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Water Supply and Prospects in Baja California

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ABSTRACT

The water supply infrastructure of Baja California, México is vital to the society, economy, and environment of this rapidly developing border state. The northern municipalities of Tijuana and Mexicali currently use over forty times their natural surface water and groundwater inflows, and are at the forefront of the rapid growth that characterizes Baja California. While this international border region has been active for decades, burgeoning growth in the past forty years has overwhelmed the formerly minimal water supply infrastructure. As a result, the reliability and efficiency of the state's water supply is of paramount concern. This study provides an assessment of the water resources along the international border zone of northern Baja California and makes recommendations for analyzing and improving water management for this region.

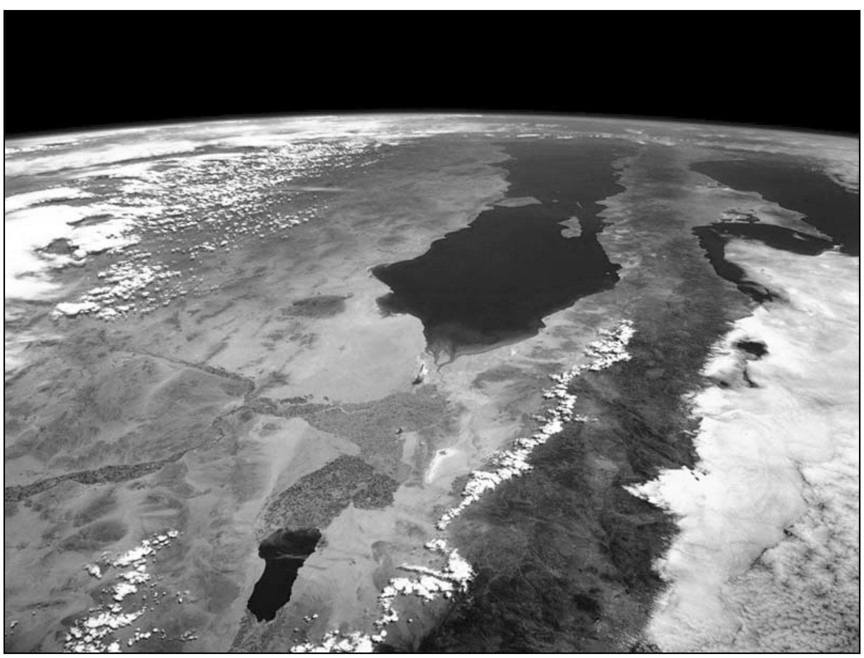

Figure 1. The western México-United States border region from space (Courtesy of Josué Medellín Azuara)

ACRONYMS

ARCT ………….	Acueducto Río Colorado-Tijuana
BECC ....………...	Border Environment Cooperation Commission
CALVIN …..…….	California Value Integrated Network
CCBRES ………..	California Center for Border and Regional Economic Studies
CEA ...……………	Comisión Estatal del Agua
CEC ……………..	Commission for Environmental Cooperation
CESPM ..…………	Comisión Estatal de Servicios Públicos de Mexicali
CESPT …………..	Comisión Estatal de Servicios Públicos de Tijuana
CESPTE …………	Comisión Estatal de Servicios Públicos de Tecate
CMS .…………….	Cubic Meters per Second
CNA ……………..	Comisión Nacional del Agua
COLEF …………..	Colegio Frontera de la Norte
CONEPO ………..	Consejo Estatal de Población de Baja California
COSAE ………….	Comisión de Servicios de Agua del Estado de Baja California
DWR …………….	Department of Water Resources, State of California
USEPA …………..	United States Environmental Protection Agency
GDP ……………..	Gross Domestic Product
GIS ………………	Geographic Information Systems
HEC-PRM ……….	Hydrological Engineering Center Prescriptive Reservoir Model
IBWC ……………	International Boundary and Water Commission
IID ……………….	Imperial Irrigation District
IMPlan …………..	Instituto Municipal de Planeación, Ciudad de Tijuana
INEGI …………...	Instituto Nacional de Estadística Geografía e Informática
IWTP ……………	International Wastewater Treatment Plant
LPCD ……………	Liters Per Capita per Day
MCM ……………	Million Cubic Meters
MGD …………….	Million Gallons per Day
NADBank ……….	North American Development Bank
NAFTA ………….	North American Free Trade Agreement
PB ……………….	Planta de Bombeo (Pumping Plant)
PIF ………………	Programa Industrial Fronterizo
SARH …………...	Secretaría de Agricultura y Recursos Hidráulicos
SCERP …………..	Southwest Center for Environmental Research and Policy
SDSU ……………	San Diego State University
SEDECO ………..	Secretaría de Desarrollo Económico
SEMARNAT ……	Secretaría de Medio Ambiente y Recursos Naturales
SWRCB …………	State Water Resources Control Board, State of California
USBR ……………	United States Bureau of Reclamation

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1. INTRODUCTION

The México-United States border region is bonded by a common geography characterized by its booming population and scarce water supply. The natural rivers of this region are among the most regulated, used, and contaminated waterways in the world. These rivers are currently used to the extent that they often no longer discharge to their respective termini, such as the Colorado River, whose billions of cubic meters of annual flow no longer reach the Sea of Cortés. This situation is largely driven by upstream diversions and economic forces that make the border region one of the most productive geographic regions in México. This is also one of the driest regions in México and its explosive growth has put tremendous strain on the limited water resources.

The purpose of this study is to provide an overview of the surface water supply of the border region of Baja California, México. This study presents several aspects of how water is delivered to the different demands in the border region, placing emphasis on the current demands for this resource and the physical infrastructure in place to supply water to these demands. This study then goes on to provide forecasts for how water demands will evolve in Baja California and recommendations for satisfying this region's growing appetite for water. Therefore, this study will help provide a foundation for in-depth analyses of border waters to be carried out over the course of several years.

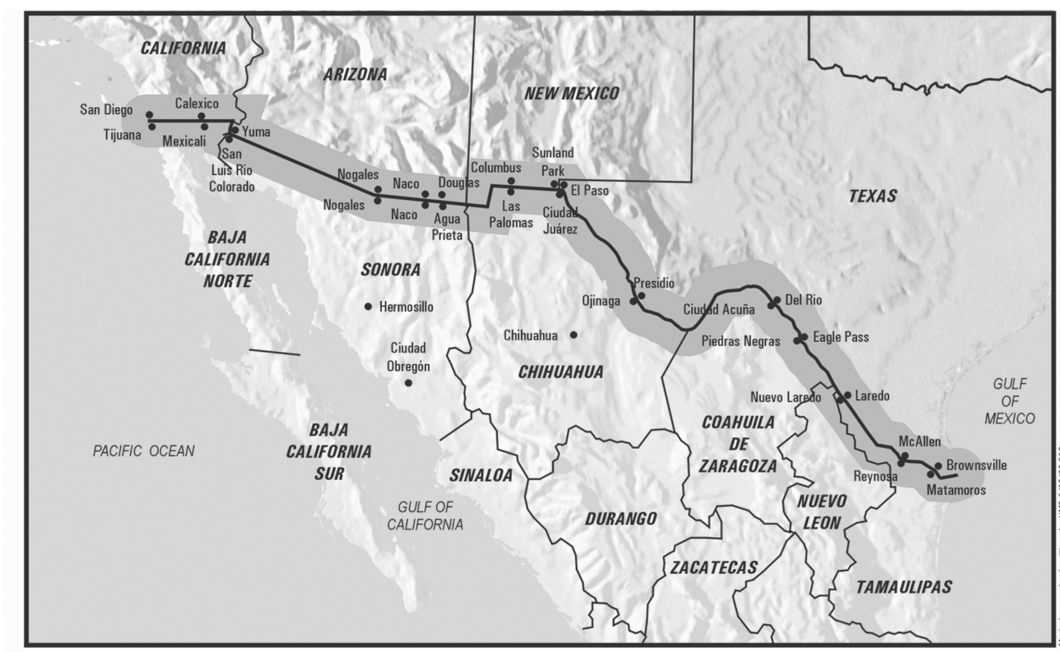

Figure 2. The México-United States Border Region. (Courtesy of USEPA)

From isolation to economic prominence

The border between Baja California, México and California, United States is constantly changing and rapidly evolving. Established in the Guadalupe-Hidalgo treaty of 1848 and modified in 1853 under the Treaty of La Mesilla, this region has historically been home to phenomena ranging from illegal immigration and drug trafficking to cultural exchange and intermixing not seen in any other part of México or the United States (Lorey, 1999). The *frontera*, or frontier as it translates from Spanish, was largely unexplored when it was finalized in 1853; it was also a land of great potential. Soon after 1853, American speculators such as Harrison Grey Otis, with his Colorado River Land Company, quickly began to tap the fertile lands in the Mexicali Valley for unregulated agricultural profits, while Mexican workers grew to see the border as a frontier of economic opportunity. Years later, with the initiation of prohibition in the United States, the City of Tijuana instantly became a hallmark of the untamed West, where Americans could go to bars, drink, and gamble, all while enjoying the border's protection from American law. During the Second World War, the border region became an important source of migrant workers who kept the U.S. economy moving while much of the American workforce was at war.

This *frontera* continued to be largely unregulated and unexplored through the early 1960s. Indeed, at thousands of kilometers from México City and in an entirely different geographic setting, the border region had in many ways been marginalized from central México's economic development. Once considered a geographic buffer or no man's land between the two countries, the border region is now considered key in Mexican national development programs and the opening of Mexican commerce to the exterior (González Aréchiga, 1988). Much like the economic boom sparked in California after 1849, the Baja California border region has been thrust to the forefront of its nation's economy with the inception of agricultural development, the 1965 Border Industrial Program *(Programa Industrial Fronterizo, PIF)*, and its rapid population growth.

These phenomena have rapidly increased Baja California's economic standing. In the twentieth century alone, the once sparsely inhabited Baja California border region became one of México's primary agricultural, industrial, and tourist regions. The state population reflects these dramatic changes: it experienced an increase in population from approximately 20,000 in 1900 to 2.5 million in 2000 (the country's population increased from 12.7 to 97.5 million in this time period) (CONEPO, 2004). As happened to its neighbor to the north, however, this economic boom has consumed vast amounts of natural resources and has caused changes that are overwhelming both Mexican and American agencies.

Prime among these changes is the region's voracious appetite for water. Agricultural, urban, and industrial demands compete for limited water supplies from the Colorado River, groundwater, and surface water runoff. As the border region population and industry continue to grow annually at approximately 4% and 10%, respectively, this competition for water is growing. The natural water supplies necessary to meet these demands are scarce. The Colorado River and groundwater are tapped by the border cities of Baja California for approximately 1,850 and 590 million m^3 per year, respectively, with rainfall collection being minimal and irregular (Trejo, 2001). In total, this translates to an approximate use of 2.5 billion m^3 of water per year for the border region. The supply to meet this demand is shrinking. In most years, all available surface water is used and groundwater resources are being withdrawn much faster than they are being recharged. This paints a very serious picture for the sustainable development of this booming *frontera*.

Literature review

Geography uses both human and physical contexts to examine the earth's natural resources and how humans utilize and modify these resources. Many geographers continue to research natural resources and, more specifically, regional water issues throughout the world. Existing geographic literature on water pertinent to this study includes topics such as inter-basin water transfers (Beckinsale, 1969), choice in water use (O'Riordan, 1969), and spatial analysis of river systems (Greco and Plant, 2003). These topics, whose principles can be applied to a variety of geographic regions, form the foundation of natural resources studies used in this project.

In addition to natural resources geography, the binational nature of the study region necessitates research on México-U.S. borderlands. The study of borderlands utilizes multidisciplinary perspectives and concepts to examine phenomena specific to these unique regions (Stoddard, 2002). In the context of this study, the term borderlands includes political geography, cultural geography, and economic geography. Existing literature on these topics includes research on the evolving nature and significance of international borders (Ferguson and Jones, 2002), the people who inhabit these regions, called *fronterizos* (Martínez, 1996), and the ties between these topics and economics (Sadowski-Smith, 2002), respectively.

The first geographic literature specifically on Baja California consists mainly of topographic and cultural descriptions written by Spanish explorers and Fathers. These descriptions were written by authors such as Francisco de Ulloa (1539), Hernando de Alarcón (1540), and Father Kino (1701-1702) (Sykes, 1937). These explorers were searching for precious metals and what they considered to be rich centers of population. Their expeditions were unsuccessful and the Baja California region remained inhabited primarily by indigenous groups well beyond México's independence from Spain in 1821 (Sykes, 1937). Literature on the region thus remained minimal until the 1853 Gadsden Purchase, when the United States purchased from México approximately 78,000 square kilometers south of the Gila River from California to El Paso.

Having established the Baja California-California international border in 1853, interest in the region's natural resources began to spread, largely because this region was to be immediately developed for the southern transcontinental railroad. Of particular importance to the region's development was a geologist on an 1853 railroad research party named W. S. Blake (Sykes, 1937). Blake determined that what is now called the Imperial Valley is below sea level and could thus be used for irrigated farming. This discovery was followed in 1859 by Dr. Oliver M. Wozencraft, the person credited with making the first large scale reclamation plan in the Colorado River region (Sykes, 1937). Wozencraft introduced his plan as legislation to Congress, which authorized him to begin development of the Imperial Valley (IID, 2004). While Wozencraft's plan was never implemented, it paved the way for other reclamation-oriented work, which ultimately led to the agricultural development of the Imperial and Mexicali valleys at the turn of the twentieth century.

The ensuing literature was primarily oriented towards travel descriptions of the state, and use of Baja California's surface and groundwater for agricultural purposes in the Mexicali Valley region (Mendenhall, 1909; Pillsbury, 1941). The two primary issues during this period were the quantity and, later, the quality of Colorado River water flowing south into México. Water quantity was addressed with the 1944 U.S.-México Water Treaty and quality was addressed with IBWC minutes 242 and 241, in 1973 and 1979, respectively (IBWC, 2004).

Recent literature on the border region's natural resources has evolved towards sustainable development. Two notable reports that marked the beginning of region-wide studies of the region are Henderson's 1964 dissertation, "Agriculture and Livestock Raising in the Evolution of the Economy and Culture of the State of Baja California, México" and Hundley's "Dividing the Waters: A Century of Controversy Between the United States and México" (Henderson, 1964; Hundley, 1966).

Many of these more recent studies of natural resources in the border region have been in geographic assessment and policy, both national and binational. Two of the most important geographic disciplines used are remote sensing and Geographic Information Systems (GIS). Some of the services these two systems can provide in assessing and analyzing border region water are soil moisture runoff (Baumgartner, et al, 1997), sediment transport modeling (Gurnell and Montgomery, 2000), and agricultural pollution analysis (Kovar and Nachtnebel, 1993), among others.

A major source of border region environmental data is San Diego State University (SDSU). With several groups addressing a wide spectrum of border issues, the ongoing spatial assessment and analysis at this University has provided researchers with a vast amount of data to support many analyses (SDSU, 2004; SCERP, 2004). Additional agencies and institutions helping to expand water supply studies to a region-wide level are the International Boundary and Water Commission (IBWC), the City of Tijuana Municipal Institute of Planning (IMPlan), the Colegio de la Frontera Norte (COLEF), the Border Environmental Cooperation Commission (BECC), the City of San Diego Office of Binational Affairs, and the Southwest Center for Environmental Research and Policy (SCERP) (IBWC, 2004; SDSU, 2004; Gavaldón, 2002; SCERP, 2004).

While these and many other agencies promote studying the border region as a cohesive unit, relatively few region-wide studies of its water supply have been completed. The following quotes express the need for this type of study:

> "Due to the arid climate and the burgeoning population of San Diego, Tijuana, Tecate and Ensenada, there is a critical need for a local, integrated water management plan." (USEPA, 1996)

> "By 2005, promote the assessment of water system conditions in 10 percent of the existing water systems in the border cities to identify opportunities for improvement in overall water system efficiencies." -Objective 4 of the EPA Border 2012 Plan (USEPA Border 2012, 2004)

> "A study should be undertaken to develop a plan that optimizes the operation of the (*Rodríguez*) reservoir relative to the use of the available storage volume, while protecting or even improving the water quality." (CDM, 2003)

A Geographic assessment of the frontier

This study takes a step toward assessing the border as a unified region by discussing the water supply infrastructure of the four Baja California municipalities connected with a common surface water conveyance system: Mexicali, Tecate, Tijuana, and Playas de Rosarito. Ensenada, while significant to the state's water demands, is not connected to the inter-tied water infrastructure of the border region and is not discussed in detail. Disciplines employed in this project include geography, engineering, hydrology, and borderlands studies. As such, this study is part of a larger movement of researching earth processes as an interlinked system (Ernst, 2000), which is, ironically, what early explorers such as J. W. Powell called for long before the Baja California-California region was developed (Reisner, 1986).

Chapter one assesses the current surface water supply of Baja California with a geographic overview of the state. Chapter two introduces the physical and human geographical aspects of this region that interact with water. Chapter three discusses water demands, i.e., how the growing population uses and sometimes strains water resources. With the need established, Chapter four discusses how these demands are met through the region's extensive water supply infrastructure and management. Because of the increasing strain between demands and supply, Chapter five looks at prospects for meeting future demands. Chapter six consists of discussion and conclusions.

2. GEOGRAPHIC DESCRIPTION

Located in the Northwestern corner of the United Mexican States, the State of Baja California is the state most distant from the core of the country and the capital, México City. With its boundary geographic coordinates at 32° 43' north to 28° 00' north latitude, 112° 47' west to 117° 07' west longitude, Baja California is surrounded by the Pacific Ocean to the west, Baja California Sur to the South, and the Sea of Cortés and the State of Sonora to the east (INEGI, 1998). Its international border lies in the north and northeast where the international border established in 1853 separates it from the State of California and a short stretch of the Colorado River separates it from the State of Arizona.

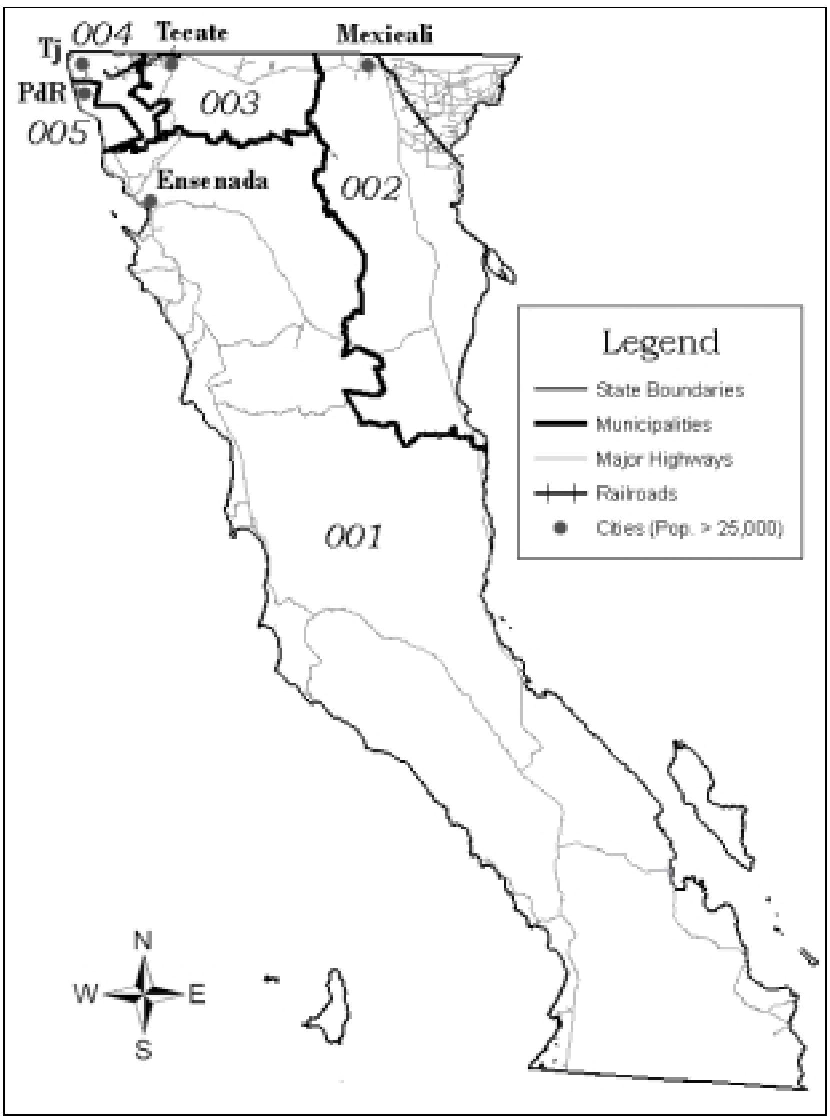

Figure 3. Baja California (After SEMARNAT)

Political
Baja California covers 71,609 km², 3.7 percent of the national total, and spans 220 kilometers of the 3,100 km México-US international boundary (ConsulMX, 2004). This territory is divided into five municipios, or municipalities: Ensenada, Mexicali, Tecate, Tijuana, and Playas de Rosarito, numbered 001 to 005, respectively. The municipality of Mexicali is home to the state capital, the City of Mexicali. With respect to water supply, each municipality has its own works as well as state and federal works, as discussed in Chapter four.

Population
The population in the border region gives it a constantly evolving character. Many immigrants from different parts of México, as well as from other areas such as Central America, come to the Border for economic reasons. It is commonly known that the jobs available at the Border provide a living wage, a phenomenon not common for unskilled workers in central and southern parts of México. Many people move to the Border to find employment and live; many others come to the border as a staging ground for entering the United States. Border cities often become bottlenecks for these transiting workers, who frequently must work on the Mexican side of the Border for a period before crossing. Accordingly, the populations of border cities such as Tijuana and Mexicali, with annual growth rates of 5.0 percent and 2.3 percent, are increasing rapidly (CONEPO, 2004).

Economic activity
Economic activity in Baja California primarily consists of agriculture in the Mexicali Valley and the coastal regions, industrial production in Tijuana and Mexicali, and tourism along the Pacific Coast. As a whole, the state of Baja California's Gross Domestic Product (GDP) was just under 144 billion pesos, approximately 13.8 billion US Dollars (2002 prices), or 3.18 percent of México's GDP in 1999. Approximately 20 percent of Baja California's contribution to the GDP is from industrial manufacturing, 3 percent is from agriculture, and almost 30 percent from commerce, restaurants, and tourism (SEDECO, 2004). Other economically important sectors are transportation, financial services, and social services.

The only irrigated agriculture in Baja California is in the Mexicali Valley, otherwise known as national Irrigation District 014. Initiated in the early 1900's by Harrison Grey Otis and his Colorado River Land Company, the first major economic activity in this valley was cotton production. The valley has since diversified its crops and now grows much of México's wheat, green alfalfa, and tomatoes, among other crops. With 94% of its productive surface being watered artificially, this district owes its agricultural prominence to irrigation (Anguiano, 1995).

The vast majority of the state's industrial production happens in its *maquiladoras*. Located almost exclusively in Tijuana and Mexicali, these foreign-owned factories and assembly plants are a direct result of the 1965 Border Industrialization Program. While the Baja California-California border region accounts for only 7 percent of the total length of the México-US border, as of November 2003 it is home to 879, or approximately 25 percent, of México's *maquiladoras* (SEDECO, 2004). These numbers not only speak to the state's exceptionally high level of economic importance and productivity, but also indicate why Baja California consumes an exceptionally high amount of natural resources.

Tourism is increasingly important to the economy of Baja California. As of October, 2003, areas of highest hotel occupation in the study area, in descending order, are Mexicali, Tijuana, Tecate, and Rosarito (SEDECO, 2004). The tourist areas in this state are generally the coastal regions of Tijuana and Playas de Rosarito. These areas are visited by tourists who travel the coast, enjoy the nightlife, and buy articles ranging from clothes to pharmaceuticals (SignonSanDiego, 2004).

Transportation

Transportation in Baja California consists of roads, airports, railways, ports, and ports of entry at the international border. Baja California has 2,535 km of paved roads that connect the main cities in the state. Some of these are built and operated by the federal government, while others are built and operated by private companies. Additionally, the state has 4,449 km of paved roads in rural areas and 3,906 km of dirt roads that connect remote communities in the state (Baja State Tourism Secretariat, 2004).

The state has four international airports, serving the cities of Tijuana, Mexicali, Ensenada, and San Felipe, respectively. The busiest is Tijuana's *Abelardo J. Rodríguez* international airport, which conveyed approximately 2.3 million passengers and 53,000 metric tons of cargo in 1997 (SDSU, 2000). There are two railways in Baja California: one in the West and one in the East. The western line connects the City of Tijuana to the Municipality of Tecate and crosses the international border. The eastern line connects irrigation district 014 to the international border, via the City of Mexicali. Several shipping ports line the coast of Baja California, most notably in Ensenada, San Felipe, and Playas de Rosarito, with the port of Ensenada being the second-busiest tourist port in México. The state has six land ports of entry, dispersed in Tijuana, Tecate, and Mexicali. Tijuana is the busiest with almost 53 million people crossing northbound at its San Ysidro and Otay Mesa ports in 1999 alone (SDSU, 2000). This large number is, in large part, due to the San Ysidro port, which is commonly regarded as the busiest international border crossing in the world.

Climate

The California-Baja California part of this border consists of two climatic regions, separated by the Sierra San Pedro Mártir mountain range at approximately 160 kilometers east of the Pacific Ocean. The westernmost part of the border is considered semiarid and is home to the San Diego-Tijuana sister city region. This part of the border region receives approximately 25-49 centimeters of precipitation per year (Bergman and Renwick, 2002). Heading inland and over the mountain range, the climate quickly changes to arid desert. This classification goes east through the City of Mexicali to the Colorado River, the easternmost limit of the California-Baja California border that receives less than 25 centimeters of precipitation per year (Bergman and Renwick, 2002).

Soils

The small amount of precipitation that characterizes the entire border region necessitates heavy groundwater use on both sides of the border. The subsurface geology holding this water is primarily dry with relatively little organic matter. The only exception is the Colorado River basin in the northeast corner of the state, which includes clay and organic matter due primarily to deposition from the Colorado River (Bergman and Renwick, 2002).

Topography

The topography of Baja California consists of a high level of relief. The west to east cross-section of the study area begins at sea level at the Pacific Ocean and ends at sea level in the Colorado River Basin. The state is divided from north to south by the Sierra San Pedro Mártir mountain range. These mountains reach a maximum altitude of 3,096 meters and separate the regions of Playas de Rosarito, Tijuana River Valley, Tecate, and Ensenada in the west from the Mexicali Valley and the City of Mexicali in the east. These mountains rise to 1,060 meters in northern Baja California and are important to the state's water conveyance because they are the greatest obstacle in delivering Colorado River water to the western side of the state. Another region of topographic interest in Baja California is the Laguna Salada Basin, historically known as the Macuata Basin. At approximately 3 m below sea level, the Laguna Salada is the lowest point of the state.

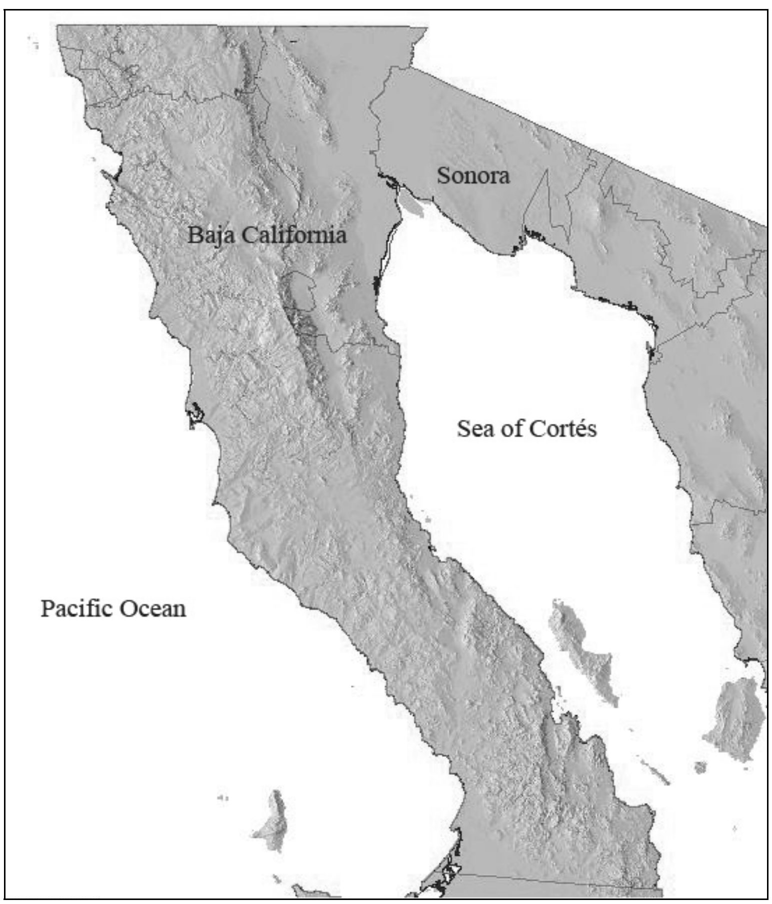

Figure 4. Baja California Topography (After SEMARNAT)

Groundwater

While this study does not assess groundwater availability or use, it is an important part of the water supply of Baja California. The urban areas of Tijuana, Mexicali, and Tecate extract 80, 82, and 3.3 million cubic meters (MCM) of groundwater per year, respectively (Trejo, 2001). Agriculture in the Mexicali Valley (including the acreage in the State of Sonora) withdraws approximately 500 MCM annually (Trejo, 2001). These numbers are highly dependent upon surface water supplies, which are preferable largely because of their lower extraction costs. Total groundwater withdrawals are approximately 590 MCM per year from the region's aquifers, which are increasingly overdrafted (Trejo, 2001).

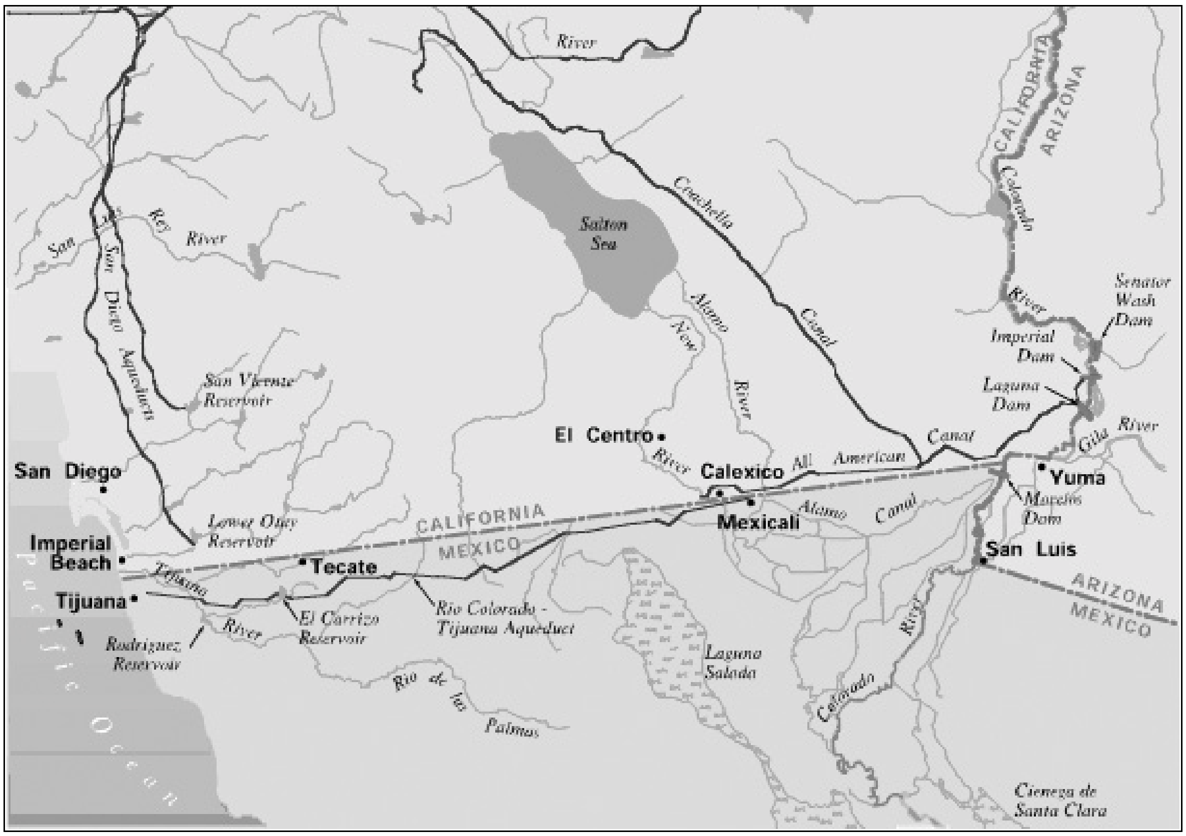

Figure 5. Border Region Rivers (California DWR)

Surface water

Four primary natural conduits carry surface water across the Baja California-California international border: The Colorado, Alamo, New, and Tijuana Rivers. The largest and only one that flows south is the Colorado River, which passes through seven states in the United States before it crosses the international border. This river descends approximately 1,920 kilometers from its sources in the United States to México, where it forms the border between the states of Arizona and Baja California. Once the river flows south beyond the international boundary, it separates the states of Baja California and Sonora until it terminates into the Sea of Cortés.

The Colorado River is the hallmark of water supply in the Western Americas. Once a wild and free-flowing river, it has been dammed, controlled, and contaminated to the point where all of its natural flow has been tapped by man; it has been made into a political dividing line; and it is the lifeline of a desert region that cannot support growth naturally. Consequently, its resources have been a continual source of controversy, both national and international. The annual amount of Colorado River water crossing into México guaranteed by the 1944 "Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande" treaty is 1.85 billion cubic meters, or 1.5 million acre-feet. In comparison, the United States' annual allotment of Colorado River water totals 18.5 billion m^3 (15 million acre-feet) and is divided among 7 states. The primary use of México's allotment in Baja California is agriculture.

The other three major rivers that cross the Baja California-California border are the Tijuana, the Alamo, and the New Rivers. All three originate in México and flow north into the United States. The Tijuana River was once the primary water supply for the City of Tijuana, but is now primarily an effluent conveyance line for this city. This river travels north through the city of Tijuana where it collects much of the city's industrial and urban wastewaters, continues north across the international border, then turns west and travels approximately 10 kilometers before emptying into the Pacific Ocean. The Tijuana River has been cited as having "The highest concentrations of suspended solids, Cd, Cu, Ni, Pb, Zn, and PCB's (polychlorinated biphenyls) among the eight largest creeks and rivers in Southern California." (Gersberg, et al, 2000) It has consequently been the source of several environmental problems ranging from beach closures in the United States to deterioration of the Tijuana Estuary. Its waters now receive primary treatment on the northern side of the border at the International Wastewater Treatment Plant (IWTP), which frequently treats its capacity of 25 million gallons, or approximately 95,000 cubic meters, per day.

The New River and the Alamo River were initially fed by the Colorado when it broke out of its riverbed and flooded the Salton Sink, forming the Salton Sea in 1905. These two rivers now collect agricultural, urban, and industrial runoff on both sides of the border and provide the Salton Sea with most of its inflows. The Alamo River originates approximately three kilometers south of the border and flows through the Imperial Valley for approximately 96 kilometers before emptying into the Salton Sea. This river flows approximately 864 MCM per year into the Salton Sea (SWRCB, 2002). The New River originates 32 kilometers south of the border and flows through Mexicali, then through the Imperial Valley for about 80 kilometers before it empties into the Salton Sea. The New River flows approximately 530 MCM per year into the sea (SWRCB, 2002).

3. WATER DEMANDS

Water demands in Baja California have grown continually since the late 1800's. As in many arid regions of high economic output, this state is now feeling the strain of competing interests for a limited resource. Three phenomena are primarily responsible for this increasing strain. The first is the extensive agriculture that has existed for over one hundred years, primarily in the Mexicali Valley, the region that comprises the majority of Mexican National Irrigation District 014. The second is the explosive growth of industry in the border region. Located almost exclusively along the Mexican side of the border, the Baja California border region is now home to approximately 25% of México's *maquiladoras*. The third large water user is the border region's rapidly growing population that sustains the state's agriculture, industry, and commerce. These people typically move to the border to find relatively steady work, or to use the border region as a staging ground to immigrate into the United States.

All indicators point to continued growth for the border region. The largest cities of Baja California are within 10 km of the state's northern border with California, which has made international trade highly profitable. Water use plays a vital role in sustaining this supercharged economy. The Mexican national Secretariat of Economic Development (SEDECO) divides water demands into four categories: agricultural, urban (domestic, commercial, and municipal), industrial, and available. As can be expected of an arid region with high amounts of agricultural production, agricultural demands for water are by far the highest, at 86.4% in 1995; domestic, commercial, and municipal use accounted for 4.9%, industrial 0.5%, and 8.2% of the state's water delivery capacity was listed as available supply during the same year (SEDECO, 2003).

This chapter divides water demands in Baja California into agricultural, urban, industrial, and environmental categories. Agricultural demands in the state can be further divided into two main regions: the Mexicali Valley and the Coastal Zones. Both regions are economically important to the state economy, but only Mexicali Valley is connected to the state surface water supply infrastructure. The Coastal Zones consist of the municipalities of Tecate, Tijuana, and Ensenada, with Ensenada accounting for the vast majority of the cultivable surface area. The Coastal Zones almost exclusively use local surface water runoff and groundwater; hence, this report focuses on the Mexicali Valley agricultural region. For urban demands, the municipalities of Tecate, Mexicali, and Tijuana are discussed. Playas de Rosarito receives all of its surface water from Tijuana and is served by Tijuana's water commission and is therefore discussed as part of Tijuana. Collectively, these urban regions are home to a population of 2,361,850, or 85.2 percent of the total state population (CONEPO, 2004). The industrial regions of the state discussed in this report are in Tijuana, Mexicali, and Tecate. These are the most industrially active regions in the state of Baja California, and are among the most active in all of México. Because industrial water users receive their surface water supplies from the same sources as urban demands, industrial water demand statistics are included as part of urban demands. Environmental demands are dispersed in Baja California and are discussed as a state-wide demand.

Agricultural Demands

Agriculture is the largest and longest-standing major water demand in Baja California. As mentioned earlier, this economic sector was initiated around the turn of the 20th century when Baja California almost instantly became one of México's most important cotton producers. With over 400,000 hectares of land suitable for agriculture, the state has since diversified its production to become one of México's largest producers of a wide variety of agricultural products. For the agricultural year of 1998 through 1999 Baja California was México's greatest producer of wheat, green onions, celery, dates, and olives (CCBRES, 2004). The state was also among México's top three producers of cotton, grapes, tomatoes, green alfalfa, and asparagus during the same year.

The Mexicali Valley accounts for most of this production. For the agricultural year of 1998 through 1999, the Mexicali Valley produced approximately three quarters of Baja California's green alfalfa, wheat, cotton, and asparagus (CCBRES, 2004). Located in the northeast corner of Baja California, this valley makes up most of national Irrigation District 014. This district was formed in 1938 by then President Lázaro Cárdenas as a political move representing the country's shift toward centralizing control of natural resources (Walther Meade, 1996). Approximately 208,000 of the 350,000 hectares of the Colorado River irrigation basin actually receive irrigation. Approximately 181,000 of these hectares are in the Mexicali Valley; the remaining hectares are in San Luis Río Colorado in the State of Sonora (Trejo, 2001).

Because of the region's arid climate, water demands per hectare of irrigated surface area in Baja California are relatively high. For example, cotton, the primary crop of the state, requires up to 13,700 cubic meters of water per hectare per year (Hearne and Trava, 1997). According to Henderson (1964), "As the coefficient of irrigation on the Mexican Colorado Delta has been about 4.5 feet (4.4984 feet) per year, 1,500,000 acre-feet of water will irrigate 333,451 acres or 135,000 hectares of farm land." The agricultural water demands in the Mexicali Valley also depend on temporal factors. The Valley has two cultivating periods, known as spring-summer and fall-winter; additionally, some crops are perennial. When and if a crop will be grown is largely determined by water availability.

The Mexicali Valley has approximately 2,740 MCM of water per year (total of surface and groundwater) available to sustain its production and, given Baja California's water shortages, it is probably safe to assume all of this water is used (Trejo, 2001). The remaining 1,100 MCM per year of the water used by Irrigation District 014 comes from its 725 wells scattered throughout the district (Hearne and Trava, 1997). Annual flows in the Colorado River determine how much of this region's water comes from the Colorado River, and how much comes from groundwater.

Table 1. Baja California Agricultural Demands

District	*Annual Water Demand*	*Area (Hectares)*	*Growth Rate*
Mexicali Valley	(Approx.) 3 Billion m^3	250, 000[1]	Not Applicable
Coastal	*	252, 500[2]	*

Notes: [1]Trejo, 2001; [2]Baja.com, 2004; *Unknown by author

Urban Demands

While agriculture is the longest-standing and largest water demand in Baja California, urban demands are the fastest-growing. These demands were almost negligible at the turn of the 20th century, when the populations of Tijuana and Mexicali were approximately 240 and 400, respectively. Agricultural and tourism growth caused the border population to grow at a relatively steady rate until the initiation of the 1965 Border Industrialization Program. This program was designed to attract foreign investment and employ the thousands of Mexican workers who had been repatriated after the termination of the United States' *bracero* guest-worker program in 1964. As this economic development program became more successful, many workers began to move to border cities to work and live. The promise of reliable employment and a living wage offered by *maquiladoras* continues to attract workers from all parts of México and Central America.

The national census of 2000 measured the population of Baja California at slightly less than 2.5 million, which makes it the 15th largest state in México (New México State University, 2004). More recent estimates put the border state's total population at 2.7 million in 2002 (CONEPO, 2004). With an annual growth rate of 4.0 percent, Baja California is the second-fastest growing state in México (Baja California, 2004). Tijuana and Mexicali account for most of this population, while Tecate and Playas de Rosarito are considerably smaller. The coastal city of Ensenada, while outside the geographic scope of this study, has a population between the larger and smaller border cities and is the state's only major population center not along the border.

Tijuana

Tijuana was originally supplied by groundwater, small rivers, and surface water runoff, but the city's growth has consistently overwhelmed the surrounding region's natural water supply. This situation is primarily driven by the city's growing population of *maquiladora* workers, citizens who commute to work daily to San Diego, and its transient population. This transient population includes people who come to Tijuana to work and stage for eventual immigration to the United States, as well as people who travel from the United States to Tijuana and Playas de Rosarito for tourism and shopping. With current water demands at approximately 78,500 liters per person per year, Tijuana's growth will likely continue to outstrip its water supply (State of Baja California, 2004).

This situation first came to a head in early 1970, when the City of Tijuana was forced to contract with the United States to purchase an emergency supply of up to 18.5 MCM per year for five years (Nathanson, 2001). In spite of the Construction of the Colorado River-Tijuana Aqueduct (*Acueducto Río Colorado-Tijuana, ARCT)* the City of Tijuana has again been forced to turn to the City of San Diego for a new five-year standby emergency arrangement. This agreement, known as International Boundary and Water Commission (IBWC) Minute Number 310, allows Tijuana to use San Diego infrastructure to transport its Colorado River apportionment when the ARCT becomes overwhelmed. This emergency agreement will use the same infrastructure connecting Otay Water District to the City of Tijuana that was used starting in 1970.

Mexicali

While the City of Mexicali shares some characteristics with Tijuana, this capital city has grown for slightly different reasons. The most prominent difference is the city's connection to agriculture in the Mexicali Valley, which grew rapidly at the turn of the 20th century. Population growth stabilized for approximately half of the century, then began to increase drastically with the inception of the Border Industrialization Program. The City of Mexicali again reached a relatively steady, albeit higher, growth rate after the inception of this program. The city's population used approximately 36,500 liters of water per person per year in 2003 (CESPM, 2003).

Tecate

Located between the state's two largest cities, Tecate is nationally known for producing the beer that carries the city's name. While this border city has the smallest population of the three, it is the fastest-growing, and continues to experience growth in its industrial and tourist industries.

Table 2. Baja California Annual Urban Demands

Municipality	*Total City Water Demand (MCM)*	*Population (2002)* [4]	*Growth Rate*[4]
Tijuana and Rosarito	104.6 (2001) [1]	1,458,486	5.0
Tecate	8.3 (2002) [2]	89,411	5.2
Mexicali	81.3 (2002) [3]	813,853	2.3
Ensenada	Unknown	411,785	3.9
Total	194.5 (Not including Ensenada)	2,773,535	4.0

Notes: [1]CDM, 2003; [2]CESPTE, 2004; [3]CESPM, 2004; [4]CONEPO, 2004
Population and Growth Rate data are for municipalities

Industrial Demands

Industry in Baja California represents a vital component of the state's economy. Although industrial water demands are a small percentage of the state's total water demand, industry represents two important components in Baja California: It accounts for approximately 22% percent of the state's economic production, and is the catalyst for population growth in the border region.

Industrial water demands in the border region are driven almost exclusively by the *maquiladora* industry. As of November of 2003, Baja California is home to 31.1% of the national total of these plants (SEDECO, 2004). This industry is an economic boon for foreign companies, which invest money in buildings in México, pay Mexican workers approximately two dollars an hour to perform assembly and manufacturing tasks, and transport the finished products just across the border into the United States, where they are distributed by American companies. The primary products assembled and/or manufactured in *maquiladoras* are electrical/electronic goods, automotive parts, and textiles. These foreign companies can carry out their operations under Mexican business, labor, and environmental laws, which are generally much more lax and less enforced than their American counterparts. The resulting water issues created by this industry are thus typically related to water quality problems generated by industrial wastewater.

Tijuana
Tijuana is the busiest industrial city on the Mexican side of the México-United States border. The total amount of water invoiced by the *Comisión Estatal de Servicios Públicos de Tijuana* (CESPT) to meet this demand in 2001 was 8.2 MCM (CDM, 2003). Tijuana is very popular as an industrial region because of its proximity both to San Diego and the Pacific Ocean. This geography allows for products to be assembled and manufactured inexpensively, then quickly shipped internationally.

Mexicali
The City of Mexicali has less industrial activity. The products assembled and manufactured in this region are typically shipped by ground transportation to the United States, with its sister city of Calexico being directly across the border. While the city of Mexicali does not benefit from the same proximity to multiple modes of shipping, its geographical proximity to the Colorado River affords it lower industrial water costs.

Tecate
The City of Tecate is not geographically close to a sister city in California, nor is it close to a significant water source. Its industrial activity is, therefore, relatively low compared to the other border cities.

Table 3. Baja California Industrial Demands

City	*Total Water Demand*	*Number (11/03)*[2]	*Employment Growth*[2]*
Tijuana	Approx. 6.5% of City[1]	560	2.2%
Tecate	Included with City	110	1.4%
Mexicali	Included with City	136	-3.7%

Notes: [1]CDM, 2003; [2]SEDECO, 2004
*Employment Growth is 11/02-11/03

<u>Environmental Demands</u>

Environmental water demands in Baja California are classified, along with indigenous demands, as non-traditional demands (Mumme and Barajas, 2002). Non-traditional water uses include tribal nations, ecological resources, and rural communities- ironically, the region's only water users before being marginalized by economic development (SCERP pdf, 2004). As a result, legislation pertaining to environmental water demands in Baja California is relatively undeveloped. One important legislative beginning for Colorado River Delta restoration is the IBWC's minute 306, which "addresses the need for binational cooperation in the assessment of ecological needs in the Colorado River Delta…" (Mumme and Barajas, 2002).

The importance of this minute is to formally acknowledge the interests of the governments of México and the United States in conserving the Tijuana River and Delta region, two of Baja California's most highly impacted natural waterways (López, 2001).

This piece of legislation begins to address the multitude of environmental issues in the region, such as omissions of regulations of water use in Baja (Brañes, 1991). Additionally, México's induction into NAFTA has forced México to integrate into an international economic configuration in which sustainable growth must be a target; this increases environmental water demands in México (Guzmán Pineda, 1998).

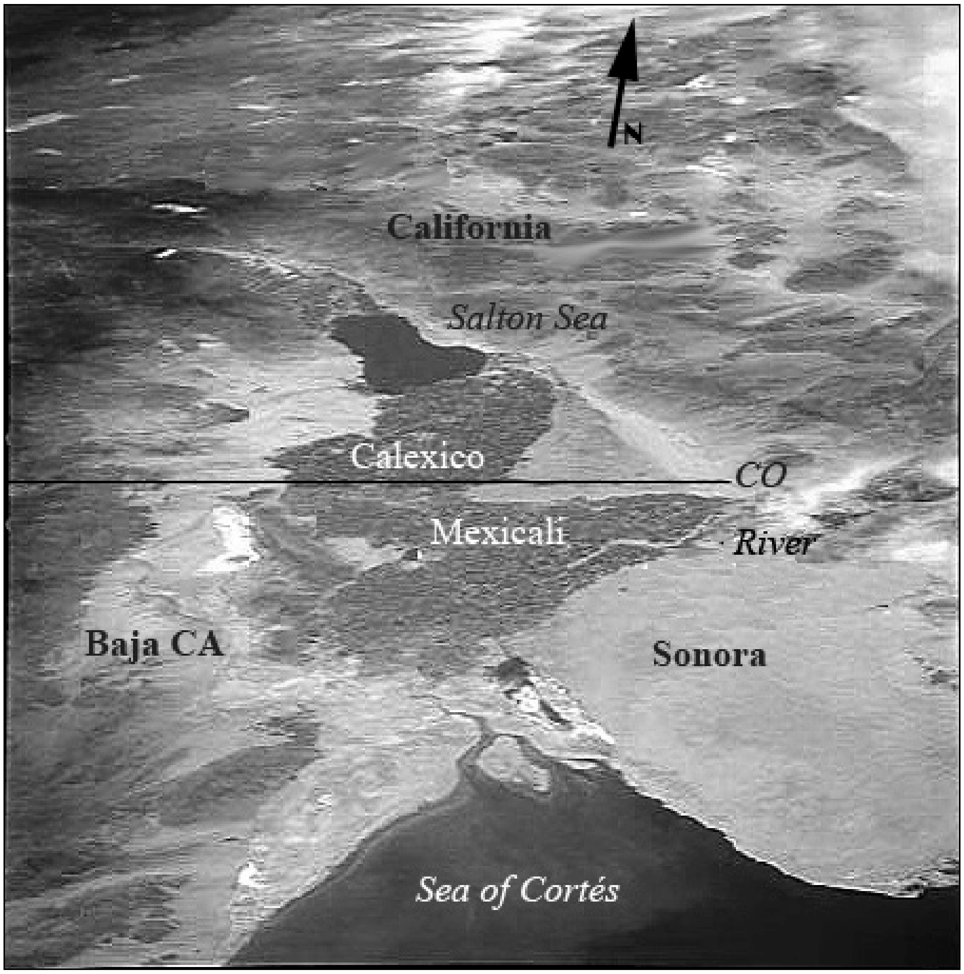

Figure 6. The Colorado River Delta and the Salton Sea. Black line indicates approximate BC-CA international boundary. (Source Unknown)

Two of the most prevalent environmental demands in Baja California are the Colorado River Delta region and the Tijuana Estuary. The movement to restore and protect the Colorado River Delta is largely a response to the environmental damage resulting from decades of upstream diversions of the Colorado River waters, both in the United States and in México. Once a navigable waterway to the Sea of Cortés, "In more recent years, the river does not reach to the gulf." (López, 2001) The diversion of all Colorado River water has resulted in large die-offs of plant and animal species dependent on the river. Studies of impact assessments and restoration projects are still largely preliminary, but it has been estimated that the amount of water needed to sustain the original flora and fauna in the Delta region is as low as 110 MCM per year (López, 2001). Even these minimal environmental demands are not being met largely due to the region's growing economic importance as a production zone.

Located in Southwestern San Diego, California, the Tijuana River Estuary has been suffering from, among other factors, increased sedimentation in the Tijuana River (USEPA, 1996). This river is among the most contaminated in the United States, suffering from environmental problems including animal die-offs and beach closures. Many of this river's problems also affect the Estuary, which has prompted the IBWC to fund projects such as the International Wastewater Treatment Plant (IWTP) in San Diego to treat Tijuana River water before it empties into the Pacific Ocean.

Conclusions

Water demands in Baja California are growing at a rate that most researchers believe is unsustainable. As urban demands continue growing as a function of population growth, competition for the border region's limited water resources is becoming more of an issue. This situation is being relieved temporarily by transfers from agriculture to urban uses, but urban users such as the City of Tijuana are still in a position of needing to contract with the United States. These factors, when combined with increased environmental demands, are quickly putting the border region into a difficult position.

4. WATER SUPPLY INFRASTRUCTURE AND MANAGEMENT

Representing over a century of increasing demands and diversified needs along the *frontera*, the water supply infrastructure of Baja California is extensive and sophisticated. Demographic and economic forces continue to increase water demands, as is evidenced by the City of Mexicali's recent application to the National Water Commission *(Comisión Nacional del Agua, CNA)* for additional Colorado River water. This rising demand for water resources simultaneously increases demand on the water supply infrastructure. Mexican, American, and binational governance and management are also evolving to keep pace with economic growth in the border region.

Because both infrastructure and governance are critical for delivering water from the source to the consumer, this chapter discusses water supply infrastructure and water supply management in Baja California. The first part of this chapter discusses the components of the surface water supply system needed to transport, store, and treat water for human use: dams and reservoirs, conveyance (canals and pipes), pumping plants, and treatment plants. This system can be further divided into primary conveyance and secondary conveyance. Primary conveyance is the infrastructure that delivers water from sources to demand areas: cities, agricultural regions, industrial regions, and environmental regions. Secondary conveyance is the infrastructure that distributes water supply within the demand regions, such as the water distribution infrastructure within the City of Tijuana.

Given the geographic scope of the Baja California-California border region, the inter-tied primary conveyance infrastructure of Baja California is discussed in this study. The primary system serves the cities of Mexicali, Tecate, and Tijuana, and the agricultural region of the Mexicali Valley. The infrastructure connecting Playas de Rosarito, the beach city just south of Tijuana, is classified as secondary infrastructure and is the only secondary infrastructure included. This chapter presents Baja California's inter-tied water supply in the following order: dams and reservoirs, conveyance, pumping plants, and treatment plants. The infrastructure serving the Mexicali Valley is discussed separately. Additionally, the urban and agricultural regions of Baja California are characterized by their extensive use of wells to extract groundwater. While this supply accounts for a considerable amount of water use in Baja California, the scope of this study necessitates focusing on surface water only. This surface water infrastructure is displayed on the following page in Figure 6.

The second part of this chapter reviews water governance and management in Baja California, México. This section discusses the division of districts, pertinent legislation and laws, and agencies involved in water management, regulation, and governance. The combination of these two parts gives a basic understanding of how water is carried from source to user in Baja California, physically and institutionally.

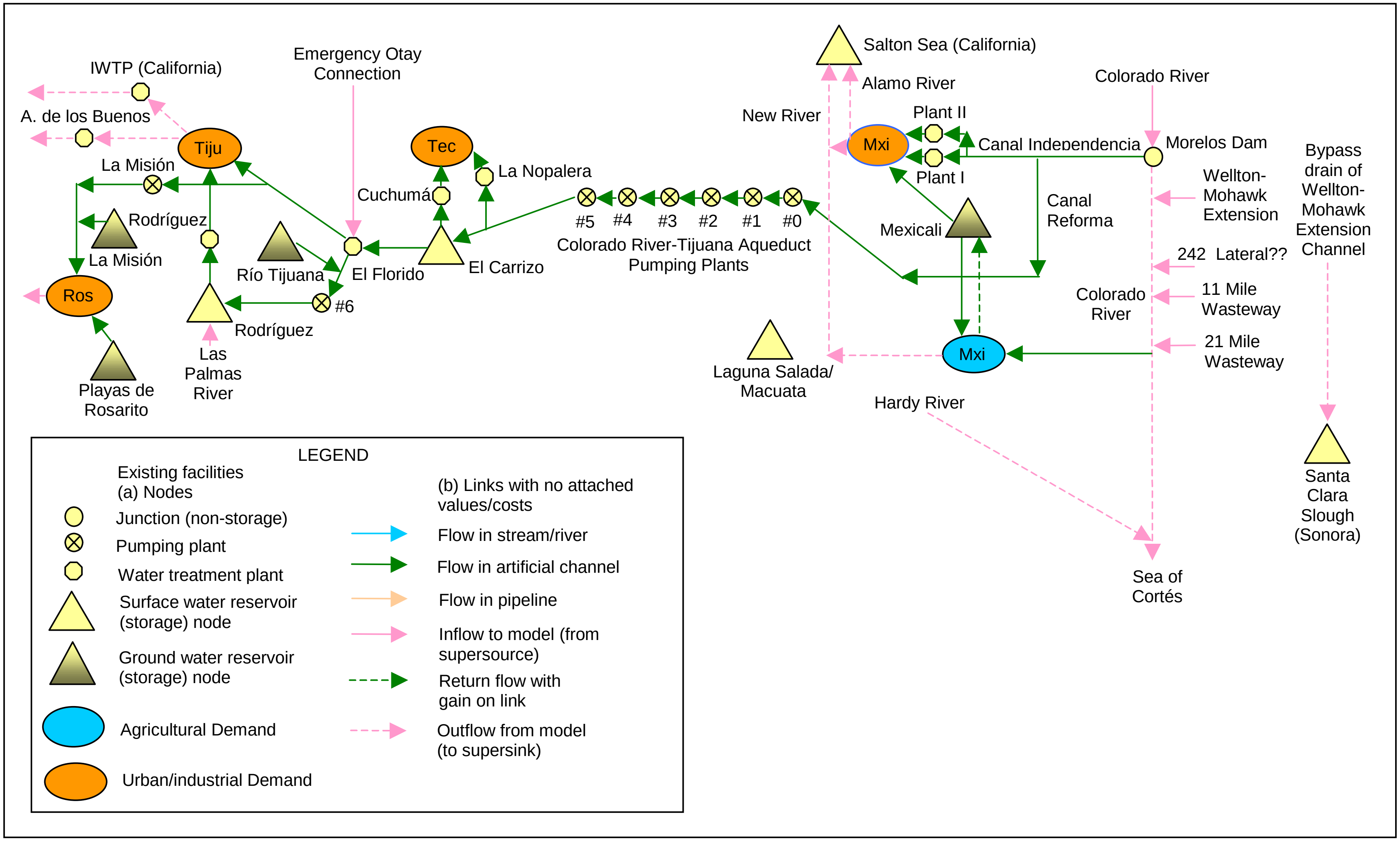

Figure 7. Baja California Water Supply Infrastructure

Part I: Water Supply Infrastructure
Dams and Reservoirs

The primary infrastructure hub
Almost all of the water used in the study region comes from the Colorado River. This water enters México at the easternmost international border between California and Baja California, from where it travels two kilometers south to the Morelos Dam. With no true storage capacity, this dam serves as the primary switchyard for Colorado River waters entering México. This dam was completed in 1950 and spans 426 m across the Colorado River, with "20 electrically-operated, radial gates to control stages of the Colorado River to enable diversions through the adjoining intake structure that supports 12 radial gates which control diversions westward to the canal system in México." (IBWC, 2004) The secondary purpose of this dam is flood control, which it handles through the river part of the dam. This infrastructure is designed to handle a flood of 9,911 cubic meters per second (cms) and the intake structure is designed to handle 226 cms (IBWC, 2004), although it is currently limited by sediment accumulation and vegetation overgrowth (Robinson, 2004). Waters leaving the dam either are diverted westward for urban use or continue southward for agricultural use.

All westward-bound Colorado River waters go to the City of Mexicali, where they are either used in the city or delivered further west through the Colorado River-Tijuana Aqueduct (*Acueducto Río Colorado-Tijuana, ARCT*). Construction on this aqueduct began in 1975 as a response to the water shortage in Tijuana that necessitated a five year diversion from the United States. The aqueduct was put into service in 1982, with an initial conveyance capacity of 2,050 liters per second. The aqueduct's capacity was increased in 1988 and again in 1993 for a total conveyance capacity of 4,000 liters per second, or approximately 126 MCM per year. The aqueduct spans 123 km and crosses the mountainous region *la Rumorosa* to a maximum elevation of 1,060 meters to reach the *el Carrizo* reservoir in western Baja California (COSAE, 2004).

Tijuana's supply reservoir
Built as the terminus reservoir of the Colorado River-Tijuana Aqueduct, the *el Carrizo* reservoir is the primary supply reservoir for the cities of Tecate, Tijuana, and Playas de Rosarito. This reservoir, per CNA request, should always maintain a minimum of a three-month supply for Tijuana and Playas de Rosarito, a procedure that maintains water quality and gives the cities a safety buffer in case of drought or aqueduct malfunctions (CDM, 2003). When rainfall is minimal and this region relies on Colorado River water, *el Carrizo* provides up to 95% of Tijuana's water supply.

Tijuana's rainfall collection reservoir
The *Abelardo L. Rodríguez* reservoir was built in 1937 as the primary supply reservoir for the city of Tijuana and is now used primarily for surface water runoff collection. It is fed by surface water runoff and the *las Palmas* River, which flows into the southern side of the reservoir. A rainy period in 1993 was the last time the *Rodríguez* reservoir was the primary supply for Tijuana. During this period, the *Comisión Estatal de Servicios Públicos de Tijuana* (CESPT) did not divert any Colorado River water for 18 months

(CDM, 2003). This situation was exceptional, as the region's semiarid climate makes natural inflows highly unpredictable. In 1993, this reservoir was connected to the *el Carrizo* reservoir via the *Rodríguez* reservoir aqueduct. When the *el Carrizo* reservoir's demands are met, this connection is used to divert water to the *Rodríguez* reservoir for extra storage (CDM, 2003). This diversion also allows for facility maintenance, decreased evaporation losses, and decreased energy expenditures when the Colorado River Tijuana aqueduct is not in use. Because this reservoir is supplied primarily by natural hydrology it is generally considered an unreliable source.

Table 4. Baja California Dams and Reservoirs

City	*Dam*	*Total Capacity (MCM)*	*Usable Capacity (MCM)*	*Basin Area (Hectares)*	*Elevation (m)*
Mexicali	Morelos[1]	N/A	N/A	N/A	30
Tijuana	El Carrizo[2]	39.8	34.4	238	253 [(3)]
	Rodriguez[2]	137.9	134.4	550	156

Notes: [1]Robinson, 2004; [2]SEDECO, 2004; [(3)]CDM, 2003

<u>Conveyance</u>

The primary network of surface water conveyance connecting the aforementioned facilities is extensive. These conveyance facilities include a selection of lined concrete canals, concrete tunnels (in the ARCT), and tubing made of steel or ductile iron.

Mexicali

The Morelos Dam feeds into the *Canal Independencia*, the primary conveyance line that feeds the city's two primary treatment plants. Colorado River waters destined westward pass through the southern edge of the City of Mexicali in the *Reforma* canal, where it connects to the Colorado River-Tijuana Aqueduct (COSAE, 2004).

Tecate

Colorado River water is carried through the ARCT through a series of pressurized steel tubing, pressurized ductile iron tubing, concrete tubing, and concrete tunnels. As the water finally descends the western slope of *La Rumorosa*, it passes through a system of pressure reducers on its way to western Baja California. This water either continues west to the *El Carrizo* reservoir in the ARCT or is diverted north to the *La Nopalera* Treatment Plan and into the City of Tecate in the *Las Auras* Canal (CESPTE, 2004). The water entering the *El Carrizo* reservoir is the City of Tecate's second Colorado River water supply. Delivered through the *Carrizo-Cuchumá* Canal, this water passes water through the *Cuchumá* treatment plant before arriving at the city (CESPTE, 2004).

Tijuana

Colorado River water is carried to Tijuana from the *El Florido* Treatment Plant via two primary routes: the first is directly from the treatment plant to a series of canals. The second is through the *Rodríguez* Reservoir Aqueduct, which carries water to Pumping Plant (*Planta de Bombeo*) PB-6, and into the *Rodríguez* Reservoir. Water is carried from the reservoir to the *Rodríguez* Treatment Plant, and finally to the City of Tijuana in a canal that parallels the Tijuana River. A third and final conveyance facility capable of delivering Colorado River water to the City of Tijuana is an emergency connection with the Otay Reservoir in San Diego, California (CDM, 2003).

Playas de Rosarito
Water delivered to Playas de Rosarito is treated in *El Florido* treatment plant, then conveyed through the *la Misión-Tijuana* aqueduct. This aqueduct is fed by the *La Misión* pumping plant in Tijuana and is the primary surface water source for Playas de Rosarito (CDM, 2003). Located at approximately 200 kilometers from its water source, this beach region is the final recipient of Colorado River-Tijuana Aqueduct water.

Table 5. Baja California Conveyance

City	*Conveyance Line*	*Capacity (lps)*	*Conveyance Type*	*Diameter (m)*
Mexicali	Canal Independencia		Lined Canal	
	Canal Reforma		Lined Canal	
Tecate	ARCT	4,000	Combination	
	Las Auras Canal		Lined Canal	
	Carrizo-Cuchumá Canal		Lined Canal	
Tijuana	El Florido-Tijuana Canals		Lined Canal	
	Rodriguez Reservoir Aqueduct		Ductile Iron Pipe	1.22
	Feeder to Rodriguez Tx Plant		PVC Pipe	0.915
	Rodriguez Tx Plant to Tijuana		Transmission Main	0.76
Rosarito	Misión-Tijuana Aqueduct	250	PVC and AC Pipe	0.508

Notes: All listed Capacities and Diameters are from CDM, 2003.
Items left blank are unknown by author.

<u>Pumping Plants</u>

Colorado River water destined for the western cities in Baja California is carried approximately 26 km by gravity from the Morelos Dam to Pumping Plant PB-0 , the first of a series of six pumps necessary to lift Colorado River water over the 1,060 meter peak of *La Rumorosa*. Each of the six pumping plants is preceded by a sedimentation tank with a capacity of 32,750 m^3 (COSAE, 2004). PB-0 consists of four pumps of mixed flow type. The remaining five plants, sequentially numbered PB-1 through PB-5, also consist of four pumps each, with these being of horizontally-mounted centrifugal type. Pumping plants PB-1 through PB-5 are also equipped with suction tanks. All of the pumping plants are designed to run on three pumps, with the fourth to be used as a reserve in case of malfunction or maintenance on one of the operating pumps.

The remaining pumps in the study area are PB-6 and *la Misión*, both of which are located in the Municipality of Tijuana. PB-6 serves to pump water from the *el Florido* treatment plant to the *Rodríguez* Reservoir. Located in the City of Tijuana, the *la Misión* pumping plant provides the City of Playas de Rosarito with its supply of Colorado River water. This pump feeds the *Herrera* Storage Tank in the City of Tijuana. Located 144 m above sea level, this tank gravity-delivers water to Playas de Rosarito through the *la Misión-Tijuana* aqueduct (CDM, 2003).

Table 6. Baja California Pumping Plants

City	*Plant*	*Rated Capacity (lps)*	*Suction Tank Capacity (m3)*	*Distance Pumped (km)*	*Elevation (m)*
Mexicali[1]	#0	1,333	N/A	4.00	-0.80
	#1	1,333	8,100	19.50	29.85
	#2	1,333	8,100	7.15	147.00
	#3	1,333	8,100	6.60	223.00
	#4	1,333	8,100	1.70	380.00
	#5	1,333	8,100	1.23	700.25
Tijuana[2]	#6	9,000 HP	*	8.50	*
	La Misión	*	N/A	*	3

Notes: [1]COSAE, 2004; [2]CDM, 2003; * Unknown by author

Treatment Plants

The Cities of Mexicali, Tecate, and Tijuana each have two primary treatment plants. Each plant is slightly different in terms of type and treatment capacity. Water destined for Playas de Rosarito is treated in Tijuana.

Mexicali

Mexicali receives its Colorado River water directly from the river. Mexicali's two water treatment plants are aptly named Treatment Plants One and Two (*Plantas Potabilizadoras I and II).* Treatment Plant One utilizes an eight-step patented clarification process to clean water for the city, while Treatment Plant Two utilizes a nine-step direct filtration process (CESPM, 2004).

Tecate

The City of Tecate is the first recipient of Colorado River-Tijuana Aqueduct water, which is gravity fed to the city from the hills of *La Rumorosa.* Tecate's primary treatment plants are *Cuchumá* and *La Nopalera* (or *Las Auras*), both of which use direct filtration.

Tijuana

All Colorado River water bound for Tijuana and Playas de Rosarito is treated at *el Florido* Treatment Plant (CDM, 2003). Outflows from this plant are split in two directions: the first and primary supply is directly to the city of Tijuana, while the second outflow goes to pumping plant number six, which then feeds into the *Abelardo L. Rodríguez* reservoir. Water bound for the City of Tijuana from this reservoir is first conveyed to the *Rodríguez* water treatment plant. Both the *El Florido* and *Rodríguez* treatment plants use conventional clarification and filtration.

Table 7. Baja California Treatment Plants

City	*Plant*	*Rated Capacity (lps)*	*Elevation (m)*
Mexicali[1]	Plant #1	1,250	10
	Plant #2	2,000	10
Tecate[1]	Cuchumá	125	*
	La Nopalera	175	*
Tijuana[2]	El Florido	3,900	240
	Rodriguez	600	175

Notes: [1]SEDECO, 2004; [2]CDM, 2003; * Unknown by author

Agricultural water supply infrastructure

While the water supply infrastructure that connects Baja California's urban regions is extensive, most of México's Colorado River apportionment is used for agriculture. This irrigation water is exclusively used in México's Irrigation District Number 014, where it is delivered to numerous users via an extensive canal network, primarily in the Mexicali Valley. This canal system is made up of 424 kilometers of main channels, 2,152 kilometers of secondary channels for irrigation districts, 2,350 kilometers of concrete channels, and 2,376 kilometers of open-air channels (Trejo, 2001). This conveyance system has no primary reservoirs, pumping plants or treatment plants.

The supply of Colorado River water delivered to México is augmented south of the Morelos Dam by agricultural discharges from the State of Arizona. While this infrastructure is outside the geographic scope of this study, it does contribute to the water supply used by Irrigation District Number 014. This water comes primarily from the Yuma Project irrigation district and is delivered to the Colorado River through a network of canals that discharge agricultural runoff into the eastern side of the Colorado River. The water delivered through these canals contributes to México's allotment of 1.85 billion m^3 of Colorado River water. For the period of 1939-2001 these canals contributed an average of over 31 MCM per year to the Mexican section of the Colorado River (IBWC Bulletin, 2001; 23, 25). This water is primarily used in Irrigation District 014.

Part II: Water governance and management

Federal management

As with the region's water supply infrastructure, water governance and management in Northern Baja California is unique because of the region's binational character. Indeed, the region is home to both Mexican waters and waters that cross the international border in both directions. As a result, Northern Baja California is affected by Mexican and American agencies and laws, as well as a host of binational agencies and treaties that work to bridge the gaps between México and the United States. While an analysis of the myriad of agencies and laws involved in managing Baja California's waters and conveyance infrastructure is beyond the scope of this study, it is important to have an understanding of pertinent Mexican laws and the 1944 U.S.-México water treaty.

Water in México is considered part of the national patrimony and is thus ultimately under the control of the federal government. Federal, state, and local water rights are defined in the 1992 National Water Law, which is based on article 27 of the Constitution of the United Mexican States. This water law, a direct result of the National Development Plan of 1989-1994, replaced the Federal Water Law of 1972 as a first step toward improving water governance in México. The implementation of this plan was largely a response to the economic crisis in México in the early 1980s, a time that forced the Mexican government to break from its traditional management practices and streamline its operations.

The National Water Law began to accomplish this by providing the foundation for the National Water Commission, (*Comisión Nacional del Agua, CNA*), which the Mexican federal government appointed as the "Sole federal water authority responsible for water management." (Gorriz, et al, 1995). One of five decentralized administrative bodies within the Secretariat of Agriculture and Water Resources (*Secretaría de Agricultura y Recursos Hidráulicos, SARH*), the CNA was put in charge of overseeing the national transition towards decentralization of the country's irrigation and drainage sectors. The CNA accomplishes this largely through a part of the National Water Law called Title of Concession. This title defines requirements for transferring water management from the CNA to local water users as well as the role of all parties involved.

State agencies

Traditionally characterized by its central control, the national Mexican governance system is currently giving state and local governments more control over their respective regions. In Baja California, the State agency that oversees waters is the State Water Commission (*Comisión Estatal del Agua, CEA*). This commission serves under the CNA as the coordinator of activities directly related to potable water, sewage, and treatment in Baja California. The CEA also serves as the coordinator of State water projects and politics (CEA, 2004).

While the CEA is largely responsible for administrative tasks related to water projects, the agency that has the dual role of administration and direct interface with the communities of Baja California is the State Water Services Commission (*Comisión de Servicios de Agua del Estado de Baja California, COSAE*) (COSAE, 2004). This decentralized organism of the government of Baja California is in charge of guaranteeing the timely supply of water throughout the state, promoting the use of chlorinated water in rural zones, and the reuse of wastewater throughout the state (COSAE, 2004). The primary responsibility of the COSAE that pertains to this study is the agency's responsibility of administrating, operating, and maintaining all inter-municipal aqueducts in Baja California. Prime among these aqueducts is the Colorado River-Tijuana Aqueduct, the lifeline of Baja California's *maquiladoras* and their surrounding cities.

Local Management

The four local agencies that serve the five municipalities in the State of Baja California are: the State Commissions of Public Services of Ensenada, Tijuana, Tecate, and Mexicali (*Comisión de Servicios Públicos, CESPE, CESPT, CESPTE, CESPM*), respectively. The region of Playas de Rosarito is served by the Commission of Tijuana. These commissions are all decentralized public organisms of the State Government, which are governed by the 1979 State of Baja California State Public Commissions Law. Under this law, the four commissions are administered by counsels of seven people:

1. The State Governor
2. The Secretary of Human Settlements and Public Works
3. The Secretary of Planning and Finances
4. A Citizen Representative, selected by the Governor
5. Two representatives from the private sector
6. The respective Municipal President

This law holds the commissions responsible for potable water and sewage systems, carrying out or contracting out works, and systems operation and maintenance within their respective municipalities (Baja California, 2003). While municipal water users are served by state-run agencies, Irrigation District 014 is supervised directly by the CNA.

Binational governance and management

<u>1944 Water Treaty</u>

The primary binational document that governs many of the waters managed by these agencies and laws is the 1944 U.S.-México Water Treaty. Signed in Washington, DC on February 3, 1944, this law replaced previous laws from 1848 and 1853, which only regulated navigation on the Colorado River and the Rio Grande. The 1944 law addressed water supply on both of these rivers and the Tijuana River and entrusted the International Boundary and Water Commission (IBWC) with the application of treaty, regulation, and exercise of rights and obligations. Of interest to this study are articles 3, 10, and 16. Article 3 establishes the order of priority for the use of international waters, as follows:

1. domestic and municipal
2. agriculture and stock raising
3. electric power
4. other industrial uses
5. navigation
6. fishing and hunting
7. any other beneficial uses which may be determined by the commission

(Joint committee, 1953)

Article 10 guarantees 1.85 billion cubic meters, or 1.5 million acre-feet, to be delivered to México annually. Additionally, this article establishes that in years of surplus, the United States will deliver to México a total quantity not to exceed 2.1 billion cubic meters, or 1.7 million acre-feet, annually. In years of shortage, the allotment to México "will be reduced in the same proportion as consumptive uses in the United States are reduced." (Joint committee, 1953)

Article 16 of the treaty is important because it is the first official binational agreement that the IBWC shall study how to "improve existing uses and to assure any feasible further development" of the Tijuana River (Joint committee, 1953). Given this river's binational nature, this study includes recommendations for storage and flood control plans, and recommendations for improving works on both sides of the border to be submitted to both governments.

NAFTA

One of the most influential recent pieces of legislation is the North American Free Trade Agreement (NAFTA) between Canada, United States, and México. This agreement was signed trilaterally and opened the doors for increased trade within the Americas. The primary impact of this agreement on Baja California was an increase in industrial activity in the form of more *maquiladoras*. Three agencies were created along with NAFTA to offset the environmental impacts of this trade agreement. The first is the Border Environment Cooperation Commission (BECC), which was created to work with national, state, and municipal agencies and private investors to spearhead, develop, and supervise environmental infrastructure projects in the border region. The second is the North American Development Bank (NADBank), which was created to finance BECC projects on both sides of the border. Both of these agencies were established by México and the United States. The third agency is the Commission for Environmental Cooperation (CEC), which was created by Canada, the United States, and México as a side agreement to NAFTA. The CEC provides consulting and watchdog services to carry out the environmental components of NAFTA.

Conclusions

The fundamental goal of water supply infrastructure and management is to deliver water from source to user as efficiently as possible. While the Colorado River water is a relatively reliable supply, the region's infrastructure is not. Reasons contributing to this are evaporation, leaking infrastructure, and theft. Data available on Baja California's water supply infrastructure capacities indicate that losses in Tijuana alone were measured at 23.5% in 2001; it is estimated that up to 70% of the water conveyed in Irrigation District 014 is lost to those listed and other factors (CDM, 2003). These issues will need to be addressed, both in terms of infrastructure and management, to facilitate the Baja California border region's continued growth.

5. WATER SUPPLY PROSPECTS

In its natural state, the Baja California region was one of the most naturally diverse regions in the world. During the first written history when Spanish explorers began studying the region systematically, the indigenous groups living in Baja California largely raised their crops with primitive irrigation (Henderson, 1964). Historical accounts point out that these groups lived in small enough numbers that they did not significantly affect the region's ecological balance. The changes brought about early in the 20th century quickly and drastically altered this balance. As evidenced by the 1964 Henderson dissertation "Agriculture and Livestock Raising in Baja California", water supply has long been at the forefront of issues faced by agricultural and urban interests in this state. And Henderson's 1,090 page dissertation was written before the region's industrialization and population booms. The state's natural diversity is now giving way to intensive population growth, *maquiladora* activity, and cross-border commerce.

The region's water supply infrastructure will be responsible for feeding this growing population and economy, which requires regional leaders to begin planning for the future of Baja California's water supply now. This chapter gives an overview of the future of water demands in Baja California, then discusses methods for addressing these demands and how to use the current water supply infrastructure to optimize the state's current water supply.

Future urban demands

Some of the issues these regional demands will face in the future include population and infrastructure growth, infrastructure improvements, land use change, and economic expansion. Of the four demands discussed, future urban demands are expected to grow most. As mentioned earlier, the current population of the State of Baja California is approximately 2.5 million inhabitants. This number is projected to grow to between 2.9 to 5.3 million inhabitants by the year 2020, with the city of Tijuana representing most of this population at a projected 1.7 to 3.8 million inhabitants. The second largest metropolitan area is Mexicali, which is projected to have a population of 1.1 to 1.4 million by 2020 (Peach and Williams, 2000).

Future agricultural demands

Baja California jumped to the forefront of cotton production to become one of México's most productive agricultural regions at the turn of the twentieth century. It is not likely, however, that this sector will continue to grow in the foreseeable future, both due to the limited irrigation water supply and area of cultivatable land. The demands for water will thus likely stay close to their current levels, but the region may actually experience some supply reductions in the near future. The areas directly affected by these probable reductions will be forced to make their operations more efficient, or pursue other avenues of importing additional water. Additionally, groundwater contamination is increasingly an issue in both the Mexicali Valley and in coastal agricultural regions.

Future industrial demands

In spite of the large amount of industrial activity along the border, this sector represents a relatively small percentage of Baja California's total water demands. The *maquiladora* industry accounts for the vast majority of industrial activity along the border region, and this sector's growth has actually begun to decline since September, 2001. This is due both to the economic fallout of the September 11 terrorist attacks as well as the movement of some companies to Asian markets, where wages undercut those of México. The *maquiladora* industry could eventually resume its previous growth rate of approximately 12 percent per year (Latin Focus, 2004). The future of industrial water demands will thus likely be similar to current demands (INEGI Estadísticas Económicas, 2004).

Future environmental demands

Environmental water demands along the northern border are likely to increase as the importance of practicing sustainable growth becomes more apparent, both environmentally and economically. The *Reserva de la Biósfera Alto Golfo de California-Delta del Río Colorado* is a prime example of the Mexican government's action to satisfy both of these interests. Established under a 1993 decree signed by then Mexican President Salinas de Gortari, this reserve protects parts of Sea of Cortés waters, the municipality of Mexicali in the State of Baja California, and the municipality of San Luis Río Colorado in the State of Sonora. This decree serves to protect rare and endangered species such as the Marine *vaquita*, a small porpoise indigenous to this region, as well as species of economic importance such as the large amounts of shrimp that use the Colorado River Estuary for reproduction (CONANP, 2004).

Binational actions to achieve sustainable growth include the Border XXI program and the Border 2012 program. The Border XXI program was a five year program initiated in 1996 by agencies from both countries, including the United States Environmental Protection Agency (EPA) and the Mexican Secretariat of Environment and Natural Resources (SEMARNAT). This program was designed to put binational environmental work into a common framework, but the program was commonly criticized for putting forth ideas without laying out a plan for achieving them (Kourous, 1999). This program was superseded in 2003 by Border 2012, whose mission is, "to protect the environment and public health in the U.S.-México border region, consistent with the principles of sustainable development" (USEPA, 2004). Established by the EPA, SEMARNAT, the ten border states, and U.S. tribal governments, the first goal of this program is to reduce water contamination. A large part of this goal is to increase water conveyance efficiency in the border region to allow excess waters to be used for environmental restoration.

Some longer established environmental water demands in Baja California include maintenance and restoration of the Colorado River watershed and the Tijuana estuary. Additionally, indigenous groups in the region such as the Cucupá have not been given sovereign rights under Mexican National Law. If this changes in the future, addressing these groups' water needs will increase non-traditional water demands.

Managing water into the future

With water demands increasing and total natural supply decreasing due to groundwater depletion, the water supply situation in Baja California will continue to change. If demands continue to increase, regional leaders will have options to address this issue:

1. increase the potable water supply:
   - recycling
   - desalination
   - efficiency
2. redistribute the current supply:
   - agriculture to urban transfers
   - system-wide modeling

Several alternatives are being explored to increase the water supply in Baja California. The first is to recycle water for reuse, of which one of the most prominent options is through a privately-run American firm called Bajagua. This company is working to enter into a fee-for-services contract with the United States International Boundary and Water Commission (USIBWC) for the ownership, construction and operation of a Secondary Treatment facility in Tijuana. This facility would be built just south of the border, where it would receive the primary treated water from the IWTP as well as additional untreated sewage from the City of Tijuana. With a proposed treatment capacity of 50 million gallons (approximately 189,000 cubic meters) per day, the Bajagua project would reclaim treated effluent for industrial reuse, public greenbelts, and potential groundwater recharge in Tijuana. Bajagua could provide “upwards of 37,000 acre-feet of reclaimed water per year, which represents 56% of Tijuana’s current usage.” (Bajagua, 2004) The Bajagua plant would comply with laws in the U.S., México and California for secondary water, and its construction would be funded by private investors, leaving the operating costs to be paid by the IBWC.

A second alternative is seawater desalination, which would provide the border region with an almost unlimited amount of water, albeit at a high cost. With current desalination costs in the range of U.S. $800 per thousand cubic meters ($1,000 per acre-foot), prosperous agencies such as the San Diego County Water Authority Regional Water Facilities Master Plan discuss pursuing water recycling and transfers from agriculture before desalination (California, 2003). With high costs, even the more prosperous Baja California border cities of Tijuana and Mexicali cannot afford to have desalination as a realistic option for large-scale water production in the near future.

The third option for meeting demands is to redistribute the region's current water supply, and regional leaders have already begun calling for this. Higher demands for this limited resource will increase its economic value, and it follows that the demands that are prepared to pay more for this resource will receive more, at the cost of supply to other demands. This scenario will most likely mirror California, where urban demands, with their higher willingness-to-pay (WTP), are buying water from users with lower WTP water uses, i.e. agricultural areas. As urban demands increase in Baja California, the value of this resource will also increase and farmers will likely find it more profitable to sell water to urban areas such as Mexicali and Tijuana.

This type of transfer can be facilitated by urban areas paying agricultural water users to make their operations more efficient through lining dirt canals with concrete and using more efficient irrigation techniques. These practices reduce agricultural water losses to evaporation and ground infiltration, which allows the saved water to be used by urban demands; they also reduce return flows to agriculture, which reduces groundwater supplies to these users. Additionally, urban users could pay farmers to fallow their land to make available more water that would have been used for irrigation.

Another possibility to supply the Mexican border region would be to use binational agreements. This could be done through conveying part of the Mexican apportionment of Colorado River water through United States conveyance infrastructure, as was done in the emergency transfer from Otay Reservoir to the City of Tijuana from 1970 to 1975. Mexican cities could also investigate the option of purchasing water from American users. This type of transfer might be feasible if the Mexican urban demands' willingness-to-pay is high enough that the transfer would be economically beneficial to American agricultural water users.

An organized quantitative understanding of the current supply
The geographic location of this *frontera* affords regional leaders several possibilities for redistributing the current water supply, either within Mexican national boundaries, or through international agreements. All aspects of Northern Baja California's natural hydrology point to this international region's interconnectedness; the man-made infrastructure further connects the international neighbors. It is thus economically and environmentally practical to study the water supply infrastructure of Baja California as a unit connected with its northern neighbor.

Understanding water problems and management opportunities along the *frontera* is thus a complicated endeavor. Water demands are rising as the border region continues developing, but the region's surface water supply is fixed and its groundwater supply is decreasing. Clearly, this situation cannot go on "as is". The quotes included at the beginning of this study are a small sample of the numerous calls to address this dilemma by transcending political boundaries and studying the border region as a whole. Performing this type of study requires some quantitative understanding of Baja California's water supply and water demands, and creating this kind of analytical foundation requires a common framework.

The modeling framework proposed by this study would integrate the data presented into an existing data management and analysis system that can examine the economic and engineering aspects of the Baja California-California border region water management system. The California Value Integrated Network (CALVIN) water optimization model is suitable for integrating these water supply studies of the inter-tied Baja California-California border region. This will be a first step in overcoming the fragmented understanding of this scarce natural resource.

CALVIN description

The California Value Integrated Network (CALVIN) model was developed at the University of California, Davis to address the type of water issues experienced in the arid west coast and has already proven its worth as a tool for prescribing management alternatives for California's water resources (Newlin, et al. 2002; Draper et al. 2003; Tanaka and Lund 2003; Pulido and Lund, 2004). This economic-engineering optimization model divides the State of California into five inter-tied hydrologic regions (Figure 7) and covers 92% of the state's population and 88% of its irrigated acreage (Jenkins, et al. 2001). The inter-tied Baja California water supply infrastructure discussed in this study serves 83.5% of the state's population and 100% of its irrigated acreage. Integrating these data into CALVIN as Region 6 would provide a step toward managing border waters economically.

The CALVIN model performs two major functions. First, it "integrates the operation of water facilities, resources, and demands for California's great inter-tied system" (Jenkins, et al, 2001). The model uses the state's current water management infrastructure to achieve this, with water availability, conveyance and reservoir capacities, and environmental requirements acting as constraints. The second function this model performs is to operate the facilities and allocate water so as to minimize the total regional costs, which include both operating costs and agricultural and urban scarcity costs.

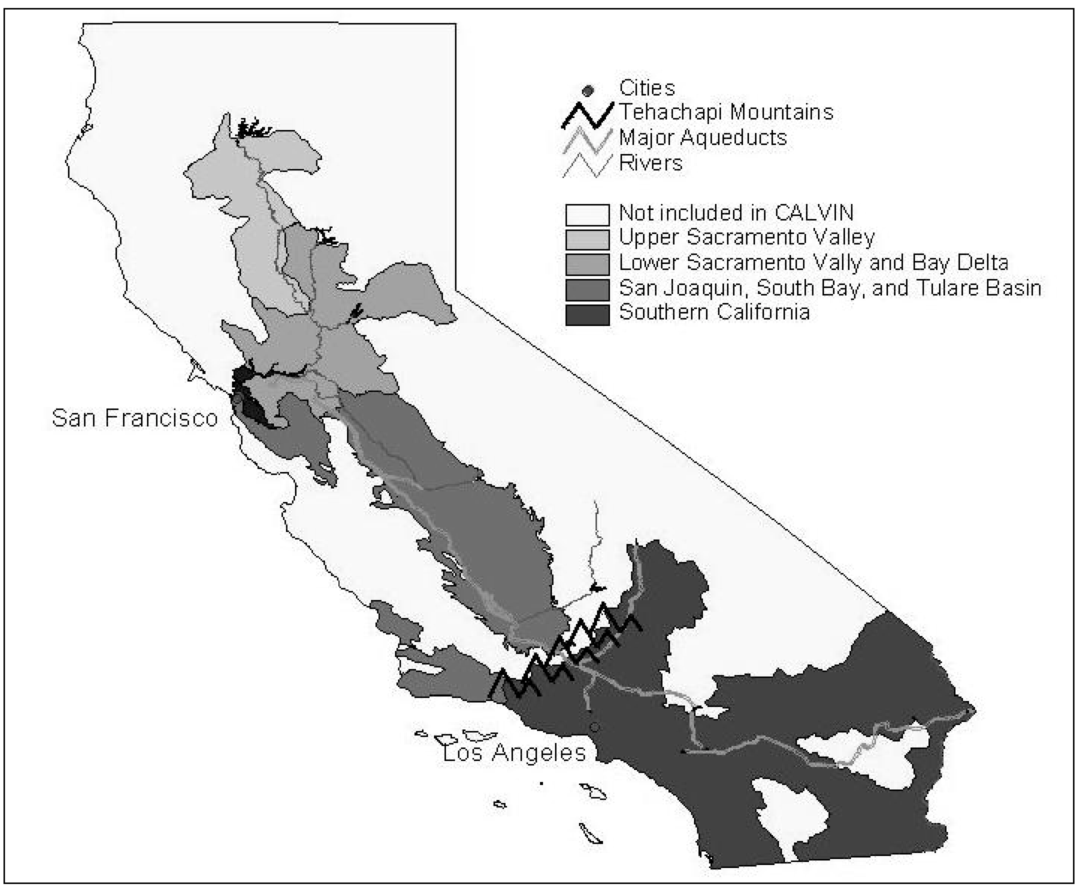

Figure 8. CALVIN Coverage

How it works
The CALVIN model uses a deterministic optimization approach that can be interpreted in an implicitly stochastic manner (Draper, 2001). Deterministic optimization assumes that the problem or systems are well known and that there is no uncertainty associated with most input variables. CALVIN requires a significant amount of input data, which includes both physical and economic information. Some of these include reservoir (surface and ground), pumping plant, and conveyance capacities, environmental requirements, and evaporative and infrastructure loss rates, reuse rates, operating costs, and agricultural and urban water values. Time series of inflows are also needed. CALVIN uses a 72-year continuous historic hydrology (water years 1921-1993), which includes two periods of extended drought (1929-1934 and 1987-1992) and the most severe drought of record (1976-1977). This range of input hydrologies allows insights to be produced regarding operations and allocations with hydrologic variability. The monthly time step hydrology is considered to be reasonable representation of the range of hydrologic conditions that California experiences (Ritzema, 2002). Figure 8 shows the necessary inputs for CALVIN as well as what results the model produces.

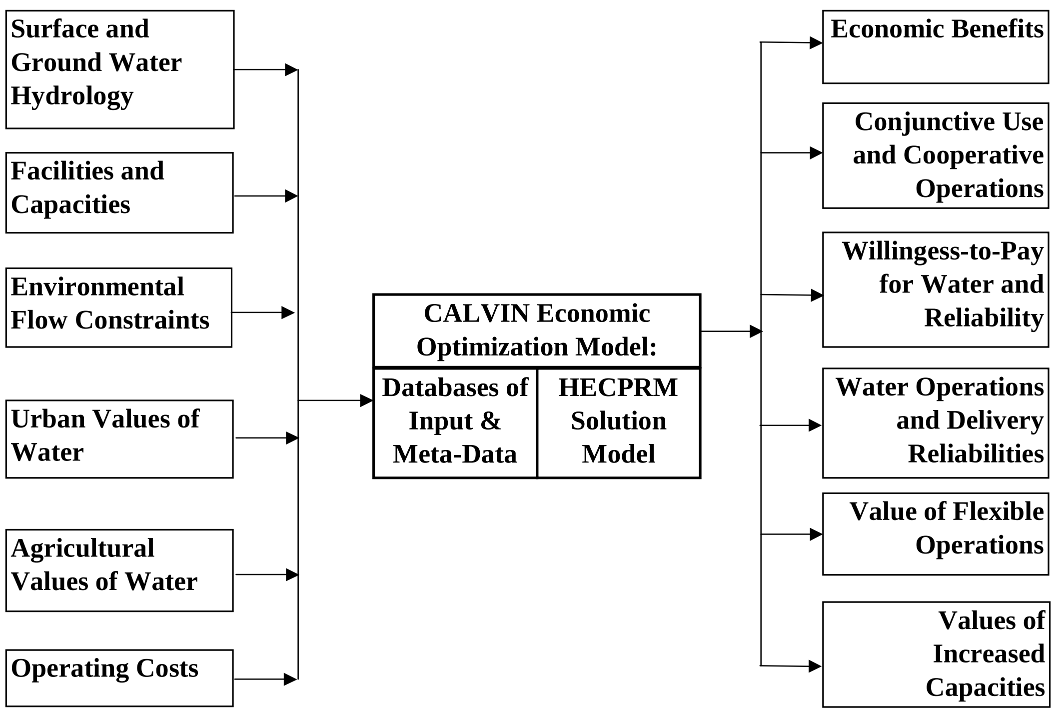

Figure 9. CALVIN Flowchart (Jenkins, et al, 2001)

As seen in figure 9, CALVIN uses a network flow optimization solver called the Hydrological Engineering Center Prescriptive Reservoir Model (HEC-PRM) to find the least cost solution subject to specified constraints (HEC, 1991).

Like all models, CALVIN is subject to limitations. CALVIN assumes that flexible, economically responsive water allocations (eg., market) exists, where willing buyers and sellers have perfect knowledge of each other and the future (referred to as perfect foresight). Perfect foresight tends to reduce scarcity and scarcity costs, because the model is able to anticipate droughts and thus increases the volume of water in storage in the surface and groundwater reservoirs. Draper (2001) points out that perfect foresight can cause unrealistic storage operations prior to drought and wet years, but that this problem is muted by the presence of large amounts of groundwater or other over-year storage. Also, CALVIN has fixed economic water demands, water use efficiencies, and environmental requirements. Despite these limitations, CALVIN is one of the most comprehensive economic-engineering models of California to date.

Benefits of the modeling framework
While several types of computer models can be used to assess different aspects of water supply, an optimization model is ideal for Baja California because it can suggest promising management alternatives (Ritzema, 2002). In optimization modeling, objectives are defined explicitly and the model quickly narrows possible management policies to an optimal set of alternatives (Draper, 2001). CALVIN will thus allow leaders on both sides of the border to evaluate the effects that changes in their water management decisions would have on their own systems and on those of other water managers. Optimization models are being used by agencies such as the United States Bureau of Reclamation (USBR) and the California Department of Water Resources (DWR) because of their ability to lay out management alternatives (USBR, 2002; DWR, 2004). Developing an optimization model of Baja California would give leaders a tool to forecast the effects of future water supply changes, be they institutional, hydrologic, or infrastructure related.

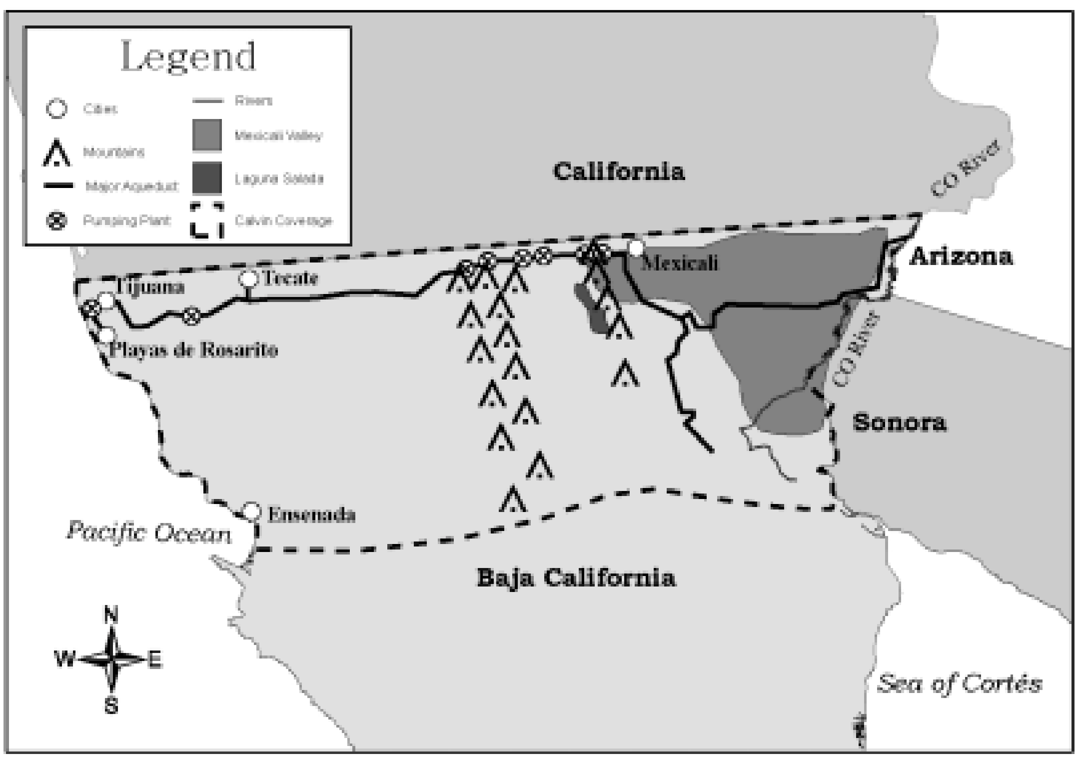

Figure 10. Proposed CALVIN Region 6 Coverage
(Infrastructure locations are approximate)

CALVIN Region 6: Baja California

Adding Baja California to the existing CALVIN model would result in a preliminary quantitative understanding and analytical framework for the water supply infrastructure of the Baja California – California portion of the México-U.S. border. Some of the resulting data and analytical tools would be:

-Economic and engineering quantification of current and likely future water supply problems in this region.
-An ability to identify and explore economic, engineering, and policy solutions to water supply problems within this region of México.
-An ability to identify and explore economic, engineering, and policy solutions to water supply problems in the greater binational region.
-Potential to expand this framework to include salinity problems and water quality aspects of the region's water problems.
-Baseline data for future studies of environmental impacts of industrialization and urbanization.
-An ability to add the City of Ensenada to a region-wide water supply analysis tool if/when this coastal city connects to the Colorado River-Tijuana Aqueduct.

These tools would be useful to many agencies and institutions involved in border water management. Additionally, the proposed framework would be dynamic, in that it could be added to or modified to suit specific projects, depending on the user's needs. This type of adaptability is especially important to changing and evolving regions, such as the Baja California-California border.

6. DISCUSSION AND CONCLUSIONS

The natural hydrology of the Baja California-California border region is highly inter-tied. With many of its rivers and aquifers crossing the international border and terminating within the Californias, these two politically separate regions are now being drawn together by their shared geography and economics. What distinguishes Baja California is the urgency of its water supply issues, both in its natural and man-made waterways. Water quantity and quality problems are increasingly challenging the border region's natural resources.

A prime example of this urgent situation is the Colorado River. Reduced to a small percentage of its original flow by the time it enters México, this river is the primary water supply for the majority of Baja California. Its precious water is carried across the state via the Colorado River-Tijuana Aqueduct (ARCT), a lifeline that is energy inefficient and less than 100% reliable (Nathanson, 2001). This inefficient and relatively unreliable lifeline operated at full capacity in 2000 because the Colorado River is the only source capable of supplying Tijuana and Tecate. In spite of this resource being overstretched, Baja California is increasingly reliant on the ARCT; the City of Ensenada is now working to connect to the aqueduct and add its 400,000 residents to the growing population that relies on Colorado River water. Additionally, potentially large unmet indigenous and environmental demands for the Colorado River Delta are neglected in favor of economic growth. As these demands become less "non-traditional", they will undoubtedly add to the diversity and volume of demands on this river's water resources.

Another factor increasing strain on the border region's major water problems is deteriorating water quality. For example, the City of Ensenada was once capable of surviving on groundwater and surface water runoff, but years of groundwater overdraft have allowed saltwater to infiltrate into its aquifers. With an abundant supply of ocean water, desalination could be an attractive option if/when salt removal processes become more affordable. However, the more immediate solution to this demographically and economically important region's saltwater intrusion problems is to connect to the ARCT. While this connection will provide Ensenada with an important water supply, it will further strain the ARCT and the other cities it supplies, providing a clear example of how the actions taken in one city have an increasingly profound ripple effect on the water supply in the rest of the state.

Several calls have been made to address this situation on a region-wide scale, but the border region is still largely characterized by its lack of transboundary (national and international) coordination. The quotes cited from USEPA and CDM are some of the many calls to study the Baja California-California border region as an inter-tied region. Having recognized the need to coordinate efforts to address the border region's impending water supply difficulties effectively, researchers are now taking the first steps in this direction. The proposal put forth in this study aims to facilitate this region-wide work, while also facilitating the next step of researching the Baja California and California sides of the border as a single, codependent region. Applying the proposed framework to the Baja California border region would allow more integrated and insightful analysis of cross-border water supply policy and management issues, both for the short-term and the long-term. This chapter lists future work that would be useful to build on the information presented and conclusions reached by this study.

Future work

Because the surface water supply is intimately connected with groundwater, precipitation, and many other factors not discussed, this study is a small piece of the puzzle to managing the natural resources of the *frontera*. Future work to build on this study can include:

-Integrating the water demand and water supply data presented into CALVIN.
-Connecting the information presented to a similar groundwater study; this would provide a comprehensive overview of border waters.
-Integrating the Municipality of Ensenada if/when it makes the transition from local surface and groundwater sources to the Colorado River-Tijuana Aqueduct.
-Expanding the schematic to include the primary conveyance and return flow system of Mexicali Valley.
-Economic representation of Mexican urban and agricultural demands.
-Field research in Mexicali City and Valley.
-Specification of environmental flows for the Colorado River Delta.
-Integrating a climate study to the information presented; this would permit assessment of additional factors such as surface water evaporation rates.
-Involving researchers on both sides of the border. This will be a fundamental element of a strong binational project.

Conclusions

1) *The Baja California border region continues to be distinct. Traditionally marginalized, this region is now one of the most economically and culturally important regions of México.* This region's high level of growth and productivity necessitates that leaders plan for sustainable growth, as this region has very limited natural resources.

2) *The existing water supply infrastructure of northern Baja California is extensive.* Numerous storage and conveyance facilities already supply and the border region with water.

3) *The management of the water supply infrastructure of the cities and municipalities of Baja California is highly regionalized.* The variety of agencies and companies primarily represent local interests.

4) *The water supply infrastructure of Baja California is highly connected and codependent with its counterpart in southern California.* With both natural and man-made waterways carrying water across the border in both directions, Mexican and American water interests rely on each other for some amount of their respective water supplies.

5) *Options to address border region water supply issues are abundant.* Agricultural to urban transfers, binational cooperation, water use efficiency, surface-groundwater

conjunctive use, wastewater reuse, and desalination are among the prime possibilities to optimize the current water supply.

6) Optimization modeling can provide insight as to how regional leaders can make their water management operations more efficient and effective. This type of modeling can suggest promising management alternatives.

7) Given the region's geographic location, many natural resource issues are binational in nature and the appropriate data must be available to handle them as such. As the border region becomes more interdependent, its minimal water supply should be studied as an integrated system.

FIN

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