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Supplementary Documentation for an Environmental Impact Statement Regarding the Pantex Plant

Geohydrology

Los Alamos

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GEOHYDROLOGY

by

William D. Purtymun and Naomi M. Becker

ABSTRACT

This report documents work performed in support of preparation of an Environmental Impact Statement (EIS) regarding the Department of Energy's Pantex Plant near Amarillo, Texas. The Pantex Plant is located in Carson County on the Southern High Plains of West Texas. The report presents regional geology, geologic structure, and hydrology along with detail geology and hydrology at and adjacent to the Pantex Plant. The Ogallala Formation forms the upper surface of the High Plains and contains the principal aquifer. Water from the aquifer is pumped for municipal, industrial, and agricultural supply. The past water production and future water supply for the plant are discussed. Also, the annual water requirements for the County are projected along with hydrologic effects on the aquifer at and adjacent to the plant until the year 2020. The chemical quality of surface and ground water is presented. A brief description is given of sanitary landfill operations at the plant and natural resources of the adjacent area. Geologic and hydrologic hazards in the area are discussed.

I. INTRODUCTION

This report documents work performed in support of preparation of an Environmental Impact Statement (EIS) regarding the Department of Energy's Pantex Plant near Amarillo, Texas. The EIS addresses continuing nuclear weapons operations at Pantex and the construction of additional facilities to house those operations. The EIS was prepared in accordance with current regulations under the National Environmental Policy Act. Regulations of the Council on Environmental Quality (40 CFR 1500) require agencies to prepare concise EISs with less than 300 pages for complex projects. This report was prepared by Los Alamos National Laboratory to document details of work performed and supplementary information considered during preparation of the Draft Environmental Impact Statement.

The study of the geohydrology of the Department of Energy (DOE) Pantex Plant and adjacent area was made to gain an understanding of the geology, hydrology (surface and ground water), natural resources, and geohydrologic hazards. The study was made through a literature search. Major investigations used in compiling the following report were Cronin 1964, Long 1961, McAdoo 1964, Bell and Morrison 1979, and Stewart 1980.

The Department of Energy reservation consists of two tracts of land: the Pantex Plant (14.2 mi^2 or 9100 acres of developed land, office building, warehouses, laboratories, test and production facilities) and Pantex Lake (1.7 mi^2 or 1077 acres of undeveloped land now leased for grazing) located about 2.5 mi northeast of the Pantex Plant. The Pantex Lake tract has been retained by DOE for possible future development of a water supply for Pantex Plant.

The data compiled from the literature search were expressed in English Units; thus, for consistency the information is also reported in English Units. The following table, conversion from English Units to Metric Units, is included for the reader who wishes to convert to Metric Units.

Multiply English Units	By	To Obtain Metric Unit
Inch (in.)	2.54	Centimeter (cm)
Foot (ft)	0.3048	Meter (m)
Mile (mi)	1.609	Kilometer (km)
Square mile (mi^2)	2.590	Square kilometer (km^2)
Acre-feet (acre-ft)	1233	Cubic meter (m^3)
Gallons (gal)	3.785	Liter (ℓ)
Gallons/minute (gpm)	0.06309	Liter/second (ℓ/s)
Gallons/day/square foot (gpd/ft^2)	0.0124	Square meter/day (m^2/day)
Cubic feet/second (ft^3/s)	0.02832	Cubic meter/second (m^3/s)
Fahrenheit (°F)	5/9 (F-32)	Centigrade (°C)

II. GEOGRAPHY

The Pantex Plant is located on the Southern High Plains in Texas. The Southern High Plains, the extension of the Great Plains Province that extends from Canada to Mexico, are located in eastern New Mexico and western Texas (Fig. 1). The plains are formed by Tertiary gravel deposits carried eastward from the Rocky Mountains (Lobeck 1941).

The Pantex Plant is northeast of Amarillo and south of the Canadian River (Fig. 1). The topography at the plant is comprised of relatively flat uplands

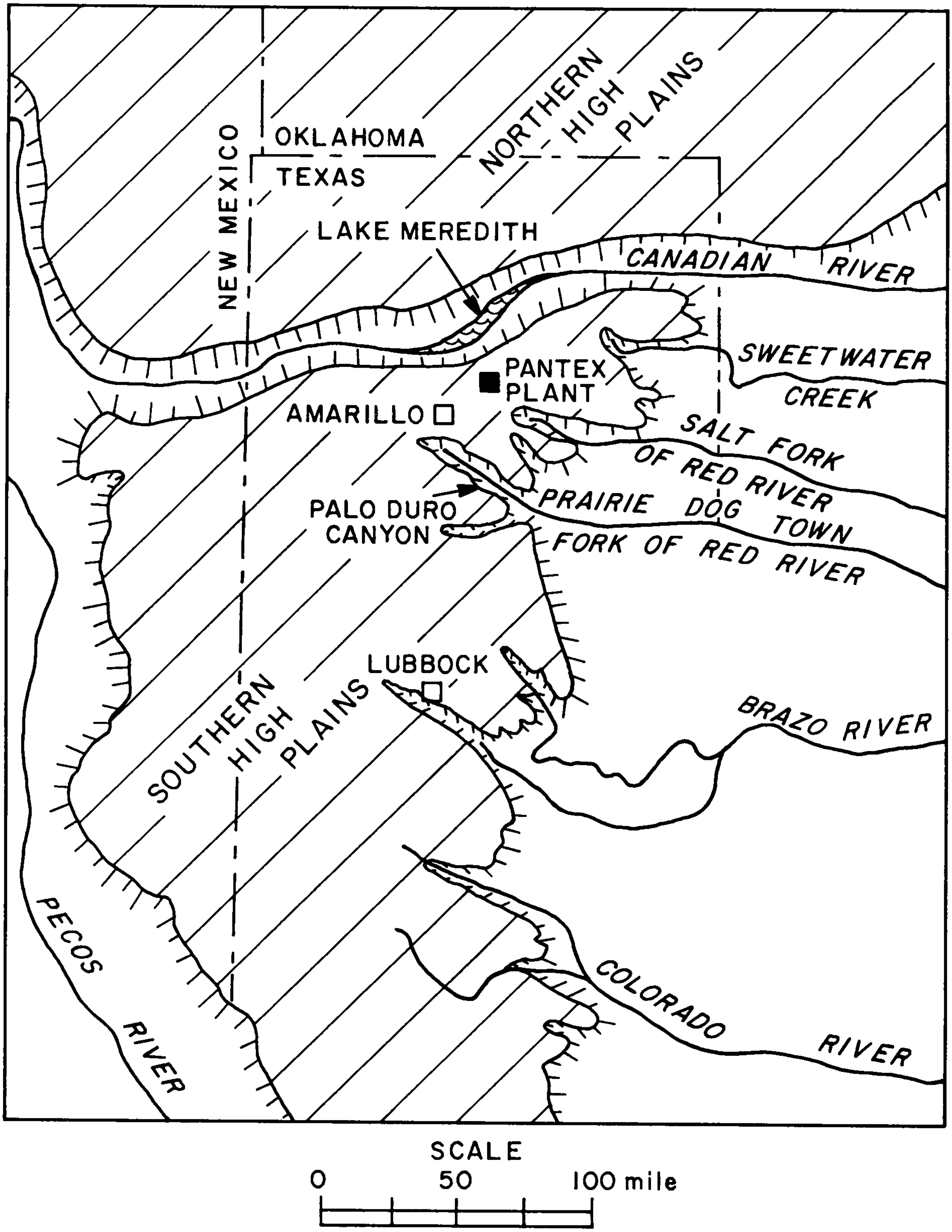

Fig. 1. Physiographic features of the Northern and Southern High Plains of Texas.

or plains containing playa basins. North of the plant 2 to 4 mi, rolling breaks form the escarpment above the Canadian River. The plains area is poorly drained. Nearly all the precipitation on the plains evaporates, infiltrates the surface soil, or if precipitation is heavy, runs off into the many playas (natural depressions). The breaks form the transition between the plains and the Canadian River north of Pantex and the escarpment and lower valleys east of Pantex. Runoff from the breaks contributes to the Canadian River and the streams along the eastern escarpment of the high plains.

The climate at the Pantex Plant is characterized by a wide range in temperature and precipitation, low humidity, and an occasional wind storm. The amount of precipitation varies widely within short distances. Local heavy rainfall within a short time is common (Long 1961).

Weather records have been collected at Amarillo since 1892 and are an indication of the climate at the Pantex Plant. The mean annual precipitation for this period at Amarillo is 20 in. Most of the precipitation falls during the growing season, starting in mid-April and extending into late October. The annual precipitation varies widely from year to year ranging from less than 10 in. in 1956 to more than 40 in. in 1923 (Long 1961).

The mean annual temperature is 57°F with the mean monthly temperatures ranging from 36°F in January to 78°F in July. The lowest temperature recorded at Amarillo was -16°F in February 1899 and the highest was 108°F in June 1953.

The low humidity, strong winds, and high summer temperatures result in a high evaporation rate from a free water surface. Based on observations of an evaporation pan at Amarillo, the annual average evaporation rate was 86 in. for the period 1951-59 or about 90 in. annually.

III. GEOLOGY

The oldest rocks in the area are of the Permian System that are exposed along the Canadian River and in Palo Duro Canyon (Fig. 2). Overlying the Permian rocks in the same general area are the sediments ("red beds") of the Triassic System. The gravels of the Tertiary System form the caprock of the plains at Pantex and the eroded breaks to the north along the escarpment or canyon cut by the Canadian River. The Tertiary gravels at the site are covered by a thin veneer of windblown sand of the Quaternary System (Table I). The fill deposits in the playa basins are also part of the Quaternary System.

A. Permian System

The Permian System is composed of salt, gypsum, anhydrite, dolomite, red shale, and sandstone in the upper two-thirds; limestone dolomite and shale in the lower one-third. The thickness of these sediments is probably in excess of 2000 ft.

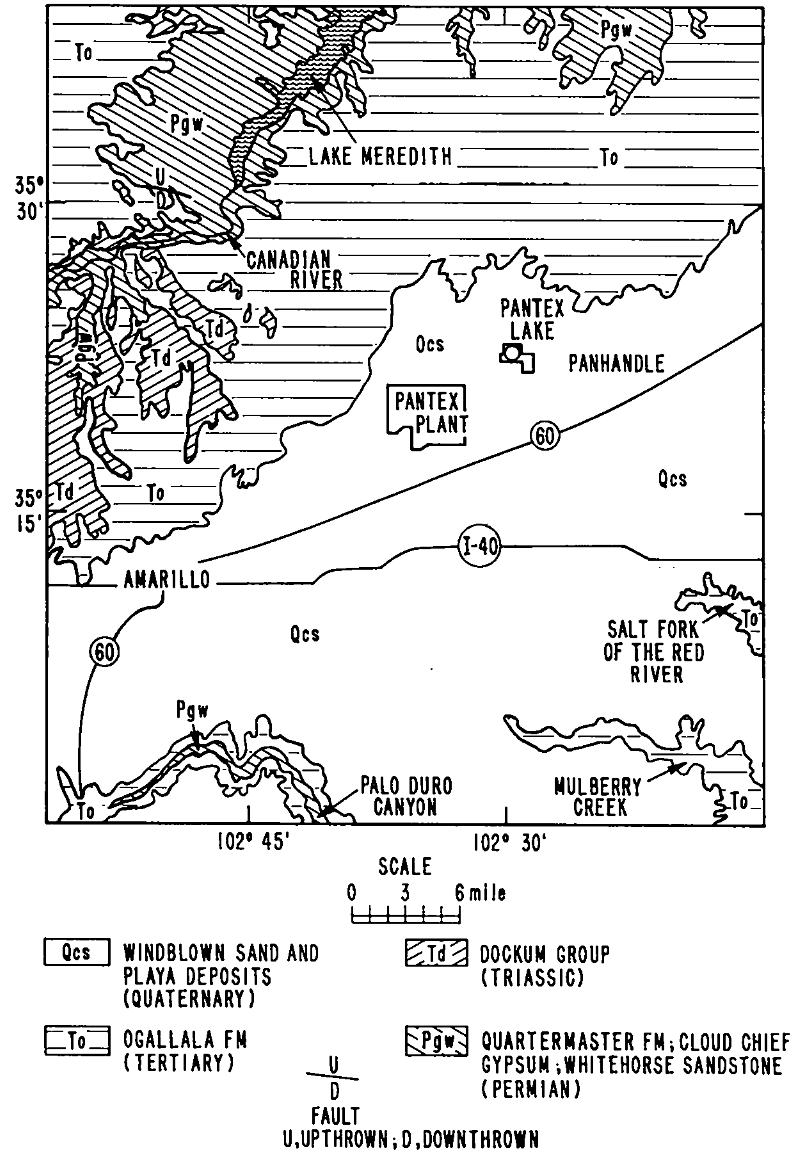

Fig. 2. Geology in the vicinity of the Pantex Plant (Barnes 1969).

TABLE I

GEOLOGIC SYSTEMS AND WATER-BEARING CHARACTERISTICS*

System and Units	Approximate Thickness (ft)	Character of Rocks	Water Bearing
Quarternary			
Windblown Sand Cover	~50	Clay loam--caliche	Above water table
Playa Deposits	>50	silt and clay	Above water table
Tertiary			
Ogallala Formation	~900	Gravel, sand, silt, clay, and caliche	Main aquifer, principal source of municipal, industrial, and irrigation water supply. Well yield can be greater than 1000 gpm. Quality good, TDS <500 mg/ℓ.
Triassic	~250	Red, brown, or gray sandstone and dark red shale (red beds)	Yields only small quantities of water for individual domestic and stock use. Water may be of poor quality. TDS may exceed 1000 mg/ℓ.
Permian	>2000	Salt, gypsum, anhydrite, dolomite, red shale in upper two-thirds; limestone, dolomite, and shale in lower part	Yields only small quantities of water to stock wells. Most water saline.

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*Modified (Long 1961).

The oldest Permian sediments are of the Blaine Formation. These sediments are composed of interbedded shales, siltstones, gypsum, and dolomite. The shales have indistinct bedding to massive bedding with various shades of red and gray. The siltstones, moderately indurated, range from orange to red, and greenish gray. The gypsum is thin bedded to massive, white, bluish gray, and pink. The dolomite is locally calcitic and argillaceous in various shades of gray, and pale grayish yellow. The Blaine Formation does not outcrop in the area of the Pantex Plant but is found in the subsurface.

Overlying the Blaine Formation, in ascending order, are the Permian sediments of the White Horse Sandstone, Cloud Chief Gypsum, and Quartermaster Formation. The formations are composed of shale, siltstone, sandstone, and gypsum that are interbedded. The shales and siltstones are moderately indurated, evenly to thin bedded, and are shades of red, reddish brown, and reddish orange. The sandstones are fine-grained quartz, with some silt ranging in color from red to reddish orange. Gypsum beds are thin and discontinuous. The White Horse Sandstone, Chief Cloud Gypsum, and Quartermaster Formation undivided are shown as outcrops along the Canadian River in Fig. 2 and are found in the subsurface beneath the Pantex Plant.

The Permian rocks yield only small quantities of water to stock wells. Most of the water is too saline for municipal, industrial, or agricultural use (Cronin 1964, Long 1961).

B. Triassic System

The Triassic System is represented by the sediments of the Dockum Group, which is considered to be Late Triassic in age. The sediments lie unconformably on the Permian rocks in the western part of the area. To the north of the Pantex Plant, the Triassic rocks thin and to the east they are absent (Barnes 1969).

The Dockum Group consists, in ascending order, of the Tecovas and Trujillo Formations. The Tecovas Formation consists of shale, clay siltstone, and sand in various shades of red maroon, gray, greenish gray, yellow, and purple. The Trujillo Formation consists of conglomerate, sandstone, and shale. Colors range from gray to red. These formations are generally referred to as red beds underlying the Ogallala Formation. The thickness of the Dockum Group in the area ranges up to 250 ft.

The Triassic sediments are less than 100 ft thick underlying the Pantex Plant. The thin section and lack of permeability of the sediments will yield only small quantities of water to wells. The quality of water may be poor, some of which may be saline (Cronin 1964, Long 1961).

C. Tertiary System

The Ogallala Formation of Pliocene Age of the Tertiary System forms the upper surface of the Southern High Plains. The source of the Ogallala sediments was predominantly in the mountainous region (Rocky Mountains) to the west of the plains. Uplift of the mountains and subsequent erosion supplied the sediments, which were deposited on the eroded surface to the east. Thus, the plains were built by deposition from streams originating in the mountains and flowing eastward and southeastward across the plains. The first Ogallala sediments, mainly coarse sand and gravel, filled the pre-existing valleys in the bedrock. Later sediments covered the entire area, the coarser material being deposited in the new stream channels and the finer material in the interstream areas. Thus the sediments in the Ogallala rapidly change in character because they were deposited mainly by braiding streams (Cronin 1964, Long 1961). Since Tertiary time, the Pecos and Canadian Rivers in New Mexico and Texas have cut through the Ogallala Formation into the underlying older rock, removing the Ogallala along their stream valleys between the High Plains and the mountainous areas to the west (Fig. 1). Headward erosion by tributaries of the Red and Brazos Rivers and their tributaries has formed an irregular escarpment at the eastern edge of the Southern High Plains. Thus, the Southern High Plains formed by the Ogallala Formation now stand above the areas to the east and west, isolated geologically and hydrologically from the Rocky Mountains.

The Ogallala Formation consists of light-colored sand, silt, clay, and gravel. A white calcareous material (caliche) generally is found near the top of the formation, although it has been reported in well logs throughout the formation. The formation is thicker in the old valleys cut into the red-bed surface, the thickness ranging from less than a few feet at the Permian outcrop areas to over 900 ft. The thickness of the Ogallala at Pantex is about 700 ft.

The Ogallala Formation is the principal source of ground water in the area. The formation furnishes water for municipal, industrial, and agricultural use.

D. Quaternary System

The windblown sand and playa deposits of the Quaternary System are of Pleistocene Age (Barnes 1969). The windblown sand that overlies the Ogallala Formation at Pantex is described as mainly clay with silt, sand, and gravels that is calcareous with caliche nodules. The colors vary from pink to grayish red, reddish brown, and olive gray. The windblown sand forms a distinct soil profile (Fig. 3).

The soils (windblown sand) on the uplands at the Pantex Plant are of the Pullman clay loam series. The Pullman soil series consist of grayish-brown clay loam of very low permeability with a dark-brown clay subsoil. These soils are

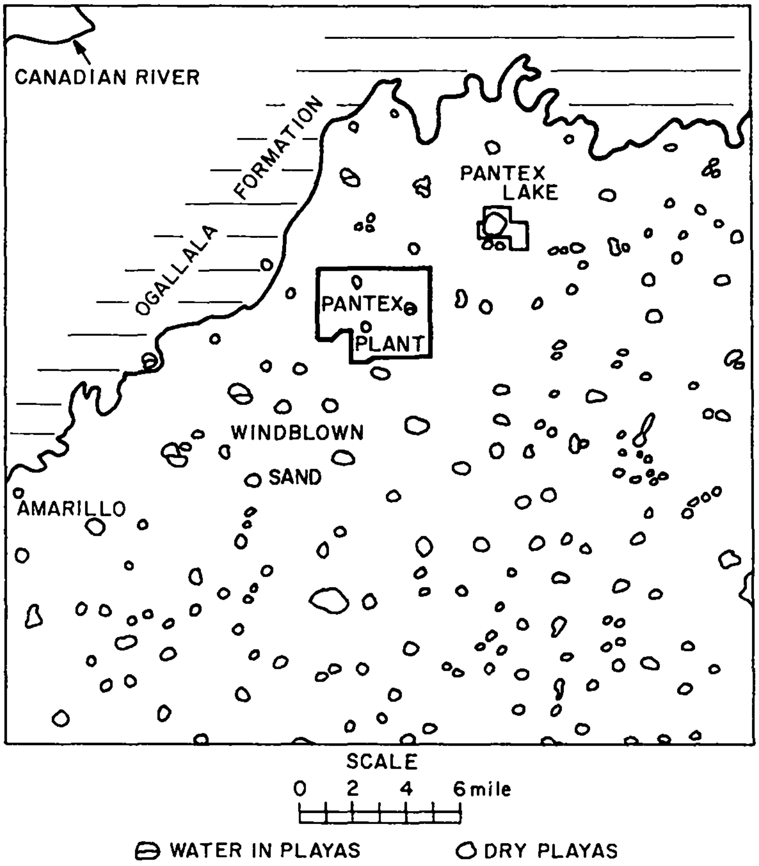

Fig. 3. Windblown sand and playa deposits (Barnes 1969).

formed from fine textured calcareous sediments that have originated from loess or other windblown materials.

A typical soil profile of the Pullman series consists of the A zone of dark grayish brown silty clay loam about 0.5 to 1 ft thick. The underlying B zone consists of dark brown to dark reddish brown clay and silty clay that becomes plastic when wet and extremely hard when dry. The B zone is from 3 to 5 ft thick. The underlying C zone is a pinkish white silty clay that contains soft concretions of calcium carbonate (caliche). The thickness ranges from 3 to 6 ft at the Pantex Plant. The A, B, and C zones are in turn underlain by over 50 ft of silt and clay that overlie the gravels of the Ogallala Formation (Jacquot 1962).

The intake rate (permeability) of water into the soil is low, ranging from 0.2 to 0.6 in./h for the A zone, <0.06 in./h for the B zone, and from <0.06 to 0.2 in./h for the C zone (Pringle 1980). Thus, prolonged flooding by irrigation or rainfall is required for large quantities of water to percolate into the soil. The Pullman clay loam requires about a 5-in. application of water for irrigation of wheat or sorghum. One to three applications of water may be needed during the early growing season. If there is sufficient precipitation during this period, irrigation is not needed.

The low permeability and depth of infiltration of water from precipitation and irrigation into the Pullman soil are reflected in a study of soil moisture in deep borings by the US Department of Agriculture (USDA) at the Bushland Research Station. The study concluded that, under present land management and irrigation practices, the possibility of infiltration of water through the Pullman soil and underlying unsaturated sediment of the Ogallala Formation into the Ogallala Aquifer is remote (Aronovice 1972).

The playas are large depressions (as much as one mile in diameter and up to 50 to 60 ft below the general level of the plain) formed in the upper surface of the Ogallala Formation. The basins are numerous in the upland surface in and adjacent to the Pantex Plant (Fig. 3). The playa deposits formed in the depression are of the Randall clay soil series.

The Randall clay soils are dark gray, very low permeability clayey soils in deposited depressions or playa basins. The soils are deep and generally consist of noncalcareous massive clay. They have formed from sediments washed in from the surface of the surrounding plain. A typical soil profile consists of an A and C zone; no B zone is described (Jacquot 1962). The A zone consists of dark gray to brownish gray silty clay loam in the upper section underlain by a dark clay with a thickness of about 6 ft. The C zone is a light brownish gray clay which exceeds a thickness of 20 ft. The intake rate (permeability) of water into the clay is from <0.06 to 0.2 in./h, thus allowing little, if any, water in the playa to infiltrate into the underlying sediments of the Ogallala Formation (Pringle 1980).

The playa basins were formed by breaching of the caprock (caliche) by water and subsequent removal of material by wind erosion. There is no indication of breaching of the playa basins by faulting. Studies of wind deposits on the leeward side of the basin show no displacement that would indicate any displacement because of faulting or solution (Reeves 1965, 1966A, 1966B).

Playa deposits at the Pantex Plant consist of clay loam with organic materials 2 to 7 ft thick. The color ranges from dark gray to black. The clay loam is underlain by a caliche zone at Playa Basin No. 1. The zone, less than 3 ft, consisted of limestone stringers and fragments, some gravels, and a dark brown clay. Underlying the clay loam or caliche zone is a silty clay which contains some gravels and some isolated limestone fragments. The clays are very dense, ranging in color from a dark gray to a light reddish brown, to a light brown or a dark brown. The thickness of the silty clay deposits on the Pantex Plant exceeds 30 ft. Permeability tests of the silty clay deposits taken at 16 test holes at Playa Basin No. 1 and 12 test holes at the Playa Basin No. 2 at Pantex indicate the playa basin deposits were impermeable with intake rates of <0.06 in./h (Tillery 1980).

The windblown sand (Pullman or Randall soil series) does not contain any water. The playa basins do, in places, hold intermittent ponds. Intermittent ponds in the basins occur with storm runoff from the upland surface. Water from some of the basins is pumped to the upland surfaces for crop irrigation.

E. Geologic Structure

In the Pennsylvanian Period (200-260 million years ago) major uplift of the Precambrian basement rocks formed the Amarillo Uplift in a northwest-southeast trending line. A minor uplift occurred on the southern flank of the major uplift (Fig. 4). The Palo Duro structural basin formed to the south.

The area was covered by a shallow sea during the Permian Period (180 to 200 million years ago), depositing salts, anhydrites, limestones, shales, and sandstones. Uplift and erosion of the area during the Triassic Period (150 to 180 million years ago) resulted in deposition of the continental red shales, siltstones, and sandstones.

Another period of submergence and uplift during the Cretaceous Period (60 to 125 million years ago) resulted in the removal of the marine sediments.

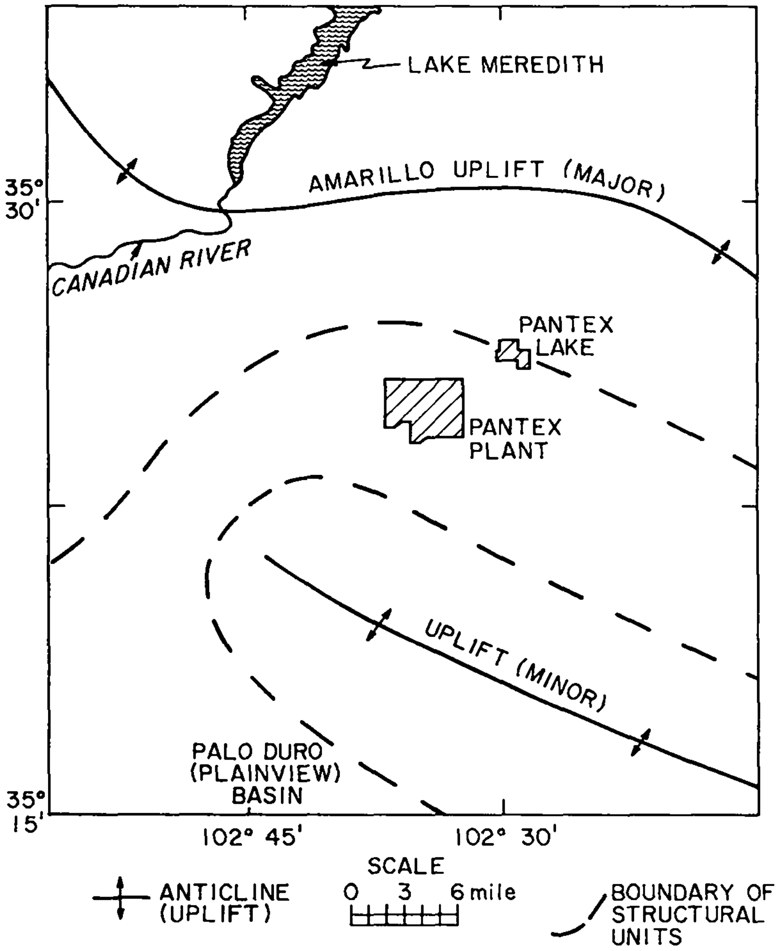

Fig. 4. Geologic structure in the vicinity of the Pantex Plant (Cronin 1964).

Gravels were transported and deposited eastward from the Rocky Mountains during the Tertiary Period. These gravels formed the upper surface at the Southern High Plains, which has since been modified by erosion, windblown sand, and dissection by streams along the Canadian River and at the edge of the escarpment.

The structure of the Amarillo Uplift affected the deposition of sediments during the Permian, Triassic, and Tertiary Period. Sediments thin over the uplift and thicken into the basins. Sediments of the Triassic and Permian age thicken over 5000 ft in the Palo Duro Basin south of the Pantex Plant (Cronin 1964).

The thickness of the Ogallala Formation in part is related to the underlying basin structure as well as the surface of the Triassic or Permian sediments that have been modified by erosion. The plant lies on the northern flank of the minor uplift south of the major Amarillo Uplift. There is a thickening of the Ogallala Formation to the north, into the basin. The Ogallala Formation thins over the top of the minor uplift south of the plant and then thickens southward into the Palo Duro Basin (Fig. 4.)

Structural features of the Precambrian basement rocks (subsurface interpreted from seismic studies) show three major faults in the vicinity of the Pantex Plant. They are not considered active (Blume 1976). Movement on these faults was largely responsible for the elevation of the Amarillo Uplift. The largest fault is about 25 mi north of the Pantex Plant and strikes generally east-west along the axis of the Amarillo Uplift. The second fault passes about 7 mi north of the plant, striking in a northwesterly direction. The third fault is about 7 mi south of the plant, striking nearly east-west. These faults are in the Precambrian basement rock and do not displace the overlying sediments.

The only evidence of surface faulting in the area is one fault about 4 mi in length located about 20 mi northwest of the Pantex Plant (Fig. 2). The fault displaces rocks of Triassic System but does not displace the sediments of the Ogallala Formation. The movement on the fault took place over 7 million years ago, before the deposition of the Ogallala Formation.

An active fault is often expressed on the land surface as a series of linear physiographic features, for example, scarps, troughs, narrow lakes, and "sag ponds," linear drainage patterns, and sharp changes in vegetation. Recent activity is indicated if displacements can be found in man-made features such as roads, fence lines, or orchard rows. No such surface indications of faulting were discovered at Pantex Plant (Blume 1976).

Faulting may also be detected by displacement in buried sediments. The Ogallala Formation has been found to be heterogeneous and locally devoid of marker beds where fault displacement could be detected. The surface of the Triassic and Permian rocks that form the base of the Ogallala Formation indicated moderate relief but disclosed no evidence of faults (Blume 1976).

Active faults frequently cause ground water barriers. Such a barrier may be due to the displacement of an aquifer so that it lies in contact with less permeable strata, or it may be due to the impermeability of the crushed and altered material in the fault zone itself. A map of the top of water table disclosed no ground water irregularities attributable to faulting. The contours are seen to run unbroken and roughly perpendicular to the known NW-SE alignment of basement faults of the Amarillo Uplift (see section on Hydrology). A seismic survey made in the area of Zone 12 within the Pantex Plant failed to detect any abrupt discontinuities in the subsurface that could be attributed to faulting (Blume 1976).

The Ogallala lies unconformably upon the sediments of the Triassic and Permian Systems. The Triassic sediments do not occur north and east of a line running roughly northwestward from the northeast corner of Pantex to the Canadian River. Northeast of this line the sediments of the Ogallala thicken over the underlying sediments of the Permian (Fig. 5).

IV. HYDROLOGY

The master surface water stream in the area is the Canadian River located about 25 mi north of the Pantex Plant. The river flows eastward into Lake Meredith, a manmade reservoir. To the east of the plant, the eastern edge of the Southern High Plains is drained by Sweetwater Creek and a little further to the south by the Salt Fork of the Red River (Fig. 1). Palo Duro Canyon, about 20 mi south of Amarillo, was formed by the Prairie Dog Fork of the Red River. The floor of the canyon lies about 1000 ft below the surface of the high plain.

Local drainage in the plains area covered by the windblown sand is into the playa basins (Fig. 3). At the Pantex Plant and adjacent area, there is no drainage into any streams. All surface drainage is into playa basins.

The main or principal aquifer in the area is the Tertiary gravels of the Ogallala Formation. Water occurs in the lower part of the formation perched on the relatively impermeable Triassic red beds of silts, clays, shales, and silty sandstones. At the Pantex Plant, water for industrial and some agricultural use is pumped from the aquifer in the Ogallala Formation.

A. Surface Water

The surface water gaging station on the Canadian River upstream from Lake Meredith has been operated by the US Geological Survey for about 43 yr (USGS 1980). The Canadian River at this station has a drainage area of about 19 445 mi^2 (4069 mi^2 of closed basins within the drainage area are noncontributing) in eastern New Mexico and the Panhandle of Texas. The average annual discharge at the station for 42 yr of record has been 342 ft^3/s or about 247 800 acre-ft/yr. The maximum discharge for the period of record was 135 000 ft^3/s on July 25, 1941.

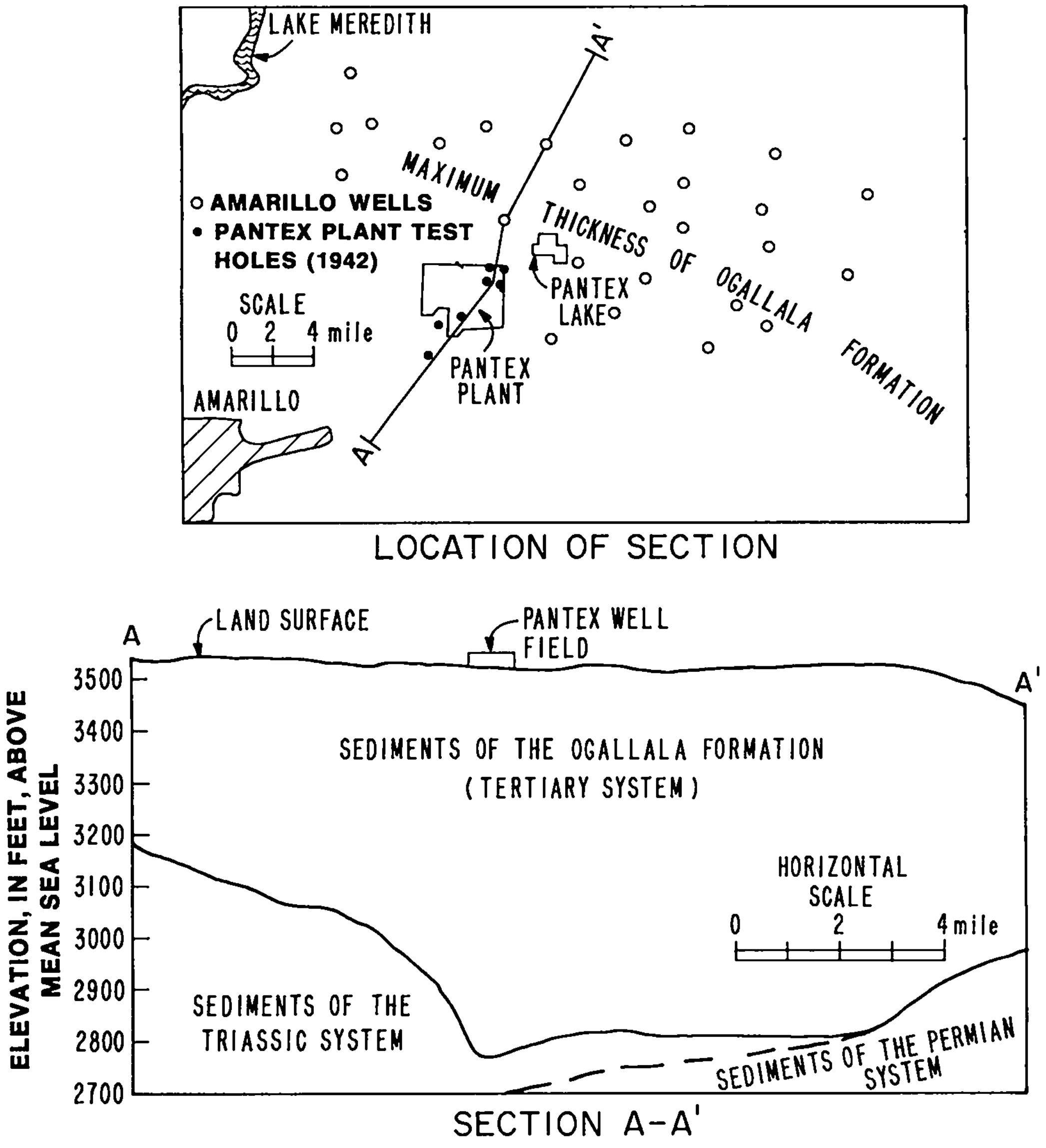

Fig. 5. Section showing Ogallala Formation overlying sediments of the Triassic and Permian Systems (Blume 1976).

No flow conditions have occurred at times in January 1924 to December 1925 and on August 7 and 8, 1940. At other times, low flow is maintained by the release of sanitary effluent from the Amarillo disposal plant into East Amarillo Creek, a tributary to the Canadian River. Some regulation of flow is made upstream by Conchas and Ute Reservoirs in New Mexico where there is diversion for irrigation (USGS 1980).

Lake Meredith is formed by a rolled earthfill dam 6,410 ft long. The dam was built by the US Bureau of Reclamation for the Canadian River Municipal Water Authority for flood control and municipal and industrial supply for the cities of Amarillo, Borger, Brownfield, Lamesa, Levelland, Lubbock, O'Donnel, Pampa, Plainview, Slaton, and Tahoka. The dam was completed in October 1964. Data regarding the dam and lake are given in Table II.

The maximum storage in the lake for the period of record 1964-1979 was 546 000 acre-ft (elevation 2914.91 ft) on April 28, 1973, while the minimum was 219 000 acre-ft on April 10 and 11, 1967 (elevation 2883.10 ft) (USGS 1980). The lake capacity according to elevation is shown in Table II.

As an example, during the water year 1979 (Oct. 1978 through Sept. 1979), the maximum storage was 338 400 acre-ft (elevation 2896.56 ft) on October 10, 1978, and minimum storage was 289 400 acre-ft (elevation 2990.93) August 17, 1979. During that water year, about 72 421 acre-ft were diverted from the lake for municipal and industrial supply. The minimum monthly amount used during the water year 1979 was 4365 acre-ft in November 1978. The maximum monthly amount was 8365 acre-ft in July 1979 (Fig. 6). The average inflow into the lake is about 247 800 acre-ft/yr with about 72 421 acre-ft or 29% used in 1979 for municipal and industrial supply (USGS 1980).

All surface water drainage at the Pantex Plant is into playa basins. The surface area at the plant is quite level with slopes varying from a 10-ft drop in 4000 ft to a 10-ft drop in 500 ft near each of the playa basins. The drainage from most of the plant is into three onsite playa basins. The drainage from the southwest portion of the plant is into a playa located on the property of the Texas Tech University Research Farm and portions of the drainage along the northern boundary of the plant into a playa beyond the plant boundary (Fig. 7). Treated sanitary effluent, as well as effluent from manufacturing process, is released into Playa Basin No. 1. Water may be pumped from the playas for irrigation when they contain sufficient amount of water (Becker 1982B).

B. Ground Water

Development and use of ground water in Texas are controlled by the individual landowners. Ground water management was made the responsibility of local people with local option for ground water law.

The Permian rocks yield only small quantities of water to a few stock wells in the area. Most of the water is saline. The Triassic rocks should also be expected to yield only small quantities of water, perhaps enough for domestic or stock use. The quality of the water may also be saline (Long 1961).

TABLE II

HYDROLOGIC DATA OF LAKE MEREDITH*

Design Criteria	Elevation (ft)	Capacity (acre-ft)
Top of dam	3011.0	---
Design flood	3004.9	2 434 200
Crest of drop inlet	2965.0	1 407 600
Top of conservation pool	2936.5	864 400
Crest of flood-control works (inverted)	2894.0	313 700
Lowest gated outlet (inverted)	2850.0	43 050
Lake Capacity According to Elevation		
	2890.0	277 000
	2892.0	295 100
	2894.0	313 700
	2896.0	332 900
	2897.0	342 700

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*USGS 1980.

Note: Drainage area above dam, 20,220 mi^2, of which 4172 mi^2 probably is noncontributing.

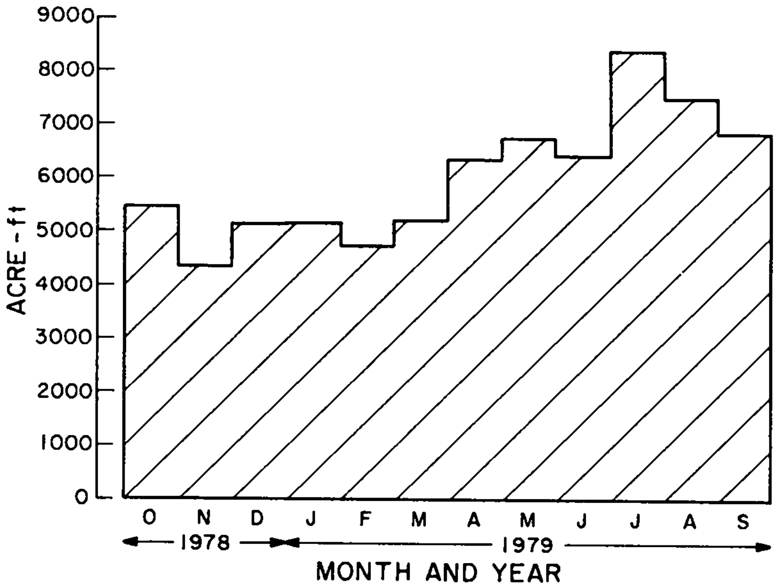


Fig. 6. Diversion from Lake Meredith for municipal and industrial supply, Water Year 1979 (USGS 1980).

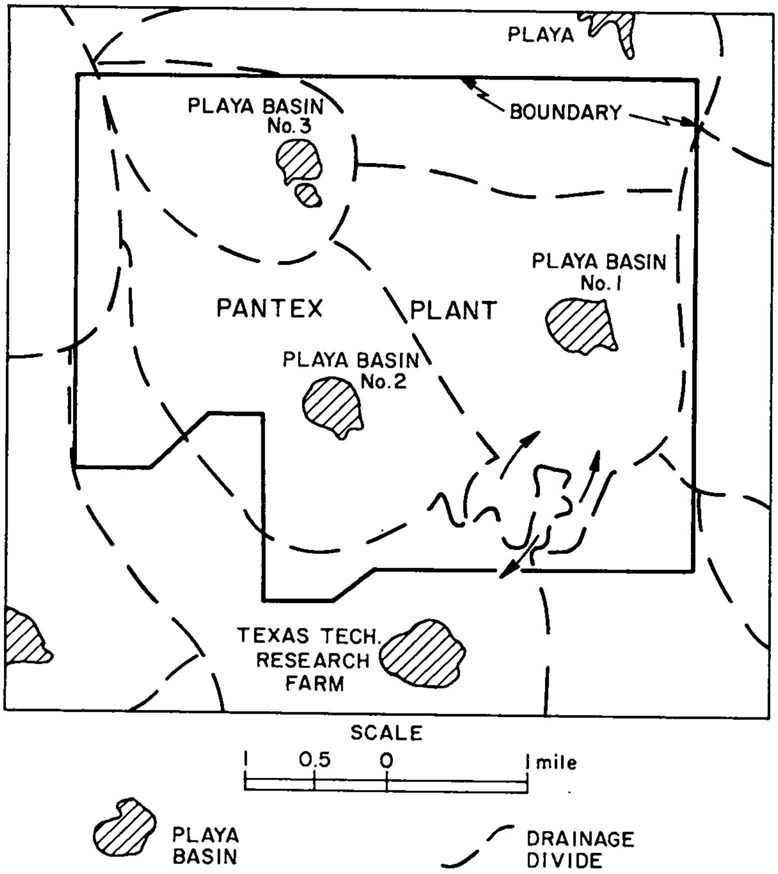


Fig. 7. Drainage areas at the Pantex Plant (Becker 1982B).

The Ogallala Formation in the Southern High Plains in Texas and adjoining parts of New Mexico is the principal water-bearing formation. It supplies almost all of the ground water used for municipal, irrigation, domestic, and stockwatering purposes (Long 1961, Cronin 1964, 1969). It is the principal or only water-bearing formation in the area of the Pantex Plant. Perched water in the Ogallala Formation above the main ground water body may furnish enough water for livestock use.

1. Ground Water Management. Ground water is controlled by the individual landowner in Texas. The Texas Water Rights Commission and the Texas Water Devlopment Board are the two state agencies with major involvement in ground water; however, their activities are limited to fact finding, data gathering, and analysis of the ground water situation. The state agencies have no control over drilling of irrigation wells or quantities of water pumped for irrigation.

Ground water management was made the responsibility of local people with the passage of a local option ground water control law in 1949, allowing the establishment of local Ground Water Management Districts (GMD). The three operational districts in the Ogallala area of West Texas were all formed by local voters approval within boundaries drawn by the Texas Water Rights Commission at the request of local people (USDA 1977). The Pantex Plant is located in Panhandle Groundwater District No. 3.

The GMD have the authority to require permits, space wells, prohibit waste, and limit the quantity of water pumped. They have exercised all their authority except limiting the quantity of water pumped. Permits are required, tailwater pits to eliminate waste are encouraged but not mandatory, and spacing of wells is dependent on casing size and well yield. An 8-in. well (560 to 1000 gpm) must be at least 400 yards from another well or set back from the property line, while a 4-in. well (70 to 265 gpm) can be 200 yards from an existing well or set back from the property line in GMD.

The spacing of wells is a management practice that allows a general water level decline over a larger area. Wells close together cause abrupt water level declines that increase the cost of production and deplete the aquifer in that area at a greater rate. Supply wells at Pantex (450 to 1100 gpm) are at intervals greater than 400 yards apart.

2. Regional Ground Water in the Ogallala Formation. The Ogallala Formation consists of sediments (silts, clays, sands, and gravels) deposited eastward from the high lands in New Mexico during the Tertiary Period, forming a continuous blanket of sediments into Texas. The Ogallala Formation of the Southern High Plains in Texas has been hydrologically isolated from the surrounding areas by erosion (USDA 1966).

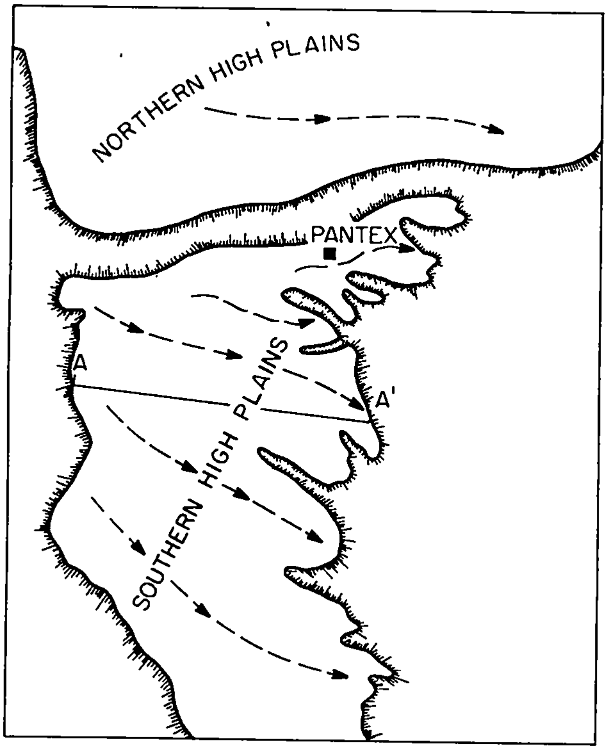
Ground water in the Ogallala Formation generally occurs under water table conditions; that is, the upper surface of the saturated material or water table is unconfined (atmospheric pressure) and the water in a well will not rise above the water level found in the formation. Locally, slight artesian pressures may exist where water is confined beneath lenticular bodies of silt and clays. The relatively impermeable silts, clays, and shales of the Triassic or Permian rocks that underlie the Ogallala Formation form the lower boundary of the aquifer (Fig. 8).

The thickness of the zone of saturation of the Ogallala Formation varies throughout the Southern High Plains, chiefly because of the unevenness of the topography of the upper surface of the underlying Triassic or Permian rocks. The irregularities in the topography of the upper surface of the Triassic or Permian rocks were caused by erosion of these surfaces after the formations were deposited and because of the influence of uplift in the basement rocks that resulted in variations in the thickness of the sediments as they were deposited. The saturated thickness of the Ogallala Formation in the Southern High Plains ranges to more than 350 ft.

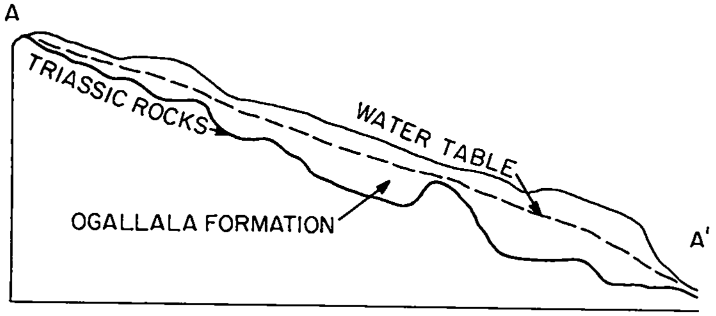
The configuration (shape and slope) of the water table in the Southern High Plains shows that the general movement of the water in the Ogallala Formation is to the east-southeast toward the eastern plains escarpment (Fig. 8). The discharge area for the aquifer is along the eastern escarpments in the form of springs and seeps, some giving rise to perennial streams. In other areas, such as seep discharge, the evapotranspiration rates are so high that the discharge is depleted along the outcrop.

Recharge to the aquifer is from water moving into the Southern High Plains of Texas from New Mexico by underflow. The recharge is probably small but fairly constant from year to year (Cronin 1964). The other source of recharge to the aquifer is from precipitation on the land surface. The amount and rate of recharge are dependent on the amount, distribution, and intensity of the precipitation, amount of soil moisture when precipitation occurs, temperature, vegetative cover, and permeability of soil or rock material at the infiltration site. Based on the variabilities of these factors, it is difficult if not impossible to determine the amount of recharge that enters the Ogallala Formation in the Southern High Plains. However, it is a well-established fact that in most parts of the Southern High Plains (where there is irrigation, industrial use, and population growth) that water from the Ogallala Formation is being depleted. This means that withdrawal of water from the aquifer is greater than the amount of recharge and therefore the water table (top of the zone of saturation) is declining.

The hydrologic properties of the Ogallala Formation vary from place to place because of different lithology of the aquifer. Aquifer tests indicate a transmissivity range of 6 000 to 34 000 gpd/ft^2 and an average specific yield of about 0.15 (Miller 1964). In most areas where there is a saturated thickness of the Ogallala Formation of at least 100 ft, a well will yield over 800 gpm (Bell 1979).



GENERALIZED MOVEMENT OF GROUND WATER



GENERALIZED GEOLOGIC SECTION

Fig. 8. Generalized movement of ground water in the Ogallala Formation (Long 1961, Cronin 1964).

3. Ground Water in the Ogallala Formation at and Adjacent to the Pantex Plant. Ground water at and adjacent to the Pantex Plant occurs in two modes. In the first mode, the main ground water body at and adjacent to the Pantex Plant water occurs in the lower part of the Ogallala Formation, which is underlain by relatively impermeable shales of the Triassic and Permian System (Fig. 9). In the second mode, the ground water is perched by layers or lenses of impermeable rocks in the Ogallala Formation above the main aquifer.

The main zone of saturation in the gravels in the base of the Ogallala Formation furnishes the industrial supply for the Pantex Plant, a part of the municipal supply for Amarillo, and domestic and irrigation water for nearby farms. The water in the aquifer occurs under unconfined conditions.

The thickness of the Ogallala Formation and zone of saturation varies considerably within the immediate area of the plant. The plant is located on the northeast flank of a minor uplift (geologic structure), which results in thickening of gravels and zone of saturation to the northeast. Contours of the top of the water table indicate the general movement of water at the plant is to the north (Fig. 10) (TDWR 1979). The rate of movement and direction of water in the aquifer are disturbed by pumpage from the Amarillo municipal wells and irrigation wells in the area north of the plant. Pumpage from these wells, which supply part of the water for Amarillo, has caused a ground water depression to form (Fig. 10). Prior to development of the Amarillo water supply north of Pantex, ground water movement was to the east; however, since heavy pumpage began the depression has reversed the direction of movement.

The saturated part of the Ogallala Formation extends well beyond the limits of the plant. A partial barrier to the movement of water into the plant area occurs to the south and southwest where the Ogallala Formation thins and Triassic and Permian shales form the partial barrier (Fig. 5). To the north and northeast of the plant the Ogallala Formation thickens into the basin. As a result, the saturated thickness of the Ogallala is greater than at the Plant, resulting in a large amount of water in storage in the Pantex Lake area.

Two of the three test wells drilled in 1976 at Pantex encountered perched water above the main zone of saturation in the Ogallala Formation (Fig. 9). A stock well just north of the plant boundary is also completed into a perched zone above the main zone of saturation (Long 1961). These perched water bodies are of local extent and are not considered dependable sources of water supply. Testing indicated they could be bailed dry within a short time.

Precipitation or irrigation on the upland plain may be a source of water recharged to the Ogallala Formation; however, the uplands are composed of a clay loam that is relatively impermeable. This combined with rapid runoff and high evapotranspiration would inhibit most, if not all, infiltration of water from precipitation and thus, recharge to the aquifer. Precipitation and industrial and sanitary runoff into the playa basins may contribute recharge to the

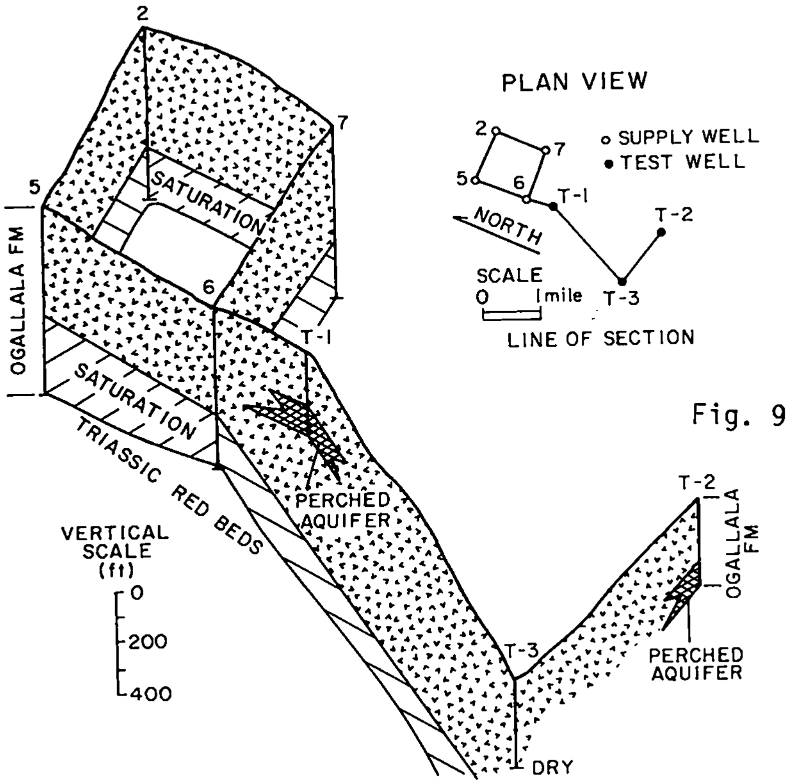


Fig. 9. Diagrammatic section of the Ogallala Formation at the Pantex Plant.

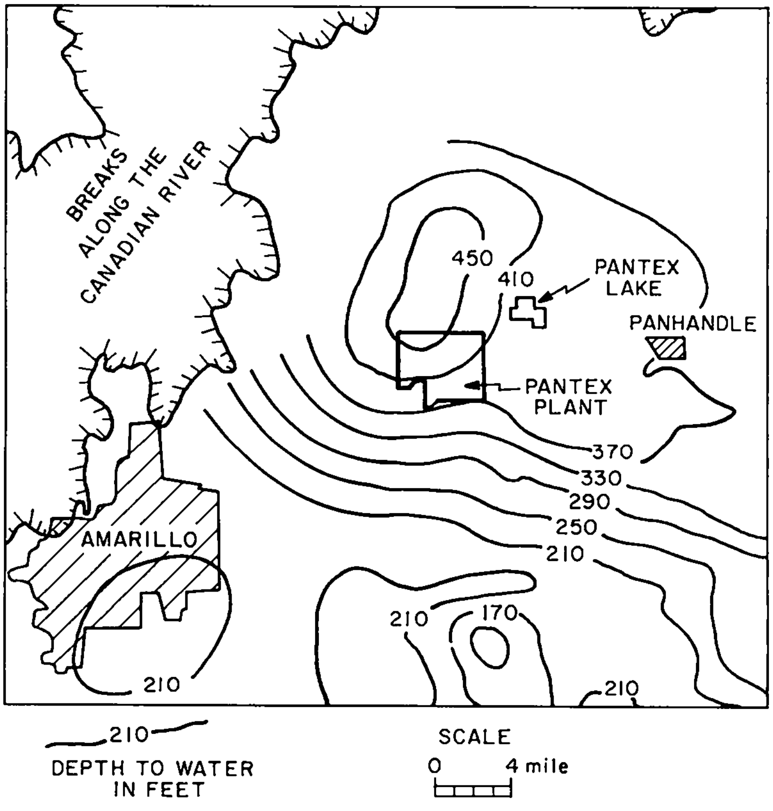


Fig. 10. Generalized contours on the top of the aquifer showing depth to water in the Ogallala Formation at and adjacent to Pantex (TWDR 1974).

aquifer; however, the relatively impermeable sediments found in these playa basins prevent most if not all infiltration of water from the playas to the aquifer. The large amount of storage in the ground water reservoir is due to a slow accumulation over a long period of time. At present, the rate of withdrawal of water from the aquifer greatly exceeds any recharge, and the water table is declining as the water stored in the aquifer is diminished by pumpage.

4. Storage and Use of Ground Water from the Ogallala Formation. Water is pumped from the Ogallala Formation for industrial, municipal, and agricultural supply. The growth of cities and use of water have greatly expanded. One of the well fields that supplies water to Amarillo lies to the north and northeast of the Pantex Plant. This well field consists of 37 wells (May 1982) completed in the Ogallala Formation. For the period October 1979 through September 1980, the total use of water at the city of Amarillo was about 14.0 x 10^9 gal. Of this total about 6.7 x 10^9 gal were from the reservoir at Lake Meredith. The remaining 7.3 x 10^9 gal of water were pumped from wells. About 5.1 x 10^9 gal of the pumpage were from wells north of the Pantex Plant. The other 2.2 x 10^9 gal of water were produced from the well field southwest of Amarillo.

The volume of water stored in the Ogallala Formation was projected by the Texas Department of Water Resources. The projections were based on a storage coefficient (specific yield) of 15% (Bell 1979). Other factors used to project the volume of water in storage and use for the 10-yr intervals from 1980 to 2020 were estimates of recharge (natural and irrigation) and the water use pattern from 1960 to 1972 (Bell 1979).

The projected decline in storage in the Ogallala Formation in a 900 mi^2 area (Carson County) is 4280 x 10^3 acre-ft, from 8820 x 10^3 acre-ft of storage in 1980 to 4540 x 10^3 acre-ft of storage in the year 2020. Total pumpage from the aquifer during this 40-yr period will be about 5020 x 10^3 acre-ft, while recharge (natural and irrigation) will return about 740 x 10^3 acre-ft to the aquifer (Table III). The projected annual pumpage from the aquifer will decline from 148 x 10^3 acre-ft for the period 1980-1990 to 105 x 10^3 acre-ft for the period 2010-2020 (Table III). The decline in annual pumpage between the first and last decade reflects the increased energy costs associated with greater pump lifts as the aquifer is being depleted. It will not be economically feasible in the future to produce irrigation water for certain crops (Bell 1979).

Based on water use in Carson County for an 8-yr period (1955-1962), the Ogallala Formation produced about 30% for industrial and municipal supply and about 70% for irrigation (McAdoo 1964). The projected annual pumpage from the Ogallala for the years 1980 through 1990 is 148 x 10^3 acre-ft. Based on past usage patterns, about 104 x 10^3 acre-ft will be used for irrigation and 44 x 10^3 acre-ft for industrial and municipal supply.

The amount of water pumped for irrigation is related to annual precipitation and area of irrigated crops; thus, year after year, the amount can vary

TABLE III

PROJECTED STORAGE, DECLINE FROM STORAGE, RECHARGE, AND PUMPAGE
FROM THE OGALLALA AQUIFER IN CARSON COUNTY,
1980-2020*
(in 10^3 acre-ft)

Year	Storage
1980	8820
1990	7540
2000	6420
2010	5430
2020	4540

Year From To	Decline in Storage	Recharge	Pumpage	Average Annual
1980-1990	1280	200	1480	148
1990-2000	1120	180	1300	130
2000-2010	990	200	1190	119
2010-2020	890	160	1050	105
Total	4280	740	5020	-

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*Bell 1979.

considerably. Precipitation during the critical part of the growing season will result in a reduced amount of pumpage for irrigation.

Irrigated crops in Carson County for 1979 amounted to 86.6 x 10^3 acres. Of this, 55% was planted in wheat and 45% was planted in sorghum for grain (USDA 1980). With projected annual irrigated pumpage of 104 x 10^3 acre-ft for 86.6 x 10^3 acres, each acre would receive about 1.2 acre-ft of water.

C. Development of Water Supply at the Pantex Plant

The initial water supply for the US Army Ordnance Depot, which preceded the present Department of Energy Pantex Plant, was from five wells completed into the Ogallala Formation in 1942 (Stewart 1980). The well field was laid out in about one square mile in the northeast corner of the present plant area, southwest of the intersection of roads FM-293 and FM-2373. Of these five original wells, four were abandoned in the 1970s and one (No. 6) remained operational (Fig. 11). The four wells (No. 2, 5, 7, and 11) were abandoned due to well deterioration. Sand entered the wells, resulting in reduced pumping rates which were too low for economical operation.

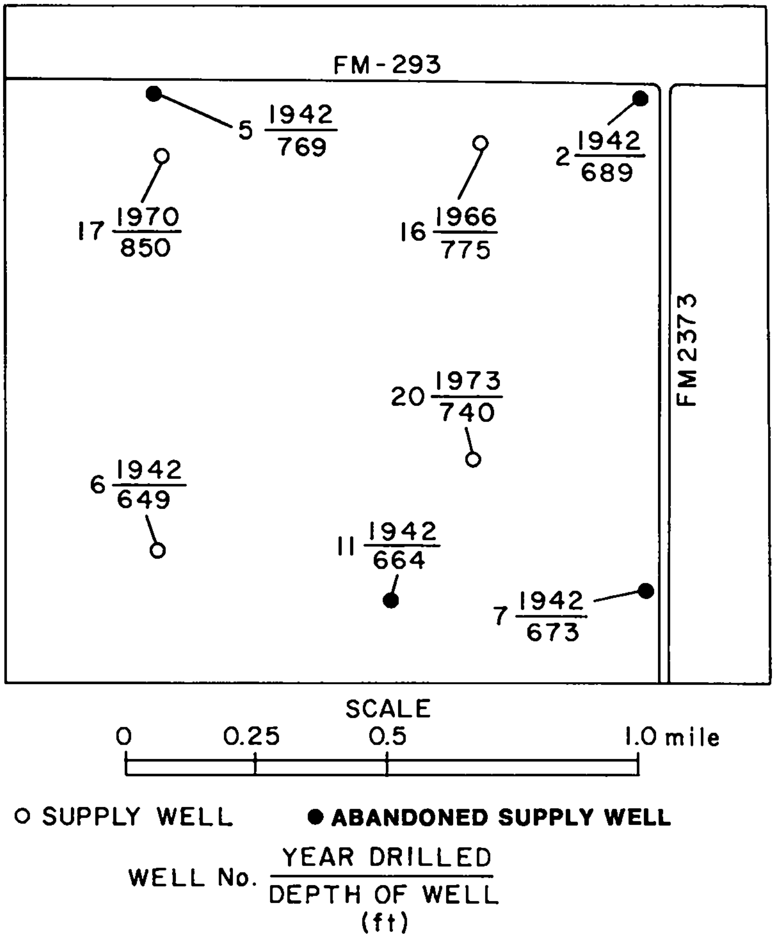

Fig. 11. Location of wells in the Pantex well field (Stewart 1980).

Three new wells were drilled in the period 1966 through 1973. The production from the wells No. 6, 16, 17, and 20 has remained at 350 x 10^6 gal for the past 3 yr (Fig. 12). The total production from the well field since 1958 has been 11,006 x 10^6 gal. Production records prior to 1958 are not available.

The water demand from the wells for industrial use at the Pantex Plant and irrigation demand by Texas Tech University (DOE provides water for the university) have fluctuated over the past 23 yr (Fig. 12). The total amount of pumpage has generally declined since 1964 when 670 x 10^6 gal of water was produced. Of this, the Pantex Plant used 550 x 10^6 gal or 82%. About 120 x 10^6 gal, or 18%, were delivered to Texas Tech University (Fig. 12). By comparison, of the cumulative 1050 x 10^6 gal of water produced in 1978, 1979, and 1980, 997 x 10^6 gal, or 95%, were used by Pantex. About 53 x 10^6 gal, or 5%, were delivered to Texas Tech University.

The amount used by Texas Technological University for the 23 yr of record has ranged from 4 x 10^6 gal in 1978 to 160 x 10^6 gal in 1965 (Fig. 12). The average annual amount delivered during the period of record is about 70 x 10^6

gal. This water is used offsite at the Texas Tech facility south of the Pantex Plant (Fig. 7).

The projected demand or pumpage for the Pantex Plant (not including water delivered to Texas Tech University) for the year 1981 through 1990 ranges from 350 x 10^6 in 1981 to 400 x 10^6 gal in the years 1985-86, declining to 380 x 10^6 gal for the years 1988-90 (Fig. 13) (Stewart 1980, Laseter 1982A).

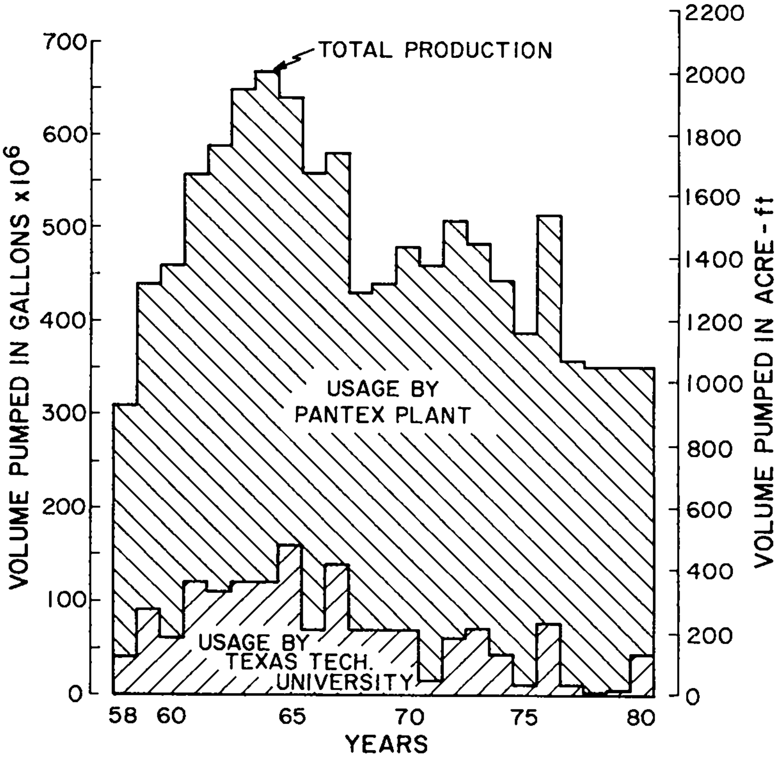

Fig. 12. Pumpage from the Pantex well field 1958-1980 (Stewart 1980).

The projected average annual use 1981-1990 is about 383 x 10^6 gal, slightly less than the average annual use 1971-80 of 387 x 10^6 gal. The projected annual production from Carson County during 1980-1990 is 148 x 10^3 acre-ft (4.8 x 10^{10} gal) compared to Pantex, which would require about 1.2 x 10^3 acre-ft (4 x 10^8 gal). Over the same period, the Pantex pumpage would be less than 1% of the water pumped from the Ogallala aquifer in the county. Further comparing, assuming 1 acre-ft of water per acre is typical for irrigation, the amount pumped for the Pantex Plant would irrigate about 1200 acres. The 1200 acres would be about 1.5% of the 86.6 x 10^3 irrigated acres in Carson County in 1979.

One of the largest producers of water from the Ogallala Formation adjacent to the Pantex Plant is the city of Amarillo. Production from the city's well field for the years 1975 through 1980 ranged from 3.23 x 10^9 gal to 5.06 x 10^9 gal (Table IV). By comparison, the water used at Pantex Plant for the same period has ranged from 0.325 x 10^9 gal to 0.436 x 10^9 gal. The production from the Pantex well field for use at the Pantex Plant has been about 9% of the production from the Amarillo well field. As previously stated, the heavy pumpage from the Amarillo field has caused a ground water basin to form in the aquifer north of the Pantex Plant (Fig. 10).

The distribution of the projected annual 4 x 10^8 gal of pumpage (peak demand 1985, 86) at Pantex is estimated as follows.

	%	10^6 gal
1. Manufacturing and Production Processes	40	160
2. Plant Operations Resulting in Sanitary Effluent	49	196
3. Use in Steam Plant	7	28
4. Lawn and Landscape Irrigation	2	8
5. Operation of Cooling Towers	2	8
	100	400

Effluents from manufacturing and production processing are released into drainage channels that flow into Playa Basin No. 1 within the plant boundaries; however, very little, if any, of this effluent reaches the playa basins because of the high evaporation rates and infiltration into the soil adjacent to channels (Fig. 7). Blowdown from the steam plant and water used in the cooling towers also drain to Playa Basin No. 1, but very little, if any, of this effluent reaches the basins. The sanitary effluent after treatment is released into Playa Basin No. 1 and is sometimes pumped out for irrigation of adjacent farm land. There is no release of any of the effluents offsite at the Pantex Plant.

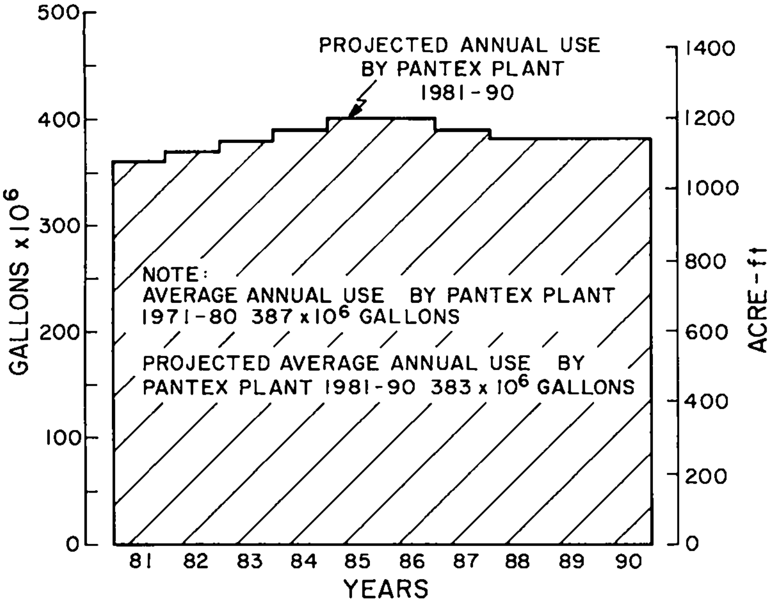

Fig. 13. Projected annual use by Pantex Plant 1981-1990 (Laseter 1982A).

TABLE IV

ANNUAL PRODUCTION OF AMARILLO WELL FIELD AND PANTEX WELL FIELD IN CARSON COUNTY, 1975-1980

(in 10^9 gallons)

Year		Amarillo*	Pantex Plant**
1975		3.37	0.374
1976		3.23	0.436
1977		4.68	0.344
1978		4.47	0.346
1979		4.57	0.345
1980		5.06	0.325
	Total	25.38	2.170

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*Water year Oct.-Sept. Water pumped from well field north of Pantex Plant.

**Water supply for Pantex Plant does not include water delivered to Texas Tech University.

1. Present Production and Distribution System. The present water system at the Pantex Plant consists of four operating wells: two ground-level tanks and two elevated storage tanks (Table V). The wells pump into a ground-level storage tank near the No. 1 Pump Station. Water flows by gravity to a clear well under the No. 1 Pump Station building. Water level in the clear well is controlled by a Clayton level control valve. Water is then pumped from the clear well into the plant distribution system. The number of wells and pumps operating at any given time is dependent upon the plant demand. The No. 2 Pump Station pumps directly into the water system from the second ground-level storage tank. The capability also exists for pumping directly into the system from any of three water wells without going through the No. 1 pump station. It is possible to pump approximately 3500 gpm into the system. All pumps and wells are started and stopped manually (Stewart 1980).

In addition to the domestic water system, the plant has two fire protection water loops, one in the warehouse area of Zone 12 and the other in Zone 11. Each system is equipped with an automatic-starting diesel-driven fire pump, rated at 2500 gpm with 100-psi net head. The pressure on the loop is maintained at 125 to 150 psig by a 10-gpm jockey pump. The reservoir is automatically filled from the plant water distribution system. The plant water distribution system is supplemented with a remotely controlled, manual-starting diesel fire pump, rated with 2000 gpm at 90-psi net head. This pump is located at Pump Station No. 2 (Stewart 1980).

2. Hydrologic Data 1942-1980. The well field at the Pantex Plant occupies an area of about 1 square mile (Fig. 11). Pumpage from the Ogallala Formation for the past 38 yr has resulted in water-level declines and some changes in hydrologic characteristics. Water supply for Amarillo north of the Pantex Plant has resulted in water-level declines that have extended into the Pantex well field. Pumpage from the Amarillo well field has accelerated the water-level decline and increased pumping lifts in the adjacent areas (Fig. 10).

Water-level measurements in individual wells have varied; however, the average saturated thickness of the aquifer has decreased 70 ft, from 320 ft in 1942 to 250 ft in 1980 (Fig. 14). The yields for four wells in the field in 1980 ranged from 450 to 1120 gpm (Fig. 14). The decline in saturated thickness has resulted in increased pumping lifts averaging 70 ft, from 367 ft in 1942 to 437 ft in 1980. The annual rate of water level decline from 1942 to 1980 has ranged from 1.5 to 2.1 ft/yr with an average for rate of decline for the field of 1.8 ft/yr.

Observation wells are measured by the Texas Water Development Board in principal aquifers such as the Ogallala Formation to observe water level changes. A number of these wells are located around the Pantex Plant (Fig. 15) (TDWR 1979). During the period 1970 through 1976 water levels were determined in 39 of these wells to calculate the annual rate of water level

TABLE V

PRODUCTION AND DISTRIBUTION SYSTEM, PUMPS, CAPACITY, AND LINE PRESSURE AT PANTEX PLANT*

Storage Tanks		Capacity (gal)
Ground-level storage, two, each		2.25×10^6
Elevated storage, two, each		0.18×10^6
Wells		**Capacity (gpm)**
No. 6		450
No. 16		1120
No. 17		630
No. 20		1120
Pump Stations	**Pressure at Station (psi)**	**Capacity (gpm)**
No. 1		
40 hp (pump)**	54	800
50 hp (pump)**	60	1100
75 hp (pump)**	66	1300
Combinations	70	1500
40 hp + 50 hp (pumps)	75	1600
40 hp + 75 hp (pumps)	80	1700
50 hp + 50 hp + 75 hp (pumps)	85	1900
No. 2		
30 hp (pump)***	--	--
75 hp (pump)+	75	1000

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*Becker 1982B.

**Electric motor with backup natural gas engine.

***Electric motor only.

+Electric motor with backup gasoline engine.

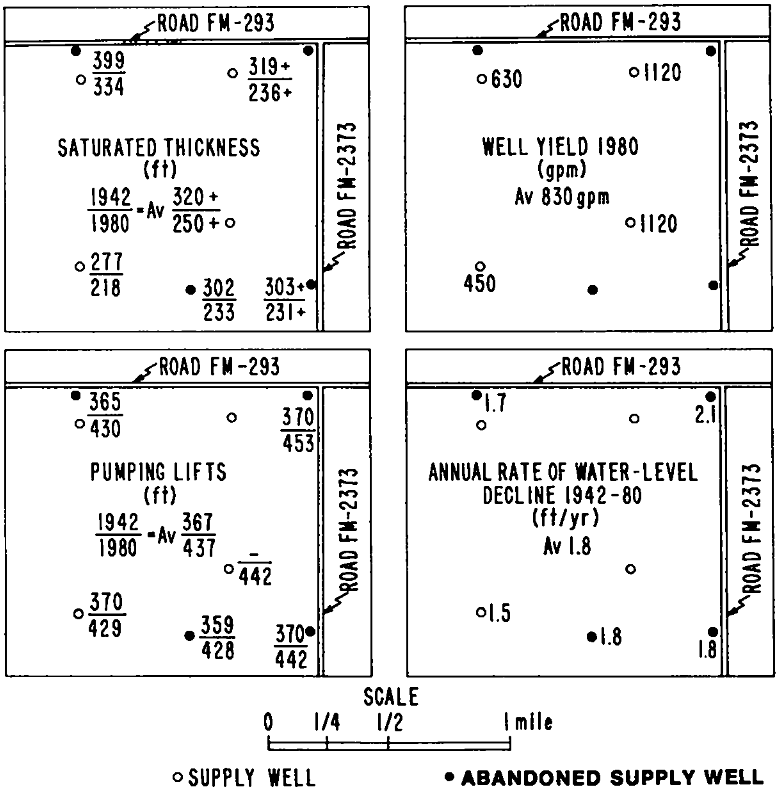

Fig. 14. Well and aquifer characteristics in the Pantex well field 1942 and 1980 (Stewart 1980).

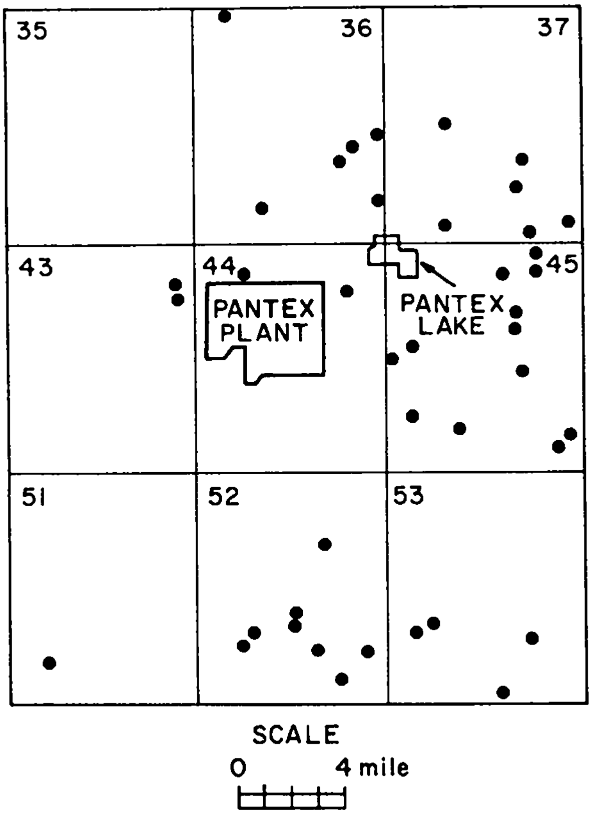

Fig. 15. Location of observation wells around Pantex Plant (TDWR 1979).

TABLE VI

ANNUAL AVERAGE RATE OF WATER-LEVEL DECLINE IN OBSERVATION WELLS AROUND PANTEX PLANT, 1970-1976*

Location	No. of Observation Wells	Average Rate of Water-Level Decline (ft/yr)
36	6	1.4
37	5	1.9
43	2	0.8
44	2	1.4
45	11	1.0
51	1	1.9
52	8	**
53	4	1.6
Total	39	Average 1.2

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*TDWR 1979.

**Average slight rise of 0.2 ft/yr.

decline in the area. In location 52, south of Pantex, the average water level in eight wells rose slightly (Fig. 15 and Table VI). In the remainder of the locations, 36, 37, 43, 44, 45, 51, and 53, water level declines ranged from 0.8 to 1.9 ft/yr. These rates of water level decline are within the range of the water level declines in the Pantex wells of 1.5 to 2.1 ft/yr for the period 1942-1980.

3. Projected Hydrologic Data 1980-2020 in Pantex Well Field. Studies by the Texas Department of Water Resources have resulted in projections of saturated thickness, well yields, pumping lifts, and rates of water level decline to the year 2020 (Bell 1979). The conclusions reached by the study were that:

> "The Ogallala aquifer in Carson County contained approximately 9.6 x 10^6 acre-ft of water in 1974. Historical pumpage has exceeded 150 x 10^3 acre-ft annually, which is about six times the rate of natural recharge to the aquifer in the county. This overdraft of pumpage from the aquifer is expected to continue, ultimately resulting in reduced well yields, reduced acreage irrigated, and reduced agricultural production.
>
> "There is a very uneven distribution of ground water in the county. Some areas have ample ground-water resources to support current usage

through the year 2020; whereas in the other areas of the county, ground water is currently in short supply.

"The procedure used to obtain the projections was a network of observation wells where routine water levels were determined. These basic data were supplemented by records of well logs. The wells were chosen to obtain the best projections of future conditions in which the base of the Ogallala Formation or aquifer was determined or estimated." (Bell 1979).

The water-use patterns between 1960 and 1972, as reflected in the changes in water levels, measured in the High Plains of Texas were used as the principal data source for developing an aquifer depletion schedule. In developing and applying the depletion schedule, adjustments through time were made to reflect the effects of depletion of the aquifer on its ability to yield water. That is, as the aquifer's saturated thickness decreases, its ability to yield water to wells is reduced, the well yields decline, less water is pumped, and there results a lessened rate of further aquifer depletion (Bell 1979).

The saturated thickness in 1980 in the Pantex well field ranged from 218 ft to more than 334 ft. The saturated thickness increased from the southwest to the northeast. This greater saturated thickness is due to thickening of the Ogallala Formation into the basin off the flank of the minor uplift. The withdrawal of water from the Pantex well field and adjacent wells used for irrigation and municipal supply will result in a projected decreased saturated thickness of the Ogallala by the year 2020 (Fig. 16). In the previous 38 yr (1942 to 1980) the decline in average saturated thickness in the Pantex field was 70 ft, while in the next 40 yr the projected thickness will decrease about 110 ft more.

Projected yields in the Pantex Field for each well should remain greater than 1000 gpm, based on the expected saturated thickness of the aquifer (Fig. 17) (Bell 1979). In general, based on the projected saturated thickness at the year 2020, wells can be developed in the Pantex field that will yield at least 1000 gpm (Fig. 17).

The pumping lifts will increase as the saturated thickness decreases (Fig. 18). The average pumping lift increased about 70 ft, from 367 ft in 1942 to 437 ft in 1980. The projected pumping lift in the year 2020 will be from a depth of about 590 ft. This represents an increase of about 150 ft between 1980 and 2020. The average annual rates of water-level decline from 1942 to 1980 were 1.8 ft/yr (Fig. 14). The projected average annual rate of water-level decline for the 10-yr period 1980 to 1990 is estimated at 3.1 ft/yr; 1990 to 2000 at 2.9 ft/yr; 2000 to 2010 at 2.5 ft/yr; and 2010 to 2020 at 2.2 ft/yr (Fig. 19) (Bell 1979).

Based on projected hydrologic characteristics of the aquifer by the Texas Department of Water Resources, water supply at the Pantex Plant derived from the

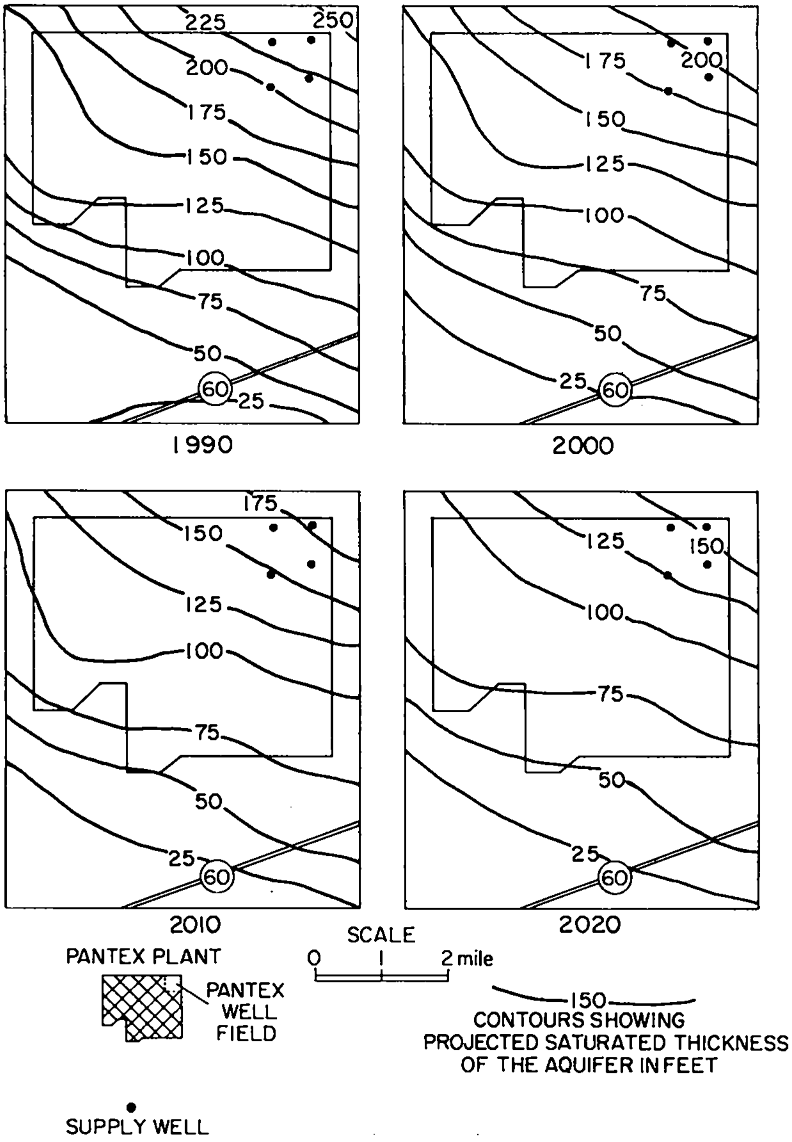


Fig. 16. Projected saturated thickness of the Ogallala Aquifer for the years 1990, 2000, 2010, and 2020 at and adjacent to Pantex (Bell 1979).

Ogallala Formation should be ample till at least the year 2020 (Bell 1979). We infer that, as agricultural use declines because of the large increase in cost of energy to pump from greater depths, there will be ample water for a much longer period of time. The amount of annual pumping will decline, and as a result, the annual rate of water-level decline will decrease.

4. Potential Ground Water Development at Pantex Lake. The Department of Energy has retained a parcel of land, Pantex Lake, about 2.5 mi northeast of the

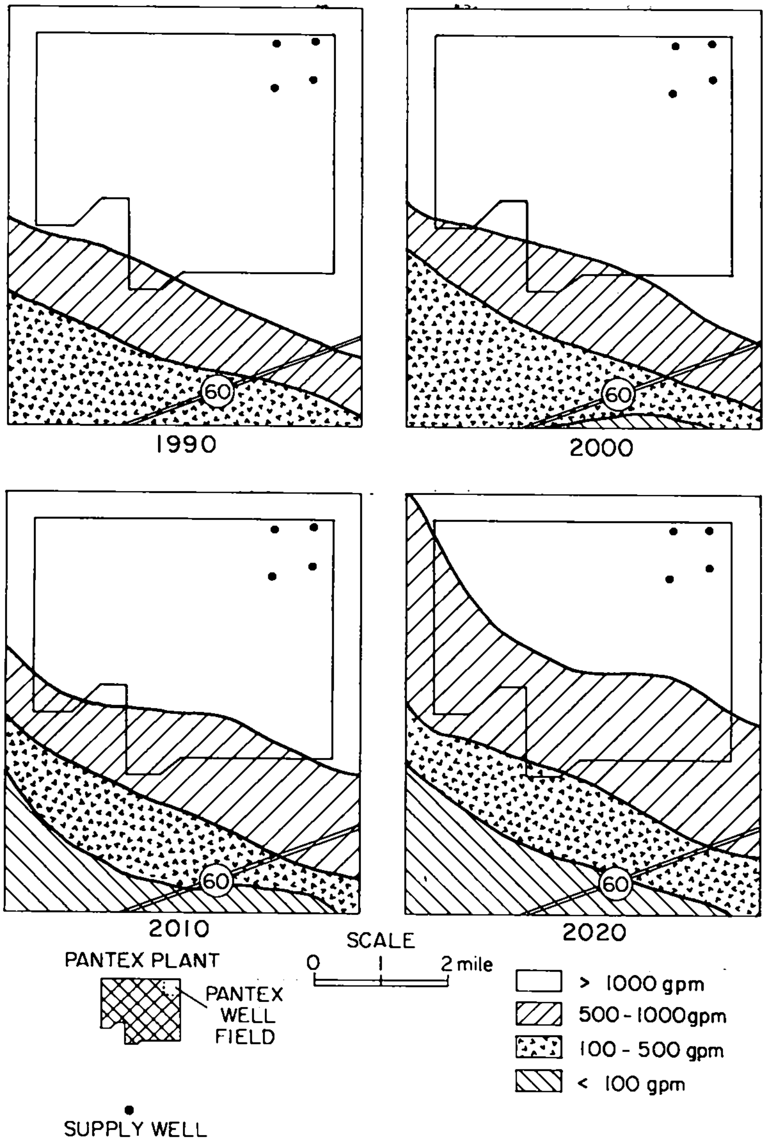


Fig. 17. Projected wells yields from the Ogallala Aquifer for the years 1990, 2000, 2010, and 2020 at and adjacent to Pantex (Bell 1979).

Pantex Plant for possible well field expansion for water supply for the Pantex Plant. Pantex Lake is an area of 1077 acres (1.7 sq mi) located in and around a playa basin. The playa basin contains only an intermittent pond, depending on runoff from precipitation. The land is undeveloped and leased for grazing.

The area has a geohydrologic potential for locations of high yield wells (≈1000 gpm) that could supply water to the Pantex Plant from the Ogallala Formation. At the present rate of production from the Ogallala Formation at and adjacent to the Pantex Plant, as previously stated, water supply at the Plant

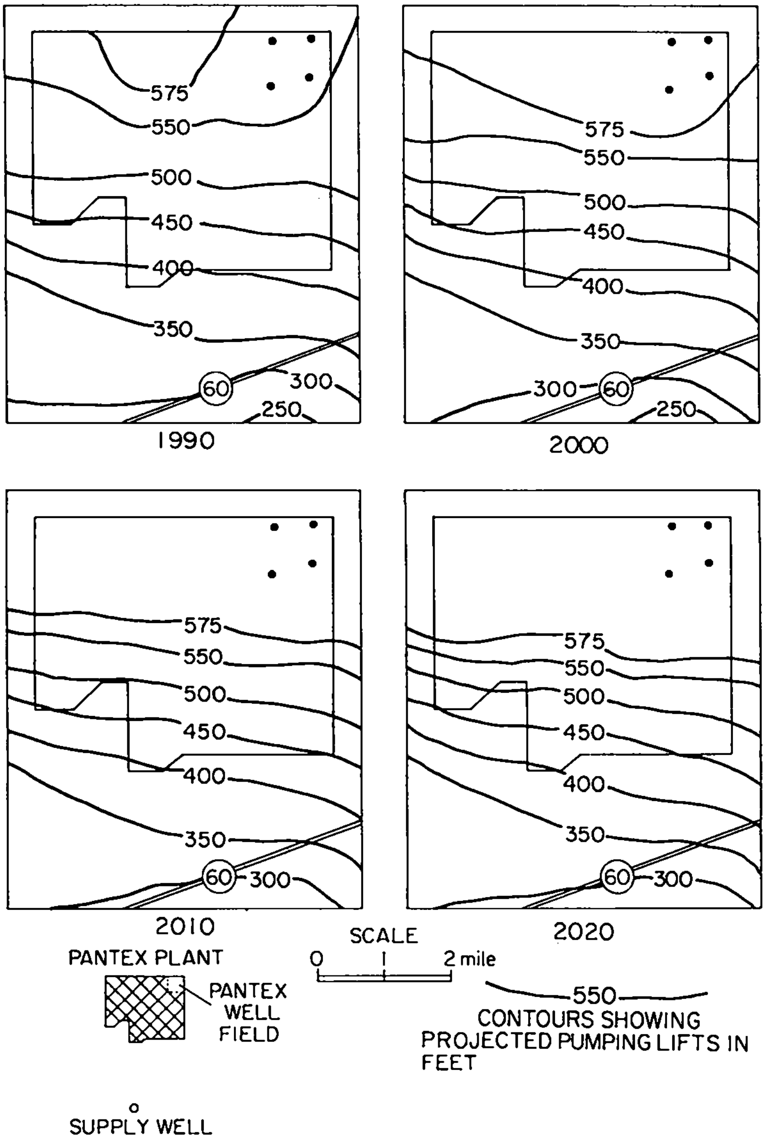


Fig. 18. Projected pumping lifts from the Ogallala Aquifer for the years 1990, 2000, 2010, and 2020 at and adjacent to Pantex (Bell 1979).

should be sufficient till the year 2020. However, if increased production for the city of Amarillo should occur, this would result in excessive decline in the water table and storage in the aquifer.

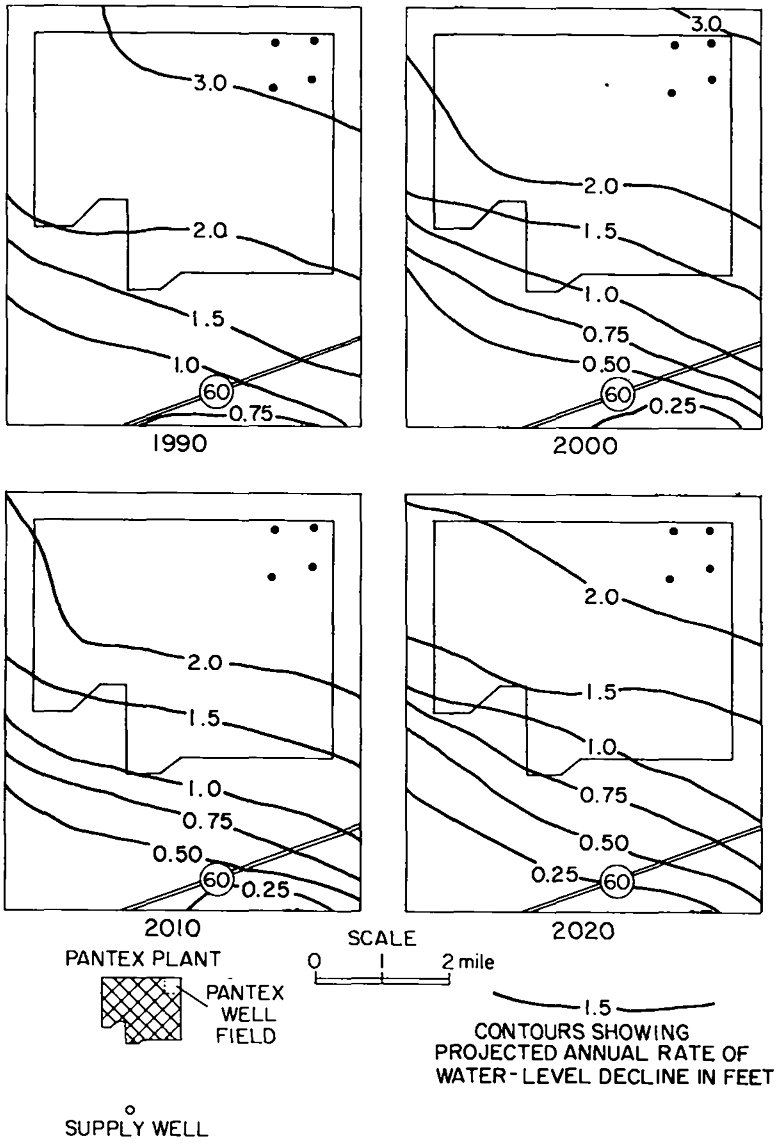


Fig. 19. Projected annual rate of water-level decline in the Ogallala Aquifer for the years 1990, 2000, 2010, and 2020 at and adjacent to Pantex (Bell 1979).

The Ogallala Formation thickens northeast of the Pantex Plant into a basin cut into the underlying Triassic rock. As a result, at Pantex Lake the saturated thickness of the Ogallala Formation is about 50 ft thicker than in the Pantex well field. The extra 50 ft of saturated thickness could yield a 10- to 15-yr additional water supply to the Pantex Plant. For this reason, the land should be retained by the DOE (Heard 1982A).

The saturated thickness of the Ogallala Formation at Pantex Lake in 1980 was about 310 ft (Heard 1982B). Projections of saturated thickness of the Ogallala by the Texas Department of Water Resources are 275 ft in 1990, 240 ft in 2000, 215 ft in 2010, and 190 ft in 2020 (Bell 1979). By comparison, in the year 2020, the projected saturated thickness of the Ogallala Formation at the Pantex Well Field will be about 140 ft and at Pantex Lake about 190 ft.

The rate of water-level decline based on wells in the area of Pantex Lake from 1970 through 1976 has been about 1.5 ft/yr (TDWR 1979). The projected water-level decline from 1980 to 2000 is estimated at about 3.5 ft/yr and from 2000 to 2020 at 2.5 ft/yr (Bell 1979).

Wells completed in a 190-ft saturated section of the Ogallala Formation will yield as much as 1000 gpm. Based on an area of 1.7 sq mi at Pantex Lake, over 10 high yield wells (≈1000 gpm) can be spaced 400 yards apart as required by the Texas Panhandle Ground Water District No. 3 regulations.

D. Quality of Water

Surface and ground water contains minerals that are naturally occurring through dissolution of minerals by the water as it passes over or through the earth materials. Some minerals may be added to the surface or ground water by release or discharge of waste waters from municipal sanitary sewage treatment or industrial processes. Water quality is useful to determine the suitability of water for various uses and to document deterioration of quality caused from waste water release.

1. Quality of Surface Water in the Canadian River and Lake Meredith. Surface water in the Canadian River above Lake Meredith and at Lake Meredith (monitored by the US Geological Survey) contains predominate ions of sodium and chloride (Table VII). The flow of the Canadian River at the time the sample was collected was about 10 cfs (base flow) reflecting high concentrations of minerals in the water. Dilution of base flow by storm runoff reduces the mineral concentration in the water. Some sanitary effluent from the Amarillo Treatment Plant is released into East Amarillo Creek, a tributary to the Canadian River upstream from the lake (Fig. 20) (USGS 1980). The mineral concentrations at low or base flow in the Canadian River are much greater than found in Lake Meredith whose storage results from storm runoff (Fig. 21).

2. Quality of Ground Water in the Ogallala Formation at the Pantex Plant. The ground water on the Pantex Plant in the Ogallala Formation includes water in both the perched aquifers and main aquifer (lower part of the Ogallala). These aquifers were the subject of intense sampling and analyses during December 1980 through February 1981. Analyses were made by Control for Environmental Pollution, Incorporated, and the Los Alamos National Laboratory (Ferenbaugh 1981, Adams 1981).

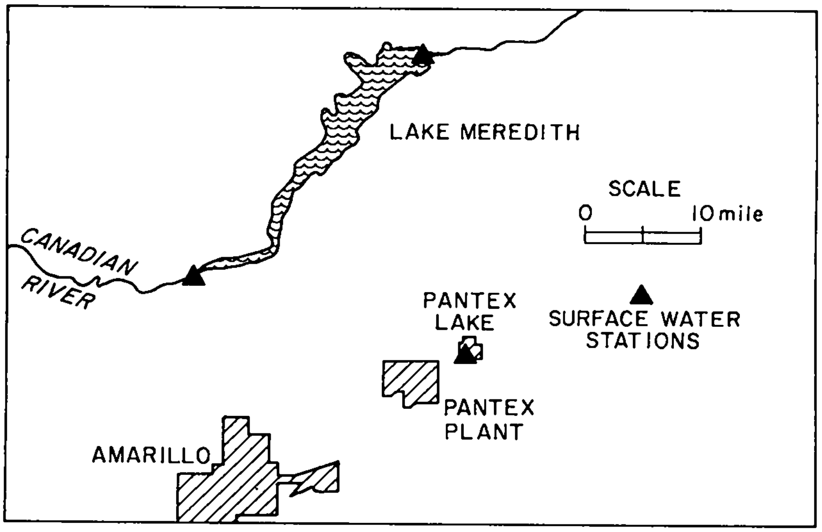
Water samples from the perched aquifer penetrated by test holes 1 and 2 are completely different in chemical quality from each other. Perched water from test well 1 (Fig. 20) contains principally ions of sodium and bicarbonate,

TABLE VII

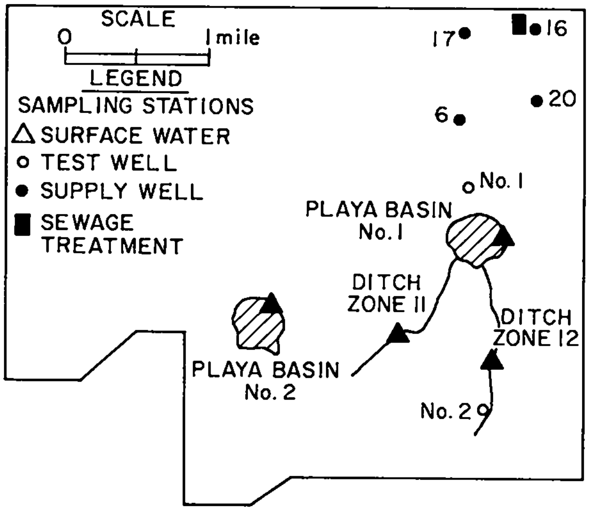
CHEMICAL QUALITY OF SURFACE WATER FROM THE CANADIAN RIVER AND LAKE MEREDITH AND GROUND WATER AT THE PANTEX PLANT

	Canadian River	Lake Meredith	Test Holes		Supply Wells			
			No.1	No. 2	No. 6	No. 6	No. 16	No. 20
Date	12/78	12/78	2/81	2/81	2/42	2/81	2/81	2/81
Chemical (mg/ℓ)								
SiO_2	14	6	4	4	31	36	28	39
Ca	200	44	36	20	36	48	42	40
Mg	63	27	9	32	22	29	26	29
Na	720	290	38	15	22	23	27	30
K	7.0	8.0	-	-	6.1	-	-	-
CO_3	0	0	0	0	0	0	0	0
HCO_3	190	190	175	140	240	215	215	225
SO_4	680	280	3	30	16	23	22	17
Cl	1000	310	28	30	12	10	10	15
F	0.4	0.8	0.5	1.5	1.3	2.1	1.9	2.4
N	0.4	-	0.1	0.2	4.3	1.4	1.4	1.5
TDS	2780	1060	232	194	270	266	268	308
Total Hard	760	220	125	180	180	240	210	220
Conductance (μmho)	4400	1840	530	420	450	470	460	500

Source: Dates 12/78 USGS 1980,
2/81 Adams 1981,
2/42 Long 1961.



OUTLYING STATION



PANTEX PLANT STATIONS

Fig. 20. Location of quality of surface and ground water stations.

while the perched water from test well 2 is a magnesium and bicarbonate type water (Fig. 22) (Adams 1981). The quality of water from both perched aquifer wells is also quite different from that found in the main aquifer (Table VII). The total dissolved solids (TDS) in the perched aquifer are low (less than 300 mg/ℓ); however, the high concentration of calcium and magnesium results in a hardness ranging from 125 to 181 mg/ℓ (Table VII) (ASTM 1969). The quality of the water in the perched aquifers is good; concentrations of constituents are below standards for drinking water for domestic or municipal use (Table VIII) (USEPA 1975, 1979). The perched aquifers are of limited extent and are not capable of supplying water to the Pantex Plant.

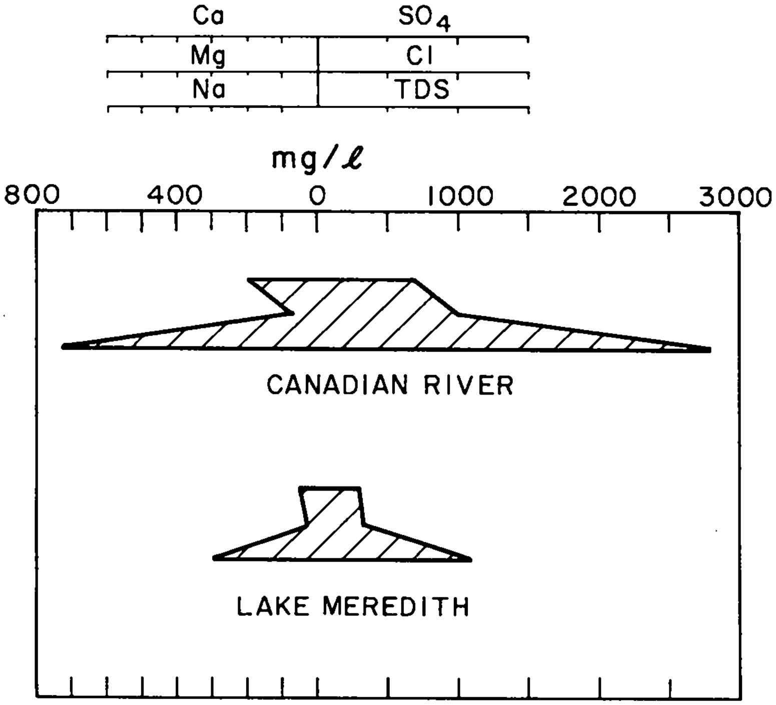


Fig. 21. Quality of water from the Canadian River and Lake Meredith, December 1979.

Water in the main aquifer in the Ogallala contains principally ions of calcium and bicarbonate (Fig. 22). Water quality is good; TDS concentrations are less than 300 mg/ℓ. Total hardness ranges from 210 to 240 mg/ℓ, resulting in water that is very hard (ASTM 1969). The water will need treatment to keep scale (mineral deposits) from forming in boiler feed lines. At the Pantex Plant, water is treated prior to use in processing where scale could form. Analyses from three of the wells in the field show no significant variations in chemical constituents between individual wells (Table VIII, Fig. 22). The water from wells completed in the main aquifer of the Ogallala Formation meets Federal drinking water standards (USEPA 1975, 1979) with one exception. Well 20 has fluoride; water from well 20 mixed with water from other wells will reduce the concentration of fluoride to an acceptable concentration.

The first supply wells for the Pantex Plant were drilled and placed in operation by 1942. A comparison of 1942 water analysis from one of the wells with the average of a number of constituents analyzed for in 1981 indicates little or no detectable change in the water quality (Fig. 23, Table VII). The withdrawal of water from the aquifer since 1942 has resulted in no deterioration of the quality of water.

The possibility of effluents from the plant operations at Pantex contaminating the aquifers in the Ogallala Formation is remote. The upland

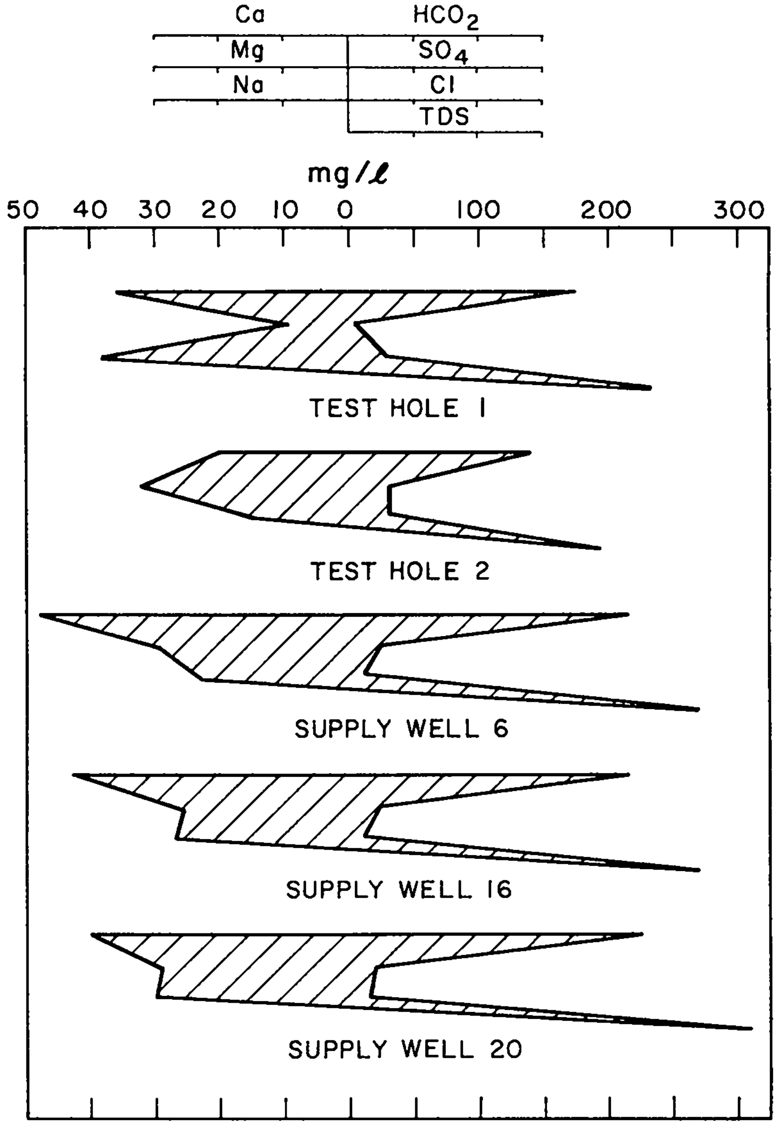


Fig. 22. Quality of water from test holes (perched aquifers) and supply wells (main aquifers) in the Ogallala Formation, February 1981.

surface in the plant area is underlain by the impermeable Pullman soil series, whereas in the playa basin the impermeable Randall clay soils have been deposited. The high evaporation from soils and open water sources (ditches and ponds in playa basins) and transpiration of water through plants and shrubs along ditches and in playas substantially reduce the amount of water that could infiltrate through silts and clays of soil and sediments in the playa basin. If water should infiltrate through the thick soil zone and sediments in the playa basin, it must move through 360 to 420 ft of unsaturated silts, clay, sands, and gravels that overlie the aquifers in the Ogallala Formation.

TABLE VIII

ANALYSES FOR DRINKING WATER REGULATIONS, TEST WELLS AND SUPPLY WELLS AT PANTEX, FEBRUARY 18, 1981

(Analyses in mg/ℓ)

Analysis	Standards*	Test Wells		Supply Wells		
		No. 1	No. 2	No. 6	No. 16	No. 20
Primary Standards						
Ag	0.05	<0.01	<0.01	<0.01	<0.01	<0.01
As	0.05	<0.01	<0.01	<0.01	<0.01	<0.01
Ba	1.0	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	0.01	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	0.05	<0.001	<0.001	0.003	0.003	0.003
F**	2.2	0.5	1.5	2.1	1.9	2.4
Hg	0.002	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
NO_3	45	0.4	0.9	6.1	6.1	6.6
Pb	0.05	<0.001	<0.001	0.001	0.002	0.002
Se	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Secondary Standards						
Cl	250	22	35	10	10	11
Cu	1	<0.001	0.002	<0.001	<0.001	0.002
Fe	0.3	0.07	0.07	0.09	0.09	0.09
pH	6.5-8.5	6.7	7.7	7.5	7.4	7.7
SO_4	250	3	43	29	32	46
TDS	500	239	215	306	267	308
Zn	5	<0.1	<0.1	<0.1	<0.1	<0.1

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*USEPA 1975, 1979; Analyses, Ferenbaugh 1981.
**Based on annual temperature of 57°F.

3. Quality of Surface Water at Pantex Lake and Pantex Plant. The quality of surface water at Pantex Lake and Pantex Plant is determined and reported in the "Environmental Monitoring Report for the Pantex Plant Covering 1981." The report is prepared by Mason and Hanger-Silas Mason Company, Incorporated, operators of the Pantex Plant for DOE (Laseter 1982B). The surface water stations are Pantex Lake, Sanitary Effluent, Playa Basin No. 1, Playa Basin No. 2, and ditches containing effluent from plant operations in Zones 11 and 12. These surface waters are not used for municipal or domestic supply but have the

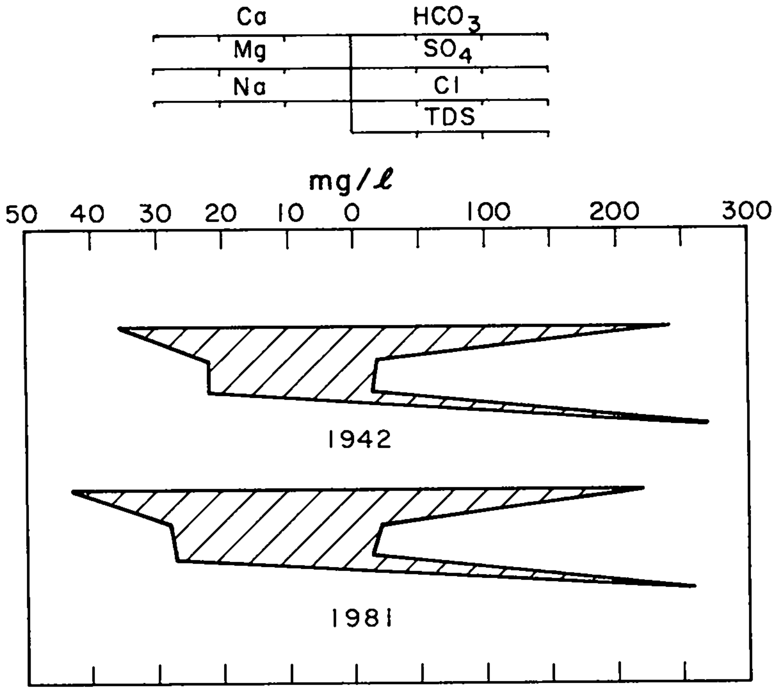

Fig. 23. Quality of water from the Pantex well field in 1942 compared to the quality of water in 1981.

potential for use as irrigation waters. The maximum concentrations of chemical constituents, organic chemicals, and explosives in the waters are shown in Table IX along with standards or criteria for irrigation (Dawson 1974).

Pantex Lake is an area retained by DOE for possible well field expansion to furnish water supply for the Pantex Plant (Sec. V.C.4). The Pantex Lake area includes a large playa basin that contains an intermittent lake. The lake at times contains runoff water from precipitation and perhaps some return flow from irrigation (Fig. 20). In the past the playa received treated sanitary effluent from an Air Force Base once located near Amarillo. None of the runoff originates as effluent from the Pantex Plant (Fig. 7). Chemical quality of water at the lake is acceptable for irrigation (Table IX). Organic chemical and explosive concentrations are below limits of detection. Organic chemicals (pesticides) could be present from runoff from farm lands; however, explosives would not be present as there is no hydrologic connection of water in the lake with any of the Pantex Plant's operation.

Sanitary effluents were sampled at the sanitary treatment plant in the northeast corner of the Pantex Plant (Fig. 20). The plant treated about 170 x 10^6 gal in 1980. The effluent was released into Playa Basin No. 1. The quality of the effluents is within irrigation criteria. Explosive contamination should not be present and was not detected in the effluents.

TABLE IX

QUALITY OF SURFACE WATER AT PANTEX LAKE AND PANTEX PLANT*

Chemical Constituents	Standards or Criteria in mg/ℓ for Irrigation**	Maximum Concentrations of a Number of Analyses in mg/ℓ					
		Pantex Lake	Sanitary Effluents	Playa Basin No. 1	Playa Basin No. 2	Drainage Ditch to Red Lake Playa	
						Zone 12	Zone 11
Arsenic	0.1	0.01	<0.01	<0.01	<0.01	<0.005	<0.0
Barium	1.0	0.2	-	0.3	0.2	-	-
Cadmium	0.005	0.004	0.006	0.005	0.005	0.003	0.0
Chromium (total)	-	<0.001	0.014	0.005	<0.001	<0.005	<0.001
Chromium (+6)	1.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.005
Copper	0.2	0.035	0.070	0.020	0.020	0.02	0.01
Cyanide	-	0.005	0.011	0.030	0.005	<0.005	0.02
Fluoride	10	0.7	-	2.8	0.4	-	- 09
Iron	5	0.05	0.30	0.08	0.08	0.04	0.0
Lead	5	<0.001	0.009	0.005	<0.001	<0.005	0.08
Mercury	-	0.0001	0.0003	0.0001	0.0016	<0.0001	0.001
Nitrate (N)	-	0.3	0.9	0.8	0.1	0.7	0.6013
Phenol	-	0.022	0.006	0.021	0.009	0.012	0.0
Phosphate	-	0.35	0.86	1.1	0.08	0.04	0.816
Silver	-	<0.01	-	<0.01	<0.01	-	- 5
Sulfate	200	23	110	102	17	25	87
Selenium	0.02	<0.005	-	<0.005	<0.005	-	-
Total Dissolved Solids	-	370	533	566	236	234	688
Total Suspended Solids	-	1.7	1.0	1.0	1.0	<1.	<1
Zinc	5.0	0.02	0.09	0.06	0.02	0.01	0.0
pH (No units)	-	8.2	7.6	7.6	7.8	8.0	7.75
Hardness	-	201	222	255	147	166	220
Organic Chemical							
Endrin	-	<0.0002	-	<0.0002	<0.0002	-	-
Lindane	-	<0.004	-	<0.004	<0.004	-	-
Methoxychlor	-	<0.1	-	<0.1	<0.1	-	-
Toxaphene	-	<0.005	-	<0.005	<0.005	-	-
2, 4-D	-	<0.1	-	<0.1	<0.1	-	-
2,4,5,-TP (silvex)	-	<0.01	-	<0.01	<0.01	-	-
Oil/grease	-	3.0	1.0	1.0	4.0	11	10
Explosives							
RDX	-	<0.004	<0.004	<0.004	<0.004	0.20	0.2
HMX	-	<0.004	<0.004	<0.004	<0.004	0.48	1.2
PETN	-	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Miscellaneous							
BOD	-	-	41.7	47.3	-	-	-
COD	-	-	-	289	-	-	-

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*Laseter 19828.
**Dawson 1974.

The perennial lake in Playa Basin No. 1 is maintained by release of sanitary effluents and some process effluents and runoff from precipitation. Water from the lake is used for irrigation of crops grown in the northeast corner of the Plant by Texas Tech University. Water quality is good, low in TDS (<550 mg/ℓ); and chemical constituents are lower than the criteria mentioned for irrigation (Table IX). Organic chemicals (pesticides) are below limits of detection. Lake water shows no trace of explosive contamination from effluents that are released into ditches that drain into the lake.

Playa Basin No. 2 contains water only when precipitation results in a large amount of runoff. At present, there is no release of sanitary or industrial effluents into the playa. Water in the playa, which is dry most of the time, is not utilized for irrigation or any other purpose. Water quality reflects water from natural runoff areas with low TDS (<250 mg/ℓ). There are no detectable organic chemicals or explosive contamination in the playa water.

Ditches in the uplands around Zones 11 and 12 carry industrial effluents into Playa Basin No. 1 (Fig. 20). High-explosive wastes in water used in machining or processing of high explosives are conveyed from buildings to settling and filtering treatment stations where most of the high-explosive particles are extracted. The treated effluents contain some fine-grained particles and traces of dissolved high explosives are released into ditches. The chemical constituents of water in the ditches are within criteria for irrigation (Table IX). High explosives (RDX and HMX) are present in trace amounts in the effluent in the ditches; however, they are not detectable in water in Playa Basin No. 1. Most high explosives (HMX, PETN, RDX, TATB, and TNT) used now or in the past at Pantex are insoluble (less than 0.1 g of dissolved explosive at room temperature per 100 mℓ of water) (Dobratz 1981). The ditches are flushed several times a year with storm runoff that disperses the high explosive particles downgradient to Playa Basin No. 1, so that a high buildup of explosives does not occur near points of effluent release.

V. LANDFILL DISPOSAL AND STORAGE

There are nine classifications of sanitary solid waste landfill repositories at the Pantex Plant (Table X). All are closed now except three. These receive general sanitary wastes (B), construction debris (D), and waste products from explosives (G) (Fig. 24) (MHSM 1980).

The length, width, and depth of the pits vary (Fig. 24). The deepest pits were dug to about 30 ft. This is well within the sandy clay that makes up the lower section of the windblown sand cover of the plain overlying the upper part of the Ogallala Formation. The sandy clay which overlies the gravels of the Ogallala Formation is of low permeability, allowing little if any infiltration of water through the sandy clay underlying the pits. The high evaporation rate in the area will deplete most if not all precipitation before it penetrates through the cover of the closed pits and wastes into the sandy clay. There is

TABLE X

MATERIALS IN SOLID WASTE LANDFILL AREAS*

Classification	Materials
A	Closed sanitary landfill contains paper, food wastes, glass, plastic materials, empty pesticide containers, grease/oil trap sludge, empty petroleum and petroleum solvent containers (two areas).
B	Open sanitary landfill contains paper, cafeteria grease, oil trap sludge, gloves, plastic materials, rinsed empty pesticide and solvent containers (one area).
C	Closed construction debris landfill contains broken construction materials such as brick, concrete, wood, structural steel, asphalt, sheetrock, paper, conduit, pipe, wire, glass, plastic, and waste petroleum products (twenty-two areas).
D	Open construction debris landfill, same as Location C except no waste petroleum products (one area).
E	Closed contaminated landfill contains materials contaminated with high explosives, such as paper and waste products and burned high explosive products (two areas).
F	Closed contaminated landfill contains concrete contaminated with high explosives and waste products from high explosive test firing (two areas).
G	Open contaminated landfill contains burn residue from high explosives and waste products from high explosive test fire and waste products from burned chemicals (two areas).
H	Closed construction landfill contains concrete only from igloo demolition (seventeen areas).
J	Closed pit containing carbon black from fire at building 10-7 (one area).

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*MHSM 1980. Locations shown in Fig. 24.

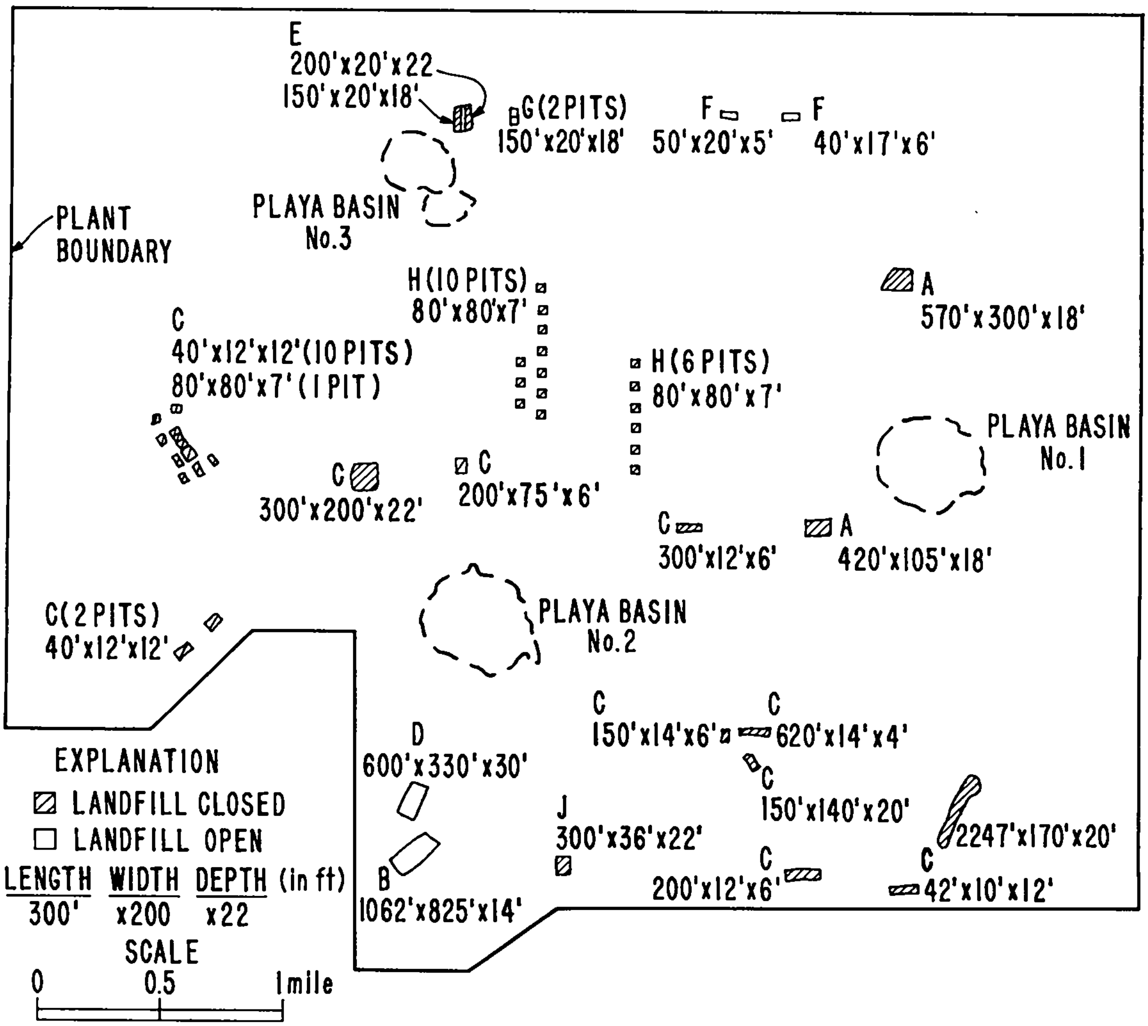

Fig. 24. Location of solid waste landfill areas at the Pantex Plant (MHSM 1980).

little, if any, indication of recharge to the aquifer in the lower part of the Ogallala Formation, thus little, if any, probability of the sanitary landfill pits contaminating water in the aquifer.

VI. NATURAL RESOURCES

Natural resources in the regional area of the Pantex Plant are ground water, oil, natural gas, helium, limestone, sand, and gravel. Ground water was discussed in Sec. V.

The first commercial oil in the Texas Panhandle was found in Carson County (Pantex Plant is located in Carson County) in May 1921, and the first commercial natural gas production began in Potter County (west of the Pantex Plant) in December 1918 (Totten 1956). These areas form the giant Panhandle Oil and Gas Field (Fig. 25). Most of the oil and gas production is to the northwest, north, and northeast of the Pantex Plant along the axis of the Amarillo Uplift (Fig. 4). The gas production is mainly from limestones and dolomites in the lower Permian System and thin upper section of the Pennsylvanian System. The Pennsylvanian section is apparently absent beneath the Pantex Plant. Oil and gas reservoirs are at a depth of 3000 to 8000 ft along the axis and flanks of the Amarillo Uplifts. Test drilling for oil and gas in the area adjacent to the Pantex Plant has failed to locate any gas or oil reservoirs at depth. This is probably due in part to the lack of geologic structure to form oil and gas reservoirs and the absence of the lower rocks of the Permian System and upper rocks of the Pennsylvanian System.

Production from Carson County in 1979 was about 97 x 10^6 MCF (million cubic feet) of natural gas and 1.3 x 10^6 barrels of oil (Stone 1981). The area of production in Carson County is in the northern half and northeastern part of the county about 10 to 15 mi from the Pantex Plant.

The industrial development of the area is related to the production of oil and gas; their importance grew after the expansion of the Panhandle Oil and Gas Field in 1926. The industries depending on the petroleum products are synthetic rubber, carbon black, pipeline companies, refineries, and petrochemical plants.

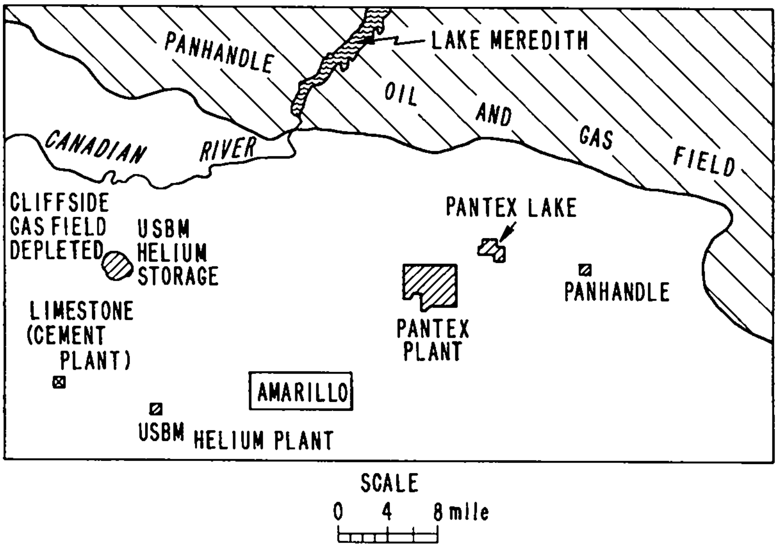

Fig. 25. Natural resources (oil, gas, helium, and limestone) in the area of the Pantex Plant.

The development of the petroleum industry in the Panhandle Oil and Gas Field was located in a belt of relatively high-mineralized water. As a result, many of the industries had to procure water of a better quality from wells outside the belt (McAdoo 1964). Prior to 1961, a substantial part of oil field brines in the area was disposed of in surface pits. Some evidence indicated local contamination from the surface pits. Under a ruling by the Texas Railroad Commission in 1962, the use of surface pits for the disposal of oil field brines was discontinued. Since that time oil field brine disposal has undergone a change to subsurface injection into deep geologic units which contain water of a similar poor quality. However, the disposal of brine into these pits prior to 1962 can have a long-lasting effect of contaminating the aquifer.

A helium reserve has been established by the US Bureau of Mines northwest of Amarillo (Fig. 25). Helium, a by-product of natural gas, is injected into an underground reservoir (Cliffside Gas Field). The reservoir is in the limestones and dolomites in the lower section of Permian rocks at a depth of 4500 to about 5500 ft.

Limestone used for the manufacture of cement is mined from limestone (caliche) in Ogallala Formation northwest of Amarillo or west of the Pantex Plant (Fig. 25). The limestone is removed by surface mining and manufactured into cement at the site.

Sand and gravels used in construction are mined mainly from terraces along the Canadian River north of the Pantex Plant. Local deposits of gravel occur in the breaks between the Canadian River and high plains along stream channels and terraces above the channel (Stone 1981).

Operations of the Pantex Plant do not affect the natural resources of the area.

VII. GEOLOGIC AND HYDROLOGIC HAZARDS

Natural geologic and hydrologic hazards considered at the Pantex Plant are earthquakes, subsidence caused by ground water withdrawal or "sink hole development," and flooding at the site caused by large amounts of precipitation.

A. Earthquakes

The Pantex Plant lies within Zone 1 on the seismic risk map of the United States (ICBO 1979). Zone 1 will have minor damage to structures due to distant earthquakes with fundamental periods of greater than 10 s. This is in comparison to Zone 3 where, for example, California would report major damage.

Historically, Texas has been recognized as one of the least seismic-active areas of the United States. Only 17 earthquakes of intensity V or greater on the modified Mercalli scale have had centers in Texas since the first historical

TABLE XI

SUMMARY OF MAJOR EARTHQUAKES IN THE SOUTHERN HIGH PLAINS*

Date	Approx. Distance from Pantex Plant (mi)	Intensity Modified Mercalli Scale	Magnitude
January 8, 1891	400	VII	--
March 27, 1917	20	VI	--
July 25, 1925	10	VI	--
August 16, 1931	350	VIII	--
June 19, 1936	20	VI	--
March 11, 1948	70	VI	--
June 20, 1951	80	VI	--
April 9, 1952	210	VII	5.5
July 20, 1966	20	V	4.8

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*Blume 1976.

observation was made in 1882. The largest recorded earthquake in Texas was of intensity VIII about 350 miles southeast of the plant. In the Texas Panhandle and eastern New Mexico, no shock of intensity VIII or even VII has been reported. Practically all knowledge of Texas earthquakes from 1882 until 1948 is based on noninstrumental observations. Significant seismic events of the region are listed in Table XI (Blume 1976).

1. Seismic Hazard. Blume and Associates (1976) estimated from the historical data that the maximum credible earthquake that could occur in the Southern High Plain would be a magnitude (M) of 6.5 on the Richter scale with a peak acceleration of 0.33 g (320 cm/s^2) with a vertical acceleration of 0.22 g (215 cm/s^2). The recurrence interval for the earthquake approaching an $M = 6.5$ is in the order of one per 1000 yr. The probability that the Pantex Plant will not suffer a peak acceleration as large as 0.33 g (M6.5) in a period of 100 yr is more than 99% (Blume 1976).

For structural design of facilities Blume and Associates use a recurrence interval of 30 years. They determined that there is an 80% probability of an earthquake of about an $M = 5.5$ (intensity of VII) with a peak acceleration value of 0.085 g (80 cm/cm^2) and a vertical acceleration of 0.055 g (55 cm/s^2) in a 30-yr period (Blume 1976).

2. Associated Seismic Hazards. Other geologic hazards that may be initiated by earthquakes are ground rupture along fault zones and soil failure such as liquefaction, which may occur because of ground motion even at great distances from the earthquake's epicenter.

There are no known reports of surface rupture due to surface fault displacement at the plant (Blume 1976). The earthquake of July 25, 1925, near Panhandle (intensity VI) was studied in considerable detail. It was reported that no fissures or other evidence of displacement of earth movement was noted (Pratt 1926). If faults exist in the subsurface beneath the Pantex Plant, they do not extend into the rock of the Ogallala Formation or displace the rock beneath the Ogallala. There is no apparent active faulting present at the Pantex Plant; therefore, there is no measurable hazard apparent from ground surface rupture on an existing fault at the plant (Blume 1976).

The upper 35 ft of surface soils are fine grained and cohesive. Standard penetration tests in the soil range from 20 to 60 blows/ft; unconfined compression tests indicate characteristic shear values of 4000 lbs/ft^2, cohesion greater than 800 lbs/ft^2, and an angle of friction equal to 30°. These strength and cohesion values, considered together with an extremely deep water table, indicate that liquefaction hazard at Pantex Plant is negligible. The soils are fine grained and cohesive, thus nonuniform settlement due to reduction of void space in the soil at the Pantex Plant is unlikely (Blume 1976).

B. Land Subsidence

Land subsidence in the area of the Pantex Plant has been evaluated in regard to declining water tables and the possibility of "sink hole" development in the subsurface.

The aquifer is in the Ogallala Formation at a depth of about 420 ft at the Pantex Plant. The water level decline since 1942 has been about 1.8 ft/yr. The aquifer is made up of sands, gravels, and boulders. The depth to water and the type of sediments (sands, gravels, and boulders) being dewatered make it improbable that land subsidence will occur in the area of the Pantex Plant.

The playas on the upland plain underlain by the Ogallala Formation are formed by the leaching of caprock (the caliche) followed by surface blowout due to wind erosion. Thus the playa basins are formed by surface phenomena. The development of "sink holes" by solution of limestones and anhydrite is equally unlikely as these rocks are found in the deep Permian System under the site (below the Ogallala at depths of about 8000 ft). There has been no known occurrence of "sink holes" developing in the area around the Pantex Plant.

C. Flooding

A drainage study was made for the Pantex Plant and adjoining Texas Tech University Research Farm (Becker 1982B). All drainage in the area is into local playa basins (Fig. 7). The major drainage at the Pantex Plant is into playa basins onsite with the exception of areas along the north and south boundaries. A flooding analysis made of buildings in Zones 11 and 12 of the main manufacturing area at Pantex found that, even with all the drainage culverts blocked, flooding was not expected to occur from a maximum 24-h rainfall (100-yr frequency, 6.75 in.) except at buildings 12-42 and 12-64, where the floor elevations are below ground level. Flooding caused from the 6 and 24-h storms with varying recurrence intervals from 1 to 100 yr was also examined. It was found that the playas would contain all runoff, with occasional flooding of three or four abandoned igloos in the Playa Basin No. 3 (Fig. 7). It was concluded that flooding caused by intense rainfall would not endanger the Pantex Plant nor its operations.

VIII. SUMMARY

A. Geology

The Pantex Plant is located on the Southern High Plains in Texas south of the Canadian River (Fig. 1). The plant is underlain, in ascending order, by sediments of Permian, Triassic, Tertiary, and Quaternary systems. Of major importance is the Ogallala Formation of the Tertiary System, which furnishes the water supply to the plant as well as municipal and industrial supply to nearby towns and irrigation water to adjacent farm areas. The near surface sediments of the Quaternary system are windblown sands on the plains and playa deposits in the basins which formed in the surface of the plain. The sand has developed into a sandy clay loam about 50 ft thick. It includes a soil zone at the surface, caliche, and dense sandy clay at depth. The playa deposits are sandy clays. Both the windblown sand and playa deposits restrict the infiltration of water (precipitation, irrigation, or ponded runoff) so that little, if any, recharges water in the Ogallala Aquifer.

B. Hydrology

The Canadian River, about 25 miles north of the plant, is the master stream in the area. A part of the flow of the Canadian River is impounded at Lake Meredith. There, some is diverted, mixed with water pumped from the Ogallala Formation, and used for municipal and industrial supply in cities in the high plains.

The annual precipitation in the area is about 20 in. Most of the precipitation falls during the period mid-April to late October. The mean annual temperature is 57°F. Annual evaporation is about 90 in. Runoff from precipitation in the area of the Pantex Plant is into playa basins. Runoff does not reach the drainage of the Canadian River or other streams to the south and east of the plant along the escarpment of the High Plains (Fig. 1).

The Ogallala Formation consists of gravels deposited eastward from the highlands in New Mexico. The main aquifer at the Pantex Plant is in the lower part of the Ogallala which is underlain by the relatively impermeable sediments of Triassic or Permian Systems. The Ogallala Formation in the Southern High Plains is hydrologically isolated from other aquifers or other recharge sources.

The annual production of water from the Ogallala Formation for use at the Pantex Plant for the past 10 yr has been about 387 x 10^6 gal (1188 acre-ft), while the projected average annual use 1981-1990 will be about 383 x 10^6 gal (1175 acre-ft). The projected annual use for the period 1980 to 1990 in Carson County (the county in which the Pantex Plant is located, 900 mi^2) is about 148 x 10^3 acre-ft. Of this, about 104 x 10^3 acre-ft will be for irrigation and 44 x 10^3 acre-ft for municipal supply and industrial use. By comparison, the average annual projected pumpage of about 1.2 x 10^3 acre-ft at the Pantex Plant is only about 1% of the total projected amount of pumpage from the Ogallala Formation in Carson County.

There were 86.6 x 10^3 acres of irrigated crops in Carson County in 1979. The average irrigated acre receives about 1 acre-ft of water annually. If the water production at the plant were used for irrigation, it would irrigate about 1200 acres or about 1% of the total irrigated acreage in Carson County in 1979.

The use and distribution of maximum projected annual pumpage (1985 to 1986) of 400 x 10^6 gal at the Pantex Plant are projected as follows.

	%	10^6 gal
1. Manufacturing and Production Process	40	160
2. Plant Operations Resulting in Sanitary Effluent	49	196
3. Use in Steam Plant	7	28
4. Lawn and Landscape Irrigation	2	8
5. Operation of Cooling Towers	2	8
	100	400

Effluent from manufacturing and production processing and water used in the steam plant, for irrigation and cooling towers, are released or may flow into drainage channels that ultimately end up in playa basins. However, most of the effluents from these sources are lost to evapotranspiration or infiltrate into soil along the channels before reaching the playa basins. The sanitary effluents released into Playa Basin No. 1 are sometimes pumped out for irrigation use.

Water pumped from the Ogallala Formation in the entire region is being depleted, since pumpage exceeds recharge. The water is used for municipal and industrial purposes and irrigation of crops. At the plant, the water level decline from 1942 to 1980 has been about 1.8 ft/yr with a total decline of about 70 ft over this period. The water level decline at the plant is mainly a regional decline because of heavy pumpage of wells that supply water to Amarillo. The city of Amarillo well field is located immediately north of the plant. This field produced 5.1 x 10^9 gal in 1980 as compared to 0.35 x 10^9 gal produced from the well field at Pantex. The water level in the Amarillo municipal field has declined between 0.8 and 1.9 ft/yr from 1970 to 1976. Primarily because of the municipal pumping, the projected rate of decline at the plant and adjacent areas will be 2 to 3 ft/yr to the year 2020. At this time the aquifer at the plant should have a saturated thickness of 125 to 150 ft. With this saturated thickness wells can be constructed to yield in the vicinity of 1000 gpm.

At Pantex Lake, the saturated thickness of the Ogallala Formation is about 50 ft thicker than at the Pantex Plant. The additional thickness would retain an additional 10 to 15 yr water supply for the plant if water in the Ogallala should be depleted at a greater rate than projected.

Quality of water from the Ogallala Formation is good. It meets US Environmental Protection Agency's criteria for municipal water supply. However, the water is hard, containing a large amount of calcium and magnesium that may require treatment for certain uses. It is presently treated at the plant in areas where soft water is required. There is no indication of contamination of the Ogallala aquifer by effluents or activities at the plant.

Operations at the plant will not affect the natural resources of the area, surface and ground water, oil and gas reserves, storage of helium, operations for removal of limestone (manufacture of cement) or gravel for the construction industry. Though natural geohydrologic hazards are present (earthquake and flooding at plant), their possible occurrence and damage potential are low.

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