

CHAPTER 6 - DIABLO PLATEAU AQUIFER

Location and Extent

The Diablo Plateau covers all but the southern part of Hudspeth County, Texas (Figure 6.1). The plateau is juxtaposed against regional grabens that formed by Quaternary-age lateral extension and normal faulting. The Campgrande fault displaces Cretaceous strata against bolson deposits southwest of the fault, forming an escarpment of more than 400 ft (Fisher and Mullican, 1990). 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 study area.

Stratigraphy and Water-Bearing Characteristics

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 Campgrande 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 (Kreitler and others, 1987). 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 (Ashworth, 1995). Lithologic control for this aquifer outside the Dell City area is extremely limited.

The Cretaceous strata are reported to be at least 200 ft thick (Kreitler and others, 1987), and occupy the south-southwestern part of the study area. It is not yet

known whether the Cretaceous strata in the Diablo Plateau are a unitary aquifer system, or if these rocks comprise several poorly connected aquifers (Fisher and Mullican, 1990).

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 (Mayer, 1995). Of these, only the Victorio Peak and Bone Spring Formations comprise the main aquifer. For convenience, the water bearing strata beneath the Diablo Plateau (Texas) and Otero Mesa (New Mexico) are grouped as the "Diablo Plateau aquifer." This aquifer includes the water bearing strata in the Dell City area. Diablo Plateau and Otero Mesa are terms used herein to describe separate physiographic provinces in Texas and New Mexico, not water bearing strata.

Aquifer tests conducted in the Diablo Plateau aquifer (Kreitler and others, 1987) 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 (Kreitler and others, 1990). Scalapino (1950) reports that only 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 (Table 6.1).

Aquifer test data could not be located for the Otero Mesa region of New Mexico. Recent work by Mayer (1995) suggests that the transmissivity of Permian carbonate rocks in Otero Mesa is controlled by fracture density and orientation, and by local lithology. Mayer (1995) developed a ground water flow model for the region that provided transmissivity estimates ranging from 9.3 ft²/day to 9,300 ft²/day.

Potentiometric Surface Map and Water Levels

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 (Figure 6.2). Flow from both regions converges towards Dell City and the Salt Basin along flowpaths with average hydraulic gradients of 0.0004 (Kreitler and others, 1987), although gradients are as steep as 0.001 (measured between wells 48-24-903 and 48-12-901). 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 (Figure 6.3). 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, totalling 25 to 45 ft of drop area-wide (Ashworth, 1995). Since then, irrigation pumpage diminished, and water levels have risen slightly (Figure 6.3).

Ground-Water Availability

Volumes of ground water in the Diablo Plateau/Otero Mesa proper cannot be estimated with available data due to very limited information on aquifer permeability and saturated thickness. In the Dell City area, Ashworth (1995) estimates that a sustained yield of 90,000 - 100,000 acre-ft/year may be derived in the irrigation district without additional drawdown.

Recharge Areas

Tritium and carbon-14 (¹⁴C) levels measured in wells on the Diablo Plateau (Figure 6.4) indicate that most of the ground water samples contain recent water (i.e., water recharged within the last 50 years). The tritium and ¹⁴C 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 mi²) as demonstrated by the areal distribution of tritium-rich samples (Figure 6.4). Most recharge probably takes place during flooding of the ephemeral creeks ("arroyos") that cross the plateau. Chloride profiles in soil water show lower chloride concentrations (less than 500 mg/L) in the creek soils and higher chloride concentrations (greater than 5,000 mg/L) in the inter-arroyo soils (Kreitler and others, 1990). This is indicative of significant recharge and flushing in the arroyos and smaller amounts of recharge in the interarroyo areas.

With calculated recharge rates of 0.0005 in/yr to 0.009 in/yr (Kreitler and others, 1987), the recharge rates over much of the plateau are perceptibly small. An exception is the Dell City irrigation district, which is estimated to receive about 31,000 acre-feet of non-irrigation recharge each year (Gates and others, 1980), mainly from the Sacramento River drainage basin (Young, 1976). The relatively high rates of recharge in this area imply higher local permeability, focused runoff, and rapid infiltration rates locally.

In the Otero Mesa area most of the recharge reaches the water table through creekbeds and depressions that temporarily store precipitation runoff. Mayer (1995) estimated a composite recharge rate of 0.007 in/yr over the 1,900 mi² occupied by the Otero Mesa. The Sacramento River ends about 45 miles northwest of Dell City, its flow captured by fractures and permeable sinks that replenish Otero Mesa locally.

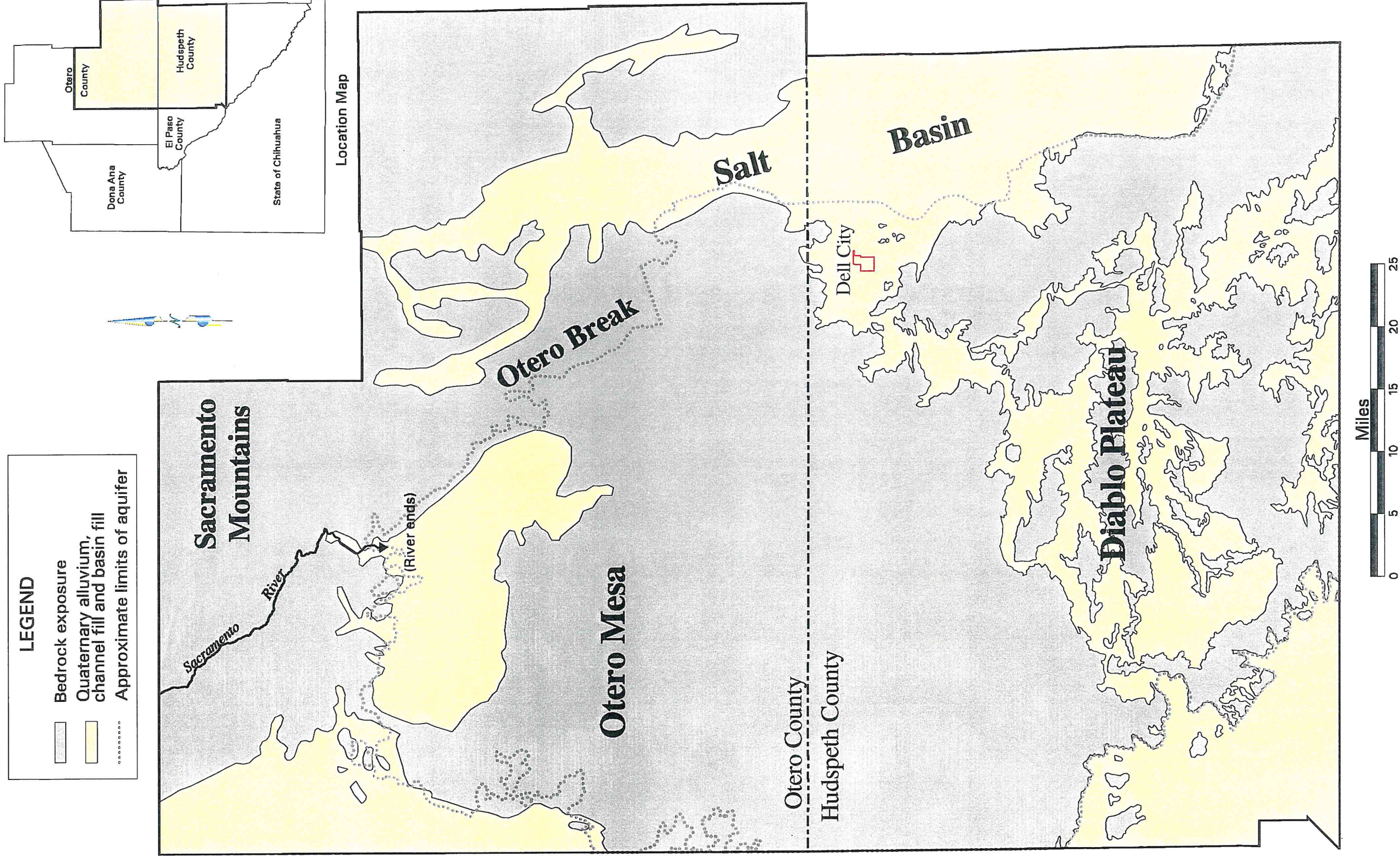


Figure 6.1. Location and extent of the Diablo Plateau aquifer and surrounding region.

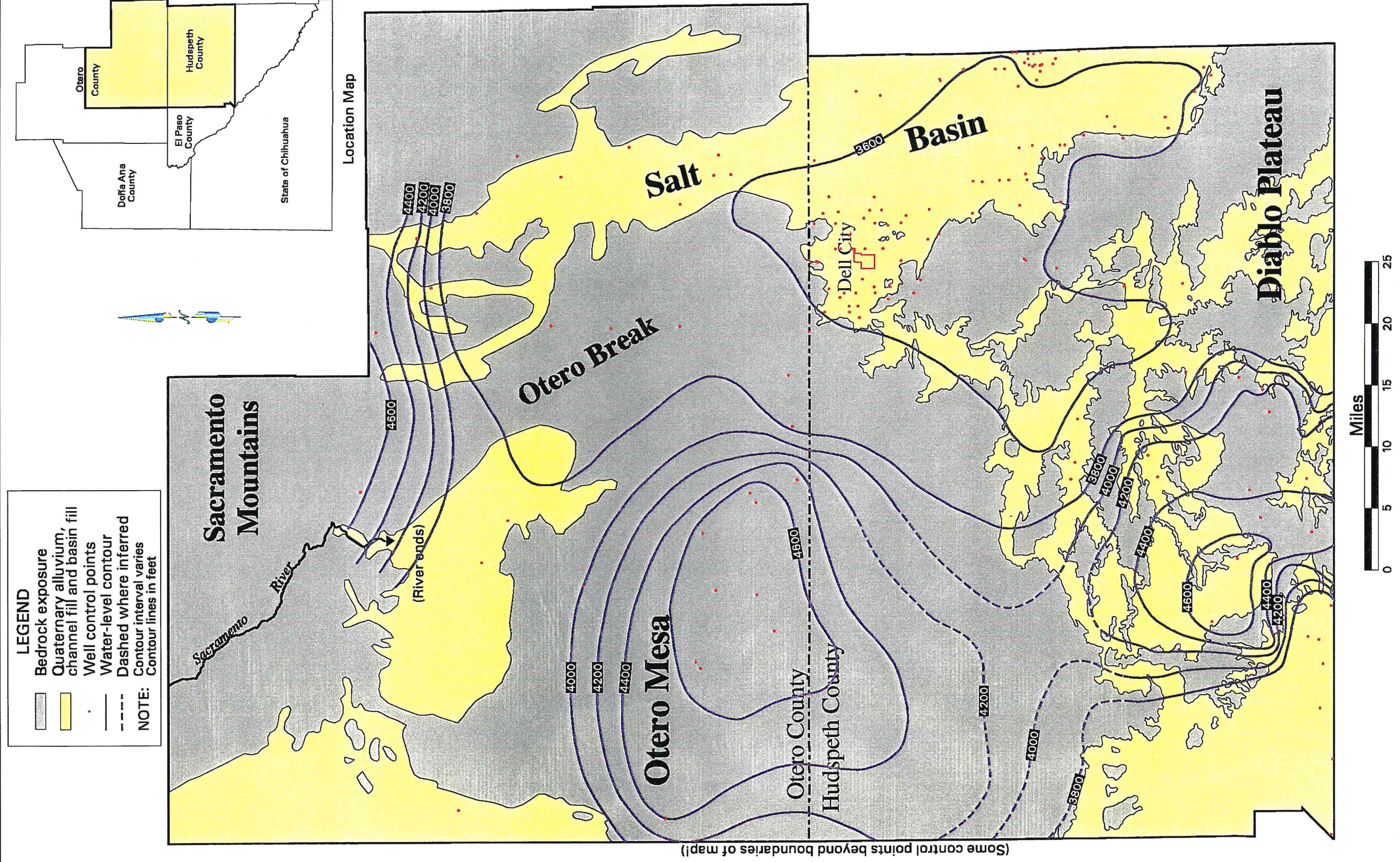


Figure 6.2. Regional potentiometric surface map for the Diablo Plateau aquifer and surrounding regions. Data for the Dell City area gathered in 1994. Other data in less developed and undeveloped areas gathered at various times. We assume quasi-steady state ground-water flow in undeveloped areas (source of data, Texas Water Development Board; Kreitler and others, 1986; Mayer, 1995).

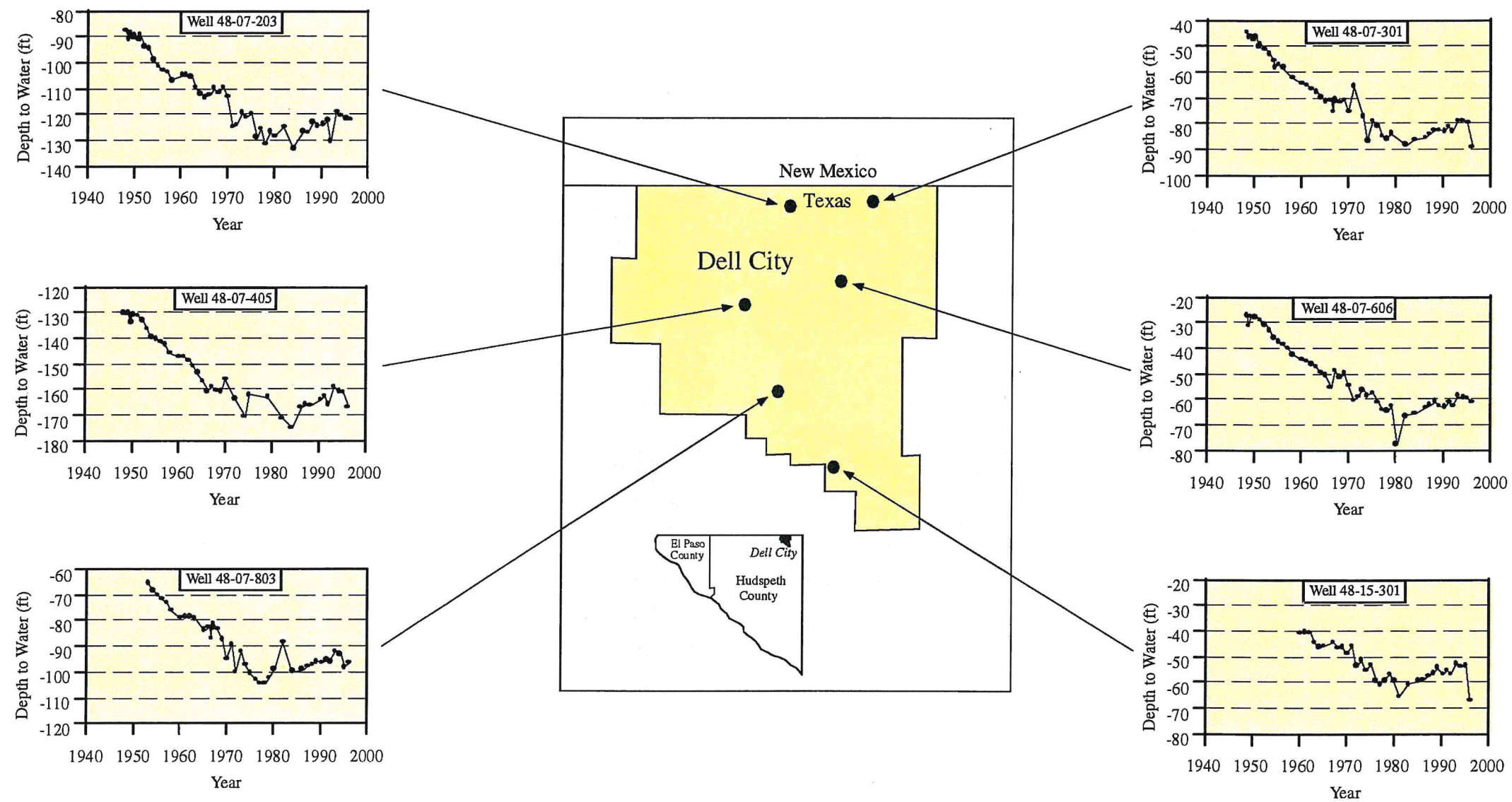


Figure 6.3. Hydrographs of selected wells in the Dell City area (modified from Ashworth, 1995).

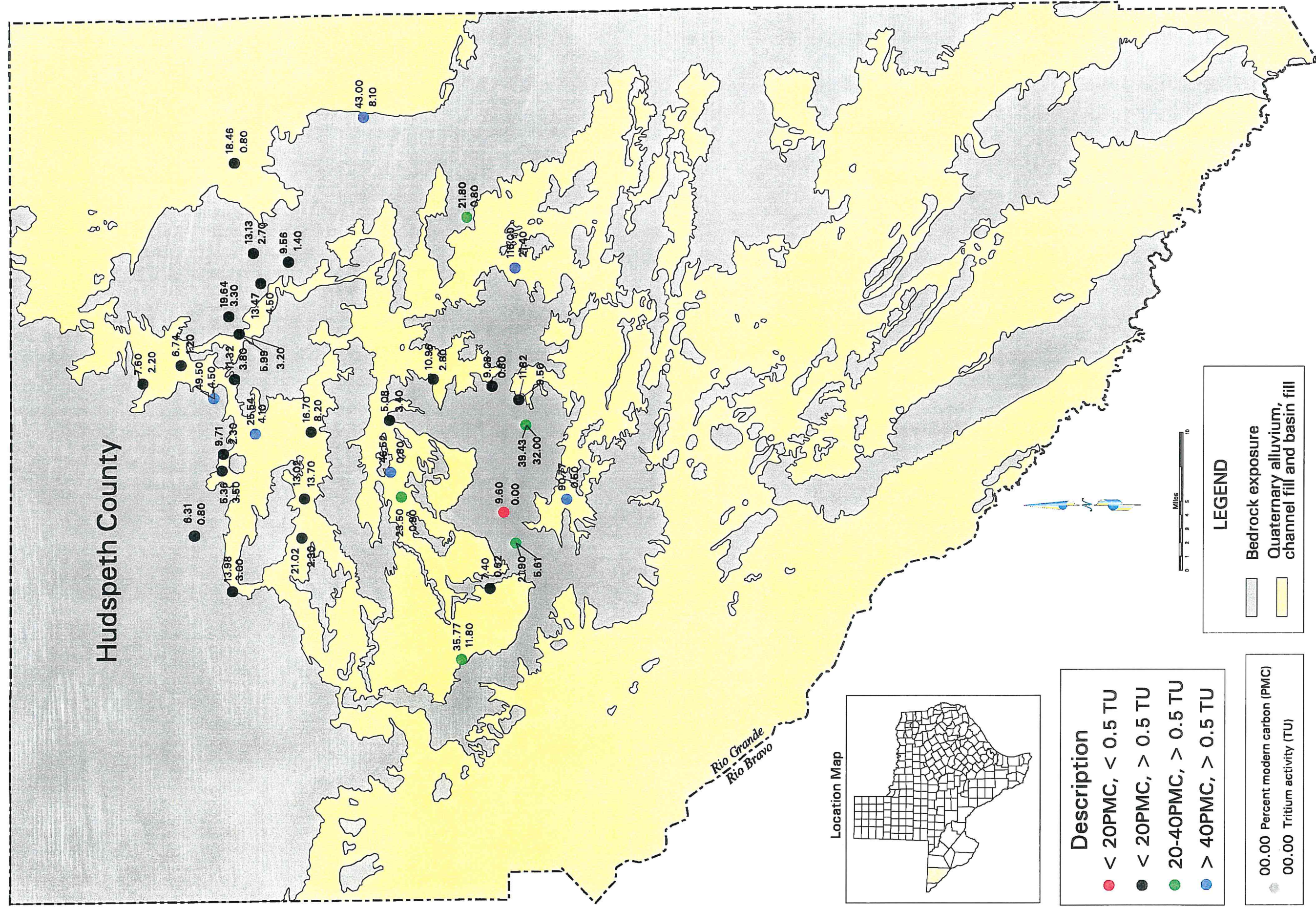


Figure 6.4. Map showing tritium activities (TU) and percent modern carbon (PMC) of ground water in the Texas portion of the Diablo Plateau aquifer (source of data, Kreitler and others, 1986).

**Transmissivity Results From Aquifer Tests
In The Diablo Plateau Aquifer**

State well number	Transmissivity (ft ² /day)	Water Bearing Strata
48-07-106	47,723.0	Permian
48-20-601	3.8	Permian
48-07-107	51,937.0	Permian
48-21-401	16.2	Permian
48-29-301	69.2	Permian
48-37-302	6,683.0	Cretaceous
48-39-101	0.5	Cretaceous

Table 6.1. Transmissivity values derived from aquifer tests in the Diablo Plateau aquifer (data from Logan, 1984; Kreitler and others, 1987).

Discharge Areas

Ground water in the Diablo Plateau aquifer is lost by discharge by irrigation wells, by ground-water evaporation, and possibly by interbasin ground-water flow (Figure 6.5). Before extensive irrigation began discharge also occurred through naturally flowing springs such as: Crow Springs, located east-northeast of Dell City; Washburn and Persimmon Springs north of Cornudas; Cove Spring on the southern side of the Paint Waterhole Mountains; Shot Springs in the Antelope Hills; Sulphur Springs on the east side of the salt flat; Cottonwood Springs southeast of the flat; and Aparejo (Harness) Springs on the southern side of Black Mountain (Brune, 1981).

Since 1958 about 85,000 acre-ft/yr has been pumped from the Dell City area for irrigating about 30,000 acres of cropland (Ashworth, 1995). Water levels in the aquifer have dropped and have eliminated most springflow (Figure 6.3). Natural discharge by evaporation occurs in the wet playas east of Dell City, as suggested by the shallow (3 ft) water table, thick capillary fringe, and upward hydraulic gradients in the salt flats (Kreitler and others, 1990).

Ground water from the Diablo Plateau aquifer may also discharge to the southeast at Balmorhea Springs and at the Cenozoic alluvial aquifer of Pecos County through interbasinal flow (LaFave and Sharp, 1987; Kreitler and others, 1990), although this hypothesis has not been proven (Figure 6.5). Permian carbonate units of the Diablo Plateau aquifer may be hydraulically connected to limestones beneath the Quaternary sediments of the Salt Basin. If permeability pathways exist in rocks beneath bolson sediments, ground water could travel along regional flowpaths to points of lower fluid potential at natural discharge areas southeast of the Diablo Plateau.

Water Quality

General hydrochemistry

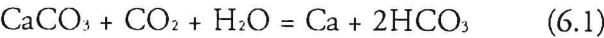
Ground water in the Diablo Plateau aquifer is fresh to brackish, with total dissolved solids (TDS) concentrations as low as 500 mg/L in the Sacramento River area, to over 3,800 mg/L in central-western Otero Mesa where water-bearing strata are interbedded with the gypsiferous Yeso Formation (Plate 1). In the Dell City area, where return flow from irrigation leaches salts from the soils and evaporates, TDS concentrations reach 6,500 mg/L (Plate 1).

Hydrochemical facies in the area vary from Na-Ca-HCO₃ and Na-SO₄ in the southwest to Na-SO₄, Ca-SO₄, and Na-Cl in the north and northeast (Figure 6.6). 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.

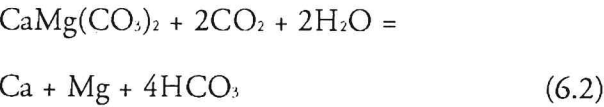
Origin of solutes

Prominent mineral dissolution and precipitation reactions that may control the hydrochemistries of the Diablo Plateau aquifer include:

Calcite dissolution and precipitation:



Dolomite dissolution:



Gypsum dissolution:



Halite dissolution:



and ion exchange:

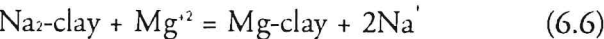
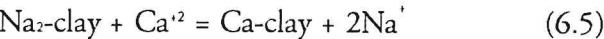


Figure 6.7 shows the relationship between the concentration of (Ca + Mg) versus HCO₃ concentration. If all (Ca + Mg) were derived from calcite and dolomite dissolution, then data would plot along a line with a slope of 1:2, as stated by the calcite dissolution equation (6.1). Yet, all points are above the 1:2 line, thus indicating an additional source of Ca and Mg. A potential source of Ca is the Yeso Formation which contains gypsum (Mayer, 1995). To account for the Ca derived from gypsum dissolution, the SO₄ concentration is subtracted from (Ca + Mg), which is then plotted as a function of HCO₃ (Figure 6.8).

The majority of data points plot below the 1:2 line, indicating that although carbonate and gypsum dissolution explain much of the variations in Ca, Mg, and HCO₃ concentrations, another process, such as ion exchange between Ca and/or Mg and Na is removing Ca and/or Mg from solution. To test this hypothesis the concentration of (Na - Cl) is plotted against (Ca + Mg - SO₄ - 0.5HCO₃). The quantity (Na - Cl) represents "excess" Na; that is, Na coming from sources other than halite dissolution, assuming all Cl is derived from halite dissolution. The quantity (Ca + Mg - SO₄ - 0.5HCO₃) represents the Ca and/or Mg coming from sources other than gypsum and carbonate dissolution. These two quantities represent the maximum amount of Na and (Ca + Mg) available for ion exchange processes. The data (Figure 6.9) plot on a line with slope close to unity, suggesting cation exchange between Ca, Mg, and Na.

Figure 6.10 plots (Na/Cl) ratios versus Cl concentrations. Ratios of Na to Cl range from 0.3 to 4.0, and tend to approach unity with increasing chlorinity.

Most of the Diablo Plateau/Otero Mesa samples show (Na/Cl) ratios greater than one due to ion exchange between dissolved Ca or Mg and adsorbed Na. Ratios less than one are common among the samples from the Dell City irrigation district and are attributed to a process of "reversed ion exchange", which occurs when dissolved Na is exchanged for bound Ca and Mg.

The water chemistry changes along flowpaths as ground water moves across the Diablo Plateau towards Dell City from a Na-mixed facies to a mostly Ca-SO₄ composition (Figure 6.11). These changes occur as a result of gypsum dissolution and reversible ion exchange.

Isotopic analyses

Stable isotopes of hydrogen vs oxygen in ground water (δ²H versus δ¹⁸O) cluster along the global meteoric water line (GMWL, Craig, 1961), pointing to a meteoric origin for ground waters of the Diablo Plateau aquifer (Figure 6.12). This assertion is strengthened by tritium data (Figure 6.4). The majority of samples have tritium, some of them up to 32 TU (Kreitler and others, 1986), indicating recharge of modern precipitation into the aquifers of the Diablo Plateau. Age determinations based on ¹⁴C activities yielded ground-water ages from modern to 23,000 years old (Kreitler and others, 1986). Generally, the youngest waters, which also show the highest tritium activities occur in the southwestern part of the plateau while the older waters with less tritium are encountered towards the northeast (Figure 6.4). Some waters also display higher tritium activities accompanied by low percentages of modern carbon (PMC). This combination suggests mixing between old ground waters and modern ground waters.

Historical change

Except for the Dell City area, the ground water resources in the Diablo Plateau aquifer are largely undeveloped. It is assumed here that the only changes with time in ground-water chemistry occurred in the

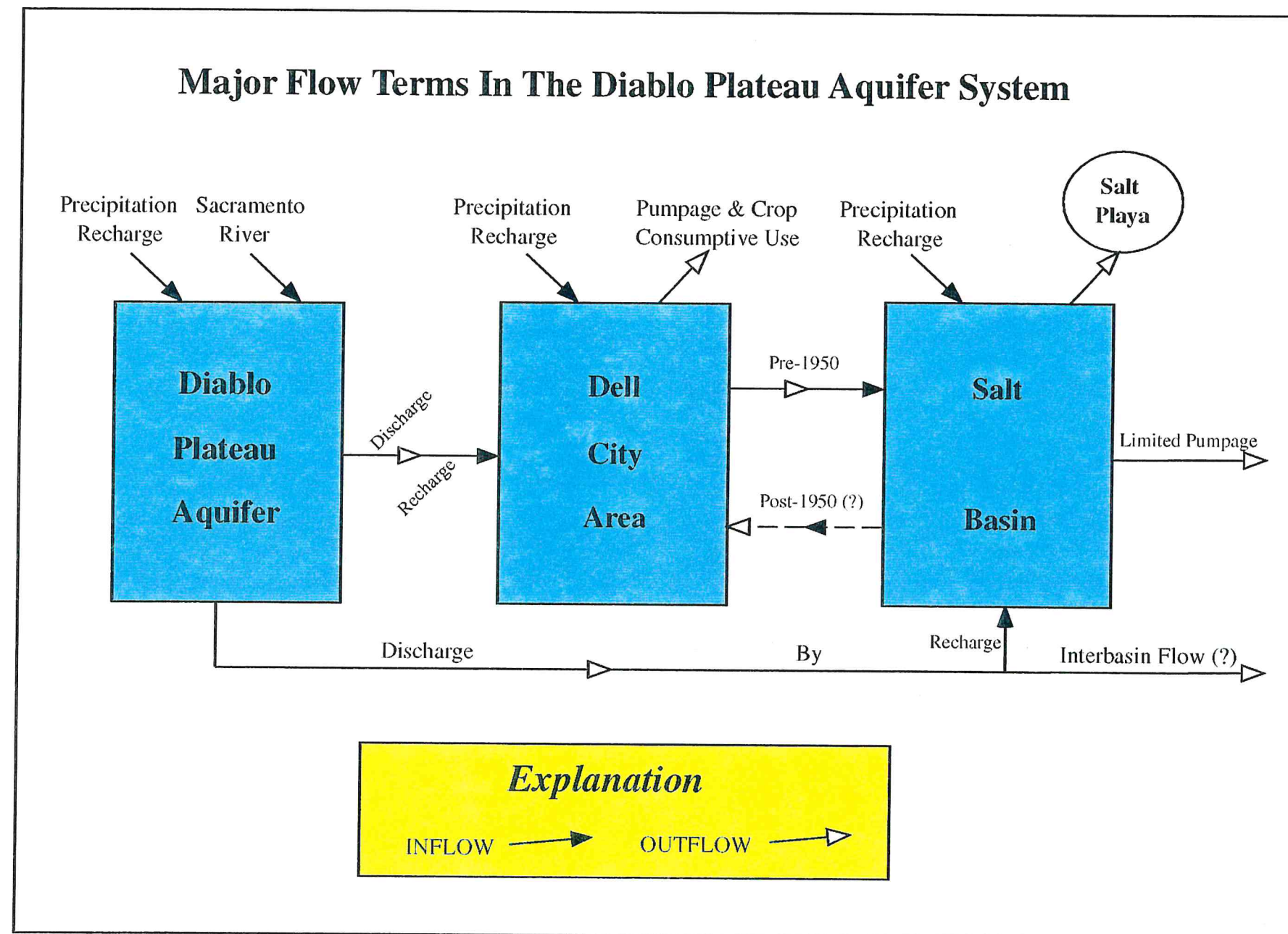


Figure 6.5. Major flow terms in the Diablo Plateau aquifer system.

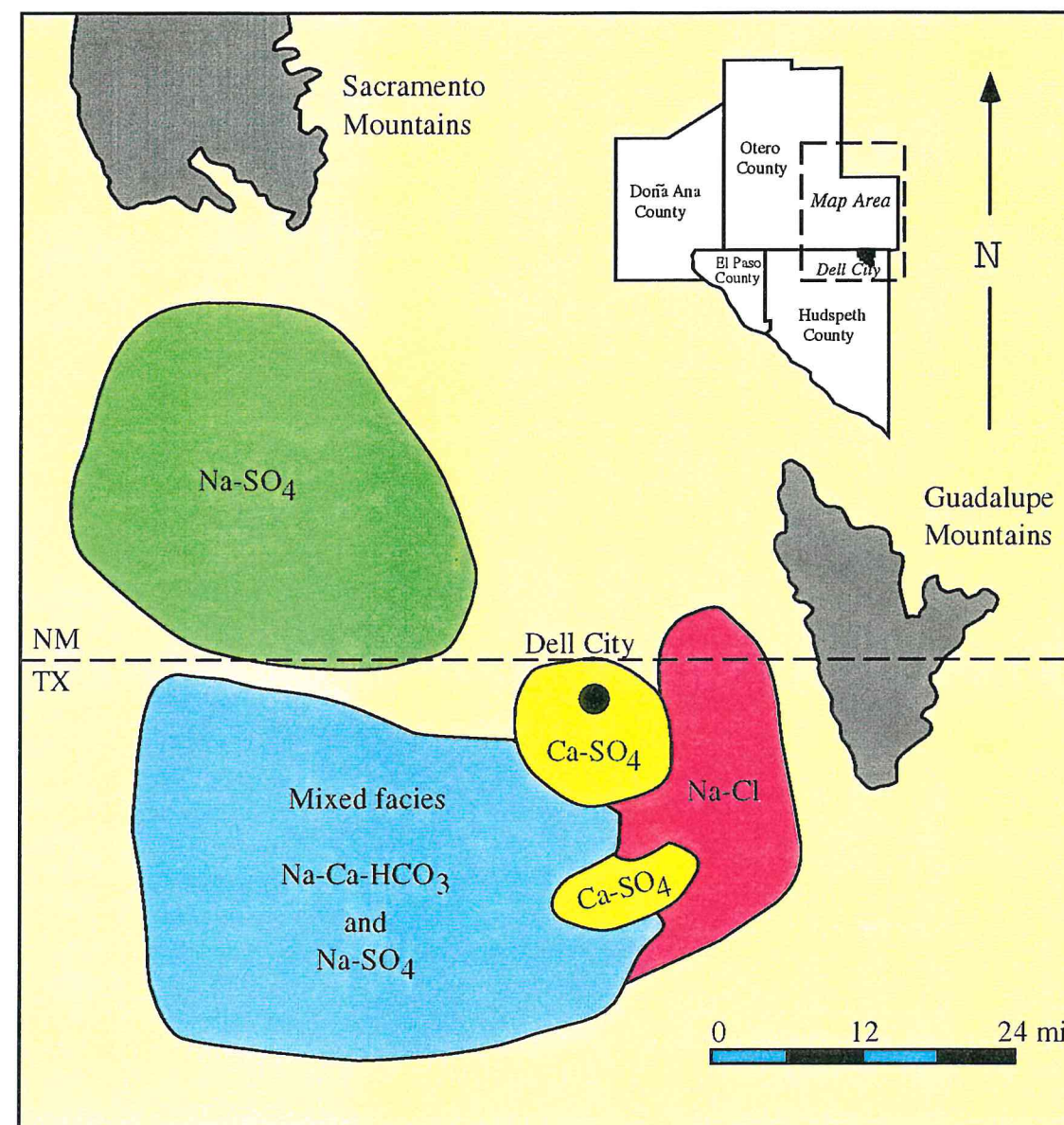


Figure 6.6. Areal distribution of ground-water facies in parts of the Texas and New Mexico portions of the Diablo Plateau aquifer (source of data, Texas Water Development Board; Kreitler and others, 1986; Mayer, 1995).

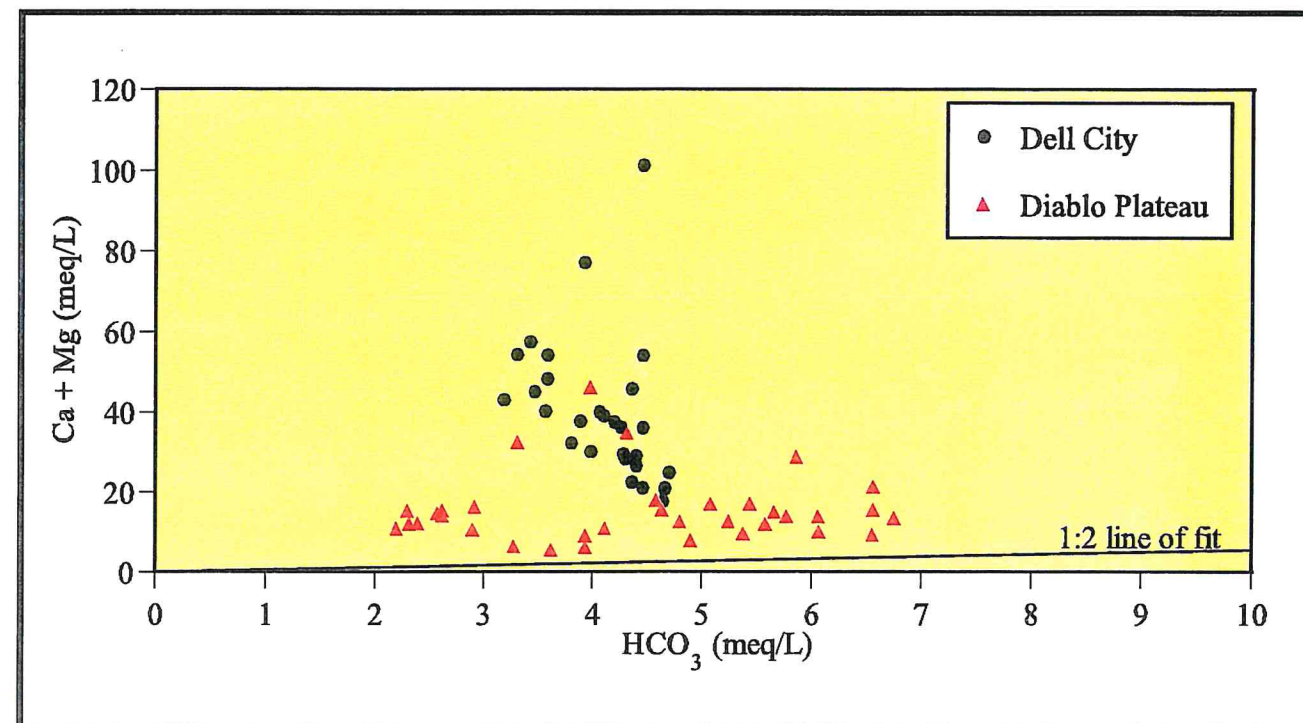


Figure 6.7. Plot of $(\text{Ca} + \text{Mg})$ vs HCO_3^- .

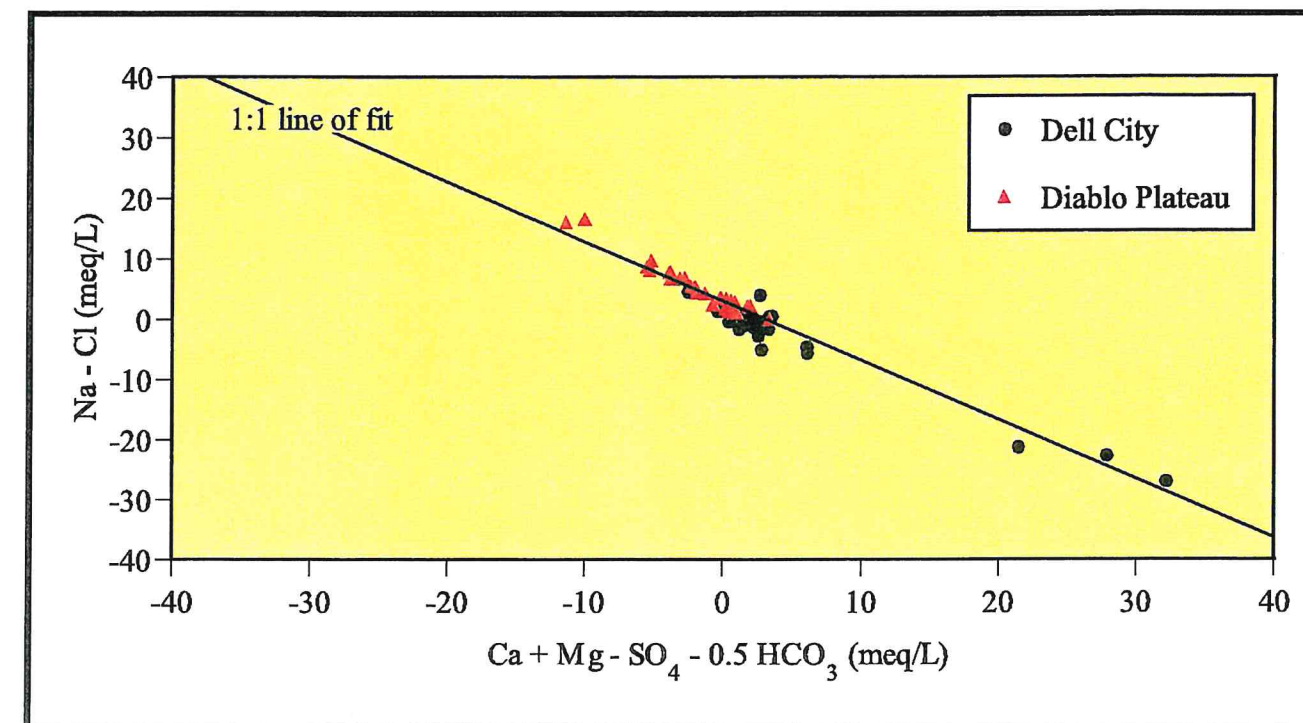


Figure 6.9. Plot of $(\text{Na} - \text{Cl})$ vs $(\text{Ca} + \text{Mg} - \text{SO}_4 - 0.5\text{HCO}_3^-)$.

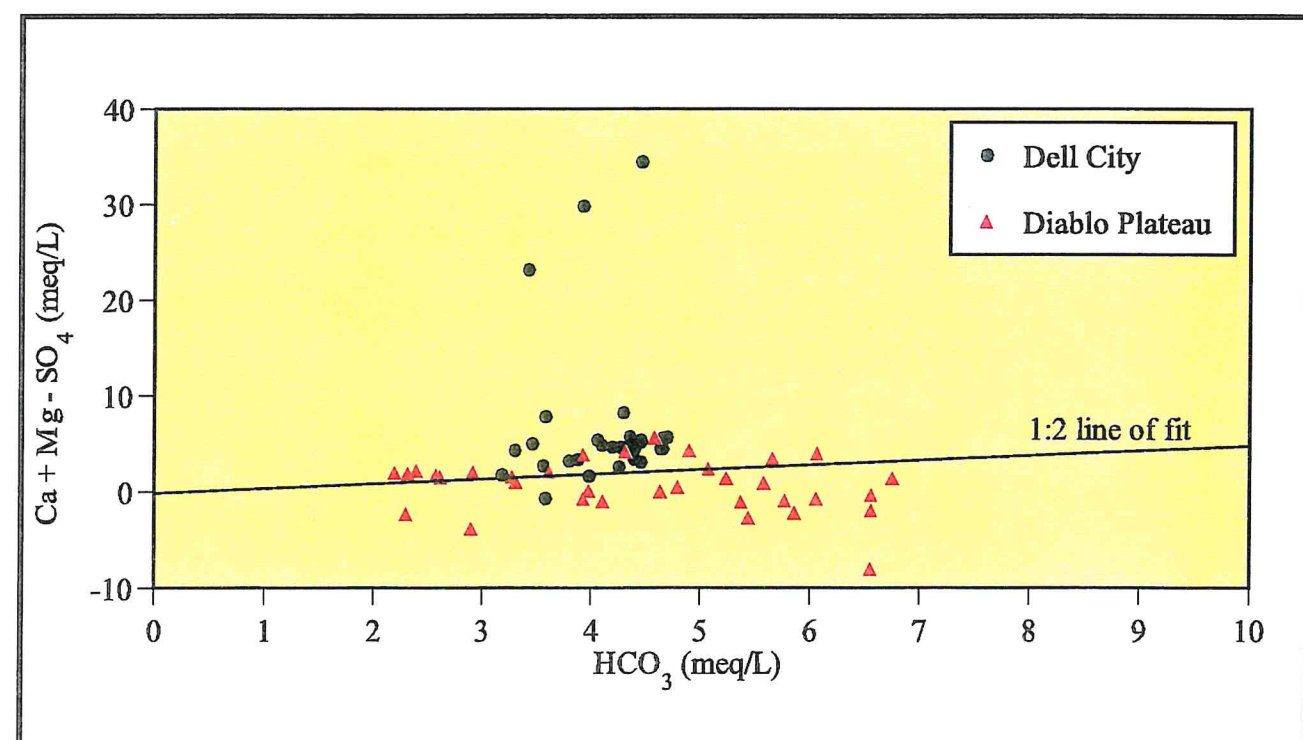


Figure 6.8. Plot of $(\text{Ca} + \text{Mg} - \text{SO}_4)$ vs HCO_3^- .

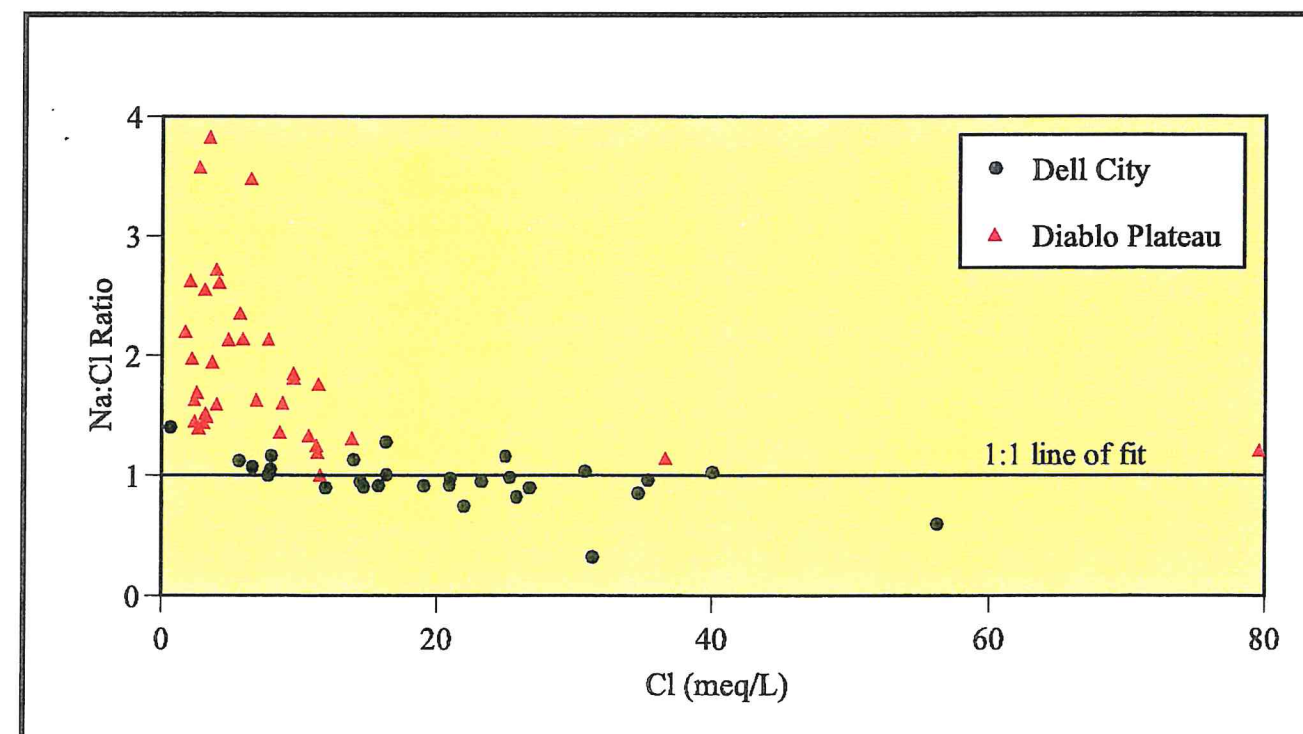


Figure 6.10. Plot of (Na/Cl) ratio vs Cl .

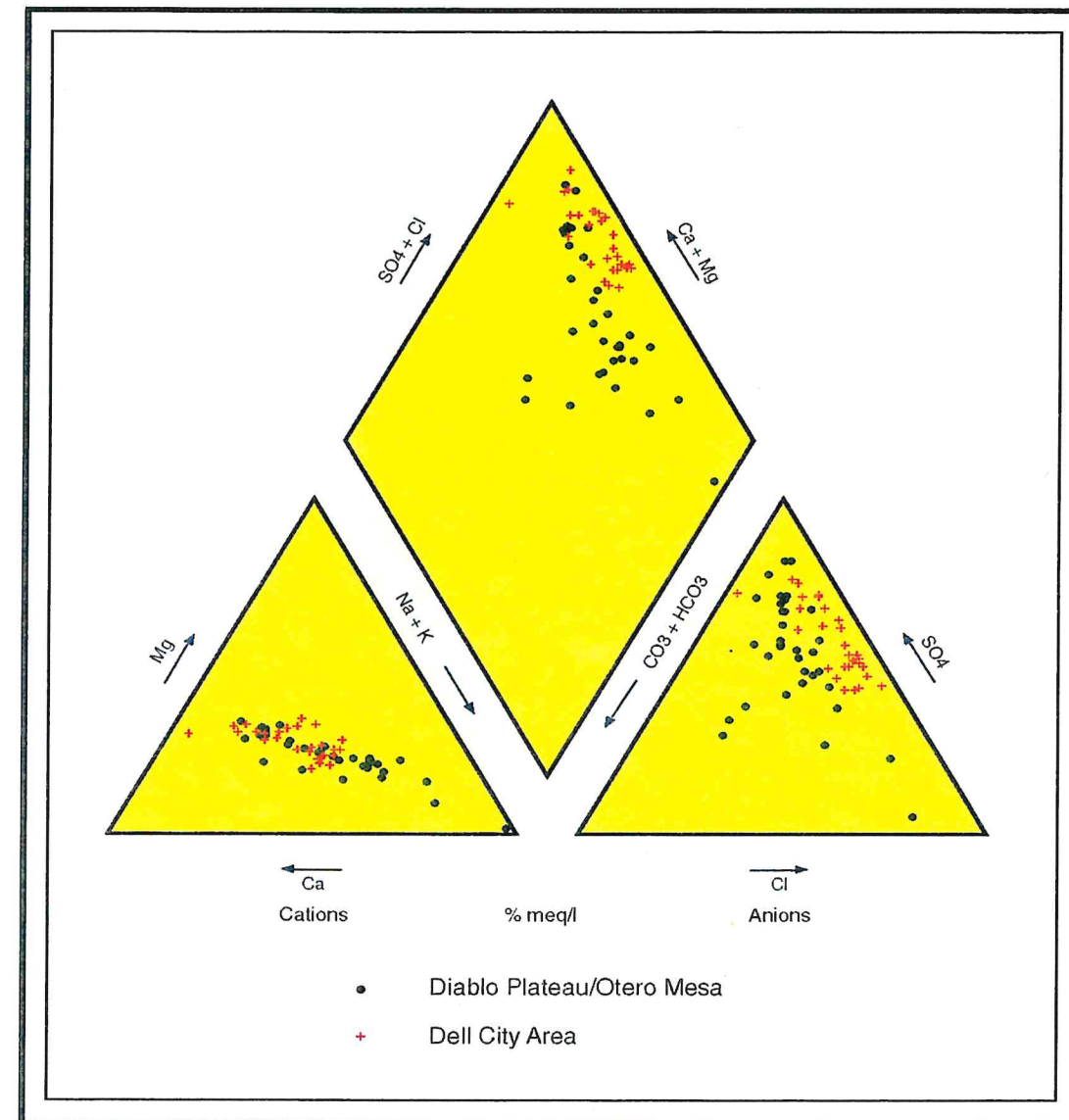


Figure 6.11. Piper diagram illustrating geochemical types for ground water in the Diablo Plateau aquifer (source of data, Texas Water Development Board; Kreitler and others, 1986; Mayer, 1995).

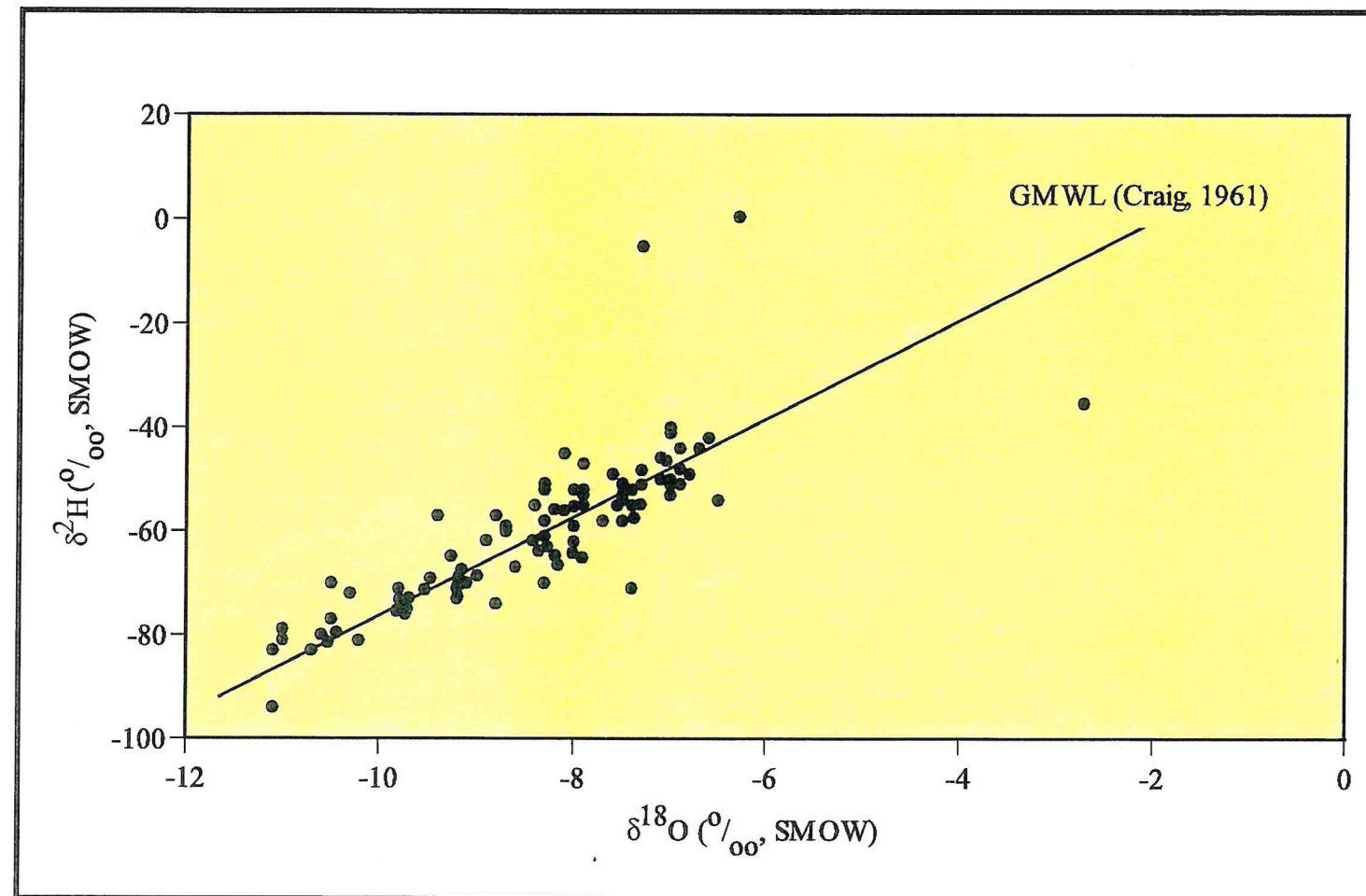


Figure 6.12. Plot of $\delta^2\text{H}$ vs $\delta^{18}\text{O}$ (source of data, Kreitler and others, 1986).

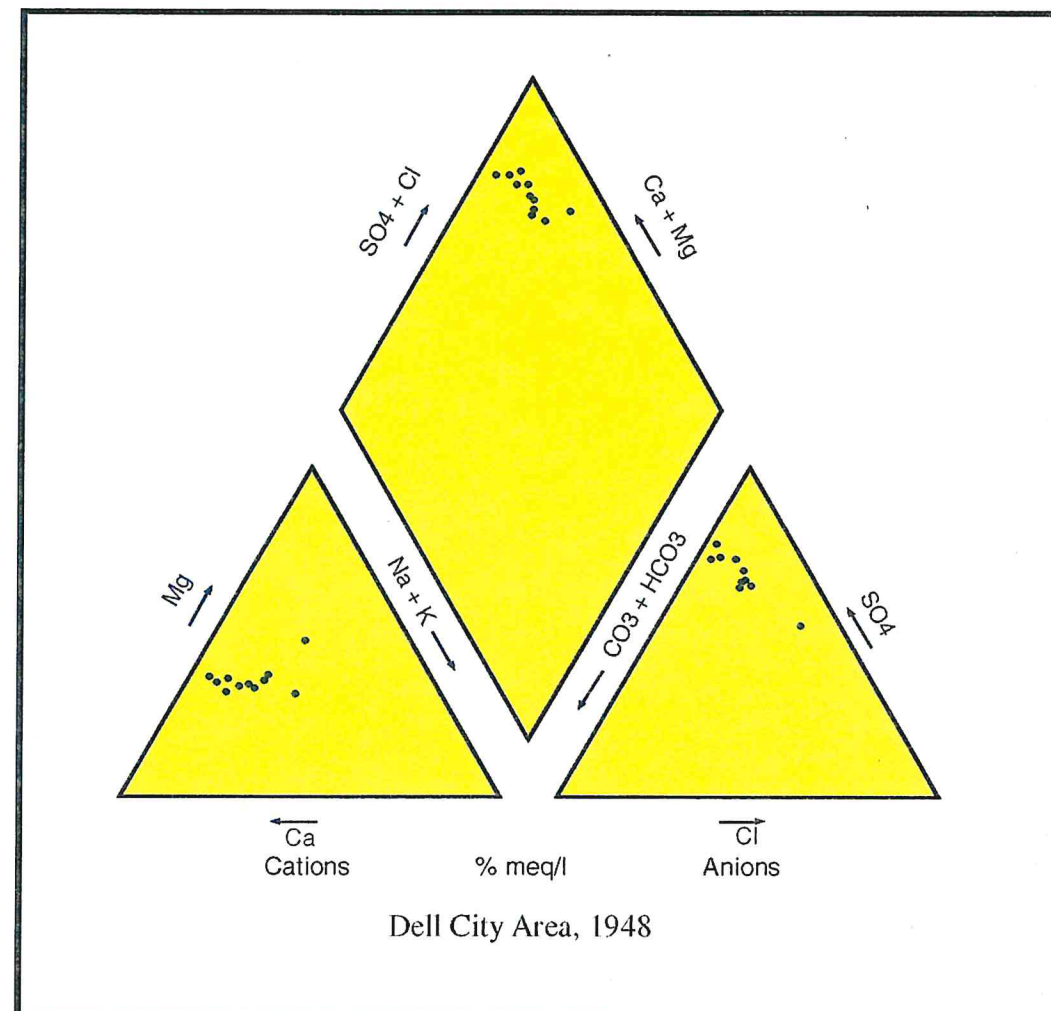


Figure 6.13a. Chemical composition of Dell City ground water in 1948 (source of data, Texas Water Development Board).

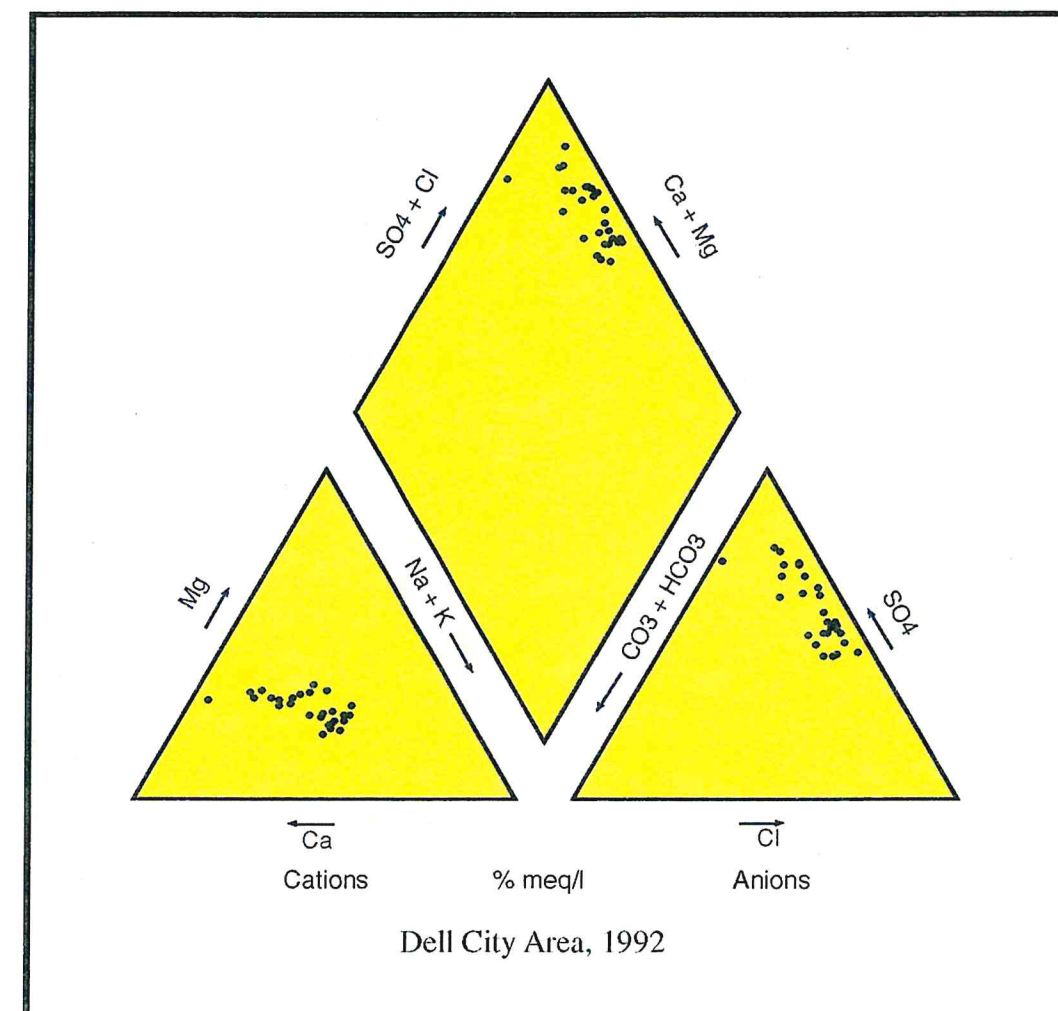


Figure 6.13b. Chemical composition of Dell City ground water in 1992 (source of data, Texas Water Development Board).

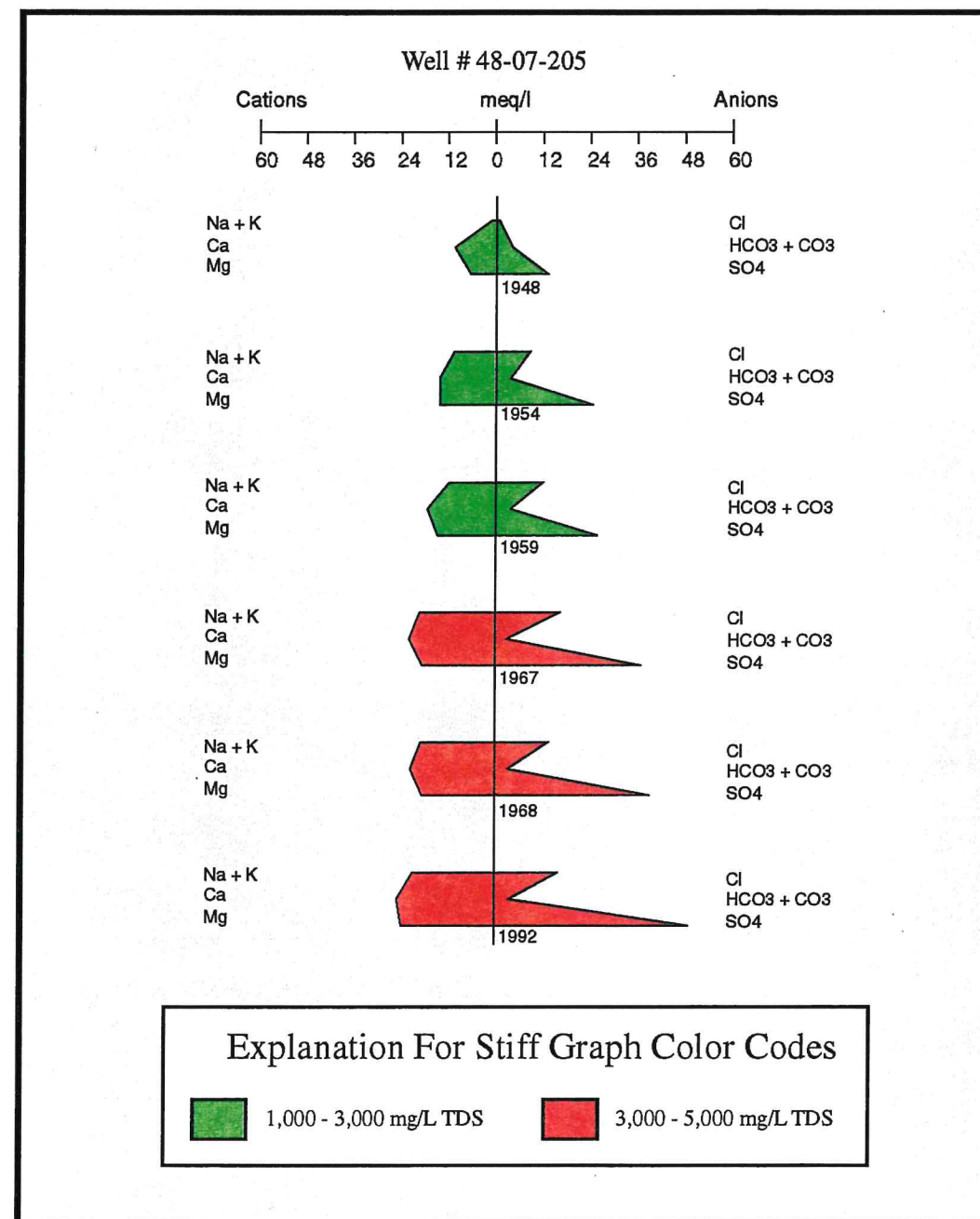


Figure 6.14a. Stiff diagram showing major ion chemistry changes through time in well 48-07-205 (source of data, Texas Water Development Board).

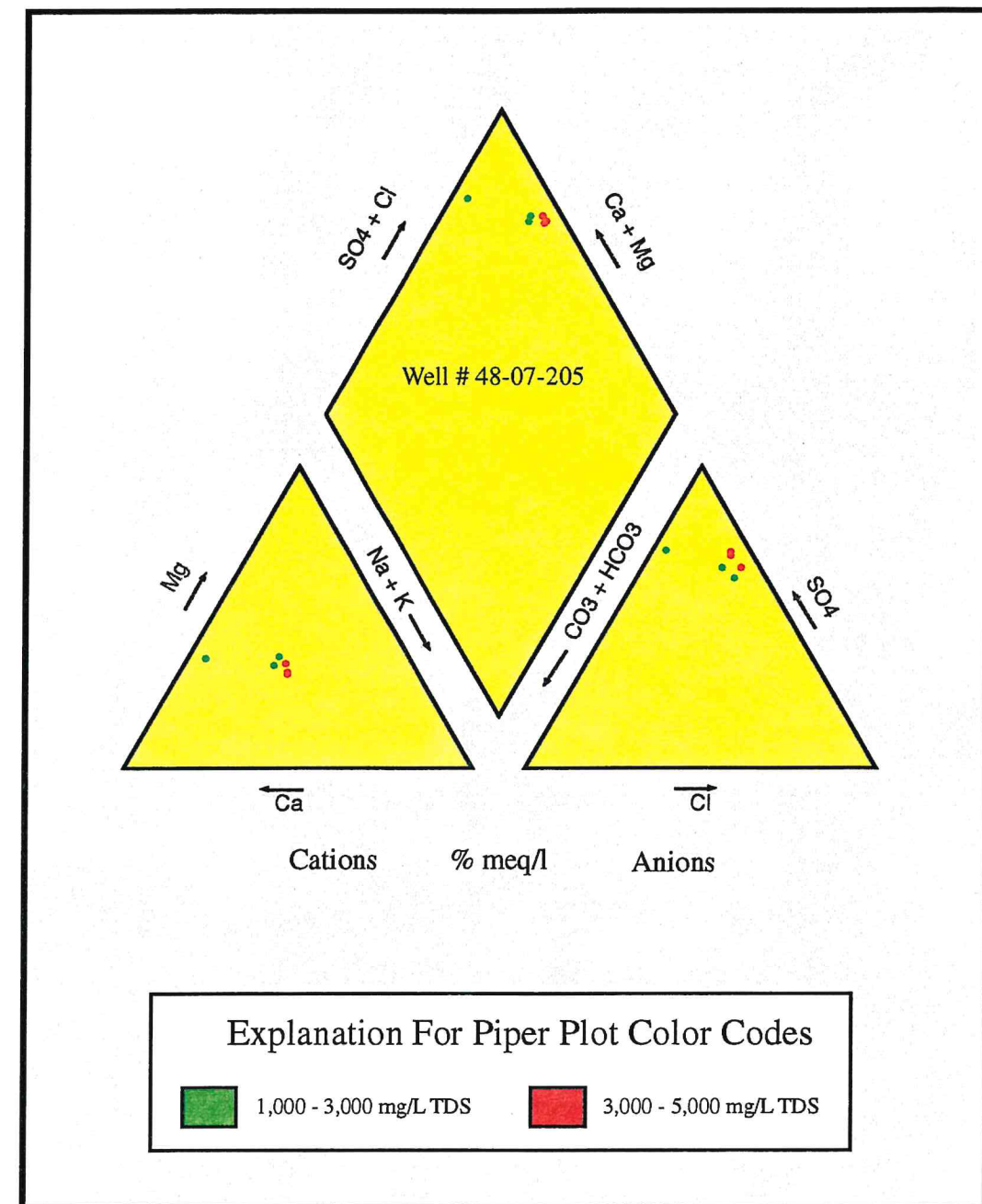


Figure 6.14b. Piper diagram showing major ion chemistry changes in well 48-07-205, also represented in Figure 6.14a (source of data, Texas Water Development Board).

Dell City irrigation district, and the rest of the flow system is fairly stable with respect to dissolved solutes.

Figure 6.13 shows Piper diagrams for 1948 and 1992 ground-water chemistry in Dell City irrigation wells. Data indicate an overall shift from a Ca-SO₄ type in 1948 to a Ca-Na-SO₄-Cl type in 1992. Changes in water chemistry through time in irrigation well 48-07-205 are shown in Figure 6.14. The major trends identifiable on the Stiff diagram are a pronounced increase in sulfate, chloride, and sodium concentrations, moderate increases in calcium and magnesium, coupled with a decrease in bicarbonate ion concentration. Overall, this translates into a steady salinization of water from this well by as much as 3,500 mg/L total dissolved solids.

To account for the temporal change in calcium, magnesium, bicarbonate, and sulfate, the following model could be employed (Mayer, 1995): gypsum dissolution causes an increase in sulfate and calcium ions concentration, followed by calcite oversaturation and precipitation (Mayer, 1995). The loss of carbonate ions leads to dedolomitization (Back and others, 1983), and to the solution of magnesium. In this light, increases in chloride and sodium ions concentrations could be explained by either halite dissolution, or mixing with an evaporative brine, such as irrigation return flow.

Susceptibility to Contamination

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 (TWC, 1989), the principal activity in the region. The DRASTIC index for general, municipal, and industrial sources ranges from 80 - 124 (TWC, 1989).

High tritium activities in most of the samples collected from the Diablo Plateau aquifer, along with stable isotope signatures that indicate a meteoric component of recharge provide uncompromising evidence of precipitation recharge to the Diablo Plateau aquifer. The

recharge rate is not high however and the bulk ground-water ages, identified by ¹⁴C, are generally old. The isotope data suggest that any contaminants carried by infiltrating rainwaters to the saturated zone may be diluted by copious quantities of much older ground water.

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RECOMMENDATIONS

In establishing the Transboundary Aquifer GIS coverages and binational aquifer maps, a significant amount of data was acquired, verified, and evaluated. The value of any coverage or map is dependent on there being a sufficient amount of data to adequately and accurately characterize the subject matter. The following recommendations are intended to recognize specific data inadequacies, and also to suggest future projects and activities that might enhance our understanding of the local aquifers.

- Recharge to and contamination susceptibility of aquifers are significantly influenced by the geology of an area. The geology of the Texas portion of the project area is currently being refined by the BEG. Revisions of existing maps should be digitized as replacements for the existing geology coverage. Mexico geology (Figure 1.5) should be more accurately and completely digitized.
- The extent of the Conejos Medanos (Mesilla) aquifer in Mexico should be better delineated and digitized. Hydrogeologic data from this aquifer is needed for addition to its extent in New Mexico and Texas.
- Wells in Mexico, especially those in the Rio Grande/Rio Bravo alluvium, should be accurately located using GPS equipment. Well head elevations should be determined within an accuracy at least equal to those on the U.S. side (U.S. based on five-foot topographic map contour intervals). This will allow for better regional mapping of ground-water movement.
- Specifically, potentiometric surface maps and hydrographs for the Mexican portion of the Rio Grande aquifer should be added to maps prepared in this report for the U.S. part of the aquifer. The absence of well elevations in Mexico precluded the preparation of binational maps for the Rio Grande aquifer.
- The proliferation of colonias on the Rio Grande alluvial floodplain, many of which are without adequate water and wastewater facilities, may have intensified contamination of the shallow aquifer by untreated or poorly treated sewerage. Effects of development on water quality should be monitored and evaluated for potential problems.
- Better estimates of irrigation pumpage volumes should be made in the U.S., especially in Texas.
- The thickness of basin fill, storage coefficients, and quantities of fresh and slightly saline ground water in the Mexican part of the Hueco Bolson are not well known and are very difficult or impossible to estimate with available data. Further studies should be conducted to derive better stratigraphic data and better estimates of recoverable ground water in storage.
- Quantification of recharge potential, similar to the process developed by the NMWRRI, should be applied in Texas and Mexico.
- Computer ground-water flow models of the Hueco Bolson aquifer currently being developed by Mexico and the U.S. should be supported. The same binational modeling effort should be made at a later date for the Mesilla/Conejos Medanos aquifer.
- Radioisotope data is needed to determine ground-water ages, ground-water residence times, recharge areas, and areas of cross-formational flow. The quality of the ground-water flow models being developed by the USGS and Mexican government will improve if isotope data is available.

- Mechanisms of salinization of heavily developed parts of the Hueco Bolson are not completely understood. Several factors may be responsible for salinization, including brackish water upconing, downconing, leakage along the annular spaces of wells, lateral migration, leakage from mud interbeds, and freshwater depletion. Studies to determine the precise mechanisms of salinization would help the City of El Paso and Ciudad Juarez employ pumping schemes for reduced salinity.

- Mexican well data generated prior to about 1990 was available only in hard copy. This data should be converted to electronic files.

- A formal procedure and timetable for binational ground-water data exchange should be reestablished. This data should be recognized for its authenticity by both Mexican and U.S. governments, and should be in an electronic format adaptable for GIS applicants. It is important that this data be made easily accessible.

- The binational technical work group established for this project should extend this work, so as to include more input on the hydrogeologic properties and processes operative in the Mexican portion of the transboundary aquifers, and to seek technical solutions to common ground-water problems.

- A binational aquifer water-level and water-quality monitoring network should be established. Monitoring frequency and procedural protocol should be agreed upon and subsequent data should be shared on a continuous real-time basis.