

The Rio Grande/Río Bravo of the U.S. and Mexico

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1. Physical and human geography

1.1 Rio Grande and tributaries

The Rio Grande, called the Río Bravo (del Norte) in Mexico, is the fifth largest river on the North American continent. It extends from the eastern side of the Rocky Mountains in Colorado to its mouth at the Gulf of Mexico, a total length of about 3100 km, passing through three states in the United States and four states in Mexico (see Fig. 1). The basin has an estimated area of

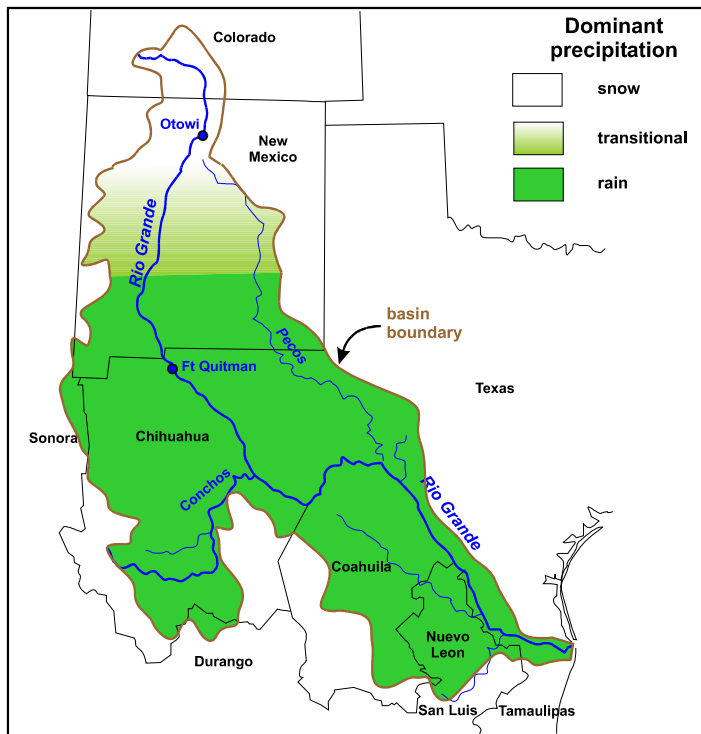


Figure 1 - Rio Grande basin

Table 1 - Main stem stream flow gauges on Rio Grande, with identification (ID) used by agency maintaining records, and elevation of the gauge datum (meters NGVD)

<i>gauge</i>	<i>ID</i>	<i>records*</i>	<i>datum</i>	<i>gauge</i>	<i>ID</i>	<i>records*</i>	<i>datum</i>
Cerro	13020101	USGS	2167	Candelaria	08-3712.00	IBWC	871
Taos	13020101	USGS	1844	Presidio†	08-3715.00	IBWC	783
Embudo	08279500	USGS	1765	Presidio‡	08-3742.00	IBWC	772
Otowi	08313000	USGS	1673	Johnson Ranch	08-3750.00	IBWC	623
Cochiti	08317400	USGS	1593	Rio Grande Vge	08375300	USGS	549
San Felipe	08319000	USGS	1559	Foster Ranch	08-3772.00	IBWC	353
Alameda Bridge	08329918	USGS	1526	Amistad	08-4509.00	IBWC	274
Alameda	08329928	USGS	1521	Del Rio	08-4518.00	IBWC	265
Albuquerque	08330000	USGS	1508	Quemado	08-4557.00	IBWC	234
Isleta	08330875	USGS	1484	Eagle Pass	08-4580.00	IBWC	208
Bosque Farms	08331160	USGS	1481	El Indio	08-4587.00	IBWC	177
Elephant Butte Dam	08361000	USGS	1293	Laredo	08-4590.00	IBWC	107
Caballo Dam	08-3625.00	IBWC	1262	Falcon Dam	08-4613.00	IBWC	n/a
El Paso	08-3640.00	IBWC	1135	Rio Grande City	08-4647.00	IBWC	30
American Dam	08-3650.00	IBWC	1132	Anzalduas Dam	08-4692.00	IBWC	0
Fort Quitman	08-3705.00	IBWC	1052	San Benito	08-4737.00	IBWC	0
Castolon	08374550	USGS	914	Brownsville	08-4750.00	IBWC	0

* USGS – U.S. Geological Survey; IBWC – International Boundary and Water Commission
† above Rio Conchos
‡ below Rio Conchos

900,000 km² (literature value ranging $\pm 3\%$), lying in seven Mexican states and four U.S. states. (This is based upon tracing the orographic divides between adjacent drainages, but includes several basins that drain to their interior so their runoff does not enter the Rio Grande tributary system. These noncontributing drainages make up 47% of the total basin.) For ease of reference to the reader, the main stream flow gauges are tabulated in Table 1.

The Rio Grande originates in the Rocky Mountain massif of Colorado and New Mexico, mainly the San Juan, Sangre de Cristos, Jemez and Tusas mountains, and flows through New Mexico to El Paso, Texas. Below El Paso it forms the international border between the United States and Mexico. This 1600 km long segment of the Rio Grande is the longest river border in the world between countries at different levels of development (Herzog, 1990). By contrast, the other major river in the American Southwest—the Colorado—marks the border for a short distance only. Since Rio Grande and Colorado border waters are managed under the same bi-national

treaty arrangement (see section on governance), this feature of the Rio Grande must be kept in mind in all of the following discussion.

For the present discussion it is useful to divide the river system into three main reaches: (1) the Upper Rio Grande, from the headwaters in Colorado down to the stream flow gauge at Fort Quitman, Texas; (2) the Lower Rio Grande, from the Fort Quitman gauge to the river's mouth in the Gulf of Mexico, and (3) the Rio Conchos, the major tributary rising in the mountains of the Sierra Madre in Mexico and flowing into the Rio Grande main stem near Presidio (see Fig. 1).

From Colorado to the mouth in the Gulf of Mexico, the morphology of the basin alternates between narrow canyons and broad alluvial valleys (e.g., Schmidt et al., 2001). In the headwaters area, generally above Otowi (Table 1), the topography of mountains and gorges is dramatic. The channel falls from some 2000 m in elevation, and much of the river is narrow and swift, popular among canoeists and trout fishers. However, substantial modifications have been made to the river and watershed since the nineteenth century, mainly to supply irrigation needs, especially in the broad alluvial San Juan valley. These include installation of over 50 dams, and the implementation of the San Juan-Chama Project (of the U.S. Bureau of Reclamation, USBR), by which a net importation of water is made from the Colorado basin to the Rio Grande. The principal tributaries above Otowi are the Conejos River in Colorado and the Rio Chama in New Mexico.

From Otowi southward through New Mexico down to the gauge at Fort Quitman, the river channel lies in the Rio Grande Rift valley and falls about 400 m. This reach is characteristically bosque and desert. The sediments are fertile. The principal tributaries entering this reach of the river are the Galisteo Creek, the Jemez River, the Rio Puerco, and the Rio Salado. Here the river is the water supply for extensive irrigated agriculture as well as for several major cities, including Albuquerque, Las Cruces, El Paso and Juárez.

Commented [J1]: El Paso and Juarez use groundwater for city use.

From Fort Quitman through the Big Bend, the river falls about 700 m, mainly in the dramatic canyons of this reach, to the headwaters of Amistad Reservoir. It is in this reach that the

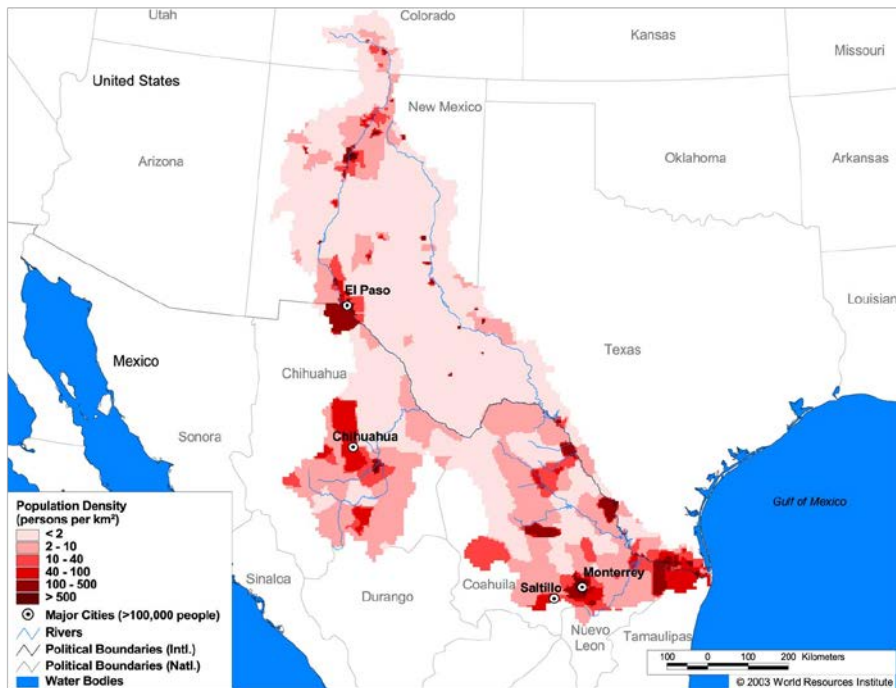


Figure 2 – Population Density

principal tributary of the Rio Conchos conflues with the Rio Grande. More about the Rio Conchos.

Below the confluence of the Rio Grande and Rio Conchos, the river receives the flow of two major tributaries, the Pecos and the Devils, all of which flow into Amistad Reservoir. The reach below Amistad is primarily coastal plain with a low gradient to the Gulf. Below Falcón reservoir another area of extensive irrigated agriculture and growing cities has developed in the Lower Rio Grande Valley (LRGV.)

1.2 Population

Albuquerque, El Paso-Juárez and a string of cross-border cities in the LRGV are the main population centers on the main stem of the Rio Grande (see Figure 2). Most of the border stretch of the river has seen rapid population growth, with population doubling every twenty years since 1960. Growth is driven by several factors: high birth rates, availability of cheap irrigation water, tax advantages for cross-border manufacturing (maquiladoras), and in-migration from interior Mexico to more prosperous border communities. The main population centers in the border segment of the Rio Grande—Paso del Norte and LRGV—depend for their economic livelihood on their upstream reservoirs (see Figure 3).

In the border segment of the basin population has doubled every twenty years since 1960. This trend will continue into the future. The Paso del Norte (Las Cruces, El Paso, Cd. Juárez) has a current population of 3 million. Population will reach 6 million by 2060. The Lower Rio Grande Valley, covering the last 270 river miles (434 km), has a current population of 3.5 million, about equally divided between twin cities on both sides of the border.

1.4 Land use

The general patterns of land use in the Rio Grande/ Rio Bravo basin are displayed in Figure 4. Clearly, the majority of the basin is grassland and scrubland, characteristic of the arid to semi-arid climate. Several parts of the basin enjoy fertile soil—the result of sediment accumulation in the days before the river was dammed. Rain fed farming is impossible west of the 100th parallel, which crosses the basin close to the river's mouth. Therefore, irrigated farming is dominant. In the main agricultural regions, Colorado, the Paso del Norte (Las Cruces, El Paso and Cd. Juárez) and the LRGV, farmers can produce three to four crops a year. In Texas, urbanization and the right to sell or lease water rights to cities, leads to a small decline in agricultural land use. New Mexico and Mexico laws do not allow creating water markets. As a result, they see no decline in agricultural land use.

The lower 250 km of the Rio Grande have rich alluvial soil. Taking advantage of good soil quality and Rio Grande water, the LRGV has become a center for irrigated agriculture on both sides of the international border.

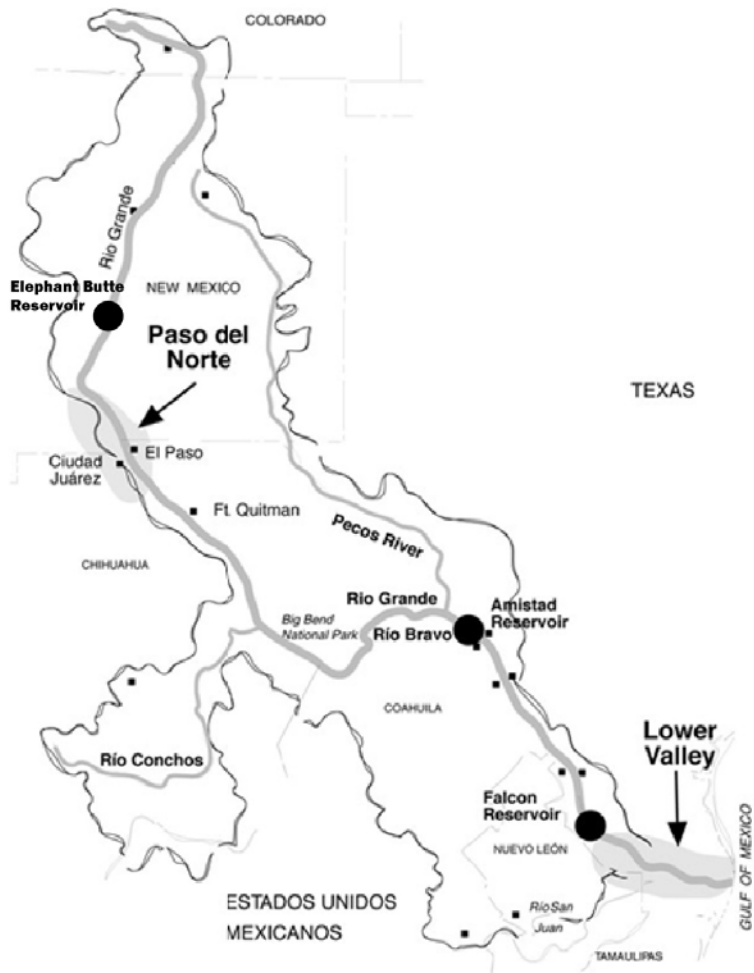


Figure 3—Population centers, economic centers and reservoirs

1.5 Economy

Farming, services, commerce and manufacturing (maquiladoras) are the main economic activities on the border. In the Texas border region drilling for oil and gas has re-emerged as an important sector of the economy as a result of horizontal drilling and fracking of shale resources. Paso del Norte and LRGV are important suppliers of fruits, vegetables, corn and sorghum. The

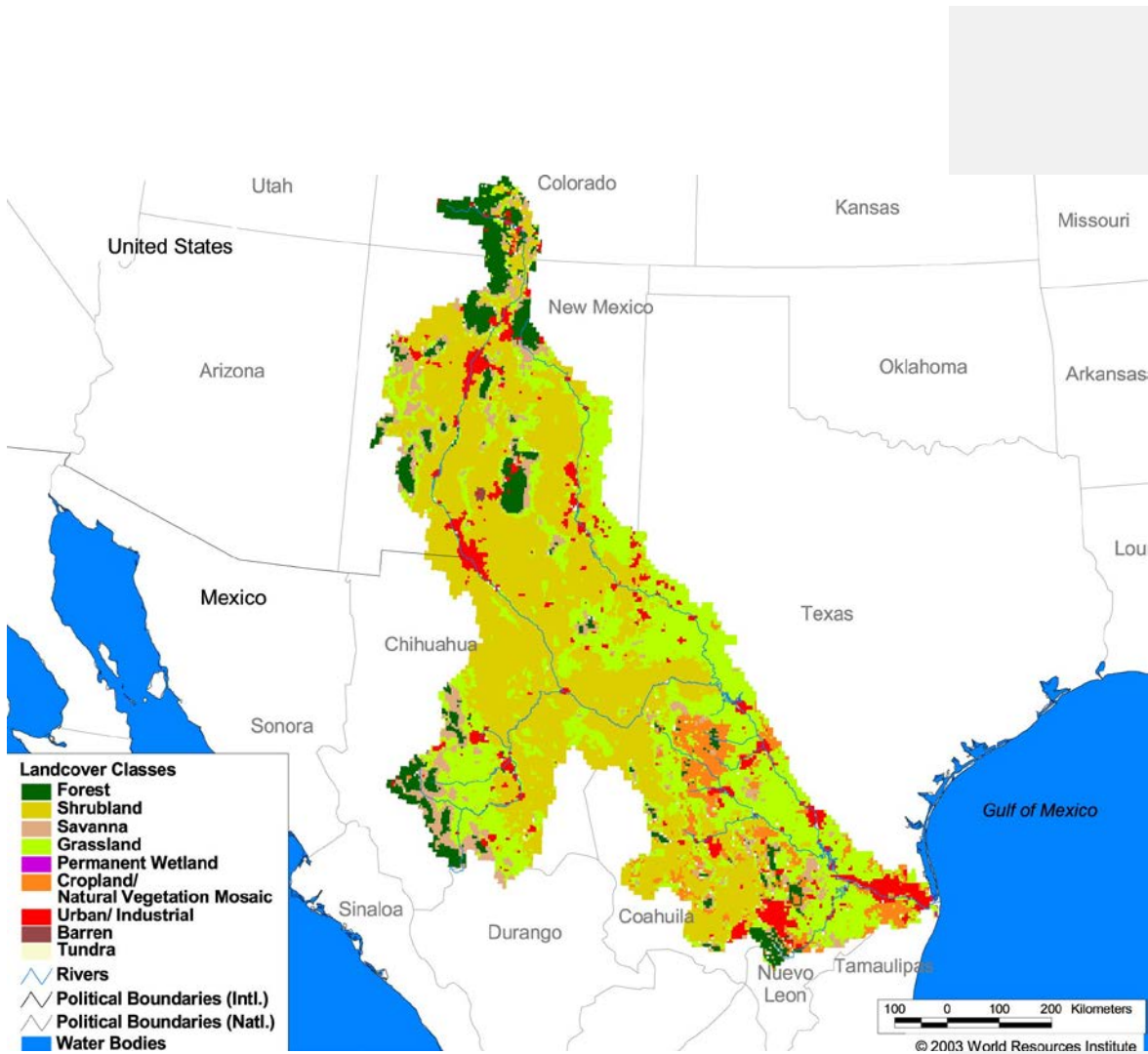


Figure 4 – Land use

state of Tamaulipas, for example, is responsible for 17 per cent of Mexico's agricultural production. Throughout the basin the amount of irrigated land varies greatly from year to year, primarily depending on water availability.

2. Hydrology

2.1 *Climatology and natural hydrology*

Except for the high mountainous regions in the upper reaches of the basin, the climate of the Rio Grande varies from arid to semi-arid. In general, precipitation occurs as intense storm events widely separated in both time and space. Precipitation climatology is different in the three major reaches, with respect to the synoptic drivers of precipitation, the geographical distribution of precipitation (and therefore sources of runoff into the river channels), and its seasonality. For the Upper Rio Grande:

- Primary sources of runoff are snowmelt and rainfall at higher elevations
- Synoptic drivers of precipitation are mid-latitude disturbances (mainly winter), and the North American monsoon (mainly late summer). Both systems interact with the complex orography of Colorado and northern New Mexico
- The southern reach lies in the rain shadow of the Rockies, so is semi-arid in the north to arid in the south.
- Rainfall in the southern reach is thought by some meteorologists to be forced by the El Nino-Southern Oscillation (ENSO)

For the Lower Rio Grande, in contrast:

- The primary source of runoff is storm rainfall
- Synoptic drivers of precipitation are mid-latitude disturbances and tropical storms from the Gulf of Mexico
- The Lower Rio Grande lies entirely in the rain shadow of the Rockies, so is arid in the west and semi-arid in the east
- The bulk of Lower Rio Grande water originates in Mexico.

Table 2 - Annual precipitation at selected stations in Rio Grande Basin

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For the Rio Conchos:

- Primary sources of runoff are snowmelt and rainfall at higher elevations
- Synoptic drivers of precipitation are the North American monsoon and tropical storms from the Pacific, interacting with the mountainous orography of the basin.
- Rainfall is thought by some meteorologists to be controlled by ENSO

The domination of snow versus rainfall as the primary source of runoff is indicated in Fig. 1. Despite the regular occurrence of snow in the higher elevations of the Conchos basin, its flow is predominantly due to rainfall, while the main stem of the Upper Rio Grande derives its flow mainly from snowmelt. Rainfall statistics at selected stations are presented in Table 2.

While this section addresses “natural” hydrology of the basin, it must be recognized that natural hydrology has not been manifested since the nineteenth century. Heavy diversions, primarily agricultural, have reduced Upper Rio Grande flow to practically zero at Fort Quitman. This is illustrated by the time series of annual flows and cumulative reservoir capacity shown in Figure 5. This is also the reason for dividing the Upper and Lower rivers at Fort Quitman, because hydrologically the River at Fort Quitman becomes a new river. From Fort Quitman to Presidio (above the Conchos) there is little river flow, and this reach is sometimes referred to as the “forgotten river” because of its comparative neglect by water planners.

The Lower Rio Grande is rejuvenated by the Conchos. With 24.0 m³/s discharge it is the most important tributary, providing about two-thirds of year-round stream flow in the Lower Rio Grande. A second tributary to the Lower Rio Grande, the Pecos, delivers 7.50 m³/s on the United States side. Like the Upper Rio Grande, the hydrology of the Lower Rio Grande has been

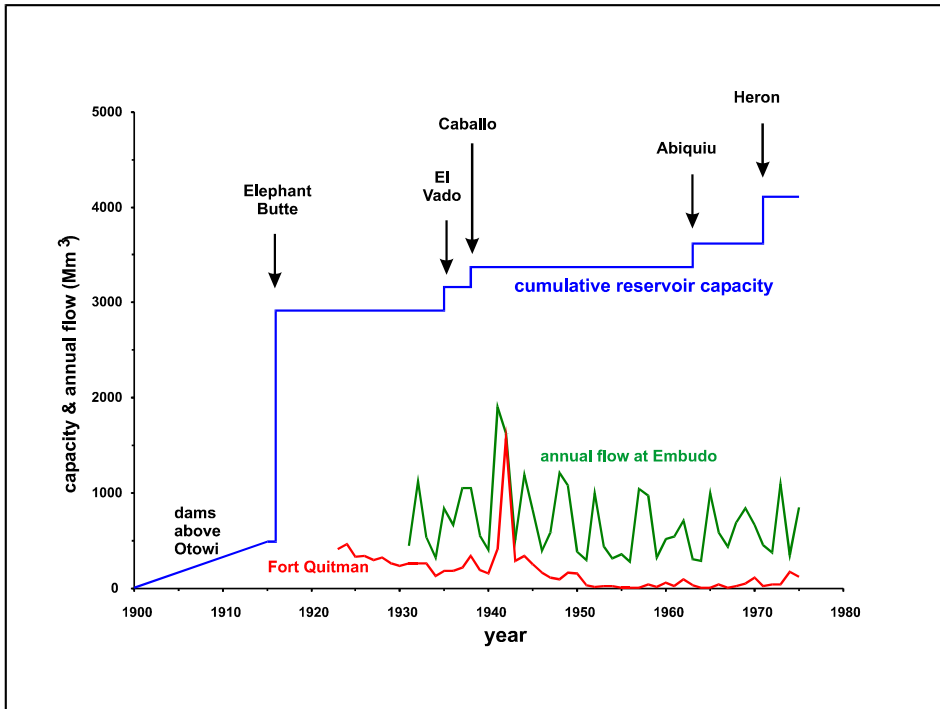


Figure 5 - Annual flows at Embudo and Ft. Quitman (see Table 1) and cumulative reservoir capacity on Upper Rio Grande, 1900-1975

substantially altered by reservoir construction and the attendant diversions, for both flood control and agriculture (see Section 2.3 on Water Engineering, below), so its hydrology has not been “natural” since the mid-1950s. In the lowermost reach of the Lower Rio Grande, below Brownsville, the combination of diversions for irrigation and municipal-industrial water use, and the diversion of floodwaters around the Lower Rio Grande Valley directly to the Gulf, has reduced the river flow to nearly zero. The only river flow in this reach is the small amount of runoff deriving from rainfall on the coastal watershed. There is no longer a true estuary, and much of the time, the mouth of the Rio Grande is blocked by a sandbar.

2.2 Groundwater

As remarked above, the Rio Grande channel flows through alternating regions of canyons and alluvial valleys. These alluvial valleys are the locations of shallow aquifers fed by runoff and infiltration from the surrounding mountains and by infiltration of precipitation directly on the valley floor. Sediments. The alluvial layer is hundreds to thousands of feet, and, though permeable throughout, the permeability typically decreases with depth. In the New Mexico reach, for analysis purposes geohydrologists typically consider the groundwater source to be made up of a shallow, highly permeable layer, overlying a deeper, less permeable aquifer. The alluvium is permeable and in direct contact with the river, so there is an exchange between the two. El Paso and Cd. Juárez meet urban demand almost entirely from groundwater. The main aquifer—Hueco Bolson—has been over pumped and is expected to run dry by 2025. A secondary aquifer—Mesilla Bolson—has mostly brackish water. El Paso Water Utilities, with help from the federal government, has built the largest land-based desalinization plant to use Mesilla water for drinking water. Both Hueco and Mesilla aquifers underlie New Mexico, West Texas and parts of the Mexican state of Chihuahua. Mexico has started an ambitious program to tap additional aquifers.

Irrigation districts in the Paso del Norte use groundwater during drought periods. The same strategy does not work in the LRGV where ground water is of poor quality.

Groundwater resources have been studied extensively, jointly by the IBWC and state water agencies. Yet conjunctive water planning and management of groundwater does not exist.



Figure 6 – Major engineering structures on Rio Grande/ Rio Bravo

2.3 Water engineering

All branches of the Rio Grande, viz. the Upper Rio Grande, the Lower Rio Grande, and the Rio Conchos, have been extensively engineered to control and store the waters of the river. The massive extent of water engineering on the main stem of the Rio Grande is shown in Figure 6. The principal reservoirs on the main stem of the Rio Grande and the Rio Conchos are tabulated in Table 3.

Table 3 - Principal reservoirs on Rio Grande and Río Conchos, Chronologically by date of deliberate impoundment

<i>name</i>	<i>volume (Mm³)</i>		<i>date</i>	<i>name</i>	<i>volume (Mm³)</i>		<i>date</i>
	<i>supply</i>	<i>flood</i>			<i>supply</i>	<i>flood</i>	
Upper Rio Grande							
North of Otowi				South of Otowi			
8 dams	4		1855-1893	Elephant Butte	2433	62	1916
55 dams	486	482	1894-1915	El Vado	242		1935
				Caballo	280	403	1938
				Abiquiu	247	1442	1963
				Heron	495		1971
				Cochiti		886	1973
Rio Conchos				Lower Rio Grande			
La Boquilla	2903	3278	1913	Falcón	3273	624	1953
Madera	348	478	1949	Amistad	4174	2152	1969
Leon	356	832	1968				
San Gabriel	255	317	1981				

The headwaters of the Rio Grande have been substantially plumbed since the nineteenth century to provide irrigation waters mainly to the San Juan valley. In the period 1855-1893, eight dams were constructed upstream from Otowi for irrigation water supply, and in the period 1894-1915 another fifty-five dams were built. These are mainly small dams on tributaries to accomplish the storage and temporary transport of water to the agricultural areas served, but illustrate the complexity of water supply in this area. After 1970, the San Juan-Rio Chamas (SJRC) Project of USBR subsumed many of these in a larger scale project that included interbasin transfers (in fact transmountain transfers, across the continental divide) from the adjacent San Juan basin into the Rio Grande. A good summary of the engineering infrastructure and operations in the reach from the SJRC to the backwater of Elephant Butte is given in Appendix A of Llewellyn and Vaddey (2013).

Heron is a key reservoir for the SJRC Project, as it provides storage prior to distribution to various users. Abiquiu and Cochiti were originally intended for flood control and sediment retention only. Abiquiu is now also used to store Albuquerque's allocation from the SJRC Project. Cochiti includes a small permanent pool (50,000 ac-ft) for recreation. Jemez is operated

as a dry reservoir. The reader is reminded that reservoirs for flood control and for water supply are operated in fundamentally different ways. For flood control, the object is to maximize the capacity to store floods, so the reservoir is evacuated as quickly as possible after a flood event, and is empty most of the time. For water supply, the object is to maintain a supply of water in storage, so inflow events are captured to the extent of available capacity and the reservoir is full as much of the time as possible. Multipurpose reservoirs may accomplish both flood control and water supply, in which case the total capacity is subdivided into separate “pools” for each function, the former being emptied after flood events, and the latter being maintained at capacity as inflow permits. There may be a third pool for power generation. The data in Table 3 reflect the most current information available to these writers. Over time, some of these reservoirs have experienced a re-allocation of their capacities to accommodate changing requirements for flood control, water supply and power generation.

Elephant Butte on the Upper Rio Grande, closed in 1916, and La Boquilla on the Rio Conchos, closed in 1913, are the oldest dams in the world using modern engineering techniques. Elephant Butte is a multipurpose reservoir for water supply and power generation, with some limited flood control. The reservoir serves as the main hydrological structure of the U.S. government Rio Grande Project that supports irrigated agriculture in southern New Mexico, West Texas, and Northern Mexico. The project served as a model for water engineering in the Colorado. A short distance downstream from Elephant Butte, Caballo dam was built in 1938. This allows for year-round energy production at Elephant Butte, since Caballo can capture the power releases from Elephant Butte, and release this water on a seasonal basis for irrigation. This works well for the farmers, but severely reduces environmental flows during the months when no irrigation release is called for.

On the Lower Rio Grande, i.e., downstream from Fort Quitman, the International Reservoirs Amistad and Falcón provide water for irrigation and for municipal and industrial use by cities in the Lower Rio Grande Valley (LRGV). The two reservoirs are operated as a tandem system by the IBWC. Falcón was the first to be constructed, in response to the devastating floods of the 1940's, and was completed in 1953, early in the Drought of the Fifties. The time history of inflows into the reservoir and its storage is shown in Figure 7. The reservoir was nearly empty

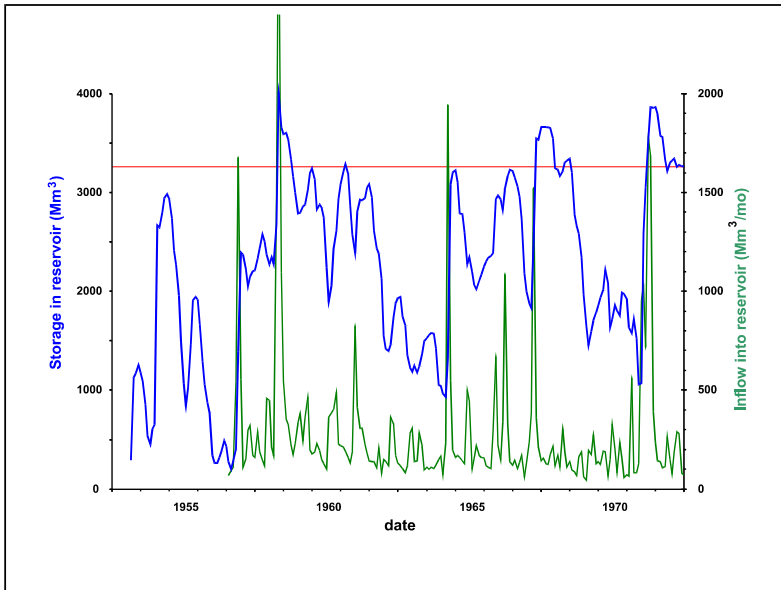


Figure 7(a) - Time history of storage and inflows in Falcón, 1953-72

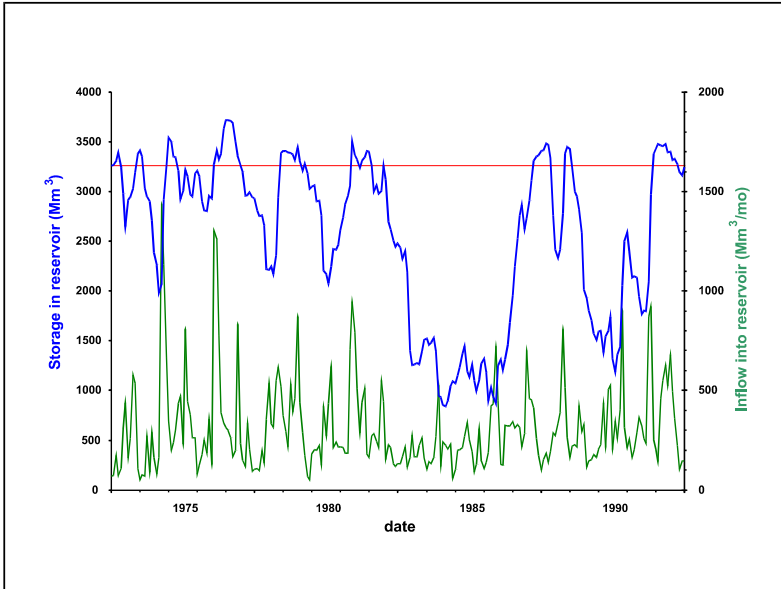


Figure 7(b) - Time history of storage and inflows in Falcón, 1973-92

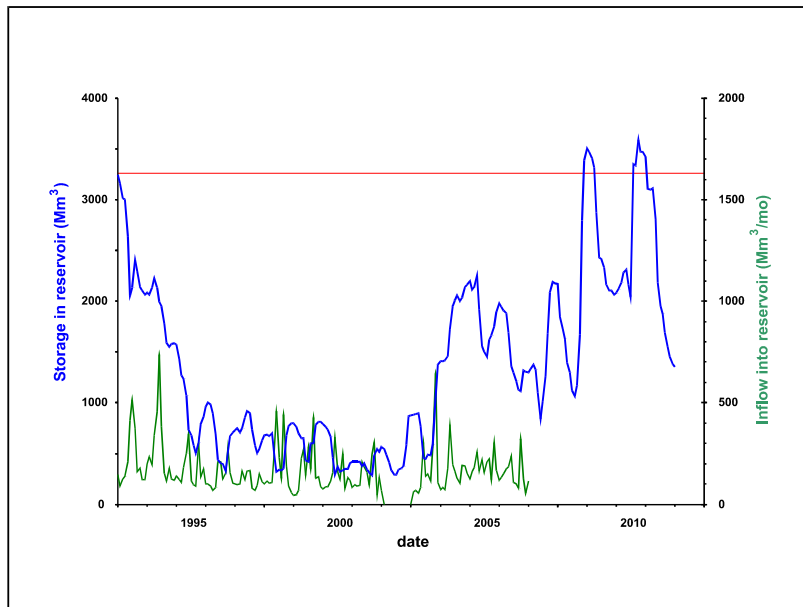


Figure 7(c) - Time history of storage and inflows in Falcón, 1993-2011

for the first year after closure, but then was brought to 91% of capacity by a single event late in 1954, a tropical storm land falling on the Rio Grande. Its then contents diminished due to the drought conditions until 1958.

Amistad, upstream from Falcón, was closed in 1968. The time history of inflow and storage to Amistad is presented in Figure 8. System operation began when both reservoirs achieved full storage, in late 1973. Typically in tandem operation Falcón is drawn down first, thereby maximizing the ability to capture flood events and minimizing losses due to evaporation (because the area-volume ratio of Amistad is higher than Falcón).

The river flow in the Lower Rio Grande can be described as a low base flow on which are superposed high flow events widely separated in time, and corresponding to land falling tropical

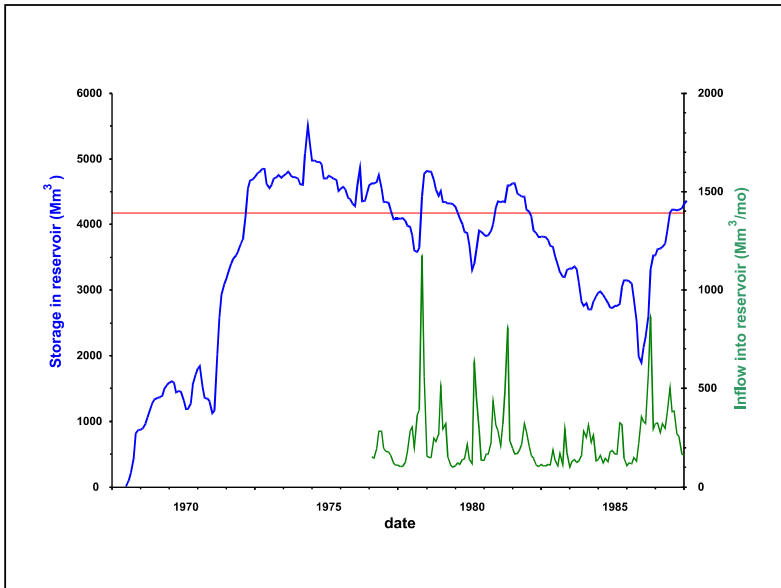


Figure 8(a) - Time history of storage and inflows in Amistad, 1968-87

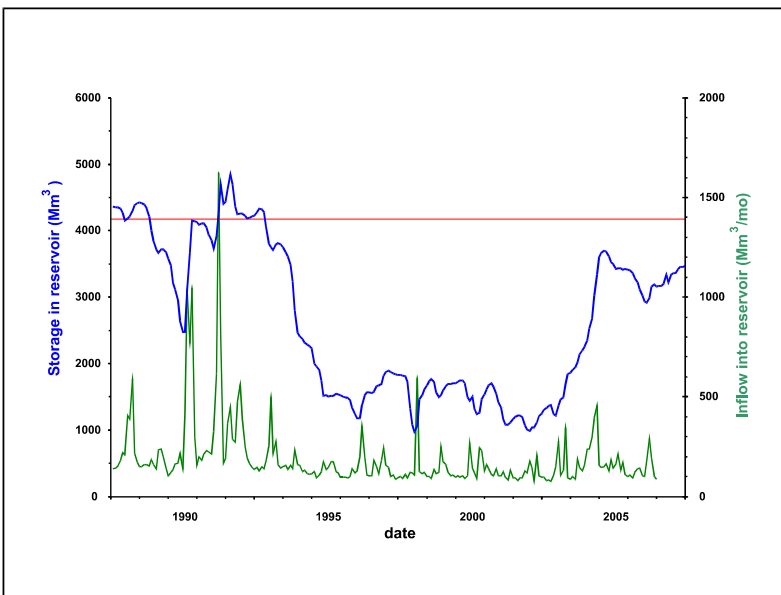


Figure 8(b) - Time history of storage and inflows in Amistad, 1988-2007

storms or rare seasons of particularly active frontal passages. Both Amistad and Falcón can be described as being in a continuous state of drawdown, except for occasional diluvial events that bring the reservoirs to capacity.

3. Governance

3.1 Institutions

Water management in the basin is a complex maze of international, state, regional and local institutions. Even so, the system works to the satisfaction of both agricultural and urban users, except during drought years. (See below under Conflicts).

The U.S. Federal government, in 1902, established the *Bureau of Reclamation*, a part of the U.S. Department of the Interior. The Bureau's mission was to assist with development of the American West. Control of Rio Grande waters at Elephant Butte reservoir was one of the earliest projects of the Bureau. As mentioned, it served as a dry run for larger projects on the Colorado.

In the U.S. part of the basin, Colorado, New Mexico and Texas share water under the *Rio Grande Compact* (53 Stat. 785). The compact was agreed to in 1939, and has not been changed since. Colorado and New Mexico are represented on the compact commission by their state engineers, while the Texas commissioner is appointed by the governor of Texas. The chairman of the commission is appointed by the president of the United States. The compact provides for the apportionment of Rio Grande water above Fort Quitman, Texas and provides for the operation and maintenance of about 20 gauging stations above Fort Quitman. The amount of water Colorado has to deliver to New Mexico, and New Mexico must deliver to Texas, is fixed as a function of the water flowing at defined river gauges.

Created by the 1906 convention between Mexico and the United States (see next section), the *International Boundary and Water Commission* (IBWC) is responsible for the construction, maintenance and operation of international dams and other water infrastructure, water accounting between the two countries, diplomatic problem solving (the minute system), flood control and technical investigations. IBWC is organized in Mexican and United States sections, headquartered in Cd. Juárez and across the river in El Paso. Both sections report to their respective ministries of foreign affairs.

Conchos waters are overseen by the Mexican Comisión Nacional del Agua (Conagua).

Intense competition for river water in the LRGV has found a unique solution on the Texas side of the border. The courts appointed a Rio Grande Water Master to settle differences and allocate water received from the IBWC to irrigations districts and cities, both under normal and drought conditions. The water master is now an agent of the state of Texas.

At the local level, farmers are organized in *irrigation districts*. These are non-profit organizations with an elected board and appointed managers responsible for allocating water to individual farmers and maintaining water distribution systems. City *water utilities* are responsible for management of urban water and treatment of waste water.

3.2 Laws, agreements, compacts, treaties

Competition for surface and groundwater prevails throughout much of the basin. In the Upper Rio Grande water rights are contested between irrigation, growing cities (in particular Albuquerque, New Mexico) and Indian tribes.

Colorado, New Mexico and Texas share water under the Rio Grande Compact (see above).

Mexico and the United States share Rio Grande water under two international treaties.

Bi-national management of the Rio Grande began with the *Convention of 1906*. Under this agreement the United States allocates 60,000 ac-ft/yr (74 M m³) to Mexico to be used for irrigation in the Cd. Juárez area. In exchange, Mexico withdrew its longstanding complaints about limited access to Upper Rio Grande water. An existing International Boundary Commission, responsible for marking the border between the two countries, saw its authority expanded to manage river waters on the border with Mexico—from the Gulf of Mexico to California. The water mandate became the principal function of the reformed agency, as shown by the requirement that the two commissioners, one from each country, must be professional

engineers. To this day the International Boundary and Water Commission (IBWC) functions as the most important bi-national institution on the US-Mexico border.

The *Treaty of 1944* stipulates that Mexico, in exchange for receiving United States water in the Colorado basin, transfers to the U.S. portion of Rio Grande water no less than 350,000 ac-ft/yr (432 Mm³/yr, 36 Mm³/mo), averaged over 5-year cycles. The purpose of the 5-year cycle averaging in the Treaty is to allow years of deficit delivery to be made up in years of excess flow. There are also complicated provisions to allow Mexico to carry over deficits into additional 5-year cycles.

While the 1944 treaty does not grant the IBWC authority to control water quality, this has changed gradually. The treaty allows for rule-making by the IBWC, called the *minute process*. Under this system the Mexican and U.S. sections of the IBWC study pressing water issues and submit recommendations for action. Over time, 319 Minutes were issued, covering a variety of issues, including construction of new reservoirs, salinity, flood control, and, in at least two dozen cases, sanitation (water quality). Each minute, at the end of sometimes year-long study and discussion, is signed by the American and Mexican commissioner of the IBWC, submitted to the two governments, and becomes part of the bi-national water management system if neither government raises objections within thirty days after execution. The vast majority of IBWC Minutes were approved by the two governments. This rule making power works slowly but efficiently to address emerging issues. The system bypasses the difficulty of formal confirmation of international agreements by the U.S. Senate. (For the text and approval status of minutes 180 to 312 see www.ibwc.gov. For more information on the minute process see Umoff, 2008).

3.5 Water pricing

Agricultural water is heavily subsidized. Mexico does not put a price on water. In the United States, irrigation districts must repay a share of government subsidies for the construction of storage reservoirs. Once this debt has been paid, farmers are charged small amounts for the administrative costs of irrigation districts.

3.6 Conservation and increased efficiency

Education, water pricing and model projects to advance these goals are in their infancy. The current use of more than 80 percent of river water for irrigation can be reduced substantially by improvements in water distribution and irrigation techniques. Water metering, changes in crop patterns, more realistic water pricing, and storage of flood waters need to be implemented on a large scale. Cities need to reduce losses from aging water pipes.

The potential for doing more with less is great. An irrigation district in the LRGV convinced their members to replace open air distribution ditches with underground pipes. Farmers reduced their water use by 40 percent, but still harvested the same value of crops. The same district did better than its neighbors when water supply was curtailed during a drought period.

3.7 Water planning

In the United States, water planning is a function of the states. In Mexico, it is a responsibility of the Comisión Nacional del Agua (Conagua). In their water planning both countries consider changes from reservoir sedimentation, population growth, and changes in land use. Climate change, on the other hand is hardly considered. For example, the 2012 water plan for Texas acknowledges that “climate change and climate variability both pose challenges to water planning, because they add uncertainty”. To meet the challenge the Texas Water Development Board “monitors climate science for applicability to the planning process.”

In Texas, legislation passed in 1996, created regional water planning groups with membership of all stake holders. One group each covers the Texas portions of the Paso del Norte and the LRGV. Observers from New Mexico and Mexico are invited to attend meetings, but do not participate in decision-making.

4. Water use

4.1 Agriculture

Agriculture uses 80 to 88 percent of river water.

4.2 Cities

Cities and industry use 12 percent of river water.

4.3 Industry

Ever since the beginning of the century, horizontal drilling and fracking of shale oil and gas have caused sharply increased water demand on the U.S. side of the LRGV.

4.4 Environment

Environmental flow has been substantially reduced by the heavily engineered river system. The floods and high flow pulses reaching the Paso del Norte and the LRGV are diminished. Increase water demand in the Rio Conchos have dramatically reduced the late summer/early fall high flow pulses entering the Rio Grande. As a result, significant ecological damage occurred in both upper and lower Rio Grande.

4.5 Energy (hydropower)

5. Water budget

6. Challenges

6.0 Data availability

6.1 Sedimentation

The Rio Grande basin, particularly the higher elevations with their young mountains, are a prolific source of sediments, and siltation in the basin, particularly in the New Mexico reach, has been a historic problem. Several reservoirs, e.g., Chochiti, have been constructed for the express purpose of flood control and sediment retention.

The U.S. Bureau of Reclamation has studied Elephant Butte sedimentation since 1915, a year before the dam was completed. By now a data set covering almost a century is available. The 1999 survey reported a 23.3% loss of storage capacity since closure. The report projected additional 5% losses for future 14 year intervals. The 2007 survey corrected these findings as follows: "Since the last reservoir survey in 1999, the reservoir volume has increased 1,228 acre-feet (1.5 million m³) due to the dewatering and resulting compaction of the previous measured sediments that have been exposed during the extended drought conditions. The average annual rate of sediment accumulation since 1915 is 6,575.6 acre-feet (8.1 million m³) compared to the 1999 study computation of 7,253.2 acre-feet (8.9 million m³)." Thus, between 1915 and 2007, 23.16% of storage capacity was lost (U.S. Department of Interior, 2008).

In the Lower Rio Grande the greatest siltation occurs in the upstream reservoir — Amistad. From the closure of Amistad in 1968 through 1992, when the lake was extensively surveyed by the IBWC, 760,800 acre-feet (938 million m³) had been lost to storage in the combined Falcon-Amistad system, about 12.5% of conservation capacity, of which 95% is in Amistad. Projected to the present, the loss of conservation capacity due to siltation is about 22

Available data document an annual storage volume loss of 0.25% in Elephant Butte. The Amistad loss is in the range of 0.5% (IBWC and Ward data) to 0.6. The measured plus

projected loss for Elephant Butte (1915-2060) amounts to 36.5%. For Amistad (1968-2060) the loss will amount to 55.2%. It is possible that Amistad will lose somewhat less in future years because some siltation from the main tributary, the Río Conchos, is caught by recently built reservoirs in Mexico. Even so, reservoir losses in the 40% range are highly significant for both economic impact regions — the PdN and the LRGV rates of siltation after their construction, though this has ameliorated in recent years primarily due to interception in reservoirs upstream or in the Conchos tributary..

6.2 Climate change impacts

The Rio Grande basin has been plagued with multi-year droughts once or twice each century. The region has been identified in the IPCC model runs as one in which human-induced climate change will be exhibited as both increases in air temperature and decreases in rainfall. According to the IPCC, storm tracks reaching the American Southwest are moving northward. This will bring less precipitation to the Rio Grande basin. On the other hand, occasional storms from the Gulf of Mexico or the Pacific may become more frequent. Throughout the basin evaporation losses will increase as the temperature rises. Timing and volume of upstream snowfall have already changed over the last twenty years. Taking these factors together, there will be less river water in most years.

According to a 2013 study by the U.S. Bureau of Reclamation and Sandia National Laboratory climate change will make it difficult for New Mexico to implement Rio Grande Compact rules that guarantee a prescribed flow of water in the Rio Grande Basin to Texas. Climate change will cause reduced flows due to higher rates of evaporation and smaller expected snow packs. (U.S. Department of the Interior, 2013). Texas water officials are suing New Mexico over water deliveries related to the Rio Grande Compact.

6.3 Water quality

Natural water quality in the basin is variable. Water deriving from the snowpack in the upper basin and from seasonal runoff is typically of good quality, as is water from the Rio Conchos. Pecos water, particularly at low flows, is saline, due to interflow from a briny aquifer cut by the

river in eastern New Mexico. The development of irrigated agriculture in the Upper Rio Grande and in the Lower Rio Grande Valley has impacted the water quality in these respective reaches. More about nutrient loads in the Upper and salination in the Lower.

Mexican communities on the Rio Grande for many years released untreated waste water. The single largest number of IBWC minutes is devoted to improving sanitation. Under side agreements to the North American Free Trade Agreement (NAFTA) the United States helped Mexico to build primary and secondary treatment plants. Tertiary treatment is still a way off in Mexico. So is sewage treatment in small Mexican communities.

6.4 Groundwater

In the Middle Rio Grande Albuquerque has reduced its use of groundwater to 41 per cent. The cities of Las Cruces, El Paso and Cd. Juárez depend entirely on groundwater. In 1998 the IBWC published a study of the aquifers underlying the Paso del Norte (IBWC, 1998). The study predicted “the depletion of recoverable freshwater reserves of the bi-nationally shared aquifers by the middle half of the 21st century”. Many years earlier, in the 1960s, Minute 242 had addressed United States concerns about Mexican groundwater pumping. The Minute was primarily concerned with shared groundwater in Arizona, but briefly addressed the groundwater future of the entire border region. It was agreed that the two governments shall consult with each other prior to developing new surface or groundwater projects that might adversely affect the other country. This is as far things have come. Even today, there is no comprehensive agreement on ground water. No IBWC Minute has ever focused on groundwater in the Paso del Norte. In 2006, the United States passed the United States-Mexico Transboundary Aquifer Assessment Act. The lead agencies are the U.S. Bureau of Reclamation and the Water Resource Research Center at the University of Arizona. What little has been accomplished to date under the act is focused on aquifers in Arizona and Sonora.

6.5 Conflicts

Texas is suing New Mexico before the U.S. Supreme Court alleging that New Mexico interferes with water deliveries to Texas that are prescribed under the Rio Grande Compact. Specifically, Texas asks that New Mexico stop pumping groundwater along the border of the two states so that more of the river could flow south to farmers and residents in the Paso del Norte. Texas alleges that New Mexico water users are improperly intercepting (i.e., diverting or pumping) surface water and groundwater within New Mexico that reduces Rio Grande Project allocations to the Texas Project beneficiary, El Paso County Water Improvement District No. 1. The federal government has also weighed in. In its motion to intervene in the case, the government contends that groundwater pumping in New Mexico is tapping the shallow aquifer that would otherwise drain back into the Rio Grande and flow to Texas.

New Mexico has appealed the case, arguing that the U.S. District Courts, not the Supreme Court should settle the case. In January 2014 the Supreme Court rejected the New Mexico appeal and the case continues before the Supreme Court.

In the Lower Rio Grande, the arid, lower reach of the basin, recent droughts have resulted in a deficit of the treaty-mandated minimum delivery from Mexico to the United States of 432 Mm³/yr (350,000 ac-ft/year). On average, the Conchos flow represents about 80% of the flow into this reach of the Rio Grande.

For many years Mexico delivered more Conchos water to the Rio Grande than required by the 1944 water treaty. Exceptional drought and increased water demand by Mexican farmers and cities caused Mexico to fall behind in Conchos deliveries during two five-year delivery cycles from 1992 to 2002. As mentioned earlier, the treaty allows water debts to be repaid during five-year cycles. The 1990s drought led to a severe water conflict between the two countries

In 1995, IBWC Minute 293 stated that “the current storage of waters belonging to Mexico [in Conchos reservoirs] would be just sufficient to cover needs for Mexico through June 1996.” Recognizing the threat to Mexican communities Minute 293, in accordance with Article 9(f) of

the Treaty, authorized Mexico to use some of the waters belonging to the United States, that were stored in Amistad and Falcón reservoirs. Minute 308, agreed to in 2002, proposed new ways to deal with drought management. The two governments followed up on the IBWC recommendation and Mexico paid back its water debt in 2005. (For a case study of how IBWC minute 308 helped resolve the 1990s conflict see Umoff 2008.)

References

- Everitt, B., 1991: Channel responses to declining flow on the Rio Grande between Ft. Quitman and Presidio, Texas. *Geomorphology* 6, 225-242.
- Herzog, L. A., 1990: *Where north meets south: Cities, space and politics on the U.S.-Mexico border*. Austin: Center for Mexican-American Studies, University of Texas.
- IBWC, 1998: *Tranboundary Aquifers and Binational Ground Water Database for the City of El Paso/Ciudad Juárez Area*. www.ibwc.state.gov/Water_Data/binational_waters.htm.A
- Llewellyn, D., and S. Vaddey, 2013: *West-wide climate risk assessment: Upper Rio Grande impact assessment*. Upper Colorado Region, Bureau of Reclamation, Albuquerque.
- Schmandt, J., North, G.R., Ward, G.H., How sustainable are engineered rivers in arid lands?, [J. sustain. dev. energy water environ. syst., 1\(2\), pp TBA, 2013, DOI: TBA.](#)
- Schmidt, J., B. Everitt, and G. Richard, 2001: Hydrology and geomorphology of the Rio Grande and implications for river rehabilitation. In: *Aquatic fauna of the northern Chihuahuan desert* (G. Garrett and N. Allan, eds.). Lubbock: Museum of Texas Tech University, *Special Publications* 46, 25-45.
- Scurlock, D., 1998: *From the rio to the sierra: An environmental history of the Middle Rio Grande Basin*. General Technical Report RMRS-GTR-5. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- Umoff, A. A., 2008: An analysis of the 1944 U.S.-Mexico water treaty: Its past, present, and Future. *Environs: Environmental Law and Policy Journal* 32, 69-98).
- U.S. Department of Interior, Bureau of Reclamation, 2008: *Elephant Butte Reservoir: 2007 reservoir survey*. Washington, D.C., Government Printing Office.
- U.S. Department of Interior, Bureau of Reclamation, 2013: *Impacts of Climate Change on the Upper Rio Grande Basin: Adaptation and Mitigation Strategies*. Washington, D.C., Government Printing Office.
- Wilson, Lee, 1999: Surface water hydrology of the Rio Grande basin. Presented at: Forty-fourth Annual New Mexico Water Conference, Santa Fe. New Mexico Water Resources Research Institute, Las Cruces.

