

CHAPTER 5 - RIO GRANDE AQUIFER

Location and Extent

Near the southeastern limit of the Mesilla Valley, the Rio Grande is constricted between the Sierra de Cristo Rey and the Franklin Mountains in a canyon known as the "El Paso narrows." Here the canyon is about 1,500 ft wide. Rock cut terraces are visible on the south side of the river that rise a few hundred feet above the modern channel.

Southeast of the El Paso narrows, the Rio Grande flows across a broad alluvial floodplain, the "El Paso Valley" that has incised the surface of the Hueco Bolson (Figures 1.2 and 5.1). Near El Paso, the El Paso Valley is about 6 to 8 miles wide and is a little more than 200 ft deep (USBR, 1973). The valley trends nearly 90 miles east, southeast to Fort Quitman where the valley again is constricted in a valley between the Sierra de la Cieneguilla and the Quitman Mountains. The valley deepens along its southeasterly trend and is almost 330 ft deep near Fabens, 30 miles below El Paso. The valley wall is disrupted frequently by arroyos that incise the Hueco Bolson and floodplain surfaces.

Stratigraphy and Water-Bearing Characteristics

Sediment types

The Rio Grande alluvial floodplain in the Mesilla and El Paso Valleys 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 (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.

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 Mesilla and El Paso Valleys. Total thickness of the Rio Grande alluvium is reported to average about 210 ft in the United States (IBWC, 1989). Average thickness is about 170 ft in Mexico (IBWC, 1989). Saturated alluvium thicknesses average 188 and 148 ft respectively in the American and Mexican portions of the floodplain, El Paso Valley (IBWC, 1989).

Windblown sand and silt deposits overlie the Rio Grande alluvium at several localities. Where dunes and other windblown deposits are present, they often border the outer margins of the Rio Grande floodplain. Most dunes are less than 15 ft thick (IBWC, 1989). Windblown deposits are surfaces for infiltration and recharge because they are well sorted and sparsely vegetated.

Aquifer properties

Aquifer tests are not available for the Rio Grande aquifer in the El Paso Valley. Lee Wilson and Associates (1986) report that hydraulic conductivity values probably vary from 20 to 250 ft/day. Calibration of a three-dimensional finite difference model provided bulk hydraulic conductivity values of 65 ft/day (Lee Wilson and Associates, 1986). In an earlier model, Meyer (1976) derived average transmissivity values for the Rio Grande alluvium of about 4,000 ft²/day. The hydraulic conductivity value is about 21 ft/day in Meyer's model. Specific yield for the unconfined aquifer probably ranges from 0.15 to 0.35 ft/day (Lee Wilson and Associates, 1986). Coarser deposits trend toward lower values and fine textured deposits trend toward higher values. Most of the principal water bearing strata have specific yields that range from about 0.15 to 0.20 (Alvarez and Buckner, 1980; IBWC, 1989).

Potentiometric Surface Maps and Water Levels

Water level contour maps prepared with data collected in 1973 - 74 (Figure 5.2) and 1994 - 1995 (Figure 5.3) illustrate losing stream, underflow, and baseflow conditions on different segments of the alluvial floodplain (Figure 5.4). The condition of losing stream is apparent along the Chamizal zone (Figure 5.1) 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 (Figure 5.4) 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 (Figures 5.2 and 5.3).

The condition of baseflow prevails between county line and Fort Quitman (Figure 5.4). 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 (Figures 5.2 and 5.3).

Hydrographs prepared with data collected from 1970 to 1995 illustrate annual water-level fluctuations and explain temporal changes in the potentiometric surface maps (Figures 5.5 and 5.6). Increasing and decreasing water-level elevations correspond to areas where ground water is added or depleted from the aquifer. Depletion of storage has occurred along and several miles below the Chamizal zone (Figure 5.1) due to (1) grout lining of the Rio Grande channel and (2) heavy pumping in the Hueco-Tularosa aquifer (Figure 5.5). Lining of the channel intensified drawdowns because of hydraulic detachment of the water table from the river (i.e., an unsaturated zone now exists between the stream bed and the water table). Depletion of storage in the Hueco Bolson is partially replenished by leakage from the Rio Grande aquifer at the expense of its own stor-

age. Limited surface irrigation combined with extensive paved surfaces along this heavily urbanized reach allow little recharge from the surface and exacerbates depletion of the Rio Grande aquifer.

Between the Chamizal zone and the El Paso/Hudspeth county line, most hydrographs indicate small annual fluctuation, but generally no appreciable net change in storage (Figures 5.1 and 5.5). The large number of drain laterals along this heavily irrigated area help to maintain nearly constant water-levels. Drains tap the bank storage in the alluvial aquifer.

Between county line and Fort Quitman, several hydrographs indicate net addition of water to storage (Figures 5.1 and 5.6). Excessive surface water applied to the floodplain has added additional storage to the shallow water table aquifer. Drains along this segment of the floodplain apparently are not present in sufficient density to maintain constant ground-water levels.

Many of the hydrographs illustrate notable drawdowns in 1977 and 1978 (Figures 5.5 and 5.6). Irrigation pumping in the El Paso Valley totaled 88,260 and 92,850 acre-feet in 1977 and 1978 (IBWC, 1989). The pumpage rate averaged only 43,360 acre-ft/year between 1950 and 1984 (IBWC, 1989). Heavy pumping and temporary drawdown in 1977 and 1978 were a result of drought conditions and reduced surface flows.

Ground-Water Availability

Surface area of alluvial floodplain between the El Paso narrows and Fort Quitman (Figure 5.1) is about 152 mi² in the United States and about 123 mi² in Mexico. Average saturated thicknesses are about 188 ft in the United States and about 148 ft in Mexico (IBWC, 1989). Using these figures and a specific yield of 0.2, the total volume of water in the Rio Grande aquifer in the study area is an estimated 5.99 million acre-ft (3.66 million acre-ft in the United States and 2.33 million acre-ft in Mexico). Values are approximate due to uncertainty in estimates of alluvial thickness and spatial variability of specific yield. Volumes of

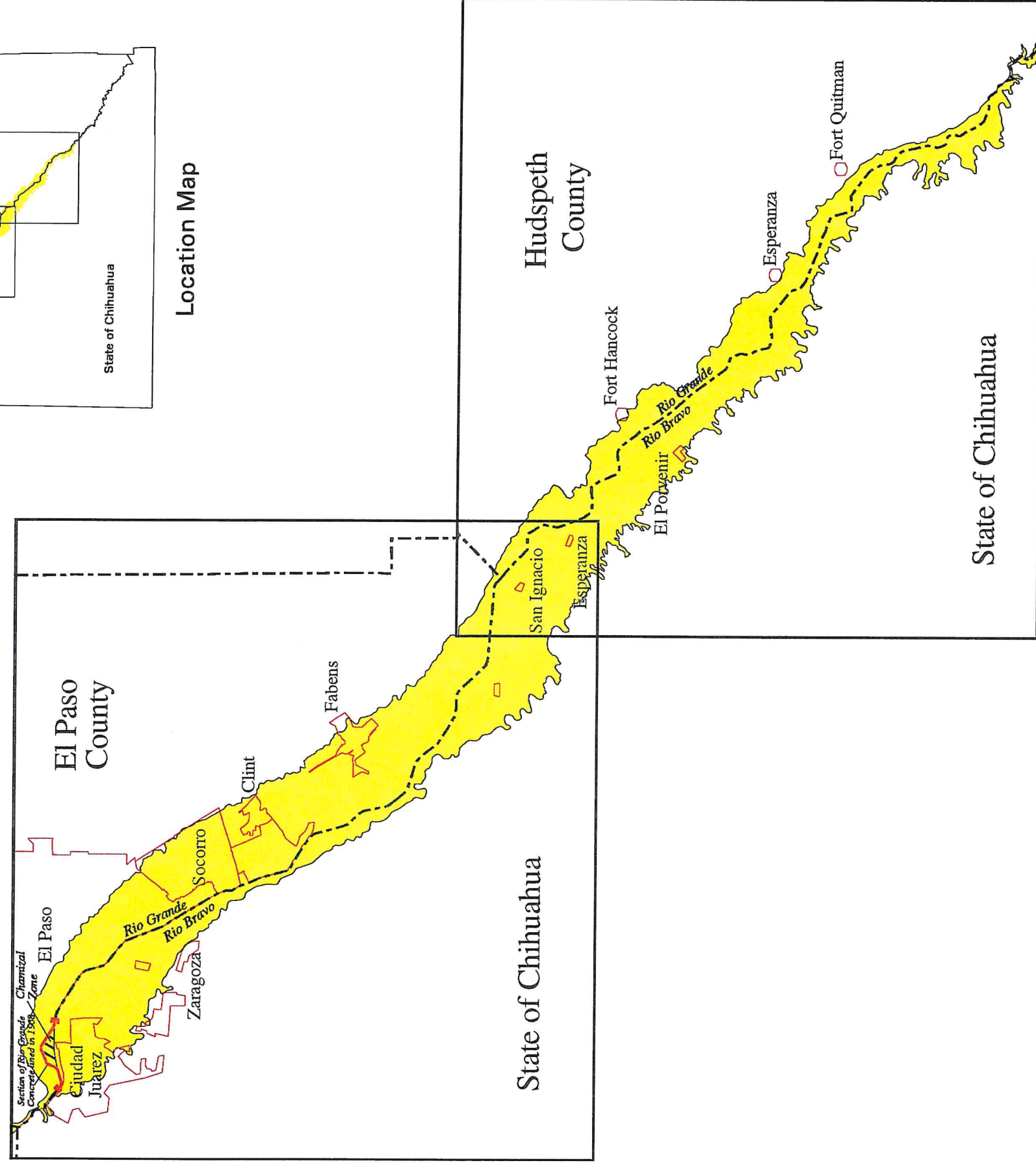
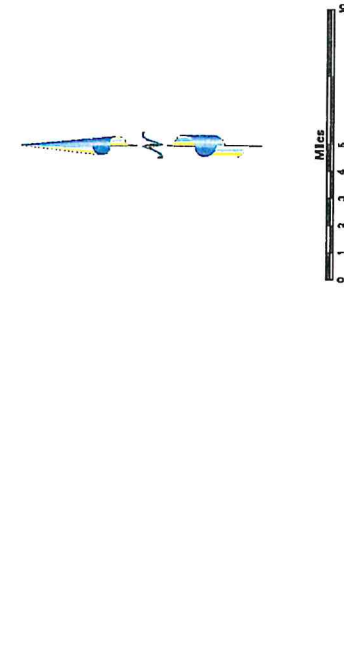


Figure 5.1. Location of the Rio Grande aquifer in the study area

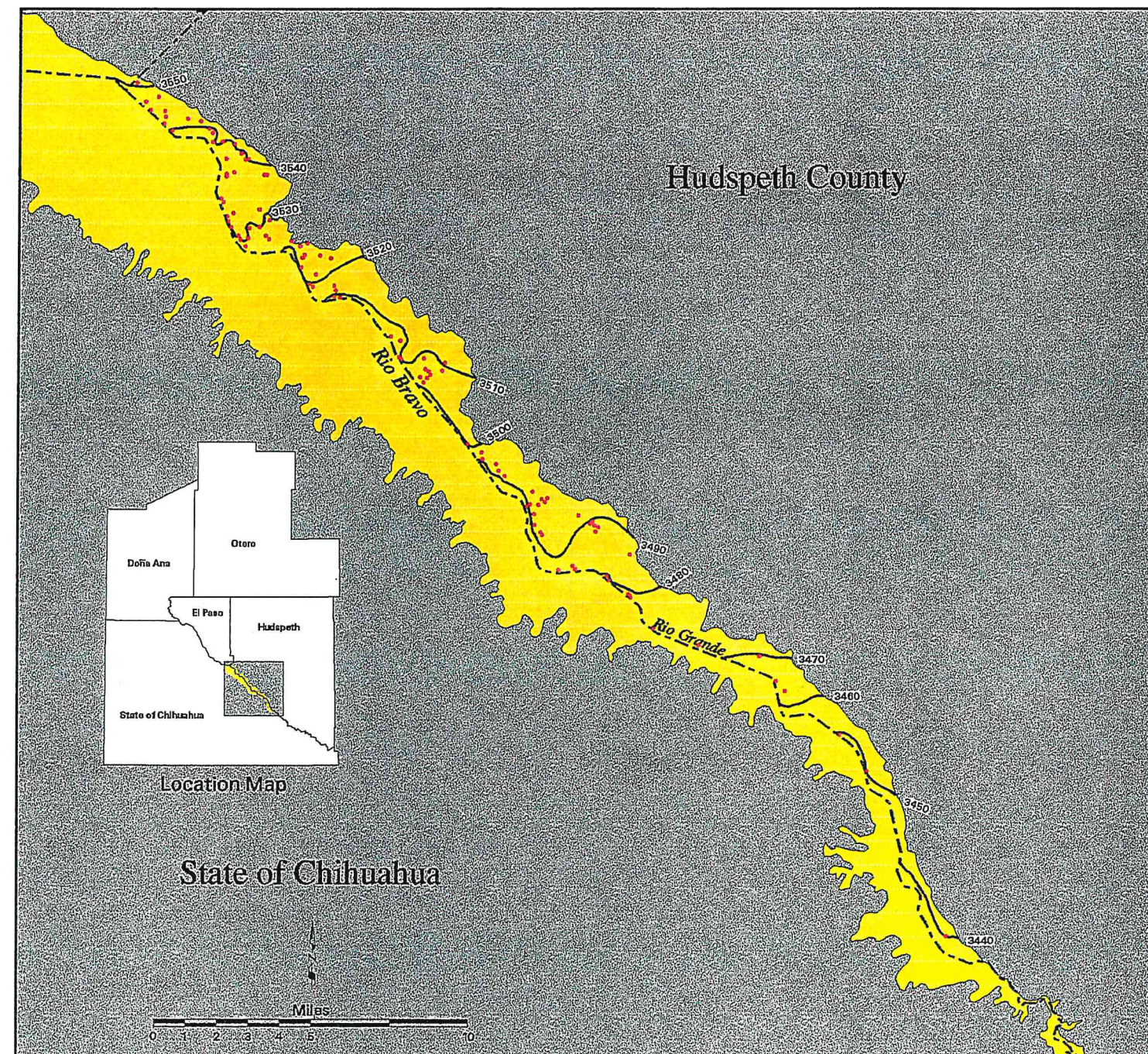
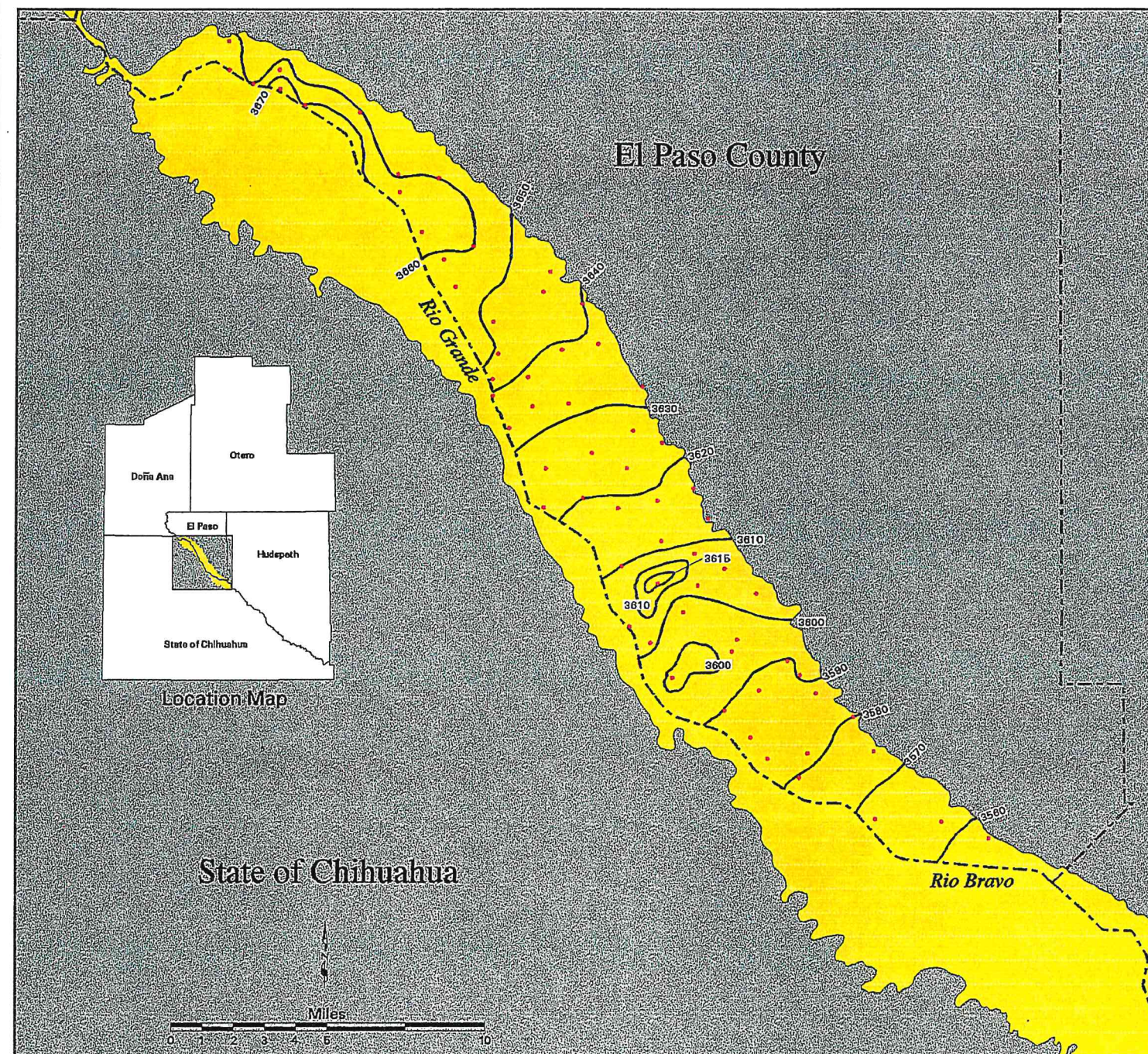


Figure 5.2. Water level contour map for the Rio Grande aquifer in El Paso and Hudspeth Counties, 1973 and 1974. Map illustrates losing stream, underflow, and baseflow conditions at different segments of the floodplain (source of data, Texas Water Development Board).

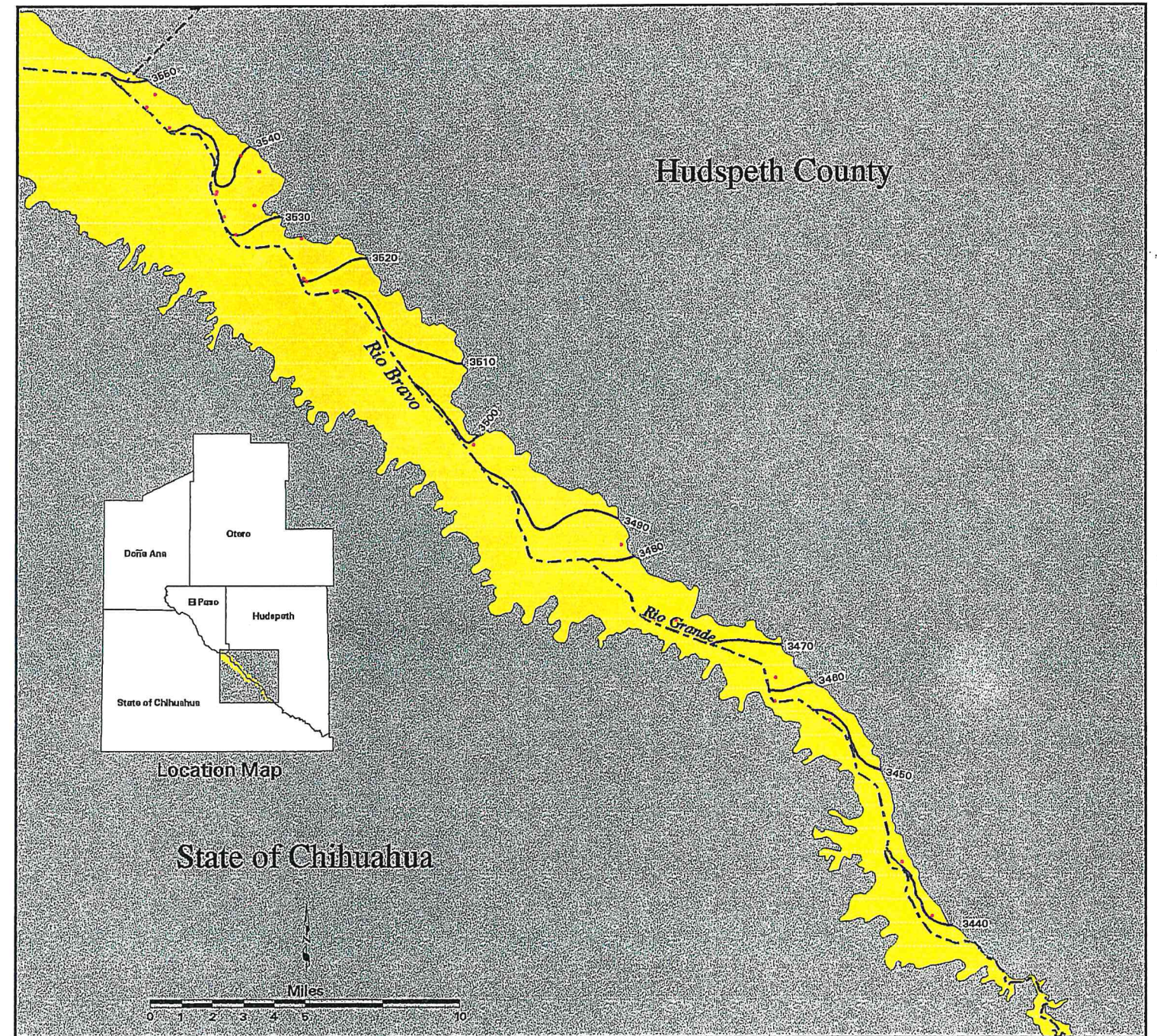
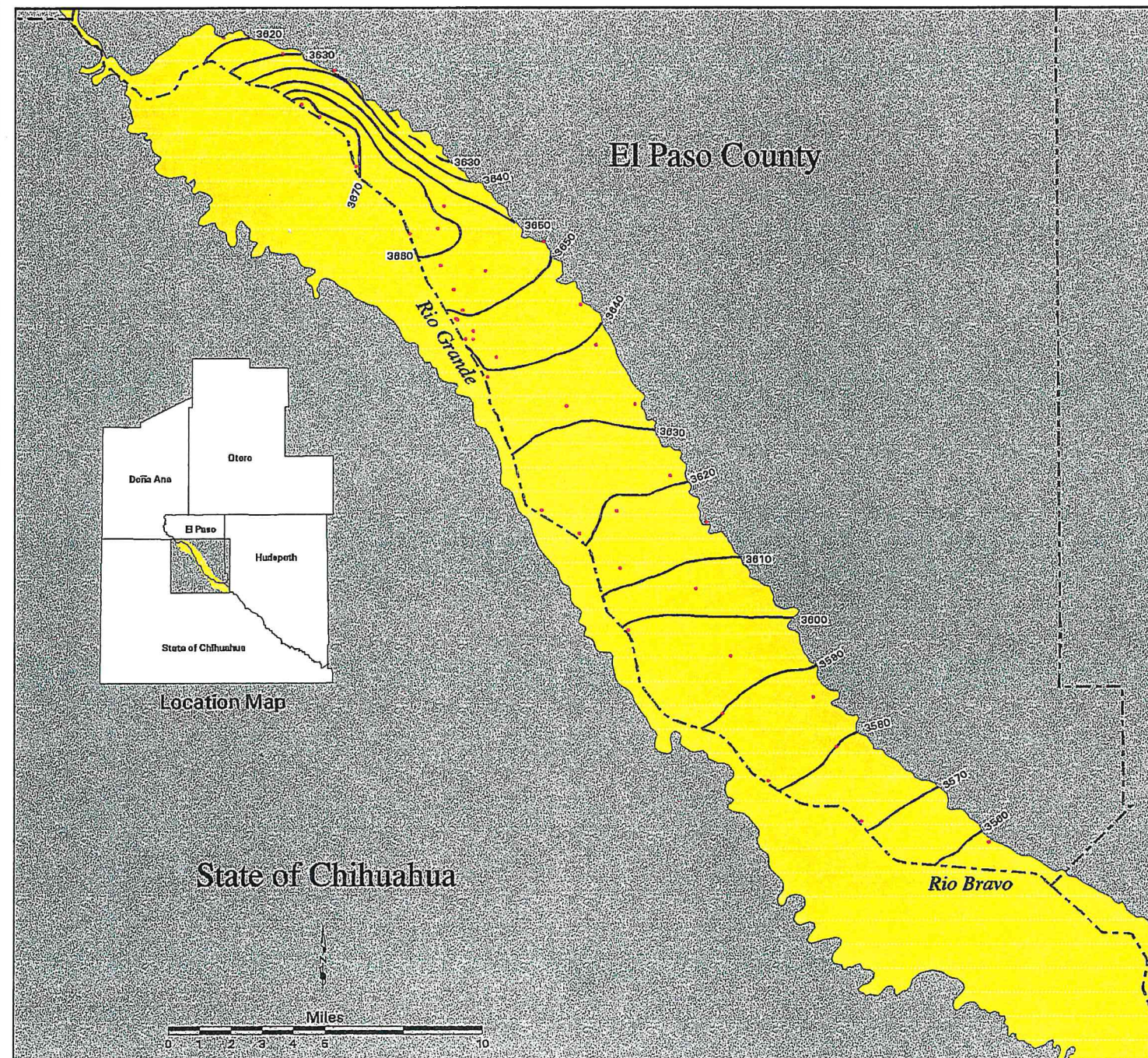


Figure 5.3. Water level contour map for the Rio Grande aquifer in El Paso and Hudspeth Counties, 1994 and 1995. A comparison of figures 5.2 and 5.3 indicates that drawdowns have intensified in the El Paso area since 1973 (see figure 5.1 for delineation of the El Paso area. Source of data, Texas Water Development Board).

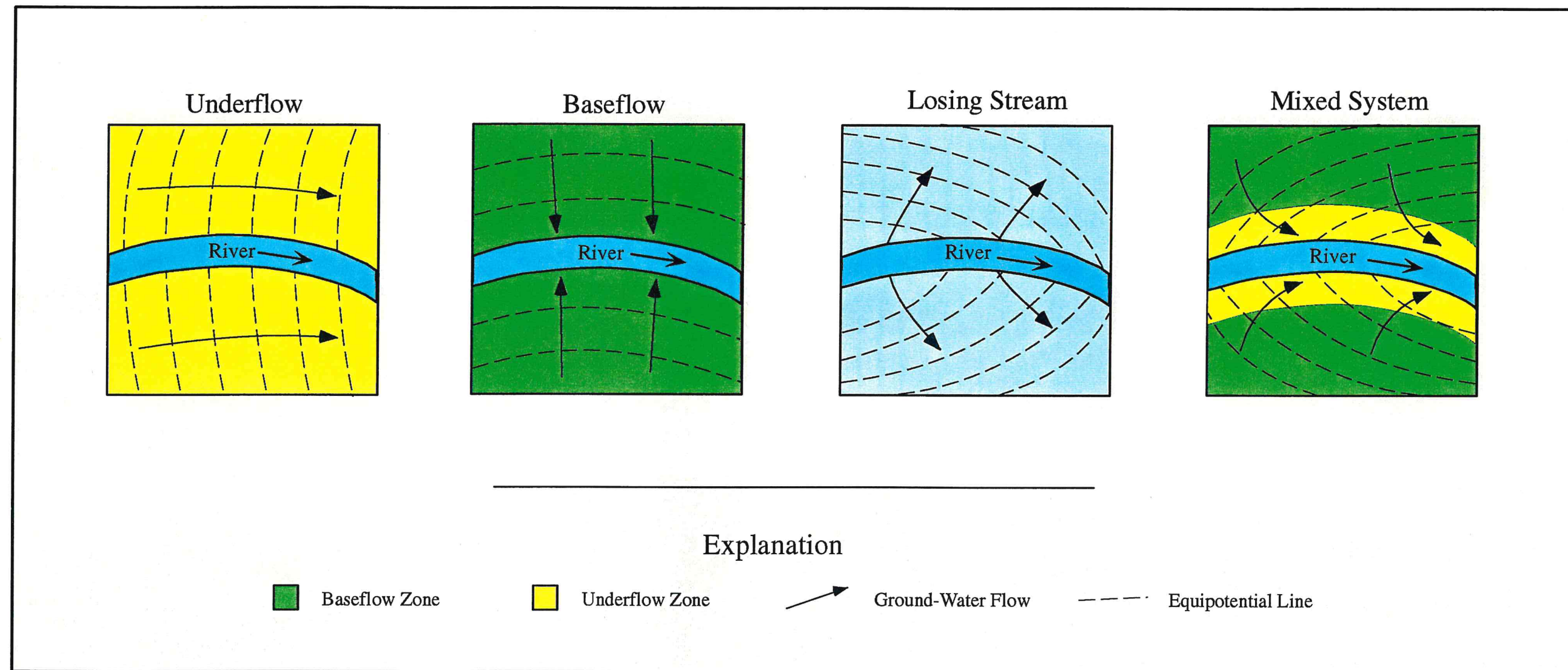


Figure 5.4. Diagram illustrating underflow, baseflow, losing stream, and a mixed system that includes underflow and baseflow components of flow in an alluvial aquifer hydraulically connected to a river (modified from Larkin, 1988).

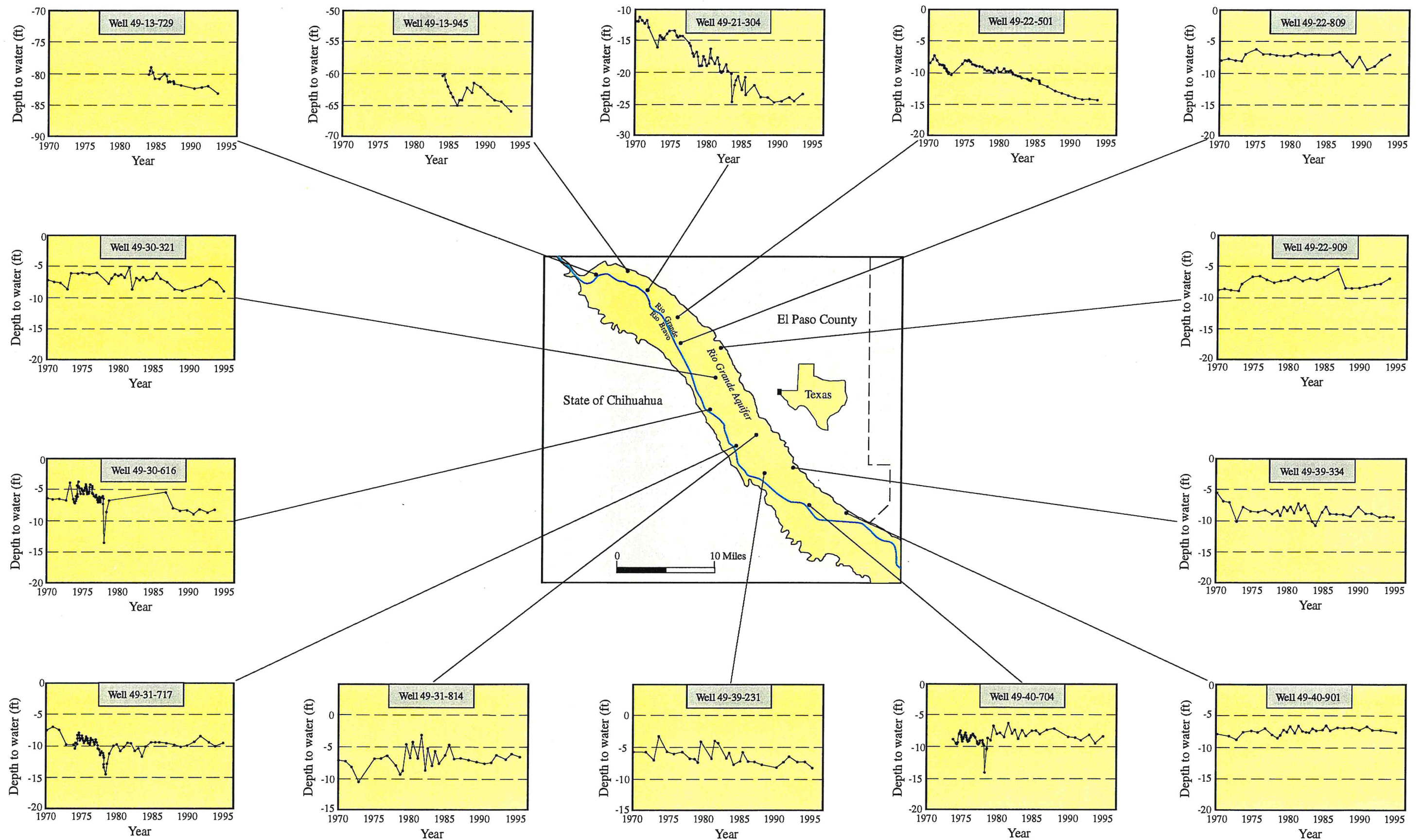


Figure 5.5. Hydrographs illustrating water-level changes in the Rio Grande aquifer in El Paso County between 1970 and 1995 (source of data; Texas Water Development Board).

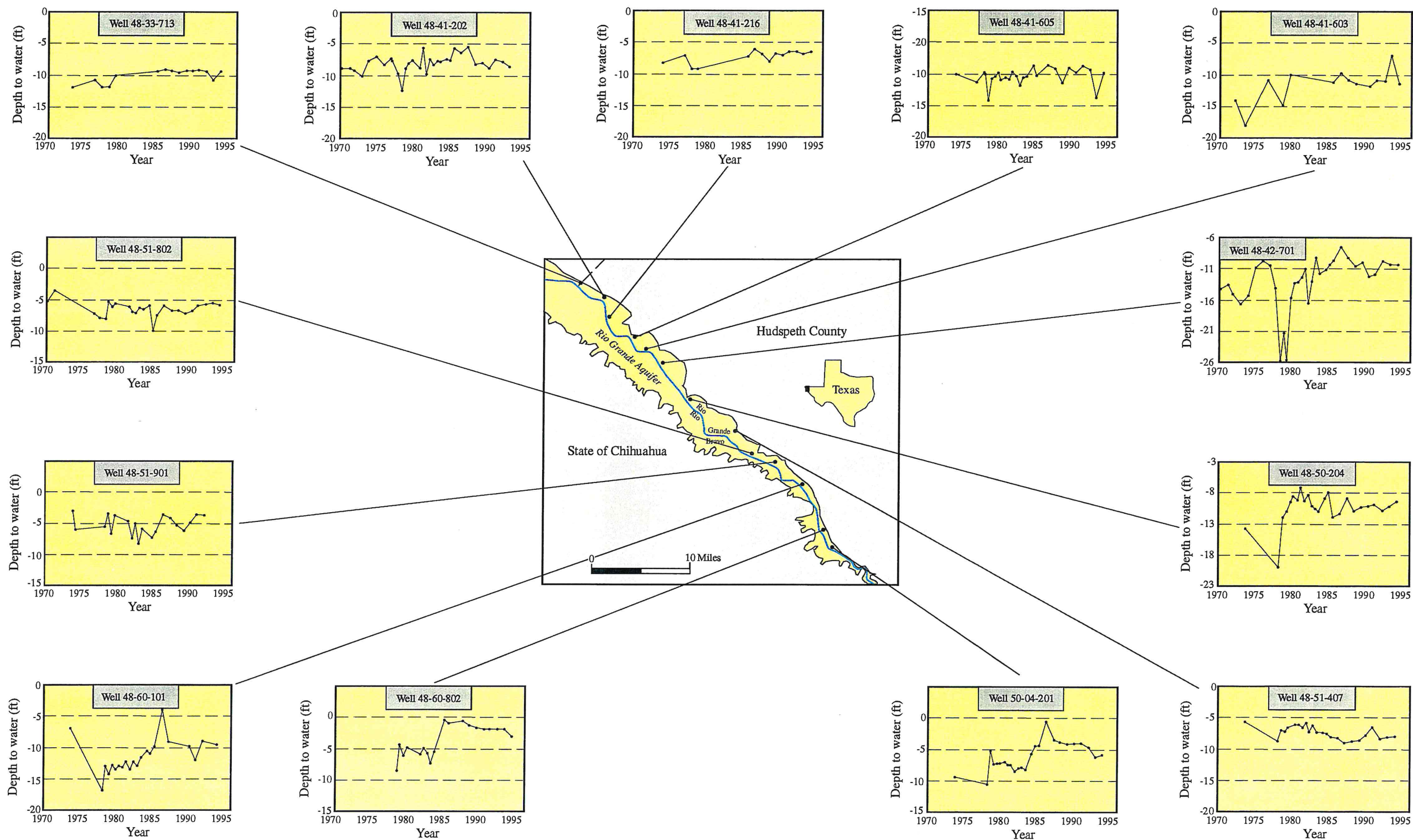


Figure 5.6. Hydrographs illustrating water-level changes in the Rio Grande aquifer in Hudspeth County between 1970 and 1995 (source of data; Texas Water Development Board).

fresh, slightly saline, and moderately saline ground water cannot be estimated accurately with available data.

Recharge Areas

Recharge to the Rio Grande aquifer along irrigated reaches is due primarily to infiltration of surface water that has been applied to irrigable crops (Figure 5.7). Hydrographs indicate considerable fluctuation of a few feet to several feet in response to recharge from irrigation (Figures 5.5 and 5.6). Major ion data also shows clear evidence of direct recharge due to surface irrigation. State well 48-41-624, for example, had increasing salinities between 1986 and 1988 (Figure 5.8). When the well was resampled in 1989, total dissolved solids had decreased substantially. A chemical trilinear plot (Figure 5.8) indicates dilution of salt-laden ground water due to mixing with dilute Rio Grande water during the 1989 irrigation season.

Recharge also occurs to some extent by direct seepage from canal 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, irrigation return flows, and recharge from cross-formational flow with the Hueco Bolson (Figure 5.7). Quantification of the amounts and spatial variability of recharge to the alluvial aquifer is infeasible with available data.

Information on recharge areas and ages of alluvial ground waters are provided by radioisotopes collected downstream of the El Paso/Hudspeth county line (Fisher and Mullican, 1990). Radioisotopes indicate tritiated ground water and ground water with high percentages of modern carbon (Fisher and Mullican, 1990). Tritium activities in wells screened in alluvium varied from 0.0 to 27.2 tritium units (TU), with most values greater than 10.9 TU. Most tritium data indicate a recent meteoric component in ground water, less than 50 years before present (b.p.). Carbon-14 values

varied from 51 percent modern carbon (pmc) to 116 pmc and corrected ground-water ages varied from 188 to 3,489 years b.p. Isotopic results suggest mixing of modern waters (0 - 50 yrs b.p.) with slightly to moderately old waters (1,000 - 10,000 yrs b.p.).

Discharge Areas

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 (Figure 5.7). The principal mode of discharge varies along the floodplain. Along the heavily urbanized Chamizal zone (Figure 5.1), discharge occurs primarily by cross-formational leakage from the alluvium to the Hueco Bolson where storage in the alluvial aquifer is depleted by heavy 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 county line to Fort Quitman, discharge occurs by irrigation pumping, by seepage to the Rio Grande, and by leakage to a few drains. Phreatophytes account for some discharge along the Rio Grande channel and canal laterals. These channels, in general, are kept relatively free of phreatophytes west of Fort Quitman.

Water Quality

General hydrochemistry

Few American ground-water data are available for the Rio Grande aquifer after 1979 below the El Paso narrows, so maps present dated, but fairly extensive information for the American portion of the Rio Grande alluvium. Data are current, but are somewhat limited in Mexico. Comparison of historical and current American data do not indicate significant changes in overall water quality in the alluvial aquifer between the 1970's and present; but current data are too scant to define temporal changes.

Stiff diagrams indicate Na-SO₄ ground waters in El Paso County (Figure 5.9). Below the El Paso/Hudspeth county line, chloride increasingly becomes the dominant anion in the cation/anion pairing (Figure 5.10). Mexican ground waters follow the same general trend, but show greater scatter in the segment of the floodplain across from Hudspeth County (Figures 5.9 and 5.10). Ground-water samples frequently were collected in and beneath arroyo deposits that conformably overlie earlier alluvial floodplain deposits in Mexico. Arroyos act as recharge areas after episodic precipitation and runoff events and ground-water chemistries have wide scatter due to commingling of dilute runoff waters and older alluvial ground waters.

Total dissolved solids in El Paso County vary substantially, but fall mostly within the 1,000 to 3,000 TDS range (Figure 5.9). Total dissolved solids are higher in alluvial deposits in Hudspeth County, falling mostly within the 3,000 to 6,000 TDS range (Figure 5.10). 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, more enriched alluvial waters.

Sources of salinity

Increasing salinities below the El Paso narrows are related to sewage outfalls, river/aquifer dynamics, and historical differences in irrigation activities. Intensive irrigation in the region began in the late 1800's. Solutes in irrigation water become concentrated in soils due to low atmospheric moisture and high evapotranspiration rates (Figure 5.11). A series of droughts in the 1940's and 1950's resulted in severe degradation of river water quality and deposition of large amounts of salts in irrigated fields (Young, 1981). These salts are readily remobilized by leaching to the shallow Rio Grande aquifer. Salts eventually return to the river.

Historical monthly water quality and streamflow data show changes in river water quality and discharge between El Paso and Fort Quitman (Figure 5.12). Spatial changes in sulfate, chloride, sodium, and total

dissolved solids for most months indicate appreciable decline in river water quality downstream. Data indicate that water quality improves when discharge is high during the irrigation season. This is an artifact of dilution by copious quantities of dilute reservoir water and by stagnation of saline baseflow as a result of high river stage.

River salinities fluctuate spatially downstream of El Paso due to inflows from several sources that both dilute and enrich Rio Grande water with respect to total dissolved solids (Figure 5.13). Sources of dilution are principally from precipitation runoff from rural and urban areas, although sewage outflows may sometimes dilute higher TDS waters in the Rio Grande. Overall enrichment between El Paso and Fort Quitman is clearly defined. Surface water samples collected annually at El Paso and Fort Quitman indicate very little scatter of water quality constituents. Grouping of analyses fall into distinct clusters (Figure 5.14). The "El Paso" and "Fort Quitman" clusters correspond generally to evolutionary trends in the Rio Grande aquifer in El Paso County and Hudspeth County, respectively (Figure 5.15). Despite wide scatter in Rio Grande aquifer data (Figure 5.15), the analyses show a clear relationship between river and aquifer water quality between El Paso and Fort Quitman. Results imply ample fluid exchange and salt recycling between the river and aquifer.

Increasing salinities in both the river and Rio Grande aquifer along the downstream trend generally reflects the tendency for salts to be recycled in irrigation water, to return to the Rio Grande, and then to be reapplied to crops (Figure 5.13). Near El Paso, relatively dilute irrigation waters are enriched by evaporation and leaching when applied to crops. Enriched return flows are reapplied to crops downstream. By this process, the salinities in the Rio Grande and the Rio Grande aquifer increase in a perpetual manner downstream, and elevated salinities in the Rio Grande result in elevated salinities in the Rio Grande aquifer (and vice versa). This process is a basic function of evapotranspiration, con-

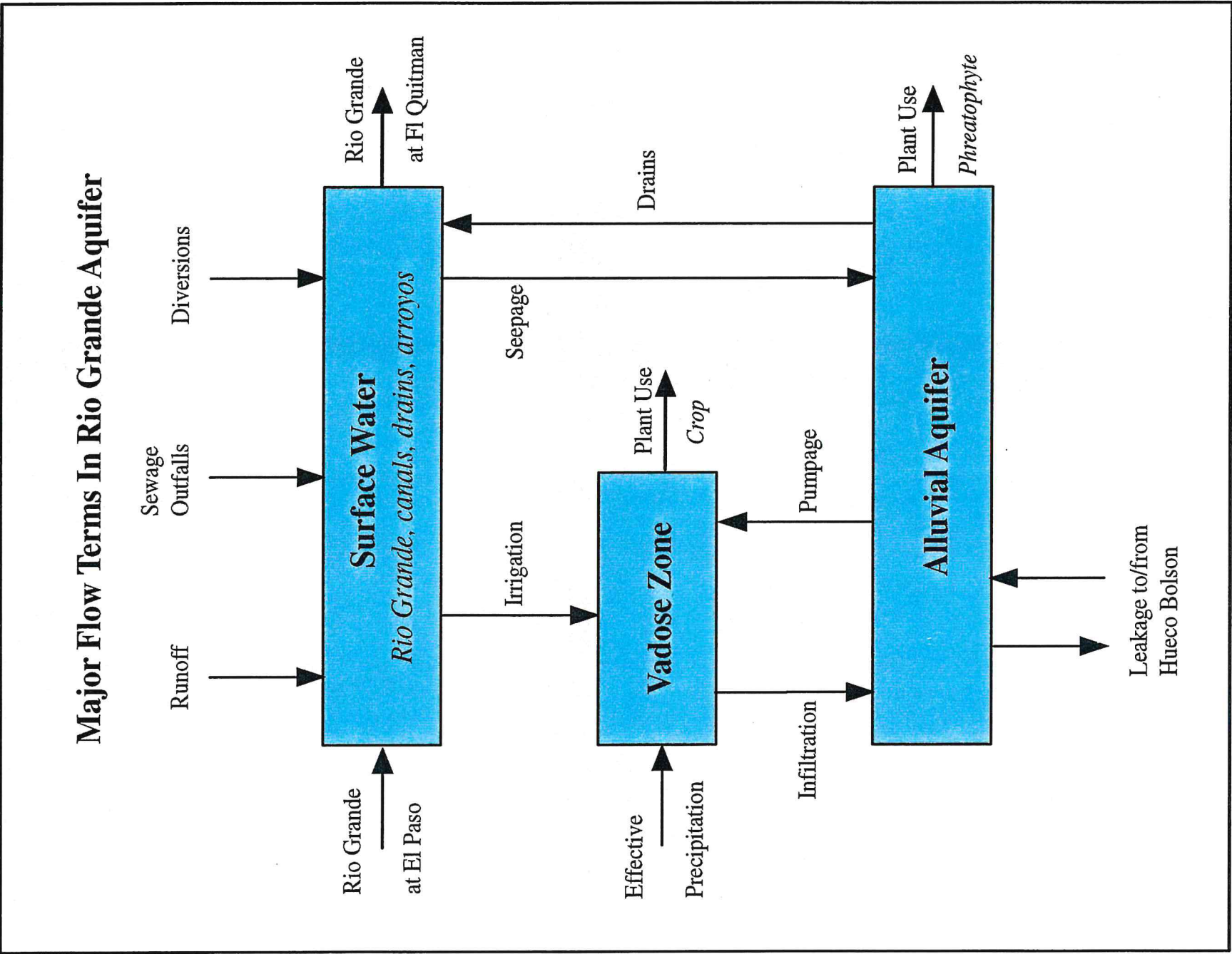


Figure 5.7. Major flow components in the Rio Grande aquifer.

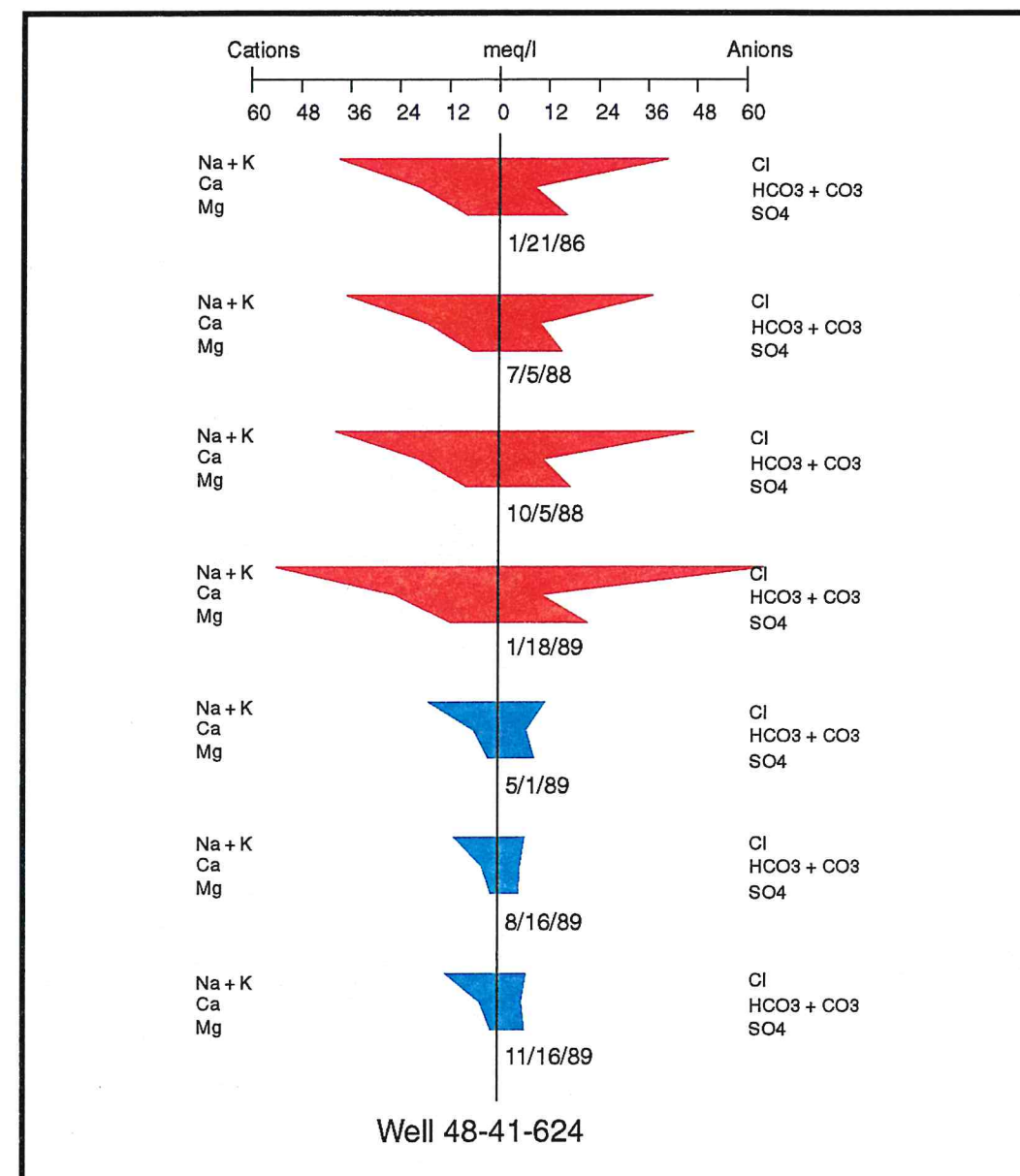


Figure 5.8a. Located adjacent to the Rio Grande, well 48-41-624 had increasing total dissolved solids in samples collected between 1986 and 1989. When the well was resampled in May, 1989, total dissolved solids had decreased substantially (source of data, Texas Water Development Board).

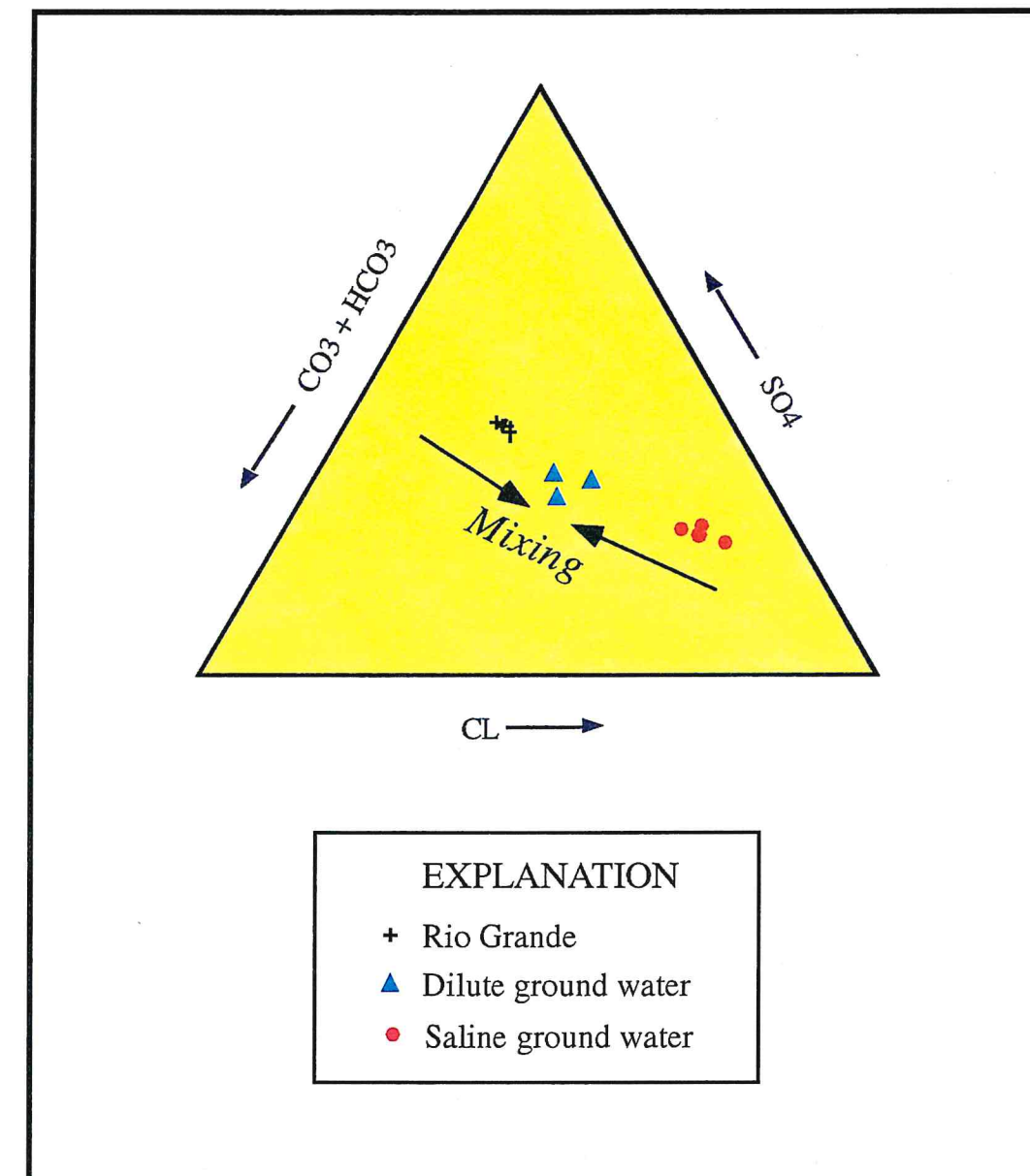
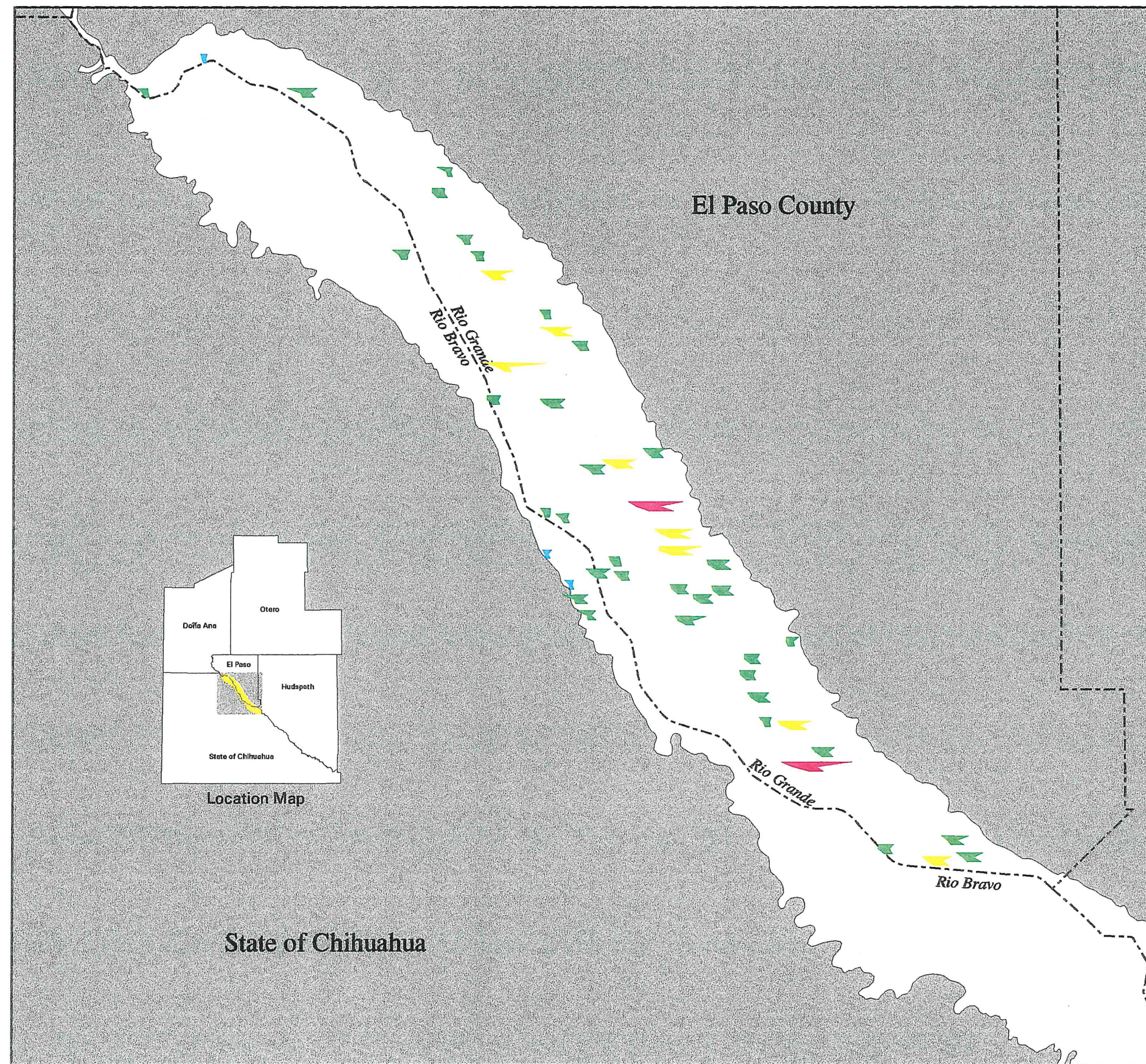
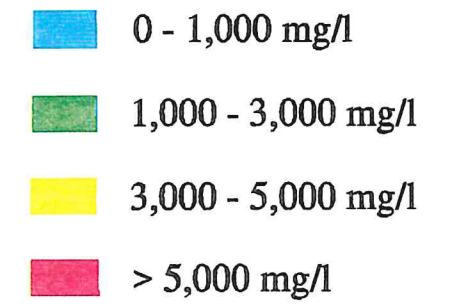


Figure 5.8b. The trilinear plot shows enriched well samples from Figure 5.8a (1986 - 1989), dilute well samples (May, 1989 and later), and Rio Grande samples collected in 1989. Results indicate dilution of ground water due to mixing with Rio Grande water (source of data, Texas Water Development Board).



Total Dissolved Solids



American Data 1972-1979

Mexican Data 1993 - 1994

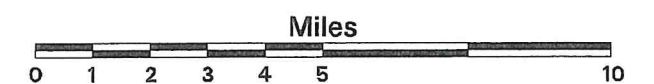
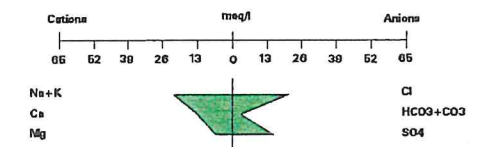
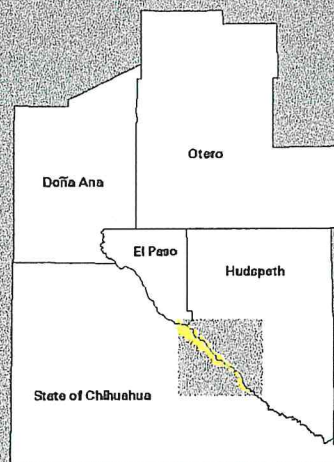
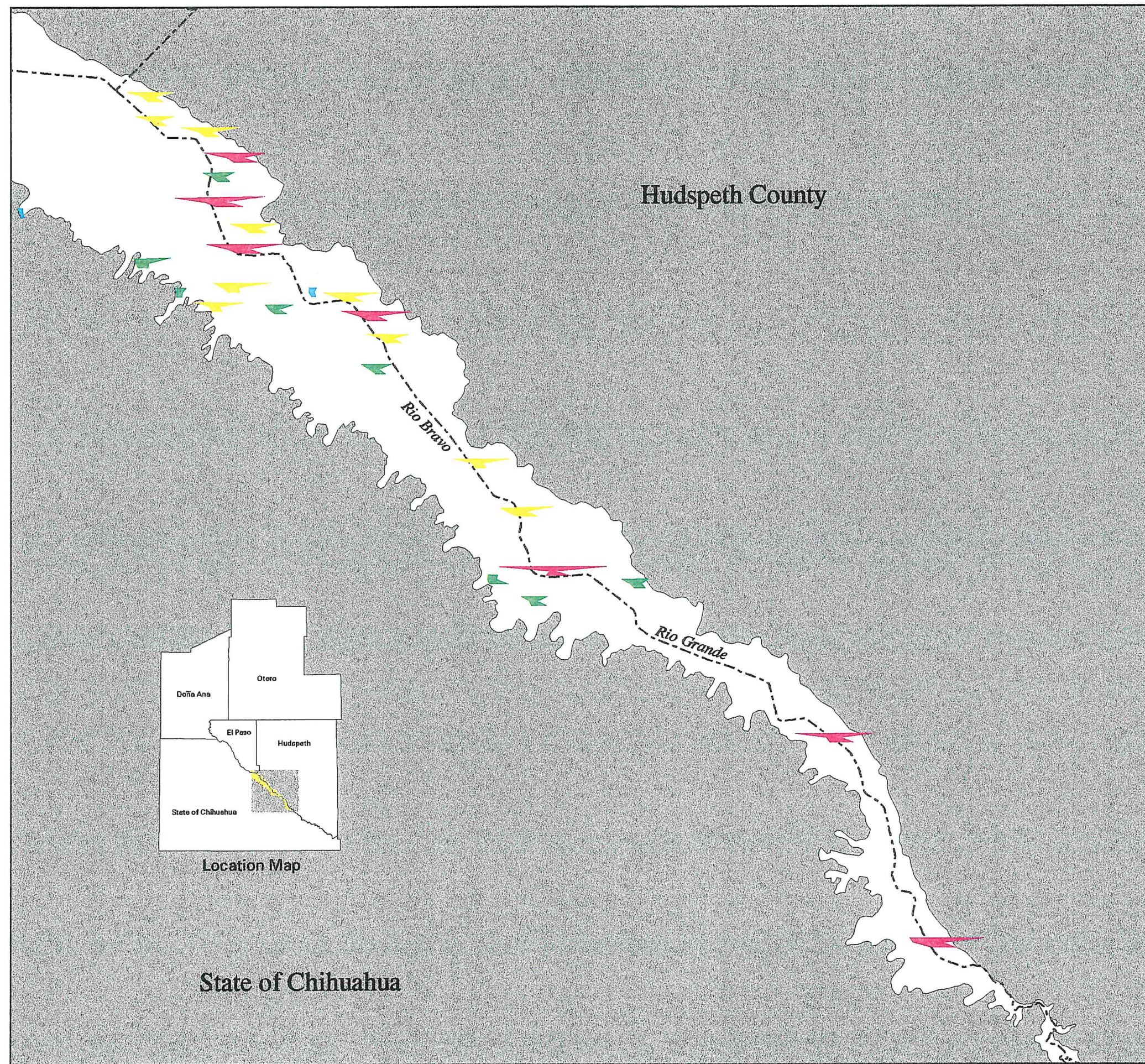


Figure 5.9. Stiff plots show Na-SO₄ ground waters with salinities usually less than 3,000 mg/L in the Rio Grande aquifer above the El Paso/Hudspeth County line (source of data, Texas Water Development Board; Comision Nacional del Agua).



Location Map

Total Dissolved Solids

- 0 - 1,000 mg/l
- 1,000 - 3,000 mg/l
- 3,000 - 5,000 mg/l
- > 5,000 mg/l

American Data 1974 - 1977
Mexican Data 1994

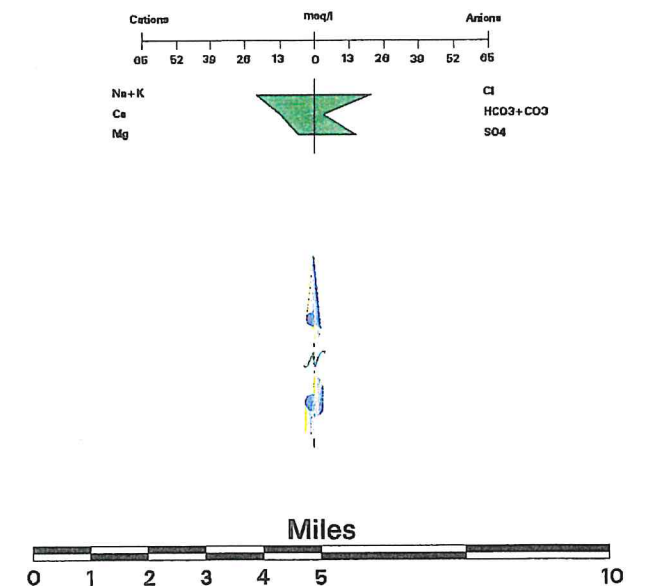


Figure 5.10. Stiff plots show Na-SQ -Cl ground waters with salinities usually greater than 3,000 mg/L in the Rio Grande aquifer below the El Paso/Hudspeth County line (source of data, Texas Water Development Board; Comision Nacional del Agua).

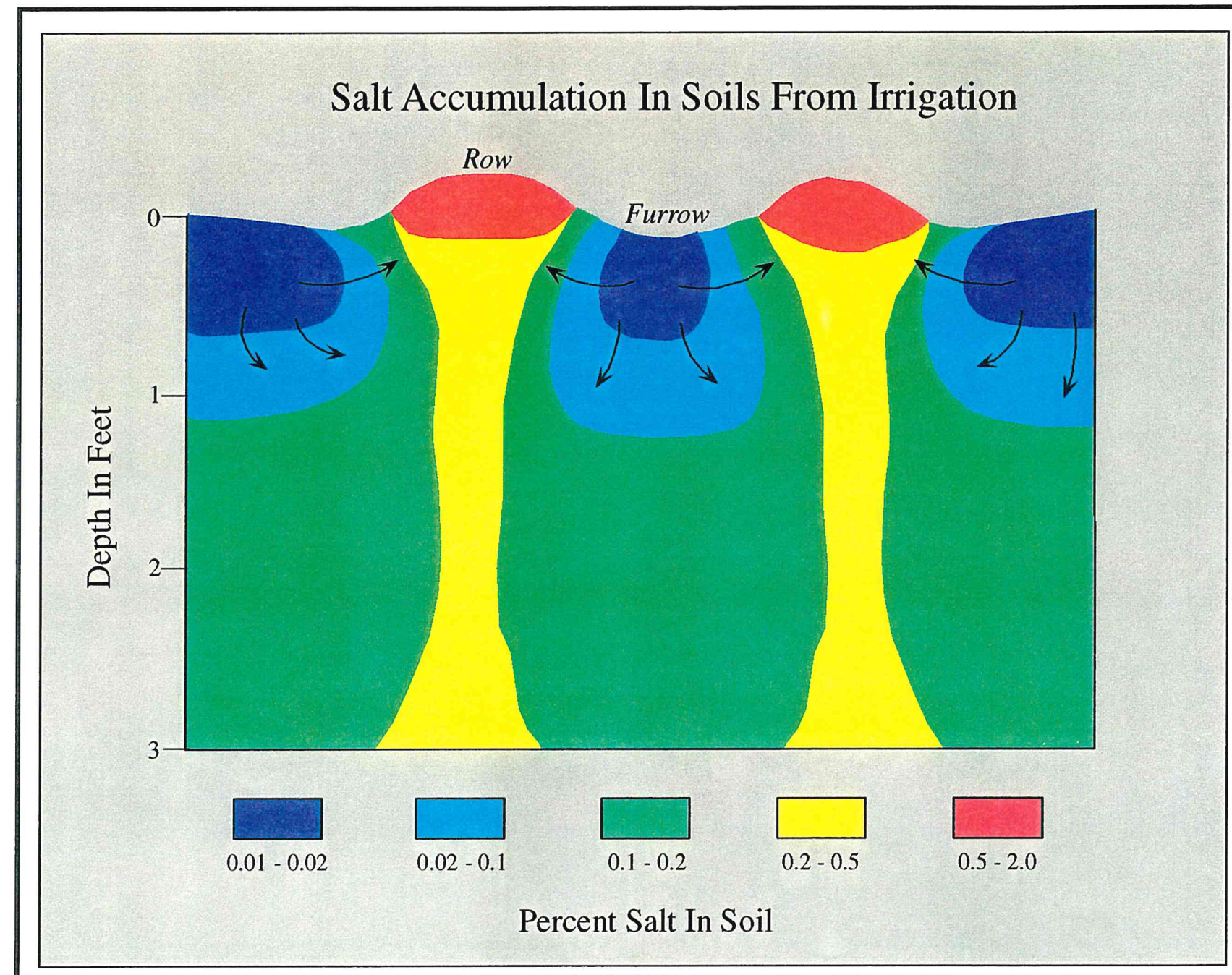


Figure 5.11. Diagram showing how dissolved salts in irrigation water become concentrated in irrigated soils due to high evapotranspiration rates (modified from Longnecker and Lyrly, 1959).

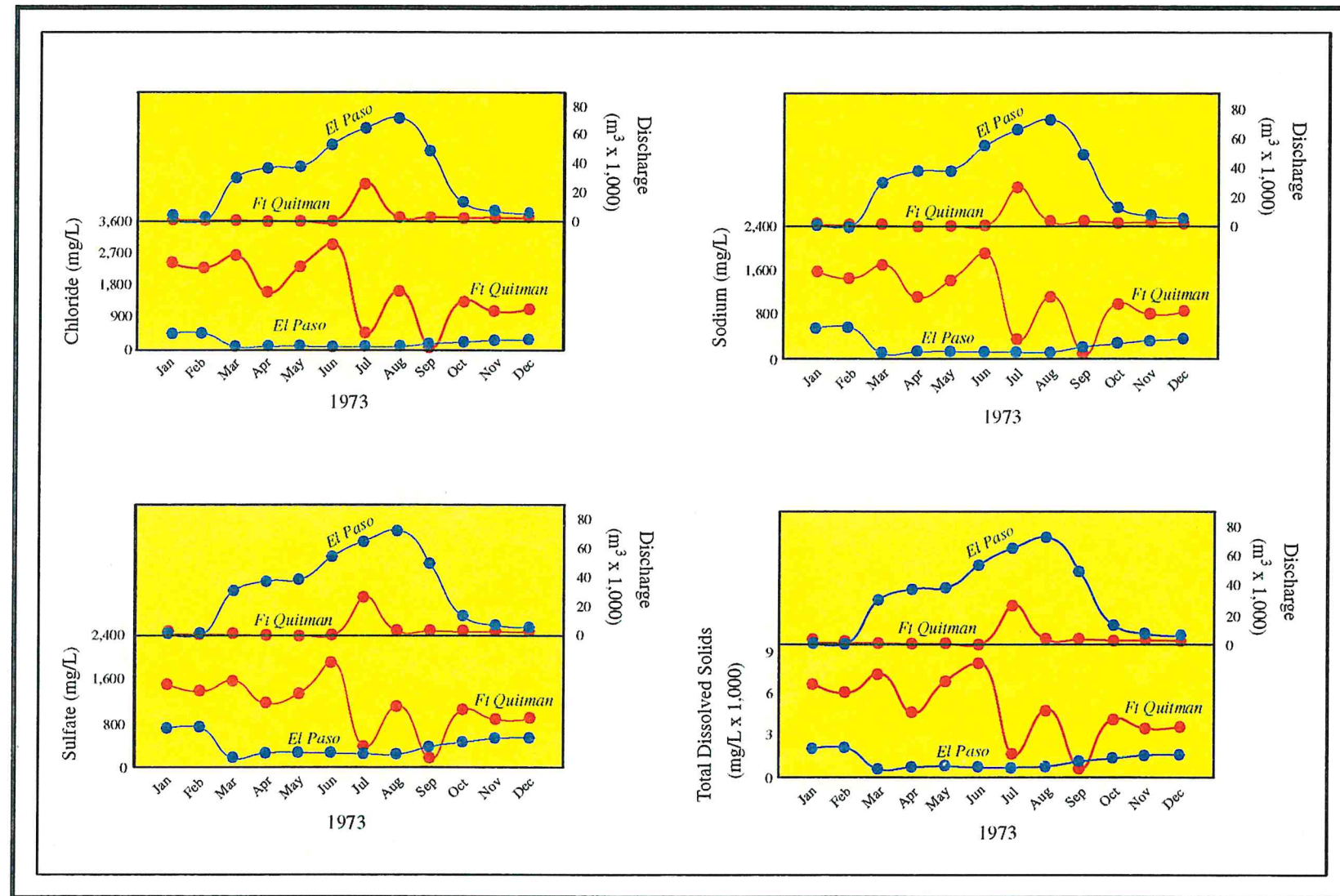


Figure 5.12a. Diagram comparing water quality and streamflow discharge for the Rio Grande at El Paso and Ft Quitman, 1973. Spatial changes in Cl, SO₄, Na, and TDS for most months indicate appreciable decline in surface-water quality downstream of El Paso. Water quality improves when discharge is high as an artifact of dilution by large quantities of dilute reservoir water and by stagnation of saline baseflow as a result of high river stage (source of data, IBWC Water Bulletin series "Flow of the Rio Grande and Related Data").

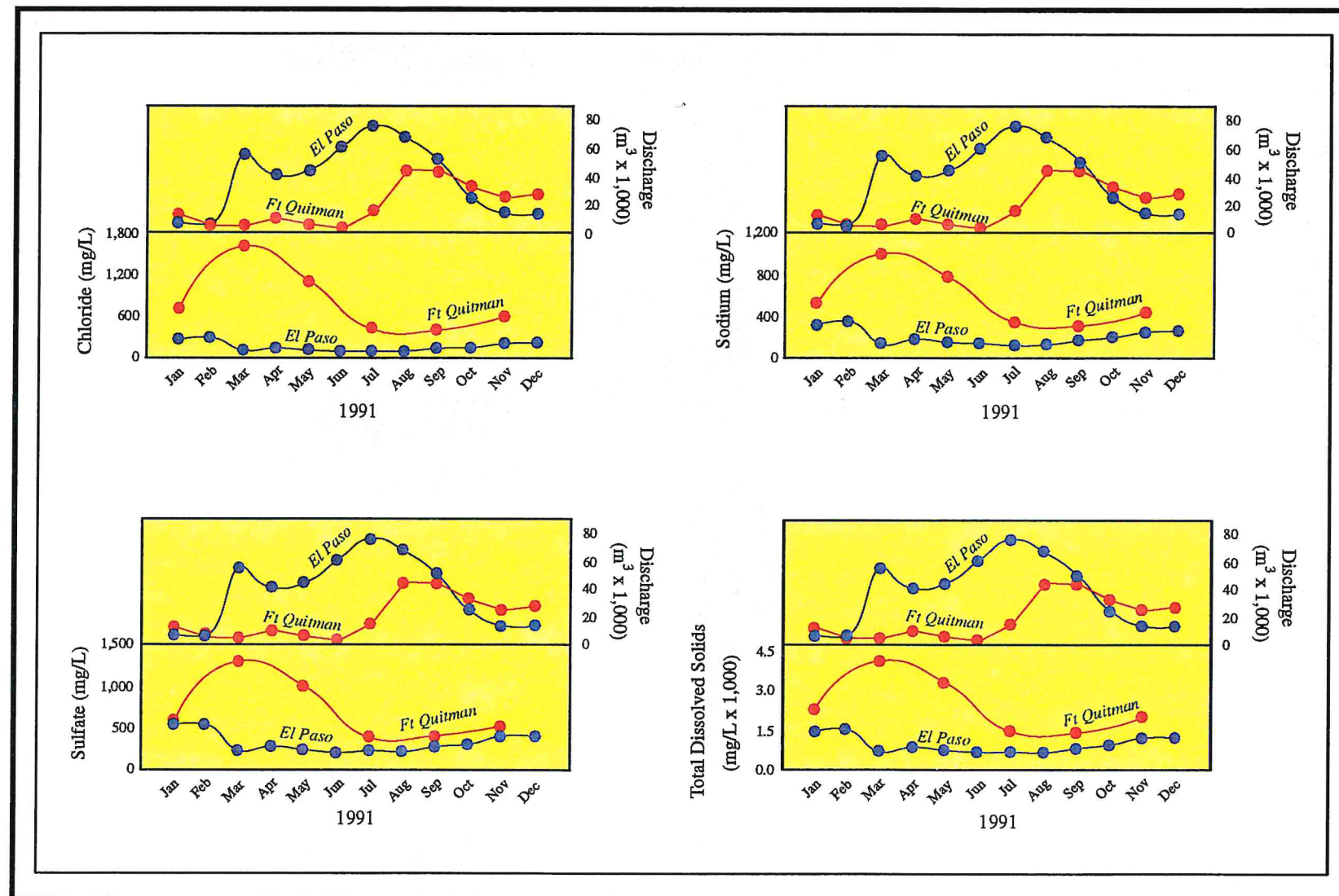


Figure 5.12b. Diagram comparing water quality and streamflow discharge for the Rio Grande at El Paso and Ft Quitman, 1991. Spatial changes in Cl, SO₄, Na, and TDS for most months indicate appreciable decline in surface-water quality downstream of El Paso. Water quality improves when discharge is high as an artifact of dilution by large quantities of dilute reservoir water and by stagnation of saline baseflow as a result of high river stage (source of data, IBWC Water Bulletin series "Flow of the Rio Grande and Related Data").

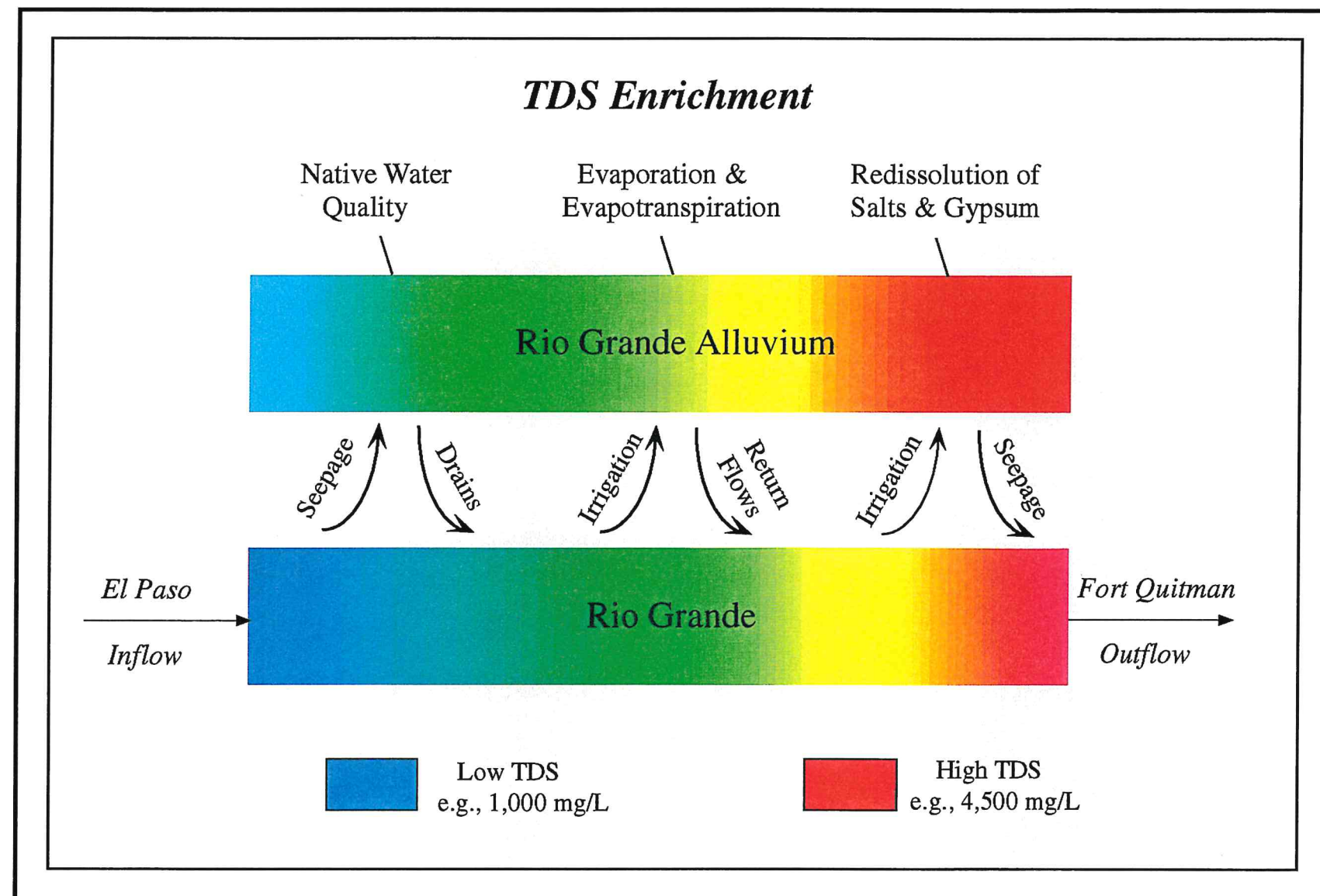


Figure 5.13. River salinities fluctuate downstream of El Paso due to inflows from several sources that both dilute and enrich Rio Grande water with respect to total dissolved solids. An overall pattern of salt water enrichment occurs between El Paso and Fort Quitman.

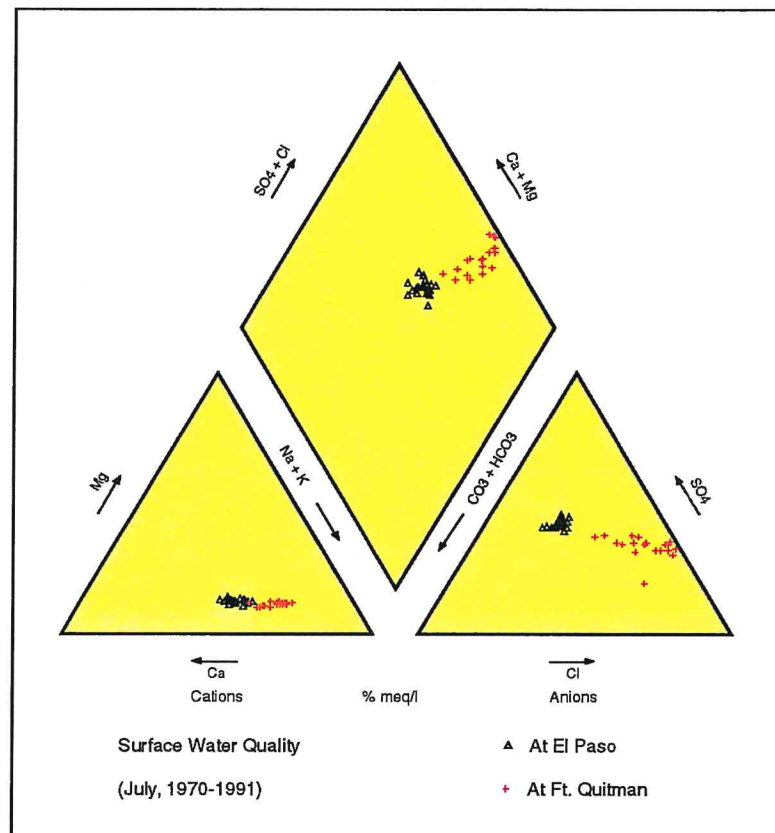


Figure 5.14a. Piper diagram shown in time series that illustrates surface water at the El Paso and Fort Quitman gage stations, January, 1970 - 1991. Surface water groups into distinct clusters of different hydrochemical types at the two gage stations (source of data, IBWC Water Bulletin series "Flow of the Rio Grande and Related Data").

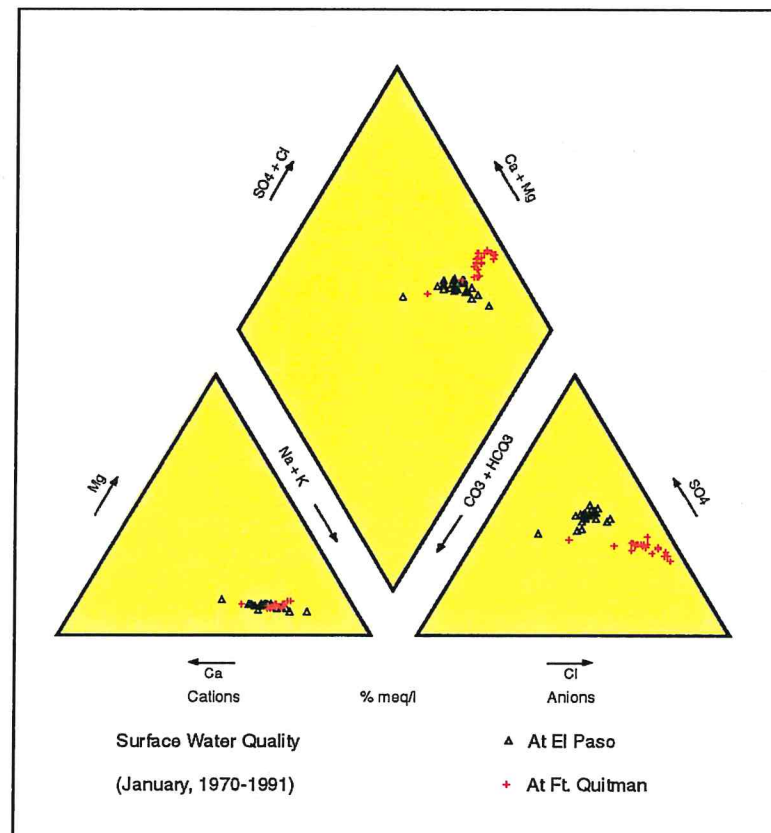


Figure 5.14b. Piper diagram shown in time series that illustrates surface water at the El Paso and Fort Quitman gage stations, July, 1970 - 1991. Surface water groups into distinct clusters of different hydrochemical types at the two gage stations (source of data, IBWC Water Bulletin series "Flow of the Rio Grande and Related Data").

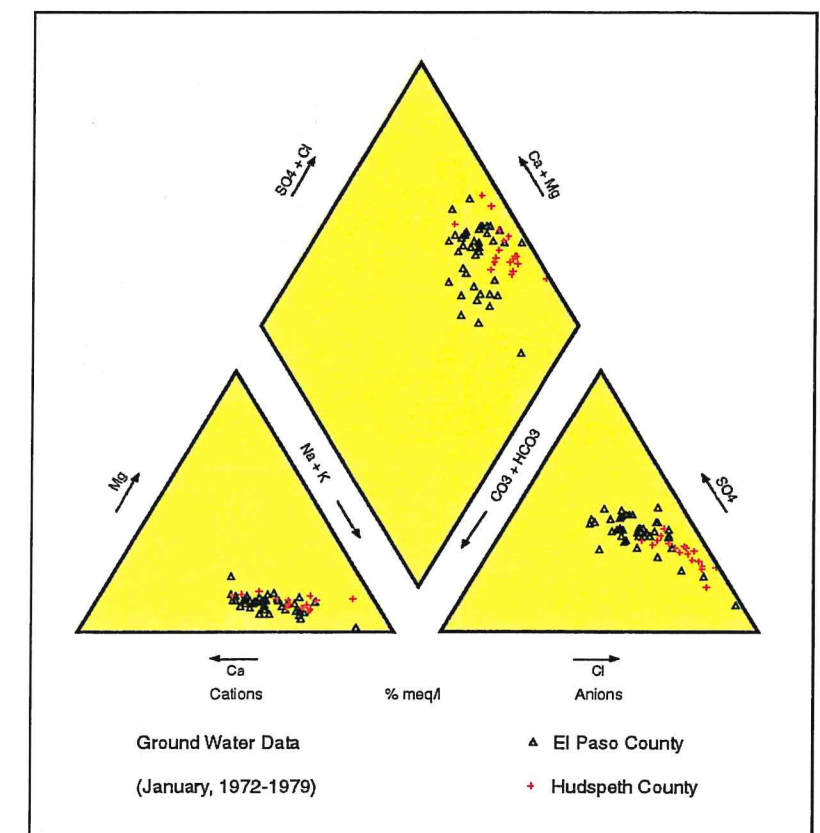


Figure 5.15. Piper diagram for the Rio Grande aquifer in El Paso and Hudspeth counties. These data indicate a clear relationship to surface water quality (Figure 5.14) at El Paso and Fort Quitman (source of data, Texas Water Development Board).

sumptive use, and enriched return flow (Figures 5.13 and 5.16).

Evaporation of water in the Mexican part of the Rio Grande aquifer is indicated clearly with stable isotope data (Figure 5.17). These data (Payne, 1976) indicate evaporative enrichment of alluvial ground water, probably during application of irrigation water to irrigable crops. Enrichment of soil water with heavier stable isotopes, and simultaneous enrichment of salts in soil water occurs as a result of evapotranspiration of water from soil profiles, and leaching of salts and enriched soil water to the shallow water table.

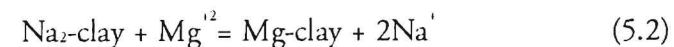
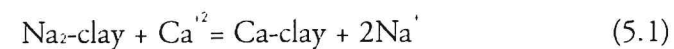
Stream and canal seepage act to partially control salinities. Where there is seepage from rivers and canals to the alluvial aquifer, especially between the Chamizal zone and county line, the seepage helps to maintain dilute concentrations in the aquifer. Along this reach, the heads in the Rio Grande aquifer are generally equal to or below the head in the stream. This favors direct seepage to the alluvial aquifer, especially when river stage is high due to irrigation releases, or flood stage. Below the El Paso/Hudspeth county line, heads in the alluvial aquifer tend to be slightly higher than heads in the river during normal stage. This condition minimizes direct seepage from the river, except when stream stage is abnormally high.

Upwelling waters from undeveloped portions of the Hueco-Tularosa aquifer and southeastern Hueco aquifer may dilute or enrich Rio Grande water with respect to dissolved solids, depending on the spatial variability of salinity in each aquifer. The data appear to indicate that dilution of Rio Grande water occurs in the Fabens artesian zone. Data in other areas are insufficient to determine effects of cross-formational flow on salinities.

Origin of solutes

Understanding the origin of natural solutes in the aquifer is a first step in deciphering anthropogenic contamination. A discussion of the origin of solutes in the Rio Grande aquifer is therefore provided.

Changing ion ratios with increasing chlorinity (i.e., salinity) are the most conspicuous hydrochemical trends in the aquifer. (Na/Cl) molar ratios decrease from 2.4 to 0.6 with increasing chlorinity (Figure 5.18). (Na/Cl) ratios greater than 1.0 at low chlorinities are partly due to excess sodium in infiltrating river waters. (Na/Cl) ratios are slightly higher in the aquifer and recharge by river water cannot account for all of the excess sodium in the aquifer. Clay particles are probably adsorbing calcium and magnesium in solution in exchange for bound sodium. At lower chlorinities (< 35 mmols/L Cl), the reversible ion exchange reactions are:

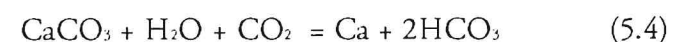


With increasing chlorinity, the (Na/Cl) ratios decrease (Figure 5.18). A molar ratio close to 1.0 indicates halite dissolution:

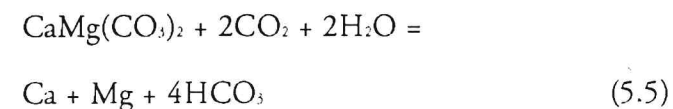


(Na/Cl) ratios are usually less than 1.0 for chlorinities greater than 35 mmols/L Cl (Figure 5.18). This indicates that ground waters are not evolving towards complete equilibrium with halite. The (Ca + Mg)/HCO₃ molar ratios increase with chlorinity (Figure 5.19). Calcium and magnesium are being added to solution at a greater rate than bicarbonate. The (Ca + Mg)/HCO₃ ratio would be less than or equal to 0.5 if magnesium and calcium originate solely from the dissolution of carbonate minerals in alluvial sediments or cement, as indicated by the governing equations:

For calcite dissolution ([Ca + Mg]/HCO₃ = 0.5):



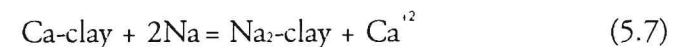
For dolomite dissolution ([Ca + Mg]/HCO₃ = 0.5):



Having (Ca + Mg)/HCO₃ ratios greater than 0.5 at higher chlorinities indicates an additional source of calcium and/or magnesium (Figure 5.19). A possible source of excess calcium could come from dissolution of gypsum:

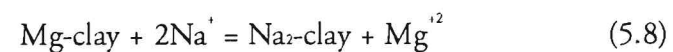


or reversible ion exchange:



Average (Ca/SO₄) ratios do not change for the full range of chlorinity (Figure 5.20), suggesting that (1) gypsum dissolution is the primary source of calcium at increasing salinities (releasing 1 equivalent calcium for 1 equivalent sulfate), and that (2) calcium is not substantially liberated by ion exchange. Reaction 5.6, instead of reaction 5.7 is the primary source of most of the additional calcium.

(Na/Cl) molar ratios less than 1.0 at chlorinities greater than 35 mmols/L Cl (Figure 5.18) probably result from the loss of sodium for bound magnesium:



(Mg/SO₄) ratios show an additional source of magnesium with increasing chlorinity (Figure 5.21), supporting the hypothesis of exchange of bound magnesium for sodium (reaction 5.8). That sodium is exchanged preferentially for bound magnesium (in lieu of bound calcium) is a function of the low selectivity coefficient for the magnesium versus calcium exchange pair. Valid for large ranges of ratios of magnesium to calcium and ionic strength, selectivity coefficients are typically in the range 0.6 to 0.9 (Jensen and Babcock, 1973) indicating that magnesium is released preferentially in clays in exchange for sodium in solution.

These analyses, along with stable isotopes (Figure 5.17) indicate evolution of water chemistry from a dilute, Na-SO₄ water that is similar in composition to Rio Grande water, to a more concentrated Na-Cl-SO₄ water through a number of simple chemical reactions and processes:

- Evaporation of water.
- Exchange of calcium and magnesium for bound sodium at chlorinities lower than 35 to 40 mmols/L Cl.
- Reverse exchange of sodium for bound magnesium and calcium by cation exchange at chlorinities greater than 35 to 40 mmols/L Cl, preference to magnesium exchange due to the Mg/Ca selectivity coefficient.
- Dissolution of halite and gypsum for the full range of salinities.

Historical change

Water quality data are too limited to assess long term changes in the chemistry of the Rio Grande aquifer. Most of the water quality data were collected between 1970 and 1980, an inadequate time interval to assess historical change.

An obvious relationship was shown between salinities and chemistries in the Rio Grande and Rio Grande aquifer between El Paso and Fort Quitman (compare Figures 5.14 and 5.15). Historical water quality data from the Rio Grande potentially may be used as proxy data for temporal changes in the Rio Grande aquifer along upstream and downstream segments of the floodplain. Data at the Fort Quitman gage station clearly indicate increasing salinities in the Rio Grande since 1936 (Figure 5.22). If these are suitable proxy data for historical changes in aquifer water quality, then water in the aquifer has been degraded profoundly during the period of record.

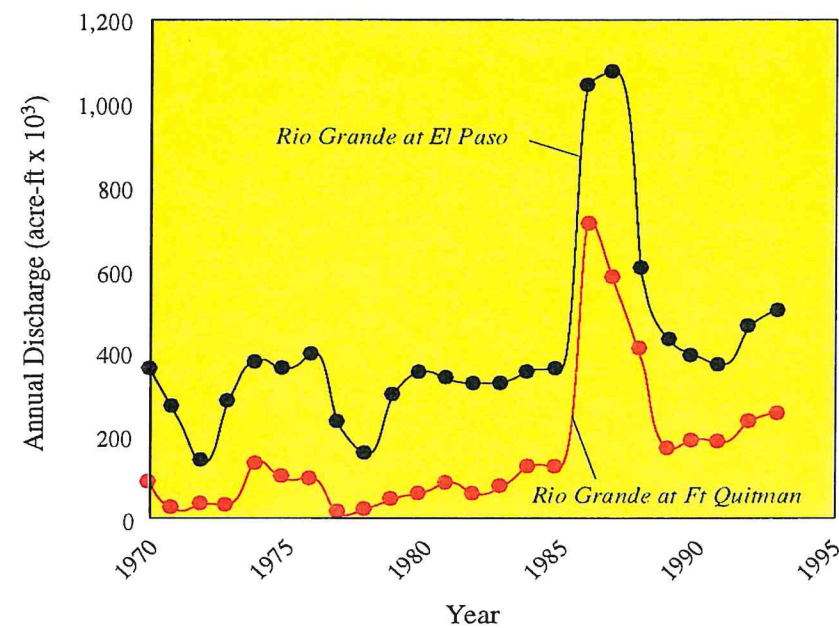


Figure 5.16. Comparison of discharge quantities in the Rio Grande at El Paso and Fort Quitman. Substantial loss of discharge is due to evapotranspiration by crops and other consumptive uses that tend to concentrate salts in fields and to enrich return flows with respect to total dissolved solids (source of data, IBWC Water Bulletin series "Flow of the Rio Grande and Related Data").

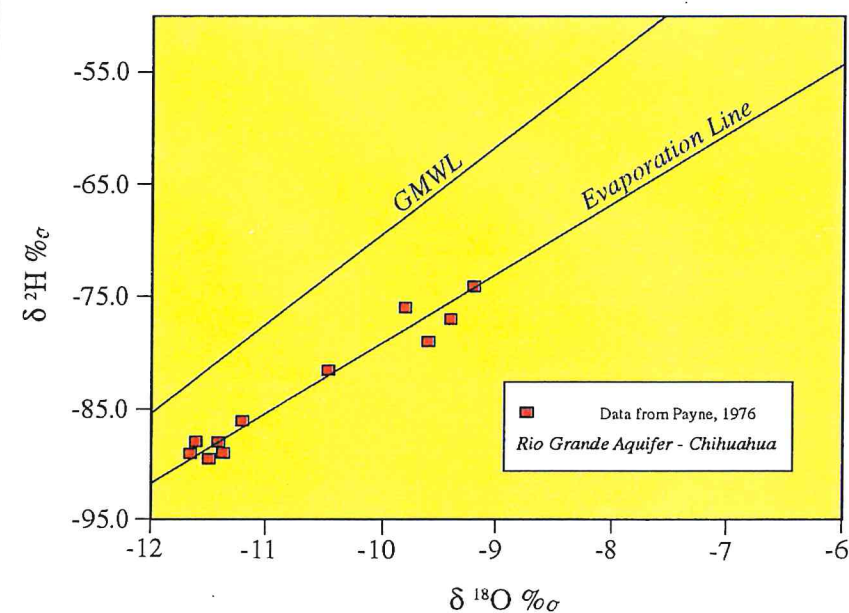


Figure 5.17. Binary plot of $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ values for Rio Grande aquifer waters in the Mexican part of the alluvial aquifer. Stable hydrogen and oxygen isotope ratios in ground waters plot along the evaporation line, indicating evaporative enrichment of water, probably during irrigation (source of data, Payne, 1976).

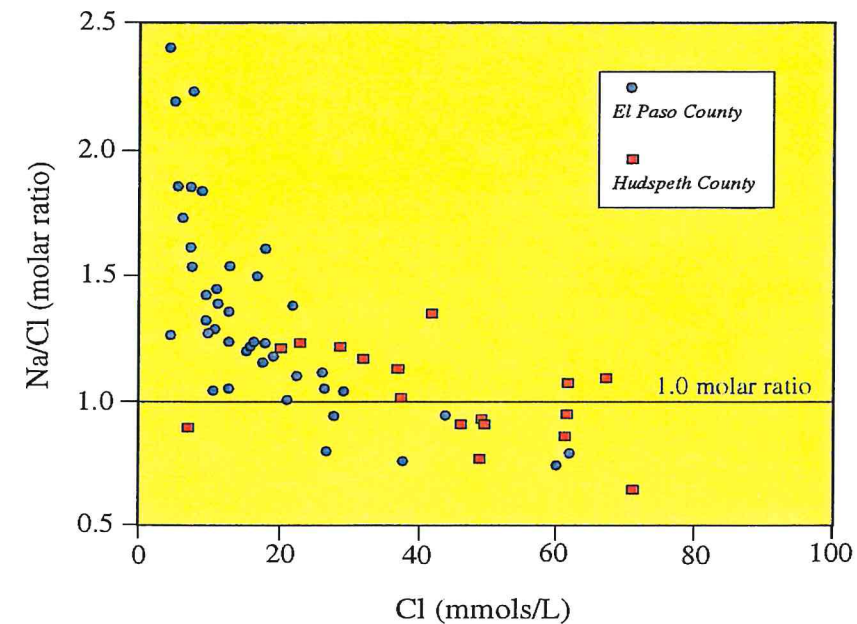


Figure 5.18. Scatter plot showing (Na/Cl) molar ratios vs molar Cl for samples collected from the Rio Grande aquifer in El Paso and Hudspeth Counties. (Na/Cl) molar ratios decrease from 2.4 to 0.6 with increasing chlorinity (source of data, Texas Water Development Board).

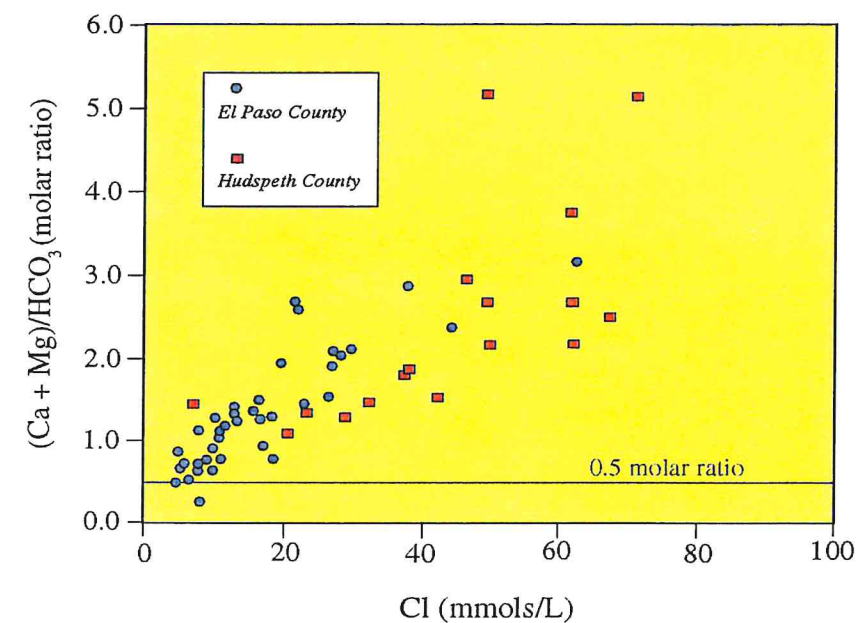


Figure 5.19. Scatter plot showing (Ca+Mg)/ HCO_3 molar ratios vs molar Cl for samples collected from the Rio Grande aquifer in El Paso and Hudspeth Counties. Points above the 0.5 ratio line indicate a source of calcium and/or magnesium other than dissolution of carbonate rock (source of data, Texas Water Development Board).

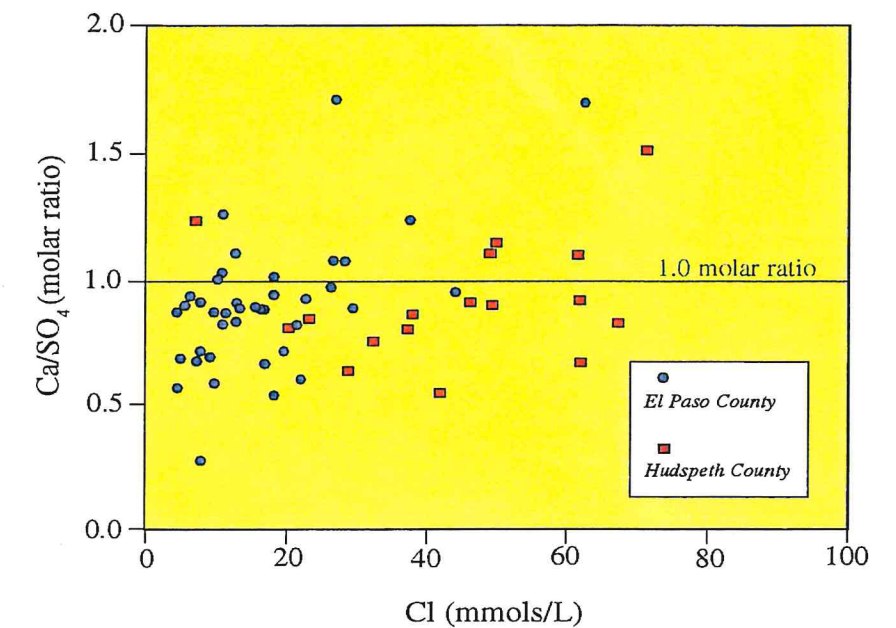


Figure 5.20. Scatter plot showing (Ca/ SO_4) molar ratios vs molar Cl for samples collected from the Rio Grande aquifer in El Paso and Hudspeth Counties. Average (Ca/ SO_4) ratios do not change with increasing chlorinity (source of data, Texas Water Development Board).

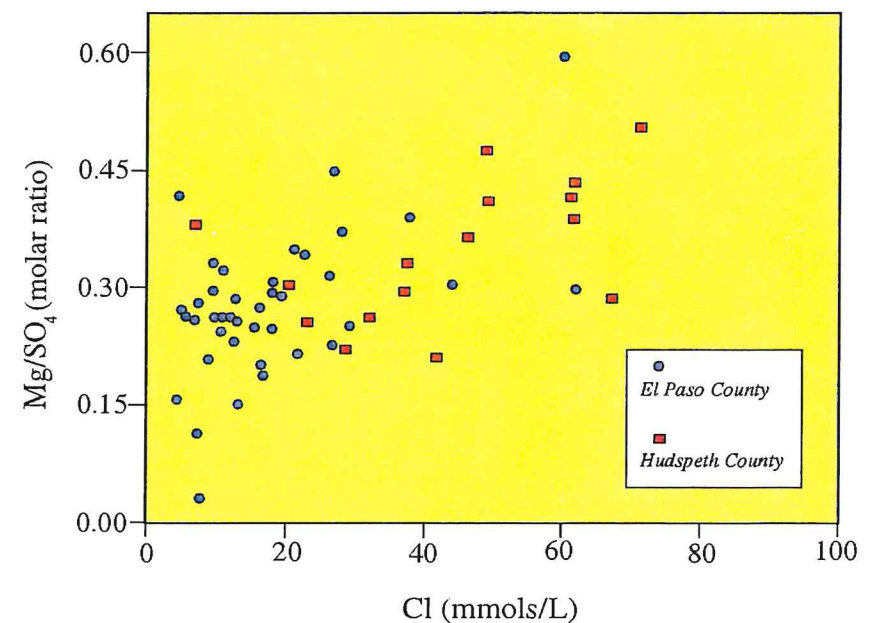


Figure 5.21. Scatter plot showing (Mg/ SO_4) molar ratios vs molar Cl for samples collected from the Rio Grande aquifer in El Paso and Hudspeth Counties. Average (Mg/ SO_4) ratios increase with increasing chlorinity, suggesting an additional source of Mg (source of data, Texas Water Development Board).

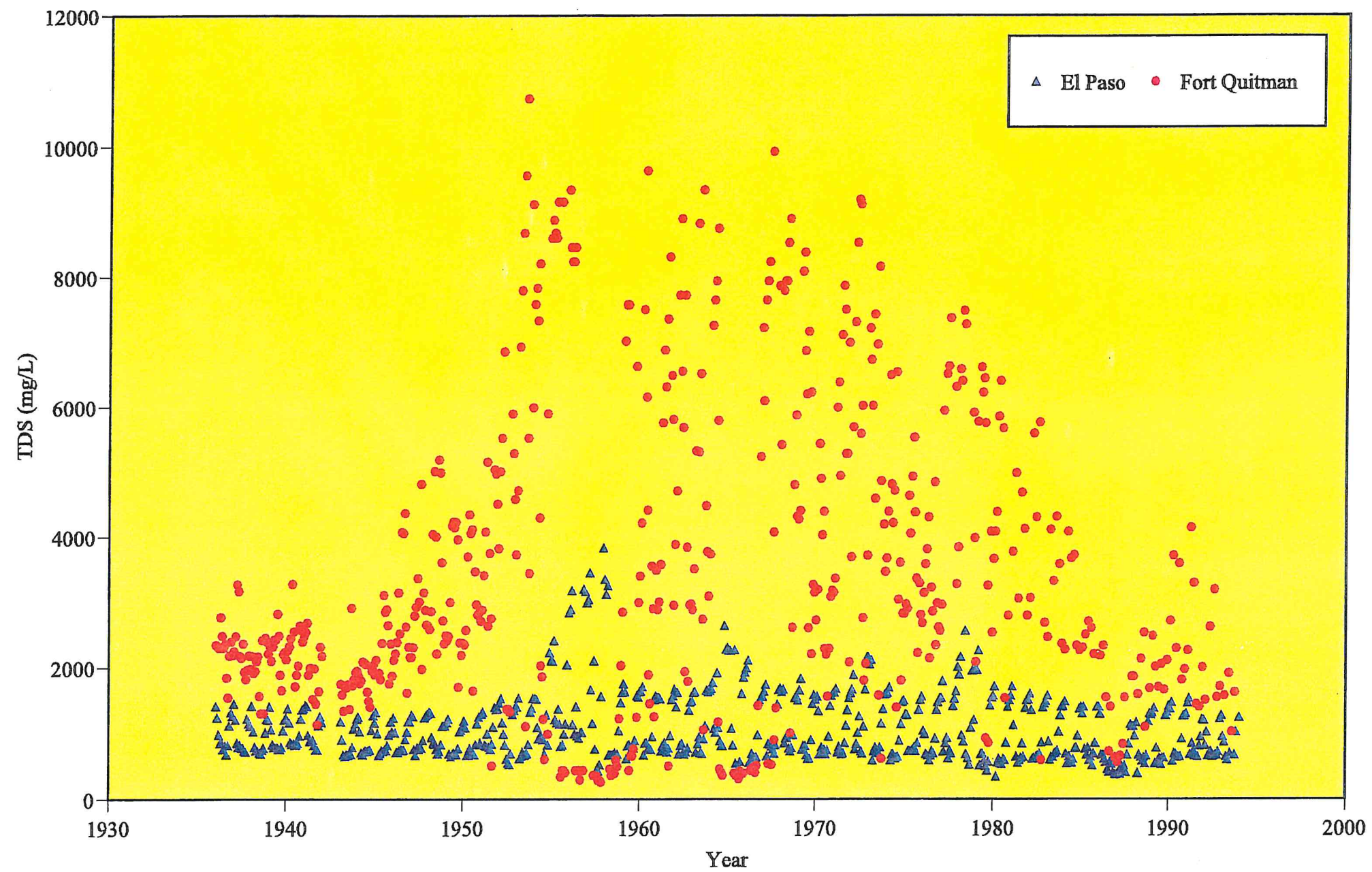


Figure 5.22. Time series graph of increasing salinities in the Rio Grande (source of data, IBWC Water Bulletin series "Flow of the Rio Grande and Related Data").

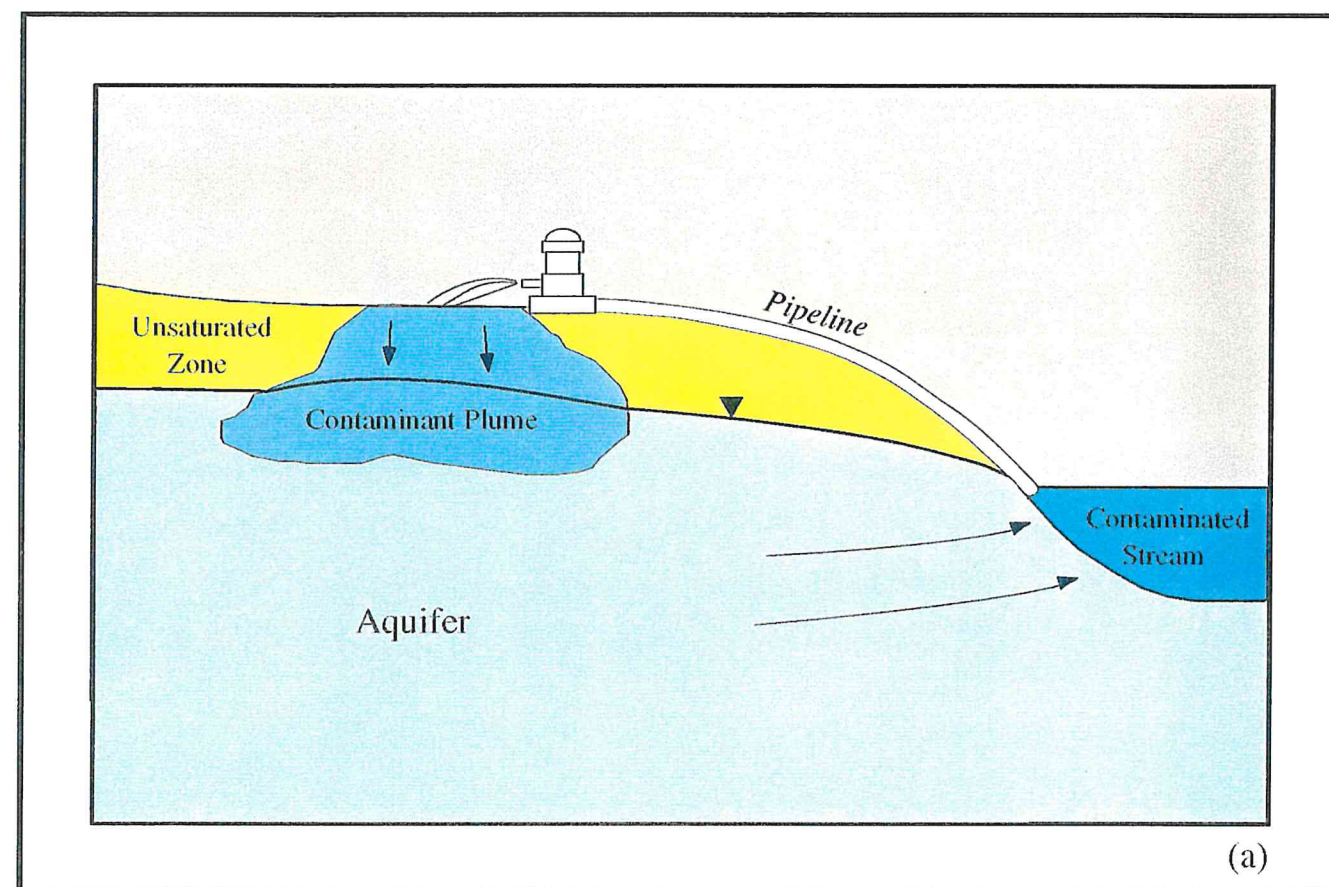


Figure 5.23a. Diagram illustrating contamination of an alluvial aquifer from a contaminated stream. Direct application of surface water may contaminate the aquifer.

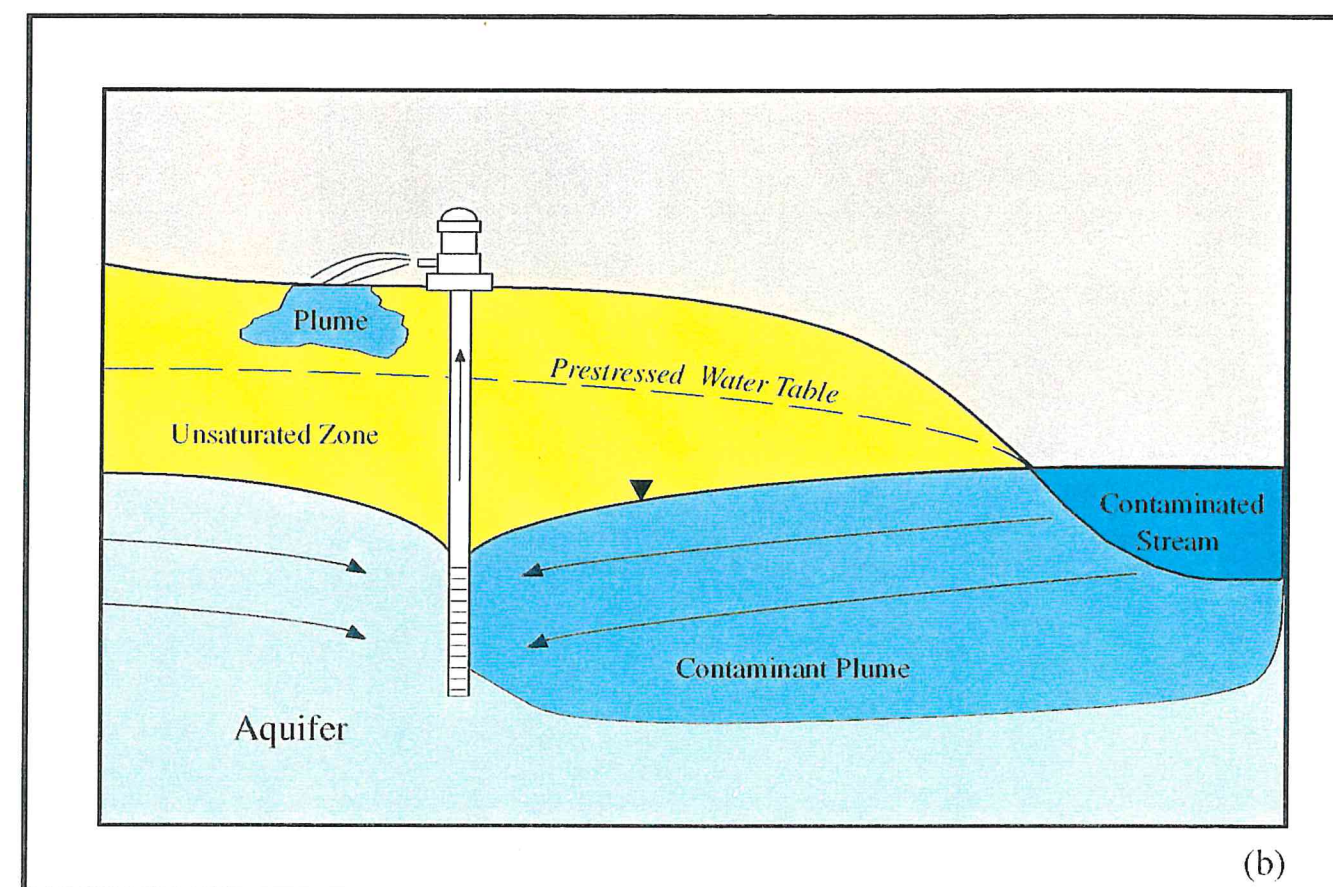


Figure 5.23b. Diagram illustrating contamination of an alluvial aquifer from a contaminated stream. Induced infiltration of contaminated surface water may contaminate the aquifer.

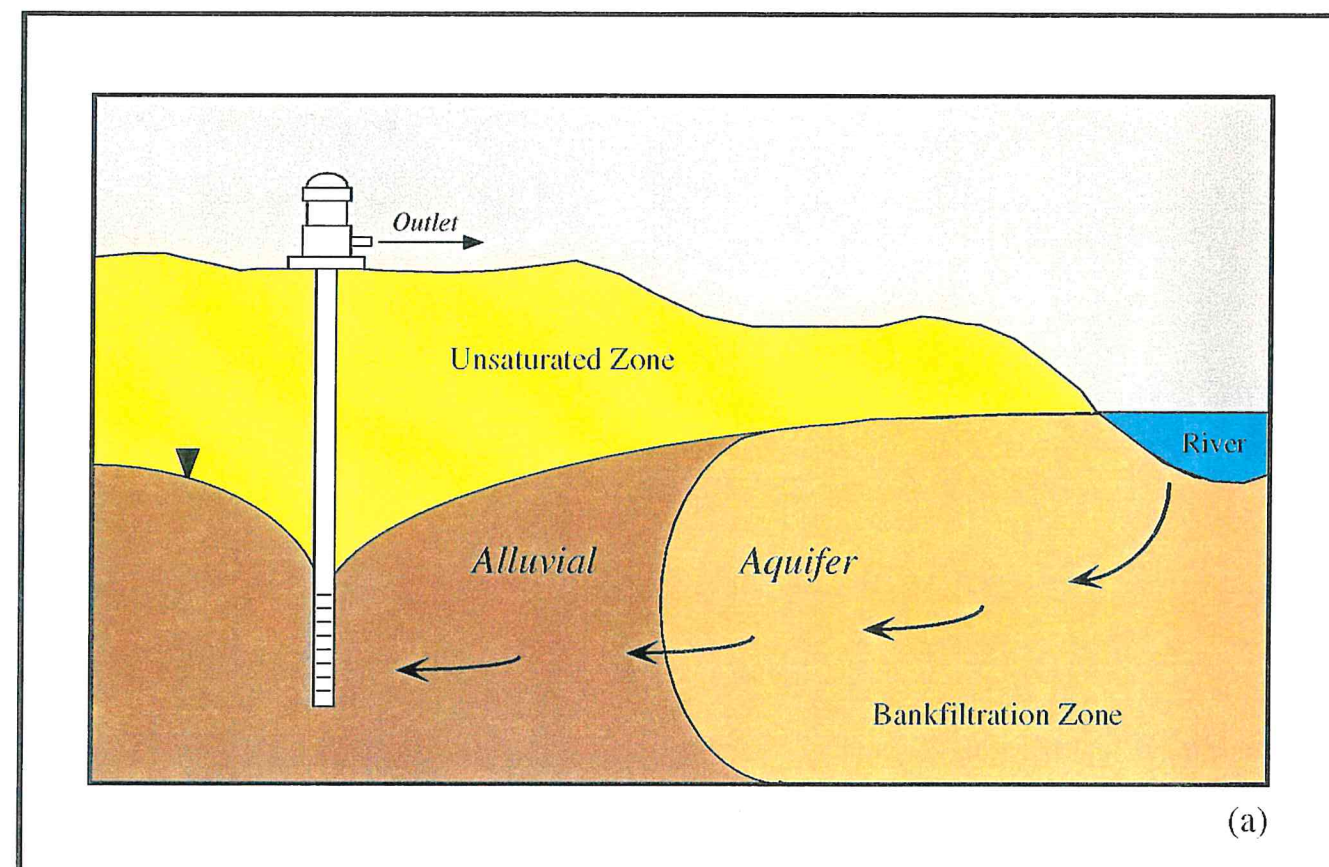


Figure 5.24a. Bankfiltration during induced infiltration from a river to a high-capacity well in a porous alluvial aquifer. Bankfiltration immobilizes and degrades many undesirable pollutants during transport from a contaminated river to the pumping well. This results in natural pre-treatment of poor quality river water.

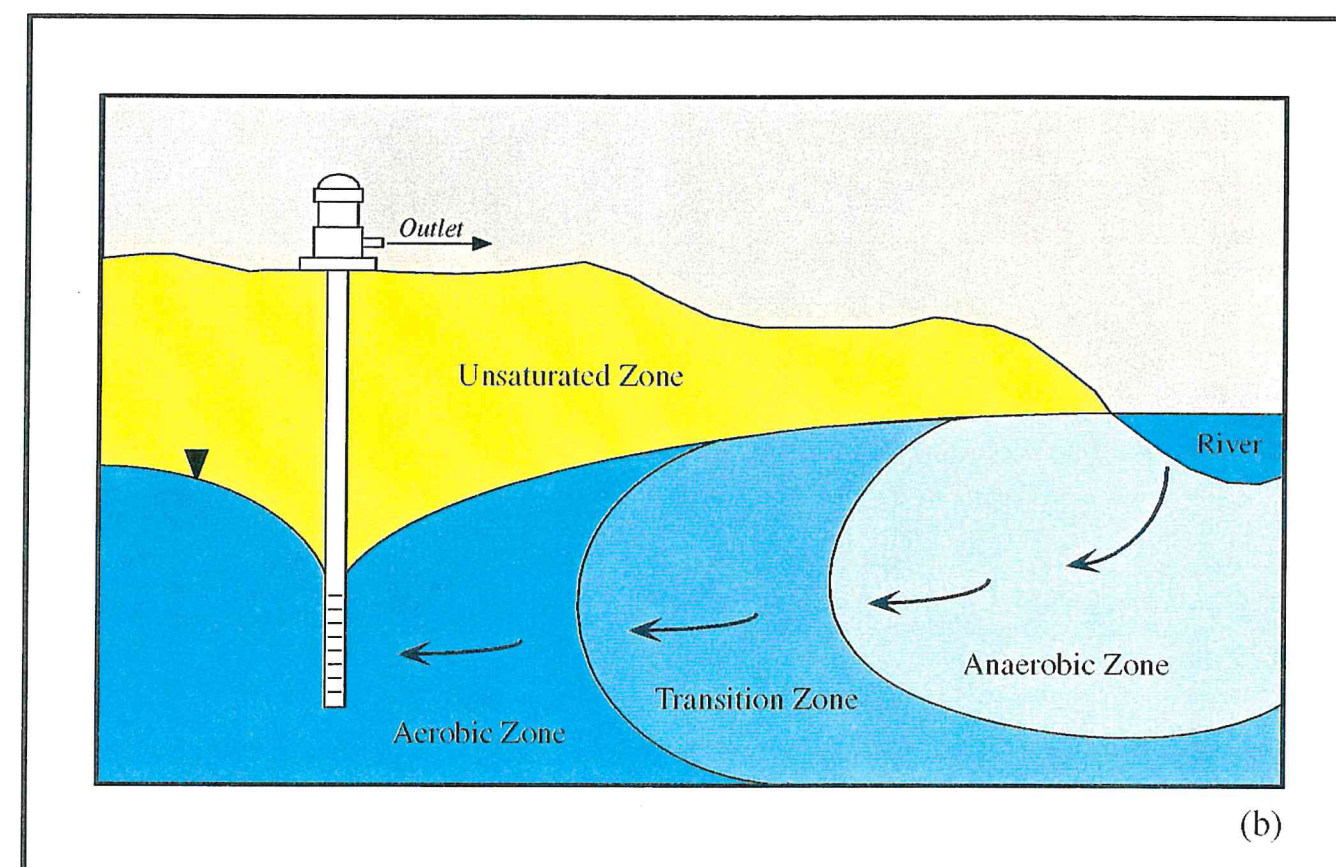


Figure 5.24b. Bankfiltration often creates redox zones as a result of microbial reduction of river micronutrients that have penetrated the aquifer during infiltration of river water. Close to the river, in the anaerobic zone, many metals and pollutants are mobile. In the aerobic zone, metals are fixed, and pesticides and organic pollutants may be biologically degraded.

Susceptibility to Contamination

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 (Cross and Terry, 1991).

Where the Rio Grande aquifer is hydraulically connected to the Rio Grande, contaminants carried by the river can readily contaminate the aquifer. Contamination can occur due to (a) direct application of contaminated surface water, or by (b) induced infiltration of contaminated surface water (Figure 5.23). 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, municipal discharges, and low flows in the fall and winter. The quality of Rio Grande water deteriorates further along and downstream of the City of El Paso/Ciudad Juarez corridor. 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).

Induced infiltration occurs when drawdown from a high capacity well(s) reverses the hydraulic gradient between the well and the stream (Figure 5.24). The removal of suspended or dissolved substances in the infiltrated river water is called "bankfiltration." Bankfiltration may actually have a beneficial effect on drinking water supply and does not necessarily contaminate the aquifer. The process immobilizes and degrades undesirable pollutants by porous filtering, chemical attenuation, and biological decomposition during induced infiltration from a river to a high-

capacity well (Figure 5.24). Even after many decades of well pumping, bankfiltration continues to remove more than 75 percent of the dissolved organic constituents in river water and as much as 95 percent of the heavy metals without substantial clogging (Sontheimer, 1980; Brand and others, 1989). In-situ pretreatment of heavily polluted river water by bankfiltration coupled with secondary (standard) water treatment usually ensures a high-quality drinking water supply.

Waters of very different chemistry and temperature mix during bankfiltration. The mixing gives rise to complex interactions between soils, bacteria, pollutants, and geochemical species. Organic micronutrients are concentrated in river water and settle in interstitial spaces in streambed and alluvial sediments during bankfiltration (Schwarzenbach and Westall, 1981; Brand and others, 1989). Microbial reduction of micronutrients often creates an anaerobic zone in the aquifer which remobilizes the pollutants (especially trace elements and heavy metals). The anaerobic zone is localized within a few tens of meters of the stream/aquifer interface (Brand and others, 1989). Beyond the anaerobic zone, the subsurface alluvial environment usually is first moderately, and then strongly, aerobic (Figure 5.24).

In the aerobic zones, trace elements and heavy metals are immobilized and many other pollutants are reduced to harmless chemical compounds. Weakly immobilized pollutants that have intruded into the aerobic zone may be remobilized (Brand and others, 1989). Nevertheless, a permanent aerobic zone is established at some distance from the stream/aquifer interface where redox conditions are perennially oxidizing and where water wells may be more safely located.

Future studies of the Rio Grande aquifer should identify aerobic zones where it is safer to install water wells. Water wells located too close to the river in the anaerobic zone may have higher yields, but may not derive the cleansing benefits of bankfiltration.

References

- Alvarez, H.J., and Buckner, A.W., 1980, Ground-water development in the El Paso region, Texas, with emphasis on the resources of the lower El Paso Valley: Texas Department of Water Resources Report 246, 346 p.
- Brand, K.H., Hotzl, H., and Kass, W., 1989, Transport and fixation of cadmium, copper, lead and zinc in a porous aquifer: Proceedings of the International Symposium on Contaminant Transport in Groundwater, Stuttgart, p. 459 - 460.
- Cech, I, and Essman, A., 1992, Waste sanitation practices on the Texas-Mexico border - implications for physicians on both sides: Southern Medical Journal, v.85, no.11, p. 1053 - 1064.
- Cross, B.L., and Terry, D.P., 1991, A ground water protection strategy, the City of El Paso: Texas Water Commission Report 91-01, 154 p.
- Eaton, D.J., and Anderson, J.M., 1987, The State of the Rio Grande/Rio Bravo: University of Arizona Press, Tucson, 331 p.
- Fisher, R.S, and Mullican, W.F., III, 1990, Integration of ground-water and vadose-zone geochemistry to investigate hydrochemical evolution, a case study in arid lands of the northern Chihuahuan Desert, Trans-Pecos, Texas: The University of Texas at Austin Bureau of Economic Geology Geological Circular 90-5, 36 p.
- IBWC (International Boundary and Water Commission), 1989, Ground water conditions in El Paso/Juarez Valley: Hydraulics Branch, Planning Division, 43 p.
- Jensen, H.E., and Babcock, K.L., 1973, Cation-exchange equilibria on a Yolo loam: Hilgardia, 41, p. 475 - 488.
- Larkin, R.G., 1988, Hydrogeologic Controls on Underflow in Alluvial Valleys - Implications for Texas Water Law: Unpublished M.A. thesis, University of Texas at Austin, 135 p.
- Lee Wilson and Associates, Inc., 1986, Exhibit 1 of the City of El Paso in support of its applications to appropriate ground water in New Mexico: Unpublished consultant's report prepared for the El Paso Water Utilities Public Services Board, 75 p.
- Longnecker, D.E., and Lyster, P.J., 1959, Some relations among irrigation water quality, soil characteristics and management practices in the Trans-Pecos area: Texas Agricultural Experiment Station Report MP-373, 17 p.
- Meyer, W.R., 1976, Digital model for simulated effects of ground-water pumping in the Hueco Bolson, El Paso area, Texas, New Mexico, and Mexico: U.S. Geological Survey Water-Resources Investigations Report 85-4219, 94 p.
- Payne, B.R., 1976, Environmental isotopes as a hydrogeological tool: Arbeitstag, "Isotope in der Natur" Gera, ZFI Mitteilungen / Zentralinstitut für Isotopen- und Strahlenforschung, 5; p. 177 - 199.
- Schwarzenbach, R.P., and Westall, J., 1981, Transport of non-polar organic compounds from surface water to ground water - laboratory sorption studies: Environmental Science and Technology, v.15, no.11, p. 1360 - 1367.
- Sontheimer, H.J., 1980, Experience with riverbank filtration along the Rhine River: American Water Works Association, v.72, no.400, p. 386 - 390.
- USBR (U.S. Bureau of Reclamation), 1973, Water Resources of El Paso County, Texas: Rio Grande Project, New Mexico - Texas Project Office, El Paso, Texas, 97 p.
- Young, P.W., 1981, Evaluation of surface and ground irrigation water; the Lower El Paso Valley emphasizing Hudspeth County, Texas: West Texas Council of Governments, 219 p.