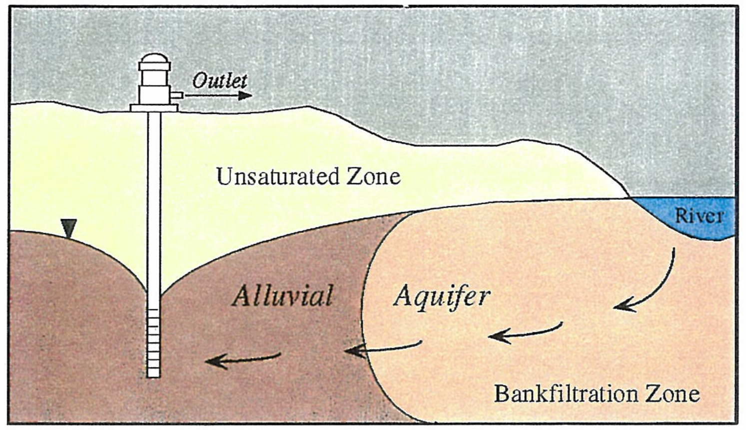

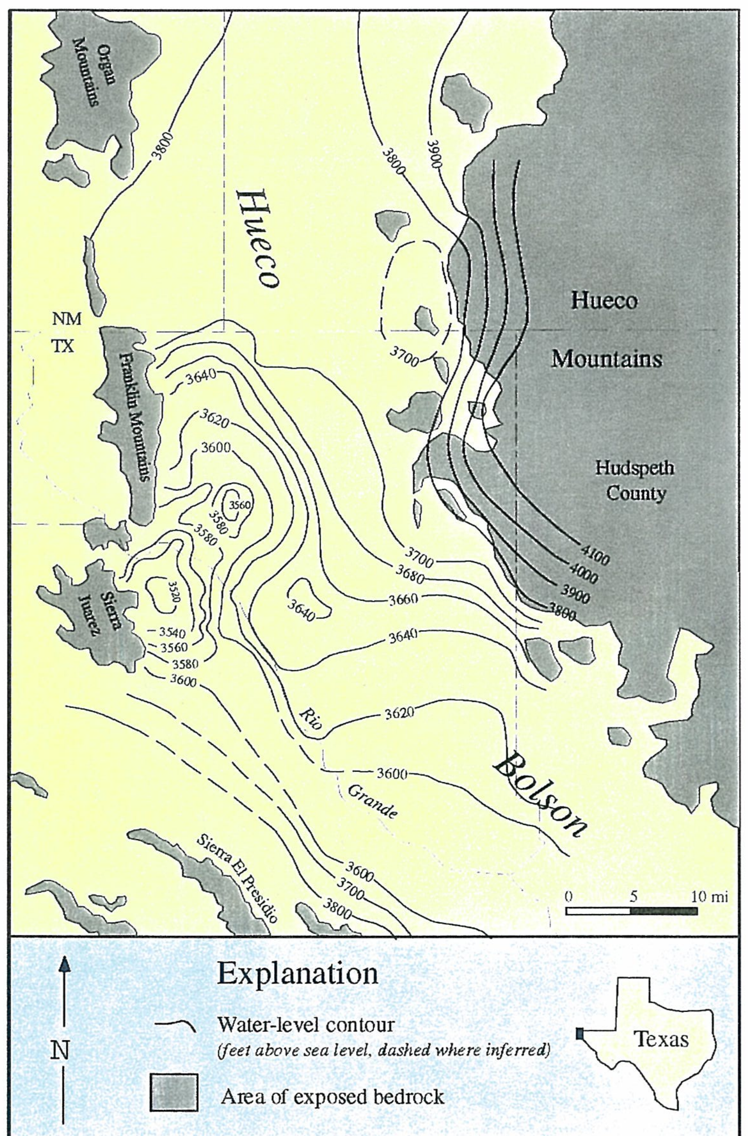

Transboundary Aquifers of the El Paso/Ciudad Juarez/Las Cruces Region

Prepared By

Texas Water Development Board
New Mexico Water Resources Research Institute

In Cooperation With

Comision Nacional Del Agua
Junta Municipal de Agua y Saneamiento de Ciudad Juarez
International Boundary and Water Commission
Comision International de Limites y Aguas

Prepared For

U.S. Environmental Protection Agency, Region VI

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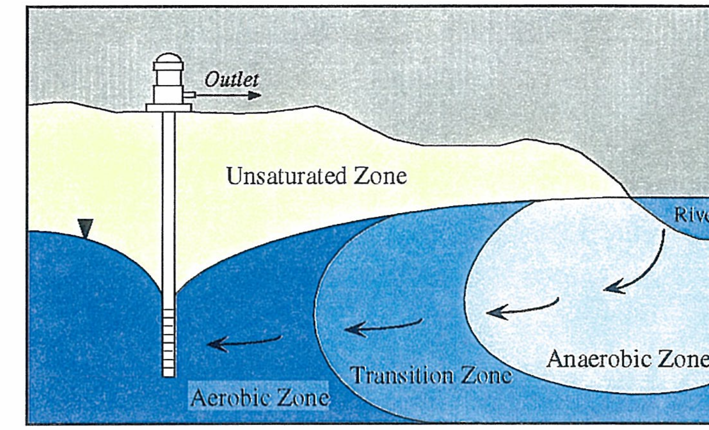

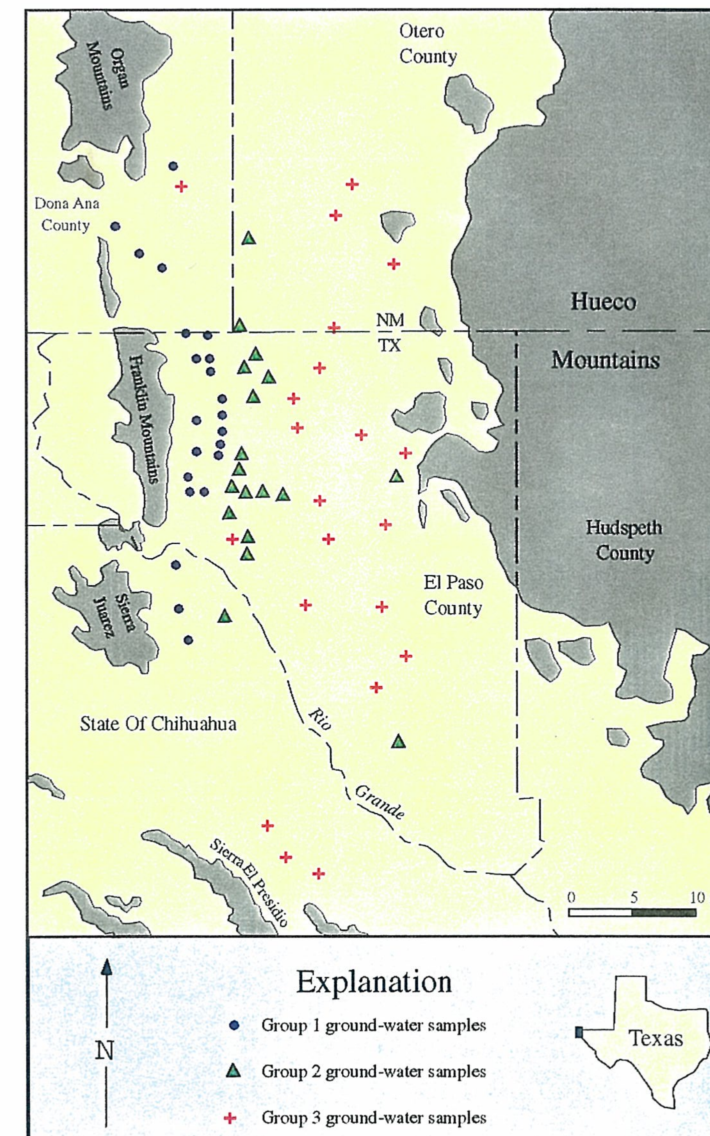

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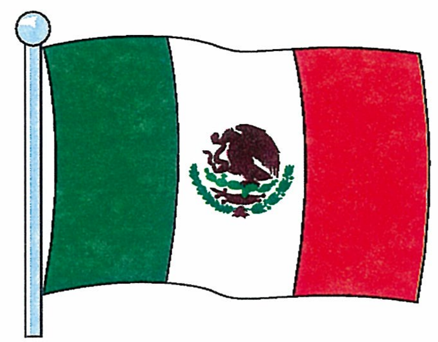

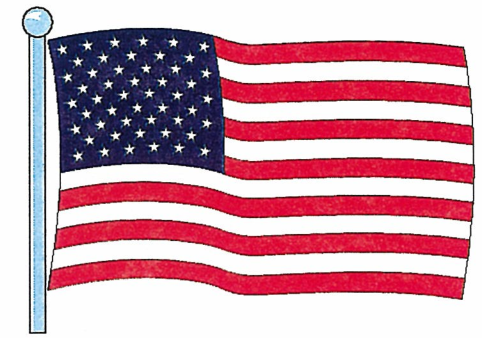

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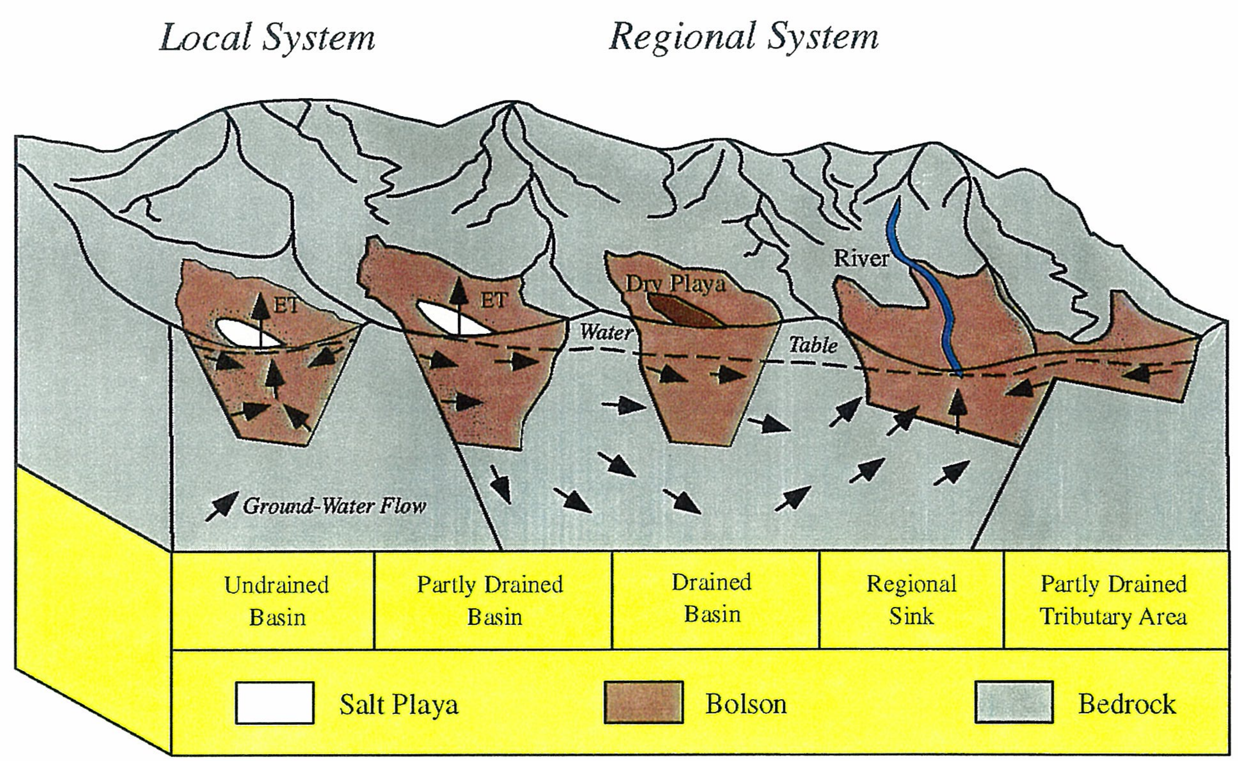

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Final Report

Joint contract report prepared by the Texas Water Development Board, Water Supplies/GIS Sections, and New Mexico Water Resources Research Institute for the U.S. Environmental Protection Agency, Region VI, under interagency contract numbers X 996343-01-0 and X 996350-01-0

EXECUTIVE SUMMARY

At the request of the U.S. Environmental Protection Agency, the Texas Water Development Board and the New Mexico Water Resources Research Institute undertook this study to characterize binational aquifers in parts of far west Texas, south central New Mexico, and northeastern Chihuahua, Mexico. The study area lies along a corridor centered at the City of El Paso\Ciudad Juarez metroplex and extending 62 mi (100 km) on either side of the international border. Assessments were made of the Mesilla Basin ground-water aquifer system, Rio Grande aquifer (Leasburg Dam to Indian Hot Springs), Hueco-Tularosa aquifer, southeastern Hueco aquifer, and Diablo Plateau aquifer. Technical and administrative assistance and data were provided by the Comision Nacional Del Agua, Junta Municipal de Agua y Saneamiento de Ciudad Juarez, International Boundary and Water Commission, and Comision Internacional de Limites y Aguas.

Many of the surface and ground-water resources along the transboundary corridor are shared between the two nations, yet little binational study of these resources has been undertaken. A number of environmental and hydrologic problems have been identified that will require the cooperation of both nations to solve. Solutions to water-related problems can be derived only when a better understanding of transboundary water resources is attained. This study is an important step toward attaining a better understanding of these binational resources.

To complete this study, data from several sources had to be combined into one data base. GIS coverages of ground water, surface water, and land use attributes were developed from the new data base. Study results for each aquifer are as follows:

Mesilla Basin Ground-Water Aquifer System

• The Mesilla basin ground-water aquifer system (the Rio Grande Floodplain Alluvium, Mesilla Bolson, and the Jornada del Muerto Bolson) are connected hydrologically, however the connections are restricted by aquitards and/or faults and therefore described as separate aquifers. The Mesilla basin aquifer system is an extensive intermontane aquifer system which extends from southern New Mexico to northern Mexico. It is surrounded by mountains which form the boundaries.

• Productive aquifers in the Mesilla basin ground-water system occur in both late Pleistocene to Holocene-Rio Grande alluvium deposits and the upper Tertiary and Quaternary unconsolidated sedimentary deposits of the Santa Fe Group. The surface water system is comprised of the Rio Grande and its tributaries and a network of canals, laterals and drainage ditches that discharge to the river. The surface drainage of the Mesilla basin covers approximately 11,000 square miles.

• Total water use in 1990, both surface water and ground water, for all categories was about 513,841 acre-feet of which 145,663 was from ground-water sources. Depletions were 246,279 acre-feet of which 96,895 was from ground water.

• There are two major potential sources of ground-water contamination which might impact the Mesilla Bolson: agricultural activity and high density residential septic tanks. The agricultural activity can again be broadly sub-divided into two major impact categories: cropping and dairies. The cropping activities which may have a negative impact on the ground water are: fertilization practices, pesticide and herbicide use, and irrigation practices. The number of milk cows in Doña Ana County in 1994 was estimated to be 31,000 and are largely concentrated south of Las Cruces along the eastern border of the Mesilla Bolson. Of the estimated 40,000 residents of southern Doña Ana County, New Mexico, fewer than 7% are on sewered wastewater systems. The majority use on-site waste treatment systems.

• The Rio Grande Floodplain Alluvium, between Leasburg dam and the El Paso narrows, is not a confined aquifer and consists of alternating and interfingering layers of clay and fluvial facies. These deposits extend laterally for hundreds of feet beyond the valley slopes with a basal gravel layer about 30 to 40 feet thick. It generally runs the width of the valley and is approximately 80 feet deep. The water table is approximately 10 to 25 feet below the land surface. Ground water within the alluvium is generally unconfined and typically moves southeastward down the valley at an average gradient of about 4 to 6 feet per mile; however, the direction is somewhat influenced by nearby hydraulic structures such as the river, drains, canals, well pumpage and heavily irrigated fields. Recharge to the aquifer occurs primarily as vertical flow from the surface water system (river, canals, laterals, and drains) and irrigated cropland fields. The quality of the water generally reflects the quality of the surface water system, ranging from about 500 TDS to over 1,000 TDS. The majority of discharge from the floodplain alluvium occurs through evapotranspiration of irrigated crops, flow to drain system, irrigation pumpage, municipal pumping, and industrial pumping. Transmissivity values range from 10,000 to 30,000 ft^2/day, hydraulic conductivity of 100 to 350 ft/day, and an estimated specific yield value of 0.2. The specific capacities ranges from 10 to 217 gpm/foot drawdown with an average of 69 gpm/foot drawdown.

• In the Mesilla Bolson the major source of fresh ground water is from the Quaternary-Tertiary age Santa Fe Group. The extent of the aquifer system within the Santa Fe Group is controlled by the surrounding faults which create an effective barrier to ground-water flow, although a small amount of flow may enter or leave the bolson at low barrier points. The Santa Fe Group has thick sequences of clay and silt facies that interfinger with fluvial facies, which create confined/leaky aquifer conditions in the basin fill. These facies vary in depth from 280 feet in the northern part of the bolson to over 2,000 feet near the center of the bolson.

• Three hydrostratigraphic units are commonly referred to: upper unit, middle unit and deep unit. The upper unit is generally only saturated in the northern third of the bolson and consists of gravels with lenticular deposits of clay. This unit may be the most permeable based on larger grain sizes and less cementation. The middle hydrostratigraphic unit is less permeable than the upper unit due to a greater degree of cementation. This unit also consists of gravel and lenticular deposits of clay. The deep unit consists of a uniform fine sand and averages approximately 600 feet in thickness. In general, the basin fill deposits of the Santa Fe Group are deep under the Mesilla Valley and generally thin toward the basin edges. The maximum thickness of Santa Fe Group deposits is estimated as approximately 2,500 feet. The deep hydrostratigraphic group rests on a bedrock of limestone conglomerate which is generally considered impermeable. Hydraulic conductivity's range from 2 - 68 ft/day, 1 - 100 ft/day and 1 - 34 ft/day for upper, middle and deep hydrostratigraphic units respectively. Estimates of transmissivity range from 2,600 ft^2/day for the upper intermediate unit to 4,700 ft^2/day for the deep zones and storage coefficient of 0.00043 in the southern portion.

• In the West Mesa area, the transmissivity of 5,900 ft^2/day was calculated for a well screened at selected intervals between 710 to 1,210 feet. In the northern section of West Mesa the transmissivity was estimated at 10,000 ft^2/day and a storage coefficient of 0.00002. Based on aquifer tests, the transmissivity ranged from 10,900 ft^2/day to 40,000 ft^2/day throughout the bolson. The average horizontal hydraulic conductivity was 67 ft/day. These tests also provided evidence that the horizontal hydraulic conductivity apparently decreases with depth. Vertical hydraulic conductivity values were found to range from 0.21 ft/day to 3.0 ft/day for the entire thickness of the confining layer.

• The majority of recharge occurs through mountain front recharge and through vertical flow of ground water from the floodplain alluvium. The quality of the ground water varies both with depth and areally. The upper unit generally reflects the quality of the alluvium which provides the most significant portion of the recharge, however this varies due to influence of confining clay and silt facies. The middle unit is generally of better quality, but decreases from north to south. This unit is the most heavily developed providing most all of the public and private drinking water supplies. The quality of the deep unit is generally less than the middle unit especially in the southern portion. The majority of the discharge occurs as municipal and industrial pumping.

• The Jornada del Muerto Bolson is east of the Mesilla Bolson. It covers approximately 3,344 square miles and is approximately 12 miles across at its widest section. It does not have a noticeable boundary with the Mesilla Bolson. The two bolsons are separated by a subsurface Tertiary volcanic rock high bounded by normal faults.

• The Santa Fe Group in the Jornada del Muerto Bolson is composed of a fluvial facies, a clay facies, and an alluvial-fan facies. The zone of saturation is most likely in older alluvial-fan deposits or in the fine-grained units of the clay facies. The clay facies is the predominant facies in the zone of saturation in the northern and extreme southern sections of the Jornada del Muerto Bolson. The depth to the water table is between 300 to 575 feet and the thickness of the saturated sediment is between 400 to 500 feet.

• The ground water in the northern part of the bolson moves south down the valley and west at an average gradient of 150 feet per mile. Ground water from the southern part of the bolson moves north and west at an average gradient of 10 feet per mile. The specific capacities for wells in the southern section of the Jornada del Muerto Bolson is about 5 gpm/foot drawdown. Estimated transmissivity values in this area range from 5,000 ft^2/day to 15,000 ft^2/day. Recharge occurs primarily from precipitation and infiltration of mountain runoff through major arroyos. Ground water in the southern section of the Jornada del Muerto Bolson is classified as fresh and water in the northern section of the bolson is classified as slightly saline.

Hueco-Tularosa Aquifer

• A 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. 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.

• Total surface area of the portion of the Hueco-Tularosa aquifer evaluated in this report is 4,160 mi^2. 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, Texas, and Mexico.

• Well yields in the New Mexico part of the Tularosa-Hueco aquifer vary greatly. Most of the wells produce water from alluvial fans that flank the mountains. 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. 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. South of the New Mexico/Texas State line, well yields in the Hueco Bolson, just east of the Franklin Mountains, are as much as 1,800 gpm. Wells underlying Ciudad Juarez yield from 300 to 1,500 gpm.

• Published hydraulic conductivity values derived from 37 aquifer tests in the Tularosa Bolson vary from 1.0 to 320.0 ft/day. Most wells are installed in alluvial fans. 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. 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. 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.

• 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. Ground water is at or near ground surface at Alkali Flat due to evaporative discharge from a 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. Drawdowns in the Hueco Bolson near the New Mexico/Texas State line has been relatively small, not exceeding 30 ft. Current depth to ground water beneath the City of El Paso is usually between 250 and 400 ft at distances from the Rio Grande. Present depth to ground water beneath Ciudad Juarez varies from about 100 to 250 ft, except near the Rio Grande where depths are often less than 70 ft.

• In heavily developed parts of the Hueco-Tularosa aquifer, 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 between 50 and 100 ft. Focal points of drawdown are shown beneath El Paso and Ciudad Juarez.

• Most ground-water discharge from the Hueco Bolson is due to pumping withdrawals for municipal and military water supply. Quantities of ground water pumped from the Hueco Bolson from municipal and other sources have increased by a factor of almost 6 since 1950. Recent trends indicate that municipal pumpage in Mexico increased about 12.5% between 1990 and 1994. Municipal and military pumpage in the United States decreased 24.0% during the same time interval. Pumping trends reflect the increased dependance on ground water in Mexico, and partial conversion from ground water to surface-water use in the United States.

• 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.

• Chloride and other dissolved ions have increased over time in many of the municipal wells in El Paso and Ciudad Juarez. Hydrochemical plots show a pattern of salinization of wells that have had significant long-term drawdowns. Chloride now exceeds 250 mg/L in several of the wells in the area. 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 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.

• Nitrate data collected between 1994 and 1995 indicate 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 NO_3-N drinking water standard. Many of the samples in El Paso County tested between 5 and 10 mg/L NO_3-N. All of the wells in Ciudad Juarez and immediate vicinity are less than 5 mg/L NO_3-N.

• In the Ciudad Juarez area, residential water supplies were tested in 1987 for possible contamination of ground water by sewage. Fecal coliform was used 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. 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.

Southeastern Hueco Aquifer

• The southeastern Hueco Bolson is separated geographically from the Hueco-Tularosa Bolson at the El Paso/Hudspeth County line. A southeast trending linear aquifer, the bolson extends for 55 miles from the El Paso/Hudspeth County line to its southeastern limit at Indian Hot Springs. The bolson is bounded on the north by the Finlay, Malone, and Quitman Mountains and Diablo Plateau. The Sierra de San Ignacio, Sierra de La Amargosa, Sierra de San Jose Del Prisco, Sierra de Las Vacas, and Sierra de Carrizalillo define its southern boundary. For convenience, the southeastern Hueco aquifer is designated to include water bearing strata in both the flanking highlands and plateaus and saturated bolson fill. The southeastern Hueco Bolson and bounding mountains and plateaus that are hydraulically connected to the bolson along ground-water divides are grouped as one aquifer, the southeastern Hueco aquifer.

• The thickness of the bolson fill of the southeastern Hueco aquifer decreases from as much as 8,500 ft at the El Paso/Hudspeth county line to an infinitesimal thickness where the bolson thins out near Indian Hot Springs. Saturated bolson fill is principally the lower basin fill series. The lower basin fill is mostly lacustrine clay, bedded gypsum, and minor sand, silt, and clay from both alluvial fans and local fluvial deposits. The upper basin fill series, a second lithologic unit, is thin and contains little water east of the El Paso/Hudspeth County line. The upper basin fill deposits were formed in alluvial fan, fluvial, and lacustrine systems and are composed of sand and gravel and minor silt and clay.

• Transmissivity values in the Cretaceous strata and bolson fill north of the Rio Grande are all relatively low. Well yields do not exceed 200 gpm usually and most well yields are less than 50 gpm. Aquifer tests performed in wells screened or open in Cretaceous strata gave transmissivity values between 0.22 and 1.50 ft^2/day. Aquifer tests in wells completed in bolson silts and sands gave transmissivity estimates between 0.43 and 94 ft^2/day. Higher transmissivity values are characteristic of a higher percentage of sand and gravel in the basin. Lower transmissivity values are characteristic of mud-rich sediments deposited in lacustrine and playa environments. Aquifer tests in basin fill indicate relatively low transmissivity values, sufficient only for livestock and domestic use.

• North of the Rio Grande, the regional potentiometric surface map shows high hydraulic heads and ground-water divides along the Diablo Plateau, Finlay Mountains, and Quitman Mountains. Areas of high head in the mountains and plateaus define focal points of recharge in the southeastern Hueco aquifer. Hydraulic head gradients in the Cretaceous and other bedrock strata are as much as 0.07 along ground-water divides and are as little as 0.04 along mountains fronts. Hydraulic gradients in the bolson fill are about 0.008. South of the Rio Grande, the potentiometric surface slopes to the river from high topographic elevations along mountain fronts. Springs flow at high elevations from the mountains in Mexico. These probably discharge from locally perched flow systems that do not define hydraulic head in the zone of regional saturation. Data are not adequate to define regional hydraulic heads beneath these mountains. Hydraulic gradients south of the Rio Grande, from mountain fronts to the river, are about 0.01 to 0.03.

• The southeastern Hueco aquifer can almost be considered undeveloped, especially north of the Rio Grande. Low capacity domestic and livestock wells are used to satisfy the needs of the local population and livestock industry. This is partly a function of the low yield and relatively high salinities of the aquifer.

• Total dissolved solids in the southeastern Hueco aquifer are typically greater than 1,000 mg/L in the mountains, increasing to as much as 4,000 mg/L in the bolson. The hydrochemical facies of southeastern Hueco aquifer ground waters on the United States side of the study area varies from Ca-Mg-HCO_3 and Na-SO_4 along the Diablo Plateau to Na-SO_4-Cl beneath the floor of the basin. In Mexico, waters vary from Ca-Mg-HCO_3 beneath the Sierra de San Ignacio, Sierra de La Armagosa, and the Sierra de San Jose Del Prisco to Ca-Mg-SO_4-Cl waters beneath the basin floor. Typically these ground waters have TDS that vary between 1,000 and 3,500 TDS. Indian Hot Springs is an exception; Na-Cl water with TDS higher than 7,000 mg/L discharges from Cretaceous carbonate and clastic rocks at the hot springs.

• Bedrock units exposed in the southeastern Hueco aquifer are moderately susceptible to contamination. The Diablo Plateau has a moderate ground-water pollution potential (DRASTIC index) that ranges from 95 - 124 for agricultural sources. The DRASTIC index for general, municipal, and industrial sources is lower, ranging from 65 - 94.

• The southeastern Hueco Bolson has a higher DRASTIC index, ranging from 110 - 124 for agricultural sources and from 80 - 94 for general, municipal, and industrial sources. Some qualification of this ranking is required. Even though the potential for contaminants at land surface being carried with infiltrating precipitation to the saturated zone is possible along arroyos, the potential for contamination along areas of the basin floor that are not juxtaposed to arroyos is generally small. The relatively dry climate, specific retention of the soil, and intensity and distribution of rainfall does not provide adequate moisture for wetting fronts to reach the saturated zone except along arroyos.

Rio Grande Aquifer

• Southeast of the El Paso narrows, the Rio Grande flows across a broad alluvial floodplain that has incised the surface of the Hueco Bolson. The Rio Grande alluvial floodplain in the El Paso/Juarez Valley is underlain by a complex mosaic of braided and meandering river deposits. Formed during alternating periods of scour and fill in the late Quaternary Period, the river deposits consist of irregularly distributed gravels, sands, clay, and silt lenses and beds. Alluvial fill consists of reworked bolson fill material, eroded bedrock, and extrabasinal sediments transported by the Rio Grande from its headwaters in New Mexico and Colorado to the El Paso/Juarez Valley.

• Water level contour maps prepared with data collected in 1973 - 74 and 1994 - 1995 illustrate losing stream, underflow, and baseflow conditions on different segments of the alluvial floodplain. The condition of losing stream is apparent along the Chamizal zone where drawdown cones from municipal well fields have reversed the hydraulic gradient between the river and the Rio Grande aquifer. Drawdowns have intensified along the Chamizal zone since 1973. Alluvial underflow predominates between the Chamizal zone and the El Paso/Hudspeth county line. Along this stretch of floodplain, ground-water flows subparallel to the direction of surface discharge, and head in the aquifer is approximately equal to the head in the river. The head elevation along this reach did not change significantly since 1973. The condition of baseflow prevails between county line and Fort Quitman. Flow is oriented subperpendicular to the direction of surface discharge and ground water clearly discharges to the Rio Grande. Hydraulic head in this part of the floodplain has increased since 1973.

• Recharge to the Rio Grande aquifer along irrigated reaches is due primarily to infiltration of surface water that has been applied to irrigable crops. Recharge also occurs to some extent by direct seepage from diversion canals and river channels, although lining of the Rio Grande channel along the Chamizal zone limits recharge by the river locally. Other sources of recharge to the Rio Grande alluvium include direct precipitation on the floodplain surface, seepage from irrigation canals and drains, infiltration of runoff along arroyos, and recharge from cross-formational flow with the Hueco Bolson. Quantification of the amounts and spatial variability of recharge to the alluvial aquifer is infeasible with available data.

• Ground water is discharged from the Rio Grande alluvium by irrigation pumping, by subsurface seepage to the Rio Grande, by leakage to drains, and by cross-formational leakage to the Hueco Bolson. Along the heavily urbanized Chamizal zone, discharge occurs primarily by cross-formational leakage from the alluvium to the Hueco Bolson where storage in the Rio Grande aquifer is depleted by heavy municipal pumping in the bolson aquifer. From Chamizal zone to the El Paso/Hudspeth County line, discharge occurs by irrigation pumping and by leakage to the many drains which help to maintain nearly constant water-levels in the alluvial aquifer. From the county line to Fort Quitman, discharge occurs by irrigation pumping, by seepage to the Rio Grande, and by leakage to a few drains.

• Stiff diagrams indicate sodium-sulfate type ground-waters in the Rio Grande aquifer in El Paso County. Below the El Paso/Hudspeth County line, chloride increasingly becomes the dominant anion in the cation/anion pairing. Mexican ground waters follow the same general trend, but show greater scatter in the segment of the floodplain across from Hudspeth County. Ground-water samples frequently were collected in and beneath arroyo deposits that overlie earlier alluvial floodplain deposits in Mexico. Arroyos act as recharge areas after episodic precipitation events and ground-water chemistries have wide scatter due to commingling of dilute runoff waters and older alluvial ground waters.

• Total dissolved solids in the Rio Grande aquifer in El Paso County vary substantially, but fall mostly within the 1,000 to 3,000 TDS range. Total dissolved solids are higher in alluvial deposits in Hudspeth County, falling mostly within the 3,000 to 6,000 TDS range. In both regions, total dissolved solids are lower in the Mexican part of the floodplain aquifer due to mixing of dilute runoff waters with older, higher salinity waters. This is an artifact of well locations closer to arroyos on the floodplain in Mexico.

• Historical monthly water quality and streamflow data show changes in river water quality and discharge between El Paso/Ciudad Juarez and Fort Quitman. Spatial changes in sodium, sulfate, chloride, and total dissolved solids for most months indicate appreciable decline in river water quality downstream. Data indicate that water quality improves when river discharge is high during the irrigation season.

• Rio Grande waters are already contaminated above the El Paso/Ciudad Juarez metroplex. Contaminants include TDS, fecal coliforms, sulfates, and chlorides. 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.

• The Rio Grande aquifer is highly susceptible to contamination. The aquifer can be contaminated rapidly by land application of fertilizers and pesticides, by leaching from septic tanks and feedlots, and by infiltration of chemicals or hazardous waste from storage facilities or from accidental spills. Consisting mostly of permeable unconsolidated deposits, the aquifer has received a DRASTIC index greater than 154 across much of the study area.

Diablo Plateau Aquifer

• The Diablo Plateau covers all but the southern part of Hudspeth County, Texas. The plateau is juxtaposed against regional grabens that formed by Quaternary-age lateral extension and normal faulting. The Campogrande fault displaces Cretaceous strata against bolson deposits southwest of the fault, forming an escarpment of more than 400 ft. Together with Otero Mesa to the north, the Diablo Plateau is a gently eastward-sloping structure situated at an elevation of between 4,400 and 5,200 ft. It is bounded by the Hueco-Tularosa Bolson on the southwest, by the Steeruwitz Hills, Carrizo Mountains, Van Horn Mountains, and Wylie Mountains on the south and southeast, and by the Salt Basin and Otero Break on the northeast. The edge of the Sacramento Mountains define the northern boundary of the aquifer.

• In Texas the Diablo Plateau consists of two rock units: (1) the Permian carbonate and evaporite rocks of Leonardian and Guadalupian age in northern Hudspeth County and, (2) the Cretaceous carbonate and clastic rocks of the Finlay, Cox, and Campogrande Formations, which outcrop roughly south of the Dell City parallel. The primary water-bearing units over much of the Diablo Plateau are Permian rocks with an average thickness of 1,300 ft. Ground water is encountered at depths from 200 ft to 1,500 ft. In the Dell City area the Permian aquifer is locally known as the Victorio Peak-Bone Spring aquifer. Lithologic control for this aquifer outside the Dell City area is extremely limited.

• In New Mexico, the plateau (known as the Otero Mesa) is composed almost entirely of Permian carbonate, clastic, and evaporite rocks of the Yeso, Victorio Peak, Bone Spring, and San Andres Formations. Of these, only the Victorio Peak and Bone Spring Formations comprise the main aquifer.

• Aquifer tests conducted in the Diablo Plateau aquifer suggest that permeabilities in the aquifer are solution-and-fracture controlled. Video logs run in several test holes revealed continuous vertical fractures and grapefruit-size dissolution cavities. Approximately 44 percent of wells drilled in the Dell City area are prolific; many wells produce 100 gpm or less, even when drilled near wells successfully pumping 2,000 gpm. This response is an artifact of the high transmissivity contrast which characterizes the Permian and Cretaceous carbonate rocks in the Diablo Plateau region.

• The potentiometric map for the Diablo Plateau aquifer and surrounding region indicates that ground-water flow is generally from southwest to northeast beneath the Diablo Plateau and from northwest to southeast beneath Otero Mesa. Flow from both regions converges towards Dell City and the Salt Basin along flowpaths with average hydraulic gradients of 0.0004, although gradients are as steep as 0.001. The Dell City area is encompassed by a shallow, broad cone of depression in the potentiometric surface that has formed as a result of extensive irrigation and ground-water development. A "trough" runs beneath the Sacramento River towards Dell City, its widely spaced contour lines suggesting high transmissivity along the trough. The potentiometric surface is near land surface in the Salt Basin where ground water discharges by evaporation.

• The ground-water resources in the study region are mostly undeveloped, except in the Dell City irrigation district. Hydrographs of six wells in the Dell City area show significant changes in water levels since predevelopment. The rest of the system is almost at steady state. As pumping exceeded recharge, water levels dropped constantly until the mid-1980's at an average rate of 1.3 ft/year, totaling 25 to 45 ft of drop areawide. Since then, irrigation pumpage diminished, and water levels have risen slightly.

• Tritium and carbon-14 (^{14}C) levels measured in wells on the Diablo Plateau indicate that most of the ground water samples contain recent water (i.e., water recharged within the last 50 years). The tritium and ^{14}C values display significant changes within short distances and no clear distribution pattern, thus emphasizing the practical importance of fracture and karstic flow. Recharge occurs over the entire plateau (approximately 2,900 mi^2) as demonstrated by the areal distribution of tritium-rich samples. Most recharge probably takes place during flooding of the ephemeral creeks ("arroyos") that cross the plateau.

• Ground water in the Diablo Plateau aquifer is fresh to brackish, with total dissolved solids (TDS) concentrations as low as 500 mg/L in the Sacramento River area, to over 3,800 mg/L in central-western Otero Mesa where water-bearing strata are interbedded with the gypsiferous Yeso Formation. In the Dell City area, where return flow from irrigation leaches salts from the soils and evaporates, TDS concentrations reach 6,500 mg/L. Hydrochemical facies in the area vary from Na-Ca-HCO_3 and Na-SO_4 in the southwest to Na-SO_4, Ca-SO_4, and Na-Cl in the north and northeast. The change in chemistry from southwest to north/northeast can be attributed to the changing lithology from Cretaceous carbonates to evaporate-rich Permian rocks along flowpaths, and to ground-water evaporation and mixing.

• The Diablo Plateau aquifer is moderately susceptible to contamination. The Diablo Plateau has a moderate ground-water pollution potential (DRASTIC index) that ranges from 95 - 124 for agricultural sources, the principal activity in the region. The DRASTIC index for general, municipal, and industrial sources ranges from 80 - 124.

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CHAPTER 1 - INTRODUCTION

Preface

Purpose

At the request of the U.S. Environmental Protection Agency (USEPA), the Texas Water Development Board (TWDB) and the New Mexico Water Resources Research Institute (NMWRRI) undertook this study to characterize binational aquifers in parts of far west Texas, south central New Mexico, and northeastern Chihuahua, Mexico. The study area lies along a corridor centered at the City of El Paso\Ciudad Juarez metroplex and extending 62 mi (100 km) on either side of the international border. The study uses well-established hydrogeological, hydrochemical and numerical modeling techniques to trace ground-water flowpaths, to assess regional water quality, and to define aquifer recharge and discharge areas and areas susceptible to contamination.

Many of the surface and ground-water resources along the transboundary corridor are shared between the two nations, yet little binational study of these resources has been undertaken. A number of environmental and hydrologic problems have been identified that will require the cooperation of both nations to solve. Solutions to water-related problems can be derived only when a better understanding of transboundary water resources is attained. This study is an important step toward attaining a better understanding of these binational resources.

To complete this study, data from several sources had to be combined into one data base. GIS coverages of ground water, surface water, and land use attributes were developed from the new data base. This report provides results of the study. Appendix C provides documentation of GIS coverages.

Participating agencies

Key participants in the project included the TWDB and the NMWRRI. TWDB team-members included Barry Hibbs, principal hydrogeologist and co-project manager; John Ashworth, geologist and co-project manager; Radu Boghici, assistant hydrogeologist; Mark Hayes, Erika Boghici, and Darrell Peckham, GIS analysts; Steve Moore and Frank Bilberry, engineering technicians; and Jay Galvan, Steve Gifford and Mike McCathern, layout and cartography. NMWRRI team-members included Bobby Creel, project manager; Adrian Hanson, environmental engineer; Zohrab Samani, hydrogeologist; John Kennedy, GIS analyst/geologist; and Pamela Hann and Kenny Stevens, research assistants. Several technical and support staff from the Texas Water Development Board, New Mexico Water Resources Research Institute, and New Mexico State University made ancillary contributions.

Assessments of the Mesilla Bolson aquifer, Jornada del Muerto Bolson aquifer, and Rio Grande aquifer (Leasburg Dam to the El Paso narrows) were performed by the New Mexico team. Assessments of the Hueco-Tularosa aquifer, southeastern Hueco aquifer, Diablo Plateau aquifer, and Rio Grande aquifer (El Paso narrows to Indian Hot Springs) were performed by the Texas team. Collation of regional GIS coverages from the Texas and New Mexico teams and report assembly and publication were performed by the Texas Water Development Board.

The Comision Nacional Del Agua (CNA), Mexico, and Junta Municipal de Agua y Saneamiento (JMAS) de Ciudad Juarez, provided hydrologic data and technical assistance. Logistics of international data transfers were facilitated by the U.S. and Mexican sections of the International Boundary and Water Commission (respectively, IBWC and Comision Internacional de Limites y Aguas, [CILA]).

Acknowledgments and disclaimer

Research supported by the U.S. Environmental Protection Agency under USEPA contract numbers X 996343-01-0 and X 996350-01-0. The views and conclusions in this report are those of the TWDB and NMWRRI and should not be interpreted as necessarily representing the official opinions of the USEPA, IBWC, CILA, CNA, or JMAS.

Adjunct research institutions and public agencies are credited for providing technical and administrative assistance for this study. These include the University of Texas Bureau of Economic Geology (BEG); the Center for Environmental Research Management (CERM) at the University of Texas at El Paso (UTEP); the IBWC and CILA; the U.S. Geological Survey (USGS), New Mexico State District Office, Albuquerque; the Public Services Board (PSB), City of El Paso; the JMAS, Ciudad Juarez; the Texas Natural Resource Conservation Commission (TNRCC); the Texas Natural Resources Information System (TNRIS); and the New Mexico Environment Department (NMED). Several individuals are acknowledged for providing technical and administrative assistance and data. They include Chris King of the USEPA; Bruce Darling of LBG Guyton Associates; Jim Mayer of Georgia Southern University; Edward Collins and William Mullican of BEG; Nancy Lowery of CERM; Sylvia Waggoner, Cruz Ito, Rong Kuo, Carlos Pena, Jim Robinson, and Jose Valdez of IBWC; Antonio Rascon of CILA; Mike Kernodle, Brennon Orr, and Linda Beal of the USGS; Ernest Rebuck; Sayeed Joraat, and Roger Sperka of El Paso PSB; Francisco Nunez of Ciudad Juarez JMAS; and Miguel Pavon of TNRIS.

Regional Geographic Setting

Location

The area encompassed by this study lies between north latitudes 33 24' 32" and 30 30' 00" and west longitudes 107 18' 18" and 104 50' 31". The study area includes all of Doña Ana and Otero Counties, New Mexico and all of El Paso and Hudspeth Counties, Texas. Part of northeastern Chihuahua, Mexico is included in the study area (Figure 1.1). Total land surface area encompassed by the study is about 24,900 mi^2, of which nearly 8,800 mi^2 is in Mexico. Principal transboundary aquifers in the region include the Hueco-Tularosa aquifer and the Mesilla Bolson aquifer (Figure 1.2). These aquifers are extensively developed and satisfy most of the municipal and industrial water demands in the City of Las Cruces, City of El Paso, and Ciudad Juarez. Other aquifers include the southeastern Hueco aquifer, the Diablo Plateau aquifer, the Rio Grande aquifer, and the Jornada del Muerto aquifer (Figure 1.2). Of the latter, only the Rio Grande aquifer is extensively developed and transboundary in extent.

Topography and drainage

The study area lies primarily within the southeastern segment of the physiographic Basin and Range Province. The topography is dominated by long, narrow mountain ranges, intermontane basins (flats and draws), and gently sloping plateaus (Figure 1.3). The most prominent topographic feature in the New Mexico part of the study area is the Sacramento Mountains in Otero County. The highest peak in the Sacramento Mountains is Sierra Blanca at 12,003 ft above sea level. The Organ Mountains of Doña Ana County reach a peak elevation of 9,012 ft. The Franklin Mountains of El Paso County, Texas, and the Eagle Mountains of Hudspeth County, Texas, attain respective elevations of 7,192 and 7,484 ft. The Sierra de Las Vacas, the highest topographic mountain range in the Mexican part of the study area, reach a peak elevation of 7,218 ft.

Surface drainage for the Sacramento Mountains and Otero Mesa is to the Tularosa Basin and Salt Basin, two internal drainage, closed basins (Figures 1.3 and 1.4). Surface drainage for the U.S. parts of the Mesilla and Hueco Basins is mostly captured by the Rio Grande, the principal surface drainage in the study area. The Mexican portion of the Hueco Basin is also drained by the Rio Grande. The Mesilla Basin (referred to as Bolson de Mesilla - Samalayuca in Mexico [de La O Carreno, 1957]) is drained partly by the Rio Grande and partly by Laguna Coyames in Mexico. The Diablo Plateau drains mostly into the Salt Basin to the east and

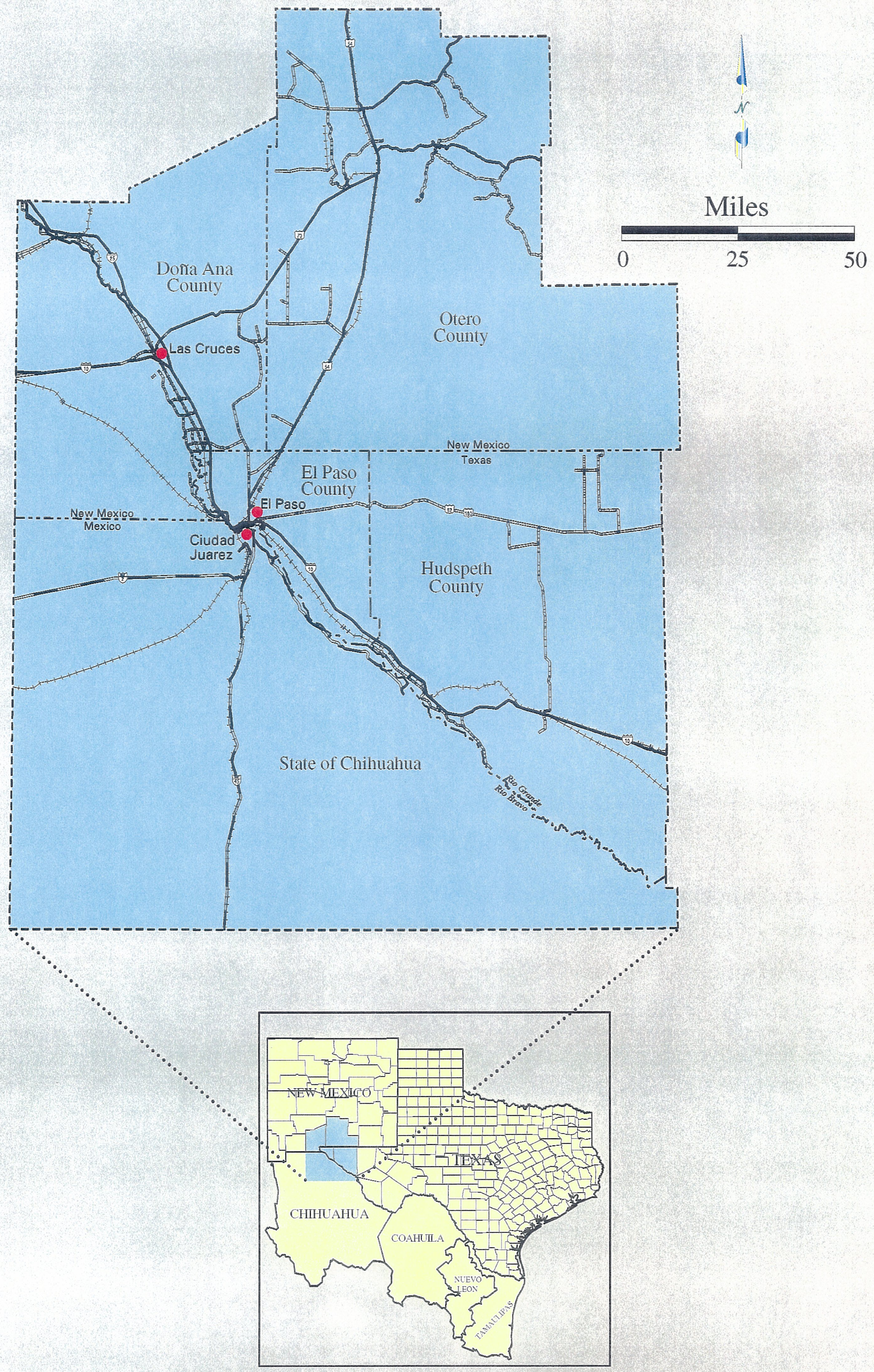
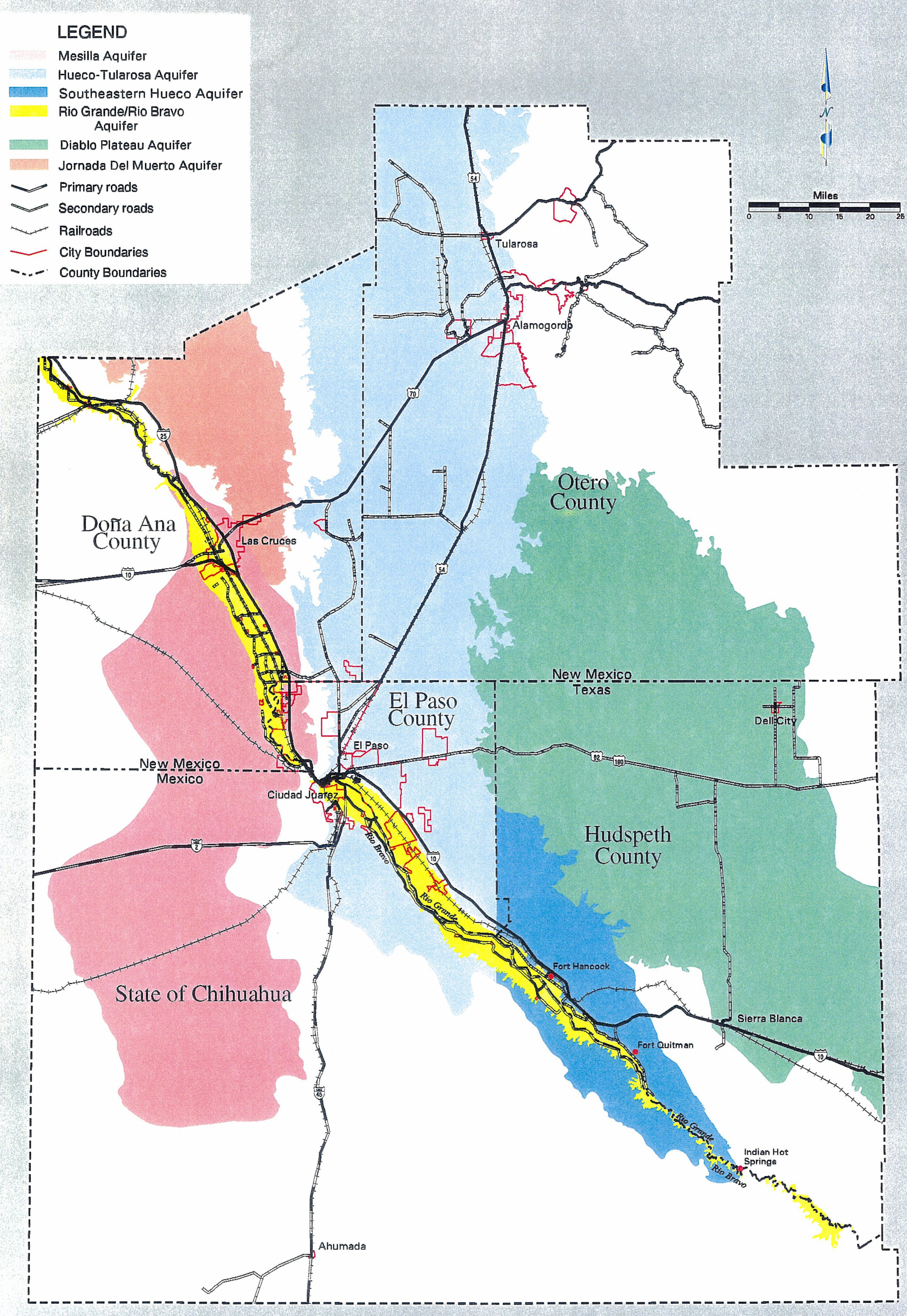


Figure 1.1. Location of study area.



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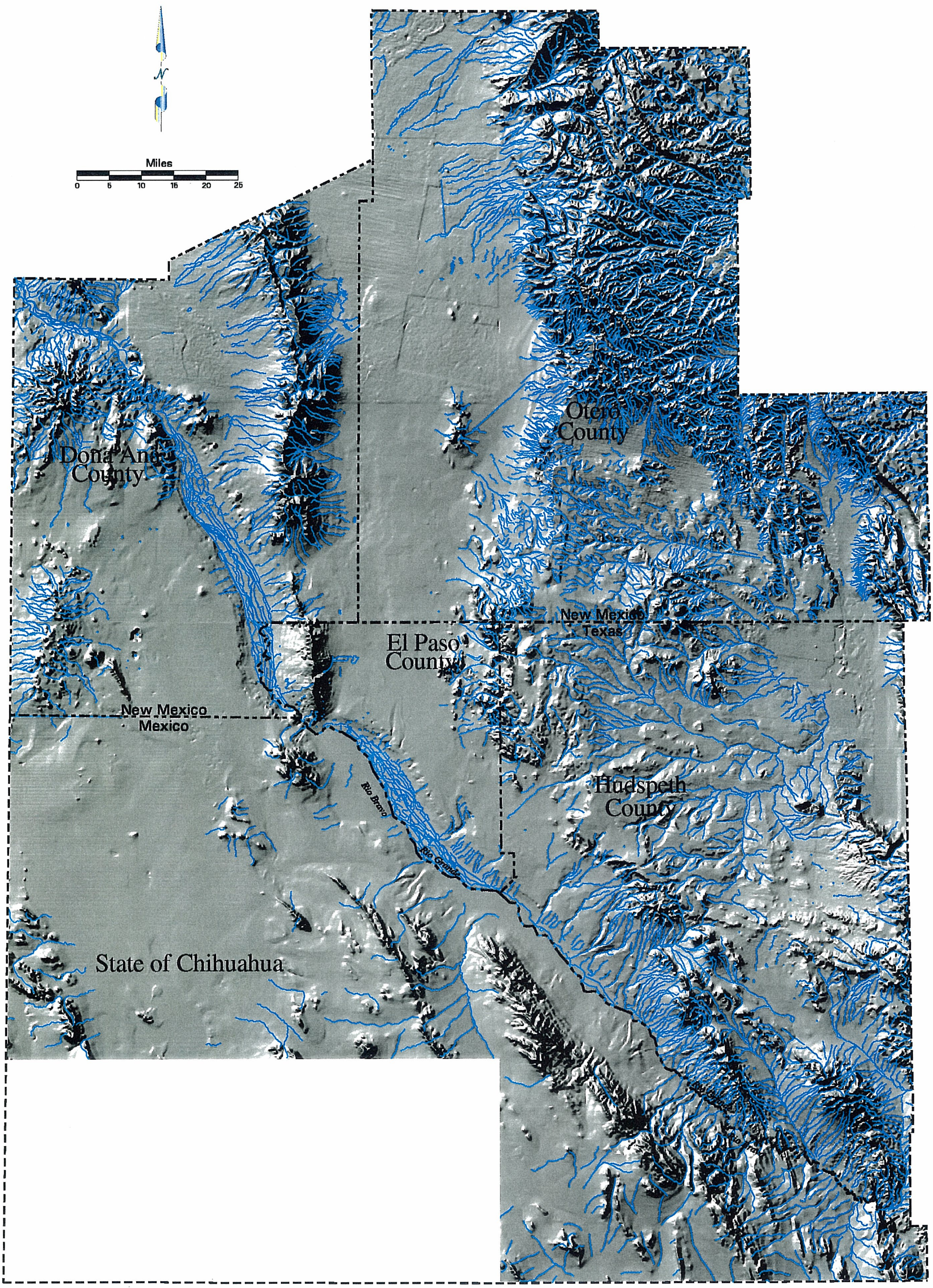

Figure 1.3. Three –dimensional depiction of surface topography and principal drainage in the transboundary study area.

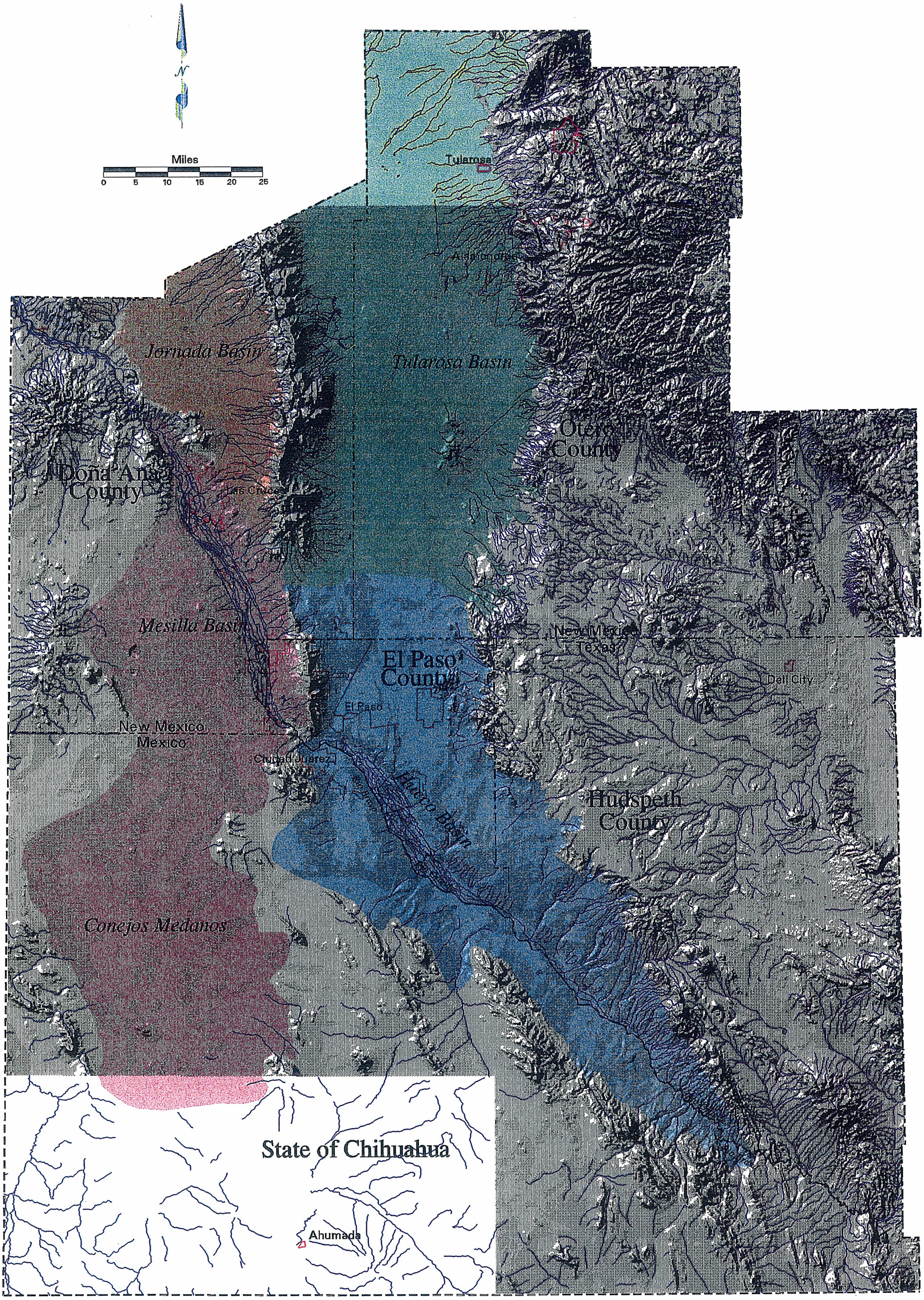

Figure 1.4. Surface drainage basins in the study area. These are defined by surface drainage characteristics and not by intrabasin and interbasin ground-water flow.

partly to the Rio Grande to the south along a drainage divide (Figure 1.3).

Climate

The study area is typical of the arid southwest, with mostly clear skies and limited rainfall and humidity. Average annual precipitation varies from as little as 6 in/yr in low lying basins to as much as 30 in/yr in the pine covered pinnacles in the Sacramento Mountains (USBR, 1984). Average annual rainfall over most of the study area is less than 12 in/yr.

Climatological data have been collected for decades at and near the major metropolitan areas. The climate at Las Cruces is arid in low-lying areas and semiarid in mountainous region. Average annual precipitation at Las Cruces, mostly in the form of rain, is 8.39 in (Frenzel and others, 1992). Nearly one-half of precipitation is from thunderstorms that occur from July through September. Large diurnal changes in temperature up to 30°F are common, especially during the summer months (Frenzel and others, 1992). Mean annual temperature is 60°F in Las Cruces.

The climate is arid to semiarid in the El Paso/Ciudad Juarez area (IBWC, 1989). Precipitation is mostly from thunderstorms that occur sporadically during the summer months. Precipitation records at several meteorological stations indicate that average annual rainfall along the El Paso/Ciudad Juarez corridor is about 10 in (IBWC, 1989). Temperatures during the summer may reach 100°F for several days. Normal night time temperatures during the summer vary from high 60°F to mid 70°F. Winter temperatures occasionally are below freezing and usually range from 40°F to 60°F (IBWC, 1989).

Toward the eastern part of the study area, near the City of Sierra Blanca, Texas, the subtropical-arid climate is characterized by high mean temperatures with large daily and annual fluctuations, and low mean precipitation with widely separated annual extremes (Larkin and Bomar, 1983). Average annual low temperatures are nearly 48°F and average high temperatures are close to 80°F (Larkin and Bomar, 1983). Precipitation is mostly in the form of local and irregular summer showers (Nativ and Riggio, 1990). Winter rainfall accounts for less than one-third of total precipitation (Larkin and Bomar, 1983). Mean annual precipitation in Sierra Blanca is 12 inches.

Population and economy

The population of Doña Ana County was estimated to be 155,469 in 1994 up from the 1990 census of 135,510 (USDC, 1995 and 1991). This was an increase of 14.73%. The increase between 1980 and 1990 was 40.66%. The 1990 census indicates that there were 49,148 households in Doña Ana County with an average of 2.95 persons per household. Aside from the household figures for Las Cruces (22,509), Hatch (411), Mesilla (715), and Sunland Park (2,963), the unincorporated areas had a total of 22,550 households.

The economy of Doña Ana County is largely dependent upon government jobs. In 1988, state and local government work provided 11,100 jobs and $167.4 million for county residents (USDC, 1990). This was the single largest category of earnings for the county, followed by private services with 10,900 jobs and $119.2 million. Federal work provided 4300 jobs and $105.1 million for the county in the same year. By 2020, the county earnings through private services are expected to reach $277.0 million per year for 17,600 jobs and should represent the largest source of income for Doña Ana County (USDC, 1990). State and local government work should provide $270.6 million through 12,700 jobs.

Doña Ana County has traditionally been an important producer of agricultural goods. In 1988 $18.8 million was earned in Doña Ana County through its farms. This constituted one of the largest segments of income for the county (USDC, 1990).

Otero County, had a population of 54,307 in 1994. The largest municipality is Alamogordo, which had a 1994 population of 29,628. The economy of Otero County before 1940 was based primarily on crop agriculture, livestock, and some mining (USBR, 1984). The population at that time was about 10,000. Isolated and flat areas in the Tularosa Basin were selected by the military in the early 1940's as sites for explosive and missile testing and the population grew to its present number mostly to support military infrastructure. Sand, gravel, and building stone provide the only substantial mining base.

The City of El Paso is the largest city in El Paso County, Texas. Census information compiled in 1995 indicated that 583,431 people lived in the City of El Paso, or 87% of the county total (668,358). Fort Bliss (14,202) and smaller cities and rural areas accounted for the remaining county population of 84,927. Colonias populations are estimated to total 72,754 in El Paso County (TWDB, 1995).

El Paso is an important center of commerce and industry. Industries include smelting and metal refineries, gasoline refineries, meat packing and food processing facilities, and light manufacturing. Military installations in and adjacent to El Paso provide a substantial economic base. Rural areas, especially in the El Paso/Juarez Valley, host a number of agricultural industries, including irrigated agriculture, livestock, poultry, and dairy production.

Hudspeth County is the most rural county in the U.S. part of the study area. Total population in Hudspeth County was 3,422 in 1995. The largest cities in 1995 were Fort Hancock (1,993), Sierra Blanca (700), and Dell City (779). Irrigated agriculture is the principal activity in the Dell City and Fort Hancock areas. Dell City uses ground water for irrigation and Fort Hancock uses Rio Grande water mostly, and some ground water. The economy of Sierra Blanca is sustained by the ranching industry, interstate travel, and interstate sludge disposal facility. Rural areas not adjacent to these cities are almost entirely ranching operations, except near the Rio Grande, where irrigated agriculture is common.

The population of Ciudad Juarez, northeastern Chihuahua Mexico was 850,000 in 1990 (USEPA, 1996). The population grew to 1,010,000 in 1995 (USEPA, 1996). We could not determine the number of residents in rural parts of the Mexican study area, but place the number at fewer than 50,000. Principal industries in Ciudad Juarez include industrial manufacturing, services, and tourism. Irrigated agriculture is common along the Rio Grande. Ranching operations are the principal activities in rural areas at distances from the river.

History of ground-water development

Mesilla Basin ground water has been a source of water for agriculture, municipal and industrial use since the early settlement in the area. Prior to 1950, non-agricultural withdrawals were negligible. It is estimated that non-agricultural ground-water withdrawals have increased from about 6 ft^3/s in 1950 (Frenzel and others, 1992) to upwards of 60 ft^3/s in the late 1980's (NMSEO, 1992). Ground water pumping for agriculture as a supplemental source of irrigation water constitutes a large volume of extraction from the Mesilla Basin. In the late 1940's, there were approximately 70 irrigation wells in both the Rincon and Mesilla Valleys combined. During the drought of 1951 - 57, several hundred wells were drilled in the Mesilla Valley. Many wells were also drilled during the shortage of surface water from 1963 to 1966. As of 1975 there were about 920 useable irrigation wells in the Mesilla Valley (Frenzel and others, 1992) most of which were drilled and completed in the floodplain alluvium.

The number of irrigated acres in the Mesilla Valley increased from about 25,000 acres near the turn of the century to about 77,000 acres during 1940 - 1975 which is about two-thirds of the area of the valley. In the Mesilla Valley after 1975, a large number of deep wells were drilled through the alluvium and completed in the Mesilla Bolson deposits in order to obtain higher quality water than that available from shallow wells. The City of Las Cruces is currently pumping about 17,000 - 18,000 acre-ft of water per year for municipal use.

The first water supply wells in the City of El Paso/Ciudad Juarez area probably were dug by early Spanish missionaries. These shallow wells were used to augment surface water supplies, especially during droughty periods when there was little or no streamflow in the Rio Grande (White, 1987). The first municipal water supply well for the City of El Paso was dug in 1892 (Sayre and Livingston, 1945). Subsequently other wells were installed and by 1918 the City of El Paso had about 150 wells screened in the Hueco Bolson (IBWC, 1989). Presently there are 142 city wells screened in Hueco Bolson sands and gravels. Hundreds of shallow irrigation wells have been drilled in the El Paso Valley, but many are active only during prolonged droughty spells. Estimates of the number of irrigation wells are not available because well inventories have not been conducted in sufficient detail to make accurate estimates.

Ciudad Juarez drilled its first water supply well in 1925 (IBWC, 1989). The number of wells drilled by the city peaked in the 1950's when there was a prolonged shortage of surface flows in the Rio Grande. Today, Ciudad Juarez maintains about 170 operational water wells; 100 or so of these are normally active. The drilling of an irrigation well is recorded in 1935 in Juarez Valley (de la O'Carreno, 1957), and by 1949 over 100 irrigation wells had been installed (IBWC, 1989). The number of irrigation wells in and adjacent to the Juarez Valley totaled 1,120 in 1980 (IBWC, 1989). Some of these draw water from deeper Hueco Bolson sands and gravels, although several are screened in the Rio Grande alluvium.

Regional Geologic Setting

Geologic characteristics

The southeastern Basin and Range province is defined by topographically high mountain ranges and plateaus separated by normal faults from adjacent basins. Geologic units in the study area range from Precambrian to recent (Figure 1.5). The ages of strata in outcrop are primarily Precambrian, Cretaceous, and Tertiary in mountainous areas, Cretaceous and Permian in plateaus, and Tertiary and Quaternary in bolson areas.

Major geologic features in the area formed in response to the Rio Grande rift, a fault bounded structural feature with uplifted blocks on the east/southeast and west/southwest. Uplifted blocks sometimes rise a few thousand feet above valley floors due to vertical displacement along normal faults. Many of the complex grabens have subsidiary grabens within the main basin (Wilkins, 1986; Collins and Raney, 1991). The basins are asymmetrical and structural relief, in general, is greater on the west and southwest sides of the basins (Chapin, 1971).

Basin fill of Cenozoic age was derived from erosion of rocks from flanking highlands, interbedded in some places with volcanic flows and tuffs. Basins include, from northwest to southeast, the Mesilla Basin, Tularosa Basin, and Hueco Basin (Figure 1.4). The Mesilla and Hueco Basins are "open" basins, and surface runoff in these basins is drained by the Rio Grande. The Tularosa Basin is a "closed" basin, having no exterior surface drainage. Open and closed basins are phrases sometimes used to describe interbasin ground-water flow, or lack thereof, to other basins or through-flowing streams in the basin-and-range province. The conventions used by Eakin and others (1976) are used in this report to describe ground-water flow (Figure 1.6). According to their convention (Eakin and others, 1976), the Mesilla and Hueco Basins are "regional sinks" and the Tularosa Basin is a "partly drained" basin (Figure 1.6). "Open" and "closed" basins are used hereafter to describe surface runoff and surface drainage in basins (Figure 1.4), not ground-water flow.

Consolidated rock types are important to the makeup of the hydrostratigraphy of the study area. These include, from oldest to youngest, Precambrian metamorphic rocks that are weakly fractured; Paleozoic (especially Permian) carbonate and clastic rocks that are fractured and sometimes intensely karstified; Mesozoic (mostly Cretaceous) rocks that are fractured and occasionally karstified; and Tertiary and Quaternary volcanic intrusive and extrusive rocks that are usually fractured and jointed.

Semi-consolidated to unconsolidated sediments include Cenozoic basin fill, Quaternary Rio Grande alluvium, and recent alluvial deposits not associated with the Rio Grande (Figure 1.5). The Cenozoic basin-fill sediments consist largely of sand and gravel lenses interstratified with silt and clay. Significant amounts of interbedded volcanics are shown in some geologic logs, especially in the lower basin fill. Depositional environments included alluvial fans, riverine systems, and ephemeral lakes and saline playas. Vertical offset by Basin and Range faults and tabular and lenticular geometries of sand, silt, and clay deposits create significant intrastratigraphic discontinuities.

The Rio Grande alluvial deposits form a complex mosaic of braided and meandering river deposits. Formed during alternating periods of scour and fill in the late Quaternary Period, the river deposits consist of irregularly distributed gravels, sands, clay, and silt lenses and beds (USBR, 1973; Alvarez and Buckner, 1980). Lenses and beds are highly irregular in extent and thickness and correlations across short distances are difficult or impossible to make with available data. Recent alluvial deposits not formed by the Rio Grande are associated with arroyos that drain the mountains and flanking plateaus. Typically these deposits are poorly sorted sands, silts, and gravels.

Geologic history

During much of the Paleozoic Era, the study area was covered over large areas by shallow seas (Wilkins, 1986). Carbonate and clastic rocks were deposited in and adjacent to the seas, especially during the Permian Period (Henry, 1979). Seas had regressed by the Triassic and Jurassic Periods and weathering and erosion of continental rock masses formed extensive red beds in northern parts of the Rio Grande rift. Triassic and Jurassic rocks were eroded or were not deposited prior to formation of Cretaceous rocks in the southern part of the rift.

Seas had transgressed by the Cretaceous Period and marine environments were the sites of deposition of thick sequences of limestone and clastic sediments (Henry, 1979; Wilkins, 1986). These and older rocks were deformed during the Late Cretaceous, Early Tertiary Laramide orogeny. Major thrust faults developed along the southeastern edge of the study area as a result of the orogeny, and deformation produced a series of north-northwest trending folds (Henry, 1979). Andesite intrusions and volcanic flow associated with Laramide faulting and volcanic activity continued through the Oligocene (Wilkins, 1986).

Rifting began at least 18 million years ago and took place along a north-northwest structural trend (Wilkins, 1986). The region was uplifted from elevations near sea level to several thousand feet above sea level during the late Tertiary. Block-faulting was superimposed on Laramide fault and fold structure, and thick sequences of bolson fill were deposited as a result of block faulting and uplift. Extension, along with uplift and erosion of flanking highlands formed the graben-type basins. Normal fault movement continues to the present in some parts of the study area (Belcher and Goetz, 1977).

The ancestral Rio Grande became a through-flowing river in the study area during the late Pliocene to early Pleistocene (Gustavson, 1990). Incision of the Rio Grande was affected by integration of the Upper Rio

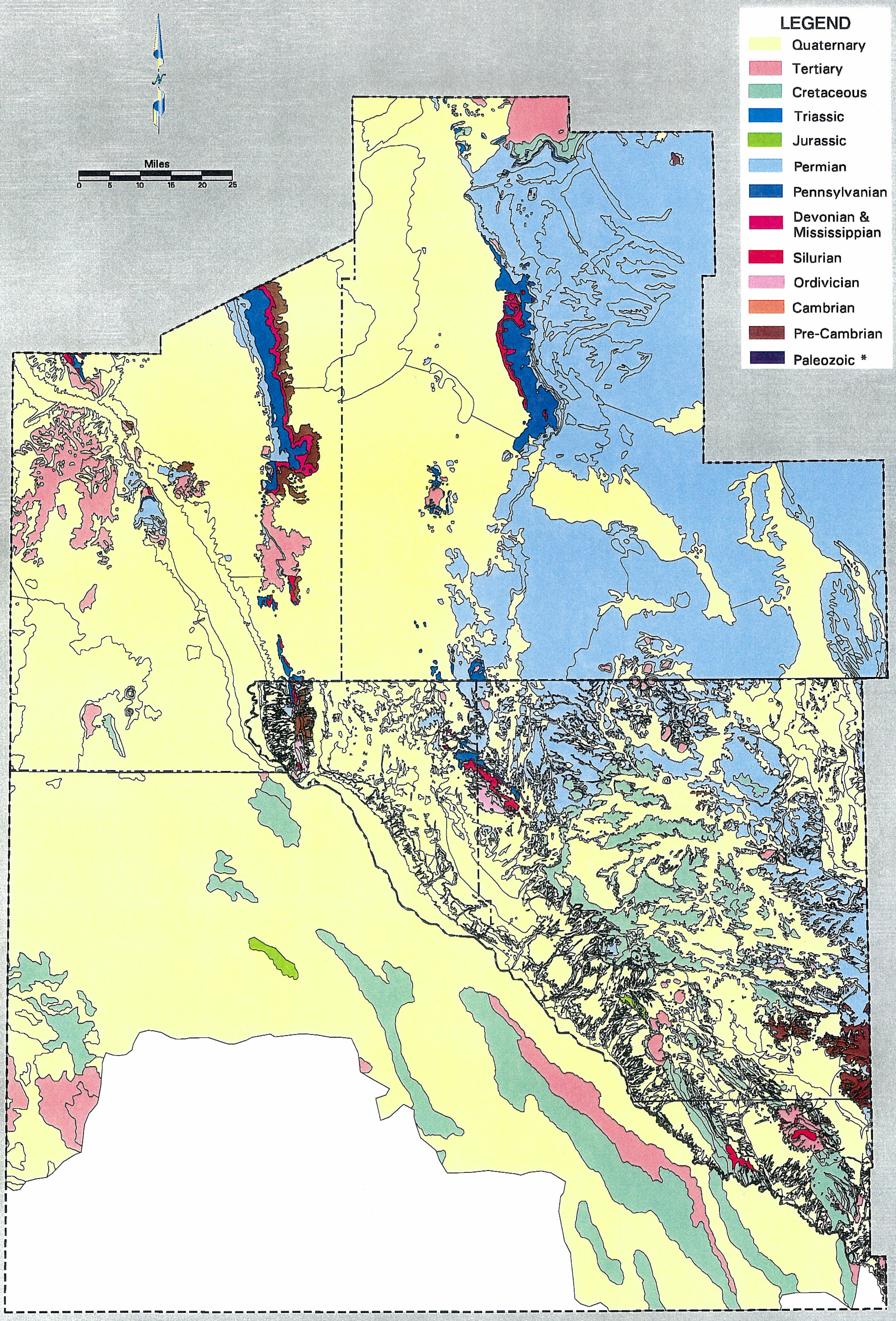

Figure 1.5. Geologic coverage map of the regional study area (source, Texas Bureau of Economic Geologic atlas sheets; Instituto Nacional de Estadistica, Geografia e Informatica geology sheets; New Mexico Geological Society highway geologic map).

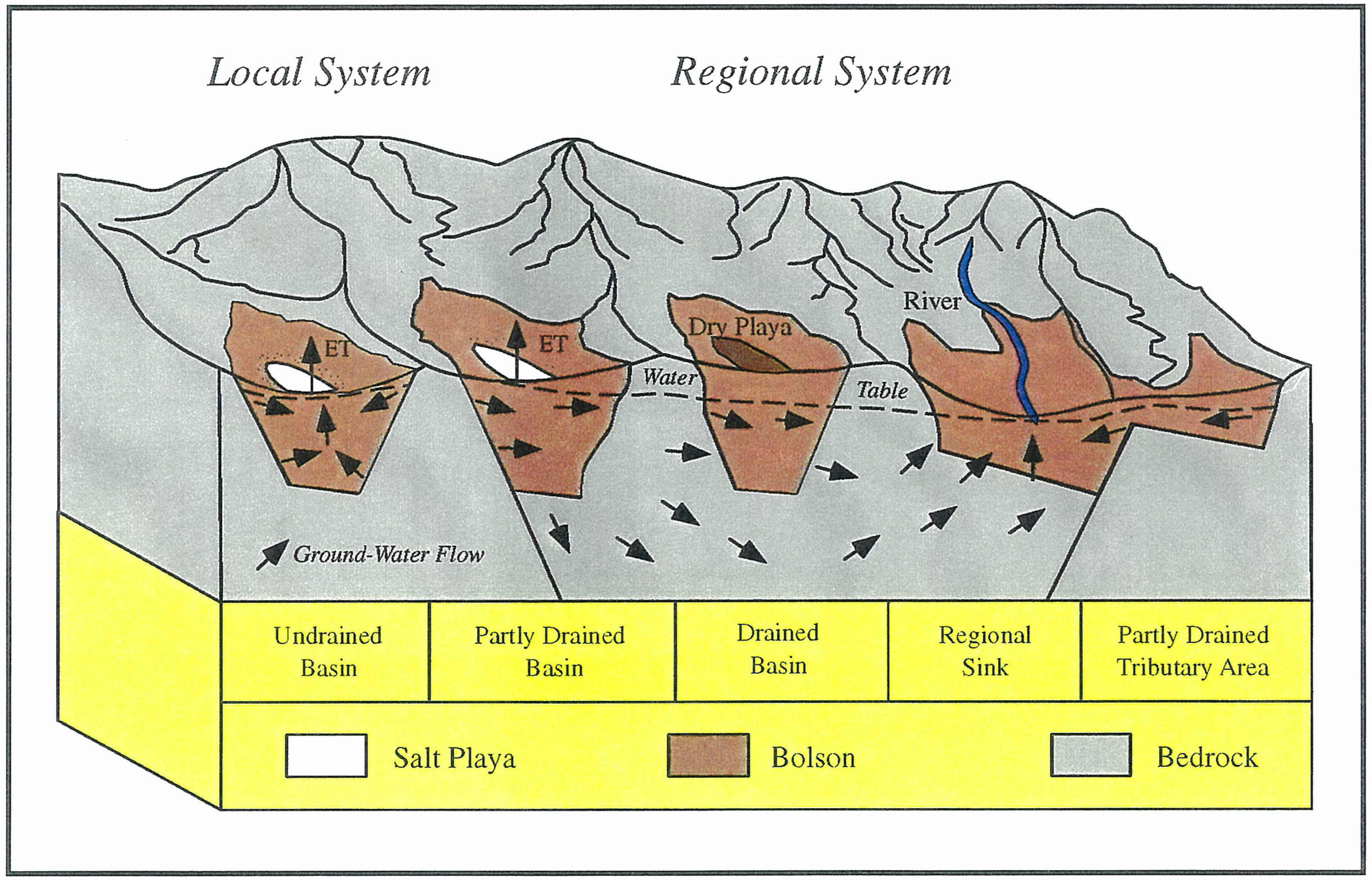

Figure 1.6. Conceptual hydrogeologic model showing undrained basins, partly drained basins, drained basins, and regional sinks (modified from Eakin and others, 1976).

Grande system with the lower Rio Grande system and drainage into the Gulf of Mexico. Basins in the study area display arroyo dissection of basin fill that developed in response to new base level of the Rio Grande.

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CHAPTER 2 - MESILLA BASIN GROUNDWATER AQUIFER SYSTEM

This section will describe three groundwater aquifers within the Mesilla basin groundwater aquifer system. These are the Mesilla Bolson, the Rio Grande Floodplain Alluvium, and the Jornada del Muerto Bolson. These are shown in the western edge of the study area in Figure 1.2. These three groundwater aquifers are connected hydrologically, however the connections are restricted by aquitards and/or faults and therefore are considered and described as separate aquifers. The discussion of these groundwater systems (Mesilla basin aquifers) first includes general information of location, extent of the aquifers, climate, development, and use of the resource followed by sections specific to each of the aquifers such as regional structure, depositional history, geology, water bearing characteristics, quality, recharge and discharge.

Location and Extent

The Mesilla basin aquifer system is an extensive intermontane aquifer system which extends from southern New Mexico to northern Mexico. It is surrounded by mountains which form the boundaries of the aquifers. The eastern boundary consists of the San Andres Mountains, San Augustin Mountains, Organ Mountains, Bishop Cap and the Franklin Mountains. The East and West Potrillo Mountains, Aden Hills and Sleeping Lady Hills are on the west. On the north, there are Robledo Mountains and Doña Ana Mountains. On the southeast are the Sierra de Cristo Rey at the international boundary and the Sierra de Juarez just north of the international boundary. The Rio Grande enters the basin through Selden Canyon between the Robledo Mountains and Doña Ana Mountains. From Selden Canyon the river traverses the Mesilla basin diagonally for approximately 60 miles until it exits into the Hueco Bolson through the El Paso narrows between the Franklin Mountains and the Sierra de Cristo Rey. The Rio Grande floodplain and lands adjacent to the floodplain define the Mesilla Valley which is a low gradient, narrow, alluvial valley ranging in width from a few hundred feet to about 5 miles near Las Cruces. Altitude of the valley varies from 3,980 feet at Leasburg Dam in Seldon Canyon to 3,729 feet at the El Paso narrows.

Steep bluffs rise up from the Mesilla Valley floor, and form the walls of the valley. To the west of the Valley the bluffs immediately level off and form the broad piedmont slope that extends for over 20 miles until it intersects the mountain fronts. This broad mesa is known as the West Mesa, and it encompasses approximately 750 square miles. The Jornada del Muerto is another broad mesa on the east side of the Mesilla Valley that extends 100 miles north from Las Cruces to San Marcial. To the east and south of the Valley, the bluffs level off slightly and quickly meet the base of the San Andres Mountains, Organ and Franklin Mountains. The Mesilla Valley is located on the eastern side of the Mesilla basin and is characterized by a broad erosional surface of low topographic relief produced by the meandering Rio Grande. An extensive remnant of an earlier basin-floor surface, the "West Mesa" of recent water resource publications (Wilson and others, 1981; Myers and Orr, 1985), that predates river-valley incision is preserved between the Mesilla Valley and the East Potrillo and Robledo mountain uplifts to the west.

The surface water system is comprised of the Rio Grande and its tributaries and a network of canals, laterals and drainage ditches that discharge to the river. The Rio Grande, which is the main surface-water feature associated with the Mesilla Valley, is the primary source of irrigation water in the Mesilla Valley. The Rio Grande is a highly regulated stream with reservoir storage and channel stabilization throughout the area. The operation of the river is controlled by an irrigation project (Rio Grande Project), interstate compact, and international treaty. Operation of the Rio Grande is based on discharge at upstream index stations and storage in upstream reservoirs (Nickerson and Myers, 1993). The water is administered by the Elephant Butte Irrigation District (EBID) and El Paso County Water Improvement District #1 (EPCWID). To control water flow, surface water for the area is stored in two large reservoirs, Caballo Reservoir and Elephant Butte Reservoir. Elephant Butte Reservoir is about 75 miles upstream from Leasburg Dam, and Caballo Reservoir is about 45 miles upstream from Leasburg Dam. The discharge of the Rio Grande in the Mesilla Valley is regulated by releases from these two reservoirs and diverted into an extensive network of canals. An extensive network of drains carries return flows back to the river. Percha Dam, Leasburg Dam, and Mesilla Dam are diversion dams along the Rio Grande that divert water into irrigation canals. Percha Dam diverts water for the Rincon Valley, Leasburg Dam diverts water for the northern portion of the Mesilla Valley, and Mesilla Dam diverts water for the southern portion.

Streamflow in the river and the amount of water diverted for irrigation may vary greatly from year to year. Surface water is supplemented by groundwater primarily in years when surface supplies are insufficient for crop requirements. Groundwater is used for all domestic water needs both public and private.

Several arroyos flow into the Rio Grande mainly from the mountains on the east side of the basin. Flow in some of the large arroyos is blocked by retention dams near Las Cruces and El Paso. Flow in other arroyos reaches the valley, but probably does not contribute much flow to the discharge of the Rio Grande.

The two principal mechanisms for recharge in the Mesilla basin is seepage from the Rio Grande and from deep percolation of applied irrigation water. The convergence of the surface flow from time to time into arroyos where it can rapidly infiltrate deep into the alluvial sediments may provide a secondary mechanism for natural recharge of groundwater. This type of recharge is referred to as mountain front recharge or slope front recharge (Frenzel and Kaehler, 1990). Mountain and slope front recharge comprise only a very small portion of total recharge to the Mesilla basin aquifers.

History of Groundwater Development

In the Mesilla Valley, agriculture is a major activity. Agriculture in the valley is irrigated by surface water from the Rio Grande Project, which consists of Elephant Butte and Caballo reservoirs. Discharge from the reservoirs has been highly variable over time, due to variances in the hydrologic cycle and differing operational parameters. The flow into Elephant Butte Reservoir has averaged about 904,000 acre-feet per year (1895-1985) and past the Elephant Butte gaging station about 872,000 acre-feet per year (1915-1992).

Historically, irrigators have used irrigation practices that effectively use the groundwater system as a reservoir in a combined stream-aquifer system. During years of plentiful surface water, irrigators divert most of the irrigation water from the Rio Grande. According to Blaney and Hanson (1965) about two thirds of the applied irrigation water may replenish the groundwater system. However more recent studies in the Mesilla Valley (Sammis 1996, personal communication) has shown that only about one third of the applied irrigation water seeps into the groundwater system. Some groundwater seeps into drains that discharge to the Rio Grande. During years of inadequate surface water supply, the shortfall is made up from groundwater causing lower than usual groundwater levels and diminished drain discharge. Groundwater levels generally recover after a normal irrigation season. Studies conducted in the wells installed by the Bureau of Reclamation have shown that the water table in the Mesilla Valley fluctuates about four feet between the irrigation and nonirrigation season.

Groundwater Investigations

Groundwater investigations have been conducted in the Mesilla basin since the early 1900. Slichter (1905) was one of the first to report on the groundwater conditions of the Mesilla Valley. His report included information about well occurrence, pumping rates, and depth to water table. Lee (1907) provided a more detailed record of the geology, depth to water, hydraulic gradients and water quality for the shallow aquifer (Rio Grande Alluvium) of the Mesilla basin during pre-development years.

The earliest comprehensive reports of hydrology of the area are in U.S. Geological Survey Water Supply Papers by Sayre and Livingston (1945), Conover (1954), Knowles and Kennedy (1958) and Leggat, Lowry and Hood (1962). King and others (1971) discussed both the geology and groundwater resources of the Las Cruces area. This report was followed by a more comprehensive work on the hydrogeology of the region by Wilson and others (1981). Wilson and White (1984) presented aquifer test data for the central Mesilla Valley, and Myers and Orr (1985) presented aquifer test data for the northern West Mesa area. A report by Hernandez and others (1987) included estimates of municipal water use for 1984. Nickerson (1989) reported aquifer test data based on the stage changes in the Rio Grande. Hawley and Lozinsky (1992) reviewed electric logs, identifying upper, middle, and lower hydrostratigraphic units of the Santa Fe Group. Groundwater flow model studies include Gates and others (1984), Peterson and others (1984), Frenzel and Kaehler (1990), Frenzel (1992) and Hamilton and Maddock (1993).

Geologic/Geohydrologic Setting

Regional structure

The Mesilla basin aquifers (Figures 1.2 and 2.1) are defined geologically and hydrologically by structural boundaries. They are bounded by uplifted blocks of bedrock or by relatively impermeable volcanic rocks and are filled with alluvial sediment from surrounding mountains and with fluvial sediment carried in by the ancestral Rio Grande. The Mesilla basin is at the southern end of a north-trending series of structural basins and flanking mountain uplifts that comprise the Rio Grande rift (Chapin and Seager, 1975; Seager and Morgan, 1979; Chapin, 1988). The rift extends through New Mexico from the San Luis Basin of south-central Colorado to the Hueco Bolson and Bolson de los Muertos area of western Texas and northern Chihuahua, Mexico (Hawley, 1978).

The area's geology (Figure 2.2) includes numerous mountain ranges and outcrops forming impermeable and semi-impermeable boundaries for the intermontane bolsons and the valley of the Rio Grande. For the most part, the mountains in the region consist of fault-block uplifts with a general north-south trend (Kottlowski, 1958).

The Robledo Mountains consist of a tilted fault-block uplift that has the form of a wedge-shaped horst. They are bound on the east and west by faults and tilt toward the south. The peaks and high ridges are mostly underlain by thick-bedded carbonate rocks of Paleozoic age. The western portion of the Mesilla basin commonly is called the West Mesa. The West Mesa is approximately 300 feet above the present valley floor. The West Potrillo Mountains reflect the primary form of the basaltic volcanic cones and flows that underlie the West Mesa. The Aden Hills, the Sleeping Lady Hills, and the Rough and Ready Hills are comprised of a belt of small peaks, ridges, buttes, and elongated mesas underlain by Tertiary volcanic rocks. The Sierra de Cristo Rey and the Sierra de Juarez are in Mexico. To the east, Goat Mountain is similar in composition to that of San Diego Mountain. Small fault-block uplifts form Tortugas Mountain and Bishop Cap Mountain. The San Andres, San Augustin, Organ and the Franklin Mountains are similar in composition to the Caballo Mountains (King and others, 1971).

Productive aquifers in the Mesilla basin occur in both late Pleistocene to Holocene-Rio Grande alluvium deposits and the upper Tertiary and Quaternary unconsolidated sedimentary deposits of the Santa Fe Group. Generally, the groundwater system of the Mesilla basin is divided into three zones based on lithology, borehole geophysical logs, chemical quality of water and the differences in water levels under stress. The shallow zone is referred to as floodplain alluvium deposits and basin fill deposits within the Mesilla Valley and consists of a mixture of gravel and coarse sand. The formation below the floodplain alluvium, Santa Fe Group deposits, refers to alternate layers of fine to coarse-grained sand, silty clay, and some gravel. Lenticular deposits of silty clay occur throughout the sand deposits which have predominantly medium to fine grain sizes. The deep zone of the Santa Fe Group aquifer consists of a more uniform fine to medium grain size with some silt and clay (Nickerson, 1989). Frenzel (1992) divided the system into the Rio Grande Alluvium deposits and three hydrostratigraphic units within the Santa Fe group.

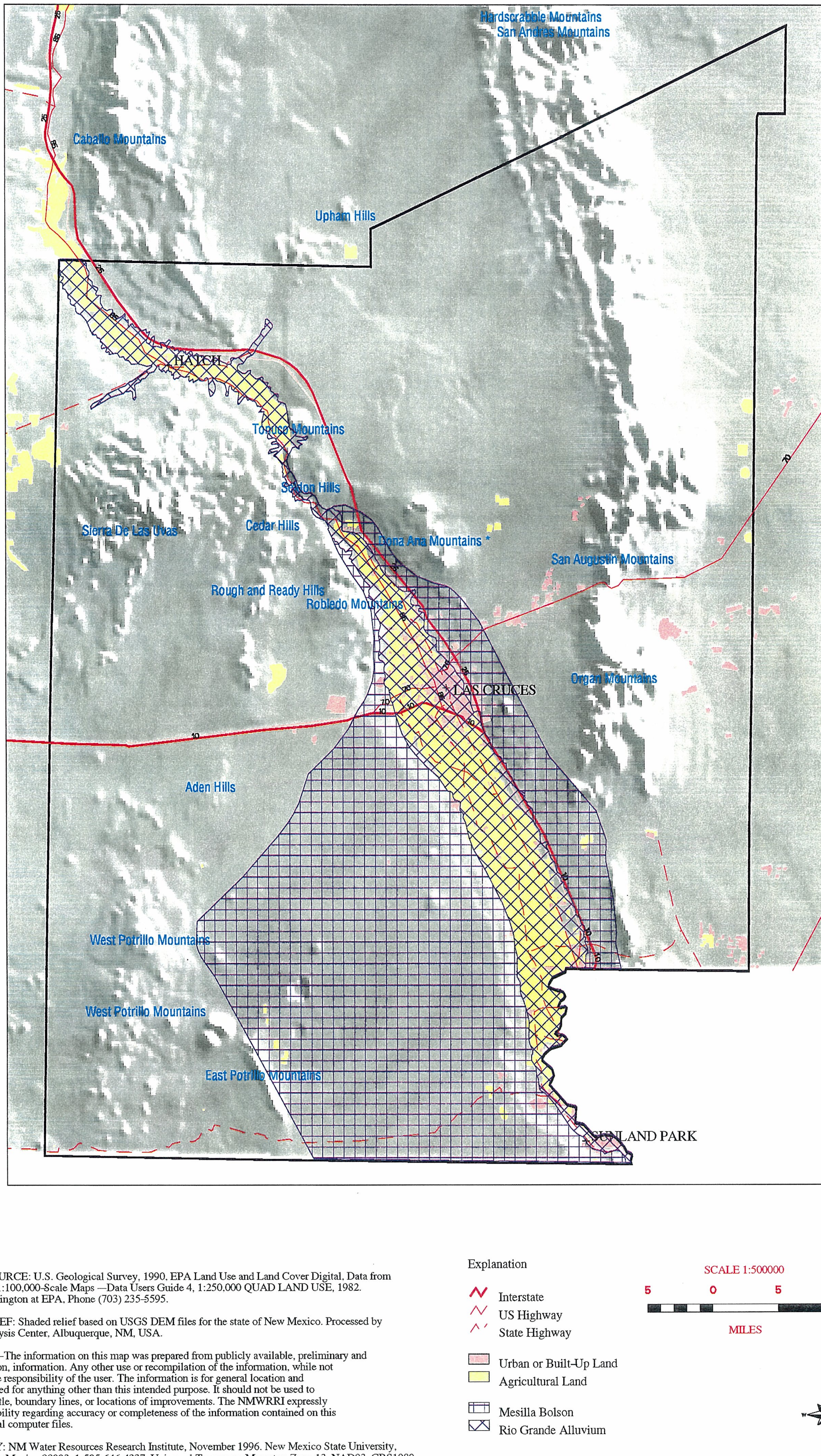
The surface drainage of the Mesilla basin covers approximately 11,000 square miles. The Rio Grande enters the basin through Selden Canyon, between the Robledo Mountains and the Doña Ana Mountains, and exits through the El Paso narrows, between the Franklin Mountains and the Sierra de Cristo Rey. The Mesilla Valley, created by the latest incision of the Rio Grande, extends from Leasburg to northwest El Paso along the eastern portion of the Mesilla basin. The altitude of the valley ranges from 3,980 feet at Leasburg Dam to 3,729 feet at the El Paso narrows. The Mesilla Valley is about 50 miles long and is about 5 miles across at its widest section. The Mesilla Valley covers an area of approximately 110,000 acres (Frenzel and Kaehler, 1990).

Depositional history

The bolsons within the study area contain groundwater systems primarily consisting of basin-fill aquifers composed of unconsolidated alluvial deposits. The aquifer system may be divided into two main geologic units: the Rio Grande floodplain alluvium and the Santa Fe Group (King and others, 1971). It was deposited by the latest incision of the Rio Grande from the late Pleistocene to the Holocene age. Beneath the Rio Grande floodplain alluvium is the Santa Fe Group. The Santa Fe Group is an intermontane basin-fill unit composed of alluvial deposits of Miocene to middle Pleistocene age (Wilson and others, 1981). The Santa Fe Group can further be broken down into three facies:

- alluvial-fan facies, composed of various size sediments ranging from gravel to clay, which is formed by the erosion of the nearby hills and mountains.
- clay facies, possibly produced by the continued erosion of alluvial-fan facies, deposited in ancient lake and playa deposits, and by deposition of overbank deposits due to seasonal flooding; and
- fluvial facies, consisting of well-sorted sand and gravel deposited axially by the Rio Grande and its major arroyos (King and others, 1971). Because the layers were directly deposited by the Rio Grande, the horizontal permeability greatly exceeds the vertical permeability, usually by several orders of magnitude (Wilson and others, 1981).

Within the Mesilla basin the Santa Fe Group is laterally divided by Pleistocene age normal faults called the Jornada fault zone. These faults split the Mesilla Bolson from the Jornada del Muerto Bolson along a transect north to south from the Doña Ana Mountains, through Tortugas Mountain, to Bishop Cap Mountain. A hydrologic connection between the aquifers exists along this fault zone. Frenzel (1992) estimated that the inflow to the Mesilla was equal to the discharge from the Jornada. Shoemaker (1996) estimated the discharge from the Jornada to the Mesilla along the common boundary to be equal to about 2,860 acre-feet per year.



LAND USE SOURCE: U.S. Geological Survey, 1990, EPA Land Use and Land Cover Digital, Data from 1:250,000–and 1:100,000-Scale Maps —Data Users Guide 4, 1:250,000 QUAD LAND USE, 1982. Contact: Ed Partington at EPA, Phone (703) 235-5595.

SHADED RELIEF: Shaded relief based on USGS DEM files for the state of New Mexico. Processed by Earth Data Analysis Center, Albuquerque, NM, USA.

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Figure 2.1. Shaded Relief Map with Urban and Agricultural Land Use

RIO GRANDE FLOODPLAIN ALLUVIUM

The Rio Grande Floodplain Alluvium is not a confined aquifer and consists of alternating and interfingering layers of clay and fluvial facies. The alluvium generally runs the width of the valley and is approximately 80 feet deep. Alluvial deposits extend laterally for hundreds of feet beyond the valley slopes (Wilson and others, 1981). The floodplain alluvium has a basal gravel layer about 30 to 40 feet thick. The water table in the valley is approximately 10 to 25 feet below the land surface. Groundwater within the alluvium is generally unconfined and typically moves southeastward down the valley at an average gradient of about 4 to 6 feet per mile; however, the direction is somewhat influenced by nearby hydraulic structures such as the river, drains, canals, well pumpage and heavily irrigated fields (Wilson and White, 1984).

The majority of discharge from the floodplain alluvium occurs through evapotranspiration of irrigated crops, flow to drain system, irrigation pumpage, municipal pumping, and industrial pumping. A small amount of river underflow exits at El Paso narrows (Slichter 1905). According to Wilson and others (1981), transmissivity values range from 10,000 to 30,000 ft^2/day. This transmissivity values translates into hydraulic conductivity of 100 to 350 ft/day. Frenzel (1992) estimated a specific yield value of 0.2.

Recharge

The majority of recharge to the floodplain alluvium is through applied irrigation water and seepage from the Rio Grande and its tributaries. A small amount of underflow probably recharges the alluvium at Selden Canyon (Frenzel, 1992). This possible underflow recharge at Selden Canyon was also confirmed by Avalos (1994). An example of this recharge occurred on January 15, 1986, when an abrupt rise in Rio Grande stage due to a scheduled upstream release caused a rapid rise of groundwater levels. This rapid response of groundwater levels to a rise of flow in the Rio Grande indicates a strong hydraulic connection between the river and the floodplain alluvium. Records of mean daily water levels in monitoring wells maintained by the USGS and mean daily river stage clearly indicate that the water levels in the wells in the floodplain alluvium follow the trends of the river stage throughout the year. Recharge from precipitation is considered minor. The net recharge to the aquifer is directly related to Rio Grande streamflow and the volume of river water used for irrigation (Nickerson and Myers, 1993). The Rio Grande acts both as a gaining as well as a losing stream along its 60 mile length from Leasburg Dam to El Paso narrows (Hamilton and Maddock 1993).

Discharge

Most groundwater discharge from the Alluvium takes place in the vicinity of the valley-margin and floodplain surfaces (Nickerson and Myers, 1993). This discharge occurs in several different ways:

- flow to agricultural drains
- seepage to the Rio Grande in the gaining reaches of the stream
- well discharge
- evapotranspiration
- discharge from interbasin groundwater outflow is considered minor (Wilson and others, 1981)

When the water table in the floodplain alluvium aquifer intersects a drain channel, discharge to the channel occurs. Some drains flow all year, while others flow periodically, varying with water levels in the shallow aquifer. Much of the irrigation water that infiltrates to the water table is thus returned by drains to the river (Nickerson and Myers, 1993).

Discharge to the Rio Grande in the gaining reaches of the river occurs when the potentiometric surface of the aquifer rises above the river stage. Seepage investigations show that the Rio Grande is usually a losing stream through most of the Mesilla Valley. Gains, however have been reported between Leasburg Dam and Las Cruces (Wilson and others, 1981) and immediately upstream from the El Paso narrows in the southern end of the Mesilla Valley.

Hydrologic Characteristics

The specific capacities ranges from 10 to 217 gpm/foot drawdown with an average of 69 gpm/foot drawdown. Based on these specific capacities of shallow irrigation wells that perforated the floodplain alluvium south of Las Cruces, the transmissivity was estimated to range from 10,000 ft^2/day to 20,000 ft^2/day (Wilson and White, 1984).

Water Quality

An attempt was made to evaluate if water quality degradation had occurred over time by plotting conductivity and nitrates vs time over an extended period. This was less informative than hoped because there were no shallow wells with a complete long term record.

MESILLA BOLSON

The major source of the fresh groundwater within the Mesilla Bolson is from the Quaternary-to-Tertiary age Santa Fe Group. The extent of the aquifer system within the Santa Fe Group is controlled by the surrounding faults which create an effective barrier to groundwater flow, although a small amount of flow may enter or leave the bolson at low barrier points.

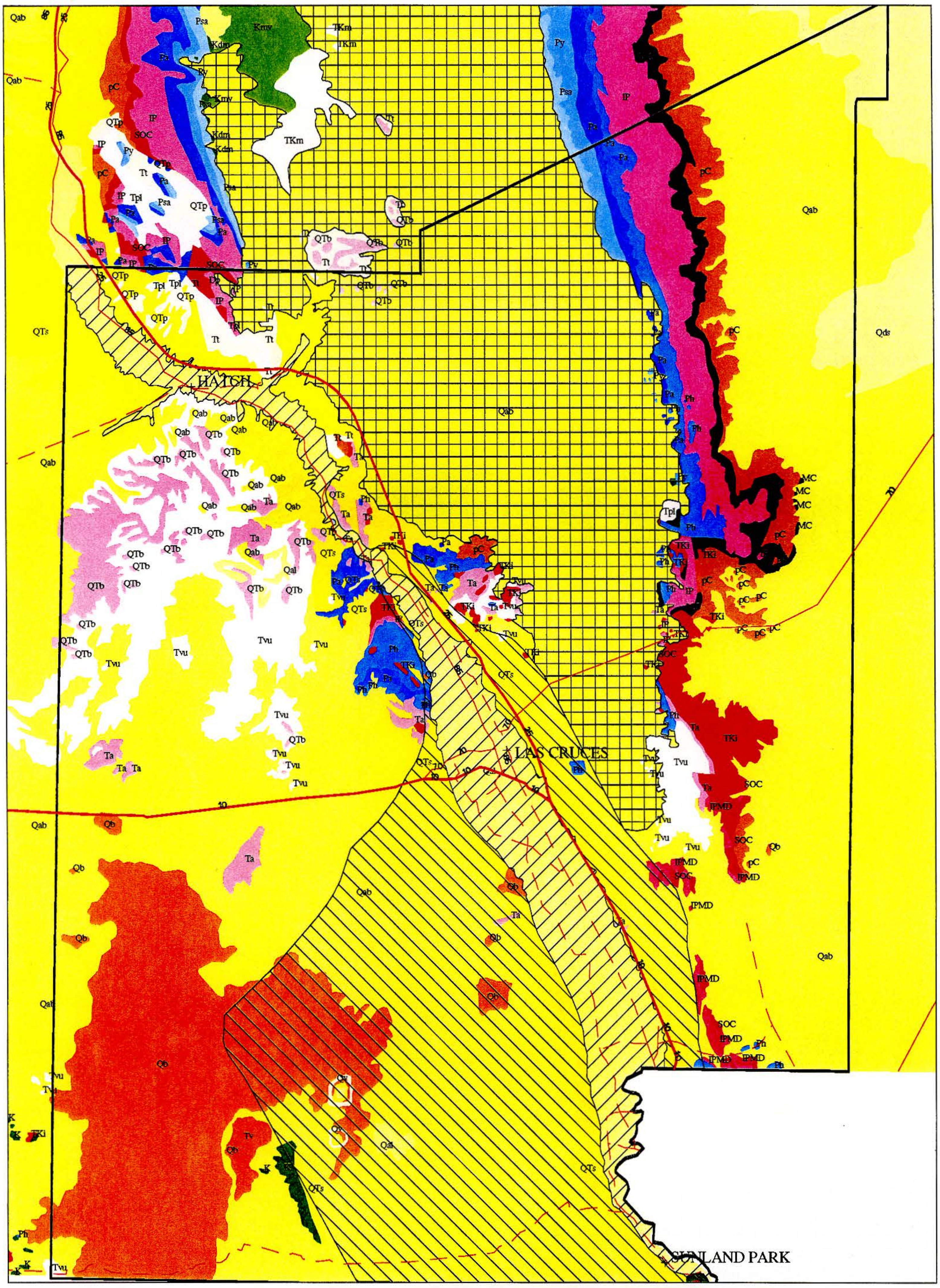
Saturated Thickness

The Santa Fe Group has thick sequences of clay and silt facies that interfinger with fluvial facies, which create confined/leaky aquifer conditions in the basin fill. The largest amounts of freshwater can be found in the fluvial facies. This facies varies in depth, due to the volcanic activity within the region, from 280 feet in the northern part of the bolson to over 2,000 feet near the center of the bolson. In some areas of the northern West Mesa, the fluvial facies extends to depths close to 2,500 feet below the surface. In the southern section of the bolson, well fields near Canutillo, Texas withdraw a substantial amount of water from depths up to 1,100 feet below the surface. The southeastern sections of the bolson contains a thick clay facies. At the El Paso narrows, a bedrock high prevents much of the groundwater from leaving the valley.

Hydrologic Characteristics

The Santa Fe Group hydrological characteristics vary from place to place due to heterogeneity of its lacustrine, playan, fluvial and alluvial deposits. Hawley and Lozinsky (1992) defined the Santa Fe Group as consisting of three hydrostratigraphic units which are referred to as upper unit, middle unit and deep unit. The upper unit is generally only saturated in the northern third of the bolson and consists of gravels with lenticular deposits of clay. This unit may be the most permeable based on larger grain sizes and less cementation. The middle hydrostratigraphic unit is less permeable than the upper unit due to a greater degree of cementation. This unit also consists of gravel and lenticular deposits of clay. The lower unit consists of a uniform fine sand and averages approximately 600 feet in thickness. In general, the basin fill deposits of the Santa Fe Group are deep under the Mesilla Valley and generally thin toward the basin edges. The maximum thickness of Santa Fe Group deposits is estimated as approximately 2,500 feet. The lower hydrostratigraphic group rests on a bedrock of limestone conglomerate which is generally considered impermeable. Frenzel (1992) estimated hydraulic conductivity's ranging from 2 - 68 ft/day, 1 - 100 ft/day, and 1 - 34 ft/day for upper, middle and lower hydrostratigraphic units respectively. The median hydraulic conductivity estimates fall at 25 ft/day for the upper unit, between 13 - 14 ft/day for middle unit and between 11 - 14 ft/day for the lower unit.

Other authors (Nickerson, 1989; Myers and Orr, 1985; Alvarez and Buckner, 1980) have provided esti-



SOURCE: Dane and Bachman 1965, Geology of New Mexico, 1:500,000 map, USGS in cooperation with New Mexico Tech, New Mexico Bureau of Mines & Mineral Resources, and UNM, Geology Dept., (digital file scanned and georeference corrected by USGS/WRD).

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Explanation

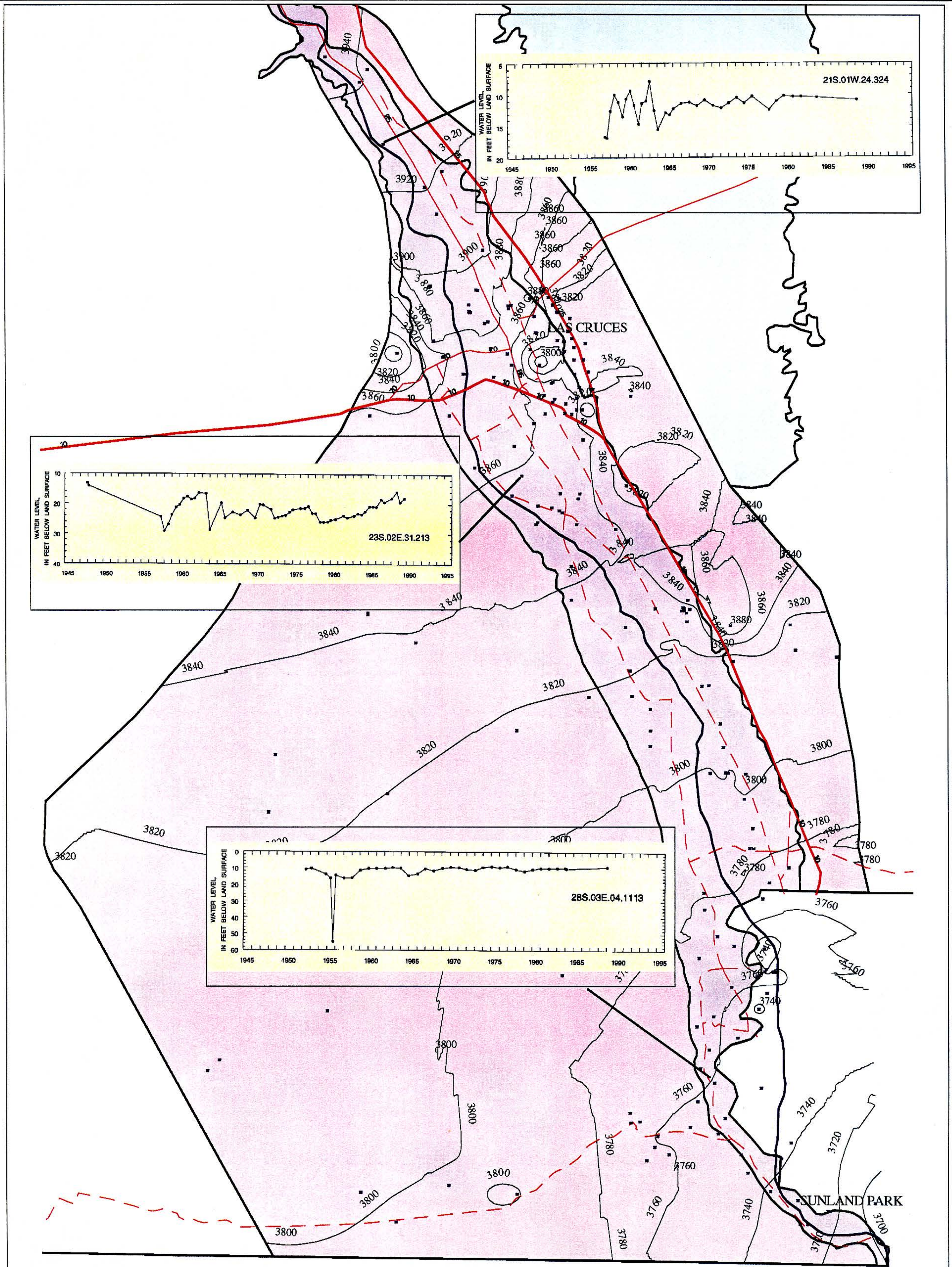
- Interstate
- US Highway
- State Highway
- Mesilla Bolson
- Rio Grande Alluvium
- Jornada del Muerto

SCALE 1:500000

5 0 5 10

MILES

Figure 2.2. Surface Geology of Dona Ana County, New Mexico



NEW MEXICO AQUIFER SOURCE: Kernodle, J. M., 1992, Summary of U.S. Geological Survey Ground Water Flow Models of Basin-fill Aquifers in the Southwestern Alluvial Basins Region, Colorado, New Mexico, and Texas: U.S. Geological Survey, Open-File Report 90-361, Albuquerque, New Mexico.

USGS MONITORING WELLS SOURCE: Wilkins, D.W., and Garcia, B.M., 1995, Ground-water Hydrographs and 5-year ground-water-level changes, 1984-93, for selected areas in and adjacent to New Mexico: U.S. Geological Survey Open-file Report 95-434, Albuquerque, New Mexico.

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Explanation

- USGS Monitoring Wells
- Water Level Contour Lines 20 foot interval
- Interstate
- US Highway
- State Highway
- Rio Grande
- Mesilla Bolson
- Rio Grande Alluvium
- Jornada del Muerto

SCALE 1:250000

1 0 5 10

KILOMETERS

Figure 2.3. Water Level Contours and Selected Hydrographs for the Mesilla Bolson and Rio Grande Alluvium Aquifers

mates of transmissivity based on pump tests. Nickerson (1989) reports transmissivity of 2,600 ft^2/day and less than or equal to 4,700 ft^2/day for the upper intermediate and deep zones and storage coefficient of 0.00043 for the Santa Fe Group aquifer at Canutillo. Myers and Orr (1985) studied aquifer properties in the West Mesa area and calculated transmissivity of 5,900 ft^2/day for a well screened at selected intervals between 710 to 1,210 feet below surface. The authors concluded that this was probably conservative and that transmissivity may be as great as 6,800 ft^2/day. Spiegel (1972) estimated transmissivity of 10,000 ft^2/day and a storage coefficient of 0.00002 for a well in the northern section of West Mesa. Gates and others (1984) reported a storage coefficient of 0.0007 for the medium-depth and deep aquifers under the floodplain within the Mesilla Valley. Avalos (1994) calculated transmissivity values ranging from 800 ft^2/day to 6000 ft^2/day for the City of Las Cruces Well Field. Based on aquifer tests, the transmissivity ranged from 10,900 ft^2/day to 40,000 ft^2/day throughout the bolson. The average horizontal hydraulic conductivity was 67 ft/day. These tests also provided evidence that the horizontal hydraulic conductivity apparently decreases with depth (Wilson and White, 1984). Vertical hydraulic conductivity values were found to range from 0.21 ft/day to 3.0 ft/day for the entire thickness of the confining layer.

Recharge

The majority of recharge to the Santa Fe Group aquifer occurs through mountain front recharge along the Franklin, Organ, Robledo, West Potrillo and East Potrillo mountains, and the Aden-Sleeping Lady, Rough and Ready Hills complex and through vertical flow of groundwater from the floodplain alluvium in the Mesilla Valley region. Recharge into the Santa Fe Group from the groundwater in the floodplain alluvium moves down through layers of sand and around clay layers. Cones of depression also influence the movement of groundwater into the Santa Fe Group.

Discharge

The majority of the discharge from the Santa Fe Group aquifer system occurs as municipal and industrial pumping in the Mesilla Valley. It is clear from plotting of USGS water-level data that the municipal cones of depression from Las Cruces and Canutillo have a significant regional impact on the direction of groundwater flow (Figure 2.3). The potential impact of this change in the local groundwater flow direction was further investigated in the particle tracking work by Hanson and Samani (1995).

Water Quality

The general water quality in the Mesilla basin aquifers is shown by the use of stiff diagrams in Plate 1. The reader is cautioned that the stiff diagrams do not provide information on the depth of the water sample which can strongly influence the quality. There is an overall general trend of decreasing dissolved solids concentration with depth. This may be attributed, in part to the effects of surface irrigation practices and evapotranspiration (Frenzel and others, 1990). As part of the applied water evaporates or is transpired, the dissolved solids in the water are concentrated. This water is recharged to the shallow groundwater system. Frenzel and others (1990) described the factors in the valley which will have a major impact on water quality in the Mesilla Bolson. From their analysis the current irrigation practices allow the soils in the valley to be kept flushed of salts. Most of the flushing water tends to be captured by the drain system and returned to the river. Some may move into the shallow groundwater.

This shallow groundwater can be mixed into the deeper high quality groundwater through pumping activity. The cone of depression formed by the pump may act as a mixing zone. Wilson and White (1984) reported on pumping tests for five EBID wells during the 1976 - 78 irrigation seasons. Four of the five wells showed no change in water quality from pumping. The fifth well showed a reduction in water quality. It appeared that the wells that did not show a reduction in water quality were constructed in a manner that prevented poorer quality shallow water from moving down into the screened zone. It was noted that irrigation wells constructed with cement casing or blank casings set in a thick clay layer at approximately 200 feet or more below the land surface produce the water with the smallest specific conductance. Thus it appears that good construction practices can minimize the impact of localized vertical mixing.

Volume with TDS less than 10,000 mg/L

Wilson and others (1981) estimated the thickness of the saturated sediments in the Mesilla Bolson containing freshwater (<300 mg/L TDS) from Less than 400 feet near the edges to more than 2,400 feet near the center of the Mesilla Valley. He estimated the volume of the freshwater in storage beneath the Mesilla Valley, with the thickest zone generally following the present course of the Rio Grande, to be about 66 million acre-feet and an additional 34 million acre-feet beneath the West Mesa (Wilson, et al., 1981).

Avalos (1994) estimated the freshwater zone of the mesilla Bolson to be limited to the top two layers of the aquifer, with an average thickness of 700 feet and a surface extent of about 612 thousand acres. With a specific yield of 0.2 (Frenzel and Kaehler, 1990) then the volume of freshwater would be about 85.7 million acre-feet.

JORNADA DEL MUERTO BOLSON

Location and Extent

The Jornada del Muerto Bolson is east of the Rio Grande Valley. It is bordered by the Caballo Mountains and Point of Rocks to the west, the Doña Ana Mountains, San Diego Mountain, and Tortugas Mountain to the southwest, and the Organ Mountains and the San Andres Mountains to the east. The Point of Rocks appears to be the remnant of a former cover of andesites, basalts, rhyolite tuffs, and associated sedimentary rocks, that have been disrupted by a combination of erosion, faulting, and warping. The Doña Ana Mountains are domal uplifts composed mainly of Tertiary igneous rocks. San Diego Mountain appears to be a peak formed by the erosional remnant of Tertiary igneous intrusive rock. Tortugas Mountain is a small fault-block uplift. The Organ Mountains and the San Andres Mountains are similar in composition to the Caballo Mountains (King and others, 1971).

The Jornada del Muerto Bolson covers approximately 3,344 square miles and is approximately 12 miles across at its widest section. It does not have a noticeable boundary with the Mesilla Bolson. The two bolsons are separated by a subsurface Tertiary volcanic rock high bounded by normal faults that extend from the Doña Ana Mountains to Tortugas Mountain, to Fillmore Pass. There is no evidence that the Rio Grande ever flowed through the Jornada del Muerto Bolson (King and others, 1971). The latest incision of the Rio Grande was restricted from entering the Jornada del Muerto Bolson by the Caballo Mountains (King and others, 1971).

Hydrologic Characteristics

The Santa Fe Group in the Jornada del Muerto Bolson is composed of a fluvial facies, a clay facies, and an alluvial-fan facies. Throughout the bolson, the fluvial facies is usually above the water table. The portion of the bolson that is south of the Point of Rocks and north of the Doña Ana Mountains has a fluvial facies layer that is more than 325 feet deep. It is possible that the lowest portions of this facies dips below the water table. The zone of saturation is most likely in older alluvial-fan deposits or in the fine-grained units of the clay facies. The clay facies is the predominant facies in the zone of saturation in the northern and extreme southern sections of the Jornada del Muerto Bolson. Water production is mainly in the southern region of the Jornada del Muerto on the lower slopes of the large alluvial-fan facies north of Highway 70 and south of the Point of Rocks. The depth to the water table is between 300 to 575 feet and the thickness of the saturated sediment is between 400 to 500 feet. Four wells drilled into the large alluvial-fan of the southern San Andres Mountains have penetrated more than 1,000 feet of alluvial sediment and pump a substantial amount of water (King and others, 1971). The City of Las Cruces currently is in the process of establishing a well field in the southern portion of the Jornada del Muerto Bolson. Shoemaker and Finch (1996) in a report prepared for the City of Las Cruces estimated that the ultimate rate of annual withdrawal from the aquifer could be about 9,000 acre-feet per year.

Groundwater Movement

Groundwater movement in this bolson varies greatly. The groundwater in the northern part of the bolson moves south down the valley and west toward the Rio Grande into the Rincon Valley at an average gradient of 150 feet per mile. Groundwater from the southern part of the bolson moves north and west into the Rincon Valley at an average gradient of 10 feet per mile. There is some evidence that groundwater in the southern section may move west across the subsurface igneous boundary into the Mesilla Bolson through subsurface channels that have been eroded through the boundary. It has been speculated that large amounts of fresh water could be pumped from one of these channels (Wilson and others, 1981). Shoemaker and Finch (1996) estimated that subsurface groundwater flow across the boundary from the Jornada del Muerto into the Mesilla Bolson amounted to about 2,860 acre-feet per year. Frenzel's (1992) model estimated about 3,790 acre-feet of flow per year from the Jornada into the Mesilla across their common boundary. The specific capacities for wells in the southern section of the Jornada del Muerto Bolson is about 5 gpm/foot drawdown. Estimated transmissivity values in this area range from 5,000 ft^2/day to 15,000 ft^2/day (Wilson and others, 1981).

Recharge

Recharge into the Jornada del Muerto Bolson occurs primarily from precipitation and infiltration of mountain front runoff through major arroyos (Frenzel and Kaehler, 1990).

Water Quality

Groundwater in the southern section of the Jornada del Muerto Bolson is classified as fresh. The hardness of the water ranges from 24 to 320 mg/l. Water in the northern section of the bolson is classified as slightly saline. In the Rincon Valley, where most of the groundwater is discharged, dissolved-solids concentrations taken from depths of 130 ft to 150 ft, and 250 ft to 280 ft were 1,800 and 2,820 mg/L respectively. Both Shoemaker and Finch (1996) and Icerman and Lohse (1983) reported that some water enters the aquifer in the form of geothermal water moving upward, presumably along a fault zone or zones, in the area east of Las Cruces. Shoemaker and Finch (1996) estimated the volume to be about 59 acre-feet per year.

WATER USE

Total water use, both surface water and groundwater, is summarized by category in Tables 2.1 through 2.4 for Doña Ana County, New Mexico for the years 1990, 1985, 1980, and 1975, respectively. The groundwater withdrawals numbers are not separated by aquifer source (Alluvium, Mesilla Bolson, or Jornada Bolson) and include withdrawals from each. In 1990 the total water withdrawals for all categories was 513,841 acre-feet of which 145,663 was from groundwater sources (Wilson, 1992). Depletions were 246,279 acre-feet of which 96,895 was from groundwater. Of the 96,895 acre-feet of groundwater depleted in 1990, 73% (70,900 acre-feet) was used by irrigated agriculture, 19% (18,797 acre-feet) was used by public and private domestic water uses (Table 2.1). Water use by irrigated agriculture varies from year to year and depends upon the quantity of surface water available with groundwater use providing a supplemental supply. All public and private domestic needs rely on groundwater. In 1990 there were 32 public water supply systems in the county that pumped 28,956 acre-feet (most of which were measured) with depletions estimated to be 17,410 acre-feet (Table 2.1). These water systems are shown on Figure 2.4.

In 1975 the groundwater depletions in the county were 60,740 acre-feet for all uses, 53,710 acre-feet in 1980, and 50,958 in 1985 (Figure 2.5 and Table 2.5). The irrigated agriculture uses dominate and vary from year to year depending upon the availability of surface water. Excluding irrigated agriculture, the remaining groundwater depletions were 10,980 acre-feet in 1975, 15,380 acre-feet in 1980, 17,509 acre-feet in 1985, and 25,995 acre-feet in 1990 (Sorensen, 1977; Sorensen, 1982; Wilson, 1986; and Wilson, 1992) (Figure 2.6).

SUSCEPTIBILITY TO CONTAMINATION

Land Ownership and Land Use

The federal government is the largest landholder with 1,782,350 acres or 73% of the land in Doña Ana County. Of this total, the Bureau of Land Management (BLM) administers 63% (1,123,833 acres), and the military controls 31% (547,808 acres). The State of New Mexico holds a total of 11% of the land in Doña Ana County, and 16% of the land is privately owned. The largest percentage of private agricultural land in the county lies under the jurisdiction of the Elephant Butte Irrigation District, which administers the delivery of surface water to about 90,730 acres of cropland.

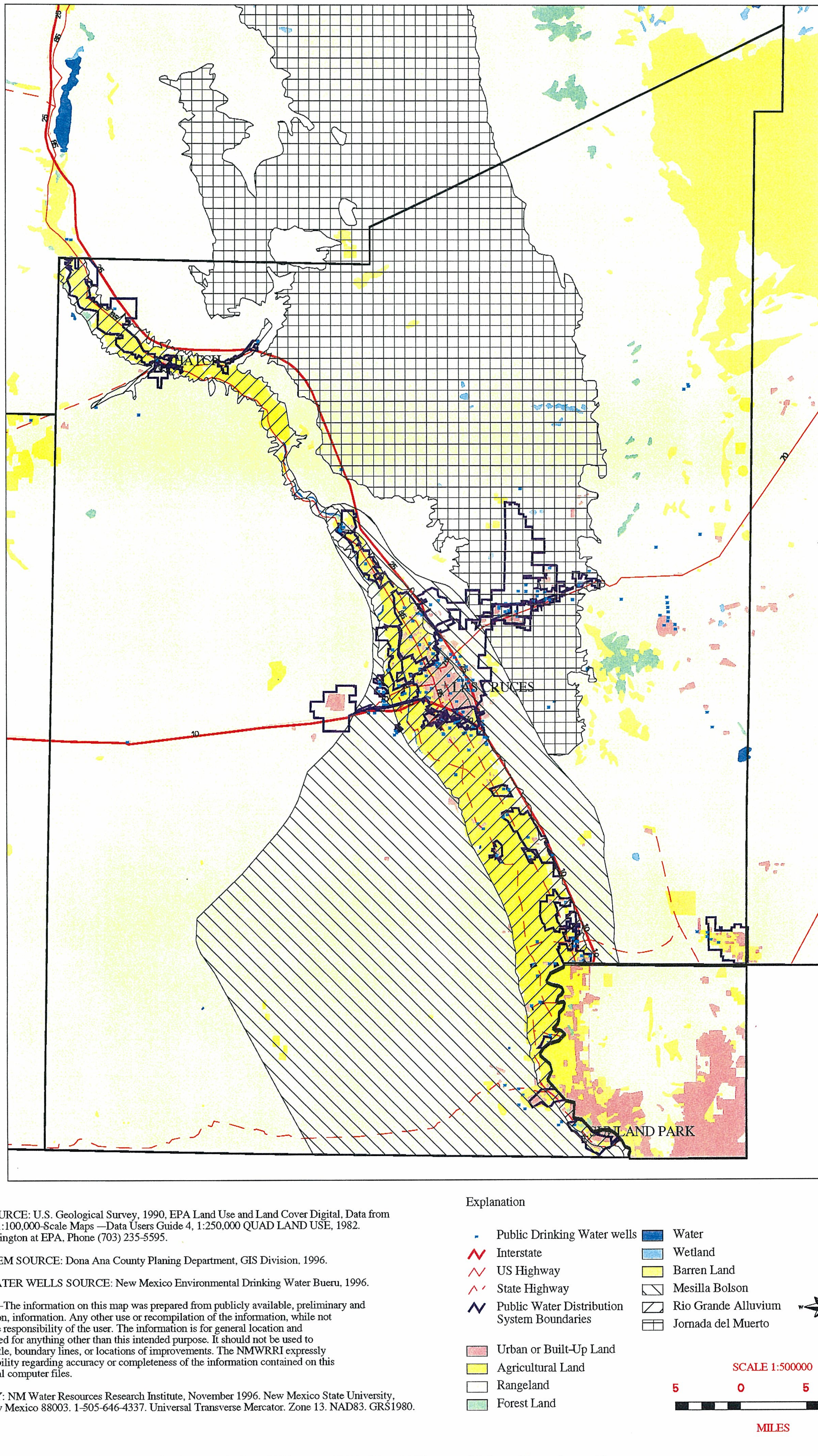
Land use in Doña Ana County is regulated by zoning and subdivision laws adopted by the county under state statutes. Residential developments and business permits are reviewed by state and local agencies. Two zoning authorities administer policy and regulations in the unincorporated portions of Doña Ana County. The Extraterritorial Zoning Commission (ETZ) has jurisdiction within five miles of Las Cruces, and the Doña Ana County Planning and Zoning Commission (PZC) reviews zoning and subdivisions outside of the ETZ and in the unincorporated areas of the county. Sunland Park, Las Cruces, Hatch, and Mesilla are incorporated municipalities, and each has its own zoning and subdivision regulations.

Land-use statistics were reported for two categories of land: vacant lands (undeveloped tracts of federal, state, and private land holdings) and non-vacant lands. This classification was used to show the effects that undeveloped land has on the county's land statistics. The largest category of land use is agricultural (69.9%) followed by residential (16.4%). These percentages are much lower when vacant lands are included. Land use is shown on Figure 2.4. The land use shown on this map is 1982 data. If the agricultural area shown on this map is compared to the public water supply systems also shown on the map, it is apparent that a significant amount of agricultural land has been converted to residential use over the past 14 years. The land use information is of interest if the surface use has a potential impact on groundwater quality. Any activity that produces a soluble contaminant and which provides a transport mechanism (water) is a potential groundwater contamination source. The residential areas with septic tanks, and agricultural areas which perform flood or furrow irrigation are both potential pollution sources.

Special-use permits

Until 1993, zoning in Doña Ana County was carried out through the approval of special-use permits. Each permit application was considered by the PZC, and permits were approved or denied based on review by county staff, state and local agency comments and recommendations, and public comment. Most applications were approved with certain conditions.

In 1993, Doña Ana County adopted a new interim zoning ordinance which prohibits some industrial and commercial land uses until a new comprehensive plan is adopted. The largest non-residential land-use category in Doña Ana County is commercial at 42% with industrial second at 37%. Public (7%) and residential (6%) land uses lie within the miscellaneous category. Interestingly, multi-family residential special-use-permit approvals make up a small percentage of the overall



LAND USE SOURCE: U.S. Geological Survey, 1990, EPA Land Use and Land Cover Digital, Data from 1:250,000–and 1:100,000-Scale Maps —Data Users Guide 4, 1:250,000 QUAD LAND USE, 1982. Contact: Ed Partington at EPA, Phone (703) 235-5595.

WATER SYSTEM SOURCE: Dona Ana County Planing Department, GIS Division, 1996.

DRINKING WATER WELLS SOURCE: New Mexico Environmental Drinking Water Bueru, 1996.

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Figure 2.4. Public Water Wells, Water Distribution Systems, and Land Use in Dona Ana County, New Mexico

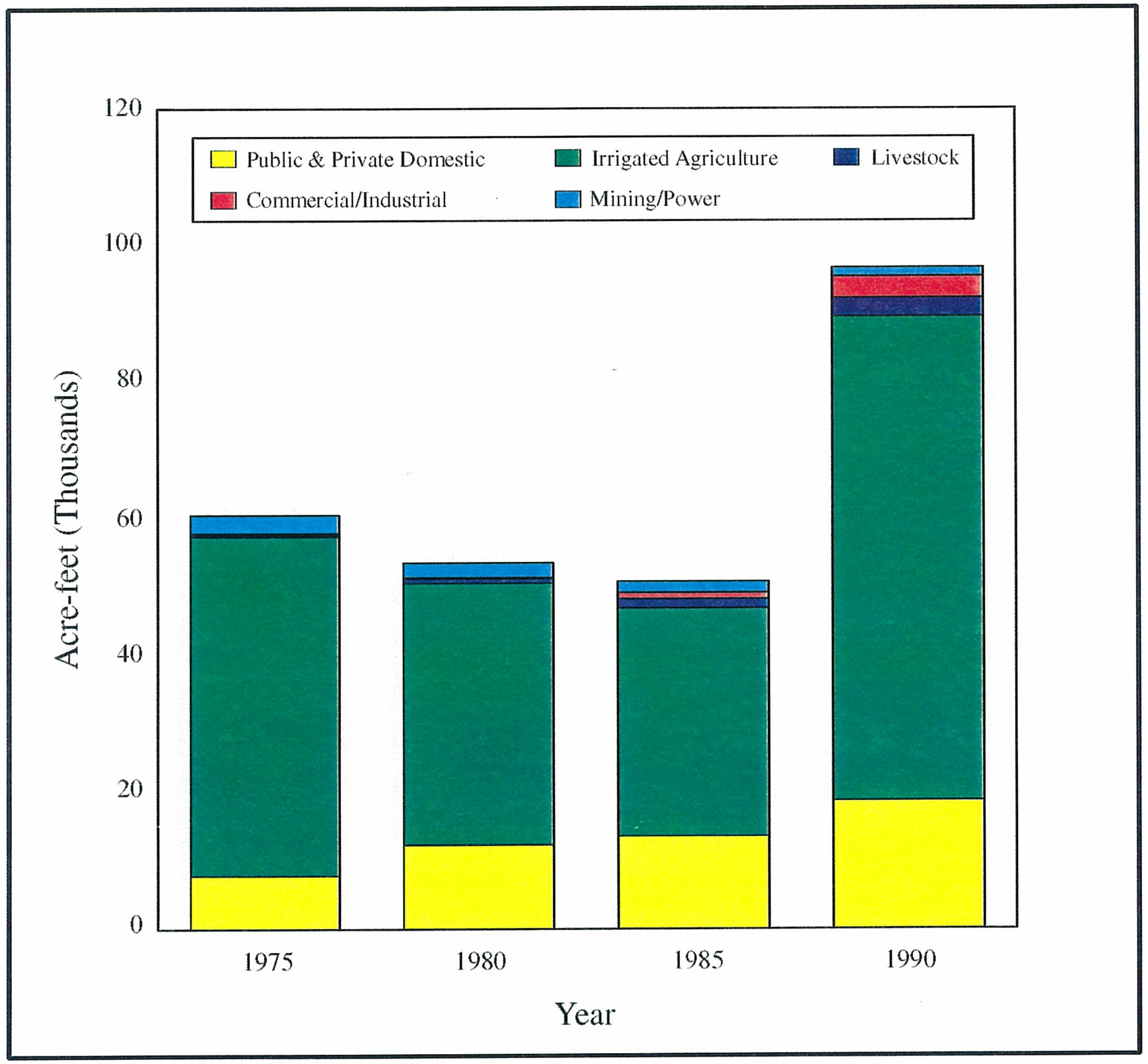


Figure 2.5. Groundwater depletions by category in Doña Ana County, New Mexico for 1980, 1985, and 1990 (source of data, Sorensen, E.F., 1977; Sorensen, E.F., 1982; Wilson, B.C., 1986; Wilson, B.C., 1992).

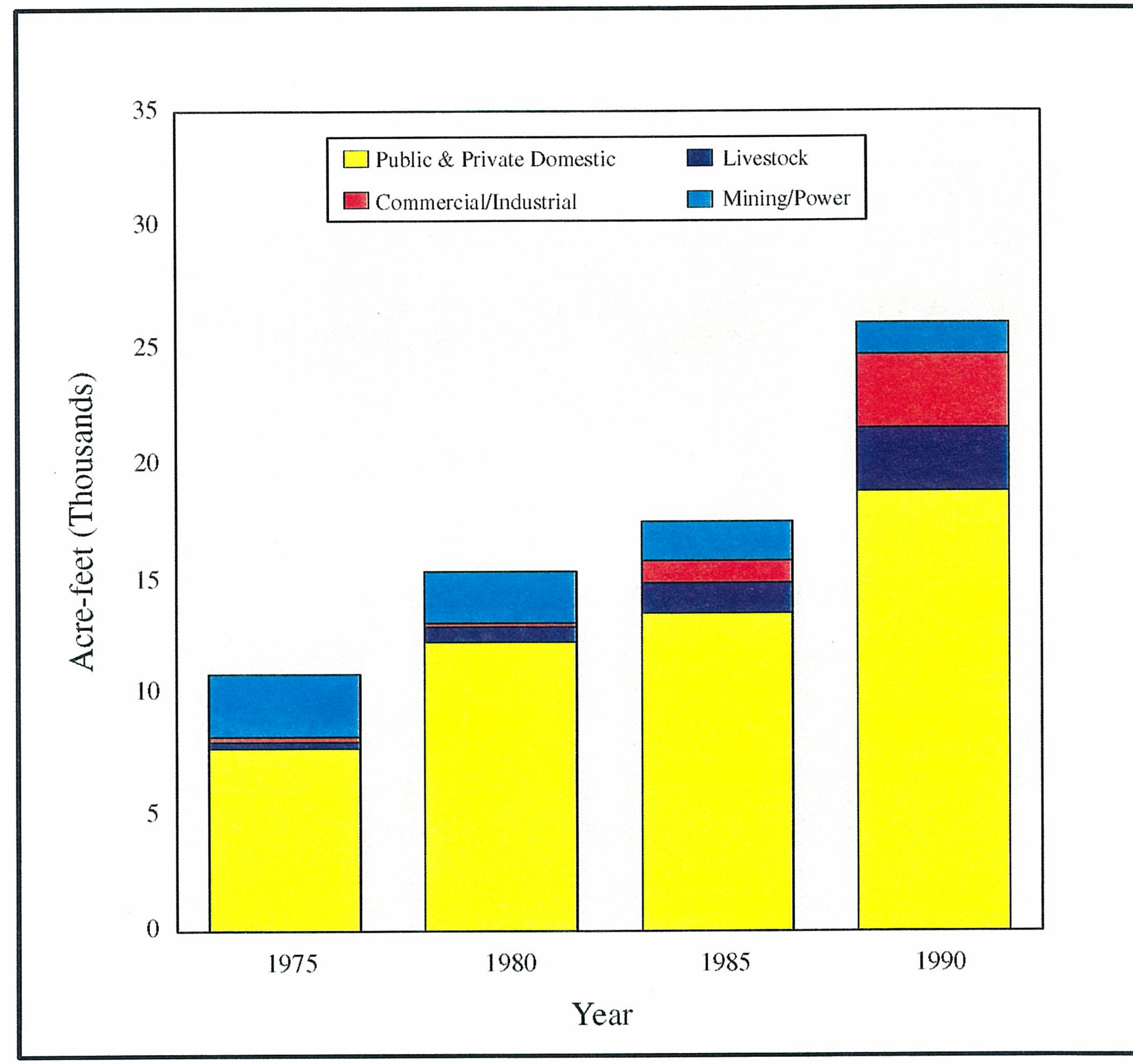


Figure 2.6. Groundwater depletions by category excluding irrigated agriculture in Doña Ana County, New Mexico for 1980, 1985, and 1990 (source of data, Sorensen, E.F., 1977; Sorensen, E.F., 1982; Wilson, B.C., 1986; Wilson, B.C., 1992).

Table 2.1. Water Use by category in Doña Ana County, New Mexico in 1990 in acre-feet.

	WSW	WGW	TW	DSW	DGW	TD	RFSW	RFGS	TRF
Public Water Supply *	0.00	28955.98	28955.98	0.00	17409.69	17409.69	0.00	11546.29	11546.29
Domestic (self-supplied) *	0.00	2311.64	2311.64	0.00	1386.98	1386.98	0.00	924.66	924.66
Irrigated Agriculture	368042.00	104989.00	473031.00	149254.00	70900.00	220154.00	218788.00	34089.00	252877.00
Livestock (self-supplied)	48.04	2977.30	3025.34	48.04	2708.47	2756.51	0.00	268.83	268.83
Commercial (self-supplied)	88.80	4547.25	4636.05	81.70	3077.55	3159.25	7.10	1469.70	1476.80
Industrial (self-supplied)	0.00	129.49	129.49	0.00	69.54	69.54	0.00	59.95	59.95
Mining (self-supplied)	0.00	44.80	44.80	0.00	11.15	11.15	0.00	33.65	33.65
Power (self-supplied)	0.00	1707.09	1707.09	0.00	1331.53	1331.53	0.00	375.56	375.56
Reservoir Evaporation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**368178.84**	**145662.55**	**513841.39**	**149383.74**	**96894.91**	**246278.65**	**218795.10**	**48767.64**	**267562.74**

Column definitions: WSW=Withdrawals Surface Water, WGW=Wighdrawals Ground Water, TW=Total Withdrawals, DSW=Depletions Surface Water, DGW=Depletions Ground Water, TD=Total Depletions, RFSW=Return Flows Surface Water, RFGW=Return Flows Ground Water, TRF=Total Return Flows.

* Detail below list withdrawals and calculated depletions for Public Water Supply and Domestic (self-supplied).

	Measured	WGW	DGW(calculated)
Anthony Water Works	Y	542.60	347.26
Berino Water Users Assn.	Y	196.00	98.00
Butterfield Park MDWCA	Y	84.88	42.44
Chaparral Water System	Y	879.64	439.82
Delara Estates MDWCA	Y	88.33	44.17
Desert Sands MDWCA	Y	77.54	38.77
Doña Ana MDWCA	Y	1,063.06	531.53
Ft. Seldon Subdivision	Y	88.10	44.05
Garfield MDWCA	Y	202.15	101.08
Green Valley MHP	Y	19.00	9.50
Hacienda Acres Water System	Y	286.51	143.26
Hatch Water Supply System	Y	285.44	182.68
Holly Gardems MHP	Y	24.59	12.30
Las Alturas Estates	Y	173.51	86.76
Las Cruces Municipal System	Y	16,904.92	10,142.95
Mesa Development Ctr., Inc.	Y	89.00	44.50
Mesilla Park Manor Water	Y	202.27	101.14
Mesilla Water System	Y	209.46	104.73
Mesquite MDWCA	Y	513.15	256.58
Moongate Water System	Y	563.00	281.50
Mountain View MDWCA	Y	83.69	41.85
Picacho Hills Water System	N	557.98	457.54
Raasaf Hills Water System	Y	16.32	8.16
Rincon Water Consumers Co-op	N	47.77	23.89
Rural self-supplied homes	N	2,311.64	1,386.98
San Andres Estates Water System	Y	127.61	63.81
Santa Teresa Water System	Y	2,356.80	1,932.58
Skoshi Mobile Home Park	Y	18.38	9.19
Sunland Park Water System	Y	870.92	435.46
Talavera Water Co-op1	Y	8.95	4.48
University Estates	Y	424.13	212.07
Vista Real MHP	Y	25.28	12.64
White Sands Missile Range	Y	1,925.00	1,155.00
Total		**31,267.62**	**18,796.62**

Source: Wilson, B.C., (1992)

Table 2.2. Water Use by category in Doña Ana County, New Mexico in 1985 in acre-feet

	WSW	WGW	TW	DSW	DGW	TD
Urban *	0	16021	16021	0	8012	8012
Rural *	0	5399	5399	0	2701	2701
Irrigated Agriculture	376465	58183	434648	139150	33449	172599
Livestock	136	1576	1712	136	1309	1445
Stockpond Evaporation	340	0	340	340	0	340
Commercial	0	1792	1792	0	930	930
Industrial	0	57	57	0	32	32
Minerals	0	181	181	0	60	60
Military	0	2058	2058	0	1235	1235
Power	0	1601	1601	0	1601	1601
Fish and Wildlife	0	0	0	0	0	0
Recreation	160	2485	2645	160	1629	1789
Reservoir Evaporation	0	0	0	0	0	0
Total	**377101**	**89353**	**466454**	**139786**	**50958**	**190744**

Column definitions: WSW=Withdrawals Surface Water, WGW=Wighdrawals Ground Water, TW=Total Withdrawals, DSW=Depletions Surface Water, DGW=Depletions Ground Water, TD=Total Depletions.

Detail below list withdrawals for Urban, Rural and Military.

	Urban/Rural	WGW
Anthony	U	374
Chaparral	U	439
Doña Ana	U	427
Las Cruces	U	14781
White Sands Missile Base	M	2048
Butterfield Park	R	84
Hacienda Acres MHP	R	121
Hatch	R	214
Mesilla	R	188
Mesilla Park	R	158
Pecan Valley Estates	R	36
Rincon	R	43
San Andres Estates	R	113
University Estates	R	138
Other Rural	R	4653
Total		**23817**

Source: Wilson, B.C., (1986).

Table 2.3. Water Use by category in Doña Ana County, New Mexico in 1980 in acre-feet

	WSW	WGW	TW	DSW	DGW	TD
Urban *	0	14179	14179	0	7089	7089
Rural *	0	4878	4878	0	2439	2439
Irrigated Agriculture	395860	58110	453970	166640	38330	204970
Livestock	257	738	995	257	642	899
Stockpond Evaporation	340	0	340	340	0	340
Commercial	0	234	234	0	141	141
Industrial	0	51	51	0	31	31
Minerals	0	181	181	0	59	59
Military	0	2010	2010	0	1209	1209
Power	0	2150	2150	0	2150	2150
Fish and Wildlife	0	0	0	0	0	0
Recreation (land based only)	255	3030	3285	255	1620	1875
Reservoir Evaporation	0	0	0	0	0	0
Total	**396712**	**85561**	**482273**	**167492**	**53710**	**221202**

Column definitions: WSW=Withdrawals Surface Water, WGW=Wighdrawals Ground Water, TW=Total Withdrawals, DSW=Depletions Surface Water, DGW=Depletions Ground Water, TD=Total Depletions.

Detail below list withdrawals for Urban, Rural and Military.

	Urban/Rural	WGW	DGW(calculated)
Anthony	U	220	110
Chaparral	U	—	—
Doña Ana	U	336	168
Las Cruces	U	12070	6035
White Sands Missile Base	M	—	—
Berino	R	20	10
Butterfield Park	R	26	13
Hacienda Acres MHP	R	111	56
Hatch	R	108	54
Mesilla	R	180	90
Mesilla Park	R	117	58
Mesquite	R	68	34
Organ	R	110	55
Pecan Valley Estates	R	31	16
Rincon	R	25	12
San Andres Estates	R	68	34
University Estates	R	170	85
Other Rural	R	3844	1922
New Mexico State Univesity	U	1553	776
Total		**19057**	**9528**

Source: Sorensen, E. F., (1982).

Table 2.4. Water Use by category in Doña Ana County, New Mexico in 1975 in acre-feet

	WSW	WGW	TW	DSW	DGW	TD
Urban	0	9705	9705	0	4852	4852
Rural	0	3508	3508	0	1754	1754
Irrigated Agriculture	412270	72930	485200	153600	49760	203360
Livestock	268	269	537	268	269	537
Stockpond Evaporation	180	0	180	180	0	180
Manufacturing	0	365	365	0	219	219
Minerals	0	181	181	0	59	59
Military	0	2000	2000	0	1200	1200
Power	0	3503	3503	0	2627	2627
Fish and Wildlife	250	0	250	250	0	250
Recreation (land based only)	0	0	0	0	0	0
Reservoir Evaporation	255	0	0	0	0	0
Playa Lake Evaporation	3200	0	3200	3200	0	3200
Total	**416423**	**92461**	**508629**	**157498**	**60740**	**218238**

Column definitions: WSW=Withdrawals Surface Water, WGW=Wighdrawals Ground Water, TW=Total Withdrawals, DSW=Depletions Surface Water, DGW=Depletions Ground Water, TD=Total Depletions.
Source: Sorensen, E. F., (1975).

Table 2.5. Summary of groundwater depletions by category for Doña Ana County, New Mexico, 1975, 1980, 1985, 1990.

	1975	1980	1985	1990
Public & Private Domestic	7806	12357	13577	18796.67
Irrigated Agriculture	49760	38330	33449	70900.00
Livestock	269	642	1309	2708.47
Commercial/Industrial	219	172	962	3147.09
Mining/Power	2686	2209	1661	1342.68
Total	**60740.00**	**53710.00**	**50958.00**	**96894.91**

Sources: Sorensen, E.F., (1977), Sorensen, E.F., (1982), Wilson, B.C., (1986), Wilson, B.C., (1992).

land uses permitted in Doña Ana County. Single family residential and agricultural uses are permitted by right and no special-use-permit is required.

Colonias in Doña Ana County

According to the US Government Accounting Office, a colonia is defined as follows:

- an unincorporated community situated within 100 kilometers of the US/Mexico border
- designated by the county or state in which it is located
- lacking adequate potable water, adequate sewage systems, and safe, sanitary housing
- was in existence before November 1990

By this definition, Doña Ana County has designated thirty-four communities as colonias. Most of these communities are located within the service areas of public water utilities, privately owned water utilities, and water associations. However, due to economic limitations, new residents often have no access to these utilities. The cost of extending water lines is prohibitive, and in many cases, water utilities do not have the capacity to accept new connections. Drilling a domestic water well in the area costs between $5,000 and $8,000. Many residents may dig or drive their own shallow wells and haul in potable water due to the poor water quality in the Rio Grande Floodplain Alluvium aquifer. This wide spread use of shallow wells makes water quality information on the alluvium aquifer of great interest. Unfortunately there appears to be very little water quality data available on the aquifer.

Under the State of New Mexico's 1973 Land Subdivision Act, (Section 47-6-1, et seq., NMSA, 1978) four parcels of land may be divided within three years before subdivision plat approval is required. Therefore, lots may be split without providing access to utilities such as water and sewage disposal. Developers of these marginal subdivisions argue that they provide property ownership opportunities for low-income families. However, the cost of developing utilities becomes a heavy burden on buyers of these undeveloped lots. In some cases, the water table is less than four feet below ground surface, requiring a modified septic tank drainfield. Many homes are built in flood zones without adequate drainage. Families often must haul potable water when local water associations cannot economically extend water lines to these developments.

During the years from 1991 to 1993, the number of building permits issued for mobile homes and site-built homes in the unincorporated areas of the county averaged 1,016, a 4.5% increase in households, per year. This growth was concentrated in the Las Cruces Five Mile-Extraterritorial Zone and the South Valley of the county. This trend was continuing in 1994.

In 1993 the county was ranked as the twelfth poorest in New Mexico in per capita personal income. In many areas, the low income levels have contributed to poor infrastructure development for basic utilities, including drinking water and wastewater treatment. Figure 2.4 shows the location of public water supplies and wells in the Mesilla basin aquifers. Figure 2.7 shows the location of septic tanks in this same region.

From 1980 to 1990, the median income of Doña Ana County residents rose faster than inflation in the county. However, at the same time, the percentage of county residents below the poverty level rose from 22.7% to 26.5% (South Central Council of Governments 1994).

From 1988 to 1993, the labor force in Doña Ana County increased by 7.0% with declining increases each year. In this period, the number of employed persons in the county increased by 5.3%, and the number of unemployed persons increased by 26.9%. Unemployment in each year was lowest in January and highest in June, following the same trend as the size of the labor force.

Agriculture

Most of the region's farming activities are restricted to the valley (Figures 2.1 and 2.4) where the land surface is fairly level and the mean depth to the water table is about 180 cm. The main field crops grown in the area are cotton (22,850 acres), orchards (18,605), alfalfa (15,700), chile (6,000), corn (4,000), and onions (3,900) (Lansford and others, 1996). Crop production is extensively supported by irrigation. Most irrigation is done using flood irrigation systems, with little or no tail-end water.

Historical irrigation practices have used the groundwater system effectively as a reservoir in a combined stream-aquifer system. During years of sufficient surface water, most of the water needed for irrigation is diverted from the Rio Grande. Water levels in shallow observation wells located near the Rio Grande vary with river stage. Water levels in observation wells near the river increase and decline in response to the amount of infiltration of applied irrigation water (Nickerson and Myers, 1993). A portion of the shallow groundwater seeps into irrigation drains that discharge to the Rio Grande. During years of inadequate surface-water supply, groundwater is used as a supplemental water supply. This causes abnormally low groundwater levels resulting in less water being discharged to the drains. Groundwater levels generally return to normal after an irrigation season when surface water is plentiful.

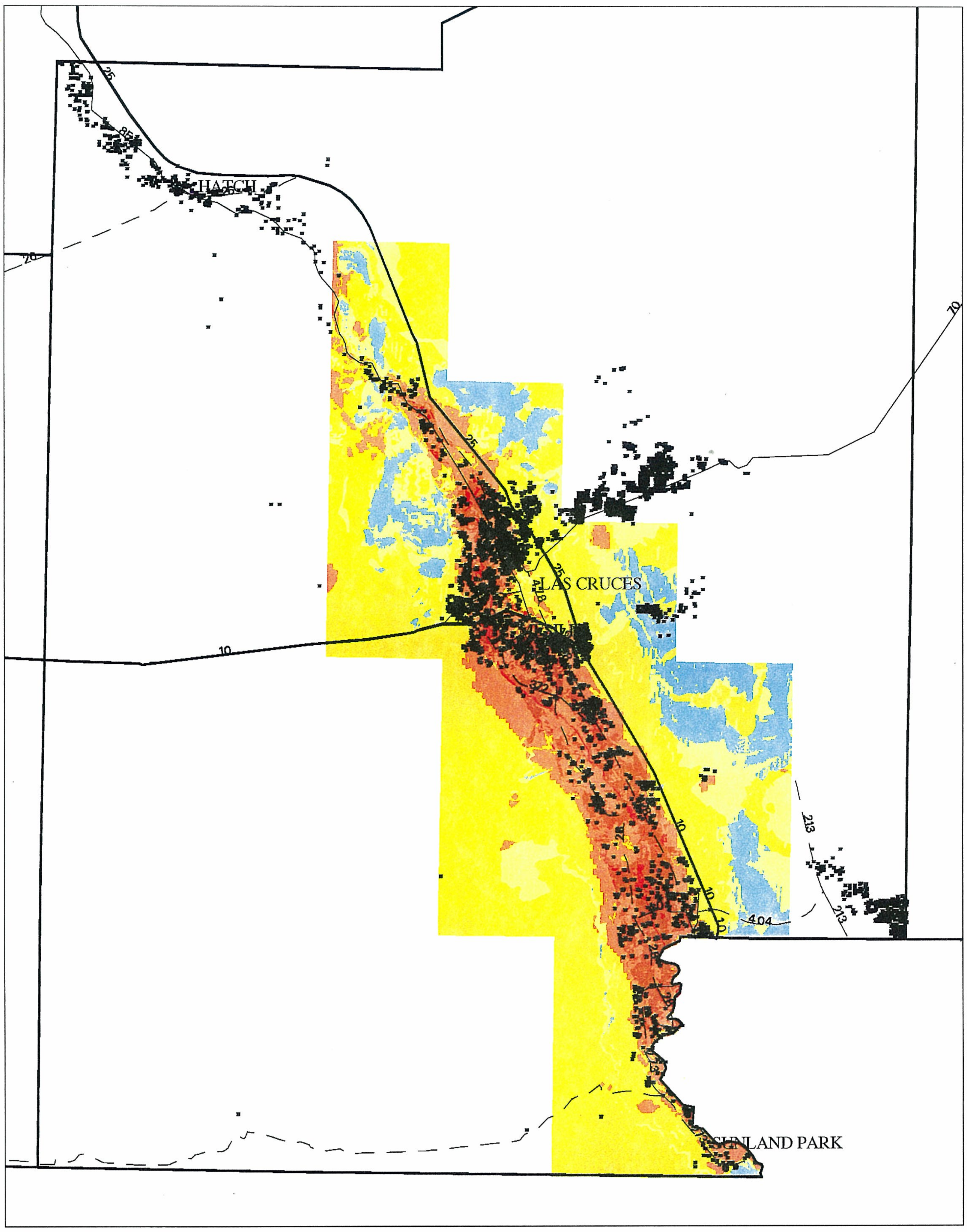
Sources of Contamination

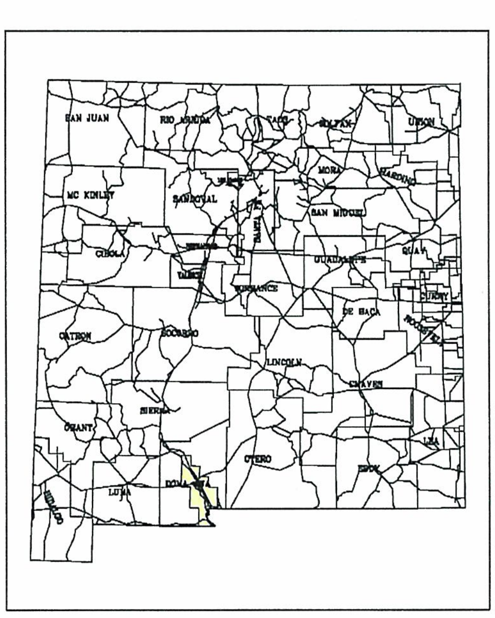
There are two major potential sources of groundwater contamination in the Rio Grande Valley which might impact the Mesilla Bolson: agricultural activity and high density residential septic tanks. The agricultural activity can again be broadly sub-divided into two major impact categories: cropping and dairies.

Aquifer sensitivity assessment

A study has been completed to assess the natural sensitivity of the groundwater aquifers in the Mesilla Valley of southern New Mexico and to assess, using a model, the potential impact that farmers' and selected irrigation scheduling practices may have on selected pesticides leaching and concentrations below the root zone (Creel and others, 1997).

This assessment of the natural sensitivity of the groundwater aquifers employed a regional Geographic Information System (GIS) to determine and map the relative sensitivity of aquifers to contamination sources. The DRASTIC model was used to assess aquifer sensitivity by combining data sets that describe the depth-to-groundwater, recharge rates, aquifer material, soils composition, land slope, vadose zone materials, and saturated hydraulic conductivity. The study evaluated the data requirements and techniques necessary to employ the DRASTIC model so that it could be utilized in other regions of New Mexico. GIS coverages were developed for each of the DRASTIC parameters and combined into a natural sensitivity coverage for the study area. The resulting natural sensitivity values were grouped into six categories: very slight - indicating that the groundwater aquifer is very well protected and risk of contamination from nonpoint sources is very low; slight - the groundwater aquifer is reasonably well protected, but because one or more of the hydrologic parameters are conducive to contaminate transport, there is a higher level of risk of nonpoint pollution; low - the groundwater aquifer is somewhat protected, but more than one of the parameters are conducive; moderate - the groundwater aquifer is susceptible to contamination because few natural protections exist; severe - the groundwater aquifer is much more susceptible to contamination due to several hydrologic conditions; and extreme - all hydrologic parameters are conducive to the rapid transport of contamination to the groundwater aquifer. Results indicated that of the 2,282 km^2 included in the study area less than one percent was classified as extreme, slightly over 10 percent as severe,





Explanation

- Septic Tanks
- Interstate
- US Highway
- State Highway
- County Line
- VERY SLIGHT –groundwater aquifers are very well protected and risk of contamination from non point sources is very low (overall DRASTIC index less than 86).
- SLIGHT –groundwater aquifers are reasonably well protected, but because one or more of the hydrologic parameters are conducive to contaminant transport, there is a higher level of risk of non point pollution (overall DRASTIC index from 87 to 112).
- LOW –groundwater aquifers are somewhat protected, but more than one of the parameters are conducive to contaminant transport (overall DRASTIC index from 113 to 139).
- MODERATE –groundwater aquifers are somewhat susceptible to contamination because few natural protections exist (overall DRASTIC index from 140 to 175).
- SEVERE –groundwater aquifers are much more susceptible to contamination due to several hydrologic conditions (overall DRASTIC index from 176 to 200).
- EXTREME –all hydrologic parameters are conducive to the rapid transport of contamination to the groundwater aquifers (overall DRASTIC index greater than 200).

SOURCE: Creel, B., Sammis, T., Kennedy, J.F., Sitze, D.O., Asare, D., Monger, H. C., and Samani, Z. A., Groundwater Aquifer Sensitivity Assesment and Management Practices Evaluation for Pesticides in the Mesilla Valley of New Mexico: New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, New Mexico (in press).

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KILOMETERS

Figure 2.7. Septic Tanks and Natural Sensitivity of the Mesilla Valley Dona Ana County, New Mexico

almost 19 percent as moderate, almost 43 percent as low, almost 16 percent as slight, and over 12 percent as very slight.

Cropping activity

The cropping activities which may have a negative impact on the groundwater are: fertilization practices, pesticide and herbicide use, and irrigation practices. Some examples will be used to demonstrate the magnitude of the problem. Nitrate concentrations of 10 - 40 mg/L have been reported in the shallow groundwater just below onion fields (Gallego, 1994). Fertilization in excess of plant use may move down past the root zone and go to the groundwater if it is not intercepted by a drain.

The other major inorganic agricultural contaminant of concern, besides nitrate, in both surface and groundwater is salinity. The TDS of the river water progressively increases as the Rio Grande flows toward the south (Wierenga, 1979). The increased salinity of the groundwater is due to irrigation return flow from about 400 miles of open drains installed along the agricultural fields in the Mesilla Valley and the influx of treated wastewater from municipalities. The drain ditches intercept the water table in the valley and drains the incoming seepage from agricultural fields into the Rio Grande. The drains play an important role in the quality of the groundwater by intercepting and draining the seepage water from the farms. However, drains do not intercept the entire seepage water, thus some of the seepage water replenishes the aquifer in the areas where pumping is taking place. The recharge of the aquifer by seepage water contributes to salinization of the groundwater through lateral and vertical migration of the salt. It is speculated that if the current practice of furrow irrigation was switched to drip irrigation, the quantity and quality of water seeping into the aquifer would be drastically reduced. However, there is so little baseline data available, it is difficult to quantify the magnitude of the existing flux. It is equally difficult to predict the impact of changing irrigation and fertilization practices without first having an accurate understanding of the existing situation.

Dairies

The number of milk cows in Doña Ana County in 1994 was estimated to be 31,000 (USDA, 1994). The dairy activity is largely concentrated south of Las Cruces along the eastern border of the Mesilla Bolson. There are ten dairies along an eight mile stretch between Mesquite and Vado (Figure 2.8). In terms of waste production, each cow can be viewed as the waste equivalent of 15 - 20 people. This is roughly equivalent to the waste load of 465,000 people. The wastewater from these dairies are either stored in lagoons or applied to the agricultural fields through sprinkler or conventional flood irrigation. The seepage from lagoons, corrals and agricultural fields which cover several hundred acres, all contribute to increased groundwater salinity and nitrate contamination in the area. Figures 2.9 thru 2.11 are a detailed site map, groundwater contour map, and a contamination map, respectively. It is seen that the water directly under the dairies contains nitrate concentrations in the 100 to 150 mg/L range. Jacquez and Samani (1992) measured groundwater nitrate contamination ranging from 20 to 200 ppm and salinity of more than 1,500 ppm in the groundwater under the dairies. At this time the nitrate is not moving significantly in the groundwater. The dairies production wells are containing the majority of the plume. However, in the event the dairies cease pumping water or new production wells are developed in the vicinity, the plume would be free to move downgradient and could do significant damage to adjacent groundwater. The potential mobility is illustrated by the nitrate in the Figure 2.11 which has already started to move. The nitrate that is moving to the south is nitrate associated with the treated dairy wastewater applied to irrigated fields outside of the cone of depression formed by the dairy production wells.

Septic tanks

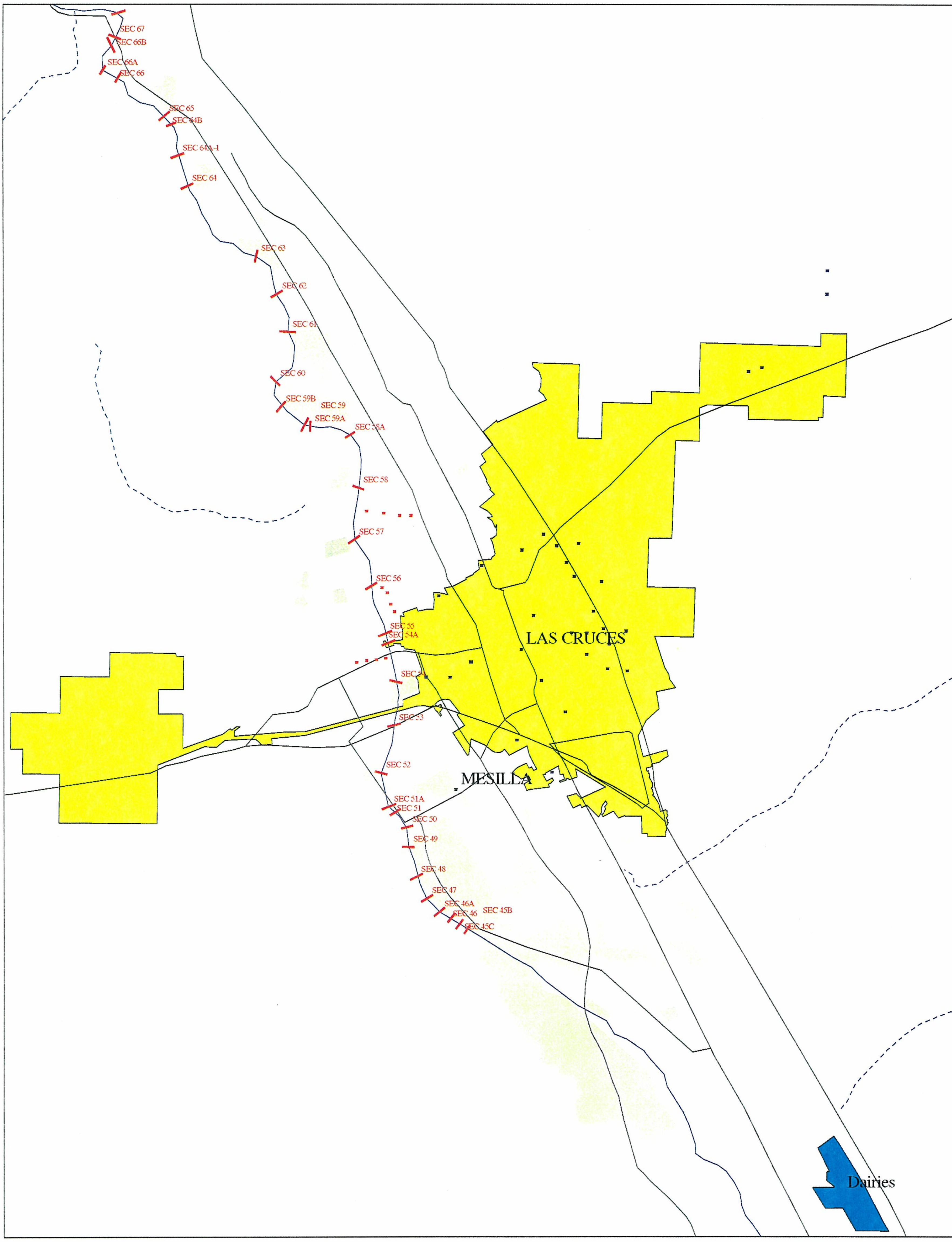
Although the nitrate levels associated with the groundwater under the dairies are significantly higher than those expected in septic tank effluent (150 mg/L vs 45 mg/L), and the volume of septic tank effluent is less than the volume of wastewater produced by the dairies. The waste produced is still very significant. It is estimated, based on figures from the 305(b) report, that the volume of waste water discharged to the groundwater may be as high as 2.2 MGD from septic tanks over the Mesilla Bolson. This represents approximately 825 lb/day of nitrogen being discharged into the subsurface environment from septic tanks over the Mesilla Bolson. Septic tanks are considered the single largest non-point source of groundwater contamination in the state of New Mexico. According to Water Quality and Water Pollution Control In New Mexico 1994, the Clean Water Act 305(b) report, more than 50 percent of the identified cases of groundwater contamination in the state of New Mexico are attributed to non-point (diffuse) sources. Most of these cases involve large numbers of small, household septic tanks and cesspools distributed over rapidly developing areas in unsewered subdivisions and un-incorporated rural areas. It is estimated that there are over 170,000 septic tanks and cesspools in the State with a subsurface discharge of 51,000,000 gallons of waste water every day (NMWQCC, 1994).

While these septic tank discharges and their impact on groundwater is a State wide problem, the areas of greatest concern are the regions associated with the Colonias, many of which are over the Mesilla Bolson. The 305(b) report (NMWQCC, 1994) referred to Colonias as one of the more serious environmental concerns facing New Mexico along its southern border. The report notes that "Congestion, uncontrolled urban development, and lack of basic environmental health and sanitation facilities have become significant problems in many communities on both sides of the border" (NMWQCC, 1994). Of the estimated 200,000 residents in El Paso County, Texas and over 40,000 residents of southern Doña Ana County, New Mexico, fewer than 7% are on sewered wastewater systems. The majority use on-site waste treatment systems.

The majority of the current Colonia residents are first and second generation, low income, migratory families of Mexican descent. In New Mexico the vast majority of the Colonias with their overwhelming concentrations of people and concurrent health and environmental concerns occur along the 44 mile stretch of the Rio Grande Valley from Las Cruces to the El Paso/Ciudad Juarez Metro area. In Doña Ana County alone, 43 percent of all dwellings in the un-incorporated areas were mobile homes according to 1990 data. Of these residents (about 40,000 people), only 20% are connected to public water supplies. This leads to serious environmental and public health concerns because the groundwater is very sensitive to environmental damage from non-point sources like septic tanks and their associated liquid disposal systems (drainfields).

This is illustrated by combining the natural sensitivity information map with the location of on-site liquid waste facilities (septic tanks) in Doña Ana County (Figure 2.7). The septic tank data was developed in 1994 by the Doña Ana County Planning Department by use of county land parcel database. Parcels that have had building permits issued or had mobile home utility connections, that were not served by a liquid waste treatment system were assumed to have on-site liquid waste facilities (septic or cesspool). The location of the on-site facility was calculated as the centroid of the parcel polygon. This database is shown as dots on the natural sensitivity map. It is seen that most of these septic tanks between Las Cruces and the Texas/Mexico Border are located in the naturally sensitive portion of Mesilla Valley.

The potential groundwater problems associated with dense septic tank development are well documented. Because of the reliance on groundwater in the arid southwest, this area is particularly vulnerable to damage. Very few of the individuals building homes in the Colonias and similar developments can afford the luxu-



ORCHARD LOCATION SOURCE: U.S. Geological Survey, 1990, EPA Land Use and Land Cover Digital, Data from 1:250,000–and 1:100,000-Scale Maps —Data Users Guide 4, 1:250,000 QUAD LAND USE, 1982. Contact: Ed Partington at EPA, Phone (703) 235-5595.

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Explanation

- Cities
- Las Cruces Water Wells
- Simulated Particle Path (modified from Hanson and Samani 1995)
- Roads
- County Line
- Perennial Streams
- Intermittent Streams
- Canals
- Sections (modified from Hanson and Samani 1995)
- City limits of Las Cruces
- Location of Dairies
- Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural Areas

Figure 2.8. Dairies, Particle Tracking Sections, and Orchard Location

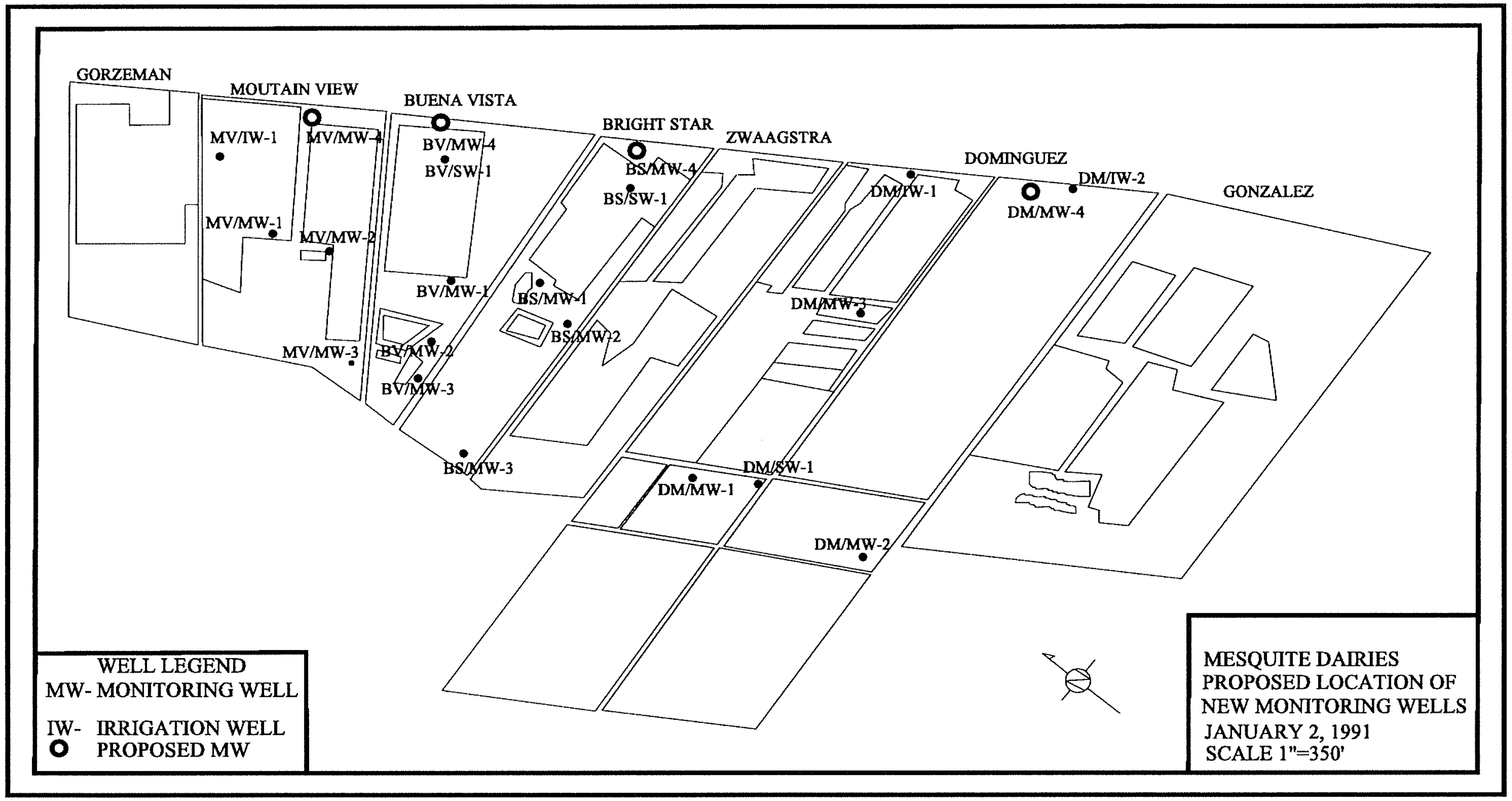

Figure 2.9. Dairy site map detail.

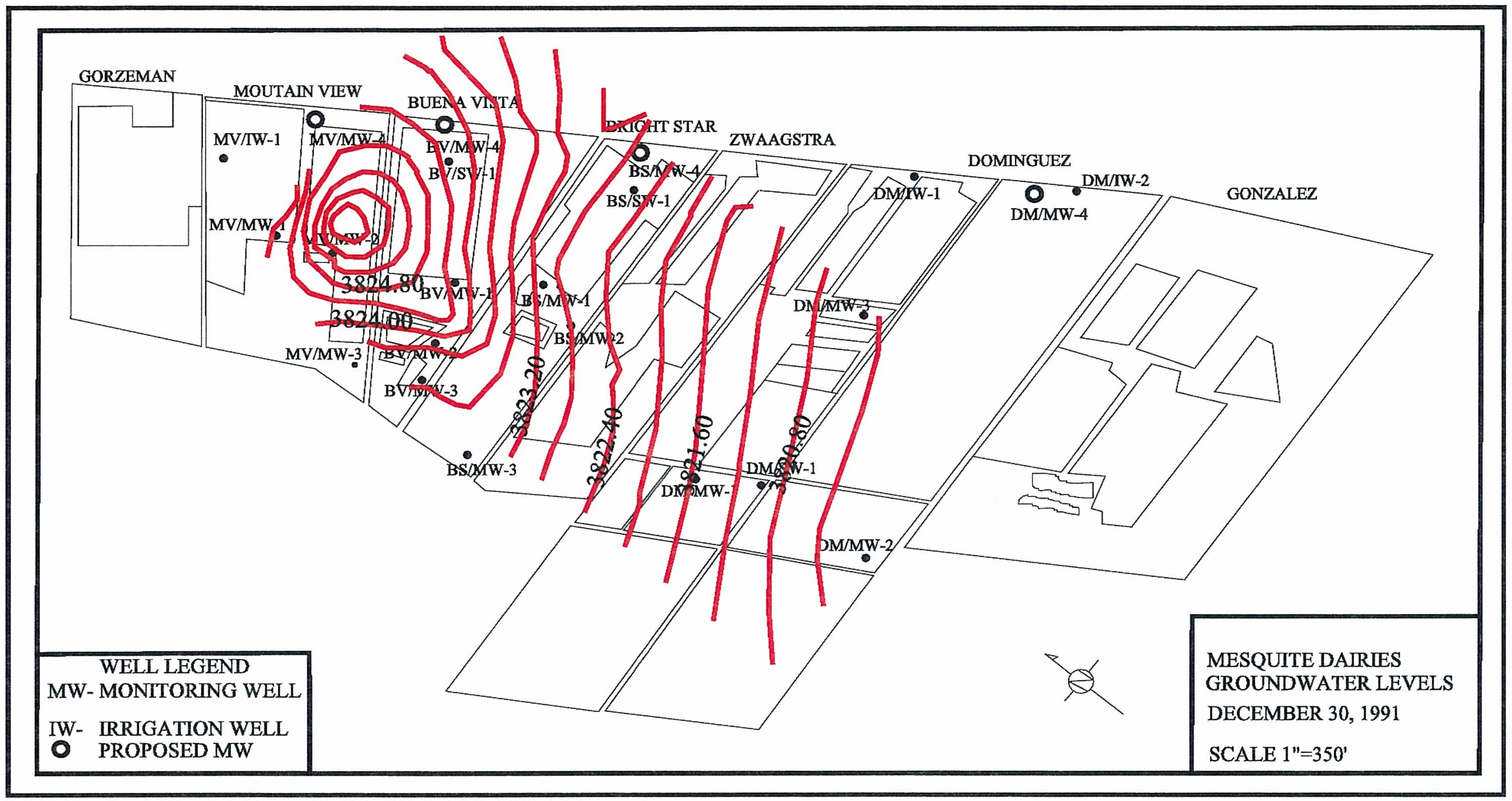

Figure 2.10. Dairy groundwater levels.

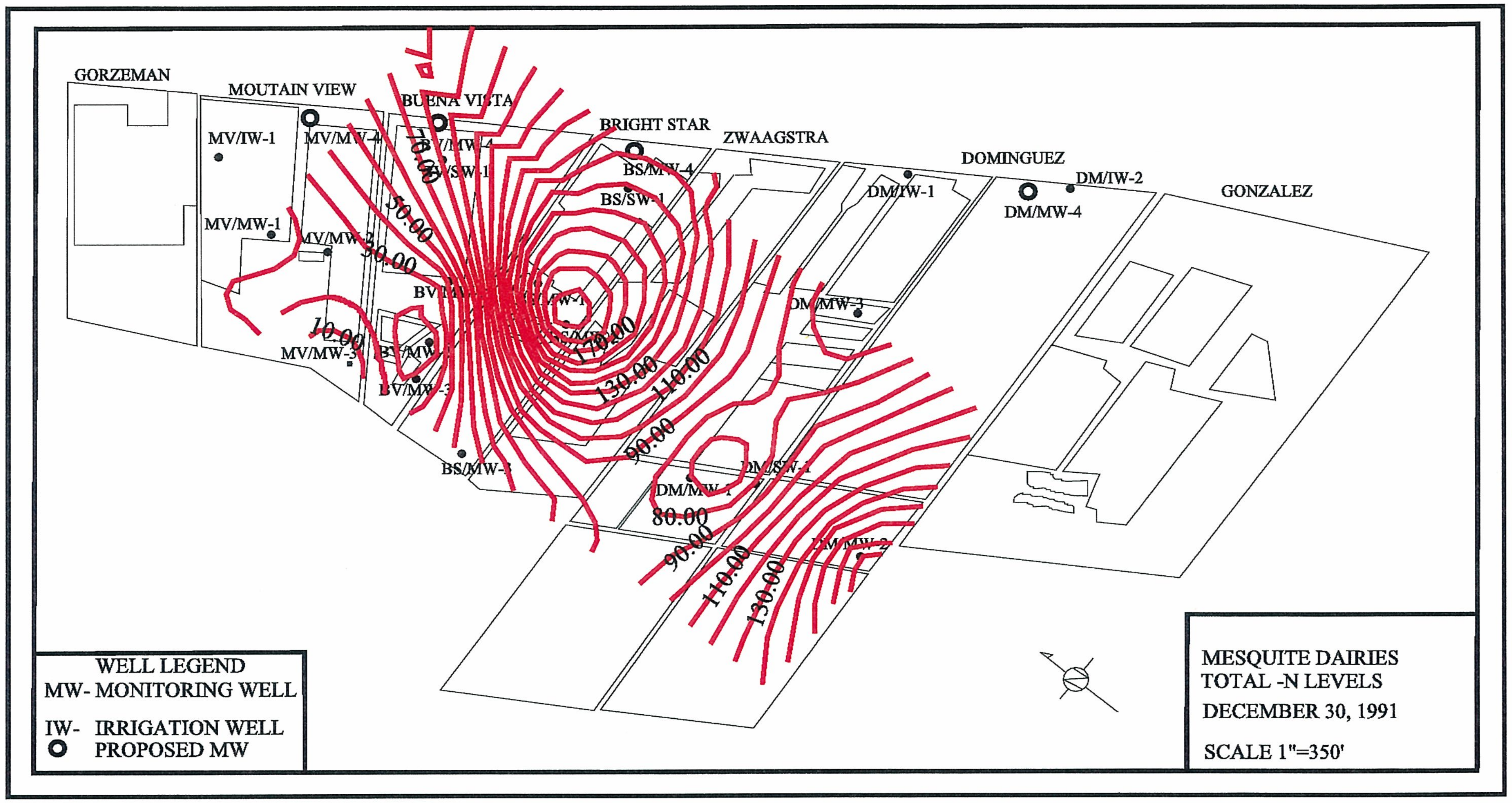

Figure 2.11. Dairy groundwater nitrate levels.

ry of hiring a contractor to install their septic tank and drainfield system. Many of the residents of Doña Ana County and El Paso Counties are extremely poor with the average annual incomes less than $9,500. While the average incomes remain low, growth is very rapid exceeding 15 percent per year in the region. The development scenario just described has caused concern among County Planning Staffs and state environmental professionals, and represents a severe threat to groundwater in the Mesilla basin aquifers. Regardless of the nitrogen form when it is discharged from the septic tank, it will eventually be converted to nitrate. There is little possibility of the nitrate being removed from the groundwater, so it will build up over time. This will become a critical problem when the groundwater levels of nitrate approach 10 mg/L, which is the Safe Drinking Water Act (SDWA) Maximum Contaminant Level (MCL) for nitrate.

Particle tracking

One means of estimating the impact of a pollution source on the aquifer is to use a particle tracking model. Particle tracking simulations have been performed in the Mesilla Bolson near Las Cruces, NM (Hanson and Samani, 1995) to evaluate the potential for contaminate migration from the Rio Grande into the adjacent aquifer. The river reach near Las Cruces was selected since the large cone of depression associated with the City well field is a worst case condition. For the Hanson and Samani (1995) study, simulated particles were released at different stations, located at the midpoint of a cross-section, from the bottom of the Rio Grande stream bed and then tracked for a period of 50 years. An overview of the cross-sections modeled is shown in Figure 2.8.

The rate and direction of particle transport from the river to the adjacent groundwater was directly related to hydraulic gradient. The simulation showed that between sections 57 and 58, which were under strong influence of the cone of depression created by the Las Cruces City Well Field, the particles moved east toward the cone of depression at a rate of 160 feet per year. Between sections 55 and 56, which were not affected by the cone of depression, the movement of the particles were parallel to the river channel. At sections 55 and 54, which were outside of the zone of municipal well field influence but were influenced by irrigation wells on the west side of the river, the simulated particles moved toward the west at a rate of 60 feet per year. It is clear from Figure 2.3 that the cone of depression for the municipal well field may have an impact on the transport of contaminants in the aquifer. The quality of the river water can have significant impact on the adjacent groundwater especially since some of the municipal wells are located less than 4,000 feet from the river.

There is evidence from water quality data collected by the City of Las Cruces that the cone of depression formed by the City's well field facilitates the vertical and lateral transport of contaminants from the agricultural area on the west side of the river, under the river and into the City well field. Particle tracking simulations were conducted by the City of Las Cruces (Gallego, 1994) to evaluate the potential for contamination of City's public water supply wells outside of the irrigated areas due to chemical application within the irrigated areas in the valley. The simulation showed that nitrate contamination in the groundwater below the agricultural fields can apparently reach and contaminate City's wells which are several miles outside of the agricultural areas along the interstate I-10. The results of this simulation were confirmed by actual measurement of elevated nitrate levels within the modeled wells.

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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 mi^2 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 mi^2. 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.

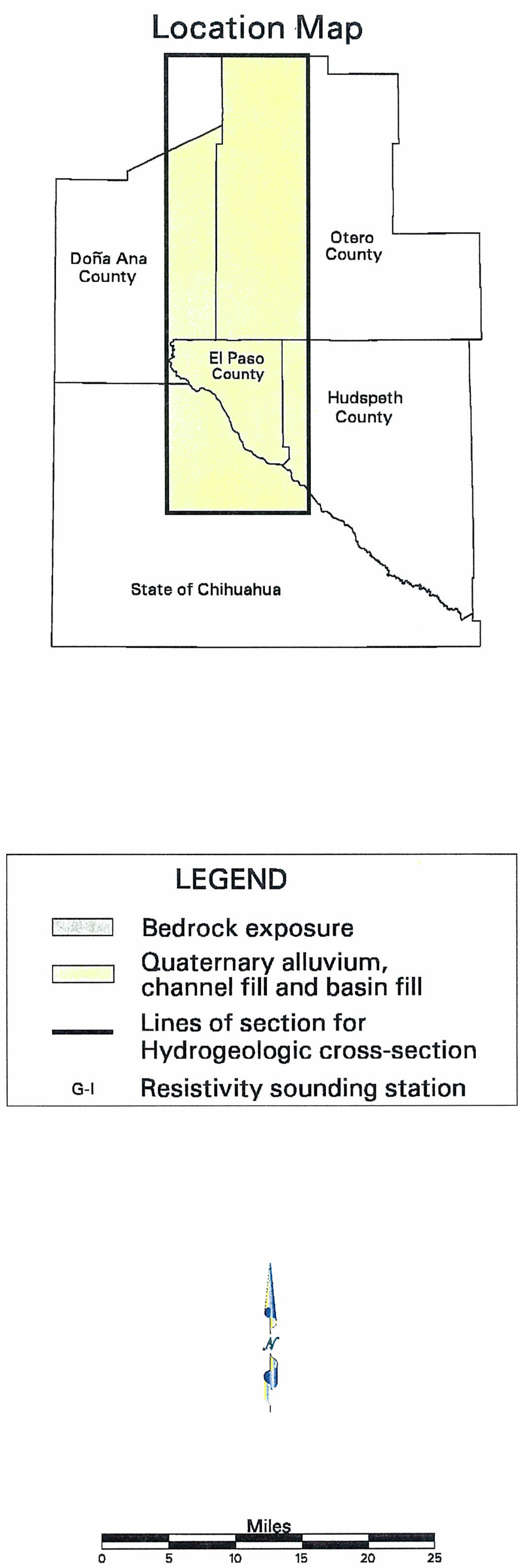
Thick sequences of Paleozoic sedimentary rocks are exposed in the Sacramento Mountains. Precambrian granites, Precambrian metamorphic rocks, and Paleozoic sedimentary rocks are exposed in the San Andres Mountains. The northern Organ Mountains consist of masses of Tertiary intrusive rocks to the north, 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 (Sandeen, 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 (Orr 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).



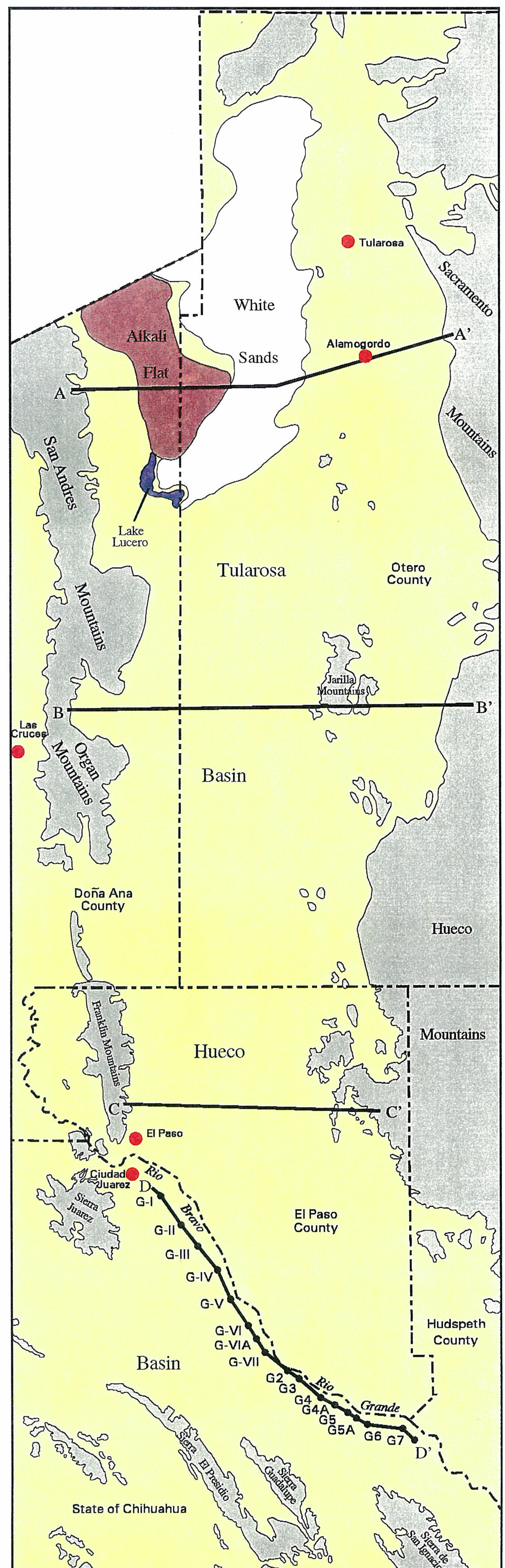


Figure 3.1. Location and extent of the Hueco–Tularosa aquifer.

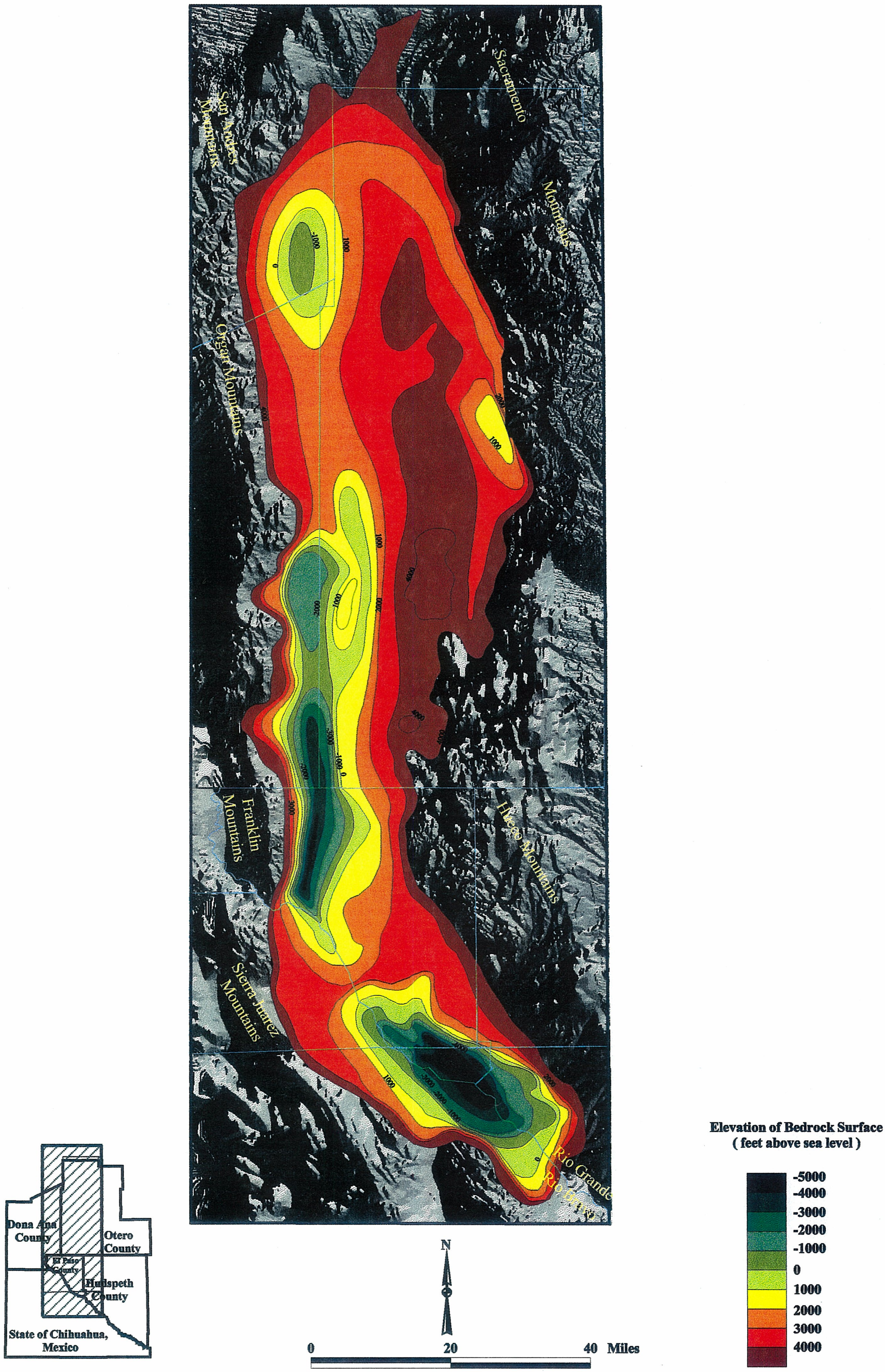


Figure 3.2. Bedrock configuration map beneath the Hueco and Tularosa Bolsons (source, Davis and Legatt, 1967; McLean, 1970; Lee Wilson and Associates, 1986; Collins and Raney, 1991; map prepared by E. Boghici).

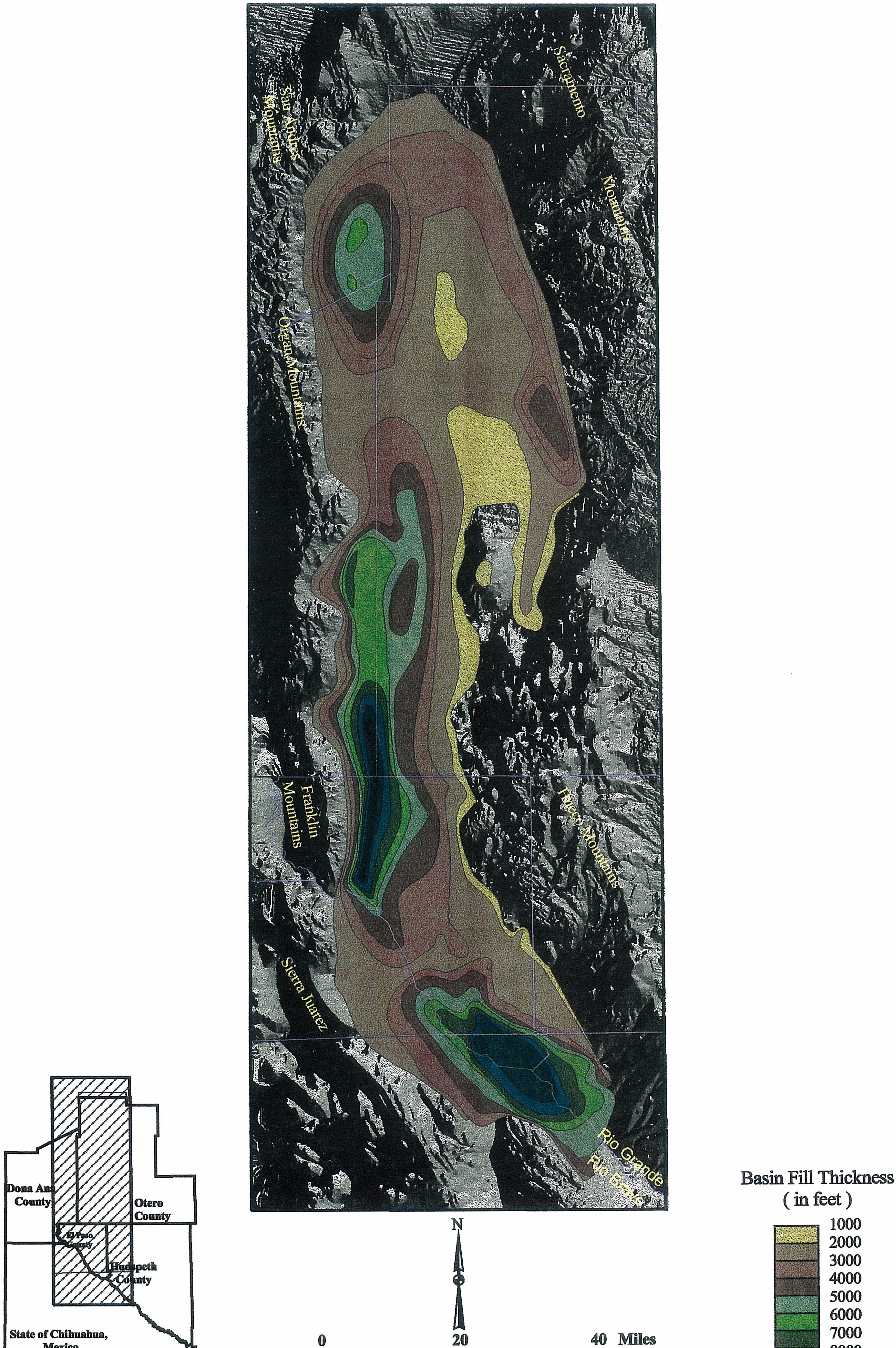


Figure 3.3. Basin fill thickness map for the Hueco and Tularosa Basins (source, Collins and Raney, 1991; Davis and Legatt, 1967; Lee Wilson and Associates, 1986; McLean, 1970; map prepared by E.Boghici).

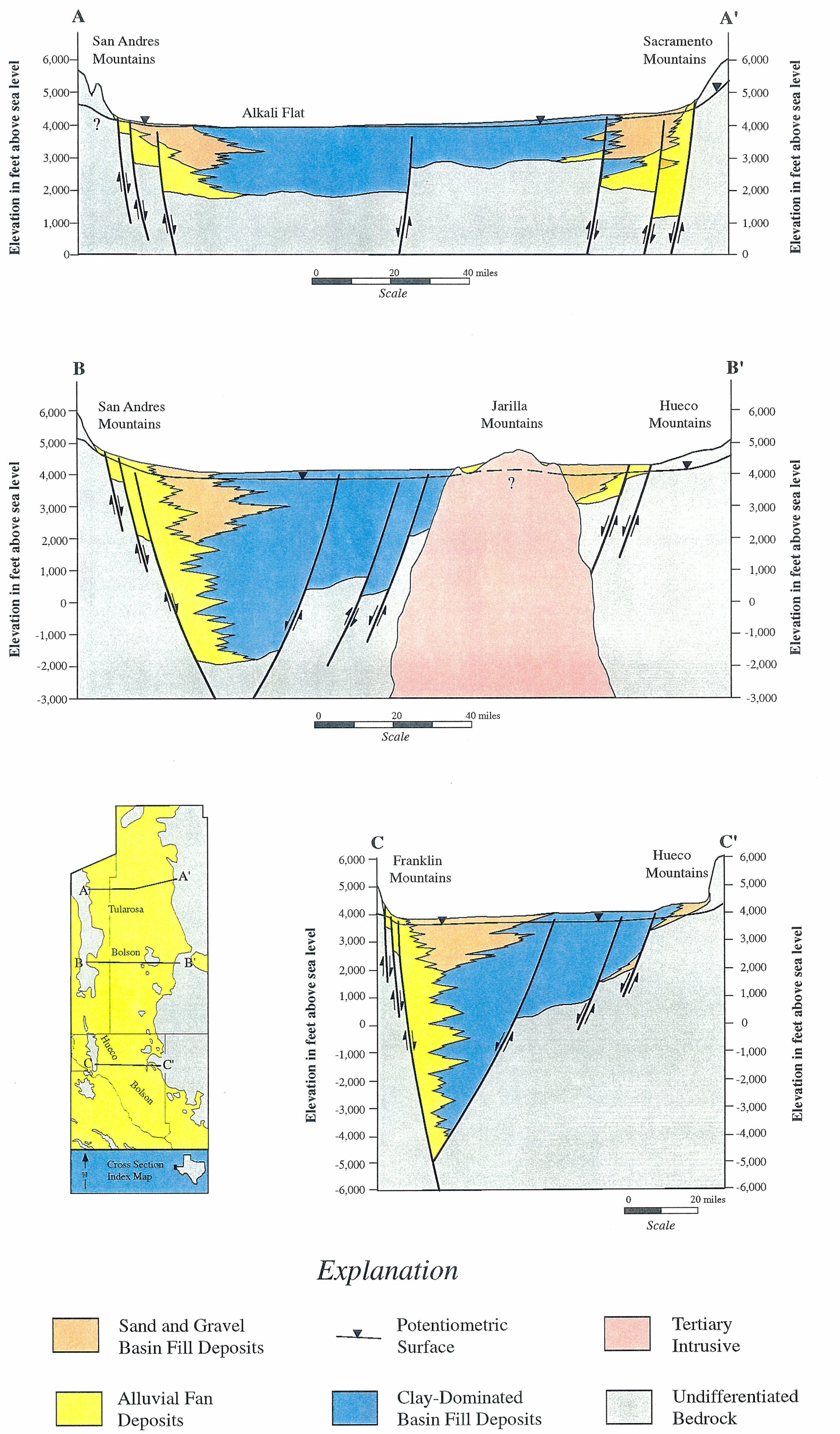


Figure 3.4. Geneneralized hydrogeologic cross sections A - A', B - B', and C - C' across the Hueco-Tularosa aquifer (Basin fill/bedrock contacts selected from maps prepared by Davis and Legatt, 1967; McLean, 1970; and Lee Wilson and Associates, 1986. Cross section C - C' modified from Lee Wilson and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

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

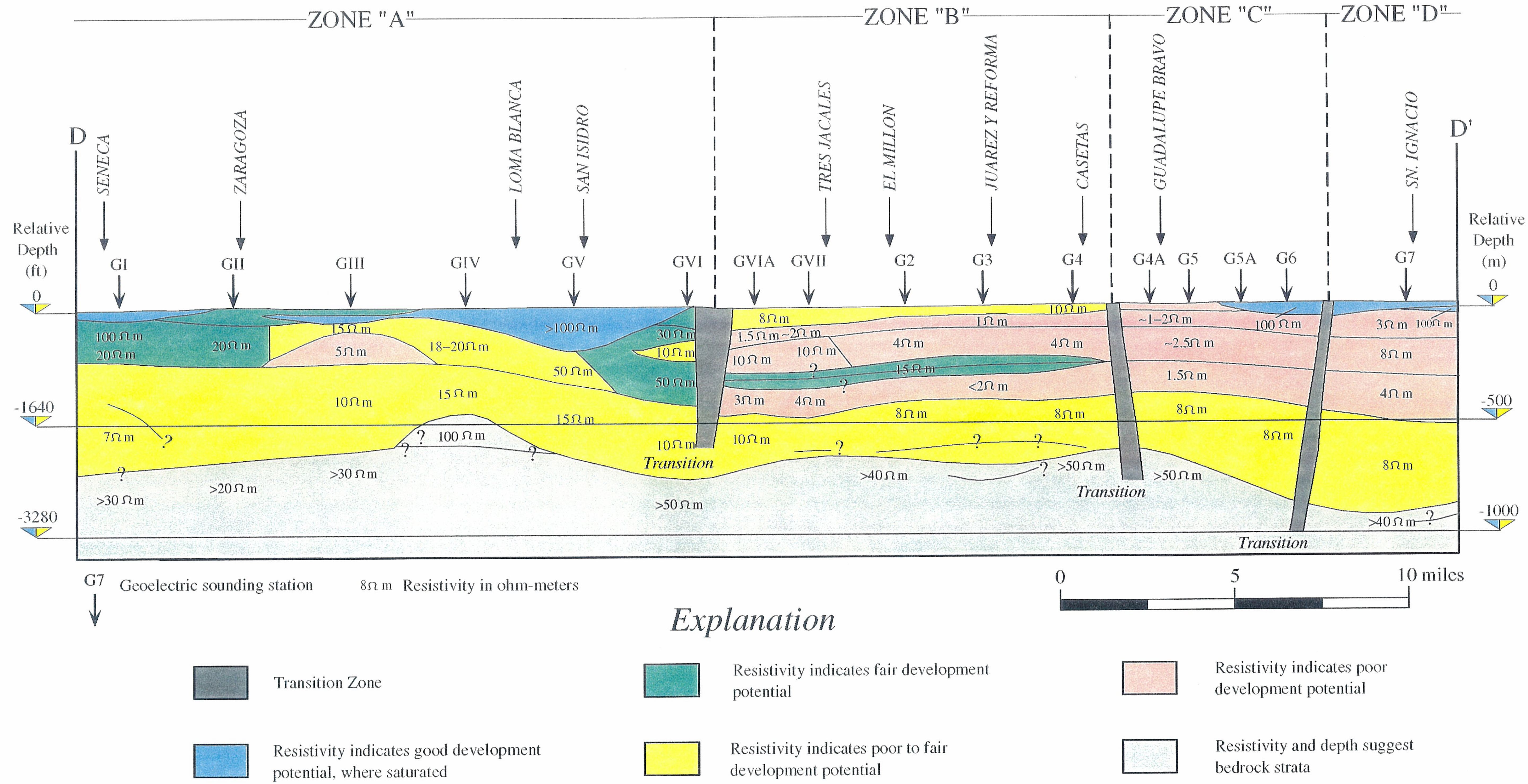


Figure 3.5. Geoelectric cross section D - D' across the Hueco-Tularosa aquifer, northern Chihuahua, Mexico. The map shows interpreted average real resistivities (modified from Geo Fimex, 1970; line of section shown on Figure 3.1).

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 ft^2/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 heterogeneous 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 ft^2/day. McLean (1970) indicated that transmissivities in the alluvial fan material on the eastern side of the basin may range up to 20,000 ft^2/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 ft^2/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 ft^2/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 ft^2/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

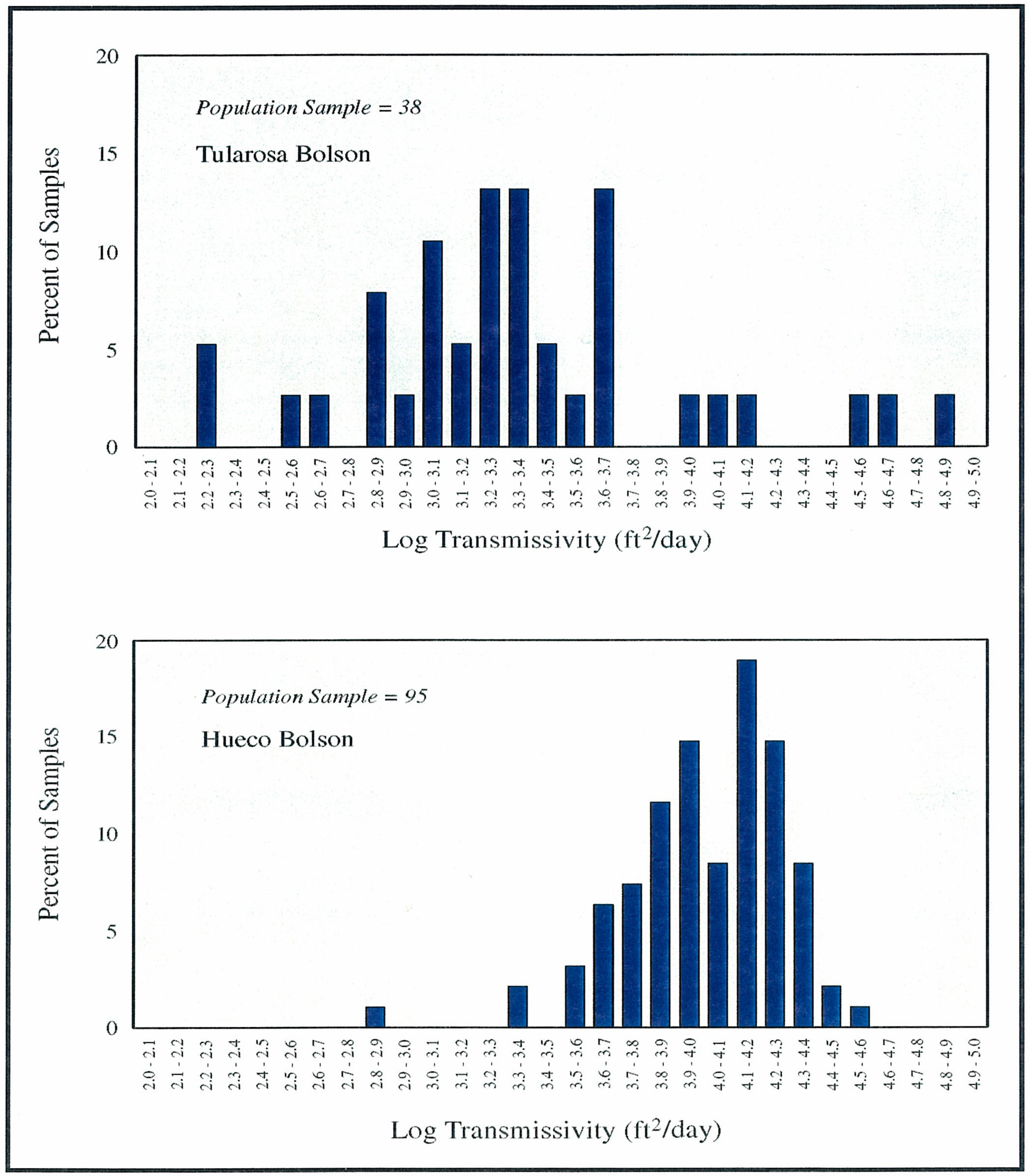


Figure 3.6. Comparison of transmissivity values derived from aquifer tests in the Tularosa and Hueco Bolsons (source of data, Kelly and Hearne, 1976; Lee Wilson and Associates, 1986; Orr and Myers, 1986).

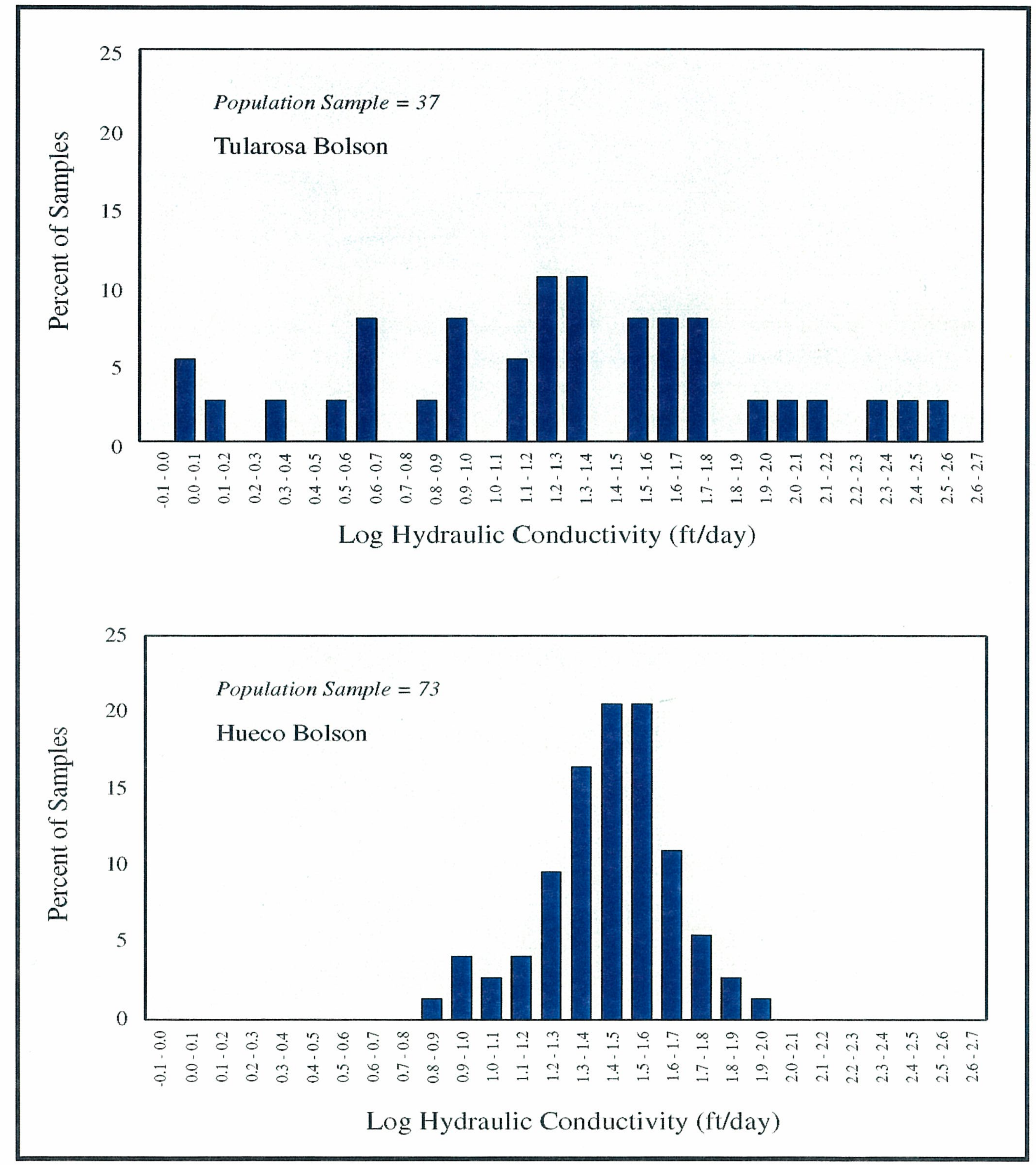


Figure 3.7. Comparison of hydraulic conductivity values derived from aquifer tests in the Tularosa and Hueco Bolsons (source of data, Kelly and Hearne, 1976; Lee Wilson and Associates, 1986; Orr and Myers, 1986).

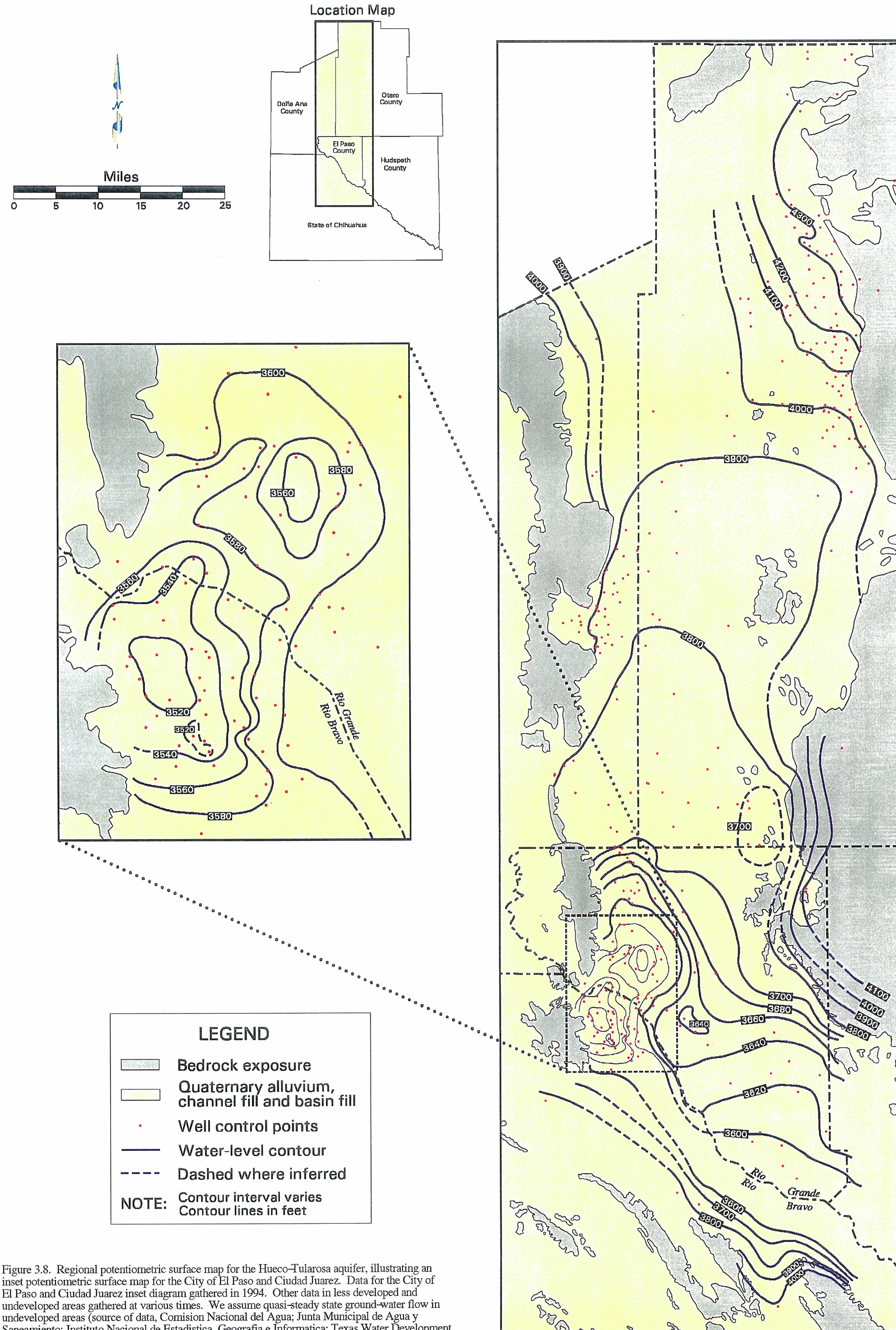
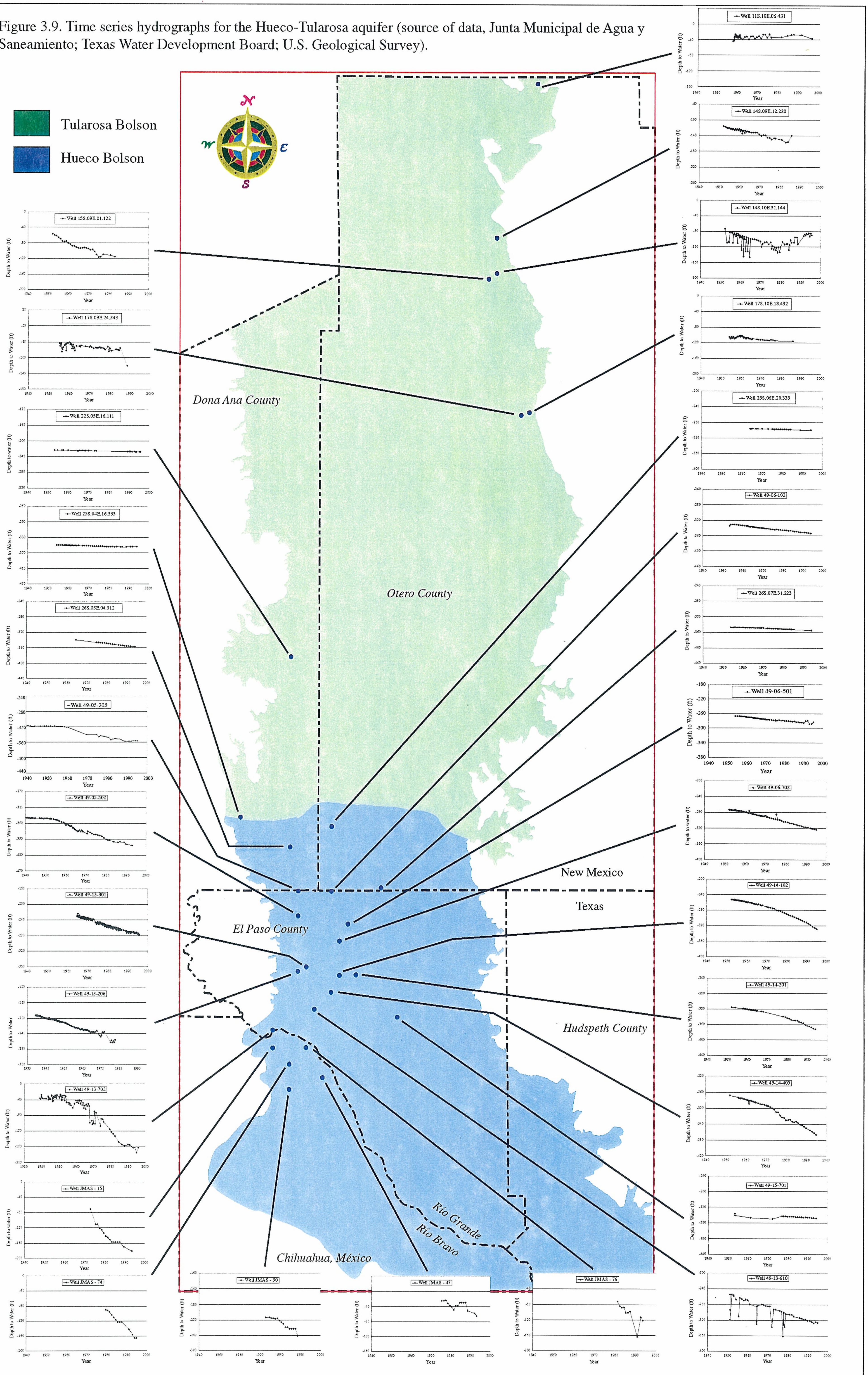


Figure 3.8. Regional potentiometric surface map for the Hueco-Tularosa aquifer, illustrating an inset potentiometric surface map for the City of El Paso and Ciudad Juarez. Data for the City of El Paso and Ciudad Juarez inset diagram gathered in 1994. Other data in less developed and undeveloped areas 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 Estadistica, Geografia e Informatica; 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).



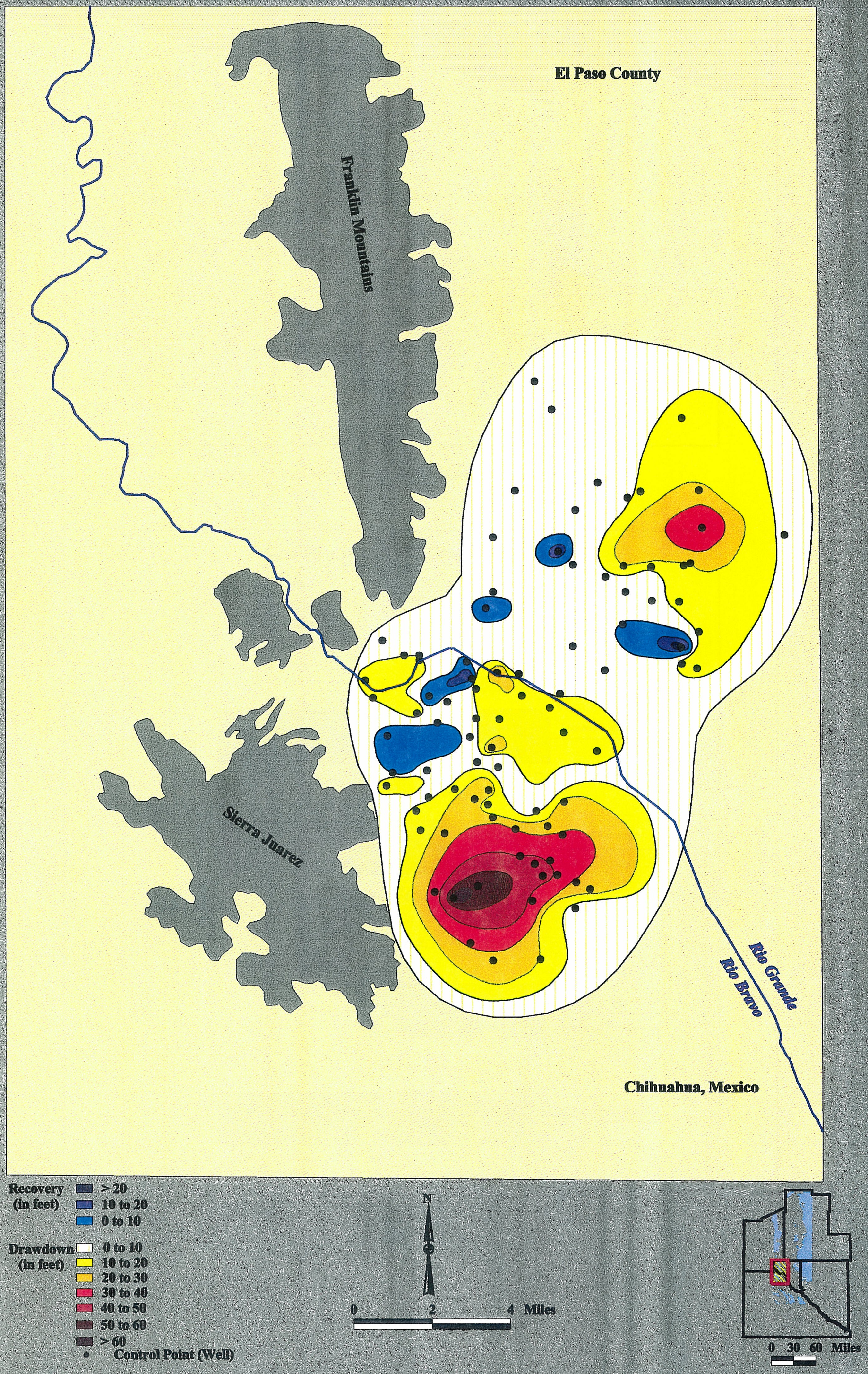


Figure 3.10. Change in water levels for the City of El Paso - Ciudad Juarez area, 1987/1988 to 1992/1993. (source of data, Texas Water Development Board; City of El Paso Public Services Board; Junta Municipal de Agua y Saneamiento).

between 1987/1988 and 1992/1993 presents drawdowns 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 playas.

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 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 dependance 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-HCO_3-SO_4 and Ca-Cl-SO_4 waters, except for ground waters high in the Sacramento Mountains which are Ca-HCO_3 ground waters. Ground waters with greater than 1,000 mg/L TDS have a Ca-Cl-SO_4 signature, and ground waters with less than 1,000 mg/L TDS have a Ca-HCO_3-SO_4 signature. These ground waters are influenced by dissolution of limestone and gypsum.

The mountain and mountain front samples in group 2 are Ca-HCO_3 and mixed cation-HCO_3-SO_4 type ground waters with TDS less than 1,000 mg/L. Eastward along the basin floor, ground waters have a Na-Cl-SO_4 and mixed cation-SO_4-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-HCO_3 and Na-HCO_3-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-HCO_3 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 SO_4, and lower concentrations of HCO_3 than upgradient waters. These are principally Na-Cl and Na-Cl-SO_4 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-SO_4 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 HCO_3, and by the addition of Cl and SO_4. 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:

$$CaCO_3 + H_2O + CO_2 = Ca + 2HCO_3 \quad (3.1)$$

$$CaMg(CO_3)_2 + 2CO_2 + 2H_2O = Ca + Mg + 4HCO_3 \quad (3.2)$$

$$CaSO_4 \cdot 2H_2O = Ca + SO_4 + 2H_2O \quad (3.3)$$

Plotting the quantity (Ca + Mg) against HCO_3 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 HCO_3) and dolomite (1 mole of [Ca+Mg] to 2 moles of HCO_3). Many of the

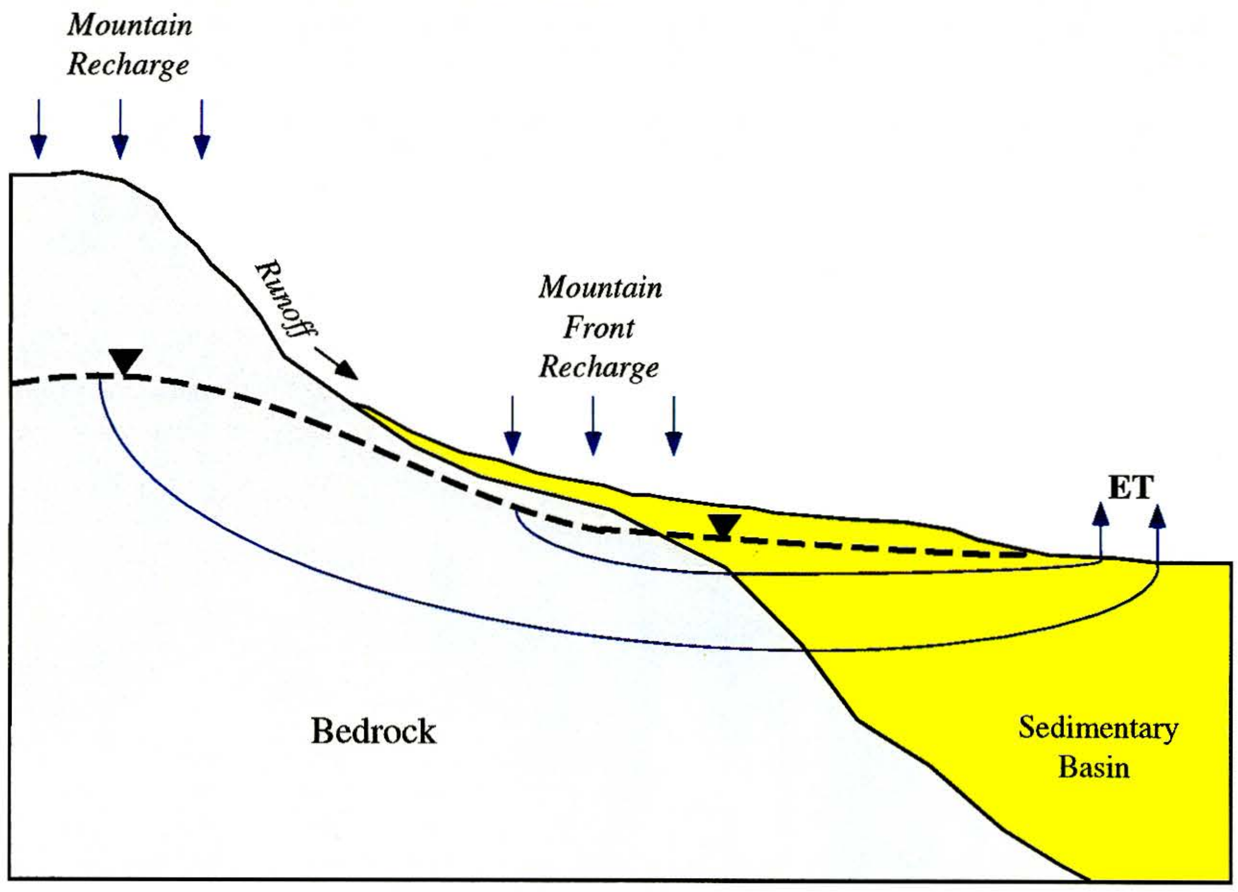


Figure 3.11. Conceptual diagram illustrating mountain front recharge.

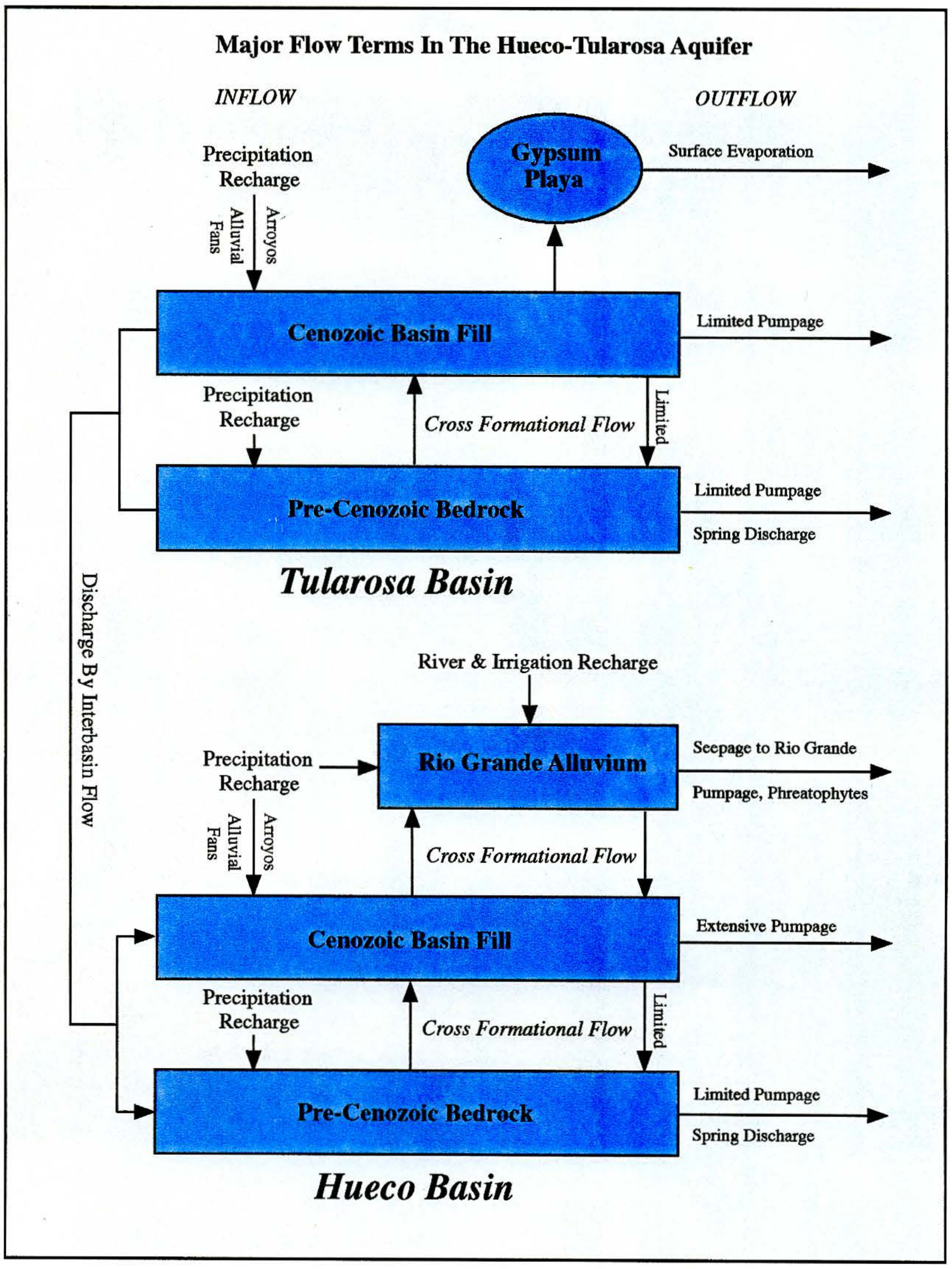


Figure 3.12. Major flow components of the Hueco - Tularosa aquifer.

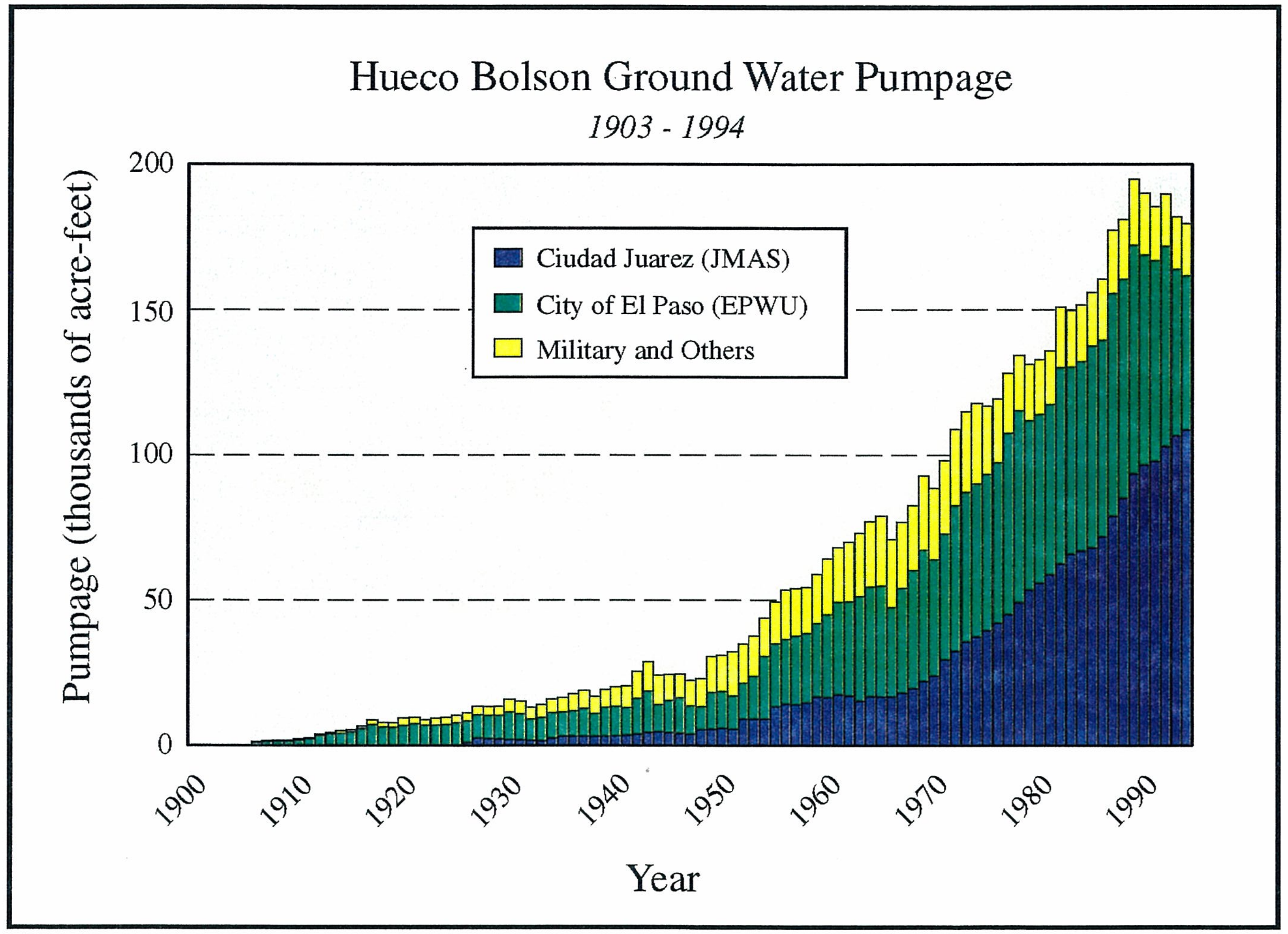
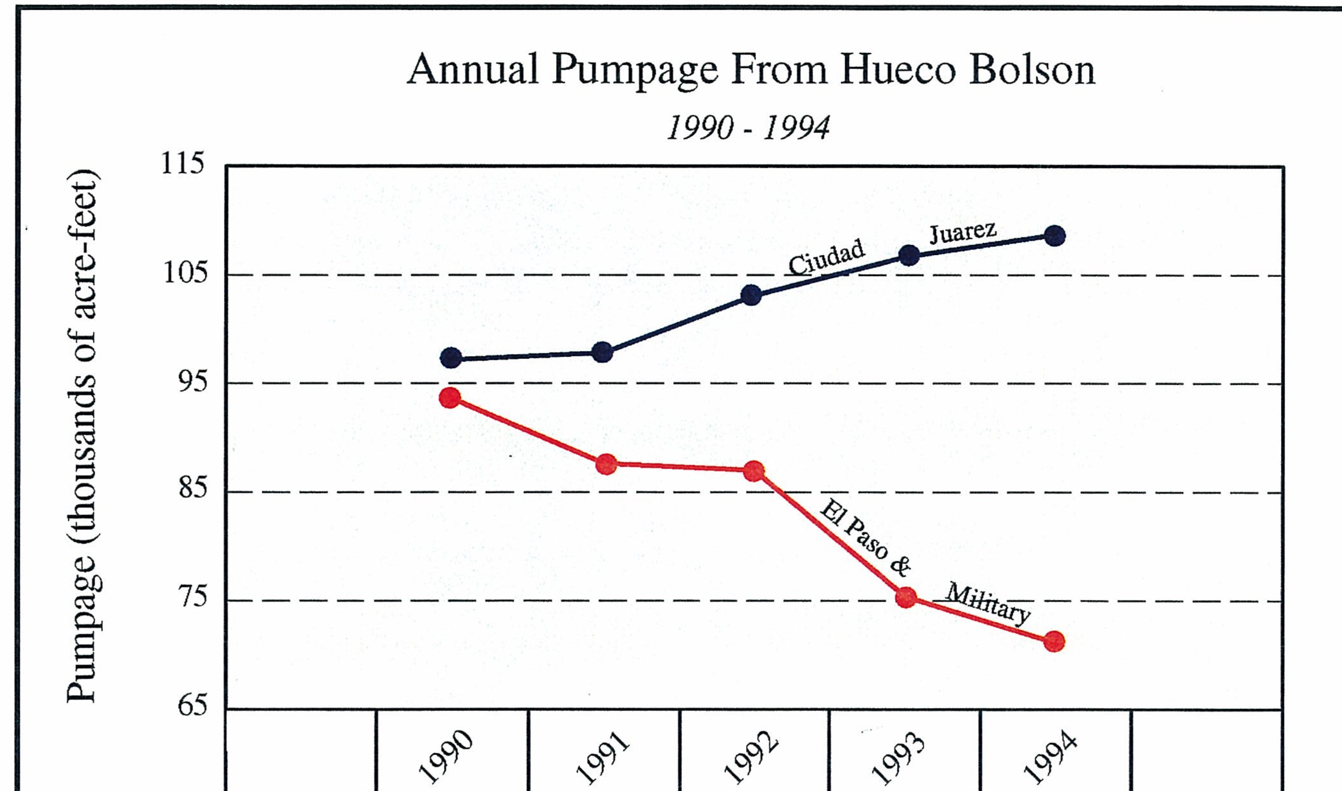


Figure 3.13. Ground-water pumpage from the Hueco Bolson; 1903 - 1994 (source of data, City of El Paso Public Services Board).



	1990	1991	1992	1993	1994
Ciudad Juarez	97.2	97.8	103.1	106.6	108.7
El Paso & Military	93.6	87.6	87.0	75.4	71.1

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).

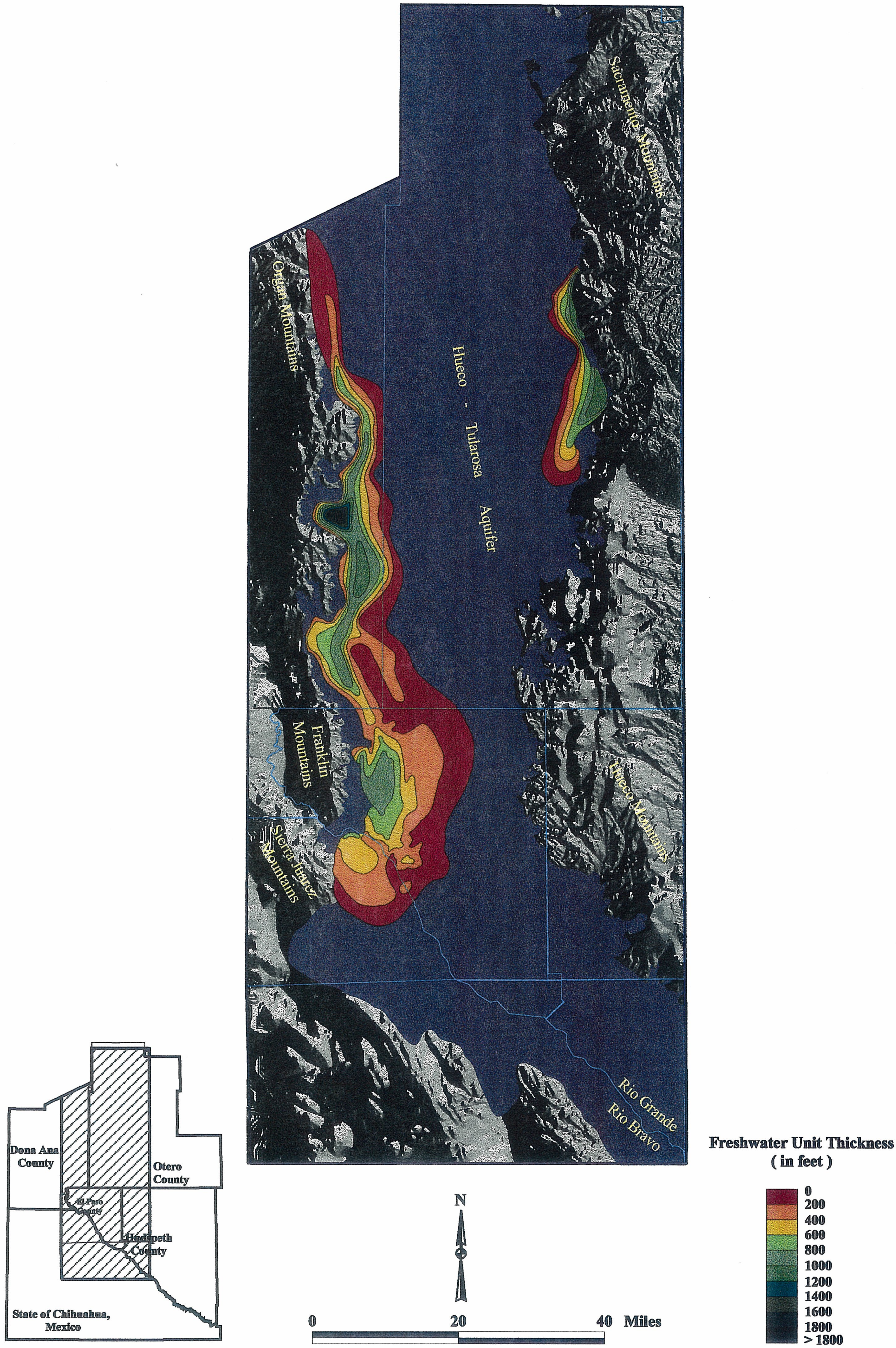


Figure 3.15. Approximate thickness of the freshwater unit (TDS < 1,000 mg/L) in the Hueco - Tularosa aquifer (modified from maps prepared by McLean, 1970, and Lee Wilson and Associates, 1986).

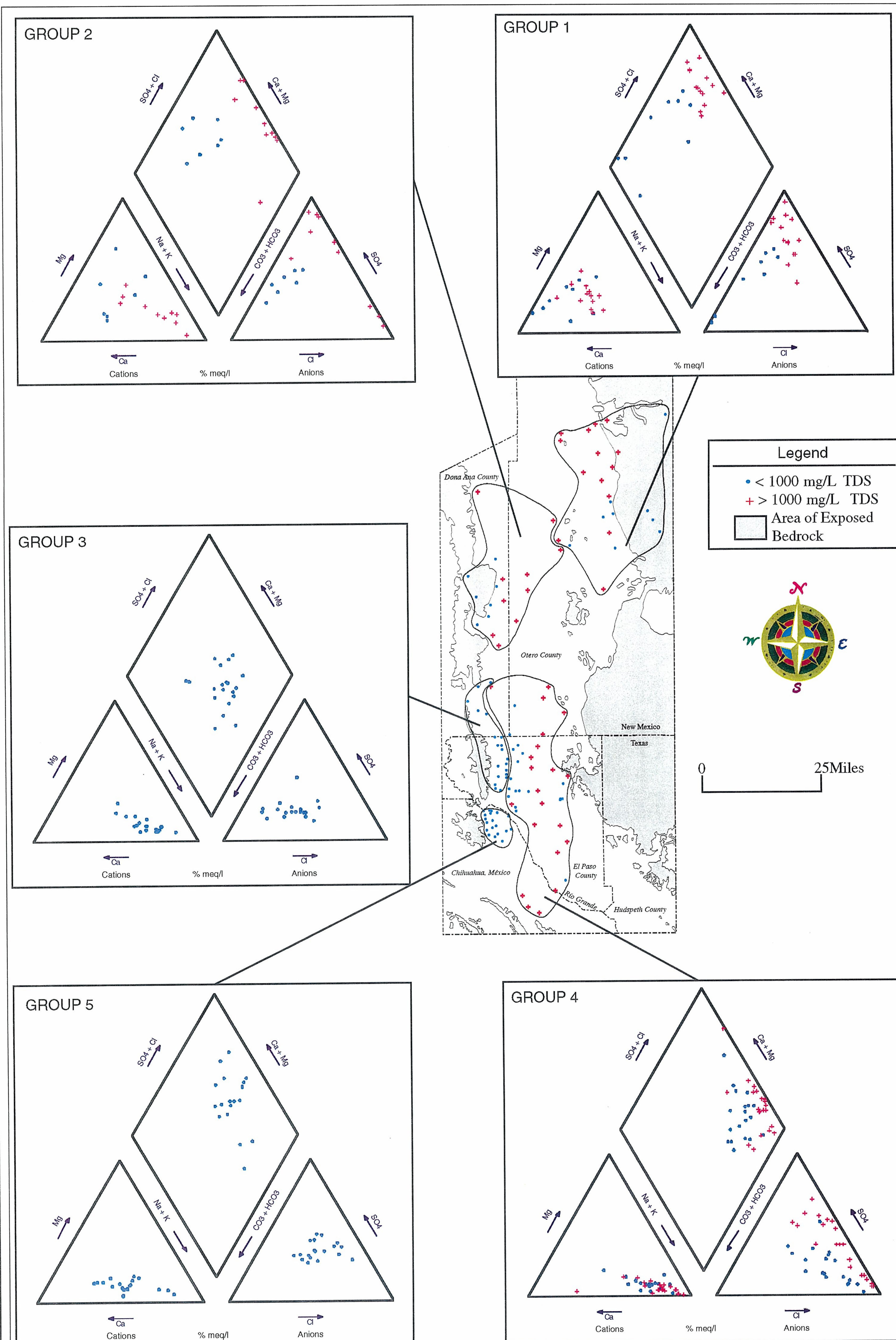


Figure 3.16. Piper diagrams illustrating geochemical types for the Hueco-Tularosa aquifer (source of data, Comision Nacional Del Agua; Junta Municipal de Agua y Saneamiento; Instituto Nacional de Estadistica, Geografia e Informatica; Texas Water Development Board).

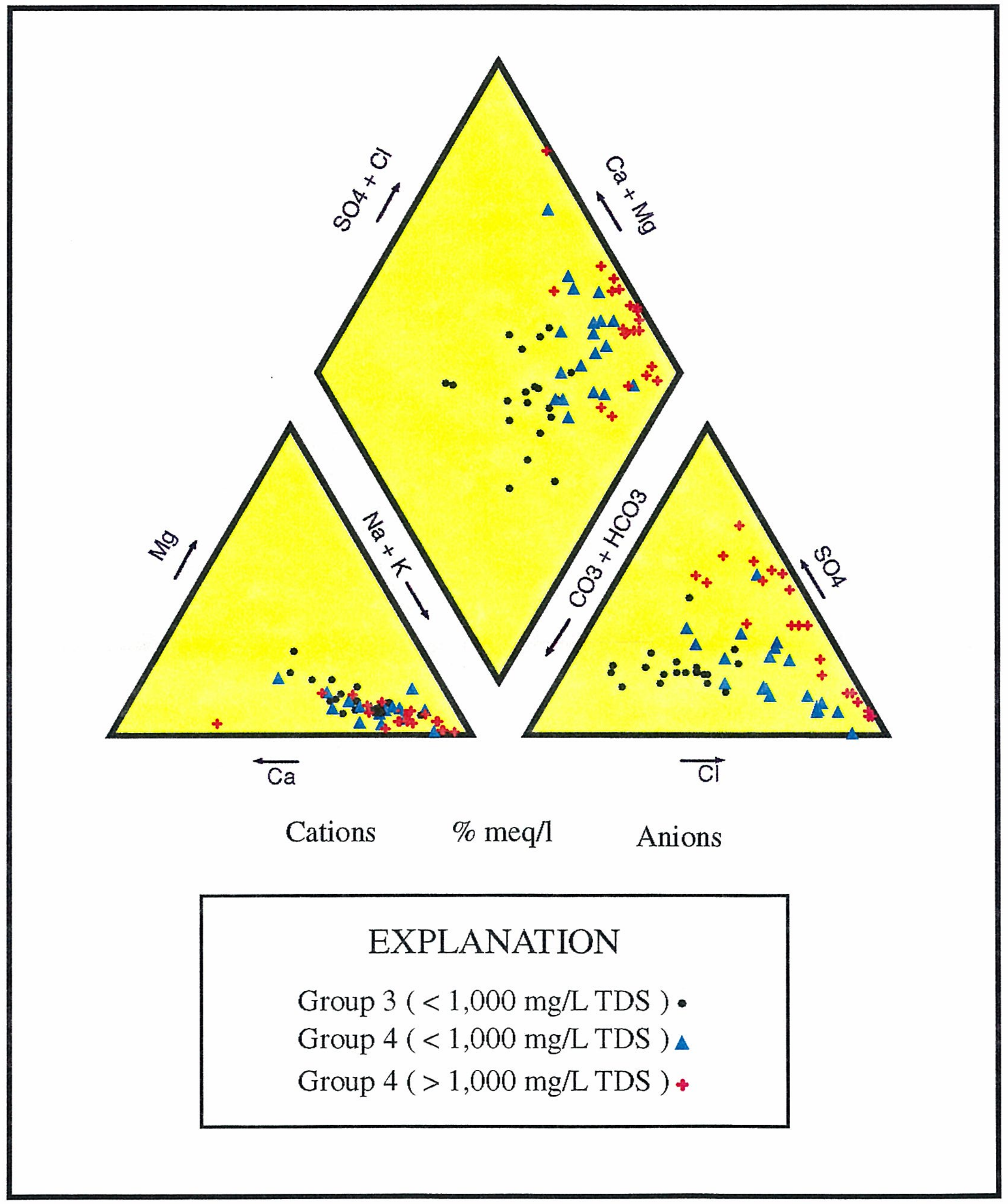


Figure 3.17a. Piper diagram for group 3 and group 4 ground waters in the Hueco-Tularosa aquifer (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

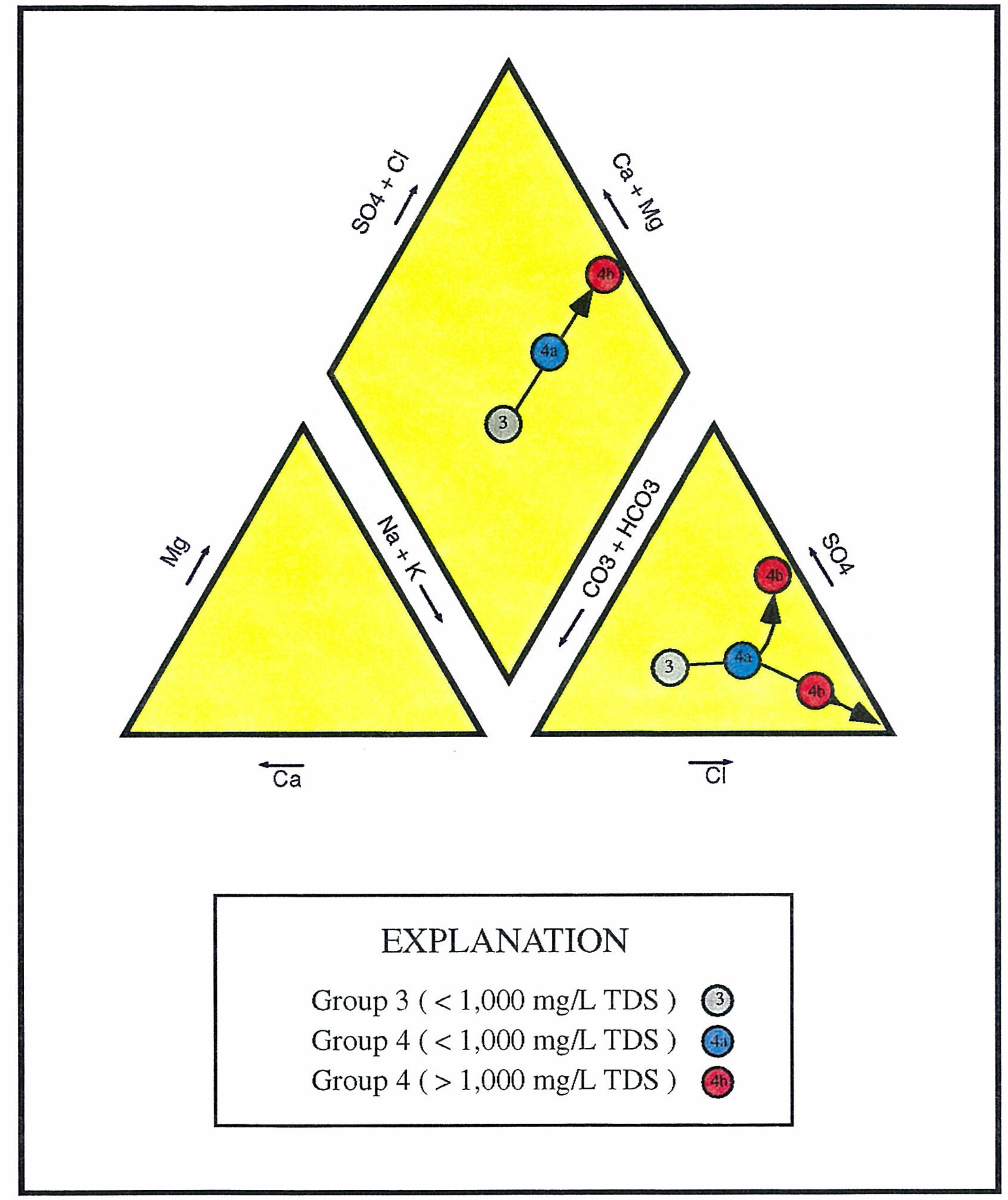


Figure 3.17b. Geochemical evolution diagram that represents possible evolutionary paths for data shown in Figure 3.17a (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

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 - SO_4) is plotted against HCO_3 (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:

$$Na_2\text{-clay} + Ca^{+2} = Ca\text{-clay} + 2Na^{+} \quad (3.4)$$

$$Na_2\text{-clay} + Mg^{+2} = Mg\text{-clay} + 2Na^{+} \quad (3.5)$$

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 - SO_4 - 0.5HCO_3). The quantity (Na - Cl) represents excess Na coming from sources other than halite dissolution (Figure 3.20). The quantity (Ca + Mg - SO_4 - 0.5HCO_3) 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 - SO_4 - HCO_3) 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 (-HCO_3) from the quantity (Ca + Mg + Na - SO_4 - HCO_3) 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 HCO_3 derived from dissolution of calcite is important in dilute waters only (salinities less than 10 meq/L Cl).

Removing (-SO_4) from the quantity (Ca + Mg + Na - SO_4 - HCO_3) 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 - HCO_3) against the independent variable anion (SO_4). Removing (-Cl) from the quantity (Ca + Mg + Na - Cl - HCO_3) 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-HCO_3 to Na-HCO_3 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-HCO_3 to Na-HCO_3-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-SO_4 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

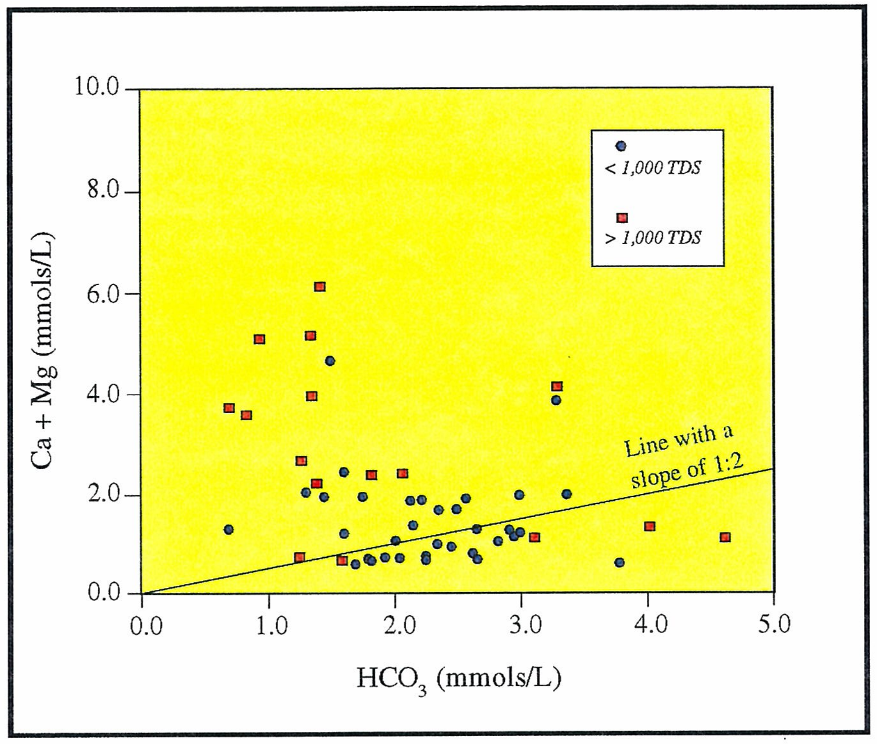


Figure 3.18. (Ca + Mg) vs HCO 3 plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

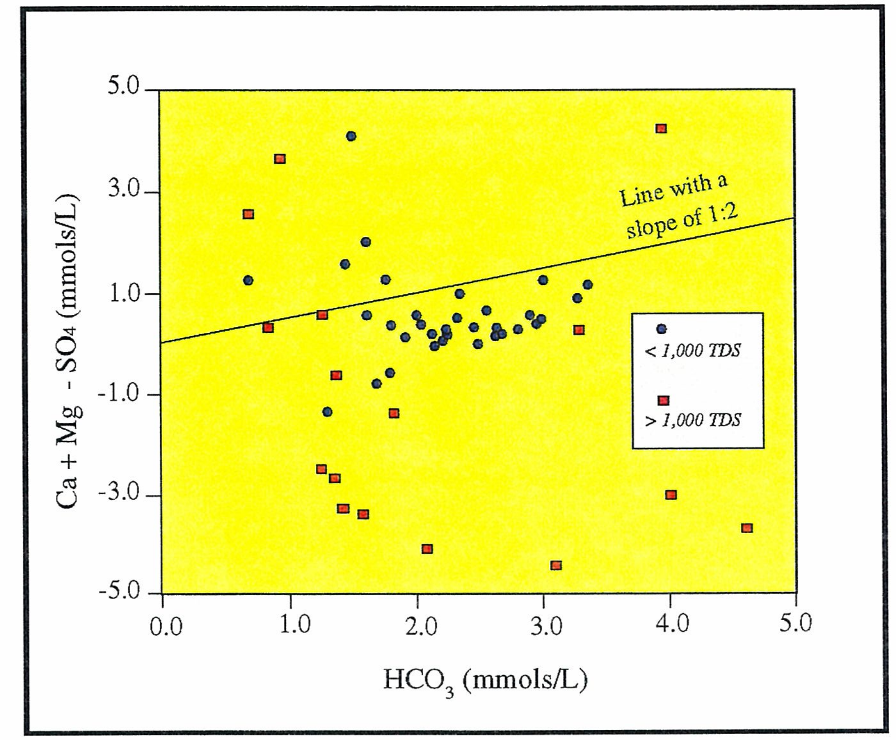


Figure 3.19. (Ca + Mg - SO 4) vs HCO 3 plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

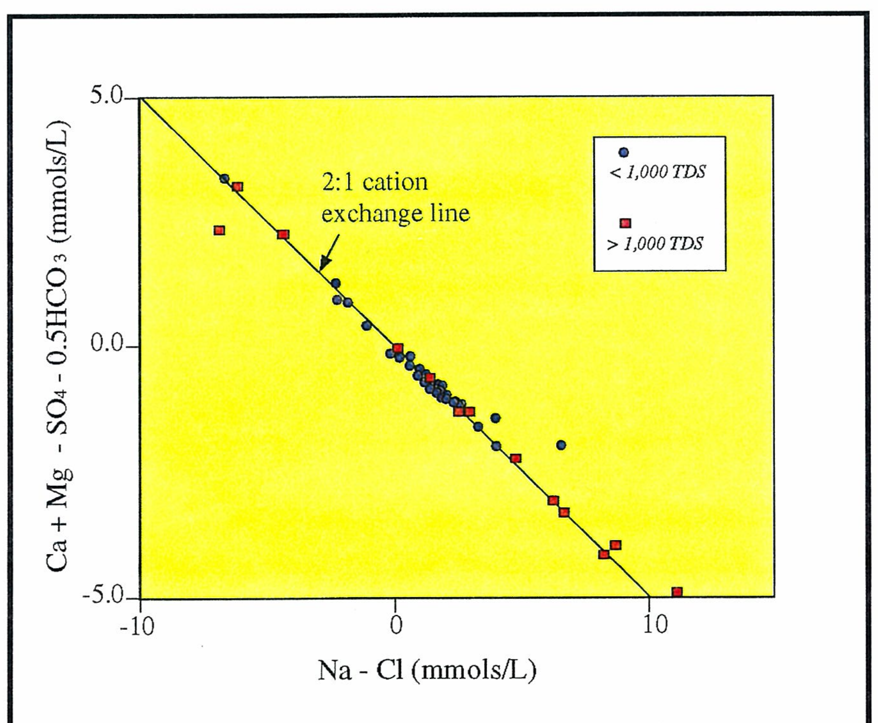


Figure 3.20. (Ca + Mg - SO 4 - 0.5HCO 3) vs (Na - Cl) plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

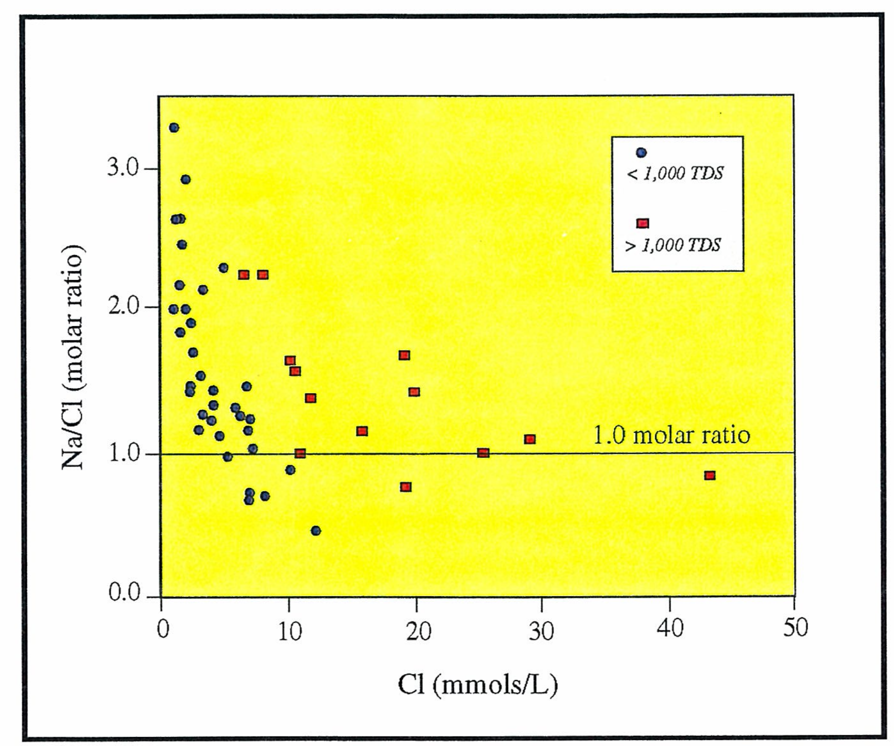


Figure 3.21. (Na/Cl) vs Cl plot, group 3 and group 4 ground waters (source of data, Texas Water Development Board; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

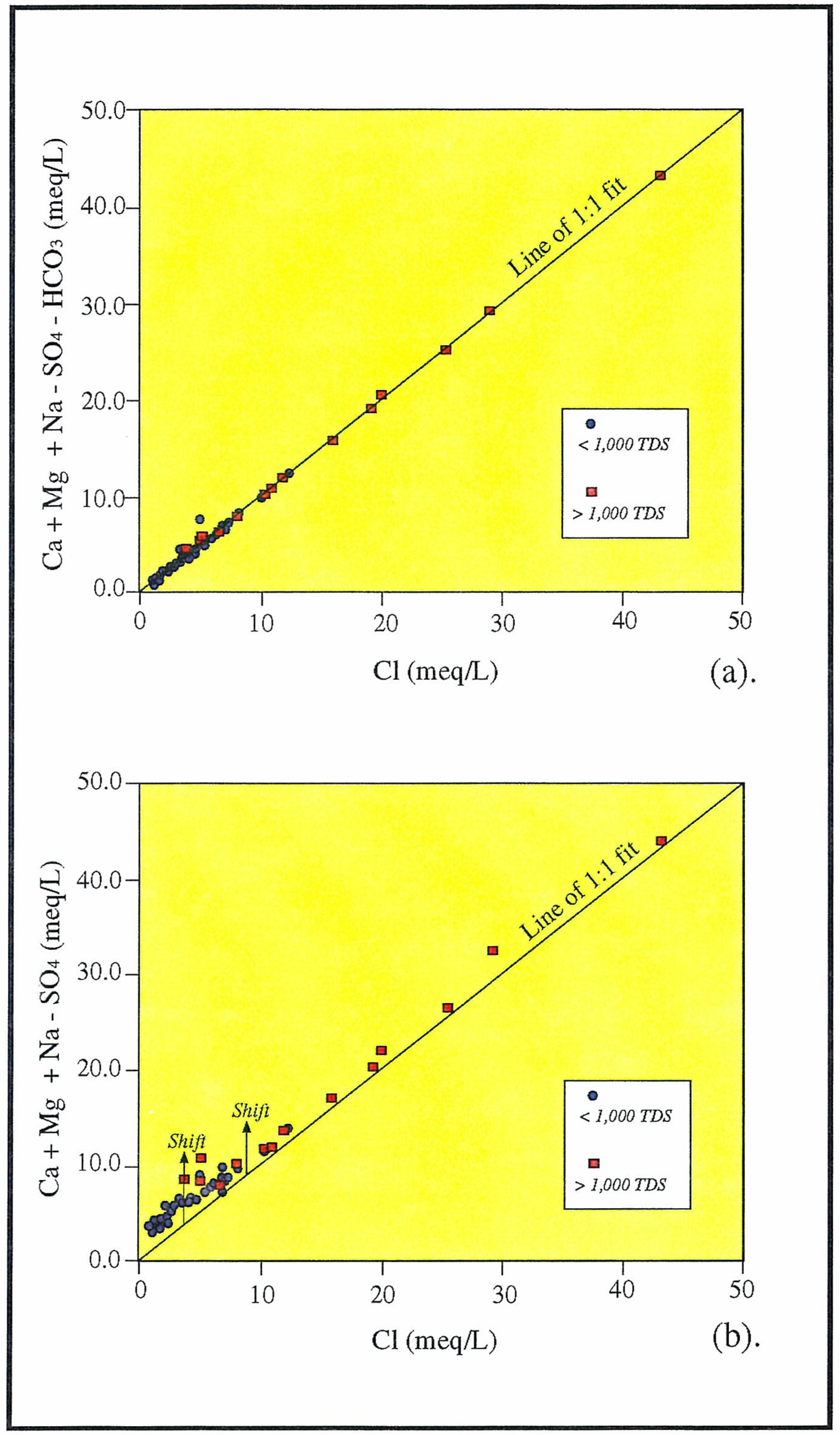


Figure 3.22. Upper figure (a); a plot of (Ca + Mg + Na - SO_4 - HCO_3) vs Cl in group 3 and group 4 ground waters gives an excellent 1:1 fit. Lower figure (b); the shift caused by removing (-HCO_3) from the term (Ca + Mg + Na - SO_4 - HCO_3) gives the amount of mass due to dissolution of calcite (source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

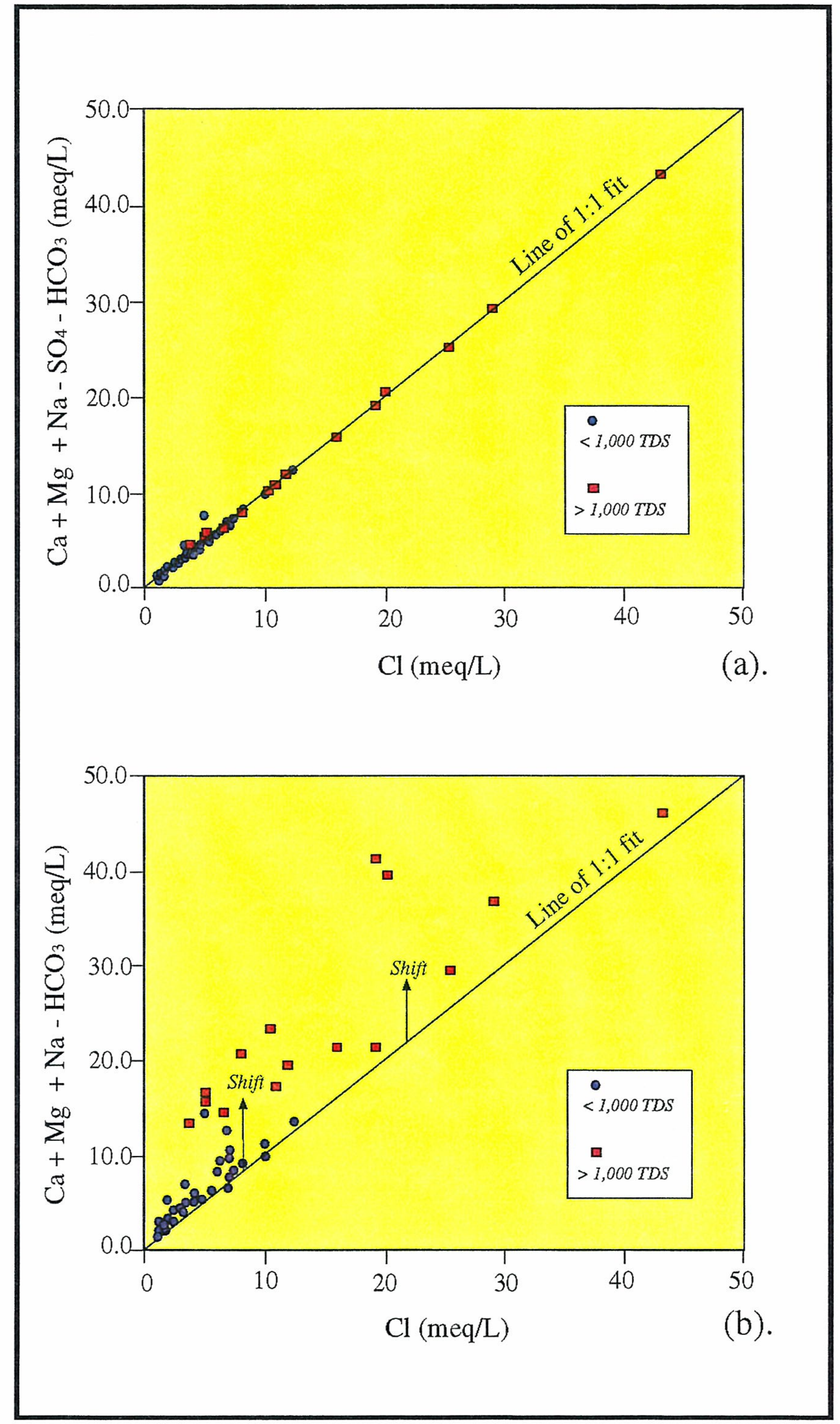


Figure 3.23. Upper figure (a); a plot of (Ca + Mg + Na - SO_4 - HCO_3) vs Cl in group 3 and group 4 ground waters gives an excellent 1:1 fit. Lower figure (b); the shift caused by removing (-SO_4) from the term (Ca + Mg + Na - SO_4 - HCO_3) gives the amount of mass due to dissolution of gypsum (source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

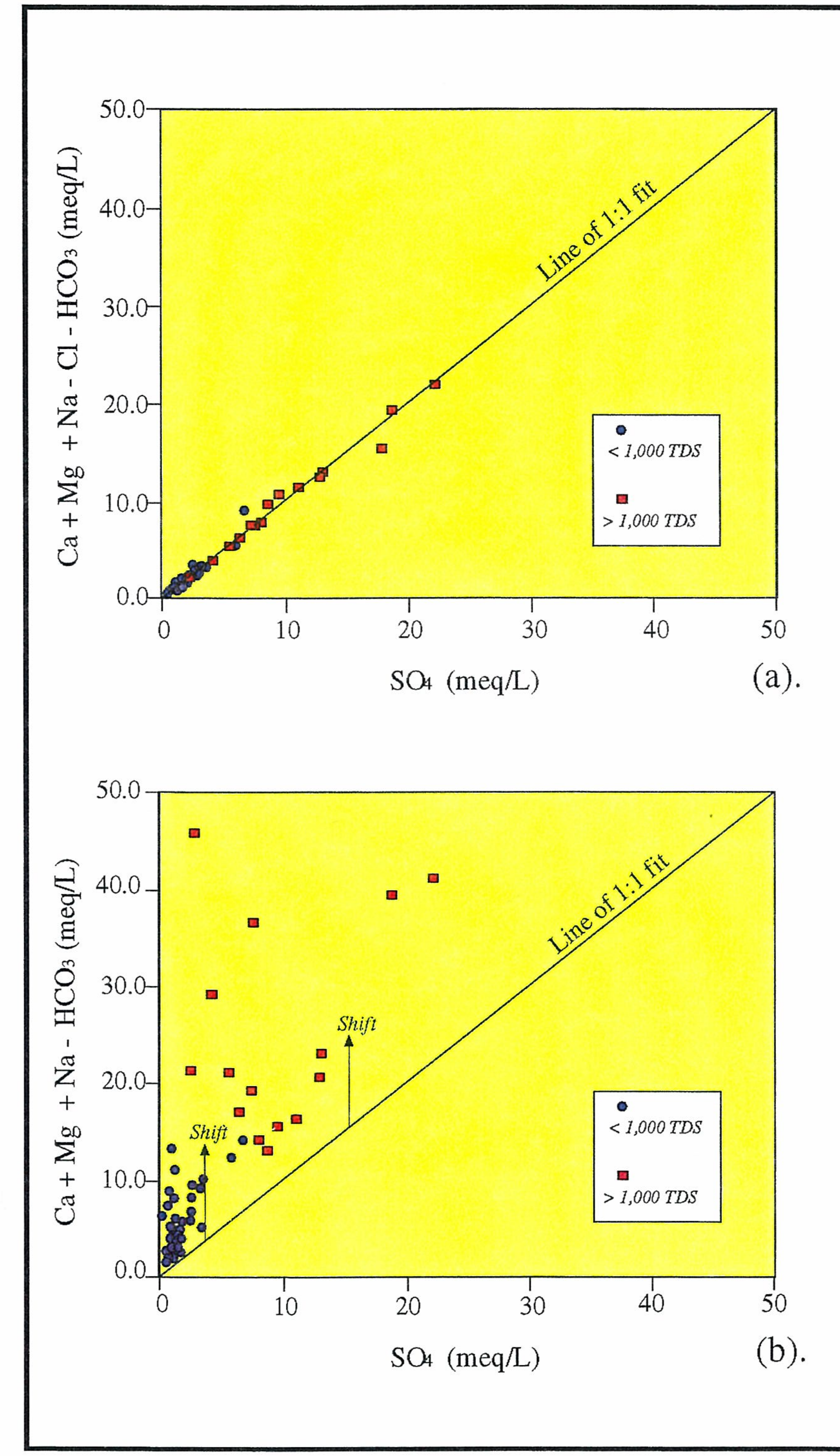


Figure 3.24. Upper figure (a); a plot of (Ca + Mg + Na - Cl - HCO_3) vs SO_4 in group 3 and group 4 ground waters gives an excellent 1:1 fit. Lower figure (b); the shift caused by removing (-Cl) from the term (Ca + Mg + Na - Cl - HCO_3) gives the amount of mass due to dissolution of halite (source of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

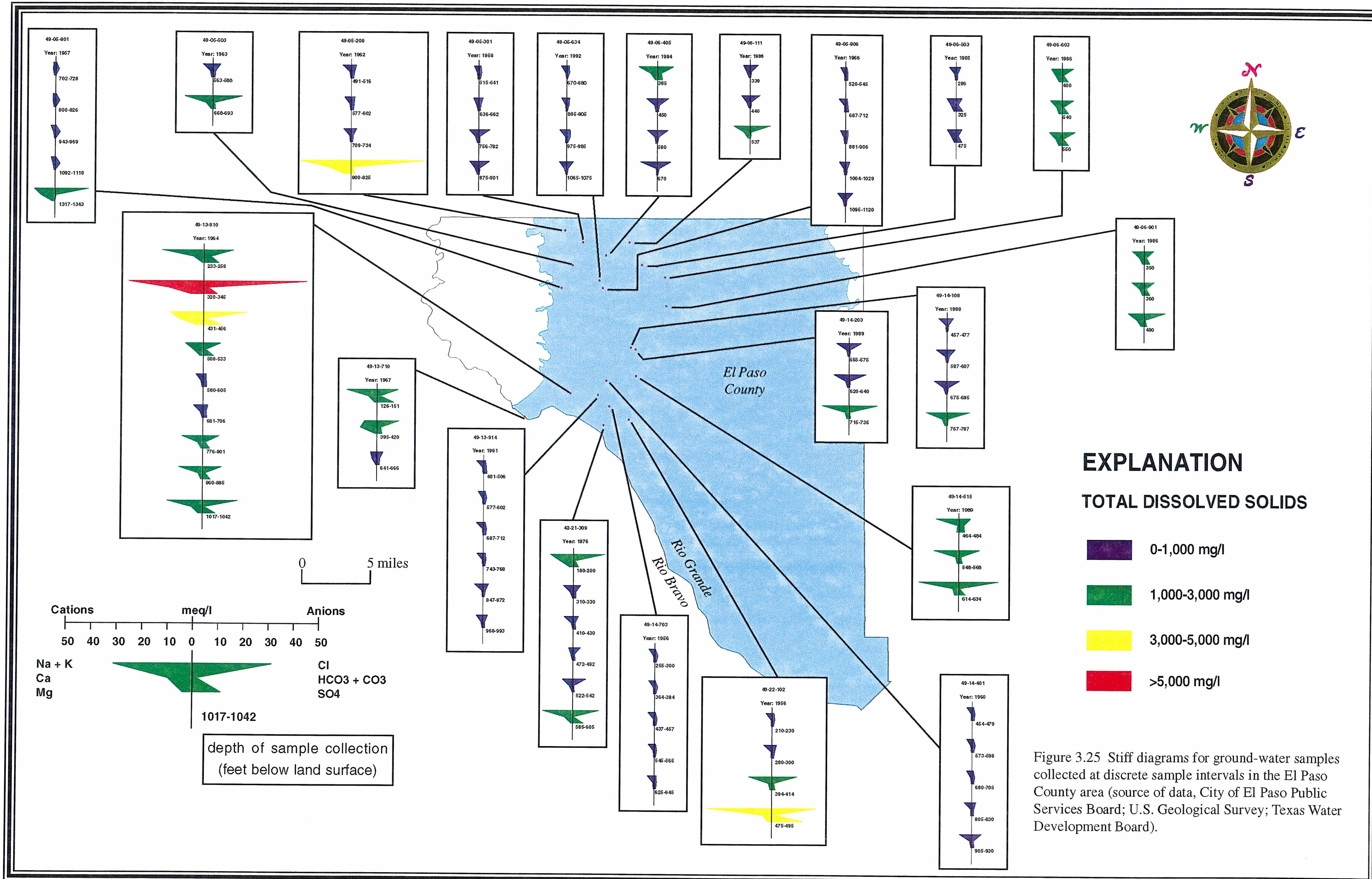


Figure 3.25 Stiff diagrams for ground-water samples collected at discrete sample intervals in the El Paso County area (source of data, City of El Paso Public Services Board; U.S. Geological Survey; Texas Water Development Board).

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-SO_4 type ground water.

In southern El Paso County, the dilute, Na-HCO_3 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-HCO_3 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-SO_4 water with TDS greater than 3,000 mg/L at 475 ft. The Na-HCO_3 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-SO_4 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-SO_4 type ground water is present at several intervals between 223 and 533 ft. The only dilute samples in this test hole are Na-HCO_3-SO_4 ground waters and Na-Cl-SO_4 ground waters at 580 and 681 ft. Na-Cl-SO_4 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 pumping. 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-SO_4-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 substantial 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

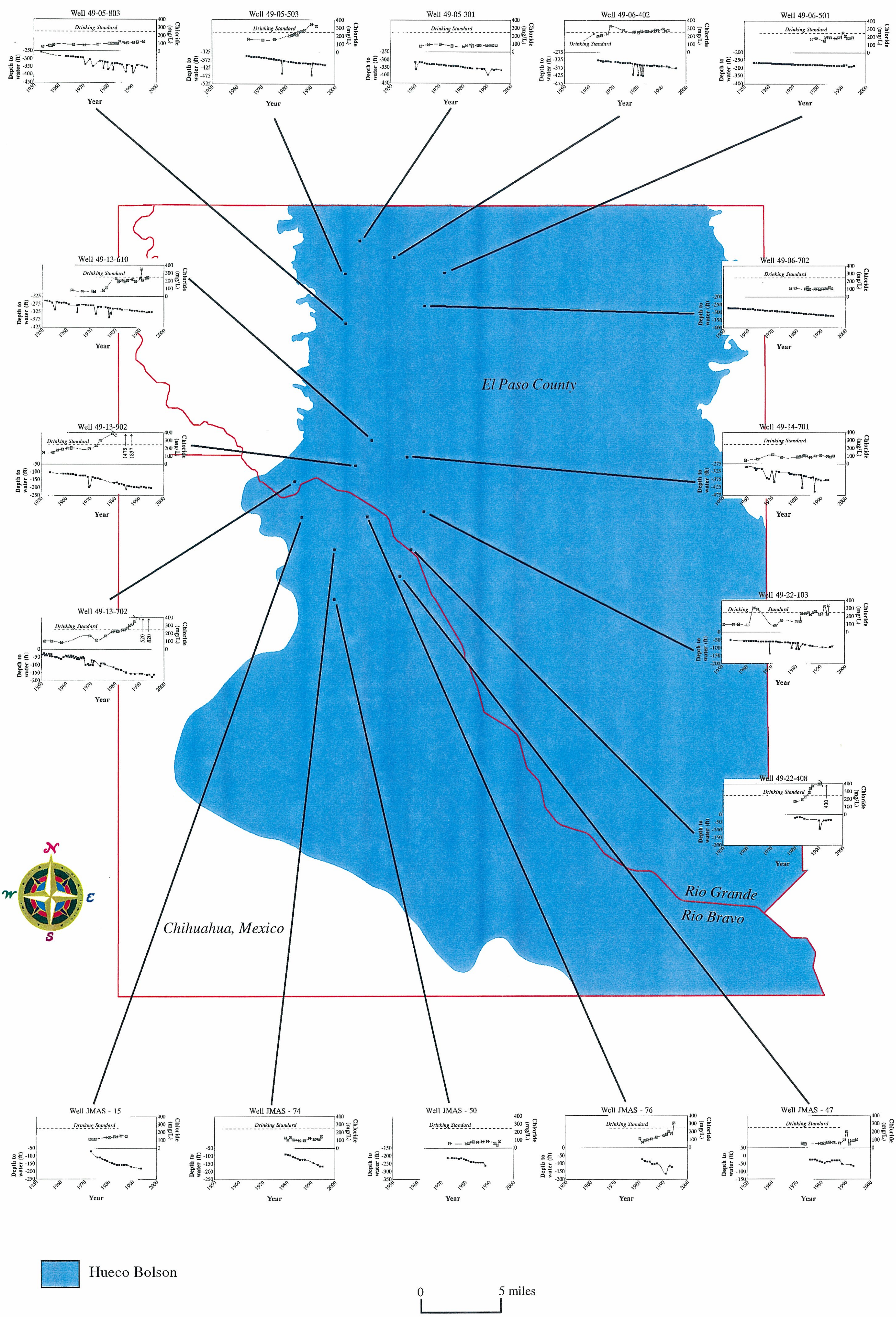


Figure 3.26. Comparison of change of chloride in ground water with drawdown in City of El Paso and Ciudad Juarez municipal water wells (source of data, Texas Water Development Board; Junta Municipal de Agua y Saneamiento).

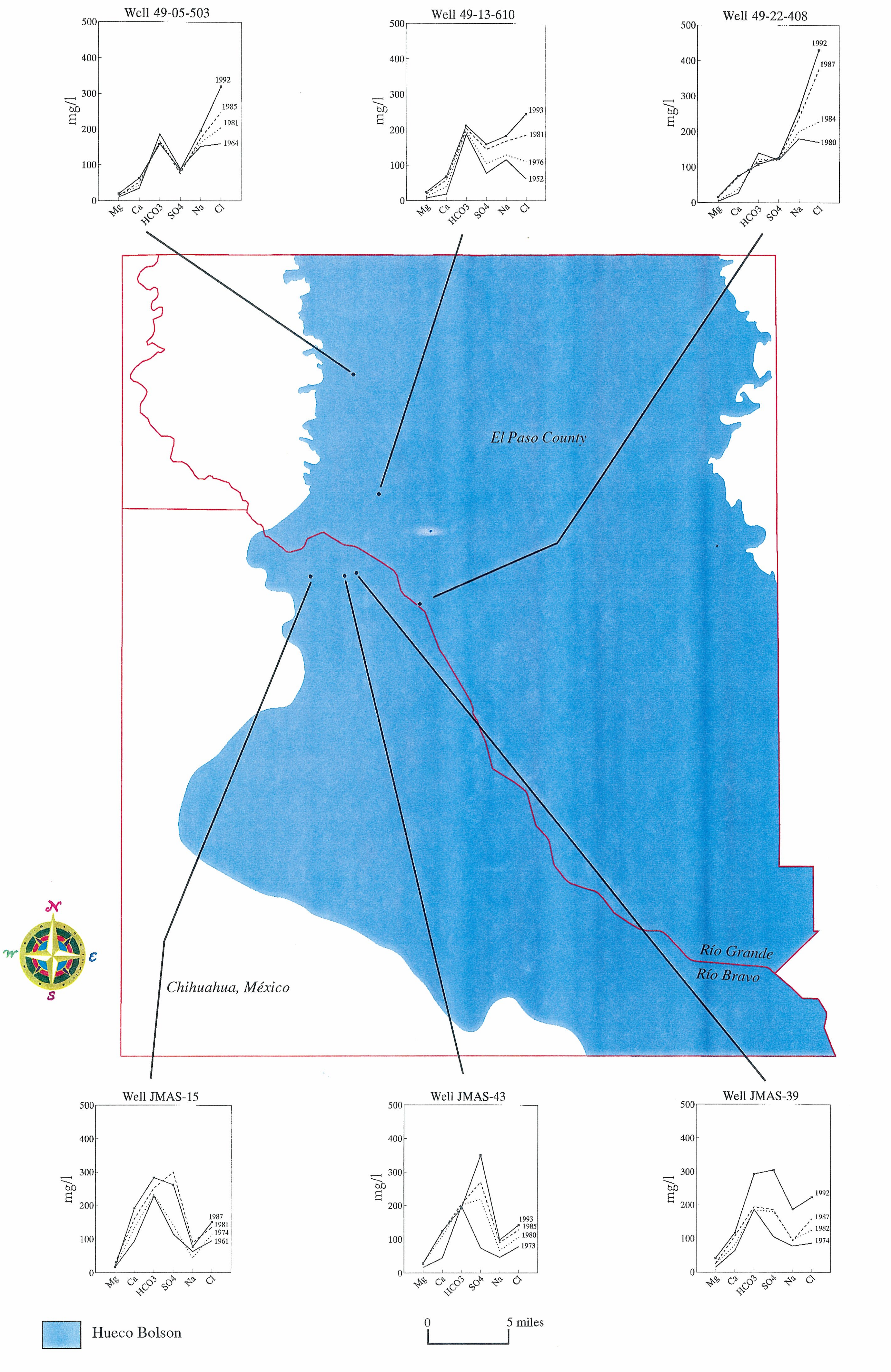


Figure 3.27 Time series hydrochemical plots for municipal wells in the City of El Paso and Ciudad Juarez area showing increasing concentrations of major elemental constituents in ground water (source of data, Texas Water Development Board; Junta Municipal de Agua y Saneamiento).

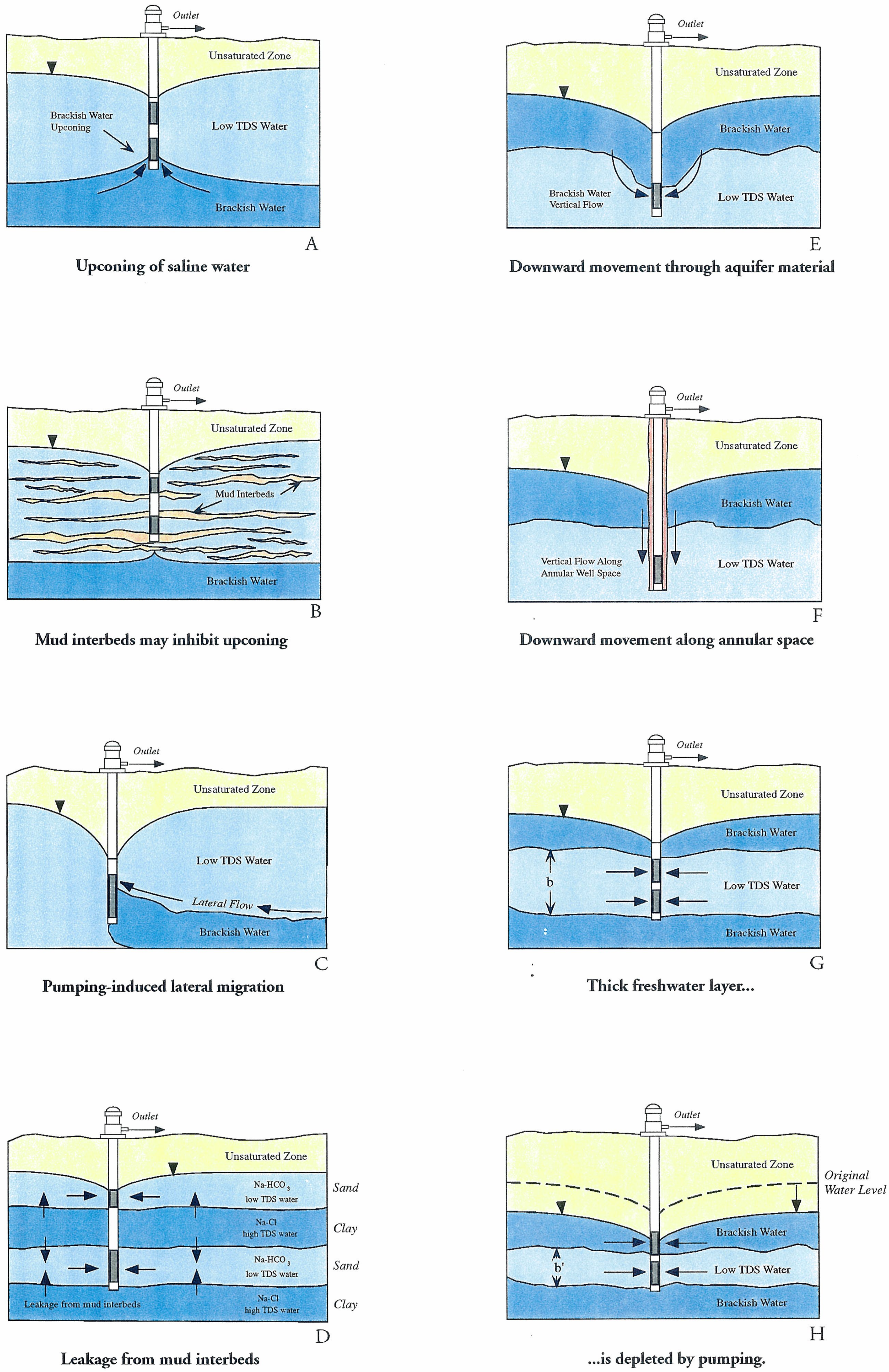


Figure 3.28. Possible sources of salinization of ground water in the City of El Paso/Ciudad Juarez area. Upconing has been proposed as a possible mechanism of salinization of water wells (a), but layered strata may minimize the effects of upconing (b). Salinization of water wells may occur as a result 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 lense is depleted due to long term pumpage (h).

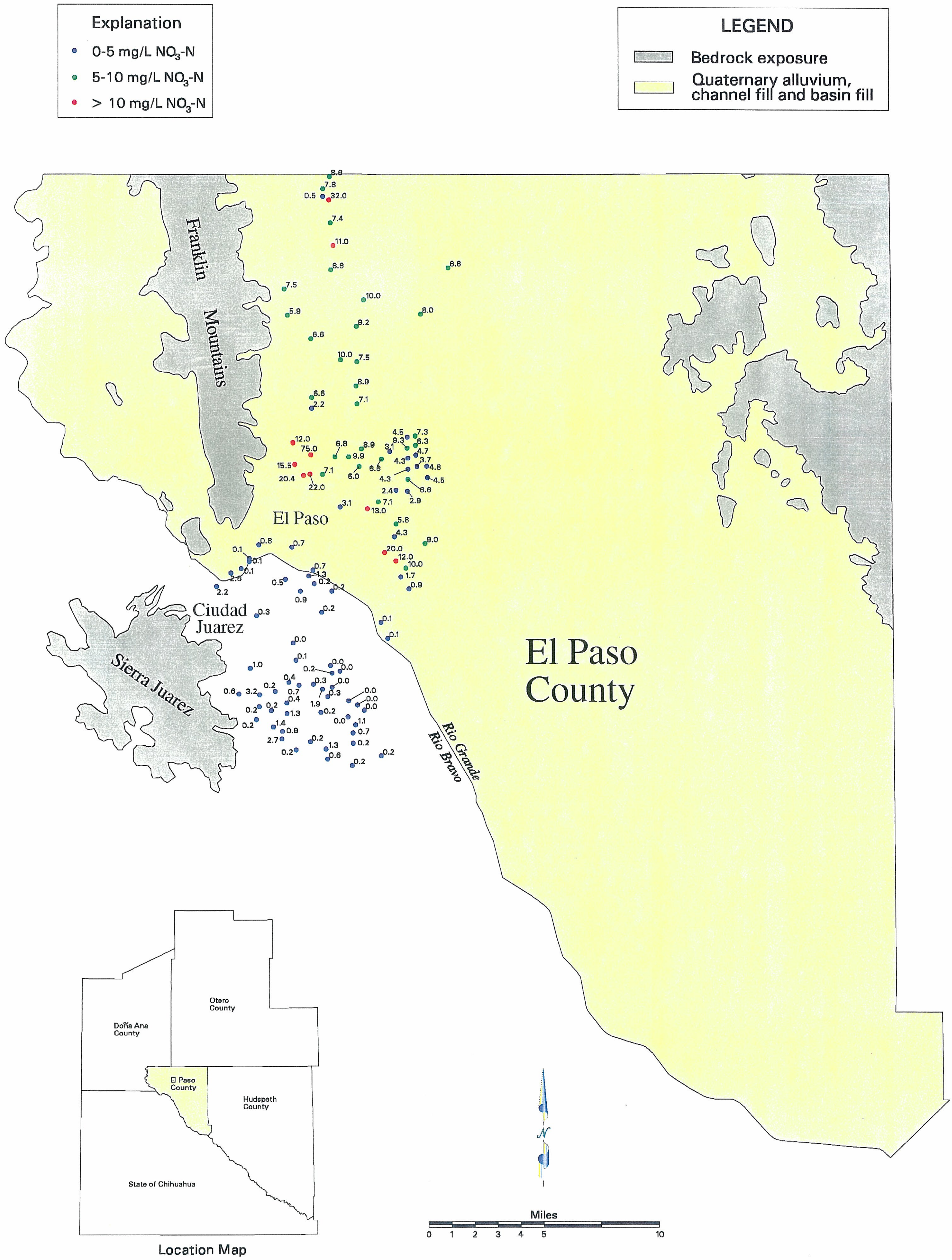


Figure 3.29. Nitrate concentrations in military, City of El Paso, and Ciudad Juarez municipal wells. All values reported as mg/L nitrate as nitrogen (NO_3–N). Data collected 1994 –1995 (source of data Texas Water Development Board; Junta Municipal de Agua y Saneamiento; City of El Paso Public Services Board).

Fecal Coliforms In Well Water

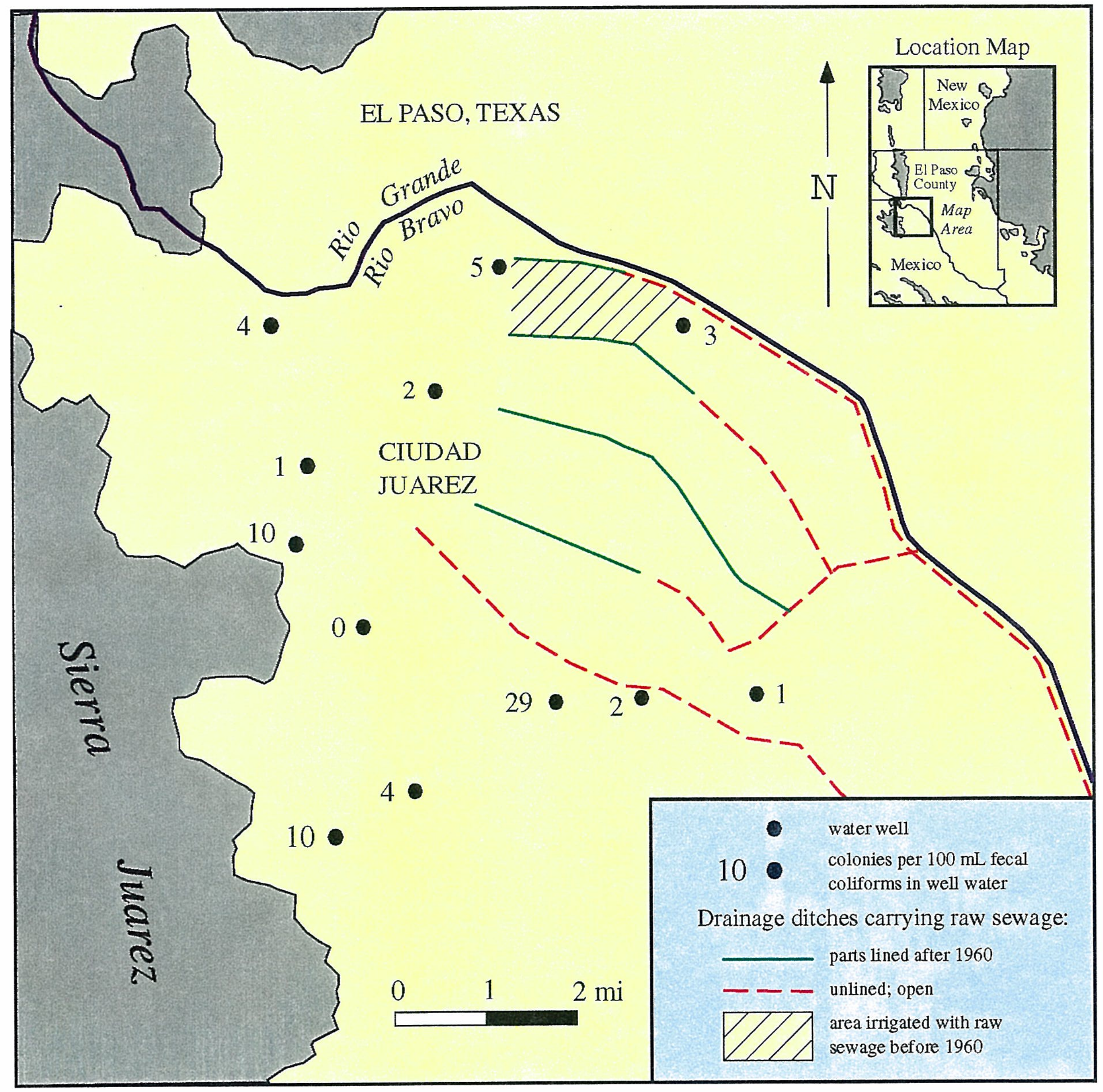


Figure 3.30. Diagram showing fecal coliform levels in 12 well-water samples collected in the Ciudad Juarez metropolitan area. These data were collected in 1987 (modified from Cech and Essman, 1992).

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 NO_3-N drinking water standard (Figure 3.29). Many of the samples in El Paso County tested between 5 and 10 mg/L NO_3-N. All of the wells in Ciudad Juarez and immediate vicinity are less than 5 mg/L NO_3-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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