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UNIVERSITY RESEARCH SUPPORTS GROUNDWATER AVAILABILITY STUDIES OF THE HUECO BOLSON AQUIFER, EL PASO/JUAREZ AREA

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Water supply and water quality problems facing the City of El Paso and Ciudad Juarez are complex and interrelated. The twin-cities share the water resources of the Hueco Bolson, a Tertiary and Quaternary basin fill aquifer that spans the international border. The binational metroplex is located at the junction between the western edge of Texas and the northernmost part of Chihuahua, Mexico. Over-pumping of the Hueco Bolson aquifer has resulted in drawdown of the water table, encroachment of brackish groundwater, and the early retirement of wells.

In response to these issues, Mexican and American universities formed a partnership to study the surface and ground-water resources of the El Paso/Juarez area. Governmental agencies are participating in the project by providing existing data, access to water wells, and other support services. The research team is applying a suite of isotopic tracers to provide an understanding of the spatial dynamics of the aquifers by tracing water from areas of recharge to regions of discharge. The team is also using a variety of geochemical and isotopic tracers to answer questions about increasing salinity in the developed parts of the aquifer. With an increased understanding of the flowpaths of the aquifer systems, the team is addressing stream-aquifer interactions between the groundwater systems and the Rio Grande. By combining an understanding of isotopic and geochemical changes in the river system with the information about the groundwater systems, the team is calculating fluxes of water and solutes from the groundwater system to the river system. Finally, this geochemical and isotopic information is being used by the municipal partners to constrain physical and management models of groundwater to utilize the fresh and saline water resources of the Hueco Bolson more effectively.

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Environmental Isotopes and Numerical Models
Estimate Induced Recharge in the El Paso/Juarez Area

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Abstract

This paper provides a brief overview of the history of groundwater use in the Hueco Bolson aquifer and discusses issues of induced recharge and cross-formational flow from the Rio Grande and Rio Grande aquifer. The twin-cities of El Paso and Juarez share the water resources of the Hueco Bolson, a Tertiary and Quaternary basin fill aquifer spanning the international border. Over-pumping of the Hueco Bolson aquifer has resulted in drawdown of the water table, encroachment of brackish groundwater, and the early retirement of wells. Pumping cones of depression in municipal wellfields are the focal points of drawdown. Most of the drawdowns near municipal wellfields vary from 50 to 150 ft (15 to 45.5 m). Drawdown in the Hueco Bolson aquifer induces cross-formational leakage from the overlying Rio Grande aquifer. So long as the alluvial aquifer is itself replenished from recharge from unlined channels, the Rio Grande aquifer will account for a major component of recharge to the Hueco Bolson. Confirming and quantifying the amount of induced recharge will allow policy makers to make better projections of water availability. To this end, we use environmental isotope tracers and numerical models to confirm induced leakage from the Rio Grande aquifer to the Hueco Bolson.

Geology of the Hueco Bolson

The Hueco Bolson covers about 2500 square miles (6,500 square kilometers) in New Mexico, Texas, and Chihuahua (Figure 1). In Texas, the Hueco Bolson occupies portions of El Paso and Hudspeth Counties. The Tularosa Basin in New Mexico bounds the Hueco Bolson on the north. The boundary between the Tularosa and the Hueco is a subtle topographic boundary, and does not represent a geologic or hydrologic boundary, and groundwater flows from the Tularosa into the Hueco. The Franklin Mountains bound the Hueco on the west; the Hueco Mountains are the eastern boundary, and the Sierra Juarez is the southern boundary (Figure 2).

The Hueco Bolson lies within the Rio Grande Rift and is downdropped by normal faults in relation to the bounding mountains. Consolidated strata that provide small to moderate quantities of water in the highlands range in age from Precambrian to Tertiary. Most of the water wells in bedrock are shallow, and penetrate only a few tens of feet of saturated bedrock. The most prolific bedrock aquifers are karstified and fractured carbonate and clastic rocks. Intrusive and extrusive rocks and metamorphic rocks are not usually highly prolific.

The Organ Mountains consist of masses of Tertiary intrusive rocks to the north, and Paleozoic, Cretaceous, and lower Tertiary sedimentary rocks to the south (Figure 2). The Franklin Mountains include sequences of Paleozoic carbonate rocks and Precambrian and Tertiary intrusive rocks. The Hueco Mountains are mostly carbonate and clastic rocks of Paleozoic and Cretaceous age. The part of the Diablo Plateau bounding the Hueco Bolson consists mostly of Permian and Cretaceous carbonate rocks and some Tertiary intrusive rocks. The Sierra Juarez, Sierra El Presidio, and Sierra Guadalupe of northern Chihuahua, Mexico are mostly carbonate and clastic rocks of Cretaceous age (Figure 2)..

Basin fill sediments are usually weakly consolidated, heterogeneous materials that overly Precambrian through Tertiary rocks (Wilkins, 1986). Fort Hancock deposits in the Hueco Bolson include lacustrine muds, interbedded with layers of bentonitic claystone and siltstone and some discontinuous sand lenses. Overlying the Fort Hancock Formation is the Camp Rice Formation, a Pliocene unit that consists of stream-channel and floodplain deposits that are the most prolific and dilute water bearing units in the Hueco Bolson. Camp Rice deposits are juxtaposed against fanglomerates that flank the margin of the basin (Strain, 1966). Deposits in the Camp Rice Formation include predominantly gravels and sands, interbedded with muds, volcanic ash, and caliche (Wilkins, 1986). Sand and gravel sediments in the Camp Rice Formation are thickest along the Franklin and Organ Mountains, becoming thinner and finer-textured to the east (USBR, 1973). Throughout the basin, the percentage of clay increases generally with depth (Orr and Risser, 1992). At its maximum extent, Hueco Bolson deposits are up to 8000 ft (2,450 m) thick.

Geology of the Rio Grande Alluvium

Southeast of El Paso, the Rio Grande flows across a broad alluvial floodplain, the "El Paso Valley" where the river has incised the surface of the Hueco Bolson (Figure 1). Rio Grande alluvium overlies the Hueco Bolson deposits in the valley portion of the area (Figure 1). Near El Paso, the El Paso Valley is about 6 to 8 miles (9.7 to 12.9 km) wide and is a little more than 200 ft (61 m) deep (USBR, 1973). The valley trends nearly 90 miles (145 km) east-southeast to Fort Quitman, where the valley is constricted between the Sierra de La Cieneguilla and the Quitman Mountains. The valley deepens along its course and is almost 330 ft (100 m) deep near Fabens, 30 miles (48 km) below El Paso. The valley wall is disrupted frequently by arroyos that incise the Hueco Bolson and floodplain surfaces.

A complex mosaic of braided and meandering river deposits underlie the Rio Grande alluvial floodplain in the El Paso Valley (Figure 1). Formed during alternating periods of scour and fill in the late Quaternary Period, the alluvial deposits consist of irregularly distributed gravels, sands, clays, and silts (Hibbs and Boghici, 1999). Alluvial deposits are derived from reworked basin fill material, eroded bedrock, and extrabasinal sediments transported by the Rio Grande from its headwaters in New Mexico and Colorado. Total thickness of the Rio Grande alluvium is reported to average about 210 ft (64 m) (IBWC, 1989). Windblown sand and silt deposits overlie the Rio Grande alluvium at several localities. Where dunes and other windblown deposits are present, they often border the outer margin of the Rio Grande floodplain. Windblown deposits are surfaces for infiltration because they are well sorted and sparsely vegetated.

The surface water in the Rio Grande and the associated ditches and drains that were constructed for the delivery and removal of agricultural water interact with the groundwater in the Rio Grande alluvium. Groundwater in the alluvium, in turn interacts with the deeper Hueco Bolson groundwater.

Past Analyses of Induced Recharge in the Hueco Bolson

Lippincott (1921) was apparently the first to discuss the interaction of the Rio Grande and the Hueco Bolson. Groundwater pumping in the Hueco began in 1903 with the first of several wells constructed about three miles north of the Rio Grande. After reviewing the history of the groundwater level declines and water quality changes in the Mesa wellfield, Lippincott (1921) concluded that the wells were being fed, in part, from the Rio Grande. Lippincott (1921), however, was not able to quantify the rate of inflow.

As pumping continued, more data were collected, and as the science of hydrogeology improved over the decades, the understanding of the interaction also improved. In a report by the Texas Board of Water Engineers, Smith (1956, pg. 11) provided one of the earliest qualitative discussions. Smith (1956, pg.11) noted that prior to development, the vertical gradient between the Hueco Bolson and the overlying alluvium in Texas was upward, and groundwater discharged from the Hueco Bolson to the Rio Grande alluvium, and thence to the Rio Grande as baseflow. Increases in pumping resulted in decreased groundwater levels in the Hueco Bolson, and resulted in a reversal of the vertical gradient. As a result, Smith (1956, pg.11) reported that the alluvium became a source of recharge to the Hueco Bolson rather than a discharge area.

Recharge from the Rio Grande alluvium occurs where pumping cones of depression have reversed the natural hydraulic gradient between the Hueco Bolson and the alluvium. Where the Rio Grande channel is lined with low-permeability grout along the Chamizal zone, the alluvium recharges the Hueco Bolson at the expense of its own storage. Where the Rio Grande is not lined the alluvium, in turn, is replenished by infiltration of river water and unlined agricultural channels.

Model studies predicted that only 5,600 acre-ft/year (6,900,000 cubic-meters/year) comes from mountain front recharge and inflow from the Tularosa Basin to the Hueco Bolson (Heywood and Yager, 2003). Model analysis indicated that the recharge from the Rio Grande alluvium to the Hueco Bolson was about 10,000 acre-ft/year (12,300,000 cubic-meters/year) in predevelopment times (prior to 1903) and has been over 50,000 acre-ft/year (61,700,000 cubic-meters/year) since the mid 1980s (Heywood and Yager, 2003). Lining of the Rio Grande channel in 1973 along the Chamizal zone with a low permeability grout reduced recharge locally by the Rio Grande significantly. However, unlined canals and areas of the Rio Grande that are unlined below Chamizal still provide an ample source of recharge to the Rio Grande aquifer.

The understanding of groundwater in the Hueco Bolson and the Rio Grande alluvium area evolved from qualitatively describing the interaction between the surface water and groundwater to a quantitative understanding of the relationships between pumping, storage decline, natural recharge and leakage from the alluvium.

Empirical and Isotope Data on Induced Recharge

Historical groundwater withdrawals from Juárez and from municipal and military wellfields in the El Paso area have increased from 40,000 acre-ft/year (49,340,000 cubic-meters/yr) in the early 1950's to approximately 180,000 to 190,000 acre-ft/year (222,000,000 to 234,000,000 cubic-meters/yr) after 2000. Reversal of the hydraulic gradient because of heavy pumping in the Hueco Bolson created a significant source of recharge form the Rio Grande and Rio Grande aquifer.

Cross-formational flows between the Rio Grande, Rio Grande aquifer, and Hueco Bolson aquifer are indicated by isotopic and hydraulic head data collected at a multi-level well nest in the El Paso/Juárez Valley (Figures 1, 3, and 4). The Rio Grande is unlined at this location. Wells screened above 200 ft (61 m) are installed in the Rio Grande aquifer and wells screened below 200 ft (61 m) are installed in the Hueco Bolson aquifer. The hydraulic head gradient is oriented vertically downward (Figure 3). Mixing between Rio Grande water, Rio Grande aquifer water, and Hueco Bolson aquifer water is indicated by stable isotope data (Figure 4). Wells at intermediate depths show stable isotope signatures that are intermediate between the isotopically heavy water from the shallowest well in the Rio Grande aquifer (JL-49-21-324) and the isotopically lighter water at the deepest well (JL-49-21-322).

Tritium (^{3}H) data provide clues to the distribution of recharge and relative ages of groundwater. Pre-1950 values for tritium in northern hemisphere precipitation were about 5 tritium units (TU), where one TU is equal to one atom of ^{3}H in 10^{18} atoms of hydrogen. Tritium has a half life of 12.3 years (Mazor, 1991) and ^{3}H values less than about 0.5 TU usually indicate groundwaters recharged before 1952, provided that extensive dilution by older groundwaters has not occurred (Mazor, 1991). Tritium in northern hemisphere precipitation increased to more than 2,000 TU as a result of above-ground testing programs for nuclear weapons in the 1950's and 1960's. Tritium has decreased to near-background levels in recent years (Mazor, 1991).

Tritium is highest in intermediate wells screened between 181 and 358 ft (55 and 109 m) (Figure 4), indicating residual “bomb” tritium, probably recharged between 1960 and 1985. At this distance from the natural recharge areas in the mountains, any tritiated water must have come from the Rio Grande. Post 1952 and tritiated groundwater penetrates to a depth of almost 600 ft 183 m) below ground surface at the well nest (Figure 4). This could develop only because of induced infiltration from the Rio Grande aquifer. The hydrogeologic data indicate downward vertical flow and recharge to the Hueco Bolson aquifer from the Rio Grande aquifer and Rio Grande. Empirical data on induced recharge are site-specific. Modeling studies are employed to provide a regional and quantitative estimate of induced recharge.

Modeling Studies on Induced Recharge

For purposes of this analysis, the Rio Grande alluvium was subdivided into an “urban” area and a “rural” area (Figure 5). The “urban” area was defined generally as the area significantly affected by historic pumping based on a comparison of groundwater flow patterns in 1903 and 2002. The “rural” area was defined generally as the area not significantly affected by pumping based on a comparison of groundwater flow patterns in 1903 and 2002.

The analysis was further extended by considering the groundwater flow from the urban alluvium into and out of the Texas and Chihuahua portions of the Hueco and groundwater flow from the rural alluvium into and out of the Texas and Chihuahua portions of the Hueco. There was also minor flow between the urban and rural alluvium that is not discussed in this analysis. The groundwater budgets for this analysis were developed from the groundwater flow model developed by Heywood and Yager (2003) using ZONEBUDGET (Harbaugh, 1990).

Figure 6 summarizes the flow between the “urban” and “rural” Rio Grande alluvium and the Texas and Chihuahua portions of the Hueco Bolson. Note that negative flows represent flow out of the deeper bolson deposits and into the alluvium, and positive negative numbers represent flow from the alluvium into the deeper bolson deposits.

Between 1903 and about 1940, groundwater in the Texas portion of the Hueco Bolson moved into the urban and rural alluvium. Pumping during these years caused a decrease in the flow rate in the area of the urban alluvium, but the net effect was that the alluvium acted as a discharge area for the Texas portion of the Hueco. Note that in the earliest years, discharge to the alluvium was slightly higher in the urban alluvium than in the rural alluvium. After about 1940, groundwater in the urban alluvium began to recharge the Hueco Bolson in Texas. The rate of this recharge increased until about 1990, when pumping in Texas decreased. The decrease in pumping in Texas resulted in a decrease in the rate of inflow from the alluvium.

In contrast, groundwater from the Texas portion of the Hueco Bolson continues to discharge into the rural portion of the Rio Grande alluvium. The rate of discharge has been slightly affected, but the rural alluvium remains a discharge area for groundwater from the Hueco.

The Chihuahua portion of the Hueco has been recharged from both the urban and rural alluvium since 1903. Note that the rate of recharge prior to significant pumping (about 1940) was higher in the urban alluvium than in the rural alluvium. After the significant increase in pumping, the rate of recharge increased dramatically in the urban alluvium, but remained relatively constant in the rural alluvium. The rural alluvium acted as a minor discharge area of the Chihuahua portion of the Hueco during the drought of the 1950s, but then returned as a recharge source subsequent to the end of the drought.

Conclusions

Environmental isotopes and numerical models verify induced infiltration from the Rio Grande aquifer to the Hueco Bolson aquifer. The amount of induced infiltration is substantial, amounting to nearly 30% of current municipal pumping from El Paso and Juarez. So long as sections of the Rio Grande channel and agricultural channels remain unlined within and below the El Paso-Juarez corridor, the amount of leakage from the Rio Grande/Rio Grande aquifer to the Hueco Bolson will continue to account for most of the current recharge to the bolson. Complementary use of environmental isotopes and numerical models also provided synergistic hydrogeologic analyses.

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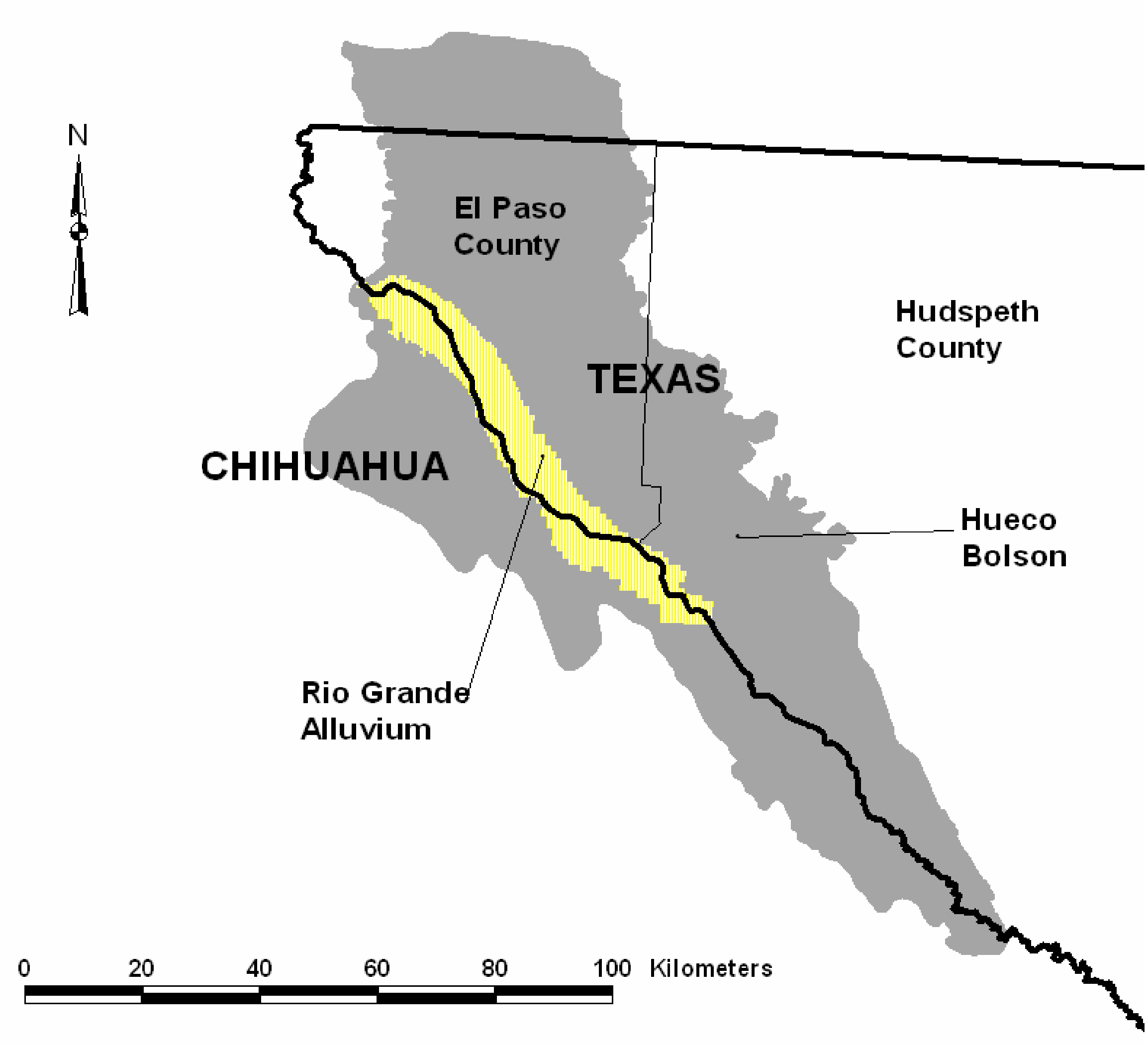


Figure 1. Location of Hueco Bolson and Rio Grande alluvium.

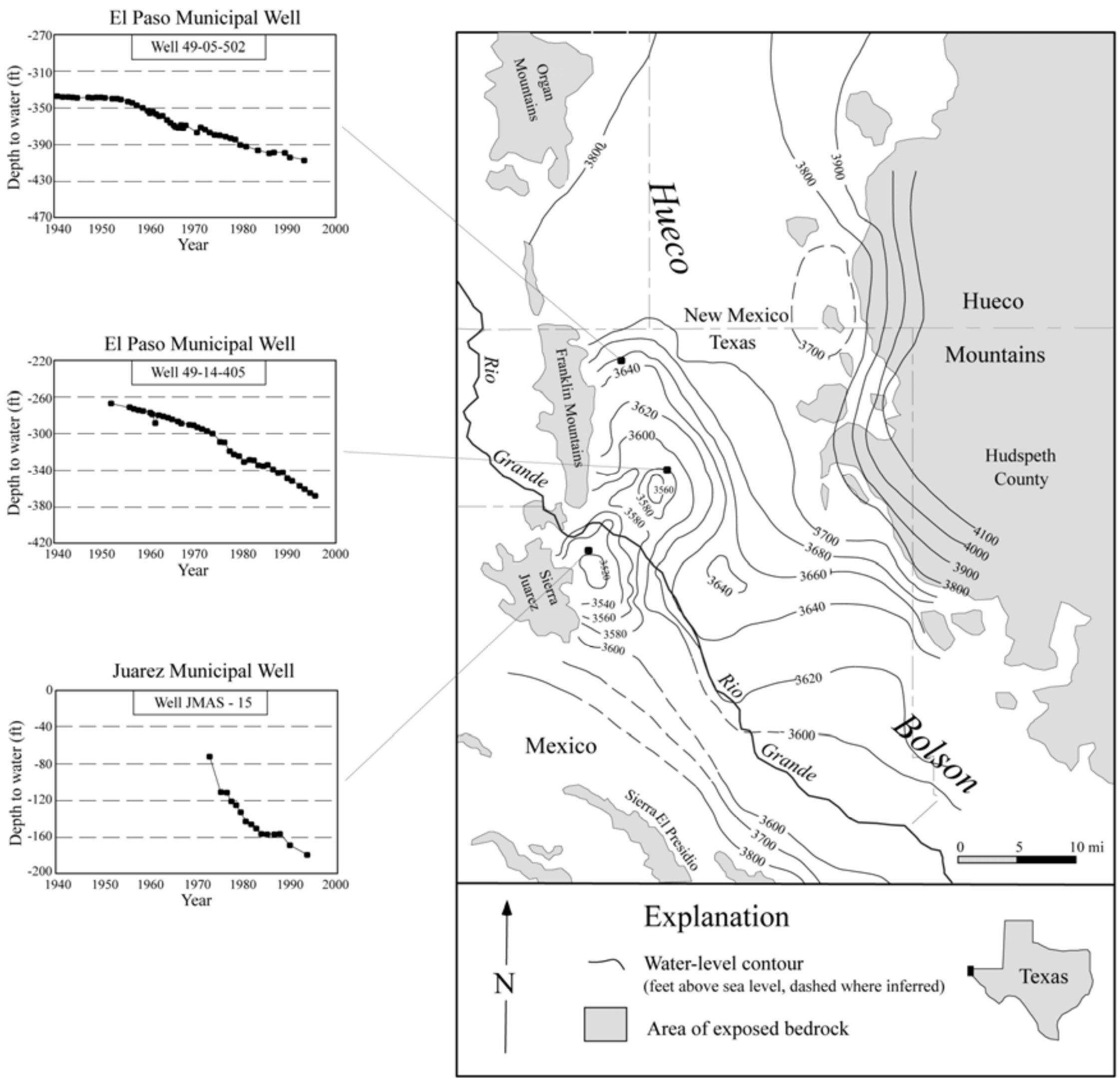
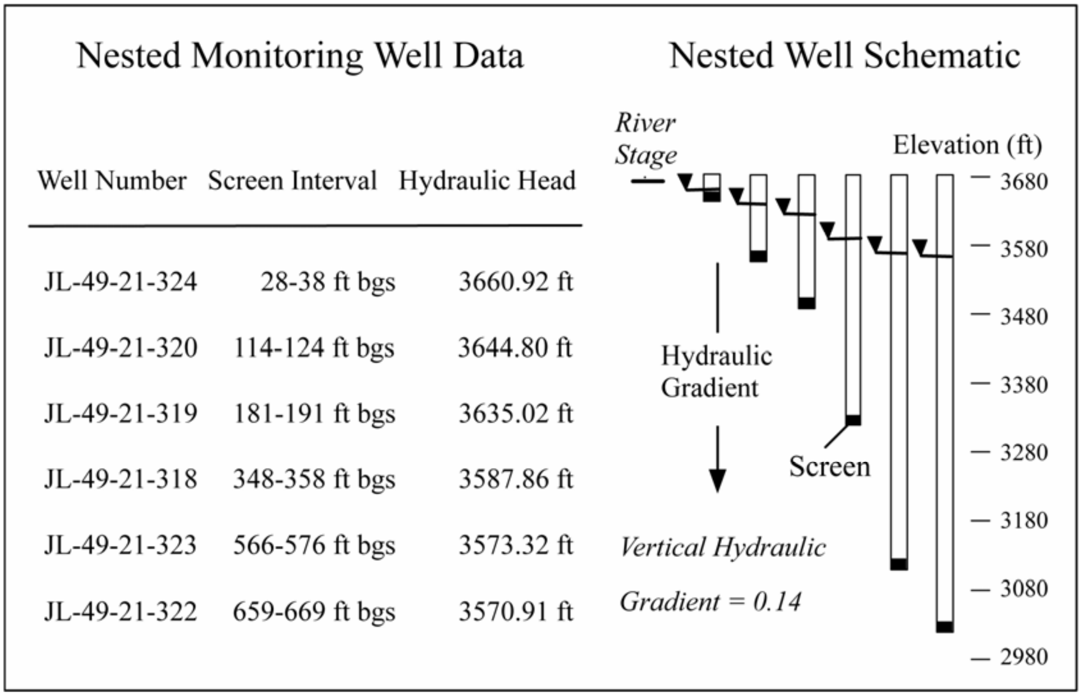


Figure 2. Potentiometric surface map for the Hueco Bolson aquifer, showing water-level drawdown hydrographs in Texas and Mexico (shown by black symbols, well 49-14-405 and JMAS-15 are located in the urban centers of El Paso and Juárez, respectively). Drawdown beneath El Paso and Juárez has reversed predevelopment groundwater flowpaths.



Nested Monitoring Well Data

Well Number	Screen Interval	Hydraulic Head
JL-49-21-324	28-38 ft bgs	3660.92 ft
JL-49-21-320	114-124 ft bgs	3644.80 ft
JL-49-21-319	181-191 ft bgs	3635.02 ft
JL-49-21-318	348-358 ft bgs	3587.86 ft
JL-49-21-323	566-576 ft bgs	3573.32 ft
JL-49-21-322	659-669 ft bgs	3570.91 ft

Figure 3. Hydraulic head data collected from a well nest near an unlined segment of the Rio Grande. The well nest is located approximately 200 ft (61 m) from the Rio Grande. Data indicate downward hydraulic head gradient between the Rio Grande, Rio Grande aquifer (up to 200 ft bgs), and Hueco Bolson aquifer (200 ft and more, bgs).

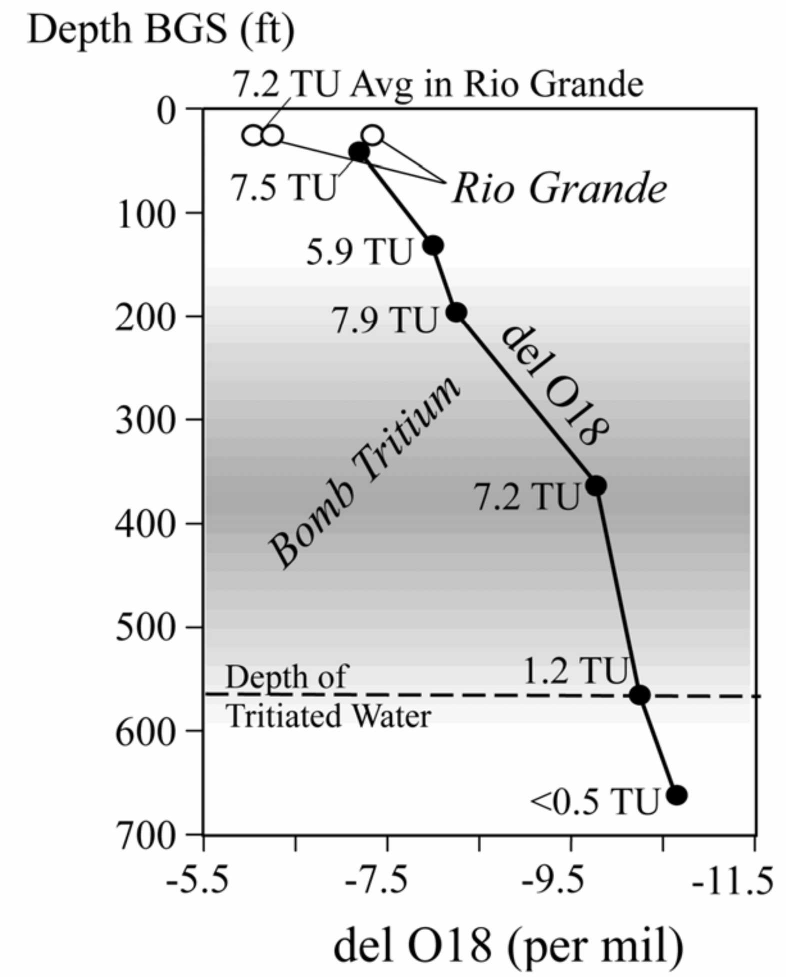


Figure 4. Stable isotope and tritium data collected from the well nest near the Rio Grande. Tritium at depths up to 566 ft (172.5 m) indicates cross-formational leakage from the Rio Grande aquifer to the Hueco Bolson aquifer.

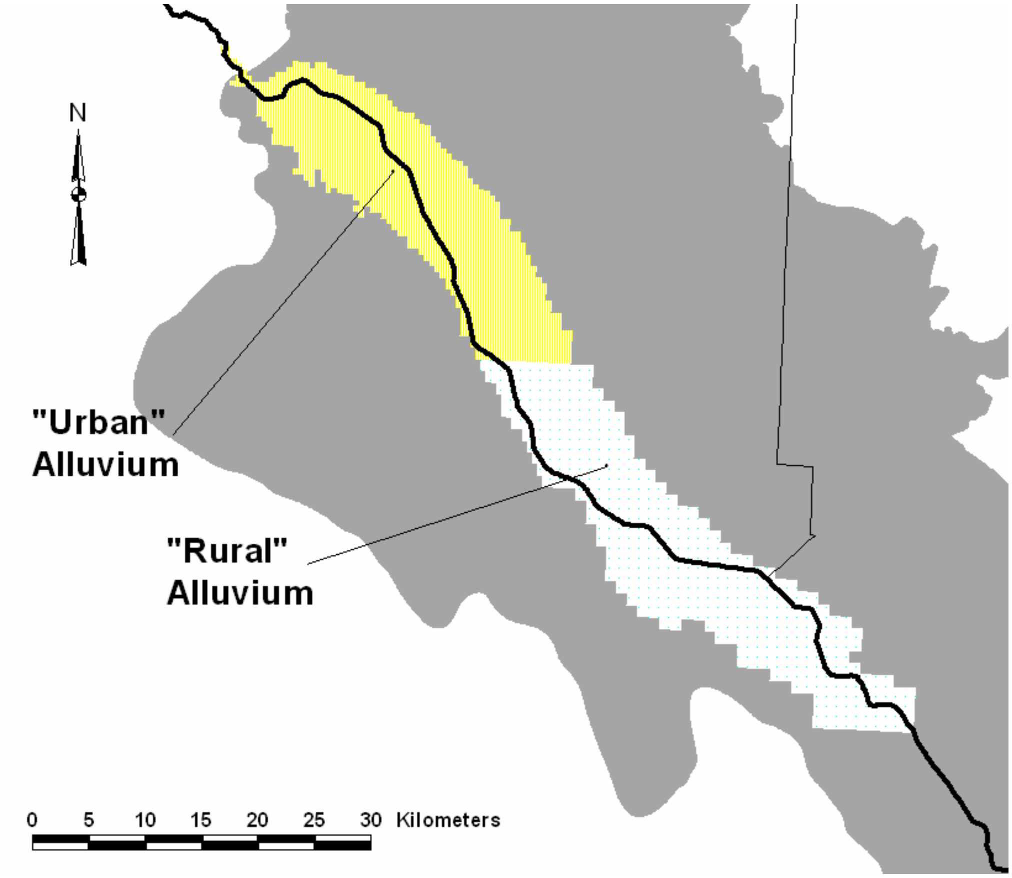


Figure 5. Location of “Urban” and “Rural” alluvium.

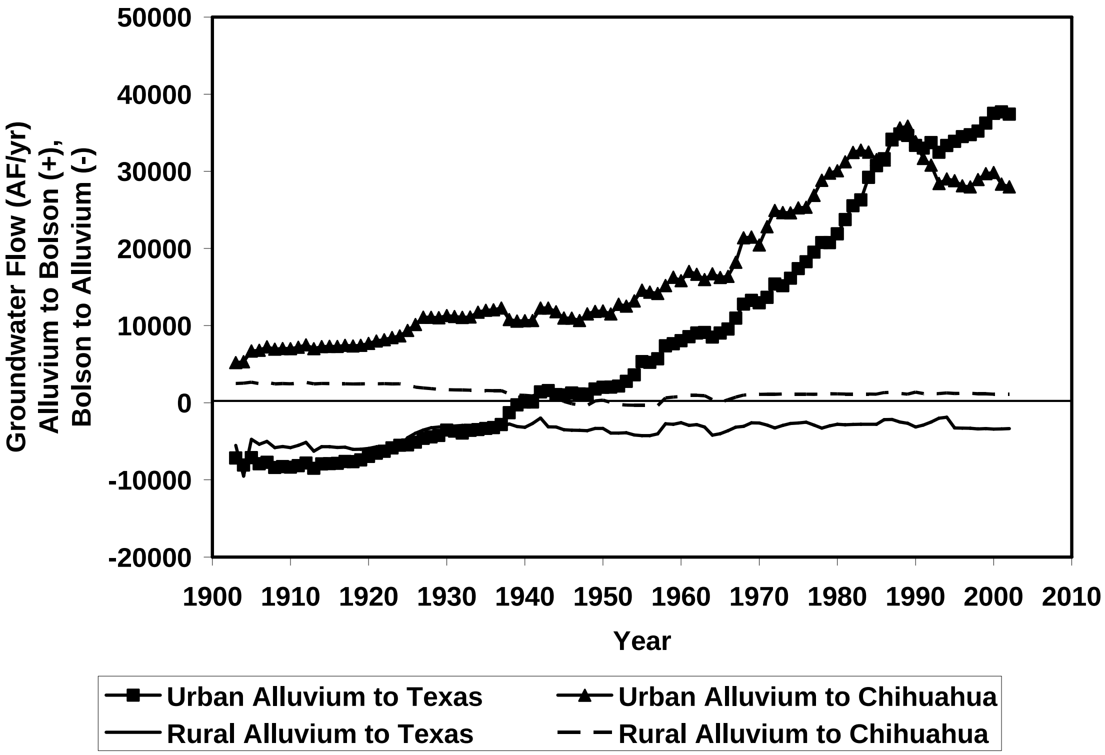


Figure 6. Flow Between Rio Grande alluvium and Hueco Bolson.