Ground-Water and Surface-Water Hydrology of Fort Wolters, Parker and Palo Pinto Counties, Texas

Final Report

R. Stephen Fisher, Principal Investigator
Robert E. Mace
Erika Boghici

assisted by
Conrad A. Kuharic and Martina Blüm

prepared for

Adjutant General's Department of Texas
Texas Army National Guard
James F. Resner II
and
The Nature Conservancy of Texas
Contract No. Texas THCB-95-1-05-01
T. James Fries, Project Manager

Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

May 31, 1996

CONTENTS

Figures

Tables

EXECUTIVE SUMMARY

Ground-water and surface-water investigations of Fort Wolters, Parker and Palo Pinto Counties, Texas, were conducted to provide the Texas Army National Guard information needed to preserve environmental quality and resources while planning and conducting training and preparedness activities. Spatial information such as surface geology, watersheds, elevation data, floodplains, well locations, and water levels were converted to digital files and submitted to the Texas Army National Guard Geographic Information System office at Camp Mabry, Austin, Texas, for future use in managing the training facility. Similar investigations were conducted at Camps Barkeley, Bowie, Mabry, Maxie, and Swift. Results of those studies are presented separately.

Previously published reports and public data files were examined to obtain background information on the camp and surrounding area. These data were used to guide more focused studies on the training facility. Ground-water studies included locating existing wells in and near the camp, installing new wells as needed, testing and sampling selected wells, determining ground-water levels, chemical compositions, and aquifer hydraulic properties, and developing a conceptual model of ground-water flow. Surface-water studies focused on delineating watersheds and mapping floodplains.

Although no major aquifers underlie the Fort Wolters area, many wells in the Mineral Wells Formation yield small quantities of water. Depths to water north of the fort are approximately 100 to 150 ft; deeper wells commonly have a sulphur smell. Seven wells at the training facility and 106 wells nearby were found during a well survey. Most wells were 100 to 150 ft deep and had standing water within 40 ft of land surface. Ground-water quality is generally fresh. Ground-water recharge on Fort Wolters occurs as rain falls on the outcrops of minor aquifer units, and ground-water discharge occurs primarily into the Brazos River or its tributaries.

Fort Wolters resides in the Brazos River Basin. Although most of the streams in the fort drain into Lake Mineral Wells, drainage in the southwestern part of the fort is to Rock Creek and then to the Brazos River. Floodplains that would result from a 100-yr storm exist as halos closely confined to the beds of major streams.

INTRODUCTION

This report summarizes ground-water and surface-water studies at Fort Wolters, Parker County, Texas, conducted by the Bureau of Economic Geology (BEG), The University of Texas at

Austin, for the Texas Army National Guard. This work was part of a larger study of Texas Army National Guard training facilities that included Camp Barkeley (Taylor County), Camp Bowie (Brown County), Camp Mabry (Travis County), Camp Maxey (Lamar County), and Camp Swift (Bastrop County). These investigations, in conjunction with aquatic and biological surveys conducted by the Texas Parks and Wildlife Department, provide information needed by the Texas Army National Guard to plan and conduct training and preparedness activities in a way that will protect and enhance environmental resources without compromising training needs and national security readiness. Reports of similar investigations of the other training facilities are presented separately.

This report contains results of hydrogeologic and hydrologic analyses and describes how data files were prepared to provide digital Geographic Information System (GIS) coverages of the camp and surrounding area. The hydrogeologic analyses contain information regarding hydrostratigraphy, camp and perimeter well surveys, monitor well drilling, ground-water levels, well testing, aquifer properties, ground-water chemistry, and a conceptual ground-water flow model. The hydrologic analyses contain information regarding streams and drainage basins in and near the camp, watershed delineations, stream-flow duration, flood frequency, and floodplain analysis. The GIS data preparation section contains descriptions of the original data sets, how they were obtained, and how they were processed to obtain GIS coverages for the camp.

Physical Setting

Fort Wolters lies just northeast of Mineral Wells, Texas. Most of the training facility is in Parker County, although a small part of the western edge of the fort is in Palo Pinto County (fig. 1). Fort Wolters borders Lake Mineral Wells State Park on the western, northern, and eastern sides. Intermittent streams flow through Fort Wolters, draining into Lake Mineral Wells as part of the Brazos River drainage basin.

The geomorphology of the reservation is dominated by steep escarpments and moderately sloped to flat upland areas. The elevation ranges from 950 ft at the bottom of the escarpment to 1,060 ft in the upland areas. The escarpment follows a northeast-southwest trend, and a north-south-trending steep valley dissects the upland area in the western part of the reservation.

Greenwade and others (1977) described soils of Parker County, and Moore (1981) described soils of Palo Pinto County. The general soil map of Parker County shows soils at Fort Wolters are of the Truce-Bonti association. In this association, 38 percent of the soils are of minor

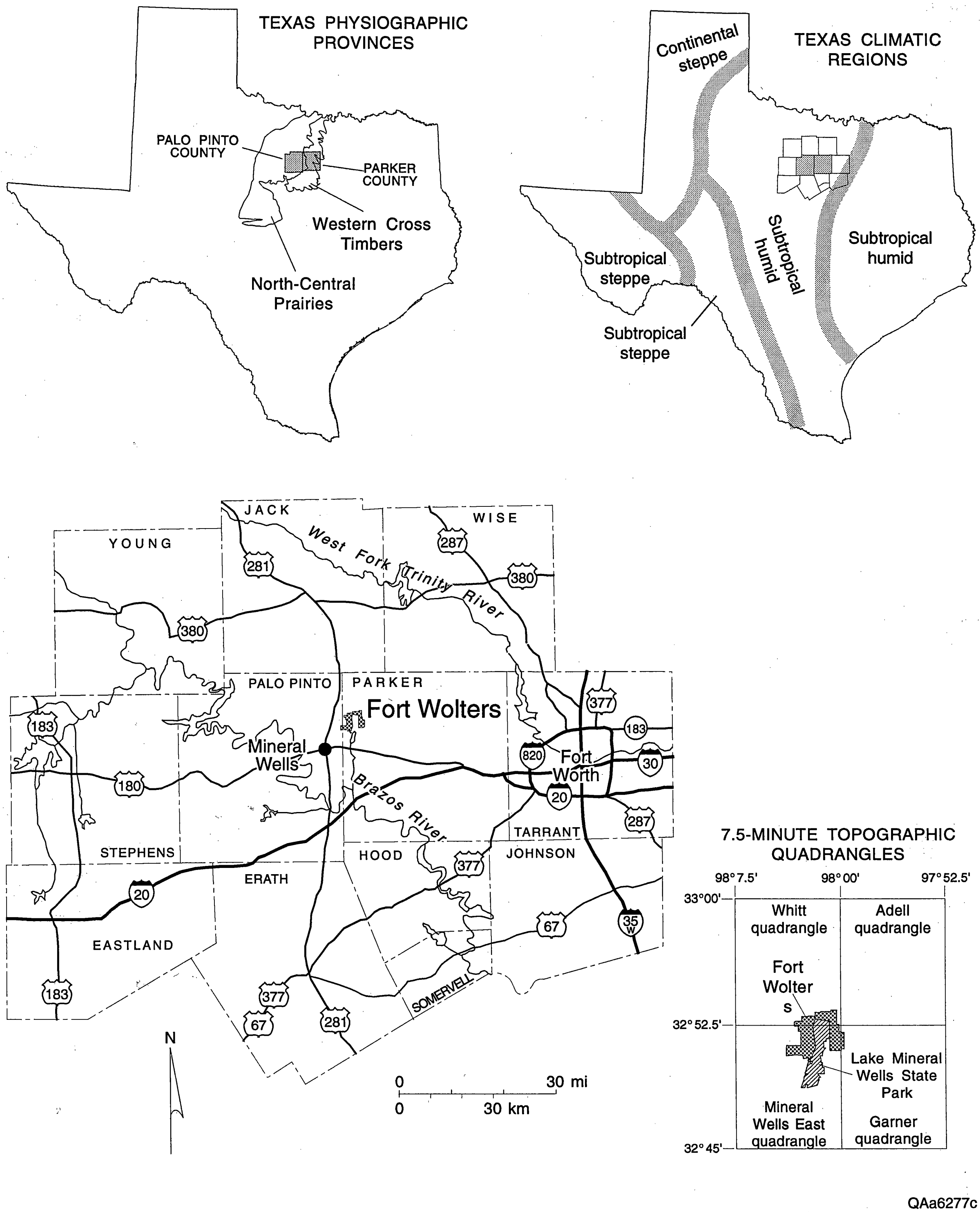


Figure 1. Index map of North-Central Texas region showing location of Fort Wolters (from Avakian and Wermund, 1994).

extent. Slopes are gentle to moderately steep and have deep and moderately deep sandy or loamy soil profiles. This association is underlain by sandstone or shaly clay. The soils at Fort Wolters in Palo Pinto County are in the Bonti-Truce-Shatruce association, which are soils generally similar in slope and depth to the association in Parker County. This association covers 31 percent of the county and consists of Bonti soils (22 percent), Truce soils (18 percent), Shatruce soils (10 percent), and other soils (50 percent). Shatruce soils are typically on escarpments where stones and boulders are abundant.

The fort lies within the oak forest and prairie vegetation zone (Kier and others, 1977) and has a subtropical subhumid climate (Larkin and Bomar, 1983). Snowfall is infrequent, and there is an average of 50 freezes during the year (Bomar, 1983). Winds measured at a weather station east of Mineral Wells in the Dallas–Fort Worth area are usually from the south at 9 to 13 mph (Bomar, 1983). There is, however, a strong northerly wind component during the winter and spring months measured at Wichita Falls to the north of Mineral Wells, having an average northerly wind speed of 11 mph (Bomar, 1983).

The average mean monthly high temperature is 77°F, and the average mean monthly low temperature is 53°F. Monthly average minimum low temperatures are 32°F in January, and monthly average maximum high temperatures are 97°F in July (Bomar, 1983). The average annual precipitation measured at Mineral Wells is 29 inches, and peak rainfalls occur in April, May, and September.

The average annual gross lake surface evaporation rates of Parker and Palo Pinto Counties average between 67 and 73 inches annually, values increasing from east to west. Highest rates occur during July, and lowest rates occur during January (Larkin and Bomar, 1983).

Geology and Hydrostratigraphy

The Mineral Wells Formation is the only geologic unit exposed at the surface of Fort Wolters (fig. 2). The Mineral Wells Formation, part of the Pennsylvanian-age Strawn Group, consists of shale with interbedded sandstone and limestone (Avakian and Wermund, 1994). Sandstone and limestone members are the Hog Mountain Sandstone, informal sandstone unit 1, the Village Bend Limestone, Lake Pinto Sandstone, Dog Bend Limestone, informal sandstone unit 2 (sometimes referred to as the Devils Hollow Sandstone), and the Turkey Creek Sandstone.

Shaley portions of the Mineral Wells Formation vary from thin-bedded and fissile to blocky and show a range of greenish, bluish, reddish, and yellowish-gray colors (Avakian and Wermund,

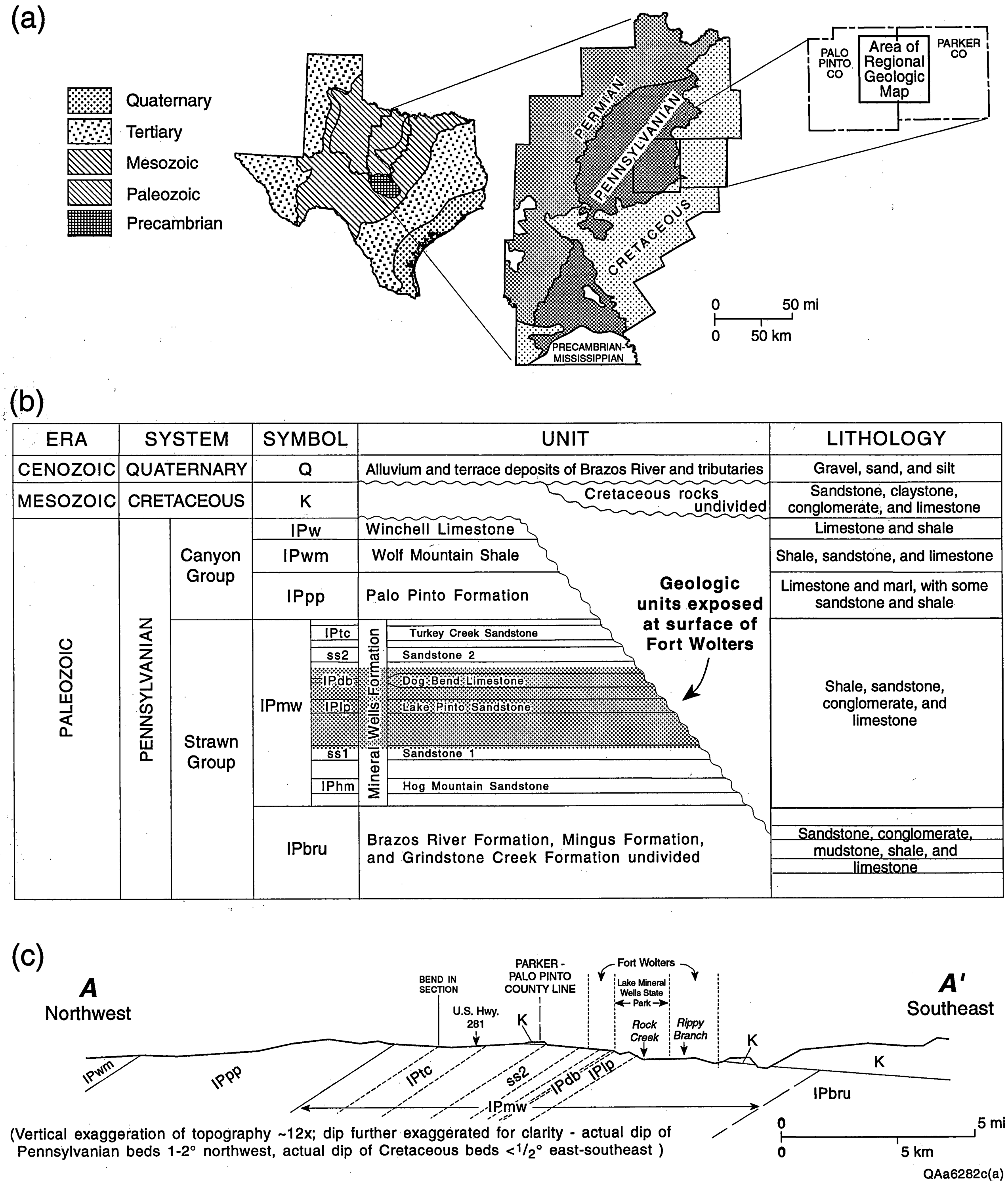


Figure 2. (a) Generalized geologic map, (b) stratigraphic column, (c) schematic cross section, and (d) regional geologic map for the Fort Wolters area (from Avakian and Wermund, 1994).

(d)

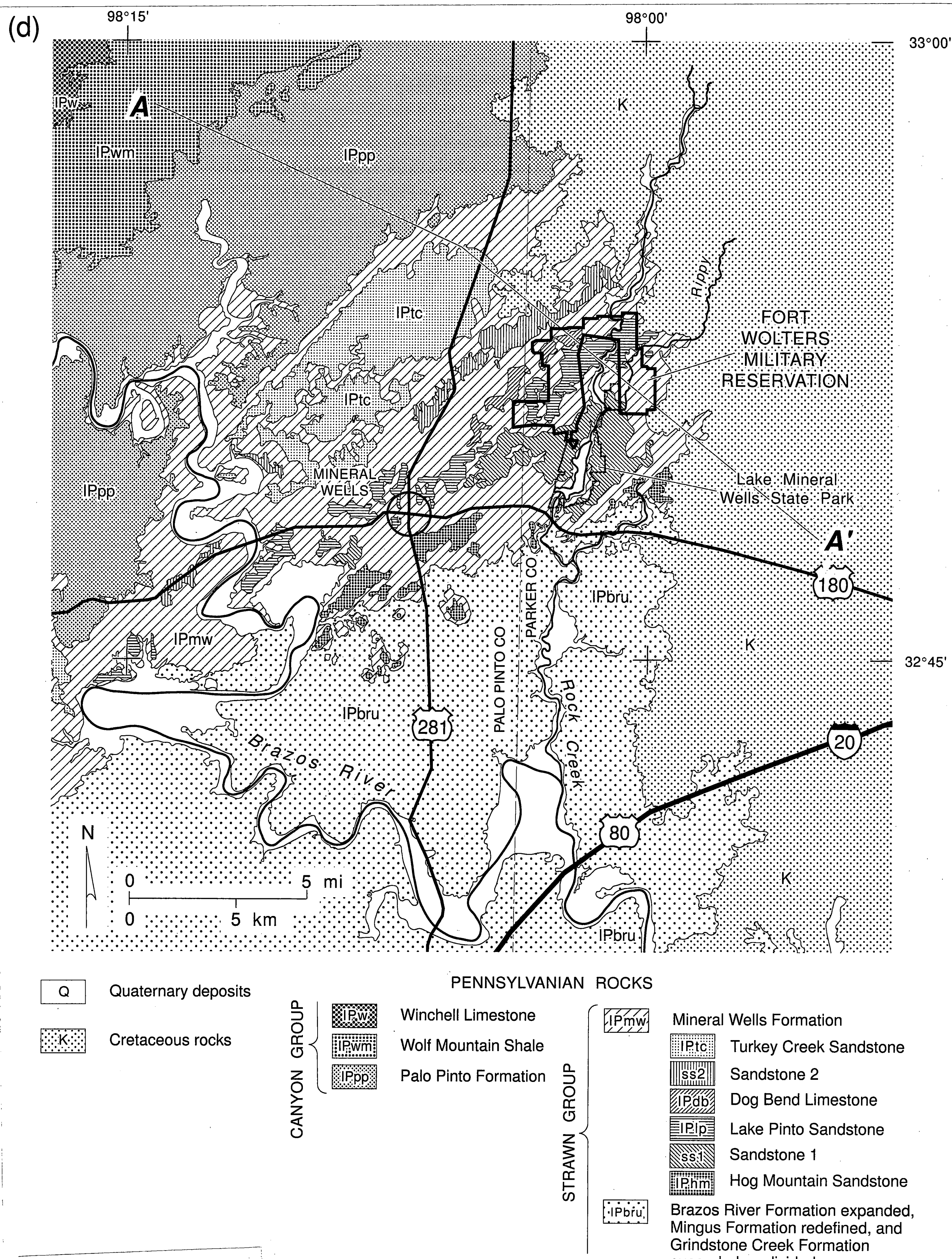


Figure 2 (cont.)

QAa6282c(b)

1994). The Hog Mountain Sandstone is the basal member of the Mineral Wells Formation and is about 25 ft thick. Informal sandstone unit 1 is about 25 ft above the Hog Mountain Sandstone and is conglomeratic. Village Bend Limestone is 10 ft thick and is finely crystalline and weathers medium light gray to yellowish gray (Trice, 1984, p. 85–86). The Lake Pinto Sandstone is about 50 ft thick and is a medium- to fine-grained sandy shale that is pale grayish brown to reddish brown. The Dog Bend Sandstone is an algal wackestone to mudstone that is finely crystalline, locally sandy, and up to 5 ft thick (Trice, 1984, p. 88). Informal Sandstone unit 2 is fine grained and is about 12 ft thick. Turkey Creek Sandstone crops out northwest of Fort Wolters.

Unconsolidated alluvium overlies Fort Wolters along the floodplain of Rock Creek. The alluvium is dark and silty to sandy (Flemming and Associates, 1971, VI-4). Small colluvial deposits are common at the base of shale slopes underlying resistant sandstones (Avakian and Wermund, 1994).

The Texas Water Development Board (TWDB) does not consider any of the formations on Fort Wolters to be major suppliers of ground water. However, hundreds of low-yield wells completed in the Mineral Wells Formation produce water of varying quality in the Fort Wolters area. Local drillers told us that water-bearing intervals in the area are sandstone, pea gravel, and conglomerate rock (which has small, finger-sized conduits) at depths of 18 to 500 ft. The sandstone aquifers are thin (~10 ft thick) and have shallower water that is generally of poorer quality. North of Fort Wolters, depth to water-bearing intervals is 100 to 150 ft. The drillers also mentioned that some shallow wells produce small amounts of gas and oil. Wells that reach depths between 280 and 450 ft commonly have a smell of sulphur.

Water-producing intervals in the Fort Wolters area include the Lake Pinto Sandstone, Informal sandstone unit 1, the Hog Mountain Sandstone, and the Brazos River Formation (fig. 3).

METHODS

Ground-Water Analysis

Well Inventory

We visited Fort Wolters to locate wells in and near the camp. For wells in the camp, detailed measurements and descriptions were taken, including well location, type, depth, water level, diameter, and casing construction. Camp personnel were interviewed concerning known or potential well locations. We drove on all roads in the camp to investigate adjacent land for

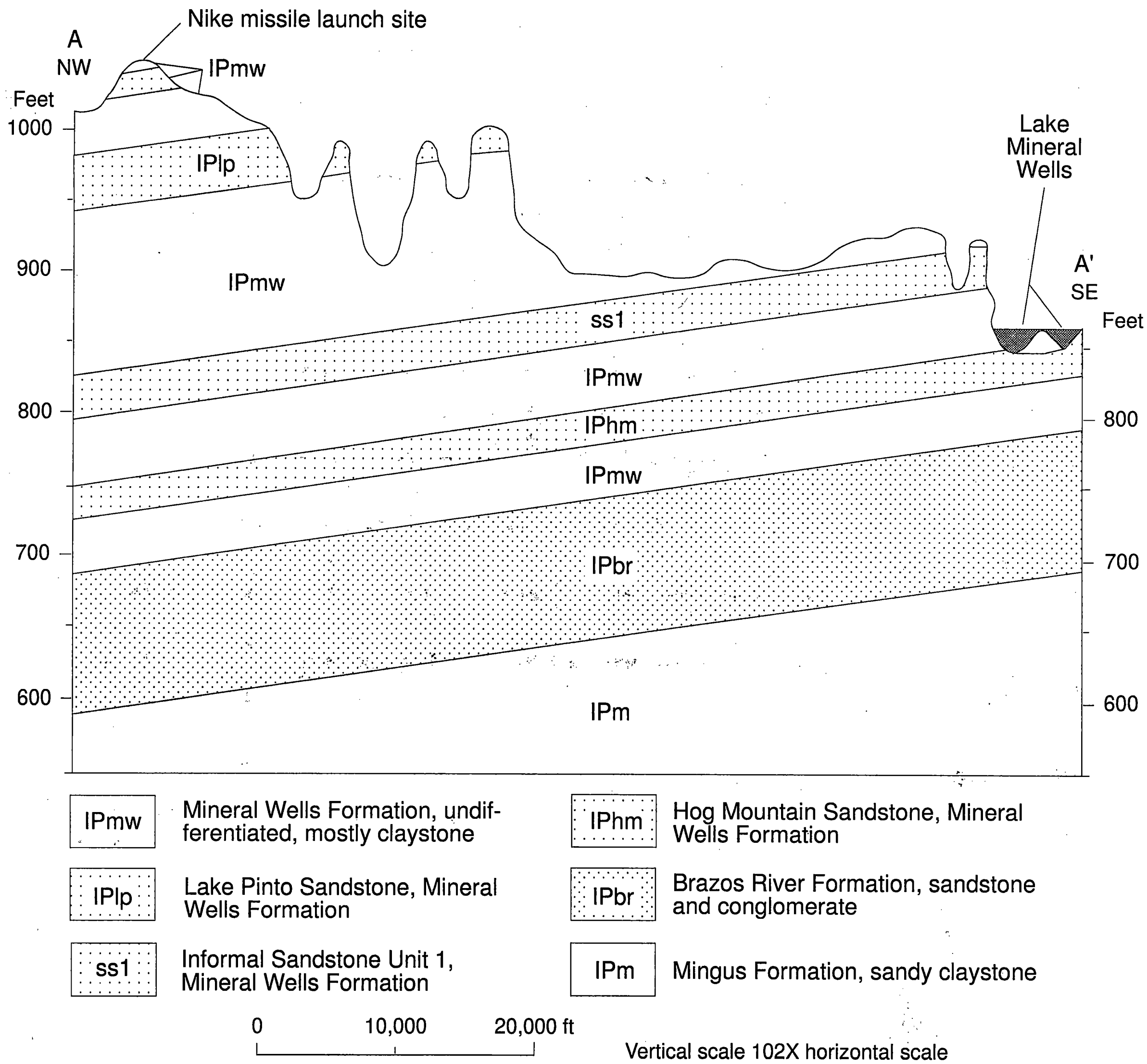


Figure 3. Geologic cross section of the geology beneath Fort Wolters (after U.S. Department of the Army, 1994).

evidence of wells. We also inventoried wells near the camp and measured water level and well depth where possible.

Monitor Well Installation

Installation of monitor wells at Fort Wolters included (1) selecting and staking appropriate hydrogeologic sites for well locations, (2) arranging access to the well sites and a source of water, (3) drilling the well, (4) purging the wellbore, (5) installing casing, and (6) developing the cased well. Drilling sites were chosen at areas that would be best to investigate the hydrogeology of the sites but still be accessible to a drilling rig. Before staking the well sites, we contacted camp commanders to ensure that the locations would not interfere with camp activities and would not be located near any known buried utilities. We also coordinated our drilling with the camps to ensure that our activities would not interfere with training schedules.

We drilled the monitor wells with a Central Mine Equipment 75 drilling rig. Depending on the geology, we used hollow-stem augering, solid-stem boring, rotary/wet coring, or a combination thereof to install the wells. Most wells were installed using hollow-stem augering. A few wells required solid-stem boring or rotary/wet coring because of the presence of hard rock. The drilling mud we used for solid-stem boring and rotary/wet coring was biodegradable Super Mud. Where possible, we collected core and cuttings for inspection at our facilities.

After the well was drilled, we augered or flushed the cuttings from the hole and cleaned the wellbore with a bailer, usually removing 1 to 2 wellbore volumes of water. Well completion consisted of installing 2-inch well screen and pipe, placing a sandpack around the screen, placing a bentonite seal above the sandpack, grouting to a few feet below land surface, installing a well guard, and cementing the guard in place with a well pad. We installed either 10- or 20-ft-long 0.010-inch slotted screen in the wells. The sandpack consisted of 20/40 sand and straddled the screen. We installed locking above-ground well guards on each of the wells. Once the well was completed and the cement had dried, we developed the well again with a bailer or an electrical submersible pump.

Well Testing

We conducted two pumping tests and two bail tests in four wells at the camp. For pumping tests, we first installed an electric submersible pump or, in the case of one preexisting well, used the installed pump. The well was allowed to rest unpumped until water levels stabilized. When the pump was started, water levels were measured with an electronic water-level meter or with a pressure transducer. We measured pump discharge rate using a 12-gal carboy and a stopwatch. Once water-level drawdown reached a quasi-steady-state, the pump was turned off and water-level recovery was measured. Drawdown and recovery data were input into a spreadsheet and interpreted for transmissivity using the Theis type curve and Theis recovery method (Theis, 1935) and the Jacob straight-line method (Cooper and Jacob, 1946).

For bail tests in which water is rapidly removed from the well and recovery is monitored, we allowed the well to rest until water levels stabilized if a pump was installed in the borehole. When the pump was started or a bailer volume of water was removed from the wellbore, water levels were measured with an electronic water-level meter. Once the water level reached the level of the pump or a bailer volume of water was removed, the pump was turned off and water-level recovery was measured. Recovery data were input onto a spreadsheet and interpreted for transmissivity using the Cooper and others (1967) curve matching method.

Ground-Water Sampling

Ground-water samples were collected from the two monitoring wells drilled during this project. One well was sampled using a bailer to collect water. The second well was sampled during the pumping test. For sampling using a bailer, our procedure was to first remove and discard one bailer volume (approximately 500 mL) to rinse the bailer before sampling. A second bailer volume was then collected and the water used to measure pH and temperature at the well site. Water from the next bailer run was used to rinse field filtration equipment. Ground water produced by subsequent bailer runs was passed through a 0.45-micron filter and collected in sample bottles that had first been rinsed three times with filtered sample water. For samples collected during the pumping test, we waited until several wellbore volumes had passed through the pump and tubing and then collected an aliquot for pH and temperature measurement. We then rinsed the filtration equipment with well water and rinsed all sampling bottles with filtered water. Ground-water samples were then filtered and collected in bottles for subsequent analysis. Aliquots intended for cation and trace metal analyses were preserved by adding 6N nitric acid to lower the pH to a value less than 2. Aliquots for all other analyses were filtered but otherwise untreated.

Surface-Water Analysis

Watershed Delineation

Watersheds were delineated for Fort Wolters using the hydrologic functions of ArcInfo Grid (ESRI, 1993). This method takes digital elevation models and determines flow directions and points of flow accumulation along hypsography. For each stream link between different order streams, the program determines subwatersheds, or drainage areas, corresponding to that stream link (Maidment, 1995).

Floodplain Analysis

Floodplain analysis involves determining the area adjacent to a river or stream that will flood for a specified return period (for example, a 100-yr flood). The standard procedure is to determine the 100-yr flood at key points in the stream and use backwater computation to determine stages upstream (Linsley and others, 1982, p. 452). If available, the 100-yr flood is usually determined from stream-gauge records. However, this type of data is usually unavilable, and regional frequency methods or loss rate and unit hydrograph applied to the 100-yr rainfall can be used (Linsley and others, 1982, p. 452). Because most of the camps lack stream-gauge records, we used the loss rate and unit hydrograph method to estimate the 100-yr floodplain.

Our floodplain analysis consisted of (1) designing 100-yr 24-hr synthetic storms, (2) determining the 100-yr flood hydrographs at strategic points in the watersheds, (3) assessing 100-yr flooding surfaces, and (4) mapping the 100-yr floodplains on 1:2,400 USGS topographic maps.

To design the 100-yr 24-hr synthetic storms, we first used maps published by the U.S. Weather Bureau (Herschfield, 1961, as shown in Chow, 1964, p. 9–56) to determine the 100-yr 24-hr rainfall for each camp and fort. We then used these rainfall rates with the SCS Type II distribution (Bedient and Huber, 1988) to generate the synthetic storms.

To determine the 100-yr flood hydrographs, we used HEC-1 (Hydrologic Engineering Center, 1981) with SCS unit hydrographs (Soil Conservation Service, 1957) and Muskingum routing (McCarthy, 1938). Input to HEC-1 included subbasin drainage area, runoff curve numbers, basin lag, routing storage coefficient, and routing weight factor. Runoff curve numbers are used to define the unit hydrographs and are a function of soil type, vegetation, land use, antecedent moisture, and the hydrologic properties of the catchment surface. Basin lag, also called catchment lag, is the elapsed time, or response time, between rainfall and runoff occurrence and is partly a function of hydraulic length, catchment gradient, drainage density, and drainage patterns. The routing storage coefficient, or time constant, is a function of the channel reach length and the speed of the flood wave. The routing weight factor is a function of the flow and channel characteristics that affect the dispersion of the flood wave downstream.

We delineated detailed subwatersheds and determined subwatershed drainage areas with ArcInfo (ESRI, 1993). We calculated weighted curve numbers in ArcInfo for each subwatershed using STATSGO (Soil Conservation Service, 1991) digital hydrologic soil data and land use data assuming moderate antecedent moisture conditions (I_a = 0.25 inch). Because most of the watersheds were ungauged, we estimated the basin lag, t_p, using the following equation (Linsley and others, 1982, p. 224):

$$t_p = C_t\left(\frac{LL_c}{\sqrt{s}}\right)^n \quad (1)$$

where C_t is a constant that varies between 1.8 and 2.2 for units of miles (Snyder, 1938), L is the distance to the upstream watershed divide, L_c is the stream length, n is 0.35 for valley drainage areas (Linsley and others, 1982, p. 225), and s is the channel gradient. For this study, we chose a mean C_t value of 2.0. We assigned the routing storage coefficient as 0.20, a typical value for most natural streams (Linsley and others, 1982, p. 219). We measured L, L_c, and s from USGS 1:24,000 topographic sheets. We estimated the routing traveltime constant, K, using the following equation (Linsley and others, 1982, p. 465–541):

$$K = \frac{bL\sqrt{A}}{\sqrt{s}} \quad (2)$$

where A is the drainage area and b is a constant between 0.04 and 0.08 for L in miles and A in square miles. For this study, we chose a mean b value of 0.06. With the above data input into HEC-1, we modeled 100-yr flood hydrographs for subwatersheds in or just outside the camps and fort. We recorded peak flows for these 100-yr flood hydrographs for assessing flooding depths.

We used HEC-RAS (Hydrologic Engineering Center, 1995) to estimate 100-yr flooding surfaces at the locations where we determined the flood hydrographs. Input to HEC-RAS included topographic cross sections at hydrograph locations, stream lengths between cross sections, Manning's n values, discharge rates, and stream-flow boundary conditions. We measured topographic cross sections from USGS 1:24,000 topographic sheets perpendicular to the stream path. Using a map roll gauge, we measured stream lengths between cross sections from the topographic sheets. We assumed Manning's n values to be 0.06 on the banks (Hydrologic Engineering Center, 1995) and 0.05 in and near the stream channel. HEC-1 supplied the peak 100-yr discharge rates for each hydrograph location. We assigned the stream-flow boundary condition at the output end of the model as a critical depth boundary. In all simulations we assumed subcritical flow. After inputting the above information, HEC-RAS determined the flood surface at each of the chosen locations.

We mapped the 100-yr floodplains by transcribing the 100-yr flood surfaces estimated by HEC-RAS onto USGS 1:24,000 topographic sheets and interpolating between and extrapolating from hydrograph locations. Once mapped, the floodplains were digitized in ArcInfo GIS and were printed.

GIS Data Preparation

An effort was made to move spatial hydrologic and hydrogeologic information into a GIS. Where possible, databases with spatial coordinates were uploaded into the GIS and interpreted data such as contour maps were digitized and attributed. The information was placed into ArcInfo GIS so that data coverages could be overlaid and compared. Care was taken to ensure that proper projections were used when transferring information from digital files downloaded from State computers or when digitizing from USGS topographic sheets. Well postings and hydrologic and hydrogeologic analysis were done on virgin USGS topographic sheets to facilitate data automation and to ensure the best possible data transfer.

A data dictionary was prepared for the coverages for Fort Wolters to ensure that subsequent users will be informed of the method of data automation and the accuracy of the information. All GIS data files were delivered to the Office of the Adjutant General of the Texas Army National Guard at Camp Mabry for inclusion in its GIS program.

GROUND-WATER HYDROLOGY

Well Inventory

TWDB records, site personnel, and a field survey of fort grounds provided information for locating wells in Fort Wolters. We located seven wells during our survey (fig. 4):

- **FWT-B001** is a 2-inch-diameter drilled monitor well having a measured depth of 10 ft and a water level of 5.35 ft below land surface. The casing is made of PVC and extends 1.25 ft above grade. The well is located at the Nike missile launch site in an unlocked well vault. The U.S. Army Center for Health Promotion and Preventive Medicine drilled this well to conduct a site investigation of the missile launch site (USACHPPM, 1994).

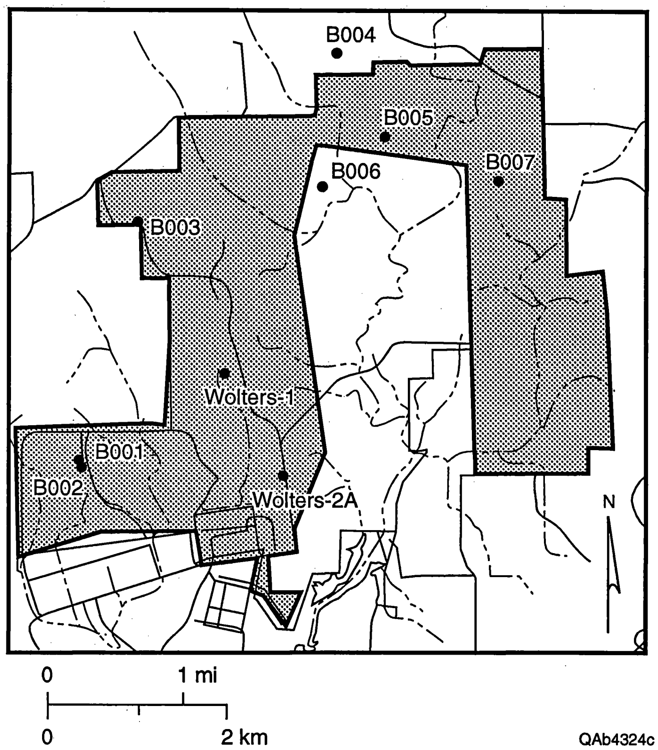


Figure 4. Well locations at Fort Wolters, including monitor wells drilled during this study.

- **FWT-B002** is a 5.75-inch-diameter drilled water well having a measured depth of 59.3 ft and a water level of 54.4 ft below land surface. The casing is made of PVC and extends 1.8 ft above grade. The well is located just east of the Nike missile launch site without a well vault or a cap. Camp personnel suggested that the well was drilled 20 years ago in an unsuccessful attempt for a water supply for the missile site. The well was reportedly 800 ft deep when drilled.

- **FWT-B003** is a 7.75-inch-diameter drilled water well having a reported depth of 680 ft and a water level of 66.7 ft below land surface. This well is reportedly screened at 260 ft (L. D. Daugherty, 1995, personal communication). The casing is made of steel and extends 0.94 ft above grade. The well is located on the northwest helicopter training pad and is inside a locked well guard. The wellbore is open because a local driller (L. D. Daugherty) pulled pipe earlier this year. The well was screened in this manner to increase the storage in the wellbore.

- **FWT-B004** is a capped gas well operated by Hunter Energy RRC No. 101685, TXNM 51857. This gas well is located in the northern part of the camp. Gas could be smelled leaking from the wellhead.

- **FWT-B005** is a gas well operated by London Petro, RRC No. 110804.

- **FWT-B006** is a gas well operated by London Petro, TXNM 41544. This well is just off Fort Wolters, but access to the wellhead is through fort property. A sign indicates that this well is part of a Fort Wolters lease.

- **FWT-B007** is a 7-inch-diameter drilled water well having an unknown depth and a water level of 135.5 ft below land surface. The casing is made of steel and extends 1.35 ft above grade. The well is located near the northeast helicopter training pad and is inside a well house. The wellbore is capped and has a working pump and production pipe down the hole.

A total of 106 wells were mapped during the perimeter well survey (app. 1, fig. 5). Well depths, water levels, or electrical conductance data were obtained at 29 wells. Well depths ranged from 35 to 520 ft, most of the wells (36 percent) being between 100 and 150 ft deep. Well depths are distributed in three groupings: 15 wells between 50 and 200 ft, 3 wells between 250 and 300 ft, and 7 wells between 400 and 550 ft. Depths to water ranged from 5.5 to 187 ft, and

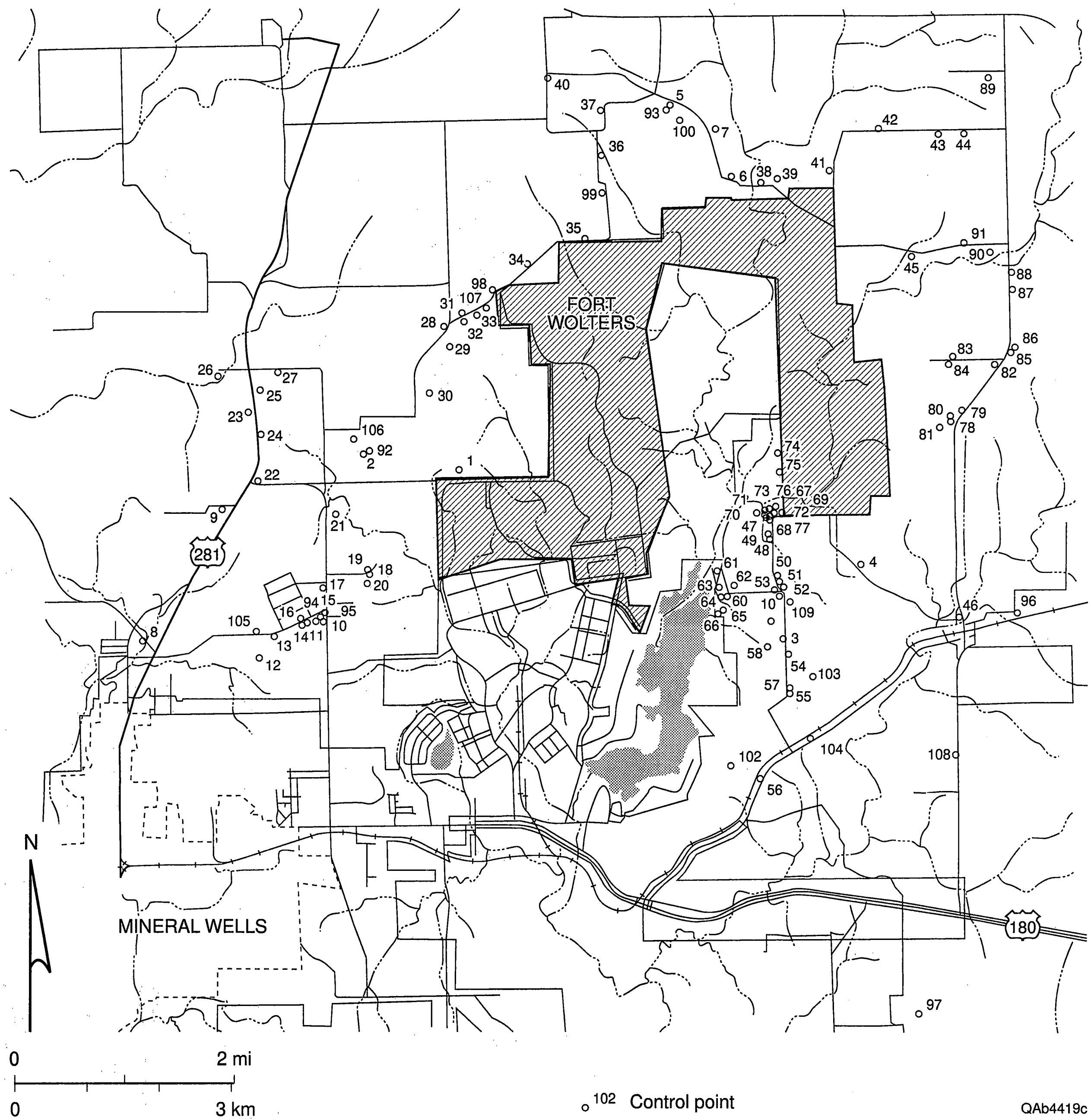


Figure 5. Private wells located near Fort Wolters.

45 percent of the wells had water levels less than 20 ft from land surface and 70 percent of the wells had water levels less than 40 ft from land surface. In general, deeper wells had deeper water levels. Electrical conductance values ranged between 600 and 9,250 micro-ohms; all but one of the measured values were less than 3,000 micro-ohms, and 79 percent of the values were less than 1,500 micro-ohms. These correspond approximately to total dissolved solids between 380 and 5,920 mg/L. Based on these measurements, 79 percent of the wells had fresh water (<1,000 mg/L TDS), and the rest had brackish water (>1,000 and < 10,000 mg/L TDS). Electrical conductance is not correlated with well depth or depth to water. Most wells in the area are in use for either lawn or household purposes. Some areas are not serviced by a water-supply system and rely solely on their wells for water supply.

Two local well drillers said that water is produced from sandstone, pea gravel, and conglomerate rock, and that water is found between 18- and 500-ft depths in most parts of the area. The sandstone aquifers are thin (~10 ft thick) and generally have shallower water of poorer quality. North of Fort Wolters, water is reached at depths of 100 to 150 ft. They also mentioned that some shallow wells produce small amounts of gas and oil (confirmed by one landowner north of the fort boundary). Wells that reach depths between 280 and 450 ft commonly have a sulfur smell. Yields are generally low in the area, and many wells are drilled deep in order to increase well storage to promote a reliable water supply. Water quality to the south of Mineral Wells is generally not as good as in the area around Mineral Wells.

Monitoring Well Construction

We drilled and completed two wells at Fort Wolters in the Mineral Wells Formation. WOLTERS-2 is 52.2 ft deep and is located in the southern part of the eastern arm of the fort (fig. 4). WOLTERS-1 is 73.9 ft deep and is located on a nearby hill overlooking WOLTERS-2 (fig. 4). We initially tried rotary/wet coring to install WOLTERS-2 but had difficulty with losing circulation and having water flow from desiccation cracks at land surface near the hole and the drilling rig. We filled and sealed this uncompleted well and used hollow-stem augering to install another well, WOLTERS-2A, nearby. On WOLTERS-1, we used hollow-stem augering to install 9 ft of surface casing and hollow-stem augering to reach total depth. Detailed well schematics and drilling reports are included in appendix 2.

Hydraulic Properties

There are no aquifer tests reported in the Mineral Wells Formation in Palo Pinto or Parker Counties. Well yields are reportedly small and producing horizons thin, so we do not expect transmissivities to be high. We conducted site-specific aquifer tests at Fort Wolters that may represent the first aquifer tests in the area. Monitor well WOLTERS-1, completed in the Mineral Wells Formation (consisting of shale and mudstones interbedded with sandstone), had a low transmissivity of about 0.2 ft^2/day (fig. 6). Monitor well WOLTERS-2A, also completed in the Mineral Wells Formation (consisting of clay and sand), had a transmissivity of about 6 to 8 ft^2/day (fig. 7). Well FWT-B003, a preexisting well also thought to be completed in the lower Mineral Wells Formation, had a transmissivity of about 2 ft^2/day (fig. 8). Well FWT-B007, a preexisting well thought to be completed in the lower Mineral Wells Formation, had a transmissivity of about 20 ft^2/day (fig. 9).

Ground-Water Chemistry

TWDB files had limited water chemistry data for the Mineral Wells Formation, the Strawn Group, the Brazos River Formation, and a well completed in both the Mineral Wells Formation and the Brazos River Formation (table 1). In addition, Schoch (1918) and Plummer and Hornberger (1935) analyzed ground waters from the Hog Mountain Sandstone and the Brazos River Formation in the Minerals Wells area (table 2). Total dissolved solids (TDS) for the Mineral Wells Formation ranged from 411 to 3,936 mg/L and had a geometric mean of 1,050 mg/L. Seven of the samples (54 percent) were brackish (1,000 mg/L < TDS < 10,000 mg/L). TDS for the Strawn Group ranged from 249 to 2,937 mg/L and had a geometric mean of 910 mg/L. Seven of the samples (58 percent) were brackish. TDS for the Hog Mountain Sandstone ranged from 4,085 to 8,419 mg/L and had a geometric mean of 5,754 mg/L. All of the samples were brackish. TDS for the Brazos River Formation ranged from 209 to 8,132 mg/L, having a geometric mean of 1,621 mg/L. Eight of the samples (50 percent) were brackish.

Waters from the Mineral Wells Formation are predominantly sodium bicarbonate in composition (fig. 10a). Waters from the Strawn Group are mostly calcium bicarbonate in composition (fig. 10b). The water composition of the Brazos River Formation is predominantly calcium bicarbonate (fig. 11a), although near Mineral Wells the Upper Brazos River Formation is sodium sulfate water and the Lower Brazos River Formation is a sodium bicarbonate/chloride water (fig. 11b). The Hog Mountain Sandstone is a sodium sulfate water (fig. 11b).

Results from the chemical analyses of ground water collected from the Fort Wolters monitor wells and a preexisting well in the fort are shown in table 3. Water samples collected from these wells are sodium chloride or mixed-ion water types.

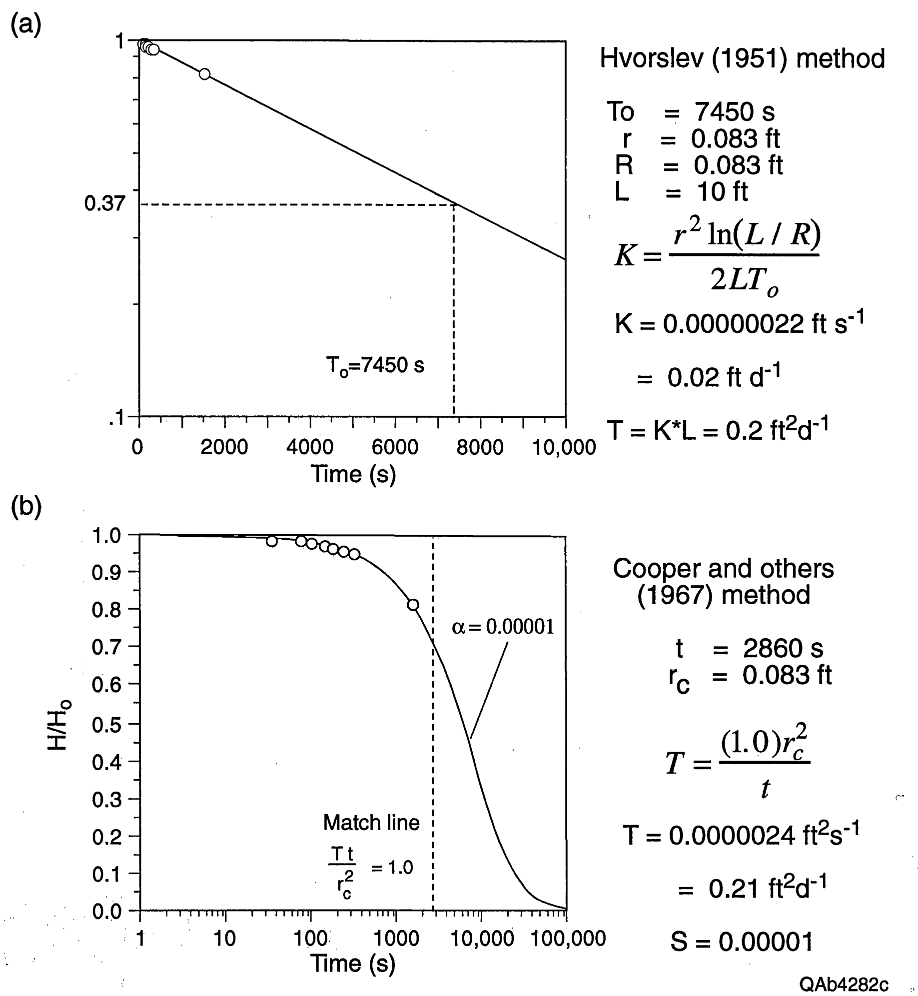


Figure 6. Interpretation of bail test results at WOLTERS-1 in Fort Wolters using the (a) Hvorlslev (1951) method and (b) Cooper and others (1967) method.

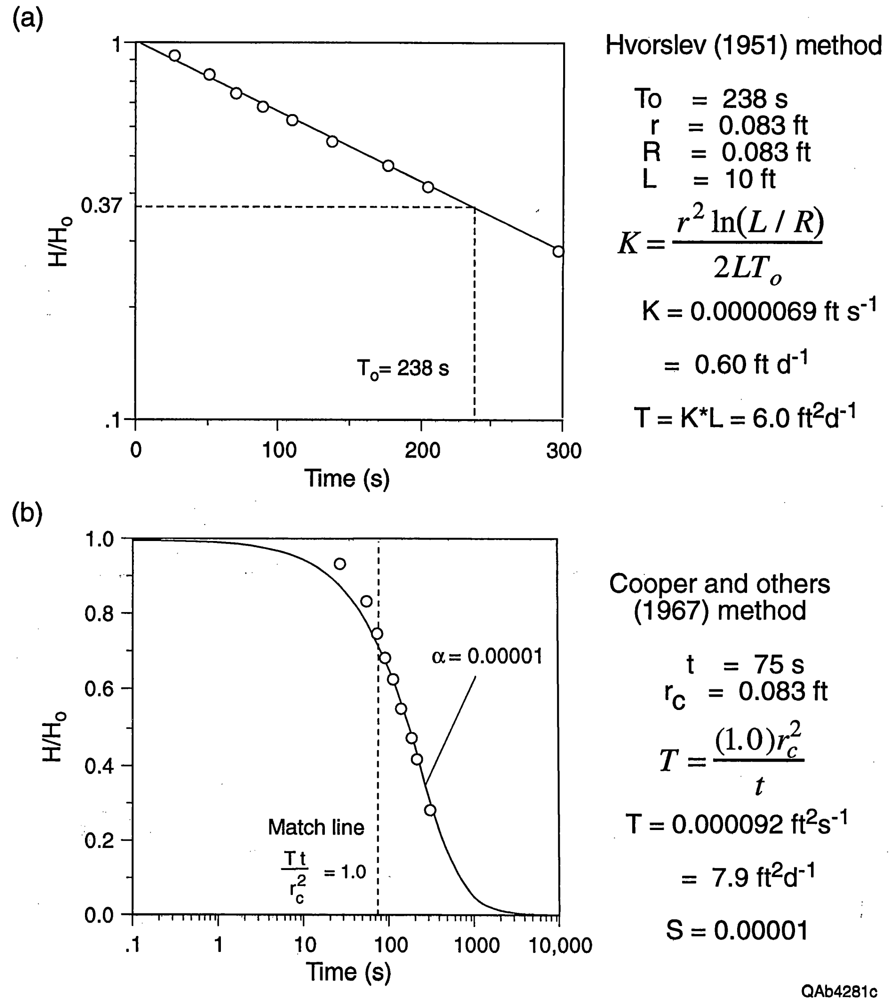


Figure 7. Interpretation of bail test results at WOLTERS-2A in Fort Wolters using the (a) Hvorlslev (1951) method and (b) Cooper and others (1967) method.

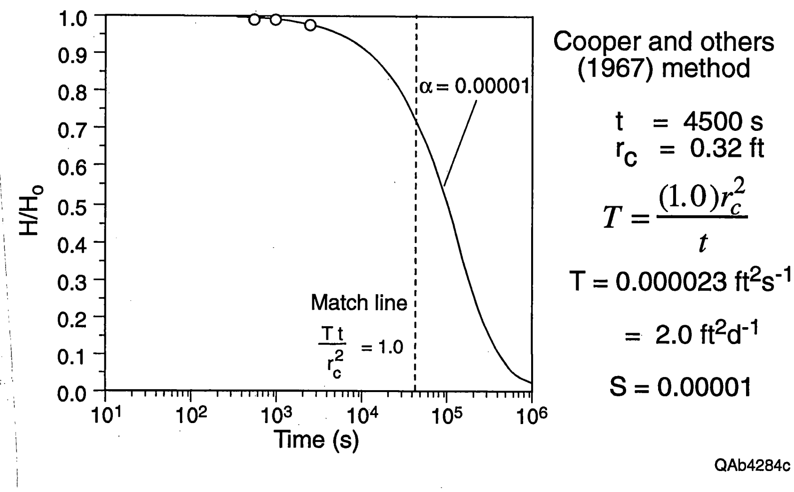


Figure 8. Interpretation of bail test results at FWT-B003 in Fort Wolters using the Cooper and others (1967) method.

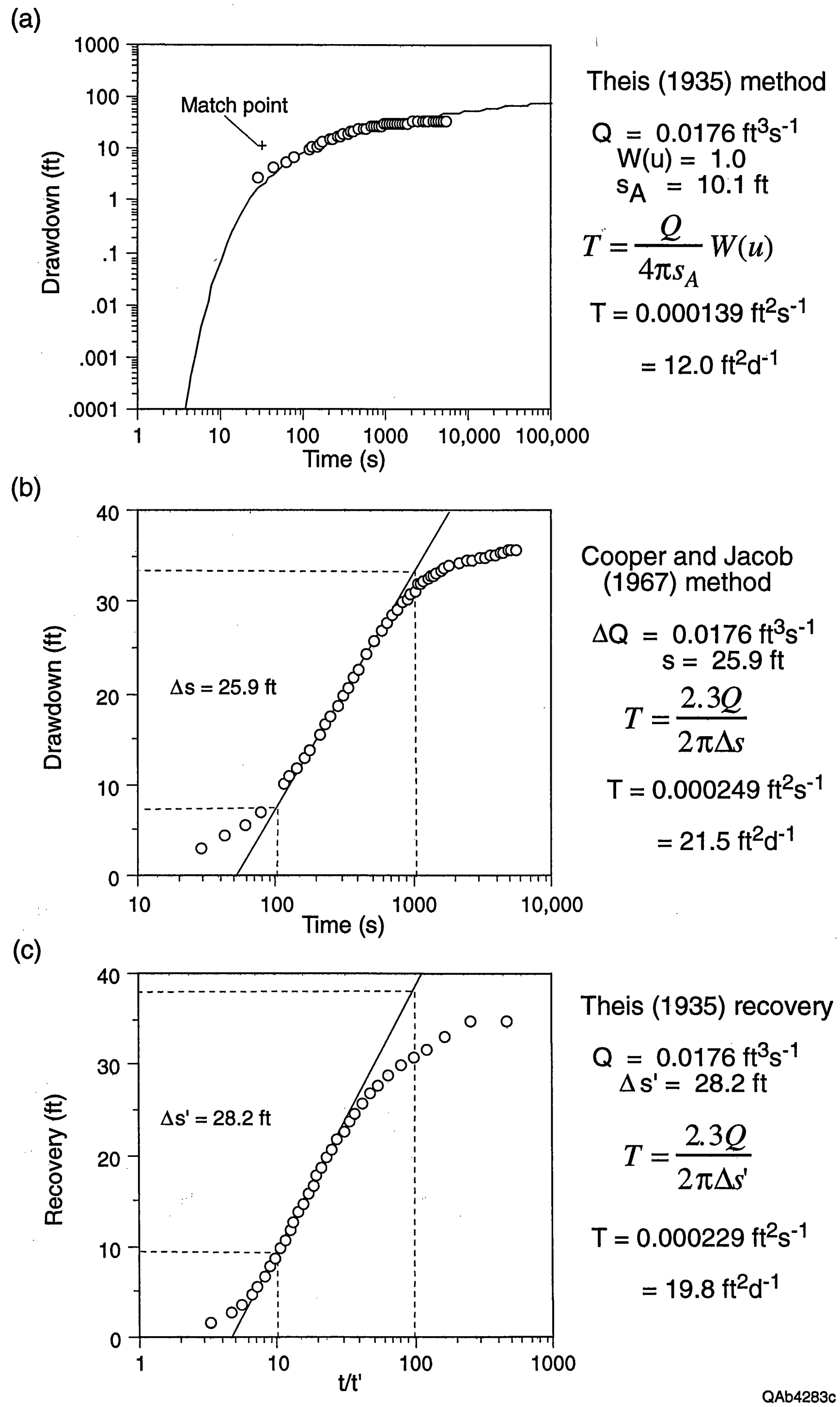


Figure 9. Interpretation of pumping test results at B007 in Fort Wolters using the (a) Theis method, (b) Jacob method, and (c) Theis recovery method.

Table 1. Chemical analyses of selected ground waters from the Mineral Wells Formation, Strawn Group, Mineral Wells/Brazos River Formation, and the Brazos River Formation in Palo Pinto County.

State well number	YR	Temp (C°)	Si (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Sr (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	F (mg/L)	NO_3 (mg/L)	pH	TDS (mg/L)	Total alk (mg/L)	Total hardness (mg/L)	Spec. cond. (μΩ)
Mineral Wells Formation:																		
3108202	1983	-	29	4	2	414	1	-	622	224	125	1.4	3	8.3	1109	510	19	1968
3114803	1960	-	15	126	9	30	-	-	390	42	38	0.1	-	6.8	451	319.67	352	751
3114805	1978	22	14	33	15	148	-	-	400	79	41	0.3	0.4	8.2	527	328	143	948
3115501	1960	-	11	43	17	1390	-	-	612	972	1200	0.9	1.5	7.8	3936	501.64	178	6030
3115502	1991	-	-	43	11	705	5	1.79	606.5	692	270	1.21	7.75	-	2035	497	154	2930
3116101	1960	-	18	182	72	201	-	-	651	353	202	0.4	0.8	6.6	1349	533.61	750	2070
3116401	1960	-	14	14	7	215	2.3	-	386	74	95	0.8	2.2	7.7	614	316.39	69	1020
3116501	1988	24	-	-	-	-	-	-	225.8	-	-	-	-	7.3	-	185	-	1000
3122202	1964	-	8	48	18	86	-	-	314	92	28	0.4	0.4	7.7	435	257	194	800
3122501	1964	-	14	60	13	520	-	-	660	299	352	0.7	0.4	7.1	1583	540	204	2976
3122503	1964	-	13	67	11	175	-	-	467	48	120	0.4	0.5	7.4	664	383	215	1235
3122504	1991	-	-	125	13	22	1.1	0.93	452.8	15	11	0.45	0.04	-	411	371	366	742
Strawn Group:																		
3123702	1982	24	9	50	8	29	-	-	157	34	42	0.2	0.3	8	249	129	160	490
3124202	1976		15	55	16	23	10	-	279	17	14	0.5	0.7	7.3	288	229	203	525
3124203	1976		15	308	95	334	17	-	630	750	463	0.4	5.1	7.2	2297	520	1160	4370
3124204	1976		19	89	27	456	6	-	497	398	387	0.4	1.7	7.5	1628	407	334	3045
3124207	1982	22	15	115	9	25	-	-	409	16	16	0.3	1.1	8	398	335	323	729
3124208	1976	-	22	271	103	291	18	-	1635	4	437	0.5	0.4	7.3	1950	1340	1099	4056
3131102	1960		11	6	3	398	-	-	542	56	272	1.1	1.5	7.7	1015	444.26	25	1760
3131501	1991	23	-	3.9	1.9	697	5.9	0.47	643.1	246	467	1.89	0.35	8.3	1741	527	18	2850
3132101	1960		17	123	17	29	0.5	-	401	55	38	0.2	3.2	-	480	328.69	377	801
3132401	1960		10	14	6	1150	-	-	756	80	1300	3.8	2	7.7	2937	619.67	58	4990
Mineral Wells/Brazos River Formations:																		
3115601	1991	23	-	11	7.5	177	4.2	1.13	403.9	46	53	0.92	0.08	7.8	499	331	59	835
Brazos River Formation:																		
3116803	1931		-	710	167	508	-	-	296	507	1180	-	999	-	4216	242.62	-	-
3122602	1982	22	24	30	7	28	-	-	88	27	40	0.2	10.4	7.3	209	72	106	375

Table 2. Ground-water chemistry analyses from the Strawn Group in the Mineral Wells area.

Well #	Formation	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	Solids (mg/l)	Depth (m)	Analysis number
19	IP_{hm}	66	39	1663	255	3087	454	5564	53	-[c]
19a	IP_{hm}	246	233	1016	182	2981	516	5174	53	-[c]
8	IP_{hm}	-	-	-	-	-	-	4085	40	-[c]
11	IP_{hm}	-	-	-	-	-	-	4804	46	-[c]
21	IP_{hm}	287	193	2266	1630	3742	301	8419	36	-[c]
20	IP_{hm}	41	17	1194	339	1753	570	-	49	-[c]
22	IP_{ubr}	202	89	2338	840	4306	357	8132	66	-[c]
23	IP_{ubr}	386	394	1453	410	4461	639	7743	68	-[c]
32	IP_{ubr}	103	62	2041	997	3075	423	6701	-	-[c]
6	IP_{ubr}	108	77	1836	434	3465	445	6365	52	-[c]
14	IP_{ubr}	270	256	868	271	2720	490	4850	66	-[c]
30	IP_{ubr}	182	172	1074	128	2917	344	4817	-	-[c]
24	IP_{lbr}	20	18	177	116	88	309	728	94	-[c]
83	IP_{lbr}	43	16	152	150	48	297	706	122	-[c]
25	IP_{lbr}	25	13	139	58	63	332	630	49	-[c]
9	IP_{lbr}	-	-	-	-	-	-	664	118	-[c]
A[a]	IP_{lbr}	224	26	434	808	261	305	2077	24	-[c]
B[b]	IP_{lbr}	119	30	43	142	119	232	685	16	-[c]
B[b]	IP_{lbr}	96	18	39	125	67	188	533	16	-[c]
8	IP_{hm}	333.8	372.5	1699	905.1	4166	592.5	8136	40	2499[d]
8	IP_{hm}	64.36	58.18	1379	243.8	2474	695.8	4955	42	2506[d]
8	IP_{hm}	107.2	29.69	1742	210.2	2948	-	5588	42	2508[d]
8	IP_{hm}	223.3	163	1554	903.2	2687	648.5	6308	42	2513[d]
8	IP_{hm}	258.6	275.9	1243	494.4	3235	444.2	6028	42	2514[d]
8	IP_{hm}	88.6	60.5	1397	242.1	2495	691.7	5016	42	2515[d]

A[a] Webster farm 4.5 mi SE of town
B[b] Metz Bros. camp highway 1, 4.5 mi SE of town
c Plummer and Hornberger (1935)
d Schoch (1918)

IP_{hm} Hog Mountain Sandstone
IP_{ubr} Upper Brazos River Formation
IP_{lbr} Lower Brazos River Formation

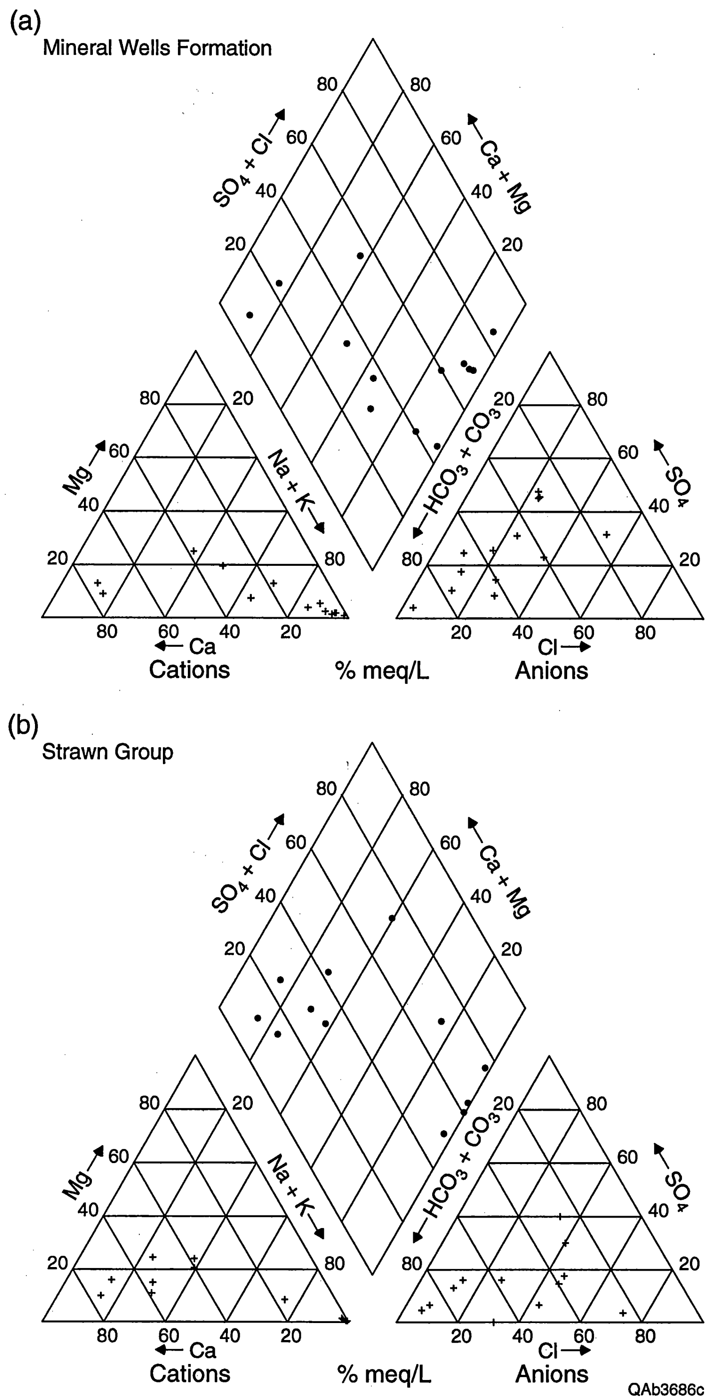


Figure 10. Trilinear diagram showing chemical composition of ground-water samples from the (a) Mineral Wells Formation and (b) Strawn Group in Palo Pinto County.

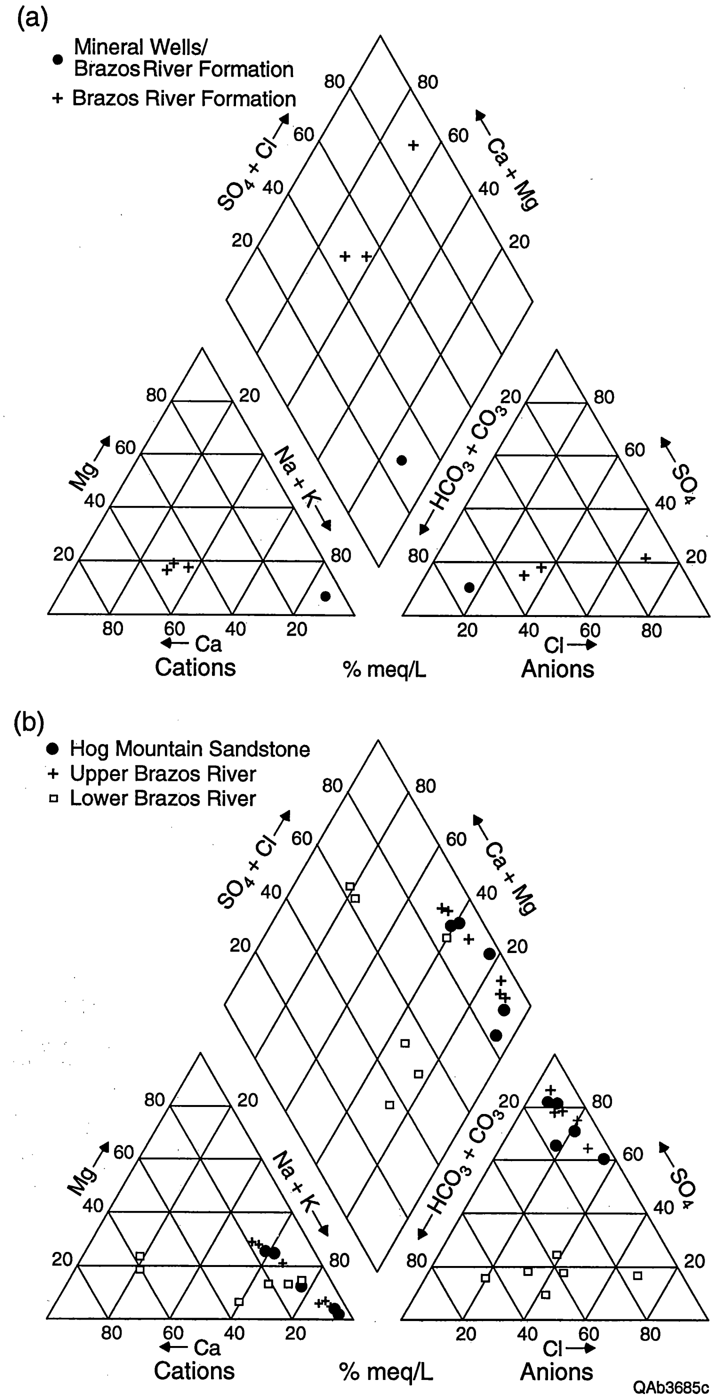


Figure 11. Trilinear diagram showing chemical composition of ground-water samples from the (a) Mineral Wells/Brazos River Formation (well completed in both formations) and Brazos River Formation (TWDB data) in Palo Pinto County and (b) Hog Mountain Sandstone and Upper and Lower Brazos River Formation in the Mineral Wells area (Schoch, 1918; Plummer and Hornberger, 1935).

Table 3. Chemical analyses of ground-water samples from Fort Wolters wells (mg/L).

Well ID	Wolters B007	Wolters-1	Wolters-2
pH	na	18.5	6.7
Temp (C)	na	7.6	25.8
Na	224	163.2	2180
K	1	5.56	5.58
Mg	3.2	2.96	345.4
Ca	4.5	26.4	478.9
F	1.3	1.9	bd
Cl	56.4	104.6	2106
Br	0.2	0.8	7.3
NO_3	bd	1.8	3.9
SO_4	44.3	74.8	3390
HCO_3	426	234	617

na: not analyzed.
bd: below detection.

Water Levels

TWDB board files had sufficient water-level data to construct long-term hydrographs for the Mineral Wells Formation (fig. 12a, b), Brazos River Formation (fig. 12c), and the Strawn Group (fig. 12d). These hydrographs show somewhat similar patterns of water-level fluctuations that are probably due to variations in recharge to the geologic strata (fig. 12).

Depths to water vary from formation to formation and vary spatially within formations. On the basis of our perimeter well survey, depth to the water level is greater at greater depths (fig. 13), and depths range from 5.5 to 187 ft below land surface. This suggests that the producing intervals are, to some extent, hydraulically separated from each other. Most measured water levels (45 percent) were within 20 ft of land surface.

Water-level elevations in wells in the camp are different, depending on the depth of the well (table 4). Depths to water in preexisting wells in the camp were 5.3, 53.8, 66, and 135.6 ft below land surface as measured in August 1995. Water levels in FWT-B002 are not reliable because although the well is reported to be 800 ft deep, measured depth is only 59 ft, suggesting that perhaps the well has collapsed or has been partially filled. Water levels have not varied much during the course of our study, variations being no more than a couple of feet, even in the shallow well FWT-B001.

We did not contour water levels in the Mineral Wells Formation because of the complexity of the geology and the uncertainty about which formation measured wells intersected. Well depth is not necessarily a good indicator of which part of the formation is being sampled because some wells are screened much shallower than the total depth to increase borehole storage. Because the formations do not have high yields, some private wells may have still been recovering from a past drawdown when measured. Furthermore, no well records exist for any of the wells measured, so the completion interval or the geology is for the most part unknown. Well depth is also uncertain because most values are based on landowner memory. For reference, we have included a map showing the measured water-level elevation and the measured or reported depth to water for wells in and near Fort Wolters (fig. 14).

Instead of creating a water-level contour map, we have posted water-level elevation with measured or reported well depth. Ground water in the shallow soil and weathered zone most likely follows the topography and discharges into local and major creeks and streams. On the basis of water-level measurements, ground-water flow in sandstones and conglomerates of the Mineral Wells Formation is more uncertain. However, our hypothesis is that in the outcrop ground-water

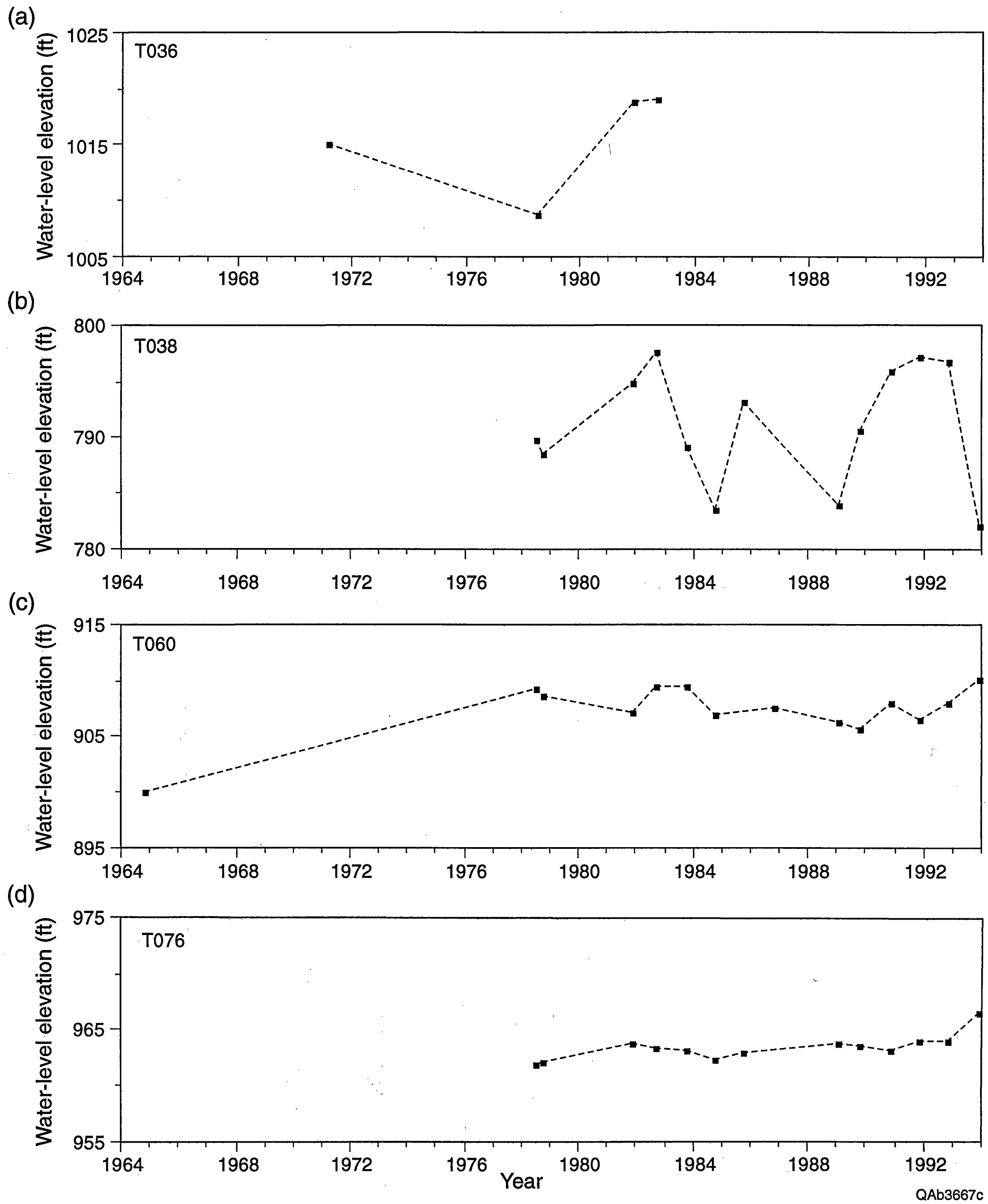


Figure 12. Water levels measured in the Mineral Wells Formation for (a) well 31-14-805 and (b) well 31-15-502, in the Brazos River Formation for (c) well 31-22-602, and in the Strawn Group in (d) well 31-31-502 in Palo Pinto County.

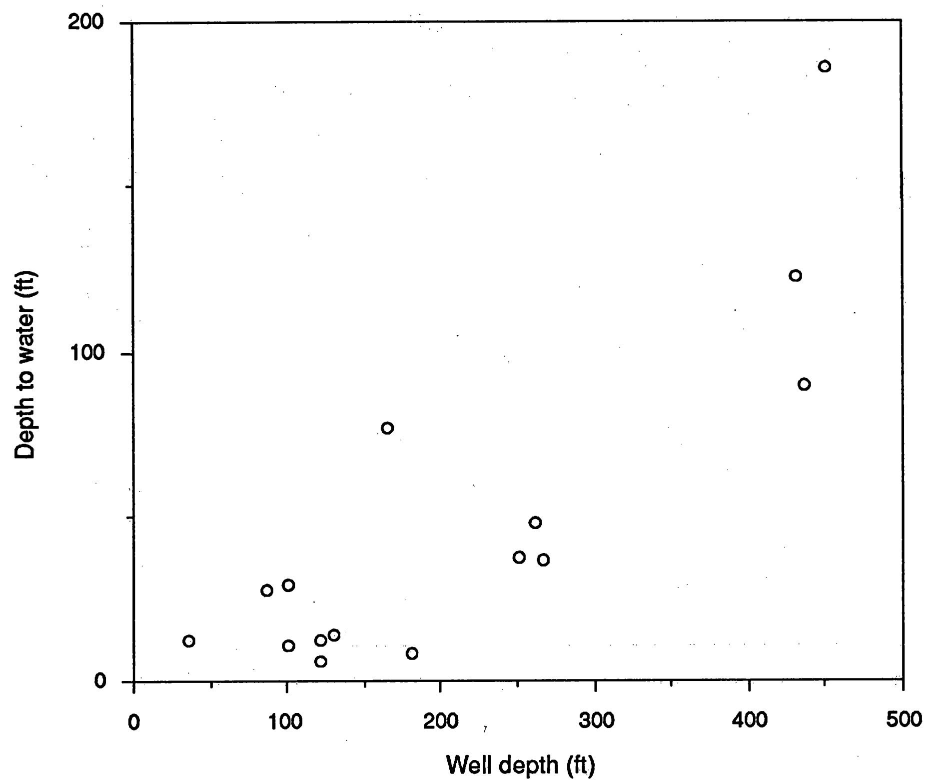


Figure 13. Relationship between well depth and depth to water.

Table 4. Water-level measurements in Fort Wolters wells.

Date	Time	Depth to water (ft)	Water-level elevation (ft)
FWT-B001			
9/27/95	-	6.60	1035.43
11/27/95	1514	8.47	1033.56
1/4/96	1630	7.82	1034.21
3/3/96	1740	8.36	1033.67
FWT-B007			
9/27/95	1450	136.92	864.43
11/28/95	0830	137.59	863.76
4/3/96	1805	137.22	864.13
FWT-B003			
9/28/96	-	67.68	953.08
11/28/95	0820	68.79	951.97
1/4/96	1440	69.31	951.45
3/3/96	1800	71.26	949.50
WOLTERS-1			
1/4/96	1530	12.73	994.27
4/3/96	1405	12.60	994.40
WOLTERS-2A			
1/4/96	1640	10.31	896.69
4/3/96	1730	10.39	896.61

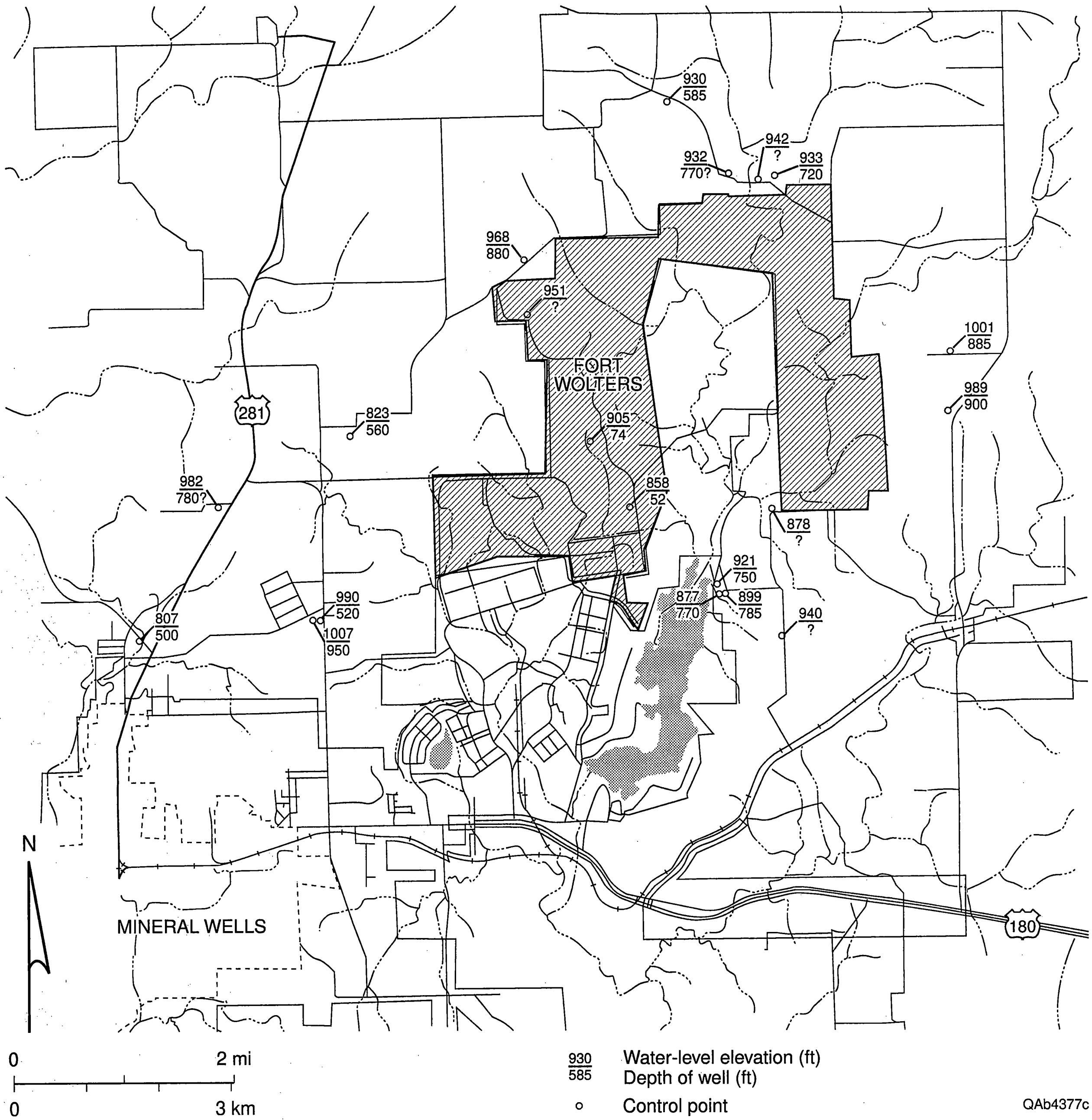


Figure 14. Map of water levels and well depths measured in and near Fort Wolters.

flow is strongly influenced by topography. Some of the recharge, however, moves into the sandstones and conglomerates and progresses downdip toward the west and southwest. The observation that water levels are partly a function of depth agrees with this conceptual model because younger sandstones crop out at a higher elevation than older sandstones and conglomerates (fig. 3).

Conceptual Flow Model

Rain falls on the outcrop of the Mineral Wells Formation, and a small percentage percolates into the ground to recharge the shallow unconfined aquifer. Recharge to the aquifer is greater in higher elevations and in sandier and fractured patches of the outcrop. This water moves from topographic highs toward topographic lows through the weathered zone, where it discharges to local creeks and streams. Some of the flow follows longer flow paths through permeable formations and discharges into local major topographic lows.

Recharge of the Lake Pinto Sandstone and Informal sandstone unit 1 is derived from the outcrop at Fort Wolters. Recharge of the Hog Mountain Sandstone is also through the outcrop and may be facilitated by Lake Mineral Wells (fig. 3). The Brazos River Formation crops out south of the area and is overlain by the Trinity aquifer farther east in Parker County (fig. 2, cross section). Recharge of the Brazos River Formation beneath Fort Wolters is therefore probably derived from ground water flowing in the Trinity aquifer. Discharge from the shallower intervals may be directed toward major tributaries to the Brazos River, whereas discharge from the deeper intervals may be directed toward the Brazos River.

SURFACE-WATER HYDROLOGY

Principal Streams and Watersheds

Fort Wolters resides in the Brazos River basin (zone 3) (TDWR, 1983). Most of the fort is drained by Rock Creek or its tributaries, which feed into Lake Mineral Wells (fig. 15). The southeastern part of the fort is drained by Rippy Branch, which feeds into Rock Creek. The southwestern part of the fort drains to the southwest into a couple of unnamed creeks that feed into Rock Creek south of the fort. Rock Creek ultimately empties into the Brazos River about 8 miles south of the fort.

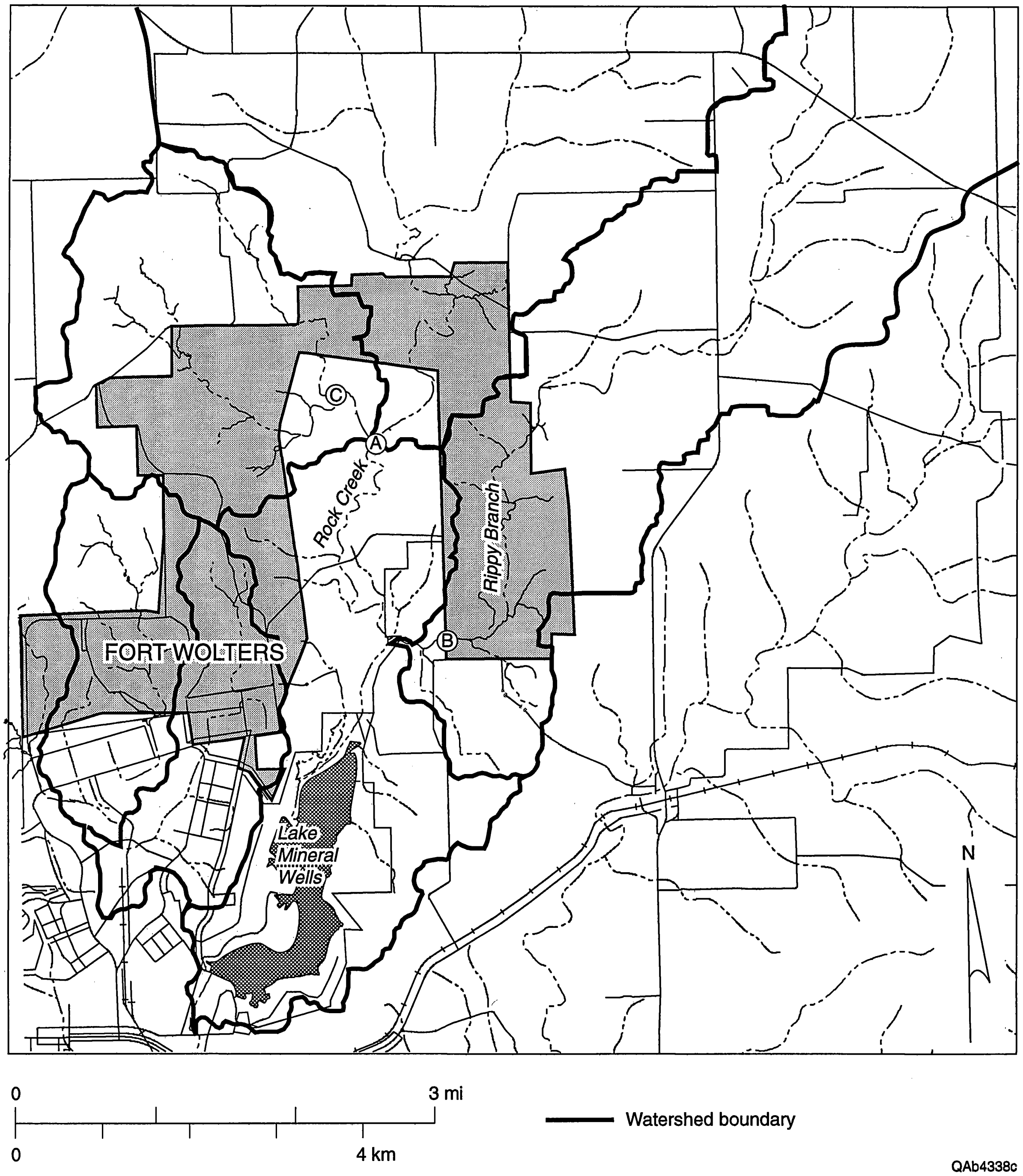


Figure 15. Watershed delineations of the Fort Wolters area. Points A, B, and C refer to flood hydrographs shown in figure 17.

Floodplain Analysis

Two major streams, Rock Creek and Rippy Branch, cross Fort Wolters. Fort Wolters is also cut by several minor creeks. These streams and creeks do not have major 100-yr floodplains. The floodplains, existing as halos around the stream beds, generally become wider downstream (fig. 16). Floodplains are wider about higher order streams such as Rock Creek and Rippy Branch, except where the floodplain has steep slopes. The 100-yr 24-hr rainfall is 9.0 inches and has a maximum SCS Type II distributed rainfall intensity of 3.83 inches/hr (fig. 17a). This 100-yr rainfall results in a maximum flow of 12,085 cubic feet per second (cfs) in Rock Creek near the fort boundary (fig. 17b for point A in fig. 16), 6,516 cfs for Rippy Branch near the fort boundary (fig. 17c for point B in fig. 16), and 3,448 cfs for a northwest tributary to Rock Creek (fig. 17d for point C in fig. 16).

GIS Data Preparation

Several layers of data and information were automated for inclusion into a GIS. These layers include:

- Roads
- Watersheds
- Digital elevation map (DEM)
- Floodplains
- Soil maps
- Location of off-camp wells
- Location of on-camp wells
- Water-level maps

The data dictionary for these coverages is included in appendix 3.

SUMMARY

Ground-water and surface-water hydrologic studies were conducted to provide information needed by the Texas Army National Guard to plan and conduct training activities at Fort Wolters while preserving environmental quality and resources.

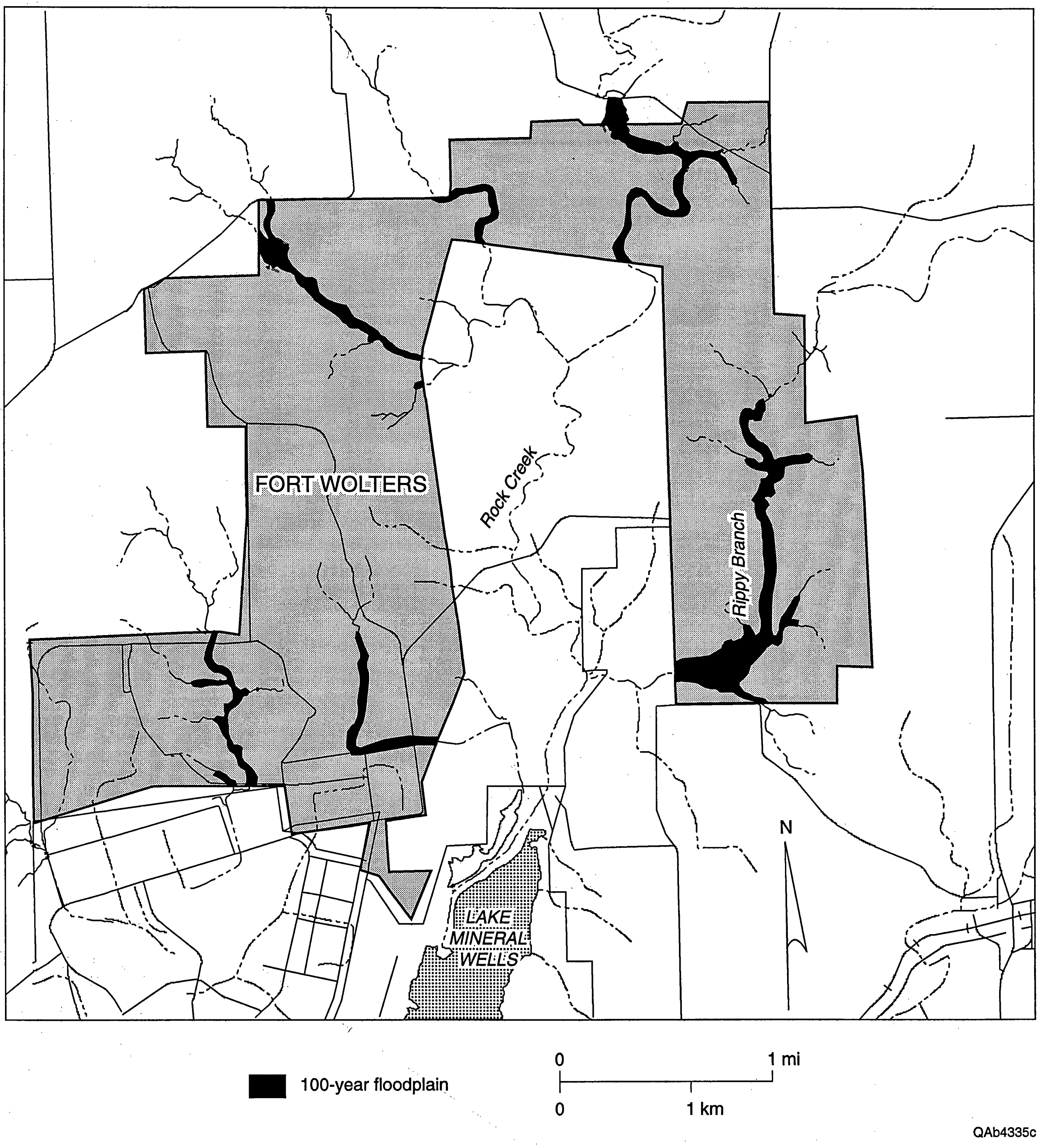


Figure 16. One-hundred-year floodplains of Fort Wolters.

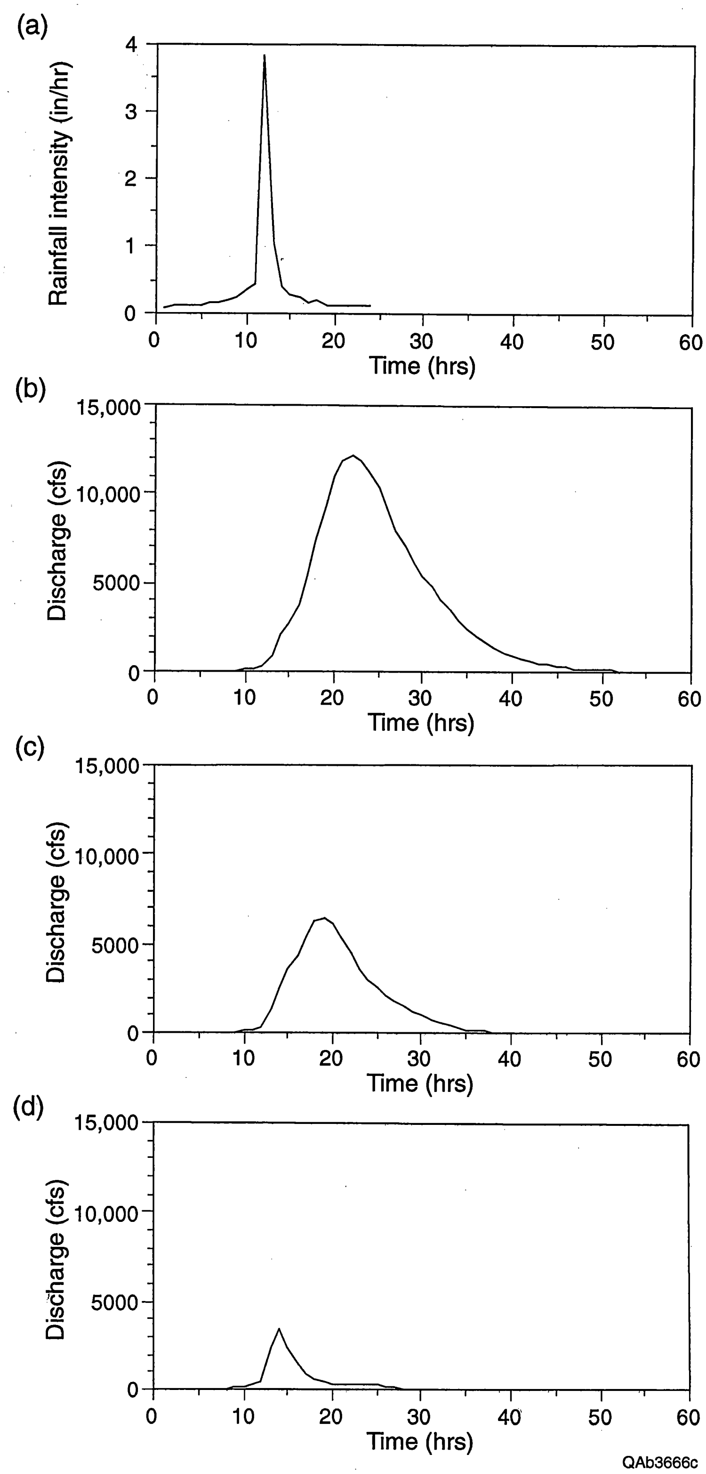


Figure 17. Flood hydrograph analysis of Fort Wolters, including (a) 100-yr 24-hr SCS Type II distributed rainfall intensity and the 100-yr flood hydrographs near the camp boundary of (b) Rocky Creek (point A, fig. 15), (c) Rippy Branch (point B, fig. 15), and (d) a northwest tributary to Rocky Creek (point C, fig. 15).

Although no major aquifers exist in the Fort Wolters area, many local wells produce low yields of generally brackish water. Texas Water Development Board files show that the water-producing zones are typically thin (about 10 ft thick) and that depths to water vary from about 20 to several hundred feet. Seven wells at the fort and 106 located nearby were found during a well survey. Well depths and depths to water vary considerably. Deeper wells tend to have deeper water levels, and many wells appear to be drilled deeper than necessary to increase wellbore storage. A conceptual ground-water flow model, developed as a result of our investigations, suggests that recharge at Fort Wolters occurs as rain falls on the Hog Mountain sandstone outcrop. Discharge from shallower strata probably occurs by means of flow to tributaries of the Brazos River, whereas discharge from deeper strata probably occurs by means of flow to the Brazos River.

Most of the training grounds are drained by Rock Creek or its tributaries, which flow into Lake Mineral Wells. Surface water at the southeastern part of the fort drains into Rippy Branch, then into Rock Creek, and ultimately to the Brazos. Streams at Fort Wolters do not have significant 100-yr floodplains; instead, flooded areas resulting from a 100-yr storm are closely confined to stream beds. A 100-yr rainfall would be expected to produce maximum flows of about 12,000 cfs in Rock Creek near the fort boundary and lesser flows in Rippy Creek and Rock Creek.

Ground-water contamination caused by training activities is not likely to be a serious problem because the water table is generally deep and water quality is already marginal for most domestic uses. Ground-water contamination is most likely to result from spills or debris on the sandy parts of topographically high areas of the camp. Surface-water contamination is most likely to result from spilled chemicals or debris being swept into surface drainages and then into streams or into Lake Mineral Wells during rain storms.

ACKNOWLEDGMENTS

This work was funded by the Texas Army National Guard under interagency contract THCB-95-1-05-1. We thank Jim Fries of The Nature Conservancy of Texas, Project Manager, for helpful discussions and suggestions. Jim Resner, Paul Powell, and William Furr of the Texas Army National Guard Adjutant General's Office ensured access to the camp and to previous reports. Major Gary Huffman greatly assisted this study by providing access to Fort Wolters and information regarding wells on the camp grounds. Bill Mullican, Jordan Foreman, William Doneghy, Bart Kelley, Andy Graham, and Sammy Jacobo assisted with drilling and documenting monitor wells. Alan Dutton reviewed the draft report. Graphics were drafted by Nancy Cottington, Patrice A.

Porter, Jana S. Robinson, Scott Schulz, and Tari Weaver. Editing was by Bobby Duncan, and word processing and layout were by Susan Lloyd.

REFERENCES

Avakian, A. J., and Wermund, E. G., 1994, Physical environment of Fort Wolters military reservation, Parker and Palo Pinto Counties, Texas: The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for Texas Adjutant General's Department under Letter of Agreement Number TX93-ED3-02 ENV244-D3, 90 p.

Bedient, P. B., and Huber, W. C., 1988, Hydrology and floodplain analysis: Reading, Mass., Addison-Wesley, 630 p.

Bomar, G. W., 1983, Texas weather: Austin, Texas, University of Texas Press, 265 p.

Brown, L. F., Jr., Goodson, J. L., and Harwood, P., 1972, Geologic atlas of Texas, Abilene sheet: The University of Texas at Austin, Bureau of Economic Geology, scale 1:250,000.

Chow, V. T., 1964, Handbook of applied hydrology, a compendium of water-resources technology: New York, McGraw-Hill, variously paginated.

Cooper, H. H., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well field history: Transactions of the American Geophysical Union, v. 27, p. 526–534.

Cooper, H. H., Bredehoeft, J. D., and Papadopulos, I. S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, p. 263–269.

ESRI, 1993, Cell-based modeling with Grid: ArcInfo user's guide: Redmond, Calif., Environmental Systems Research Institute, variously paginated.

Fleming and Associates, 1971, A comprehensive water plan for water and sewer, Parker County: Fort Worth, Texas, D. H. Fleming and Associates, Consulting Engineers, variously paginated.

Greenwade, J. M., Kelley, J. D., and Hyde, H. W., 1977, Soil survey of Parker County: U.S. Government Printing Office, U.S. Department of Agriculture and Soil Conservation Service, 90 p.

Herschfield, D. M., 1961, Rainfall frequency atlas of the United States, for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: U.S. Weather Bureau, Technical Report 40.

Hvorslev, M. J., 1951, Time lag and soil permeability in groundwater observations: Vicksburg, Miss., U. S. Army Corps of Engineers Waterways Experimental Station Bulletin 36, unpaginated.

Hydrologic Engineering Center, 1981, HEC-1 flood hydrograph package, user's manual and programmer's manual: updated 1988: Davis, Calif., U.S. Army Corp of Engineers, variously paginated.

___________ 1995, HEC-RAS river analysis system: Davis, Calif., U.S. Army Corp of Engineers, variously paginated.

Kier, R. S., Garner, L. E., and Brown, L. F., Jr., 1977, Land resources of Texas: The University of Texas at Austin, Bureau of Economic Geology, special report, 42 p.

Larkin, T. J., and Bomar, G. W., 1983, Climatic atlas of Texas: Texas Department of Water Resources, 151 p.

Laury, R. L., 1982, Geology of the type area, Canyon Group, North-Central Texas, *in* Cromwell, D. W., ed., Middle and Upper Pennsylvanian System of North-Central and West Texas (outcrop to subsurface): symposia and field conference guidebook: Permian Basin Section, Society of Economic Paleontologists and Mineralogists Publication 82-21, p. 87–122.

Linsley, R. K., Jr., Kohler, M. A., and Paulhus, J. L. H., 1982, Hydrology for engineers: New York, McGraw-Hill, 508 p.

Maidment, D. R., 1995, Hydrologic data sets and tools for their interpretation: GIS & Hydrology Workshop presented at the 15th annual ESRI User Conference, Palm Springs, California, variously paginated.

McCarthy, G. T., 1938, The unit hydrograph and flood routing: unpublished paper presented at a conference of the North Atlantic Division, U.S. Army Corps of Engineers.

McGowen, J. H., Proctor, C. V., Jr., Haenggi, W. T., Reese, D. F., and Barnes, V. E., 1987, Geologic atlas of Texas, Dallas sheet [revised]: The University of Texas at Austin, Bureau of Economic Geology, scale 1:250,000.

Moore, J. D., 1981, Soil survey of Palo Pinto County: U.S. Government Printing Office, U.S. Department of Agriculture and Soil Conservation Service, 150 p.

Plummer, F. B., and Hornberger, J., Jr., 1935, Geology of Palo Pinto County, Texas: University of Texas Bulletin 3524, 240 p.

Schoch, E. P., 1918, Chemical analyses of Texas rocks and minerals: University of Texas Bulletin No. 1814, 256 p.

Soil Conservation Service, 1957, Use of storm and watershed characteristics in synthetic hydrograph analysis and application: Washington, D.C., U.S. Department of Agriculture.

__________1991, State soil geographic data base (STATSGO): Washington, D.C., U.S. Department of Agriculture Miscellaneous Publication No. 1492.

Snyder, F. F., 1938, Synthetic unit hydrographs: Transactions of the American Geophysical Union, v. 19, pt. 1, p. 447–454.

TDWR, 1983, Water for Texas, planning for the future: Austin, Texas, Texas Department of Water Resources, 39 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Transactions of the American Geophysical Union, v. 16, p. 519–524.

Trice, E. L., 1984, Conodont biostratigraphy and stratigraphic relationships of the Strawn Group (Pennsylvanian), Colorado and Brazos River Valleys, Central Texas: Baylor University, Master's thesis, 140 p.

USACHPPM, 1994, Draft site inspection no. 38-26-1340-95, Texas Army National Guard, Fort Wolters, Texas: Department of the Army, U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, Maryland, Draft report, variously paginated.

U.S. Department of the Army, 1994, Draft site inspection no. 38-26-1340-95, Texas Army National Guard, Fort Wolters, Texas: Draft site inspection report, U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, Maryland, variously paginated.

Appendix 1

Well Survey around Camp Perimeter

Appendix 1. Well survey around Fort perimeter.

Well #	Date	Cond. (μΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Well use	Land surface elevation (ft)
S001	7/17/95	-	-	-	-	-	-	-
S002	7/17/95	-	450	186.5	0.00	6.00	lawn	1011
S003	7/17/95	-	-	9.85	2.00	4.00	-	948
S004	7/17/95	-	-	-	-	-	-	-
S005	7/17/95	-	435	89.7	1.75	4.00	house	1022
S006	7/17/95	1000	200-300	37.53	0.90	4.00	house	969
S007	7/17/95	-	-	-	-	4.00	house	-
S008	7/17/95	9250	430	122.65	1.50	-	-	928
S009	7/17/95	-	220-280	48.12	-	-	-	1014
S010	7/17/95	-	500	~230	-	-	aband	-
S011	7/17/95	-	85	27.85	1.30	-	-	1035
S012	7/17/95	-	-	-	-	-	-	-
S013	7/17/95	-	-	-	-	-	-	-
S014	7/17/95	-	-	-	-	-	-	-
S015	7/17/95	-	-	-	-	-	-	-
S016	7/17/95	-	-	-	-	-	-	-
S017	7/17/95	-	-	-	-	-	-	-
S018	7/17/95	-	103	-	-	-	-	-
S019	7/17/95	-	502	-	-	-	-	-
S020	7/17/95	-	>500	-	-	-	-	-
S021	7/17/95	1200	90	-	-	-	yard	-
S022	7/17/95	-	-	-	-	-	-	-
S023	7/17/95	-	-	-	-	-	-	-
S024	7/17/95	-	-	-	-	-	-	-
S025	7/17/95	-	-	-	-	-	-	-
S026	7/17/95	-	-	-	-	-	-	-
S027	7/17/95	-	-	-	-	-	-	-
S028	7/17/95	-	-	-	-	-	-	-
S029	7/17/95	-	-	-	-	-	-	-
S030	7/17/95	-	-	-	-	-	-	-
S031	7/17/95	-	-	-	-	-	-	-
S032	7/17/95	-	-	-	-	-	-	-
S033	7/17/95	-	-	-	-	-	-	-
S034	7/17/95	1000	165	77.43	1.90	4.00	house	1036
S035	7/17/95	-	-	-	-	-	-	-
S036	7/17/95	-	-	-	-	-	-	-
S037	7/17/95	-	-	-	-	-	-	-
S038	7/17/95	-	-	13.1	0.20	-	-	945
S039	7/17/95	2600	250-275	36.7	0.00	-	house	971
S040	7/17/95	-	-	-	-	-	-	-
S041	7/17/95	-	-	-	-	-	-	-
S042	7/17/95	-	-	-	-	-	-	-
S043	7/17/95	-	-	-	-	-	-	-
S044	7/17/95	-	-	-	-	-	-	-
S045	7/17/95	-	-	-	-	-	-	-
S046	7/17/95	-	-	-	-	-	-	-
S047	7/17/95	-	-	-	-	-	-	-
S048	7/17/95	-	-	-	-	-	-	-
S049	7/17/95	-	-	-	-	-	-	-
S050	7/17/95	-	-	-	-	-	-	-
S051	7/19/95	600	-	24.82	0.42	4.00	lawn	918
S052	7/17/95	-	-	-	-	-	-	-
S053	7/17/95	-	-	-	-	-	-	-
S054	7/17/95	-	-	-	-	-	-	-
S055	7/17/95	-	-	-	-	-	-	-
S056	7/18/95	-	-	-	-	-	-	-
S057	7/18/95	-	-	-	-	-	-	-

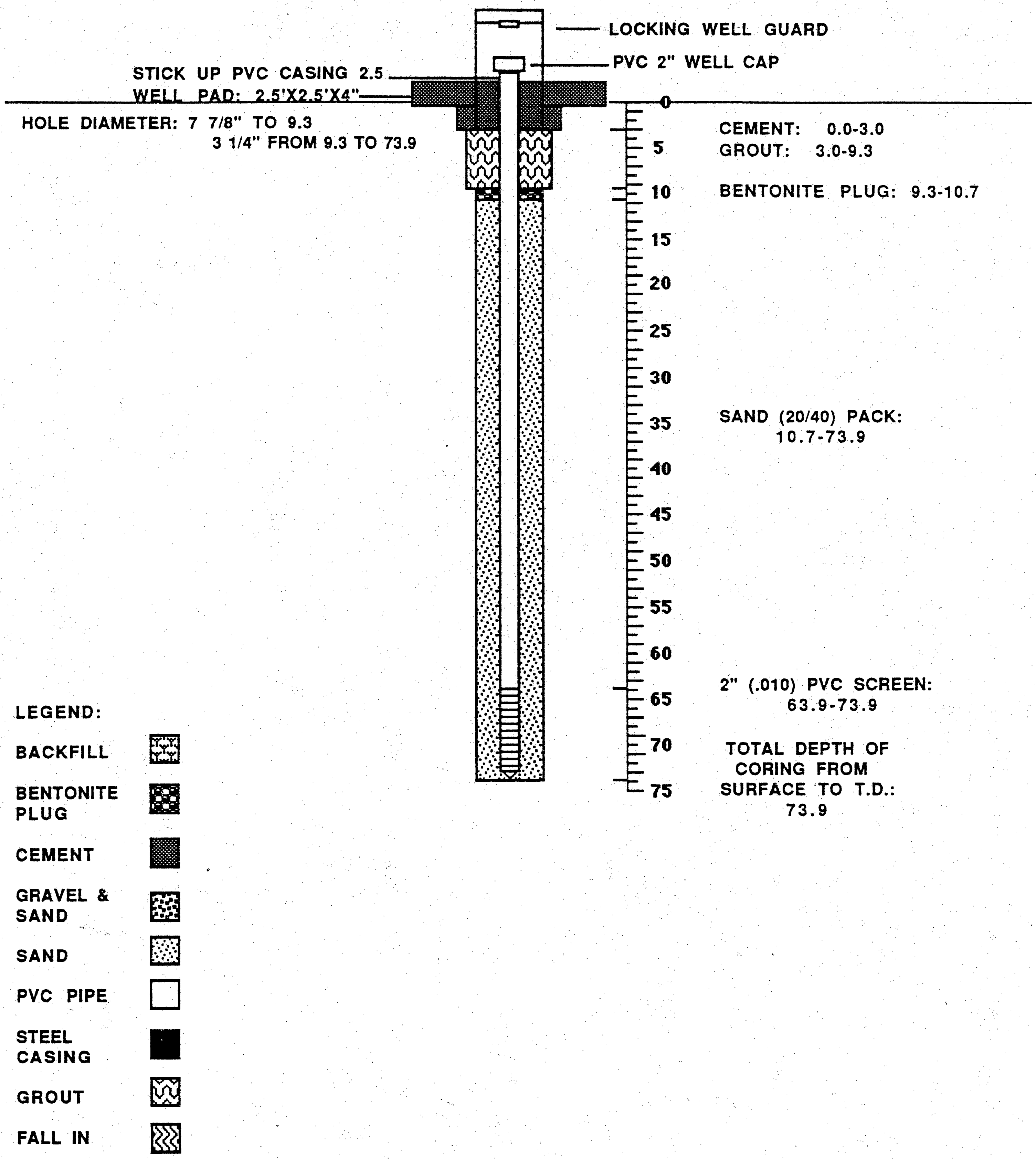
Appendix 1. Well survey around Fort perimeter.

Well #	Date	Cond. (µΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Well use	Land surface elevation (ft)
S058	7/18/95	-	-	-	-	-	-	-
S059	7/18/95	-	-	-	-	-	-	-
S060	7/18/95	600	120	6.5	1.00	4.00	house	893
S061	7/18/95	-	-	-	-	-	-	-
S062	7/18/95	-	-	-	-	-	-	-
S063	7/18/95	1100	180	8.5	0.83	4.00	house	877
S064	7/18/95	1300	120	13.25	0.42	4.00	livestock	891
S065	7/18/95	-	-	-	-	-	-	-
S066	7/18/95	-	-	-	-	-	-	-
S067	7/19/95	-	-	-	-	-	-	-
S068	7/19/95	-	-	-	-	-	-	-
S069	7/19/95	-	-	-	-	-	-	-
S070	7/19/95	600	-	-	-	-	house	-
S071	7/19/95	-	-	-	-	-	-	-
S072	7/19/95	-	-	-	-	-	-	-
S073	7/19/95	-	-	-	-	-	-	-
S074	7/19/95	-	-	-	-	-	-	-
S075	7/19/95	-	-	-	-	-	-	-
S076	7/19/95	-	-	-	-	-	-	-
S077	7/19/95	900	<100	12.35	-	4.00	-	-
S078	7/19/95	-	-	-	-	-	-	-
S079	7/19/95	-	-	-	-	-	-	-
S080	7/19/95	-	100	11.1	0.80	4.00	aband	996
S081	7/19/95	900	100	~12-40	-	-	house	-
S082	7/19/95	-	-	-	-	-	-	-
S083	7/19/95	2000	130	14.37	1.00	4.00	house	1015
S084	7/19/95	-	-	-	-	-	-	-
S085	7/19/95	-	-	-	-	-	-	-
S086	7/19/95	-	-	-	-	-	-	-
S087	7/19/95	-	-	-	-	-	-	-
S088	7/19/95	-	-	-	-	-	-	-
S089	7/19/95	-	-	-	-	-	-	-
S090	7/19/95	1150	35	12.74	3.25	36.00	house	998
S091	7/19/95	-	-	-	-	-	-	-
S092	7/17/95	-	110	-	-	-	aband	-
S093	7/17/95	-	90	-	-	-	aband	-
S094	7/17/95	-	125	-	-	-	aband	-
S095	7/17/95	-	520	-	-	-	aband	-
S096	7/18/95	-	-	-	-	-	-	-
S097	7/18/95	-	-	-	-	-	-	-
S098	7/18/95	-	-	-	-	-	-	-
S099	7/18/95	-	-	-	-	-	-	-
S100	7/18/95	-	-	-	-	-	-	-
S101	7/18/95	-	-	-	-	-	-	-
S102	7/18/95	-	-	-	-	-	-	-
S103	7/18/95	-	-	-	-	-	-	-
S104	7/18/95	-	-	-	-	-	-	-
S105	7/18/95	-	-	-	-	-	-	-
S106	7/18/95	-	-	-	-	-	-	-
S107	7/18/95	-	-	-	-	-	-	-
S108	7/18/95	-	-	-	-	-	-	-
S109	7/18/95	-	-	-	-	-	-	-

Appendix 2

Detailed Well Schematics and Drilling Reports for Monitor Wells

WATER MONITOR SCHEMATIC
FORT WOLTERS #1
DRILL DATE: 12/1/95
NATIONAL GUARD PROJECT



Send original copy by certified mail to: TNRCC, P.O. Box 13087, Austin, TX 78711-3087 *Please use black ink.*

ATTENTION OWNER: *Confidentiality Privilege Notice on Reverse Side*

State of Texas WELL REPORT

Texas Water Well Drillers Advisory Council
P.O. Box 13087
Austin, Texas 78711-3087
512-239-0530

Fort Wolters #1

1) OWNER Texas National Guard (Name) ADDRESS P.O. Box 5218 (Street or RFD) Austin (City) Tx (State) 78763 (Zip)

2) ADDRESS OF WELL: County Parker Fort Wolters Rt. 4 Bldg 1202 (Street, RFD or other) Mineral Wells (City) Texas (State) 76067-9500 (Zip) GRID # 31-16-2

3) TYPE OF WORK (Check):
☒ New Well ☐ Deepening
☐ Reconditioning ☐ Plugging

4) PROPOSED USE (Check): ☒ Monitor ☐ Environmental Soil Boring ☐ Domestic
☐ Industrial ☐ Irrigation ☐ Injection ☐ Public Supply ☐ De-watering ☒ Testwell
If Public Supply well, were plans submitted to the TNRCC? ☐ Yes ☐ No

5) 32° 51' 34" 98° 2' 31" N

6) WELL LOG:
Date Drilling:
Started 11/28 19 95
Completed 12/1 19 95

DIAMETER OF HOLE

Dia. (in.)	From (ft.)	To (ft.)
7 7/8	Surface	9.3
3 1/4	9.3	73.9

7) DRILLING METHOD (Check): ☐ Driven
☐ Air Rotary ☐ Mud Rotary ☒ Bored
☐ Air Hammer ☒ Cable Tool ☐ Jetted
☒ Other Augered, N/X Wireline

From (ft.)	To (ft.)	Description and color of formation material
0.0	3.6	Red, sandy clay
3.6	54.1	Sandstone, weathered limestone
54.1	73.9	Grey shale

(Use reverse side if necessary)

8) Borehole Completion (Check): ☐ Open Hole ☒ Straight Wall
☐ Underreamed ☐ Gravel Packed ☐ Other
If Gravel Packed give interval . . . from ft. to ft.

CASING, BLANK PIPE, AND WELL SCREEN DATA:

Dia (in.)	New or Used	Steel, Plastic, etc. Perf., Slotted, etc. Screen Mfg., if commercial	Setting (ft.) From	Setting (ft.) To	Gage Casting Screen
2"	N	PVC Schedule 40 - 65'	2.5' Above Surface	63.9	
2"	N	PVC Schedule 40 - 10'	63.9	73.9	.010

9) CEMENTING DATA: [Rule 338.44(1)]

Cemented from 4" Above Surface ft. to 3.0 ft. No. of Sacks Used 3
ft. to ft. No. of Sacks Used
Method used Hand Poured
Cemented by Drill Crew
Distance to septic system field lines or other concentrated contamination N/A ft.
Method of verification of above distance N/A

10) SURFACE COMPLETION
☒ Specified Surface Slab Installed [Rule 338.44 (2) (A)]
☒ Specified Steel Sleeve Installed [Rule 338.44 (3)(A)]
☐ Pitless Adapter Used [Rule 338.44 (3)(b)]
☐ Approved Alternative Procedure Used [Rule 338.71]

11) WATER LEVEL:
Static level ft. below land surface Date
Artesian flow gpm. Date

12) PACKERS: Type Depth

13) TYPE PUMP:
☐ Turbine ☐ Jet ☐ Submersible ☐ Cylinder
☐ Other
Depth to pump bowls, cylinder, jet, etc., ft.

14) WELL TESTS:
Type test: ☐ Pump ☐ Bailer ☐ Jetted
Yield: gpm with ft. drawdown after hrs.

15) WATER QUALITY:
Did you knowingly penetrate any strata which contained undesirable constituents?
☐ Yes ☐ No
Type of water? Depth of strata
Was a chemical analysis made? ☐ Yes ☐ No

I hereby certify that this well was drilled by me (or under my supervision) and that each and all of the statements herein are true to the best of my knowledge and belief. I understand that failure to complete items 1 thru 15 will result in the log(s) being returned for completion and resubmittal.

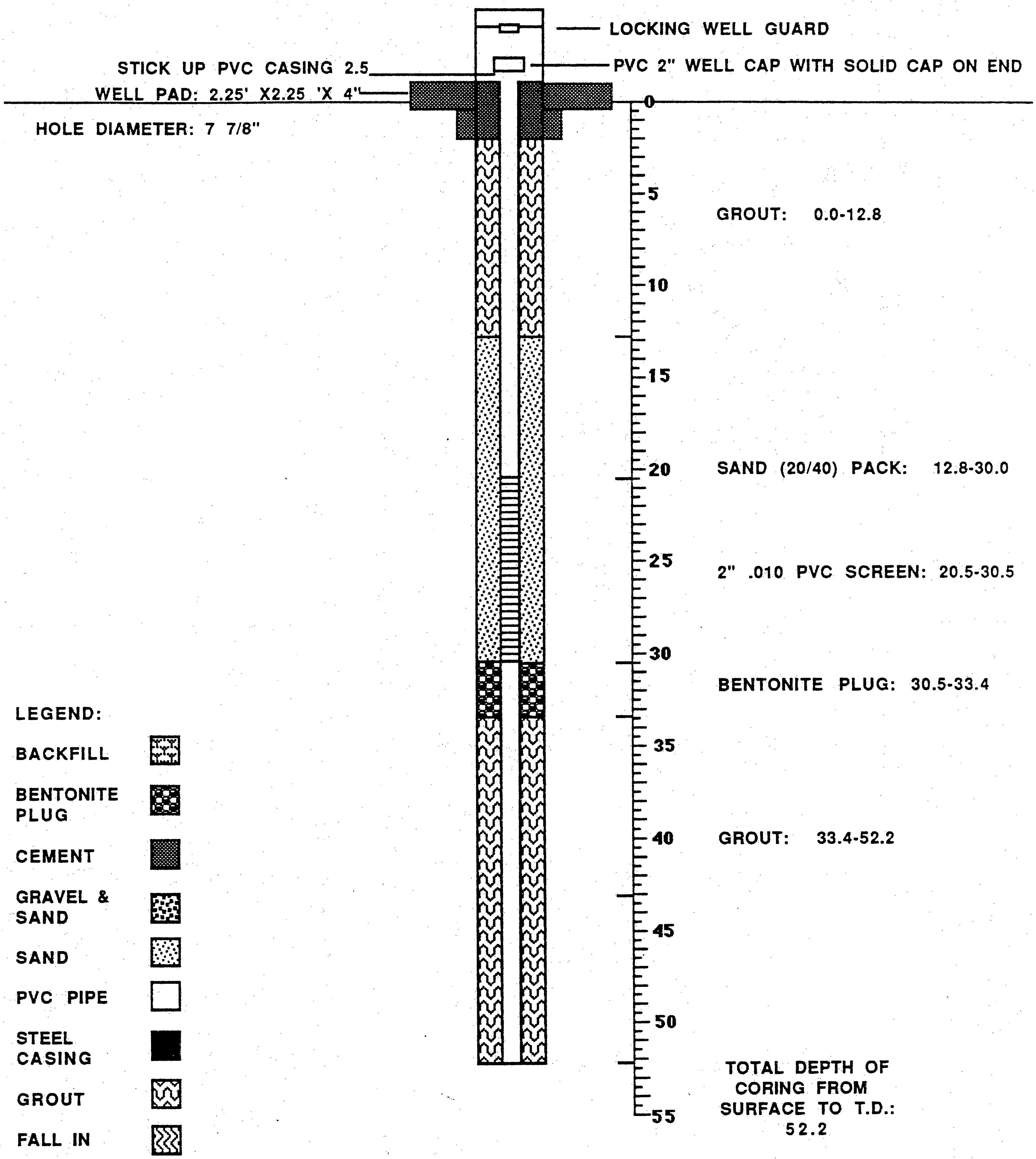
COMPANY NAME University of Texas/Bureau of Economic Geology (Type or Print) WELL DRILLER'S LICENSE NO. 3187-M

ADDRESS P.O. Box X University Station (Street or RFD) Austin (City) Texas (State) 78701 (Zip)

(Signed) James Doss (Licensed Well Driller) (Signed) Jordan Forman (Registered Driller Trainee)

Please attach electric log, chemical analysis, and other pertinent information, if available.

WATER MONITOR SCHEMATIC
FORT WOLTERS #2A
DRILL DATE: 12/5/95
NATIONAL GUARD PROJECT



Send original copy by certified mail to: TNRCC, P.O. Box 13087, Austin, TX 78711-3087 *Please use black ink.*

ATTENTION OWNER: *Confidentiality Privilege Notice on Reverse Side*

State of Texas WELL REPORT

Texas Water Well Drillers Advisory Council
P.O. Box 13087
Austin, Texas 78711-3087
512-239-0530

Fort Wolters #2A

1) OWNER Texas National Guard (Name) ADDRESS P.O. Box 5218 (Street or RFD) Austin (City) Tx (State) 78763 (Zip)

2) ADDRESS OF WELL: County Parker Fort Wolters Rt. 4 Bldg 1202 (Street, RFD or other) Mineral Wells (City) Texas (State) 76067-9500 (Zip) GRID # 31-16-3

3) TYPE OF WORK (Check): ☒ New Well ☐ Deepening ☐ Reconditioning ☐ Plugging

4) PROPOSED USE (Check): ☒ Monitor ☐ Environmental Soil Boring ☐ Domestic ☐ Industrial ☐ Irrigation ☐ Injection ☐ Public Supply ☐ De-watering ☒ Testwell
If Public Supply well, were plans submitted to the TNRCC? ☐ Yes ☐ No

5) 32° 52' 6" 98° 2' 6" N

6) WELL LOG:
Date Drilling:
Started 12/4 19 95
Completed 12/5 19 95

DIAMETER OF HOLE

Dia. (in.)	From (ft.)	To (ft.)
7 7/8	Surface	52.

7) DRILLING METHOD (Check): ☐ Driven ☐ Air Rotary ☐ Mud Rotary ☒ Bored ☐ Air Hammer ☒ Cable Tool ☐ Jetted ☒ Other Augered

From (ft.)	To (ft.)	Description and color of formation material
0.0	3.5	Brown top soil
3.5	18.5	Tan clay with caliche
18.5	23.5	Clay, gravel, sand, water
23.5	52.2	Shale and sand

(Use reverse side if necessary)

8) Borehole Completion (Check): ☐ Open Hole ☒ Straight Wall ☐ Underreamed ☐ Gravel Packed ☐ Other
If Gravel Packed give interval . . . from ____ ft. to ____ ft.

CASING, BLANK PIPE, AND WELL SCREEN DATA:

Dia (in.)	New or Used	Steel, Plastic, etc. Perf., Slotted, etc. Screen Mfg., if commercial	Setting (ft.) From	Setting (ft.) To	Gage Casting Screen
2"	N	PVC Schedule 40 - 20'	2.5' Above Surface	20.5	
2"	N	PVC Schedule 40 - 10'	20.5	30.5	.010
2"	N	PVC Schedule 40 - 20'	30.5	50.2	

9) CEMENTING DATA: [Rule 338.44(1)]
Cemented from 4" Above Surface ft. to 3.0 ft. No. of Sacks Used 4
____ ft. to ____ ft. No. of Sacks Used ____
Method used Hand Poured
Cemented by Drill Crew
Distance to septic system field lines or other concentrated contamination N/A ft.
Method of verification of above distance N/A

10) SURFACE COMPLETION
☒ Specified Surface Slab Installed [Rule 338.44 (2) (A)]
☒ Specified Steel Sleeve Installed [Rule 338.44 (3)(A)]
☐ Pitless Adapter Used [Rule 338.44 (3)(b)]
☐ Approved Alternative Procedure Used [Rule 338.71]

11) WATER LEVEL:
Static level ____ ft. below land surface Date ____
Artesian flow ____ gpm. Date ____

12) PACKERS: Type Depth

13) TYPE PUMP:
☐ Turbine ☐ Jet ☐ Submersible ☐ Cylinder
☐ Other ____
Depth to pump bowls, cylinder, jet, etc., ____ ft.

14) WELL TESTS:
Type test: ☐ Pump ☐ Bailer ☐ Jetted
Yield: ____ gpm with ____ ft. drawdown after ____ hrs.

15) WATER QUALITY:
Did you knowingly penetrate any strata which contained undesirable constituents?
☐ Yes ☐ No
Type of water? ____ Depth of strata ____
Was a chemical analysis made? ☐ Yes ☐ No

I hereby certify that this well was drilled by me (or under my supervision) and that each and all of the statements herein are true to the best of my knowledge and belief. I understand that failure to complete items 1 thru 15 will result in the log(s) being returned for completion and resubmittal.

COMPANY NAME University of Texas/Bureau of Economic Geology (Type or Print) WELL DRILLER'S LICENSE NO. 3187-M

ADDRESS P.O. Box X University Station (Street or RFD) Austin (City) Texas (State) 78701 (Zip)

(Signed) James Doss (Licensed Well Driller) (Signed) Jordan Forman (Registered Driller Trainee)

Please attach electric log, chemical analysis, and other pertinent information, if available.

TNRCC-0199 (Rev. 11-01-94) TNRCC COPY

Appendix 3

Data Dictionary for GIS Coverages

GIS DATA DICTIONARY

Several layers of spatial hydrologic and hydrogeologic data were input to the Bureau of Economic Geology GIS system. Maps were digitized using a Calcomp digitizing table, under the ArcEdit module of GIS ArcInfo, on a Sparc500 Workstation. When possible, the data from the paper originals of the U.S. Geological Survey (USGS) 1:24,000-scale, 7.5-minute topographic maps were either transferred on Mylar or digitized during one session to minimize the distortions related to environmental factors. The digital data base, regardless of the original projection, will be delivered in the Universal Transverse Mercator (UTM) coordinate system, with the following parameters:

Ellipsoid: Clarke 1866

Horizontal Datum: NAD27

Units: meters

Zone 14

The digital data represent the following.

Digital Elevation Models (DEM) were acquired from MicroPath at 1:24,000 scale, where available (View, Buffalo Gap, Paris, Lake Bastrop, Elgin East, McDade, Graford East, Mineral Wells East, Mineral Wells West, and Whitt), or were created from digital elevation contours and streams using the Grid module of ArcInfo (Topogrid). The cell size for DEMs is 30 m, with a horizontal accuracy of ±3 m and a vertical accuracy of ±10 m. The DEMs were used to delineate watersheds of interest.

Watersheds represent polygon coverages encompassing the drainage areas. They were outlined from DEMs for Camp Swift, Camp Mabry, Camp Barkeley, and Fort Wolters or were defined from USGS topographic quads and then transferred to a digital format. Possible inaccuracy might be related to human error and imperfections of the digitizing equipment. Given the USGS-stated positional accuracy of ±40 ft for its 7.5-minute quads, and the inadvertent positional shifts that may have been introduced during the digitizing process, it can be estimated that the positional accuracy of most features will be approximately ±50 ft.

Floodplains are polygon coverages, digitized from USGS topographic quads, with the aforementioned accuracy estimate.

Well locations are point coverages, digitized from USGS topographic quadrangles; they include existing and recently drilled wells, with an internally assigned well name (number) as an item in the Point Attribute Table (PAT). They include wells on and around the camps.

Soil maps are generalized soil maps at 1:250,000 scale compiled by the U.S. Department of Agriculture Soil Conservation Service. They contain polygons describing groups of soil types and attached attribute tables with extensive sets of numerical values, including their hydrologic properties, which were used to specify the percentage of the map unit occupied by soils in each hydrologic group. The digital data were obtained from the Texas Natural Resources Information System (TNRIS) ftp site.

Water levels represent water-level contours, which, owing to scarcity of control points and the inherent interpolation problems of the software, were hand drawn and then digitized from Mylar overlays.

Cultural features include roads and generalized streams at 1:24,000 scale, at various extents around the camp. They were obtained from the TNRIS ftp site and are the latest version of Texas Department of Transportation (TxDOT) urban maps. These files were originally digitized from USGS 7.5-minute quadrangles. Updates are made periodically using TxDOT highway construction plans, aerial photographs, official city maps, and field inventory. These files contain most of the features found on 7.5-minute quads, except for items such as contour lines, fence lines, jeep trails, electrical transmission lines, oil and gas pipelines, and control data monuments.

The county map files are based on the following map projection system:

TEXAS STATEWIDE MAPPING SYSTEM (NAD27)

Projection: Lambert Conformal Conic

Ellipsoid: Clarke 1866

Datum: North American 1927

Longitude of Origin: 100 degrees west (-100)

Latitude of Origin: 31 degrees 10 minutes north

Standard Parallel #1: 27 degrees 25 minutes north latitude

Standard Parallel #2: 34 degrees 55 minutes north latitude

False Easting: 3,000,000 ft

False Northing: 3,000,000 ft

Unit of Measure: feet (international)

Positional Accuracy: These digital maps were created primarily for the purpose of producing county/urban published maps. Certain features, particularly railroads and streams, have been displaced in congested areas so as to insure map readability at county map scales.

Miscalculation of false northing and easting required reprojection of the DGN digital files, at the correct values (914,400 ft), in order to obtain the perfect overlay with several preexisting county and quadrangle files.

FORT WOLTERS

Base maps: the USGS 7.5′ topographic quadrangles, Mineral Wells East, Mineral Wells West, and Whitt, are in the State Plane coordinate system, North Central Zone (5351), datum NAD27, units in feet.

Coverage name	**Coverage type**	**Initial projection**	**Final projection**	**Source**	**Accuracy**	**Description**
Offcamprdutm	Arc	Texas State Plane	UTM	TXDOT digital county files	±50 ft	Highways and off-camp well locations
Arcamprdutm	Arc	Texas State Plane	UTM	TXDOT digital county files	±50 ft	Highways near the camp
Boundutm	Polygon	State Plane North Central Zone	UTM	Texas Parks and Wildlife digital files	unknown	Camp boundary. Recently acquired land was added by digitizing from topographic quads
Streamsutm	Arc	UTM	UTM	Delineated from DEMs	±40 ft	Streams and rivers in the contributing watersheds delineated from watershed analysis; threshold = 2,500
Wshedutm	Polygon	UTM	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft	Watersheds corresponding to stream segments
Fplainutm	Polygon	State Plane North Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.005	Floodplains
Fpstreamutm	Arc	State Plane North Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.004	Stream orders and cross sections used for the HEC-RAS model
Soilsutm	Polygon	Texas State Plane	UTM	STATSGO digital database	unknown	1:2,500,000-scale distribution of soils in the watersheds
Wtswellsutm	Point	State Plane North Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.004	Location of off-camp wells
Wtcwellsutm	Point	State Plane North Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.002	Location of on-camp wells
Wlevwells	Arc	State Plane North Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.005	Digitized locations for wells with known water-level measurements