Texas Water Development Board
Report 334

Evaluation of the Ground-Water Resources of the Western Portion of the Winter Garden Area, Texas

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ABSTRACT

In 1985, House Bill 2 was enacted by the Sixty-ninth Texas Legislature, which recognized that certain areas of the State were experiencing, or expected to experience within the next 20 years, critical ground-water problems. One area so identified for study includes Dimmit, La Salle, and Zavala Counties and portions of Maverick, McMullen, and Webb Counties, all of which form the western portion of what is known as the Winter Garden area. This study area is located southwest of San Antonio and southeast of Del Rio, and is bounded on the west by the Rio Grande. The climate of the region is semi-arid with low to moderate rainfall and a high rate of evaporation. Agriculture and petroleum production dominate the regional economy.

Water needs for the western portion of the Winter Garden Area are supplied primarily from the Carrizo aquifer. Surface water accounts for only 11 percent of the total water used and is only available from widely scattered, small-capacity retention structures and through water rights from the Rio Grande and Nueces River. Several less productive aquifers that overlie the Carrizo aquifer are unsuitable for heavy development due to their poor water quality and low transmissivity.

High well yields from the Carrizo aquifer and the suitability of its water for irrigation farming have led to heavy agricultural development over the years. Ground water used for irrigation amounts to about 82 percent of the total water used in the area.

The chemical quality of water in the Carrizo aquifer is generally fresh and meets Texas Department of Health drinking water standards. Dissolved solids usually range from 450 to 1,000 milligrams per liter with low sodium, chloride, and sulfate concentrations. The sodium hazard and sodium-adsorption ratio are usually low; and the salinity hazard is low to medium, thus making Carrizo ground water especially suitable for irrigation.

Ground-water contamination in the study area appears to be very localized in extent. The two potential means of contamination in the region are from brines associated with petroleum production and saline-water encroachment into the Carrizo aquifer from overlying water-bearing units which contain poor quality water. In the Carrizo outcrop area, where direct infiltration of recharge occurs through its sandy soils, leakage of oilfield brine from unlined surface disposal pits may have caused localized contamination, particularly before the Railroad Commission of Texas 1969 no-pit order. In some areas of Dimmit and Zavala Counties, excessive water-level declines due to heavy pumpage may lead to infiltration of highly-mineralized water from the overlying Bigford Formation into the Carrizo through improperly completed or abandoned wells.

Previous work by the Texas Water Development Board indicates that approximately 118,000 acre-feet per year of ground water is available in the study area for development. Heavy ground-water withdrawals have been removing water from storage in the Carrizo aquifer for many years, and large areas of water-level declines are evident in Dimmit, La Salle, McMullen, and Zavala Counties. Even though the total annual projected water demands are expected to decrease from 132,905 acre-feet to 118,764 acre-feet by the year 2010, localized heavy pumpage could still result in significant water-level declines and extensive cones of depression.

INTRODUCTION

Purpose and Scope

In 1985, the Sixty-ninth Texas Legislature enacted House Bill 2 which recognized that certain areas of the State were experiencing, or were expected to experience within the next 20 years, critical ground-water problems. The Bill directed the Texas Department of Water Resources to identify such critical ground-water areas, conduct studies of those areas, and submit its findings and recommendations on whether a ground-water conservation district should be established in the respective areas to help solve or manage any ground-water problems (Subchapter C, Chapter 52, Texas Water Code).

The study area covered by this report includes all of Dimmit, La Salle, and Zavala Counties, and portions of Maverick, McMullen, and Webb Counties (Figure 1). These counties comprise the western portion of the Winter Garden area, which is defined as the region between the San Marcos River and the Rio Grande where the Carrizo aquifer contains fresh to slightly saline water (Klemt and others, 1976). Emphasis in this report will be on ground-water availability and the potential for contamination of ground-water resources by saline waters.

Geography

Topography and Drainage

The study area is located southwest of San Antonio and southeast of Del Rio along the Rio Grande (Figure 1). As part of the south Texas Coastal Plains province, the area is characterized by a rolling topography, which gently slopes southeastward toward the Gulf of Mexico. Three major rivers, the Rio Grande, Nueces, and Frio dissect the region (Figure 2).

Drainage in the region is by the aforementioned rivers and their tributaries. The Frio and Nueces Rivers generally meander southeastward before merging with the Atascosa River in Live Oak County and eventually empty into the Gulf of Mexico. The Rio Grande flows southeastward before turning east to empty into the Gulf of Mexico. The only major surface-water body in the study area is Choke Canyon Reservoir on the Frio River just above its juncture with the Atascosa River (Figure 2).

Climate

The climate of the western portion of the Winter Garden area is influenced by several factors including: 1) its proximity to the Gulf of Mexico and the southern Great Plains; 2) the changes in land surface elevation from the high plains and mountains to the coastal plain; and 3) the position of the State west of the center of the Bermuda high pressure cell (Larkin and Bomar, 1983). These influences have created a subtropical and semiarid climate in the western portion of the Winter Garden area. Summertime temperatures average about 83°F with highs usually into the upper 90s and

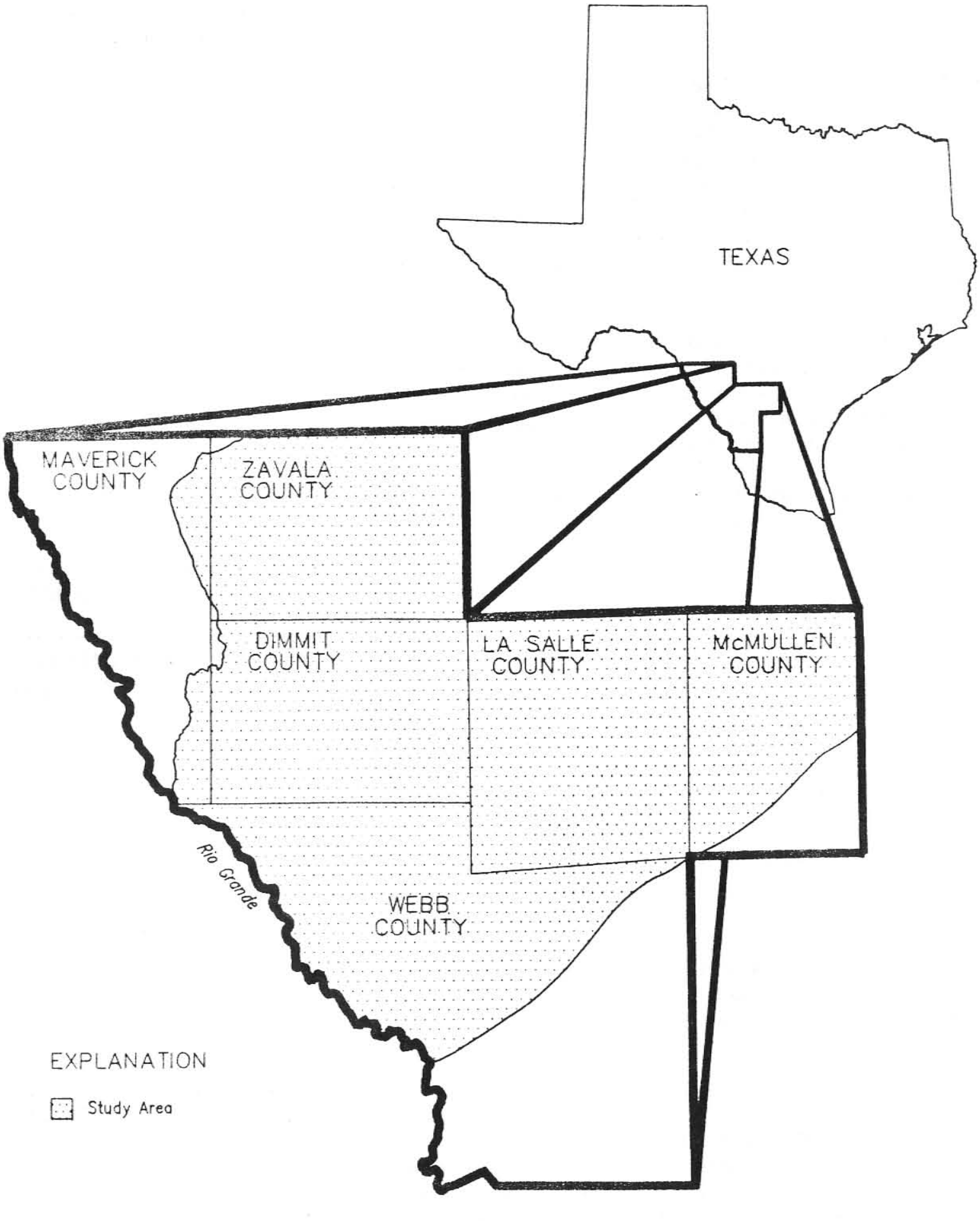

Figure 1

LOCATION OF STUDY AREA

sometimes reaching extremes of over 100°F. Winter temperatures average about 59°F, but can dip into the 20s when severe cold fronts sweep through the region.

The average annual precipitation ranges from 26 to about 21 inches from east to west across the study area (Figure 2). Most precipitation falls in the spring from April to June and in late summer and early fall from August to October. From late summer to early fall is the hurricane season during which storms may move ashore along the upper Mexican or Texas coasts. As these storms move inland and dissipate, tremendous amounts of rainfall can occur over a very short period of time and cause extensive flooding of area rivers and their tributaries.

The average annual gross lake evaporation varies from 65 to 83 inches from east to west across the study area. Lake-surface evaporation rates are highest in the summer months (Figure 2).

Economy

The economy of the region is primarily agricultural, including both intensive irrigation farming and ranching. In 1985, agriculture accounted for $156 million of income for the region (Texas Agricultural Statistics, 1985). Approximately 90,000 acres were irrigated that year, mainly with ground water from the Carrizo aquifer. The area is a leader in the State in the production of vegetables and pecans.

Oil and gas production is an important industry in Dimmit, Maverick, McMullen, and Webb Counties, and a secondary industry in La Salle and Zavala Counties. Oil was first discovered in the area in McMullen County in 1918. Further development of oil and gas resources occurred in Maverick, Webb, and Zavala Counties in the 1920s and 1930s. Oil was discovered in La Salle County in 1940 and in Dimmit County in 1943. In 1989, 8.25 million barrels of crude oil and 431.4 million cubic-feet of natural gas were produced in the western portion of the Winter Garden area (Railroad Commission of Texas, 1989).

Previous Investigations

To date, there have been numerous ground-water investigations covering individual counties in the study area, and one major report covering the entire Winter Garden area. The results of these investigations have been published as reports or bulletins by the Texas Water Development Board and its predecessor agencies.

The most comprehensive ground-water study covering the area was made by the Texas Water Development Board and published in two volumes as Report 210 (Klemt and others, 1976; Marquardt and Rodriguez, Jr., 1977). This report covered the geohydrology of the Eocene-age aquifers in the area; particularly the extent of water-level declines in the Carrizo aquifer and availability and quality of its ground-water resources. In addition, research work for various phases of Report 210 were published as separate reports (Duffin and Elder, 1979; Elder and others, 1980), or as open-file reports (Opfel and Elder, 1977).

Several smaller reports concerning some of the counties within the study area have also been published by the State water agencies. Among the counties covered by published ground-water investigations are Dimmit (Mason, 1960) and La Salle and McMullen (Harris, 1965). In addition, historical well records, water levels, and water quality analyses collected by the U.S. Geological Survey are available for all counties in the study area (Turner and others, 1940; Outlaw and others, 1952; Follett, 1956).

Other regional reports covering various major and minor aquifers in the study area include an investigation of ground-water availability from aquifers within the State by the Texas Department of Water Resources (Muller and Price, 1979), and hydrogeologic studies by the Bureau of Economic Geology of the University of Texas (Fisher and McGowan, 1967; Guevara and Garcia, 1972; Ricoy and Brown, Jr., 1977; Hamlin, 1988).

Geologic mapping of the western portion of the Winter Garden area is best represented on the San Antonio Sheet, Crystal City-Eagle Pass Sheet, the Del Rio Sheet, and the Laredo Sheet of the Geologic Atlas of Texas published by the University of Texas, Bureau of Economic Geology (Barnes, 1974, 1976a, 1976b, 1977). Soil surveys published by the Soil Conservation Service of the U.S. Department of Agriculture are available for Dimmit, McMullen, and Zavala Counties (Soil Conservation Service, 1977 and 1985).

The Texas Water Development Board, in accordance with its legislatively mandated data-collection activities, maintains a network of 620 wells in the six counties of the study area. These wells are visited annually to obtain water-level measurements. In addition, as part of its water-quality monitoring program, the Board has chemical analyses of water samples collected from 1,262 wells in the study area.

HYDROGEOLOGY

Geology

Regional Structural Setting and Depositional History

Since Mesozoic time, deposition within the Gulf Coast Basin has been influenced by two major embayments, the Rio Grande and the Houston, situated on either side of a structural high, the San Marcos arch (Figure 3). During the Mesozoic era, deposition within the Rio Grande Embayment was dominated by marine clastics and carbonates. As the basin filled with material, its depositional facies changed to sands and shales. Transgressive and regressive sequences alternated during Eocene times as the Gulf Coast shoreline moved gradually southeastward.

At the beginning of the Eocene, the Rio Grande Embayment formed a bight, or curved open bay, on the northwestern part of the paleo-Gulf of Mexico. Fluvial systems converged on the embayment from the west, northwest and north (Figure 4) carrying clastic debris from the mountainous areas far to the west (Belcher, 1975). Quartz sand eroded from nearby exposed older sedimentary rocks probably was also an important source of sediment (Hamlin, 1988).

Galloway (1981) recognized fluvial axes in the Tertiary-age deposits of the Texas Gulf Coastal Plain. These axes are dip-oriented, sand-rich belts, aprons, or sheets separated by inter-fluvial areas of lower sand content. Hamlin (1988) mapped several Carrizo-upper Wilcox fluvial axes based on sand-body geometry, distribution, and orientation (Figure 4). Carrizo-age rivers entering the area along the central and southwestern fluvial axes tended to be deflected toward the structural axis of the Rio Grande Embayment. This led to a north-south strike orientation for the Carrizo Sand in the western part of the study area and a southwest-northeast strike orientation in the northern and eastern portions of the study area.

Prior to the deposition of the Carrizo Sand, prodelta mudstones of the middle Wilcox Subgroup predominated. Wilcox-age deltas prograded across shelf deposits of the Midway Group and extended onto the shelf edge and slope of the embayment. During this regression, bed-load braided channels graded downstream into mixed-load meandering channels that carried sediment into the delta systems along the shelf edge. As shelf progradation slowed due to subsidence and stacking of delta sequences, bed-load fluvial systems migrated coastward, eventually dominating the depositional facies of the Carrizo Sand with massive sand sequences. Toward the end of the Carrizo depositional event, transgressive marine waters began encroaching on the broad, sandy coastal plain from the east and south. Mixed alluvial systems, characterized by meandering channel rivers, became dominant across the coastal plain by the end of Carrizo deposition (Hamlin, 1988).

During Post-Carrizo deposition the Rio Grande Embayment was inundated from the east by the transgressive sequences of the Reklaw Formation, the Queen City Sand, and the Weches Formation. The western side of the embayment was higher in elevation at this time than the east side and this factor, coupled with continued sediment influx from the west, caused the deposits on the western side of the embayment (south and west of the

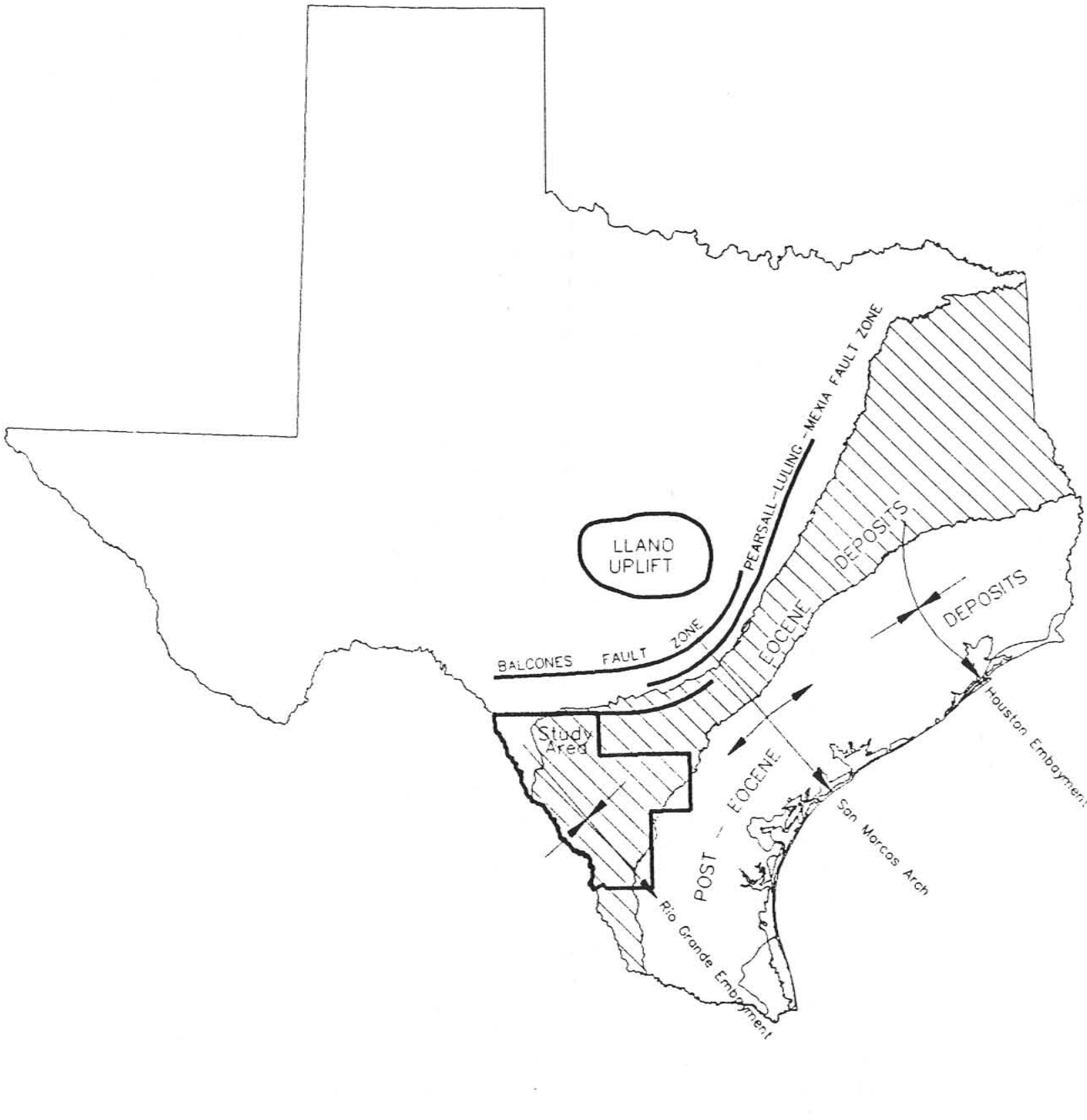

Figure 3

REGIONAL STRUCTURE AND DEPOSITIONAL TRENDS
OF THE TEXAS GULF COASTAL PLAIN

Modified from Galloway, 1981

Formation and the overlying El Pico Clay, interfingered into the marine deposits (the Reklaw, Queen City, and Weches Formations) to the east (Plummer, 1932).

Marine transgression was interrupted briefly by a regression during Sparta time, but continued with the deposition of the Cook Mountain Formation. The Sparta Sand and overlying Cook Mountain Formation interfingered with the Laredo Formation along the present-day Frio River. This subdivision between the deposits to the west-southwest of the Frio River and the deposits to the east-northeast of the river is based on lithologic differences between the Laredo Formation to the west and the Sparta Sand and Cook Mountain Formation (Eargle, 1968). At the end of the Eocene, the sea retreated, and deposition was dominated by the continental deposits of the Yegua Formation and overlying Jackson Group.

Nomenclature and Stratigraphic Relationship of Aquifers

Table 1 shows the vertical and horizontal relationships of the geologic units in the study area, and their water-bearing properties. The stratigraphic relationship of the strata of the lower Eocene, in particular the Carrizo Sand, has been somewhat controversial in the past. The Carrizo Sand was originally assigned to the Claiborne Group based on research done on its outcrop area (Plummer, 1932). Later subsurface studies revealed that the Carrizo is closely associated with the Wilcox Group, especially downdip where it corresponds to the upper Wilcox (Hargis, 1962, 1985; Eargle, 1968; Fisher, 1969; Bebout and others, 1982). Current geologic surface maps classify the Carrizo Sand as the basal unit in the Claiborne Group (Barnes, 1974, 1976a, 1976b, 1977). Hamlin (1988) in a regional study on the Carrizo Sand, shows it corresponding to the uppermost unit in the Wilcox Group in the subsurface (greater than 4,000 feet in depth), but separates it above the Wilcox Group in the outcrop and shallow subsurface (less than 4,000 feet in depth). For the purpose of this report, the classification used by the Geologic Atlas of Texas Crystal City - Eagle Pass Sheet (Barnes, 1976a) is followed (Table 1).

The Wilcox Group and the overlying Carrizo Sand contain the major aquifers in the study area. Both these units crop out in a north-south direction along the western side of the study area and in a southwest-northeast direction in the north-northeastern portion of the study area (Figure 5). South and west of the Frio River, the Wilcox Group has been differentiated as the Indio Formation (Trowbridge, 1932). Subsequent workers have limited the downdip extent of the Indio Formation (Hargis, 1985; Hamlin, 1988).

The Wilcox Group and the Carrizo Sand thicken considerably in their downdip sections within the study area (Figures 6 and 7). The Wilcox Group can obtain a maximum thickness up to 2,800 feet. In McMullen County, near the center of the Rio Grande Embayment, the base of the Wilcox can be as deep as 6,800 feet below the land surface.

Figure 5 shows the horizontal extent of fresh to slightly saline water in the Wilcox and Carrizo aquifers, while Figures 6 and 7 show the vertical extent of fresh to slightly saline water. Because some of the sands in the Wilcox Group may be hydraulically connected with the Carrizo Sand, both aquifers are often linked together as the "Carrizo-Wilcox aquifer" (Klemt and

Table 1. - Water–Bearing Characteristics of the Eocene Deposits in the Study Area.

System	Series	Group	Geologic Unit West of Frio R.	Geologic Unit East of Frio R.	Hydrologic Units West of Frio R.	Hydrologic Units East of Frio R.	Approximate Thickness (In Feet) West of Frio R.	Approximate Thickness (In Feet) East of Frio R.	Character of Rock West of Frio River	Character of Rock East of Frio River	Water–Bearing Properties West of Frio River	Water–Bearing Properties East of Frio River
Tertiary	Eocene	Jackson	Undifferentiated				0–500		Clay, tuff, sandstone and siltstone.		Yields small quantities of slightly to moderately saline water in the outcrop area.	
		Claiborne	Yegua Formation				700 – 1,000+		Clay, silt with interbedded thin lignites and sandstones. Some minor beds of limestone and oyster shells are found.		Yields small quantities of slightly to moderately saline water in the outcrop area.	
			Laredo Formation	Cook Mountain Formation	Laredo Aquifer		600 - 700	400 - 500	Glauconitic sand and clay. Some gypsiferous clay and impure limestones.	Fossiliferous clay and shale. Some interbedded sandstone and limestone.	Yields small to moderate quantities of fresh to moderately saline water.	Yields small quantities of slightly to moderately saline water.
				Sparta Sand		Sparta Aquifer		40 - 200		Medium to fine sand. Some interbedded clay.		Yields small to moderate quantities of fresh to moderately saline water.
			El Pico Clay	Weches Formation			700 - 1,500	50 - 200	Clay with interbedded sandstones, clay-stones, and lignite coal lenses.	Fossiliferous, glauconitic shale and sand.	Yields small quantities of slightly to moderately saline water.	Not known to yield water.
				Queen City Sand		Queen City Aquifer		500 - 1,400		Marine, medium to fine sand with interbedded clay and shale.		Yields small to moderate quantities of fresh to slightly saline water.
			Bigford Formation	Reklaw Formation	Bigford Aquifer		200 - 900	200 - 400	Sands with interbed-ded silts and shales. Plant remains are abundant.	Clay with interbedded glauconitic sand.	Yields small to moderate quantities of fresh to very saline water.	Yields small quantities of slightly to moderately saline water to wells in or near the outcrop.
			Carrizo Sand		Carrizo Aquifer		150 - 1,200		Coarse to fine sand, massive, cross–bedded with a few partings of carbonaceous clay.		Principal aquifer in the study area. Yields moderate to large quantities of fresh to slightly saline water.	
		Wilcox	Indio Formation	Wilcox Group Undif.	Wilcox Aquifer		0 - 2,800		Interbedded sand, clay, and silt with discontin-ous beds of lignite. The shale and clay sometimes contain gypsum.		Yields small to moderate quantities of fresh to slightly saline water.	
		Midway	Kincaid Formation	Midway Group Undif.			0-300		Shale, sandstone and limestone.		Not known to yield water.	

- Yields of Wells, in gallons per minute (gal/min): Small, less than 50 gal/min; moderate, 50–500 gal/min; large, more than 500 gal/min.
- Quality of Water, in milligrams per liter (mg/l) dissolved solids: Fresh, less than 1,000 mg/l; slightly saline, 1,000 - 3,000 mg/l; moderately saline, 3,000 - 10,000 mg/l; very saline, 10,000 - 35,000 mg/l.

References: Barnes (1974, 1976a, 1976b,1977)
Guevara and Garcia (1972)
Hamlin (1988)
Hargis (1985)
Klemt and Others (1976)

others, 1976). Above the Carrizo Sand, to the west and south of the Frio River, are the Bigford Formation and the El Pico Clay; and, to the north and east of the Frio River, their counterparts are the Reklaw Formation, Queen City Sand, and Weches Formation (Table 1). The interfingering of these geologic units is estimated on Figure 7. Of these units, only the Bigford Formation and the Queen City Sand contain usable quality ground water (less than 3,000 milligrams per liter dissolved solids) and are minor aquifers within the study area. The outcrop of the Bigford Formation parallels the outcrop of the Carrizo and Wilcox (Figure 8). The Queen City Sand does not crop out within the study area and is only delineated in the subsurface of La Salle and McMullen Counties.

The down-dip limit of fresh to slightly saline water in the Queen City-Bigford aquifer cuts across the study area in a northeast-southwest line from Webb to McMullen County (Figure 8). The vertical extent of the Queen City-Bigford aquifer is shown in Figures 6 and 7.

The Laredo Formation and the Sparta Sand are the uppermost geologic units in the study area that contain usable-quality water. The Laredo aquifer extends south and west of the Frio River and the Sparta aquifer extends north and east of the Frio River (Table 1). The outcrop area of these two formations runs in a north-south direction from Webb County to Zavala County in the study area. The down-dip limit of fresh to slightly saline water within the Sparta-Laredo aquifer parallels the outcrop and runs from eastern Webb County up through eastern La Salle County (Figure 9). Figures 6 and 7 show the vertical extent of the Sparta-Laredo aquifer.

Recharge, Movement, and Discharge of Ground Water

Recharge to each of the aquifers is primarily by infiltration of precipitation in their outcrop areas. The permeabilities of these sandy soils can vary from a low of 0.06 inches per hour to a high of 6.0 inches per hour (Soil Conservation Service, 1977 and 1985). The average annual rate of recharge by infiltration for the Carrizo aquifer in Dimmit, Zavala, and Maverick Counties is about 25,000 acre-feet per year (Turner and others, 1948). The rates of recharge by infiltration for the other aquifers in the study area have not been determined.

Ground-water flow is controlled by various natural influences that make up the geohydrologic environment such as geology, topography, and climate. After infiltration in the outcrop area, water within an aquifer generally moves through the vadose zone into the zone of saturation. Once it reaches the zone of saturation, flow follows the direction of the slope of the potentiometric surface. The potentiometric surface is used to describe water-level contours which are representative of a single flow system within an aquifer.

Figure 10 shows the potentiometric surface of the Carrizo aquifer in 1990. Ground water flows down-gradient, from areas of high hydraulic head to areas of lower hydraulic head. In general, the highest heads in the Carrizo aquifer are in the outcrop areas in Dimmit and Zavala Counties (Figure 10). The lowest heads are downdip in a large depression in southeastern Zavala, northeastern Dimmit and northern La Salle Counties (Figure 10). Arrows

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northeastern Dimmit and northern La Salle Counties (Figure 10). Arrows on Figure 10 generally show the direction of ground-water movement in 1990 in the aquifer toward the depression which extends into southern Frio County (north of LaSalle County).

Discharge from the Carrizo aquifer is primarily by irrigation pumpage. Heavy pumpage from the aquifer resulted in the cessation of flow from Carrizo Springs as early as 1929. No appreciable spring flow has been reported in the study area (Brune, 1975).

Cross-formational flow is a significant aspect of regional ground-water movement in the Carrizo aquifer and overlying water-bearing units (Harris, 1965; Klemt and others, 1976; Hamlin, 1988). Hamlin (1988) suggests that since dip-parallel ground water flow rates and formation transmissivity within the Carrizo Sand decrease downdip, cross-formational flow (upward leakage) must be occurring in the deeper parts of the aquifer.

Except in areas of continuous heavy pumpage, the heads of the Carrizo aquifer are higher than those in overlying aquifers (Harris, 1965; Hamlin, 1988). These vertical hydraulic head differences indicate a potential for the upward leakage of water from the Carrizo aquifer into overlying water-bearing units, such as the Bigford Formation in Dimmit and Zavala Counties. However, this vertical leakage is reversed in Dimmit and Zavala Counties, where extremely heavy irrigation pumpage has dramatically lowered the hydraulic head in the Carrizo aquifer below the hydraulic head of the overlying Bigford aquifer. In this area downward leakage is occurring (Mason, 1960). Klemt and others (1976) estimated through computer simulations of the total ground-water budget of the Carrizo aquifer that approximately 9,500 acre-feet per year of ground water is leaking into the Carrizo from overlying aquifers, primarily in the areas of heavy pumpage in Dimmit and Zavala Counties.

Aquifer Hydraulic Characteristics and Productivity of Wells

Table 2 shows the results of aquifer tests which have been conducted in the study area. The Carrizo aquifer shows very high coefficients of transmissibility, ranging from 8,200 gallons per day per foot (gpd/ft) to 80,000 gpd/ft. The average coefficient of permeability in the Carrizo is approximately 200 gpd/ft^2 (Klemt and others, 1976).

As a comparison, the coefficient of transmissibility for the Wilcox aquifer is about 44,000 gpd/ft., while the Queen City-Bigford aquifer and the Sparta-Laredo aquifer have average coefficients of 14,000 gpd/ft and 5,000 gpd/ft, respectively (Klemt and others, 1976). Yields from wells completed in the Carrizo aquifer are usually large, that is, well over 500 gpm. Yields from wells completed in the Queen City-Bigford aquifer and the Sparta-Laredo aquifer vary considerably from small (less than 50 gpm) to large (greater than 500 gpm).

Variations of flow parameters in the Carrizo aquifer can be attributed to differences in sand grain sorting in its many depositional facies. Flood plain, abandoned channel fill, and lacustrine facies are characterized by a fine-grained sand size and varied lithology which inhibit ground-water flow. Channel-fill deposits in the Carrizo form massive, medium to coarse-grained sand bodies that serve as major flow conduits within the aquifer (Figure 4) (Hamlin, 1988).

Table 2. - Results of Aquifer Tests in Dimmit, La Salle, and Zavala Counties

Well Number	Aquifer	Producing Interval (depth in feet)	Average Discharge (gpm)	Specific Capacity (gpm/ft)	Coefficient of Transmissibility (gpd/ft)	Coefficient of Storage	Coefficient of Permeability (gpd/ft^2)	Remarks
Dimmit Co.								
‡	Carrizo		1,000		80,000			Recovery of pumped well
‡	Carrizo		500		22,800			Recovery of pumped well
‡	Carrizo		316		34,300			Recovery of pumped well
‡	Carrizo		415		11,000			Recovery of pumped well
‡	Carrizo		164		20,900			Recovery of pumped well
‡	Carrizo	1,565 - 1,765	400	9.3	26,400		132.0	Recovery of pumped well
‡	Carrizo		350	4.0	8,800			Recovery of pumped well
‡	Carrizo		550		13,400			Recovery of pumped well
La Salle Co.								
77-30-801	Carrizo	1,800 - 2,051		20.4	46,000	0.00019	183.3	Drawdown in observation well
77-30-802	Carrizo	1,740 - 2,030	1,000	17.7	35,000		120.7	Recovery of pumped well
77-39-401	Carrizo	2,100 - 2,483	165	3.7	8,200		21.4	Recovery of pumped well
77-56-801	Carrizo	3,400 - 3,500	110	3.0	9,100		91.0	Recovery of pumped well
78-25-801	Carrizo	2,500 - 3,000	155	6.3	29,000		58.0	Recovery of pumped well
77-46-803	Sparta	300 - 600	570	2.0	3,500		11.7	Recovery of pumped well
77-55-701	Sparta	700 - 800	22	1.6	1,500		15.0	Recovery of flowing well
77-62-701	Sparta	340 - 580	110	0.3	1,100		4.6	Recovery of pumped well
Zavala Co.								
‡	Carrizo		934		35,600	0.0001		Drawdown in observation well
‡	Carrizo		934		38,200			Drawdown in observation well
‡	Carrizo		934	18.3	35,500			Recovery of pumped well
‡	Carrizo	962 - 1,218	934		44,600	0.0001	174.2	Drawdown in observation well

‡ State Well Number not assigned

From Harris, 1965, and Myers, 1969

The down-dip limit of the study area coincides with the Wilcox growth-fault zone. This zone is a complex of syndepositional faults associated with the deltaic sedimentation of the Wilcox Group and lies slightly beyond the downdip extent of slightly- saline water in the Carrizo aquifer. Faults within the fresh-water part of the Carrizo aquifer can have displacements of tens to hundreds of feet. Offsetting of sand bodies in the Carrizo-Wilcox aquifer can decrease transmissivities and dip-oriented hydraulic conductivities, but can also create zones of increased vertical permeability (Hamlin, 1988).

Water Levels

Historically, large ground-water withdrawals due to intensive irrigation pumpage have lowered water levels drastically in the Carrizo aquifer in the Winter Garden area. From 1920 to 1970, as much as 240 feet of net water-level decline occurred in some areas (Klemt and others, 1976, Figure 20). The largest declines occurred in Dimmit, La Salle, and Zavala Counties, particularly near the Crystal City-Carrizo Springs area of Zavala and Dimmit Counties, in northeastern La Salle County, and in northeastern McMullen County. A comparison of the current altitude of water levels in the Carrizo aquifer with the top of the aquifer as delineated in Klemt and others (1976) shows two areas in Dimmit and Zavala Counties where the aquifer is being de-watered due to heavy pumpage (Figure 10).

Hydrographs of selected wells completed in the Carrizo aquifer show fluctuations in water levels during the period from 1970 to 1990 (Figure 11). The water level in well #76-08-401 in Maverick County has shown a steady 10 foot decline since 1970 with little fluctuation, whereas most down-dip wells display large fluctuations in addition to an overall steady water level decline. Some of these fluctuations can be as severe as 30 to 40 feet within a short period of years, and probably reflect increases or decreases in pumpage on a seasonal basis. A steady decline with little fluctuation probably reflects continuous pumpage.

Of particular interest is the water-level history of the Carrizo aquifer as documented in State well #77-33-301, located in Dimmit County to the southwest of Carrizo Springs near Carrizo Creek (Figures 11 and 12). The U.S. Geological Survey and the Texas Water Development Board have made continuous water-level measurements in this well since March of 1930. From 1930 to 1990, the water level in this well declined 72 feet. Since 1984, however, the water level has remained fairly stable, reflecting the decline in pumpage in the area in the 1980s (Figure 12). The decline in the water level by 72 feet in well #77-33-301 reflects the long-term pumping activity in the vicinity of Carrizo Springs. Heavy irrigation pumpage in this area has resulted in the de-watering of the Carrizo aquifer.

Hydrographs of water levels in selected wells completed in the Queen City-Bigford and Sparta-Laredo aquifers show much less water-level variation downdip (Figure 13). Because pumpage from these aquifers is small and considerably less than from the Carrizo aquifer, very little appreciable change is evident. In areas of heavy pumpage from the Carrizo aquifer in Dimmit and Zavala Counties, however, the water level of the Queen City-Bigford aquifer may have been lowered due to induced leakage downward into the Carrizo aquifer (Mason, 1960; Klemt and others, 1976). Wells completed in the Bigford aquifer in or near the outcrop area of the Bigford Formation show much more fluctuation in their water levels (Figure 13).

Water Quality

The chemical quality of ground water is dependent upon several factors including the solubility of minerals present within the formation, the length of time the water is in contact with the rock, adsorption and ion exchange rates, and equilibrium relationships. Usually concentrations of dissolved solids in ground water increase with depth because of associated geologic constraints that inhibit circulation.

The Texas Department of Health (TDH) sets the standards for drinking water quality and reporting requirements for public supply systems and has established Maximum Contaminant Levels (MCL) for various chemical constituents in water (Texas Department of Health, 1977). Some of the constituents and their maximum MCLs are as follows:

Chemical Constituent	MCL for Drinking Water
Dissolved Solids	1,000 mg/l
Chloride	300 mg/l
Sulfate	300 mg/l
Iron	0.3 mg/l
Gross Alpha	15 pCi/l
Gross Beta	50 pCi/l

Ground water in the Carrizo aquifer is characterized by excellent chemical quality. Over most of the study area, the dissolved solids content of Carrizo water is less than 1,000 mg/l (Figure 14). Chloride and sulfate concentrations range from very low (about 30 mg/l) to excessively high (exceeding TDH drinking water limits.) Dissolved solids, chloride, and sulfate concentrations tend to increase in the Carrizo aquifer with depth and distance from the outcrop of the Carrizo Sand. However, in the recharge area of the aquifer, dissolved solids, chloride, and sulfate concentrations can vary widely. Higher values in or near the outcrop may be due to formation mineralogy but could also indicate contamination through poorly completed wells or leakage from more saline aquifers into the Carrizo aquifer.

Figure 15 is a Piper diagram showing the ground-water chemistry of the Carrizo aquifer. The wide scattering of data points on the diagram is due to the increase in sodium and bicarbonate concentrations with depth. Ground water within the Carrizo aquifer trends from a calcium-sodium-bicarbonate-chloride (CA-Na-HCO_3-C1) hydrochemical facies to a sodium-bicarbonate (Na-HCO_3) hydrochemical facies.

Ground-water quality of the Queen City, Bigford, Sparta, and Laredo aquifers is somewhat poorer than that of the Carrizo. In some localized areas, ground water from these overlying units is fresh (less than 1,000 mg/l dissolved solids), but over much of the rest of the study area the concentrations of many of the chemical constituents exceed TDH recommended drinking water limits. Figures 16, 17, and 18 show plots of analyses for these minor aquifers except for the Sparta. Analyses of ground water from wells completed in the Sparta aquifer were not available in the study area.

Ground water in the Bigford aquifer is similar to that of the Carrizo aquifer in its chemical constituent ratio (Figure 16), and trends towards a sodium-

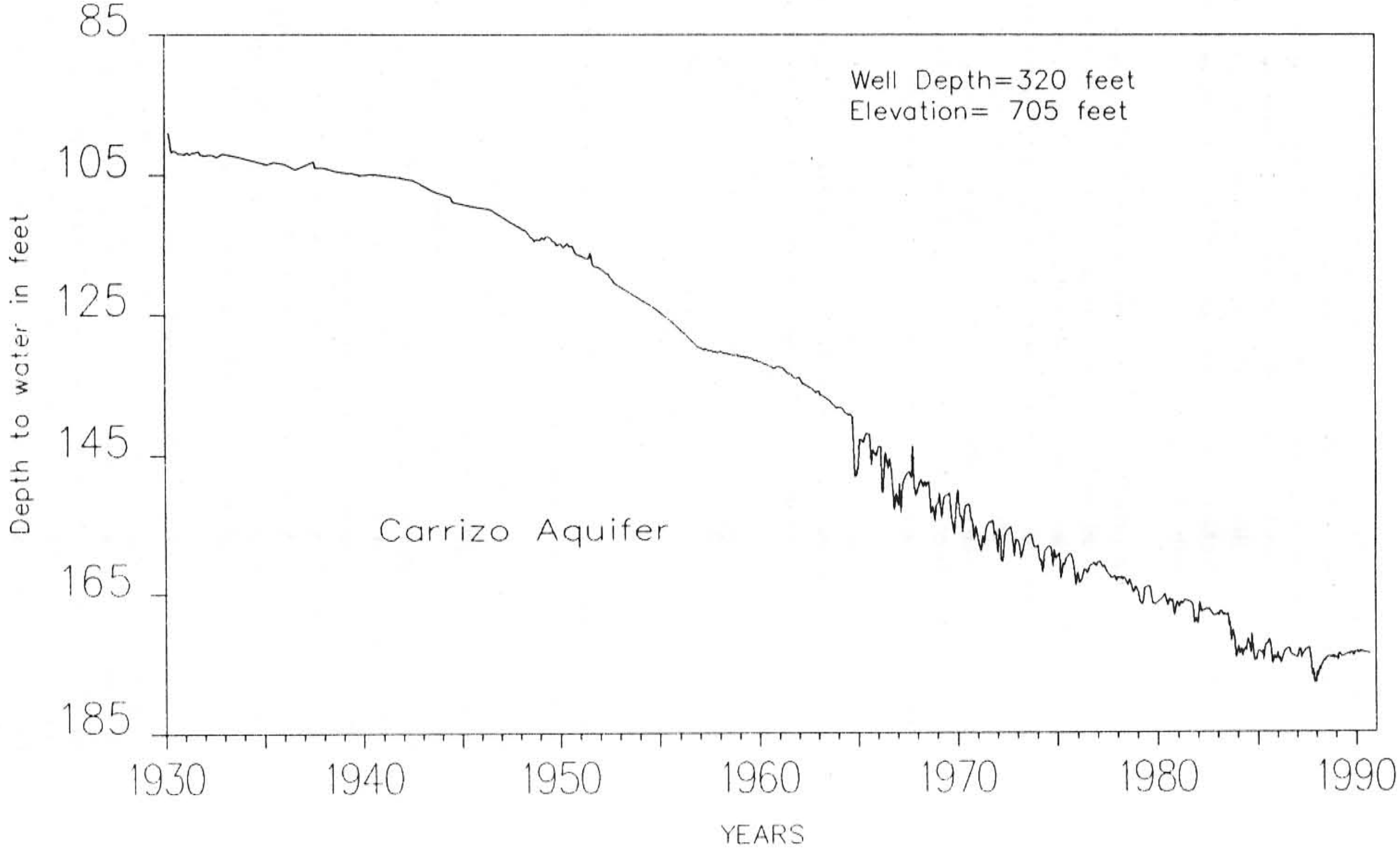


Figure 12

HYDROGRAPH OF WELL 77-33-301
DIMMIT COUNTY

bicarbonate-chloride (Na-HCO_3-Cl) hydrochemical facies. Ground-water chemistry in the Queen City aquifer is also represented by a sodium-bicarbonate-chloride (Na-HCO_3-Cl) hydrochemical facies with an extremely high sodium content (Figure 17). Ground water from the Laredo aquifer shows high concentrations of sodium and chloride and trends toward a sodium-chloride (Na-Cl) hydrochemical facies (Figure 18).

A large amount of data has been collected by the U.S. Department of Agriculture relative to the classification of water for irrigation use in arid and semi-arid areas (U.S. Salinity Laboratory Staff, 1954). Classification of irrigation waters should be used as a broad guideline, as other factors such as soil texture, infiltration rate, farm management practices, drainage conditions, climatic factors, and salt tolerances of different crops also affect the suitability of water for irrigation.

The major characteristics of ground water that are most important in determining its suitability for irrigation use are: 1) total concentration of soluble salts; 2) relative proportion of sodium to the other cations; 3) concentrations of boron or other elements that may be toxic; and 4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium (U.S. Salinity Laboratory Staff, 1954). The first three characteristics are known respectively as the salinity hazard, the sodium-adsorption ratio (alkali hazard), and the boron hazard.

The salinity hazard is measured by the electrical conductivity (in micromhos per centimeter) of water and reflects the total concentration of soluble salts in the water. The sodium-adsorption ratio is defined by the expression

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where Na^+, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.

By plotting the sodium adsorption ratio (SAR), or alkali hazard, against the salinity hazard, a graphical representation of the suitability of water for irrigation purposes can be demonstrated (U.S. Salinity Laboratory Staff, 1954). Figure 19 shows the irrigation suitability range of recent analyses for water from the aquifers within the study area. Water from the Carrizo aquifer is the most suited for irrigation, ranging from medium to very high as a salinity hazard and from low to very high as a sodium hazard. Waters from the Queen City, Bigford, and Laredo aquifers usually have a high to very high salinity hazard and low to very high sodium hazard. Water from the Sparta aquifer has a very high salinity hazard and a very high sodium hazard.

Depending on plant sensitivity, the maximum permissible level of boron in irrigation water ranges from 1.0 to 3.0 mg/l (Scofield, 1936; Wilcox, 1955). Only three analyses of water from 42 wells completed into the Carrizo aquifer in Dimmit, La Salle, and Zavala Counties and sampled by the Texas Water Development Board in September 1990 show boron levels greater than 3.0 mg/l. Historical analyses in the Board's database indicate a relatively low number of analyses with boron levels exceeding 3.0 mg/l. Insufficient data exists to make an accurate determination of boron concentration in the other aquifers within the study area.

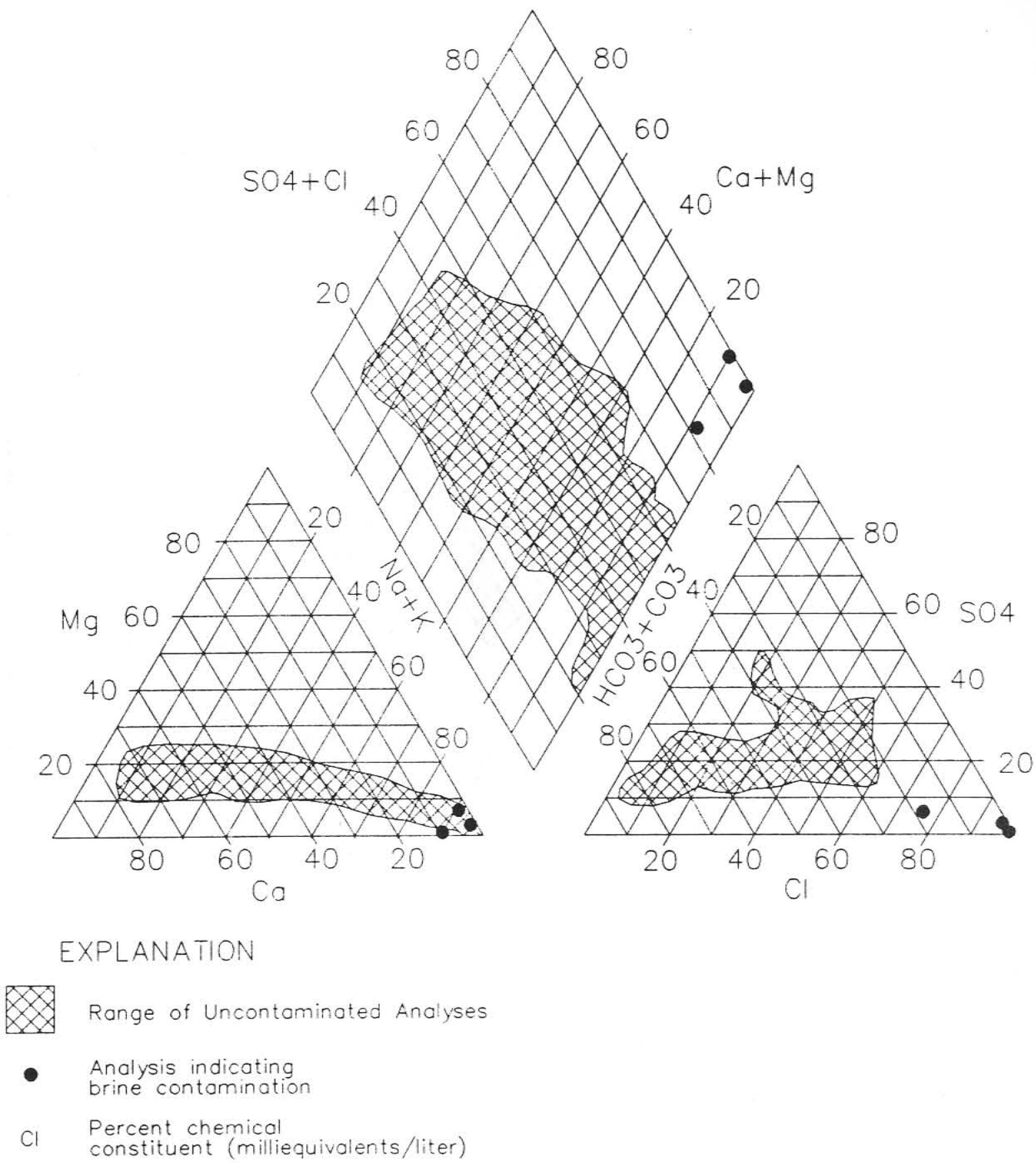
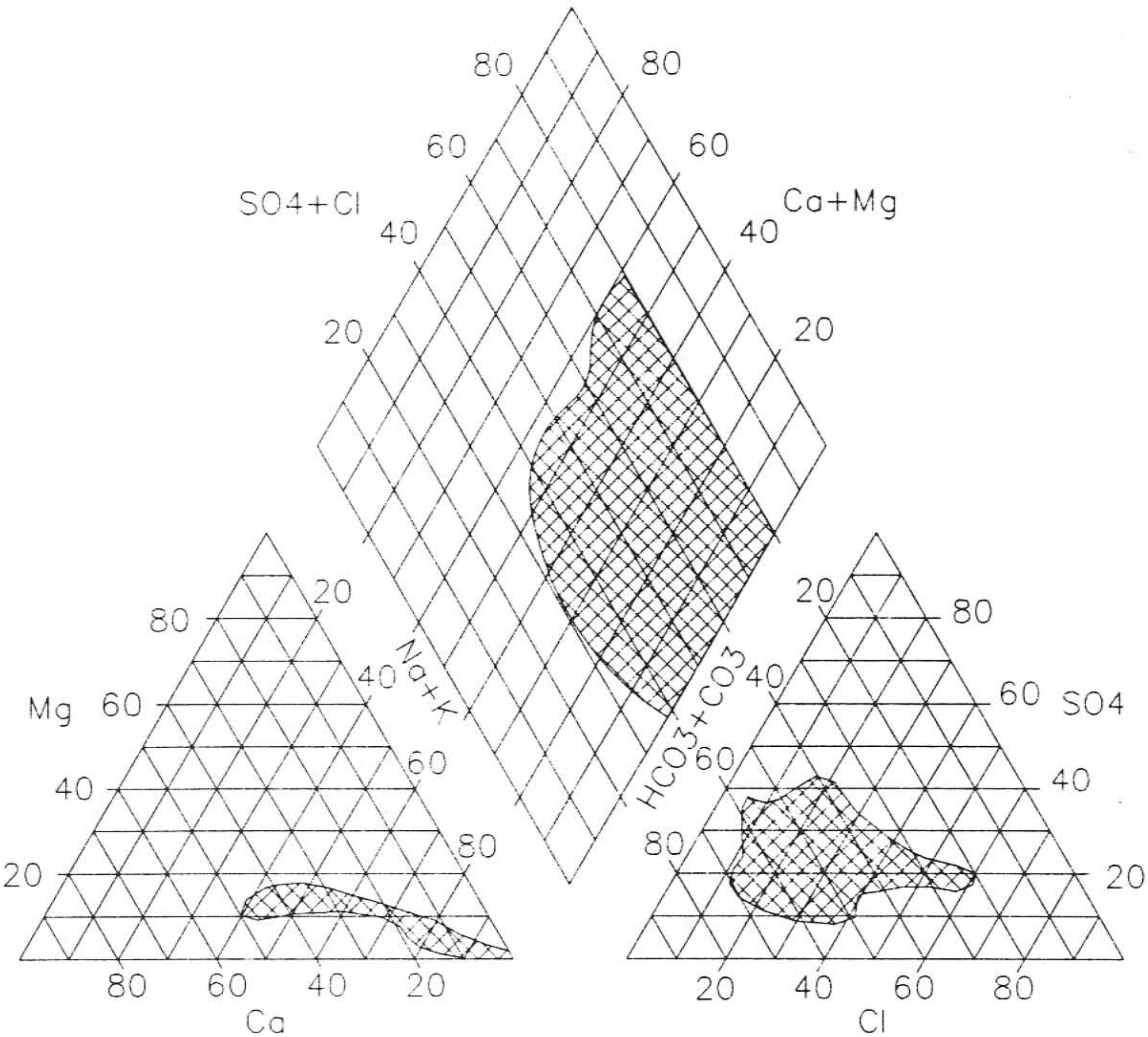


Figure 15

PIPER DIAGRAM OF CARRIZO AQUIFER GROUND-WATER QUALITY

Diagram from Piper, 1944



EXPLANATION

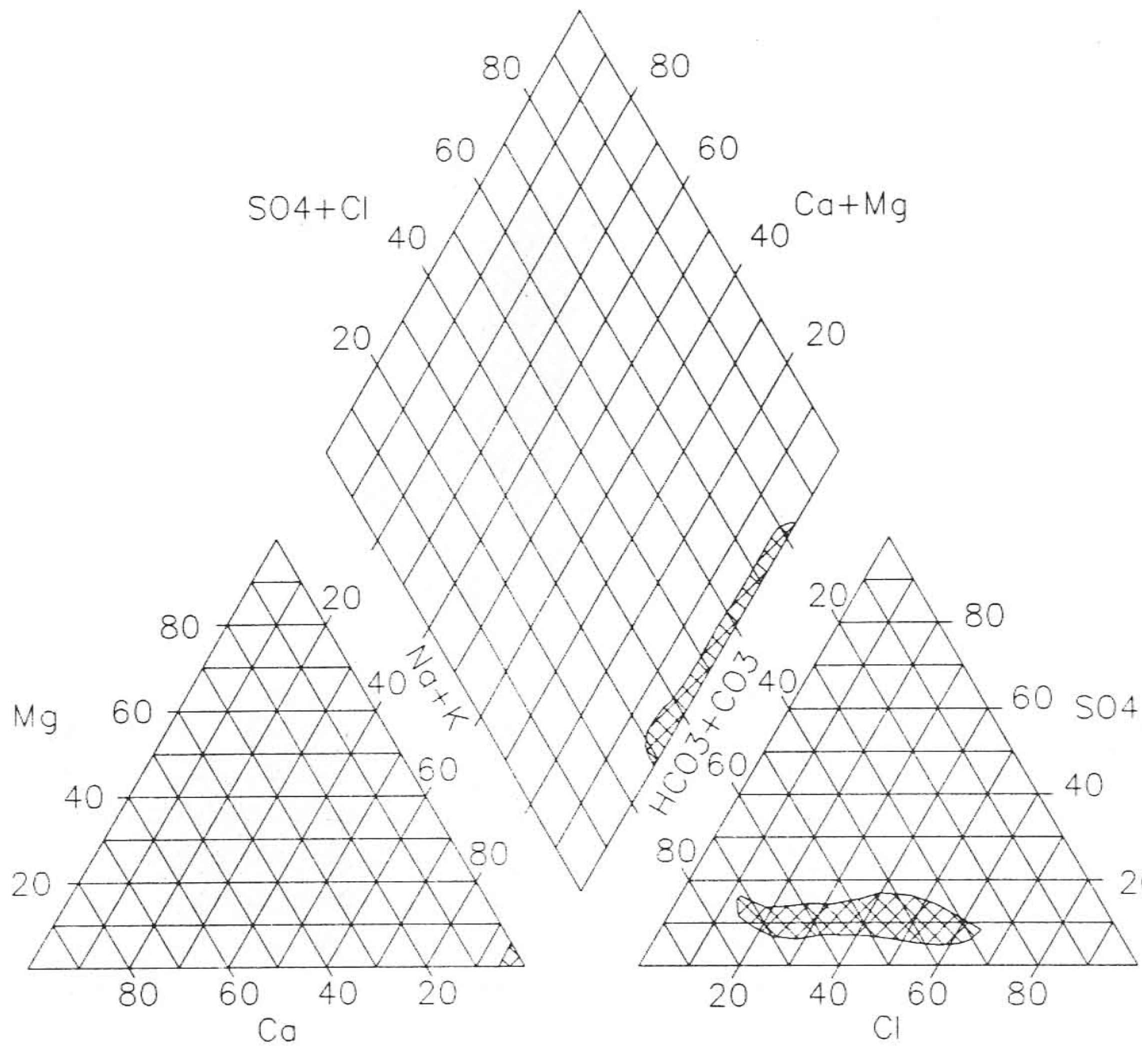
Range of Uncontaminated Analyses

Cl — Percent chemical constituent (milliequivalents/liter)

Figure 16

PIPER DIAGRAM OF BIGFORD AQUIFER GROUND-WATER QUALITY

Diagram from Piper, 1944



EXPLANATION

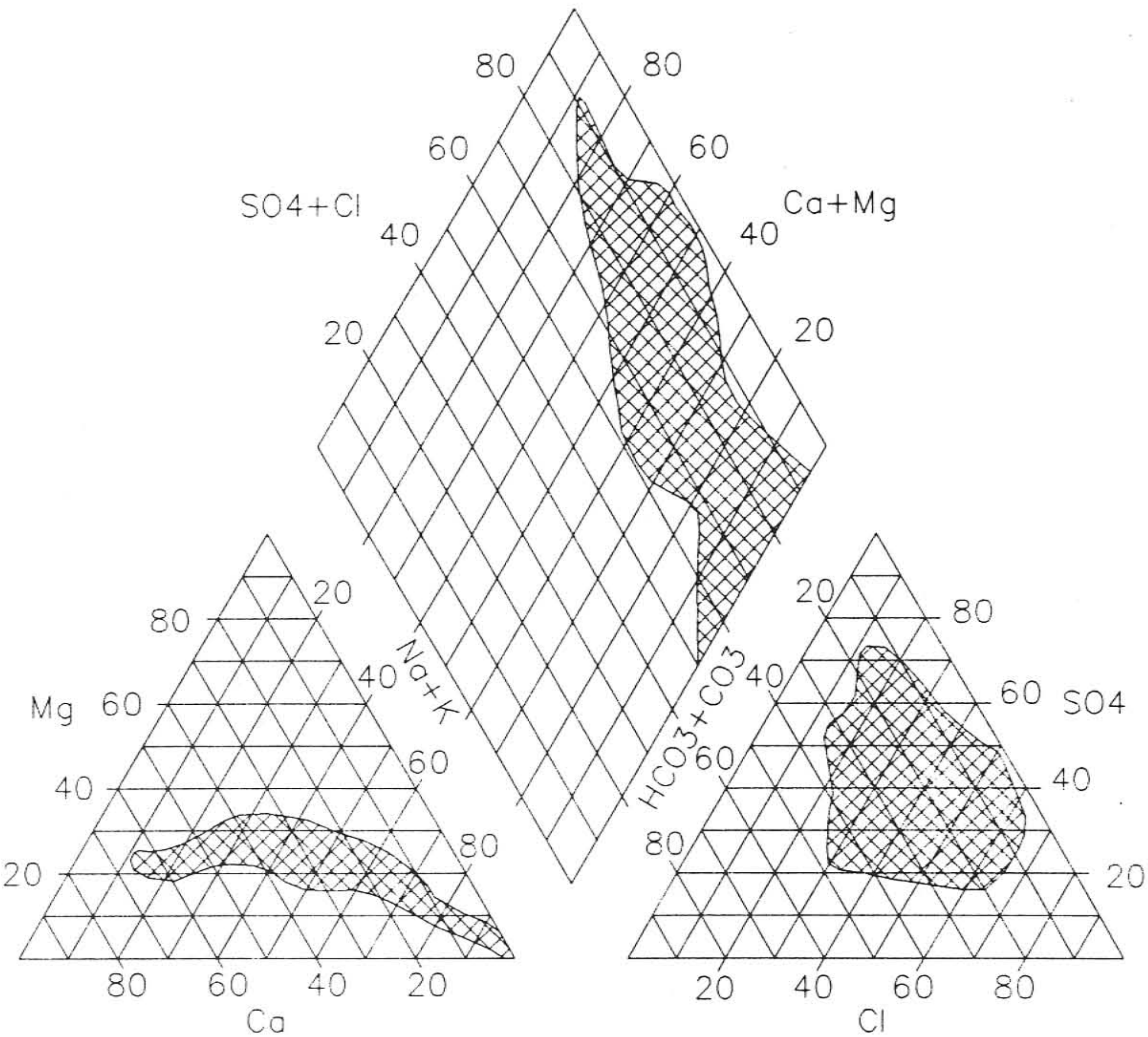
Range of Uncontaminated Analyses

Cl — Percent chemical constituent (milliequivalents/liter)

Figure 17

PIPER DIAGRAM OF QUEEN CITY AQUIFER GROUND-WATER QUALITY

Diagram from Piper, 1944



EXPLANATION

Range of Uncontaminated Analyses

Cl — Percent chemical constituent (milliequivalents/liter)

Figure 18

PIPER DIAGRAM OF LAREDO AQUIFER GROUND-WATER QUALITY

Diagram from Piper, 1944

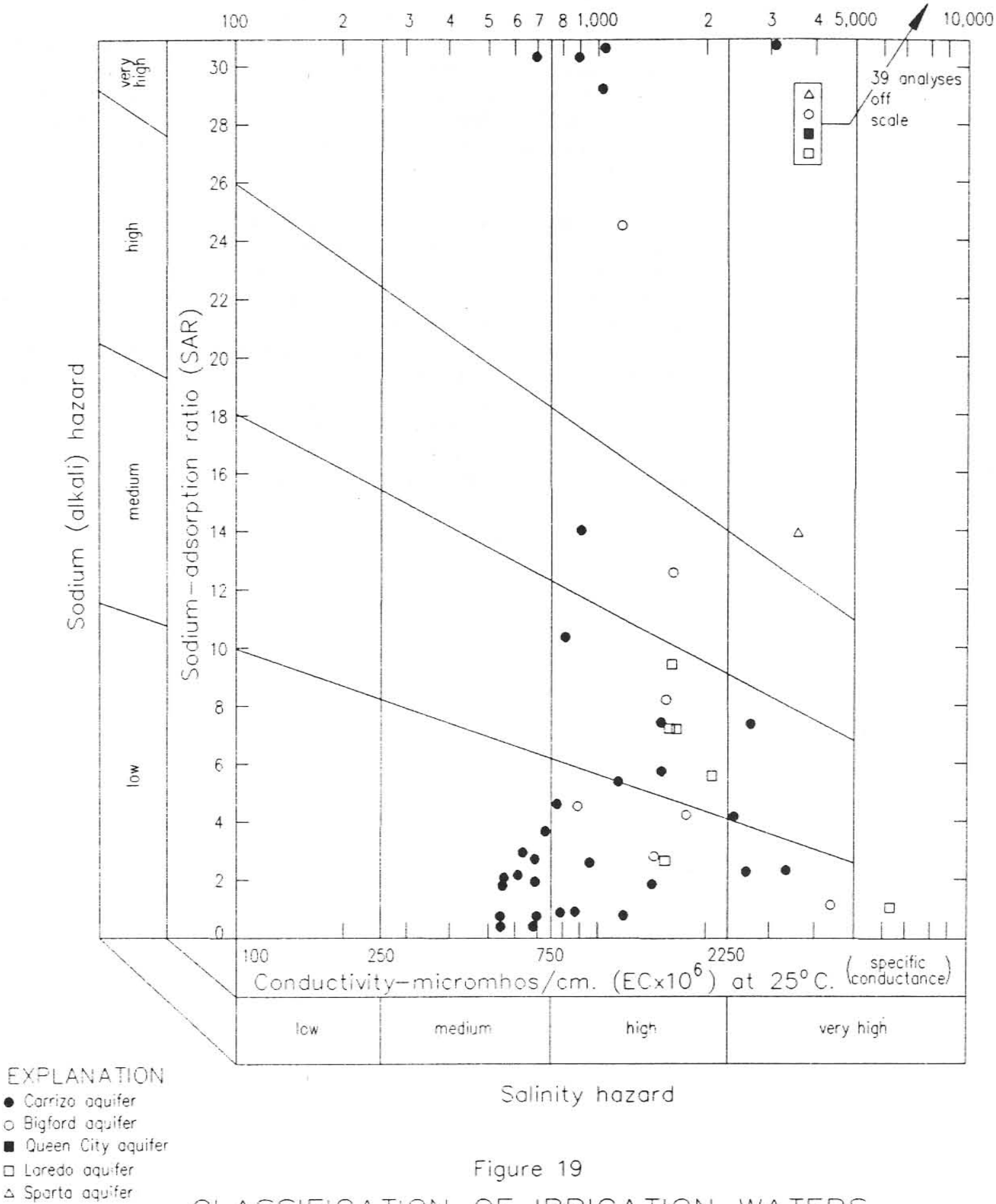


Figure 19

CLASSIFICATION OF IRRIGATION WATERS IN THE WESTERN PORTION OF THE WINTER GARDEN AREA

(Diagram From U.S.Salinity Laboratory Staff, 1954, p.80)

Water samples collected by the Board in September 1990 from 42 wells in Dimmit, La Salle, and Zavala Counties were analyzed for various pesticides and metals. An examination of these analyses did not show any significant levels of either pesticides or heavy metals. Eleven analyses, however, showed an iron concentration above the TDH recommended drinking water limit of 0.3 mg/l. An examination of historical analyses in the Board's database reveals 89 of 279 analyses for iron in the area exceeding MCL. High iron concentrations can be indicative of formation mineralogy, but may also be the result of corrosion of metal casing or water storage or delivery facilities.

Eighteen analyses of ground water from wells completed in the Carrizo aquifer in Dimmit, La Salle, and Zavala Counties were collected in September 1990 for this study and analyzed for radioactivity. Specifically, analyses of the samples were performed to determine the gross alpha and gross beta emissions. Alpha-particle radiation, which is measured in picocuries per liter (pCi/l) can be very dangerous when the radioactive substance is ingested or inhaled into the lungs. Alpha-particle radiation cannot penetrate human skin. Beta-particle radiation, which is also measured in pCi/l, is capable of penetrating several millimeters of human skin and can be harmful when emitted inside the human body. None of the analyses for gross alpha and gross beta exceeded the MCLs.

GROUND-WATER PROBLEMS

Declining Water Levels

Before 1900, development of ground water from the Carrizo aquifer was primarily for domestic, livestock, and public supply purposes. With the introduction of the efficient deep-well turbine pump, large-scale irrigation development took place during the period from 1900 to 1930 in Dimmit and Zavala Counties. In later years, irrigation development spread to the other counties within the study area.

Currently, irrigation from both surface and ground-water sources comprises 90 percent of total water usage in the study area (Table 3) with most of the irrigation water coming from the Carrizo aquifer. The results of such heavy pumpage were realized as early as 1929 when the perennial springs at Carrizo Springs, which naturally discharged ground water from the Carrizo aquifer, ceased to flow (Brune, 1975). From 1920 to 1970, water-level declines of as much as 240 feet in the Carrizo aquifer were measured in the study area (Klemt and others, 1976). Water-level declines in the aquifer continued from 1970 to 1990 as shown on Figure 11, which indicates declines greater than 100 feet in northeastern McMullen County, 60 feet in north-central La Salle County, 40 feet in northwestern Dimmit County, and 60 feet in northeastern Zavala County.

Such severe water-level declines within the Carrizo aquifer have created serious problems. Well yields in portions of Dimmit, Maverick, and Zavala Counties have decreased due to de-watering of the unconfined portions of the aquifer in and downdip of the Carrizo Sand outcrop. This de-watering has removed large amounts of water from storage and thus reduced the unconfined saturated thickness and transmissivity of the aquifer. Such de-watering is demonstrated by the hydrographs of well #76-08-401 (Figure 11) and well #77-33-301 (Figures 11 and 12). Dewatering of the aquifer down-dip of the outcrop probably has occurred within the Carrizo Springs-Crystal City area and within portions of northern Zavala County (Figures 10 and 11).

The long-term decline of water levels in portions of the Carrizo aquifer cause well operators to use larger pumps at deeper settings in order to meet the irrigation demand. Under de-watering conditions, additional wells are needed to supplement existing wells, and these conditions cause increases in operating costs for all well operators.

Well Construction

Prior to the large-scale development of ground water for irrigation in Dimmit and Zavala Counties, the hydrostatic head of the Carrizo aquifer was considerably higher than the hydrostatic head of more highly mineralized water in the overlying Bigford aquifer. With large-scale development, the hydrostatic head of the Carrizo aquifer has been lowered considerably, and in some areas is below that of the overlying Bigford aquifer, possibly allowing poorer quality Bigford water to leak downward into and commingle with the Carrizo water. This downward leakage of mineralized water has probably been compounded by the existence of abandoned wells with corroding, or improperly cemented wells, that were drilled through the Bigford Formation to reach the Carrizo aquifer.

Table 3. Historical (from 1980) and Projected (from 1990) Water Use by Use Categories[1*] (In Acre-Feet)

County	Year	Public Supply		Irrigation		Other [2]		Totals	
		Ground	Surface	Ground	Surface	Ground	Surface	Ground	Surface
Dimmit	1980	2,779	0	19,051	4,305	1,433	125	23,263	4,430
	1985	2,212	0	20,821	1,462	1,384	157	24,417	1,619
	1990	*2,803		*16,800		*1,715		*21,318	
	2000	*3,342		*15,120		*1,897		*20,359	
	2010	*3,892		*14,168		*2,029		*20,089	
La Salle	1980	998	0	10,759	2,604	181	719	11,938	3,323
	1985	996	0	3,003	583	74	943	4,073	1,526
	1990	*1,099		*8,400		*1,064		*10,568	
	2000	*1,212		*7,560		*1,238		*10,010	
	2010	*1,303		*7,084		*1,238		* 9,625	
Maverick	1980	19	0	2,240	0	132	34	2,341	34
	1985	21	0	1,500	0	162	29	1,681	29
	1990	*22		*356		*197		*575	
	2000	*23		*362		*228		*633	
	2010	*24		*396		*228		*648	
McMullen	1980	78	0	0	0	512	593	590	593
	1985	129	0	0	0	457	282	586	282
	1990	*156		*0		*1,187		*1,343	
	2000	*162		*0		*1,270		*1,432	
	2010	*163		*0		*1,281		*1,444	
Webb	1980	198	985	0	11,616	132	1,171	330	13,772
	1985	229	1,783	0	3,520	114	1,037	343	6,340
	1990	*1,878		*5,376		*1,549		*8,803	
	2000	*2,302		*4,838		*1,795		*8,935	
	2010	*2,526		*4,534		*1,795		*8,855	
Zavala	1980	2,068	0	81,800	25,070	1,518	793	85,386	25,863
	1985	2,154	0	94,200	5,454	1,130	1,018	97,484	6,472
	1990	*2,547		*85,200		*2,551		*90,298	
	2000	*2,799		*76,680		*3,064		*82,542	
	2010	*2,900		*71,852		*3,351		*78,103	
Totals	1980	6,140	985	113,850	43,595	3,908	3,435	123,898	48,015
	1985	5,741	1,783	119,524	11,019	3,321	3,466	128,586	16,268
	1990	*8,505		*116,132		*8,268		*132,905	
	2000	*9,840		*104,580		*9,492		*123,912	
	2010	*10,808		* 98,034		*9,922		*118,764	

1–Water use for the years 1980 and 1985 are based on reported and site–specific computed use.
*–Water use for the years 1990, 2000, and 2010 are based on 1989 Texas Water Development Board Revised High Series projections used in the 1990 Texas Water Plan update. Projections do not separate ground–water and surface water use.
2–Other includes manufacturing, mining, and livestock uses.

Improperly completed wells and abandoned wells with corroded casing can serve as pathways for localized contamination from underlying and overlying saline or polluted water zones (Figure 20). Analyses of water from some wells in the outcrop area of the Carrizo Sand and its immediate downdip area in Dimmit and Zavala Counties show high dissolved solids concentrations which may indicate such localized contamination. This type of contamination can become widespread in areas where improperly completed and/or abandoned wells are concentrated.

Twelve recently sampled wells completed in the Carrizo aquifer above the down-dip limit of fresh water have analyses with dissolved solids, chloride, and/or sulfate concentrations that exceed the MCL's (Figure 14). Computer analysis did not indicate brine contamination in any of these samples, therefore, some other condition must be causing these higher levels. The most likely cause is the downward leakage of more highly-mineralized water from overlying strata into the Carrizo aquifer through the uncemented annular space between the well casing and the borehole. The locations of these twelve wells suggest that this problem is localized, but generally occurs within the area delineated on Figure 14. This area occurs within the region having the most water-level decline as indicated on Figure 11 and within the large water-level depression as indicated on Figure 10.

Oil and Gas Production

The first oil field discovered in the area was in McMullen County in 1918. Since that time numerous fields have been discovered and developed in the upper Cretaceous strata that underlie the Eocene-age aquifers. These oil and gas fields are scattered across the six counties of the study area (Figure 21). Production activity has fluctuated over the years, and most field discoveries have occurred since 1955. Development of the Austin Chalk trend in the 1970s and early 1980s helped boost oil and gas industry activity (Figure 22).

Brine is often produced in tremendous quantities as a by-product of oil and gas production. From the first discovery to 1982, the following amounts of brine were produced from oil and gas wells (including the parts of Maverick, McMullen, and Webb Counties that are outside the boundaries of the study area):

Dimmit County	- 5.45 million barrels
La Salle County	- 3.14 million barrels
Maverick County	- 61.50 million barrels
McMullen County	- 2.60 million barrels
Webb County	- 140.30 million barrels
Zavala County	- 3.38 million barrels
Total	**- 216.37 million barrels**

(Source: Railroad Commission of Texas, 1982)

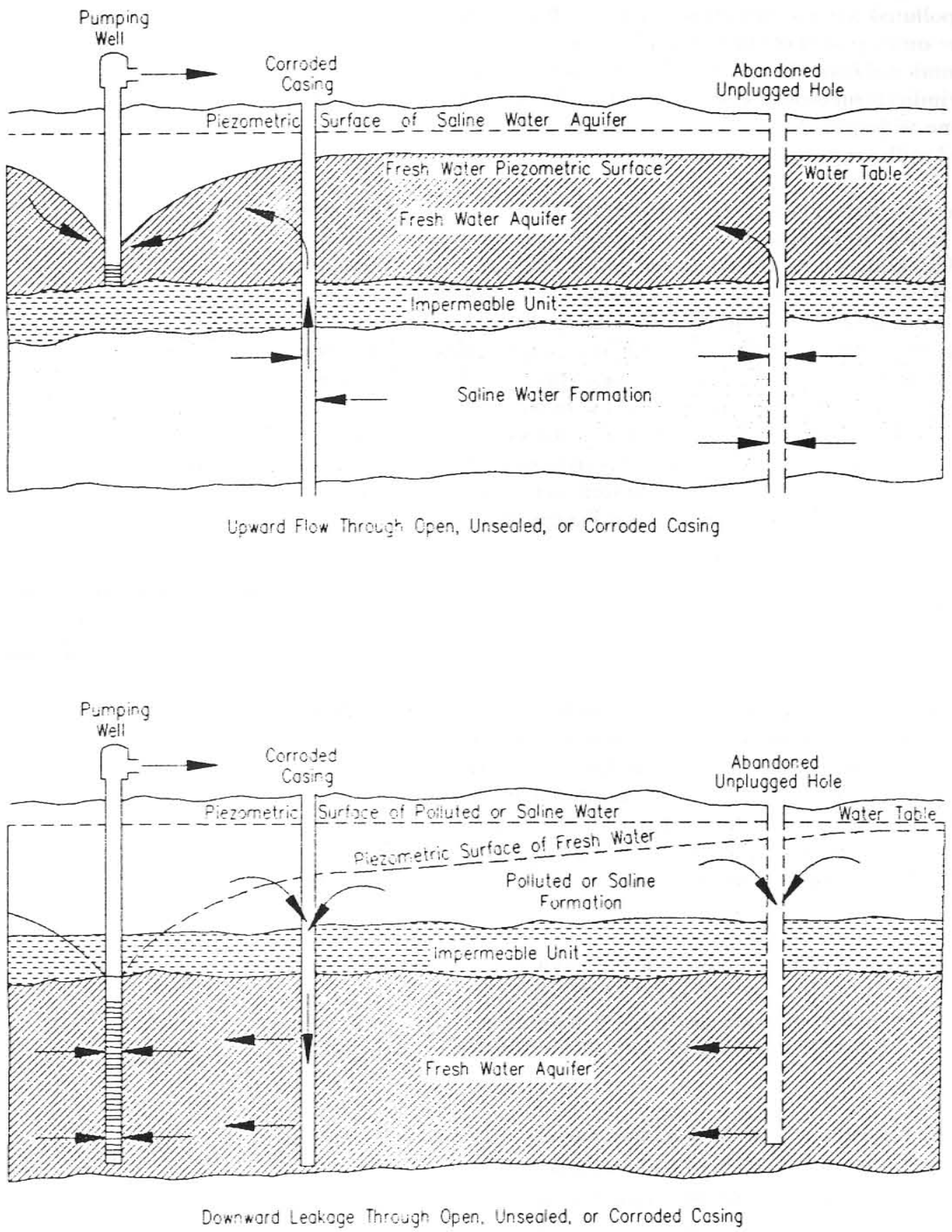


Figure 20

UPWARD FLOW AND DOWNWARD LEAKAGE THROUGH OPEN, UNSEALED, OR CORRODED CASINGS

(From Texas Water Commission, 1989, Figure 44)

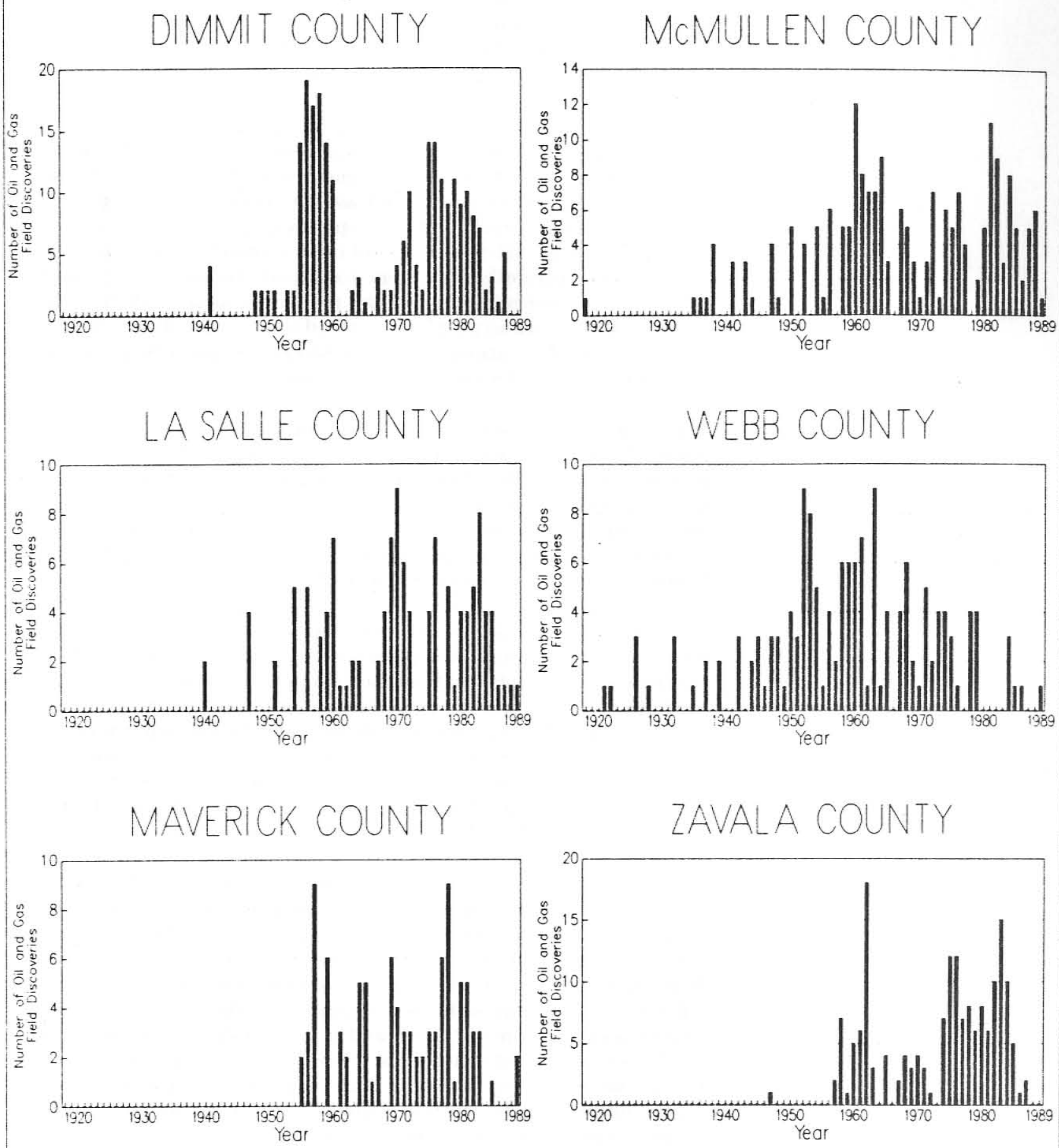


Figure 22

HISTORY OF THE DISCOVERY OF OIL AND GAS FIELDS BY COUNTY, 1918 TO 1989

Data from Railroad Commission of Texas, 1982

In the early days of the petroleum industry, brine disposal was unregulated and was often by discharge into nearby streams or gullies. As the industry grew and production increased, two different disposal methods became standard practice, disposal of brine into surface evaporation pits, and injection of brine through disposal wells into deep saline water-bearing zones.

Before being halted by the Railroad Commission of Texas' statewide no-pit order of January 1, 1969, the most common method of disposing of brine was into unlined surface pits on the lease site (Texas Water Commission, 1989). This practice resulted in the evaporation of water from the brine, leaving behind the solids of salts and other minerals. Where pits were constructed on permeable soils, brine seeped into the subsurface forming a brine plume immediately below the pit. Under most conditions, this lateral and downward seeping brine reached an unconfined water-bearing strata and formed a contamination plume within the aquifer. Some pits can still be permitted under special circumstances.

Following the no-pit order, the petroleum industry switched to "saltwater disposal" wells as a means of disposing of brine. These wells, which must be permitted by the Railroad Commission of Texas, inject brine into deep, saline water-bearing strata. Proper injection pressure during operation of the well must be maintained because injection pressure that is not regulated, coupled with corroded casing, can result in the contamination of overlying fresh-water zones by saline water (Figure 20).

In order to assess the degree of contamination of the aquifer in the study area by oilfield activities, a computer simulation program to detect brine contamination was obtained from the Railroad Commission of Texas and modified by Board staff. Previous investigations into contamination caused by oilfield brine and naturally mineralized water have shown that certain chemical ratios, such as chloride/sulfate and chloride/sodium, and concentrations of certain constituents, such as chloride, bromide, iodide, and strontium, are excellent indicators of such contamination (Collins, 1975; Knuth and others, 1980; Novak and Eckstein, 1988).

Of the 1,262 analyses of water from 620 water wells in the study area, 879 were sufficiently complete to use in the computer program analysis for contamination assessment. The analysis program, and further evaluations, determined only 3 analyses (all from the Carrizo aquifer) with probable brine contamination. Water from these wells displayed extreme sodium-chloride (Na-C1) facies on the Piper diagram plot (Figure 15). Two of these wells are located in Dimmit County, and one well is located in Webb County. Of the two wells in Dimmit County, one is located on the outcrop of the Carrizo Sand southwest of Carrizo Springs; and the other well is located approximately 12 miles south of Carrizo Springs and downdip from the outcrop. The well in Webb County is located in the northwest part of the county about midway between FM 1472 and U.S. 83, and is about 8 miles downdip from the outcrop of the Carrizo Sand. Due to the limited nature of this study, the cause of probable brine contamination in these three wells was not determined.

Other indicators of brine contamination are elevated levels of strontium, bromide, and iodide (Collins, 1975). An examination of analyses of water samples collected in September 1990 revealed no such elevated levels. The three wells mentioned previously, whose analyses indicated brine contamination, were not sampled for any of these constituents.

This evaluation of available chemical analyses suggests a lack of widespread contamination from oilfield brines. However, the following conditions could mask the actual occurrence of contamination: 1) contaminated areas may have gone undetected due to lack of sampling in these areas; 2) contamination may be so slight as to be unnoticed in sampled analyses; and 3) severely contaminated wells have probably been abandoned and may be unavailable for sampling.

Saline-Water Encroachment

Saline-water encroachment is the process by which salt water, due to its heavier density, invades a fresh-water zone. The displacement of freshwater by salt water within the aquifer most often occurs along its downdip limit and can be accentuated by heavy pumpage. The downdip limits of fresh and slightly saline water have not changed appreciably since they were delineated by Klemt and others (1976).

HISTORICAL AND PROJECTED POPULATION AND WATER USE

Population

Current and projected population figures for the study area are listed in Table 4. In 1985 the total population was 35,448, and the area had a very low density. This figure is expected to increase by about 39 percent by the year 2010. About 60 percent of the current and projected population reside in the cities of Asherton, Carrizo Springs, Crystal City, Cotulla, and Tilden.

Water Use

Historical and projected water use for the western portion of the Winter Garden area is shown on Table 3. The data for 1980 and 1985 are differentiated between surface-water and ground-water use and are based on reported site-specific computed use. Projected water use for the year 1990, 2000, and 2010 is based on the 1989 Texas Water Development Board Revised High Series projections, but does not differentiate between surface-water and ground-water use.

As of 1985, surface water accounted for 11 percent of the total amount of water use in the study area. Most of the surface-water use was concentrated in Webb and Zavala Counties (Table 3). Most of this surface water comes from local sources, such as creeks, stock tanks, pits, and small impoundments on the Nueces River.

Local sources and impoundments represent small diversion dam structures built by landowners holding rights to water in either the Nueces River or the Rio Grande. These rights were originally guaranteed by the Spanish government when Texas and Mexico were Spanish colonies and are recognized by the State of Texas today. A permitted water right must be held in order to divert water from a river for irrigation or municipal use, but use of surface water for livestock does not require a permitted water right. Of the total amount of surface water use in the study area, 68 percent is used for irrigation, 11 percent for public supply, and 21 percent for other uses (primarily livestock).

In 1985, ground water accounted for 89 percent of the water used in the study area. Irrigation use comprised about 90 percent of all water use in that same year. All water uses except irrigation are projected to increase slowly through the year 2010. However, total water use peaked in 1980 and is projected to decline steadily through the year 2010 as a result of an economic decline in agriculture.

Table 4. Historical (from 1980) and Projected (from 1990) Population*

County	Year	Cities	Rural**	Totals
Dimmit	1980	8,460	2,907	11,367
	1985	9,140	2,749	11,889
	1990	9,075	2,541	11,616
	2000	11,656	2,541	14,197
	2010	14,359	3,106	17,465
La Salle	1980	3,912	1,602	5,514
	1985	4,204	1,553	5,757
	1990	3,781	1,451	5,232
	2000	4,443	1,608	6,051
	2010	5,052	1,828	6,880
Maverick	1980	***	33	33
	1985	***	35	35
	1990	***	36	36
	2000	***	41	41
	2010	***	45	45
McMullen	1980	300	402	702
	1985	302	561	863
	1990	288	587	875
	2000	315	646	961
	2010	333	692	1,025
Webb	1980	***	6,530	6,530
	1985	***	4,858	4,858
	1990	***	5,422	5,422
	2000	***	7,021	7,021
	2010	***	8,151	8,151
Zavala	1980	8,334	3,332	11,666
	1985	8,421	3,625	12,046
	1990	8,452	3,670	12,122
	2000	9,207	5,231	14,438
	2010	10,112	5,675	15,787
Totals	1980	21,006	14,806	35,812
	1985	22,067	13,381	35,448
	1990	21,596	13,707	35,303
	2000	25,621	17,088	42,709
	2010	29,856	19,497	49,353

* Population for the years 1980 and 1985 is based on Bureau of Census statistics. Population for the years 1990, 2000, and 2010 based on 1989 Texas Water Development Board Revised High Series population projection used in the 1990 Texas Water Plan.

** The term "Rural" includes unincorporated areas and all rural populations.

*** This portion of the county contains no cities in the study area.

POTENTIAL FOR ADDITIONAL WATER DEVELOPMENT

Potential for Additional Ground-Water Development

A mathematical model of the Carrizo aquifer developed by the Texas Water Development Board in the early 1970s used specified water-level decline criteria to demonstrate the ability of the aquifer to meet projected (expected) ground-water withdrawals through the year 2020 (Klemt and others, 1976). Application of the model estimated that approximately 330,000 acre-feet of ground water could be withdrawn annually during the period from 1970 to 2020 for the entire Winter Garden area (which includes all or portions of ten additional counties east of this study area). Within the study area for the same period, approximately 118,000 acre-feet per year of ground water could be withdrawn from the Carrizo aquifer. The model application did not permit water levels to decline more than 400 feet below the land surface or the top of the Carrizo aquifer (Klemt and others, 1976).

However, to meet this specified, restrictive water-level decline criteria, ground-water withdrawals imposed in the model application had to be manipulated in a manner that does not fit the actual historical, the actual current, or the expected distribution of ground-water withdrawals from the aquifer. As indicated by Klemt and others (1976), ground-water withdrawals in areas historically and currently developed had to be reduced, while ground-water withdrawals in areas not likely to ever have significant development had to be increased.

In actuality, this model application is only one of many ground-water availability scenarios to determine a specific amount of ground water that can be removed from the aquifer under specified conditions (in this case a water-level decline criteria). Therefore, on a gross basis, without consideration to actual or reasonably expected future distribution of ground-water withdrawals, the total projected annual ground-water use to the year 2010, as inferred in Table 3, will probably be less than the 118,000 acre-feet annual amount determined to be available from the model application by Klemt and others (1976).

Continued heavy pumping from the Carrizo aquifer in areas already experiencing severe water-level declines will increase the amount of water removed from storage and create excessive water-level declines that will hamper further development (Figure 10). Ideally, areas that currently show only minor water-level declines or water-level rises are the most suited for future development.

Previous studies have shown that the other aquifers in the study area have limitations for future development (Klemt and others, 1976; Muller and Price, 1979; Hamlin, 1988). Water from the Wilcox aquifer is suitable for irrigation use, but since the Wilcox aquifer occurs at greater depth downdip from its outcrop area than the overlying Carrizo, it is generally not used. Low transmission capacities, coupled with generally high SAR ratios and a high salinity, preclude any major development of ground water from either the Bigford, Queen City, Laredo, or Sparta aquifers.

Potential Means for Increasing Aquifer Recharge and Availability

Potential means of increasing recharge to the Carrizo aquifer include water catchment structures on the outcrop area, injection wells, and brush clearing. Artificial recharge occurs when natural recharge is augmented so as to increase the amount of water entering the aquifer. By constructing a series of dikes within basins, runoff could be retained and infiltration increased. In addition, the beds of intermittent streams could be developed to increase infiltration.

Experimentation has been conducted using injection wells to deliver water from the surface into the Carrizo aquifer near Crystal City in Zavala County (Klemt, and others, 1976). Initially high injection rates had to be drastically reduced after only a short period of time; and clogging of the aquifer through the presence of algae, silt, and entrained air had to be overcome for injection well operation to be successful. The completion of injection wells into zones of low permeability, as well as poor well design, can also have a detrimental affect on injection rates. Without a carefully designed program that includes a suitable source of surface water, injection wells may not be feasible.

Transpiration is the emission of water vapor to the atmosphere by plants. The greatest loss of water by transpiration in the study area occurs on rangeland that contains large concentrations of brush and woody plants, mesquite being the most dominant. A mesquite stand that has a canopy shading 50 percent of the soil can use as much as nine inches of water per month during the growing season (Hoffman, 1967). According to Rechenthin and Smith (1967), "a grassland restoration program, involving the control of undesirable plants and replacing them with grass, would result in a saving of water, most of which would be available for deep percolation into underground aquifers and as return flow to streams."

Conservation, the least costly method of increasing availability to the Carrizo aquifer by using less water in storage, can be implemented in many ways. Because of its extensive use for agricultural purposes, irrigators can realize the greatest conservation of ground water by installing water-saving equipment, planting drought resistant crops, and implementing conservation management techniques. Municipalities can likewise achieve significant decreases in water use by upgrading facilities and encouraging conservation practices by their customers.

In addition, area ground-water resources can be better managed by using proper well completion techniques and allowing for adequate well spacing. Too many high-capacity wells in too small an area can drastically lower an area's water level by overlapping their localized cones of depression.

Potential for Surface-Water Use

Although significant increases in surface water would help meet future water demand, this would only be possible through the construction of major reservoirs on either the Nueces or Frio Rivers. However, such construction projects would be dependent on the availability of flow in these rivers; cost of the projects; voter approval; potential environmental impact such projects might have on the downstream courses of the rivers; and water-quality of the reservoirs. This alternative requires further study.

The potential for conjunctive use of ground and surface water is a possibility only on a limited, localized scale. Without a major source, current surface-water use cannot be significantly increased. However, on a local basis, surface-water impoundments such as stock tanks can augment water supply for stock and irrigation purposes.

Projected Availability through the Year 2010

1990 was a peak year for water use within the study area (Table 3; Texas Water Development Board, 1989). Total water demand is then expected to decline to about 118,764 acre-feet per year by the year 2010 (Figure 23). If surface-water use is deducted from the total use, the demand is less than the estimated 118,000 acre-feet per year of ground water that is available for development from the Carrizo aquifer. However, heavy irrigation pumpage will continue to cause water-level declines and deterioration of water quality in localized areas.

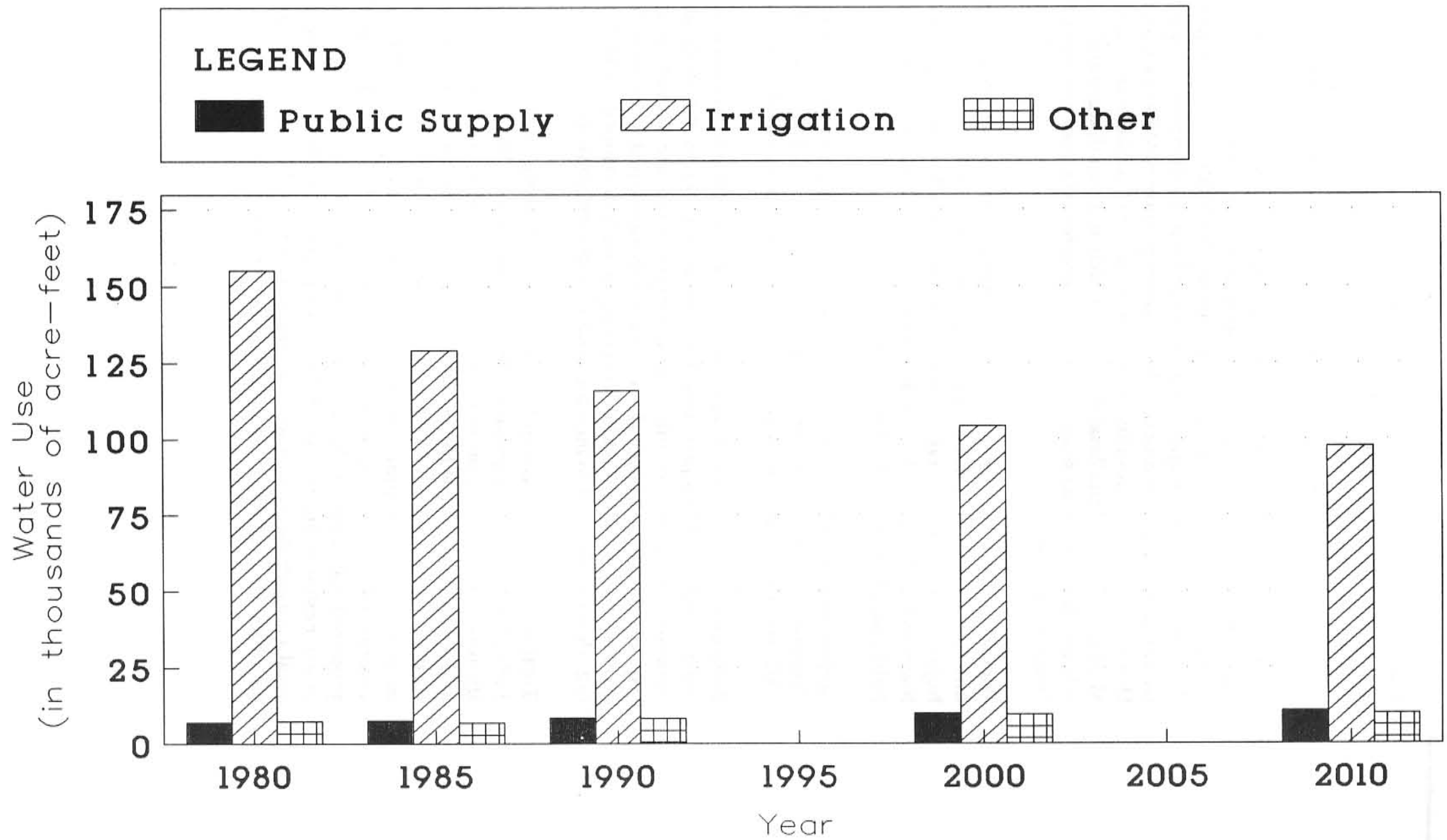


Figure 23
HISTORICAL AND PROJECTED WATER USE

Data from Texas Water Development Board, 1989

SUMMARY

The Carrizo-Wilcox aquifer provides about 98 percent of the total ground water used in the western portion of the Winter Garden area. In 1985, irrigation comprised some 90 percent of all water use. Surface water, in 1985, accounted for only 11 percent of total water use in the study area.

Ground water from the Carrizo-Wilcox aquifer is of very good quality, especially close to the outcrop in eastern Maverick, Dimmit, and Zavala Counties. Because of the good quality and the high-yield characteristics of the aquifer, intensive irrigation farming is widespread throughout Dimmit, La Salle, and Zavala Counties, and the eastern portion of Maverick County. Heavy pumpage has resulted in severe water-level declines in Dimmit, McMullen, La Salle, and Zavala Counties, which indicates that ground water is being depleted from storage at a much greater rate than the aquifer is being replenished.

Water from the smaller aquifers that overlie the Carrizo is generally unsuited for irrigation due to high concentrations of sodium chloride and high sodium-adsorption ratios. In addition, these aquifers have considerably lower well yields than the Carrizo, which inhibit their development for public supply in most of the study area.

Surface water is only a minor source of the water supply in the study area. Primarily retained behind small structures on creeks and streams, surface water supplies tend to be localized and scattered about in small quantities.

Previous studies estimated that approximately 118,000 acre-feet per year of water could be developed from the Carrizo aquifer in the study area. However, withdrawal of this annual amount from the Carrizo aquifer requires that areas historically and currently developed need to reduce ground-water withdrawals while areas not currently developed (or likely not ever developed) need to increase ground-water withdrawals.

Total combined surface- and ground-water use in the area in 1985 was 144,854 acre-feet, with ground-water use comprising 128,586 acre-feet of the total. This figure is projected to decrease to a total combined surface- and ground-water use of 132,905 acre-feet in 1990. For the next twenty years total water use is projected to steadily decline within the study area as a result in an expected continued decrease in irrigation. By the year 2010, it is estimated that 118,764 acre-feet per year of water will be used. Though this projected water demand for the year 2010 is about the same as the amount of water estimated to be available for development from the Carrizo aquifer, local concentrations of heavy pumpage in Dimmit, La Salle, and Zavala Counties will continue to cause areas of severe water-level declines.

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