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Physical and Biological Features of the Colorado River

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INTRODUCTION

A great deal of information on the Colorado River Watershed is available in works by Sykes (1937) during the first quarter of the 20th century and in descriptions by early settlers while traveling across a vast desert, limited by what was then known as the Sea of Bermejo. These first Europeans discovered, among other marvels, the majestic and imposing Colorado River forming what are known today as the Imperial and Mexicali Valleys. They learned that the sediments constantly brought by the Colorado River were being reshaped by coastal processes. There was a natural channel in the Laguna Salada (Salt Lake), between Sierra Cucapah and Sierra de Juarez, that would quite possibly have been navigable. And there was a vast extension of land constantly being watered and fertilized—the Colorado River Delta. Amidst this great desert environment, the Colorado River Delta rises as an oasis surrounded by uniquely shaped plant species that owe their form to living under extreme drought conditions. A wide variety of animal life also exists there.

This chapter provides an overview of the physical and biological features of the region. It lays out chronologically the past and present history of the Colorado River, it then continues with a descrip-

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tion of its current state. Finally, it ends with a description of the trend toward a potential recovery of the flows and significant flood waters that existed prior to the construction of dams in the United States.

PHYSICAL FEATURES

Geology

The ancient history of the formation of the Baja California peninsula, as it is known today, dates back 135 million years to the Mesozoic era. It began with an active system of faults known today as the San Andreas and its parallel branches, the Elsinore and San Jacinto faults. The high activity of this system caused the detachment of an immense block that formed what is now known as the Salton Trough (Gastil, Phillip, and Allison 1975; Singer 1998). After this deep depression formed, an intensive erosion process filled it with sediment of gravels and sands from the San Bernardino Mountains.

This transportation and sedimentation process lasted approximately 70 million years and today those sands and gravels have partially consolidated into sandstone and conglomerates (Muffler and Roe 1968, Singer 1998). The depth of the sediment layers deposited over several million years ranges from 2,060 meters (m) in Indio to nearly 6,000 m in the case of deposits located at the current U.S.-Mexican border. The Mexicali Valley is also part of this depression, as evidenced by a stratigraphic column of the different sedimentation events at Cerro Prieto. Their possible ages range from the Mesozoic to recent times and depth ranges from 2,000 m to 2,500 m (Puente and de la Peña 1978).

At this time, the Baja California peninsula had not yet detached from the continental mass (this process did not begin until the Miocene era, approximately 5 million years ago). The San Andreas fault system became active once more and began forming the Proto-Gulf of California as well as causing the separation of the Baja California peninsula (Gastil, Phillip, and Allison 1975). Other authors suggest that the main San Andreas fault became active again 4 million years ago (Elders, et al. 1972, Singer 1998). Regardless of

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which detachment hypothesis is most accepted, the separation continues today and the peninsula will eventually detach from the continental shelf. As Elders, et al. (1972) indicate, this separation is occurring at a rate of 5 centimeters per year.

The Salton Trough encompasses the Imperial and Mexicali Valleys and is part of the San Andreas fault system, one of the most active in the world (Lira 1994) and a result of the collision of the Pacific and North American plates. The high seismicity of the entire region is attributed to this system. Because the region as a whole has great economic importance due to its geothermal energy fields and its significant agricultural potential, tectonic, seismic, geophysical, and sedimentary research on it is continuous. This work indicates that as this large mass of land detached from the continental shelf, the marine waters of the ancient proto-gulf reached as far as the northern edge of what is known today as the Salton Sea, approximately 260 kilometers (km) north of the U.S.-Mexican border. After the formation of the proto-gulf and the detachment and expansion of the current Gulf of California, the Colorado River began its great task of conveyance, sediment discharge, and leveling of this deep depression.

Singer (1998) reports that during the glacial periods of the Pleistocene, which occurred in the last 2 million years, the Colorado River has been depositing its sediments, building the delta into its current shape as it flows into the Gulf of California. There were four glacial periods during the Pleistocene, each with their respective interglacial period (Derruau 1970). During those vast expanses of time, the river ran with abundant floodwaters. During interglacial periods, however, the amount of water flowing in the river and its accompanying sediment load diminished significantly, leading to droughts and intense evaporation that at times left the riverbed dry and barren.

According to Singer (1998), just more than 1 million years ago the already-formed Colorado River Delta served as a barrier that kept the waters and sediments of the river from continuing on to the sea. Instead, it filled the deep depression known as the Salton Sink, where the Imperial and Mexicali Valleys now lie, giving birth to Lake Cahuilla. This ancient body of water was possibly one of the largest freshwater lakes—its surface area may have reached 3,320

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km², perhaps six times the size of today's Salton Sea, and expanded even into part of the Mexicali Valley. This ancient lake has left several clues about its existence, such as in the beach lines from Indio to Cerro Prieto in the Mexicali Valley, where coastline watermarks reach as high as 12 m. According to existing data, this has not occurred since the end of the last glacial period approximately 21,000 years ago and the end of the Pleistocene 12,000 years ago (Ortega 1995).

Evidence of the lake exists from just 1,200 years ago; this evidence also suggests that by 1600 AD the lake had completely disappeared. However, testimonials collected during the Spanish explorations about the existence of an ancient lake indicate the natives of the region had used it in ages past. The formation and disappearance of this ancient lake demonstrates how dynamic the Colorado River was. At times it would convey a large amount of sediment, causing the formation of banks or dams that diverted its flow or changed its course and created bodies of water that were constantly fed. At other times, the flow would stop and these bodies of water would begin to dry out from evaporation and the lack of a fresh water supply. Today, the Colorado River Delta covers more than 7,700 km and is located completely within what is known as the Mexicali Valley.

Seismicity

The chronology of Baja California's seismic history was first recorded during the early Spanish explorations. However, there are many information gaps within this short period and several earthquakes occurred for which there are no records (Molina 1991). Molina provides eye-witness accounts and contributes chronology and possible magnitude data for earthquakes recorded between 1776 and 1988. Lira (1994) reports that the first seismographic network was established in 1963 by the Universidad Nacional Autónoma de México (UNAM), the California Institute of Technology (Caltech), and the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE). A second network was established between

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1977 and 1978, and a year later the Northwestern Seismic Network, allowing greater coverage and the capability of obtaining more data on this highly seismically active region.

Lira also presents a timeline of the frequent seismic activity between 1973 and 1993, making reference to the exact location, magnitude, and fault system associated with the quake. He concludes that the Cerro Prieto and Imperial faults are responsible for most of the quakes recorded during this period with magnitudes of between 1 and 6.6 on the Richter scale.

González (1990) traces the Imperial Fault and the rifts it is causing at Ejido Saltillo. The fault has exhibited a drop of the western block and rise of the eastern block, with a 1 m differential over the last 13 years. He concludes that a small, broad valley is currently being formed as a result of Imperial fault activity.

THE COLORADO RIVER

The age of the Colorado River is still uncertain. Singer (1998) suggests that the lifting of the Colorado Plateau began seven million years ago, thus modifying its drainage. The new uplift of the plateau led to the formation of a drainage network with small creeks toward the southern end of the plateau, which gave new life to the ancient Colorado River. The renewed river found old courses, remaking its drainage pattern, cutting and forming the famous Colorado Canyon as it approached its final destination, the Salton Trough. Once it could no longer discharge its waters at this depression, it unloaded its sediment into the already-formed Gulf of California. Evidence of these events can be found in the sediment deposits correlated to the ages and types of rock, as well as fossils located in the formations aged approximately 11.8 million years. This leads to many authors' theories that the river is between seven million years and ten million years old.

Although its age may not be, it is certain that the river, from ancient times until prior to its being controlled by enormous dams, had always been a river with a sizable sediment load. It was composed of sands, gravels, silts, and clays (Muffler and Roe 1968, Singer 1998, and Puente and de la Peña 1978) that are deposited and divergent along today's Colorado River Delta.

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The flow of the Colorado River has been fully controlled since the construction of Hoover Dam in 1935 and Glenn Canyon Dam, which filled between 1963 and 1980. The river's annual average flow totals 15.4 million acre-feet (MAF); however, some records indicate that during intense snow seasons in the upper basin, the volume may have increased to as much as 24.3 million acre-feet per year (MAF/y). Mexico, through the water treaty it signed with the United States in 1944, receives an allocation of 1.5 MAF/y.

Hydrologic Region No. 7, Colorado River

The Colorado River begins its flow in the United States and drains into the Gulf of California. The portion of the river managed by Mexico begins at Morelos Dam and serves the border between the states of Baja California and Sonora until it meets the Sonora-Pacifico rail line. According to the Hydrological Region classification of Instituto Nacional de Estadística Geografía e Informática (INEGI, in English National Institute of Statistics, Geography and Information), the Mexicali Valley lies within Region 7, Sub-Region 1, Río Colorado. Because the river runs on both sides of the border, all hydrographic observations about its flow are made jointly by the International Boundary and Water Commission (IBWC) in the United States and Comisión Internacional de Límites y Aguas (CILA) in Mexico.

The Mexican portion of the river is located between latitudes 31°45' and 32°40' north and longitudes 114°30' and 115°40' west. It flows through parts of both Baja California and Sonora—specifically through the municipalities of Mexicali and San Luis Río Colorado—and has a surface area of 5,923.16 km². The river borders the United States in the north, the Gulf of California in the south, the Altar desert in the east, and in the west the Cucapah Mountains, from which plains extend all the way to the river's mouth, where it forms a delta.

The aquifers located in the Mexicali Valley and Mesa Arenosa (Sandy Plateau) in San Luis Río Colorado, Sonora, are currently being exploited. The water extracted in this area is exported to Tijuana, where it is stored at the El Carrizo Dam in the municipality of Tecate.

Surface and Groundwater Quality

The greatest problem affecting the river is salinity (Singer 1998), given that an average of 10 tons of dissolved salts are conveyed downriver annually. These salts arrive at Imperial Dam, where the evaporative concentration reaches as much as 1 ton of salt per acre-foot. Average salinity is 750 parts per million (ppm) of soluble salts, or 0.75 grams of salt per liter of water. Thus, the Colorado River is a salty river, especially considering that other U.S. rivers such as the Columbia and the Mississippi contain 90 ppm and 200 ppm, respectively.

The Colorado River's salinity originates from three sources. The majority comes from the dissolution of salts in the sedimentary strata of tributary rivers flowing through the canyons of the Colorado Plateau. The second largest source is the leaching of salts from agricultural irrigation in the upper basin and the return flows that drain into the river (Singer 1998). The third source is intense water evaporation, particularly in the lower basin, where evapotranspiration occurs at a rate of 2,000 millimeters per year (mm/y). Salinity could become significantly worse if a greater volume of water is retained in the upper basin or if the average flow of the river decreases.

The first projects to control and convey surface water began early in the 20th century; salt content in 1902 was 400 ppm, by 1932 it had increased to 600 ppm, in 1963 it was 800 ppm, and by 1995 it had reached 1,050 ppm. This steady increase was due to the construction of controls, reservoirs, and dams. But above all, when the waters of the Colorado Basin were divided to increase the irrigable surface an intensive use of agrochemicals began. This caused the concentration and accumulation of salts, both in the groundwater and in the flows of the river (Sánchez and Mata 1997).

According to Mexico's Comisión Nacional del Agua (CNA, in English National Water Commission) (1995), the aquifer in the valley is overexploited—its deficit is 28,400 AF/y—and Mesa Arenosa is underexploited—its annual recharge and extraction are 121,600 AF/y and 82,700 AF/y, respectively. Of the surface water that enters the delta, Mexico's allocation, according to the 1944 Water Treaty, is 1.5 MAF/y. Of this allocation, 1.36 MAF/y is delivered directly to

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Morelos Dam and 14,000 AF/y is diverted toward Lindero Sur (southern border). A 470 km major conveyance channel network begins at Morelos Dam, as does a 2,432 km minor conveyance network. Both are lined with hydraulic concrete.

The second-largest water reservoir for delta water is a shallow, non-isometric, free-type aquifer with a permeability of 0.1 square meters per second (m^2/s). The average annual extraction from the 658 wells in the Mexicali Valley aquifer and the 67 wells in Mesa Arenosa are detailed in Table 1. Obviously, the volumes provided by the two sources do not agree, making it clear the actual existing volumes and extraction rates need to be more accurately evaluated.

With regard to water quality in the aquifer, the increase in mineralization in the areas of Riito, Tulecheck, Aeropuerto, and Cerro Prieto, as well as the increase in salinity, could be attributable to geothermal water intrusion. The water quality of the aquifer located to the east, toward San Luis Río Colorado, is affected by a mixture of geothermal waters, seawater that evaporates and moves up into the valley through the fault system, as well as by seepage of Colorado River water. Instituto Mexicano de Tecnología de Agua (in English, Mexican Water Technology Institute) has been monitoring the aquifer for 30 years and concluded there is a 2% annual increase in mineralization, equivalent to 20 milligrams per liter (mg/L) (Sánchez and Mata 1997).

**Table 1. Annual Average Extraction from the
Mexicali Valley Aquifer and Mesa Arenosa**

Source	Mexicali	Mesa Arenosa
Paredes 1992	750,640 AF/y	79,940 AF/y
GAS-CNA 1996	891,770 AF/y	121,605 AF/y

Notes: ¹Census rate 1900-1921; ²Census rate 1930-1950

Sources: Unikel (1976), Arreola and Curtis (1993), INEGI population census 1990-2000, Sánchez and Mata 1997

Weather Characteristics

The Colorado River Delta belongs to the Sonoran Desert Geomorphic Province (Shreve and Wiggins 1964). According to the Köppen model as modified by García (1981), the entire province exhibits BW-type weather, which is dominated by very arid or very dry climates. This indicates a dry, warm desert with winter rains and very extreme temperatures. The annual median temperature is 22°C (72°F), annual precipitation averages 54.2 mm (2.13 inches), and the annual temperature variance is 17.7°C (63.9°F). These climatic characteristics do not, however, reflect the delta's extreme character. The data presented in Table 2 are from three climatological stations located throughout the valley and show peak maximum temperatures, peak minimum temperatures, and the minimum yearly precipitation that has occurred more than once since 1949 (Venegas 2000).

Geomorphology

The several subunits in this province are characterized by the plant species they host. Two are the Sonora-Arizona Plains, dominated by species with sarcocaule physiognomies, columnar cacti, and microphyllus leaves, and the lower Colorado River basin subunit (today the Imperial and Mexicali Valleys), with species adapted to living in lacustris and palustris environments, thus creating wetlands and

Table 2. Temperature, Precipitation, and Evaporation in Mexicali, the Delta, and Bataquez

Station	Maximum Temperature	Minimum Temperature	Annual Percipitation	Annual Evaporation
Mexicali	54.3°C (129.7°F)	-7°C (19.4°F)	54.2 mm (2.13 in)	
Delta	57°C (134.6°F)	-3°C (26.6°F)	36 mm (1.42 in)	2,160.3 mm
Bataquez	57°C (134.6°F)	-8.9°C (16°F)	33 mm (1.30 in)	2,369.0 mm

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species that can withstand a high water table. This subunit is characterized by a nearly flat surface, making it a flood zone, with altitudes of more than 40 m where the river spills into the valley; the altitude progressively decreases until the Cucapah alluvial fan, at 14 m. Here the Cucapah mountains rise in a north-to-southeast direction and an altitude of 1,000 m.

The northeast portion of the lower Colorado River basin features the Mesa de Andrade dunes, which are located mostly within the United States. These dunes are created by winds and have maximum altitudes of approximately 100 m. Toward the northwest, the lower basin descends until it reaches sea-level, near the northwest limits of the city of Mexicali, almost at the international boundary with the United States. North from this point the altitude falls below sea level, reaching a low point of 87 m below sea level and forming the Salton Sea (see Figure 1). Toward the south the basin connects with the Gulf of California, which still exerts a great influence due to the activity of coastal processes. There are reports that during high tides, waves can reach between 3 m and 7 m. People who live near where the river flows into the sea call this process “el burro” (Tapia 2002). The coastal processes and waves created by high tides introduce sea sediments into the delta and mix saltwater with freshwater. Unfortunately, today no freshwater exists to dilute the seawater, which results in a significant increase in salinity (Luecke, et al. 1999).

On the western side, nearly against the Cucapah mountains, a volcanic structure called Cerro Prieto rises against a nearly flat landscape and has an altitude of 220 m. It is a Pleistocene volcano that last erupted 700,000 years ago. Today, it is inactive and around it lies the largest geothermal field in Mexico, which produces 750 megawatts of energy.

Soils

Soil studies are invariably conducted on a superficial layer, in most cases never greater than 2 m in depth. They allow the study of events such as geochemical, geomorphologic, and climatological processes. Characterizing the soils of the delta requires attention to the geological and geomorphologic details, as well as to the alternating glacial and interglacial periods. It also requires attention to

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intense Colorado River erosion, transportation, and sediment load accumulation events in the Salton Trough. This process lasted for at least 3 million years during the Plio-Pleistocene and involved the depositing of mostly fine sediments of sand, silts, and clays. These types of sediments from a more recent age make up the soils of alluvial origin. They exhibit great granulometric variance depending on the topographic characteristics of the areas traversed by the main flow of the river.

It is clear that the transformation of primary minerals into secondary materials, specifically in the case of clays, has not taken place in the delta. They were all transported by the river and continually renewed by new sediment contributions until they formed the flood plain as it is known today. This behavior defines the granulometrics of the sediments and their settlement, as well as the discordant layers of medium sands, followed by clays or silts, and so on successively, without a defined deposit sequence characteristic of a flood and sediment load accumulation area.

Based on this characterization, the soils of the delta are alluvial in origin with medium to fine textures. That is, the different strata are mostly layers of clays and silts, interspersed with fine sands. Due to these characteristics, the soils are deep, heavy, have poor drainage, high fertility, and are susceptible to salt intrusion. This type of soil would be considered an entisol.

Two works on soil in the Imperial Valley—Pierre, MacKenzie, and Zimmerman (1974) and Zimmerman (1981)—report the physical and chemical properties of the soils, their taxonomic classification, and define five series of soils. They also report the minimum area that can be mapped with individual characteristics for each, but conserve the characteristic order, which holds the highest rank under U.S. classification.

The series of soils determined in this study are essentially the same as those that have been mapped for the Mexicali Valley. The series are: Meloland, Imperial, Superstition, Holtville, and Gila. The main characteristics of these are alluvial origin, absence of diagnostic horizons, arid temperatures, medium to fine textures, poorly draining, and subject to alkalinity. According to Singer (1998), these soils are classified as *Typic Torrifluvents*, *Xeric Torrifluvents*, and *Typic Torriorthents*; all belong to the order Entisols.

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Water Stress

The Colorado River's delta and water are two of the most significant issues the border region faces today. Environmental groups, ecology groups, renowned scientists who have studied the region for many years, and several non-governmental organizations are extremely concerned about the current situation in the delta. Scientific and media reports, even as far back as the 1970s and 1980s, noted that the Colorado River was in danger of drying up (Luecke, et al. 1999). Today, the delta's area has decreased by 5% (Luecke, et al. 1999), due in part to the high concentration of mostly agricultural contaminants, the spread of which provides yet another sign that the surface size of the Colorado River Delta is shrinking.

The aforementioned risk notwithstanding, during the last 20 years there have been signs that this process could be reversed, given the recovery of nearly 55,000 hectares and due to the release of surpluses from U.S. reservoirs, agricultural wastewaters from both countries, and municipal waters from the city of Mexicali. Whether this trend can be maintained is uncertain. Consider also that these types of waters, coming as they do from municipal flows and irrigation districts in both valleys, contain large concentrations of salts and contaminants, but in spite of this have proven beneficial in the recovery of areas previously lost (Luecke, et al. 1999). However, above-average precipitation for most of the region, including the upper Colorado River basin, were due to a general condition caused by El Niño Southern Oscillation events, and there is no guarantee they will occur again.

This situation could also be to a new climatological phenomenon known as Pacific Decadal Oscillation. During this phenomenon, cycles of intense precipitation last for approximately 22 years, and then drought cycles occur of approximately the same duration. Under this new hypothesis of climatic behavior, the entire north-western region of North America would experience drought until 2020 (Hare 2000).

Biotic Communities

A large number of scientific reports exist on the possible flora and fauna that the Colorado River Delta may have supported with its large volume of freshwater, vast amounts of nutrients through its sediment load, and the dynamics of intense waves in the Gulf of California. Some authors, such as Ezcurra, et al. (1999), estimate that between 200 and 400 species of vascular plants may have inhabited the delta.

When the first Spanish explorers arrived in 1540, they reported seeing jaguars, bears, deer, coyotes, and beavers (Luecke, et al. 1999). They also contacted the natives of this land, the Cucpah, who lived in the area surrounding the delta and had flourishing agriculture, including some variety of corn, beans, and squash. The Cucpah also collected a kind of grass called *trigo gentil* (gentle wheat) and may have used mesquite fruit, which they called *péchitas*, and hunted wild geese, ducks, and fish.

The environment experienced by the first explorers has changed dramatically from the environment seen by those who followed until the beginning of the 20th century due to the high degree of pollution, increase in salinity, and a nearly complete loss of freshwater. Completely stopping the contribution of sediments, and their corresponding nutrients, has caused a reduction of wetlands and the displacement of native riparian species such as poplars (*Populus sp.*) and willows (*Sallix sp.*). Exotic species that are more aggressive and more resistant to high salinity, such as the Salt Cedar (*Tamarix ramosissima*), which has a high evapotranspiration rate, took over. But regardless of the difficult situation in the Colorado River Delta, it remains the only safe habitat for a large number of migratory species because it is the only significant “fresh” water body among the wetlands of the Mexican Pacific.

Of the mastological fauna believed to have been present in the delta (Tapia 1997), thus far the river otter (possibly *Lutra* genus) and the mule deer (*Odocoileus hemionus*) have disappeared. However, Programa de Manejo de la Reserva de la Biósfera (PMRB, in English Biosphere Reserve Management Program) (INE-SEMARNAT 1995) cites the mule deer as currently inhabiting it. With regard the beaver (*Castor canadensis*), Mellnik and Luévano (1995) report there are

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still populations in the delta, and although their status is not clear, the researchers affirm that if the level of freshwater is increased, the beaver population will increase as well. The lists of species presented by Instituto Nacional de Ecología-Secretaría de Medio Ambiente y Recursos Naturales (INE-SEMARNAT) (1995), Luecke, et al. (1999), and Tapia (1997) differ, thus this chapter will rely on Luecke, et al. (1999) preferentially because it is considered the most complete work on Colorado River Delta flora and fauna.

Per the Diario Oficial de la Federación (in English Mexican Federal Register) (1994), the endangered freshwater fish desert pupfish (*Cyprinodon macularius*), and endangered bird, the Yuma clapper rail (*Rallus longirostris yumanensis*) are currently in the delta. The bobcat (*Lynx rufus*) and the totuava (*Cynoscion macdonaldi*), which is the only endangered marine fish, as well as the Vaquita (*Phocoena sinus*), the only endemic cetacean species in Mexico, whose distribution is restricted to the northernmost limit of the Gulf of California, are located nearby and are dependent indirectly upon flows from the Colorado River.

Luecke, et al. (1999) list 66 bird species, while the PMRB reports at least 80 species of land and water birds, both resident and migratory. The more frequent visitors include Osprey or fishing hawk (*Pandion haeliaetus*), American white and brown pelicans (*Pelecanus erythrorhynchos* and *P. occidentalis*), ring-billed gull (*Larus delawarensis*), least tern (*Sterna antillarum*), cormorants (*Phalacrocorax auritus*), teal (*Anas crecca*), Canada goose (*Branta canadensis*), and clapper rail (*Rallus longirostris*).

In general, between 12 and 14 mammalian species are listed. These land mammals are representative of the Sonoran and San Bernardinoian biotic provinces and include a broad diversity of rodents and species of interest for hunting, such as mule deer (*Odocoileus hemionus*), foxes (*Urocyon cinereoargenteus*, *Vulpes macrotis*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*) (INE-SEMARNAT 1995). Because there is also disagreement on the number of species and their habitat; in this case, preference is given to the Programa de Manejo de la Reserva de la Biósfera.

Marine vegetation, made up mainly of algae and sea grasses, present in the delta includes *Distichlis palmeri*, a species endemic to the Gulf of California. The allophyllus vegetation is spread out over

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small areas along the coast, preferring closed-off, low-lying areas and marshes. They are represented by short plants, leafy succulents, and perennial grasses, such as Palmer's seaheath (*Frankenia palmeri*), Mojave seablite (*Suaeda ramosissima*), salty grass (*Distichlis palmeri*), and alkali dropseed (*Sporobolus airoides*). West of Adair Bay and east of the Santa Clara Marsh, marine vegetation is made up mostly of algae and sea grasses, most prominently *Distichlis palmeri*.

CONCLUSION

The Colorado River, which has fostered important industry, agriculture, urban areas, and tourism in both the United States and Mexico, faces a critical situation due to the grave hydrological imbalance to which it was subjected during the 20th century. It was then that the river was exploited without regard for its potential deterioration due to a reduction in its flow and the construction of large dams in the United States. However, if its flow had not been controlled and large dams had not been built to prevent its enormous floods, it would not have sparked such significant development, the growth of important cities, electricity generation, the irrigation of more than 500,000 hectares of crops in the Imperial and Mexicali Valleys alone, or provided water for residential use to several million residents in both countries. The question is, What would the region become if not for the water from this prodigious river? What actions could have been taken to avoid controlling it while still promoting development on the scale achieved by these projects?

Perhaps there are no right answers. Even with today's technological developments, uncertainties abound about how to face the new challenges posed by population growth in both countries and throughout the border region without an additional Colorado River or Río Grande to sustain the coming generations. The citizens of both countries, their scientists, administrators, and all who benefit must—beyond merely engaging in binational disputes over additional volume for the states that benefit from its wealth—work to preserve what little is left of what once was a great river and delta.

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The solution lies not with rescuing or restoring habitats that existed before the 20th century. That would be largely impossible, given the great pressure being exerted by ever-increasing water and land demand in the border region of both countries. Between 1950 and 1995 the border region population in northern Mexico grew from 3.7 million to 15.2 million (Estrella, Canales, and Zavala 1999). Mexico's third largest border city, Mexicali, has an estimated population growth rate of 2.2% and will increase its population to 1.25 million residents by 2020. That nearly doubles its current population (Wright and Griffin 1998). This should motivate the development of new formulas and attitudes to make more efficient use of the scarce volumes expected to be available in the next two decades (Hare and Francis 1995; Mantua, et al. 1997).

REFERENCES

- Biondi, F., A. Gershunov, and D. Cayan. 2001. "North Pacific Decadal Climate Variability Since 1601." *American Meteorological Society* 14 (January): 5–10.
- Comisión Nacional del Agua. 1995. "Plan Hidráulico Estatal, Gerencia Regional Península Baja California." <http://www.cna.gob.mx>.
- Derrau, M. 1970. *Geomorfología*. Spain: Ariel.
- Diario Oficial de la Federación. 1994. "Norma Oficial Mexicana, NOM-059-ECOL-1994." México, D.F.: Mexican federal government.
- Elders, W., R. W. Rex, T. Meidav, P. T. Robinson, and S. Biehler. 1972. "Crustal Spreading in Southwestern California." *Science* 178 (4056): 15–24.
- Estrella, V. G., A. Canales C., and M.E. Zavala. 1999. *Ciudades de la Frontera Norte: migración y fecundidad*. Mexicali, B.C.: UABC.
- Ezcurra E., R. S. Felger, A. D. Russell, and M. Equihua. 1999. "Fresh Water Islands in a Desert Sand Sea: The Hydrology, Flora and Phytogeography of the Gran Desierto Oases of Northwestern Mexico." In *A Delta Once More: Restoring Riparian and Wetland Habitat in the Colorado River Delta*, D. F. Luecke,

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- J. Pitt, C. Congdon, E. Glenn, C. Valdés-Casillas, and M. Briggs, eds. Washington, D.C.: Environmental Defense Fund Publications.
- García, E. 1981. *Modificaciones al sistema de clasificación climática de Köppen para adaptarlo a las condiciones de la República Mexicana*. México: UNAM.
- Gastil, G., R. Phillip, and E. Allison. 1975. "Reconnaissance Geology of the State of Baja California." *The Geology Society of America Memoir* 140.
- González, J. 1990. "La falla Imperial en el Valle de Mexicali (a 50 años del temblor Imperial magnitud Richter 7.0 del 18 de Mayo 1940)." *Comunicaciones Académicas* reporte técnico: crsrr 9003.
- Hare, S. R., and R. C. Francis. 1995. "Climate Change and Salmon Production in the Northeast Pacific Ocean." Pages 357–372 in *Ocean Climate and Northern Fish Populations*, R. J. Beamish, ed. Ottawa: NRC Research Press.
- Hare, S. 2000. "The Pacific Decadal Oscillation (PDO)." <http://tao.atmos.washington.edu/pdo>.
- Instituto Nacional Ecología, Secretaría de Medio Ambiente y Recursos Naturales. 1995. "Áreas naturales protegidas. Programa de la Reserva de la Biósfera Alto Golfo de California y Delta del Río Colorado." *Programa de Manejo* 1.
- Lira, H. 1994. "Actividad sísmica registrada en el Valle de Mexicali, B.C., de 1973 a 1993." México: Comisión Federal de Electricidad.
- Luecke, D. F., J. Pitt, C. Congdon, E. Glenn, C. Valdés-Casillas, and M. Briggs, eds. 1999. *A Delta Once More: Restoring Riparian and Wetland Habitat in the Colorado River Delta*, Washington, D.C.: Environmental Defense Fund Publications.
- Mantua, N., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Flores. 1997. "A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production." *Bulletin of the American Meteorological Society* 78: 106–1079.
- Mellink, E., and J. Luévano. 1995. "Status del castor (*Castor canadensis*) en el Valle de Mexicali." Closing report, Programa Ambiental Frontera Norte-INE. Departamento de Ecología, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE).

Lining the All-American Canal: Competition or Cooperation
for the Water in the U.S.-Mexican Border?

- Molina, R. 1991. "Sismología en el Valle de Mexicali." *Travesía* 27: 69–76.
- Muffler, P., and B. Roe. 1968. "Composition and Mean Age of Detritus of the Colorado River Delta in the Salton Trough, Southeastern California." *Journal Sedimentary Petrology* 38(2): 384–399.
- Ortega, J. 1995. "La evolución del ambiente: Paleoclimatología." Pages 9–19 in *IV Curso sobre Desertificación y Desarrollo Sustentable en América Latina y el Caribe*, August–September, Colegio de Posgraduados en Ciencias Agrícolas, Montecillo, México.
- Pierre, E. R., A. J. MacKenzie, and R. P. Zimmerman. 1974. "Physical and Chemical Properties of Major Imperial Valley Soils." *Agricultural Research Service* April.
- Puente, C. I. and A. de la Peña L. 1978. "Geología del campo geotérmico de Cerro Prieto." First Symposium on the Cerro Prieto Geothermal Field, Baja California, 20–22 September, San Diego, California.
- Sánchez, O. 1990. "Crónica agrícola del Valle de Mexicali." Mexicali, B.C.: UABC.
- Sánchez D., L. F., and I. Mata A. 1997. "Impacto de las actividades agrícolas en la calidad del agua subterránea del Distrito de Riego 014, Río Colorado, B.C." IMTA, Project TH-9614, Coordinación de Tecnología Hidrológica, May.
- Shreve, F., and I. L. Wiggins. 1964. *Vegetation and Flora of Sonoran Desert*. Stanford, Calif.: Stanford University Press.
- Singer, E. 1998. *Geology of the Imperial Valley*. In *Keys to Soil Taxonomy*, 8th Ed. Washington, D.C.: USDA-NRCS. http://soils.usda.gov/technical/classification/tax_keys/.
- Sykes, G. 1937. "The Colorado Delta." *American Geographical Society* 19
- Tapia, L. A. 2002. Personal communication with the author.
- Tapia, L. A. 1997. Personal communication with the author.
- Venegas, R. 2000. "El uso de la flora urbana en ciudades de clima árido seco extremo." In *Ciudad, salud y medio ambiente*. Mexico: UAP-RNJU.

Physical and Biological Features of the Colorado River

- Wright, R., and E. Griffin. 1998. "The Imperial Valley-Mexicali Interface." <http://geography.sdsu.edu/Research/Projects/Imperial/impweb.html>.
- Zimmerman, R. P. 1981. "Soil Survey of Imperial County, California, Imperial Valley Area." Washington, D.C.: USDA Soil Conservation Service.