

CHAPTER 3 - HUECO-TULAROSA AQUIFER

Location and Extent

The Tularosa Basin extends northward for 170 mi from south-central New Mexico to a gentle surface divide about 7 mi north of the New Mexico/Texas State line. The basin is bounded on the east by the Sacramento and Hueco Mountains and on the west by the San Andres, Organ, and Franklin Mountains. The Tularosa Basin is bounded on the north by Chupadera Mesa. Our study region terminates at the northern edge of Doña Ana and Otero Counties, New Mexico (Figure 3.1), which includes 2,600 mi² of the basin's total surface area.

The surface divide near the New Mexico/Texas State line separates the Tularosa Basin (a closed basin) and the Hueco Basin (a through-flowing basin) topographically. The surface divide does not correspond to a structural or ground-water divide, and the two basins are connected by interbasin ground-water flow from New Mexico into Texas (Wilkins, 1986). Because of the interconnection, the Tularosa and Hueco Basins are considered in this report as one aquifer; the Hueco-Tularosa aquifer. For convenience, the Hueco-Tularosa aquifer is designated to include water bearing strata in both the flanking highlands and saturated bolson fill.

In Texas, the Hueco Bolson extends south from the New Mexico/Texas State line to the Sierra Juarez to the west and to the Sierra El Presidio and Sierra Guadalupe to the south. From the Sierra Juarez, the Hueco Bolson trends southeast to Indian Hot Springs. The part of the Hueco Bolson that extends southeast from the El Paso/Hudspeth County line to Indian Hot Springs is designated herein as the "southeastern Hueco Bolson." The separation is made partly for convenience and partly because of its different geographic orientation, low yield, and limited population. The southeastern Hueco Bolson and associated bedrock aquifers (collectively the southeastern Hueco aquifer) are discussed in the next chapter.

Total surface area of the portion of the Hueco-Tularosa aquifer evaluated in this chapter is 4,160 mi². Approximately 67% of its land area is in New Mexico and 22% of its land area is in Texas. About 11% of its land area is in Mexico. The aquifer is the key source of water for the City of El Paso and Ciudad Juarez, and for military installations and smaller cities in New Mexico and Texas.

Stratigraphy and Water-Bearing Characteristics

Basin geometry

The Tularosa and Hueco Bolsons are asymmetric grabens, bounded by mountains that are mostly tilted fault blocks. Faulting has produced steep escarpments on the east side of the San Andres and Franklin Mountains and moderately steep scarps on the west side of the Sacramento and Hueco Mountains. The trough of these grabens thicken generally from Alkali Flat to the New Mexico/Texas State line (Figure 3.2). From the New Mexico/Texas State line to the international border, the asymmetric shape of the basin and basin fill thickness remain fairly constant (Figure 3.3). Hydrogeologic cross sections show basin fill thickening and inferred geology at three transects across the basin (Figure 3.4). Basin fill thickness increases from a maximum thickness of 3,800 ft at Section A - A' to a maximum thickness of 9,000 ft at Section C - C' (Figure 3.4).

Rock and sediment types

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.

Thick sequences of Paleozoic sedimentary rocks are exposed in the Sacramento Mountains. Precambrian granites, Precambrian metamorphic rocks, and Paleozoic sedimentary rocks are exposed in the San Andres Mountains. The northern Organ Mountains consist of masses of Tertiary intrusive rocks to the north, and Paleozoic, Cretaceous, and lower Tertiary sedimentary rocks to the south. 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 that bounds the Hueco and Tularosa Bolsons consist 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.

Basin fill sediments are usually weakly consolidated, heterogeneous materials that overly Precambrian through Tertiary rocks (Sandeel, 1954; Wilkins, 1986). Non-indurated units in the Tularosa Bolson include gravels, sands, muds and dune deposits; mostly gypsum sand. Weakly and moderately consolidated basin fill deposits include fanglomerates, conglomerates, soft sandstones, caliche, shale, and gypsum. Coarse materials are deposited on the flanks of the mountains and formed as alluvial fans. Lacustrine deposits predominate in the center of the Tularosa Bolson and may correlate to the Fort Hancock deposits in the Hueco and Mesilla Bolsons (Strain, 1966). Gypsum playa deposits are found at Alkali Flat and in earlier deposits that now underlie the White Sands area.

Fort Hancock deposits south of the New Mexico/Texas State line 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. 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). Highly permeable bolson sediments are not abundant near the Hueco Mountains (USBR, 1973). Throughout the basin, the percentage of clay increases generally with depth (Ort and Risser, 1992).

These same general trends are shown by the electrical resistivity cross section D - D' in Mexico (Figure 3.5). Vertical electrical soundings performed in the Hueco Bolson across from San Elizario (G1 to GVI) showed that aquifer resistivities are up to 100 ohm-m in the upper 150 to 650 ft of bolson fill, probably Camp Rice equivalent deposits (Figure 3.5). The high resistivity values suggest potable waters are present in relatively coarse-textured sediments. At depths between 800 and 1,600 ft, the electrical resistivity values are usually less than 15 ohm-m. Such low values imply clay-dominated strata, perhaps Fort Hancock deposits, or strata saturated with slightly to moderately saline pore fluids (de la O Carreno, 1958; Dobrin, 1976; Kearey and Brooks, 1984). At depths greater than 2,000 to 2,500 ft, resistivity values are greater than 20 to 50 ohm-m, suggesting bedrock of probable Cretaceous age.

Southeast of GVI, (GVI to G6), electrical resistivities within the upper 650 ft of bolson fill are mostly less than 8 ohm-m, marking the transition from sand-dominated bolson deposits with potable waters, to clay-dominated bolson fill or coarse-basin fill saturated with inferior quality ground water (Figure 3.5). An exception is between G5A and D' where a 160 ft thick layer of high resistivity material (100 ohm-m) is present. This thin layer probably represents coarse-textured bolson fill that may be associated with arroyo deposits formed along the Bandejas River Arroyo (Geo Fimex, 1970).

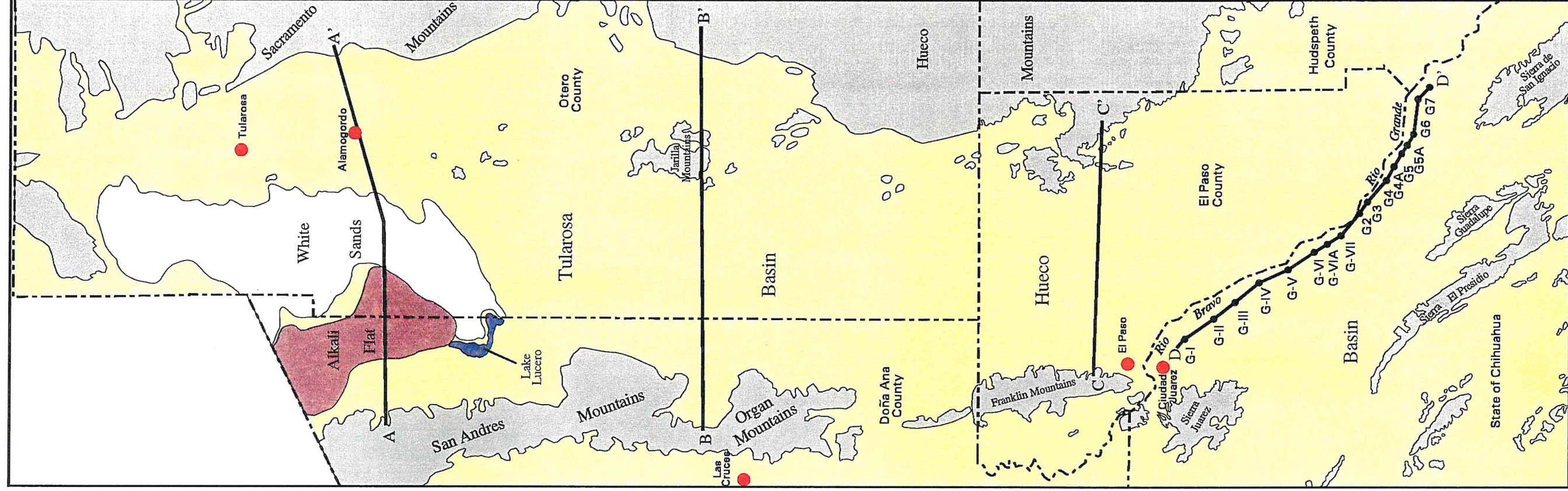
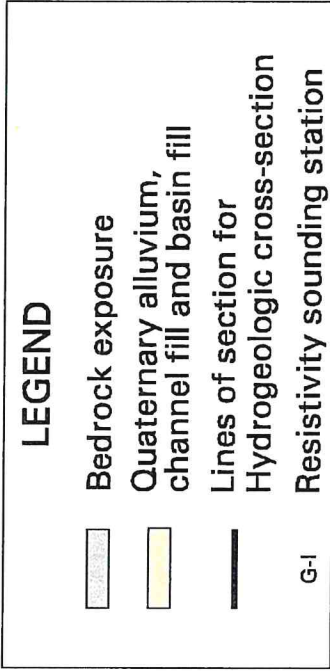
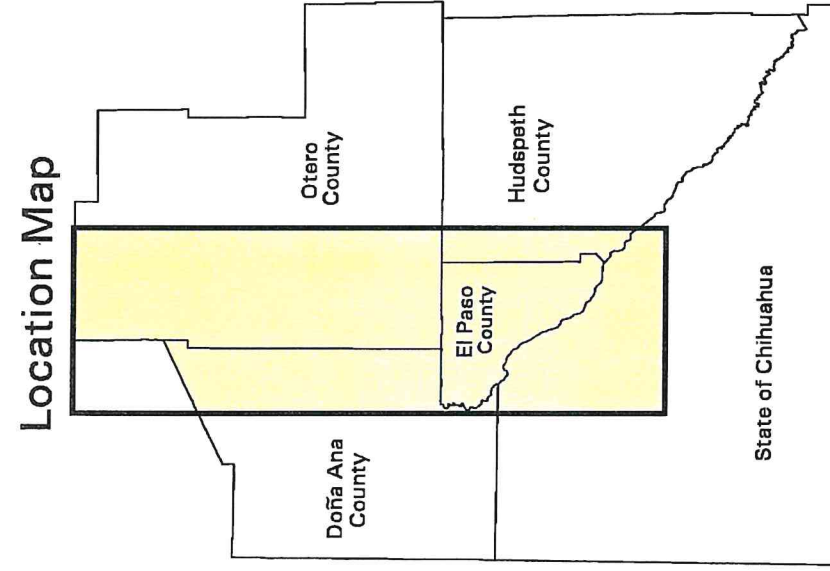
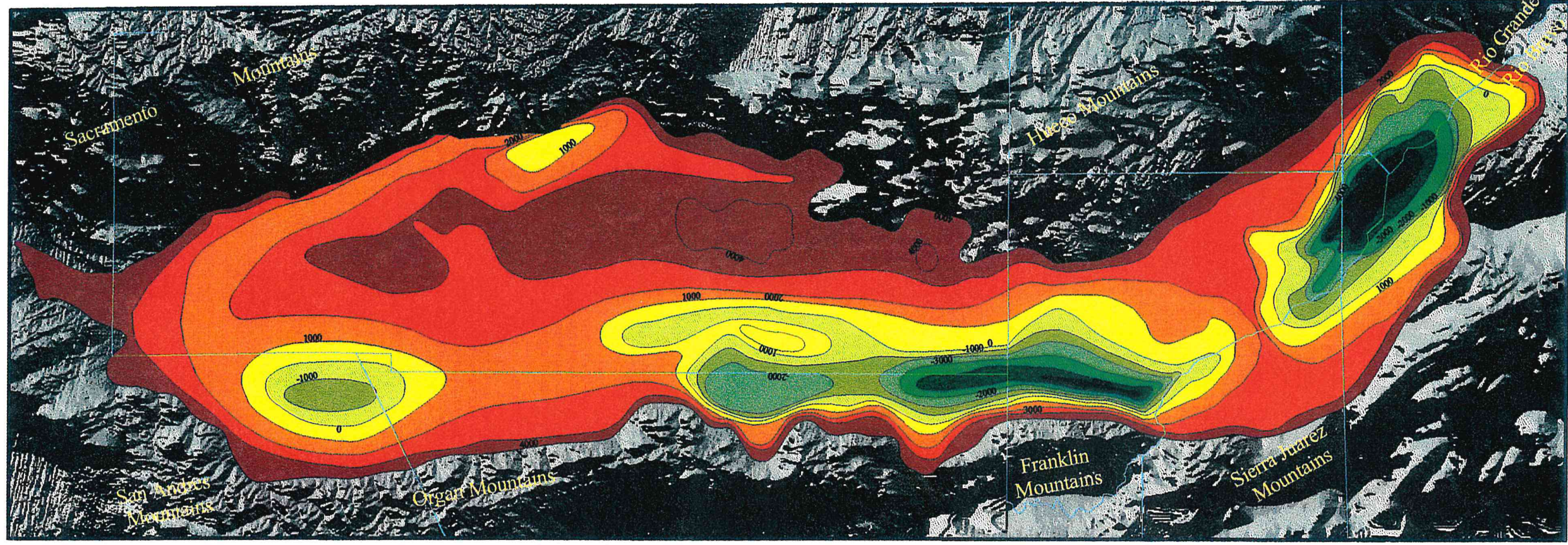
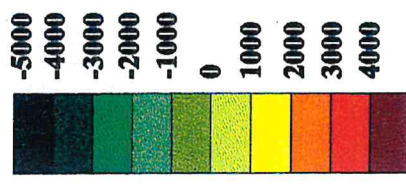


Figure 3.1. Location and extent of the Hueco-Tularosa aquifer.



Elevation of Bedrock Surface
(feet above sea level)



N

0 20 40 Miles

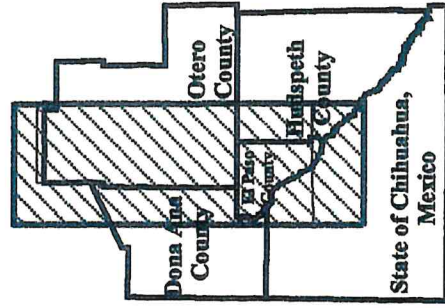
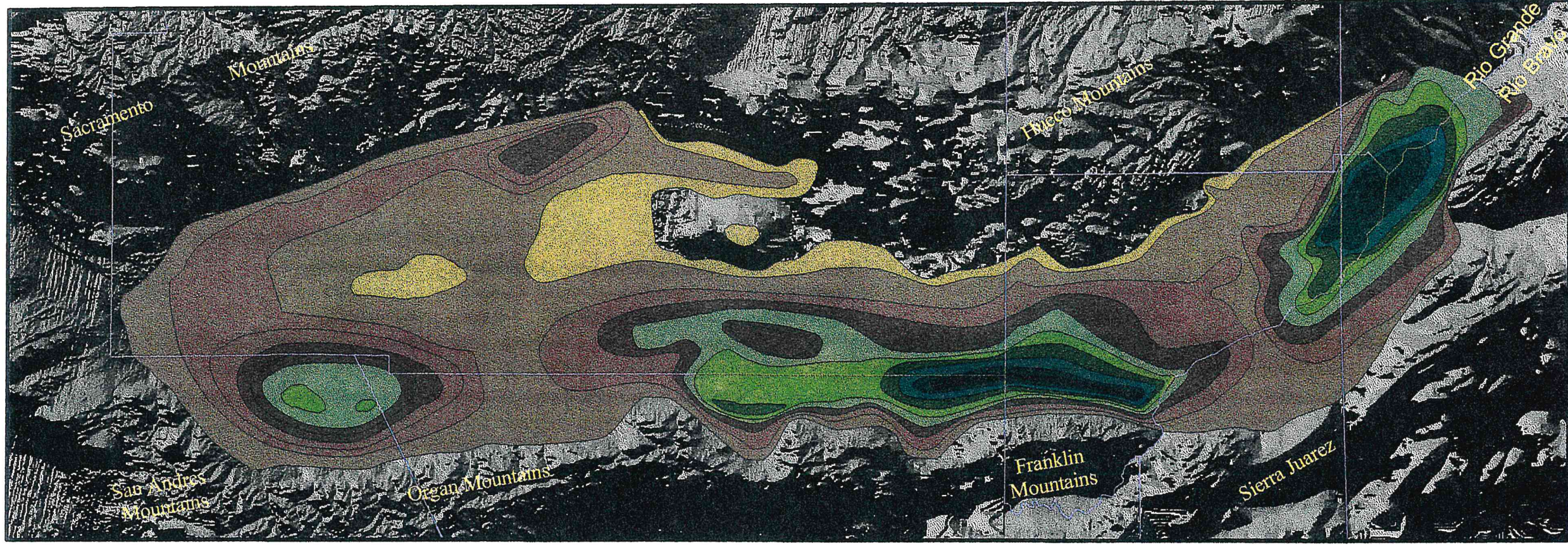


Figure 3.2. Bedrock configuration map beneath the Hueco and Tularosa Basins (source, Davis and Legatt, 1967; McLean, 1970; Lee Wilson and Associates, 1986; Collins and Raney, 1991; map prepared by E. Boghici).



Basin Fill Thickness
(in feet)

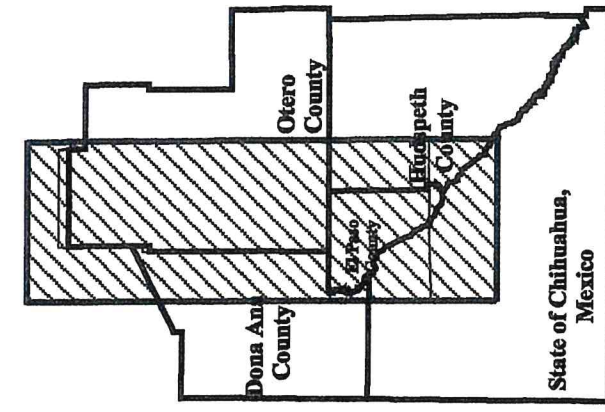
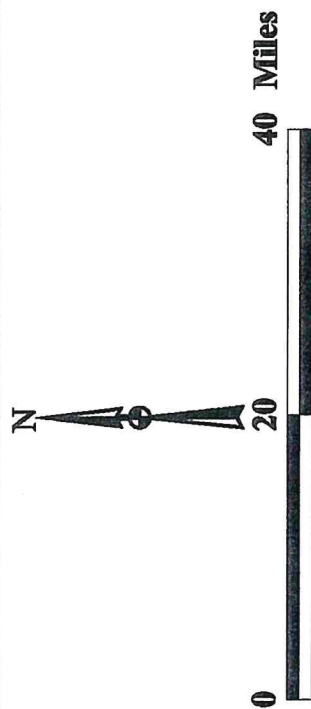
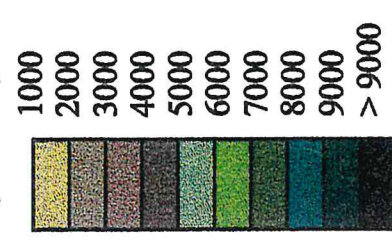
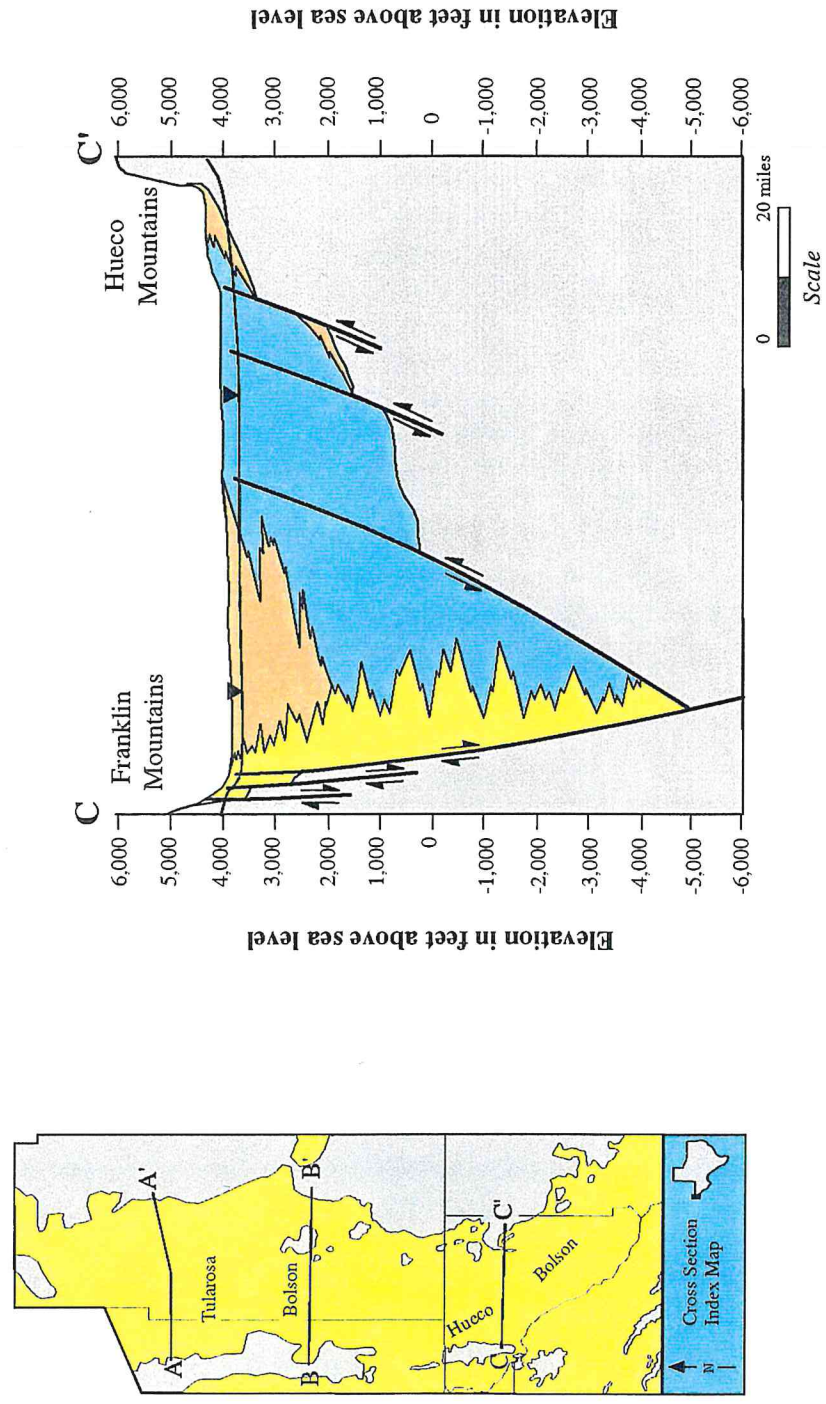
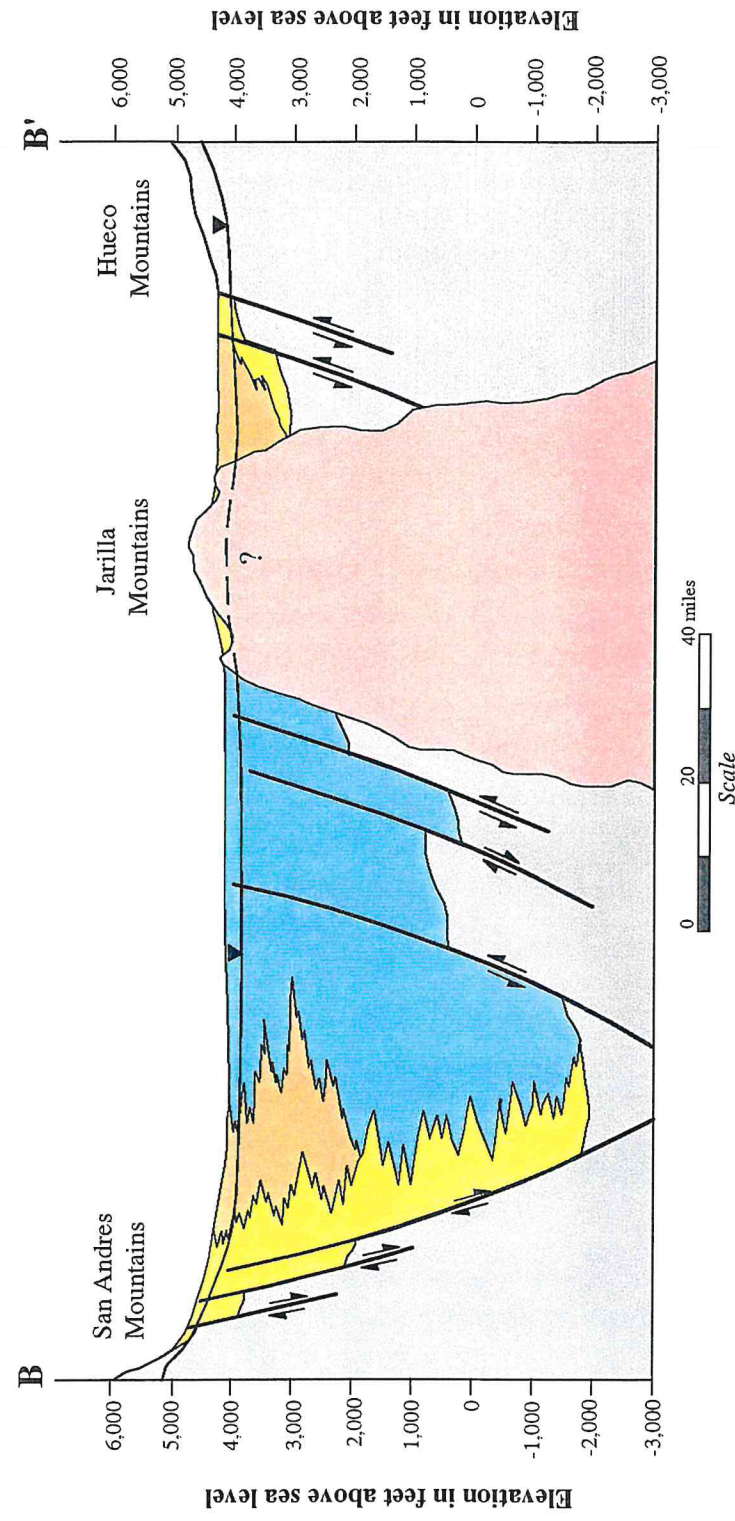
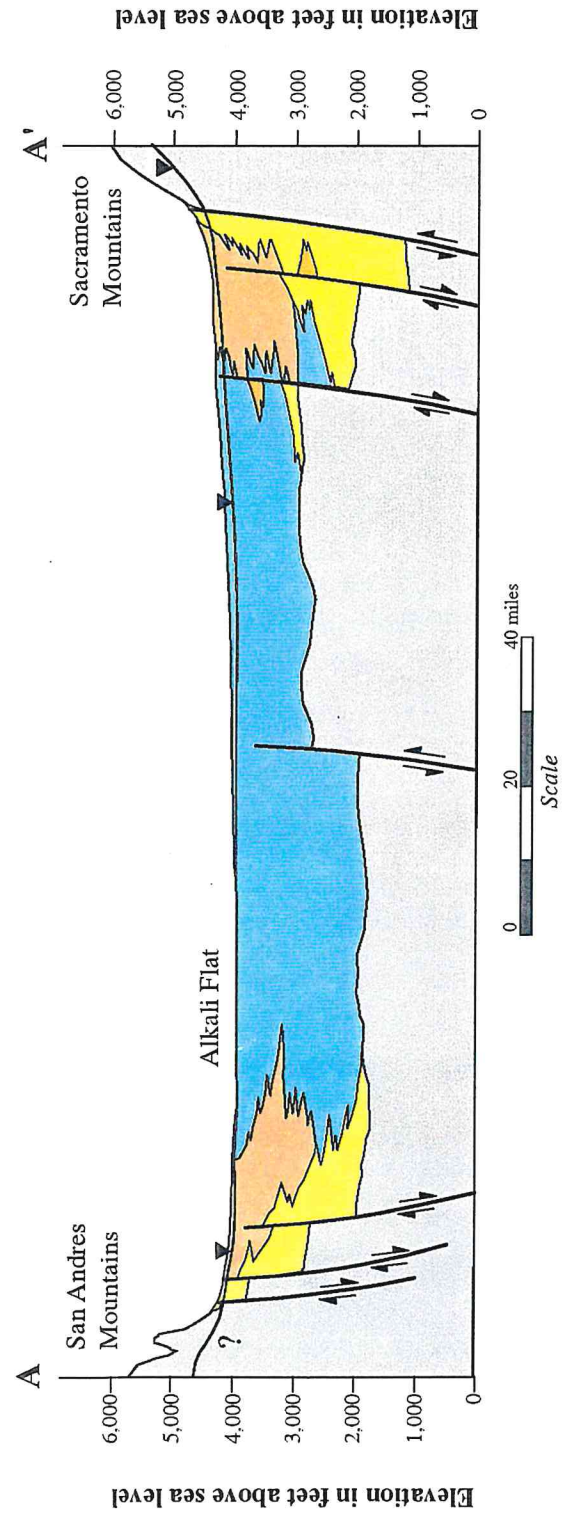


Figure 3.3. Basin fill thickness map for the Hueco and Tularosa Basins (source, Collins and Raney, 1991; Davis and Legatt, 1967; Lee Wilson and Associates, 1986; McLean, 1970; map prepared by E.Boghici).



Explanation



Figure 3.4. Generalized hydrogeologic cross sections A - A', B - B', and C - C' across the Hueco-Tularosa aquifer (Basin fill/bedrock contacts selected from maps prepared by Davis and Legatt, 1967; McLean, 1970; and Lee Wilson and Associates, 1986. Cross section C - C' modified from Lee Wilson and Associates, 1986).

Geoelectric Cross Section D - D' - Juarez Valley, Chihuahua, Mexico

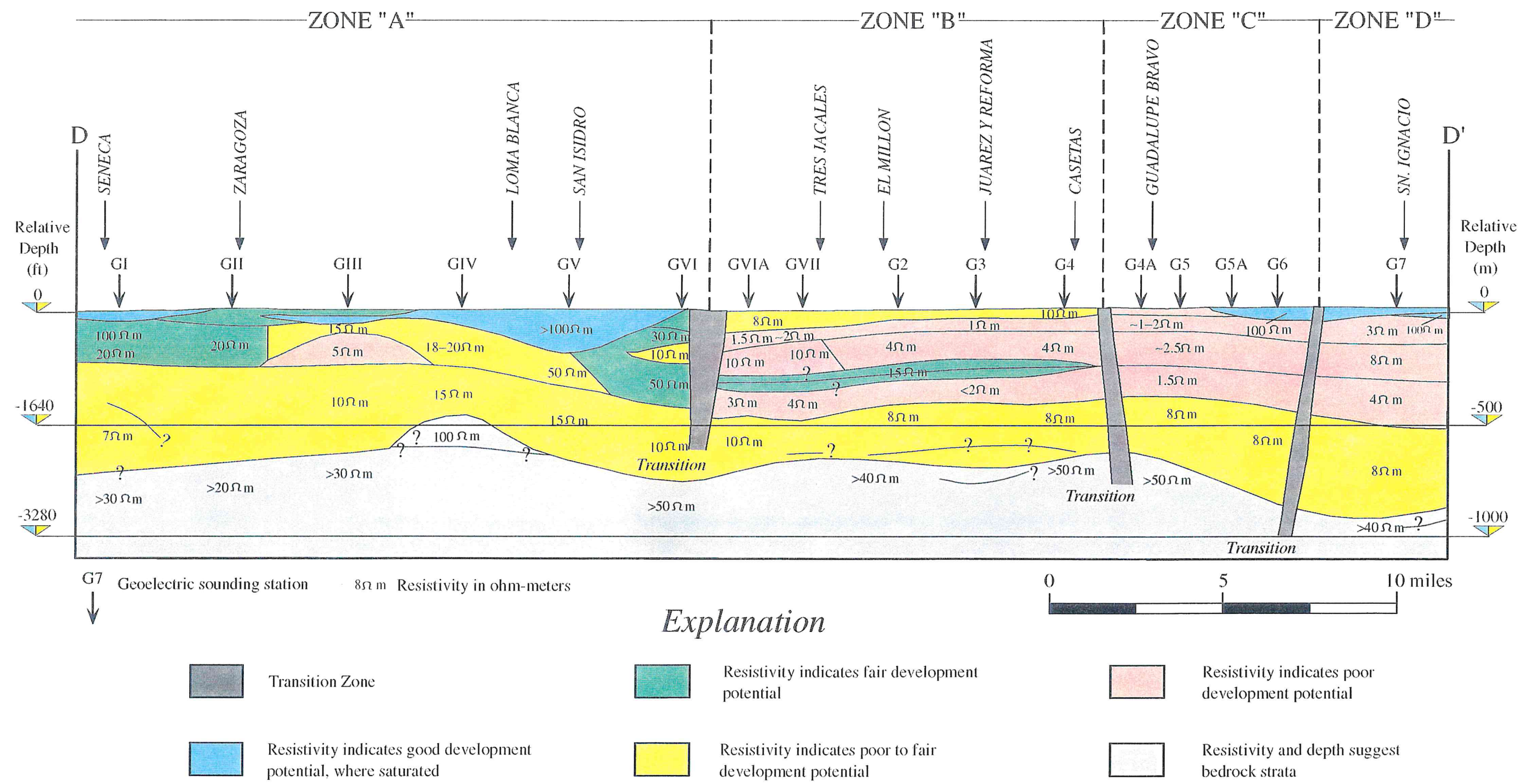


Figure 3.5. Geoelectric cross section D - D' across the Hueco-Tularosa aquifer, northern Chihuahua, Mexico. The map shows interpreted average real resistivities (modified from Geo Fimex, 1970; line of section shown on Figure 3.1).

Aquifer properties

Well yields in the New Mexico part of the Hueco-Tularosa aquifer vary greatly. Most of the wells produce water from alluvial fans that flank the mountains (Orr and Myers, 1986). Well yields of 1,400 gpm are reported at elevations high on the fans decreasing to 300 to 700 gpm at the lower edges of the fans (McLean, 1970). Well yields in the mud-rich sediments toward the center of the Tularosa Bolson are usually less than 100 gpm and sometimes less than 15 gpm (Wilkins, 1986).

Consolidated rock aquifers beneath the mountains, and alluvial fans that flank the highlands generally contain the only potable ground water in the New Mexican part of the Hueco-Tularosa aquifer (Herrick and Davis, 1965; McLean, 1970). The freshwater areas are underlain by saline water at depth. The thickness of the freshwater water lense thins to a feathers edge basinward of the alluvial fans. Few wells are present along the low lying areas of the Tularosa Basin because ground waters beneath the basin floor are not potable generally.

Most of the aquifer test data are from the western part of Hueco-Tularosa aquifer (Lee Wilson and Associates, 1986; Orr and Myers, 1986). Transmissivity estimates at the western part of the Tularosa Basin were derived from aquifer tests in alluvial fans primarily. Transmissivity estimates are available mostly for the Soledad Canyon re-entrant and adjacent areas. A few values are available for White Sands re-entrant. Transmissivity estimates on the west side of the basin vary from 160 to 79,000 ft²/day (Orr and Myers, 1986).

Aquifer tests indicate that the water bearing strata have large ranges of transmissivity and hydraulic conductivity, especially in the Tularosa Bolson (Figures 3.6 and 3.7). Variable saturated thicknesses and variations in sorting and grain size account for variability of aquifer parameters (Orr and Myers, 1986). The variability of heterogeneity is controlled mostly by the het-

erogeneous deposition of muds, sands, and gravels; by the degree of sediment sorting (usually poor); and by basinward "sieving" along arroyos and drainage areas. Coarse-textured sand and gravel deposited at elevations high in alluvial fans are succeeded by sands and muds at the basinward edges of the fans due to lower transport energies closer to the valley floor. The percentage of sand in alluvial fan material reportedly varies from 12 to more than 95 percent on the western side of the Tularosa Basin (Orr and Myers, 1986). Sand percentages decrease basinward of the flanking highlands.

On the eastern side of the basin, ground-water data are available primarily from wellfields at Holloman Air Force Base, the City of Alamogordo, and irrigated regions near the City of Tularosa. Transmissivity data from 7 aquifer tests were located for this region and values range from 400 to 5,000 ft²/day. McLean (1970) indicated that transmissivities in the alluvial fan material on the eastern side of the basin may range up to 20,000 ft²/day along the mountain front, but these higher values were not found in the published literature. Most ground-water development and well test information on the east side of the basin are poorly documented (Orr and Myers, 1986).

South of the New Mexico/Texas State line, well yields in the alluvial fan and Camp Rice deposits east of the Franklin Mountains yield as much as 1,800 gpm (Wilkins, 1986). Transmissivity values in wells along the northern part of El Paso County vary typically from 4,000 to 28,000 ft²/day. Fresh water deposits underlying the central and southern part of the City of El Paso have transmissivity values that vary typically from 4,000 to 15,000 ft²/day. Yields from these wells are 500 to 800 gpm (IBWC, 1989). Wells underlying Ciudad Juarez yield from 300 to 1,500 gpm (IBWC, 1989). Transmissivity values of the Hueco Bolson underlying Ciudad Juarez vary from 14,000 to 24,000 ft²/day (IBWC, 1989). The storage coefficient of the Hueco Bolson has been measured in the range of 0.093 to 0.000286 (Lee Wilson & Associates, 1986).

Published hydraulic conductivity values derived from 37 aquifer tests in the Tularosa Bolson vary from 1.0 to 320.0 ft/day (Figure 3.7). Most values are between 4.0 and 63.0 ft/day. Ranges illustrate the heterogeneity of alluvial fan sediments. Published hydraulic conductivity values derived from 73 aquifer tests in the Hueco Bolson vary from 6.4 to 98.9 ft/day (Figure 3.7). The range is smaller in the Hueco Bolson and follows a slightly skewed log probability distribution (almost log normal).

Comparison of hydraulic conductivity values between the Tularosa and Hueco Bolsons suggest more homogeneous aquifer strata in the Hueco Bolson (Figure 3.7). Wells in the Hueco Bolson are installed primarily in Camp Rice deposits, a moderately sorted, mostly fluvial deposit. The alluvial fan deposits in New Mexico have a much wider range of hydraulic conductivity due to poor sorting and extreme heterogeneity. Equivalent Camp Rice deposits in the Tularosa Bolson either do not exist or are saturated with saline ground waters and are not developed.

Potentiometric Surface Map and Water Levels

Near the cities of Tularosa and Alamogordo, on the eastern flank of the Tularosa Basin, the potentiometric surface map slopes to the southwest with a hydraulic gradient of 0.01 - 0.0019 (Figure 3.8). Hydraulic head exceeds 4,400 ft along the Sacramento Mountains and defines areas of mountain front recharge. Hydraulic head exceeds 4,100 ft and hydraulic gradients are about 0.04 along the White Sands re-entrant, a narrow gap between the Organ and San Andres Mountains. White Sands re-entrant is a less prolific recharge area.

Along the basin floor, the hydraulic gradient is extremely flat (~0.0001) between Alkali Flat and the New Mexico/Texas State line. An almost imperceptible ground-water divide may be present at White Sands that separates ground water recharged north of White Sands from southward flowing ground water that moves into the Hueco Bolson. Ground water moves

south from the Tularosa Basin into the Hueco Basin and eventually moves into Texas across the New Mexico/Texas State line.

In El Paso County hydraulic gradients are steep (0.02) on the Hueco Mountains and are probably even steeper on the Franklin Mountains. Data are not sufficient to map hydraulic head at the Franklin Mountains. Ground water tends to flow along the axis of the basin toward the Rio Grande, except where large pumping cones of depression beneath the City of El Paso and Ciudad Juarez have reversed the natural hydraulic gradient. These cones of depression have created an artificial ground-water divide just north of the Rio Grande (Figure 3.8).

Depth to ground water in the Hueco-Tularosa aquifer is variable. Depth to ground water near the Cities of Tularosa and Alamogordo at the flanks of the Sacramento Mountains is between 20 and 150 ft. Drawdowns in many municipal wells, up to 100 ft, have been recorded in this area (Figure 3.9). Ground water is at or near ground surface at Alkali Flat due to evaporative discharge from the wet gypsum playa.

Depth to ground water near the White Sands Missile Range Headquarters, at interior portions of the basin, is up to 400 ft. Little drawdown has been recorded there (Figure 3.9). Drawdowns in the Hueco Bolson near the New Mexico/Texas State line has been relatively small, not exceeding 5 - 30 ft. Depth to ground water in this area is about 300 - 350 ft.

South of the New Mexico/Texas State line, drawdowns since 1940 are up to 150 ft. Pumping cones of depression in municipal wellfields are the focal points of drawdown. Most of the drawdowns near municipal wellfields vary from 50 to 100 ft (Figure 3.9). Some of the highest rates of drawdown have occurred beneath Ciudad Juarez; for example, over 100 ft of drawdown has been recorded at JMAS-15 in less than 25 years (Figure 3.9). Steep rates of decline are shown for most of the other municipal wells in Ciudad Juarez. A drawdown map computed with water-level data collected

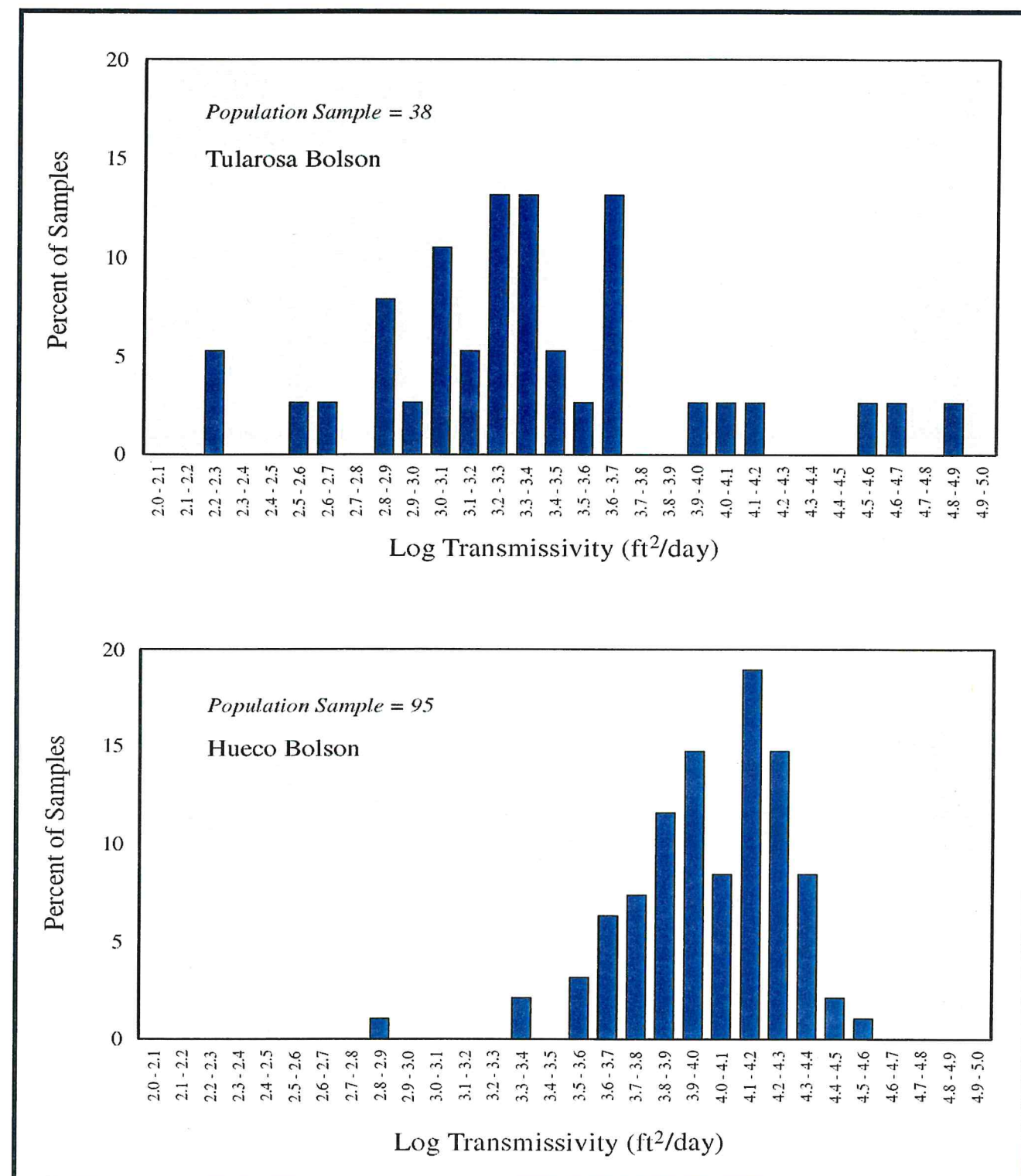


Figure 3.6. Comparison of transmissivity values derived from aquifer tests in the Tularosa and Hueco Bolsons (source of data, Kelly and Hearne, 1976; Lee Wilson and Associates, 1986; Orr and Myers, 1986).

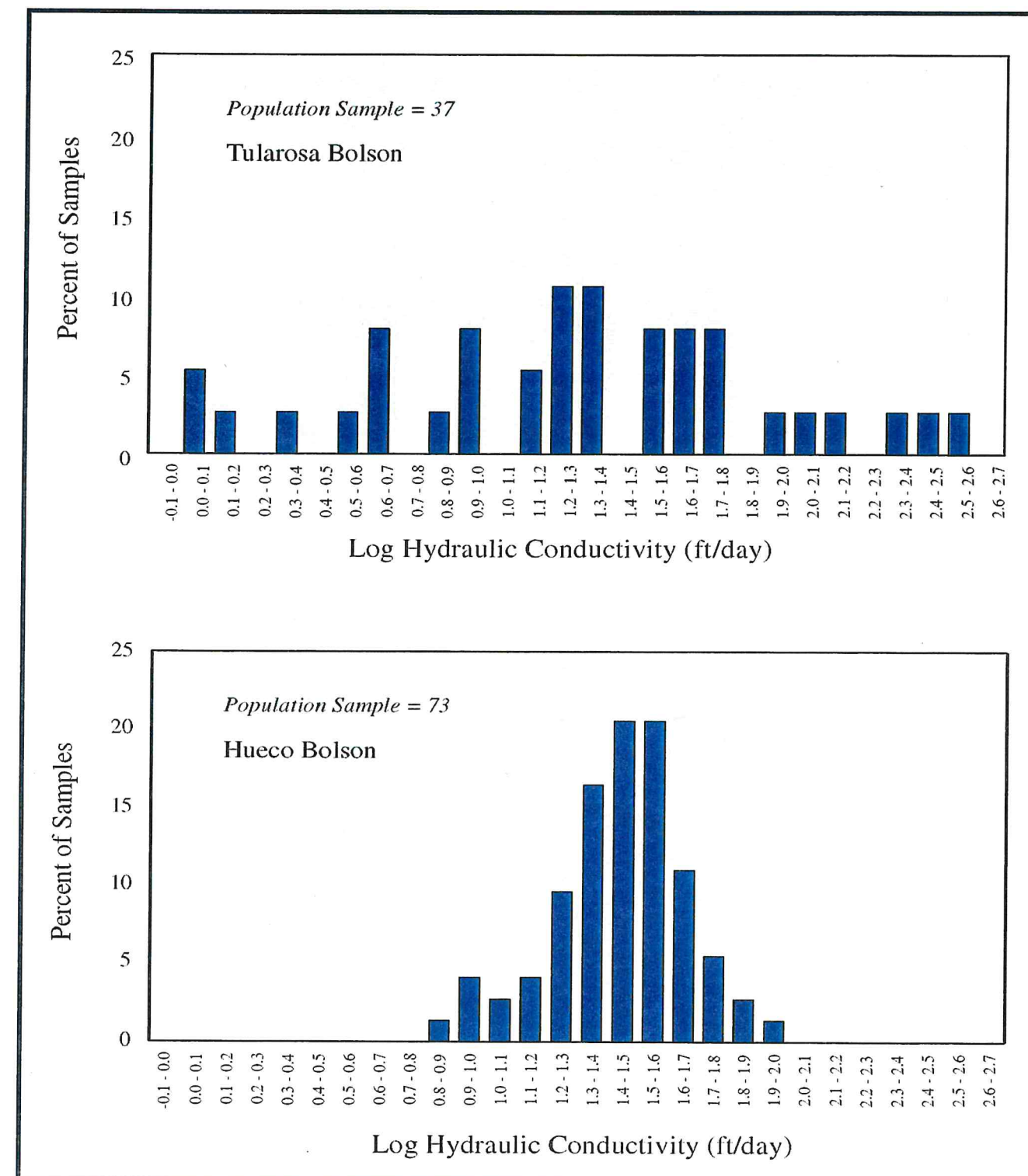
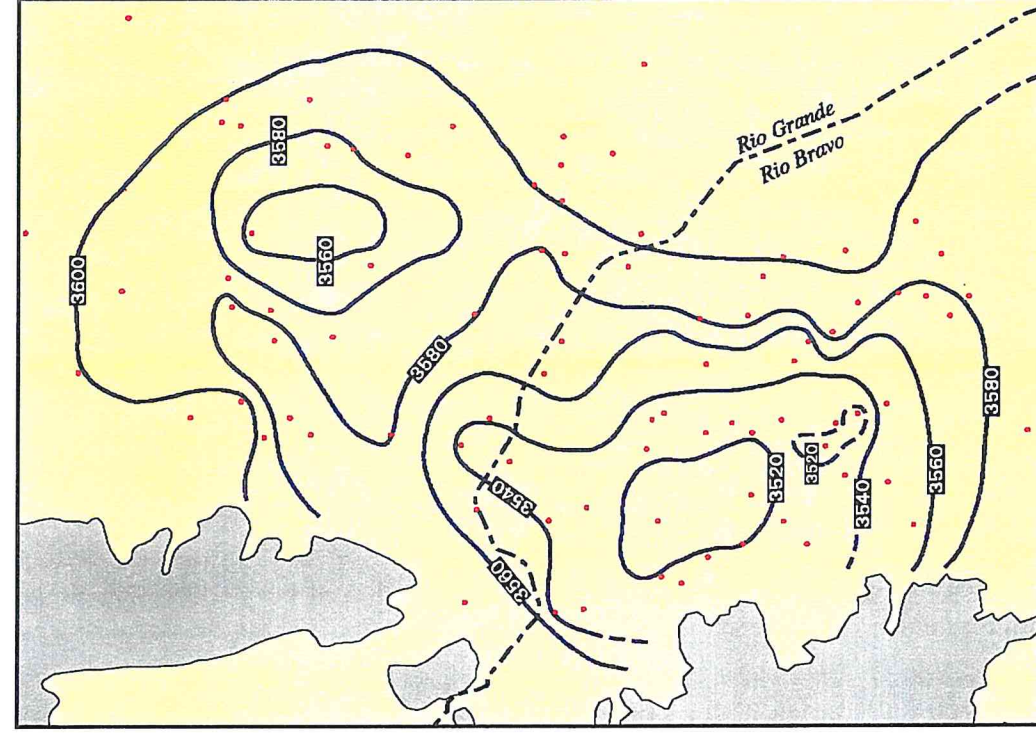
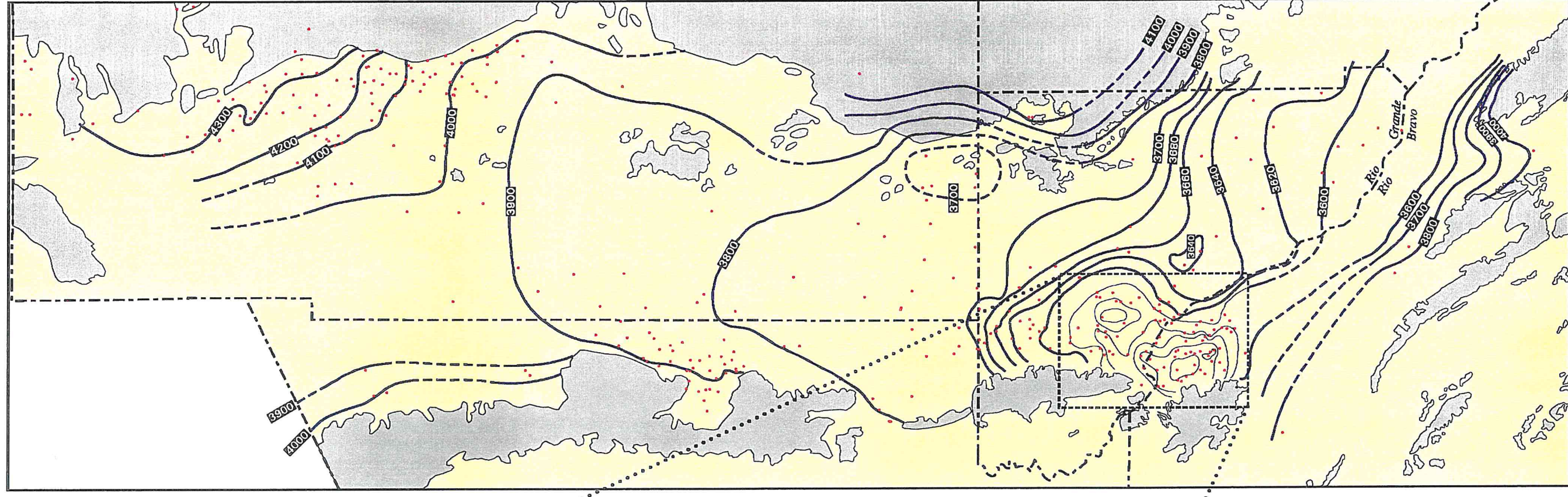
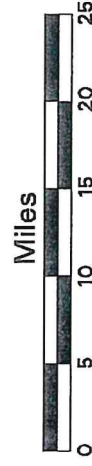
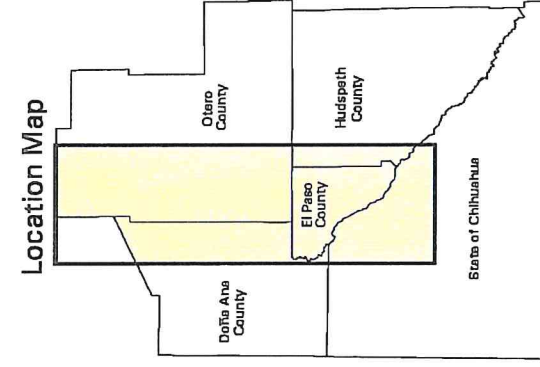


Figure 3.7. Comparison of hydraulic conductivity values derived from aquifer tests in the Tularosa and Hueco Bolsons (source of data, Kelly and Hearne, 1976; Lee Wilson and Associates, 1986; Orr and Myers, 1986).

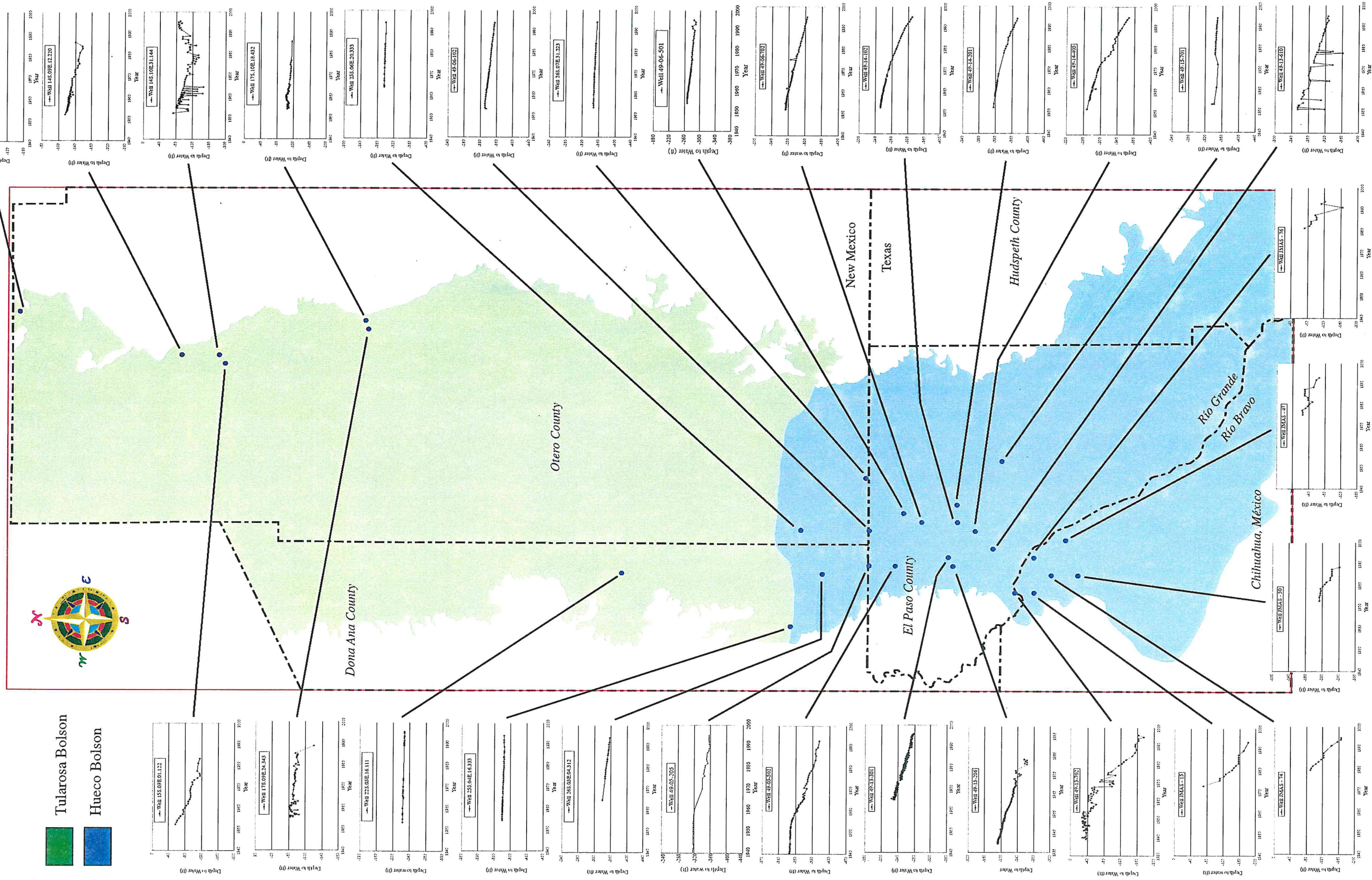


LEGEND

-  Bedrock exposure
-  Quaternary alluvium, channel fill and basin fill
-  Well control points
-  Water-level contour
-  Dashed where inferred
- NOTE:** Contour interval varies in feet

Figure 3.8. Regional potentiometric surface map for the Hueco-Tularosa aquifer, illustrating an inset potentiometric surface map for the City of El Paso and Ciudad Juarez. Data for the City of El Paso and Ciudad Juarez inset diagram gathered in 1994. Other data in less developed and undeveloped areas gathered at various times. We assume quasi-steady state ground-water flow in undeveloped areas (source of data, Comision Nacional del Agua; Junta Municipal de Agua y Saneamiento; Instituto Nacional de Estadística, Geografía e Informática; Texas Water Development Board; U.S. Geological Survey).

Figure 3.9. Time series hydrographs for the Hueco-Tularosa aquifer (source of data, Junta Municipal de Agua y Saneamiento; Texas Water Development Board; U.S. Geological Survey).



between 1987/1988 and 1992/1993 presents draw-downs in the Hueco Bolson beneath the City of El Paso and Ciudad Juarez (Figure 3.10). Focal points of drawdown are shown beneath both cities.

Ground-Water Availability

Several ground-water availability studies have been conducted to estimate the amount of recoverable fresh and slightly saline ground water in the Hueco-Tularosa aquifer. Calculations require an estimate of the volume of saturated sediments, both fresh and slightly saline, and an estimate of the specific yield of the sediments. Recoverable resources are computed by multiplying the specific yield by the volume of fresh or slightly saline ground waters. Historical estimates of recoverable resources in the Hueco-Tularosa aquifer (mostly bolson material) include (compiled by Lee Wilson and Associates, 1986):

- The Hueco Bolson in Texas contains 7,400,000 acre-ft of recoverable ground water with less than 250 mg/L Cl (about 750 mg/L TDS). The quantity of recoverable ground water in New Mexico is 6,200,000 acre-ft (Knowles and Kennedy, 1956).
- The quantity of freshwater in the Hueco Basin in New Mexico (including the western part of the Tularosa Basin) is about 17,000,000 acre-ft (McLean, 1970).
- Recoverable storage of freshwater in the Texas part of the Hueco Bolson is estimated to total about 10,640,000 acre-ft; another 4,000,000 acre-ft is potentially recoverable from the Mexican part of the Hueco Bolson (Meyer, 1976).
- The Texas segment of the Hueco Bolson contains 9,950,000 acre-ft of recoverable fresh water (<1,000 TDS) and 110,000 acre ft of slightly saline water (TDS between 1,000 and 1,500 mg/L). An additional 4,000,000 acre-ft

of ground water in storage with TDS between 1,000 and 3,000 mg/L is theoretically recoverable (White, 1987).

White's (1987) estimates were derived for the year 1980. Between 1981 and 1991, approximately 990,000 acre-ft of mostly freshwater was pumped from the Texas portion of the Hueco Bolson by military bases and by the City of El Paso. Using an estimated recharge rate (natural and artificial) of between 10,000 and 14,000 acre-ft/year during this time frame (Meyer, 1976; Orr and Risser, 1992; USEPA, 1995), the remaining volume of fresh ground water in storage in the Texas portion of the Hueco Bolson at the end of 1991 was about 9,100,000 acre-ft; although, perhaps an additional 100,000 - 150,000 acre-ft was captured from the Texas part of the Hueco Bolson by Ciudad Juarez and other ground-water pumpers in Texas and Mexico. Information is lacking to make similar estimates in the Mexican part of the Hueco-Tularosa aquifer.

Using numerical models and projected pumping rates, Meyer (1976) predicted that 7,400,000 acre-ft of freshwater would be available in the Texas portion of the Hueco Bolson in the year 2020. Knowles and Alvarez (1979) used Meyer's model and higher projected pumping rates and predicted the amount of freshwater remaining in storage would be about 5,600,000 acre-ft. Conversion to surface water, conservation and water recycling and reuse, and exploitation of other ground-water basins may be required for these estimates not to be met or exceeded (Ashworth, 1990).

Recharge Areas

Recharge to the New Mexican part of the Hueco-Tularosa aquifer is mostly by mountain front recharge along the mountains that flank the highlands. Mountain front recharge occurs at ephemeral streams and arroyos that are incised in bedrock and alluvial fans around the perimeters of bolsons (Figure 3.11). Ephemeral streams have steep gradients in mountains that slope gradually where the ephemeral channels

overlie alluvial fans. Some recharge occurs directly on mountain surfaces. Recharge is ordinarily greater on the alluvial fans except where calcic zones are well developed in soil profiles in the fan sediments (Hibbs and Darling, 1995). These zones impede infiltration and act as surfaces for runoff across the broad alluvial fans. Mountain surfaces can be a more prominent recharge area where calcic zones are well developed in alluvial fans. Alluvial fans formed by erosion of carbonate rocks have well developed calcic zones, whereas fans formed from erosion of crystalline intrusive and extrusive and metamorphic rocks have moderately-to-poorly developed calcic horizons (Darling and others, 1994). Infiltration rates and storage are usually lower in crystalline and metamorphic rocks, which accentuates surface runoff and recharge at the fans.

Most of the mountain and mountain front recharge occurs from widespread winter frontal systems of low intensity and long duration. High-intensity and localized thundershowers during the summer months produce short duration flows and limited recharge (Wilkins, 1986). Precipitation recharge is usually absent along basin floors due to the substantial excess of evapotranspiration over precipitation, and great depth to ground water. Fine textured soils and caliche line sediments on the basin floor and impede infiltration along drainages and dry plays.

Recharge to the Texas and Mexican parts of the Hueco-Tularosa aquifer is by mountain and mountain front recharge and by cross-formational flow from the Rio Grande alluvium. Other sources of recharge include interbasin ground-water flow from the Tularosa Bolson to the Hueco Bolson, underflow from the Mesilla Bolson through Fillmore Pass, and wastewater injection at the Fred Harvey wastewater treatment plant (Figure 3.12).

Mountain front recharge is mostly along the Franklin Mountains on the American side of the bolson and along the Sierra Juarez, Sierra El Presidio, and Sierra Guadalupe on the Mexican side of the bolson.

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 along the Chamizal zone. 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.

Total recharge to the Hueco-Tularosa aquifer is not easy to estimate. Meinzer and Hare (1915) estimated that recharge to the Tularosa Basin exceeds 100,000 acre-ft/year. This estimate is probably excessive. Much of the older literature assumed that recharge to the desert basin is a significant percentage of the precipitation falling on mountain drainage areas. Sayre and Livingston (1945) for example, estimated that mountain front recharge to the Hueco Bolson is approximately 25% of precipitation falling on mountain and mountain front surfaces. More recent studies, bolstered by environmental isotopes and numerical models, indicate that recharge along mountains and mountain fronts is a smaller percentage of precipitation falling on mountain drainage areas; perhaps 1 to 3% (Kelly and Hearne, 1976; Orr and Risser, 1992).

Model studies predicted that 5,600 acre-ft/year comes from mountain front recharge to the Hueco Bolson (Meyer, 1976). Model analysis indicated that the recharge from the Rio Grande alluvium to the Hueco Bolson was 33,278 acre-ft/year between 1968 and 1973 (White, 1987). Lining of the Rio Grande channel in 1973 along the Chamizal zone with a low permeability grout reduced recharge by the Rio Grande significantly. Simulated recharge from underflow from the Tularosa Basin is about 3,700 acre-ft/year (Orr and Risser, 1992). Simulated recharge from underflow through Fillmore Pass is about 260 acre-ft/year (Orr and Risser, 1992).

The injection of treated wastewater at the Fred Harvey Wastewater Treatment Plant provides a limited

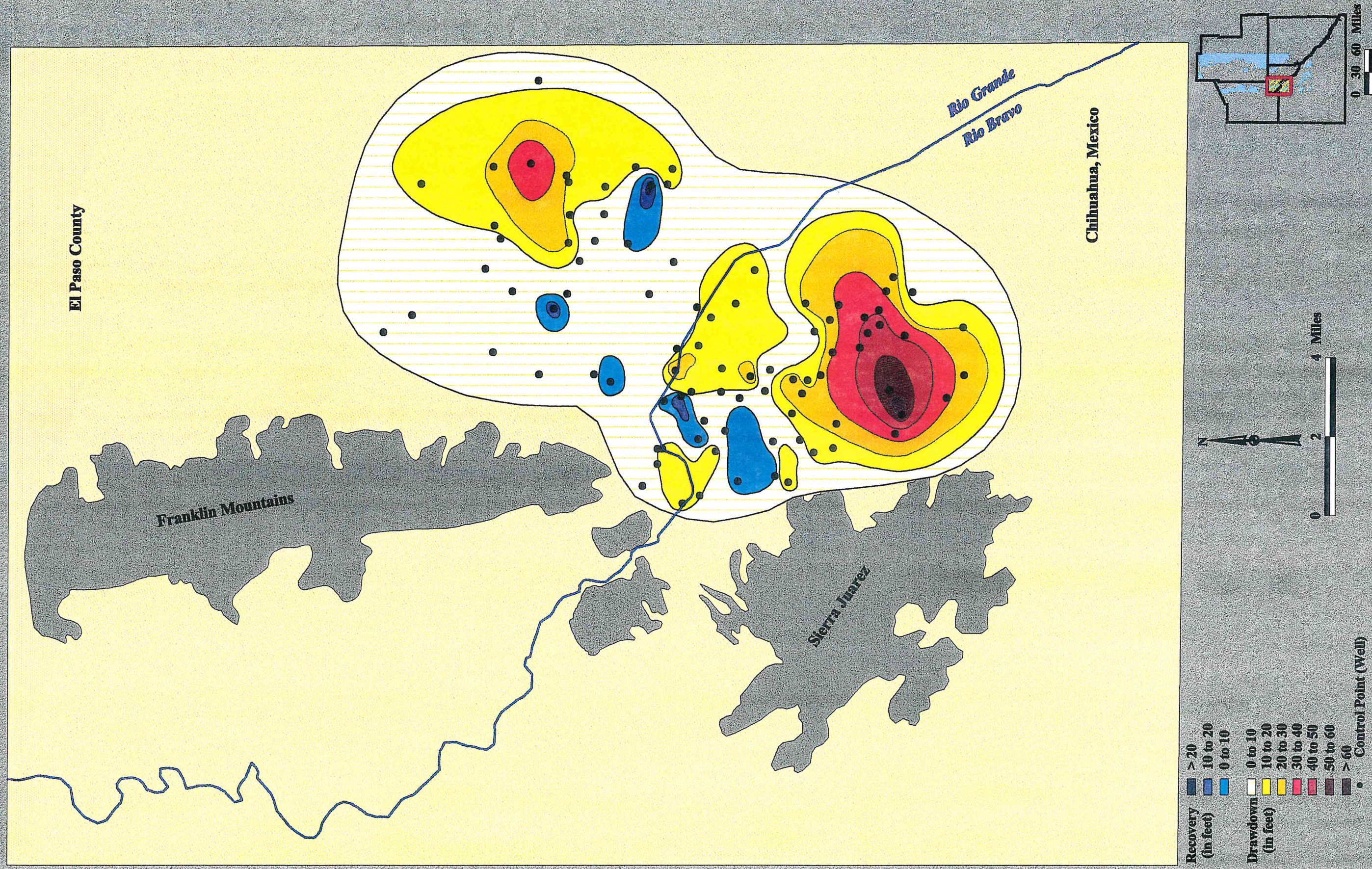


Figure 3.10. Change in water levels for the City of El Paso - Ciudad Juarez area, 1987/1988 to 1992/1993. (source of data, Texas Water Development Board; City of El Paso Public Services Board; Junta Municipal de Agua y Saneamiento).

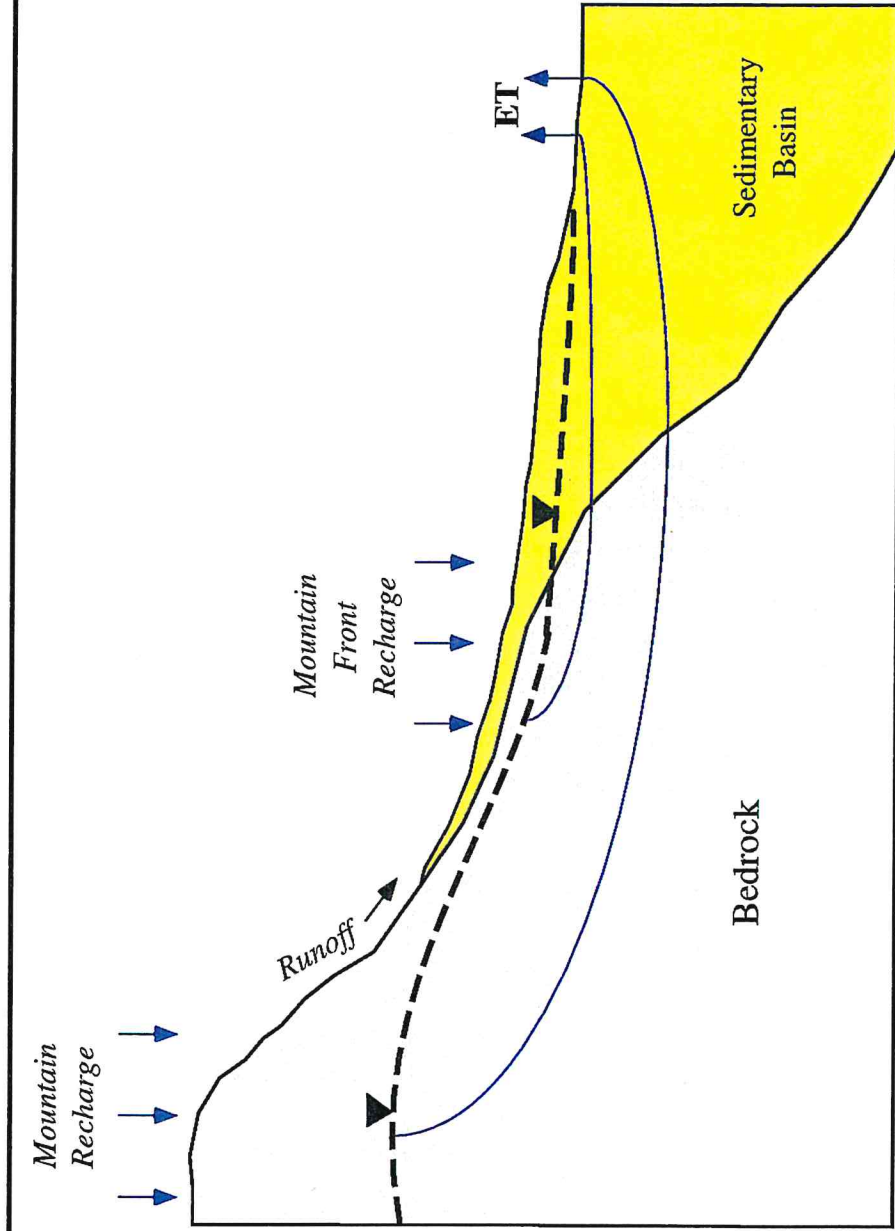


Figure 3.11. Conceptual diagram illustrating mountain front recharge.

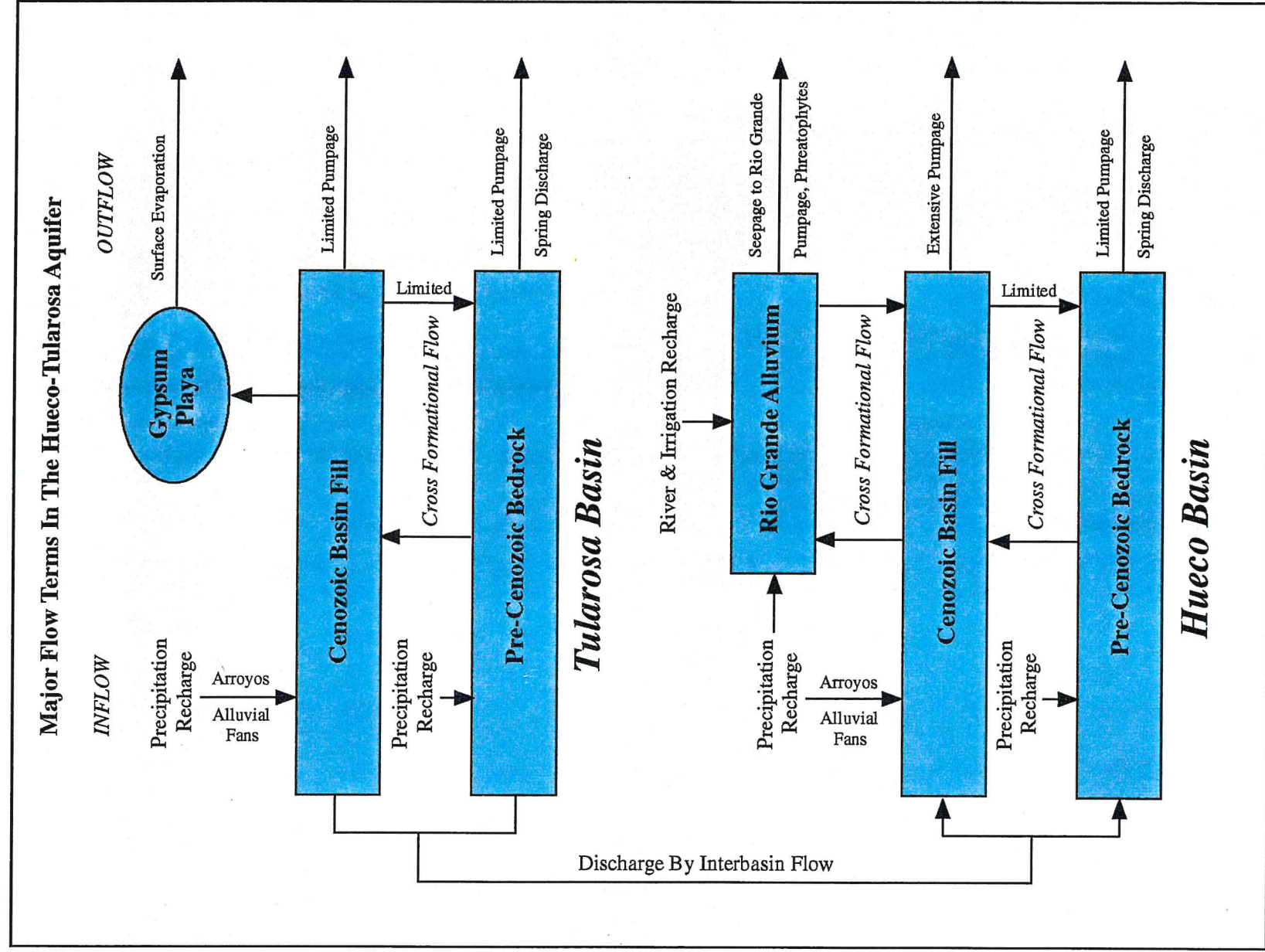


Figure 3.12. Major flow components of the Hueco - Tularosa aquifer.

amount of recharge to the Hueco Bolson. In 1993, recharge by injection averaged 3,800 acre-ft/year (USEPA, 1995). This volume is about 2% of the 188,000 acre-ft/year pumped from the aquifer in 1993 (USEPA, 1995).

Discharge Areas

Discharge from the Hueco-Tularosa aquifer under natural conditions is by direct evaporation from bare soil where the capillary fringe is near land surface (at wet playas), by leakage to springs and to streams, by consumptive use by phreatophytes, and by interbasin and cross-formational flow (Figure 3.12). Well pumpage accounts for the largest component of discharge from the aquifer.

Ground water is discharged from the Tularosa Basin by well pumping, by evaporation on the wet playas, by spring discharge, and by interbasin discharge to the Hueco Basin. Ground-water withdrawals for irrigation totaled 22,720 acre-ft in the Tularosa Basin in 1980 (USBR, 1984). Municipal pumping accounted for another 1,474 acre-ft of withdrawal (USBR, 1984). The amount of discharge by interbasin flow to the Hueco Basin is an estimated 3,700 acre-ft/year (Orr and Risser, 1992). Quantities of ground-water discharge due to leakage to springs and evaporation at playas are not known.

Most discharge in the Hueco Bolson is due to withdrawals for municipal, industrial, and military water supply. In 1994 the volumes of ground water pumped from the Hueco Bolson reportedly were 53,090 acre-ft by the City of El Paso, 108,569 acre-ft by Ciudad Juarez, and 18,000 acre-ft by military and other sources (PSB, 1997). Quantities of ground-water pumped from the Hueco Bolson from municipal and other sources have increased by a factor of almost 6 since 1950 (Figure 3.13). Recent trends indicate that municipal pumpage in Mexico increased about 12.5% between 1990 and 1994 (Figure 3.14). Municipal and military pumpage in the United States decreased 24.0% during the same time interval (Figure 3.14). Pumping

trends reflect the increased dependence on ground water in Mexico, and partial conversion from ground water to surface-water use in the United States.

Nearly all of the ground water in the Hueco Bolson flowed toward the Rio Grande during predevelopment times (White, 1987). There the ground water moved upward through the Rio Grande alluvium and discharged by channel seepage and by consumptive use by phreatophytes. Average simulated discharge from the Hueco Bolson to the Rio Grande between 1903 and 1920, before substantial development of the aquifer, was 6,864 acre-ft/year (Meyer, 1976).

Heavy pumpage in the Hueco Bolson reversed the hydraulic head gradient between the alluvium and the bolson aquifer in some areas. In areas where pumpage from the bolson is not great, the hydraulic head gradient between the Hueco Bolson and alluvium remains positive and artesian conditions exist. Well 49-39-202, a deep artesian well beneath the Rio Grande alluvium in the Fabens area maintained a head of 22.87 ft above land surface when it was last measured in 1978. This data clearly implies cross-formational flow from the Hueco Bolson to the Rio Grande alluvium in areas not influenced by substantial pumping.

Water Quality

General hydrochemistry

General water quality of the Hueco-Tularosa aquifer is shown in the regional stiff map (Plate 1). Ground water north of the New Mexico/Texas State line is usually greater than 1,000 mg/L TDS except in mountains and along mountain fronts, where ground waters are dilute. Many samples along the interior of the basin at or just south of Alkali Flat have TDS greater than 10,000 mg/L. Near and extending across state line to the Rio Grande alluvium, ground-waters along the Franklin Mountains are characteristically less than 700 mg/L TDS. Basinward of the recharge areas along the Franklin mountains salinities increase to over 1,000 mg/L in many wells, reaching concentrations over

1,500 mg/L in wells along the axis of the basin. Salinities of ground water underlying the Ciudad Juarez area are generally less than 1,000 mg/L. The approximate thickness of the freshwater lense (TDS less than 1,000 mg/L) is shown in Figure 3.15.

Several sets of hydrochemical analyses are clustered according to distinct hydrochemical groupings (Figure 3.16). They include (1) mountain and mountain front samples along the Sacramento mountains; (2) mountain and mountain front and gypsum playa samples along and below the San Andres and Organ Mountains; (3) mountain front samples along the Franklin Mountains; (4) basin floor samples in the Hueco Bolson (New Mexico, Texas, and Mexico); and (5) samples from Ciudad Juarez municipal wells.

The mountain and mountain front samples along the Sacramento Mountains (group 1) cluster mostly as Ca-HCO₃-SO₄ and Ca-Cl-SO₄ waters, except for ground waters high in the Sacramento Mountains which are Ca-HCO₃ ground waters. Ground waters with greater than 1,000 mg/L TDS have a Ca-Cl-SO₄ signature, and ground waters with less than 1,000 mg/L TDS have a Ca-HCO₃-SO₄ signature. These ground waters are influenced by dissolution of limestone and gypsum.

The mountain and mountain front samples in group 2 are Ca-HCO₃ and mixed cation-HCO₃-SO₄ type ground waters with TDS less than 1,000 mg/L. Eastward along the basin floor, ground waters have a Na-Cl-SO₄ and mixed cation-SO₄-Cl signature and salinities mostly greater than 10,000 mg/L (Plate 1). The high-TDS ground waters are just south of Alkali Flat, a gypsum playa, and are drawn from earlier gypsum-playa deposits (USBR, 1984). These hydrochemical signatures are commonly observed where evaporite minerals are dissolved in great quantity.

Along the Franklin Mountains are dilute, Na-HCO₃ and Na-HCO₃-Cl type ground waters (group 3). Chloride increasingly becomes a dominant anion basinward of this mountain recharge area. Typically sampled from alluvial fans, these waters, having evolved from

Ca-HCO₃ ground waters in the mountains, have probably undergone cation exchange releasing bound sodium for calcium in solution.

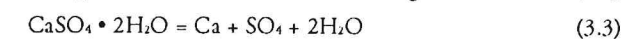
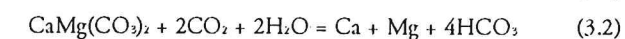
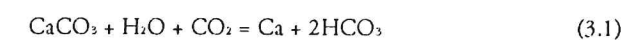
Down gradient from group 3 wells, samples from group 4 wells suggest continued hydrochemical evolution. Group 4 ground waters have higher TDS, higher percentages of Cl and SO₄, and lower concentrations of HCO₃ than upgradient waters. These are principally Na-Cl and Na-Cl-SO₄ ground waters. TDS is usually less than 1,000 mg/L just east of the Franklin Mountains and is greater than 1,000 mg/L in most samples collected along the axis of the basin.

Group 5 samples were collected from Ciudad Juarez municipal wells. Ground waters are Ca-Na-mixed anion to Na-Cl-SO₄ type ground waters with salinities less than 1,000 TDS. Ca-Na dominated waters are located at distances from the river, and Na-dominated waters are commonly found near the Rio Grande.

Origin of solutes in the El Paso/Ciudad Juarez area

Group 4 ground waters may evolve from group 3 ground waters by a process of replacement of sodium for Ca and Mg, by the loss of HCO₃, and by the addition of Cl and SO₄. The trend shown in the piper plot may result from the geochemical evolution of ground waters from the flanking highlands along with mixing with ground waters moving south along the axis of the basin (Figure 3.17).

The most likely sources of Ca and Mg in group 3 and group 4 ground waters includes dissolution of calcite, dolomite, and gypsum:



Plotting the quantity (Ca + Mg) against HCO₃ and drawing a line with a slope of 1:2 gives the amount of calcium and magnesium derived from dissolution of calcite (1 mole Ca to 2 moles HCO₃) and dolomite (1 mole of [Ca+Mg] to 2 moles of HCO₃). Many of the

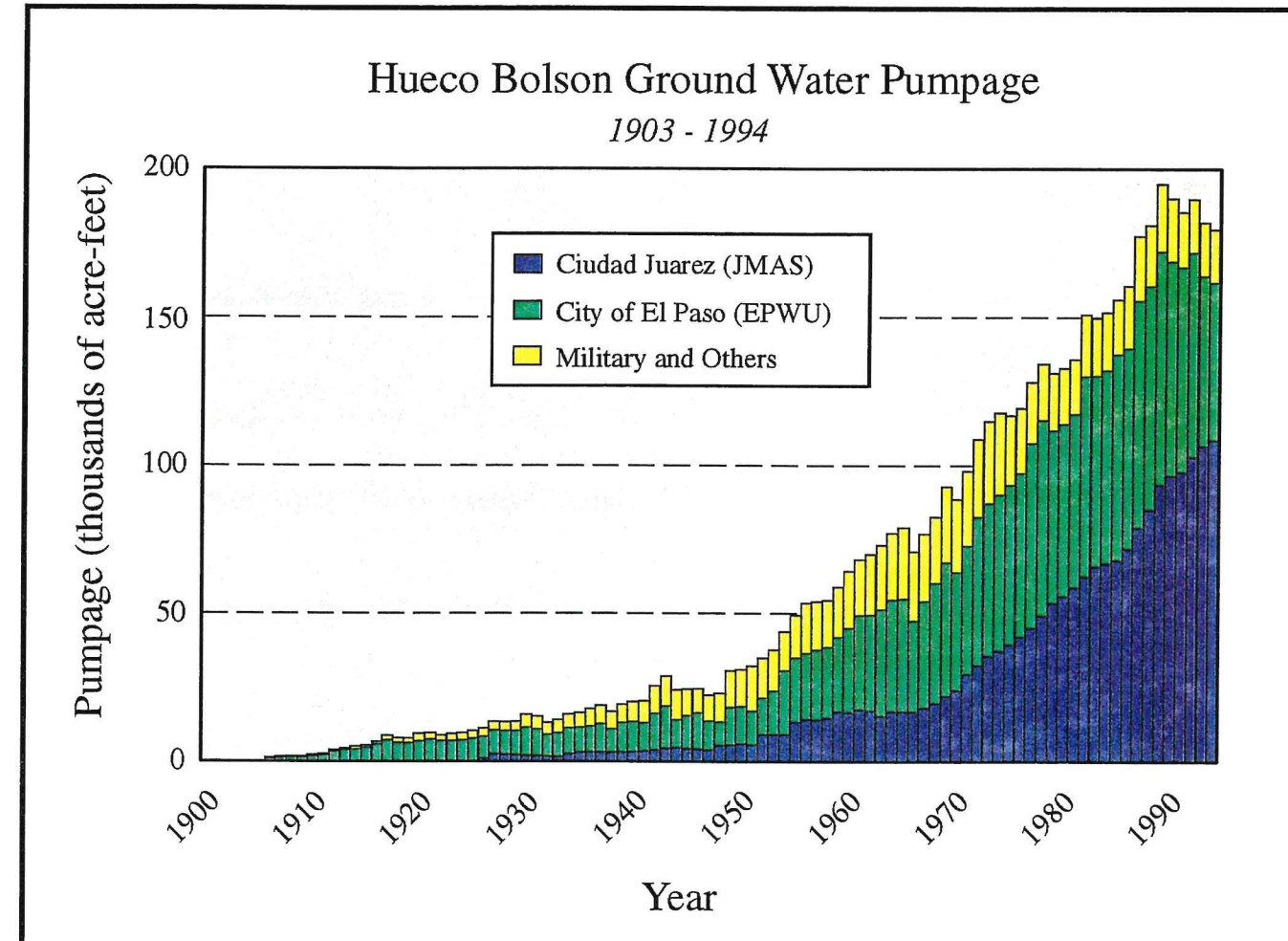


Figure 3.13. Ground-water pumpage from the Hueco Bolson; 1903 - 1994 (source of data, City of El Paso Public Services Board).

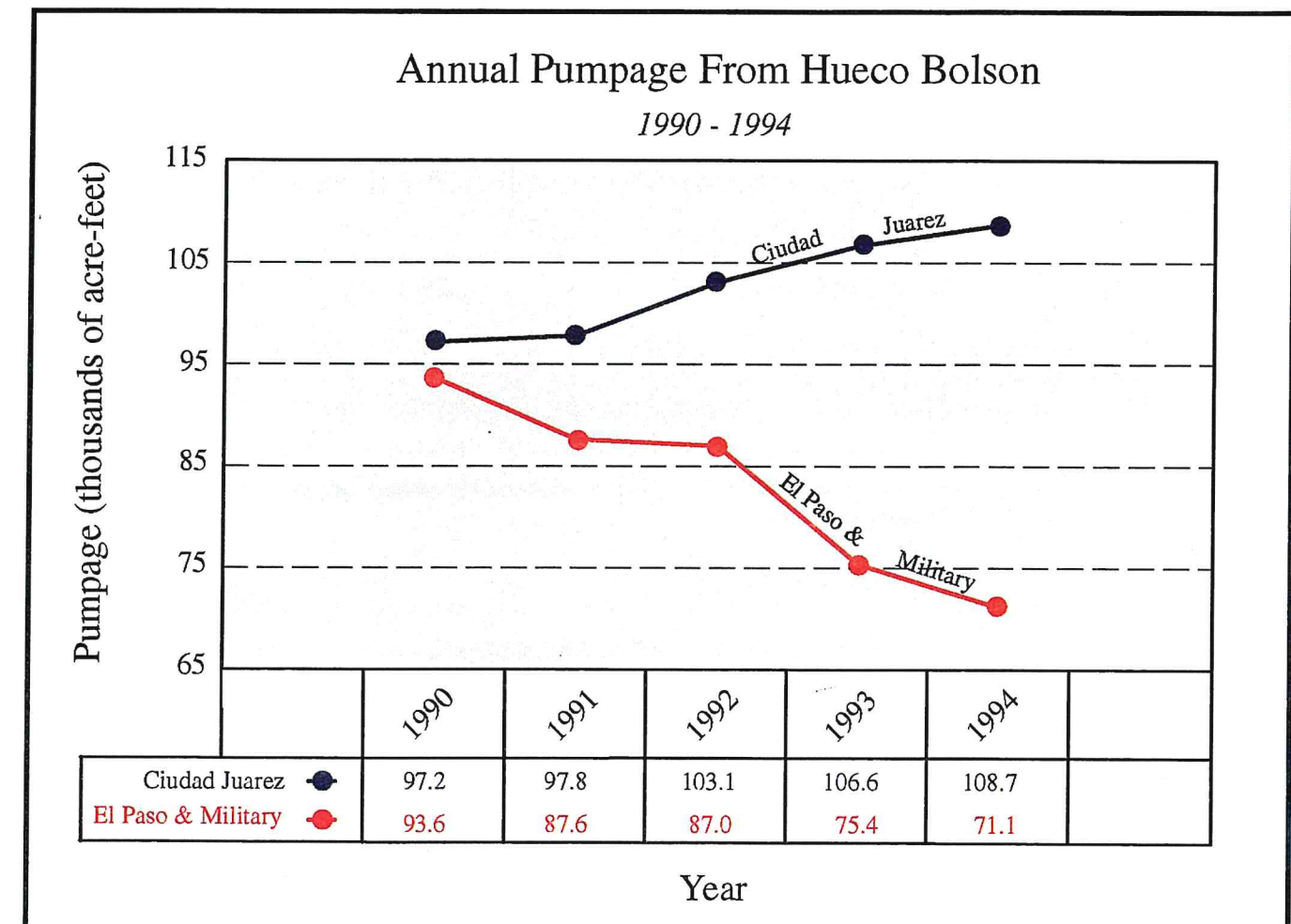


Figure 3.14. Ground-water pumpage from the Hueco Bolson; 1990 - 1994 (source of data, City of El Paso Public Services Board; Junta Municipal de Agua y Saneamiento).

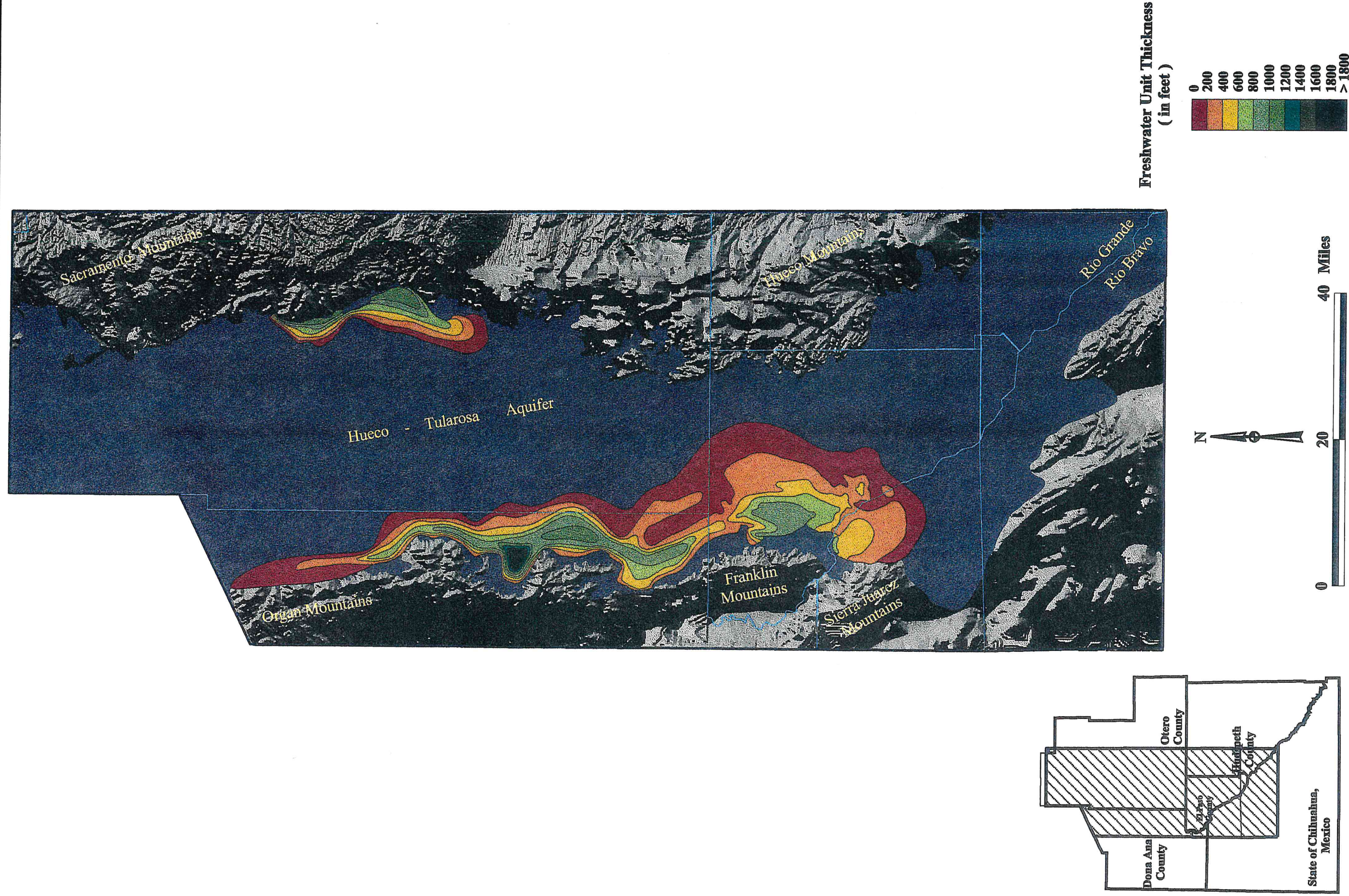


Figure 3.15. Approximate thickness of the freshwater unit (TDS < 1,000 mg/L) in the Hueco - Tularosa aquifer (modified from maps prepared by McLean, 1970, and Lee Wilson and Associates, 1986).

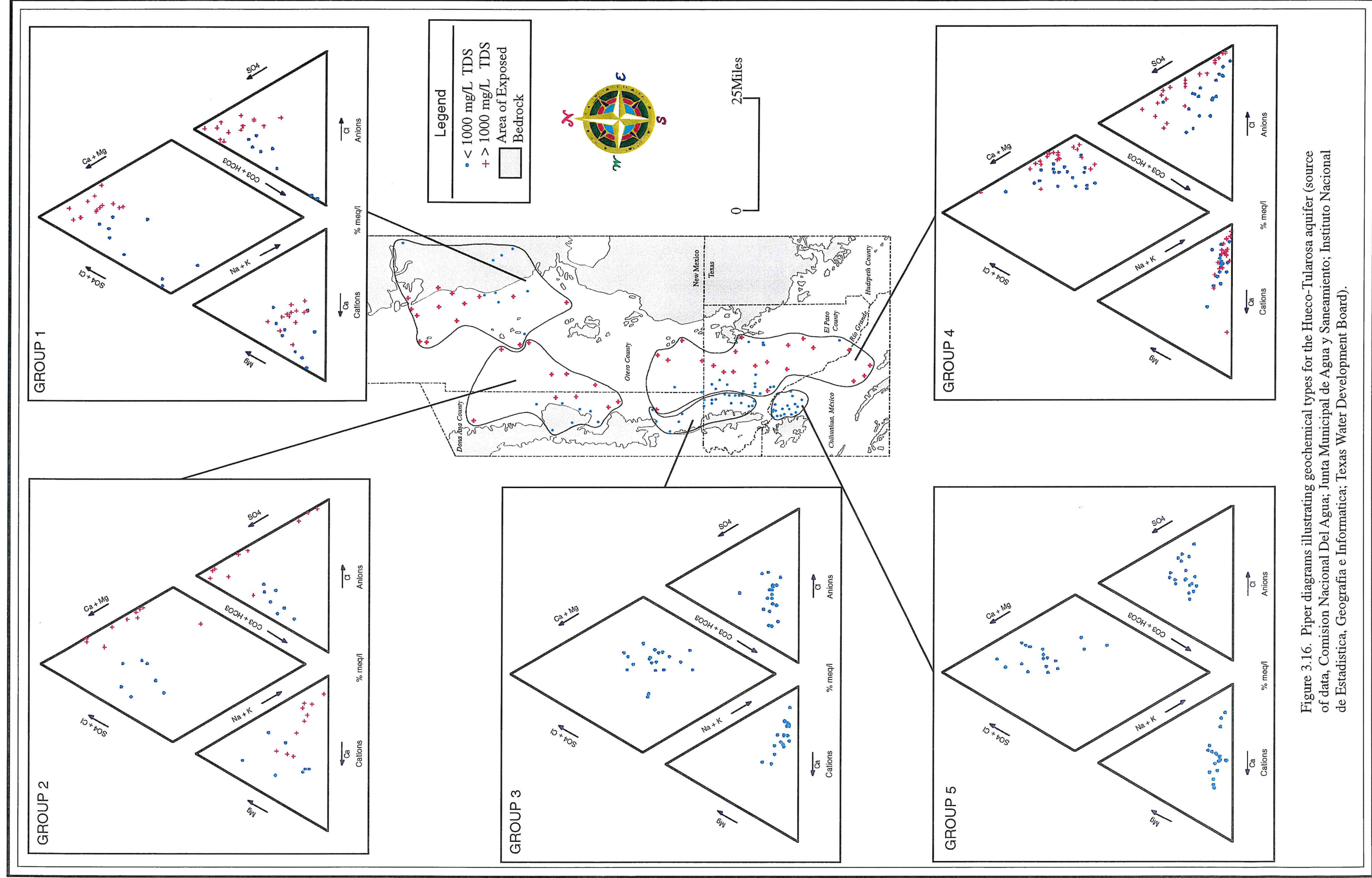


Figure 3.16. Piper diagrams illustrating geochemical types for the Hueco-Tularosa aquifer (source of data, Comision Nacional Del Agua; Junta Municipal de Agua y Saneamiento; Instituto Nacional de Estadística, Geografía e Informática; Texas Water Development Board).

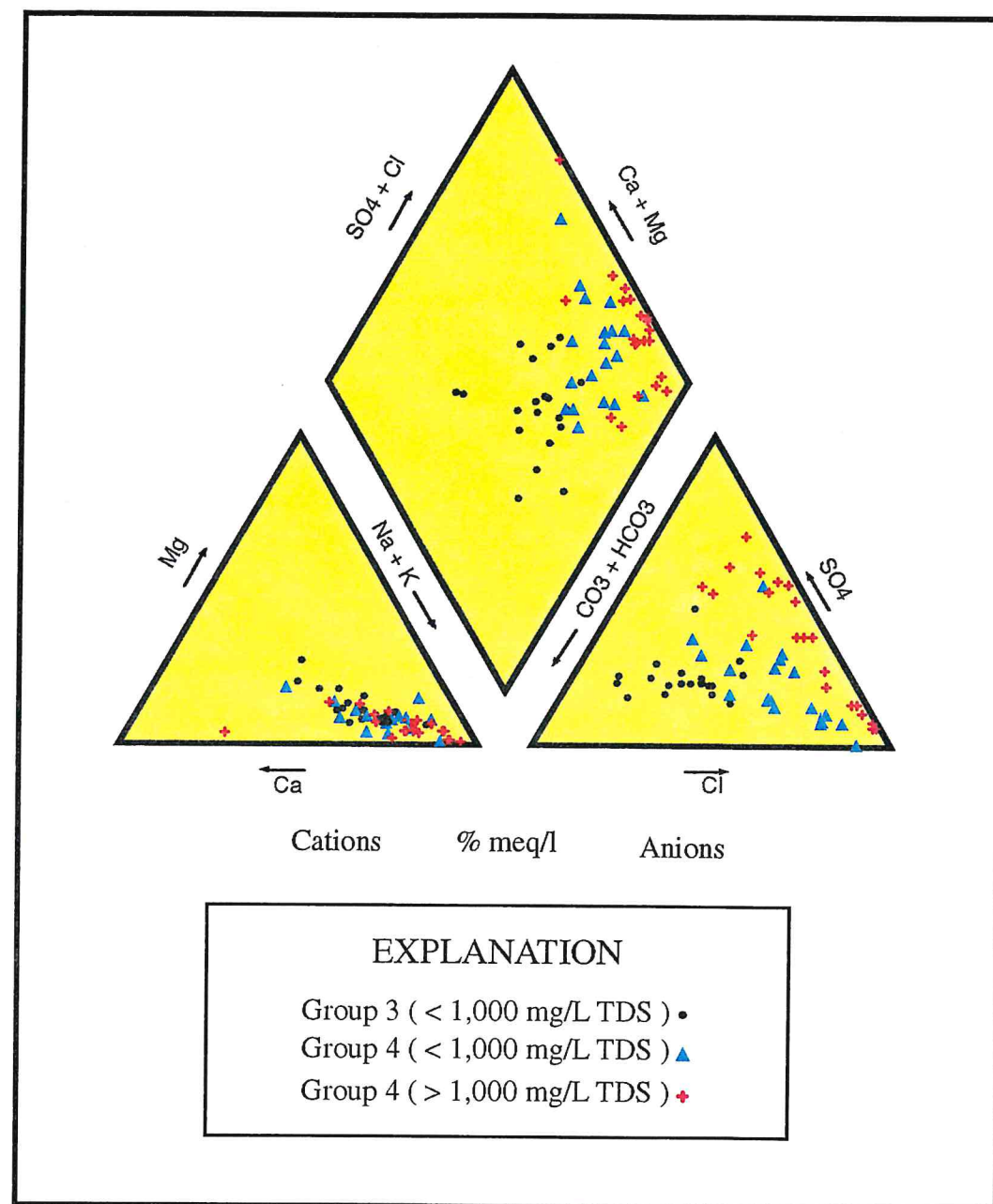


Figure 3.17a. Piper diagram for group 3 and group 4 ground waters in the Hueco-Tularosa aquifer (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

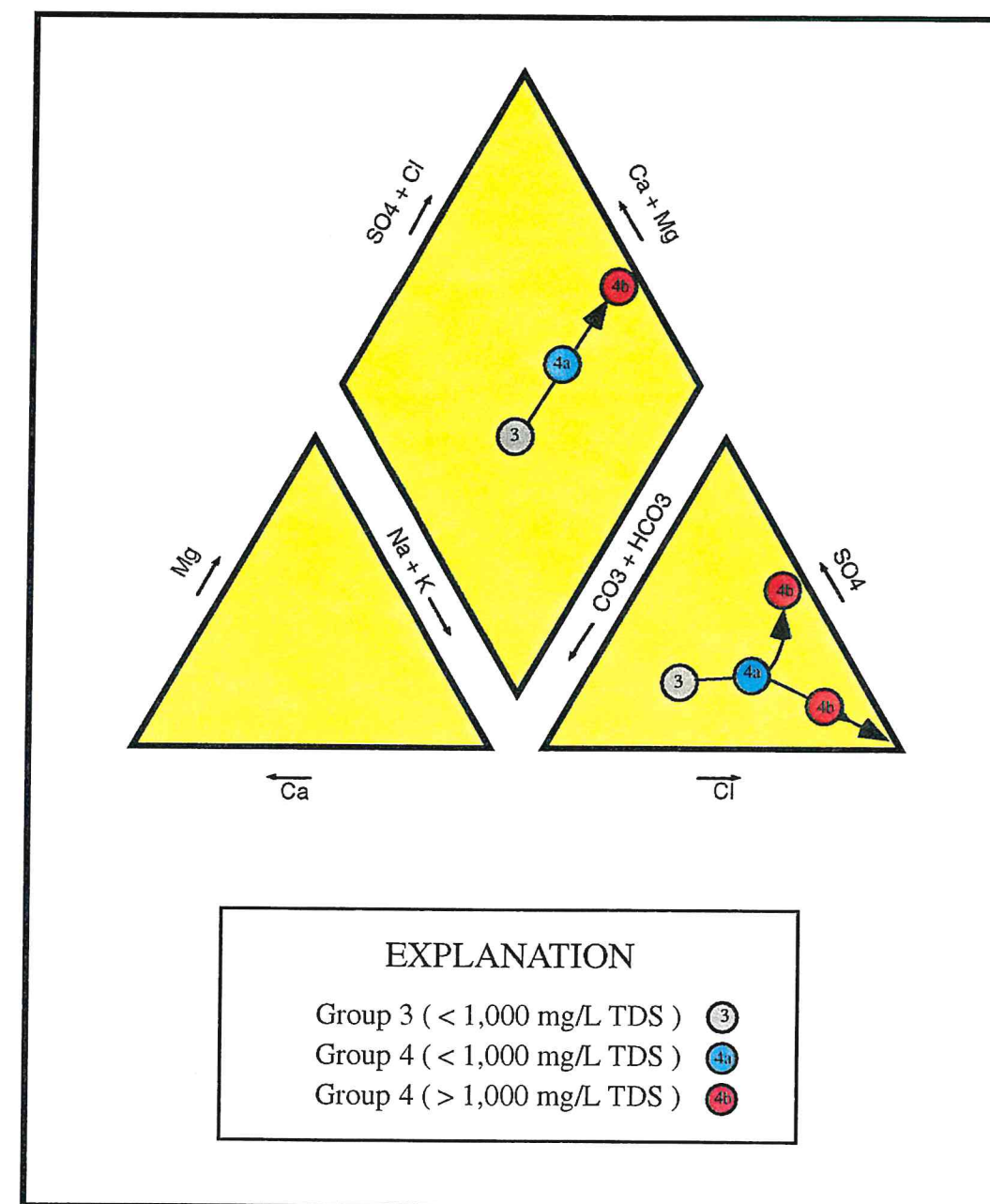
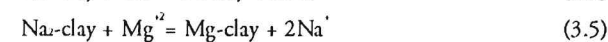
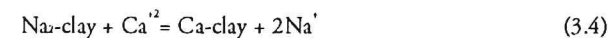


Figure 3.17b. Geochemical evolution diagram that represents possible evolutionary paths for data shown in Figure 3.17a (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

points plot near the 1:2 line (Figure 3.18), but many of the points plot above the line, indicating an additional source of Ca and Mg. To account for remaining Ca due to dissolution of gypsum, the quantity (Ca + Mg - SO₄) is plotted against HCO₃ (Figure 3.19). The majority of the points plot well below the 1:2 line, indicating that another process is removing Ca and Mg from solution. The few points plotting above the 1:2 line indicate an excess of Ca and Mg.

Cation exchange is a process that removes Ca and Mg from ground waters by substitution for bound Na on clays:



The forward reaction may account for deficient Ca and Mg shown in Figure 3.19. Reversal of the exchange process may be the source of excess Ca and Mg in the samples that plot above the 1:2 line (Figure 3.19). To test the influence of cation exchange on the hydrochemical signature of ground waters in the study area, the molar quantities (Na - Cl) are plotted against (Ca + Mg - SO₄ - 0.5HCO₃). The quantity (Na - Cl) represents excess Na coming from sources other than halite dissolution (Figure 3.20). The quantity (Ca + Mg - SO₄ - 0.5HCO₃) represents the Ca and Mg derived from sources other than dissolution of gypsum, calcite, or dolomite. Together, these quantities represent the amount of monovalent and divalent cations available for cation exchange. A 2:1 exchange line shows how much Na is contributed from cation exchange (positive Na - Cl values) and how much Ca and Mg is contributed from the reversible exchange process (negative Na - Cl values). Nearly all of the points fit the 2:1 exchange line exceptionally well (Figure 3.20). These values reflect excess or deficient Na caused by the reversible cation exchange process.

A plot of molar (Na /Cl) vs Cl for dilute (<1,000 mg/L TDS) and slightly to moderately saline (>1,000 mg/L) water in groups 3 and 4 indicates that the (Na/Cl) ratio ranges from about 3.3 to 0.5 and decreases

with increasing chlorinity (Figure 3.21). At salinities less than 8 mmols/L Cl, excess Na is due to exchange of calcium and magnesium for bound sodium on clay particles. At salinities greater than about 8 mmols/L Cl and especially above 20 mmols/L Cl, the influence of halite dissolution on the hydrochemical composition of ground water is apparent, as the sample points trend to a ratio of about 1.0.

Results indicate cation exchange and dissolution of calcite, halite, and gypsum as the principal factors influencing hydrochemical signatures in group 3 and group 4 ground waters. The contribution of mineral dissolution on hydrochemical signatures can be determined by summing the equivalent quantities of cations derived by mineral dissolution and cation exchange (Ca + Mg + Na). For example, a plot of milliequivalent (Ca + Mg + Na - SO₄ - HCO₃) versus (Cl) removes sources of cations due to dissolution of calcite, gypsum, and cation exchange (Figure 3.22a). The plot provides an excellent 1:1 fit. This is expected for halite dissolution; the source of residual Na and Cl that has not been removed from the milliequivalent quantities by subtraction. Removing (-HCO₃) from the quantity (Ca + Mg + Na - SO₄ - HCO₃) gives the amount of mass derived from the dissolution of calcite. As observed from the upward shift (Figure 3.22b), the amount of Ca and HCO₃ derived from dissolution of calcite is important in dilute waters only (salinities less than 10 meq/L Cl).

Removing (-SO₄) from the quantity (Ca + Mg + Na - SO₄ - HCO₃) gives the amount of mass derived from the dissolution of gypsum (Figures 3.23a & 3.23b). The plot indicates that gypsum dissolution is important in slightly saline ground waters with chlorinities greater than 4 meq/L.

The amount of halite dissolution is determined by plotting the milliequivalent quantities (Ca + Mg + Na - Cl - HCO₃) against the independent variable anion (SO₄). Removing (-Cl) from the quantity (Ca + Mg + Na - Cl - HCO₃) gives the amount of mass derived from halite dissolution (Figures 3.24a & 3.24b). The

upward shift is significant in all but the most dilute ground waters. This indicates that dissolution of halite is an important process for virtually the full range of salinities in group 3 and group 4 samples.

These analyses indicate that the origin and evolution of type 3 and type 4 waters are due to the following reactions and exchange processes:

- Dissolution of calcite and dolomite in dilute ground waters.
- Dissolution of gypsum in slightly saline ground waters.
- Dissolution of halite in all except very dilute ground-waters.
- Cation exchange, favoring exchange of Ca and Mg for bound Na; some reversible exchange (Na for bound Ca and Mg) in a few ground waters.

Dissolution of specific minerals is a function of their spatial variability at locations in the basin. Halite is present in small quantities along mountain flanks and along the basin floor and probably was derived by evaporation of large amounts of very dilute, salt bearing precipitation over geologic time. Gypsum is present along the basin floor and may have precipitated in gypsum playas that formed when the Hueco Bolson was a closed drainage basin. Carbonates are present in the mountains and precipitate as caliche along mountain fronts. Other rocks, such as volcanic and intrusive igneous rocks appear to contribute little to the overall dissolved load of group 3 and group 4 ground waters.

Vertical layering of hydrochemical types in El Paso County

A series of stiff plots derived from samples collected at discrete vertical intervals during test hole drilling and water quality sampling by the U.S. Geological Survey and Texas Water Development Board allows approximation of layering of hydrochemical facies in El Paso

County (Figure 3.25). Stiff clusters include samples collected between 1956 and 1967, and samples collected between 1976 and 1992. Samples collected between 1956 and 1967 may approximate predevelopment conditions, and samples collected after 1976 in heavily developed areas may reflect possible influences of mixing in vertical intervals caused by pumping from adjacent wells.

In northwestern El Paso County, hydrochemical facies include a Ca-HCO₃ to Na-HCO₃ layer that extends to 1,118 ft beneath land surface at 49-05-801 (Figure 3.25). Ground water is less than 1,000 TDS in this interval. This layer appears at 520 - 545 ft at 49-05-906 and is gradually replaced by a still-dilute, Na-Cl layer below 881 ft. The Na-Cl layer at 49-05-801 has TDS greater than 1,000 mg/L below 1317 ft. The Na-Cl facies is the only type of ground water that appears at test holes 49-05-503 and 49-05-208, increasing from dilute concentrations less than 1,000 mg/L TDS at shallow depths to concentrations that exceed 3,000 mg/L TDS at 800 ft in 49-05-208.

Test holes 49-05-634 and 49-05-906 are closely spaced and have the same general facies transitions with depth; from a Na-HCO₃ to Na-HCO₃-Cl layer in the first sampled interval to a Na-Cl layer below 1065 and 1095 ft. Ground water in these test holes is below 1,000 mg/L TDS. Little perceptible change of hydrochemical facies between test holes 49-05-634 and 49-05-906 may indicate that hydrochemical facies have not changed much with time in this area. Well samples were collected in 1966 at 49-05-906 and in 1992 at 49-05-634.

East of test hole 49-05-906, ground waters are Na-Cl to Na-Cl-SO₄ types in all sampled intervals with TDS usually less than 1,000 mg/L, increasing to more than 1,000 mg/L at 49-06-603 and 49-06-901. These test holes were sampled in 1986 and are located along the axis of the bolson, at distances from regions of extensive aquifer development and drawdown. Since drawdowns are small, samples at 49-06-603 and 49-06-901

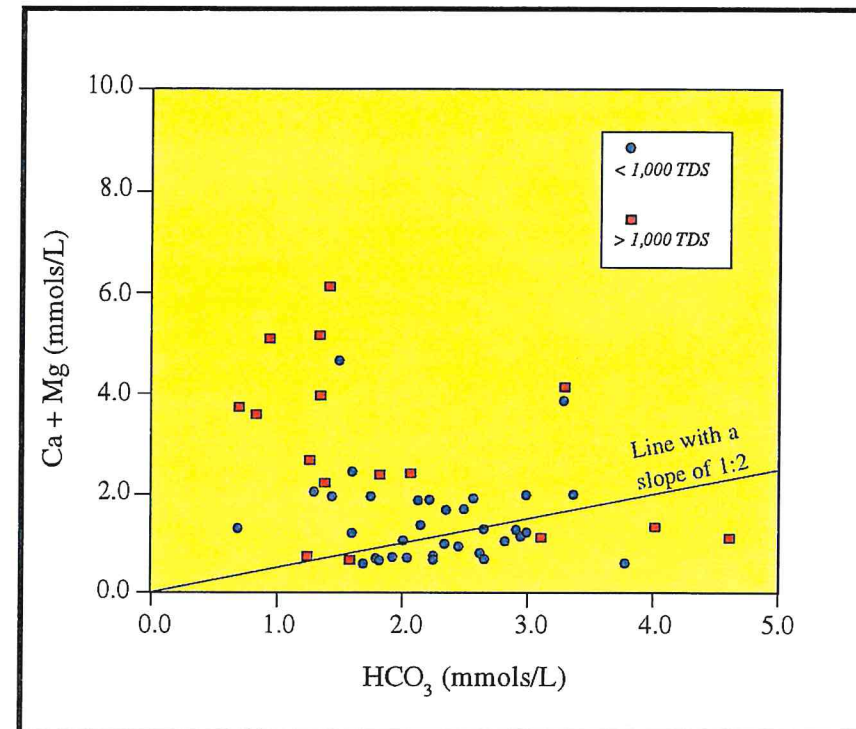


Figure 3.18. $(Ca + Mg)$ vs HCO_3^- plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

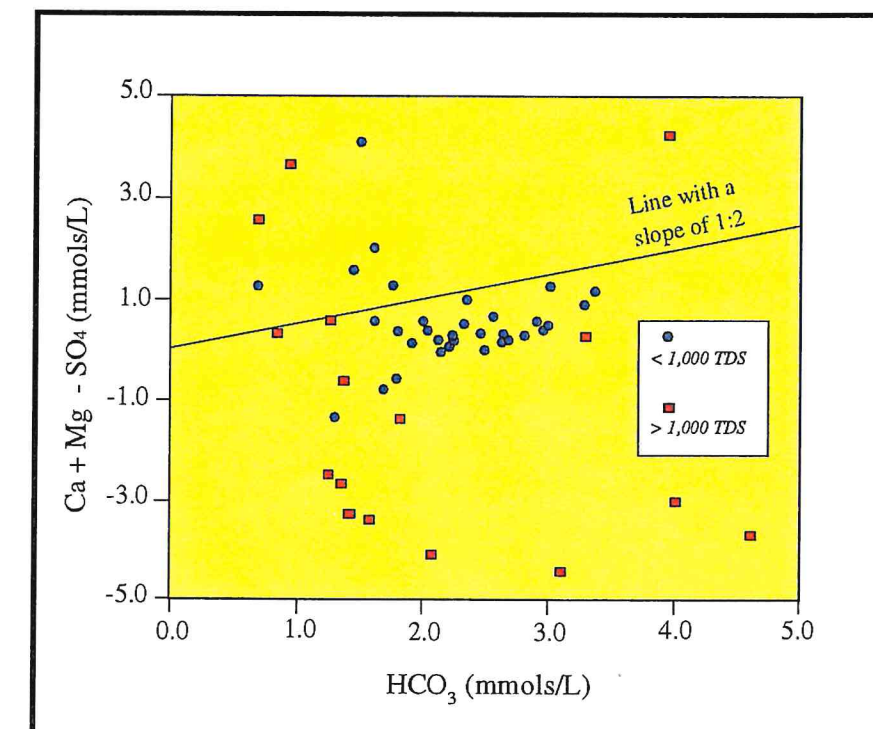


Figure 3.19. $(Ca + Mg - SO_4)$ vs HCO_3^- plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

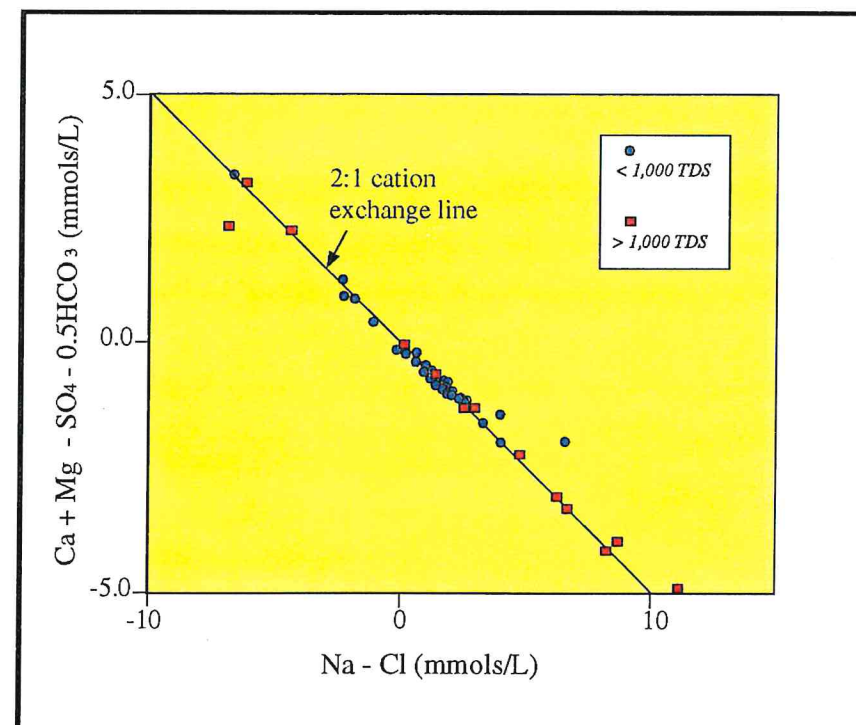


Figure 3.20. $(Ca + Mg - SO_4 - 0.5HCO_3)$ vs $(Na - Cl)$ plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

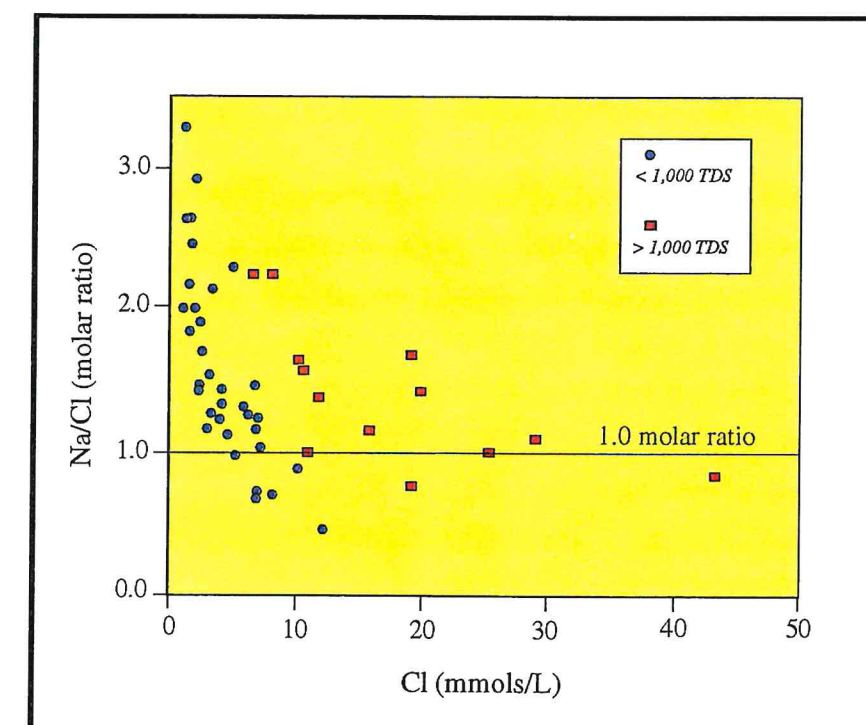


Figure 3.21. (Na/Cl) vs Cl plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

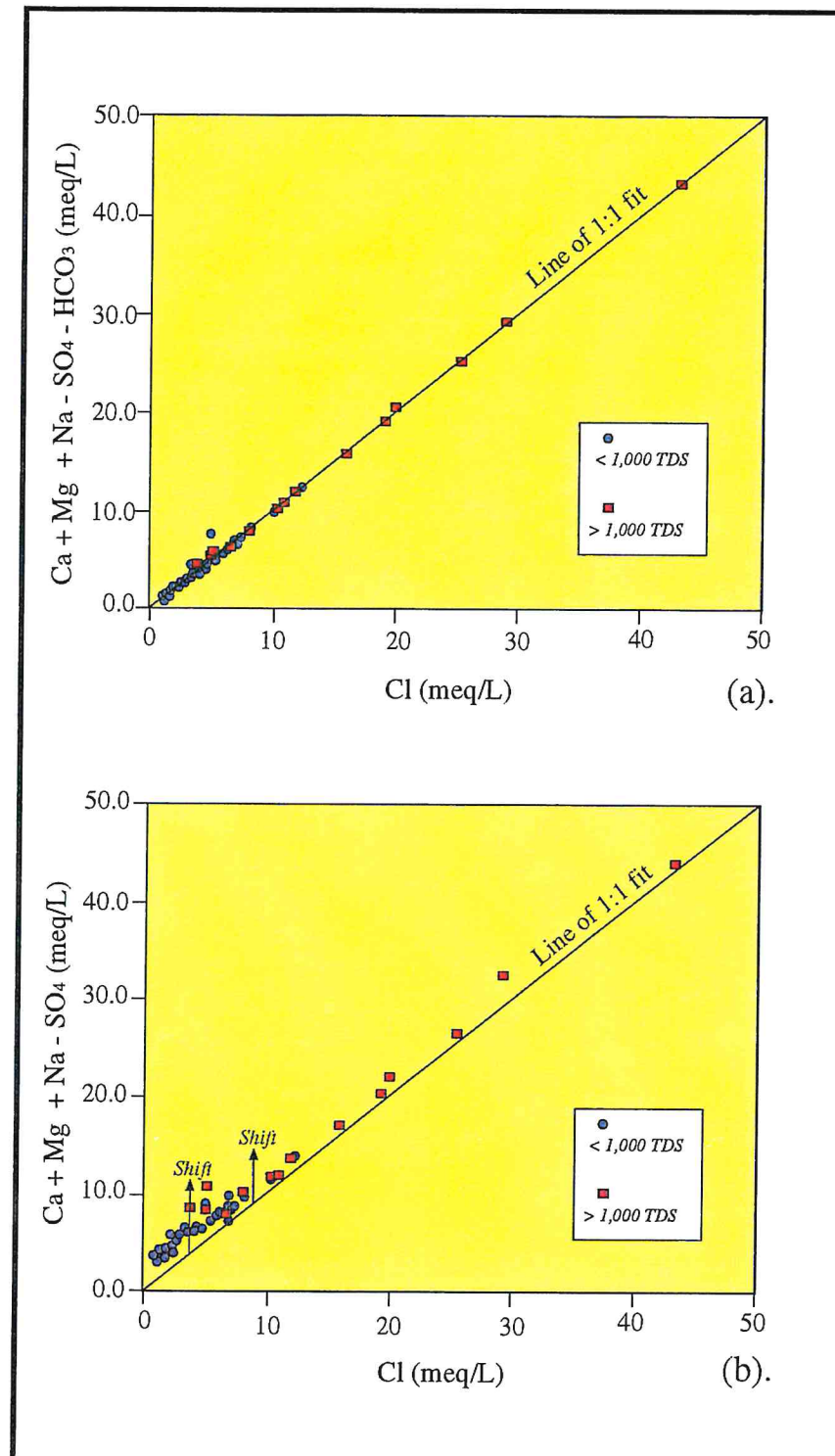


Figure 3.22. Upper figure (a); a plot of $(Ca + Mg + Na - SO_4 - HCO_3)$ vs Cl in group 3 and group 4 ground waters gives an excellent 1:1 fit. Lower figure (b); the shift caused by removing $(-HCO_3)$ from the term $(Ca + Mg + Na - SO_4 - HCO_3)$ gives the amount of mass due to dissolution of calcite (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

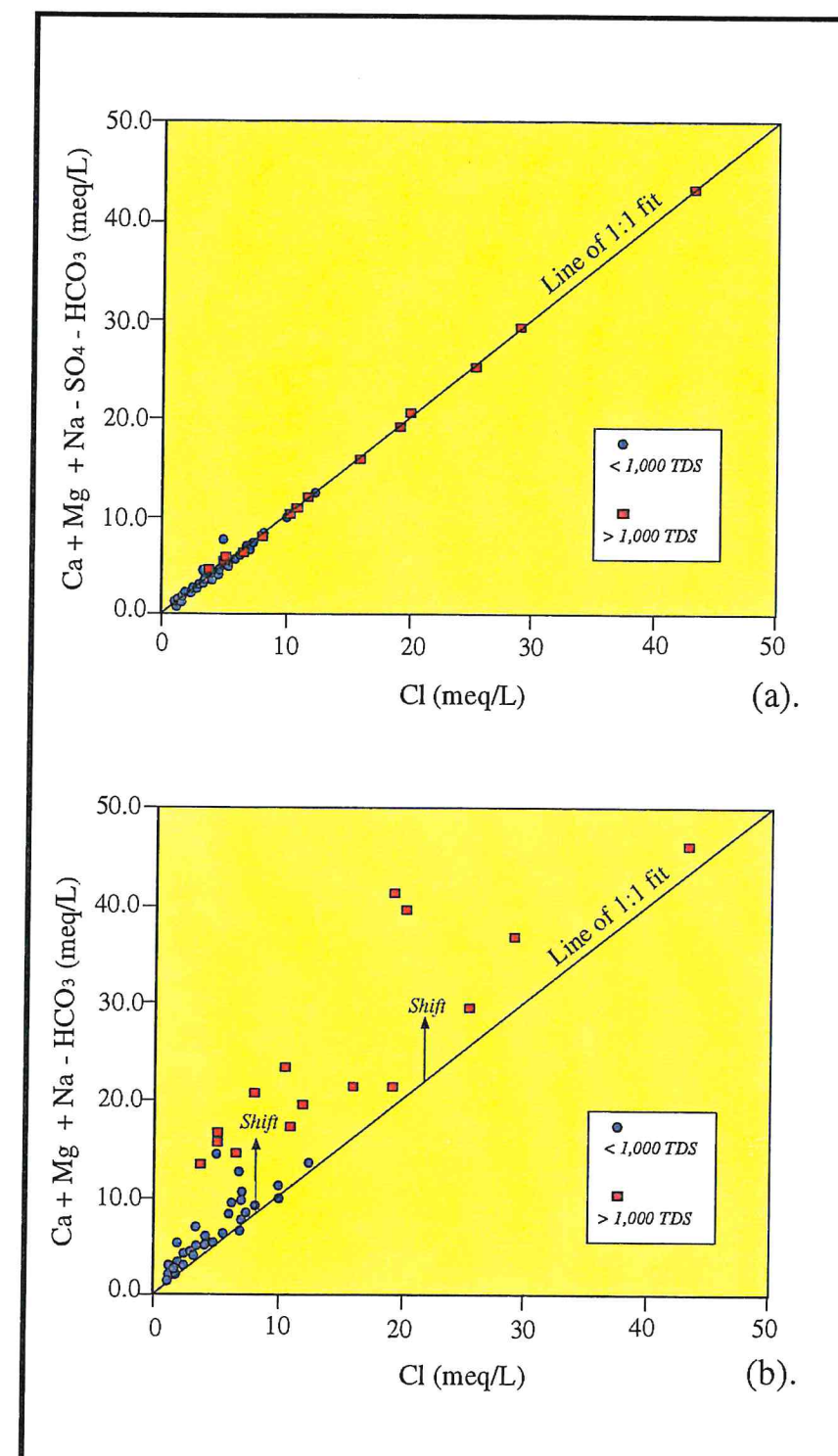


Figure 3.23. Upper figure (a); a plot of $(Ca + Mg + Na - SO_4 - HCO_3)$ vs Cl in group 3 and group 4 ground waters gives an excellent 1:1 fit. Lower figure (b); the shift caused by removing $(-SO_4)$ from the term $(Ca + Mg + Na - SO_4 - HCO_3)$ gives the amount of mass due to dissolution of gypsum (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

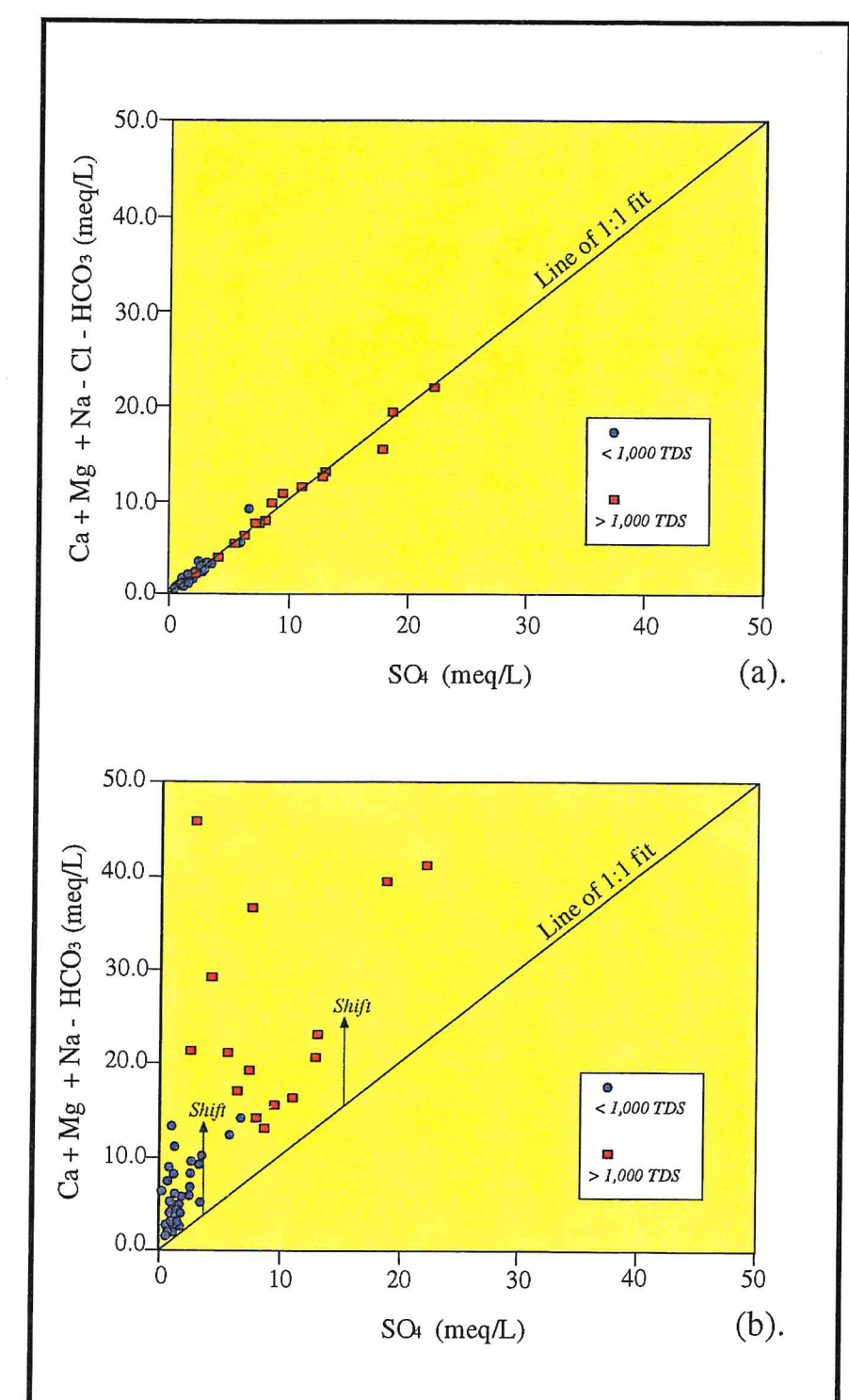
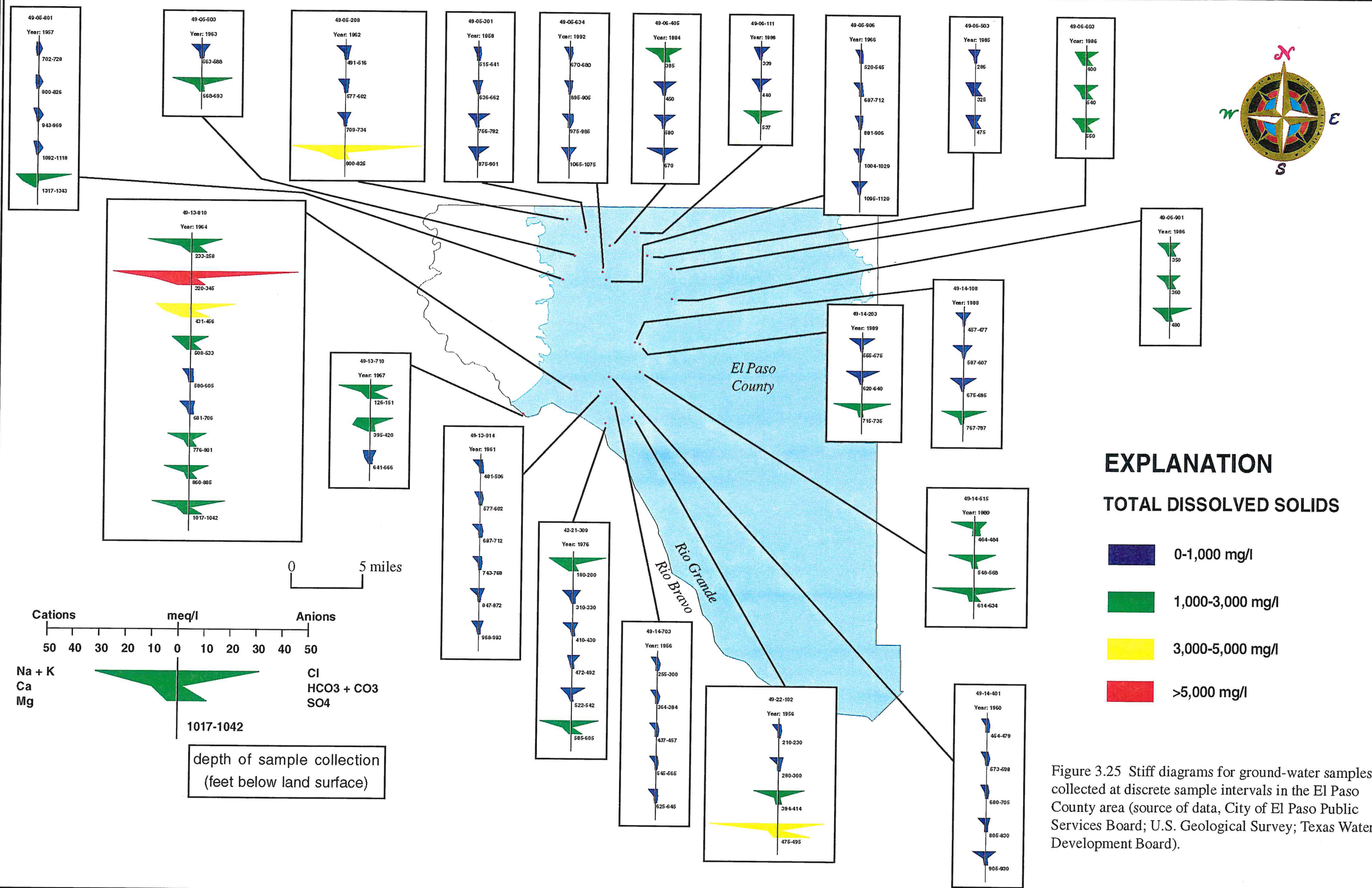


Figure 3.24. Upper figure (a); a plot of $(Ca + Mg + Na - Cl - HCO_3)$ vs SO_4 in group 3 and group 4 ground waters gives an excellent 1:1 fit. Lower figure (b); the shift caused by removing $(-Cl)$ from the term $(Ca + Mg + Na - Cl - HCO_3)$ gives the amount of mass due to dissolution of halite (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).



may almost reflect predevelopment conditions, despite the fact that they were sampled fairly recently. Results indicate that the Na-Cl layer thickens to the east, and grades laterally into a Na-Cl-SO₄ type ground water.

In southern El Paso County, the dilute, Na-HCO₃ layer is present in test holes 49-13-914, 49-14-703, 49-14-401, and 49-22-102. The Na-Cl layer is first seen at 847 ft in well 49-13-914, at 805 ft in well 49-14-401, and at 280 ft at 49-22-102 (Figure 3.25). The Na-HCO₃ layer thickens to the east (Roger Sperka, written communication, 1990). In well 49-22-102, the Na-Cl water is first seen at 280 ft and is less than 1,000 mg/L TDS, increasing to greater than 1,000 TDS between 394 and 414 ft, and grading into a Na-Cl-SO₄ water with TDS greater than 3,000 mg/L at 475 ft. The Na-HCO₃ layer is a dilute ground water that is overlain by slightly to moderately saline, or brackish ground water in the Rio Grande alluvium. Shown at 180 ft in 42-21-309 and at 126 ft at 49-13-710, the brackish layer is a Na-Cl to Na-Cl-SO₄ ground water that forms by evaporation, dissolution of halite, and dissolution of gypsum in the alluvium (see Rio Grande aquifer; Chapter 5).

An anomaly is shown at test hole 49-13-810, where the Na-Cl-SO₄ type ground water is present at several intervals between 223 and 533 ft. The only dilute samples in this test hole are Na-HCO₃-SO₄ ground waters and Na-Cl-SO₄ ground waters at 580 and 681 ft. Na-Cl-SO₄ ground waters with TDS greater than 1,000 mg/L are sampled at test intervals between 776 and 1042 ft in the well.

Historical change

The thin freshwater zone is underlain and in some places overlain by inferior quality ground waters. Mixing due to pumpage, leakage from mud interbeds and artesian confining beds, cascading waters along well casings and screens, lateral salt water encroachment, and potential upconing have started to degrade the freshwater zone. The volume of the freshwater lense is decreasing as it is depleted due to heavy pump-

ing. Chloride has increased over time in many of the municipal wells in El Paso and Ciudad Juarez (Figure 3.26). Chloride now exceeds the maximum recommended limit in several of the wells in the area (Figure 3.26).

Hydrochemical graphs shown in time series indicate how the overall chemistry of water collected from some wells in the Hueco Bolson has changed with time (Figure 3.27). Samples derived from 49-05-503 indicate that the well has experienced increasing chlorinity and little change in the concentration of other ions (Figure 3.27). The well screen is 361 to 571 ft beneath land surface. Samples taken from 49-13-610 indicate that the chemistry from the well has had substantial increases in sulfate, sodium, and chloride. The well screen is between 285 and 751 ft beneath land surface at the well. Samples taken from 49-22-408 have changed the most with respect to TDS, and had a marked upward trend in concentration of sodium and chloride (Figure 3.27). This well is located near the Rio Grande and is screened between 344 and 531 ft. JMAS-15, a Ciudad Juarez municipal well, has seen moderate increases in most ions, especially sulfate and chloride. JMAS-39 has had even greater increases in ions, especially bicarbonate, sulfate, sodium, and chloride. JMAS-43 has had an especially large increase in the concentration of sulfate since 1973 (Figure 3.27).

Salinization depends to one degree or another on several factors, including thickness of freshwater saturated sediments, location and pumping rate of the well, depth of the well screen, well construction, hydrochemistry of the basin fill, distribution and continuity of mud interbeds, and density of saline water (Orr and Risser, 1992). There are several reasons possible why salinity increased in wells. Upconing of saline ground water (Figure 3.28a) has been suggested as a possible cause of salinization (Orr and Risser, 1992). Theoretical studies have used variable density models to evaluate the potential for saline encroachment due to upconing (Orr and Risser, 1992; Groschen, 1994). Results of modeling studies seem to be conflicting.

The study by Groschen (1994) concluded that horizontal to vertical anisotropy in the basin could preclude upconing (Figure 3.28b). The study by Orr and Risser (1992) did not necessarily draw the same conclusion. Conflicting results might be resolved with a well-posed field study.

Lateral migration may account for salinization of some wells (Figure 3.28c). Hydrochemical mapping indicates that ground water is more saline along the axis of the Hueco Bolson. Pumpage may induce inferior quality water to move to wells where drawdown cones have reversed the natural hydraulic head gradient. In heavily developed areas, leakage of inferior quality ground water from mud interbeds may contribute to higher salinity of wells (Figure 3.28d). Wells often have multi-level screens in the more-permeable layers, and the leakage that arises from the intervening semi-pervious confining beds can create poorer quality yields from wells (White, 1987).

Downward movement of saline ground-water from the brackish zone near the Rio Grande probably accounts for some of the degradation of deeper wells close to the river (Figure 3.28e). It is physically more realistic for a denser, salt-laden water to move vertically downward through layered basin fill than for the dense ground water to move vertically upward against the forces of gravity. A well that is not well-constructed or that is old and corroded may act as a conduit for vertical migration of saline ground water into the freshwater zone due to differential pressures in the pumped layer and overlying layer that is not pumped (Figure 3.28f).

As the freshwater bearing zone becomes thinner by depletion in heavily developed areas, especially where the wells are overlain by the brackish, Na-Cl and Na-SO₄-Cl layer, drawdowns will result in the juxtaposition of saline water at well screens as the freshwater is pumped out from beneath it (Figures 3.28g and 3.28h).

The cause of salt water encroachment is complex and several of these processes may combine to exert a sub-

stantial influence on water quality in wells. More work on this phenomena, possibly using environmental isotopes, will be needed to assess mechanisms of salinization.

Contaminant Susceptibility and Evidence of Contamination

The Hueco-Tularosa aquifer is moderately susceptible to contamination. The Texas portion of the aquifer has a moderate ground-water pollution potential (DRASTIC index) that ranges mostly from 80 -109 for general, municipal, and industrial sources (Cross and Terry, 1991). The DRASTIC index is 110 - 124 along the slopes of the El Paso Valley, where older bolson material has been incised by the Rio Grande.

Aside from contamination by encroachment of naturally occurring, poorer quality ground water, there are anthropogenic sources of contamination along the El Paso/Ciudad Juarez corridor. Potential sources of contamination within El Paso wellhead protection areas (WHPA) include (Cross and Terry, 1991): abandoned wells (19 identified in the WHPA); active water wells, some of which may be old or poorly constructed (747); underground storage tanks (73); municipal sewage lines (5 major lines 20 inches or larger); septic tanks (812); dumps (several); underground pipelines (13 natural gas pipelines and 2 fuel oil pipelines); treated sewage injection wells (several identified near the northern-most WHPA); abandoned animal feedlots (several identified from pre-1958 aerial photographs).

Point source contamination has been detected in ground water at several sites in the El Paso area. Point source contaminants include toxic trace elements (arsenic, copper, lead, zinc), PCB's, benzene, volatile organics, glycols, gasoline, diesel, jet fuel, unspecified chemicals, and waste oil (Texas Groundwater Protection Committee, 1992). Screenings for contaminants in the water distribution system of El Paso occasionally have detected low-levels of petroleum hydrocarbons and volatile organic contaminants. The sources of these contaminants are unverified (Robert

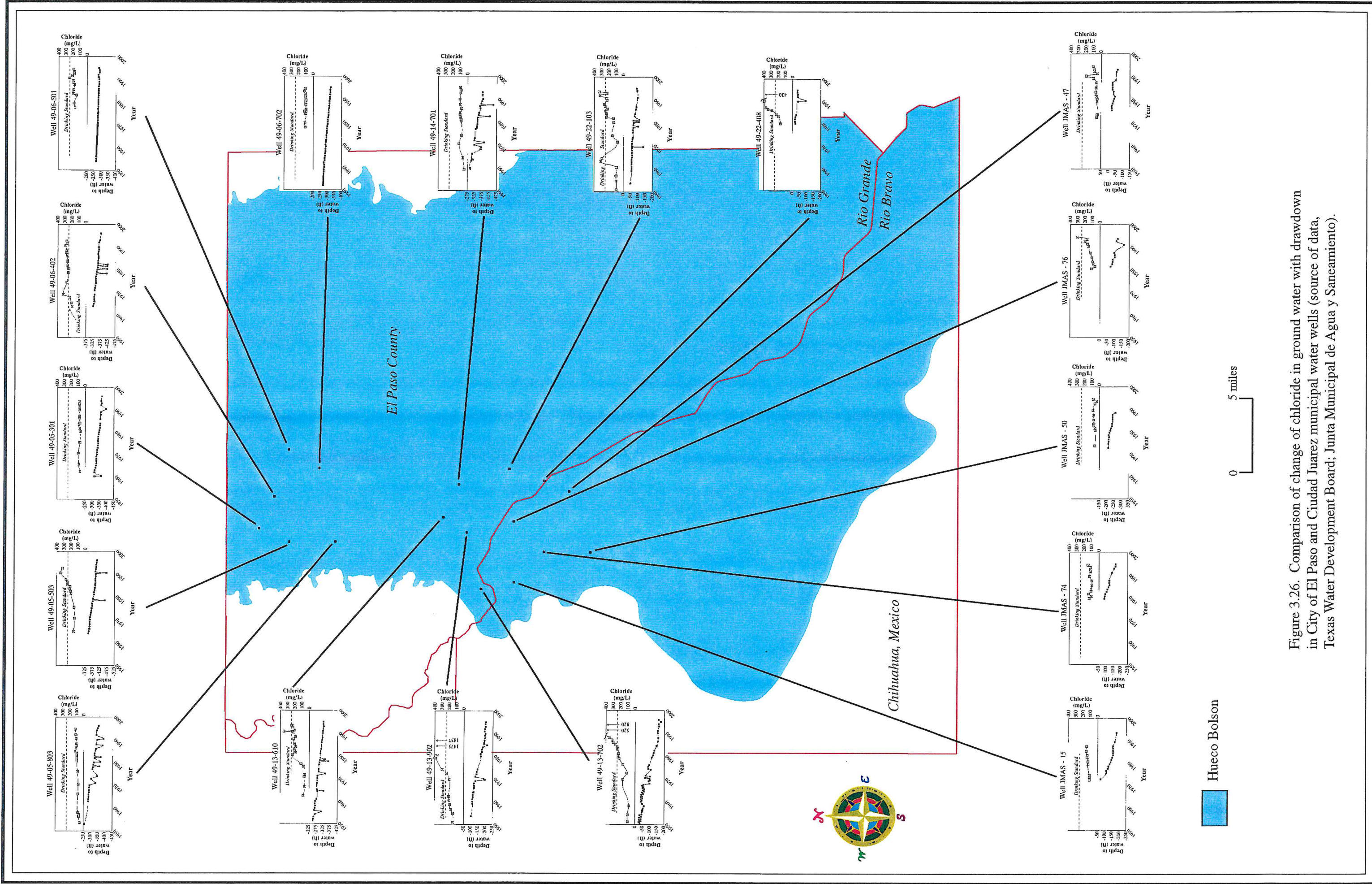


Figure 3.26. Comparison of change of chloride in ground water with drawdown in City of El Paso and Ciudad Juarez municipal water wells (source of data, Texas Water Development Board; Junta Municipal de Agua y Saneamiento).

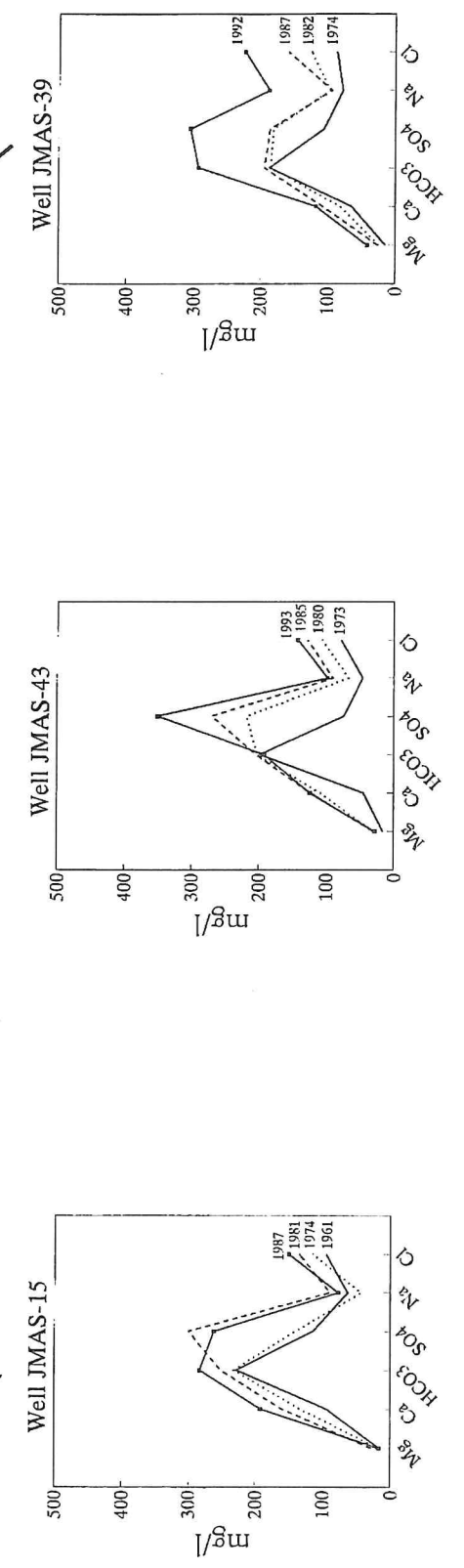
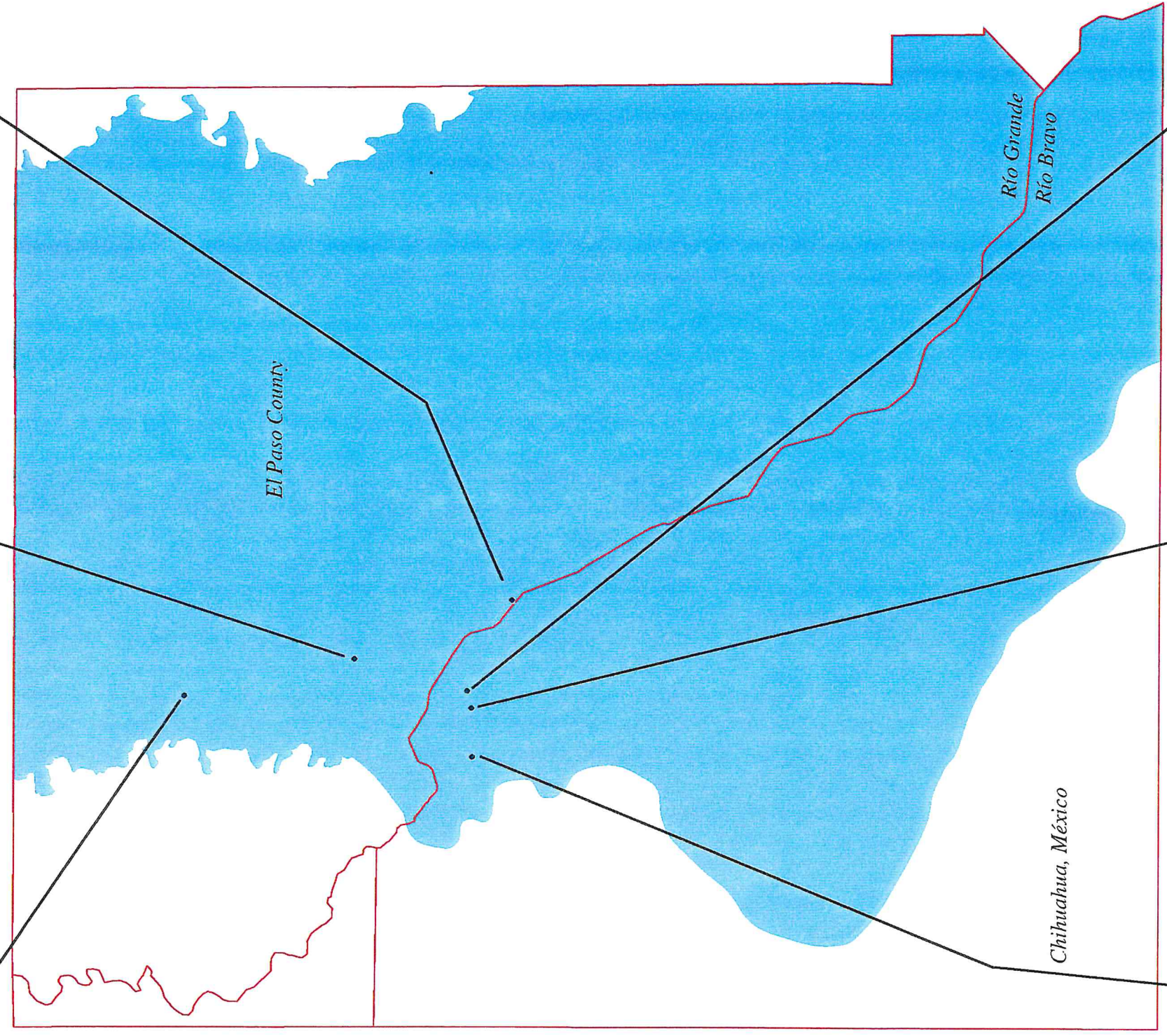
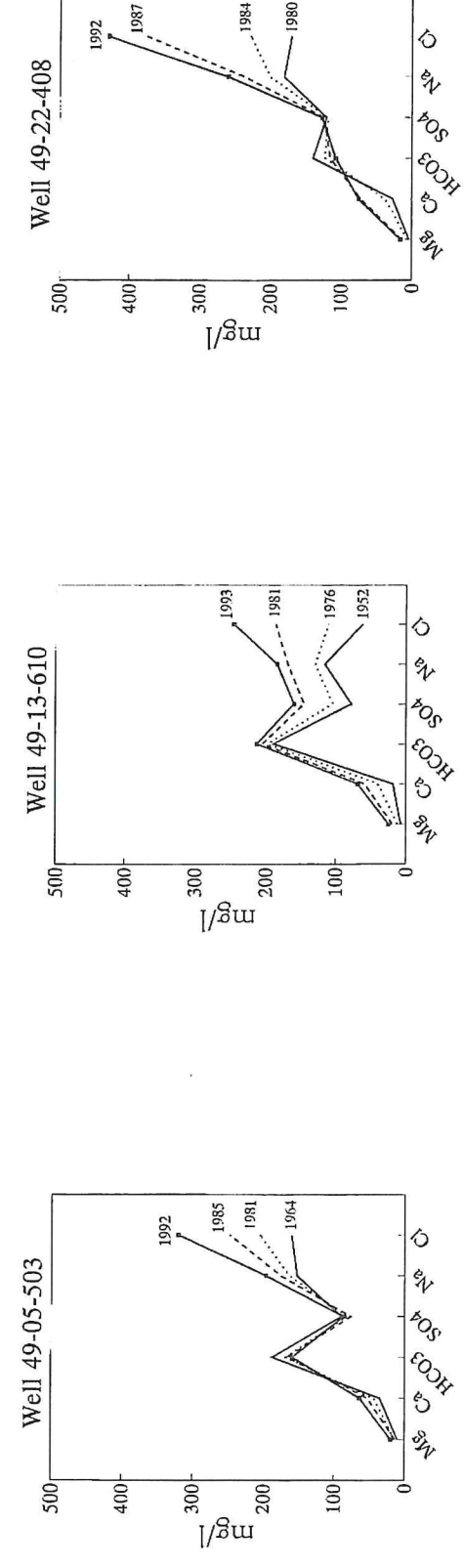
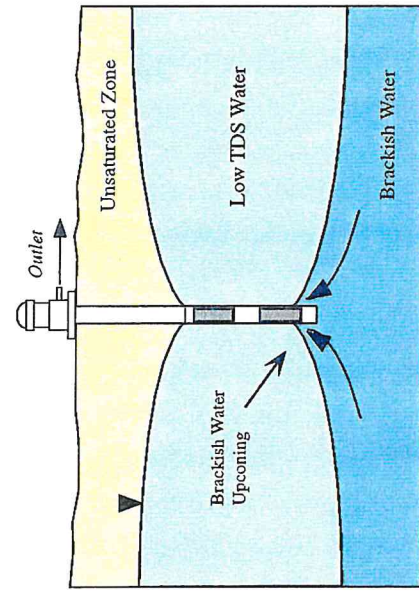
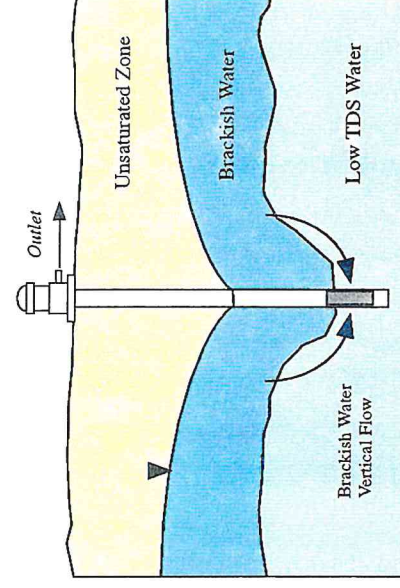


Figure 3.27 Time series hydrochemical plots for municipal wells in the City of El Paso and Ciudad Juárez area showing increasing concentrations of major elemental constituents in ground water (source of data, Texas Water Development Board; Junta Municipal de Agua y Saneamiento).



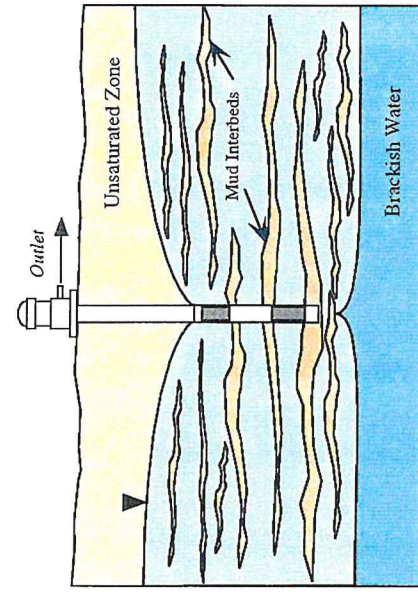
A

Upconing of saline water



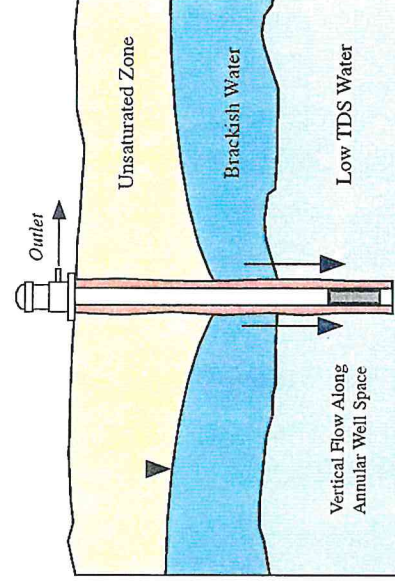
E

Downward movement through aquifer material



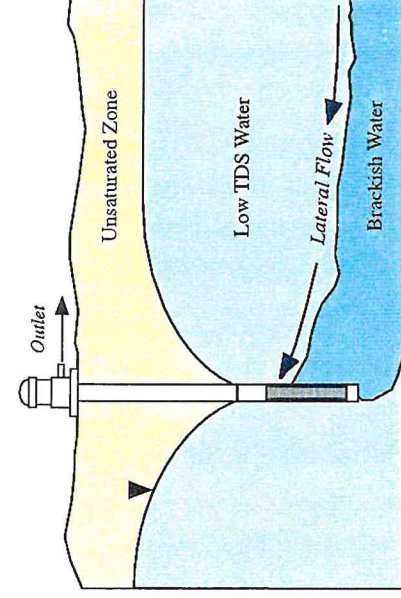
B

Mud interbeds may inhibit upconing



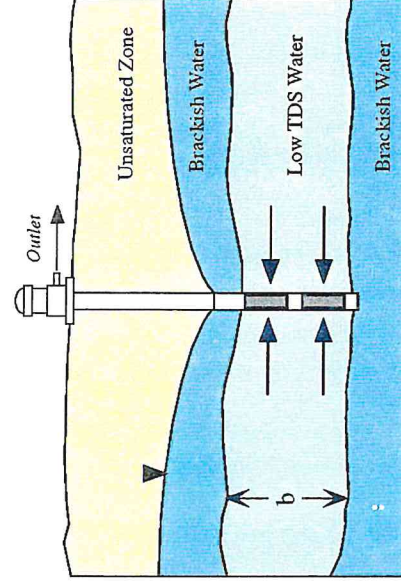
F

Downward movement along annular space



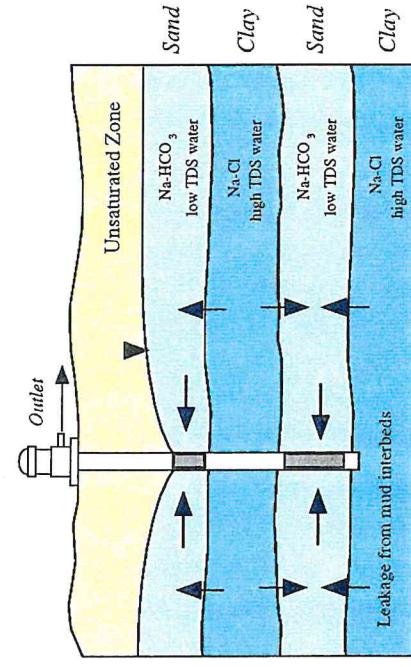
C

Pumping-induced lateral migration



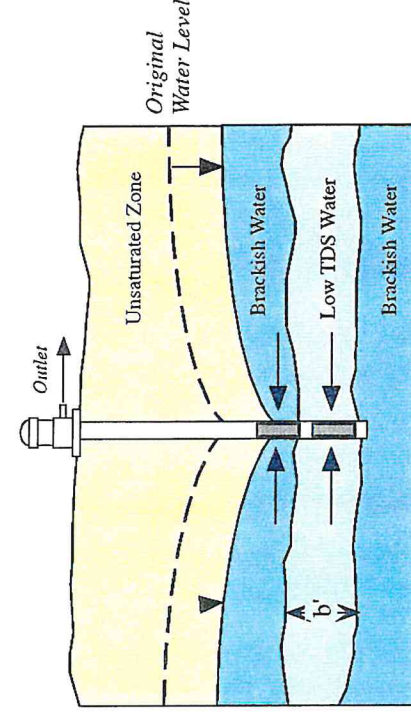
G

Thick freshwater layer...



D

Leakage from mud interbeds



H

...is depleted by pumping.

Figure 3.28. Possible sources of salinization of ground water in the City of El Paso/Ciudad Juarez area. Upconing has been proposed as a possible mechanism of salinization of water wells (a), but layered strata may minimize the effects of upconing (b). Salinization of water wells may occur as a result of lateral migration (c), or as a result of leakage from mud interbeds (d). Slightly more-dense brackish water may more easily move downward (e), especially along the annular space of a poorly constructed or abandoned well (f). Where saline ground water overlies and underlies a zone of freshwater (g), well salinization can occur as the freshwater lens is depleted due to long term pumping (h).

- Explanation**
- 0-5 mg/L NO₃-N
 - 5-10 mg/L NO₃-N
 - > 10 mg/L NO₃-N

- LEGEND**
- Bedrock exposure
 - Quaternary alluvium, channel fill and basin fill

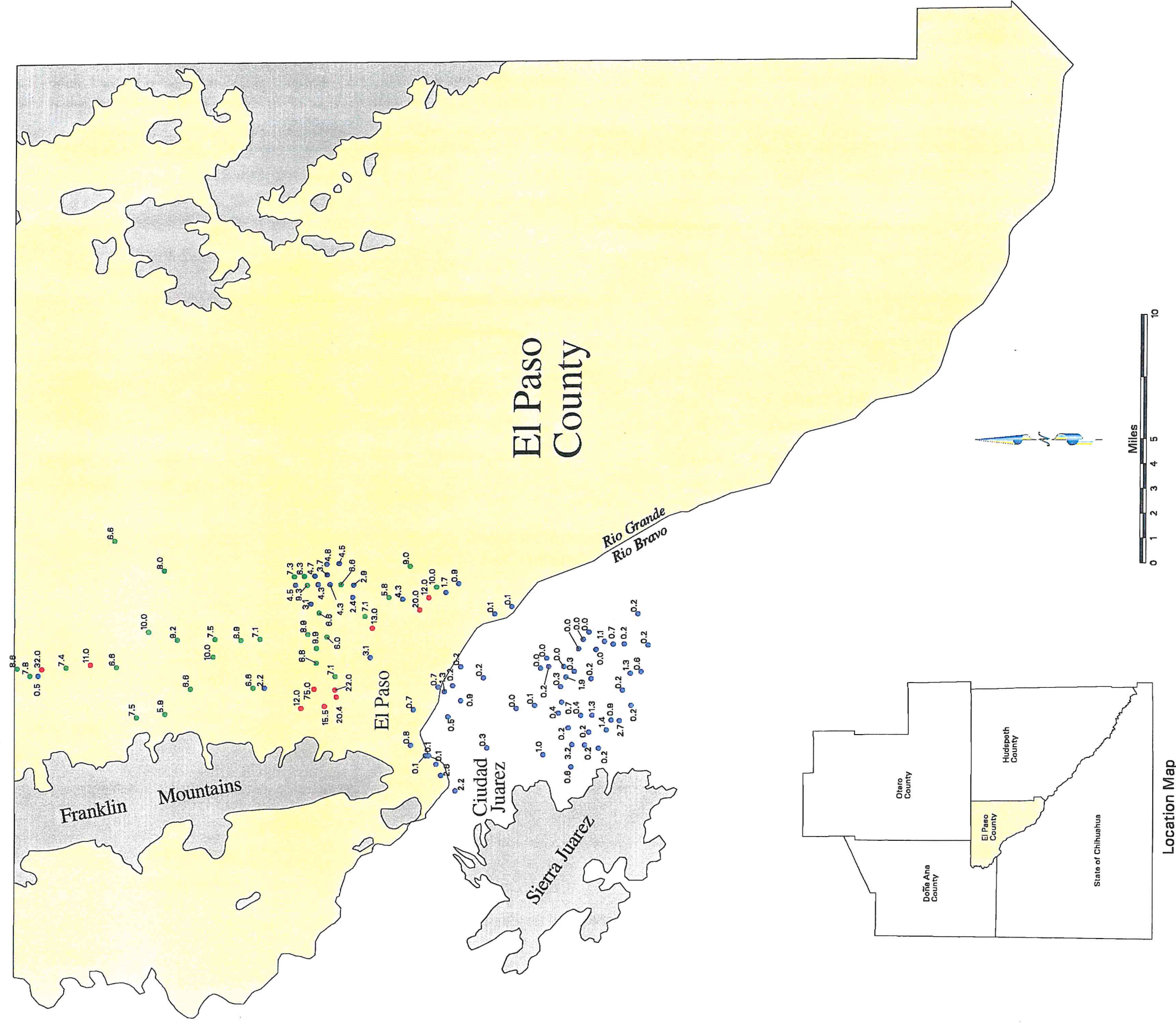


Figure 3.29. Nitrate concentrations in military, City of El Paso, and Ciudad Juarez municipal wells. All values reported as mg/L nitrate as nitrogen (NO₃-N). Data collected 1994 –1995 (source of data Texas Water Development Board; Junta Municipal de Agua y Saneamiento; City of El Paso Public Services Board).

Fecal Coliforms In Well Water

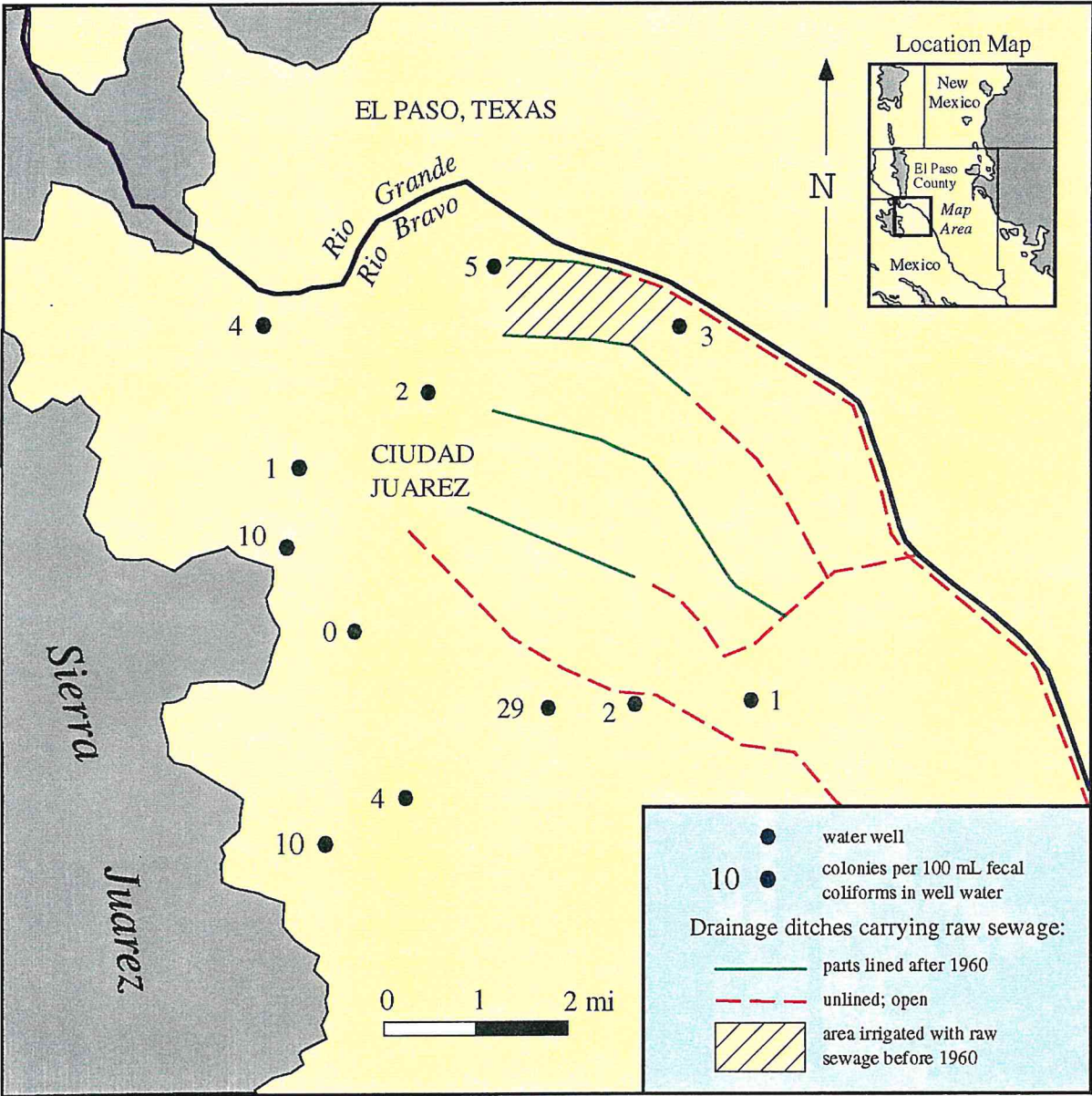


Figure 3.30. Diagram showing fecal coliform levels in 12 well-water samples collected in the Ciudad Juarez metropolitan area. These data were collected in 1987 (modified from Cech and Essman, 1992).

Blodgett, Texas Water Commission, personal communication).

In an earlier study, nitrate contamination was identified near El Paso's Old Mesa Well Field (White, 1987). Contamination probably occurred as a result of perched or shallow ground-water seepage into abandoned wells which recharge the deeper bolson aquifer (White, 1987). The abandoned wells act as conduits (Figure 3.28f) and allow shallow water to "cascade" into the deeper aquifer. Contamination was presumed to occur as a result of impounded urban runoff and deep percolation of commercial and residential lawn fertilizers.

Nitrate data collected between 1994 and 1995 indicate continuing nitrate problems in some parts of El Paso County. A cluster of wells in the vicinity of the Old Mesa Well Field in southwestern El Paso County exceed the 10 mg/L $\text{NO}_3\text{-N}$ drinking water standard (Figure 3.29). Many of the samples in El Paso County tested between 5 and 10 mg/L $\text{NO}_3\text{-N}$. All of the wells in Ciudad Juarez and immediate vicinity are less than 5 mg/L $\text{NO}_3\text{-N}$ (Figure 3.29).

In the Ciudad Juarez area, Cech and Essman (1992) tested residential water supplies in 1987 for possible contamination of ground water by sewage. They used fecal coliform as an indicator parameter. Forty-two samples were obtained; 30 from tap water and 12 from raw ground water. Ninety-one percent of raw ground-water samples were fecal coliform positive (Figure 3.30). Sixty percent of tap water samples were fecal coliform positive. The percentage of positive bacteria detections in these samples suggested that ground water beneath Ciudad Juarez was contaminated by sewage. These results may not be surprising because at the time of the sampling Ciudad Juarez had no sewage treatment facilities, and only 60% of the population was served by sewage lines (Figure 3.30). Sewage mains discharge into ditches (many of which are unlined and open) which carry the sewage to agricultural fields and into the Rio Grande (Cech and Essman, 1992).

Rio Grande waters are already contaminated above the El Paso/Ciudad Juarez metroplex. Contaminants include TDS, fecal coliforms, sulfates, and chlorides (Eaton and Anderson, 1987). Possible causes of these contaminants include irrigation return flows and municipal discharges. The quality of Rio Grande water deteriorates along the El Paso/Ciudad Juarez corridor and further downstream. Contamination is deduced by fecal bacteria as an indicator parameter. Immediately below El Paso, fecal coliforms as high as 290,500 colonies per 100 mL of water have been reported in Rio Grande water (Cech and Essman, 1992).

The exchange of water between the Rio Grande, the Rio Grande aquifer, and regional aquifers, such as the Hueco-Tularosa aquifer are explored in Chapter 5. Although the discussion deals primarily with salinity exchange, the fluxes present in these systems must be considered in light of possible anthropogenic pollutants that move from one water body to another.

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