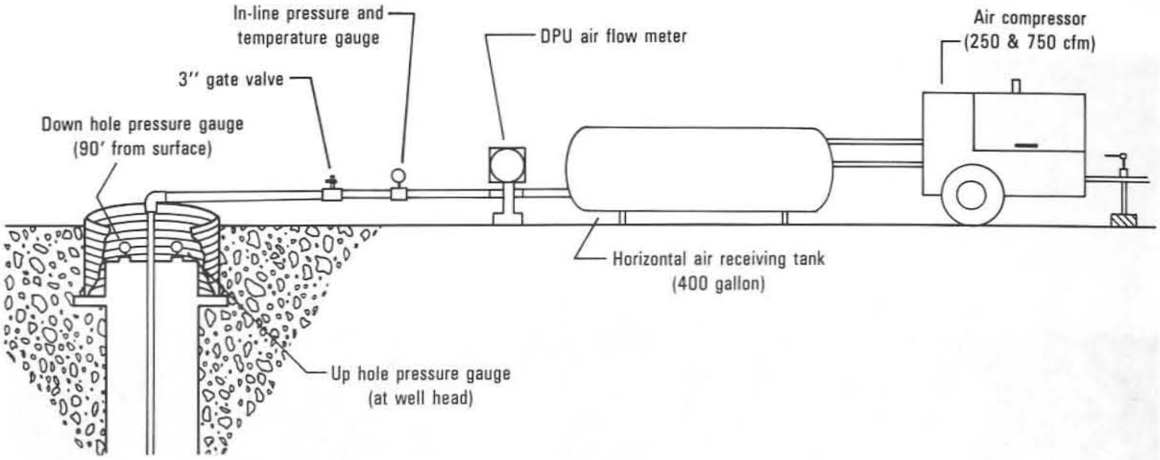


Figure 8-12.—Air Injection Test Layout (From Rauschuber, Wyatt, and Claborn, 1982)

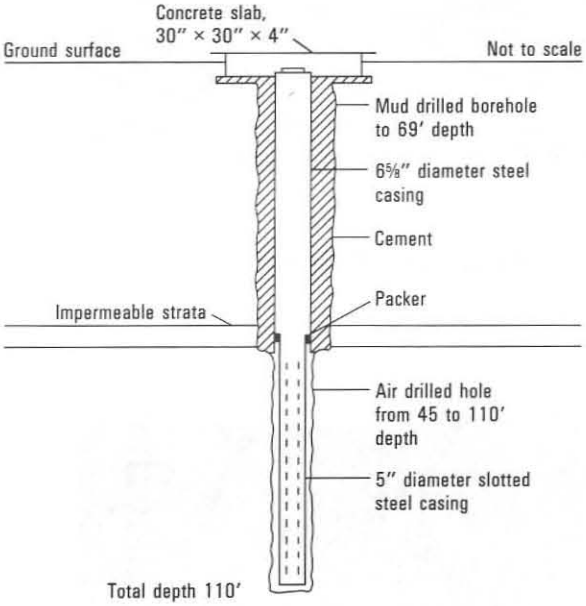


Figure 8-13.—Diagram of Air Injection Well Design (Modified from Rauschuber, Wyatt, and Claborn, 1982)

rainfalls to prevent area flooding and mosquito infestation. The drainage well, drilled prior to 1950, drains a depression which extends over a 7-acre area. Drilled to an approximate depth of 150 feet, the well has a 6-inch diameter steel pipe running to total depth. The steel pipe extends 12 inches above the surface and is slotted. The well is surrounded by a 24-inch diameter steel mesh cage to prevent well clogging (Figure 8-16). Figure 8-17 shows a diagram of the Rocksprings recharge well design.

No data are available on the injection volume of the Rocksprings drain well. The actual injection volume over a period of time will depend upon rainfall runoff, the efficiency of the well design, and the permeability of the injection formation.

Water which drains by gravity through the well into the underlying cavernous limestone was sampled in March 1982. A chemical analysis was run on the sample, with the results as shown in Table 8-4. This recharge water is essentially surface runoff from rainfall. From comparing the local aquifer water sample analysis (Table 8-3) with that of the impounded recharge water, there presently appears to be a low potential for contamination of the underground water supply. The City of Rocksprings continues to be the sole operator of the drain well.

Gulf Coast Region

The Department's investigations have found no evidence of artificial recharge injection wells operating along the Gulf Coast. This geographic region is included, however, because many

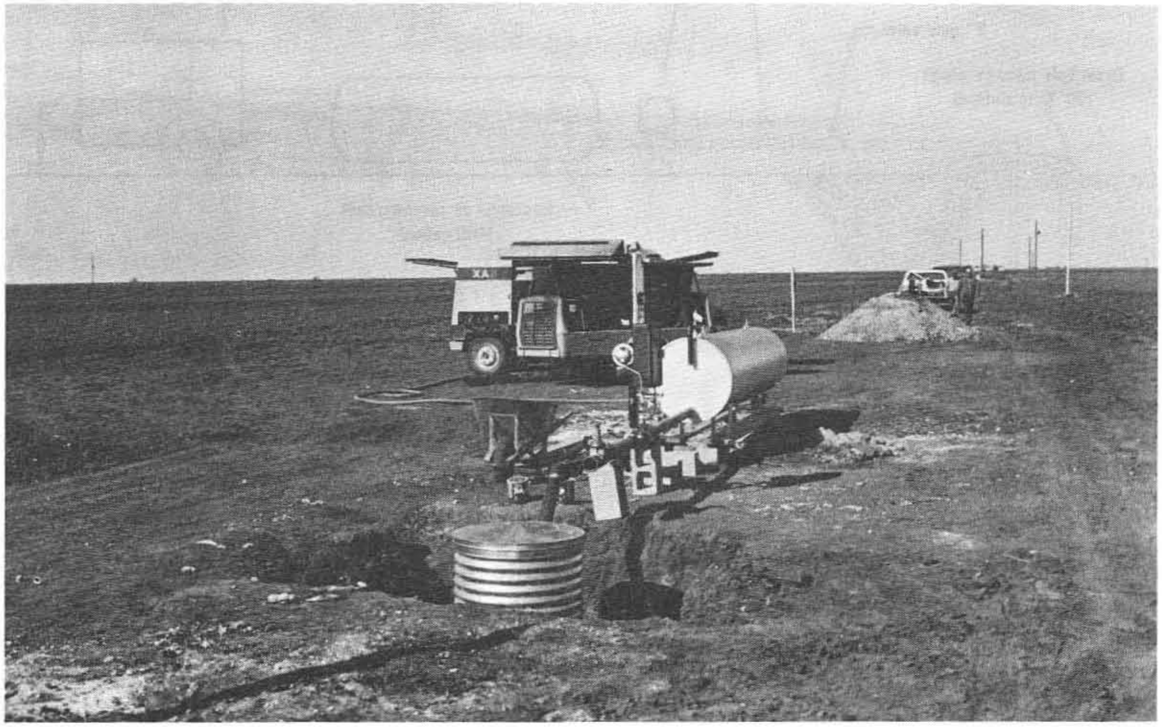


Figure 8-14.—Apparatus Used in Secondary Recovery of Ground Water

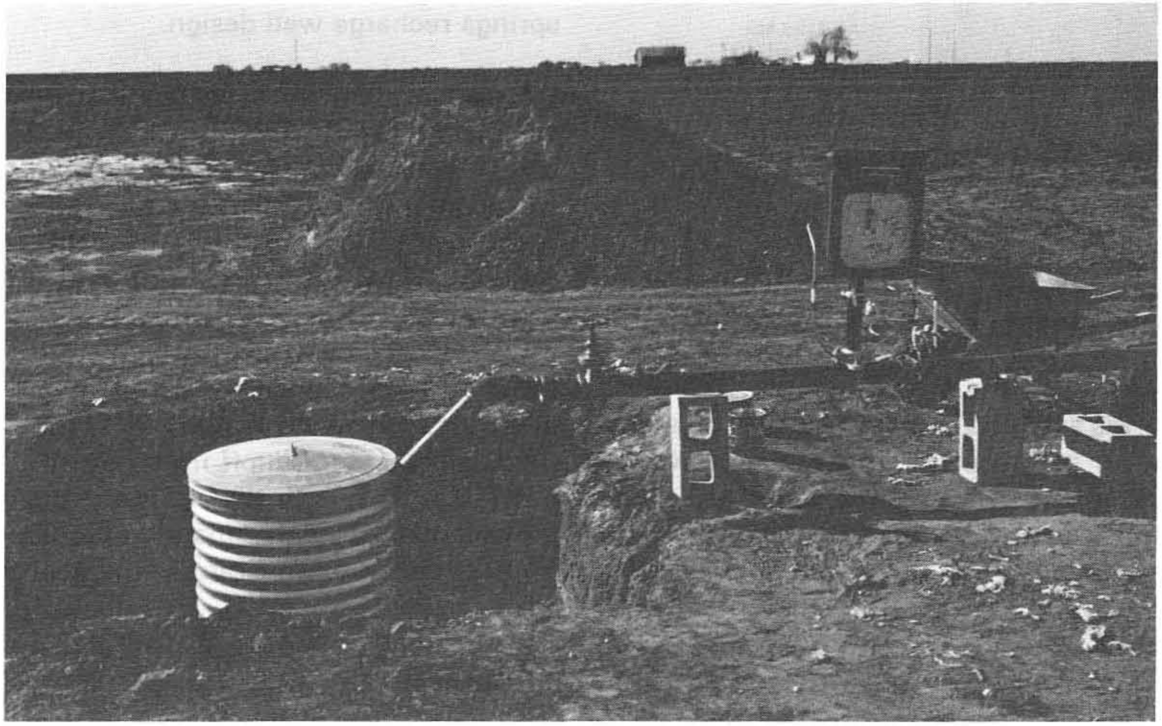


Figure 8-15.—Air Injection Hole With Pressure Recording Devices

Figure 8-16.—Recharge Drain Well in Rocksprings, Edwards County

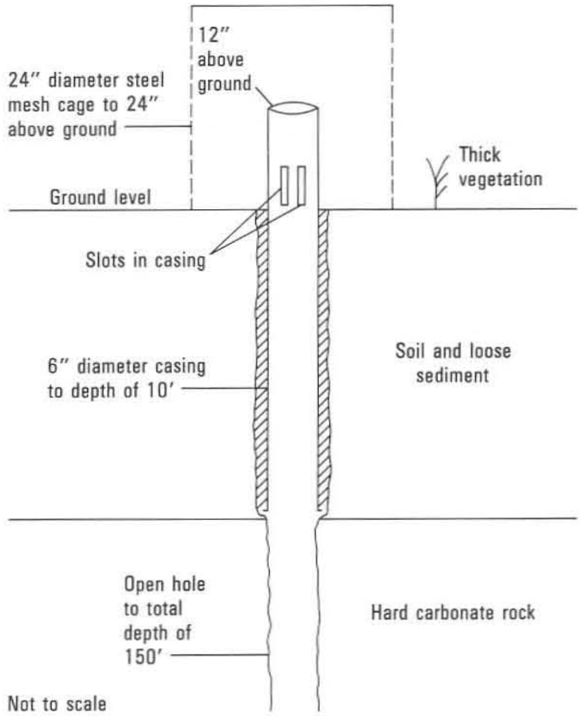


Figure 8-17.—Diagram of Recharge Well in Rocksprings, Edwards County

geologists and engineers believe that artificial recharge wells may have future applications in this area of Texas.

Geohydrology

Galveston and Harris Counties exhibit geologic and hydrologic features typical of the Gulf Coast. Barrier islands, lagoons, bays, marshes, sluggish streams, and grassy plains are all found in this area. In counties along the coast, fresh ground water is produced from the Gulf Coast aquifer (Table 2-2). In this aquifer the base of fresh to slightly saline water occurs near land surface along the immediate coastline and deepens to about 1,000 feet in the subsurface in the western part of Galveston County. Progressing inland across Harris County, the base of fresh to slightly saline water deepens to more than 2,000 feet in the subsurface. The Gulf Coast aquifer is the major source of ground water for the agricultural, industrial, domestic, and municipal needs of the area.

Assessment of Subsidence Control Wells

Land-surface subsidence has become very significant in parts of the Houston-Galveston region of Texas. Some low-lying areas of recent land subsidence along Galveston Bay are now subject to catastrophic flooding from heavy rainfall and hurricane tides. Withdrawal of water from the underlying aquifers for municipal use has resulted in a decrease in aquifer hydraulic pressure. The pressure difference between water depleted sands and the higher pressured clays causes water to move from the clays to the sands, resulting in compaction of the clays and consequent lowering of land surface elevation. Because clays are normally inelastic, most of the compaction is permanent. Less than 10 percent rebound from clay compaction and land subsidence can be expected from a total recovery of artesian aquifer pressure.

Recharge injection wells have been used to control subsidence in Long Beach, California. This project used water injection to repressure reservoirs where hydrocarbon withdrawals had caused a significant amount of subsidence. During the late 1960's, approximately 700,000 barrels of water per day were injected into the Wilmington Oil Field in Long Beach. Further subsidence was eliminated over a large portion of the field and a small amount of surface rebound has occurred in the areas of greatest injection.

Presently, Texas does not have injection wells to control subsidence in the Galveston area or any other region in the State. According to the Houston subdistrict of the U.S. Geological Survey, the wells are presently not feasible, but may be of significance in the future. Galveston area subsidence control would probably be similar to the methodology used in Long Beach, California. A schematic diagram showing the relationship of subsidence control wells to oil wells in the Long Beach area is shown in Figure 8-18.

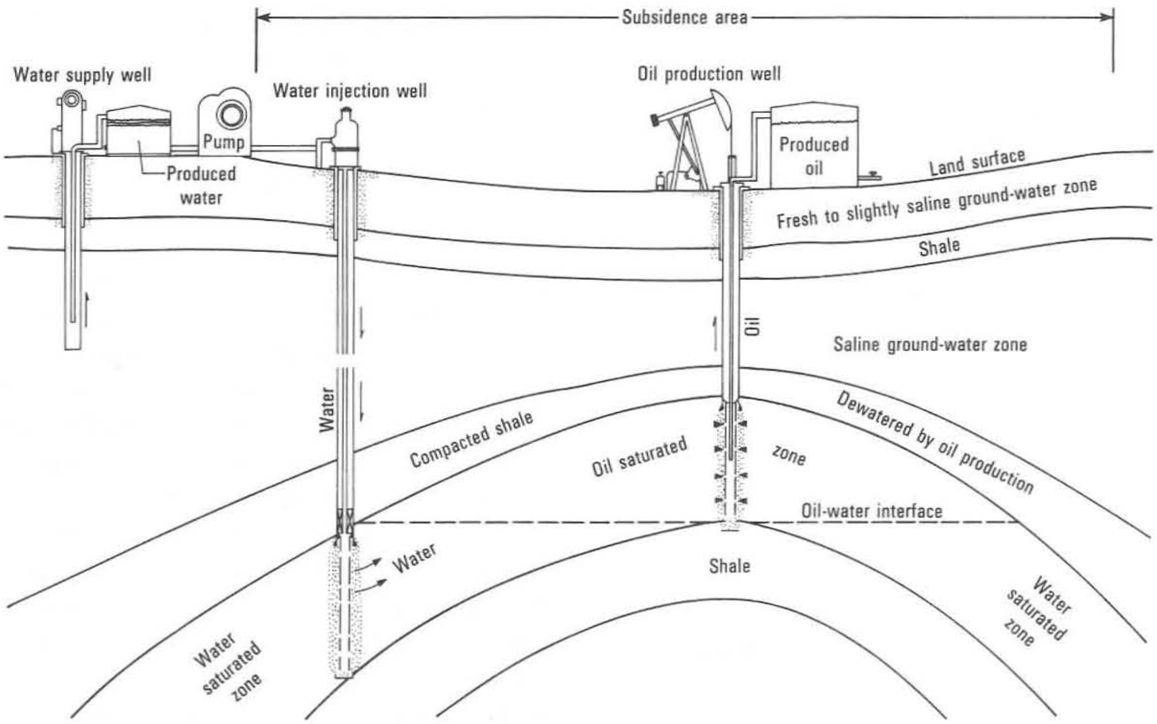


Figure 8-18.—Schematic Diagram of Subsidence Control (Water Injection) Wells and Oil Wells in Wilmington Oil Field, Long Beach, California (Modified from Allen and Mayuga, 1969)

These wells generally require more rigorous design standards in casing, cementing, and well completion than those types of artificial recharge wells which simply operate by gravity drainage. Subsidence control wells are nevertheless judged to have very low potential for ground-water contamination provided that quality of injected recharge water is maintained as good or better than that of the receiving aquifer. Also, this assessment of low contamination potential for subsidence control wells assumes careful regulation of surface injection pressures to prevent formation fracturing. It is anticipated that subsidence control wells in the Galveston and Houston areas would be constructed and operated by the Harris-Galveston Coastal Subsidence District.

Assessment of Salt Water Intrusion Barrier Wells

Salt water intrusion barrier wells may be used to prevent migration of seawater inland in major water production zones along the Gulf Coast. This may be accomplished through fresh water injection into an aquifer. Such intrusions occur where permeable formations outcrop into a body of sea water when there exists a landward ground-water flow gradient.

Barrier wells used for control of salt water intrusion do not currently exist in Texas but may be of use in the future along the extensive Texas coastline. Construction of the wells would likely resemble those of the Alamitos Barrier Project in Los Angeles, California. Figure 8-19 diagrams the construction features of the two types of salt water intrusion barrier wells used in Los Angeles. Figure 8-20 shows the basic barrier well project design which involves (a) recharging the aquifer and developing a fresh water mound, with a line of injection wells located just inland from the zone of salt water exposure and, (b) lowering the ground-water level seaward of the injection well alignment, by a series of pumping wells. The Los Angeles injection wells are approximately 300 feet deep and have 12-inch diameter stainless steel casing with a gravel pack. The project includes 18 injection wells to form a freshwater pressure ridge and 4 extraction wells to form a trough which breaks the landward gradient of intruding salt water. It should be noted that the barrier well project requires: (a) a water supply of adequate quantity and acceptable quality, and (b) a distribution system to carry water to injection wells.

Salt water intrusion barrier wells are expressly designed to remedy specific aquifer contamination problems. They are therefore assessed to have very low potential for ground-water contamination as long as quality of the injected recharge water is maintained, and surface injection pressures are regulated to prevent formation fracturing. It is anticipated that salt water intrusion barrier wells in the Houston and Galveston areas would be constructed and operated by the Harris-Galveston Coastal Subsidence District.

Legal and Jurisdictional Considerations

It is anticipated that artificial recharge wells will continue to be used in Texas; however, their use will be limited by technical and economic factors. These wells, for the most part, will be controlled or regulated by local authorities (i.e., water districts, special districts, city governments, county health departments, etc.). Artificial recharge well regulation may include: (1) issuing permits for the drilling of wells; (2) requiring reports on drilling, completion, and operation of wells; and (3) acquiring land-use rights to implement aquifer recharge projects.

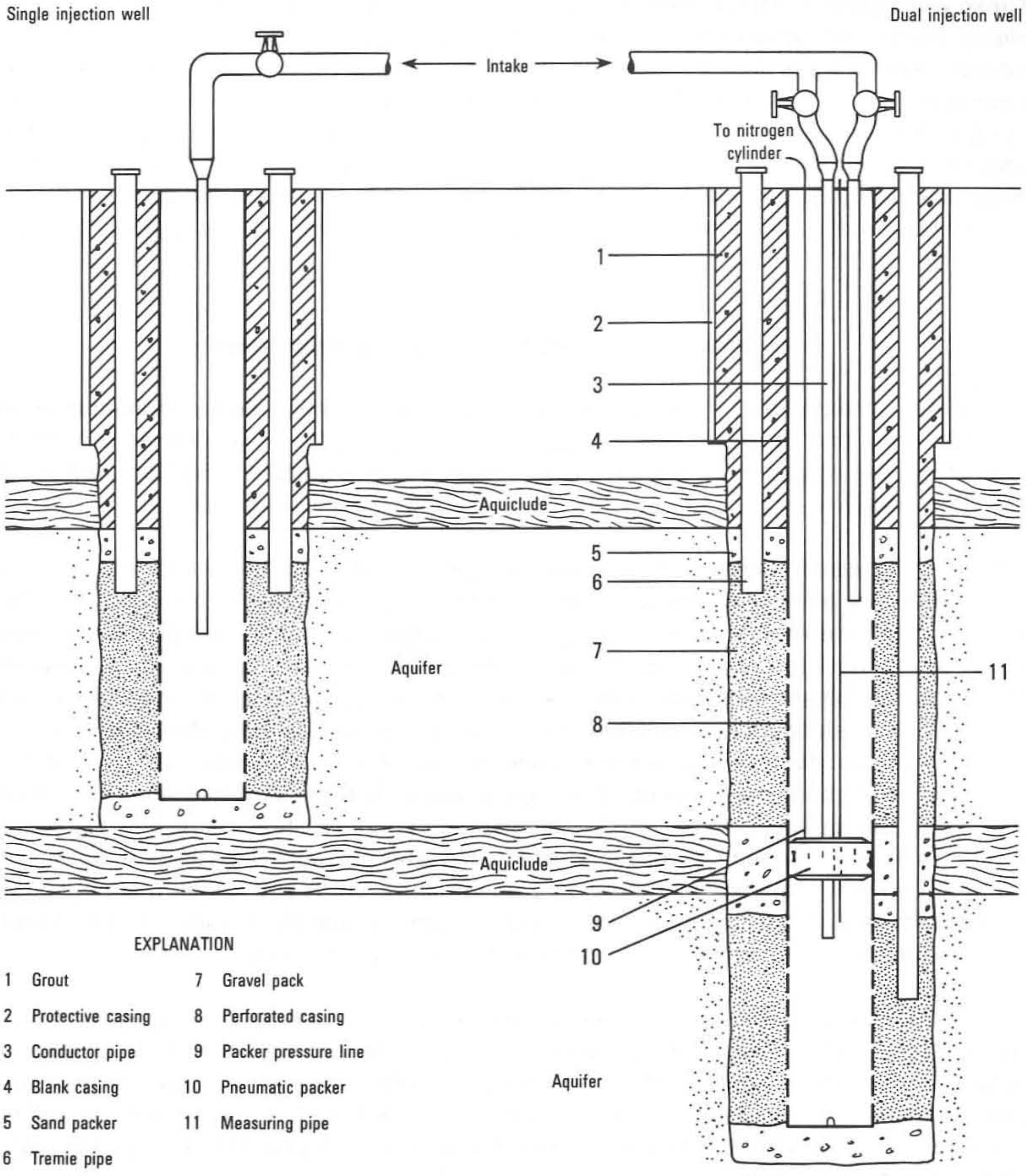


Figure 8-19.—Diagrams of Salt Water Intrusion Barrier Wells in Los Angeles, California (Modified from Los Angeles Flood Control District, 1976)

The Department will continue to review well inventory and completion data for these Class V wells, coordinate with the appropriate local authorities, and conduct site investigations to determine if additional regulations or standards are necessary.

The injection of treated domestic sewage effluent in artificial recharge wells will be regulated by permits under Chapter 26 of the Texas Water Code.

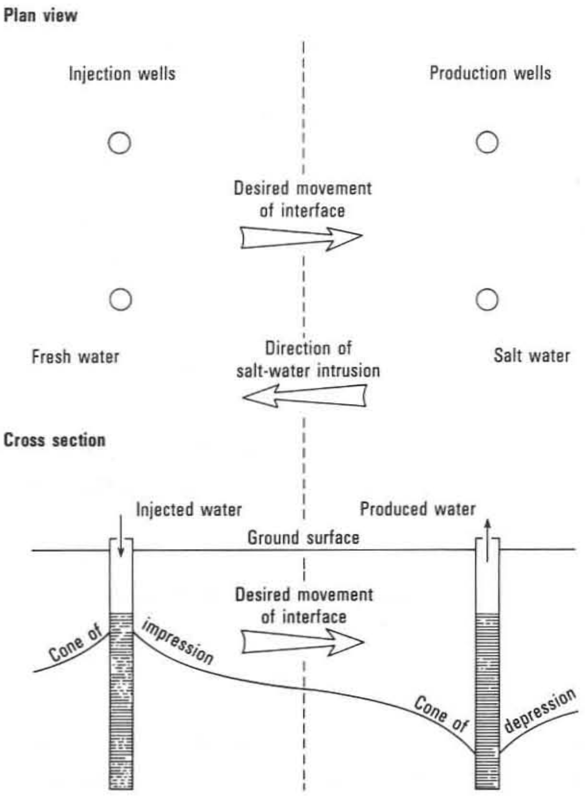


Figure 8-20.—Design of Salt Water Intrusion Barrier Well Project

Concluding Statement

Artificial ground-water recharge by wells has been practiced to a limited extent in Texas to augment declining ground-water supplies and store surplus floodwaters. The major problem which has limited the success of artificial recharge by wells is sediment in the recharge water. The ideal reservoir for recharge and storage of ground water is the unsaturated zone of an unconfined aquifer.

Also included in the category of artificial recharge wells are injection wells used to control land subsidence and salt water intrusion. Presently, there are no wells of either type operating in Texas.

No evidence for ground-water contamination from artificial recharge injection wells was found in the Department's investigation. All types of recharge wells considered are assessed to have very low potential for ground-water contamination, provided that care is taken in construction and operation of these wells to keep pollutants from entering the wells or any associated test holes.

References

Allen, D. R., and Mayuga, M. N., 1969, The mechanics of compactions and rebound, Wilmington Oil Field, Long Beach, California, U.S.A.: Presented to the Associated Internationale d'Hydrologie Scientifique in Tokyo, September 1969, 7 p.

Alvarez, H. J., and Buckner W. A., 1980, Ground-Water Development in the El Paso Region, Texas, with Emphasis on the Resources of the Lower El Paso Valley: Texas Department of Water Resources Report 246, 346 p.

Brown, R. F., and Signor, D. C., 1974, State of the Art: Groundwater, v. 12, no. 3, 10 p.

Brown, R. F., Signor, D. C., and Wood, W. W., 1976, Artificial ground-water recharge as a water management technique on the Southern High Plains of Texas and New Mexico: U.S.Geological Survey open-file report 76-730, 84 p.

Bruington, A. E., 1968, Control of sea-water intrusion in a ground-water aquifer: Presented to the 20th Annual National Water Well Association Convention and Exposition, Washington, D.C., September 24, 1968, 6 p.

Bull, William, 1975, Land subsidence due to ground-water withdrawal in the Los Banos-Kettleman City area, California, Part 2, Subsidence and compaction of deposits, studies of land subsidence: U.S. Geological Survey Professional Paper 437-F, 6 p.

Butler, Joan, Jones, Luanne, and Webbers, Ank, 1981, Class V inventory: State of Florida Department of Environmental Regulation, Bureau of Drinking Water and Special Programs, Groundwater Section, 56 p.

Claborn, B. J., Ramsey, B. H., Sweazy, R. M., Urban, L. V., and Zartman, R. E., 1981, Removal of capillary water from the Ogallala aquifer: Texas Tech University Water Resources Center, Lubbock, Texas, 35 p.

Clyma, Wayne, 1964, Artificial groundwater recharge by a multipurpose well: Texas A&M University, Texas Agricultural Experiment Station in cooperation with the U.S. Department of Agriculture, 7 p.

Dvorcek, M. J., and Wheaton, R. Z., 1970, Does artificial ground water recharge contaminate our ground waters: For presentation at the Agricultural Waste Management Conference, Cornell University, Rochester, New York, Jan. 19-21, 1970, 19 p.

Gabrysch, R. K, and Bonnet, C. W., 1975, Land surface subsidence in the Houston-Galveston region, Texas: Texas Water Development Board, Report 188, 19 p.

Garza, Sergio, 1977, Artificial recharge for subsidence abatement at the Nasa-Johnson Space Center, Phase I: U.S. Geological Survey open-file report 77-219, 82 p.

Goerdel, L. E., 1968, Feasibility study for injection of floodwater into the ground water aquifer at Dell City, Texas: U.S. Soil Conservation Service watershed plan staff, 20 p.

High Plains Research Foundation, 1974, Annual research report, Plainview, Texas, 91 p.

Johnson, A. I., and Sniegocki, R. T., 1967, Comparison of laboratory and field analysis of aquifer and well characteristics at an artificial recharge well site: Reprint from I.A.S.H. Symposium of Haifa (Israel 1967) Pub. No. 70, U.S. Geological Survey, p. 182-192.

Johnson, Philip, Crawford, Duane, and Davis, Artis, 1976, Ogallala water recharge project: Texas Tech University, Lubbock, Texas, 121 p.

King, P. B., 1942, Permian of West Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 4, p. 535-763.

________1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geological Survey Professional Paper 215, 183 p.

Knorr, D. B., 1982, Proposed groundwater recharge: Parkhill, Smith, & Cooper, Inc., El Paso, Texas, 32 p.

Los Angeles County Flood Control District, 1976, Alamitos Barrier Project, Los Angeles, California: 6 p.

Mayuga, M. N. and Allen, D. R., 1966, Long Beach subsidence: From Association of Engineering Geology, Southern California Special Publications, p. 280-285.

Petit, B. M., Jr., and Winslow, A. G., 1955, Geology and ground-water resources of Galveston County, Texas: Texas Board of Water Engineers Bulletin 5502, 219 p.

Rauschuber, D., Wyatt, Wayne, and Claborn, B., 1982, Secondary recovery study—Ogallala aquifer, progress report no. 1, pretest air injection program, Slaton, Texas: High Plains Underground Water Conservation District No. 1, Texas Tech University, and Texas Department of Water Resources, 79 p.

Scalapino, R. A., 1950, Development of ground water for irrigation in the Dell City area, Hudspeth County, Texas: Texas Board of Water Engineers Bulletin 5004, 38 p.

Schneider, A. D., Jones, O. R., and Signor, D. C., 1971, Recharge of turbid water to the Ogallala aquifer through a dual-purpose well: Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas, 10 p.

Texas Agricultural Experiment Station, 1976, Artificial recharge of runoff waters in the Texas High Plains: Lubbock, Texas, 24 p.

Valliant, J. C., 1962, Artificial recharge of surface water to the Ogallala Formation in the High Plains: Research Foundation, Halfway, Texas, 17 p.

Wyatt, W. A., Bell, A. E., and Morrison, Shelly, 1976, Analytical study of the Ogallala aquifer in Castro County, Texas: Texas Water Development Board Report 206, 63 p.

CHAPTER 9

AIR CONDITIONING RETURN-FLOW WELLS

Investigator:

Rhonda Rasco MacKinnon

AIR CONDITIONING RETURN-FLOW WELLS

Table of Contents

AIR CONDITIONING RETURN-FLOW WELLS

Introduction

Air conditioning return-flow wells are used for underground injection of water which has been produced from a supply well and used for heating or cooling in a heat pump. Also referred to as "heat-pump wells," these are a specialized type of aquifer recharge well.

For over 30 years, the technology has existed to use the temperature difference between ground water and other fluid media, such as refrigerants and air, to heat or cool homes and office buildings. The heating and cooling systems which have been developed are commonly known as ground-water heat pumps.

A heat pump is a temperature-conditioning device which transfers heat or thermal energy from one medium to another. An example of a heat pump familiar to everyone is an air-to-air heat pump or "air conditioner" which heats or cools by using air both as a heat source and a heat-receiving medium (heat sink).

A ground-water heat pump may use ground water as a heat source or heat sink. Ground-water temperatures remain very constant relative to the great variability of air temperatures in homes and buildings imposed by climatic conditions. A ground-water heat pump can be an effective air temperature-conditioning device whenever a significant differential exists between ground-water temperature and ambient air temperature in the space to be "conditioned." Water is an ideal medium for use in heat pumps because of all ordinary substances water has the greatest specific heat. Thus it can both absorb and yield much more heat in calories per degree change in the temperature of the medium than does an equal weight of air.

The basic components of a heat pump are an evaporator, a condenser, a compressor, and an expansion valve. Figure 9-1 diagrams a ground-water heat pump refrigeration loop. The heat pump consists of a closed loop containing a refrigerant which alternates between liquid and gaseous phases. For heating buildings, the refrigerant in the gaseous phase is compressed and condensed to a liquid phase, yielding heat which may be used to warm the air which circulates through a building. Next, the compressed liquid refrigerant is jetted through an expansion valve into an evaporator, lowering the liquid pressure, and absorbing heat from the ground-water source, to cause the evaporation of the liquid once again to a gaseous phase.

In order for a heat pump to work properly, the heat source (ground water) temperature must exceed the refrigerant evaporation temperature. Therefore, the efficiency of heat pumps increases with the differential between ground-water temperature and refrigerant evaporation temperature. In yielding heat to the refrigeration loop, ground water is decreased in temperature by about 7 to 10°F in the heat-pump systems investigated by the Department. When a heat-pump system is used for cooling buildings, heat is absorbed into the refrigeration loop from the air inside a building, and transferred to ground water. The general effect of air conditioning return-flow wells is to locally increase ground-water temperatures in the receiving aquifer when the system is used for cooling buildings, and to decrease ground-water temperatures when the system is used for heating buildings.

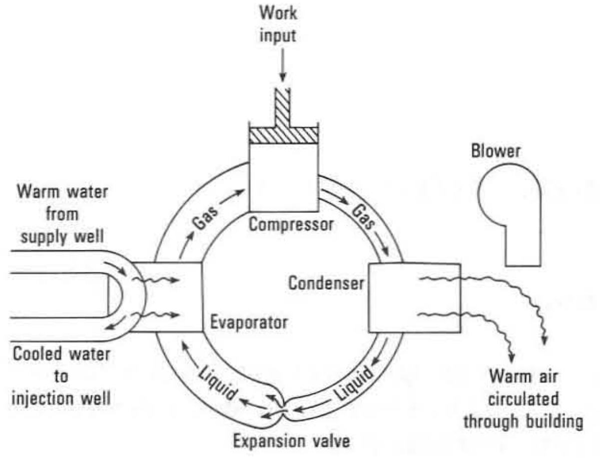


Figure 9-1.—Basic Components of a Ground-Water Heat-Pump System

The scope of the Department's investigation of heat-pump wells included the inventory of 29 heating and cooling well systems (Figure 9-2) and an extensive literature review. The inventory consisted of field location and inspection of five wells in Blanco County and five wells in Montgomery County. Locations of other heat-pump wells were obtained through water well drillers and heat-pump contractors. Water samples were obtained from three wells in The Woodlands in Montgomery County. Two wells in Williamson County were investigated in November 1980 by William P. Overesch of the Department. Those locations and water sample analyses are included in this report. The literature was researched to determine how heat-pump well systems work, their various applications, ground-water contamination potentials, and outlook for their future development.

Geohydrology

More than 50 percent of the total surface area of Texas is underlain by major or minor aquifers (Figures 2-3 and 2-4). In addition to the delineated major and minor aquifers, there are other smaller aquifers which yield small to moderate quantities of water locally. The development of ground water from all of the State's aquifers has progressed rapidly during the past half century. Future development of this valuable natural resource may involve large quantities of ground water for cooling in summer and heating in winter. Tables 2-2 and 2-3 provide brief descriptions of the major and minor aquifers of the State, listing approximate thicknesses, geologic ages, and water-bearing properties.

The efficiency of a ground-water heat-pump system is largely determined by the temperature of the supply water. Shallow ground-water temperatures correlate fairly closely with mean annual air temperatures for particular locations (Figure 9-3). Near-surface ground-water temperatures in Texas typically range from a low of about 60°F in the northwest corner of the Panhandle to a high of about 80°F in the lower Rio Grande Valley. Below a few hundred feet in the subsurface, ground-water temperatures begin to be influenced by normal geothermal gradients which result from the inherent heat of the earth.

Construction Features

Two basic construction designs of air conditioning return-flow wells are shown in Figures 9-4 and 9-5. Designs of return-flow wells are essentially the same used for the heat-pump supply wells. Diameters of these wells normally range from 3 to 10 inches for heat-pump systems for single-family dwellings. Well diameter should be determined by water disposal requirements. Where large amounts of water must be disposed of, as with heat-pump systems for large buildings, increasing well diameter will yield a corresponding increase in well capacity. In contrast, small-diameter wells are relatively economical to drill and construct. Small-diameter wells, however, tend to have more problems from sand plugging the wellbore.

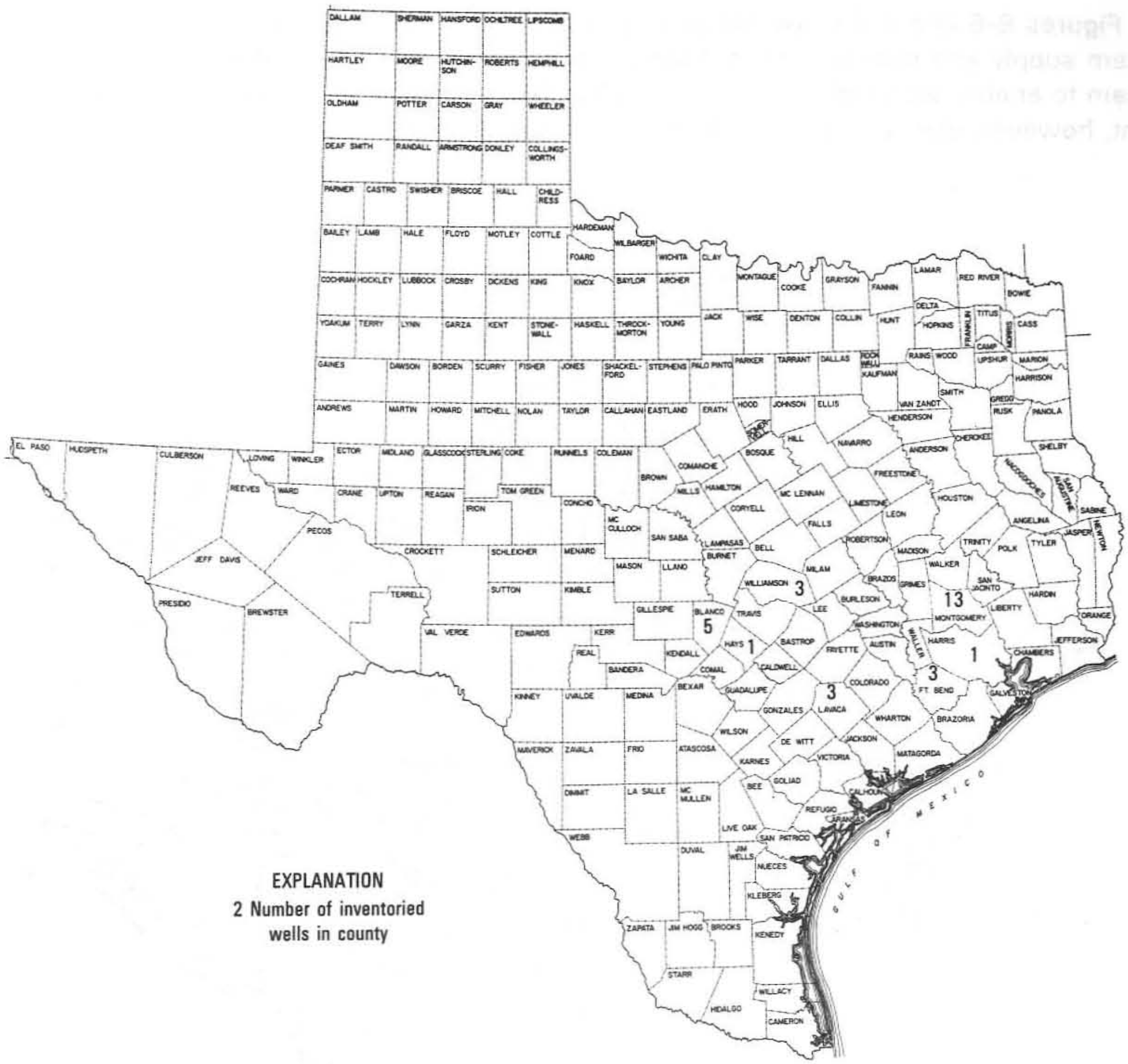


Figure 9-2.—Inventoried Air Conditioning Return-Flow Wells

Well depths are determined by the presence of porous and permeable water-bearing strata suitable for storing the injected water. Wells in The Woodlands residential development in Montgomery County which were inventoried by the Department have an average depth of about 200 feet. These wells inject into water-bearing sands of the Gulf Coast aquifer. In contrast, two wells inventoried in Williamson County in central Texas are completed in the Edwards aquifer with total depths of about 400 feet.

Polyvinyl chloride (PVC) pipe is most commonly used for well construction because it is economical, suitably durable, and corrosion resistant. Another material often used in heat-pump system wells is galvanized steel. Following casing installation, the wells are either completed with an open hole through the disposal zone in hard competent formations such as limestone, or with well screen and gravel pack in unconsolidated sand formations. Careful slot size selection is necessary to achieve optimal well performance in terms of maximum water flow with a minimum influx of solids from the formation into the wellbore.

Figures 9-6 and 9-7 show the general simplicity of wellhead installations for heat-pump system supply and injection wells. Submersible pumps may be installed on both wells in the system to enable seasonal reversal of well functions. The systems investigated by the Department, however, used pumps only on the water-supply wells.

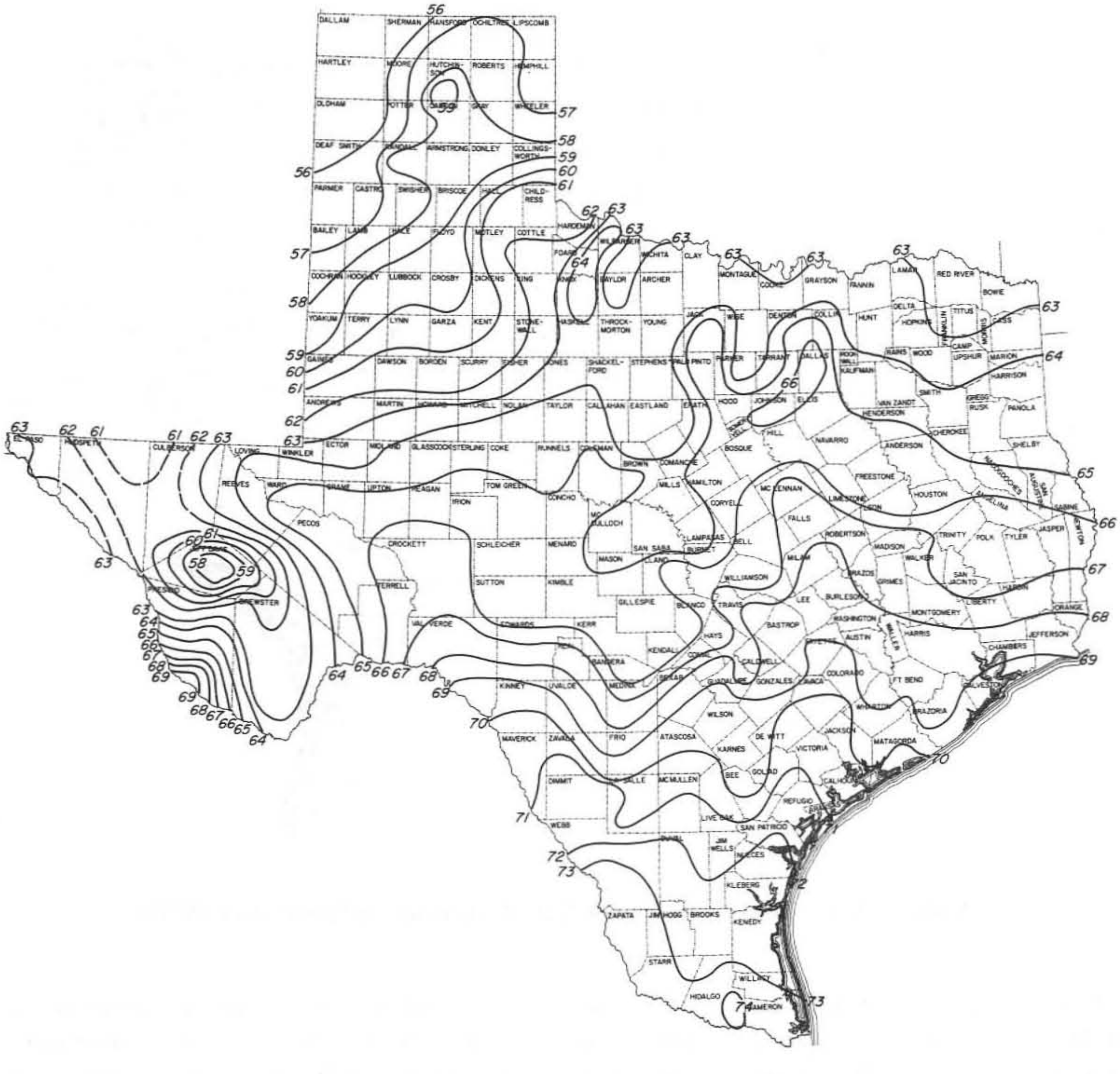


Figure 9-3.—Average Annual Temperature (°F), 1951-80

The literature on the subject of air conditioning return-flow wells includes designs for horizontal injection wells in which the heat-pump discharge water is dispersed through a horizontally emplaced well screen into the soil. These wells function best in sandy soils, and because a trench must be dug to install the horizontal well screen, the wells are necessarily very shallow. No such wells have been inventoried by the Department.

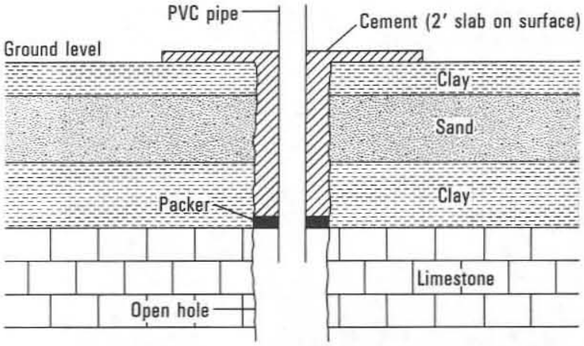


Figure 9-4.—Air Conditioning Return-Flow Well Design for Stone Formation

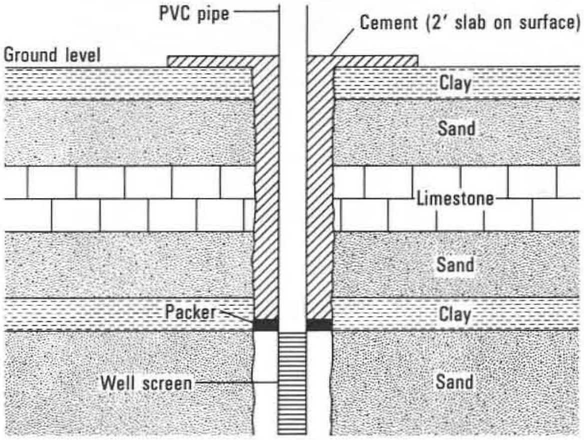


Figure 9-5.—Air Conditioning Return-Flow Well Design for Sand Formation

Well placement is an important consideration with ground-water heat-pump systems. If one aquifer is used for both supply and injection, the wells need to be spaced so that the temperature front traveling from the injection well does not reach the supply well, affecting supply water temperature and reducing heat-pump efficiency. Figure 9-8 shows a system using a single aquifer. If two aquifers are used, one for supply and one for injection, wells can be spaced closer together, since the injected water will be stratigraphically isolated from the system supply water. Being able to use closer well spacing is an advantage on small residential lots. A diagram of a two-aquifer system is shown in Figure 9-9.

Operating Practices

The basic energy requirements to run a ground-water heat-pump system consist of electric power to operate the heat-pump compressor and submersible pumps for the supply and injection wells. Incorporation of a refrigerant reversing valve in the heat pump allows the functions of the various elements in the system to be reversed seasonally to increase efficiency of heating and cooling. Also, pumps on both supply and injection wells allow the operator to backwash either well to remove sediment which may hamper well performance. None of the heat-pump systems investigated by the Department, however, are seasonally reversed, but instead accomplish satisfactory heating and cooling with a single direction of ground-water circulation.

The most common causes of diminished well performance involve occlusion of the wellbore by sediment or other debris, particularly in the screened or open-hole completion interval. To remedy sand plugging problems, wells may be backflowed, bailed, or jetted out. Also, wells may be chlorinated as needed to control algae and other biological organisms which may find favorable conditions for growth in the thermally altered water of heat-pump wells.

Nature and Volume of Injected Fluids

Standard chemical analyses and heavy-metal analyses of water samples from eight air conditioning return-flow wells are presented in Tables 9-1 and 9-2. Wells 1 and 2 are in the town of Round Rock in southern Williamson County. Wells 3 through 8 are in The Woodlands in central Montgomery County. Each injection (return-flow) well sampled is completed in the same aquifer that furnished the water supply for the heat-pump system.

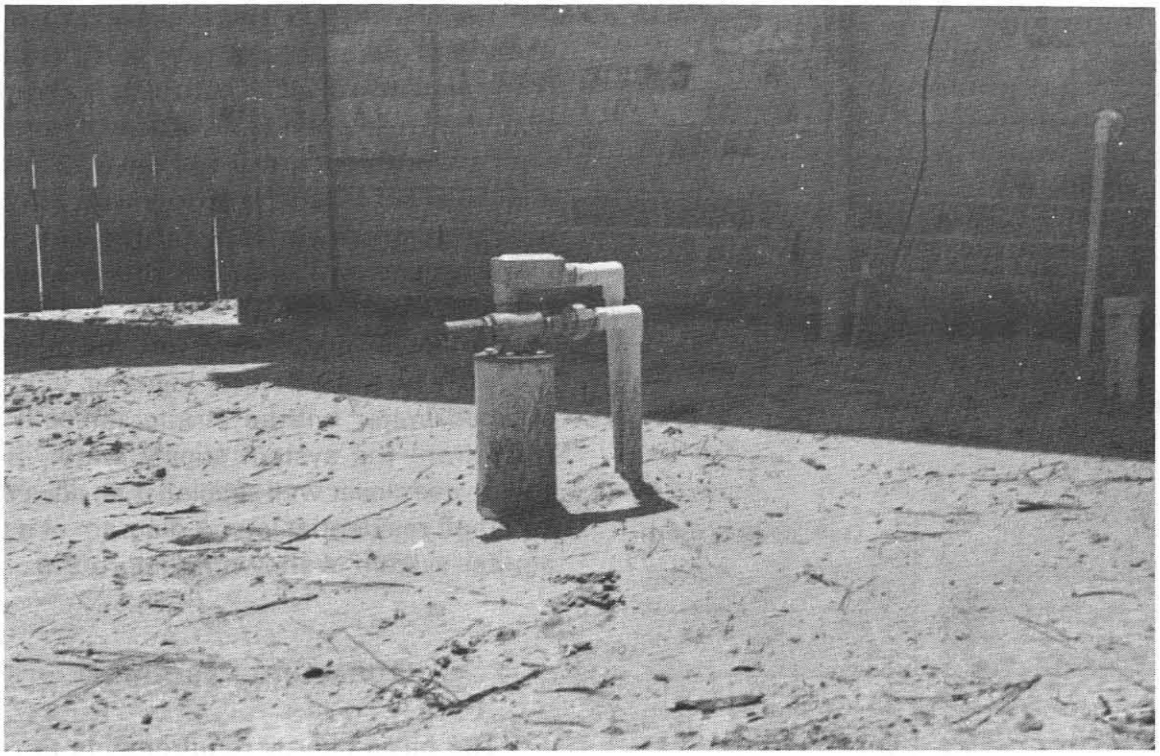


Figure 9-6.—Wellhead of Heat-Pump System Supply Well, Montgomery County

Figure 9-7.—Wellhead of Heat-Pump System Injection Well, Montgomery County

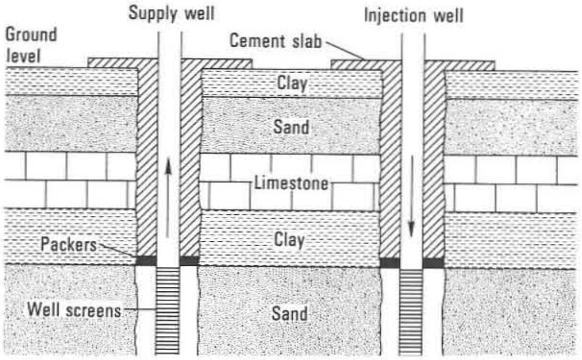


Figure 9-8.—Ground-Water Heat-Pump System Using Single Aquifer

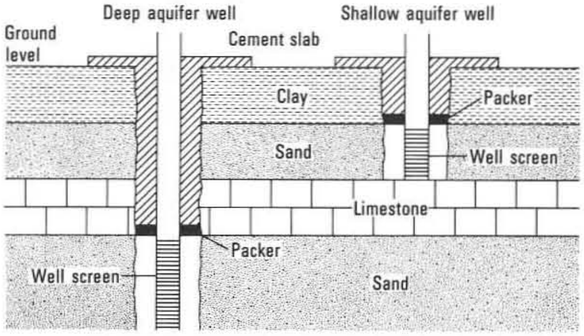


Figure 9-9.—Ground-Water Heat-Pump System Using Two Aquifers

Analyses of samples from wells 6 and 7 show lead concentrations in excess of U.S. Environmental Protection Agency standards for drinking water. However, there is insufficient historical ground-water data for the area to document the earlier presence of high concentrations of lead. At least one well driller experienced with air conditioning return-flow wells in Montgomery County has indicated in conversations with Department staff that these occurrences of lead in the ground water predated the use of heat-pump wells, and that the ground water has not been used as a source of drinking water. Department Report 136 on ground-water resources of Montgomery County (Popkin, 1971) indicates that corrosive (acidic) ground waters are found in the county in the Gulf Coast aquifer. These waters may corrode pump parts, plumbing fixtures, and iron casings in less than a year of contact. The PVC pipes used for the heat-pump wells are chemically nonreactive to such corrosive ground water. However, the metallic components of heat pumps may possibly be susceptible to corrosion and dissolution into the ground water under such conditions. The potential for contributions of metals to the acidic ground water by heat pumps is judged to be no greater than that for conventional domestic plumbing, and very small compared to the contributions which may have resulted from oil field activities in the immediate area. Production from the Conroe oil field has occurred over past decades during which time discharges of produced brines, drilling muds, and industrial chemicals to pits dug into sandy soils were commonplace.

On the Gulf Coast, inventoried heat-pump wells serving single-family residences operate at rates up to about 20 gallons per minute. In central Texas, a larger-scale heat-pump system which is planned for an office building is designed for a ground-water flow rate of up to 50 gallons per minute.

Potential Problems

The potential for contamination of ground water resulting from introduction of pollutants through air conditioning return-flow wells should be very low when wells are properly cased and cemented. Properly designed systems are, in effect, closed loops inaccessible to contamination from surface pollutants.

If ground water has been contaminated at some time prior to heat-pump use, such contamination could, however, spread from the location of the water supply well to the location of the

Table 9-1.—Chemical Analyses of Water Samples From Air Conditioning Return-Flow Wells
(Constituent concentrations are in mg/l except specific conductance and pH.)

	Well							
	1	2	3	4	5	6	7	8
Date of collection	Nov. 5, 1980	Nov. 5, 1980	Mar. 8, 1982	Mar. 8, 1982	Mar. 8, 1982	Mar. 8, 1982	Mar. 8, 1982	Mar. 8, 1982
Temp. °F	—	—	72	72	70	78	79	77
°C	—	—	22.2	22.2	21.1	25.5	26.1	25.0
pH	8.6	8.5	7.4	7.5	6.3	7.1	7.2	6.2
Specific conductance micromhos at 25°C)	509	510	554	534	296	—	—	—
Dissolved solids (sum)	305	315	364	354	218	—	—	—
Boron (B)	—	—	.21	.11	< .02	—	—	—
Silica (Si)	12	12	—	—	—	—	—	—
Calcium (Ca)	76	80	—	—	—	—	—	—
Magnesium (Mg)	23	22	—	—	—	—	—	—
Sodium (Na)	13	12	—	—	—	—	—	—
Carbonate (CO_2)	8	5	—	—	—	—	—	—
Bicarbonate (HCO_3)	316	326	—	—	—	—	—	—
Sulfate (SO_4)	23	21	—	—	—	—	—	—
Chloride (Cl)	14	13	—	—	—	—	—	—
Fluoride (F)	1.4	1.3	—	—	—	—	—	—
Nitrate (NO_3)	< .04	< .04	—	—	—	—	—	—

Wells 1 and 2 are in the town of Round Rock in southern Williamson County and inject into the Edwards aquifer at a depth of approximately 400 feet.
Wells 3 through 8 are in The Woodlands in central Montgomery County and inject into the Gulf Coast aquifer at a depth of approximately 200 feet.
Analyses were performed by the Texas State Department of Health.

Table 9-2.—Heavy Metal Anayses of Water Samples From Air Conditioning Return-Flow Wells (Constituent concentrations are measured in mg/l.)

	Well		
	6	7	8
Data of collection	Mar. 8, 1982	Mar. 8, 1982	Mar. 8, 1982
Arsenic (As)$\frac{(mg)}{1}$	< .01	< .01	< .01
Barium (Ba)	< .5	< .5	< .5
Cadmium (Cd)	< .01	< .01	< .01
Copper (Cu)	.180	.073	< .028
Chromium (Cr)	< .02	< .02	< .02
Iron (Fe)	.026	.022	< .02
Lead (Pb)	.4	.07	< .05
Manganese (Mn)	< .02	< .02	< .02
Mercury (Ha)	< .0002	< .0002	< .0002
Nickel (Ni)	< .02	< .02	< .02
Selenium (Se)	< .002	< .002	< .002
Silver (Ag)	< .01	< .01	.016
Zinc (Zn)	.240	.14	.02

Wells 6 through 8 are in The Woodlands in Central Montgomery County and inject into the Gulf Coast aquifer at a depth of approximately 200 feet.

Analyses were performed by the Texas State Department of Health.

injection well. Similarly, when the wells in a heat-pump system are completed in different aquifers, water from an already contaminated aquifer may introduce pollutants to an uncontaminated aquifer. The practice of seasonally reversing the functions of heat-pump wells, however, would tend to limit the spread of new contamination in an aquifer. In any instance where a heat-pump injection well spreads pollutants from an existing contaminated aquifer, the injection well could be backflowed to partially recover the contaminated water.

Other concerns associated with air conditioning return-flow wells involve the effects of thermal alteration on an aquifer's hydrologic properties. Thermal alteration of an aquifer could theoretically generate adverse impacts such as precipitation of mineral salts. Salt precipitation could clog pores in an aquifer, leading to inhibited ground-water movement and decreased well effectiveness. The solubility of common salts, however, is highly dependent on the degree of acidity of a solution, and only to a lesser extent on temperature. Heat-pump systems do not affect the pH of an aquifer. Thus, at the 7 to 10°F differential between supply water and heat-pump discharge water common for the systems which the Department investigated, any impact from changing the solubility of salts in an aquifer should be noticeable only over extremely long periods of time, and localized to areas of significant well development.

It should be noted that thermal alteration of an aquifer will also influence the ability of an aquifer to transmit fluid, because of the inverse relationship between temperature and fluid viscosity. That is, as ground-water temperature is elevated, viscosity of ground water decreases and the aquifer transmits fluids more easily. Although changes in individual well performance could be observed, no significant hazard would result from aquifer transmissivity changes induced by ground-water heat-pump systems.

Several studies have been accomplished using computer modeling to simulate thermal impacts on an aquifer used in a heat-pump system (Andrews, 1978; Schaetzle and Brett, 1979). Factors taken into account in the computer models include rates of ground-water movement, amounts of thermal energy added or subtracted in the system, and inherent thermal properties of the aquifer. All studies concluded that, particularly where air conditioning return-flow wells were restricted to areas of low population density, thermal alteration of aquifers would likely be of minimal proportions and not likely to produce adverse effects.

Legal and Jurisdictional Considerations

Air conditioning return-flow wells are included in the Class V category of injection wells. These wells are presently authorized by rules of the Department.

The thrust of any new regulatory program for heat-pump system wells should be directed at large-scale systems involving one or more wells operating to heat or cool multi-unit residential or office complexes, schools, and hospitals. Because of their assessed low potential for causing ground-water problems, heat-pump systems for single-family dwellings should probably be given a lesser priority for regulation. The distinguishing criteria for large-scale versus small-scale systems would be based primarily upon ground-water pumping rates. For all ground-water heat-pump systems, the Department would continue to inventory the wells, and maintain opportunity for review of project proposals for the purpose of issuing permits as necessary to protect water resources.

Concluding Statement

The Department has conducted a limited field investigation and an extensive literature review of air conditioning return-flow wells. The total number of such wells in the State is probably on the order of several hundred. Ground-water heat-pump systems have demonstrated an increased efficiency over conventional systems in heating and cooling single-family dwellings and larger buildings. The number of heat-pump system wells is expected to increase greatly in the future with ever-growing incentives to cut home and office heating and cooling costs by using less expensive forms of energy. The potential hazards to ground water from heat-pump systems have been judged to be minimal.

References

Andrews, C. B., 1978, The impact of the use of heat pumps on ground water temperatures: Ground Water, v. 16, no. 6 (Nov.-Dec.), p. 437-443.

Connelly, Jack, 1980, Ground water heat pumps in Wisconsin: Water Well Journal, July 1980, Water Well Journal Publishing Co., Worthington, Ohio, p. 49.

Davison, R. R., 1975, Storing sunlight underground: Chemical Technology, v. 5, Dec. 1975, American Chemical Society, p. 736-741.

Gass , T. E., 1982, The thermal impact of heat pump operation: Water Well Journal, Mar. 1982, Water Well Journal Publishing Co., Worthington, Ohio, p. 42-43.

Gass, T. E., and Lehr, J. H., 1977, Ground water energy and the ground water heat pump: Water Well Journal, Apr. 1977, Water Well Journal Publishing Co., Worthington, Ohio, p. 42-47.

Hildebrandt, A. F., Gupta, S. D., and Elliot, F. R., 1979, Groundwater heat pump HVAC demonstration project, phase I— design development: Texas Energy Advisory Council, Houston, Texas, 93 p.

Lehr, J. H., 1982, Two pumps in every yard: Water Well Journal, Mar. 1982, Water Well Journal Publishing Co., Worthington, Ohio, p. 8.

McCray, Kevin, 1980, How heat pump manufacturers view the industry: Water Well Journal, July 1980, Water Well Journal Publishing Co., Worthington, Ohio, p. 53-59.

Miller, Jim, 1980, The legal implications of ground water heat pump use: Water Well Journal, July 1980, Water Well Journal Publishing Co., Worthington, Ohio, p. 66-73.

National Water Well Association, 1980a, Environmental aspects of a ground-water source heat pump: pamphlet.

________1980b, Mechanics of a ground-water source heat pump: pamphlet.

Popkin, B. P., 1971 Ground-water resources of Montgomery County, Texas: Texas Water Development Board Report 136, 131 p.

Ruesink, L. E., ed., 1978, Storing blue northers: Texas Water Resources, v. 4, no. 4, Texas A&M University, College Station, Texas.

Schaetzle, W. J. and Brett, C. E., 1979, Heat pump centered integrated community energy systems, system development: University of Alabama interim report, Argonne National Laboratory.

Smith, A. E., 1980, Ground water geothermal effluent disposal methods: Ground Water Heat Pump Journal, Fall 1980, Water Well Journal Publishing Co., Worthington, Ohio, p. 14-17.

Stillman, D. I., Uhl, V. W., and Warfel, M. R., 1982, Application of a ground-water source heat pump at the Prudential energy project, Princeton, New Jersey: Paper presented at The International Ground-water Geothermal Heat Pump Conference, Columbus, Ohio, Feb. 7-8, 1982.

CHAPTER 10

AGRICULTURAL DRAINAGE WELLS

Investigator:

Seth Molofsky

AGRICULTURAL DRAINAGE WELLS

Table of Contents

AGRICULTURAL DRAINAGE WELLS

Introduction

The Lower Rio Grande Valley is the only sizeable area of the State where conditions of severely limited surface drainage, soil characteristics, and agricultural practices combine to create a potential need for agricultural drainage wells. Most of this area consists of a broad flat plain extending westward from the Gulf of Mexico to central Starr County. Surface water drainage depends primarily on man-made systems. The climate in the Lower Rio Grande Valley can be described as semitropical and semiarid. Mean annual precipitation for McAllen, Texas, is approximately 23 inches. Precipitation is highest from April through September. During this time 14 inches, or 60 percent, of the total annual rainfall typically occurs. This time period also coincides with the growing season for most crops in the region. Additional irrigation water is applied as needed.

During the 1950's drainage well systems were first installed in Hidalgo County in the Lower Rio Grande Valley to help alleviate the problem of perched water tables in agricultural areas. Widespread zones of montmorillonite clay are present in the soils of Hidalgo County which impede percolation of surface waters and lead to raised water tables. As evaporation of this water occurs, salts which in elevated amounts are detrimental to plant life are left behind in the soils. Drainage well systems act to collect near-surface waters and drain them by gravity flow into a subsurface formation, below impermeable clay beds.

Agricultural drainage wells are located almost exclusively in the southwestern portion of Hidalgo County. Approximately 90 drainage wells have been located and plotted on 7½-minute topographic maps by the Department. The total number of drainage wells in use has not been determined, but it is believed to be considerably higher than the present inventory. Figure 10-1 shows the approximate areal extent of drainage wells in Hidalgo County as of 1982, and locations of drainage wells and water wells investigated by the Department. Records of these wells including locations, depths, diameters, water levels, and status are presented in Table 10-1. The well numbers correspond to map locations on Figure 10-1. Chemical analyses of water taken from the above wells and from an irrigation canal are given in Table 10-2.

Farming Practices

Since the turn of the century agricultural production in the Lower Rio Grande Valley has grown steadily. Today it is the primary economic activity of the area. Principal crops include cotton, grain, sorghum, vegetables, and citrus. Emphasis will be placed on citrus management in this discussion because all agricultural drainage wells investigated by the Department were installed in citrus groves.

Citrus trees need approximately 45 to 50 inches of water per year, of which irrigation supplies approximately 30 inches. Water is applied as needed.

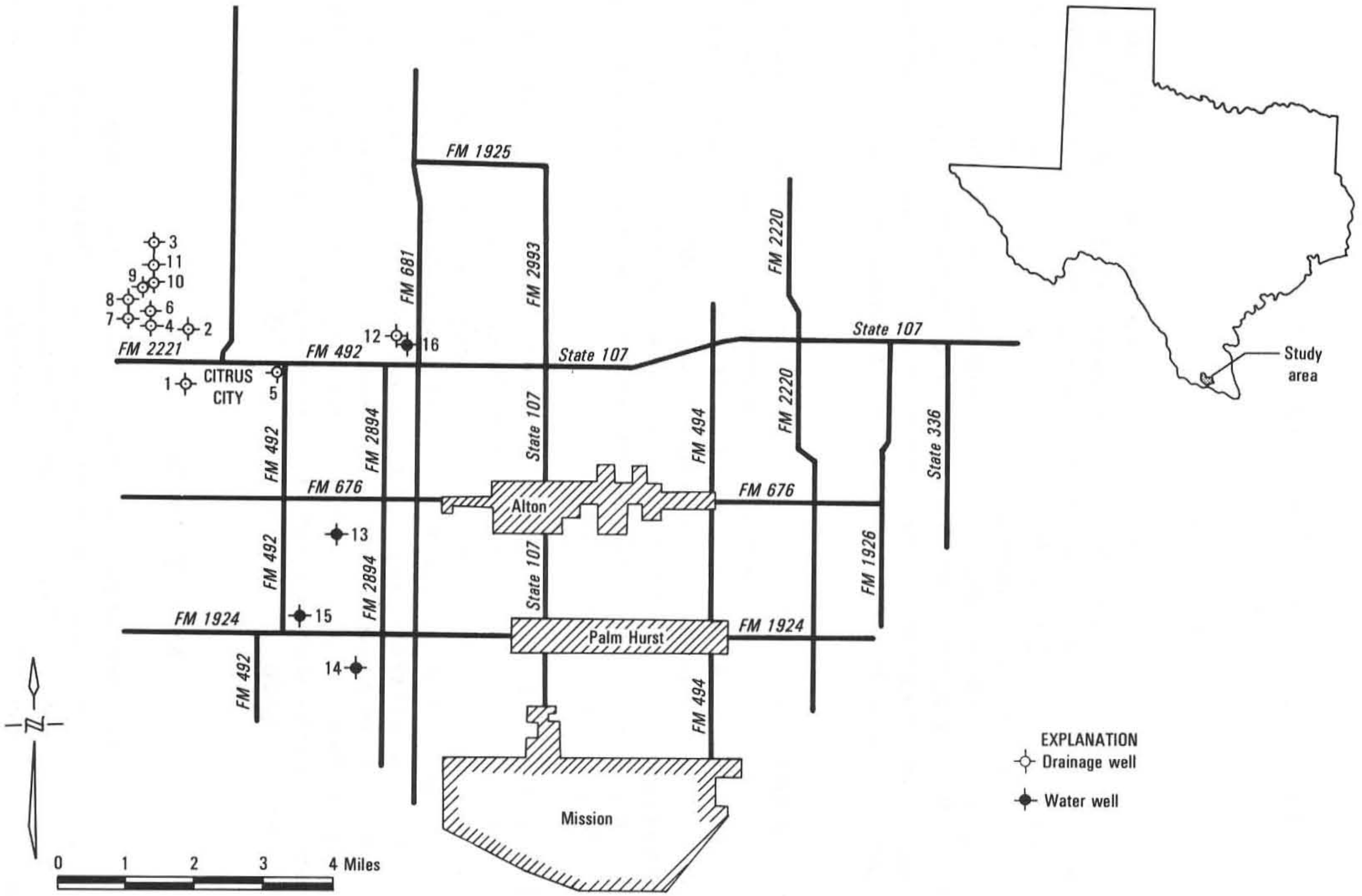


Figure 10-1

Well Location Map, Southwestern Hidalgo County

Table 10-1.--Well Records

Well	Use	Location (legal description)	Owner	Approximate depth of well (ft)	Diameter of well (in)	Status (see footnotes)	Altitude of land surface (ft)	Water level: Below land surface datum (ft)	Water level: Date of measurement	Remarks
1	Drain	Lot 22 Block 15	Bob Smith (caretaker)	70	--	[1]	220	--	--	Drains 4 acres.
2	Drain	Lot 26 Block 18	Bob Smith	70	--	[2]	223	--	--	Drains 25 acres.
3	Drain	Lot 14 Block 23	W. D. Eddy	70	--	[2]	226	--	--	--
4	Drain	Lot 24 Block 19	Frank Parker	70	--	[1]	224	--	--	Well adjacent to cistern.
5	Drain	Lot 74 Sub Doff 1	A. Jasper (Compton Grove Care, caretaker)	70	--	--	205	11.3	June 9, 1982	--
6	Drain	Lot 21 Block 19	Handels Und Wirtschafts Ag	70	--	[1]	224	--	--	Well in cistern.
7	Drain	Lot 12 Block 20	Compton Grove Care (caretaker)	70	4	[1]	226	--	--	Well adjacent to cistern.
8	Drain	Lot 16 Block 20	Valley Production (caretaker)	70	4	[1]	226	--	--	Well adjacent to cistern. Wooden frame around well.
9	Drain	Lot 1 Block 21	J. R. Prescott	70	4	[1]	226	surface	June 9, 1982	Well adjacent to cistern.
10	Drain	Lot 32-33 Block 22	Ilse Bagel	70	4	[1]	225	--	--	Well adjacent to cistern. Wooden frame around well.
11	Drain	Lot 28 Block 22	G. W. Ellis	70	4	[1]	225	--	--	Well adjacent to cistern. Wooden frame around well.
12	Drain	--	--	84	--	[3]	180	--	--	Has injection pump. Slotted completion (63-84 ft)
13	Domestic	--	Bob Mitchell	293	--	--	175	50	Reported	Drilled June 1979.
14	Public Supply	--	Rio Grande Children's Home	350	--	--	175	44	June 10, 1982	Drilled 1974.
15	Domestic and Irrigation	--	Frank Eckroat	276	--	--	183	86.3	Sept. 16, 1957	Drilled 1956.
16	Not in use	--	Maxie Lewendowski	72	4	--	180	4	Reported	Drilled 1977.

[1] Drain lines flowing into cistern (June 10, 1982).
[2] Drain lines not flowing into cistern. Water level static in cistern (June 10, 1982).
[3] Drain fluids pumped from cistern and injected into drain well.

Table 10-2.--Chemical Analyses Water From Drainage Wells and Water Wells
Analyses are in milligrams per liter except specific conductance and pH.
Analyses were performed by the Texas Department of Health in Austin.

Well	Owner	Depth (ft)	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Total hardness as ($CaCO_3$)	Specific conductance (micromhos at 25°C)	pH	Total alkalinity as ($CaCO_3$)	Boron (B)	Silica (SiO_2)
1	Bob Smith (caretaker)	~ 70	June 8, 1982	308	86	1,007	7	345	1,254	1,132	1.2	184.3	4,148	1,122	3,690	7.6	--	7.6	43
2	Bob Smith	~ 70	do	326	72	771	5	317	781	1,107	1.2	160.9	3,418	1,111	3,330	7.6	260	4.3	43
3	W. D. Eddy	~ 70	June 9, 1982	402	96	1,089	9	308	1,123	1,540	1.1	182.8	4,606	1,400	4,090	7.6	253	9.8	39
4	Frank Parker	~ 70	do	430	106	1,441	4	336	1,310	1,999	1.1	202.9	5,644	1,512	4,690	7.7	276	10.7	39
5	A. Jasper (Compton Grove Care, caretaker)	~ 70	do	326	68	982	4	341	1,142	1,196	1.4	148.1	4,016	1,095	3,660	7.8	280	6.4	43
6	Handels Und Wirtschafts Ag	~ 70	Mar. 15, 1982	356	77	846	10	345	1,047	1,111	1.1	139.6	3,790	1,206	3,460	7.6	--	6.0	41
7	Compton Grove Care, (caretaker)	~ 70	June 9, 1982	462	130	1,659	7	355	1,361	2,520	0.9	143.8	6,510	1,688	5,180	7.7	291	15	48
8	Valley Production, (caretaker)	~ 70	do	354	69	828	--	300	986	1,136	1.0	152.0	3,660	1,168	7,176	7.7	246	7.1	43
9	J. R. Prescott	~ 70	do	368	91	1,120	6	359	1,193	1,540	1.2	107.4	4,582	1,294	4,050	7.7	295	9.1	45
10	Ilse Bagel	~ 70	do	286	62	648	5	294	1,086	644	2.2	119.3	3,022	970	2,820	7.8	241	6.3	61
11	G. W. Ellis	~ 70	do	336	82	1,120	7	357	868	1,613	1.0	133.2	4,406	1,176	4,040	7.7	293	8.9	38
12	--	84	June 10, 1982	206	38	354	4	366	571	371	1.8	68.22	1,754	672	1,980	8.0	300	2.7	42
13	Bob Mitchell	293	Mar. 15, 1982	107	27	480	18.5	299	250	638	.9	21.09	1,700	378	2,720	7.8	--	2.6	23
14	Rio Grande Children's Home	~350	June 10, 1982	61	23	368	14	335	138	442	1.2	26.4	1,236	248	1,680	8.1	275	2.5	23
15	Frank H. Eckroat	276	do	79	26	350	14	324	78	496	1.3	31.98	1,214	304	1,710	8.0	266	.2	25
16	Maxie Lewendowski	72	do	836	456	3,822	94	508	2,867	6,328	1.1	<.04	14,674	3,965	32,767	7.7	417	25.2	25
--	(Irrigation Canal Water)	--	June 8, 1982	88	26	324	7	122	314	426	.7	2.26	1,284	325	1,650	7.6	100	1.06	19

NOTE: Analyses for wells 1 through 12 are of drainage well injection fluids; analyses 13 through 16 are of ground water.

Most of the irrigation makeup water is obtained from storage in Amistad and Falcon Reservoirs on the Rio Grande. In 1979, approximately 10,000 acre-feet of ground water was used in Hidalgo County for all purposes while irrigation use from surface water alone was on the order of 500,000 acre-feet. However, in times of drought, such as in 1952 and 1953, ground water supplied an estimated 25 percent of total irrigation water in the Lower Rio Grande Valley.

Quality of water from the Rio Grande varies depending upon the season and amount of precipitation. The U.S. Soil Conservation Service in Mission estimates that total dissolved solids vary from 700 to 1,500 mg/l (milligrams per liter). One sample was collected for chemical analysis from an irrigation canal near Citrus City. The dissolved solids content of this sample was 1,284 mg/l (Table 10-2).

The most widely used nitrogen fertilizer for citrus in Hidalgo County is ammonium nitrate ($NH_4 NO_3$). Ammonium sulfate ($(NH_4)_2 SO_4$) is also utilized, but to a lesser degree. Fertilizer is applied once or twice during the year. If one application is made, approximately 300 to 350 pounds per acre of fertilizer is generally used during winter months. For two applications, 150 to 175 pounds per acre is applied in winter and again in late spring. Herbicides are sometimes mixed with fertilizers.

Table 10-3 is a listing of pesticides used on citrus groves in Hidalgo County. The table includes information regarding use, toxicity, and persistence of each pesticide. Various combinations of pesticides are applied at different sites. Table 10-4 is an example of pesticide and fertilizer applications on a 20-acre grove in the study area. On this particular field, pesticides were applied four times during the year and fertilizer was applied only once.

Geohydrology

The source of ground water in the Lower Rio Grande Valley is the Gulf Coast aquifer, which includes the Goliad, Lissie, and Beaumont Formations and recent alluvial deposits (Figure 10-2). In this area, these geologic units are characterized by complexly interbedded layers and lenses of clay, silt, sand, and gravel. Hydrologic continuity occurs between the adjacent permeable beds; however, locally they are separated by layers of less permeable sediments.

A wide range in water quality exists within the local freshwater aquifer, and quality variations occur within very short distances both horizontally and vertically. Well data indicate three poorly defined zones in which beds of sand and gravel are common.

The upper or shallow water-bearing zone occurs from approximately 60 to 100 feet below land surface in the study area, and contains layers of medium to coarse grained gravel. This gravel is used as a disposal zone for many agricultural drainage wells. The shallow zone contains highly mineralized water over most of the study area. The concentration of dissolved solids for this zone ranges from 1,220 to 14,674 mg/l. Fresh to slightly saline water (total dissolved solids less than 3,000 mg/l) occurs in the southern portion of the study area near the Rio Grande, and locally in the north-central portion. Levels of nitrate (NO_3) in the shallow zone are very high throughout the study area. Nitrate levels exceeded the U.S. Environmental Protection Agency (EPA) maximum recommended concentration (45 mg/l) for drinking water supply in five wells sampled by the Department. These levels of nitrate in ground water may indicate agricultural pollution.

Table 10-3.—Toxicity and Persistence of Pesticides Used on Citrus Groves in Hidalgo County

Pesticide	Use	Toxicity[1] LD_{50} (rat)	Persistence[2]
Aldicarb (Temik)	Insecticide	0.93	0
Bromacil	Herbicide	5,200	2
Carbophenothion (Trithion)	Insecticide	10-30	0
Chlorobenzilate (Acaraben)	Insecticide	700	—
Copper Hydroxide (Kocide)	Fungicide	1,000	—
Dicofol (Kelthane)	Insecticide	600	2
Diuron (Karmex)	Herbicide	3,400	2
Ethion	Insecticide	27-65	0
Fenbutatin-Oxide (Vendex)	Insecticide	2,630	—
Glyphosate (Roundup)	Herbicide	4,320	—
Krovar (mixture of Bromacil and Diuron)	Herbicide	—	—
Methidathion (Supracide)	Insecticide	25-48	—
Oxamyl (Vydate)	Insecticide	5.4	—
Simazine (Princep)	Herbicide	5,000	3
Zineb	Fungicide	5,200+	0

---

[1] LD_{50} (rat): Number of milligrams of compound required per kilogram of animal weight to produce mortality in 50 percent of test animals.

[2] Persistence:

Rating	Time (months for 75 to 100 percent disappearance from soils)
0	1
1	1-3
2	3-10
3	10-18

The middle water-bearing zone occurs from approximately 100 to 300 feet below land surface. The dissolved solids concentration for the middle zone ranges from 1,214 to 7,004 mg/l. Over most of the study area, the middle zone contains fresh to slightly saline water. Two of the eight samples in the middle zone reported nitrate levels in excess of EPA recommendations.

The lower or deep water-bearing zone occurs from approximately 300 feet to the base of fresh to slightly saline water. The depth of the base ranges from approximately 600 feet below land surface at the study area's west and southwest boundaries to about 1,500 feet at the northeast corner. The dissolved solids concentration in the deep zone ranges from 1,160 to 4,262 mg/l. Nitrate levels were found to be lower than EPA maximum recommended concentrations.

Recharge of water to the local aquifer is derived from adjacent water-bearing beds, or by percolation of water from the land surface where streams cross outcrops of permeable sediments

Table 10-4.—Typical Pesticide and Fertilizer Applications On a 20-Acre Citrus Grove Over a 1-Year Period

Substance	Date of application	Amount applied
Nitrogen Fertilizer	Dec. 1981	100 lb/acre
Karmex	Mar. 1982	4 lb/acre
Simazine	Mar. 1982	2 lb/acre
Acaraben	Apr. 1982	½ gallon/acre
Methidathion	Apr. 1982	½ gallon/acre
Karmex	Aug. 1982	2 lb/acre
Simazine	Aug. 1982	2 lb/acre
Kelthane	Sept. 1982	1½ gallons/acre

Source: Boyd Davis, Drainage Tile Contractor, Edinburg, Texas.

or where water stands in fields and ditches. In many areas, zones of montmorillonite clay are present near the surface, which impede vertical percolation of surface waters and result in perched water tables. Generally, movement of ground water is to the southeast and east toward the coast.

Construction Features

Agricultural drainage well systems in the Lower Rio Grande Valley are composed of a network of drain lines emplaced in a field approximately 6 feet below the surface and spaced parallel to each other at intervals which vary from 75 to 225 feet. Drain lines are usually constructed of plastic pipe, but clay and concrete pipe are also used. Drain lines are perforated and packed in gravel to facilitate percolation. Plastic drain lines have a nylon filter fabric covering the perforations to exclude coarse particles from the system. Drain lines lead to a central collector, which in turn leads to a discharge point, or drainage well. Figure 10-3 is a plan view of a typical drainage tile layout for a 20-acre grove. In this particular field, plastic and concrete drain tiles are utilized. The drainage well is located in the center of the diagram.

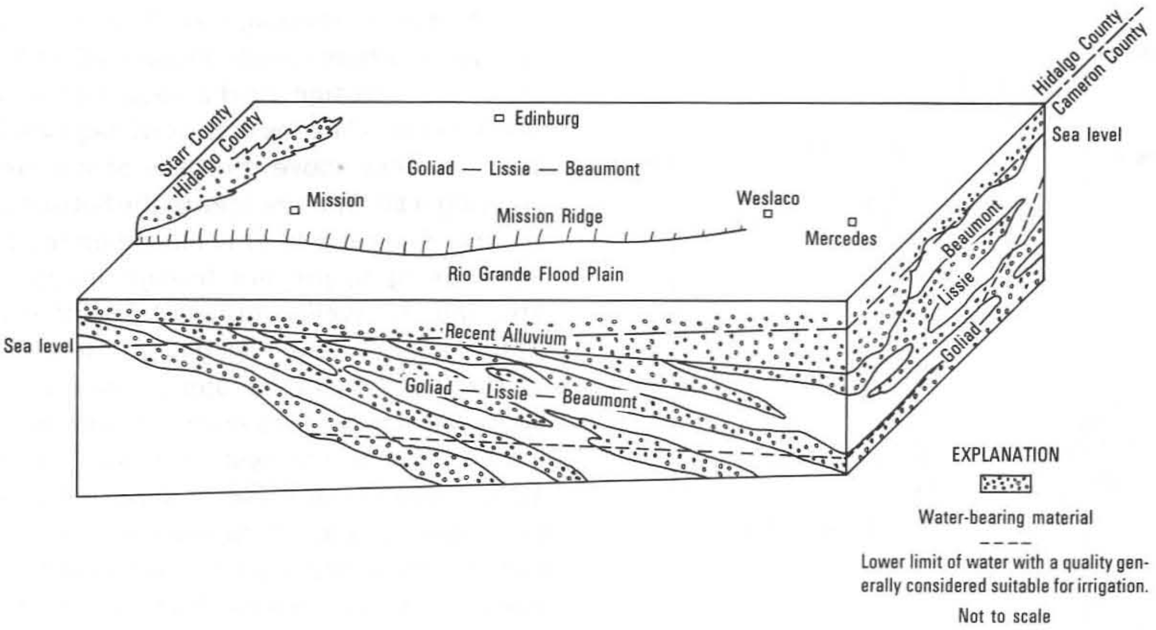


Figure 10-2.—Block Diagram Showing Water-Bearing Strata of the Gulf Coast Aquifer in the Study Area (Modified after Baker and Dale, 1961)

Fluids collected in the perforated drain tiles flow by gravity into a central collector, or cistern, before entering the drainage well. The cistern collects silt and other suspended material to help prevent drainage wells from becoming plugged.

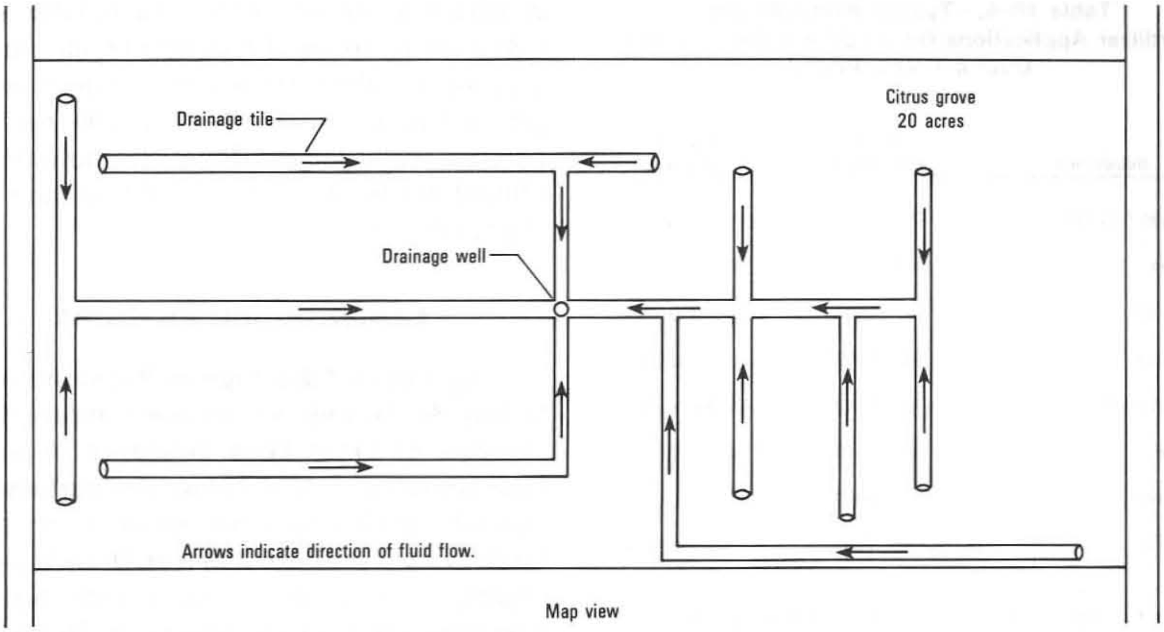


Figure 10-3.—Typical Drainage Tile Layout for a 20-Acre Citrus Grove

Three types of drainage well designs were observed in the study area. All three utilize drain tiles to transfer fluids to cisterns. The designs differ with respect to location of the drainage well in relation to the cistern, and by the method used to transfer fluids from cistern to drainage well. Records of drainage wells are presented in Table 10-1.

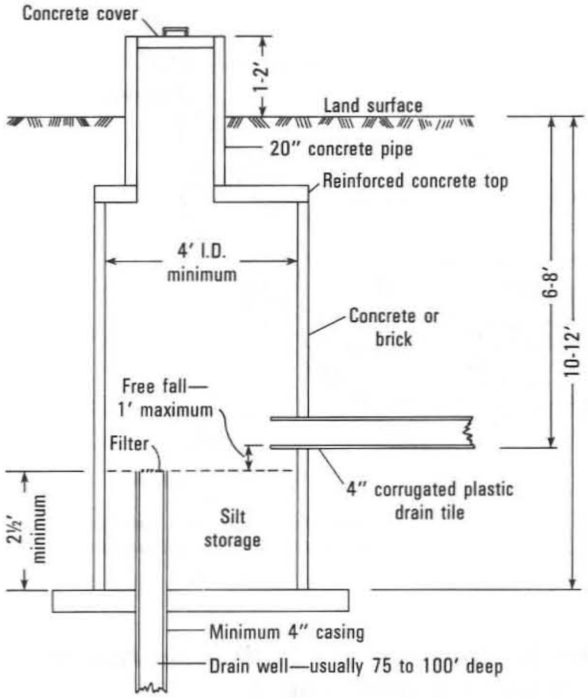
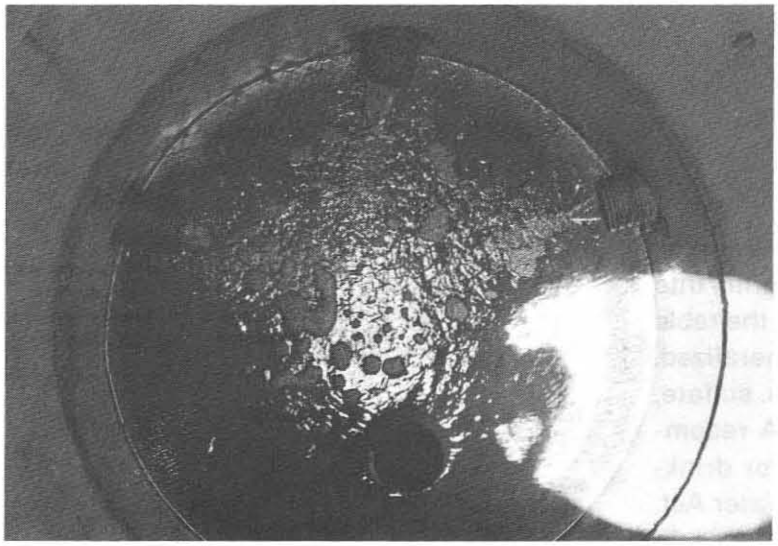


Figure 10-4.—Drainage Well Schematic—Older Type With Well Inside Cistern

A typical drainage well of the oldest design is schematically illustrated in Figure 10-4. In this design the drainage well is placed in the cistern. The top of the drainage well is at least 2.5 feet above the base of the cistern, creating a silt storage area in the bottom of the cistern. A screen filter is placed on top of the well casing to prevent foreign matter from entering the well. Figure 10-5 further illustrates this drainage well design. Here the top of the cistern stands approximately 3 feet above ground surface making it easy to locate in the field. In the system shown in Figure 10-5, three tile drain lines deposit fluids into the cistern in the silt storage area. When the cistern fills to the level of the top of the well casing, the well drains fluid by gravity flow into a subsurface formation.

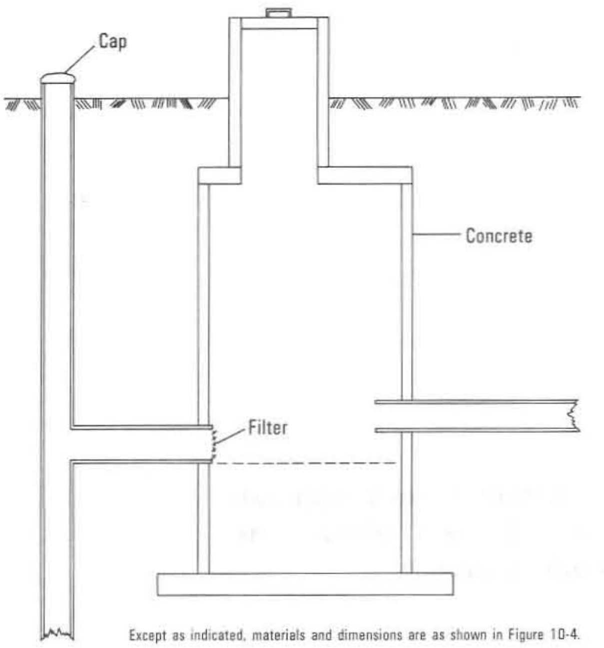
The second type of drainage well system, and a more recent design, is illustrated in Figure 10-6. This system is very similar to the older design, except the drainage well is

The cistern stands approximately 3 feet above the ground surface.



Three tile drainage lines deposit fluids into the base of the cistern in the silt storage area.

Figure 10-5.—Drainage Well System—Well Inside Cistern



Except as indicated, materials and dimensions are as shown in Figure 10-4.

Figure 10-6.—Drainage Well Schematic—Well Adjacent to Cistern

located adjacent to the cistern. A plastic pipe transfers fluid by gravity from the cistern to the drainage well. The top of the drainage well casing is above ground level, allowing for easy access to the drainage well when maintenance is required. Figure 10-7 further illustrates this drainage well design.

The most modern drainage well system observed in the study area is illustrated in Figure 10-8. In this design fluids flow into the cistern in the same manner as previous designs, but from the cistern they are transported to the drainage well using a centrifuge pump. The pump is placed near the top of the cistern and is activated when water levels rise in the cistern to the level of a float which hangs from a switch on the pump. Plastic pipe attached to the pump transfers fluids from the cistern to the drainage well where they are injected under pressure. A pressure gauge is placed in the plastic pipe just before the pipe connects with the drainage well.

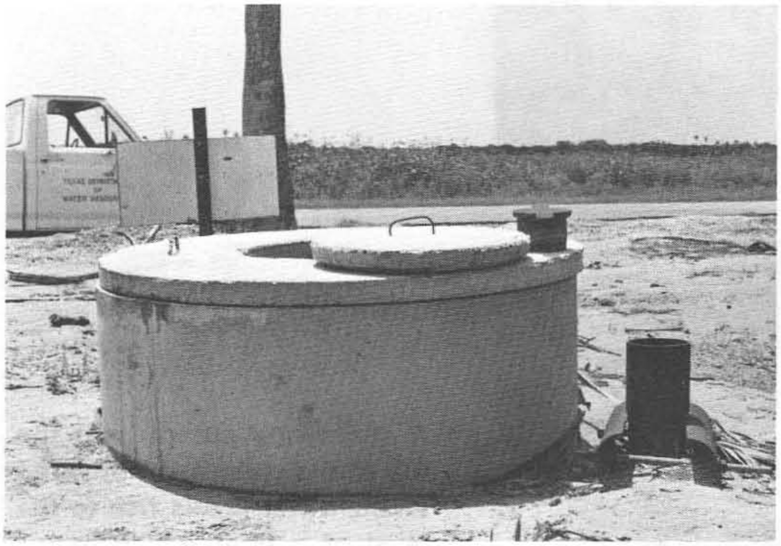
The first two types of drainage well systems discussed are by far the most common in the Lower Rio Grande Valley. The third design, because of the additional equipment, is more costly and is rarely utilized.

Wells are usually constructed utilizing 4-inch steel casing. Slotted pipe completions are the most common. The majority of drainage wells are drilled to approximately 70 feet and inject into permeable gravel (shallow zone). In some areas it is necessary to drill deeper to find a disposal zone which will readily accept drain fluids. Shallow completions are preferred by the operators, because construction costs are less.

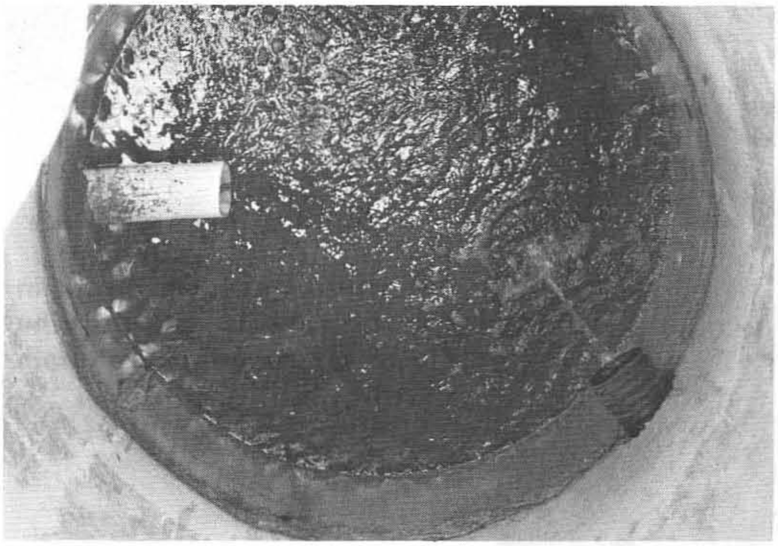
Nature and Volume of Injected Fluids

Standard chemical analyses of drainage well fluids sampled just prior to their entry into the wells are given in Table 10-2. As the table indicates, these fluids are highly mineralized. The concentration of dissolved solids, sulfate, chloride, and nitrate all exceed EPA recommended maximum concentrations for drinking water under The Safe Drinking Water Act. The following table presents the ranges in concentration of the principal chemical constituents of drainage fluids as compared to the EPA recommended limits for these constituents:

Constituent	Range of Drainage Fluid Concentration mg/l	EPA Recommended Maximum Concentration for Drinking Water mg/l
Total Dissolved Solids	1,754-6,510	500
Sulfate	571-1,361	250
Chloride	371-2,520	250
Nitrate (as NO_3)	68- 203	45

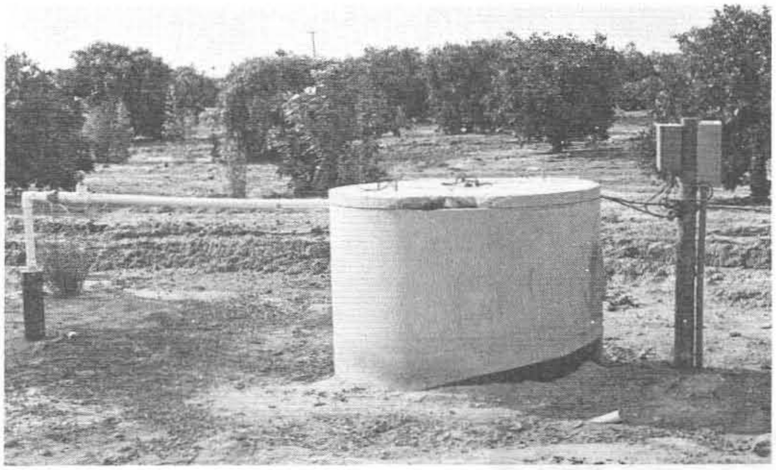


The top of the well casing is above ground level allowing for easy access when maintenance is required.

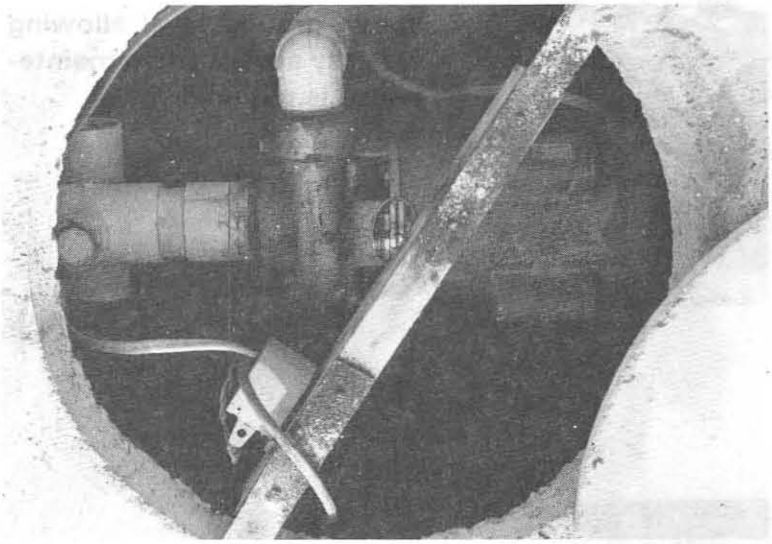


A plastic pipe transfers fluids by gravity flow from the cistern to the drain well.

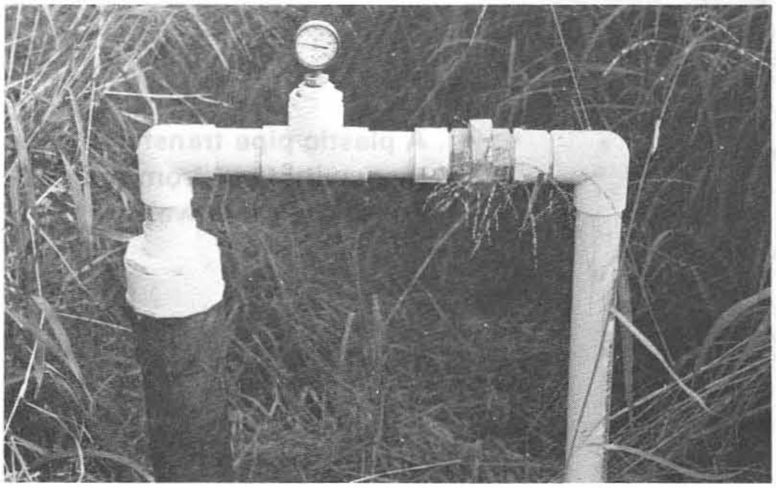
Figure 10-7.—Drainage Well System—Well Adjacent to Cistern



Fluids are pumped from the cistern to the drain well.



A centrifuge pump, near the top of the cistern, is activated when water levels rise to the level of a float which hangs from a switch on the pump.



A pressure gauge is placed in the plastic pipe just before the pipe connects to the drain well.

Figure 10-8.—Modern Drainage System Design

Nitrate levels in drainage fluids are unusually high. This is probably due to the extensive use of nitrogen fertilizers.

A total of 11 samples were collected from sites in the study area for pesticide analysis. Eight of the samples were collected from drain tile systems and the remaining three samples were taken from water wells. Pesticide analyses are presented in Table 10-5. Sample numbers correspond to map locations on Figure 10-1 and well data in Table 10-1. Sample results are reported in micrograms per liter (μg/l). Samples were analyzed for 23 different pesticides. Twenty-one of the pesticides were either absent or in amounts below the detection capability of the testing equipment. The two pesticides which showed up in the analyses were Bromacil and Simazine. These two pesticides were found in six drainage wells; they were not detected in water wells. On well 6, samples for pesticide analyses were collected on two dates (January 15, 1982 and June 9, 1982). Bromacil and Simazine were detected only in the second sample. Levels of Bromacil ranged from 1.2 to 16 μg/l. Simazine concentrations ranged from 5.5 to 16 μg/l. The EPA has no criteria or standards for Bromacil and Simazine levels in water.

Determinations of the volume and duration of drainage well injection are difficult to establish. Drainage wells operate intermittently, and volumes of water they inject vary at each well depending upon the amount of water in soil which can be collected by drain tiles. It was observed during investigations in June 1982 that operating gravity flow drainage wells were disposing of fluids at a rate ranging from 1 to 3 gallons per minute. The total volume of drainage well fluids cannot be calculated because the number of drainage wells and the dates when each was placed in service have not been determined.

Contamination Potential

Introduction of high concentrations of nitrate, dissolved solids, and pesticides into ground water can have negative health effects if the water is consumed. Health effects of human consumption of high nitrate waters have been extensively documented. Infant cyanosis (methemoglobinemia) or "blue baby" syndrome has been attributed to high nitrate concentrations in water supplies. There is evidence that consumption of high nitrate water can produce intestinal pathological conditions resulting in diarrhea. Major objections to high concentrations of dissolved solids in drinking water are the laxative effects of excessive sulfate and the generally unpleasant mineral taste of the water. A variety of insecticides, herbicides, and fungicides are used on crops in the study area at different times during the year. Pesticide analyses of fluids entering drainage wells confirmed the presence of Bromacil and Simazine in most of the drainage well samples. Bromacil and Simazine are persistent herbicides, but are relatively nontoxic to mammals. The EPA has no standards for Bromacil and Simazine levels in water.

Alternatives to Drain Wells

Drainage wells need maintenance to keep them operating efficiently. Frequently wells become plugged and must be jetted to clean them out. Drain systems are expensive to install and maintain. For these reasons, and because in some instances drainage wells do not meet drainage needs of a particular area, alternatives to drainage wells are being considered by local residents. The following is a discussion of two alternatives which may reduce or eliminate need for drainage wells.

Table 10-5.--Pesticide Analyses of Water From Selected Drainage Wells and Water Wells

Well	Date of collection	Aldrin	Chlordane	DDD	DDE	DDT	Diazinon	Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	Lindane	Methoxy-chlor	Methyl parathion	Parathion	Toxaphene	PCB	Malathion	Diethylhexyl phthalate	Dibutyl Phthalate	Ethion	Guthion	Bromacil	Simazine
1	June 8, 1982	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	1.2	8.8
2	do	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	8.2	6.4
3	June 9, 1982	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	8.6	*
4	do	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	2.9	6
5	do	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	16	16
6	Jan. 15, 1982	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	*	*
6	June 9, 1982	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	1.2	5.5
7	do	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	12	14
14	June 10, 1982	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	*	*
15	do	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	*	*
16	do	<0.02	<1	<0.25	<0.2	<0.27	<0.3	<0.1	<0.2	<0.02	<0.06	<0.03	<0.5	<0.25	<0.25	<5	<1	<0.4	<50	<5	<1	<10	*	*

NOTE: Well numbers correspond to map locations on Figure 10-1 and well data information in Table 10-1. Analyses for wells 1 through 7 are of drainage well injection fluids; analyses 14 through 16 are of ground water.
Sample results are in micrograms per liter (ug/l).
*Indicates undetectable level.

A proposition for $26 million in bonds was passed by the voters in Hidalgo County in 1975 which generated funds for construction of a main drainage ditch which now extends from Laguna Madre through Willacy County into the eastern part of Hidalgo County. In May 1982, a proposal for an additional $31 million in bonds was defeated in the county. This bond money was needed to improve the existing ditch and extend it westward toward Mission. In the future, if the drainage ditch is extended to areas in which subsurface tile drainage is utilized, drain lines could deposit fluids directly into the ditch, which would eliminate need for drainage wells.

The U.S. Soil Conservation Service, a local irrigation district, and other individuals have been developing a plan to dispose of drainage fluids into caliche pits. The pits being considered are in southern Hidalgo County, near Citrus City. They are approximately 4.5 acres in size. The plan calls for drainage tiles to dispose of fluids into a canal which would transport fluids to the pits. This scheme would eliminate need for drainage wells in areas which could utilize the caliche pits.

Legal and Jurisdictional Considerations

There are a number of governmental institutions in the Lower Rio Grande Valley which have influence on development and use of water and land resources. There are eight drainage districts in the Lower Rio Grande Valley, organized under State law, which can levy and collect taxes to construct, operate, and maintain district drainage facilities. Thirty-three irrigation districts in the region, which are local subdivisions of the State, have the authority to levy and collect taxes; construct, operate, and maintain works of improvement; acquire land, easements, and rights-of-way; and contract with the Federal government. Soil and Water Conservation Districts were established under State law to assist farmers and others with erosion control, flood prevention, and water management operations. The Lower Rio Grande Development Council was formed in 1967 and is primarily involved with industrial and economic development of the region and strengthening cooperation among local governmental subdivisions. The Council has also supported environmental assessments for the region.

The Agricultural Stabilization Conservation Service of the U.S. Department of Agriculture provides cost-share assistance for development of drainage well systems under the Agriculture Conservation Program. Funds are channeled through the U.S. Soil Conservation Service which provides technical assistance for design and construction of drainage well systems. The Service has established design specifications for drainage wells in the *National Handbook of Conservation Practices* (U.S. Soil Conservation Service, 1978). These design standards specify that the practice of drainage well use is applicable only in locations where a determination has been made that it will not cause pollution of underground waters.

Agricultural drainage wells are considered Class V wells and are subject to regulation by the Texas Department of Water Resources as injection wells.

Concluding Statement

Agricultural drainage wells appear to be localized in Hidalgo County. New drainage well systems are being constructed and their development is expected to continue until a viable alternative is found. Drainage wells dispose of fluids containing high concentrations of dissolved solids and nitrate. Two pesticides, Bromacil and Simazine, were found in drainage fluids but not in ground water. Most of the drainage wells are completed in a shallow gravel disposal zone, which in most of the study area contains high concentrations of dissolved solids and nitrate. It is reasonable to conclude from available data that drainage wells, along with other agricultural activities, may have contributed to the poor quality water found in the shallow zone. Generally, the middle and lower water-bearing zones, as defined in this report, are not suitable for disposal of drainage fluids.

References

Applegate, H. G., 1979, Environmental problems of the borderlands: University of Texas at El Paso, 124 p.

Baker, R. C., and Dale, O. C., 1961, Ground-water resources of the Lower Rio Grande Valley area, Texas: Texas Board of Water Engineers Bull. 6014, v. I, 81 p.; v. II, 336 p.

Black and Veach, Consulting Engineers, 1981, Toxic substance pollutant sampling program: Prepared for the Lower Rio Grande Development Council, McAllen, Texas.

Davis, S. N., and DeWiest, R. J. M., 1966, Hydrogeology: New York, John Wiley and Sons, Inc., 463 p.

Entomological Society of America, 1976, Pesticide index: 328 p.

Garrett, David, and others, 1976, The impact of intensive application of pesticides and fertilizers on underground water recharge areas which may contribute to drinking water supplies, a preliminary review: U.S. Environmental Protection Agency, Office of Toxic Substances, 100 p.

Jacobs, J. L., 1981, Soil Survey of Hidalgo County, Texas: U.S. Soil Conservation Survey, 171 p.

Lonsdale, J. T., and Nye, S. S., 1938, Hidalgo County, Texas, records of wells, driller's logs, water analyses, and maps showing location of wells: Texas State Board of Water Engineers duplicated rept., 71 p.

Luthin, J. N., 1957, Drainage of agricultural lands: Wisconsin, American Society of Agronomy, 620 p.

Meister Publishing Co., 1977, Farm chemical handbook.

Midwest Research Institute, 1974, Production, distribution, use and environmental impact of selected pesticides: prepared for Council on Environmental Quality, 439 p.

Preston, R. D., 1983, Occurrence and quality of ground water in the vicinity of Brownsville, Texas: Texas Department of Water Resources Report 279, 98 p.

Scalf, M. R., and others, 1968, Fate of DDT and nitrate in ground water: Robert S. Kerr Water Research Center, Ada, Oklahoma; and Southwestern Great Plains Research Center, Bushland, Texas, 46 p.

Texas Board of Water Engineers, 1941, Hidalgo County, Texas, records of wells, driller's logs, water analyses, and map showing location of wells: Texas State Board of Water Engineers duplicated rept., 102 p.

Texas Department of Water Resources, 1981, Inventories of irrigation in Texas, 1958, 1964, 1969, 1974, and 1979: Texas Department of Water Resources Report 263, 295 p.

Thomson, W. T., 1973a, Agricultural chemicals—book I, insecticides: Indiana, Thomson Publications.

________1973b, Agricultural chemicals—book II, herbicides: Indiana, Thomson Publications.

U.S. Department of Agriculture, 1969, Comprehensive study and plan of development, Lower Rio Grande basin, Texas: U.S. Department of Agriculture, 378 p.

U.S. Environmental Protection Agency, 1981, Analytical reference standards and supplemental data for pesticides and other organic compounds: Report EPA-600/2-81-011.

________1976, Quality criteria for water: Office of Water Planning and Standards, U.S. Environmental Protection Agency.

U.S. Soil Conservation Service, 1978, National handbook of conservation practices: U.S. Department of Agriculture.

Willrich, T. L., and Smith, G. E., 1970, Agricultural practices and water quality: Iowa, Iowa University Press, 415 p.

Wood, L. A., Gabrysch, R. K., and Marvin, Richard, 1963, Reconnaissance investigation of the ground-water resources of the Gulf Coast region, Texas: Texas Water Comm. Bull. 6305, 114 p.

CHAPTER 11

SEWAGE DISPOSAL WELLS

Investigator:

Steven P. Musick

SEWAGE DISPOSAL WELLS

Table of Contents

Page

SEWAGE DISPOSAL WELLS

Introduction

Sewage disposal wells include all bored or dug holes in which the depth exceeds the diameter, and which are used for disposal of water-borne human wastes or effluent resulting from partial treatment of these wastes. Common disposal methods included in this definition are injection wells, boreholes, cesspools, seepage pits, and seepage wells. This group of wells does not include those wells which inject treated domestic sewage effluent specifically for the purpose of aquifer recharge for storage and possible reuse.

In rural areas, septic tanks and cesspools replaced the pit privy for domestic waste disposal as the rural electrification program of the 1940's made inexpensive pumps supplying water to indoor plumbing systems easily available. Septic tank treatment of domestic waste frequently employed the cesspool as an addition or replacement for a conventional soil absorption system. Use of septic tanks and cesspools increased tremendously during the 1950's and steadily over the following two decades with rapid development of suburban areas around cities. Use of sewage disposal wells can develop in areas where suburban development is not served by municipal sewerage systems and where soil conditions or lot size are unsuitable for soil absorption systems.

It is difficult to establish the number of single-family residences and other establishments that use sewage disposal wells, for two reasons. First, there is generally no above-ground equipment associated with these wells to aid in well location. Like the septic tanks which they are often associated with, sewage disposal wells generally are buried beneath the surface and are not easily detected. Figures 11-1 and 11-2 are photographs of the only such wells with above-ground appurtenances located by the Department. Second, lack of regulation has precluded adequate record keeping of existing well installations.

The Department's investigation has focused upon sewage disposal wells serving 20 or more persons. This limited category consists of multiple-unit dwellings such as apartments, dormitories, motels, trailer parks, and nonresidential establishments including schools, restaurants, and light industries. Most of these wells dispose of septic tank effluent, while the remainder dispose of raw sewage. Inventoried sewage disposal wells serving 20 or more persons are listed in Appendix 4, and are located as shown in Figure 11-3. These include 4 well systems on the High Plains, 10 wells in Edwards County on the Edwards Plateau, 12 well systems in Nueces County on the coast, and 1 well in Hidalgo County.

Geohydrology

Sewage disposal wells on the High Plains penetrate the Ogallala Formation, which is the major water-bearing unit of the High Plains aquifer. Hydrologic properties vary widely in the Ogallala due to the heterogeneous nature of the sediments. These sediments are generally a good

Wastewater holding tank, submersible pump, and transmission line.

Wellhead

Figure 11-1.—Above-Ground Features of the Pax Christi Well, Calallen Area, Nueces County

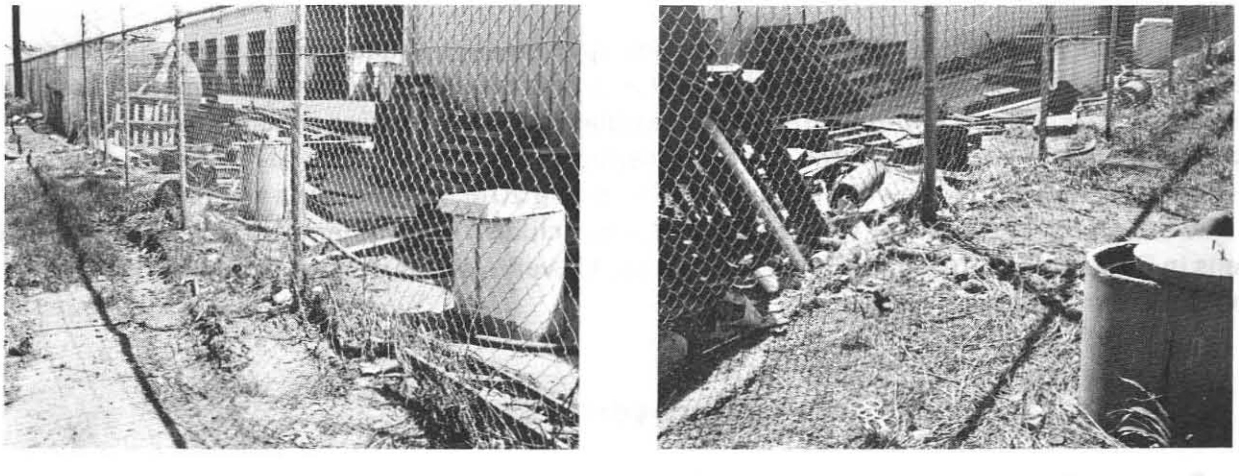


Figure 11-2.—Seepage Wells With Concrete Pipe Wellheads in Industrial Sector North of Corpus Christi, Nueces County

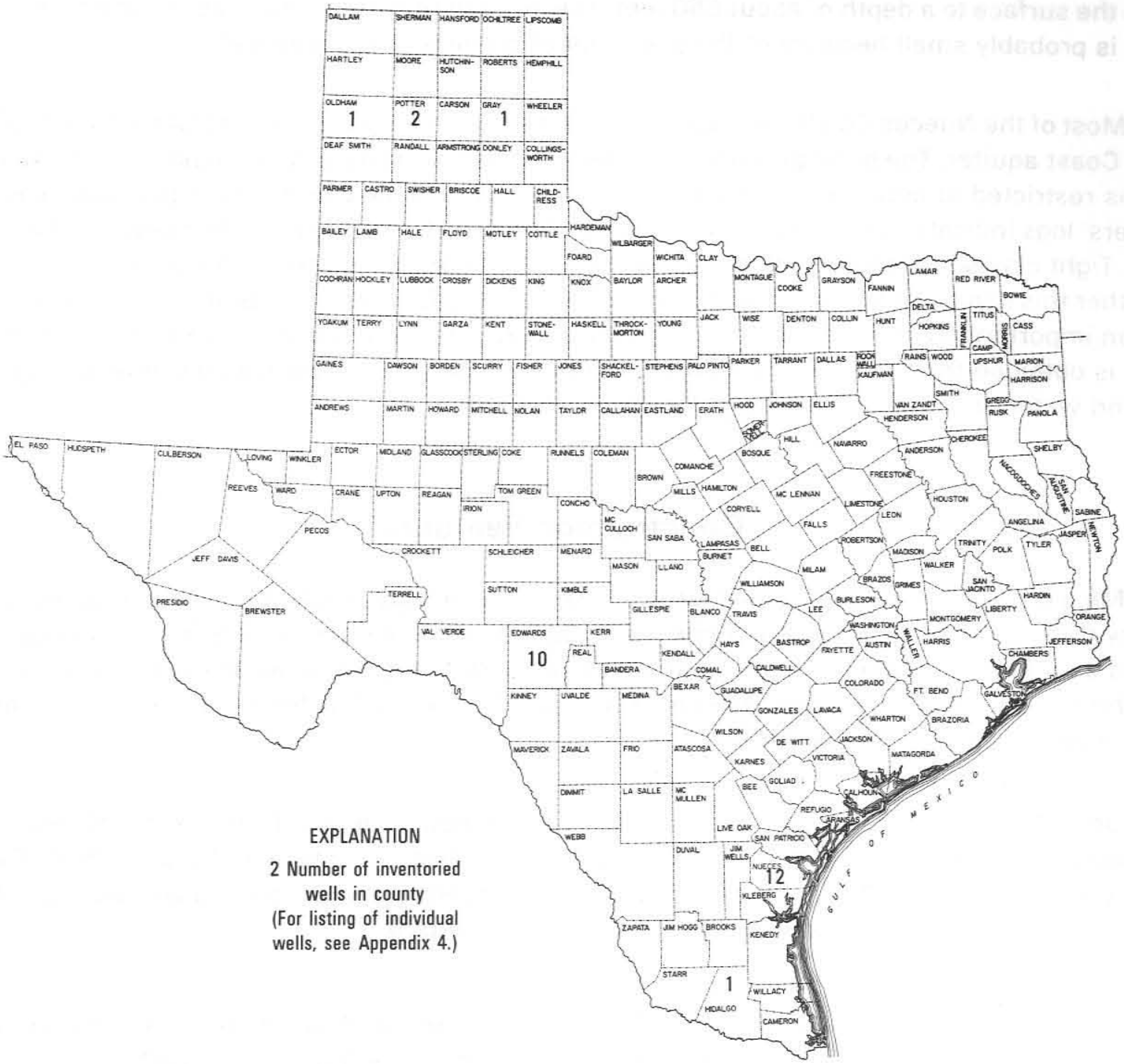


Figure 11-3.—Sewage Disposal Wells Inventoried by the Department, Each Serving 20 or More Persons

medium for mechanisms of filtering and sorption. Permeabilities range from moderate to high. Good quality ground water occurs at depths ranging from 100 to 250 feet below the surface. Sewage disposal wells in the study area range in depth from 20 to 100 feet.

Sewage disposal wells in Rocksprings in Edwards County are completed in the Edwards Limestone. This formation is the major unit of the Edwards-Trinity aquifer in the Rocksprings area, and consists of four sub-units or members as described by Rose (1972) and Long (1962). The Edwards is characterized by honeycombed limestone with numerous caverns formed by the dissolution of limestone by water percolating along joints and faults. Since water is conducted preferentially through this conduit system, the Edwards is a comparatively poor medium for filtering and absorbing contaminants from wastewater.

Water of good quality occurs in the Edwards in the Rocksprings area, at a depth of approximately 400 feet (Walker, 1979). Sewage disposal wells are drilled to a depth of 100 to 150 feet in Rocksprings. The Edwards exhibits the ability to store and conduct fluids throughout its thickness, from the surface to a depth of about 650 feet. The amount of natural recharge in the Rocksprings area is probably small because of the presence of an impervious clay soil.

Most of the Nueces County sewage disposal wells are completed in unsaturated sands of the Gulf Coast aquifer. The principal sand unit used by these wells occurs at a depth of 30 to 45 feet, and is restricted in areal extent to the northeastern part of the county along the Nueces River. Drillers' logs indicate that the sand unit is up to 15 feet thick and is sandwiched between layers of clay. Tight clay soils restrict infiltration as a source of natural aquifer recharge. It is not known whether this sand unit outcrops nearby in the valley of the Nueces River. Shallow ground water is not an important source of water in the northeastern part of the county; most water used in this area is obtained from Lake Corpus Christi. There are, however, local sources of usable-quality ground water occurring to depths of less than 100 feet.

Construction Features

Most domestic sewage disposal wells are of simple design. A hole is drilled or augered with a rotary drilling rig or by cable tool techniques. Sewage well diameters vary from 6 inches to as much as 4 feet, and depths range from about 20 to 350 feet. Some wells exist as simple open boreholes, some have concrete pipe and gravel packing, and a few have cemented steel casing with injection tubing and packer.

On the High Plains, sewage disposal wells are drilled to depths from 20 to 100 feet, with diameters generally from 2 to 4 feet. Figure 11-4 illustrates the typical design of High Plains sewage disposal wells. These wells are essentially uncased boreholes, capped with a concrete lid, and connected directly to indoor plumbing or to a septic tank.

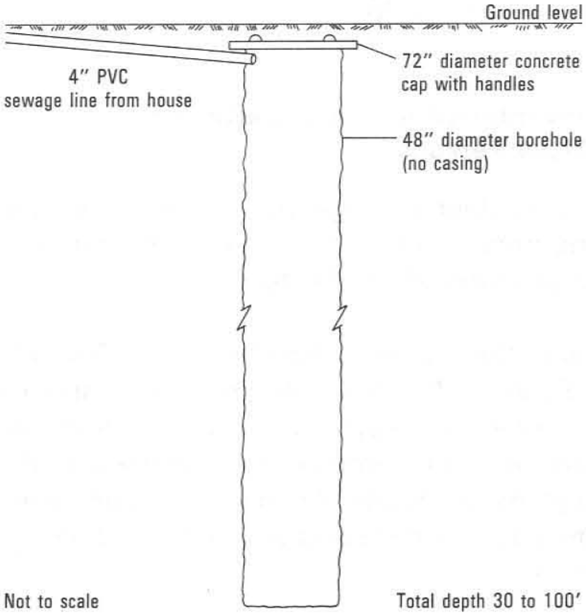


Figure 11-4.—Diagram of Typical High Plains Borehole Type of Sewage Disposal Well

Sewage disposal wells in Rocksprings, Texas, range from 100 to 150 feet deep. Figure 11-5 shows the typical design of these wells. The Rocksprings wells are boreholes 6 to 10 inches in diameter, cased from the surface with a section of pipe several feet in length, to prevent caving in.

Figure 11-6 shows the most common design of sewage disposal wells in Nueces County. These wells are usually bored holes, 24 inches in diameter and 30 to 45 feet in depth. The top 8 feet in each well is generally cased with 15-inch diameter concrete pipe, and the wells are filled with gravel from the bottom of the borehole to the base of the casing.

Figure 11-7 shows a more sophisticated type of sewage well design capable of han-

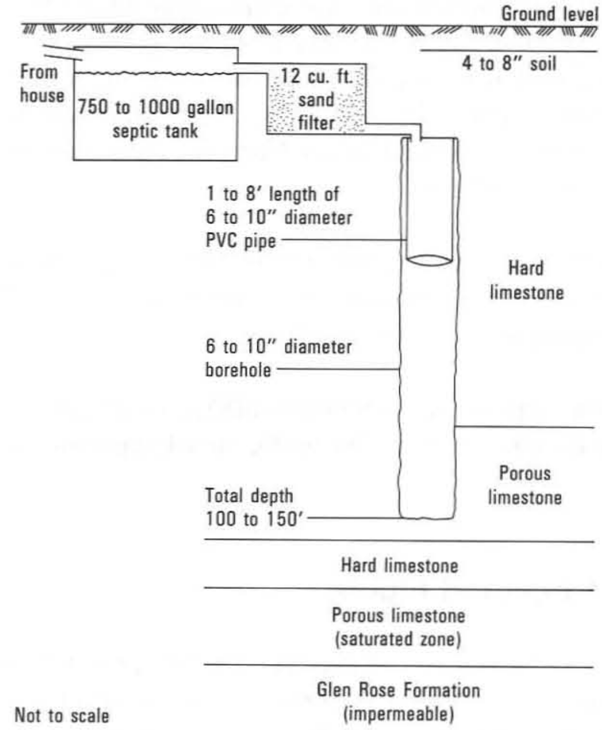
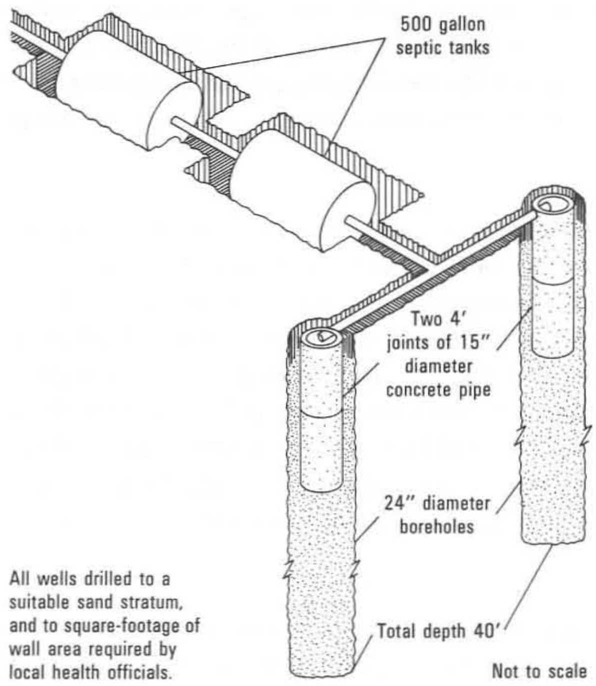


Figure 11-5.—Diagram of Typical Rocksprings Sewage Disposal Well



All wells drilled to a suitable sand stratum, and to square-footage of wall area required by local health officials.

Figure 11-6.—Diagram of Common Nueces County Sewage Disposal Well System

dling up to 15,000 gallons per day at an injection pressure up to 120 psig. This design has been implemented in four Nueces County sewage disposal wells, although only one is still in operation. A disposal well of similar design is in operation in Hidalgo County.

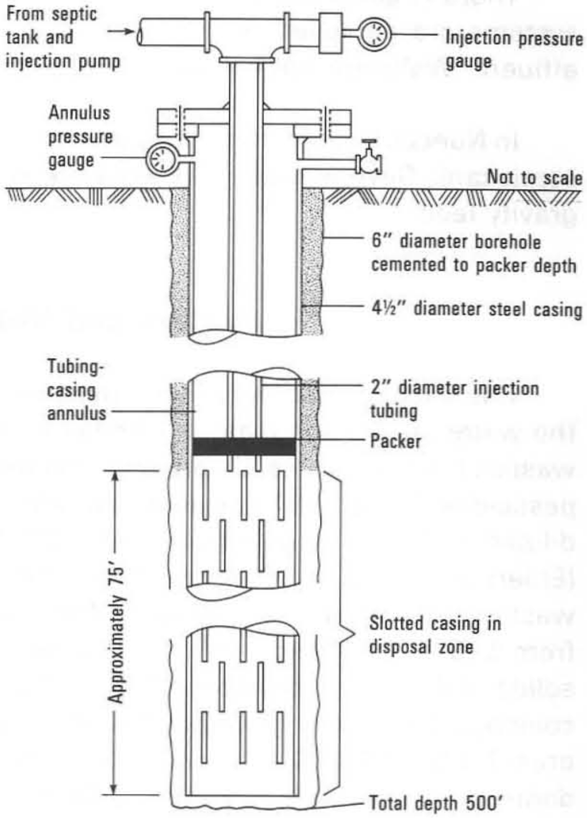


Figure 11-7.—Diagram of Nueces County Sewage Disposal Well with Cemented Casing, Through-Tubing Injection, and Annulus Leak Detection System

Operating Practices

Most sewage disposal wells operate by gravity flow from a septic tank or directly from a building's plumbing system. In a few cases, an electric pump provides pressure to drive injection. Very few wells have any preinjection treatment facilities other than a septic tank. Some operators periodically add yeast to the septic tank to promote waste decomposition, and some treat the final effluent with a germicide prior to injection in the well.

Characteristically, little consideration is given to operation of sewage disposal wells on the High Plains. In rural areas, wells are generally cesspools handling raw sewage, whereas in suburban developments they generally handle septic tank effluent. If a disposal well plugs up or caves in, another well is simply drilled as a replacement, a short distance away. Both single wells and multi-well systems are used in conjunction with individual septic tanks. No pumps are used in these wells; simple gravity flow drives the wastewater injection.

There is generally a single disposal well for each septic tank system in Rocksprings. Some systems are equipped with a sand filter for more complete removal of solids from the final effluent. Wells are not equipped with pumps, but operate by gravity feed.

In Nueces County there are generally two or more disposal wells for each 500 to 1,000 gallon septic tank. Several septic tanks may serve a single establishment. The wells mostly operate by gravity feed.

Nature and Volume of Injected Fluids

Chemical constituents found in domestic wastewater consist of dissolved solids present in the water supply and materials added by human use. These human contributions include body wastes, kitchen wastes, detergents, and miscellaneous chemicals including drugs, solvents, and pesticides (Meyer, 1973). Human excreta contribute about 50 grams of solids per capita per day, diluted in 30 to 100 gallons of water. Of this total, about 50 percent is organic and putrescible (Ehlers and Steel, 1965). Amounts of total solids and total dissolved solids contained in domestic wastewater will vary considerably. Waste samples from wells operating with septic tanks ranged from 500 to 1,200 mg/l in total dissolved solids and from 300 to 900 mg/l in total suspended solids. Table 11-1, developed from Department data, represents an average injection water composition for sewage disposal well systems operating with septic tanks in the Corpus Christi area. Table 11-2 (U.S. Environmental Protection Agency, 1974) presents a generalized analysis of domestic wastewater, which should be representative of untreated injection water for sewage wells without septic tanks.

High Plains septic tanks and sewage disposal wells are generally not accessible for sampling of injection water. The water injected in High Plains cesspools serving as disposal wells for raw sewage would be expected to have a makeup typical of domestic sewage as indicated in Table 11-2. The water injected in High Plains wells serving septic tanks might be similar in constitution to the septic tank effluent analysis in Table 11-1. Basically, septic tank treatment alters domestic sewage by decreasing both suspended solids and organic constituents. Too little is known about the operation of the four High Plains sewage wells inventoried by the Department, or any of the High Plains sewage disposal wells serving single-family residences, to accurately determine volumes of wastewater injected. A crude estimate would place daily injection volume at 75 gallons per person.

Because the Rocksprings septic tanks and disposal well systems are buried underground, no injection water samples could be obtained for analysis. The injected sewage would be expected, however, to have a makeup typical of domestic sewage (Table 11-1). The 10 wells inventoried by the Department are estimated to each inject from 600 to 8,000 gallons of sewage per day. The total number of sewage disposal wells in Rocksprings, including those serving single-family dwellings, is reported by local officials to be very large. The total number of such wells may exceed

Table 11-1.—Average Injection Water Composition for Sewage Disposal Well Systems Operating with Septic Tanks (Values are in mg/l except pH and specific conductance.)

Calcium (Ca)	64
Magnesium (Mg)	13
Sodium (Na)	134
Potassium (K)	59
Silica (SiO_2)	17
Bicarbonate (HCO_3)	251
Sulfate (SO_4)	58
Chloride (Cl)	211
Fluoride (F)	.88
Ortho-phosphate as (O-PO_4)	28
Ammonia (NH_4)	44.5
Nitrite (NO_2)	.04
Nitrate (NO_3)	.25
Specific Conductance (micromhos at 25°C)	1,267
pH	7.1
Total Dissolved Solids (TDS)	725
Total Hardness as $CaCO_3$	186
Phenolpthalein Alkalinity as $CaCO_3$	0
Total Alkalinity as $CaCO_3$	274
Biochemical Oxygen Demand—5 day (BOD_5)	71

200 within an area of 1 square mile. A crude estimate, assuming that 200 sewage disposal wells are operating in Rocksprings, is a total injection volume of 25 million gallons per year.

Of the eight active Nueces County sewage disposal wells inventoried by the Department, injection volume data are available for only one well. This well, serving a parochial school and orphanage, has been permitted by the Department. Using a standard waste disposal well design of cemented casing with tubing and packer, this well injects 2,000 to 5,000 gallons per month. Because the total number of Nueces County sewage disposal wells, including those serving single-family residences, is not accurately known, it has not been possible to estimate the total volume of sewage injected in the county.

Contamination Potential

Septic tanks provide only primary treatment of domestic sewage. In septic tank and drain field systems, the principal treatment of wastewater is accomplished by the soil. Soil is generally a very effective treatment system, employing physical filtering, particle sorption processes, and chemical and biological action to attenuate contaminants (McGauhey and Krone, 1967). Many of the wastewater constituents are taken up as nutrients by soil organisms and plants. Remaining wastewater constituents which are not attenuated in the soil by physical, chemical, or biological processes percolate downward to enter ground water, causing increased ground-water mineralization. Sewage disposal wells, cesspools, and seepage pits bypass the soil zone, disposing of wastes in deeper sediments, primarily under anaerobic conditions. Less waste attenuation occurs in these systems.

One of the most significant health hazards from contamination of ground or surface water by domestic sewage is the potential for spread of viral and bacterial pathogens. Most water-borne disease outbreaks in this country have been traced to consumption of untreated ground water (Wellings, 1980). Recent studies suggest that viruses may survive in a ground-water environment for as long as 1 year, and that viruses may travel as much as 200 feet through sandy soil (Geraghty and Miller, 1982). Table 11-3 lists human viruses which are likely to be present in sewage, and their associated diseases. In subsurface strata where significant flow may occur in fractures, bacteria-laden water may move quickly with little filtration (Allen and Morrison, 1973). Aside from the dangers of pathogens in sewage-contaminated ground water, chemical constituents of sewage may also cause ground-water problems ranging from the nuisance of mineralized taste of the water to more serious health problems such as methemoglobinemia.

Table 11-2.—Typical Composition of Domestic Sewage (All values except settleable solids are expressed in mg/l.)

Constituent	Concentration		
	Strong	Medium	Weak
Solids, total	1,200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids, (ml/l)	20	10	5
Biochemical Oxygen Demand, 5-day, 20°C (BOD_5 20°)	300	200	100
Total Organic Carbon (TOC)	300	200	100
Chemical Oxygen Demand (COD)	1,000	500	250
Nitrogen, (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrite	0	0	0
Nitrate	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chloride[1]	100	50	30
Alkalinity (as $CaCO_3$)[1]	200	100	50
Grease	150	100	50

---

[1] Values should be increased by amount in carriage water.

From U.S. Environmental Protection Agency, 1977.

Table 11-3.—Human Viruses Common in Sewage, and Associated Diseases

Virsus	Diseases or Clinical Syndromes
Poliovirus	Paralysis, aseptic meningitis, undifferentiated febrile illness.
Coxsackievirus Group A	Herpangina, aseptic meningitis, paralysis, exanthem, "common cold", undifferentiated febrile illness.
Coxsackievirus Group B	Pleurodynia, aseptic meningitis, paralysis meningoencephalitis, myocarditis, pericarditis, upper respiratory illness, pneumonia undifferentiated febrile illness.
Echovirus	Aseptic meningitis, paralysis, exanthem, respiratory disease, diarrhea.
Adenovirus	Acute febrile pharyngitis, phanyngo-conjunctival fever, acute respiratory disease, pneumonia.
Reovirus	Respiratory illness, diarrhea.
Infectious hepatitis virus	Jaundice.

From Yin, 1970

Factors which increase the ground-water contamination potential of sewage disposal wells include low waste attenuation capability of disposal zone sediments, high horizontal and vertical permeabilities in the disposal zone, and lack of adequate stratigraphic and hydrologic separation between the disposal zone and the local fresh-water aquifer. Also, contamination potential undoubtedly increases with both density of on-site sewage disposal systems (including disposal wells) and density of water wells.

Water wells may be affected by sewage disposal in two ways. First, sewage effluent entering the water table through percolation or injection will cause a contaminated plume to move down-gradient where it may be picked up in a water well. Second, lateral movement of effluent through injection strata (or through soil in the case of a soil absorption system) may contact an uncemented water well and move downward through the annulus to the water table. In evaluating impacts of septic tank systems on ground water, a density of greater than 40 units per square mile may indicate significant potential for contamination (U.S. Environmental Protection Agency, 1977) if shallow ground water resources exist in the area. Potential for ground-water contamination by the four High Plains sewage disposal well operations inventoried by the Department, and other High Plains sewage wells in isolated rural situations, is probably minimal. For these isolated wells the subsurface sediments may be reasonably effective in binding up or attenuating contaminants from the relatively low volumes of injected sewage. Any ground-water contamination which results is likely very localized.

In Texas, the threat of local ground-water contamination has occurred in a few housing developments where there was a high density of both sewage disposal wells and water wells. One case investigated by the Texas Water Development Board and the Amarillo Bi-City-County Health Department in the High Plains study area is discussed in Cooper (1970). The Texas Water Development Board investigation was conducted at the request of residents concerned about installation of sewage disposal wells in a housing development north of Amarillo. Each dwelling in the 530-acre development had an individual water supply well with gravel-packed annulus, and a septic tank system. Approximately 30 boreholes were drilled to relieve poorly designed soil absorption systems which had failed. The Board report concluded that "Sewage disposal wells...present a severe hazard to the quality of the ground water in the local area."

Though no ground-water problems from the operation of sewage disposal wells have yet been experienced in Rocksprings, there appears to be a significant potential for contamination of local water supplies. This assessment is based largely upon the reported high density of disposal wells and proximity of water supply wells. The water supply for Rocksprings is provided by one main well, with an additional well serving as a backup for times of peak demand. These water wells have open-hole completions from a depth of about 150 feet, within or near the sewage disposal zone, to their respective total depths of 625 and 563 feet. The water supply is chlorinated before distribution. Available chemical analyses for these two water supply wells show no evidence of contamination.

Contributing to the contamination potential of Rocksprings sewage disposal wells are relatively high permeabilities in both the shallow injection reservoir and the deeper water supply aquifer, and the thinness of the formation separating these two subsurface zones. Also, in contrast with the effectiveness of a properly designed septic tank drain field operated under suitable soil conditions, very little attenuation of sewage contaminants in the injection zone is likely to occur. The lack of evidence of ground-water contamination could indicate that lateral flow of contaminated water away from the supply well locations, rather than its vertical percolation into the supply well aquifer, is the dominant hydrologic process in the area. Future studies could investigate the exact relationship between stratigraphy and hydrology in the area, and mechanisms of aquifer recharge.

Contamination potential of the sewage disposal wells inventoried in Nueces County is judged to be low, because of the small number of inventoried wells and general absence of significant ground-water supplies. If single-family residence wells are considered, local contamination potential may exist. Ground-water contamination would likely correlate with areas of high sewage disposal well density. A situation similar to the one described in Cooper (1970) existed in Nueces County. Residential water wells in a small housing development were threatened by installation of sewage disposal wells, as individual septic tank soil absorption systems in the development began to fail. A combination of citizen awareness, action by county health officials, and extension of water utilities to the area prevented a health hazard in the community.

Legal and Jurisdictional Considerations

Sewage disposal wells are included in the Class V group of underground injection wells and are within the jurisdictional authority of the Department. Because jurisdictional authority for these wells also extends to other state and local agencies, opportunity exists for coordination of regulatory efforts to discourage or prohibit sewage disposal well use.

Texas law authorizes promulgation and enforcement of standards and regulations governing use of private sewage facilities. Article 4477-1 of the Texas Sanitation and Health Protection Law (Texas Civil Statutes) and its various sections require proper disposal of human wastes through methods approved by the Texas Department of Health. Incorporated cities and towns may regulate private sewage facilities, consistent with Texas Department of Health guidelines, under this Article.

The term private sewage facilities generally refers to sewage disposal systems which serve single-family residences. These systems normally use soil absorption lines to dispose of septic tank effluent, but may occasionally use sewage disposal wells to receive raw sewage or septic tank effluent for final disposal. For purposes of Sections 26.031 and 26.032 of the Texas Water Code, the term private sewage facilities has a broader meaning. It means septic tanks, pit privies, cesspools, sewage holding tanks, injection wells, and all other facilities and methods used for on-site disposal of sewage at residences and other establishments except for disposal systems operated pursuant to a permit issued by the Texas Department of Water Resources. Figures 11-1 and 11-2 illustrate a disposal system which is currently regulated by Department waste disposal well permit and, therefore, not subject to regulation as a private sewage facility.

Sections 26.031 and 26.032 of the Texas Water Code define private sewage facilities to include injection wells used for the disposal of sewage and authorize the Texas Water Development Board with consultation from the Texas Department of Health to enact orders, county by county, regulating private sewage facilities, if a public hearing shows that these facilities may cause pollution or injury to public health. These orders must be initiated at the county level. An order may also be approved for the area surrounding a lake or associated with a water district. Figure 11-8 shows counties and other designated areas where septic tank orders exist. Septic

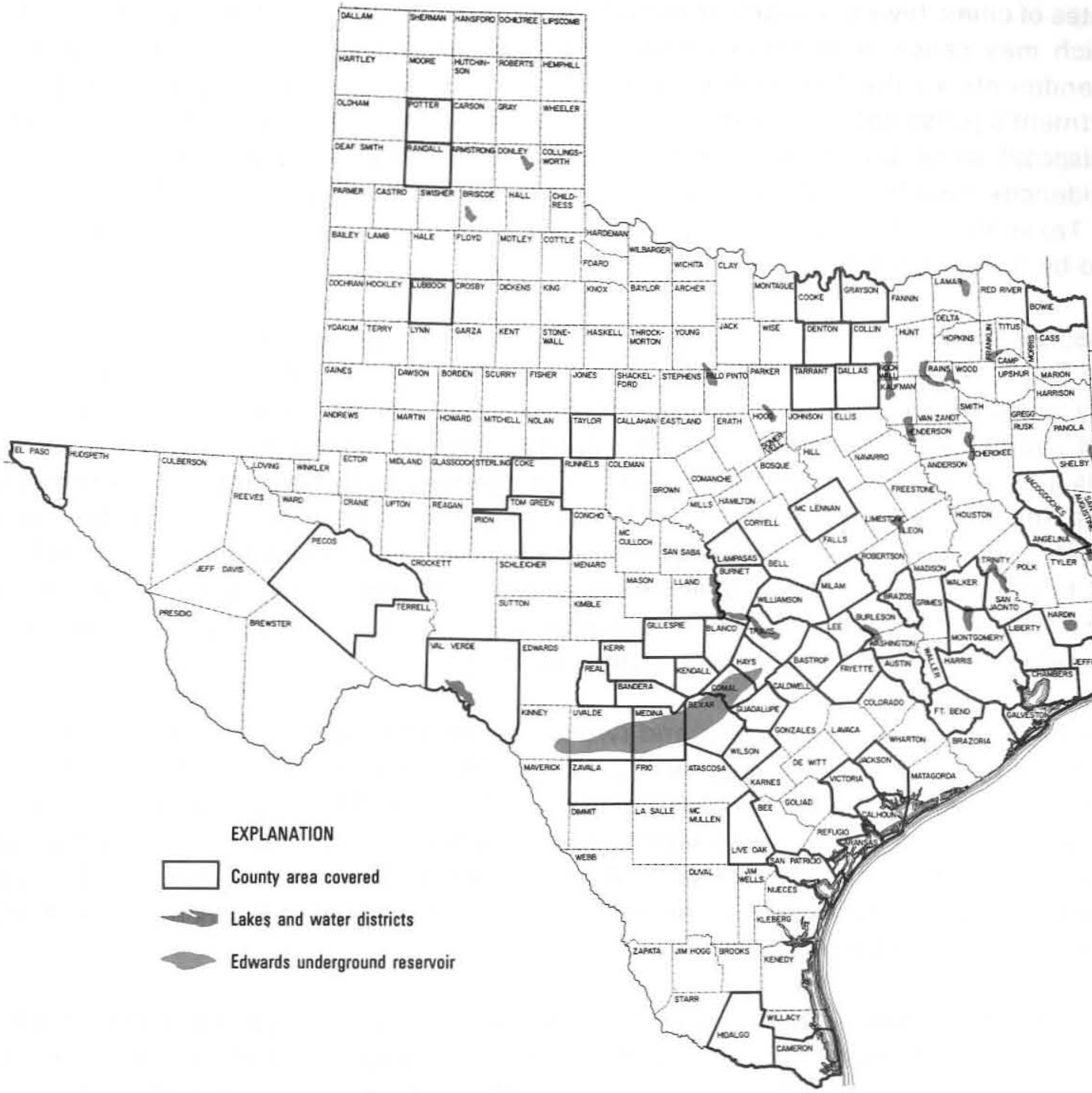


Figure 11-8.—Areas of Texas With Septic Tank Orders as of December 31, 1983

tank orders contain standards at least as stringent as those recommended by the Texas Department of Health. According to guidelines of the Department of Health, sewage disposal wells including cesspools and seepage pits are not an acceptable method of on-site disposal for private sewage facilities unless permitted by the Texas Department of Water Resources.

Texas Department of Water Resources rules regarding the Edwards Aquifer Recharge Zone require licensing of new private sewage facilities and registration of existing systems. All systems must connect to organized sewage collection systems when they become available in an area. Pit privies, cesspools, or injection wells used to dispose of sewage from private sewage facilities are prohibited from being constructed on the Recharge Zone.

The disposal of municipal waste by injection well must be authorized by Department of Water Resources Underground Injection Control Permit issued pursuant to the Injection Well Act (Chapter 27 of the Water Code) as originally adopted in 1961. Municipal waste includes sewage or other wastes of cities, towns, villages, communities, water districts, and other municipal corporations, which may cause or might reasonably be expected to cause pollution of fresh water. 1981 amendments to the Injection Well Act bring all other sewage disposal wells under the Department's jurisdiction. The Department's current rules governing injection wells address sewage disposal wells, but do not prohibit operation of sewage disposal wells serving single family residences. Regulation of these private sewage facilities is accomplished through Chapter 26 of the Texas Water Code as previously outlined. All other sewage disposal wells must be authorized by rule or permit.

The degree and type of existing regulation varies greatly among the three areas of the State in which the Department investigated sewage disposal wells. Much of the study area was not covered by septic tank orders. These areas are, however, subject to regulation by incorporated towns and county health departments. This regulation usually consists of encouraging proper system design and installation, and dissemination of information and guidelines. Often, builders, developers, and architects will consult with local public health officials for recommendations on sewage system design. Another indirect form of regulation is the requirement of a local health department inspection and approval of domestic wastewater facilities for Farmers Home Administration (FHA) financing. This inspection provides a mechanism for enforcing Department of Health guidelines and upgrading some existing facilities.

In the High Plains, three counties and two lake authorities administer septic tank orders. Included within these areas are the cities of Lubbock, Canyon, and Amarillo. These orders cover only a very small part of the High Plains study area. The City of Rocksprings, on the Edwards Plateau, has no regulatory order, but reviews septic tank and disposal well installations for basic design criteria. A similar situation exists in Nueces County, where the Corpus Christi-Nueces County Health Department reviews plans and inspects construction of septic tank and disposal well installations for compliance with design criteria.

Current private sewage facilities regulatory programs are generally of recent origin and are effective in controlling design and installation of on-site sewage disposal systems in new construction projects. These programs, however, do not generally assure upgrading of existing systems.

Concluding Statement

In Texas, regulatory authority over sewage disposal wells serving single-family residences is shared by the Department of Water Resources, the Department of Health, counties, local water districts, and local health departments. These various authorities have established mechanisms for the regulation of private sewage facilities. Regulatory programs for private sewage disposal have proven to be effective in counties where regulatory orders have been enacted. It is recommended that regulatory orders for private sewage facilities be adopted in the study areas which are not already protected. These regulatory orders should be based on current minimum standards for sewage disposal as published by the Department of Health and appropriate site-specific considerations. Sewage disposal wells for private sewage facilities are not acceptable under Texas Department of Health standards, and should be phased out and replaced by alternate methods of sewage treatment and disposal.

The investigation carried out by the Department has not identified pollution resulting from sewage disposal wells, but has shown the potential for such pollution to occur. These Class V wells differ from other Class V injection activities with regard to the fluid being injected, which in this case is clearly a waste material. The potential for contamination from these waste disposal activities varies with location. It is recommended that each proposed sewage disposal well, excluding single-family residence sewage facilities, be authorized by site-specific permit rather than by rule, and that existing wells be individually reviewed for contamination potential with appropriate action taken in each case.

References

Alexander, W. H., Jr., Myers, B. N., and Dale, O. C., 1964, Reconnaissance investigation of the ground-water resources of the Guadalupe, San Antonio, and Nueces River basins, Texas: Texas Water Commission Bulletin 6409, 106 p.

Allen, M. J., and Morrison, S. M., 1973, Bacterial movement through fractured bedrock: Ground Water, v. 11, no. 2, p. 6-10.

Aulenback, D. B., Ferris, J. J., Clesceri, N. L., and Tofflemire, T. J., 1974, Protracted recharge of the treated sewage into sand; Part III—Nutrient transport through the sand: Ground Water, v. 12, no. 5, p. 301-309.

Bouwer, H., Rice, R. C., Escaroga, E. D., and Riggs, M. S., 1972, Renovating secondary sewage by ground-water recharge with infiltration basins: U.S. Environmental Protection Agency Report EPA/WPCRS/1606 DRV 03/72, 102 p.

Buchholz, G. M., 1980, An overview of alternative onsite wastewater technology in individual onsite wastewater systems: Proc. 6th Natl. Conf., 1979, Nina I. McClelland (ed.), Ann Arbor Science Publishers, Ann Arbor, Michigan, p. 81-92.

Cooper, E. W., 1970, Possible ground-water contamination in the Rolling Hills addition, Potter County, Texas: Texas Water Development Board file report CI-6802, 15 p.

Ehlers, V. M., and Steel, E. W., 1965, Municipal and rural sanitation: McGraw-Hill Co., New York, 663 p.

Fink, W. B., and Aulenback, D. B., 1974, Protracted recharge of treated sewage into sand; Part II—Tracing the flow of contaminated groundwater with a resistivity survey: Ground Water, v. 12, no. 4, p. 219-223.

Geraghty, and Miller, Inc., 1982, Newsletter: v. 4, no. 2, 2 p.

Johnson Division, VOP, 1972, Ground water and wells: Universal Oil Products Company, St. Paul, Minnesota, 440 p.

Hughes, J. L., and Robson, S. G., 1973, Effects of waste percolation in alluvium near Barstow, Calif., *in* Underground waste management and artificial recharge (Jules Braunstein, ed.): Amer. Assoc. of Petr. Geol., Reprints of papers presented at the Second International Symposium, New Orleans, Louisiana, v. 1, p. 91-132.

Kier, R. S., Bell, D. L., and Patton, P. C., 1978, Engineering properties of land resource units in the Corpus Christi area: Bur. Econ. Geology Res. Note 9, 90 p.

Kier, R. S., and White, W. A., 1978, Land and water resources of the Corpus Christi area: Bur. Econ. Geology Report of Inv. 95, 22 p.

Klemt, W. B., 1981, Evaluating the ground-water resources of the High Plains of Texas, neutron-probe measurements of deep soil moisture as an indication of aquifer recharge rates: Texas Department of Water Resources LP-142, 31 p.

Long, A. T., 1962, Ground-water geology of Edwards County, Texas: Texas Water Development Board Bulletin 6208, 123 p.

Mackey, R. W., Small, T. A., and Rettman, P. L., 1980, Water level, recharge discharge, specific capacity, well-yield and aquifer test data for the Edwards aquifer in the San Antonio area, Texas: Texas Department of Water Resources LP-133, 83 p.

McGauhey, P. H., and Krone, R. B., 1967, Soil mantle as a wastewater treatment system, final report: Sanitary Engineering Research Lab. SERL Report No. 67-11, University of California, Berkeley, 201 p.

McGill University, Minimum Cost Housing Group, 1973, Stop the five gallon flush: Minimum Cost Housing Studies, McGill University, Montreal, Canada, 68 p.

Meyer, C. R. (ed.), 1973, Polluted groundwater, some causes, effects, control and monitoring: U.S. Environmental Protection Agency, Office of Research and Development, Env. Monitoring Series EPA-600/4-73-001b, 262 p.

Morton, R. A., 1974, Delineation and environmental application of active processes mapped in the recharge area of the Edwards aquifer *in* Approaches to Environmental Geology (E. G. Wermund, ed.): Bur. Econ. Geology Report of Inv. No. 81., p. 204-219.

Quan, E. L., Sweet, H. R., and Illian, J. R., 1974, Subsurface sewage disposal and contamination of ground water in east Portland, Oregon: Ground Water, v. 12, no. 6, p. 356-368.

Rose, P. R., 1972, Edwards Group, surface and subsurface, Central Texas: Bur. Econ. Geology Report of Inv. 74, 198 p.

Scalf, M. R., Dunlap, W. J., and Kreissl, J. F., 1977, Environmental effects of septic tank systems: Env. Rep. Series, U.S. Environmental Protection Agency, R. S. Kerr Env. Res. Lab. Rept. EPA-600/3-77-096, Ada, Oklahoma, 35 p.

Shafer, G. H., 1968, Ground-water resources of Nueces and San Patricio Counties, Texas: Texas Water Deveopment Board Report 73, 48 p.

Texas Department of Health, 1977, Construction standards for private sewage facilities: Texas Department of Health, 36 p.

U.S. Environmental Protection Agency, 1974, Land application of sewage effluents and sludges, selected abstracts: 248 p.

________ 1975, Manual of water well construction practices: Report EPA 570/9-75-001, Office of Water Supply, U.S. Environmental Protection Agency, 156 p.

U.S. Environmental Protection Agency, 1977, The report to Congress, waste disposal practices and their effects on ground water: Office of Water Supply, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, 512 p.

U.S. Public Health Service, 1975, Manual of septic tank practice: U.S. Public Health Service Pub. 526, 93 p.

U.S. Soil Conversation Service, 1963, General soil map of Edwards and Real County, Texas: U.S. Soil Conservation Service map.

University of Texas at Austin, 1975, Devils Sinkhole area-headwaters of the Nueces River: Natural Area Survey Park VII, Division of Natural Res. and Env., University of Texas, Austin, p. 117.

Walker, L. E., 1979, Occurrence, availability, and chemical quality of ground water in the Edwards Plateau region of Texas: Texas Department of Water Resources Report 235, 336 p.

Warshall, Peter, 1979, Septic tank practices: Anchor Books, Garden City, New York, 177 p.

Wellings, F. M., 1980, Virus movement in groundwater in individual onsite wastewater systems: Proc. 6th Natl. Conf., 1979, Nina I. McClelland (ed.), Ann Arbor Science Publishers, Ann Arbor, Michigan, p. 427-433.

Wesner, G. M., and Baier, D. C., 1970, Injection of reclaimed wastewater into confined aquifers: Jour. Amer. Assoc. of Water Works, v. 62, no. 3, p. 203-210.

Woodman, J. T., Kier, R. S., and Bell, D. L., 1978, Hydrology of the Corpus Christi area: Bur. Econ. Geology Research Note 12, 56 p.

Yin, S. C., 1970, Survival of bacteria and viruses in groundwater: Paper prepared for presentation at a training program, Robert S. Kerr Water Research Center, Federal Water Pollution Control Administration, Ada, Oklahoma.

CHAPTER 12

MINE BACKFILL WELLS

Investigator:

Robert W. Morris

MINE BACKFILL WELLS

Table of Contents

MINE BACKFILL WELLS

Introduction

Mine backfill wells are usually defined as wells drilled into mined-out portions of subsurface mines for the purpose of filling them by injection of a slurry of sand, mill tailings, or other solids. The term "mine backfill wells" has also been used in a different sense in reference to water wells or monitor wells drilled into backfill of surface mines. This use of the term will not be considered further in this chapter.

Only four underground mines are believed to be active in Texas: two salt mines, a limestone mine, and an abandoned silver mine being reactivated. None of these mines are believed ever to have utilized mine backfill wells in their operations. As far as can be determined, this technique of backfilling underground mines has never before been utilized in the State.

The largest, and at one time the most important, underground mines in Texas are those of the Terlingua mercury district and smaller genetically related districts in the Trans-Pecos region. Now completely abandoned, the very extensive Terlingua district workings yielded over 150,000 76-pound flasks of mercury from a number of mines during the first half of the present century. The Chisos Mine alone has over 23 miles of underground workings.

A recent project involved sealing off or filling some of the abandoned Terlingua mercury mines and prospect workings. This project included the first use of mine backfill wells in Texas.

The Terlingua mercury district, which includes the mine backfill project area, is in southern Brewster County about 80 miles south of the City of Alpine and consists of a rather narrow band extending westerly from the town of Study Butte for about 20 miles. The mining district lies just north of the western portion of Big Bend National Park as shown in Figure 12-1. The Terlingua Abandoned Mine Land Project encompasses an area within the Terlingua mercury district extending westerly from Study Butte along Farm to Market Road 170 (FM 170) about 16 miles to near Lajitas Mesa.

The major industry in this sparsely populated area is tourism. During the tourist season accomodations in and near Big Bend National Park are in short supply. Many tourists travel FM 170 enroute to and from facilities in Lajitas. Adobe and stone ruins associated with the former mine activity are clearly visible from FM 170. The land is almost entirely unfenced, and tourists attracted by the ruins can unknowingly enter areas rendered extremely dangerous by the presence of open and unmarked shafts. In 1982, a boy fell almost 300 feet to his death in one of the shafts, and in mid-1983 another person was reported missing in the area. Probably hundreds of shafts and prospect workings exist within the mercury district. Only a limited number, all easily accessible from FM 170, are included in the project.

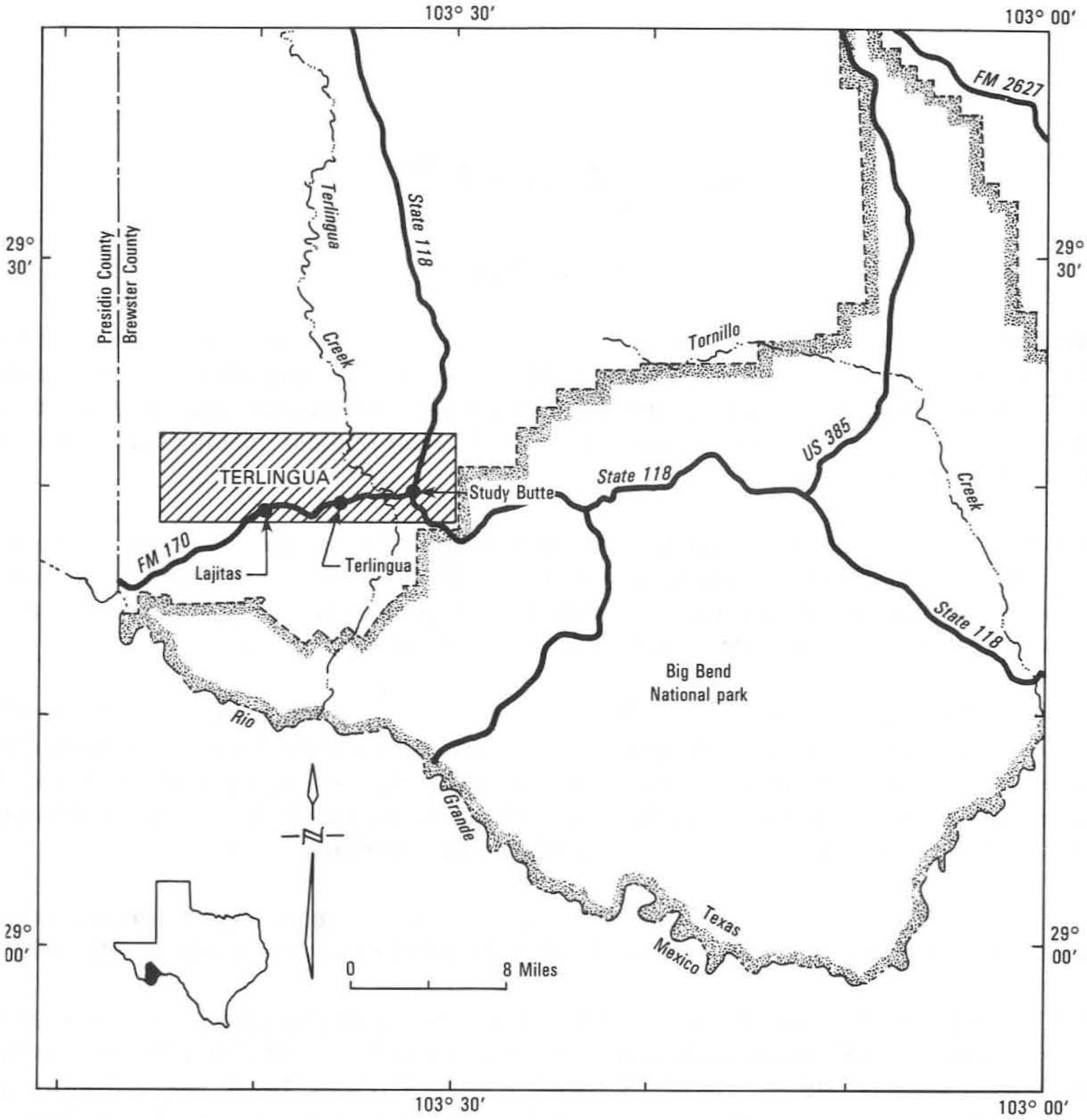


Figure 12-1.—Location of the Terlingua Mercury District in Trans-Pecos Texas (Modified after Sharpe, 1980)

Geohydrology

The Terlingua area is part of the Chihuahuan desert, which is characterized by an arid subtropical climate. Annual rainfall averages less than 12 inches, most of which occurs during the late summer months. Summer rains are often torrential and are usually highly localized. Vegetation is sparse to moderate in density, consisting mainly of desert forms such as yucca, cacti, and agave. Creosote bush, mesquite, and catclaw occur mainly along usually dry watercourses. The few trees in the area are cottonwoods which grow along the major arroyos. The abandoned mine area is located in a heavily dissected terrane of rocky slopes and ravines. Its elevation ranges from about 2,500 to 3,300 feet.

Stratigraphy and Structure

The rock strata of concern in the Terlingua area are Cretaceous sediments, dominantly limestone and shale. These are intruded by Tertiary sills, dikes, laccoliths, and plugs of variable igneous composition. Faults and tectonic fractures are abundant. The stratigraphic nomenclature utilized herein is that of the Emory Peak-Presidio Sheet of the Geologic Atlas of Texas (Bureau of Economic Geology, 1979).

The oldest stratigraphic unit entered by the deeper mine shafts of concern is the Santa Elena Limestone of late Lower Cretaceous age. Mercury is not known to occur in significant quantities below the upper part of the Santa Elena. The Santa Elena Limestone is white to light gray, fine grained, and massive in character. Its thickness is unknown in the project area, but elsewhere in the Big Bend region it is known to range from about 500 feet to more than 900 feet. The Santa Elena is the primary aquifer in the Terlingua district.

Overlying the Santa Elena is the Del Rio Clay, which ranges up to about 180 feet in thickness. The Del Rio is dominantly bluish to gray structureless clay with some interbedded flaggy limestone.

Less than 100 feet of Buda Limestone overlies the Del Rio. The Buda is a grayish white limestone containing a middle member which is argillaceous and marly.

The Boquillas Formation, the basal unit of the Upper Cretaceous, is the most prominently exposed unit in the project area. The lower Ernst Member is a bluish gray, flaggy, silty limestone grading to siltstone; the overlying San Vicente Member consists of thin to medium bedded, chalky, argillaceous limestone flags interbedded with gray marl.

The Pen Formation overlies the Boquillas. The Pen, the youngest formation of pertinence to the Terlingua mining project, is about 1,000 feet thick in the area and consists dominantly of clay, which is calcareous with thin chalk beds in the lower part and sandy with some sandstone beds in the upper part.

With one notable exception, to be discussed, the Tertiary igneous intrusions in the region have no direct relationship with the hydrology of the project area and need not be considered here. These intrusions also lack a direct relationship with the mercury mineralization, which took place later, although there is probably an indirect genetic relation in that the intrusions may have differentiated at depth from the same parent magma that was the later source of mercury-bearing hydrothermal solutions.

Aquifers

Because of complex faulting of the rock formations and extreme paucity of well data in the area, few generalized statements can be made regarding the hydrology of the Terlingua area other than to say that the Santa Elena often yields potable water and is the most important aquifer known in the area. Ragsdale (1976) records that when the Chisos Mine shafts penetrated below the 700-foot level, a large quantity of water unsuitable for household use was encountered and sealed off. Usable water was later discovered near the 800-foot level. The usable water undoubtedly came from the Santa Elena, but the source beds of the unusable water must be considered uncertain at present. The Little Thirty-Eight Mine reached a maximum depth of 375 feet without any report of water being encountered. It is probably safe to state that in most of the project area there is no ground water above a depth of several hundred feet.

A major exception to the preceding statement occurs in the vicinity of Study Butte at the eastern extremity of the project area. The Study Butte intrusion, of fine-grained quartz soda syenite, forms the hill of the same name. It is intruded into clays of the Pen Formation. The intrusion is cut by abundant joints and fractures, enabling it to function as a local aquifer. This intrusion is mentioned here because a mine shaft located near the road at Study Butte is part of the abandoned mine project. The shaft will be covered by a steel grating and is not one of the proposed mine backfill wells. The water level in the shaft is about 20 feet below land surface, approximately where water was encountered when the shaft was first opened.

Abandoned Mine Project Ground-Water Impact

The Terlingua Project plans provide that the mine shafts deeper than about 100 feet will be sealed off by emplacement of steel grates in concrete collars at the shaft openings at ground surface. These deep mine shafts, at least near the surface, are roughly square to rectangular in horizontal section. In contrast, the shafts and various prospect workings shallower than this arbitrary depth are to be filled with available solids which will include local soils and mine spoil. Shafts and workings of the shallower category will be regarded as mine backfill "wells," being generally deeper than they are wide. The backfill wells are highly variable in shape and size. While the deeper of these backfill wells resemble the deepest mine shafts in cross-sectional size and geometry, some of the shallower ones may be little more than infillings of irregularly oblong pits barely large enough for one man to have worked with hand tools.

Unlike more conventional mine backfill wells, the injected materials for the Terlingua project, usually consisting mainly of spoil removed in digging the original shafts and prospect workings, will be essentially dry, as will the wells themselves. As mentioned earlier, ground water is not known to occur above a depth of several hundred feet in the project area, except in the local Study Butte aquifer. The ground-water contamination potential of the project is apparently nil.

It is of course recognized that any open shaft into permeable sediments or any shaft backfilled with permeable material which is allowed to collect rainfall or runoff may constitute a minor source of water recharge to the unsaturated zone overlying the local aquifers. The possibility of mobilization of toxic mercury compounds from mine tailings used as backfill should be insignificant, considering that the possible effect of the mercury ore minerals on the water quality of the local aquifers has been a natural and pre-existing condition in the Terlingua mine district.

The only practicable alternative to the methods proposed (i.e., steel gratings at shaft openings, and use of mine backfill wells) is the erection of fences around the shafts. This option would be more expensive, and as demonstrated by fenced shafts in Big Bend National Park, would involve heavy maintenance expense. Some tourists have already tried to climb or burrow under fences around shafts in the park.

Legal and Jurisdictional Considerations

To eliminate the dangers of open mine shafts, the Governor declared a state of emergency on December 3, 1982, and requested federal assistance for the Terlingua Abandoned Mine Land Project. As a result, the Railroad Commission of Texas received an Administrative Grant for funds under Section 409 of Public Law 95-87 (Abandoned Mine Land Program) to remedy the hazardous situation. Railroad Commission personnel have identified 88 mine shafts or prospect workings within the mercury district which are easily accessible from FM 170 and, therefore, constitute public hazards.

The Department's authority under Chapter 27 of the Texas Water Code extends to regulation of injection wells. It has been determined that, for regulatory purposes, the shallower group of shafts and workings which are to be filled with solids are mine backfill wells, a category of Class V injection wells.

Concluding Statement

It has been shown that the Terlingua mine backfill project should have no impact upon ground-water resources. If other mine backfill wells should be proposed in the future, their potential effect upon ground-water quality should be evaluated on a case by case basis.

References

Bureau of Economic Geology, 1979, Geologic atlas of Texas, Emory Peak-Presidio sheet: Univ. Texas, Bur. Econ. Geol. map.

Hulbert, M. A., 1983, Backfill monitoring methods: Ground Water Monitoring Review, Winter 1983, p. 100-102.

Ragsdale, K. B., 1976, Quicksilver, Terlingua and the Chisos Mining Company: Texas A&M University Press, College Station, Texas.

Railroad Commission of Texas, 1983a, Environmental assessment of the Terlingua abandoned mine project, Brewster County, Texas: File report, Austin, Texas.

________ 1983b, Supplement for environmental assessment of the Terlingua abandoned mine project, Brewster County, Texas: File report, Austin, Texas.

Sharpe, R. D., 1980, Development of the mercury mining industry: Trans-Pecos Texas: Univ. Texas, Bur. Econ. Geology, Mineral Resources Circular 64.

Yates, R. D., and Thompson, G. A., 1959, Geology and quicksilver deposits of the Terlingua district, Texas: U.S. Geological Survey Professional Paper 312.

APPENDICES

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
1	Monsanto Chemical Intermediates Co. Chocolate Bayou Plant Alvin, Texas	1	Brazoria	Miocene sands 2,000-6,400 ft
2	Monsanto Chemical Intermediates Co. Chocolate Bayou Plant Alvin, Texas	2	Brazoria	Miocene sands 4,987-5,309 ft
3	Potash Company of America Dumas Plant Dumas, Texas	1	Moore	Glorieta sands 1,125-1,250 ft
4	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	4	Victoria	Oakville and Catahoula Formations 3,000-4,700 ft
13	Monsanto Chemical Intermediates Co. Chocolate Bayou Plant Alvin, Texas	3	Brazoria	Miocene sands 5,300-7,000 ft
14	Celanese Chemical Company Bay City Plant Bay City, Texas	2	Matagorda	Miocene sands 3,400-3,700 ft
16	El Paso Products Company Odessa Petro-Chemical Odessa, Texas	1	Ector	San Andres Formation 5,000-5,800 ft
20	Diamond Shamrock Corp. McKee Plant Amarillo, Texas	3	Moore	Glorieta sands 1,108-1,240 ft
28	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	5	Victoria	Oakville and Catahoula Formation 3,000-4,200 ft
29	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	6	Victoria	Oakville and Catahoula Formation 3,000-4,200 ft
30	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	7	Victoria	Oakville and Catahoula Formation 3,000-4,200 ft
32	Celanese Chemical Co. Bay City Plant Bay City, Texas	2	Matagorda	Miocene sands 3,300-3,700 ft
33	Celanese Chemical Co. Clear Lake Plant Houston, Texas	1	Harris	Miocene sands 4,600-5,400 ft
34	GAF Corporation Texas City Plant Texas City, Texas	1	Galveston	Miocene sands 3,624-4,018 ft
36	Arco Chemical Co. Lyondell Plant Channelview, Texas		Harris	Frio sands 5,500-6,950 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
45	Celanese Chemical Co. Clear Lake Plant Houston, Texas	2	Harris	Miocene sands 4,600-5,400 ft
49	Celanese Chemical Co. Bay City Plant Bay City, Texas	4	Matagorda	Miocene sands 3,350-3,575 ft
51	Badische Corporation Chemical Operations Plant Freeport, Texas	1	Brazoria	Miocene sands 5,900-6,200 ft
54	E. I. duPont de Nemours and Co., Inc. Sabine River Works Orange, Texas	ADN #3	Orange	Miocene sands 4,300-5,000 ft
55	E. I. duPont de Nemours and Co., Inc. Sabine River Works Orange, Texas	4	Orange	Miocene sands 4,300-5,000 ft
56	E. I. duPont de Nemours and Co., Inc. Sabine River Works Orange, Texas	5	Orange	Miocene sands 4,300-5,000 ft
57	E. I. duPont de Nemours and Co., Inc. Sabine River Works Orange, Texas	6	Orange	Miocene sands 4,300-5,000 ft
67	Phillips Petroleum Co. Plains Co. Polymer Plant Borger, Texas	D-2	Hutchinson	Granite wash 3,840-5,000 ft
68	Phillips Petroleum Co. Plains Co. Polymer Plant Borger, Texas	D-3	Hutchinson	Granite wash 3,840-5,000 ft
70-c	Chemical Waste Management Corpus Christi Facility Corpus Christi, Texas	1	Nueces	Miocene sands 3,470-4,700 ft
73-c	Malone Service Company Malone Plant Texas City, Texas	1	Galveston	Miocene sands 4,000-5,000
80	American Oil Company Texas City Plant Texas City, Texas	1	Galveston	Miocene sands 5,830-7,000 ft
82	E. I. duPont de Nemours and Co., Inc. Houston Plant La Porte, Texas	1	Harris	Miocene sands and Frio Formation 4,800-7,000 ft
83	E. I. duPont de Nemours and Co., Inc. Houston Plant La Porte, Texas	2	Harris	Miocene sands and Frio Formation 4,800-7,000 ft
88	El Paso Products Company Odessa Petro-Chemical Complex Odessa, Texas	2	Ector	San Andres Formation 4,900-5,900 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
91	Monsanto Company Texas City Plant Texas City, Texas	1	Galveston	Miocene sands 5,000-7,500 ft
92	Cities Service Fractionators Mont Belvieu Plant Mont Belvieu, Texas	1	Chambers	Pliocene sand 2,104-2,120 ft
99	Badische Corporation Freeport Plant Freeport, Texas	2	Brazoria	Catahoula Formation 6,700-7,400 ft
100	E. I. duPont de Nemours and Co., Inc. Beaumont Works Beaumont, Texas	1	Jefferson	Miocene and Frio Formations 3,800-4,900 ft 6,800-7,700 ft
101	E. I. duPont de Nemours and Co., Inc. Beaumont Works Beaumont, Texas	2	Jefferson	Miocene and Frio Formation 3,800-4,900 ft 6,800-7,700 ft
102	Diamond Shamrock Corporation McKee Plant Amarillo, Texas	4	Moore	Granite wash 4,790-5,080 ft
105	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	8	Victoria	Miocene and Oligocene sands 3,200-4,600 ft
106	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	9	Victoria	Miocene and Oligocene sands 3,200-4,600 ft
107	Witco Chemical Company Marshall Plant Marshall, Texas	2	Harrison	Blossom Formation 2,450-2,500 ft
109	E. I. duPont de Nemours and Co., Inc. Ingleside Plant Ingleside, Texas	2	San Patricio	Oakville Formation 4,050-4,140 ft
110	Celanese Chemical Company Bay City Plant Bay City, Texas	1-A	Matagorda	Miocene sands 3,300-5,900 ft
111	Witco Chemical Corporation Retzloff Chemical Plant Houston, Texas	1	Fort Bend	Frio Formation 5,450-7,500 ft
113	GAF Corporation Texas City Plant Texas City, Texas	3	Galveston	Miocene sands 3,750-5,800 ft
114	GAF Corporation Texas City Plant Texas City, Texas	2	Galveston	Miocene sands 3,550-5,700 ft
115	Cominco-American Camex Operations Borger Plant Borger, Texas	1	Hutchinson	Granite wash and Ellenberger Formation 3,450-6,300 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
117	Jetco Chemicals Inc. Amine Plant Corsicana, Texas	1	Navarro	Woodbine Formation 2,500-3,200 ft
120	Iowa Beef Processors, Inc. Amarillo Hide Processing Plant Amarillo, Texas	1	Potter	Wolfcamp limestones and dolomite 4,000-5,000 ft
121	E. I. duPont de Nemours and Co., Inc. Ingleside Plant Ingleside, Texas	3	San Patricio	Catahoula Formation 5,147-5,242 ft
122	Pennwalt Corporation Lucidol Division Crosby Plant Crosby, Texas	1	Harris	Frio Formation 6,000-6,700 ft
123	U.S. Steel Corporation Texas Uranium Operations Clay West Mining Project George West, Texas	1	Live Oak	Yegua Formation 3,550-4,500 ft
124	U.S. Steel Corporation Texas Uranium Operations Clay West Mining Project George West, Texas	2	Live Oak	Yegua Formation 3,550-4,500 ft
125	Velsicol Chemical Corporation Beaumont Plant Beaumont, Texas	4	Jefferson	Miocene sands 3,500-5,100 ft
126	El Paso Products Company Odessa Petro-Chemical Complex Odessa, Texas	3	Ector	San Andres Formation 4,900-5,900 ft
127	Amoco Oil Co. Texas City Plant Texas City, Texas	2	Galveston	Miocene sands 5,830-6,459 ft
128	Amoco Oil Company Texas City Plant Texas City, Texas	3	Galveston	Miocene sands 5,830-7,000 ft
129	Asarco, Inc. Amarillo Copper Refinery Amarillo, Texas	1	Potter	Brown dolomite 4,000-5,700
130	U.S. Steel Corporation Texas Uranium Operations Burns Mining Project Corpus Christi, Texas	3	Live Oak	Yegua Formation 3,600-4,600 ft
132	E. I. duPont de Nemours and Co., Inc. Sabine River Works Orange, Texas	8	Orange	Miocene sands 4,230-4,380 ft
133	American Magnesium Co. Snyder Plant Snyder, Texas	1	Scurry	Clear Fork Formation 2,600-2,700 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
134	Chevron Palangana Dome Site Benavides, Texas	1	Duval	Yegua Formation 5,968-6,597 ft
135	Texaco, Inc. Amarillo Plant Amarillo, Texas	1	Potter	Wolfcamp limestone and dolomite 3,950-5,300 ft
136	Texaco, Inc. Amarillo Plant Amarillo, Texas	2	Potter	Wolfcamp limestone and dolomite 3,950-5,300 ft
138-c	Malone Service Company Oil Reclamation Plant Texas City, Texas	2	Galveston	Miocene sands 3,800-7,000 ft
139	Witco Chemical Company Retzloff Chemical Plant Houston, Texas	2	Fort Bend	Frio Formation 5,400-7,400 ft
140	U.S. Steel Corporation Texas Uranium Operations Boots Mining Project Corpus Christi, Texas	4	Live Oak	Yegua Formation 3,550-4,550 ft
141	U.S. Steel Corporation Texas Uranium Operations Johnson Mining Project Corpus Christi, Texas	5	Live Oak	Yegua Formation 3,240-4,150 ft
142	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	1	Victoria	Catahoula and Greta Formations 3,000-4,700 ft
143	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	2	Victoria	Catahoula and Greta Formations 3,000-4,700 ft
144	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	3	Victoria	Catahoula and Greta Formations 3,000-4,700 ft
145	E. I. duPont de Nemours and Co., Inc. Victoria Plant Victoria, Texas	10	Victoria	Oakville, Catahoula and Greta Formations 3,000-4,700 ft
146-c	Chaparral Disposal Company Odessa, Texas	1	Ector	San Andres Formation 4,900-5,750 ft
147-c	Merichem Haden Road Plant Houston, Texas	1	Harris	Frio Formation 6,400-7,200 ft
148	Arco Chemical Co. Channelview Plant Channelview, Texas	1	Harris	Frio Formation 4,900-7,200 ft
149	E. I. duPont de Nemours and Co., Inc. Houston Plant La Porte, Texas	3	Harris	Miocene sands 4,850-4,900 ft 5,180-5,340 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
150	Nufuels Corporation Holiday-El Mesquite Corpus Christi, Texas	1	Duval	Yegua Formation 3,780-4,370 ft
151	Nufuels Corporation Holiday-El Mesquite Corpus Christi, Texas	2	Duval	Yegua Formation 3,780-4,370 ft
152	Corpus Christi Petrochemical Co. Olefins Plant Corpus Christi, Texas	1	Nueces	Jackson Group 7,130-7,800 ft
153	Corpus Christi Petrochemical Co. Olefins Plant Corpus Christi, Texas	2	Nueces	Jackson Group 7,130-7,800 ft
154	El Paso Product Company Odessa Petro-Chemical Complex Odessa, Texas	4	Ector	San Andres Formation 4,900-5,900 ft
155	Velsicol Chemical Corp. Beaumont Plant Beaumont, Texas	5	Jefferson	Miocene sands 4,600-6,400 ft
156	Wyoming Minerals Corp. Lamprecht Mining Project Westinghouse Uranium Resources Three Rivers, Texas	2	Live Oak	Wilcox Group 6,200-6,700 ft
157-c	Empak, Inc. (Geo-Ject) Houston, Texas	1	Harris	Frio Formation 6,800-7,500 ft
158	Mobil Oil Corporation Beaumont Refinery Beaumont, Texas	1	Jefferson	Oakville Formation 3,700-4,800 ft
159	IEC Corporation Zamzow Mine Tuleta, Texas	1	Live Oak	Yegua Formation 3,050-3,740 ft
160-c	Chemical Waste Management Port Arthur, Texas	1	Jefferson	Miocene sands 6,700-7,200 ft
161-c	Chemical Waste Management Port Arthur, Texas	2	Jefferson	Miocene sands 6,700-7,200 ft
162	Arco Chemcial Co. Channelview Plant Channelview, Texas	2	Harris	Frio Formation 5,150-7,250 ft
163	Vistron Corporation Port Lavaca, Texas	1	Calhoun	Frio Formation 6,750-8,250 ft
164	Vistron Corporation Port Lavaca, Texas	2	Calhoun	Frio Formation 6,750-8,250 ft
165	Vistron Corporation Port Lavaca, Texas	3	Calhoun	Frio Formation 6,750-7,500 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
166-c	Chemical Waste Management, Inc. Corpus Christi Facility Corpus Christi, Texas	2	Nueces	Oakville and Catahoula 3,470-4,450 ft
167-c	Waste Water, Inc. Houston, Texas	1	Brazoria	Anahuac Formations 6,150-6,350 ft
168	Everest Minerals Corporation Hobson Mine Hobson, Texas	1	Karnes	Wilcox Group 5,610-6,500 ft
169-c	Disposal Systems, Inc. (DSI) Houston, Texas		Harris	Frio Formation 6,800-7,300 ft
170	Westinghouse Electric Corporation Bruni Mine, South Texas Westinghouse Uranium Resources Bruni, Texas	1	Webb	Yegua Formation 2,900-3,950 ft
172	Shell Chemical Co. Deer Park Manufacturing Complex Deer Park, Texas	1	Harris	Frio Formation 6,800-7,650 ft
173	Shell Chemical Co. Deer Park Manufacturing Complex Deer Park, Texas	2	Harris	Frio Formation 6,800-7,650 ft
174	U.S. Steel Corporation Texas Uranium Operation Brown Mine Corpus Christi, Texas	6	Live Oak	Yegua Formation 3,200-4,300 ft
175	American Magnesium Company Snyder Plant Snyder, Texas	A	Scurry	Ellenburger Formation 8,100-8,500 ft
176	American Magnesium Company Snyder Plant Snyder, Texas	B	Scurry	Ellenburger Formation 8,100-8,500 ft
180	Witco Chemical Company Marshall Plant Marshall, Texas	3	Harrison	Rodessa Formation 5,724-6,040 ft
182	Mobil Oil Corporation Nell Mining Project Corpus Christi, Texas	2	Live Oak	Wilcox Group 6,180-7,600 ft
183	U.S. Steel Corporation Texas Uranium Operations Burns Mining Project Corpus Christi, Texas	7	Live Oak	Yegua Formation 3,500-4,500 ft
185	Caithness Mining Corp. Hebbronville, Texas	1	Duval	Yegua Formation 4,100-4,900 ft
186-c	Gibraltar Wastewaters, Inc. Austin, Texas	1	Smith	Woodbine Group 5,200-5,700 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
187	Everest Minerals Corp. Las Palmas Mining Project Corpus Christi, Texas	2	Duval	Yegua Formation 4,250-5,200 ft
188	E. I. duPont de Nemours and Co., Inc. Beaumont Works Plant Beaumont, Texas	3	Jefferson	Frio Formation 5,300-6,150 ft 6,800-7,700 ft
189	Conoco Inc. Trevino Mine Hebbronville, Texas	1	Duval	Yegua Formation 3,800-4,700 ft
190	I.E.C. Corporation Pawnee Mine Tuleta, Texas	2	Bee	Yegua Formation 2,500-3,400 ft
191	E. I. duPont de Nemours and Co., Inc. Sabine River Works Orange, Texas	9	Orange	Miocene sands
192	Diamond Shamrock Corp. McKee Plant Amarillo, Texas	5	Moore	Granite wash 4,808-5,092 ft
194	Everest Minerals Corp. Mount Lucas Mine Corpus Christi, Texas	3	Live Oak	Yegua Formation 5,200-5,900 ft
195	Tenneco Uranium Bruni Mine Houston, Texas	1	Webb	Queen City Formation 5,650-6,150 ft
196	Monsanto Company Texas City, Texas	2	Galveston	Miocene sands 6,100-7,200 ft
197	Nufuels Corporation Corpus Christi, Texas	3	Duval	Yegua Formation 3,550-4,400 ft
201	Velsicol Chemical Corp. Beaumont, Texas	6	Jefferson	Miocene sands 4,200-6,000 ft
207	E. I. duPont de Nemours and Co., Inc. Sabine Rivers Works Orange, Texas	10	Orange	Miocene sands 4,300-5,710 ft
210	Celanese Bishop, Texas	3	Nueces	Anahuac Formation 4,200-4,670 ft
212	Celanese Bishop, Texas	2	Nueces	Anahuac Formation 4,200-4,670 ft
213	Arjay, Inc. Houston, Texas	1	Harris	Catahoula Formation 4,000-4,500 ft
222	W. R. Grace & Company Organic Chemicals Division Lexington, Massachusetts	1	Harris	Frio Formation 6,600-7,535 ft

Appendix 1

Industrial Waste Disposal Wells in Texas, 1983
(c suffixed to well number designates commercial waste disposal well.)—Continued

Well number shown on figure 3-1	Company, plant name and address	Co. well no.	County	Formation and depth
223	W. R. Grace & Company Organic Chemicals Division Lexington, Massachusetts	2	Harris	Frio Formation 6,600-7,535 ft
224	Monsanto Chemical Intermediates Co. Chocolate Bayou Alvin, Texas	4	Brazoria	Miocene sands 5,800-6,150 ft
225	Diamond Shamrock Corp. McKee Plant Amarillo, Texas	1	Moore	Glorieta Formation 1,106-1,200 ft
226	Diamond Shamrock Corp. McKee Plant Amarillo, Texas	2	Moore	Glorieta Formation 1,106-1,146 ft 1,160-1,210 ft

Appendix 2

Uranium Solution Mines in Texas, 1983

Mine code shown on figure 4-1	Company	Mine	Formation (aquifer)	Original mining fluid	Yield of wells	Average porosity (percent)	Formation permeability (gpd/ft.^{2})	Average dissolved solids of ground water in mine area (mg/l)	Lease area (acres)	County
CA1	Caithness Mining Corporation	McBryde	Oakville	Sodium Na_2CO_3	small to moderate	23	35.8	1,354 slightly saline water	401.25	Duval
CA2	do	Silver Lake	do	do	do	23	35.8	1,030 fresh to slightly saline water	2,000	Jim Hogg
CH	Chevron	Palangana	Goliad	Ammonia $(NH_4)_2CO_3$	small to large	23	36.4	878 fresh to slightly saline water	6,272.0	Duval
CO	Conoco, Inc.	Trevino	Oakville	Sodium Na_2CO_3	small to moderate	24	65	1,606 slightly saline water	5,750.69	Do.
E1	Everest Minerals Corporation	Hobson	Jackson Group Whitsett Formation Tordilla Sandstone	Ammonia $(NH_4)_2CO_3$	small	23	30	1,111 slightly saline water	182.0	Karnes
E2	do	Mt. Lucas	Goliad	Sodium Na_2CO_3	very small to large	23	36.4	850 fresh to slightly saline water	4,360.0	Live Oak
E3	do	Las Palmas	Oakville	Ammonia $(NH_4)_2CO_3$	small to moderate	23	17.1	1,347 slightly saline water	3,100.0	Duval and Jim Hogg
I1	Intercontinental Energy, Corp.	Pawnee	do	do	very small to large	23	182	903 fresh to slightly saline water	325	Bee
I2	do	Zamzow	do	do	do	23	182	2,328 slightly saline water	316	Live Oak
M1	Mobil Oil Corporation	O'Hern	Catahoula Soledad Member	do	small to moderate	20	109.2	883 fresh water	270	Webb
M2	do	Holiday	do	Sodium Na_3CO_3	do	20	109.2	989 fresh to slightly saline water	2,033.5	Duval
M3	do	El Mesquite	do	do	do	20	109.2	861 fresh to slightly saline water	2,240	Do.
M4	do	Piedre Lumbre 202	do	do	do	20	109.2	5,630 moderately saline water	156	Do.
M5	do	Brelum 199	do	do	do	20	109.2	5,630 moderately saline water	165	Do.
M6	do	Piedre Lumbre 200-201	do	do	do	20	109.2	5,630 moderately saline water	192.7	Do.
M7	do	Piedre Lumbre 201-205	do	do	do	20	109.2	5,630 moderately saline water	94.0	Do.
M8	do	Brelum 106-200	do	Ammonia $(NH_4)_2CO_3$	do	20	109.2	6,110 moderately saline water	447	Do.
M9	do	Nell	do	do	very small to small	20	109.2	5,383 moderately saline water	1,230.31	Bee and Live Oak
S	Solution Engineering	--	Mine Tailings	Acid H_2SO_4	no wells	30	?	30 very low pH	1,500.0	Karnes
TN	Tenneco	West Cole	Catahoula Soledad Member	Sodium Na_2CO_3	small to moderate	20	12	956 fresh to slightly saline water	680.0	Webb
T	Texaco	Hobson	Jackson Group Whitsett Formation Deweesville Sandstone	do	small	23	109.2	1,298 fresh to slightly saline water	845.7	Karnes
US1	U.S. Steel	Moser	Oakville	Ammonia $(NH_4)_2CO_3$	very small to large	23	176	892 fresh to slightly saline water	1,249.0	Live Oak

Appendix 2

Uranium Solution Mines in Texas, 1983--Continued

Mine code shown on figure 4-1	Company	Mine	Formation (aquifer)	Original mining fluid	Yield of wells	Average porosity (percent)	Formation permeability (gpd/ft.^{2})	Average dissolved solids of ground water in mine area (mg/l)	Lease area (acres)	County
US2	U.S. Steel	Burns	Oakville	Ammonia $(NH_4)_2CO_3$	very small to large	25	250	788 fresh water	1,012.7	Live Oak
US3	do	Clay West	do	do	do	23	182	919 fresh to slightly saline water	884.0	Do.
US4	do	Boots/Brown	do	do	do	23	182	811 fresh to slightly saline water	1,025.3	Do.
US5	do	Pawlik	do	do	do	23	182	1,657 fresh to slightly saline water	1,698.0	Do.
UR1	Uranium Resources, Inc.	Longoria	Catahoula Soledad Member	Sodium Na_2CO_3	small to moderate	20	25.3	1,897 slightly saline water	722.68	Duval
UR2	do	Benavides	do	do	do	20	109.2	1,531 slightly saline water	187.0	Do.
W1	Westinghouse Electric Corporation	Bruni	do	Ammonia $(NH_4)_2CO_3$	do	25	8.9	1,238 fresh to slightly saline water	1,480.0	Webb
W2	do	Lamprecht	Oakville	do	very small to large	23	200	1,883 moderately saline water	957.0	Live Oak
W3	do	Benham	do	Sodium Na_2CO_3	do	23	156.6	2,888 moderately saline water	1,240.0	Bee and Live Oak

Appendix 3

Brine Stations in Texas as of July 1984

Station number shown on figure 5-1	Owner	Station name	County	Location	Status
1	Permian Brine Sales, Inc.	Crockett West	Crockett	27 miles west of Ozona on Interstate 10	in operation
3	do	Imperial	Pecos	2 miles south of Imperial	Do.
4	El Rey Salt Company	Lubbock	Lubbock	7 miles east-northeast of Lubbock	Do.
5	John Greer	Sheffield	Pecos	5 miles northwest of Sheffield	Do.
6	Hix Brine Company	Kermit	Winkler	1.2 miles north of State Highway 115 and 18 in Kermit	Do.
7	Mansell Brine Sales, Inc.	Andrews	Andrews	1 mile east of Andrews on Highway 176	Do.
8	do	Barstow	Ward	1.5 miles northwest of central Barstow	Do.
9	do	Basin	Ector	0.4 of a mile east-northeast of Loop 338 in northwest Odessa	Do.
10	do	Crane No. 1	Crane	11 miles northwest of Crane	Do.
12	do	Goldsmith	Ector	0.15 of a mile east of the junction of Farm Road 866 and State Highway 158 in eastern Goldsmith	Do.
13	do	Kermit	Winkler	0.3 of a mile east-northeast of the intersection of State Highway 302 and 115 southwest of Kermit	Do.
14	do	Mentone	Loving	1.5 miles southwest of Mentone	Do.
15	do	North Odessa	Ector	0.6 of a mile north-northeast of the intersection of State Highway 385 and Loop 338 near Odessa	Do.
16	do	Seminole	Gaines	3 miles southwest of the intersection of Southwest Avenue and State Highway 181 in Seminole	Do.
17	do	Sheffield	Pecos	5 miles northwest of Sheffield	Do.
18	Mansell Brine Sales, Inc.	South Odessa	Ector	located on Pool Road about 3.3 miles east of the intersection of Grandview and Pool Roads	Do.
19	Cox Transport Company	Monahans	Ward	0.2 of a mile northwest of the intersection of Loop 464 and U.S. Highway 80 west of Monahans	Do.
20	Permian Brine Sales, Inc.	Amarillo	Potter	0.25 of a mile east of Western Avenue on St. Francis Avenue in Amarillo	Do.
21	do	Andrews	Andrews	2 miles north of Andrews on Highway 385	Do.
22	do	Barstow	Ward	east of Farm Road 516 near its junction with Pecos Street in northern Barstow	Do.
23	do	Coyanosa	Reeves	3 miles north of Coyanosa	Do.
24	do	Fort Stockton	Pecos	2.4 miles west of the junction of State Highway 18 and U.S. Highway 290 in Fort Stockton	Do.

Appendix 3

Brine Stations in Texas as of July 1984—Continued

Station number shown on figure 5-1	Owner	Station name	County	Location	Status
25	Permian Brine Sales, Inc.	Grandfalls	Ward	on the north corner of the intersection of First Street and Avenue G in Grandfalls	in operation
26	do	East Kermit	Winkler	1.2 miles north of the intersection of State Highway 18 and 115 in Kermit	Do.
27	do	Mobeetie	Wheeler	2 miles west of Mobeetie on State Highway 152	Do.
28	do	North Pecos	Reeves	northeast of U.S. Highway 80 in Pecos	Do.
29	do	Odessa	Ector	on Tenth Street, 1.6 miles north of the intersection of Farm Road 1936 and Interstate Highway 20 in Odessa	Do.
30	do	Orla	Reeves	0.5 of a mile southeast of the intersection of U.S. Highway 285 and State Highway 652 in Orla	Do.
31	do	Ozona	Crockett	22 miles northwest of Ozona	Do.
32	do	Pyote	Ward	1.9 miles northwest of the intersection of Farm Road 2355 and State Highway 115 in Pyote	Do.
33	B & L Brine Sales, Inc.	Seminole	Gaines	4 miles east of Seminole Highway 385 on the north side of U.S. Highway 180	Do.
34	Salty Brine, Inc.	Denver City	Yoakum	0.8 of a mile east of the junction of State Highway 83 and East County Road east of Denver City	Do.
36	Texas Brine Corporation	.Spindletop	Jefferson	on property adjacent to West Port Arthur Road in Beaumont	Do.
38	Trey Trucks Division of Norton Wells Service, Inc.	Andrews	Andrews	west of the northwest truck bypass in Andrews	Do.
39	do	McElroy	Crane	0.2 of a mile south of the intersection of East County Road and State Highway 329 in Crane	Do.
40	Vulcan Materials Company	Denver City	Yoakum	east of Denver City	Do.
41	Wilson Systems, Inc.	Fort Stockton	Pecos	3.75 miles north of the intersection of State Highway 18 and U.S. Highway 290 in Fort Stockton	Do.
42	do	McCamey	Upton	5.4 miles northwest of McCamey	Do.
43	do	Midland	Midland	3.6 miles east-southeast of the intersection of Interstate Highway 20 and State Highway 158 in Midland	Do.
44	do	Monahans	Ward	3.4 miles northwest of the intersection of State Highway 18 and U.S. Highway 80 in Monahans	Do.
45	do	Pecos	Reeves	6.7 miles southeast of Pecos	Do.

Appendix 3

Brine Stations in Texas as of July 1984—Continued

Station number shown on figure 5-1	Owner	Station name	County	Location	Status
46	Ford Chapman	Mentone	Loving	0.25 of a mile west of Mentone on State Highway 302	in operation
47	Cox Transport Company	North Mine	Winkler	12 miles northwest of Monahans	Do.
50	Permian Brine Sales, Inc.	West Kermit	do	2.7 miles west of the intersection of State Highway 302 and 115	Do.
51	Trey Production Company	Crane	Crane	11 miles south of Imperial on Farm Road 1053	Do.
52	Chief Transport	Monahans No. 1	Ward	in Monahans at 3705 South Loop 464	Do.
54	D. D. Poyner Construction Company	Big Lake	Reagan	2 blocks south of U.S. Highway 67 outside of Big Lake	Do.
55	S. D. Company	S. D. Brine	do	0.9 of a mile west of Big Lake on U.S. Highway 67	Do.
56	Salty Sales, Inc.	Imperial	Pecos	north of Imperial, off of Farm Road 1053	Do.
57	Diamond Shamrock	McKee	Moore	7 miles south of Sun Ray and 10 miles north of Dumas located on Farm Road 119	Do.
58	Mansell Brine Sales, Inc.	Lineberry	Loving	10 miles northeast of Mentone	Do.
60	PPG Industries, Inc.	Palangano	Duval	6 miles north of Benavides on the east side of Farm Road 3196	Do.
61	Permian Brine Sales, Inc.	Big Spring	Howard	north at the Salem exit off Interstate 20 near Big Spring	Do.
62	do	East Mentone	Loving	10 miles east of Mentone on the north side of State Highway 302	Do.
63	do	North Mentone	do	0.75 of a mile north of Mentone at the "Y" of County Roads	Do.
64	Norton Well Service dba Cox Transport Company	Wickett	Ward	0.3 of a mile west of the intersection of FM 1219 and U.S. Highway 80 near Wickett	Do.
65	Permian Brine Sales, Inc.	Sand Hills Ranch	Crane	Located at the junction of Farm Road 1233 and 1053	Do.
66	Mansell Brine Sales, Inc.	Levelland	Hockley	North of State Highway 1585, 2 miles west of its intersection with U.S. Highway 385	Do.
67	M-P Construction Co.	Crane	Crane	0.5 of a mile south of the intersection of East County Road and State Highway 329, east of Crane	Do.
68	United Salt Corporation	Blue Ridge Dome	Fort Bend	3 miles east of Missouri City	Do.
69	Permian Brine Sales, Inc.	Snyder	Scurry	2 miles north of Snyder along State Highway 208 (College Avenue)	to be constructed

Appendix 3

Brine Stations in Texas as of July 1984—Continued

Station number shown on figure 5-1	Owner	Station name	County	Location	Status
70	K. E. Davis dba Snyder Brine Company	Snyder No. 1	do	100 College Avenue in Snyder	in operation
71	do	Snyder No. 2 Northyard	do	0.75 of a mile north of the Snyder city limits, 2 blocks east of Highway 208 (College Avenue)	Do.
72	Southwest Brine, Inc.	Plains	Yoakum	On the south side of Highway 82, 0.6 of a mile west of the intersection of Highway 380 and Highway 82	Do.
73	Permian Brine Sales, Inc.	Midland Farms	Andrews	2.5 miles east-southeast of the Midland Farm Oil Field	Do.
74	DBI Service, Inc.	Seminole	Gaines	4 miles north of Seminole on the west side of Highway 385	to be constructed
76	Mansell Brine Sales, Inc.	North Andrews	Andrews	8 miles north of Andrews off of U.S. Highway 385	in operation
77	do	West Andrews	do	12 miles southwest of Andrews, south of State Highway 115	to be permitted
78	Mr. Harold Massey	Massey	Ward	5 miles north of the intersection of FM 1219 and U.S. Highway 80 near Wickett	in operation
79	Pace Brine, Inc.	Levelland	Hockley	3.5 miles south and 1.0 mile west of Levelland	Do.
80	Pool Company, Inc., dba Pool Well Servicing Company	Pool	Reagan	2.5 miles north of Big Lake, on the east side of Highway 33	to be permitted
81	Permian Brine Sales, Inc.	Stanton	Martin	North of Stanton on the west side of Highway 137	Do.
82	Permian Brine Sales, Inc.	Lamesa	Dawson	0.5 of a mile northwest of Lamesa	Do.

Appendix 4

Inventoried Sewage Disposal Wells in Texas That Serve 20 or More Persons as of December 31, 1983

Well location latitude and longitude		Owner	Nature of business	Number of wells	Date completed	People served	Comments
			NUECES COUNTY				
27°51'53"	97°37'31"	Calallen Independent School District	Jr. and Sr. high school	1	1954	300+	Plugged and abandoned 1981.
27°51'43"	97°37'47"	do	do	1	1973		WDW-108. Plugged and abandoned 1981.
27°51'52.5"	97°37'30.5"	do	Elementary school	1	1966	350	WDW-27. Plugged and abandoned 1981.
27°51'47"	97°37'49"	Pax Christi Residence	Orphanage	2	1974	40	WDW-112.
27°49'31"	97°38'08"	Otis Engineering	Oilfield service company	3-5	1967	20+	--
27°49'29"	97°32'47"	Texas Barbeque	Restaurant	18-20	1979	20+	--
24°48'56"	97°28'40"	Mack Body Shop	Body shop	2	1975	20	--
27°48'56"	97°28'39"	Frell Industries	Tank fabricator	3	1975	50	--
27°48'57"	97°28'38.5"	Nueces Grain	Grain warehouse	2	--	--	--
27°48'56"	97°28'38"	Mack Services	Diesel sales and service	6	1975	20	--
27°48'56"	97°28'34"	Cummins Diesel	do	3	1967	22	--
			ROCKSPRINGS, EDWARDS COUNTY				
30°02'03"	100°13'04"	Oak Lane Mobile Park	Mobile home park	1	--	80-100	--
30°01'01"	100°12'37"	Edwards County Memorial Hospital	Hospital	1	--	20+	--
30°00'60"	100°12'30"	Spring Inn	Hotel	1	--	20-50	--
30°01'05"	100°12'23"	Villareal's	Mobile home park (rental)	1	1975	20-25	--
30°01'05"	100°12'12"	Rocksprings Independent School District	Field house	1	--	20+	--
30°01'03"	100°12'15"	do	Gymnasium	1	--	100+	--
30°01'04"	100°12'15"	do	High school	1	--	113	--
30°00'60"	100°12'13"	do	Elementary school	1	--	485	--
30°00'54"	100°12'25"	Mesa Motel	Motel	1	--	20-40	--
30°00'40"	100°12'22"	Villareal Mobile Home Space	Mobile home park	1	1975	40-50	--
			HIGH PLAINS, POTTER COUNTY				
35°17'43"	101°50'07"	Cherry Avenue Mobil Home Park	Mobile home park	7	--	80-200	--
35°18'42"	101°50'08"	Dumas Hiway Trailer Park	Trailer park	1	--	40-200	--
			GRAY COUNTY				
--	--	Sanders Mobile Home Park	Mobile home park	3-5	--	20+	--
			OLDHAM COUNTY				
--	--	Best Western Motel	Motel	--	--	--	--
			HIDALGO COUNTY				
--	--	Bentson Grove Trailer Park	Trailer park-laundromat	1	1980	20+	--
			COOKE COUNTY				
33°37'08"	97°07'54"	Aughtry's Flowers	Flower shop-water softener	1	1965	--	WDW-22. Plugged and abandoned 1974.
			SAN PATRICIO COUNTY				
27°53'54"	97°14'51"	San Patricio Municipal Water District	Washdown water	1	1968	--	Plugged and abandoned 1979.