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Randall J. Charbeneau*

Groundwater Resources of the Texas Rio Grande Basin

INTRODUCTION

The groundwater resources discussed in this paper are those of the Texas side of the Rio Grande Basin between El Paso and the Gulf of Mexico. Only those groundwater supplies which directly connect to or underlie the Rio Grande are considered. The discussion includes the groundwater hydrogeology and storage, future groundwater availability, and potential groundwater resource problems.

A geologic formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs is called an aquifer. The aquifers discussed in this paper are (in order from the Texas–New Mexico border to the Gulf) the Mesilla, Hueco, Red Light Draw, Green River Valley, Presidio, and Redford Bolsons, and the Edwards–Trinity, Carrizo–Wilcox, and Gulf Coast Aquifers. These aquifers are shown in Figure 1. Other aquifers which lie on the Texas side of the Rio Grande Basin but do not directly connect with the Rio Grande include the Salt Bolson, the Capitan, Bone Spring, Victoria Peak, and Marathon Limestones, and the Santa Rosa, Rustler, Igneous Rocks, and Cenozoic Alluvium Aquifers.

The movement and storage of groundwater in an aquifer is controlled by local hydrogeology as well as by the locations and amounts of recharge and discharge. Development of groundwater in one part of an aquifer can influence the groundwater's behavior throughout the aquifer, as well as that of any connected surface water supplies. The amount of water which can be withdrawn from an aquifer depends on how it is managed. Various concepts of basin yield are generally recognized. If groundwater is withdrawn at a rate exceeding the recharge, a "mining yield" exists which is necessarily limited in time. The "perennial yield" of a groundwater basin defines the rate at which water can be withdrawn annually under specified operating conditions without producing an undesired result. The types of undesired results of interest include 1) progressive reduction of the water resource, 2) development of uneconomic pumping conditions, 3) degradation of groundwater quality, 4) interference with prior water rights, and 5) land subsidence caused by lowered groundwater levels. The amount of withdrawal in excess of the perennial yield is termed

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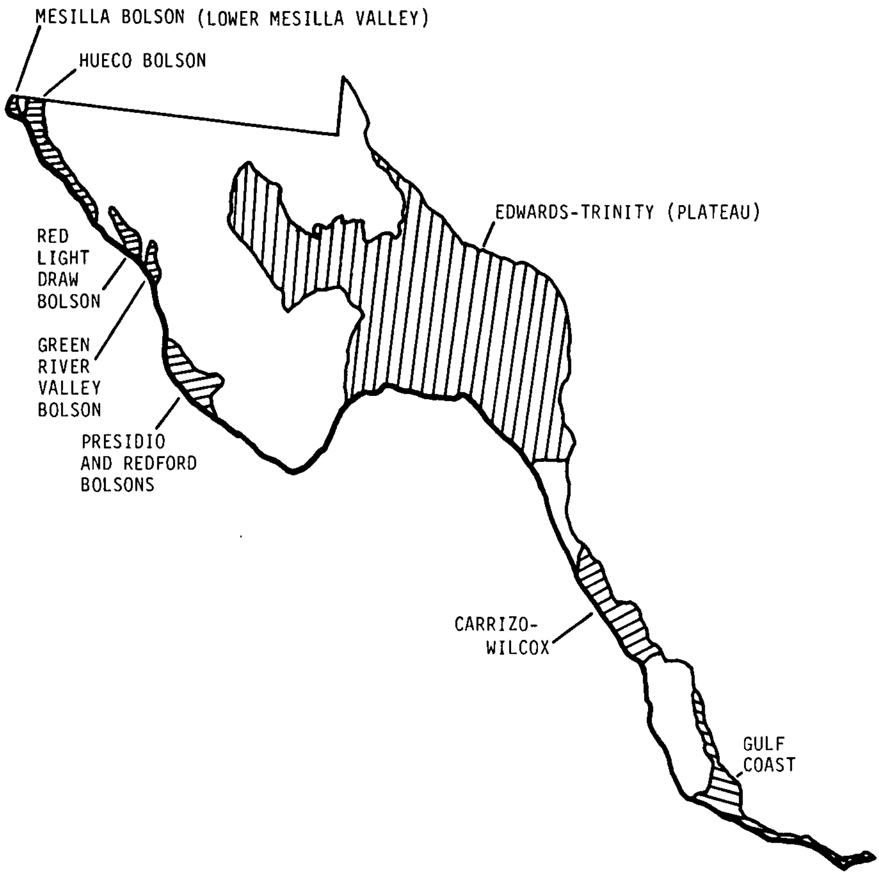

FIGURE 1.

TEXAS RIO GRANDE GROUNDWATER AQUIFERS

"overdraft." The "deferred perennial yield" refers to the use of two different pumping rates. The initial pumping rate is in excess of the perennial yield and water is removed from storage as the water levels fall. Once the water levels reach a predetermined level, a second pumping rate which is equal to the rate of recharge is used. The deferred perennial yield is greater than the perennial yield because the lowered water levels result in a decrease in groundwater discharge by evapotranspiration to the atmosphere and subsurface outflow to surface water supplies. The "maximum perennial yield" is that quantity of water available if both the surface and subsurface water supplies are managed in an optimal manner.[1]

1. D. TODD, GROUNDWATER HYDROLOGY (1980).

GROUNDWATER SUPPLIES

The major aquifers of the Rio Grande Basin are the Alluvium and Bolson Aquifer which occurs over much of the upper part of the Basin, the Edwards–Trinity (Plateau) Aquifer which covers a large area in the middle part of the Basin, the Carrizo–Wilcox Aquifer which occurs in the lower middle part of the Basin, and the Gulf Coast Aquifer which occurs in the lower part of the Basin (see Figure 1). The water quality in these aquifers ranges from fresh (0 to 1000 mg/l dissolved solids) through slightly saline (1000 to 3000 mg/l dissolved solids) to moderately saline (3000 to 10,000 mg/l dissolved solids).

Alluvium and Bolson Aquifer

Water-bearing alluvium and bolson deposits are scattered across the westernmost Texas region. Even though these sediments are completely separated geographically, they are geologically and hydrologically similar and, collectively, are considered as a single major aquifer. A bolson is a broad and nearly flat mountain-rimmed desert basin with interior drainage. Recharge occurs along the foothills of the mountains and plateaus where sediments are coarse grained and permeable. In some places, additional recharge comes from overlying alluvium. The thickness of the bolson deposits ranges from 1000 to 9000 feet (in the Hueco Bolson), however the deepest known fresh water is about 1400 feet.

The Mesilla and Hueco Bolsons are the major water resource for El Paso and Ciudad Juarez. Since this is the only area along the Rio Grande where major groundwater problems may occur, these deposits will be discussed in a later section.

Moving southeastward from El Paso along the Rio Grande, the first major groundwater resource is the Red Light Draw Bolson which is used primarily for livestock wells. This bolson lies between the Quitman Mountains to the west and the Eagle and Indio Mountains to the east. The combined section of basin fill and volcanic clastics thickens to the south, from 500 feet to as much as 3600 feet near the Rio Grande. Water-level contours show that recharge moves from the bordering mountains to the axis of the valley and then southeastward toward the Rio Grande. Most of the groundwater is fresh, containing less than 500 mg/l dissolved solids. Toward the Rio Grande, the water quality decreases with the water becoming slightly to very saline. The high salt content probably results from evapotranspiration in the groundwater discharge zone along the river. The water moves to the atmosphere leaving the salts behind. The fresh groundwater storage of the Red Light Draw Bolson is estimated to be about 600,000 acre-feet. Not all of this water can be recovered because removal of fresh water will draw in adjacent saline water. Assuming that 75% of the fresh water may be recovered, the recoverable storage of the Red Light Draw Bolson is about 450,000 acre-feet. The annual recharge

TABLE 1

AQUIFER STORAGE (1974) AND RECHARGE

Aquifer	*Recoverable Storage* (10^3 acre-ft)	Annual Recharge (10^3 acre-ft)
Mesilla Bolson	560	18.0
Hueco Bolson	10,600	6.0
Red Light Draw Bolson	450	2.0
Green River Valley Bolson	210	1.0
Presidio and Redford Bolsons	750	7.0
Edwards–Trinity (Plateau)	106,210	513.9
Carrizo–Wilcox	160	13.7
Gulf Coast	*	11.4

*Not Determined

Reference: Texas Dept. of Water Resources, Report 238 (September 1979).

is estimated to be 2000 acre-feet. No problems are known to be associated with developing groundwater in the Red Light Draw Bolson. The fresh groundwater levels up in the valley are 200 to 400 feet higher than the water levels in areas of saline water along the Rio Grande. Encroachment of saline water should not be a problem until water level declines are significant.[2]

The hydrogeologic behavior of the Green River Valley, Presidio, and Redford Bolsons is similar to that of the Red Light Draw Bolson. Recharge occurs along the sides of the bordering mountains and the water moves toward the Rio Grande. Water is mainly used for livestock, though some water is used for irrigation and, near Presidio and Redford, for domestic use. For the most part, the water is fresh within the bolsons, except near the Rio Grande where the water quality deteriorates due to discharge by evapotranspiration. The fresh water is at a higher elevation than the poorer quality water along the Rio Grande so that there are no anticipated problems with developing the fresh groundwater unless the water levels are lowered excessively. The estimated recoverable storage and annual recharge for these bolson deposits are listed in Table 1.

Edwards–Trinity (Plateau) Aquifer

The Edwards–Trinity Aquifer covers a large area in the middle part of the basin including Val Verde, Terrell, and part of Brewster Counties

2. Muller and Price, *Groundwater Availability in Texas*, TEXAS DEPARTMENT OF WATER RESOURCES REPORT 238 (Sept. 1979); and Gates, White, Stanley, and Ackermann, *Availability of Fresh and Slightly Saline Groundwater in the Basins of Westernmost Texas*, TEXAS DEPARTMENT OF WATER RESOURCES REPORT 256 (Sept. 1980).

along the Rio Grande. It is composed of sands and limestones from the Trinity Group, limestones from the Fredericksburg Group, and part of the limestone from the Washita Group. The aquifer consists of a lower section of fine- to coarse-grained sand, and an upper part of limestone with solution cavities and fractures. The thickness of the limestones reaches 1000 feet while the sand is usually less than 100 feet thick. Water quality ranges from fresh to slightly saline. The historically measured spring flows on the Rio Grande, Pecos, and Devils Rivers suggest that the annual recharge is about 514,000 acre-feet. These spring flows serve a major function in diluting the saline irrigation return flow and saline water from the Pecos river so that the water quality in the Rio Grande as it passes through this area is fresh. The recoverable storage from the Edwards–Trinity (Plateau) is estimated to be 106,210,000 acre-feet.[3]

Carrizo–Wilcox Aquifer

The Carrizo–Wilcox Aquifer, occurring in the lower middle part of the basin, is composed of an upper unit, the Carrizo Formation of the Claiborne Group, and a lower unit, the Wilcox Group. The aquifer consists of fine- to coarse-grained sand, sandstone, silt, and clay, with lignite beds in the lower section. The saturated thickness of the aquifer ranges from 200 to 700 feet. Using a digital model of the aquifer, the recoverable storage was estimated to be 160,000 acre-feet with an annual recharge of 13,700 acre-feet.[4]

Gulf Coast Aquifer

The Gulf Coast Aquifer, occurring in the lower part of the basin, is composed of the Catahoula, Oakville, Lagarto, Goliad, Lissie, and Beaumont Formations as well as Recent age surface deposits. It consists of interbedded sand, gravel, silt, and clay. The maximum thickness of fresh to slightly saline water is about 500 feet. Water quality ranges from fresh to slightly saline, with salinity increasing rapidly downdip. Approximately 11,400 acre-feet of groundwater can be withdrawn annually on a sustained basis without significant land subsidence and saline-water encroachment within the basin. Recoverable storage was not determined.[5]

GROUNDWATER AVAILABILITY

Groundwater availability in the Rio Grande Basin has been determined by the Texas Department of Water Resources either on the basis of a

3. TEXAS WATER DEVELOPMENT BOARD, CONTINUING WATER RESOURCES PLANNING AND DEVELOPMENT FOR TEXAS, VOL. 2 (May 1977).
4. *Id.*
5. *Id.*

TABLE 2

PROJECTED AVERAGE ANNUAL GROUNDWATER AVAILABILITY (10^3 ACRE-FT)

Aquifer	*1980–1989*	*1990–1999*	*2000–2009*	*2010–2019*	*2020–2029*	*2030*
Mesilla Bolson	32.9	41.4	41.4	41.4	39.5	37.8
Hueco Bolson	90.6	124.7	167.3	234.8	304.3	373.5
Red Light Draw Bolson	10.3	10.3	10.3	10.3	10.3	2.0
Green River Valley Bolson	4.9	4.9	4.9	4.9	4.9	1.0
Presidio and Redford Bolsons	20.9	20.9	20.9	20.9	20.9	7.0
Edwards–Trinity (Plateau)*	513.9	513.9	513.9	513.9	513.9	513.9
Carrizo–Wilcox	16.4	16.4	16.4	16.4	16.4	13.7
Gulf Coast	11.4	11.4	11.4	11.4	11.4	11.4
TOTAL	701.3	743.9	786.5	854.0	921.6	960.3

*Pumpage from aquifer directly depletes surface supplies
Reference: Texas Dept. of Water Resources, Report 238 (September 1979).

perennial yield or a deferred perennial yield. In the case of a deferred perennial yield, that amount of the recoverable storage which can be safely withdrawn without saline-water encroachment was assumed to be used up by the end of the year 2030. Beyond 2030 the groundwater availability is equal to the annual recharge.

In the bolson deposits it is assumed that 75 percent of the recoverable storage could be removed without significant salinity problems. For the Edwards–Trinity, recovery of water in storage directly impacts on the surface water so the availability of groundwater in this case is equal to the annual recharge. For the Carrizo–Wilcox, availability is determined so that (a) water levels will not decline to more than 400 feet below the land surface until 2030 or (b) the water levels will not decline below the top of the water bearing sands. For the Gulf Coast Aquifer, availability was determined so that water levels would stabilize at or above 150 feet below the land surface by the year 2030.

The groundwater availability figures for the Rio Grande Basin are shown in Table 2. Beyond the year 2030, the annual groundwater availability along the Rio Grande (excluding the Mesilla and Hueco Bolsons) will be 549,000 acre-feet. In addition to this, in the lower basin some groundwater is available from the Nueces–Rio Grande Basin Gulf Coast Aquifer. Note that these figures refer to groundwater availability and not groundwater use.

GROUNDWATER IN THE EL PASO AREA

The water supplies of the El Paso–Ciudad Juarez area consist of groundwater from the lower Mesilla Valley and the Hueco Bolson with surface

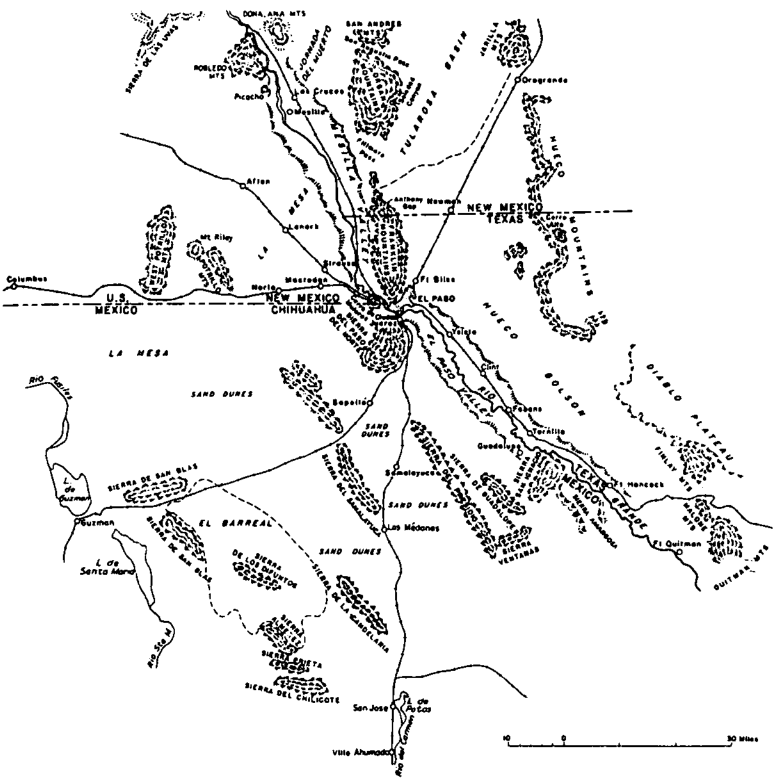

FIGURE 2.

GENERAL MAP OF THE EL PASO AREA (FROM USGS, 1945)

water from the Rio Grande playing a minor role. The Mesilla Valley of the Rio Grande crosses the east side of the Mesilla Bolson west of the Franklin and Organ Mountains (see Figure 2). The lower Mesilla Valley is that part of the valley between the Texas–New Mexico state line at Anthony and El Paso del Norte between the Franklin Mountains and Sierra de Cristo Rey (Sierra del Paso del Norte in Figure 2). The lower valley is bounded on the east by the Franklin Mountains and on the west side lies La Mesa, the undissected surface of the Mesilla Bolson.

The Mesilla Bolson extends over a wide area of New Mexico, Texas, and Mexico, from Las Cruces, New Mexico on the north, to the salt flats in Mexico about 50 miles south of the border. East and West Potrillo Mountains, 15 miles to the west of the lower valley, form the western boundary of the bolson. The basin fill of the Mesilla Bolson is composed of clay, silt, sand, and some gravel and includes the Santa Fe Group of Miocene to Pleistocene age and the Rio Grande alluvium of Holocene age. The deeper part of the Santa Fe Group was deposited in a closed basin and is coarse-grained around the margins of the bolson and fine-grained toward the center. The upper part of the basin fill was deposited by the ancestral Rio Grande or lake deposits. The Rio Grande alluvium was deposited by the river after it established its present course through the Mesilla Bolson to enter the Hueco Bolson. Three water-bearing zones are distinguished. The shallow aquifer, which includes the Rio Grande alluvium and part of the underlying Santa Fe Group, extends from the land surface to depths of 160 to 260 feet. Its quality is influenced by the Rio Grande because of irrigation and direct infiltration. In general, the water in the shallow aquifer is poorer in quality than the deeper groundwater with dissolved solids ranging from 260 to 2300 mg/l in the north to 24,800 mg/l in the south. Water level maps suggest that water moves from north to south parallel with the Rio Grande, with the lower Mesilla Valley serving as a discharge zone. The narrow outlet at El Paso del Norte restricts groundwater outflow from the valley and results in most of the water being discharged by evapotranspiration. This accounts for the increase in dissolved solids. Water level maps do not indicate that any significant amount of groundwater moves south across the border toward the salt flats in Mexico. The aquifer at medium depth, which includes most of the upper part of the Santa Fe Group, extends from the base of the shallow aquifer to depths of about 460 to 680 feet. Its water quality is better than that of the shallow aquifer. The deep aquifer extends from the middle aquifer to depths of 1200 feet or more. It commonly contains less than 300 mg/l dissolved solids.[6]

Groundwater is pumped from the lower Mesilla Valley for municipal supply, irrigation, and industrial use. Most of the municipal pumpage is by El Paso Water Utilities from the Canutillo field located towards the center of the valley. During 1957–1975 the city pumped an average of 5,500, 3,500, and 9,200 acre-feet from the upper, medium, and deep aquifers. The 1975 withdrawals were 5,000, 1,400, and 12,700 acre-feet from these aquifers, respectively. Other municipal users in the valley withdrew about 8,000 acre-feet in 1975. Irrigation usage depends on the availability of surface water. In 1973–1975, a period of adequate surface water, 3,000–5,000 acre-feet per year was pumped for irrigation. During a period of drought as much as 50,000 acre-feet per year could be used for irrigation. Current pumping for all uses from the lower Mesilla Valley is about 30,000 acre-feet per year, but during a drought could be as much as 80,000 acre-feet per year.

Water levels in the shallow aquifer have shown little long-term change because the aquifer is replenished by infiltration from canals, the river, and applied irrigation. Water levels in the medium and deep aquifers of

6. *See* Gates, White, Stanley, and Ackermann, *supra* note 2.

the Canutillo well field declined during the initial period of pumping, 1957–1960, and have essentially stabilized since 1960. This indicates that pumping is balanced by groundwater inflow, most likely from the shallow aquifer. The water level decline in the medium aquifer is 15–20 feet while that in the deep aquifer is 30–70 feet.

The thickest section of the valley containing fresh water, locally more than 1000 feet, is in the northwest part. The fresh-water section thins to the east and south, and in the southern end of the valley little or no fresh groundwater is available. The Canutillo well field is on the southeast edge of the thickest fresh-water section.

About 820,000 acre-feet of fresh groundwater is stored under the Texas portion of the lower Mesilla Valley and the adjacent Mesa to the east. About 47,000,000 acre-feet of fresh groundwater is stored under the New Mexico part of the valley and La Mesa to the west. Also, about 300,000 acre-feet of slightly saline water is stored in the Texas Rio Grande alluvium. The groundwater inflow to the three aquifers of the lower Mesilla Valley from La Mesa to the west, from the foothills of the Franklin Mountains to the east, and from Mesilla Valley north of Anthony, is estimated to be about 18,000 acre-feet per year.[7]

The Hueco Bolson includes areas in Texas, New Mexico, and Mexico (see Figure 2). The northern part of the bolson lies between the Organ and Franklin Mountains on the west and the Hueco Mountains on the east. The southern part of the bolson lies between several mountain ridges in Mexico on the west and the Diablo Plateau and Finley, Malone, and Quitman Mountains on the east.

The Rio Grande is entrenched about 200 to 250 feet into the Hueco Bolson. Its floodplain is the El Paso Valley. The valley is bordered by the relatively undissected and undrained surface of the bolson which is called the Mesa.

The primary water-bearing material of the Hueco Bolson is the unconsolidated basin fill which is divided into the Rio Grande alluvium and the older bolson deposits, mostly deposited before the Rio Grande drained the bolson. The thickest section of basin fill occurs as a trough-shaped body adjacent and parallel to the Franklin Mountains. The total thickness in this area may be as much as 9000 feet. To the southeast between El Paso and Clint the thickness is between 1000 and 3000 feet.

The ancient course of the Rio Grande probably extended into the Hueco Bolson through the Fillmore Pass between the Organ and Franklin Mountains and along the east front of the Franklin Mountains. Part of the uppermost 600–1400 feet of relatively coarse-grained basin fill east of the Franklin Mountains may be deposits of the ancestral Rio Grande. The

7. *Id.*

Rio Grande alluvium is the material deposited by the Rio Grande along its present course. It is estimated to be about 200 feet thick.

Recharge to the Hueco Bolson occurs along the mountains bordering the bolson, and at times locally along the Rio Grande. Using digital-model studies, the annual recharge around the perimeter of the northern end of the bolson, including areas in New Mexico and around Ciudad Juarez in Mexico, is estimated to be about 6,000 acre-feet. The recharge to the United States part of the bolson, excluding recharge from the Rio Grande, is estimated to be about 14,000 acre-feet per year.[8]

Before development of the Hueco Bolson as a groundwater resource, the floodplain of the Rio Grande served as the discharge zone. The first well supplying groundwater to El Paso was dug around 1892. In 1901 the development of the Mesa well field north of Fort Bliss began. By 1917 a total of 44 wells had been drilled in the Mesa field. These were pumped from a central plant by air lift, but the cost of operating and maintaining the plant was excessive because of the high lift and inefficiency of pumping with air. In 1917, development of the Montana well field at a lower elevation near the eastern side of the city began. Additional development of this field yielded sufficient water and the Mesa field was gradually abandoned. To meet increasing demand in the 1920s, two test wells were drilled in the Mesilla Valley. These yielded saline water and the project to develop a supply of groundwater from the Mesilla Valley was abandoned (until the 1950s). Deep wells were drilled in the Mesa and Montana fields to meet increasing demands.[9] A 1970 water-level map shows that much of the groundwater now flows into two cones of depression in the water table east of the Franklin Mountains, where it is discharged by municipal-supply and industrial wells.[10]

Development of groundwater from the bolson deposits near the city has lowered the water level below the water level in the overlying Rio Grande alluvium. Instead of being an area of discharge, the alluvium is now an area of groundwater recharge. A digital model of the groundwater system indicates that the river furnished between 10,000 and 20,000 acre-feet per year of recharge to the alluvium between 1953 and 1973. This recharge, which has been induced by groundwater development, is substantially greater than the 6,000 acre-feet per year of recharge under natural conditions.

The largest amount of fresh water (up to 1000 feet thick) in the Texas part of the Hueco Bolson is in the trough-shaped body adjacent to the Franklin Mountains. This body of fresh water occurs in sediments that

8. *Id.*

9. Sayer and Livingston, *Groundwater Resources of the El Paso Area, Texas*, U.S. GEOLOGICAL SURVEY WATER SUPPLY PAPER 919 (1945).

10. Gates, White, Stanley, and Ackermann, *supra* note 2.

include coarse debris eroded from the mountains and alluvium from the ancestral Rio Grande. Recharge occurs by infiltration from runoff along the Franklin and Organ Mountains. The circulation is relatively rapid and deep with dissolved solids less than 500 mg/l. Towards the east, the section of fresh water thins to less than 100 feet. The salinity of the groundwater increases to the southeast in Hudspeth County.

Municipal and industrial groundwater pumpage has steadily increased since the early 1900s. From 1906 to 1975, about 1.80 million acre-feet was pumped from the Texas part of the northern Hueco Bolson while from 1925 to 1975, about 570,000 acre-feet was pumped from the Ciudad Juarez area in Mexico. In 1975, 72,000 acre-feet was pumped from the Texas part of the northern bolson and about 40,000 acre-feet was pumped from the Ciudad Juarez area. These pumpages have resulted in a water level decline of 60–70 feet in the northern and southeastern part of El Paso and as much as 95 feet in downtown El Paso and Ciudad Juarez. Irrigation can be a big water user, varying from 10,000 acre-feet per year to as much as 150,000 acre-feet per year during drought periods.

On the basis of digital-model studies it was estimated that in 1973, 10.6 million acre-feet of fresh water was stored in the trough east of the Franklin Mountains. To the southeast in the El Paso Valley, 400,000 to 800,000 acre-feet of fresh to slightly saline groundwater is estimated to be stored. Also, it is estimated that 6.2 million acre-feet of fresh water is stored in the part of the trough east of the Franklin and Organ Mountains in New Mexico, and 4 million acre-feet of fresh water is estimated to be stored in the Ciudad Juarez area of Mexico. About 1.8 million acre-feet of slightly saline water occurs to depths of 200 feet in the Rio Grande alluvium in the El Paso Valley.[11]

Groundwater Availability

The projected water requirements for the El Paso area were estimated by the Texas Water Development Board in 1977. The total projected requirements include water for domestic, municipal, manufacturing, power, mining, and livestock purposes (water use for irrigation was not included). These requirements are shown in column two of Table 3. Projected surface-water deliveries from the Rio Grande to El Paso are included in column three. The difference between the total projected requirements and the surface-water deliveries must be made up by groundwater (column four), which is currently being supplied from the Canutillo well field in the lower Mesilla Valley and the Mesa and Montana well fields in the trough-shaped body east of the Franklin mountains in the Hueco Bolson. This total groundwater requirement consists of natural recharge to the

11. *Id.*

TABLE 3

WATER USE AND PROJECTED WATER REQUIREMENTS,
EL PASO AREA
(10^3 ACRE-FEET)

Selected Year	*Total Use*	*Surface Water*	*Groundwater*	*Mesilla Bolson*	*Hueco Bolson*
1974	111.9	14.2	97.7	24.1	73.6
1980	137.0	13.5	123.5	32.9	90.6
1990	180.0	13.9	166.1	41.4	124.7
2000	225.6	16.9	208.7	41.4	167.3
2010	294.1	17.9	276.2	41.4	234.8
2020	362.5	18.7	343.8	39.5	304.3
2030	431.4	20.1	411.3	37.8	373.5

References: Texas Water Development Board, Continuing Water Resources Planning and Development for Texas, Vol. 2 (May 1977), and Texas Dept. of Water Resources, Report 238 (September 1979).

bolsons, induced recharge caused by the lowered water table, and depletion of water recoverable from storage.

Digital model studies have been used to investigate groundwater availability in the Hueco Bolson and such studies are currently under way for the lower Mesilla Valley. In 1984, the Mesilla Bolson aquifer will reach its maximum capacity to meet its portion of the groundwater requirements in that a continued increase in the rate of storage depletion would result in excessive depletion by 2030 and intrusion of saline water into the area. Therefore, that portion of the groundwater requirements which cannot be met by the Mesilla Bolson was transferred as an increased requirement of the Hueco Bolson aquifer. The resulting water requirements from the Mesilla and Hueco Bolsons are shown in columns five and six of Table 3. At the end of the year 2030 there will remain about 25% of the recoverable fresh groundwater storage in these two bolsons.

It is possible that the groundwater remaining in storage in 2031 and some of the groundwater withdrawn between 1974 through 2030 will be slightly saline because of saline-water encroachment from the induced recharge source and movement of slightly to moderately saline groundwater from adjoining bolson deposits. Even though the future salinity of the water is not predictable, proper management of withdrawals from the aquifers such as "in well" blending of the fresh and slightly saline groundwater from each bolson will possibly be necessary.

The analysis and its results did not consider groundwater development of these bolsons in Mexico and New Mexico. Development in these two areas adjacent to Texas could adversely affect the availability estimates.

In this respect, the most critical area lies in the artesian zone of the Hueco Bolson aquifer in Mexico where Ciudad Juarez is pumping large amounts of groundwater just across the Rio Grande from the City of El Paso. Other limiting factors include the assumed availability of water from the river, lining of the river and canals, and other possible uses of groundwater storage in the Rio Grande alluvium.

If unacceptable groundwater quality degradation should occur, then the City of El Paso and other large groundwater users in El Paso County must import fresh water, solve local desalting water resource problems, and pump less groundwater and reclaim existing return flows. Sources of import water for El Paso County within Texas are few. The closest possible Texas sources of fresh water in limited quantities are in the Red Light Draw Bolson about 100 miles southeast of the City of El Paso and the southern portion of the Salt Bolson approximately 150 miles southeast of the city. The nearest sources of fresh groundwater for import are in New Mexico adjacent to El Paso County where approximately 6.2 million acre-feet of fresh water is stored in the northern extension of the Hueco Bolson and 47 million acre-feet of fresh water is stored in the northern Mesilla Valley and La Mesa to the west. However, New Mexico law presently precludes the export of groundwater outside of New Mexico borders. Also, about 4 million acre-feet of fresh water is stored in the Ciudad Juarez area of Mexico.[12]

SUMMARY AND CONCLUSIONS

The groundwater resources of the Texas Rio Grande Basin serve an important role as a water supply for domestic, municipal, manufacturing, power, mining, livestock, and irrigation purposes. The natural groundwater discharge as spring flow also controls the salinity of water in the Rio Grande through the middle and lower part of the basin. Throughout most of the basin the supplies are adequate to meet the various needs, and this condition should continue through the year 2000.

The spring flow from the Edwards–Trinity and Carrizo–Wilcox aquifers is regulated by the International Amistad and Falcon Reservoirs. The water needs of the lower basin are met by these surface water supplies along with pumpage for irrigation from the Rio Grande alluvium and the Gulf Coast Aquifer.

The area of El Paso–Ciudad Juarez is the only area of the basin which faces significant groundwater problems. The amount of fresh groundwater is limited and natural recharge is not sufficient to meet even present water requirements. The fresh groundwater reserves are being mined and in their place is encroaching saline water. This condition will continue through

12. *See* Muller and Price, *supra* note 2.

the year 2000. While there is sufficient fresh groundwater in the El Paso area to meet the needs through the year 2000, joint management of this groundwater resource by Texas, Mexico, and New Mexico is necessary to ensure an adequate water supply for the future. Questions which must be addressed concern interstate and international import and export of groundwater.

LOS RECURSOS DE AGUA DEL SUBSUELO EN LA CUENCA DEL RIO GRANDE EN TEJAS

Los acuíferos más importantes de la Cuenca del Río Grande en Tejas, son el Aluvial y el Bolson, Edwards–Trinity (La Meseta), El Carrizo–Wilcox y los de la Costa del Golfo. La calidad del agua del subsuelo varía de dulce a moderadamente salina. Casi todos los suministros de la Cuenca son adecuados para cumplir con las diversas necesidades, y esta condición continuará hasta el año 2000. El área de El Paso–Ciudad Juárez, es la única porción de la cuenca que se enfrenta a problemas importantes relativos al agua del subsuelo. La cantidad de agua dulce del subsuelo está limitada; y el reabastecimiento natural no es suficiente para enfrentarse a las necesidades actuales de agua. Los requerimientos a largo plazo en esta área requerirán la importación de agua dulce de los depósitos existentes de agua del subsuelo.

Suministros de agua del subsuelo.

Los acuíferos más importantes de la Cuenca del Río Grande son el Aluvial y el Bolson, Edwards–Trinity (La Meseta), Carrizo–Wilcox y el de la Costa del Golfo. La calidad del agua del subsuelo varía de dulce a moderadamente salina. En la región más occidental de Tejas, la Mesilla y el Bolson Hueco son los recursos más importantes para El Paso y Ciudad Juárez. Hacia el sureste, a lo largo del Río Grande, el depósito más importante de agua del subsuelo es el Bolson del Red Light Draw, que se usa principalmente para pozos de ganado. El almacenaje de agua subterránea de este bolson recuperable se estima que sea como de 450,000 acre-pies. El acuífero Edwards–Trinity cubre una vasta área en la parte media de la cuenca. El almacenaje recuperable en este acuífero se estima que es de 106,210,000 acres-pies, pero este recurso no es aprovechable, debido a su contenido de salinidad. El acuífero Carrizo–Wilcox, ubicado en la parte media baja de la cuenca, tiene un almacenaje recuperable de 106,000 acres-pies, con una recarga anual de 13,700 acres-pies. En la parte baja de la cuenca, el acuífero de la Costa del Golfo puede proveer 11,400 acres-pies aproximadamente para la explotación anual del agua del subsuelo. A lo largo de casi toda la cuenca los depósitos son adecuados para enfrentar las diversas necesidades, y esta condición debe subsistir hasta el año 2000.

El agua del subsuelo en el área de El Paso.

El área de El Paso–Ciudad Juárez es la única área de la Cuenca que enfrenta problemas importantes de agua del subsuelo. Las provisiones de agua en esta área consisten principalmente del agua del subsuelo de la parte baja del Valle de la Mesilla y el Bolsón del Hueco.

La cantidad de agua fresca es limitada y la recarga natural no es suficiente para satisfacer las necesidades actuales. Cerca de 820,000 acres-pies de agua dulce del subsuelo, se encuentra almacenada bajo la porción baja del Valle de la Mesilla en Tejas y la meseta adyacente. El bombeo normal del Valle es de aproximadamente 30,000 acres-pies por año. La parte tejana del Bolson del Hueco tiene un promedio de 10.6 millones acres-pies de agua fresca almacenada. Al sureste del

Valle de El Paso, de 400,000 a 800,000 acres-pies de agua del subsuelo que va de dulce a poco salina, se encuentra almacenada. En 1975, 73,000 acres-pies fueron bombeados de la parte tenaja del Bolsón del norte. Las tasas de recarga son de aproximadamente 18,00 acres-pies por año para el Bolsón del Hueco. Mientras tanto, el bombeo de agua del subsuelo, tanto municipal como industrial, aumenta constantemente.

Las necesidades a largo plazo en el área de El Paso–Ciudad Juárez necesitarán de la importación de agua dulce de desalinización, de reclamación de flujos de retorno, y de la administración de las provisiones de agua subterránea que existen actualmente.

Las fuentes más cercanas a Tejas de agua dulce se encuentran a 100–150 millas al sureste de El Paso. Las fuentes más cercanas para importar agua dulce del subsuelo están en Nuevo México, donde aproximadamente 6.2 millones de acres-pies de agua dulce están almacenados en la extensión norte del Bolsón del Hueco y 47 millones de acres-pies de agua dulce están almacenados en la parte norte del Valle de la Mesilla y la Mesa hacia al oeste. También, alrededor de un millón de acres-pies de agua dulce están almacenados en el área de Ciudad Juárez en México. Los problemas relativos a la exportación internacional e interestatal de agua del subsuelo deben de ser tomados en consideración.