmental characteristics (Norman, Guertin, and Feller, 2008; Norman, 2010; Norman, Feller, and Villarreal, in press). The Land Cover Trends research project at the USGS focuses on understanding the rates, trends, causes, and consequences of contemporary U.S. land-use and land-cover change, including urbanization. The results from this research provide a foundation for modeling future landscape changes and predicting the effects of these changes.

Padre Island
National Seashore, Texas

Colonias

In Spanish, the word colonia translates to neighborhood; in the United States, however, the word has taken on a whole new meaning. As a result of the 1990 Cranston-Gonzalez National Affordable Housing Act, colonias were defined as rural, mostly unincorporated communities in California, Arizona, New Mexico, and Texas within 150 miles of the United States–Mexican border that lack adequate infrastructure or housing, as well as other basic services. The colonias typically are located outside of an established municipal jurisdiction and have high poverty rates, making it difficult for residents to pay for roads, water sanitation and sewer systems, minimum-standard housing, street lighting, and other services; in Mexico, these communities are referred to as colonias marginales (poor neighborhoods; Norman, Donelson, and others, 2004; Norman, Parcher, and Lam, 2004; Lam and others, 2006; Norman, Donelson, and others, 2006; and Norman, 2010).

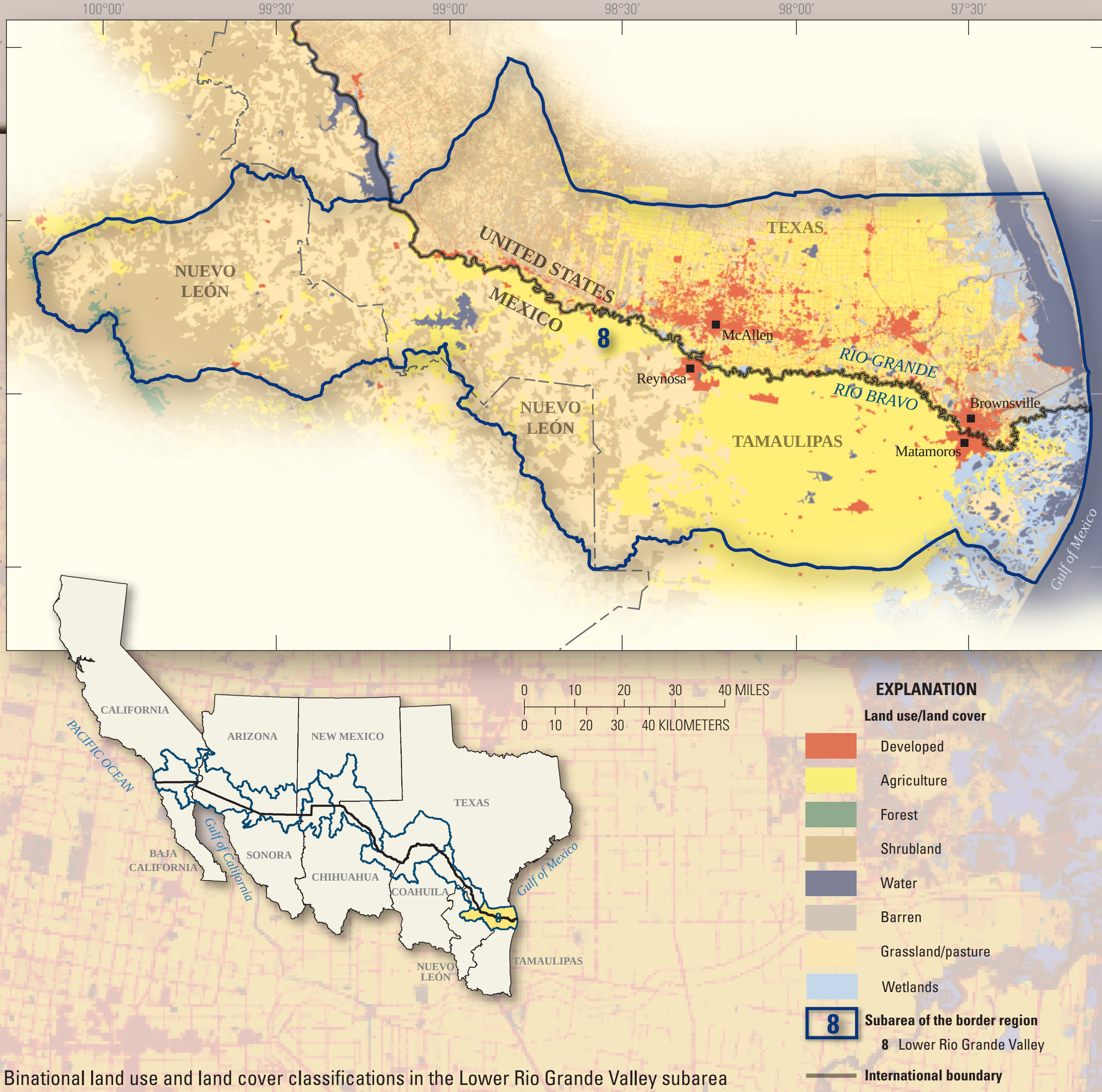
Colonias and colonias marginales are scattered along both sides of the border as makeshift settlements, commonly on private land. Because these settlements have been established outside the formally sanctioned governance of nearby cities and towns, colonia residents have traditionally struggled to gain access to the public services available in those communities. Most of the border communities in the United States have failed to acquire federally allocated dollars to improve their environment because they lack the capacity to do so. Only a very small number of colonias have relationships with funding institutions, and many lack community-based organizations that can access and use resources available to improve the local quality of life (Ward, 1999).

Houses near the United States–Mexican border in Sonora (top) and Sunland Park, New Mexico (left)

Binational Land Use and Land Cover Database

The United States and Mexico both have programs to produce land use and land cover (LULC) datasets using a nationally consistent classification scheme. The USGS National Land Cover Dataset 1992 (NLCD 1992; Vogelmann and others, 2001) and the National Land Cover Database 2001 (NLCD 2001; Homer and others, 2004) are based on the LULC classification system for remotely sensed data described by Anderson and others (1976). In Mexico, the Instituto Nacional de Estadística y Geografía (INEGI) [National Institute of Statistics and Geography] is responsible for mapping LULC. The INEGI produces the 1:250,000-scale Mapa de Uso de Suelo y Vegetación [Land Use and Vegetation Map] based on visual interpretation of remotely sensed imagery using unified regional vegetation classification systems developed over the last 70 years by many scientists (Instituto Nacional de Estadística, Geografía e Informática, 1993). An integral part of the USGS Border Environmental Health Initiative (BEHI) United States–Mexico geospatial database is an LULC dataset integrating information from both countries. Integration of the United States and Mexican data required the creation of a generalized (modified Anderson Level I) binational classification system to which both countries' LULC data could be reclassified (Anderson and others, 1976).

The 1992 and 2001 binational LULC datasets are being compared to formulate a synthesis of land-use change for major watersheds along the United States–Mexican border, and the results are being analyzed in combination with anthropogenic drivers in the border region. Trends can be used to predict future landscape changes, to monitor changes to water demands, and to statistically analyze landscape fragmentation.



Binational land use and land cover classifications in the Lower Rio Grande Valley subarea (Texas, United States, and Nuevo León and Tamaulipas, Mexico). Derived from the U.S. Geological Survey 1992 National Land Cover Dataset and data from the Border Environmental Health Initiative in the United States and the Instituto Nacional de Estadística y Geografía [National Institute of Statistics and Geography] Uso de Suelos y Vegetación [Land Use and Vegetation] dataset in Mexico.

Buildings in Lomas de Poleo, a colonia outside of Ciudad Juárez, Chihuahua

The USGS and the U.S. Department of Housing and Urban Development, in cooperation with the Mexican Instituto Nacional de Estadística y Geografía (INEGI) [National Institute of Statistics and Geography], developed a joint project to create Internet-enabled geographic information systems (GIS) to help cities along the United States–Mexican border manage issues related to urban growth and low-income housing developments. This joint project delineated colonias in Arizona and Sonora and developed publically available Internet map services of geospatial databases describing infrastructure and land use for the entire border. In Mexico, colonias marginales were also identified in this scope of work (fig. 6–1) (Norman, Donelson, and others, 2004; Norman, Parcher, and Lam, 2004; Norman, Donelson, and others, 2006). Data were integrated from various Federal agencies in both the United States and Mexico. This project was the precursor for the United States–Mexico Border Geographic Information System (USMX-GIS). The colonias designation by Federal agencies is important because it gives recognition to neighborhoods suffering from environmental justice issues and government recognition makes them eligible for associated funding.[2]

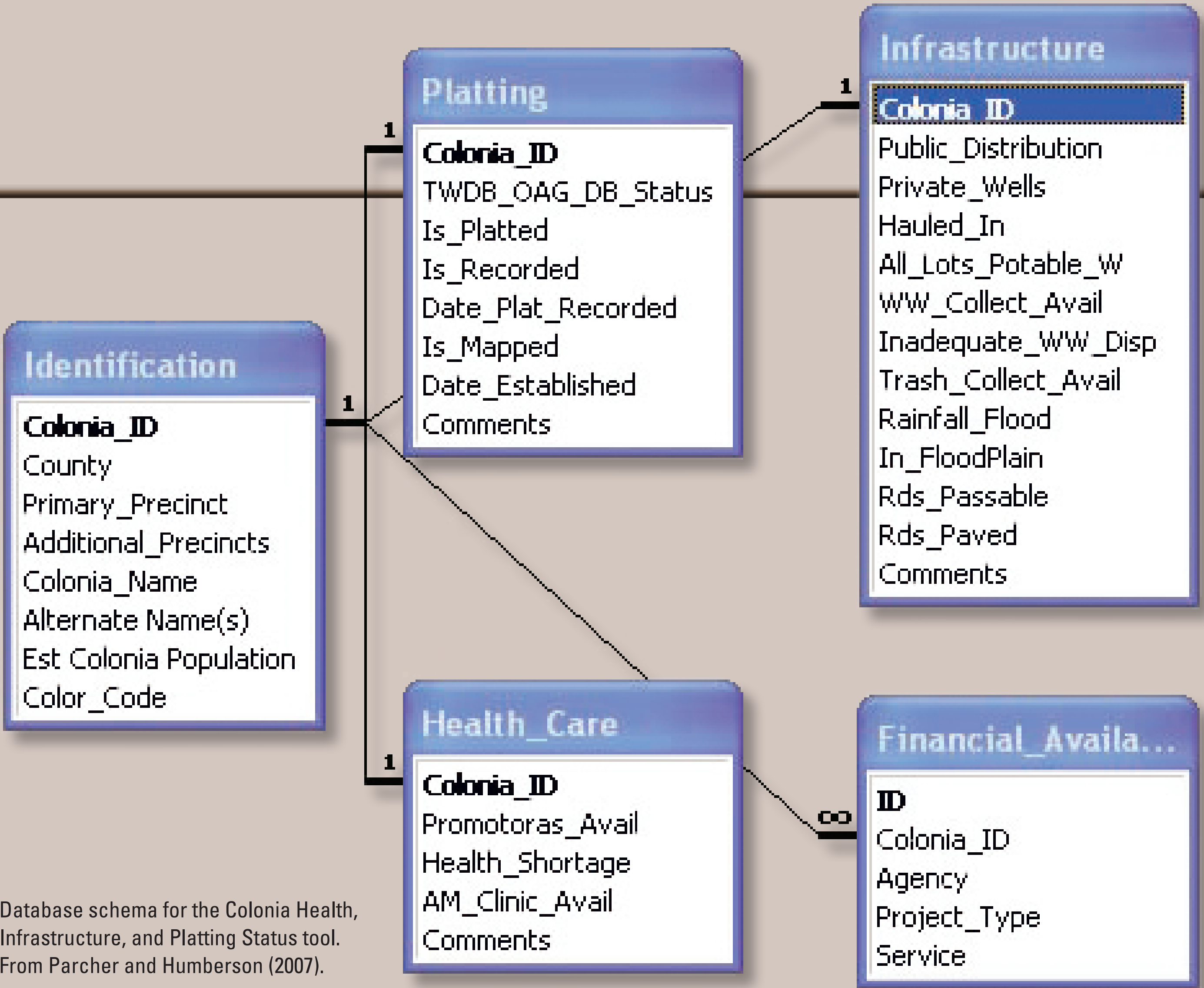
[2] For more information, see Executive Order 12898 (U.S. President, 1994), the U.S. Environmental Protection Agency–Office of Environmental Justice page for information on grants and programs (*http://www.epa.gov/environmentaljustice/grants/index.html*), and the U.S. Department of Housing and Urban Development page on funding for colonias and farmworkers (*http://www.hud.gov/groups/funding.cfm*).

Figure 6–1. Examples of colonia residences along the United States–Mexican border in a colonia at Douglas, Arizona, United States (top) and across the border in a colonia marginal at Agua Prieta, Sonora, Mexico (bottom), 2004.

CHIPS—A New Way To Monitor Colonia Development along the United States-Mexican Border

With the passing of Senate bill 827 (SB 827) by the 79th Texas Legislature in 2005, the State was mandated to create a colonia identification system and track the progress of State-funded colonia improvement projects. These efforts were spearheaded by the Office of the Secretary of State (SOS) of Texas, and as a result the SB 827 workgroup was formed (Office of the Texas Secretary of State, 2006). In order to track the progress of State-funded projects, the SB 827 workgroup created a set of infrastructure, demographic, and health-related criteria for ombudsmen in the field to collect. The ombudsmen collected data through site visits and from a variety of sources, including utility companies, county appraisal districts, and the Office of the Attorney General of Texas.

Because colonias are not uniquely identified within the census geography but instead are sometimes nested within or astride census blocks, an explicit long-term working database is needed to monitor progress, set infrastructure priorities, and measure quality of life indicators within the colonias. Based on requirements outlined in SB 827, and in cooperation with the Texas SOS, the USGS developed the Colonia Health, Infrastructure, and Platting Status tool (CHIPS). The CHIPS tool is a relational database that uses the classification criteria created by the SB 827 workgroup as a template for the database schema (Parcher and Humberson, 2007). Once these data were collected, each colonia was classified into categories, according to whether or not the colonia (1) had already been platted, (2) had a potable water supply, (3) had adequate wastewater disposal, (4) had adequate trash collection, and (5) had paved roads with adequate drainage. With the CHIPS report generator and the accompanying maps, local governments are now able to set priorities for colonia projects.



Database schema for the Colonia Health, Infrastructure, and Platting Status tool. From Parcher and Humberson (2007).

Sustainable Development

Maintaining sustainable development of this region can be facilitated by actively studying and monitoring the nexus of science, society, and resource management to determine the minimum effects that growth will have on the environment. Because the administration of the Borderlands is divided between two countries, identifying the consequences of change throughout the whole border region is difficult. As such, it is essential to regional planning efforts to understand the ramifications of human activities on both sides of the border and to provide information to decisionmakers in both countries simultaneously. Binational sustainable development includes land-use planning and management that integrates and coordinates environmental infrastructure for water, sanitation, drainage, and solid waste management; develops sustainable energy and transportation systems; combines binational disaster response strategies; and regulates industry. The economy and natural resource availability are major factors in decisions regarding urban development, settlements, agricultural practices, and the disturbance of historical natural and cultural resources. Socioeconomic concerns, including equity, are among the primary recognized components of sustainability; social factors have been described as one leg of the three-legged sustainability "stool," with the other legs being the environment and the economy (Morrison-Saunders and Therivel, 2006).

The USGS programs can identify people and communities that might be unduly affected by development plans. Norman, Villarreal, and others (2012) have developed and applied the Modified Socio-Environmental Vulnerability Index (M-SEVI) using binational census data to map vulnerable populations; this index provides a base reference to compare to models of biophysical conditions, including land-use or climate change, and examine if changes in hydrology, surface conditions, biodiversity, and (or) property values could affect low income or high minority communities unfairly, creating issues of environmental justice. The USGS can assist with sustainable-development planning in both countries by providing integrated binational databases, maps, and predictive models such as the index described above to find scenarios that reduce hazards and other effects of urbanization.

Binational Planning at Ambos Nogales

The Nogales-Nogales sister city area (Arizona-Sonora) is located in the Ambos Nogales watershed, a topographically irregular bowl-shaped area with a northward gradient. Throughout recent history, residents in both cities have been affected by flooding. Extreme flood events cause surface materials to erode, and eroded materials put pressure on over-burdened water and wastewater infrastructure in the Ambos Nogales watershed. The encroachment of population and transportation routes on the floodplains and drainages of the Nogales Wash and its tributaries poses future risks on exacerbated systems. The resulting constriction of stream channels has concentrated flow during periods of heavy monsoonal precipitation, common during summers in this area. These flows erode loose alluvial sediments and disturbed soils along the banks of washes. The primary means of regulating this runoff is a series of detention features in Nogales, Sonora. Land managers on both sides of the border seek information to increase detention feature effectiveness by optimizing future locations. Flood peaks and erosion associated with seasonal monsoonal rains must be reduced in order to enhance public safety and health.

Researchers with the USGS are using geospatial models to project the effects of possible influences such as predicted urban development, small detention reservoirs, and potential climate change on flood hydrographs and sediment yield. Using the results of coupled urban growth, erosion, sedimentation, and runoff models in a virtual environment, the USGS can also make estimates of current and future hypothetical water resource conditions to identify nonpoint source pollution. For the Ambos Nogales watershed, researchers with the USGS Geographic Analysis and Monitoring Program assessed the effects of land-use change by using hydrologic models to predict runoff volumes and peaks in order to identify best management practices to offset monsoonal flooding. They applied the SLEUTH urban growth model to the Nogales-Nogales sister city area to identify potential areas of future populations (Norman, Feller, and Guertin, 2009). Growth predictions were coupled with results from erosion-sedimentation models to simulate the effect of excluding hot-spot areas of nonpoint source pollution. Alternative future scenarios were then published that identify sustainable development zones in which Borderland populations can grow (Norman, 2007; Norman, Guertin, and Feller, 2008; Norman, Feller, and Guertin, 2009). The KINEROS2[1] model was used to evaluate the Ambos Nogales watershed vulnerability to flooding

[1] KINEROS—kinetic runoff and erosion.

Flooding on the Nogales Wash in Nogales, Arizona, damaged the waterway, as shown here near the Chula Vista Flood Control Project site in July 2010. The Ambos Nogales watershed (inset) includes the Nogales-Nogales sister city area; the international border runs diagonally through the photo with Arizona on the lower left and Sonora on the upper right.

(Norman, Huth, and others, 2010). The International Boundary and Water Commission funded a higher-resolution study to determine the effects of detention features in Nogales, Sonora, and estimate the volume of water being detained and the magnitude of discharge under various urbanization scenarios and return periods of 10, 25, and 100 years (Norman, Levick, and others, 2010). This project is considered the first step of a locally driven strategy for a binational sustainable development. By integrating current and accurate information into the general municipal plan and partial urban plans, the sister city area can implement measures that will diminish adverse effects of runoff and flooding in the downtown area, reduce nonpoint source pollution and sediment loading in surface water, and decrease human exposure to chemicals, pathogens, and disease vectors (Norman, Hirsch, and Ward, 2008; Norman, Huth, and others, 2010; Norman, Levick, and others, 2010).

Ecosystem Services

Ecosystem services are the goods and benefits that people obtain from ecosystems (DeGroot and others, 2009), such as clean drinking water or firewood. Use of this term to describe the relation of people to their ecosystems has been growing since the 1960s, and the concept has been gaining momentum as a framework in which to integrate ecological function and economics in a manner useful for evaluating tradeoffs in natural resource management (Wainger and others, 2009). The ecosystem services framework allows one to balance competing interests when deciding how best to manage and allocate natural resources (Fisher and others, 2009). It is critical for neighboring towns, counties, and even countries to monitor the forces changing their shared environment, and also to examine, document, and model potential implications for inhabitants. Given the potential importance of transboundary ecosystem services, mechanisms for monitoring the indirect and direct drivers that affect the provisioning of ecosystem services and human welfare across the United States–Mexican border are needed (López-Hoffman and others, 2010; Norman, Tallent-Halsell, and others, 2010; Norman, Villarreal, and others, 2012).

San Diego harbor

Quality of life can be defined as the degree of well-being felt by an individual or group of people. Although quality of life cannot be measured directly, it can be described in terms of physical and psychological values (Wainger and Price, 2004). There is a great disparity of economic resources in the Borderlands that affects infrastructure development and other quality of life issues. The northern region of Mexico is more affluent than the rest of the country, but the border counties in the United States are among the poorest in the country (U.S. Environmental Protection Agency, 2012b). The ability to assess risks and implement policies to protect the environment and quality of life greatly increases in complexity along international borders, where the social services, environmental regulations, lifestyles, and cultural beliefs of the neighboring countries are distinct (Parcher and others, 2006). Healthy natural systems have a profound effect on our quality of life by purifying air and water, stabilizing climate and soils, and providing raw resources. The natural resources surrounding resource-proximate human communities often contribute to the community identity and sense of place creating a location where people want to reside. Understanding the transactional relation between natural resource quality and human quality of life in resource-proximate communities is an important facet of making land management decisions. The benefits supplied to human societies by natural ecosystems are sometimes overlooked until after decisions are made and negative effects of those decisions spur public reaction. The USGS can use an ecosystem services approach to promote good decisionmaking by determining how much ecosystems contribute to a society's well-being and providing an understanding of the services and valuation (nonmonetary and monetary) of an ecosystem.

A region's ecosystem and its people are inextricably linked. The well-being of the human community relies on and influences the well-being of the ecosystem, and the natural landscape and its resources contribute to the identity of the community living within it.

AGAVES—Assessment of Goods and Valuation of Ecosystem Services in the San Pedro River Basin, United States and Mexico

A consortium of Federal, academic, and private partners have established a collaborative research enterprise in the San Pedro River basin to develop methods, standards, and tools designed to map, assess, and value ecosystem services (Semmens and others, 2008). The central premise of ecosystem services research is that the human condition is inseparably linked to the environment and that human health and well-being (including economic prosperity) depends on the important supportive functions and cultural services provided by our surrounding ecosystems, as well as on the regulation and provisioning of those systems. The AGAVES project—Assessment of Goods and Valuation of Ecosystem Services—is intended to demonstrate that scientists and stakeholders can work together to facilitate environmental management and planning by incorporating information on the goods and services derived from the San Pedro River basin.

The San Pedro River is one of the last free-flowing, perennial rivers in the southwestern United States, originating in Sonora, Mexico, and flowing north into southeastern Arizona (Thomas and Pool, 2006). The river hosts a rich riparian community with vital habitat for diverse populations of resident and migrant species. Decades of groundwater overdraft and a recent drought have significantly reduced base flows in the San Pedro River, and rapid urbanization and anticipated climate change both exacerbate this problem.

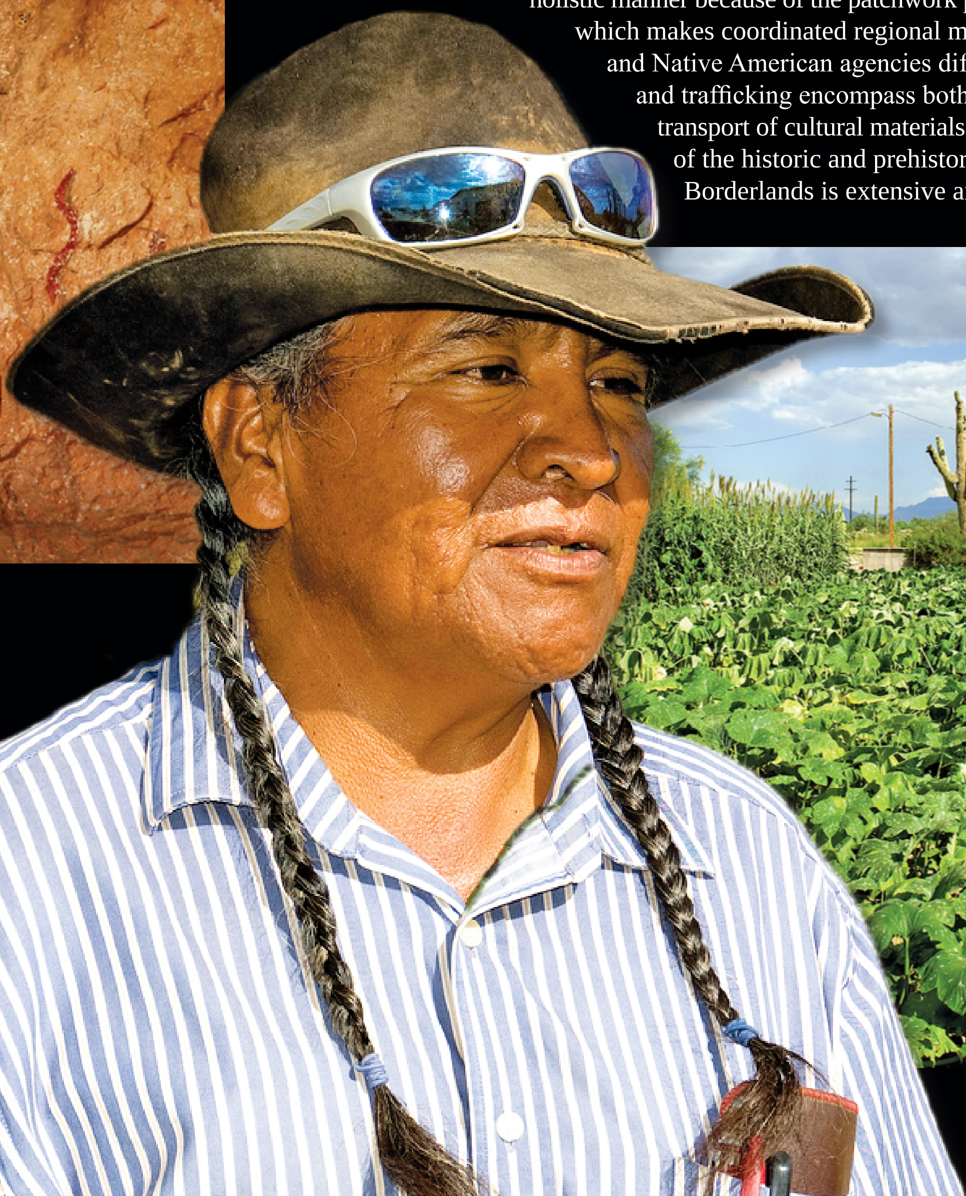
The San Pedro River

The unique combination of existing data, previous research, established partnerships, and human-induced environmental stressors on and surrounding the San Pedro River represents the ideal conditions in which to apply the ecosystem services conceptual framework and evaluate its efficacy for resource management and planning. The AGAVES project has partnered with key stakeholders and managers in the San Pedro River basin to ensure that it will address both the ecosystem goods and services of greatest concern to local residents (water, biodiversity, recreation, and carbon sequestration) and the management alternatives that are most widely accepted by the communities in the basin (controlling invasive mesquite and water augmentation). The effectiveness of these management alternatives in preserving the key services will be explored under a range of potential future conditions as defined by the degree of urban growth and climate change in the basin. The ultimate goal of the AGAVES project is to develop the methods and tools that will help resource managers understand the tradeoffs associated with management alternatives and make difficult decisions about how to best preserve the ecological and economic prosperity currently enjoyed in the San Pedro River basin.

Native American Resources

In the Borderlands, there are 26 Native American tribes recognized by the United States Federal Government and 7 Indigenous tribes recognized by the Mexican Federal Government, with populations ranging from 9 to 17,000 members. Indigenous nations divided by the United States–Mexican border include the Kumeyaay of California/Baja California; the Tohono O'odham, Pascua Yaqui, Gila River Indian Community (Akimel O'odham), Cocopah, and Yavapai-Apache of Arizona/Sonora; and the Kickapoo of Oklahoma, Kansas, and Texas/Chihuahua. Adjacent to the Native American nations in the United States are lands administered by various bureaus in the U.S. Department of the Interior, U.S. Department of Commerce, and U.S. Department of Defense.

Tribal lands are of cultural importance because they contain sites with cultural artifacts and often are the ancestral homelands of the Native Americans. In the United States, the Bureau of Indian Affairs, the Federal Bureau of Investigation, the U.S. Border Patrol, the National Park Service, and law enforcement officials of the Native American nations have documented that Native American cultural sites and resources are being lost to vandalism and trafficking of artifacts. Ensuring surveillance and law enforcement of areas with at-risk heritage sites is difficult or impossible, due in part to the remoteness of many of these sites. Further complicating the issues, the identification of sites of cultural importance is not documented in a holistic manner because of the patchwork pattern of land administration, which makes coordinated regional management by Federal, State, and Native American agencies difficult. Because vandalism and trafficking encompass both destruction of sites and transport of cultural materials, the loss to our understanding of the historic and prehistoric human occupancy of the Borderlands is extensive and irreversible.



Farm on the Tohono O'odham reservation

The USGS has a firm commitment to work collaboratively with Native American nations across the United States in areas of education, natural resources, and the development of sustainable capabilities (Marcus, 2010). In the Borderlands of Arizona and Sonora, the USGS, in collaboration with the EPA and the Bureau of Reclamation, is working with the San Xavier District of the Tohono O'odham Nation to develop a pilot tribal study to understand the effect that water and land management will have on the goods and services derived from natural and cultivated ecosystems. The goal of this tribal pilot study is to investigate the feasibility of using an ecosystem services approach to assess the ecological, economic, and social ramifications of alternative water allocation in regards to the historic ties tribal populations have to the land, their dietary practices, and the recreation value and spiritual and cultural resources of the land (Hall and others, 2010; Tallent-Halsell and others, 2010). Assistance in the preservation of cultural resources can be a cornerstone of USGS and Native American collaboration. Remote sensing, geospatial derivative maps of special areas, corridor map products, relational databases, and ground-based land surveys supported by global positioning systems (GPS) can assist Federal and Native American planners, enforcement officials, and decisionmakers.

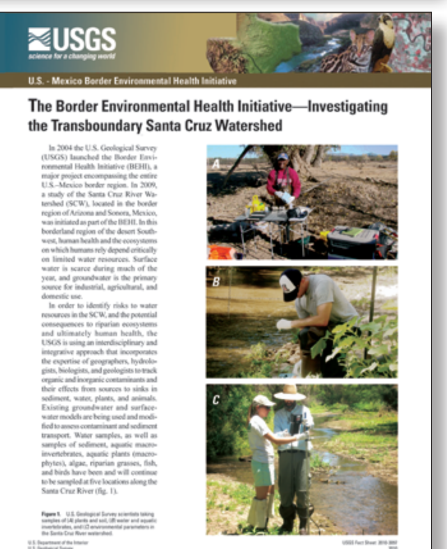
Hohokam petroglyph, Signal Hill, Saguaro National Park, Arizona

Tohono O'odham basketmaker, Arizona, 1916

Border Environmental Health Research

Consistent with environmental justice mandates, border environmental health efforts focus on reducing risks to border families, especially children, of exposure to air pollution, drinking water contaminants, pesticides, and other toxic chemicals (Parcher and others, 2006). The USGS Border Environmental Health Initiative project (BEHI; *http://borderhealth.cr.usgs.gov*) is committed to two goals: (1) to develop and maintain the USMX-GIS and natural resource databases to assist in decisionmaking concerning the United States–Mexican border region; and (2) to investigate the connections between the condition of the physical environment and environmental and health issues along the border.

The primary objective of the BEHI project is to provide binational science data in support of environmental health studies that will enable scientists, public health officials, resource managers, and concerned citizens to make informed decisions. Geographers, biologists, hydrologists, and geologists with the USGS have accomplished this goal by implementing a comprehensive binational environmental resource database within a GIS framework. The USMX-GIS developed by the BEHI project is available as both an Internet map service (*http://txpub.usgs.gov/borderhealth/*) and as a download from a file transfer protocol (FTP) Web site (*http://borderhealth.cr.usgs.gov/datalayers.html*). The databases and Internet map service provide a framework in which researchers can examine both the occurrence and distribution of disease-causing agents in the environment and their specific exposure pathways in water, air, biota, rock, and soil. A desired outcome of this project will be the identification of information gaps and enhanced opportunities for collaborative research with public health agencies and biomedical researchers.



USGS
science for a changing world

U.S. - Mexico Border Environmental Health Initiative

The Border Environmental Health Initiative—Investigating the Transboundary Santa Cruz Watershed

In 2004 the U.S. Geological Survey (USGS) launched the Border Environmental Health Initiative (BEHI), a major project encompassing the entire U.S.–Mexico border region. In 2009, a study of the Santa Cruz River Watershed (SCW), located in the border region of Arizona and Sonora, Mexico, was initiated as part of the BEHI. In this borderland region of the desert Southwest, human health and the ecosystems on which humans rely depend critically on limited water resources. Surface water is scarce during much of the year, and groundwater is the primary source for industrial, agricultural, and domestic use.

In order to identify risks to water resources in the SCW, and the potential consequences to riparian ecosystems and ultimately human health, the USGS is using an interdisciplinary and integrative approach that incorporates the expertise of geographers, hydrologists, biologists, and geologists to track organic and inorganic contaminants and their effects from sources to sinks in sediment, water, plants, and animals. Existing groundwater and surface-water models are being used and modified to assess contaminant and sediment transport. Water samples, as well as samples of sediment, aquatic macroinvertebrates, aquatic plants (macrophytes), algae, riparian grasses, fish, and birds have been and will continue to be sampled at five locations along the Santa Cruz River (fig. 1).

A B C

Figure 1. U.S. Geological Survey scientists taking samples of (A) plants and soil, (B) water and aquatic invertebrates, and (C) environmental parameters in the Santa Cruz River watershed.

U.S. Department of the Interior
U.S. Geological Survey

USGS Fact Sheet 2010-3097
2010

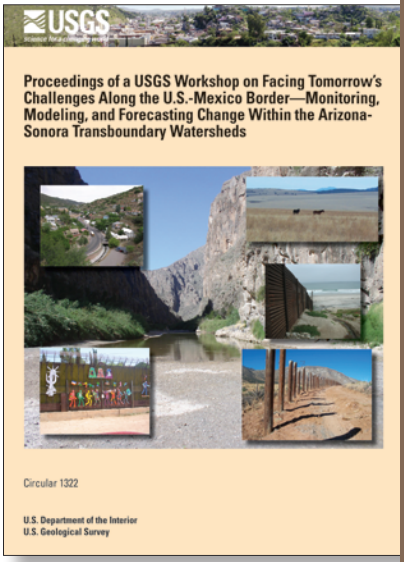
The second objective of this initiative is to examine and analyze connections between human and environmental health through collaborative opportunities with natural resource scientists, managers, and public health officials. The USGS is actively seeking to develop partnerships along the United States–Mexican border to further develop spatial products and use existing spatial data to understand the sources, distribution, and exposure pathways of environmental stressors and diseases. Some of the intended outcomes of these research efforts are to characterize unhealthy environments, to provide information on how degraded environments affect the health of humans and wildlife at the landscape and population levels, and to better understand the nexus among environment, wildlife, and human activities as those interactions contribute to overall environmental health.

The focus of current USGS BEHI research is to understand and document the complex movement of natural and human contaminants through the upper Santa Cruz River watershed in Arizona and Sonora. Because of the diversity in the natural ecosystem, an interdisciplinary team of USGS scientists has been formed to identify risks to water resources in the Santa Cruz watershed, specifically (1) natural surface-water and groundwater flow; (2) anthropogenic water flow (flood diversion, sewage effluent, wells, irrigation, etc.); (3) human population growth and urbanization; (4) sources and distribution of mineral contaminants; (5) sources and distribution of disease; and (6) the health of local flora and fauna (Callegary and others, 2010; Norman, Callegary, and others, 2010). Water samples, as well as samples of sediment, aquatic macroinvertebrates, aquatic plants (macrophytes), algae, riparian grasses, fish, and birds, are being analyzed, and existing surface-water and groundwater models are being used to assess contaminant and sediment transport. Researchers with the USGS are also working with public health officials to make the connection between water quality and its effect on human health in colonias of Nogales, Sonora. Water samples were collected during both wet and dry climates (summer and winter of 2010) and analyzed for arsenic, mercury, lead, and bacteria such as *Escherichia coli* (Caldeira and others, 2010). The results of this data collection are being compared to a survey that was initiated to investigate health factors associated with sustainable water delivery in colonias in the Borderlands by asking for a description of a household's water source, delivery, personal disinfection practices, and gastrointestinal disease frequency (Caldeira and others, 2011; Norman, Caldeira, and others, 2012). The proposer is actively seeking collaborators in Nogales, Sonora, and invites feedback on the research plan and discussion with potential collaborators.

Escherichia coli, commonly abbreviated *E. coli*

Decision Support Systems

In accordance with the USGS science strategy (U.S. Geological Survey, 2007), scientists can develop methods that can be used to minimize the negative effects of climate change and at the same time, by refining, applying, and interpreting watershed and ecosystem-process models, can increase the understanding of forces that influence the structure and functioning of ecosystems and the goods and services they provide. The USGS can support more comprehensive management strategies by providing resource managers with predictive modeling and decision-support capabilities that can forecast the effects of policy and management decisions concerning land, water, biological, and ecosystem resources using climate scenarios and data on natural and engineered changes in land use and land cover.



SCWEPM— The Santa Cruz Watershed Ecosystem Portfolio Model

At the beginning of fiscal year 2010, the EPA Ecosystem Services Research program joined forces with the USGS Border Environmental Health Initiative (BEHI) and the Geographic Analysis and Monitoring Program to develop the Santa Cruz Watershed Ecosystem Portfolio Model (SCWEPM), an online decision-support tool based on ecosystem services (Norman, Tallent-Halsell, and others, 2010). Administration and ownership of the Santa Cruz watershed is divided between four governing nations: the Tohono O'odham Nation, the Pascua Yaqui Tribe, Mexico, and the United States. These large and diverse stakeholder groups share interests in farming, ranching, mining, economic and population growth, industry, and trade, as well as essential ecosystem services supported by the environment. Their management of land use affects natural processes and shapes the lay of the land. The broad objective of this study is to develop a reliable and useful online model-based scenario evaluation framework for the binational Santa Cruz watershed that can visualize and give structure to various scenarios of the regional effects on ecosystem services of future land-use change, climate change, and potential changes to engineered discharge from wastewater treatment plants.

The Sonoran Desert, which overlaps part of the Santa Cruz watershed, is one of the largest, hottest, and most diverse deserts in North America. The dry climate is ideal for the many animals and plants that have developed adaptations to the biseasonal rainfall patterns and high temperatures, and the area also attracts humans who enjoy the warm climate, a low cost of living, an outdoor lifestyle, and scenic landscapes. However, deserts are extremely fragile and take a long time to recover from disturbance. The Sonoran Desert and the Santa Cruz watershed are within one of the most severely affected areas of the United States—the Borderlands, from southern California to west Texas—according to modeled climate change predictions; potential effects are even greater over northern Mexico (Seager and others, 2007; Kerr 2008).

Screenshot of the Santa Cruz Watershed Ecosystem Portfolio Model (SCWEPM) Web interface at *http://lcat.usgs.gov/santacruz*, developed by Dave Strong.

The Ecosystem Portfolio Model that was applied to the Santa Cruz watershed portrays the “pillars” of sustainability as three submodels that can be analyzed under various scenarios: the ecological-value submodel, the human well-being submodel, and the market land-price submodel (Labiosa and others, 2009). The SLEUTH urban growth model also was applied to the Santa Cruz watershed to envision and evaluate plausible future scenarios and potential effects on ecosystem services for the year 2050. The SCWEPM was calibrated with historical data extracted from a time series of satellite images developed for this purpose (Villarreal and others, 2011). Three specific scenarios within the SCWEPM are designed to simulate changing spatial patterns of land use under different conditions: (1) a current trends scenario, an analysis of unmanaged exponential growth; (2) a conservation scenario, with managed growth to protect the environment; and (3) a megalopolis scenario, in which growth is accentuated around a defined international trade corridor. The alternative futures explore different patterns of impervious surfaces, different levels and patterns of habitat protection and land use, and different economic incentives to help guide planning for the future (Norman, Feller, and Villarreal, in press).

(Continued on page 150)

The ecological-value submodel was the first of three components to be included in the SCWEPM. We are calibrating the Soil and Water Assessment Tool (SWAT) at seven monitoring stations to improve model performance and reliability in this arid land (Niraula and others, 2012). With further calibration of the model for water quality parameters, the results of this research will be used to examine the flow and transport of contaminants and evaluate the effects of potential land-use and climate change on ecosystem services. Richness of terrestrial vertebrate species was mapped using wildlife habitat relation models and a high-resolution binational vegetation map (see Wallace and others, 2011), and the results were validated with data from local National Park Service biological inventories. The total number of potential terrestrial vertebrates was 451, only two less than the neighboring San Pedro watershed that is well-known for its conservation strategies. When the effects of urban growth on biodiversity were assessed, the current trends scenario showed a reduction and fragmentation of mammal and herpetofauna habitat, while the megalopolis scenario showed a likely loss of bird-rich riparian habitat caused by increased groundwater use (M.L. Villarreal and others, U.S. Geological Survey, written commun., 2012).

Greater Roadrunner (*Geococcyx californianus*)

The human well-being submodel uses data and models to evaluate a set of human well-being indicators and metrics of interest to the public, land-use planners, and stakeholders. Using determinants from binational census and neighborhood data that describe levels of education, access to resources, migratory status, housing, and number of dependents, we developed the Modified Socio-Environmental Vulnerability Index to provide a simplified snapshot of the region's populace that can be used in binational planning efforts (Norman, Villarreal, and others, 2012).

The market land-price submodel evaluates the price of land as a function of LULC patterns and other predictor variables. The market land-price submodel is based on hedonic-pricing functions, which describe each land parcel's price in terms of its particular characteristics (for example, parcel size and zoning), as well as amenities and disamenities related to location. A hedonic analysis of residential property values is being developed that uses census block group data and geo-referenced environmental explanatory variables and accounts for spatial autocorrelation, lags, and (or) heterogeneity in the data (Arora and others, 2012).

The SCWEPM Web interface allows the user to explore individual value maps for each unique criterion, or the user can select and apply multicriteria weights to view an aggregated value map and holistically compare potential land-use patterns. The user can also assign weights to each criterion or subcriterion to adjust the relative importance among the different criteria. Spatially-explicit criteria will be developed using the described models and data sources, and multi-attribute utility functions will be created based on stakeholder and public value. Public surveys in neighborhoods and colonias in the Santa Cruz watershed have been initiated to determine potential indicators (Weber and others, 2010). More modeling also needs to be done; climate change projections by the Intergovernmental Panel on Climate Change (see Solomon and others, 2007) will be used to simulate the effects of climate change on the watershed.

USGS Capabilities

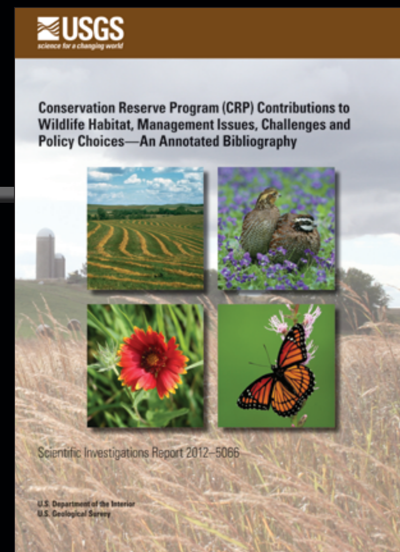
Much is yet to be learned about the relation among changing landscapes, changing demographics, and a changing climate, which are superimposed in the Borderlands on an already complex mix of environmental, economic, and societal issues due to the differences in cultural and political mores of the two nations. Changes in the environment, the economy, and society are occurring rapidly in the Borderlands relative to other regions of the continent, and the USGS, with key partners, is in a unique position to address these changes and provide the scientific support for policy decisions of both the United States and Mexico that could substantially enhance the quality of life in the Borderlands for decades to come. These concluding paragraphs offer examples of how the USGS is applying scientific methods to address the issues important to people in the Borderlands, synthesizing the capabilities highlighted and referenced throughout this chapter.

The USGS is a leader in integration of United States and Mexican scientific data, as demonstrated by the Border Environmental Health Initiative (Parcher, 2008). Specifically, the USGS has examined and analyzed connections between human and environmental health through collaborative opportunities with natural resource scientists, managers, and public health officials (Norman, Hirsch, and Ward, 2008; Norman, Callegary, and others, 2010). The USGS has also assisted with sustainable development planning by providing integrated binational databases, maps, and predictive models. These temporal urban mapping and growth predictions can be analyzed for patterns, rates, and trends in land use, as demonstrated by the alternative scenarios in the United States–Mexican Borderlands project (Norman, 2007, 2010; Norman, Guertin, and Feller, 2008; Norman, Callegary, and others, 2010; Norman, Huth, and others, 2010; Norman, Levick, and others, 2010).

The USGS can estimate population change and migration in the Borderlands in light of land-use changes and for decisionmaking scenarios (Norman, Feller, and Villarreal, in press). We also have the capability to identify and map market and nonmarket ecosystem services (Labiosa and others, 2009) while providing economic impact analyses associated with binational land management decisions and natural resource changes (Semmens and others, 2008; Norman, Tallent-Halsell, and others, 2010).

The USGS capabilities also include collecting scientific data to understand the transactional relation between natural resource quality and human quality of life in resource-proximate communities. This information can be reported in a context to facilitate land management decisions that take into account the socioecological system (Norman, Villarreal, and others, 2012). Scientists with the USGS have developed social science tools and research methods to support land management planning and decisionmaking; they have been applied in the Borderlands and on public lands throughout the Nation. Specific abilities include (1) surveying visitors, community residents, and other stakeholders about their activities on public lands and their attitudes, perceptions, and knowledge of management alternatives; (2) understanding the relations among public land management, human well-being, and community sustainability in light of phenomena such as climate change, energy development, and flooding; and (3) measuring public and decisionmaker perceptions of risk regarding human hazards. Researchers with the USGS apply traditional and state-of-the-art social science methods drawing from the fields of sociology, demography, economics, political science, communications, social-psychology, and applied industrial organization psychology. Our social science methods work in concert with our natural science capabilities.

In the unique context of the Borderlands, the USGS has the capability to use social science methods to understand the vulnerability and resilience of human communities within the context of global/climate change, facilitating the stability and sustainability of human communities (Norman, Villarreal, and others, 2012). We are also capable of working collaboratively with Native American nations in the areas of education, natural resources, and development of sustainable capabilities. Assistance in the preservation of cultural resources can be a cornerstone of that collaboration. Remote sensing, geospatial derivative maps of special areas, corridor map products, relational databases, and ground-based GPS-supported land surveys can assist Federal and Native American planners, enforcement officials, and decisionmakers (Hall and others, 2010; Tallent-Halsell and others, 2010).



Finally, the USGS can facilitate decisionmaking concerning complex problems with multiple stakeholders, integrating multiple forms of scientific data in difficult situations. We have experience in applying decisionmaking techniques such as decision analysis adaptive management, joint fact-finding, decision support, and stakeholder analysis (Norman, Tallent-Halsell, and others, 2010).

References cited in this chapter are listed in chapter 12.