Report 344

Ground-Water Resources of the Bone Spring - Victorio Peak Aquifer in the Dell Valley Area, Texas

January 1995

TEXAS WATER DEVELOPMENT BOARD

Texas Water Development Board

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Ground-Water Resources of the Bone Spring - Victorio Peak Aquifer in the Dell Valley Area, Texas

by
John B. Ashworth, Geologist

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ABSTRACT

Ground water occurs in the Bone Spring and Victorio Peak Limestones of Permian age throughout the Diablo Plateau of west Texas and southern New Mexico. In Texas, the Bone Springs-Victorio Peak is designated as a minor aquifer only in the region known as Dell Valley where its occurrence underlies irrigable lands. Water in the aquifer is concentrated in interconnected solution cavities that have developed in joints, fractures, and bedding planes. Recharge to the regional aquifer system is from infiltration of precipitation on the entire plateau area and probably from the Sacramento River in New Mexico.

Regionally, ground water moves from the Diablo Plateau toward the Salt Basin where it surfaces and evaporates in the salt flats. Movement within Dell Valley is primarily toward pumpage centers where much of the water is now captured by numerous irrigation wells.

Water-level declines of 25 to 45 feet have occurred since irrigated farming began in the late 1940s. In recent years however, the water level has remained relatively steady due to diminished irrigation pumpage. Although the elevation of the water table is currently lower in the valley than in the salt flats to the east, there has been no apparent migration of highly saline ground water from the flats. Seasonal irrigation pumpage results in water-level fluctuations of from 15 to 35 feet.

The quality of ground water underlying Dell Valley is slightly to moderately saline (1,000 to 6,500 TDS), very hard, and is dominated by elevated levels of calcium, sodium, sulfate, and chloride. Irrigation return flow and uncased and poorly constructed wells have resulted in a slow deterioration of water quality.

Approximately 90,000 to 100,000 acre-feet of water are annually recharged to the aquifer in the Dell Valley area. A comparison of water-level and pumpage trends indicates an annual pumpage not exceeding this recharge amount can be maintained without continuously lowering the water table.

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INTRODUCTION

Objective

The Bone Spring-Victorio Peak aquifer produces ground water in an irrigated region commonly referred to as Dell Valley. Because of its importance to the agricultural economy, the Texas Water Development Board (TWDB) has designated the Bone Spring-Victorio Peak as a minor aquifer and has delineated its extent in Texas based on its occurrence underlying irrigable land. This report describes the ground-water resource underlying the valley in terms of its geological and hydrological characteristics, quantity, quality, historical use, and changing conditions.

Location

The Dell Valley region is located 75 miles east of El Paso and 20 miles west of the Guadalupe Mountains in northeastern Hudspeth County (Figure 1). Dell City, with a population of approximately 500, is located in the center of the irrigation district. The valley consists of approximately 40,000 acres of irrigable land adjacent to the Salt Basin in Texas and extends northward into Otero County, New Mexico, where it is referred to as Crow Flats. The arid climate in the region is characterized by low rainfall, averaging 8 to 10 inches annually, and a high rate of evaporation, which averages nine times the precipitation rate.

Topography and Drainage

Dell Valley is a broad, alluvial, outwash plain that is bordered on the east by the Salt Basin and rises to the west and south to limestone uplands of the Diablo Plateau. The land surface elevation of the valley rises gradually from approximately 3,640 feet above sea level on the eastern edge to approximately 4,200 feet.

The Salt Basin, a closed drainage basin, drains much of the Sacramento Mountains to the north, the Diablo Plateau to the west, and the western flank of the Guadalupe Mountains. Dry salt flats within the Salt Basin are the lowest topographic features at an elevation of 3,600 feet above sea level. The flats are the location of natural discharge by evaporation of ground water flowing to and within the basin.

A major problem in the watershed is its susceptibility to flooding. Surface drainage originates in the Cornudas Mountains, Sixteen Mountains, and the Sierra Tinaja Pinta in the far western extent of the watershed. Floodwaters intermittently traverse from the highlands onto the Dell Valley alluvial plain through Eightmile, Hitson, C&L, and Washburn draws in Texas, and Cornudas and North draws in New Mexico (Figure 2). Total watershed area is approximately 600 square miles. Runoff from a storm in 1966 resulted in the largest flood in Dell Valley's recorded history, and caused approximately $3 million in damages (El Paso-Hudspeth Soil and Water Conservation District and others, 1969).

Floodwaters reaching the valley floor typically fan out in an overland or sheet-type flow causing extensive damage. However, the U.S. Department of Agriculture, Soil Conservation Service has constructed four flood control structures on the west side of the valley (Figure 2) to capture floodwaters draining through Cornudas, Hitson, C&L, and Washburn draws.

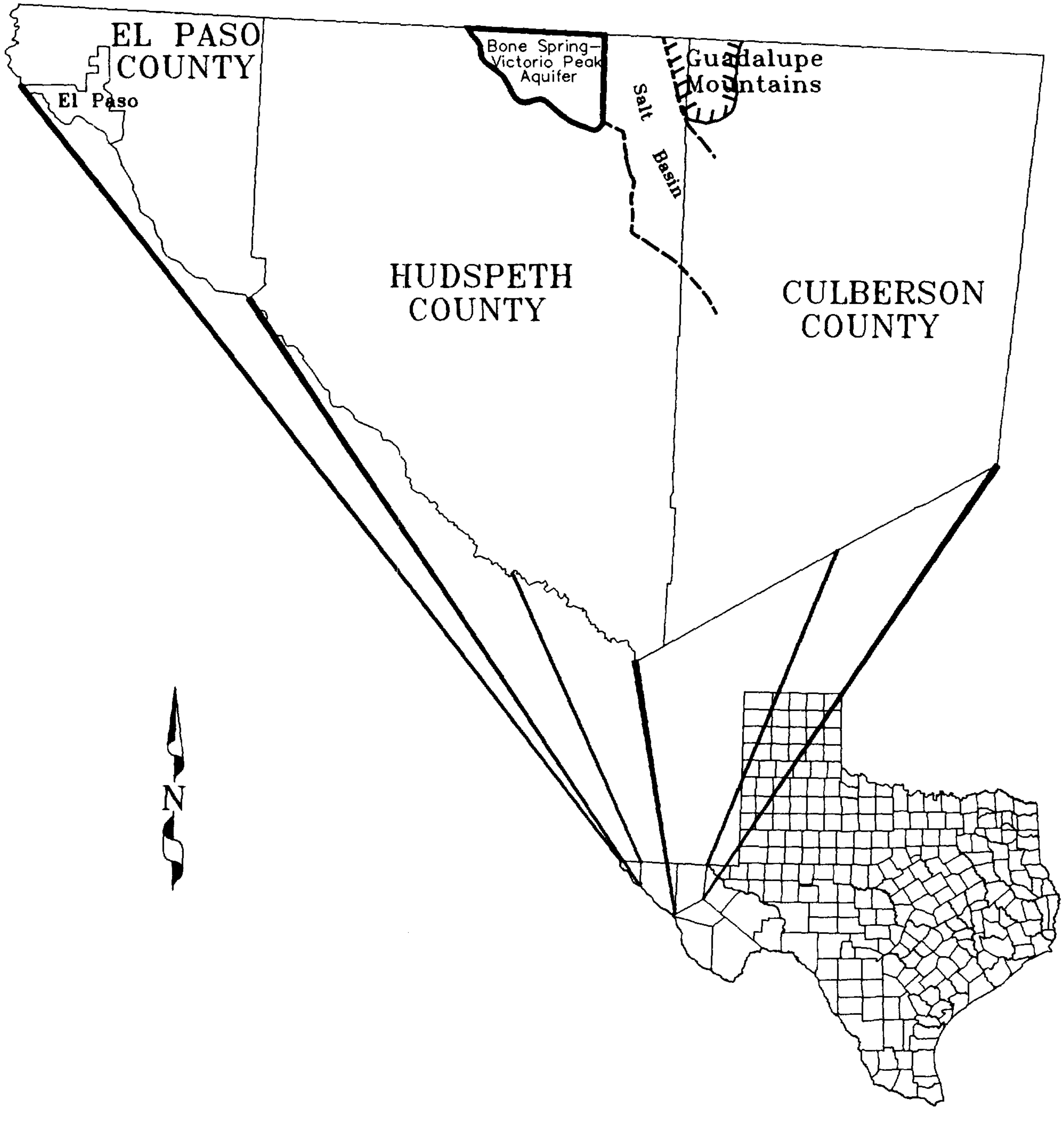


Figure 1

Location of the Bone Spring–Victorio Peak Aquifer

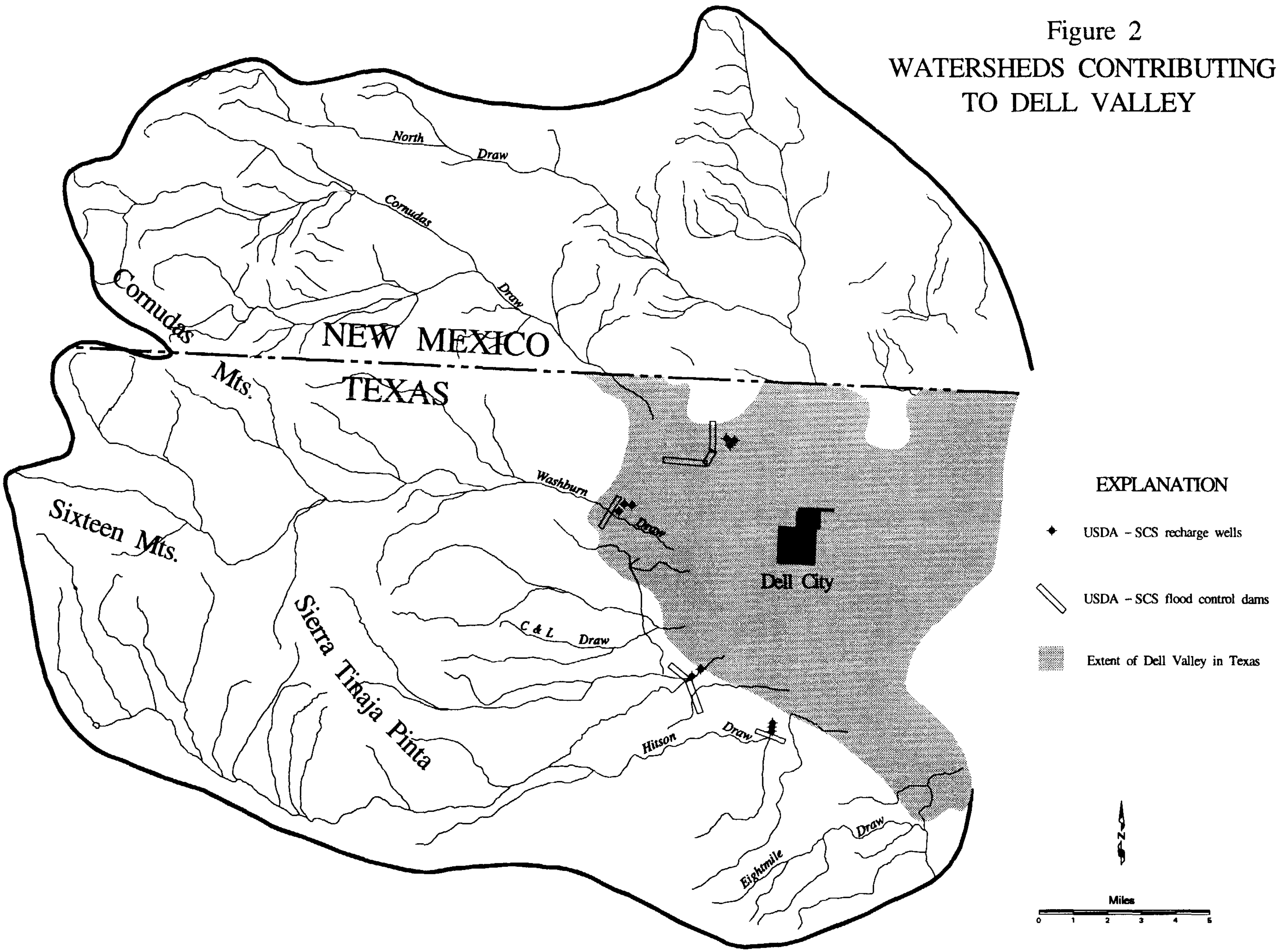


Figure 2
WATERSHEDS CONTRIBUTING TO DELL VALLEY

Acknowledgments

The author gratefully acknowledges the numerous individuals who provided information on the aquifer and its use, and thanks the many landowners who allowed access to their property and wells to measure water levels and sample for chemical quality. Specific individuals in Dell City who spent a significant amount of time and interest in the study include Eldon McCutcheon, Leroy Perry, Jerry Ziler, Gene Lutrich, and the other board members of the Hudspeth County Underground Water Conservation District. Dr. Jack Sharp and Jim Mayer of The University of Texas at Austin provided insightful discussions and reviews of the report.

Several staff members of the Texas Water Development Board were involved in the collection of data and the preparation of the report. In particular, Doug Coker, Theresa Canales, Mark Hayes, and Steve Gifford provided a significant amount of time and talent toward the completion of this project. Editing for technical content was provided by Steve Densmore, Richard Preston, Phil Nordstrom, Danna Stecher, and Barry Hibbs. Manuscript proofreading was conducted by Kathy Mills, and publication preparation was accomplished by Mike McCathern and staff.

HISTORY OF WATER USE

Springs

The first mention of water supplies in the area is recorded in scientific journals and military travel logs from the middle 1800s (e.g., Marcy, 1851; and Pope, 1854). Travelers involved in exploration and survey trips, wagon trains, and military expeditions frequently stopped at Crow Springs (also known as Ojos del Cuervo) to replenish their water supplies (Brune, 1981). The springs were also a stage stop on an early Butterfield Overland mail route. Located northeast of Dell City and near the state line, Crow Springs issued brackish water that had a strong sulfur odor and filled two shallow lakes that covered four or five acres. Shallow wells dug in the vicinity of the springs provided more potable water. As late as 1948, the springs still trickled approximately 3 gallons per minute. However, by 1950, pumping of irrigation wells drilled near the springs lowered the water table and brought an end to the discharge.

Irrigation

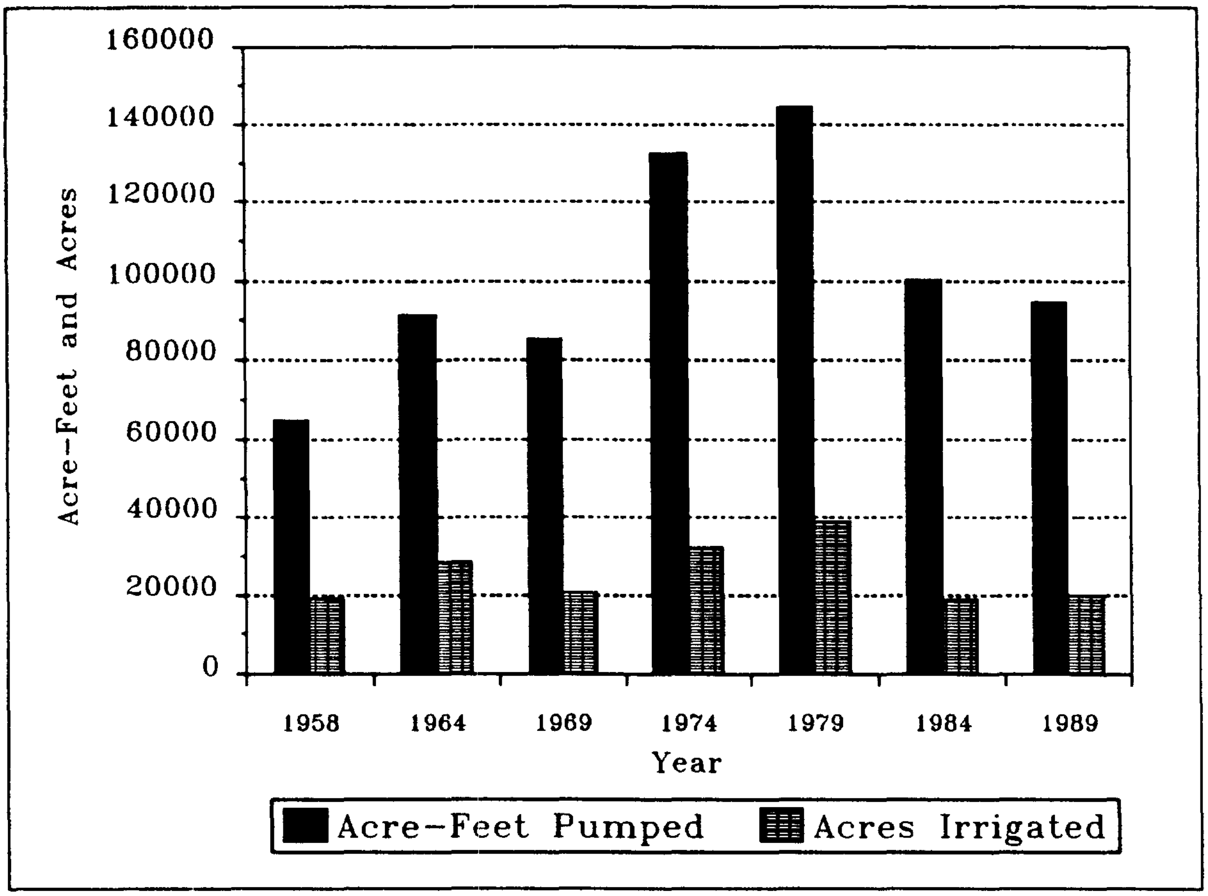
Scalapino (1950) provides documentation of early ground-water irrigation development in Dell Valley. Prior to the introduction of the first irrigation wells in 1947, the valley was primarily the site of cattle ranching, and the only use of ground water was for domestic and livestock needs. By 1949, 78 wells had been drilled; however, only 32 wells had sufficient yields to be used for irrigation purposes. About 2,500 acres were irrigated in 1948. A year later, about 6,000 acres of feed crops and cotton were irrigated with approximately 18,000 acre-feet of ground water.

Across the state line in the Crow Flats area of New Mexico, a few wells were completed with windmills for domestic and livestock use as early as 1905 and 1906 (Bjorklund, 1957). The first irrigation wells were drilled in 1949 shortly following their introduction in Dell Valley. Bjorklund reported that in 1956, 17 out of 23 wells drilled to supply water for irrigation in Crow Flats were in use to irrigate approximately 3,000 acres of cotton and alfalfa. In the combined Dell Valley-Crow Flats region, 228 irrigation wells were in use in 1956 to irrigate approximately 32,000 acres.

Irrigated agriculture in the valley continued to expand through the late 1970s. An irrigation survey conducted in 1979 showed the greatest irrigation activity as approximately 39,000 acres of cropland irrigated with 144,000 acre-feet of ground water (Texas Water Development Board, 1991). Since then, irrigation has diminished as a result of declining market conditions, increased labor expense, and government conservation programs. In 1989, approximately 20,000 acres were irrigated with 95,000 acre-feet of ground water. Figure 3 shows the amount of water pumped for irrigation use and the corresponding number of acres irrigated for specified time periods.

Public Supply

Young (1975 and 1976) provides a history of the early development of the Dell City public water-supply system. With a population of more than 500, Dell City became incorporated in 1961 and began plans for a public water-supply system. Domestic water supply had previously been provided by several private water companies; however, by 1964, it was evident that the area ground-water supply was becoming increasingly saline and a water treatment system would be necessary.



Source of data:
Modified from TWDB, 1991.

Figure 3

Irrigation Pumpage and Acres Irrigated

In 1967, the city installed an electrodialysis treatment plant with a capacity of 50,000 gallons per day (gpd). The plant was designed to mitigate as much as 2,450 parts per million (ppm) dissolved solids to potable standards. Water was supplied from a single well (North Well, 48-07-522). Dell City was the first community in the United States to incorporate saline water conversion equipment in a system financed by the Farmers Home Administration, U.S. Department of Agriculture. The plant was increased to 69,000 gpd in 1968 in order to treat enough water to satisfy peak demands. Also, an additional well (Elias or South Well, 48-07-523) was brought into the system.

By 1974, the plant had become ineffective. Chemical quality of the source water from the aquifer had deteriorated beyond the design specifications for the plant. In addition, the plant system had not been adequately maintained. The old plant was replaced in 1976 with a modern, reverse polarity-type electrodialysis plant with a 100,000 gpd capacity. The plant is currently in use and operates at a rate of 50,000 to 70,000 gpd.

In 1986, the Prather Well (48-07-219), located three miles north of town, was drilled to provide the primary source of water to the plant. The North Well is still connected to the system as a backup but is rarely used for that purpose.

The city also operates a separate water delivery system for irrigation use. Water for this purpose is pumped from the North Well and is supplemented by the by-product water from the electrodialysis treatment plant. The plant by-product water is actually of better quality than the water from the North Well. The Elias Well is used occasionally as a backup or supplement to the irrigation system (Jerry Ziler, oral commun., 1994).

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GEOLOGY

Regional Structure

The principal water-bearing rocks that underlie Dell Valley are limestones and dolomites of the Permian Leonardian series. These rocks were deposited in a shelf environment early in the development of the Delaware Basin. The Victorio Peak Limestone occupies much of the surface area immediately west of the Salt Basin on the Diablo Plateau and, along with the Bone Spring Limestone, is prominently exposed on the eastern escarpment of the Sierra Diablos south of Dell Valley (King, 1965). The formations dip eastward toward the central axis of the Delaware Basin and extend southwestward onto the Diablo Platform. Principal geologic features in the region are shown on figure 4.

The Salt Basin, a block-faulted graben filled with Tertiary and Quaternary alluvium and lacustrine (lake) deposits, separates the Permian rocks in Dell Valley from exposed Permian reef formations in the Guadalupe Mountains to the east (King, 1948)(Figure 5). Dry salt lakes, or salt flats, occur within the Salt Basin and, according to King (1948), are relict Pleistocene lakebed deposits. In a more recent study, salt flat sediments were identified as predominantly gypsum and other evaporitic minerals that are continuously precipitating as the shallow ground water evaporates (Boyd and Kreitler, 1986).

Two significant faults are of particular interest in the Dell Valley area (Figure 4). A north-south trending fault is the west boundary of the Salt Basin graben and represents the approximate eastern extent of the aquifer (Figures 4 and 5). Displacement along the fault has not been precisely determined; however, sediments on the eastern side of the fault have probably dropped several hundred feet (King, 1948; Gates and others, 1980; and Goetz, 1977).

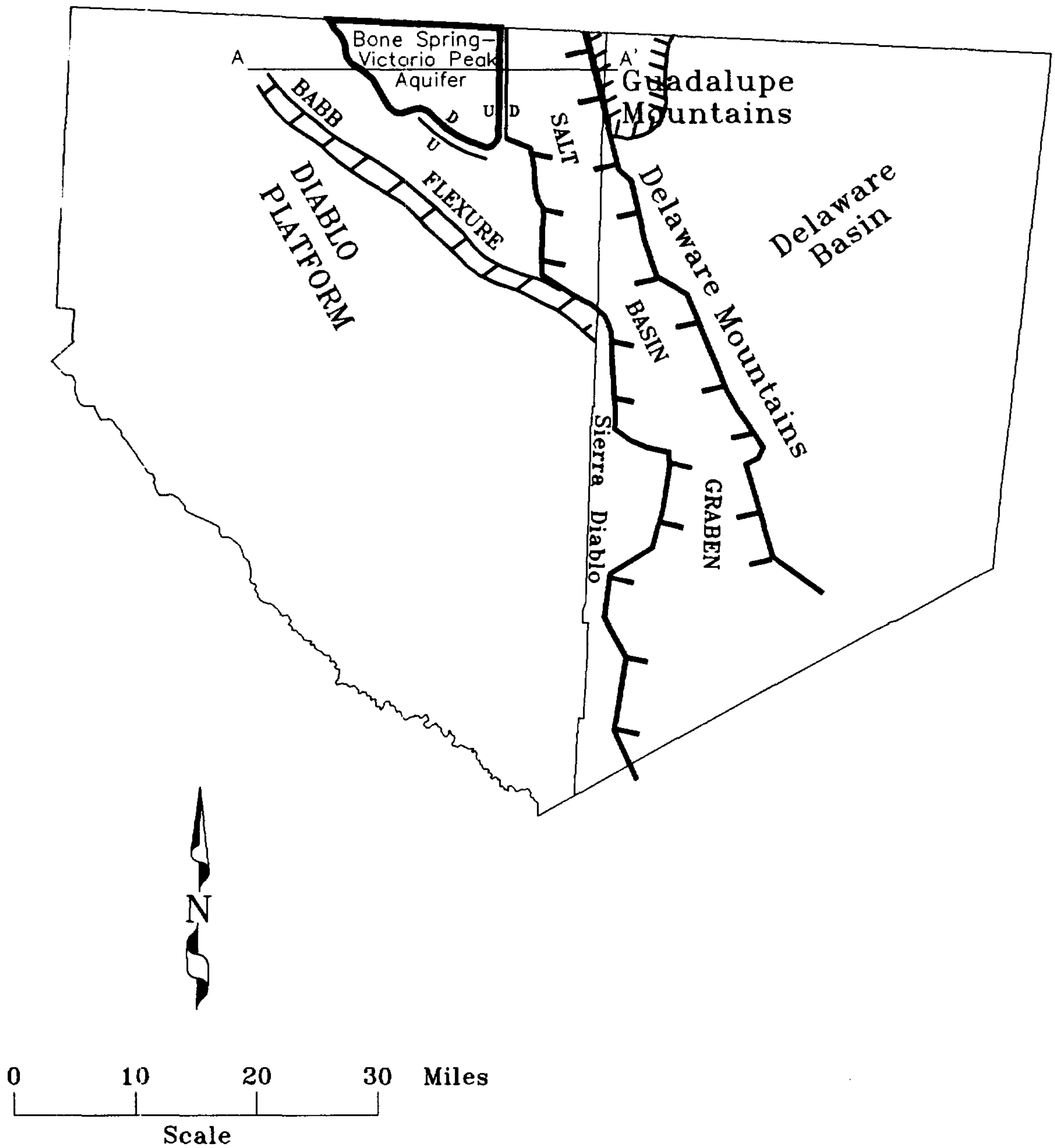
A second fault, trending northwest-southeast, forms the southern topographic edge of the valley and is also the designated aquifer boundary (Figure 4). Downward displacement of approximately 100 feet occurs on the north side of the fault. This fault and other minor, unmapped faults and fractures are probably related to the regional deformation along the Babb flexure to the south and west.

Outcropping Victorio Peak Limestone hills in the southeast part of the valley have dipping beds indicative of a southward plunging anticline (Sharp and others, 1993). Such features suggest that the bedrock surface of the valley floor undulates and is likely faulted.

An igneous intrusive body of Tertiary age, known locally as Round Mountain, crops out 3 miles east of Dell City and rises about 175 feet above the valley floor (Figure 5). Other prominent igneous peaks comprise the Sierra Pinta and Cornudas mountains approximately 10 to 15 miles west of Dell City.

Stratigraphy

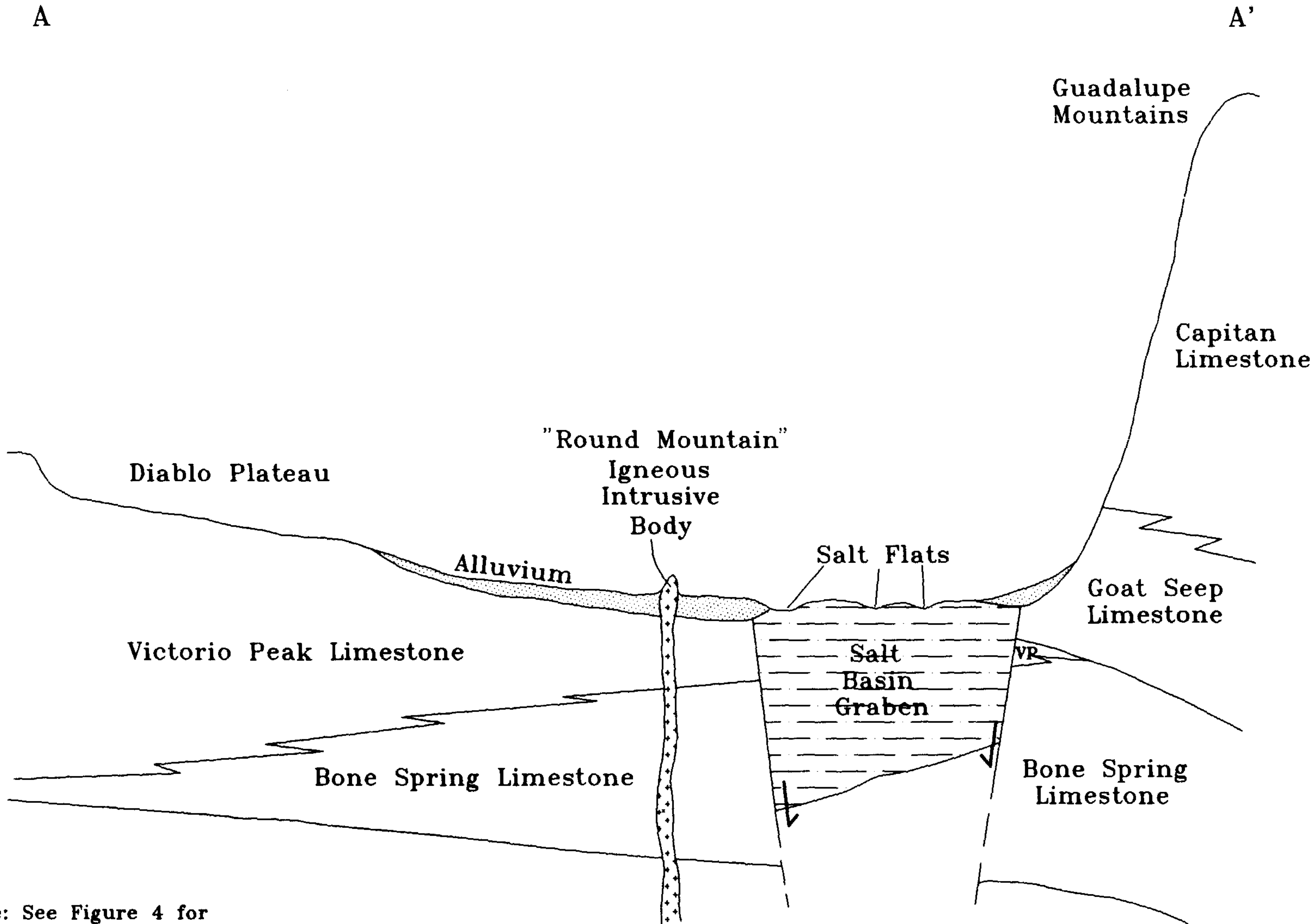
The Bone Spring Limestone is predominantly a black to dark gray cherty limestone with thin interbedded black or brown layers of siliceous shale. The Bone Spring grades upward into the Victorio Peak Limestone, a light gray, thick-bedded, mainly calcitic but slightly dolomitic, limestone. Peckham (1963) reports a thickness of at least 500 feet for the Bone Spring and 800 feet for the Victorio Peak. Both limestones have developed significant solution cavities along joints and fracture planes.



Note: A____A' is the line
of cross section shown
in Figure 5.

Figure 4

Principal Geologic Features



Note: See Figure 4 for location of section.

Figure 5

Generalized Geologic Section Across Dell Valley and the Salt Basin

Overlying much of the Permian limestone formations in the delineated aquifer area is a mantle of up to 150 feet of Quaternary and recent alluvial sediments ranging in size from boulders to silt and clay. The sediments were eroded from highlands to the west and northwest, transported by flooded streams, and deposited on the relatively flat valley floor.

Surface soils overlying the alluvium "... are largely gray silts and silt loams, underlain at depths of 1 to 3 feet by a soft marl or caliche that contains appreciable amounts of gypsum ..." (Longenecker and Lyerly, 1959). The high natural salinity of the soil suggests that at one time, the entire valley may have been covered by the salt lake that currently exists in the Salt Basin to the east. Years of irrigation water application have actually improved the chemical condition of the soil by lowering the pH and total salt and sodium content (Longenecker and Lyerly, 1959). Unfortunately, these minerals have not been eliminated but, instead, have been transported downward to the ground-water system.

HYDROLOGY

Occurrence

Ground water occurs in the Permian limestones throughout the Diablo Plateau region. However, unlike elsewhere on the plateau, the aquifer in the Dell Valley area has been developed because of its relatively shallow water table and the presence of soils capable of growing crops.

Ground water in the aquifer is concentrated in interconnected solution cavities that have developed in joints, fractures, and bedding planes that vary in size and dimension. Water-bearing zones have been encountered in wells drilled in excess of 2,000 feet. Well production is thus linked to the number and size of cavities intercepted by the well bore.

Recharge

Recharge to the regional Diablo Plateau aquifer system is derived from the infiltration of precipitation on the entire plateau area of approximately 2,900 square miles and the downward seepage of water in the Sacramento River. Kreitler and others (1987) determined that recharge on the Diablo Plateau primarily occurs as infiltration of runoff in beds of ephemeral streams, or arroyos, during occasional flash floods. Only during intense rainstorms is the rate of precipitation greater than evaporation. Logan (1984) speculated that less-severe rainfall is capable of furnishing recharge to the aquifer. The presence of tritium in most well samples collected from the plateau aquifer indicates recent recharge (Kreitler and others, 1987).

Much of the ground water in Dell Valley originates as precipitation that infiltrates into the regional aquifer system within the drainage area shown in figure 2. Karst features, such as vertical fractures and sinkholes, permit rapid access of infiltrating surface water. As ground water is withdrawn by pumping and natural discharge, additional water migrates laterally into the aquifer.

The Sacramento River, which drains the Sacramento Mountains in New Mexico, is a major source of recharge in the northern segment of the plateau (Scalapino, 1950). Water drains rapidly into the subsurface as the river leaves higher elevations and encounters the flatter surface of the plateau. J.R. Mayer (oral commun., 1994) has shown that the ground water in the northern part of the plateau is chemically similar to the water in the river but differs from ground water elsewhere in the plateau. Mayer speculates that the river source may influence the quality of the aquifer in the northern and eastern parts of Dell Valley where fresher conditions occur (Figure 13).

A change in the chemical quality of ground water in the valley over time is a possible indication that some water pumped for irrigation use has returned to the aquifer. Logan (1984) suggests that 35 percent of ground water pumped returns to the aquifer. Davis and Gordon (1970) estimate a return flow of as much as 50 percent.

A continuous water-level record in well 48-07-516 and annual irrigation pumpage in the valley for specified years are compared in figure 6. Since 1984, irrigation pumpage has varied from approximately 40,000 to 100,000 acre-feet annually. At the lower range of annual pumpage (40,000 to 60,000), water levels have risen, while at a higher range of pumpage (90,000 to 100,000), water levels have remained relatively constant. Therefore, 90,000 to 100,000 acre-feet appears to be a reasonable estimate of total annual recharge to the aquifer, which includes both lateral inflow and irrigation return flow.

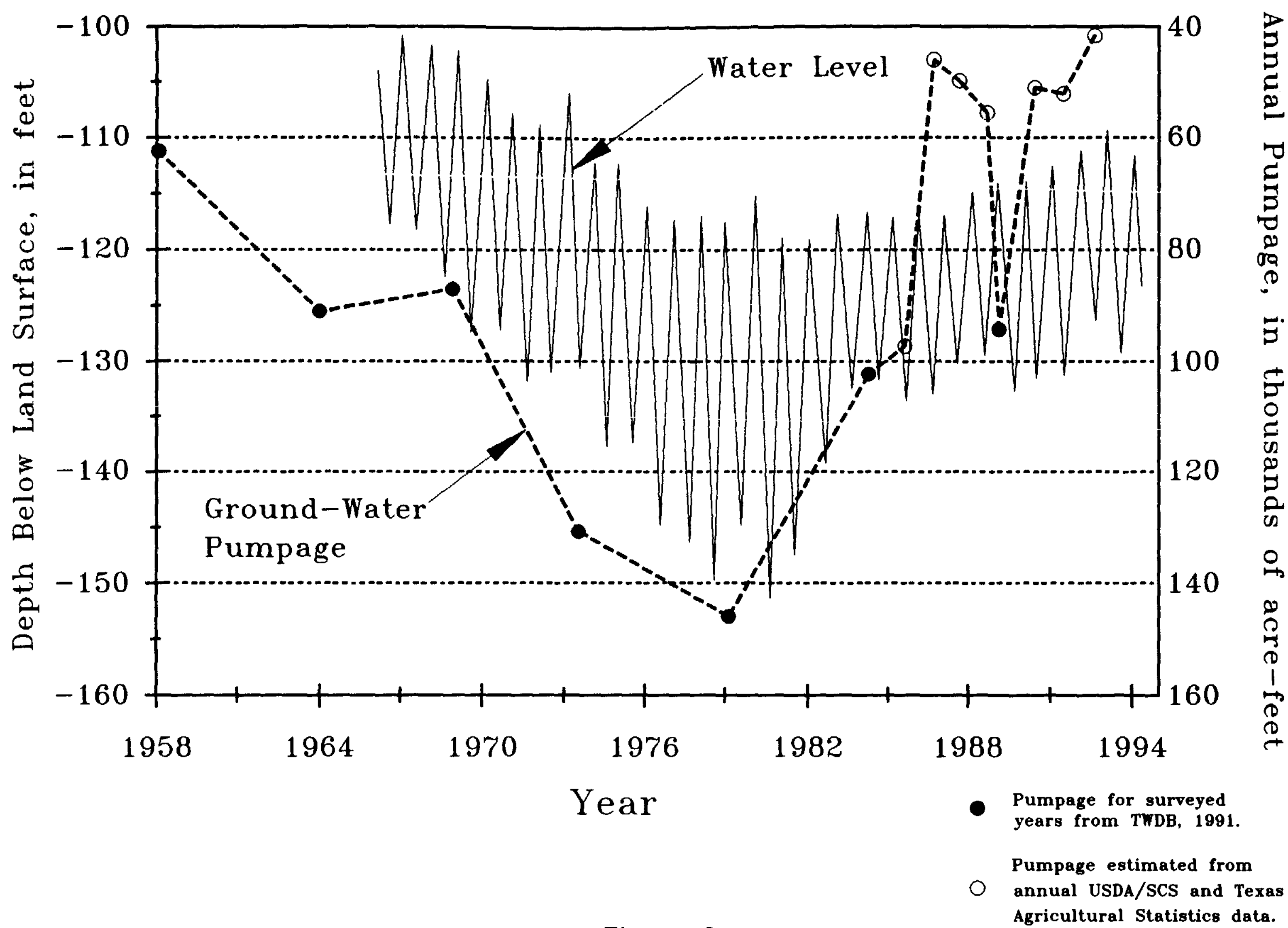


Figure 6

Hydrograph of Water Level in Well 48–07–516 and Annual Regional Pumpage during Designated Years

Construction of four flood-control structures on the western side of Dell Valley is expected to provide as much as 3,300 acre-feet of recharge annually by seepage through the highly permeable pool area (El Paso-Hudspeth Soil and Water Conservation District and others, 1969). However, there has not been enough significant rainfall to fill the reservoirs since the completion of the dams. Included in the project are 11 wells for recharging water captured by the dams (Figure 2). Each well is designed with the intention of recharging water by gravitational flow at a rate of at least 2,000 gallons per minute (Logan, 1984). Currently, the wells are in place but have not been connected to the reservoirs. Benefits expected from the artificial recharge project include improved ground-water quality, stabilization of water levels, and a better understanding of aquifer characteristics.

Movement

Regionally, ground water moves in an east to northeasterly direction from the Diablo Plateau in Texas toward the Salt Basin where it discharges naturally by evaporation from the salt flats. Across the state line in New Mexico, ground-water flow moves in a southeasterly direction toward the basin (J.R. Mayer, oral commun., 1994). A regional potentiometric surface map prepared by Kreitler and others (1987) illustrates a relatively low hydraulic gradient of 2.5 to 5 feet per mile. Within the Salt Basin, ground water percolates upward to the surface, drawn by evaporation through the capillary fringe in the flats (Boyd and Kreitler, 1986).

Some southeasterly subsurface flow may occur through the basal part of the Bone Spring and Victorio Peak Limestones beneath the Salt Basin bolsons (Davis and Leggat, 1965). Kreitler and others (1990) theorize a regional flow from the Diablo Plateau beneath the Salt Basin to the south through Permian carbonate formations.

Water-level trends shown in figure 7 indicate that ground-water movement into Dell Valley is primarily from the west, with a lesser amount entering from the north. Fresher water entering from the north may move into the eastern side of the valley (J.R. Mayer, oral commun., 1994). Southeast of the delineated valley, water movement is toward the south and southwest. This anomalous movement away from the Salt Basin is also indicated on a regional potentiometric surface map developed by Kreitler and others (1987).

Water movement on a local scale is probably controlled by the orientation and concentration of solution cavities developed along prominent fractures and bedding planes. During the irrigation season, movement is altered in the direction of pumping wells. Water-level elevations on both sides of the major fault that forms the southern boundary of the valley are relatively similar, indicating the fault does not significantly interrupt the subsurface flow. Because of the cavernous nature of the limestone aquifer, water movement is potentially rapid except where low hydraulic gradients reduce velocities.

Declining water levels caused by pumpage may reverse the ground-water flow direction on the eastern side of the valley and allow highly saline water to move westward into the irrigated region. Current water-level elevations in the central part of Dell Valley are, in fact, lower than levels in the adjacent Salt Basin, which suggests the potential for such movement does exist. However, chemical-quality analyses of water samples from wells located along the eastern side of the valley do not indicate a significant influx of saline water. The less-permeable sediments that fill the Salt Basin may hinder rapid migration of the saline water.

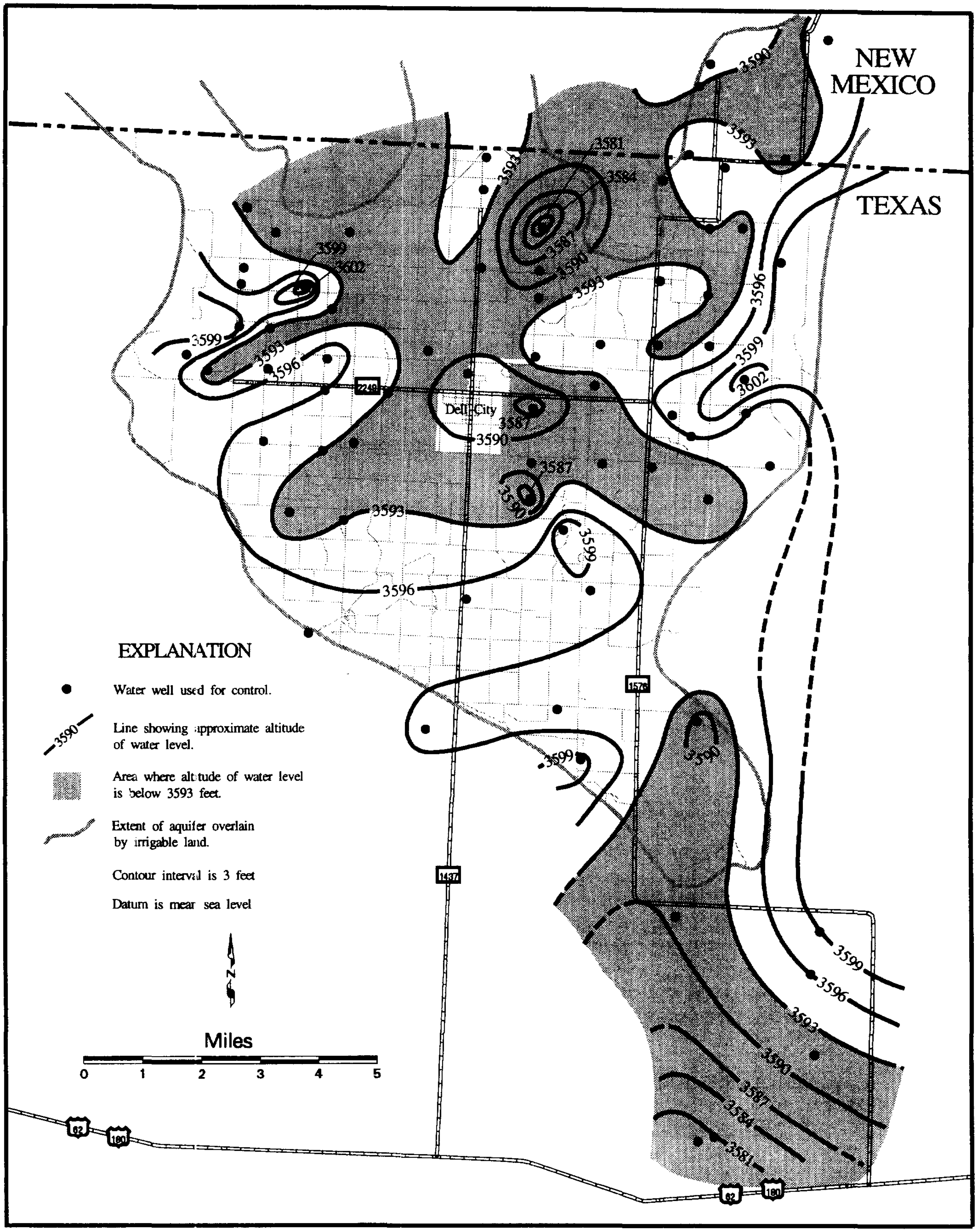


Figure 7
Approximate Altitude of Water Levels, February 1994

Discharge

Large quantities of water are discharged from the aquifer annually. Discharge occurs naturally through springs, seeps, and evaporation from the salt flats, and artificially by pumpage.

Natural Discharge

Eastward migrating ground water underlying the Diablo Plateau moves into the Salt Basin where it partially discharges by evaporation, especially from the salt flats where the water table is 3 to 10 feet below the surface (Boyd and Kreitler, 1986). Prior to irrigation development, the aquifer was at a quasi-steady state, and the amount of water discharged through evaporation from the salt flats was approximately equal to the recharge to the Bone Spring-Victorio Peak aquifer in the Dell Valley and Crow Flats areas.

Scalapino (1950) estimates that the salt flats include an area of approximately 37,000 acres in Texas and New Mexico. At an average annual gross lake surface evaporation rate of 81 inches (Larkin and Bomar, 1983), potentially 250,000 acre-feet of water could evaporate annually if the water were at the surface. However, evaporation of capillary water is undoubtedly less.

Boyd and Kreitler (1986) suggest that evaporation rates on the salt flats could theoretically range from 15.7 to 78.7 inches per year or more. At this rate 49,000 to 243,000 acre-feet of ground water could evaporate annually. Davis and Leggat (1965) estimate that approximately 40,000 acre-feet evaporates annually in the Texas portion of the Salt Basin.

Bjorklund (1957) estimates that less than 100,000 acre-feet annually was originally discharged through this manner. This estimate was based on the observation that in 1955, about 100,000 acre-feet of water was pumped from the aquifer with water levels continuing to decline, suggesting that discharge exceeded recharge.

As explained in the recharge section, water-level and pumpage comparisons since 1984 indicate that 100,000 acre-feet is a reasonable estimate for original natural discharge. These estimates provide a likely range of expected discharge by evaporation from the ground-water system.

Pumpage

With the advent of irrigated agriculture in the 1940s, pumpage has become the principal means of discharge from the aquifer. Except for a scattering of wells throughout the Diablo Plateau, almost all of the pumpage occurs in the Dell Valley and Crow Flats areas. Pumpage in the Dell Valley area reached a peak in the late 1970s with more than 140,000 acre-feet being pumped annually. Annual withdrawals for irrigation use since 1984 ranges from approximately 40,000 to 100,000 acre-feet. During the 1970s, pumpage exceeded recharge, resulting in a decline in the elevation of the water table. The historical development of ground-water use in this area is discussed more thoroughly in the section titled "History of Water Use."

Regionally, the aquifer is highly transmissive. However, at any particular location, well yields can vary significantly. Highly productive wells, producing up to 3,000 gallons per minute (gpm), are those that intersect numerous fractures and solution zones. Fractures are not, however, equally distributed throughout the aquifer, as is evidenced by the number of lower capacity wells (e.g., 300 gpm) that have been drilled in the near vicinity of highly productive wells.

Scalapino (1950) reports that between 1947 and 1949, only 32 of 78 wells drilled for irrigation were put into use. The yields of these 32 wells range from 350 to 3,000 gpm, and average 1,400 gpm. Davis and Leggat (1965) describe the results of aquifer tests conducted on 14 irrigation wells. Well yields range from 160 to 2,240 gpm. Specific capacities range from 5.2 to 63.8 gpm per foot of drawdown, with an average of 32.0 gpm per foot of drawdown.

WATER LEVELS

Current Water Level

Depth to water was measured in 72 wells in February 1994 at a time when the aquifer water level should have reached its maximum recovery just prior to the start of the spring pumping season. Altitude of the water table above mean sea level was calculated and contoured as shown on figure 7. Ninety-three percent of the measurements vary between altitudes of 3,587 and 3,602 feet, and average 3,594 feet. The lowest water levels occur near the center of the valley in the vicinity of Dell City and north of town near the location of the primary municipal supply well. The fault that forms the southern boundary of the valley does not appear to affect water levels in its vicinity. South of the delineated valley, low water levels occur in the vicinity of highway 62-180.

The relative flatness (low gradient) of the water table results in a westerly increase in depth to water as the land surface altitude increases. Depth to water ranges from a few feet below the surface in the salt flats to more than 800 feet in higher elevations of the Diablo Plateau (Kreitler and others, 1987). Within the irrigated region of the valley, depths to water range from 33 feet along the eastern side to 323 feet on the west (Figure 8).

The relative flatness of the static water table has been contributed to the unusually high permeability of the limestone (Bjorklund, 1957). The many interconnected solution channels allow for the relative ease of flow to equalize the hydrostatic head over a large area. Also, a damming effect caused by a change of permeability along the eastern side of the valley has been suggested for the flatness (Scalapino, 1950).

Seasonal Fluctuation

Water levels in the valley exhibit a seasonal fluctuation. During the irrigation season, the large quantity of water pumped from the aquifer results in a depressed water table surface as more water is being withdrawn than can be immediately replaced. However, during the winter (non-pumping) season, the water table rebounds as additional water recharges the aquifer system, and cones of depression recover. The seasonal water-level fluctuation can be observed on the hydrograph of well 48-07-516 (Figure 6). The hydrograph shows that the aquifer response is in the range of 15 to 35 feet, depending on the amount of annual pumpage.

Water-level Change

Drawdown on the aquifer occurred immediately after irrigation wells began pumping in the late 1940s. The water level dropped at an average rate of 1.3 feet per year for the next 30 years as pumpage exceeded recharge to the aquifer. By the late 1970s, water-level declines of 25 to 45 feet had occurred throughout the valley. Since then, irrigation pumpage has diminished somewhat, and water levels have remained relatively constant or, in some locations, have risen slightly. Figure 9 shows hydrographs of the historical water-level trend in six wells.

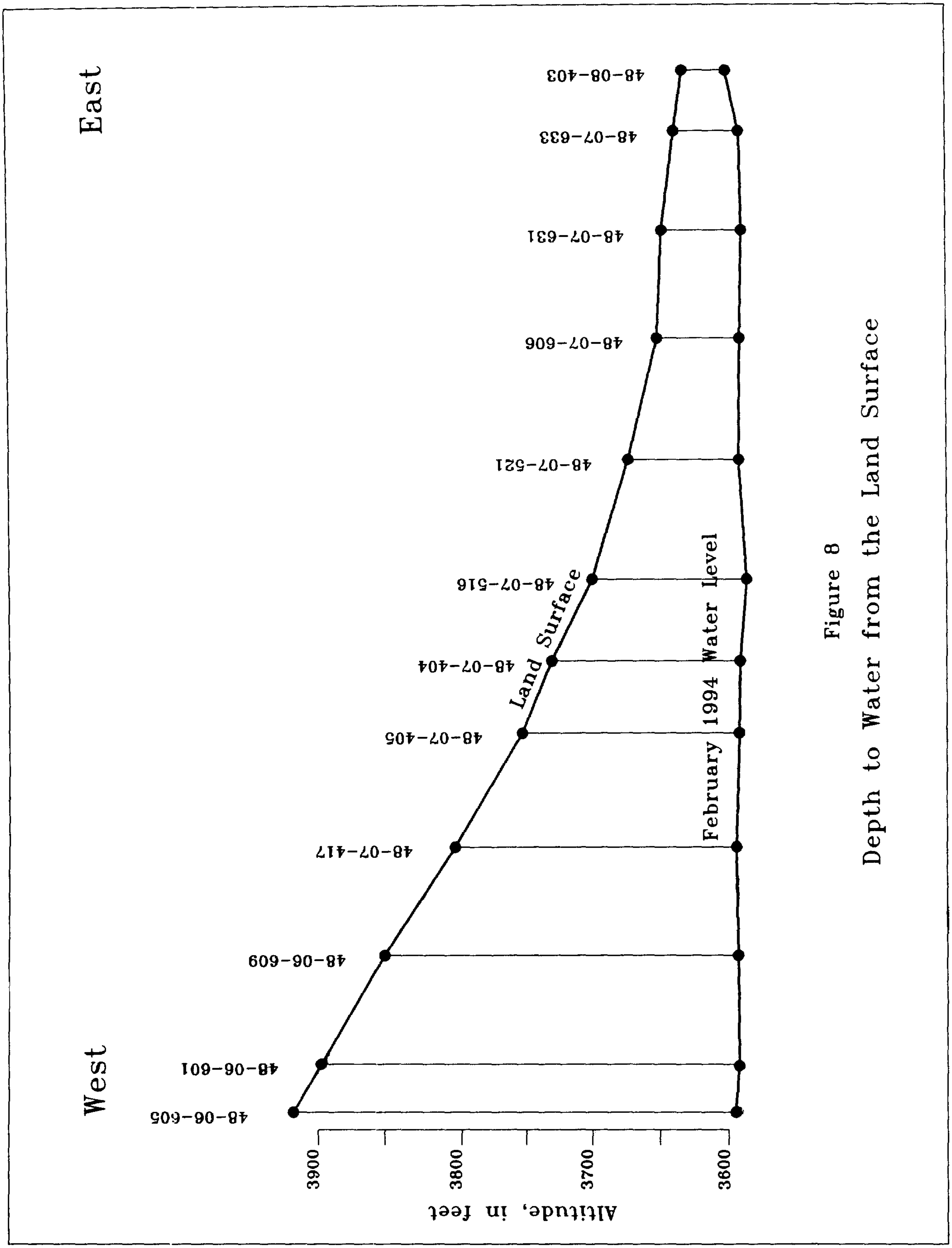


Figure 8

Depth to Water from the Land Surface

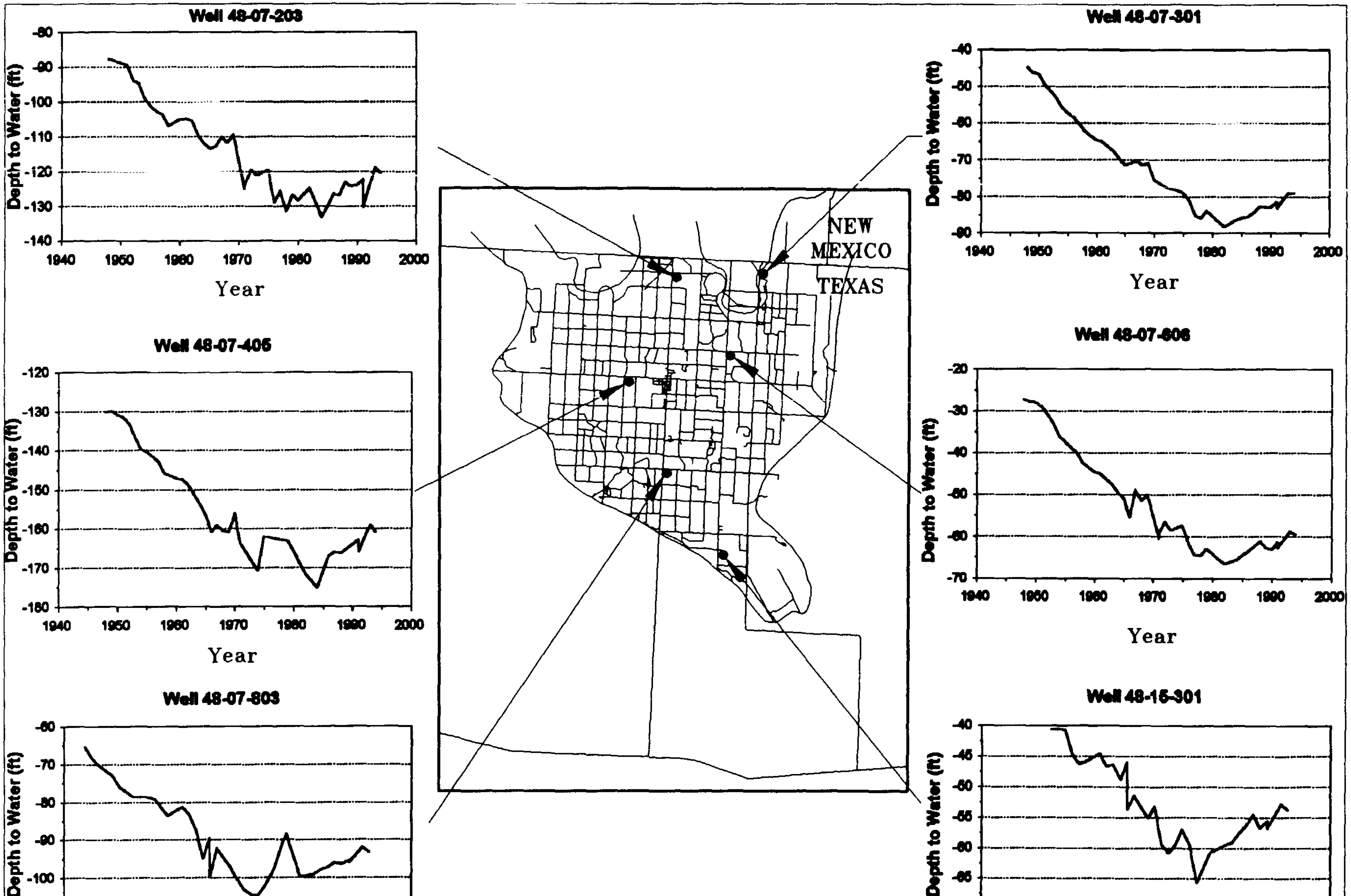


Figure 9

Hydrographs of Selected Wells

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WATER QUALITY

Chemical Quality Characteristics

The quality of ground water underlying Dell Valley is generally brackish, very hard, and dominated by elevated levels of calcium, sodium, sulfate, and chloride. The Ca-Na-SO4 chemical facies of Dell Valley water, as shown in the Piper diagram in figure 10, is similar to that found in ground water throughout the extent of the Bone Spring and Victorio Peak Limestones in the Diablo Plateau region of Texas (Kreitler and others, 1987). However, the individual constituent concentrations are greater in the valley.

The prominence of calcium, sodium, sulfate, and chloride minerals in the ground water can be traced to two dominant processes: (1) water flowing through the aquifer system and dissolving minerals along the flow path, and (2) irrigation water percolating downward through the soil zone. Calcium and sulfate minerals are readily dissolved by ground water that comes in contact with evaporite deposits in the Bone Spring and Victorio Peak Limestones. The very high hardness (as CaCO3) value is also indicative of ground water in a limestone/dolomite environment.

Irrigation water percolates with relative ease through the naturally saline soils and underlying gypsiferous caliche of the valley. However, some of the water applied to the land surface is partially evaporated, which leaves behind a slightly more concentrated dissolved mineral solution. In order to leach salt minerals from the root zone of crops, relatively large amounts of mineralized water are applied annually to the porous land surface. Thus, each application of water delivers additional dissolved minerals, especially sulfates and chlorides, downward to the aquifer.

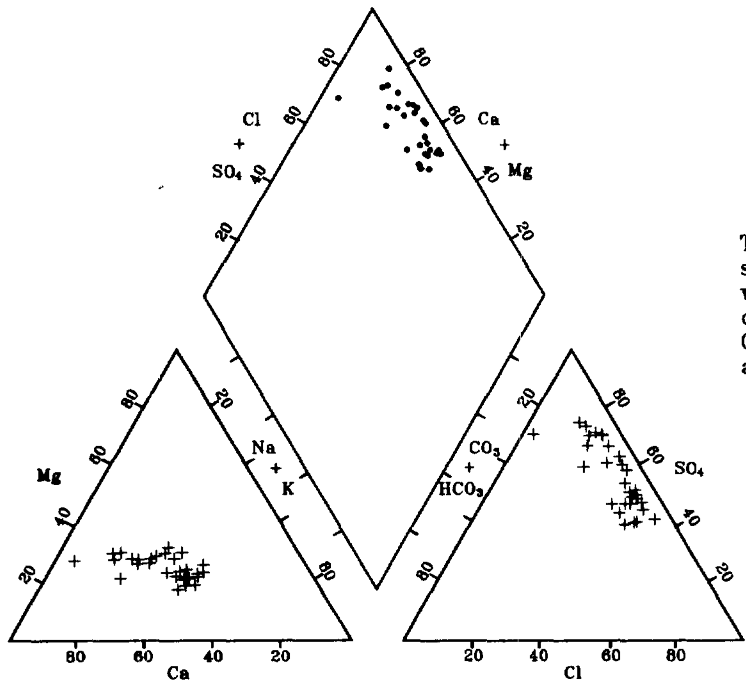
1992 Quality Survey

A water-quality survey was conducted in 1992 in which samples were collected from 30 wells and were analyzed for primary and trace inorganic minerals, nutrients, pesticides, and radionuclides. Sampling was conducted in accordance with the methods described in the TWDB *Field Manual for Ground-Water Sampling* (Nordstrom and Beynon, 1991). The chemical analysis of samples from each of the 30 wells is given in Table 1. The following quality evaluation is based on the results of the analyses from these 30 wells.

Ground-water quality is most commonly characterized in terms of dissolved concentrations of its major anion and cation inorganic constituents, and to a lesser extent with other dissolved trace elements. In combination, the amount of dissolved minerals in the water is termed "total dissolved solids," or TDS. Average, minimum, and maximum, concentration of each constituent is shown in Table 2. Figure 11 illustrates the average percent composition of each major constituent to the total. Figure 12 shows the location of wells sampled since 1979 and includes the 30 wells sampled in the 1992 survey.

Water in the Dell Valley area can be classified as slightly to moderately saline, with TDS ranging from approximately 1,000 to more than 6,500 milligrams per liter (mg/l), and averaging about 3,500 mg/l (Figure 13). TDS is greatest along a north-south strip east to southeast of Dell City where concentrations exceed 5,000 mg/l.

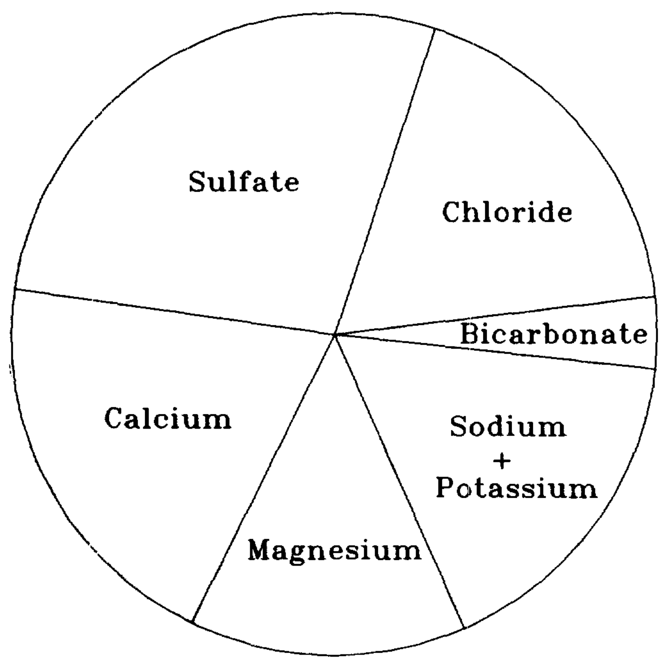
Sulfate is the most prominent constituent, with concentrations ranging from 631 to 2,448 mg/l. Calcium, sodium, and chloride also attain high levels of concentration. The concentration distribution of sulfate and chloride are illustrated in figures 14 and 15, respectively.



The thirty analyses shown on the diagram were from well samples collected in 1992. Constituent percentages are in milliequivalents.

Figure 10

Piper Trilinear Diagram Showing Composition of Major Dissolved Constituents



Pie diagram represents percentage of average constituent concentration of thirty analyses from well samples collected in 1992. Percentage based on milliequivalents per liter. Other ions present in small amounts have been purposefully omitted.

Figure 11

Average Percentage Composition of Major Dissolved Constituents

Table 1. Chemical Analyses of Water from Wells Sampled in June, 1992

State Well Number	Temp °C	Silica (SiO2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Strontium (Sr)	Bicarbonate (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	pH	Dissolved Solids	Total Hardness as CaCO3	%Na	SAR
4806901	24	21	601	153	267	10	12.30	227	1861	417	1.50	4.43	7.00	3459	2143	21	2.52
4807113	21	17	368	142	213	8	9.02	243	1366	282	2.00	17.89	6.91	2544	1512	23	2.39
4807114	21	15	283	101	162	7	6.25	266	804	233	1.35	15.10	7.07	1758	1128	23	2.10
4807205	20	16	497	285	478	10	10.90	218	2352	576	1.92	61.93	7.05	4395	2425	30	4.23
4807207	22	18	411	142	145	7	11.50	232	1394	199	1.78	13.10	6.90	2456	1622	16	1.57
4807219	22	15	242	67	20	3	5.05	283	631	22	1.37	3.85	6.87	1148	885	4	0.29
4807316	20	17	484	192	191	7	9.26	248	1662	280	1.36	22.44	6.85	2988	2008	17	1.86
4807317	21	18	439	171	305	16	8.36	272	1481	519	1.58	12.17	6.79	3104	1808	26	3.13
4807401	21	17	517	263	555	14	12.90	179	1990	898	2.00	133.65	7.08	4490	2386	33	4.96
4807426	22	17	504	217	362	10	12.60	194	1982	493	2.05	59.15	6.96	3754	2164	26	3.40
4807517	20	16	545	329	666	11	12.10	201	2400	886	2.25	105.36	7.01	5071	2727	34	5.56
4807518	19	17	833	432	771	15	21.70	239	2272	1993	1.40	60.07	6.78	6533	3880	30	5.40
4807522	22	17	533	224	377	10	12.70	211	1924	578	3.82	55.43	6.84	3838	2265	26	3.46
4807528	22	17	448	186	508	18	10.20	237	1649	824	1.47	33.60	7.00	3811	1894	36	5.09
4807529	21	17	612	287	488	10	15.70	218	2226	916	1.59	82.12	6.92	4762	2725	28	4.08
4807619	23	16	261	97	245	11	5.26	272	752	421	1.20	5.22	7.10	1948	1056	33	3.29
4807630	19	17	717	263	232	9	19.30	209	1646	1112	1.29	7.97	6.89	4127	2893	14	1.88
4807631	21	17	357	136	178	9	7.25	268	1183	274	1.40	12.93	6.96	2307	1458	21	2.03
4807706	25	19	285	82	315	15	5.56	284	793	511	1.11	5.05	7.01	2171	1054	39	4.23
4807717	23	17	365	137	470	20	7.41	261	1196	743	1.33	20.63	6.99	3105	1482	40	5.32
4807718	24	17	315	111	443	20	6.34	287	923	741	1.70	11.16	7.00	2730	1249	43	5.47
4807801	20	20	555	320	946	24	10.90	272	2448	1418	2.23	34.71	6.79	5912	2713	43	7.92
4807816	23	19	429	195	552	19	9.06	256	1577	949	1.76	27.05	6.91	3903	1883	39	5.55
4807817	22	20	438	174	573	21	9.57	260	1615	898	1.73	20.67	6.99	3898	1819	40	5.86
4807904	22	20	515	243	781	38	11.60	266	1983	1252	1.82	23.51	6.89	4999	2297	42	7.11
4807915	21	16	349	132	376	18	7.53	262	964	779	1.36	28.02	6.93	2799	1422	36	4.35
4815209	21	17	441	221	733	19	11.90	217	1802	1092	1.96	56.18	7.07	4501	2023	44	7.11
4815301	28	17	269	89	331	16	5.88	284	730	558	1.21	6.24	6.97	2163	1044	40	4.47
4815303	23	17	457	197	680	26	12.30	250	1643	1228	1.35	21.16	6.95	4405	1964	43	6.70
4815304	23	17	335	119	401	22	7.37	268	1113	676	1.41	10.40	6.96	2834	1333	39	4.79

The results are in milligrams per liter except Temp, pH, Percent Sodium (%Na), and SAR.

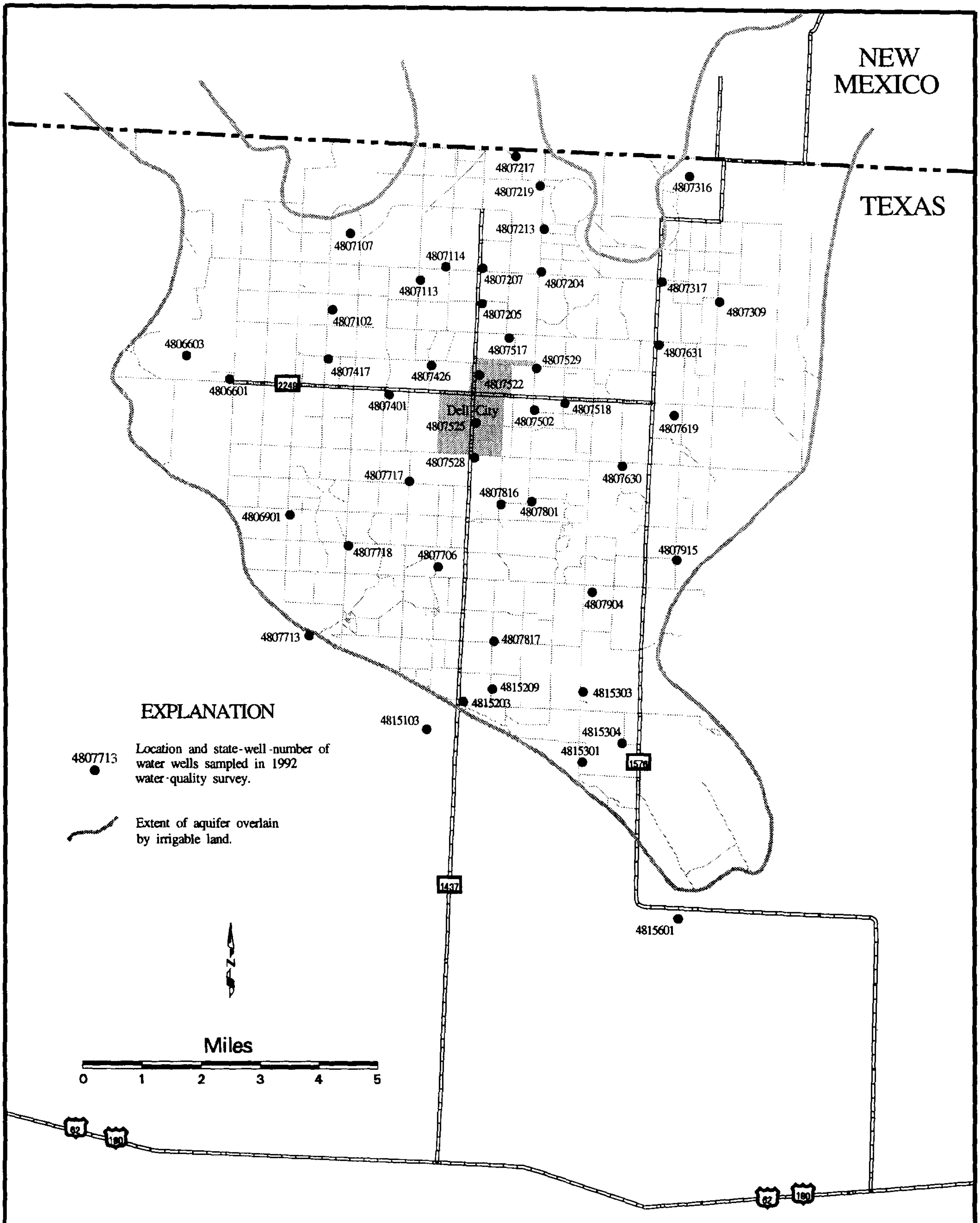


Figure 12
Location of Wells Sampled between 1979 and 1992

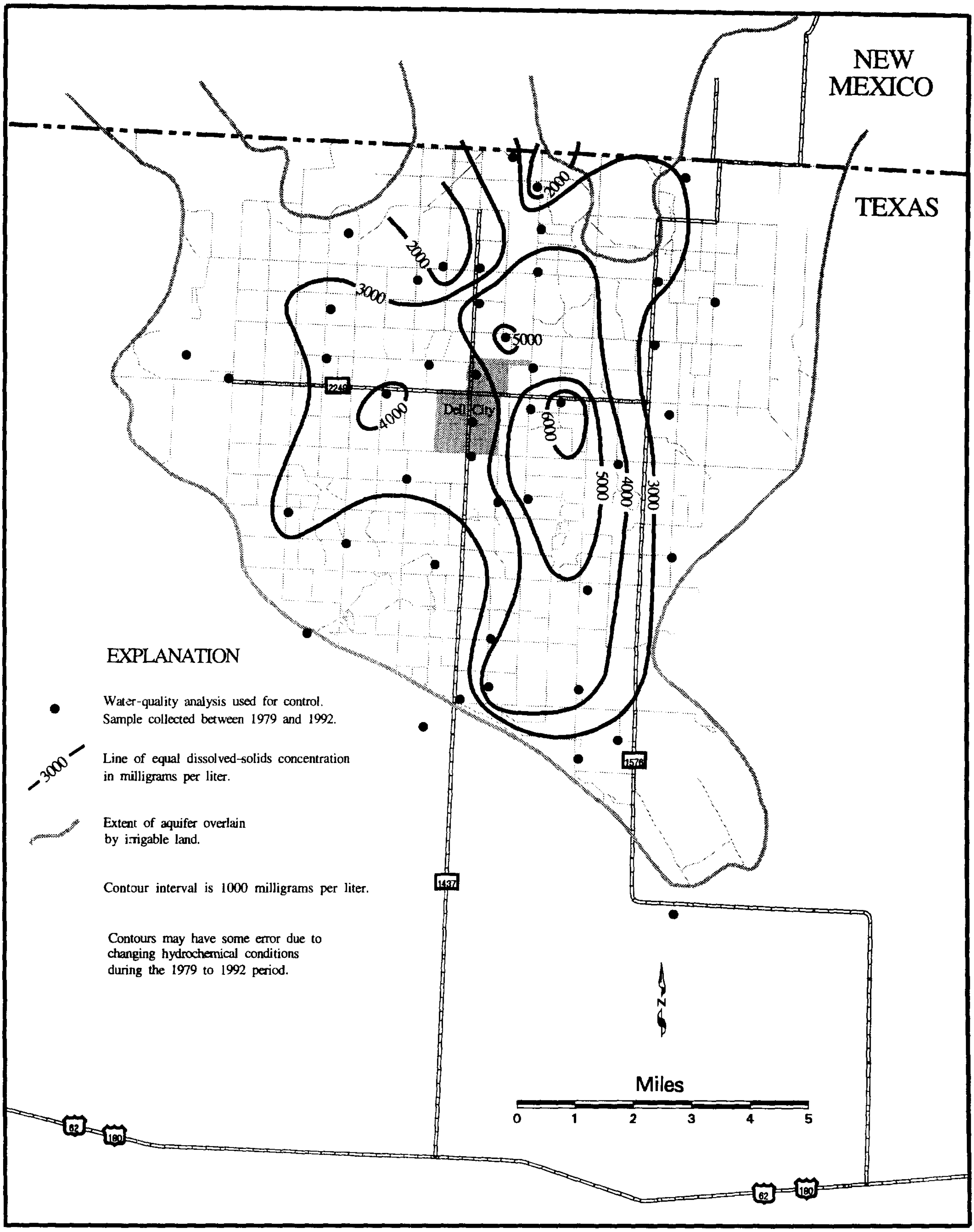


Figure 13
Dissolved-solids Content, 1979 to 1992

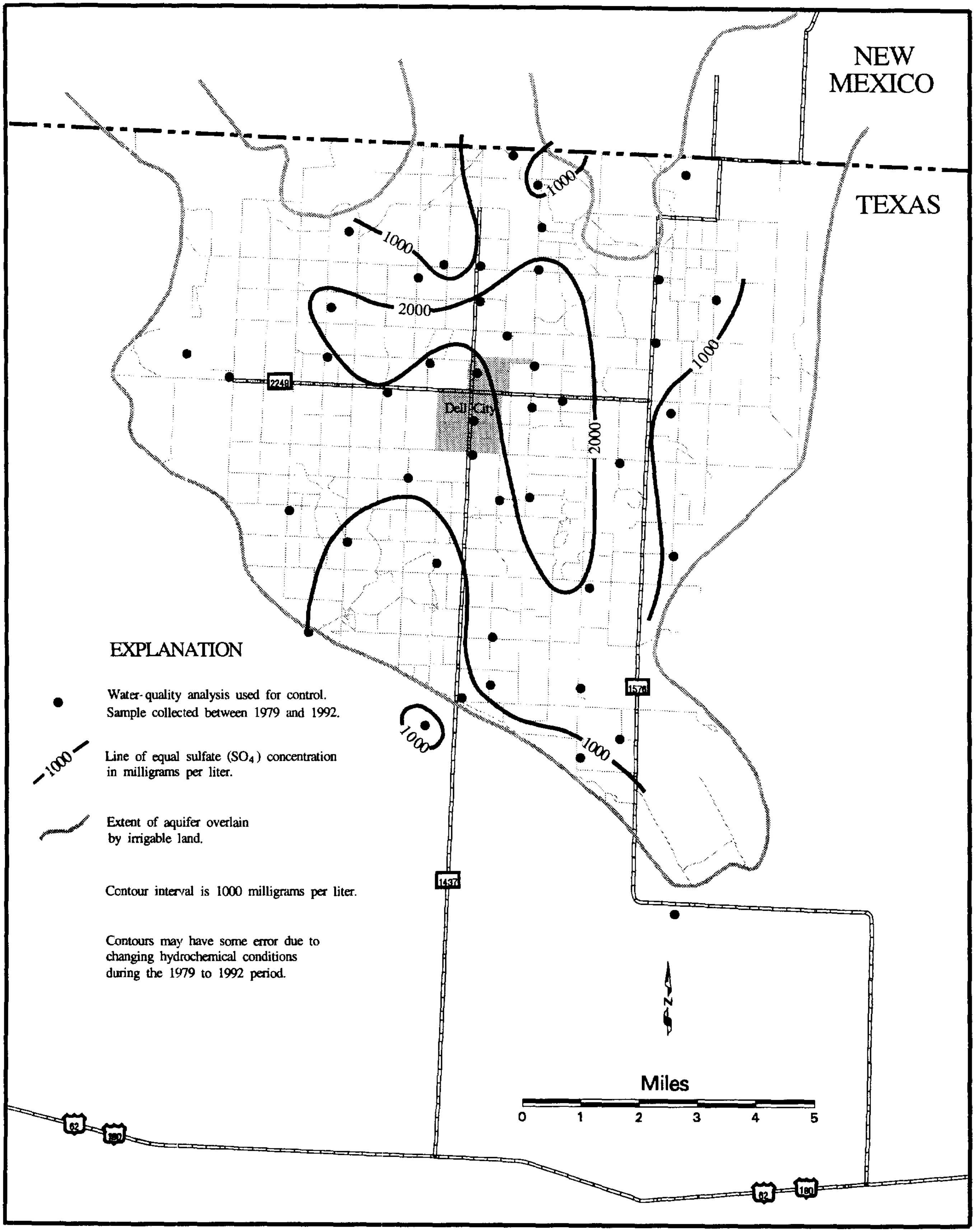


Figure 14
Sulfate Content, 1979 to 1992

Figures 13, 14, and 15 show the distribution of TDS, sulfate, and chloride concentration in wells sampled from 1979 to 1992. The 14- year time span was selected to encompass the greatest number of available samples. The contours, thus, may have some error due to changing hydrochemical conditions; however, the 1,000 mg/l contour interval will be only slightly affected.

Table 2. Average and Range of Concentrations of Major Constituents in Samples Collected in 1992

Constituent	Average (mg/l)	Minimum (mg/l)	Maximum (mg/l)
Silica	17.37	15.00	21.00
Calcium	446.83	242.00	83.00
Magnesium	190.23	67.00	432.00
Potassium	14.76	2.50	38.00
Sodium	425.47	20.00	946.00
Strontium	10.26	5.05	21.70
Bicarbonate	246.27	179.39	286.78
Sulfate	1,545.40	631.00	2,448.00
Chloride	725.60	22.00	1,993.00
Fluoride	1.68	1.11	3.82
Nitrate (NO_3)	31.10	3.90	133.70
Dissolved Solids	3,530.43	1,148.00	6,533.00
Hardness as $CaCO_3$	1,908.73	885.00	3,880.00

Water samples were analyzed for the following minor or trace inorganic constituents: arsenic, barium, copper, iodide, iron, manganese, selenium, and zinc. Concentrations were below detection limits in all samples except for one iron and five zinc analyses. However, even these did not exceed federal Safe Drinking Water Standards.

Nutrients in ground water are various derivatives of nitrogen. When found dissolved in ground water, nutrients are an indicator of contamination from, most commonly, decaying organic matter, human and animal waste, and fertilizers. Samples from the 30 wells were analyzed for ammonia, nitrite, nitrate, and Kjeldahl. All ammonia and nitrite analyses were below detection limits, and Kjeldahl values ranged from 0.2 to 1.0 mg/l. Eight of the samples had nitrate (as NO3) concentrations in excess of the recommended MCL limit for drinking water of 44.3 mg/l. The elevated nitrate concentrations were most likely derived from fertilizers transported rapidly by irrigation water return flow.

Dissolved radionuclide activity above recommended safe levels were detected in sampled water. Fourteen of 30 well samples had measured gross alpha activity in excess of the recommended maximum safe level of 15 picocuries per liter (pCi/l). Only two samples exceeded the recommended safe level for gross beta activity of 50 pCi/l. Radioactive particles, or radionuclides, are found as trace elements in most rocks and soils. The source of most of the radioactive elements in the ground water underlying Dell Valley is probably derived from the disintegration of volcanic rocks that occur in the near vicinity.

Because of the high permeability of the unsaturated zone above the aquifer, it is reasonable to expect contaminants from the surface to travel rapidly downward to the

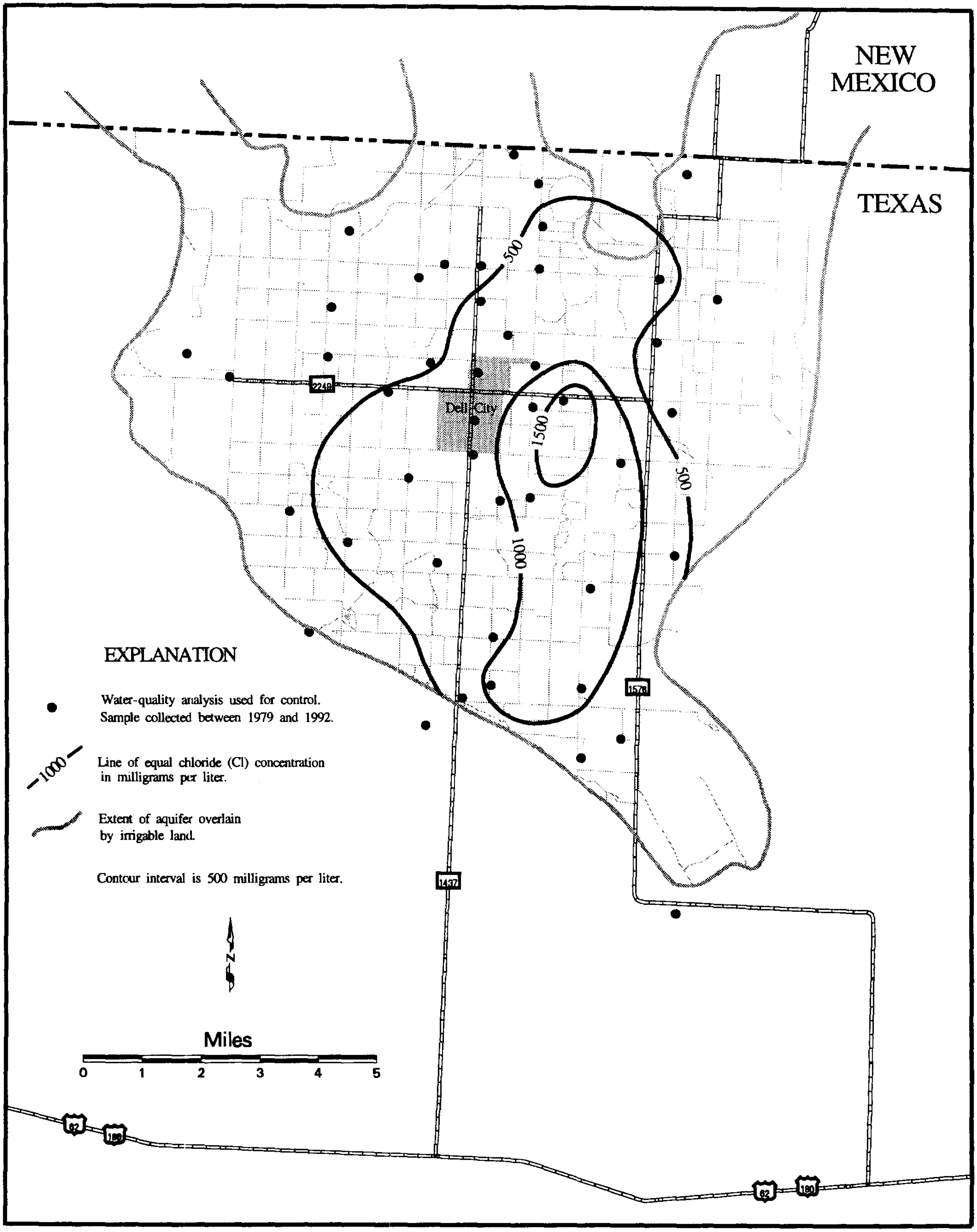


Figure 15
Chloride Content, 1979 to 1992

water table. Potential contaminants to the aquifer that pose a health hazard include various pesticides used in agriculture. A pesticide scan analysis, which included 48 organic compounds, was run on five well samples. No organic compounds were found above detection limits in any of the five wells.

Suitability for Drinking Water

The quality of water for human consumption is always of concern. In 1974, the federal Safe Drinking Water Act was adopted and standards were set for drinking-water quality. Primary standards are devoted to constituents and regulations affecting the health of consumers, whereas secondary standards deal with the aesthetic quality of drinking water. The Texas Natural Resource Conservation Commission (TNRCC) is responsible for regulating the quality of drinking water provided by public supply systems in Texas. Table 3 lists the primary and secondary maximum constituent levels (MCLs) for specific constituents as set by the TNRCC in January 1993.

Table 3 also lists the number of samples from the 1992 water-quality survey that exceed the MCLs. Of particular interest are the 24 of 30 chloride samples and all of the 30 sulfate samples that exceed set limits. Also, all 30 samples exceed MCLs for total dissolved solids. Other constituents and quality characteristics that exceed recommended standards in a lesser percentage of the samples include nitrate, gross alpha and beta, fluoride, and pH. Ground water in Dell Valley is, therefore, not recommended for human drinking purposes without prior treatment, such as the desalination process now employed for the Dell City community system.

Table 3. Percent of Sampled Constituents Exceeding Safe Drinking Water Standards

Constituent	Maximum Constituent Level (MCL) Allowed[1]	Percent of 1992 Samples Exceeding MCLs
	Primary Constituents	
Arsenic	0.05 mg/l	0
Barium	2.0 mg/l	0
Fluoride	4.0 mg/l	0
Nitrate (as N)	10.0 mg/l	26
Selenium	0.05 mg/l	0
Gross Alpha	15 pCi/l	47
Gross Beta	50 pCi/l	7
	Secondary Constituents	
Chloride	300 mg/l	80
Copper	1.0 mg/l	0
Fluoride	2.0 mg/l	13
Iron	0.3 mg/l	0
Manganese	0.05 mg/l	0
pH	≥ 7.0	67
Sulfate	300 mg/l	100
Dissolved Solids	1,000 mg/l	100
Zinc	5.0 mg/l	0

[1] MCLs set by the Texas Natural Resource Conservation Commission

Suitability for Irrigation

The suitability of ground water for irrigation purposes is largely dependent on the chemical composition of the water. The extent to which the chemical quality will affect the growth of crops is determined in part by the climate, soil, management practices, crops grown, drainage, and quantity of water applied. Primary characteristics that determine the suitability of ground water for irrigation are total concentration of soluble salts, relative proportion of sodium to other cations (calcium and magnesium), and concentration of boron or other toxic elements. These are termed the salinity hazard (specific conductance), sodium hazard (SAR), and boron hazard.

The specific conductance of water is used as an index of its salinity hazard. Specific conductance measured in 1992 in samples from 22 wells ranged from 1,438 to 8,810 micromhos per centimeter and averaged 4,720. All samples but one fell within the category of having a very high salinity hazard. Figure 16 illustrates the linear relationship between specific conductance and dissolved solids. The plot can be used to estimate dissolved solids from known specific conductance. Based on this relationship, dissolved solids are approximately 78 percent of specific conductance. This relationship varies among aquifers and even within the same aquifer.

High concentrations of sodium relative to calcium and magnesium in irrigation water adversely affect soil structure by forming a hard, impermeable crust that results in cultivation and drainage problems. An index used for predicting the sodium hazard is the sodium-adsorption ratio (SAR). SAR values computed from the analyses of the 30 well samples range from 0.3 to 7.9, and average 4.2.

SAR and specific conductance values of water samples from 22 wells are plotted on a diagram used for the classification of irrigation waters (Figure 17). The plotted data indicate that the sodium hazard increases directly with the increase in salinity hazard. Half of the samples fall within the medium sodium hazard range, while the rest are distributed in the low and high ranges. Ground waters with a specific conductance of up to 6,000 micromhos/cm have SAR values within the low to medium sodium hazard range and are being used successfully to water crops. Ground waters with specific conductance in excess of 6,000 micromhos/cm generally have a high sodium hazard and require special soil management such as good drainage and leaching in order to grow salt-tolerant crops (U.S. Salinity Laboratory Staff, 1954).

Boron is necessary for good plant growth but rapidly becomes toxic at higher concentrations. Permissible limits of boron for various crops range from 0.67 to 3.00 mg/l (Scofield, 1936). The concentration of boron in 30 well samples collected in 1992 range from 0.12 to 2.36 mg/l, and average 0.81 mg/l. Nineteen of the 30 samples exceed the lower limit; however, none exceed the upper limit. Water from the aquifer, therefore, appears to be acceptable for the irrigation of most semi-boron-tolerant crops.

Although the water is high in salinity, irrigated agriculture has been successful in Dell Valley due to the excellent permeability of the soil, the balance of the dissolved minerals, and the low sodium percent. A study by Longenecker and Lyerly (1959) shows that six to eight years of water application had definitely improved the chemical conditions in the irrigated soils versus uncultivated soils. With the application of sufficient quantities of water, resident salts in the soil profile are easily leached downward beyond the root zone of crops. Soil salinity, however, cannot be reduced below the salinity of the water used for leaching. Although the leaching process has been beneficial to crop growth, it has, unfortunately, caused a degradation of the quality of the ground water due to irrigation return flow.

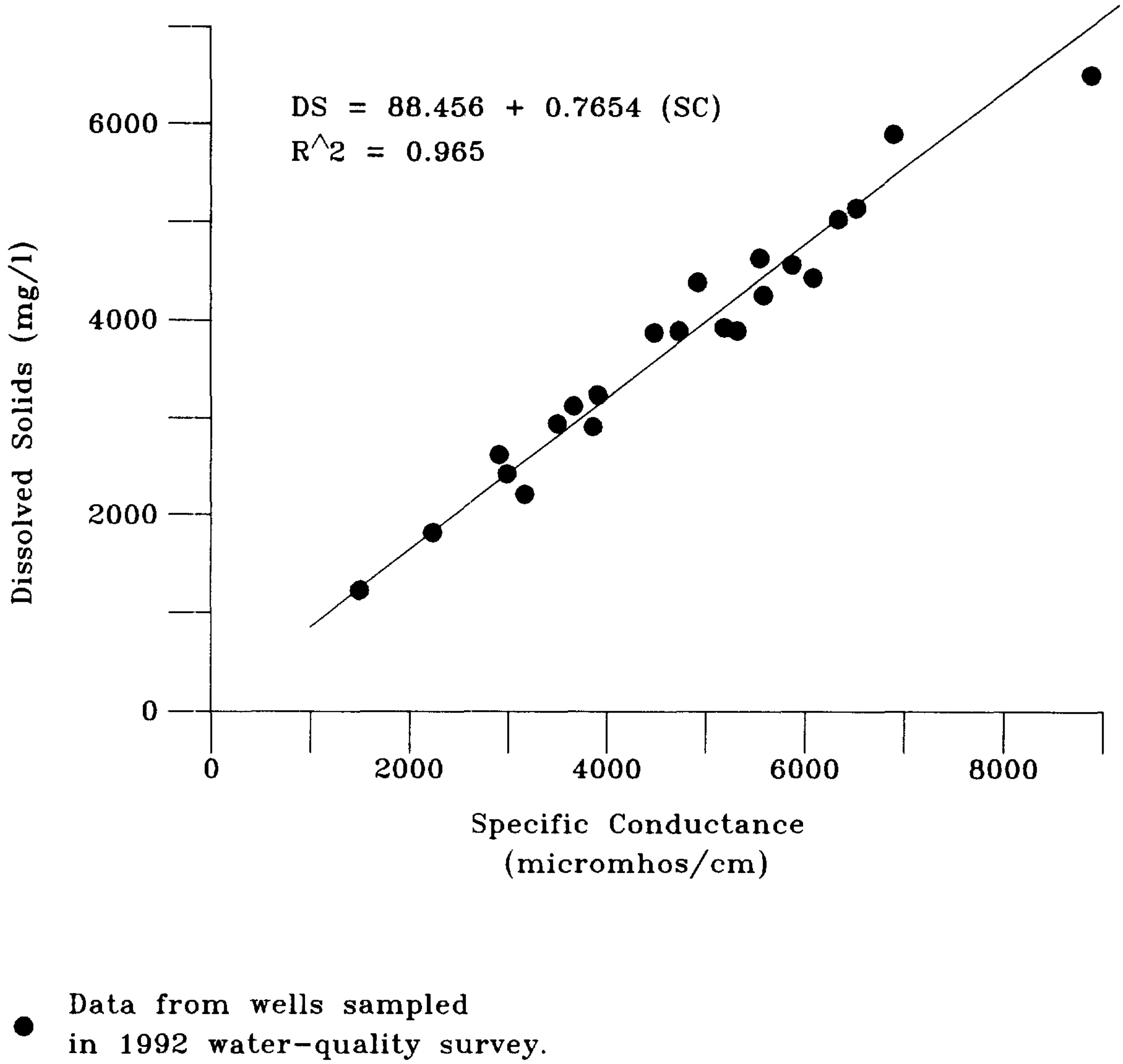


Figure 16

Relationship between Specific Conductance and Dissolved Solids

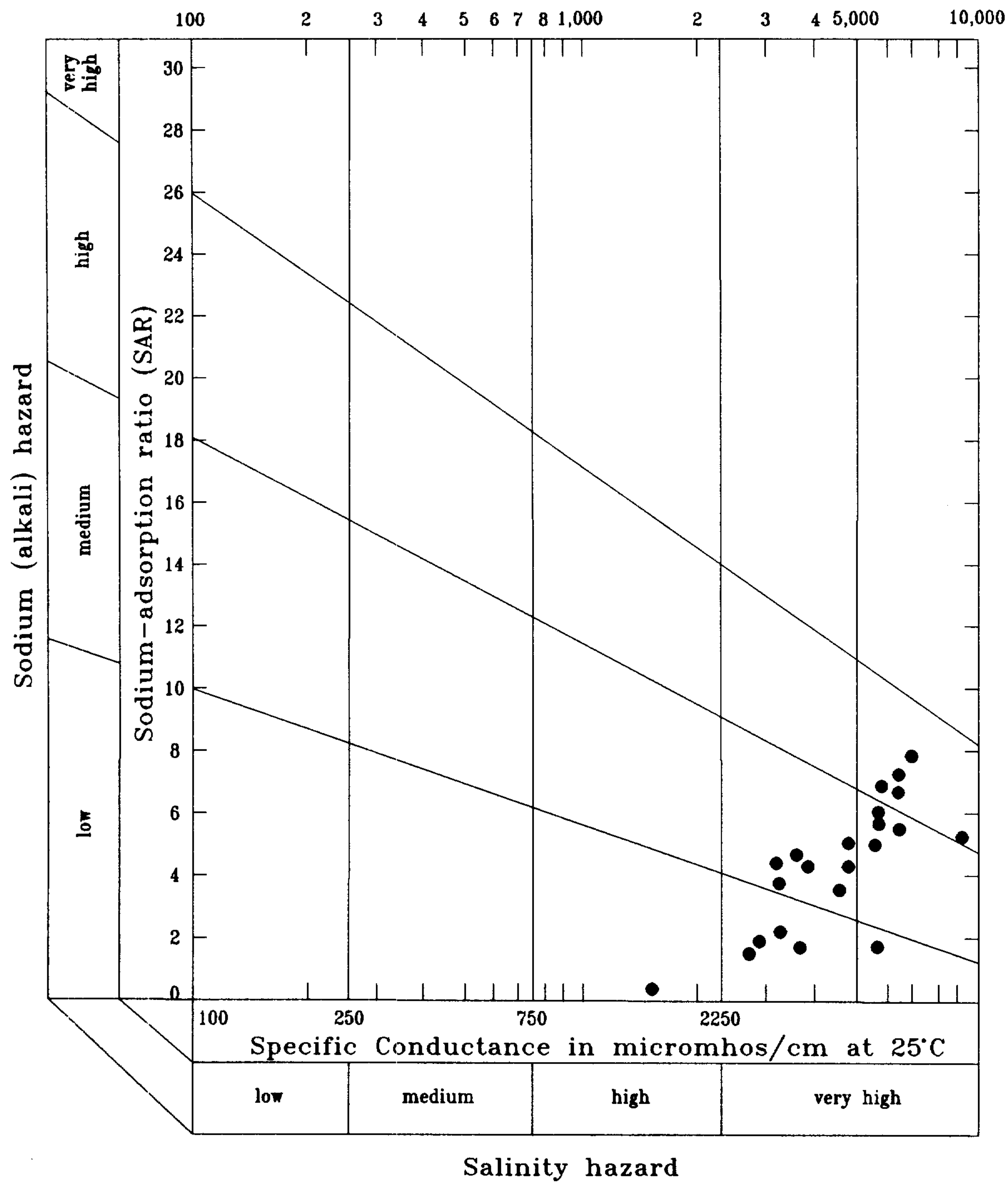


Figure 17

Classification of Irrigation Waters in Dell Valley

(After United States Salinity Laboratory Staff, 1954, p. 80)

Water-quality Change

Ground-water quality changes have been occurring since the 1940s when return flow of water from the first irrigation wells began altering the natural chemical composition of the aquifer. Water applied to agricultural land has percolated down to the water table, leaching additional minerals on its way. Also, the drilling and open completion of hundreds of wells in the valley has created a condition in which zones containing poor-quality water can mix with all other water-bearing zones.

Over time, the concentration of individual dissolved constituents in the ground water has increased. Typical water-quality change in the valley is illustrated in figure 18, which shows the increasing concentration of sulfate, chloride, sodium, and dissolved solids in samples collected from well 48-07-205 between 1948 and 1992. During this period, dissolved solids increased from 1,119 mg/l to 4,395 mg/l. The increase in sulfate concentration alone represents approximately half of the total increase.

Table 4 lists the average concentration of specified major cations and anions in water samples collected in 1967 and 1992 from eight selected wells. The table also lists the yearly increase in each constituent during the 25-year period. Total dissolved solids increased at a rate of 30 mg/l per year, while sulfate, the main contributor, increased at a rate of 16.4 mg/l per year. The disproportionate increase in sulfate is primarily the result of dissolution of gypsum as irrigation return-flow water percolates downward through the soil zone.

Table 4. Average Constituent Concentration Change Between 1967 and 1992[1]

Constituent	1967 (mg/l)	1992 (mg\l)	Yearly Increase (mg/l)
Calcium	429	476	1.9
Magnesium	192	239	1.9
Sodium	464	577	4.5
Bicarbonate	239	253	0.5
Sulfate	1,563	1,971	16.4
Chloride	830	973	5.7
Dissolved Solids	3,483	4,232	30.0

1 Average determined from wells 48-07-205, 517, 518, 619, 801, 904, and 48-15-301, 304.

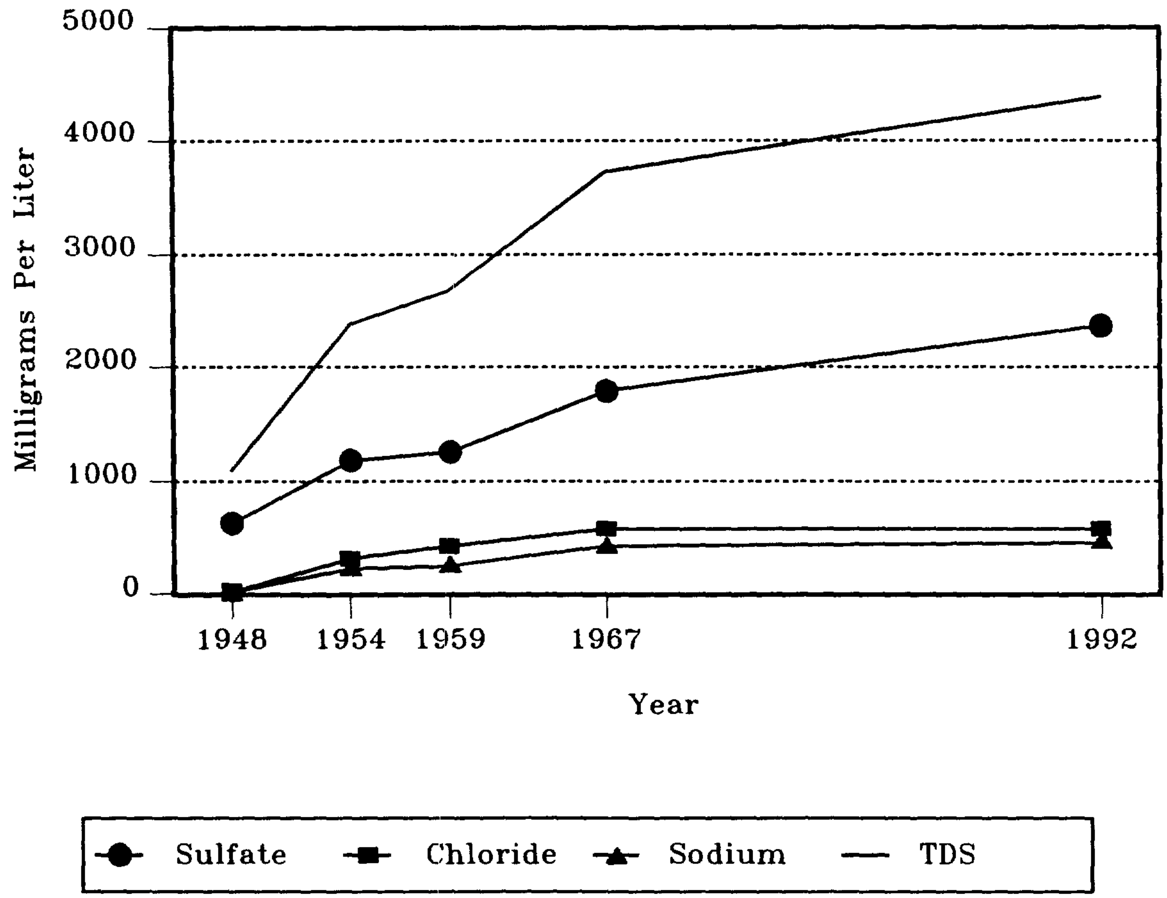


Figure 18

Water-quality Change in Well 48-07-205 from 1948 to 1992

AVAILABILITY

The amount of ground water available on an annual basis in the Dell Valley region is contingent on rates of water-level decline and water-quality deterioration. A comparison of water-level and pumpage trends (Figure 6) indicates an annual pumpage of approximately 90,000 to 100,000 acre-feet can be maintained without continuously lowering the water table. Also at this rate, the seasonal water-level fluctuation remains at about 15 feet. An increase in annual pumpage to approximately 140,000 acre-feet, such as was common in the late 1970s and early 1980s, results in a noticeably declining water level and increases the seasonal water-level fluctuation to about 30 feet. The significance of a greater seasonal water-level fluctuation is that it steepens the hydraulic gradient, which increases the likelihood of the migration of highly saline water from the salt flats to the east.

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CONCLUSIONS AND RECOMMENDATIONS

The economy of the Dell Valley region is supported almost entirely by the agricultural industry, which in turn, is dependent on the availability of ground water. Today, the Bone Spring-Victorio Peak aquifer displays the effects resulting from almost a half-century of intense use. Although water levels have remained relatively stable since the mid-1970s, a significant increase in pumpage could initiate a resurgence of declining levels, such as were common in earlier years. A comparison of historical pumpage and water-level trends indicates the region can sustain annual ground-water withdrawals of approximately 90,000 to 100,000 acre-feet without further depletion of the aquifer.

The elevation of the water table is currently lower in the valley than in the salt flats to the east. The hydraulic gradient, however, does not appear to be sufficiently steep to cause a significant migration of highly saline ground water from the flats westward. Monitoring of water levels in the valley should be maintained to warn of pending declines and the increased potential for saltwater encroachment.

Irrigation return flow and open-hole well completions have resulted in a slow deterioration of water quality. The dissolved mineral content of the water is increasing at a rate of approximately 30 mg/l per year (increasing sulfate concentration being the primary contributor). The relatively low chloride concentration increase indicates no significant migration of saline water from the salt flats to the east. Specific conductance measurements using a properly calibrated instrument should be made annually on water samples from the same selected wells along the eastern side of the valley to warn of possible saltwater migration. Dissolved solids content, and especially chloride concentration, should be monitored at least every five years.

The USDA-SCS recharge well project associated with the flood control dams should be completed. The ability to occasionally dilute the aquifer with a significant quantity of fresh water will increase the potability of the ground water and reduce crop intolerance.

Numerous wells in the valley have been abandoned, and many were improperly destroyed or neglected. These wells are not only a safety hazard for those who might accidentally step into them, but are also potentially a conduit for surface contamination. These wells also have little or no casing, thus allowing for the easy migration of water from a poor-quality zone into fresher water-bearing strata. Abandoned wells, including those that have been only partially sealed at the top, should be located and properly plugged. It may be desirable to retain certain abandoned wells for water-level monitoring use. If this is done, the wells should be reconstructed if necessary to prevent surface contamination and be maintained in a safe condition.

The Hudspeth County Underground Water Conservation District No. 1 is the logical entity to oversee the long-term maintenance of the aquifer. However, lack of sufficient funding has thusfar prevented the District from realizing its full potential. In addition to the currently established rules, the District should consider developing a water-level and water-quality monitoring program in order to warn of pending problems.

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