Hydrologic and Hydrogeologic Survey of Camps Barkley, Bowie, Mabry, Maxey, and Swift and Fort Wolters

Interim Report

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INTRODUCTION

The Bureau of Economic Geology (BEG) is conducting hydrologic and hydrogeologic studies of Texas National Guard training facilities at Camps Barkley, Bowie, Mabry, Maxey, and Swift and Fort Wolters. These investigations, in conjunction with aquatic and biological surveys conducted by the Texas Parks and Wildlife Department, will provide information needed by the Texas National Guard to plan training and preparedness activities such that environmental resources will be protected and enhanced without compromising national security readiness.

This report presents data and analyses collected and performed by BEG researchers from October through December, 1995. The activities presented in this report include results of the (1) hydrogeologic analysis, (2) surface-water analysis, and (3) well inventory on the camps and fort. The hydrogeologic analysis includes hydrostratigraphy, aquifer properties, ground-water chemistry, water levels, preliminary conceptual flow model, and drilling plans. Surface-water analysis includes description of principal streams and drainage basins, watershed delineation, and plots of flow duration and frequency. We present some results of our drilling program in the hydrogeologic analysis. Well reports will be presented in our February interim report and well tests and analyses in the final report.

This report is divided into 6 sections with each section discussing the hydrologic and hydrogeologic assessment for an individual training facility.

CAMP BARKLEY

HYDROGEOLOGIC ANALYSIS

Surface Geology and Hydrostratigraphy

Several formations of the Permian and Cretaceous system crop out on Camp Barkley. The lower elevations of the camp consist of the Vale and Choza Formations and the uplands consist of Cretaceous rocks including the Antlers Formation capped by the Fredricksburg Group. The Vale Formation, the lower part of which crops out in the northern and southern areas of the camp, mostly consists of red shales with thin and scattered lenticular sandstones in the lower part and many thin interbedded dolomite and shale stringers in the upper part. This formation is easily identified near the camp by its deep red color. The Antlers Formation, which also represents the Trinity Group in this area, consists of light colored sandstone in the upper part, silty sandstone in the middle, and light colored sandstone with some conglomerate in the lower part. On the camp, the Trinity Group forms the lower slopes of the mesas. The Fredricksburg Group consists of the Walnut Formation, the Comanche Peak Limestone, and the Edwards Limestone and is undifferentiated on geologic maps of the area. The Walnut Formation is a marly yellow clay which locally grades into shaley limestone. The Comanche Peak Limestone consists of gray, nodular, marly limestone. The Edwards Limestone is a cream to gray, crystalline limestone with abundant chert nodules. The Fredricksburg Group caps the mesas on the camp. The Vale Formation underlies the northern mesa, and the Choza Formation probably underlies the southern mesa. The composition of the Choza Formation is very similar to the composition of the Vale Formation in the Camp Barkley area.

The recognized principal aquifers in Taylor County are the alluvial deposits bordering rivers and streams and the Antlers Formation (Taylor, 1978). About 42 percent of the wells listed with the Texas Water Development Board (TWDB) are completed in alluvium and are principally located along Jim Ned Creek. North-west of Camp Barkley, there are wells completed in the alluvium of Elm Creek. About 18 percent of the wells listed with the TWDB are completed in the Antlers Formation. These wells are completed in Cretaceous outliers that are erosional remnants of the once continuous Cretaceous formations.

Water-well Inventory

We found three wells or abandoned well sites on Camp Barkley during this study (fig. 1). The only water well found was a hand-dug well in the southern part of the camp. This well (CBK-B001) is 16.9 ft deep, has a diameter of 3 ft, and holds no water though the walls appeared damp when surveyed in September 1995. The well crown consists of cement with native stone casing to 1 ft below land surface. The rest of the well is open completion with what appears to be 6 ft of clay and sand and 6 ft of colluvium. There are a few feet of rock (limestone?) near the bottom of the hole. This well has apparently collapsed because its reported depth in the TWDB files (well 30-42-401) as of 1971 was 65 ft. The water table at this well is approximately 32 ft below land surface (as measured in 1971).

The other two wells (CBK-B002 and CBK-B003) are old oil wells reported by Cpt. Decker that have been filled. We found no wells at these sites, confirming that the wells have been destroyed. Capt. Decker also mentioned that a new oil well may soon be drilled on the south-western tip of the camp.

Hydraulic Properties

There are no pumping tests reported in wells in the Antlers, Vale, or Choza Formations or in the Fredricksburg Group in Taylor County. The only reported aquifer tests are specific capacity tests in the Choza Formation and well yields in the other formations. Taylor (1978) reports three specific capacity tests with calculated specific capacities of 0.9, 3.2, and 6.8 gpm ft^{-1}. These values correspond to transmissivities of 170, 610, and 1,300 ft^2 d^{-1} using the method of Thomasson and others (1960).

Well yields represent the amount of pumping a well can sustain. However, these tests do not quantify aquifer permeability and are biased by user requirements and pump size. Nevertheless, well yields do offer information on the relative productivity of aquifers. Well yields in the formations of interest are not high with most values under 60 gpm (fig. 2). The Antlers Formation has most well yields below 40 gpm (fig. 2a). The Choza Formation has the highest well yields with values as high as 150 gpm (fig. 2b). The few well yield tests in the Fredricksburg Group and the Vale Formation have values less than 30 gpm (fig. 2c, d). The Fredricksburg Group probably has higher transmissivities than the Permian formations because the Fredricksburg Group is locally fractured.

The BEG plans to conduct aquifer tests in some nearby privately owned wells and in a well drilled on Camp Barkley for this project to better quantify hydraulic properties in these formations. These values will be reported in subsequent reports.

Water Chemistry

Each of the formations had water quality assessments reported in the TWDB files (Table 1). Total dissolved solids (TDS) for the Antlers Formation ranged from 269 to 750 mg l^{-1} with most values between 300 and 400 mg l^{-1} (fig. 3a). TDS for the Fredricksburg Group was similar and ranged from 250 to 574 mg l^{-1} with most values between 250 and 400 mg l^{-1} (fig. 3b). TDS in the Permian System were considerably higher with values in the Choza Formation ranging from 368 to 5136 mg l^{-1} with most values between 750 and 1000 mg l^{-1} (fig. 3c). TWDB files report two values of TDS, 1675 and 4200 mg l^{-1}, in the Vale Formation (fig. 3c).

Waters from the Cretaceous formations (the Antlers Formation and the Fredricksburg Group) are predominantly calcium-bicarbonate in composition (fig. 4a and 5a, respectively). Waters from the Permian formations are more chemically diverse and not easily classified. There is no dominant type of water composition in the Choza formation with many samples having almost equal proportions of Na, Ca, and Mg (fig. 4b). The water composition of the Vale Formation and undifferentiated Permian System is similar to the water composition of the Choza Formation, though Cl may be the dominant anion (fig. 5b).

The BEG will sample and analyze waters from the Antlers and Vale Formations in and near Camp Barkley to attain more site-specific data. Results will be reported in subsequent reports.

Water Levels

TWDB files had sufficient water-level data to construct long-term hydrographs for the Choza Formation (fig. 6a, b), alluvium (fig. 6c), and the Antlers Formation (fig. 6d). These hydrographs show similar patterns of water-level fluctuations that are likely due to long-term variations in recharge to the aquifers (fig. 6).

Depths to water vary from formation to formation and vary spatially within formations. Two wells in the Vale Formation were 124 and 58 ft deep with depth to water of 27 and 4.5 ft, respectively. Depth to water in the Cretaceous varied from 2 to 197 ft with well depths ranging from 15 to 294 ft. Wells measured in the Antlers Formation near Camp Barkley had depths to water of 100 to 240 ft. A hand-dug well in the southern, low-lying part of Camp Barkley (completed in alluvium/colluvium and the Vale or Choza Formation) had a water level 32 ft below land surface in 1971.

We will measure the water level in the Vale Formation on the camp when we complete our drilling program. At that time, we will construct water-level maps for the Camp Barkley area.

Preliminary Conceptual Flow Model

Rainfall percolates into the ground and recharges water-bearing units beneath Camp Barkley. This recharge most likely occurs through preferential flow paths consisting of vertically interconnected fractures. The rainfall that percolates into the Fredricksburg Group that caps the camp mesas travels to the water table and moves laterally to discharge points on the perimeters of the mesas. Part of the water moves from the Fredricksburg Group into the underlying Antlers Formation and then discharges to the perimeter of the mesas. There may also be minor amounts of water transferred from the Antlers Formation into the underlying Permian strata. Some ground water might migrate from off site into the camp through the Fredricksburg Group and the Antlers Formation from the west.

Water that exits the Fredricksburg Group and Antlers Formation either discharges through seeps and minor springs or moves into permeable colluvium created by the erosion of the mesa cliffs. A small part of the water moves into the Vale formation where it is either lost by evapotranspiration or discharges into local topographic lows.

BEG will test and sample formations underlying Camp Barkley to further constrain the conceptual model and quantify formation properties.

Drilling

The BEG drilled one well at Camp Barkley and will incorporate data from this and nearby wells into our studies. The use of existing wells around the camp saves costs because we do not need to construct deep and expensive wells. We have permission from landowners to test and sample nearby wells located to the south-east and north-west of the camp. These wells are completed in the Antlers Formation and in the colluvium along the mesa perimeter. We drilled our well in the Vale Formation near the camp entrance because there are no nearby wells in the Vale Formation, and there is little known about this formation in Taylor County.

SURFACE WATER

Principal Streams and Drainage Basins

Camp Barkley resides in the Clear Fork River Basin (TDWR, 1984) which is part of the Brazos River basin (zone 2) (TDWR, 1983). Surface water on the camp moves into first order tributaries of the Elm Creek and Little Elm Creek drainage basin. Runoff in the south and north-east areas of the camp feeds into local intermittent creeks that connect into intermittent Elm Creek. Runoff on the north-west side of the camp feeds into local intermittent creeks that connect into intermittent Little Elm Creek. These creeks flow to the north-east, through Abilene, into Lake Fort Phantom Hill, into Clear Fork Brazos River, and into the Brazos River. Drainage is dentritic. Channel slopes are steeper where streams run from the mesas into the surrounding lowlands. Camp activities such as road construction have altered drainage on the camp. For example, the entrance road leading up the mesa has directed runoff along the sides of the road leading to erosional and perhaps shortening the path of water into small streams.

Watersheds were delineated for Camp Barkley (fig. 7) 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).

Flow duration and Flood Frequency

There are no stream gauges on Camp Barkley. However, there are two gauges nearby on Elm and Little Elm Creek which accept discharge from low order creeks that drain the camp. Elm and Little Elm Creek are intermittent streams with flows as high as 1600 and 900 cubic feet per second (cfs), respectively (figs. 8a and 9a). There is no flow in Elm Creek 45 percent of the time and no flow in Little Elm Creek 80 percent of the time (figs. 8b and 9b). Using a log Pearson Type III fit to the annual maxima series, there is a 50 percent chance of having an annual flood greater than 400 cfs in Elm Creek (fig. 8c) and a 50 percent chance of having an annual flood greater than 185 cfs in Little Elm Creek (fig. 9c).

CAMP BOWIE

HYDROGEOLOGIC ANALYSIS

Surface Geology and Hydrostratigraphy

Cretaceous and Pennsylvanian System rocks crop out on Camp Bowie. The lower elevations of the camp consist of the Strawn Group, which includes shale, limestone, and sandstone with channel-fill deposits of gravel, sand, and clay (Thompson, 1967). The shale erodes easily and the sandstone occurs in several-hundred-ft wide lenses that were part of a Pennsylvanian delta system (Nance and Wermund, 1993). Usable and producable ground water would have to be attained from the Strawn Group in these sandstone lenses. Cretaceous System rocks unconformably overlie the Strawn Group on Camp Bowie. These Cretaceous rocks consist of the Travis Peak Formation, which contains, from bottom to top, conglomerate, sandstone, and limestone in the camp area (Nance and Wermund, 1993). The conglomerate consists of pebbles and small cobbles as much as 4 inches in diameter and ranges from <1 ft to ~50 ft in thickness.

More recent deposits consist of alluvium and colluvium due to erosion of the Cretaceous and Pennsylvanian rocks. These deposits are on hilltops, slopes, and on terraces and in floodplains of modern streams.

The principal aquifers in Brown County are the sands of the Trinity Group which include the Twin Mountains Formation. About 63 percent of the wells listed with the Texas Water Development Board (TWDB) are completed in the Trinity Group with about 6 percent specifically listed as completed in the Twin Mountains Formation. About 10 percent of the wells listed with the Texas Water Development Board (TWDB) are completed in the Strawn group, and less than 1 percent of the wells is completed in alluvium.

Water-well Inventory

Archeological reports, TWDB records, Mr. James Hillegas, and a field survey of the camp grounds provided information for locating wells on Camp Bowie. We found 13 wells or well sites during our survey (fig. 10).

- **CBW-B001** is an operational deep well that the camp uses sometimes for supplying water for training. The well is located near an empty house near a large pond. We were not able to measure the well due to a large wasp nest at the well head but plan to visit again to determine depth and water level of the well.
- **CBW-B002** is a 5-inch diameter drilled well with a measured depth of 197.7 ft and a water-level of 10.9 ft below land surface. The casing consists of PVC and sets 0.5 ft above grade. The borehole is open and uncovered.
- **CBW-B003** is a 4-inch diameter drilled well with an unknown depth and a water-level of 61.8 ft below land surface. We were unable to measure the depth because of production pipe in and welded cap on the well. The casing sets 0.8 ft above grade. A small shed houses the well and pump assembly.
- **CBW-B004** is a 5.25-inch diameter drilled well with a measured depth of 77.5 ft and a water-level of 72.6 ft below land surface. The casing consists of black plastic and sets 0.7 ft above grade. The borehole is open and uncovered.
- **CBW-B005** has a windmill with no access to the wellbore for measurements.
- **CBW-B006** has a windmill with no access to the wellbore for measurements.
- **CBW-B007** is a 5-inch diameter drilled well with a measured depth of 116.3 ft and a water-level of 77.1 ft below land surface. The casing consists of black plastic and sets level with grade. The borehole is open and covered with a large rock.
- **CBW-B008** is a hand-dug well located in the mid-south-eastern part of the camp. The well has a diameter of 21 inches with a stone crown that sticks up 1.58 ft from ground surface. The well is 11.4 ft deep with a depth to water of 7.0 ft. The sides of the well consist of stone at least to water level and probably to depth. The cistern is uncovered and holds water with a clear appearance.

- **CBW-B009** has a windmill with no access to the wellbore for measurements. There is an obstruction about 26 ft down the well annulus.
- **CBW-B010** is a hand-dug well located in the north-eastern part of the camp. The well has a diameter of 2.5 ft with a stone crown that sticks up 1.62 ft from ground surface. The well is 10.5 ft deep with a depth to water of 7.0 ft. The sides of the well consist of stone at least to water level and probably to depth. The well is uncovered and holds water with a murky appearance.
- **CBW-B011** is a hand-dug, bell-shaped cistern located in the north-east-central part of the camp. The well has a diameter of 3.0 ft with a stone crown that sticks up 0.88 ft from ground surface. The well is 9.1 ft deep with a depth to water of 8.0 ft. The sides of the well consist of mortared stone at least to water level and probably to depth. The well is uncovered.
- **CBW-B012** is a hand-dug well located in the eastern part of the camp. The well has a diameter of 3.0 ft with a stone crown that is at grade. The well is 21.3 ft deep and holds no water. The sides of the well consist of ungrouted stone, and a concrete slab covers the wellbore.
- **CBW-B013** is a 4.88-inch diameter drilled well with a measured depth greater than 200 ft and a water-level of 11.9 ft below land surface. The casing consists of PVC and sticks up 1.4 ft above land surface. The borehole is open and covered with a well cap.

The cultural resources staff of the Adjutant General's Department report one other location as a possible well site (William R. Furr, personal communication, 1995). However, we were not able to locate a well or cistern at this site. It is possible that these wells have been filled since the archeological survey. This site is 41BR418 and apparently has a well pipe and filled cistern. We will visit this site again for a more thorough investigation.

The TWDB reports three other wells within camp boundaries in the newly annexed property to the south. We did not find these wells during our survey and plan a more thorough search in the near future.

Hydraulic Properties

There are no pumping tests reported in wells in the Strawn Group or the Travis Peak Formation in Taylor County. The only reported aquifer tests are several well yield tests and a specific capacity test in the Travis Peak Formation. Well yields in the Travis

Peak formation range from 10 to 196 gpm with a geometric mean of 43 gpm. The sole specific capacity test in the Travis Peak Formation had a result of 117 $ft^2\ d^{-1}$ which corresponds to a transmissivity of 820 $ft^2\ d^{-1}$ using the method of Razack and Huntley (1991). Well yields in the Strawn are generally less than 20 gpm (Thompson, 1967).

The BEG plans to conduct aquifer tests in pre-existing wells likely completed in the Travis Peak Formation on the camp and in several hand-dug wells completed in the Strawn Group. We will also test two wells we plan to drill in the Travis Peak Formation and the Strawn Group. We will report test results in subsequent reports.

Water Chemistry

Each of the formations has water quality assessments reported in the TWDB files (Table 2). The alluvium has three measures of total dissolved solids (TDS): 589, 759, and 596 mg l^{-1}, all of which are fresh (TDS < 1000 mg l^{-1}) (fig. 11a). TDS for the Travis Peak Formation range from 420 to 1247 mg l^{-1} with a geometric mean of 708 mg l^{-1} (fig. 11b). A total of 22 percent of the samples is brackish (1000 mg l^{-1} < TDS < 10,000 mg l^{-1}). TDS in the Strawn Group range from 104 to 4750 mg l^{-1} with a geometric mean of 955 mg l^{-1} (fig. 11c). Many of the samples (43 percent) are brackish.

Waters from the alluvium are predominantly calcium-bicarbonate type (fig. 12a). Waters from the Travis Peak Formation are mixed with calcium-bicarbonate waters, sodium-chloride waters, and some waters with no dominant cation or anion composition (fig. 12b). Waters from the Strawn Group are also mixed with magnesium- and calcium-bicarbonate waters, sodium-chloride waters, and many waters with no dominant cation or anion composition (fig. 13).

The BEG will sample and analyze waters from the Travis Peak Formation and the Strawn Group on Camp Bowie to attain more sight specific water chemistry data. We will report results in subsequent reports.

Water Levels

TWDB files had sufficient water-level data to construct long-term hydrographs for the Travis Peak Formation (fig. 14). These hydrographs show similar patterns of water-level fluctuations that are likely due to long-term variations in recharge to the aquifers. Well 41-09-303 is located 11 miles north-east of Brownwood about 1 mile from the edge of the Cretaceous outcrop and shows water-level highstands during 1970 to 1977, 1985 to 1989, and 1993 to present and lowstands during 1963 to 1969, 1979 to 1984, and 1990 to 1991 (fig. 14a). Well 41-18-650 is located near Zephyr (east of Brownwood) and is about 3 miles from the outcrop. Water levels in this well are generally similar to well 41-09-303 but are generally lower from 1980 to 1991 (fig. 14b). Well 41-18-303 is north east of Zephyr and 5 miles from the outcrop and has water-level highstands during the early seventies and mid-nineties (fig. 14c). Well 41-18-205 is north west of Zephyr and 2 miles from the outcrop (fig. 14d).

Depths to water vary from formation to formation and vary spatially within formations. Two pre-existing wells on the camp are 78 and 116 ft deep with depths to water of 72.5 and 77 ft, respectively. These wells are likely completed in the Travis Peak, though it is unclear if they are completed within the sandstone intervals. Another well on the camp is about 200 ft deep with a water level 11 ft below land surface. This well likely extends through the entire Cretaceous section in this area. Water levels measured in shallow wells in the Strawn Group range from 7 to 10 ft below land surface.

Preliminary Conceptual Flow Model

Rainfall percolates into the ground and recharges water-bearing units beneath Camp Bowie. This most likely occurs through fractures in the limestone caps on the mesas. Greater amounts of recharge occur on topographic highs of the Cretaceous rocks and sandy areas of the Strawn Group. Ground water moves from topographic highs toward small and large scale topographic lows primarily at the edges of the Cretaceous escarpment. Some of the water circulates deeper into the subsurface and crosses into the underlying Strawn Group perhaps ultimately discharging to Pecan Bayou to the east and Indian Creek to the west. Water that exits the Travis Peak Formation either discharges through seeps and minor springs or moves into permeable colluvium created by the erosion of the escarpment.

BEG efforts to test and sample formations underlying Camp Bowie will further constrain the conceptual model and quantify formation properties.

Drilling

Camp Bowie has a large number of wells that can be used for testing. Unfortunately, the TWDB database only includes one of these wells: a partially collapsed hand-dug well. Many of the drilled wells in the Cretaceous section are probably completed in the sandy sections of the Travis Peak, but this is uncertain because of the lack of well information. Without screen interval information, we cannot determine hydraulic conductivity. There are two wells in the Strawn Group, but these are hand-dug wells with limited penetration and questionable water quality. Although the pre-existing wells are not ideal for our studies, these wells are still an important source of additional hydrogeologic information that will be incorporated into our studies.

We will drill two wells on Camp Bowie: one in the Travis Peak Formation and another in the Strawn Group. A well drilled in the Travis Peak Formation near the escarpment will allow us to measure an important water level near the edge of the Cretaceous outcrop and sample water chemistry near a discharge point from the formation. A well drilled in the Strawn Group will assure good quality physical and chemical data that will nicely compliment any samples collected from the hand-dug wells on the camp.

SURFACE WATER

Principal Streams and Drainage Basins

Camp Bowie resides in the Pecan Bayou drainage (TDWR, 1984) basin which drains into the Colorado River basin (zone 2) (TDWR, 1983). Surface water on the camp moves into first order tributaries of the Pecan Bayou drainage basin. Runoff on the north-west side of the camp feeds into local intermittent creeks that connect into intermittent Willis Creek to the north. Runoff in the north-central area of the camp feeds into Lewis Creek which drains north-east into Pecan Bayou and an unnamed creek which drains east and then south into Pecan Bayou. Runoff in the south-central area of the camp feeds into Devils River which drains east into the Pecan Bayou. Drainage in the southern part of the camp is into Mackinally Creek just south of the camp and an unnamed creek.

Watersheds were delineated for Camp Bowie (fig. 15) 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).

Flow duration and Flood Frequency

There are no stream gauges on Camp Bowie. However, there are two gauges nearby on WID No. 1 Canal near Brownwood and on the Colorado River near Winchell. WID No. 1 Canal and the Colorado River have flows as high as 70 and 58,000 cubic feet per second (cfs), respectively (figs. 16a and 17a). There is flow in WID No. 1 Canal most of the time and flow in the Colorado River 95 percent of the time (figs. 16b and 17b). Using a log Pearson Type III fit to the annual maxima series, there is a 50 percent chance of having an annual flood greater than 62 cfs in WID No. 1 Canal (fig. 16c) and a 50 percent chance of having an annual flood greater than 8700 cfs in the Colorado River (fig. 17c).

CAMP MABRY

HYDROGEOLOGIC ANALYSIS

Surface Geology and Hydrostratigraphy

Camp Mabry is geologically complex. The camp has six formations that crop out within the camp boundaries and crosses several faults associated with the Balcones Fault Zone. Wermund and Avakian (1994) describe the geology and physical environment of Camp Mabry in detail. The formations that crop out on Camp Mabry are all Cretaceous and are, oldest to youngest, (1) the upper member of the Edwards Limestone (member 4), (2) the Georgetown Formation, (3) the Del Rio Clay, (4) the Buda Formation, (5) the Eagle Ford Group, and (6) the Atco Formation of the Austin Group.

The upper member of the Edwards Limestone (member 4) is 40 ft thick and consists mostly of gray to tan, micritic, thin- to thick-bedded limestone, dolomitic limestone, and dolomite and does not have a sharp contact with the overlying Georgetown Formation. This member of the Edwards Limestone is relatively resistant to weathering, solution, and erosion.

The Georgetown Formation consists of thin interbeds of gray to tan, nodular weathering, hard, finegrain limestone, marly limestone, and marl. The formation is difficult to excavate, forms a stable foundation, and has a low infiltration capacity. This formation outcrops in the three southwest-flowing stream valleys that cross 35th street.

The Del Rio clay is common at Camp Mabry and consists of dark to light brown, gypsiferous, pryritic clays. The Del Rio clay has a high plasticity index, low bearing capacity, and high shrink-swell properties. The unit has low infiltration capacity and behaves as an aquitard.

The Buda limestone is a gray to tan, hard, fine-grained, glauconitic limestone and is generally strongly jointed. The lower Buda is somewhat less resistant than the upper part and weathers into nodular structures. In outcrop, fresh surfaces are yellowish to pink. Infiltration capacity of the Buda limestone is low.

The upper part of the Eagle Ford Formation consists of dark gray clay with the middle part having thin interbeds of sandy and flaggy limestone, chalk, clay, and bentonite, and the lower part holding gray calcareous clay. The bearing capacity of the formation is generally low, local areas have high shrink-swell properties, and infiltration capacity is low to moderate.

The Atco Formation of the Austin Chalk Group (lower unit) is a gray to white, thin- to thick-bedded, massive to slightly nodular, fine-grained limestone, marly limestone, and chalk. Bearing capacity is high and infiltration capacity is moderate and a function of fracture density.

Two major aquifers underlie Camp Mabry: the Trinity and the Edwards and associated limestones. The Trinity consists of, from oldest to youngest, the Travis Peak Formation, the Glen Rose Formation, and the Paluxy Formation. Brune and Duffin (1983) divided the Trinity into three hydrostratigraphic units: (1) the lower Trinity aquifer, which consists of the Sligo and Hosston members of the Travis Peak Formation; (2) the middle Trinity aquifer, which consists of the lower member of the Glen Rose Formation and the Hensell Sand and Cow Creek Limestone Members of the Travis Peak Formation; and (3) the upper Trinity aquifer which consists of the upper member of the Glen Rose Formation and the Paluxy Formation. Sands compose the water-bearing units of the Trinity.

The Trinity aquifers all crop out west of Camp Mabry. The lower Trinity is approximately 1700 to 2000 ft beneath Camp Mabry, and is about 1000 ft thick. The lower Trinity yields small to moderate amounts of water and can yield large amounts of water if wells are acidized. The middle Trinity is approximately 1100 to 1400 ft beneath Camp Mabry, is about 500 ft thick, and yields small to moderate amounts of water. The upper Trinity is approximately 550 to 800 ft beneath Camp Mabry, is about 610 ft thick, and yields very small to moderate amounts of water.

The Edwards and associated limestones is the only principal aquifer in Travis County (Brune and Duffin, 1983) exposed on Camp Mabry. The Edwards and associated limestones consist of the Comanche Peak Limestone, Edwards Limestone, Kiamichi Limestone, and the Georgetown Formation. Dissolution zones in the Edwards Limestone, especially the Kirschberg which lies about half-way down from the top of the Edwards, are the main water-bearing zones. The Edwards Limestone and the Georgetown Formation crop out on Camp Mabry with depth to the Kirschberg about 120 to 180 ft.

Water-well Inventory

We found no pre-existing wells on Camp Mabry. Operations Technologies Corporation (1995) report that a hand-dug well was located at the Old Deison homestead (fig. 18). This well is beneath the military parking lot of building 75 and has since been filled and paved over. This well probably sourced its water from the weathered Eagle Ford or Austin Groups and is near a small fault. We found a small, diffuse spring in Taylor Creek a few hundred feet up from a small pond near the contact of the Del Rio Clay and the

Georgetown Formation. This spring was discharging approximately 2 gpm in November 1995.

Hydraulic Properties

Texas Water Development Board (TWDB) files contain limited information on hydraulic properties of the formations that crop out and underlie Camp Mabry. Where possible, we include information studies performed in other areas.

The Trinity Group aquifer has well yields that range from 5 to 800 gpm with a geometric mean of 23 gpm (fig. 19c) and specific capacities that range from 6.7 to 280 ft^2 d^{-1} with a geometric mean of 60 ft^2 d^{-1} (fig. 19d). Using the method of Thomasson and others (1960), this specific capacity corresponds to a transmissivity of 72 ft^2 d^{-1}. Hydraulic conductivity and transmissivity in the Trinity Group aquifer range from 0.6 to 4.3 ft d^{-1} and 0 to 670 ft^2 d^{-1}, respectively (Brune and Duffin, 1983).

The Edwards and associated limestones has well yields that range from 3 to 1150 gpm with a geometric mean of 46 gpm (fig. 19a) and specific capacities that range from 30 to 55,000 ft^2 d^{-1} with a geometric mean of 660 ft^2 d^{-1} (fig. 19b). Using the method of Mace (1995), this specific capacity corresponds to a transmissivity of 570 ft^2 d^{-1}. Hydraulic conductivity and transmissivity in the Edwards range from 1.2 to 117 ft d^{-1} and 53 to 40,000 ft^2 d^{-1}, respectively, based on three pump tests in the area (Brune and Duffin, 1983). Transmissivity in the San Antonio segment of the Edwards aquifer ranges from 0.28 to 19,000,000 ft^2 d^{-1} (Mace, 1995; Hovorka and others, 1995).

The TWDB files contain no information about the hydraulic properties of the Del Rio clay in Travis County. However, the Del Rio clay should have a very low hydraulic conductivity (< 10^{-3} ft d^{-1}). The Del Rio clay is not known to yield water in Travis County (Brune and Duffin, 1983).

The TWDB files contain no information about the hydraulic properties of the Buda Limestone in Travis County. It is not known to yield water in Travis County (Brune and Duffin, 1983). However, water may move through the weathered zone where there is a greater frequency of fractures.

The TWDB files contain no information about the hydraulic properties of the Eagle Ford Group in Travis County. The Eagle Ford Group is not known to yield water in Travis County (Brune and Duffin, 1983). Bradley (1993) found the hydraulic conductivity of the weathered and unweathered Eagle Ford in the Waco, Texas area to be 0.5 and 3.7×10^{-5} ft d^{-1}, respectively. This large difference in hydraulic conductivity is due to near surface fracturing owing to unloading and weathering. Dutton and other (1994) reported hydraulic conductivities of 1.7 x 10^{-3} ft d^{-1} in the unweathered Eagle Ford Formation near Waxahachie, Texas.

The Austin Chalk Group has three measured well yields in Travis County, 10, 30, and 250 gpm, and a single measure of specific capacity, 2880 ft^2 d^{-1}. The high values of well yield and specific capacity are likely uncommon because the Austin Chalk has low permeability unless fractured due to weathering and unloading or faulting. Hydraulic conductivity measured in 37 hand-dug wells in Austin Chalk outside Waxahachie, Texas ranged from 10^{-3} to 100 ft d^{-1} with values decreasing exponentially with depth (Mace and Dutton, 1994). The Austin Chalk yields small to very small quantities of ground water in Travis County (Brune and Duffin, 1983).

The BEG has completed a well in the Edwards Formation on Camp Mabry and plans to conduct aquifer tests to better quantify hydraulic properties. We will report these values in subsequent reports.

Water Chemistry

TWDB files contain substantial water chemistry data for the Austin Chalk, the Edwards and associated limestones, the Glen Rose Formation, and the Hosston Member (Lower Trinity) (Table 3) but no data for the Eagle Ford Group, Buda Limestone, or the Del Rio Clay. The Edwards and associated limestones include the Georgetown Formation.

Total dissolved solids (TDS) for the Austin Chalk range from 148 to 798 mg l^{-1} with a geometric mean of 380 mg l^{-1} (fig. 20a). All collected water samples were fresh (TDS < 1000 mg l^{-1}). TDS for the Edwards and associated limestones range from 118 to 10,195 mg l^{-1} with a geometric mean of 417 mg l^{-1} (fig. 20b). A total of 94 percent of the collected water samples was fresh with the remainder brackish (1000 mg l^{-1} < TDS < 10,000 mg l^{-1}) and one saline (10,000 mg l^{-1} < TDS < 10,000 mg l^{-1}) sample. TDS for the Glen Rose Formation range from 179 to 7211 mg l^{-1} with a geometric mean of 813 mg l^{-1} (fig. 20c). A total of 61 percent of the collected water samples was fresh with the remainder brackish. TDS for the Hosston Member (Lower Trinity) range from 239 to 5180 mg l^{-1} with a geometric mean of 1023 mg l^{-1} (fig. 20d). A total of 53 percent of the collected water samples was fresh with the remainder brackish.

Waters from the Austin Chalk are calcium-bicarbonate in composition (fig. 21a). Waters from the Edwards and associated limestones are also predominantly calcium-bicarbonate in composition (fig. 21b) though some waters have a strong presence of sodium and chloride. Waters from the Glen Rose Formation are a mixed calcium-bicarbonate and magnesium-sulfate type with some sodium-chloride type waters (fig. 22a).

As in the Glen Rose Formation, waters from the Hosston Member (Lower Trinity) are a mixed calcium-bicarbonate and magnesium-sulfate type with some sodium-chloride type waters (fig. 22b).

The BEG will sample and analyze waters from the Edwards Limestone and possibly the Austin Chalk to attain more site-specific data. We will report results in subsequent reports.

Water Levels

Hydrographs show how water levels vary through time in Travis County. Long term water-level data were available through TWDB files for the Hosston Member (fig. 23a, b), the Edwards and associated limestones (fig. 23c, d), and the Austin Chalk (fig. 24a, b). Water levels in the Hosston Member have declined about 150 ft since 1950 (fig. 23a, b) probably due to ground-water production from the aquifer. Water levels in the Hosston Member have rebounded since 1986 (fig. 23b). Recharge events appear to affect water levels in the Hosston Formation as shown by slight increases in water-level elevation. The timing of increases and decreases in water-level elevation agree between the two wells from 1973 to 1989 where data density is greatest (fig.23a, b).

The response of water levels in the Edwards Formation to recharge can vary considerably depending on location of the recharge zone as well as connection into major or minor flow paths. Water-levels vary no more than 25 ft in a well (58-42-911) located south of Camp Mabry just south of Town Lake (fig.23c). Water-level vary about 90 ft in a well (58-42-602) located just north-east of Camp Mabry (fig. 23d). This well has greater water-level fluctuations than well 58-42-911. Therefore, well 58-42-602 is in better hydraulic connection with a recharge source than well 58-42-911. Furthermore, large water-level fluctuations suggest that the Edwards Limestone in the area connects to either the outcrop west of the fault zone or to the surface by fractures.

Two wells 0.3 miles apart in the chalk have very different water-level response which is probably due to fracturing associated with the Balcones Fault Zone (fig. 24). Well 58-43-402 has much greater fluctuations (fig. 24b) than well 58-43-502 (fig. 24a). The former is likely located in a fault zone and the latter in the weathered chalk. Mace and Dutton (in press) have observed similar behavior in Austin Chalk in Ellis County south of Dallas.

Water level elevation in the Edwards beneath Camp Mabry is approximately 440 ft (Brune and Duffin, 1983) which is about 120 ft below land surface. A 150 ft deep well drilled into the Edwards on Camp Mabry by the BEG has a water level 100 ft below land surface.

Preliminary Conceptual Flow Model

The conceptual flow model for Camp Mabry is tentative at this point owing to the geologic and hydrogeologic complexity on the camp. In particular, we do not know if the faults are sealed and act as barriers to flow or if the faults are conductive and behave as preferential flow paths to underlying formations. The continuity of hydraulic head in the Edwards Limestone suggests that at depth faults in this formation act as conduits. However, there is evidence that the faults on Camp Mabry do not transmit water. For example, a pond in the south-west part of the camp overlies a fault in contact with the Edwards. If this fault was highly transmissive, then water would not be able to collect at this location.

Under the assumption that the faults do not enhance the permeability of the formations and short circuit water to great depths, most ground-water flow on Camp Mabry is shallowly confined. Rainfall falls onto formation outcrops, and a small percentage percolates into the ground to recharge shallow unconfined water-bearing units. More recharge moves into the subsurface in the weathered zones of the limestones (Austin Chalk, Edwards Limestone, Georgetown Formation, and Buda Limestone) than in the shaley formations (Del Rio Clay and Eagle Ford Formation). This water moves from topographic highs towards topographic lows where it discharges to local creeks and streams. Surface expressions of faults may lead to greater weathering and therefore higher permeability of the formations at shallow depths. This will create anisotropy that will direct water along the orientation of the faults, at least locally. Some of the water may move further into the subsurface into underlying aquifers, though the expected amount is probably small. Preliminary evidence at the Edwards well drilled by the BEG on Camp Mabry suggests a vertical gradient of ground-water flow from the surface into the Kirschburg evaporite deeper into the Edwards Limestone.

BEG efforts to test and sample formations underlying Camp Mabry will further constrain the conceptual model and quantify formation properties.

Drilling

Two wells are proposed for Camp Mabry: one in the Edwards (which has been completed) and another in the Austin Chalk. We drilled a well in the Edwards in the southern portion of the camp because (1) the Edwards is the only major aquifer that outcrops on Camp Mabry, (2) there is a large pond north of the well site (will be able to investigate potential infiltration from the pond into the Edwards), and (3) the southern end of the camp is the presumed "outlet" of ground-water flow in the Edwards beneath the camp. A well is also proposed for the northern part of the camp in the Austin Chalk where permeabilities may be high in the fractured weathered zone.

SURFACE WATER

Principal Streams and Drainage Basins

Camp Mabry resides in the Colorado River basin (zone 3) (TDWR, 1983). Surface water on the camp moves into first order unnamed tributaries to the Colorado River and Johnson Branch. Runoff in the north and west-central areas of the camp feeds into local intermittent creeks that discharge to Lake Austin (Colorado River) near Laguna Gloria. Surface water in the southwest corner of the camp drains into an unnamed intermittent creek that discharges to Town Lake near Reed Park. There are two small ponds along the main drainage that runs through Camp Mabry. Various roads redirect runoff on the camp into the creeks.

Watersheds were delineated for Camp Mabry (fig. 25) 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).

Flow duration and Flood Frequency

There are no stream gauges on Camp Mabry and none near the camp that has data that would be useful in understanding surface water flow on the camp. Therefore, we plan to develop synthetic unit hydrographs for the camp in order to do flood plain analyses.

CAMP MAXEY

HYDROGEOLOGIC ANALYSIS

Surface Geology and Hydrostratigraphy

The Cretaceous Eagle Ford and Bonham Formations crop out on Camp Maxey. The Eagle Ford Formation covers most of the camp with the Bonham Formation cropping out in the south-eastern corner around Lamar Lake. The Eagle Ford Formation consists of shale with calcareous concretions and a few thin beds of sandstone and sandy limestone most abundant near the middle of the formation (Barnes, 1966). The Eagle Ford Formation grades into mostly quartz sand near the Lamar-Red River County line. The Bonham Formation is a greenish-gray marl and clay becoming more sandy eastward that weathers yellowish gray (Barnes, 1966).

The recognized principal aquifers in Lamar County are the Blossom Sand and the Woodbine and Paluxy Formations. About 60 percent of the wells listed with the Texas Water Development Board (TWDB) are completed in the Blossom Sand, which begins to crop out near Paris, Texas. About 14 percent of the wells listed with the TWDB are completed in the Woodbine Formation that is a quartz sand with some thin beds of lignite, volcanic sand, and tuff. The outcrop of the Woodbine Formation straddles the Red River and dips south into the East Texas Basin beneath Camp Maxey. The Woodbine Formation immediately underlies the Eagle Ford Formation and lies 200 to 350 ft below the camp. Only about 4 percent of the wells listed with the TWDB are completed in the Paluxy Formation though this formation is considered a major aquifer farther to the west. The Paluxy is comprised of fine sand, sandy shale, and shale and lies between 1200 to 1350 ft below the camp. The Eagle Ford and Bonham Formations yield small quantities of water to shallow wells and are very limited as aquifers (Nordstrum, 1982).

Water-well Inventory

TWDB records, TNRCC records, Col. Wisely, and a field survey of camp grounds provided information for locating wells on Camp Maxey. We found six wells or well sites on Camp Maxey (fig. 26) during this study.

- **CMX-B001** is hand-dug to a depth of 15.3 ft with water 11 ft below land surface. The casing is made of native stone and sets 0.25 ft above grade. The diameter of the well is 2.5 ft and flares out below surface suggesting that perhaps it used to be a cistern. Water in the well appears murky.

- **CMX-B002** is an old well site where the hand-dug well has been filled. There are remnants of brickwork at the filled well.

- **CMX-B003** is a possible well site that has a thick cement pad that possibly covers an old well.

- **CMX-B004** is an old hand-dug well or cistern filled to about 3 ft from surface. Hole diameter is about 2.5 ft with no casing or crown.

- **CMX-B005** is an old hand-dug well or cistern that has caved in to 12 ft below land surface. The diameter of the well is 2.5 ft with stone casing that is at grade.
- **CMX-B006** is an old hand-dug well or cistern that is 15 ft deep with water 8 ft below land surface. The diameter of the well is 2.5 ft with casing made of native stone that rises 1.2 ft above grade. Water in the well appears murky.

Hydraulic Properties

There are no pumping tests reported in the Paluxy, Woodbine, Eagle Ford, and Bonham Formations in Lamar County. However, there are reported values from other areas and limited well yield tests. Mace and others (1994) report transmissivity in the Paluxy Formation just west of Lamar County to range from 170 to 1,900 $ft^2\ d^{-1}$ with a geometric mean of 600 $ft^2\ d^{-1}$ based on 36 aquifer tests and storativity to range from 4.0 x 10^{-5} (confined) to 0.02 (confined/unconfined transition). Nordstrum (1982) reports that hydraulic conductivity of the Woodbine formation ranges between 0.8 and 20 ft d^{-1} with a mean of 7 ft d^{-1}. Mace and others (1994) report transmissivity in the Woodbine Formation just west of Lamar County to range from 45 to 3,500 $ft^2\ d^{-1}$ with a geometric mean of 400 $ft^2\ d^{-1}$ based on 36 aquifer tests and confined storativity to range from 2.0 x 10^{-5} to 7.1 x 10^{-4}. Nordstrum (1982) reports that hydraulic conductivity of the Woodbine formation ranges between 11 and 22 ft d^{-1} with a mean of 6 ft d^{-1}. Reported yields from the Woodbine Formation in Lamar County range from 10 to 100 gpm.

There are no aquifer tests reported in the Eagle Ford Formation in Lamar County. However, there are studies located elsewhere in the formation. Bradley (1993) found the hydraulic conductivity of the weathered and unweathered Eagle Ford in the Waco, Texas area to be 0.5 and 3.7 x 10^{-5} ft d^{-1}, respectively. This large difference in hydraulic conductivity is due to near surface fracturing owing to unloading and weathering. However, the Eagle Ford in the Waco area does not include the many sand stringers in the Eagle Ford evident on Camp Maxey. Dutton and other (1994) reported hydraulic conductivities of 1.7 x 10^{-3} ft d^{-1} in the unweathered Eagle Ford Formation near Waxahachie, Texas. Again, the Eagle Ford Formation in this area is not sandy as it is on the camp and therefore permeability may be locally much higher. The only aquifer test data reported for the Bonham Formation are three well yields (6, 6, 10 gpm) for the undifferentiated Austin Chalk Group.

The BEG has completed two wells, one in the Bonham Formation and the other in the Eagle Ford Formation and plans to conduct aquifer tests in these wells to better quantify hydraulic properties in these formations. We will report these values in subsequent reports.

Water Chemistry

TWDB files have limited water quality data for each of the formations of interest (table 4). Total dissolved solids (TDS) for the Paluxy Formation has a wide range of values from a value at 391 mg l^{-1} to three values between 1044 and 1241 mg l^{-1}. This range likely reflects the change in water facies from fresh water in the north to slightly saline water in the south. The Paluxy Formation beneath Camp Maxey probably holds the fresher water. This transition occurs 15 miles south of Paris, Texas (Nordstrum, 1982). TDS for the Woodbine Formation ranged from three values between 219 and 463 mg l^{-1} to a value at 1010 mg l^{-1}. Ground water is fresh in the north-western part of the county and slightly saline values in the south and south-east across a transition that cuts through Paris (Nordstrum, 1982). Solitary values of TDS exist for the Eagle Ford Formation and the Austin Chalk Group: 242 and 602 mg l^{-1}, respectively. These values come from relatively shallow wells completed in the formations.

Waters from the Paluxy Formation have a sodium-bicarbonate composition (fig. 27). Waters from the Woodbine Formation are chloride waters with no dominant cation type with the exception of one sample that has a sodium-bicarbonate composition similar to waters from the Paluxy Formation (fig. 27). Waters from the Eagle Ford Formation have a sodium-bicarbonate composition based on a single sample (fig. 27). Waters from the Austin Chalk Group have a calcium-sulfate composition based on a single sample (fig. 27).

The BEG will sample and analyze waters from the Eagle Ford and Bonham Formations on Camp Maxey to attain additional and more site-specific data. We will report results in subsequent reports.

Water Levels

TWDB board files had sufficient water-level data to construct long-term hydrographs for the Woodbine Formation (fig. 28 a, b), the Paluxy Formation (fig. 28c), and the Eagle Ford Formation (fig. 28d). These hydrographs show dissimilar patterns of water-level fluctuations that are likely due to proximity of the well to the outcrop and to pumping centers. Two wells in the Woodbine Formation show very different patterns of water-level fluctuation (fig. 28 a, b). Well 17-27-201, located in Brookston 6 miles west of Paris, had a decline in water level of nearly 60 ft between 1965 and 1982 and then recovered almost 50 ft from 1982 to 1991 before water levels dropped again (fig. 28a). Because this well is so far from the outcrop of the Woodbine Formation (18 miles), we believe these fluctuations are due to changes in water production from the well or from other wells in the area. It is also possible that there is regional influence from large withdrawals from the Woodbine Formation further east of the county where water levels have dropped as much as 400 ft since the turn of the century (Mace and others, 1994). The other well completed in the Woodbine Formation, 17-12-101, is located on the north side of Pat Mayse Lake and is only a few miles from the Woodbine outcrop. Water level in this well has been relatively stable since 1960 (fig. 28b) probably owing to the confined nature of the aquifer and lack of substantial pumping from the Woodbine Formation in this area. The water-level elevation of the Woodbine Formation beneath Camp Maxey is about 400 ft.

A well drilled into the Paluxy Formation, 17-29-601, near Pattonville 8 miles south-east of Paris shows a steady decline in water level since measurements began in the well in 1971 (fig. 28c). This steady decline in water level is due to the production of ground water from the aquifer locally and perhaps regionally where declines as large as 450 ft have been recorded (Mace and others, 1994). There is no information on the elevation of the water level of the Paluxy Formation beneath Camp Maxey.

Water levels appear somewhat stable in an Eagle Ford Formation well, 17-10-801, located in the north-west part of the county 12 miles west of the camp with less than 10 ft fluctuations (fig. 28d). This household well is 104 ft deep and likely taps into a sand stringer that behaves as a confined aquifer. Two shallow (~16 ft deep) hand-dug wells in the Eagle Ford Formation on Camp Maxey have depths to water of 8 to 11 ft.

We will measure water level fluctuations in the Bonham and Eagle Ford Formation on the camp when we complete our drilling program. We will construct water-level maps for the Camp Maxey area after we measure water levels in these wells.

Preliminary Conceptual Flow Model

Rainfall falls onto the Eagle Ford and Bonham outcrops, and a small percentage percolates into the ground to recharge shallow unconfined water-bearing units. Recharge to the aquifer is greater in higher elevations and in sandier patches of the outcrop. This water moves from topographic highs towards topographic lows where it discharges to local creeks and streams. Some of the flow follows longer flow paths and discharges into locally major topographic lows such as Pat Mayse Lake to the north and Hicks and Pine Creeks to the south. A small amount of flow may discharge from the Eagle Ford Formation into the underlying Woodbine Formation.

BEG efforts to test and sample formations underlying Camp Maxey will further constrain the conceptual model and quantify formation properties.

Drilling

The BEG has drilled two wells at Camp Maxey along a transect that incorporates a preexisting hand-dug well on the camp. The use of this existing well will reduce costs because we do not need to construct deep another well. One of the newly drilled wells is in the Bonham and the other is in the Eagle Ford Formation. Both of these wells are about 50 ft deep. These two wells will help us characterize the Eagle Ford and Bonham Formations.

SURFACE WATER

Principal Streams and Drainage Basins

Camp Maxey drains into the Lower Red River Basin (TDWR, 1984) which is part of the Red River basin (zone 3) (TDWR, 1983). Surface water on the camp moves into first order tributaries of the Pine Creek and the Sanders Creek (Pat Mayse Lake) drainage basins. Runoff in the north and south-west areas of the camp feeds into local intermittent creeks that drain north into Pat Mayse Lake. The lake feeds Sanders Creek which empties into the Red River to the north. Runoff on the south-east side of the camp feeds into local intermittent creeks that connect into intermittent Hicks Creek. Hicks Creek empties into Pine Creek which empties into the Red River near the very north-east corner of Lamar County.

Watersheds were delineated for Camp Maxey (fig. 29) by tracing surface water catchments on USGS 7.5 minute topographic maps. This method involves tracing surface water divides and backtracking flows lines from subwatershed collection points.

Flow duration and Flood Frequency

There are no stream gauges on Camp Maxey and none near the camp that has data that would be useful in understanding surface water flow on the camp. Therefore, we plan to develop synthetic unit hydrographs for the camp in order to do flood plain analyses.

CAMP SWIFT

HYDROGEOLOGIC ANALYSIS

Surface Geology and Hydrostratigraphy

The Calvert Bluff Formation and creek alluvium underlie Camp Swift. The Calvert Bluff Formation is the upper formation of the Wilcox Group which also consists of the

Hooper Formation (lower) and the Simsboro Formation (middle). The Calvert Bluff Formation consists of weakly to moderately consolidated, massive to thin bedded, clayey, fine- to very fine grained sandstone, siltstone, and claystone (Avakian and Wermund, 1993). The formation varies from light grey in sandy units to brown in muddy units and typically weathers yellowish-brown to red. Lignite beds and ironstone concretions are common in the lower 200 ft but also occur less commonly higher in the formation. Beneath Camp Swift, the thickness of the Calvert Bluff Formation ranges from as little as 25 ft near the Sayersville Fault to as much as 500 ft beneath the southwestern edge of Camp Swift (Gaylord and others, 1985, fig 2.3-3). The Calvert Bluff Formation is sandier in the northern reaches and a few small areas in the southern part of the camp (Henry and Basciano, 1979).

Unconsolidated alluvium and colluvium underlie stream valleys and form thin veneers on upland surfaces north of Sandy Creek (Avakian and Wermund, 1993). Principal locations of alluvium are along Big Sandy Creek, McLaughlin Creek, and Dogwood Branch. Stream-valley alluvium consists of interbedded clay, silt, and sand with varying amounts of gravel. The veneers on the upland surfaces are part of the soil profile and contain abundant pebbles and cobbles of petrified wood, quartzite, and other siliceous rocks.

Follett (1970) recognized the Wilcox Group as the most important water bearing formation in Bastrop County. However, the Simsboro and Hooper Formations are the main water-producing intervals in the Wilcox Group, both of which underlie Camp Swift. The Simsboro Formation consists mostly of weakly to slightly consolidated, cross-bedded kaolinitic quartz sandstone with some siltstone and claystone (Avakian and Wermund, 1993). The Hooper Formation consists of mudstone, sand, and sandstone with a few thin and discontinuous beds of lignite (Avakian and Wermund, 1993).

Water-well Inventory

Archeological reports, TWDB records, Sgt. West, and a field survey of camp grounds provided information for locating wells on Camp Swift. We located 7 wells or well sites during our survey and identified 8 other potential sites that may have a well we could not find or has a filled well (fig. 30).

- **CSW-B001** is a 4-inch diameter drilled well with a measured depth of >200 ft and a water-level of 109 ft below land surface. The casing is made of PVC and sets 1.00 ft above grade. The well is located within a small fenced area and does not have a locking well vault. The wellbore has a very crooked appearance which made it difficult to measure. The USGS drilled this well to assess the local geology and measure selected hydrogeologic properties of the Wilcox Group as related to potential lignite mining on Camp Swift (Gaylord and others, 1984). At completion, this well (USGS# C-12, TWDB# 58-54-303) was 220 ft deep and completed in the basal part of the Calvert Bluff Formation with screen from 200 to 220 ft.

- **CSW-B002** is a 4-inch diameter drilled well with a measured depth of 72 ft and a water-level of 66.2 ft below land surface. The casing is made of PVC and sets 0.5 ft above grade. The well is located within a small fenced area 50 ft south of CSW-B001 and does not have a locking well vault. The USGS drilled this well to assess the local geology and measure selected hydrogeologic properties of the Wilcox Group as related to potential lignite mining on Camp Swift (Gaylord and others, 1984). At completion, this well (USGS# C-13, TWDB# 58-54-304) was 330 ft deep and completed in the upper part of the Simsboro Formation with screen from 250 to 330 ft. Our depth measurement suggests that this well may have caved from 75 to 330 ft or there is an obstruction in the well.

- **CSW-B003** is a hand-dug cistern located at an old home site. The cistern has a diameter of 3 ft with a brick crown that sticks up 0.43 ft from ground surface. The cistern is 16.4 ft deep and holds no water. Cistern sides appear to be sealed with cement mortar. The cistern is uncovered and holds several pieces of trash. This cistern is noted by the cultural resources staff of the Adjutant General's Department as the 41BP156 site or Westbrook Housesite (William R. Furr, personal communication, 1995).

- **CSW-B004** is a hand-dug cistern located at an old home site a few feet away from CSW-B003. The cistern has a diameter of 3 ft with a brick crown that sticks up 1 ft from ground surface. The cistern is 15.4 ft deep and holds no water. Cistern sides appear to be sealed with cement mortar. The cistern is uncovered and holds several pieces of trash. This cistern is noted by the cultural resources staff of the Adjutant General's Department as the 41BP156 site or Westbrook Housesite (William R. Furr, personal communication, 1995).

- **CSW-B005** is a hand-dug well located near the northern boundary of the camp. The well has a diameter of 2.5 ft with a brick crown that sticks up 3.5 ft from ground surface. The well is 18.5 ft deep with a depth to water of 13.5 ft. The sides of the well are made of brick at least to water level and probably to depth. The cistern is uncovered with some debris in the wellbore and a slight oily sheen on the water surface.

- **CSW-B006** is partially filled cistern in the south-west part of the camp. The cistern has a diameter of 3 ft with no stick-up. The cistern is filled to 3 ft below ground surface, is uncovered, and holds no water. This cistern is noted by the cultural resources staff of the Adjutant General's Department as the 41BP158 site or Beck Housesite (William R. Furr, personal communication, 1995).

- **CSW-B007** is partially filled cistern 20 ft east of CSW-B006. The cistern has a diameter of 3 ft with no stick-up. The cistern is filled to 8 ft below ground surface, is uncovered, and holds no water. This cistern is noted by the cultural resources staff of the Adjutant General's Department as the 41BP158 site or Beck Housesite (William R. Furr, personal communication, 1995).

- **CSW-B008** is a 4-inch diameter drilled well with an unknown measured depth and a water-level of 77 ft below land surface. The casing is made of PVC and sets 1.5 ft above grade. The well is located within a small fenced area 50 ft north of CSW-B001 and does not have a locking well vault. The USGS drilled this well to assess the local geology and measure selected hydrogeologic properties of the Wilcox Group as related to potential lignite mining on Camp Swift (Gaylord and others, 1984). At completion, this well (USGS# C-11, TWDB# 58-54-302) was 500 ft deep and completed in the basal part of the Calvert Bluff Formation with screen from 240 to 490 ft.

The cultural resources staff of the Adjutant General's Department report several other locations as possible well sites (William R. Furr, personal communication, 1995). However, we were not able to locate wells or cisterns at any of these sites. A few sites we found what appeared to be mounds of dirt in the approximate location of the well sites. Therefore, many of these wells may have been filled since the archeological survey. The other reported sites are:

- 41BP139 - The Russel housesite. This site has scattered brick and a cistern. Construction of Highway 95 may have cut through part of the site.

- 41BP144 - W. H. Joiner Housesite? This site has a brick well and has been disturbed by a military road

- 41BP149 - Charlie Sowell Housesite. There is 20th century brick, possibly outlining a housesite. There is also an overturned top of a brick and plastered cistern.
- 41BP154 - Wayside Schoolhouse Site. The site has ironstone footings and a brick well.
- 41BP157 - Unknown. This housesite includes a well or cistern and scattered brick.
- 41BP158 - Scruggs Housesite. This site has a filled in cistern.
- 41BP163 - Well associated with the Scruggs Housesite. A historic well is located on the north side of the drainage. The well is lined with brick and the top layer is capped with cement.
- 41BP168 - Historic Well. The site is a brick well situated on the bank of a drainage.

We tried to locate these wells but had no success. In most cases we could find the housesite but not the well or cistern. In the case of 41BP168 and 41BP157 we found suspicious mounds of dirt in the approximate location of the wells suggesting that many of these wells may have been filled since the archeological survey. For example, CSW-B006 and CSW-B007 have apparently been filled since the survey.

There are likely other historic wells on Camp Swift yet to be discovered. These wells will be difficult to locate due to the thick brush and changing anthropogenic landmarks. For example, the archeological survey was not exhaustive because we found a historic hand-dug well not included in the list. Furthermore, the 1904 USGS Bastrop quadrangle shows about 50 or 60 residences in the general area of Camp Swift around the turn of the century connected by a complex array of roadways, many of which no longer exist. We did not find evidence of these housesites during our survey, but pinpointing exact locations was difficult.

Sgt. West thought there may be two other hand-dug wells in the northern part of the camp. He suggested that there may be a well east and a well west of CSW-B003. Three separate efforts to locate these wells were unsuccessful. TNRIS files suggest a drilled well is located just south of the northern boundary of the camp. We did not find this well. Given the date the well was drilled and its private ownership, we believe this well is misplotted and should be north of the camp boundary.

Hydraulic Properties

Various aquifer tests have been performed in each of the formations either reported in TWDB files or in reports. Alluvium in Bastrop County has two measured well yields of 25 and 75 gpm. The Calvert Bluff Formation has well yields that range from 3 to 600 gpm with a geometric mean of 80 gpm and specific capacities that range from 38 to 800 $ft^2\ d^{-1}$ with a geometric mean of 251 $ft^2\ d^{-1}$ (fig. 31a). Using the method of Razack and Huntley (1991), this mean specific capacity corresponds to a transmissivity of 1,400 $ft^2\ d^{-1}$. We did not find any pumping tests in the Calvert Bluff Formation in the area.

The Simsboro Formation has well yields that range from 11 to 1200 gpm with a geometric mean of 250 gpm and specific capacities that range from 630 to 10,000 $ft^2\ d^{-1}$ with a geometric mean of 2500 $ft^2\ d^{-1}$ (fig. 31b). Using the method of Razack and Huntley (1991), this mean specific capacity corresponds to a transmissivity of 4,300 $ft^2\ d^{-1}$. The average values of transmissivity and storativity of the old Camp Swift wells tested by Guyton (1942) are 6000 $ft^2\ d^{-1}$ and 0.0004, respectively (Gaylord and others, 1984). We are in the process of analyzing additional pumping test data from several area Aqua Water Supply wells.

The Hooper Formation has well yields that range from 8 to 250 gpm with a geometric mean of 80 gpm and specific capacities that range from 77 to 520 $ft^2\ d^{-1}$ with a geometric mean of 250 $ft^2\ d^{-1}$ (fig. 31c). Using the method of Razack and Huntley (1991), this mean specific capacity corresponds to a transmissivity of 1,400 $ft^2\ d^{-1}$. We are in the process of analyzing additional pumping test data from several area Aqua Water Supply wells.

The BEG has completed one well in the sandy outcrop and plans another in a silty and clayey area of the Calvert Bluff Formation plans to run aquifer tests in these wells. We will report these values in subsequent reports.

Water Chemistry

TWDB files contain water chemistry data for the alluvium and the Calvert Bluff, Simsboro, and Hooper Formations for Bastrop County (table 5). Total dissolved solids (TDS) for the alluvium range from 291 to 612 mg l^{-1} with a geometric mean of 380 mg l^{-1} (fig. 32a). TDS for the Calvert Bluff Formation range from 226 to 2187 mg l^{-1} with a geometric mean of 500 mg l^{-1} (fig. 32b). Three of the samples (12 percent) were brackish (1,000 mg l^{-1} < TDS < 10,000 mg l^{-1}). TDS for the Simsboro Formation range from 129 to 1116 mg l^{-1} with a geometric mean of 380 mg l^{-1} (fig. 32c). Two of the samples (5 percent) were brackish. TDS for the Hooper Formation range from 246 to 1411 mg l^{-1} with a geometric mean of 490 mg l^{-1} (fig. 32d). Two of the samples (13 percent) were brackish.

Waters from the alluvium are calcium-bicarbonate in composition (fig. 33a). Waters from the Calvert Bluff Formation are sodium-bicarbonate and calcium-sulfate in composition (fig. 33b). Waters from the Simsboro Formation are a mixed calcium and sodium-bicarbonate type with some sodium-chloride type waters (fig. 34a). Waters from the Hooper Formation are a calcium-bicarbonate with some sodium-chloride type waters (fig. 34b).

The BEG will sample and analyze waters from the Calvert Bluff and Simsboro Formations to attain more site-specific data. We will report results in subsequent reports.

Water Levels

TWDB board files had sufficient water-level data to construct long-term hydrographs for the Hooper Formation (fig. 35a), the Simsboro Formation (fig. 35b), the Calvert Bluff Formation (fig. 35c), and the alluvium (fig. 35d). A well (58-46-102) drilled into the Hooper Formation one mile north of Elgin shows a steady increase in water level after a steady period during the 1950s (fig. 35a). This well is located in the outcrop of the Hooper Formation and is likely showing water-level recovery since the major drought during the 1950s. Ground-water pumpage has not caused large local or regional declines in Bastrop County (Follett, 1970).

A well (58-46-301) drilled into the Simsboro Formation 5 miles east of Elgin shows a similar water-level response (fig. 35b) as the well in the Hooper Formation (fig. 35a). This Simsboro well is located in the outcrop and again is likely showing water-level recovery since the major drought during the 1950s.

A well (58-61-201) drilled into the Calvert Bluff Formation outcrop 5 miles west of Bastrop shows a rather steady water-level elevation with small fluctuations likely to variations in rainfall (fig. 35c). A well (58-60-301) drilled into Cedar Creek alluvium overlying the Wilcox Group outcrop about 10 miles west of Bastrop also shows a rather steady water-level elevation with small fluctuations likely to variations in rainfall (fig. 35d).

We also obtained water-level data from monitor wells at the Powell Bend lignite mine from the Railroad Commission. The Powell Bend lignite mine is located to the south-west of Camp Swift and has five wells that have been measured over the last 9 years. These wells were drilled through the Calvert Bluff Formation and into the upper Simsboro Formation where they were completed. The purpose of the wells was to monitor water-level and water-chemistry fluctuations to assess impact of surface mining of lignite. The wells show somewhat similar water-level responses with a period of little water-level change from 1987 to mid-1992 and water-level oscillations since mid-1992 (fig. 36). Other hydrographs from formations in the Bastrop and Camp Swift area are included in Avakian and Wermund (1993), Follett (1970), and Thorkildsen and Price (1991).

We will measure water level fluctuations in the sandy and clayey areas of the Calvert Bluff Formation and in the Simsboro Formation on Camp Swift when we complete our drilling program. We will construct water-level maps for the Camp Swift area after we measure water levels in these wells.

Preliminary Conceptual Flow Model

Rainfall falls on the outcrop of the Calvert Bluff 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 patches of the outcrop. This water moves from topographic highs towards topographic lows where it discharges to local creeks and streams. Some of the flow follows longer flow paths and discharges into locally major topographic lows such as Big Sandy Creek and Dogwood Branch. A small amount of flow moves parallel to bedding and continues downdip toward the east. There also may be flow from the Calvert Bluff Formation into the underlying Simsboro Formation.

BEG efforts to test and sample formations underlying Camp Swift will further constrain the conceptual model and quantify formation properties.

Drilling

The BEG has drilled one well and plans to drill another at Camp Swift. We placed these two wells to characterize the sandy and clayey areas of the Calvert Bluff Formation. These wells, in addition to a pre-existing hand-dug well in the sandy Calvert Bluff Formation and the three USGS wells in the lower Calvert Bluff and upper Simsboro Formations, allow a thorough investigation of the hydrogeology at the camp. The use of these existing wells will reduce costs because we do not need to construct deep another well.

SURFACE WATER

Principal Streams and Drainage Basins

Camp Swift resides in the Colorado River basin (zone 3) (TDWR, 1983). The northern part of the camp is drained by Big Sandy Creek and its tributaries which include Dogwood Creek, McLaughlin Creek, and various unnamed creeks. McLaughlin Creek collects runoff from the north-eastern half of the camp and empties into Big Sandy Creek in the north-west part of the camp. The southern part of the camp is drained by Dogwood Branch and to a lesser degree by a tributary to Harris Creek, both of which empty into Big Sandy Creek west of the camp. Big Sandy creek ultimately empties into the Colorado River.

Watersheds were delineated for Camp Swift (fig. 37) 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). These digitally calculated watersheds agree well with previously published watersheds for the area (Gaylord and others, 1984; Avakian and Wermund, 1993).

Flow duration and Flood Frequency

There is one stream gauge just outside Camp Swift on Big Sandy Creek. Big Sandy Creek has flows as high as 2,400 cubic feet per second (cfs), respectively (fig. 38a). There is flow Big Sandy Creek 85 percent of the time (figs. 38b). Using a log Pearson Type III fit to the annual maxima series, there is a 50 percent chance of having an annual flood greater than 1200 cfs in Big Sandy Creek (fig. 38c).

FORT WOLTERS

HYDROGEOLOGIC ANALYSIS

Surface Geology and Hydrostratigraphy

The Mineral Wells Formation is the only geologic unit exposed at the surface of Fort Wolters. The Mineral Wells Formation is part of the Pennsylvanian-age Strawn Group and 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, 1994). The Hog Mountain Sandstone is the basal member of the

Mineral Wells Formation and is about 25 ft thick. Informal sandstone 1 is about 25 ft above the Hog Mountain Sandstone and is conglomeritic. 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 in color. 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 finegrained 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 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. Two drillers familiar with constructing water wells in the area, L. D. Daugherty in Mineral Wells and L. D. Gray in Whitt, said that producing intervals in the area are sandstone, pea gravel, and conglomerate rock (which has small, finger sized conduits) at depths of 18 to 500 ft in most of the area. The sandstone aquifers are thin (~10 ft thick) with shallower water generally having poorer quality. North of Fort Wolters, depth to water-bearing intervals is 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 often have a smell of sulphur.

Water-well Inventory

TWDB records, site personnel, and a field survey of fort grounds provided information for locating wells on Fort Wolters. We located 7 wells during our survey (fig. 39):

- **FWT-B001** is a 2-inch diameter drilled monitor well with a measured depth of 10 ft and a water-level of 5.35 ft below land surface. The casing is made of PVC and sets 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).

- **FWT-B002** is a 5.75-inch diameter drilled water well with 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 sets 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 as an unsuccessful attempt for a water supply for the missile site. The well was reportedly 800 ft deep when drilled so it may have collapsed. However, it would have been curious to drill an 800 ft deep well in this area since all the fresh water is relatively shallow.

- **FWT-B003** is a 7.75-inch diameter drilled water well with 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 sets 0.94 ft above grade. The well is located on the north-west 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.

- **FWT-B004** is a capped gas well operated by Hunter Energy RRC# 101685, TXNM 51857. This gas well is located on the northern part of the camp. Gas could be smelled leaking from the wellhead.

- **FWT-B005** is gas well operated by London Petro, RRC# 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 with an unknown depth and a water-level of 135.5 ft below land surface. The casing is made of steel and sets 1.35 ft above grade. The well is located near the north-east helicopter training pad and is inside a well house. The wellbore is capped and has a working pump and production pipe down the hole.

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.

The BEG plans to conduct aquifer tests in some pre-existing wells on the fort and in two well drilled for this project to better quantify hydraulic properties in these formations. We will report our results in subsequent reports.

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 6). 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 7). Total dissolved solids (TDS) for the Mineral Wells Formation ranged from 411 to 3936 mg l^{-1} with a geometric mean of 1050 mg l^{-1}. Seven of the samples (54 percent) were brackish (1,000 mg l^{-1} < TDS < 10,000 mg l^{-1}). TDS for the Strawn Group ranged from 249 to 2937 mg l^{-1} with a geometric mean of 910 mg l^{-1}. Seven of the samples (58 percent) were brackish. TDS for the Hog Mountain Sandstone ranged from 4085 to 8419 mg l^{-1} with a geometric mean of 5754 mg l^{-1}. All the samples were brackish. TDS for the Strawn Group ranged from 209 to 8132 mg l^{-1} with a geometric mean of 1621 mg l^{-1}. Eight of the samples (50 percent) were brackish.

Waters from the Mineral Wells Formation are predominantly sodium-bicarbonate in composition (fig. 40a). Waters from the Strawn Group are mostly calcium-bicarbonate in composition (fig. 40b). The water composition of the Brazos River Formation is predominantly calcium-bicarbonate (fig. 41a) though 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. 41b). The Hog Mountain Sandstone is a sodium-sulfate water (fig. 41b).

The BEG will sample and analyze waters from the Mineral Wells Formation on Fort Wolters to attain more sight specific data. We will report results in subsequent reports.

Water Levels

TWDB board files had sufficient water-level data to construct long-term hydrographs for the Mineral Wells Formation (fig. 42a, b), Brazos River Formation (fig. 42c), and the Strawn Group (fig. 42d). These hydrographs show somewhat similar patterns of water-level fluctuations that are likely due to variations in recharge to the geologic strata (fig. 42).

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 with depths ranging from 5.5 to 187 ft below land surface. Most measured water levels (45 percent) were within 20 ft of land surface. Depths to water in pre-existing wells on the camp were 5.3, 53.8, 66, and 135.6 ft below land surface as measured in August 1995.

We will measure water levels in the Mineral Wells Formation on the camp when we complete our drilling program. At this time, we will construct water-level maps for the Fort Wolters area.

Preliminary Conceptual Flow Model

Rainfall 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 towards 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.

BEG efforts to test and sample formations underlying Camp Swift will further constrain the conceptual model and quantify formation properties.

Drilling

The BEG drilled and completed two wells on Fort Wolters in December 1995. We placed these wells in the Mineral Wells Formation along a presumed ground-water flowline that runs through the well at the north-west helicopter training site.

SURFACE WATER

Principal Streams and Drainage Basins

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. The south-eastern part of the fort is drained by Rippy Branch which feeds into Rock Creek. The south-western part of the fort drains to the south-west into a couple unnamed creeks which feed into Rock Creek south of the fort. Rock Creek ultimately empties into the Brazos River about 8 miles south of the fort.

Watersheds were delineated for Fort Wolters (fig. 43) 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).

Flow duration and Flood Frequency

There are no stream gauges on Fort Wolters and none near the fort that has data that would be useful in understanding surface water flow on the camp. Therefore, we plan to develop synthetic unit hydrographs for the camp in order to do flood plain analyses.

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Table 1. Chemical analyses of ground waters from the Antlers Formation, Fredricksburg Group, Choza Formation, Vale Formation, and undifferentiated Permian System in Taylor 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. (mΩ)
Antlers Formation:																		
2948403	1993	21	16	87	33	58	2.2	0.48	334.4	53	67	0.81	34.66	7.2	516	274	353	904
2948406	1969	18	11	67	22	19	-	-	273	18	21	0.6	28	7.6	320	224	256	592
2948601	1982	23	11	100	21	14	-	-	371	44	8	0.3	0.9	8.1	381	304	336	730
2948602	1970	20	10	69	44	22	4	-	383	59	20	0.5	0.4	7.6	417	314	353	790
2948605	1970	18	11	67	41	27	-	-	368	66	23	0.6	0.4	7.6	416	302	339	790
2948705	1978	21	10	57	34	55	-	-	328	103	17	1.1	0.4	8	438	269	283	800
2955602	1970	17	16	88	14	23	-	-	305	39	20	0.5	6.5	7.3	356	250	277	648
2955603	1970	18	11	102	11	9	-	-	282	22	20	0.3	39	7.4	352	231	302	640
2955604	1970	12	7	78	14	7	-	-	276	23	8	0.3	0.4	7.7	273	226	252	507
2956101	1969	21	11	79	20	7	-	-	314	16	10	0.5	3.5	7.6	301	257	274	568
2956104	1970	18	10	71	25	15	1	-	307	20	23	0.7	4.8	7.5	321	252	280	604
2956202	1969	20	12	67	18	11	-	-	275	10	13	0.6	10.5	7.9	277	225	242	510
2956206	1993	19	16	70	19	20	1.9	0.28	274.6	16	19	0.61	13.86	7.4	311	225	53	552
2956207	1970	18	15	62	18	11	-	-	260	6	17	0.5	12	7.8	269	213	232	500
2956301	1970	20	11	89	23	17	-	-	333	34	27	0.5	10.5	7.7	375	273	316	700
2956303	1970	20	10	110	45	22	-	-	382	112	53	1.2	1.5	7.6	542	313	458	1036
2956304	1970	19	8	67	31	40	-	-	338	68	28	1.2	0.4	7.7	409	277	294	765
2956502	1982	19	12	100	5	8	-	-	299	17	9	0.2	13	7.8	311	245	272	576
2956503	1970	16	11	74	25	9	-	-	328	15	10	0.5	5.5	8.2	311	269	286	580
2956601	1970	18	10	74	27	14	-	-	340	31	11	0.6	0.4	7.6	335	279	298	632
2956901	1970	18	12	98	28	25	-	-	406	52	13	0.5	1.8	7.5	429	333	360	816
2956902	1970	-	11	84	27	12	-	-	350	36	12	0.5	0.4	7.5	354	286.89	322	664
2964301	1970	10	18	99	29	11	-	-	375	28	14	0.7	34	7.8	418	307	366	770
3041401	1970	19	11	112	38	14	-	-	393	110	21	0.6	0.4	7.4	500	322	435	930
3041701	1970	18	11	90	20	15	-	-	334	44	15	0.3	0.4	7.7	359	274	308	670
3041703	1970	19	17	119	8	14	-	-	314	44	35	0.3	11	7.7	402	257	333	740
3041802	1970	21	13	142	10	24	1	-	340	24	96	0.3	0.4	7.7	477	279	394	924
3043602	1993	18	16	108	16	18	1.7	0.5	375.9	28	18	0.37	0.49	7.1	391	308	335	584
3043703	1970	19	10	96	16	35	-	-	336	50	30	0.3	14	7.9	416	275	307	770
3043803	1970	12	19	118	22	66	-	-	433	50	96	0.6	0.4	7.7	584	355	386	1078
3049102	1970	18	8	95	38	14	-	-	447	17	21	2.4	0.4	7.4	415	366	394	822
3049401	1970	21	10	101	36	20	-	-	438	36	31	0.5	6.5	7.4	456	359	398	876
3049402	1970	19	11	85	24	7	-	-	357	21	7	0.5	0.4	7.5	331	293	313	620

Table 1. (cont.)

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. (mΩ)
Antlers Formation (cont.):																		
3049601	1970	13	17	123	22	23	1	-	418	46	38	0.6	0.4	7.8	476	343	396	882
3049602	1970	15	20	115	25	34	-	-	451	42	29	0.7	0.4	7.4	487	370	388	900
3049603	1970	17	18	135	38	77	-	-	439	128	95	1	42.5	7.5	750	360	495	1395
3049605	1970	18	16	148	30	30	-	-	337	216	26	1	18	7.7	650	276	492	1155
3049901	1970	13	15	123	18	61	-	-	472	78	38	1	0.4	7.6	566	387	382	1043
3050801	1970	27	19	87	21	12	2	-	317	55	5	1.2	0.4	7.7	358	260	303	628
3051201	1970	19	13	185	12	17	-	-	388	39	58	0.3	143	7.4	658	318	510	1148
3051203	1970	14	12	105	10	12	-	-	348	16	17	0.4	0.4	7.3	343	285	304	632
3051204	1970	19	10	76	23	6	-	-	294	43	4	0.7	3	7.7	310	241	285	576
3051205	1970	18	13	95	21	9	-	-	342	36	11	0.4	12	7.7	365	280	325	665
3051301	1970	18	11	72	32	7	-	-	357	12	10	0.8	0.4	7.3	320	293	312	612
3051302	1970	18	12	85	20	12	-	-	351	15	13	0.3	0.4	7.4	330	288	296	616
3051501	1970	18	12	106	13	17	-	-	340	30	21	0.5	10	7.6	376	279	320	680
3051502	1993	21	13	123	14	29	2.6	0.59	316.1	43	46	0.36	65.08	7.2	492	259	365	640
3051601	1993	21	14	96	12	11	1.8	0.5	310	11	17	0.29	21.07	7.1	337	254	289	740
3051602	1970	21	14	93	12	10	-	-	325	12	19	0.2	0.4	7.5	320	266	282	588
Fredricksburg Group:																		
2947601	1969	19	16	99	35	59	-	-	318	58	109	0.7	41	7.2	574	261	391	1120
2947604	1982	23	12	94	13	19	-	-	304	26	24	0.6	28.8	8.1	366	249	289	679
2947902	1970	8	13	69	22	33	-	-	284	31	37	0.7	15	8	360	233	264	660
2947903	1970	14	11	64	18	13	-	-	256	14	16	0.6	9	7.8	271	210	233	498
2947904	1970	13	8	82	29	44	-	-	325	46	68	0.7	5.5	7.8	443	266	325	855
2947905	1970	6	8	64	16	9	-	-	256	11	13	0.6	3.5	7.8	250	210	226	465
2948701	1969	17	11	80	25	20	-	-	338	20	22	0.6	14	7.7	358	277	302	660
2948703	1970	13	9	75	26	11	-	-	326	20	13	0.7	6.5	7.8	321	267	296	604
2948704	1970	14	9	89	26	9	-	-	346	23	14	0.6	14	7.7	354	284	329	664
2948807	1970	15	8	70	33	12	-	-	348	24	19	0.6	0.4	7.7	338	285	312	645
2948808	1970	14	9	84	28	8	-	-	360	20	13	0.4	4.5	7.7	343	295	326	640
2956102	1970	9	10	68	19	12	-	-	279	14	15	0.6	5.5	7.8	281	229	247	522
2956103	1970	9	6	69	21	9	-	-	290	14	12	0.6	5.5	7.8	279	238	208	516
2956105	1970	12	8	67	27	11	-	-	299	20	21	0.7	8.5	7.7	310	245	277	576
2956106	1970	13	9	71	19	9	-	-	284	13	16	0.3	7	7.9	283	233	256	513

Table 1. (cont.)

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. (mΩ)
Fredricksburg Group (cont.):																		
2956107	1970	13	5	75	19	7	-	-	300	17	9	0.5	2	7.7	282	246	267	525
2956108	1970	19	10	84	21	26	-	-	271	23	63	0.5	21	7.8	381	222	297	730
2956109	1970	13	15	96	30	21	-	-	381	28	37	0.5	17	7.4	431	312	364	800
2956110	1970	9	10	84	31	9	-	-	390	12	14	0.6	3.5	7.6	355	320	339	685
2956201	1969	19	13	72	22	12	-	-	312	12	13	0.6	4.5	7.6	302	256	269	564
2956204	1970	18	10	72	22	10	-	-	311	12	12	0.6	3.5	7.8	295	255	270	506
2956205	1970	18	9	85	37	11	-	-	415	20	15	0.5	2	7.9	383	340	367	735
2956208	1970	16	12	72	22	8	-	-	307	10	13	0.5	2	7.9	290	252	271	556
2956302	1970	13	12	65	32	22	-	-	345	23	23	0.6	0.4	8.1	347	283	292	655
2956504	1970	9	10	79	43	16	-	-	388	39	22	0.5	21	8.1	421	318	376	800
3049101	1970	14	12	83	36	14	-	-	344	59	27	0.5	0.4	7.3	401	282	355	765
3049403	1970	14	20	121	27	11	-	-	459	28	16	0.3	0.4	7.6	449	376	413	840
3049607	1970	-	2	85	16	24	-	-	298	32	34	0.3	0.4	7.5	340	244	279	675
3051208	1970	23	7	71	27	8	-	-	338	21	9	0.5	5	7.7	314	277	291	576
3051209	1970	19	7	97	8	8	-	-	310	22	8	0.2	0.4	7.7	303	254	275	560
3051303	1970	18	9	102	17	7	-	-	361	23	9	0.4	3.5	7.7	348	296	325	640
Choza Formation:																		
2932709	1968	-	29	137	177	404	-	-	440	830	475	2.8	77	7.7	2348	360.66	1070	4524
2932907	1969	21	16	220	89	155	3	-	204	780	162	0.9	24	7.5	1550	167	910	2856
2932909	1969	22	7	89	70	125	-	-	211	215	257	0.6	24	7.6	891	173	510	1823
2932912	1991	22	-	207	94	164	5.8	7.89	220.9	666	292	0.62	26.43	7.1	1572	181	912	2820
2940201	1970	22	12	375	181	391	5	-	304	1560	407	1.1	90	7.5	3171	249	1680	6048
2940202	1970	20	8	114	75	140	-	-	22	620	183	0.8	0.4	6.3	1152	18	590	2268
2940203	1970	18	29	135	78	74	-	-	410	222	163	1.2	30	7.4	933	336	660	1760
2940205	1970	19	-	373	187	336	-	-	306	1280	650	1	0.4	7	2977	251	1700	5814
2940301	1969	22	27	136	107	100	-	-	410	302	121	2.4	189	7.4	1185	336	780	2160
2940303	1969	22	16	58	36	27	-	-	342	30	18	0.9	14	7.6	368	280	293	700
2940312	1969	21	15	540	82	154	-	-	205	1570	126	0.9	39	7.4	2627	168	1700	4756
2940313	1970	21	20	112	44	61	2	-	284	241	51	0.8	43	7.6	714	233	462	1296
2940314	1991	23	-	89	49	41	6.4	4.3	308.8	152	67	0.8	38.12	7.3	599	253	428	985
2940315	1970	19	24	76	55	120	-	-	377	121	136	1.7	68	7.5	787	309	416	1458
2940319	1978	22	15	569	77	193	-	-	198	1669	120	0.6	32	8	2772	162	1738	5022

Table 1. (cont.)

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. (mΩ)
Choza Formation (cont.):																		
2940320	1970	20	18	91	45	82	-	-	346	138	94	0.7	15	7.2	653	284	413	1287
2940324	1991	21	-	136	62	90	4.9	4.13	356.3	300	117	0.59	48.83	7	939	292	599	1820
2940327	1970	21	22	160	75	97	3	-	326	257	165	0.7	176	7.5	1115	267	708	2052
2940328	1970	21	21	113	71	94	2	-	383	143	179	0.7	53	7.6	865	314	570	1694
2940330	1991	21	-	359	176	259	11	16.5	375.9	945	624	0.57	180.5	6.8	2756	308	1638	4060
2940501	1970	18	36	600	383	630	60	-	580	1390	1740	1	11	7.3	5136	478	3060	10416
2940502	1970	19	17	610	290	387	8	-	265	2600	437	1.1	14	7.5	4494	217	2720	8448
2940503	1970	22	18	425	186	283	5	-	303	1000	760	1	58	7.5	2884	248	1830	5658
2940601	1981	20	31	137	69	89	-	-	389	88	245	0.9	75.9	8.1	927	319	626	1790
2940605	1969	21	18	342	63	132	4	-	273	1020	74	1.3	10	7.2	1798	224	1110	3255
2940606	1969	19	27	98	84	114	-	-	470	133	194	1.7	40	7.6	922	385	590	1769
2940607	1969	21	28	72	79	137	-	-	421	101	198	3	94.5	7.5	919	345	510	1755
2940609	1970	-	20	132	122	143	4	-	323	127	392	1	212	7.8	1311	264.75	830	2528
2940610	1991	21	-	100	73	134	6.6	16.2	325.8	120	292	1.17	-	6.7	903	267	568	1650
2940801	1969	18	18	82	42	95	-	-	334	111	66	0.7	134	7.5	712	274	377	1260
2940902	1970	21	21	75	43	85	-	-	310	36	164	1	31	7.5	608	254	367	1192
2940904	1970	24	17	92	47	67	-	-	348	129	104	1.1	2	7.6	630	285	423	1208
2956801	1969	27	17	158	27	136	-	-	411	243	139	1.6	18.5	7.3	942	337	510	1749
3025712	1970	17	19	73	100	186	-	-	472	256	170	2.4	122	7.7	1160	387	590	2144
3057301	1970	29	34	174	83	510	5	-	442	463	690	2.4	65	7.7	2243	362	780	4340
Vale Formation:																		
3033506	1970	24	13	403	248	730	4	-	320	1080	1510	1.2	54	7.2	4200	262	2030	8517
3034401	1970	17	17	53	86	451	-	-	950	419	179	3	0.4	8.1	1675	780	489	3069
Undifferentiated Permian System:																		
3033402	1979	-	19	301	255	484	-	-	419.8	882	1137	1.2	0.1	7.7	3285	344	1800	6832
3033403	1979	-	23	443	405	885	-	-	439.3	1873	1745	0.9	1.3	7.8	5592	360	2771	11340
3033701	1979	-	22	190	87	185	9	-	279.5	326	426	0.5	106.7	7.8	1489	229	832	2961
3033703	1979	-	22	300	117	177	-	-	231.9	242	819	0.4	45.4	7.9	1836	190	1229	3900
3033704	1979	-	22	429	310	1042	-	-	375.9	2822	890	1	120.8	7.5	5821	308	2345	10920

Table 2. Chemical analyses of ground waters from the alluvium, the Travis Peak Formation, and the Strawn Group in Brown 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. (mΩ)
Alluvium:																		
4117103	1970	-	22	140	17	60	-	-	510	10	89	0.3	0.4	7.1	589	416	422	1168
4117104	1970	-	17	140	23	106	-	-	472	110	109	0.3	22	7.2	759	387	444	1404
4118703	1962	-	17	65	70	88	-	-	309	58	126	0.3	20	7.4	596	413	452	1430
Travis Peak Formation:																		
4101234	1994	20	-	87	41	-	-	-	353.9	9	132	-	-	7.4	-	290	385	1087
4101244	1994	21	-	88	21	-	-	-	278.2	7	56	-	-	7.7	-	228	305	680
4101830	1972	20	38	93	20	68	-	-	332	28	119	1.2	0.4	7.5	530	272	315	960
4101918	1984	24	14	93	28	20	0.3	-	386	44	26	0.4	4.7	8.1	420	316	348	800
4102124	1984	22	14	97	35	26	0.2	-	384	49	54	0.5	6.16	8	470	315	389	930
4109303	1974	-	13	91	57	45	-	-	398	69	113	0.7	3.5	7.9	587	326	462	1192
4110320	1971	-	-	99	60	40	-	-	376	168	64	0.8	0.4	7.1	617	308	495	1183
4110424	1974	-	14	105	62	52	-	-	449	105	102	0.8	8	7.7	669	368	520	1332
4110425	1984	21	14	104	49	41	0.3	-	411	102	79	0.7	5.32	0.8	597	337	463	1216
4110602	1963	-	14	58	82	41	-	-	397	130	71	0.5	2	7.6	593	325	484	1030
4110639	1978	21	14	116	-	74	-	-	360	181	170	0.6	35	8.1	932	295	-	1661
4110640	1994	22	21	97	64	46	6.9	1.42	401.5	154	91	0.67	15.49	8	694	329	506	1227
4110641	1994	22	-	84	70	-	-	-	380.8	165	106	-	-	7.7	-	312	497	1294
4110725	1963	-	14	70	45	286	-	-	301	158	405	0.5	2	7.7	1128	247	362	2343
4110811	1963	-	12	68	58	202	-	-	447	257	157	1	2.9	7.6	977	366	410	1600
4118205	1978	15	4	59	59	317	-	-	442	330	259	1.5	0.4	7.9	1247	362	391	2432
4118303	1983	22	15	62	55	50	4	-	423	50	56	0.4	10.5	8.4	519	361	382	825
4118501	1963	-	15	126	96	85	-	-	468	88	264	1.1	60	7.3	965	384	710	1700
4118620	1962	-	11	28	23	345	-	-	580	133	190	1.8	2.9	7.2	1019	475	166	1920
4118650	1988	23	17	110	100	180	6.8	-	423	139	380	0.9	22.33	7.1	1164	347	687	2200
4223314	1962	-	21	124	17	15	-	-	418	17	28	0.4	15	6.5	442	342.62	380	736

Table 2. (cont.)

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. (mΩ)
Strawn Group:																		
4109501	1963	-	12	9	5	520	-	-	427	148	496	2	2.9	8	1404	350	42	2750
4109604	1963	-	18	79	96	94	-	-	478	259	93	1	10	7.5	885	392	590	1650
4109605	1963	-	19	81	92	92	-	-	473	240	91	1.1	9	7.6	857	388	580	1608
4109812	1963	-	30	101	19	193	-	-	406	91	213	0.9	32	7.4	879	333	330	1650
4109813	1963	-	29	96	23	73	-	-	399	61	74	0.9	3.5	7.4	556	327	335	1020
4109907	1963	-	27	85	25	44	-	-	384	38	40	0.7	10	7.8	458	315	318	825
4109908	1963	-	22	73	160	390	-	-	1010	261	435	3.3	0.4	7.7	1841	830	840	3680
4109909	1963	-	20	89	122	405	-	-	720	256	530	1	46	7.5	1823	590	720	3680
4109916	1963	-	13	46	50	293	-	-	288	144	413	1	0.4	8.1	1102	236	320	2255
4109919	1963	-	14	49	52	22	-	-	437	14	9	0.4	0.4	7.4	375	358	336	735
4109922	1963	-	12	57	48	610	-	-	234	276	850	1.6	0.4	7.5	1970	192	339	4048
4109925	1963	-	15	97	126	89	-	-	504	69	174	0.8	291	7.5	1109	413	762	2145
4109926	1963	-	11	46	36	691	-	-	227	262	948	1	0.4	7.5	2107	186	264	4284
4110108	1963	-	12	92	56	32	-	-	415	110	54	0.7	0.4	7.5	561	340	461	1100
4110718	1963	-	14	72	68	50	-	-	433	39	119	0.6	3.8	7.3	579	355	461	1195
4117101	1974	-	15	165	15	42	-	-	345	115	111	0.3	10	7.4	642	283	474	1248
4117102	1970	-	16	163	37	216	-	-	379	160	323	1.2	110	7.5	1212	311	560	2368
4117201	1963	-	18	152	15	59	-	-	321	87	142	0.3	12	7.2	643	263	440	1260
4117207	1963	-	24	130	18	240	-	-	421	156	249	0.7	30	7.3	1054	345	397	1980
4117215	1963	-	18	218	45	245	-	-	344	407	365	0.5	13	7.3	1480	282	730	2816
4117216	1962	-	15	284	73	364	-	-	511	597	565	0.2	4.2	7.2	2153	419	1007	4235
4117218	1962	-	17	42	49	17	-	-	375	15	11	2.4	4.2	8	341	307	304	652
4117219	1962	-	15	86	20	40	-	-	390	33	22	0.2	0.4	7.4	408	320	295	792
4117220	1962	-	8	90	54	1655	-	-	208	365	2470	0.5	5.3	7.4	4750	171	445	10230
4117225	1962	-	19	82	26	148	-	-	365	164	125	0.2	0.4	7.6	744	299	312	1452
4117226	1962	-	18	101	25	142	-	-	377	216	110	0.3	4.2	7.4	801	309	356	1512
4117228	1962	-	13	242	39	220	-	-	466	402	315	0.1	40.5	7.2	1500	382	763	2959
4117229	1962	-	9	300	64	149	-	-	442	211	310	0.1	409	7.2	1669	362	1011	3212
4117301	1963	-	15	64	87	49	-	-	522	17	110	0.3	11.5	7.5	610	428	518	1296
4117302	1963	-	13	22	34	169	-	-	403	55	112	1.1	25	7.9	629	330	193	1210
4117317	1962	-	16	111	12	93	-	-	340	134	73	0.2	23	7.4	629	279	326	1116
4117318	1962	-	14	123	28	113	-	-	569	90	82	0.1	0.4	7.3	730	466	421	1400
4117322	1962	-	22	70	48	56	-	-	426	30	72	0.6	20	7.7	528	349	374	1035
4117324	1962	-	15	41	36	228	-	-	403	219	138	0.4	0.4	7.9	875	330	250	1704

Table 2. (cont.)

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. (mΩ)
Strawn Group (cont.):																		
4117326	1962	-	14	291	155	454	-	-	453	555	940	0.2	13	7.4	2644	371	1363	5565
4117328	1963	-	7	52	50	97	-	-	476	31	84	0.1	0.4	7.5	555	390	333	1125
4117329	1963	-	7	134	120	1370	-	-	178	256	2410	0.4	3.1	7.6	4388	146	825	9471
4117330	1963	-	26	58	74	102	-	-	602	51	76	2.8	0.4	7.6	686	493	452	1332
4117331	1963	-	22	61	34	59	-	-	392	33	44	1	3.5	7.6	450	321	291	840
4117332	1963	-	7	132	113	1178	-	-	161	291	2080	0.4	4.7	7.5	3885	132	793	6640
4117334	1962	-	17	81	105	127	-	-	671	158	123	0.5	37	7.6	978	550	631	1890
4117336	1962	-	10	71	43	1062	-	-	215	262	1560	0.7	3.3	7.1	3117	176	353	6321
4117338	1962	-	21	180	155	473	-	-	543	595	703	1	57	7.6	2451	445	1084	4935
4117340	1962	-	22	52	96	214	-	-	655	153	194	2.5	6	7.7	1061	537	526	2100
4117341	1962	-	13	101	21	468	-	-	444	259	497	0.7	0.4	7.3	1578	364	340	3190
4117342	1962	-	15	35	47	168	-	-	478	43	156	0.4	0.4	7.7	699	392	278	1308
4117343	1962	-	23	62	102	254	-	-	600	277	230	2.4	10	7.6	1255	492	574	2406
4117345	1962	-	17	48	55	150	-	-	502	49	155	0.4	2.2	7.6	723	411	345	1470
4117346	1962	-	16	94	64	260	-	-	465	106	394	0.8	10	7.6	1173	381	497	2420
4117347	1962	-	15	70	80	89	-	-	553	75	118	0.2	2.7	7.4	721	453	502	1368
4117501	1963	-	22	366	70	469	-	-	520	373	990	0.4	4.5	6.9	2550	425	1200	5250
4117601	1962	-	18	106	73	163	-	-	527	95	262	0.5	26	7.4	1002	432	567	2088
4117605	1962	-	11	26	5	4	15	-	161	5	14	0.2	0.4	7.2	159	132	86	336
4117607	1962	-	19	162	142	233	-	-	543	444	420	0.2	11.5	7.2	1698	445	989	3410
4118101	1963	-	12	67	70	147	-	-	417	88	205	0.8	78	7.8	872	342	456	1752
4118110	1963	-	8	81	116	147	-	-	474	127	317	0.3	49	8	1078	388	680	2299
4118111	1963	-	11	56	65	189	-	-	491	127	205	0.8	0.4	7.7	895	402	407	1800
4118115	1962	-	19	74	110	341	-	-	588	301	393	1.7	32	7.5	1560	482	638	2893
4118116	1962	-	13	50	49	214	-	-	427	84	230	0.9	29	7.5	879	350	328	1650
4118117	1962	-	15	65	87	77	-	-	492	55	170	0.5	0.4	7.8	711	403	519	1145
4118118	1962	-	16	75	109	204	-	-	609	144	276	0.2	36	7.4	1159	499	637	2340
4118120	1962	-	10	39	53	95	-	-	386	28	123	1.2	0.4	7.4	539	316	316	1024
4118121	1962	-	13	26	30	251	-	-	373	95	230	1.1	0.4	7.9	829	306	188	1650
4118122	1963	18	8	95	75	933	-	-	227	297	1500	0.5	0.4	7.6	3020	186	545	6560
4118124	1963	-	14	44	48	84	-	-	460	24	60	0.8	8.5	7.5	509	377	307	1020
4118125	1963	-	8	86	88	349	-	-	322	284	563	1	0.4	7.5	1537	264	575	3264
4118203	1963	-	16	81	68	178	-	-	420	173	245	1.3	10	7.4	978	344	482	1960
4118217	1963	-	12	92	74	533	-	-	334	392	700	1	4.7	7.4	1972	274	531	3984

Table 2. (cont.)

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. (mΩ)
Strawn Group (cont.):																		
4118220	1963	-	10	109	84	515	-	-	273	307	840	0.8	0.4	7.4	2000	224	618	4160
4118420	1962	-	8	25	8	1	-	-	110	6	2	0.1	0.4	7.5	104	90	95	189
4118435	1984	23	15	167	165	161	0.4	-	686	225	465	0.4	0.8	7.7	1536	562	1097	3276
4118540	1963	-	14	85	109	65	-	-	469	100	230	1.8	4.7	7.4	840	384	661	1760
4118707	1962	-	15	73	90	20	-	-	622	23	32	0.2	15	7.5	574	510	551	1100
4118709	1962	-	14	83	100	20	-	-	722	20	28	0.1	0.7	7.3	620	592	617	1230
4118710	1962	-	11	34	61	11	-	-	382	15	20	0.1	0.6	8.2	340	313	338	650
4118806	1962	-	10	64	55	11	-	-	442	10	29	0.1	0.4	7.5	396	362	388	810
4118910	1962	-	16	53	43	18	-	-	364	11	24	0.3	6	7.4	350	298	309	650
4118930	1978	29	13	64	49	28	-	-	426	11	26	0.4	2	8.6	418	375	360	834
4125401	1978	21	11	15	9	306	-	-	412	85	188	1.8	1	8.8	846	382	73	1650
4125402	1962	-	16	11	11	193	-	-	395	42	87	0.8	0.4	7.9	555	324	73	1008
4125404	1964	-	24	150	74	267	-	-	479	165	461	1.9	42	7.6	1420	393	680	2960
4125406	1978	21	20	127	152	370	-	-	622	539	442	0.8	1	8	1957	510	940	3875
4125407	1984	22	12	38	23	309	0.5	-	501	95	238	1.4	0.09	8.1	963	411	191	1837
4125703	1962	-	11	2	5	255	-	-	574	40	46	0.9	0.4	8.1	642	470	26	1080
4125705	1962	-	16	2	2	310	-	-	682	46	68	1.1	0.4	8.3	780	559	12	1344
4133101	1962	-	11	29	22	708	-	-	661	122	765	0.8	0.4	7.7	1983	542	162	3850
4240102	1962	-	12	19	4	366	-	-	613	4	242	1.2	0.4	8	950	502	62	1740
4240105	1962	-	13	16	9	396	-	-	536	5	331	1	0.4	8.1	1034	439	77	1896

Table 3. Chemical analyses of ground waters from the Austin Chalk for Travis County and from the Edwards and associated limestones, the Glen Rose Formation, and the Hosston Member for the number 42 7 1/2-minute quadrangle of the number 58 1-degree minute quadrangle (in other words, all well numbers starting with 58-42. This area overlies the Camp Mabry area. The TWDB file contains too much information to present here.)

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. (mΩ)
Austin Chalk:																		
5835209	1970	-	9	104	5	20	15	-	281.9	68	14	0.3	37	7.7	410	231	280	696
5835605	1972	23	8	119	4	10	-	-	306.3	22	13	0.6	47	7.6	374	251	313	660
5835606	1973	22	7	100	3.04	8.7	-	-	274.6	18	16	0.4	9	7.9	297	225	262	556
5835703	1940	-	-	110	10	15	-	-	336.1	57	11	-	-	-	368	275.41	315	-
5835903	1970	22	9	107.6	5	12.4	-	-	292.9	22	27	0.3	17	7.3	344	240	289	632
5835904	1970	22	9	109	3.5	9.9	-	-	305.1	25	20	0.5	4	7.4	330	250	286	604
5835905	1940	-	-	113	5	19	-	-	275.1	35	32	-	46	-	385	225.41	302	-
5836101	1971	20	8	113.4	3.65	8.74	-	-	318.5	24	17	0.6	2.3	7.3	334	261	298	608
5836103	1971	21	11	142	5	12	-	-	357.6	26	37	0.6	27	7.2	436	293	375	792
5836105	1973	21	10	85	5	13	-	-	195.3	42	32	0.6	10	7.7	293	160	232	540
5836106	1973	21	6	105.8	3.89	15.9	-	-	219.7	49	34	0.8	36	7.6	359	180	280	664
5836203	1980	-	13	123	24	38	-	-	409	63	59	0.3	3.4	8.1	524	335.15	405	1014
5836302	1980	-	20	116	22	41	-	-	375.9	66	60	0.3	3.4	7.9	513	308	380	966
5836601	1980	27	20	58	22	9	-	-	244.1	18	15	0.1	14.3	8.1	276	200	235	507
5836603	1973	22	22	103	7	82	1	-	394.2	65	32	1.5	30	7.8	537	323	285	959
5843502	1940	-	-	25	3	22	-	-	49	15	37	-	22	-	148	40.16	77	-
5850303	1938	-	-	64	26	72	-	-	329	85	46	-	-	-	454	269.67	266	-
5850601	1980	26	20	101	23	39	-	-	331.9	66	58	0.3	3.5	7.9	474	272	346	900
5850901	1972	24	28	98	4	20	-	-	295.3	4	40	0.7	2	7.3	341	242	260	612
5851506	1971	21	20	116	9	35	-	-	284.3	98	22	0.8	4.3	7.4	444	233	326	864
Edwards and associated limestones:																		
5842308	1973	22	7	124	26	24	-	-	339.3	66	71	0.2	19	7.5	504	278	416	980
5842311	1994	20	13	160	20	36	1.2	-	427.1	85	86	0.1	34.97	7	646	350	481	1080
5842602	1940	-	-	87	25	44	-	-	366	54	37	0.2	-	-	427	299.91	319	-
5842604	1950	-	-	-	-	-	-	-	344	70	49	-	-	8.1	-	281.89	-	944
5842605	1938	-	-	158	5	57	-	-	305	55	73	-	157	-	654	249.93	414	-
5842606	1940	-	-	144	8	15	-	-	382	33	34	0.4	35	-	457	313.03	392	-
5842607	1949	-	10	71	39	177	-	-	354	172	180	-	0.04	7.5	823	290.08	337	1440
5842608	1971	19	9	57	21	32	-	-	223.3	33	59	0.3	1.5	7.8	322	183	228	636

Table 3. (cont.)

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. (mΩ)
Edwards and associated limestones (cont.):																		
5842610	1896	-	-	-	-	-	-	-	-	-	28	-	0.13	-	298	-	-	-
5842617	1973	22	16	117	8	43	-	-	267.3	72	81	0.3	8	7.7	476	219	324	900
5842618	1973	22	7	122	22	18	-	-	374.7	48	40	0.3	15	7.8	456	307	394	894
5842809	1971	23	8	68	19	6	-	-	270.9	19	12	0.6	3.3	7.5	269	222	247	510
5842810	1949	-	10	72	29	7.3	-	-	294	51	12	-	2	7.4	327	240.92	298	565
5842811	1993	20	15.29	119.7	26.49	18.51	1.78	0.17	325.8	7	32	0.2	7.47	7.5	388	267	407	772
5842813	1994	20	10	88	22	10	1.1	-	305.1	38	22	0.2	5.31	7.1	346	250	310	597
5842814	1989	-	-	68	15	16	1.1	-	305.1	30.8	20.8	0.14	6.64	-	308	250	231	-
5842816	1984	-	-	72	20	8	8	-	285.6	24	16	0.2	4.5	7.8	293	234	261	576
5842820	1982	-	-	67.7	18.9	9.6	-	-	-	32	-	0.1	0.35	6.7	345	-	247	511
5842821	1993	21	8.78	78.9	21.65	12.32	1.38	0.38	219.7	27	21	0.2	1.24	7.5	280	180	286	-
5842901	1949	-	12	84	24	5	-	-	340	12	12	-	6.9	7.6	323	278.61	308	561
5842911	1931	-	-	-	-	-	-	-	-	12	11	-	20	-	-	-	-	-
5842913	1993	20	9.67	110.3	19.27	11.73	1	0.17	291.7	16	24	0.2	7.3	7.3	343	239	354	641
5842914	1995	19	10	81	16	12	1.3	0.58	280.7	30	20	0.2	3.85	7.2	312	230	268	555
5842915	1994	21	9.6	67	21	8.7	1.2	-	268.5	37	15	0.3	3.67	7.3	295	220	253	522
5842916	1972	-	12	73	38	34	-	-	339.3	45	58	0.4	7	7.5	434	278	338	835
5842919	1972	23	7	53	14	30	-	-	179.4	23	57	0.3	0.4	7.1	272	147	189	544
5842921	1973	22	4	82	19	13	-	-	299	25	22	0.2	5	7.8	317	245	282	620
5842922	1973	21	6	77	22	22	-	-	281.9	36	38	0.2	4	7.7	343	231	282	660
5842925	1975	-	9	99	14	8	-	-	322.2	24	15	0.2	7	7.7	334	264	304	630
Glenn Rose Formation:																		
5842304	1970	24	10	374	230	1050	69	-	325	3170	540	5.6	0.4	7.2	5608	266.32	1879	10200
5842304	1973	-	10	379	234	1050	-	-	335.6	3210	550	5.8	0.6	7.2	5604	275	1908	10416
5842307	1971	24	11	363	229	1020	-	-	319.7	3000	550	5.7	0.4	7	5336	262	1847	10000
5842403	1970	-	12	210	166	76	-	-	380.8	970	41	3.2	0.4	7.4	1665	312	1207	3131
5842407	1977	-	10	108	85	17	-	-	299	351	17	4.9	0.4	7.8	743	251	619	1419
5842508	1954	-	-	-	-	-	-	-	409	-	14	-	-	7.5	-	335.15	-	1269
5842621	1970	22	10	550	254	155	-	-	289.2	2300	64	4.7	0.4	7.2	3480	237	2417	6528

Table 3. (cont.)

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. (mΩ)
Hosston Member:																		
5842103	1966	-	12	29	17	202	11	-	250.2	338	43	1.6	1.5	8	778	205	142	1408
5842202	1977	-	-	13	4	338	-	-	339.3	313	132	3.3	3.28	8.3	973	278	48	1769
5842202	1965	-	-	25	11	319	-	-	356	295	151	3.3	0.4	7.9	979	291.72	107	1848
5842202	1968	-	-	12	5	328	-	-	329.5	287	114	3.8	2	8.4	919	280	50	1705
5842202	1986	-	12	11	5	344	11	-	344.1	325	144	3.3	3.23	8.3	1027	282	48	1858
5842202	1983	-	-	14	4	342	12	-	335.6	302	136	3.2	2.92	8.4	985	283	51	1840
5842207	1971	26	12	98	51	1580	-	-	450.3	437	2230	2.1	0.4	7.7	4631	369	454	9500
5842301	1949	-	13	52	46	1300	-	-	467	724	1410	-	13	8.2	3787	382.68	318	6070
5842302	1986	23	12	44	23	863	28	-	568.7	681	694	3.9	0.04	8.2	2628	466	204	4929
5842401	1974	-	-	34	14	226	6	-	205	395	38	1.6	3.9	8.4	826	180	142	1490
5842402	1985	-	-	343	176	40	18	-	436.9	1207	32	3.7	0.04	7.9	2034	358	1580	3926
5842405	1977	-	12	69	54	143	9	-	275.8	358	29	2.1	0.4	7.8	812	226	394	1590
5842410	1977	-	16	25	11	230	8	-	217.2	368	39	1	0.4	8.1	805	178	107	1377
5842411	1977	-	14	22	11	221	7	-	217.2	367	33	0.9	0.4	8.1	783	178	100	1368
5842501	1968	-	-	69	19	9	-	-	275.8	21	15	0.3	5	7.8	273	226	250	-
5842502	1986	26	13	13.6	5.83	239	8	-	269.7	291	50	3.5	0.04	8.1	756	221	57	1332
5842503	1955	-	-	-	-	-	-	-	637.2	-	367	-	-	8.1	-	522.13	-	2840
5842504	1955	24	4.4	25	77	65	-	-	312.1	220	26	-	0.04	8.2	570	255.74	379	940
5842505	1950	-	12	22	19	249	-	-	245.1	393	44	-	1.8	7.6	861	200.82	133	1290
5842506	1950	-	-	-	-	-	-	-	206	400	52	-	-	8.3	-	168.8	-	1380
5842507	1955	-	13	28	14	338	-	-	247.1	482	92	1.1	0.04	7.8	1089	202.46	127	1680
5842510	1949	-	8.5	248	208	47	-	-	352.1	1200	28	-	0.04	-	1912	288.52	1474	2330
5842701	1967	23	11	67	53	167	-	-	257.5	477	42	1.8	0.4	7.7	945	211	385	1716
5842702	1972	-	13	204	144	123	-	-	296.5	1020	38	2.4	0.4	7.8	1690	243	1101	3171
5842801	1955	-	17	47	33	365	-	-	287	612	118	2.8	0.3	8.3	1336	235.18	253	1980
5842802	1949	-	15	58	31	319	-	-	291	580	77	1	0.04	7.4	1224	238.46	272	1830
5842806	1971	-	15	38	24	375	-	-	378.3	530	128	1.5	0.4	7.8	1297	310	193	2352

Table 4. Chemical analyses of ground waters from the Paluxy Formation, Woodbine Formation, Eagle Ford Formation, and the Austin Chalk Group (contains the Bonham Formation) in Lamar 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. (mΩ)
Paluxy Formation:																		
1721709	1984	-	-	20	1	136	-	-	275.8	61	36	1.5	0.35	8.3	391	226	54	720
1727301	1974	-	16	5	5	407	-	-	781	149	72	3.8	3.1	8.3	1044	640	33	1890
1729103	1976	36	18	5	0.12	422	-	-	793.2	150	80	3.4	0.4	8.3	1068	650	12	1890
1729601	1983	43	20	5.2	1.7	473	-	-	706.6	189	195	3.8	0	8.4	1241	589	19	2256
Woodbine Formation:																		
1712101	1971	-	39	33.8	8.63	24	-	-	101.3	6	58	0.1	0.4	6.6	219	83	120	375
1712102	1993	18	31	64	20	88	2.2	0.4	168.4	5	167	0.09	2.74	6.6	463	138	242	719
1713402	1993	18	20	78	19	59	1.9	0.52	196.5	8	158	0.18	1.86	6.4	443	161	273	755
1726202	1993	24	15	1.4	0.3	390	2.4	0.13	566.2	157	151	1.82	0.04	8.5	1010	486	4	1605
Eagle Ford Formation:																		
1710801	1983	-	12	6.2	0.85	90	-	-	233.1	4	14	0.5	0.49	8.3	242	191	18	408
Austin Chalk Group:																		
1719401	1971	-	16	103	10	78	-	-	195.3	281	12	0.6	5.5	7.2	602	160	298	1032

Table 5. Most recent chemical analyses of ground waters from the alluvium, Calvert Bluff Formation, Simsboro Formation, and Hooper Formation.

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. (mΩ)
Alluvium:																		
5853105	1978	-	19	104	46	45	-	-	466	72	42	0.4	55	7.4	612	382	449	905
5862104	1949	-	24	94	8	18	-	-	298	29	23	-	3.8	8.2	346	244.26	270	568
5862204	1942	-	14	75	16	47	-	-	271	38	34	0.2	-	7.3	357	222.13	203	-
5862205	1958	-	-	91	21	20	-	-	329	51	33	0.2	5.8	7.4	383	269.67	-	630
5862206	1957	-	-	67	13	25	-	-	248	24	40	0.3	0.4	7.4	291	203.28	224	549
5862207	1957	-	-	66	15	26	-	-	240	29	41	0.3	-	7.3	295	196.72	-	572
5863917	1972	-	15	117	8	32	-	-	285	43	45	0.2	78	7.2	478	234	326	755
5864703	1952	21	22	87	8	29	-	-	290	20	30	-	19	7.6	357	237.7	253	597
5864711	1972	-	19	110	14	9	-	-	357	15	13	0.2	22	7.5	377	293	332	700
Calvert Bluff Formation:																		
5846304	1980	26	40	52	7	34	5	-	90	60	77	0.1	0.1	6.7	319	74	161	560
5846601	1952	-	23	21	9	66	-	-	180	25	40	-	0.5	8.3	273	147.54	88	462
5846606	1946	-	-	436	144	165	-	-	-	1640	255	-	1.2	-	-	-	1680	-
5847102	1956	-	-	-	-	-	-	-	49	120	270	-	0.6	7	-	40.15	-	1090
5847402	1953	-	117	18	9	33	-	-	8	83	44	-	-	5.7	307	6.56	83	366
5847701	1989	27	34	86	19	50	5.8	-	222.1	135	50	0.4	0.04	7	489	182	292	790
5847702	1955	-	-	236	77	232	-	-	250	631	390	-	-	-	1688	204.92	908	-
5847703	1964	24	49	150	39	99	-	-	184	350	166	0.3	-	6.2	943	150.82	534	1420
5847704	1964	24	37	122	33	70	-	-	242	264	83	0.5	-	6.9	728	198.36	440	1040
5847705	1964	-	46	64	15	27	4.8	-	166	77	50	0.3	0.2	7.3	365	136.07	221	568
5847706	1966	-	46	300	61	53	6	-	364	612	119	-	-	6.7	1375	298.36	1000	-
5847708	1972	-	92	64	27	65	-	-	0	103	222	0.2	0.4	5.1	573	0	270	900
5847905	1965	27	27	24	5	70	-	-	216	27	20	0.3	0.2	7.4	279	177.05	83	449
5854203	1953	21	20	28	6	28	-	-	46	23	29	-	70	6.9	226	37.7	98	370
5854515	1981	-	51	474	103	103	6	-	521.1	879	315	0.2	0.04	8.1	2187	427	1606	4134
5855103	1972	-	53	62	14	25	-	-	148	66	53	0.9	0.4	7	347	121.31	210	584
5855105	1964	24	44	154	50	69	-	-	270	302	144	0.4	0	6.5	896	221.31	590	1340
5855201	1988	25	23	48.4	8.98	29	6.9	-	122	40	62	0.1	0.04	6.9	278	100	158	474
5855504	1980	24	42	61	11	26	8	-	200	57	32	0.1	0.1	7.7	335	164	199	481
5855704	1980	26	17	37	9	67	4	-	231	62	22	0.1	0.3	8.1	331	189	129	592
5855706	1953	24	22	25	8	73	-	-	224	44	18	-	0.2	8.1	300	183.61	96	487

Table 5. (cont.)

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. (mΩ)
Calvert Bluff Formation (cont.):																		
5861304	1953	22	44	72	6	34	-	-	131	124	17	-	21	6.9	382	107.38	204	576
5861801	1946	-	-	-	-	-	-	-	364	120	202	-	52	-	-	335.03	-	-
5862107	1966	-	14	2	2	258	1.5	-	568	51	42	0.4	0.2	8	650	465.57	14	1080
5862110	1966	26	14	3	2	288	1.6	-	632	48	56	0.7	0	8.1	724	518.03	14	1700
5862302	1980	27	18	39	9	120	5	-	253	145	36	0.1	0.1	8	496	207	134	900
5862303	1989	-	8.43	34.51	8.31	69.91	4.51	-	224.5	52	29	0.1	0.04	8.3	317	184	120	-
5862406	1977	29	13	9	3	199	-	-	315	145	48	0.2	0.4	8.1	572	258	34	920
5862506	1980	26	13	8	3	210	-	-	315	152	52	0.3	1.2	8.5	598	264	31	1050
Simsboro Formation:																		
5846204	1950	-	42	93	48	194	-	-	100	66	490	-	11	7.7	993	81.97	430	1840
5846301	1950	-	28	139	50	198	-	-	132	46	580	-	11	7.2	1116	108.2	552	2140
5846303	1955	-	42	43	11	45	6.4	-	40	42	132	0.1	-	6.5	341	32.79	152	611
5846410	1980	-	-	-	-	-	-	-	-	10	-	-	-	6.1	-	-	-	-
5846501	1972	-	-	40	10	49	-	-	22	39	133	0.2	0.4	5.8	282	18	143	608
5846502	1951	-	21	22	5	25	-	-	39	14	60	-	-	5.8	166	31.97	77	-
5846503	1950	-	-	-	-	-	-	-	82	180	256	-	-	7.6	-	67.19	-	1440
5846508	1966	23	30	36	4	20	3.7	-	84	15	46	0.1	0.2	6.3	196	68.85	104	335
5846509	1943	-	30	27	9	50	5.8	-	26	30	118	0.4	1	7.4	283	21.31	104	-
5846510	1951	-	12	27	6	30	-	-	39	22	76	-	0.05	5.7	192	31.97	96	-
5846511	1967	-	26	9	3	26	-	-	21	12	43	-	-	5.3	129	17	33	224
5846512	1980	22	10	26	7	32	6	-	16	32	86	0.1	0.4	6.1	207	13	93	423
5846516	1989	25	34	43	8.1	39	3.8	-	153.8	20	49	0.2	0.04	6.5	272	126	140	460
5846611	1989	26	52	68	12	33	4.2	-	136.7	91	59	0.2	0.04	6.8	386	112	219	645
5846707	1966	-	20	52	13	42	3	-	226	59	26	0.2	-	7.5	326	185.25	183	548
5847109	1966	-	29	130	16	37	3.2	-	300	105	83	0.2	0.2	6.7	551	245.9	390	914
5853809	1967	-	36	24	4	23	1.5	-	78	60	42	0.4	0.2	6.6	229	63.93	75	277
5853905	1953	-	34	95	19	66	-	-	294	92	85	-	0.5	7.4	536	240.98	315	915
5854205	1978	-	44	89	16	22	-	-	228	88	37	0.3	0.4	7.8	408	187	287	700
5854305	1980	-	-	-	-	-	-	-	-	69	-	-	-	7.4	-	-	-	-
5854306	1980	-	-	-	-	-	-	-	-	140	-	-	-	7.3	-	-	-	-
5854403	1988	23	13	51.4	10.6	28	3.4	-	244	11	27	0.4	0.1	7.4	264	200	172	463
5854501	1946	26	36	78	12	49	-	-	244	74	52	0.4	0	7.3	421	200	244	-

Table 5. (cont.)

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. (mΩ)
Simsboro Formation (cont.):																		
5854502	1946	27	-	78	11	47	-	-	236	68	54	0.4	-	7.4	374	193.44	240	-
5854503	1980	27	41	94	8	32	-	-	231	75	52	0.3	0.1	7.7	415	189	270	735
5854504	1946	27	-	66	12	61	-	-	243	74	49	0.4	0	7.3	381	199.18	214	-
5854505	1946	27	-	68	12	68	-	-	243	85	55	0.4	0	7.2	407	199.18	219	-
5854506	1975	-	-	87	12	26	-	-	238	71	40	0.3	8	-	361	195	266	-
5854507	1944	-	-	81	12	30	-	-	244	59	39	0.4	0.4	7.3	341	200	252	-
5854508	1942	-	-	74	11	32	-	-	206	61	48	-	-	-	327	168.85	230	-
5854513	1980	-	-	-	-	-	-	-	-	2000	-	-	-	6.6	-	-	-	-
5854516	1993	27	35	88	10	28	3.4	0.46	222.1	66	41	0.24	0.04	7.1	381	182	261	591
5854702	1953	-	28	82	8	20	-	-	294	30	8	-	0.2	7.8	320	240.98	238	556
5854705	1967	-	29	46	5	26	3.6	-	168	15	28	0.3	0.2	7	235	137.7	135	384
5854707	1978	-	23	55	8	33	3	-	205	45	27	0.2	0.4	8.3	295	168	171	504
5854801	1980	28	22	35	4	121	-	-	375	0	42	0.2	0.1	7.8	408	307	105	750
5855209	1993	36	22	12	4	80	3.4	1.11	214.8	23	12	0.18	0.04	8	263	176	47	362
5861203	1953	-	46	148	22	65	-	-	262	80	214	-	0.4	6.9	704	214.75	460	1230
5861305	1956	-	-	-	-	-	-	-	124	-	24	-	-	6.9	-	101.61	-	737
5861307	1960	-	36	106	14	41	-	-	137	260	18	1	0	6.3	543	112.3	322	756
5862114	1987	-	-	7	2	256	-	-	464	103	58	0.4	0.04	8.6	665	398	24	1215
5862115	1989	26	14	5.9	3.6	279	3.4	-	521.1	82	54	0.3	0.04	8.2	700	431	29	1100
5862116	1993	26	14	3.9	2	340	3.7	0.36	649.2	36	107	1.24	0.04	8.5	839	552	18	1223
5862305	1986	-	-	3	1	432	-	-	647	4	279	2.3	0	8.3	1053	554	14	1800
5862409	1987	-	-	4	2	325	-	-	655	56	81	1.4	0.04	9.1	804	559	19	1485
Hooper Formation:																		
5838802	1950	-	34	18	7	68	-	-	139	15	56	-	15	7.9	281	113.93	73	462
5838906	1983	-	43	62	11	29	-	-	149	29	84	0.2	0	7.7	331	122	202	525
5845905	1950	23	-	-	-	-	-	-	233	120	240	-	-	8.4	-	222.59	-	1400
5845906	1976	-	29	222	42	117	-	-	422	213	294	0.3	1.3	7.4	1126	346	730	1740
5846101	1950	-	32	70	15	51	-	-	248	22	86	-	0	8.2	397	203.22	236	691
5846102	1950	-	12	165	68	258	-	-	334	191	550	-	3.5	7.4	1411	273.69	691	691
5846103	1950	-	71	6	4	57	-	-	115	14	24	0	14	6.8	246	94.26	30	316
5846105	1957	-	39	43	13	169	-	-	201	83	197	-	-	7.2	642	164.75	161	1140
5846206	1980	23	46	110	2	42	-	-	337	26	53	0.2	0.1	7.6	445	276	281	648

Table 5. (cont.)

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. (mΩ)
Hooper Formation (cont.):																		
5846207	1950	-	32	94	17	72	-	-	266	22	144	0	21	7.2	532	218.03	304	952
5846208	1980	24	28	71	11	52	-	-	256	27	68	0.3	0.1	7.7	383	210	223	592
5846211	1980	25	36	140	10	24	-	-	277	31	130	0.1	0.1	8.5	514	239	392	775
5846402	1966	-	-	-	-	-	-	-	398	33	8	-	-	8.8	-	-	-	778
5846413	1980	-	-	-	-	-	-	-	-	69	-	-	-	7.4	-	-	-	-
5846504	1980	-	-	-	-	-	-	-	-	30	-	-	-	7.1	-	-	-	-
5846513	1970	-	29	72	12	51	-	-	235	22	88	-	-	8.1	389	193	229	-
5846515	1993	26	35	65	11	40	3.7	0.44	242.9	23	39	0.44	0.04	7.7	337	199	207	548
5854706	1980	26	15	10	3	214	-	-	381	16	125	0.3	3	8.3	573	-	39	1057
5860307	1946	22	-	-	-	-	-	-	234	100	69	-	41	-	-	191.75	-	-
5860308	1946	22	-	-	-	-	-	-	372	20	52	-	12	-	-	304.83	-	-
5861110	1974	-	31	18	7	256	-	-	394	5	216	0.5	2.5	-	729	323	74	1170
5861206	1988	25	13	71.5	13.9	43	4.5	-	280.6	17	90	0.2	0.04	7.6	391	230	236	700

Table 6. Chemical analyses of 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. (mΩ)
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

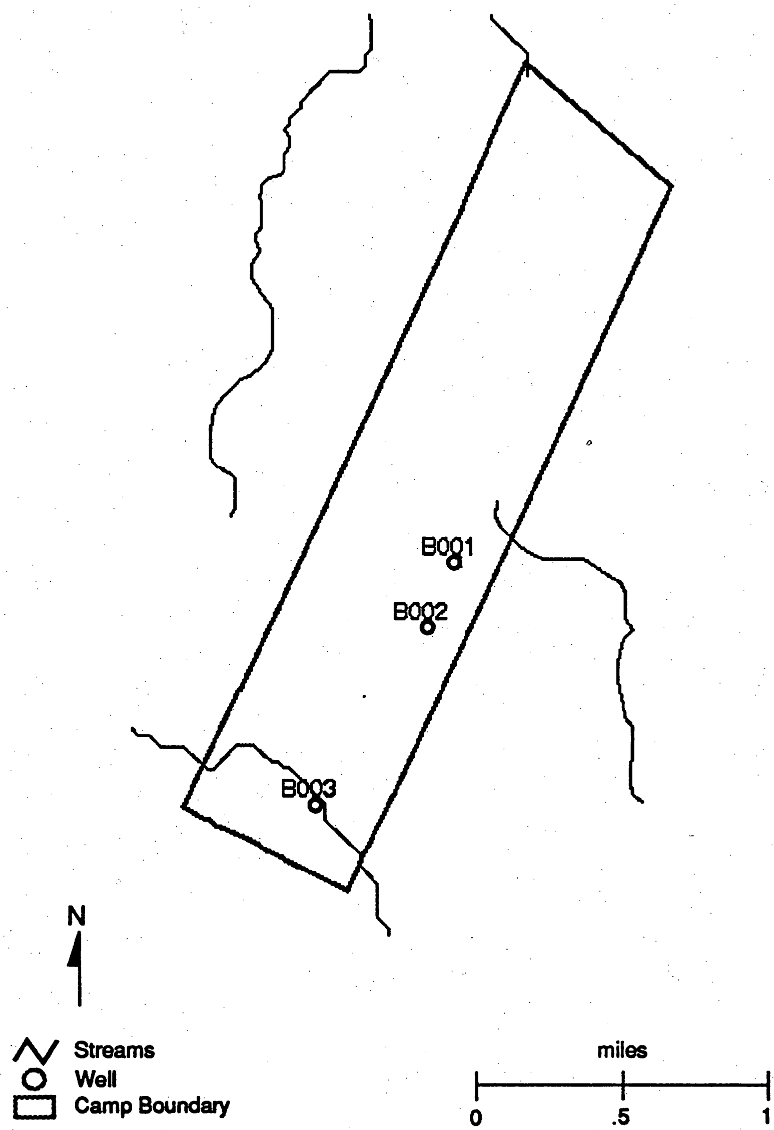


Figure 1. Wells on Camp Barkley.

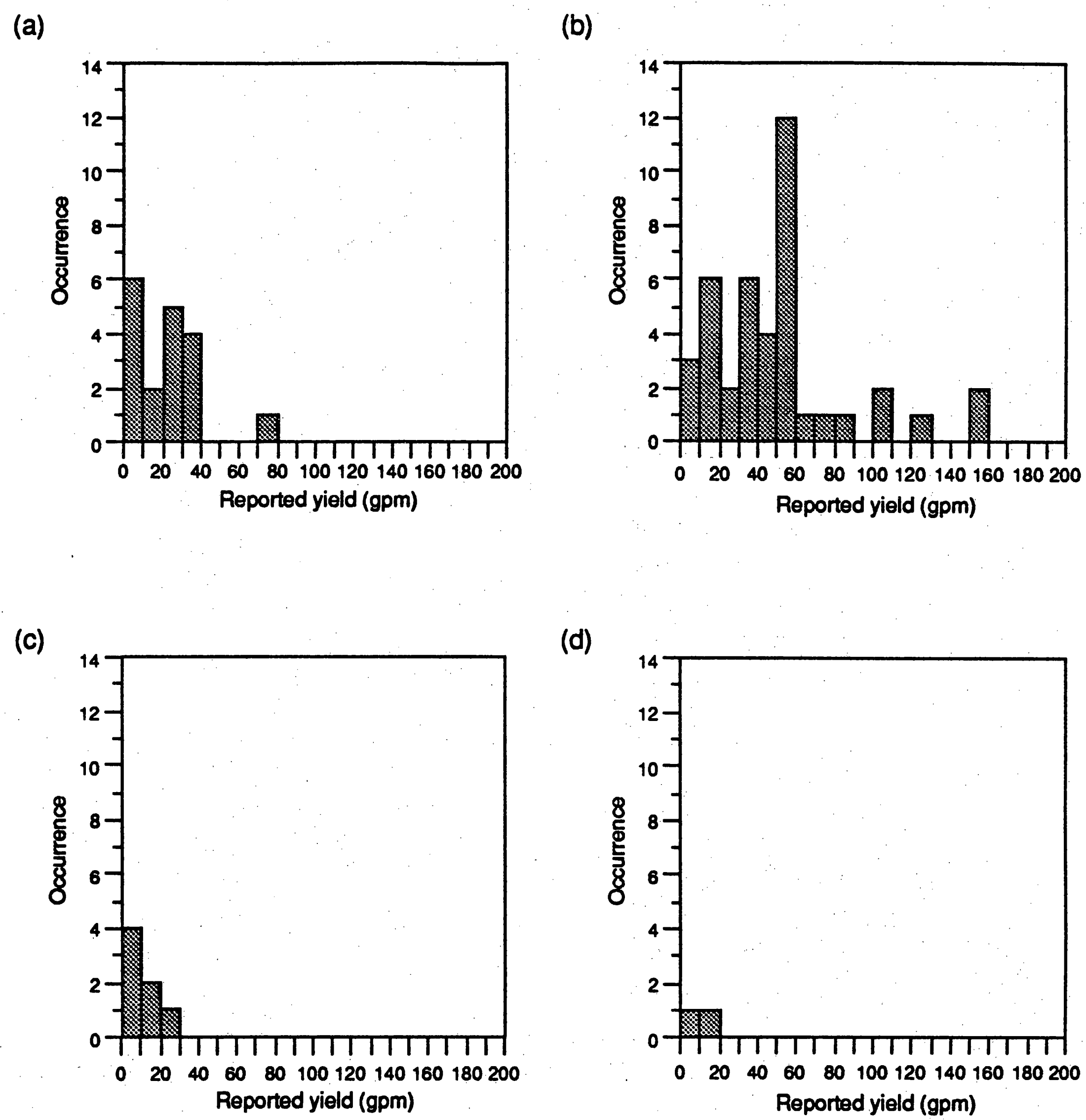


Figure 2. Well yields reported for the (a) Antlers Formation, (b) Choza Formation, (c) Fredricksburg Group, and (d) the Vale Formation in Taylor County

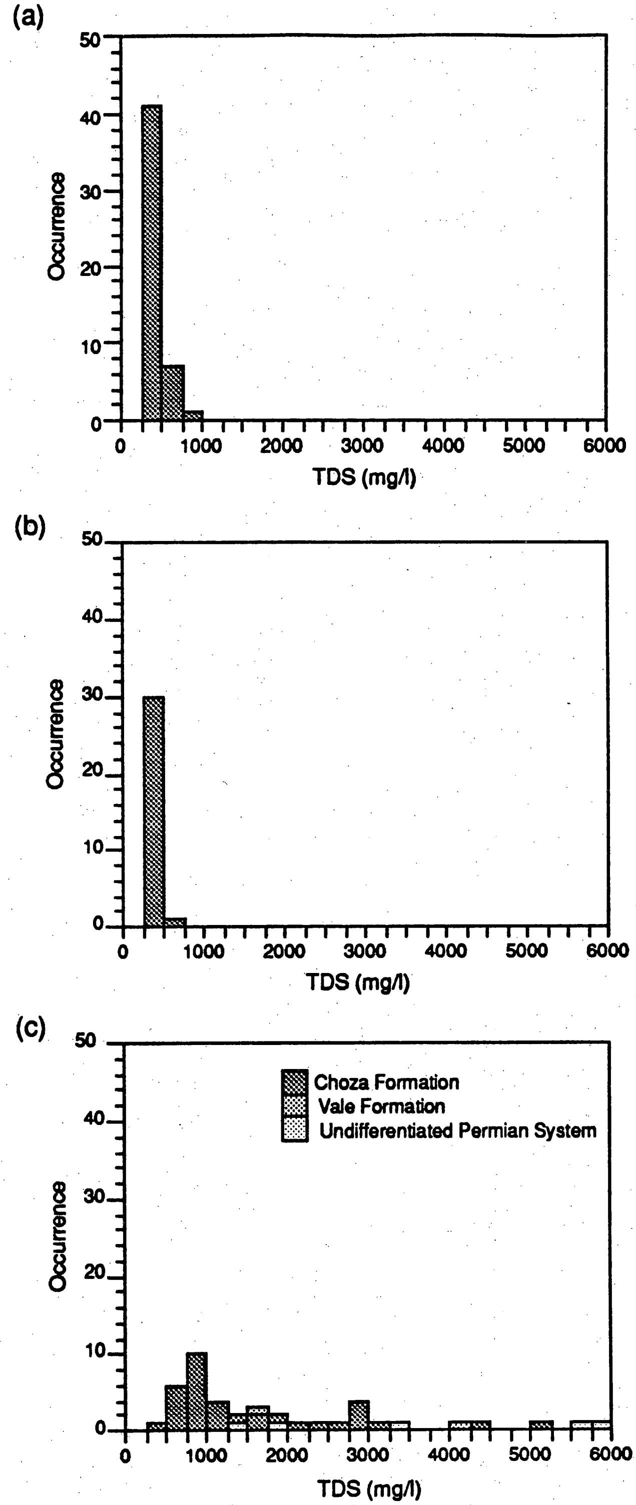


Figure 3. Histograms of total dissolved solids (TDS) in (a) the Antlers Formation, (b) the Fredricksburg Group, and (c) the Permian System in Taylor County

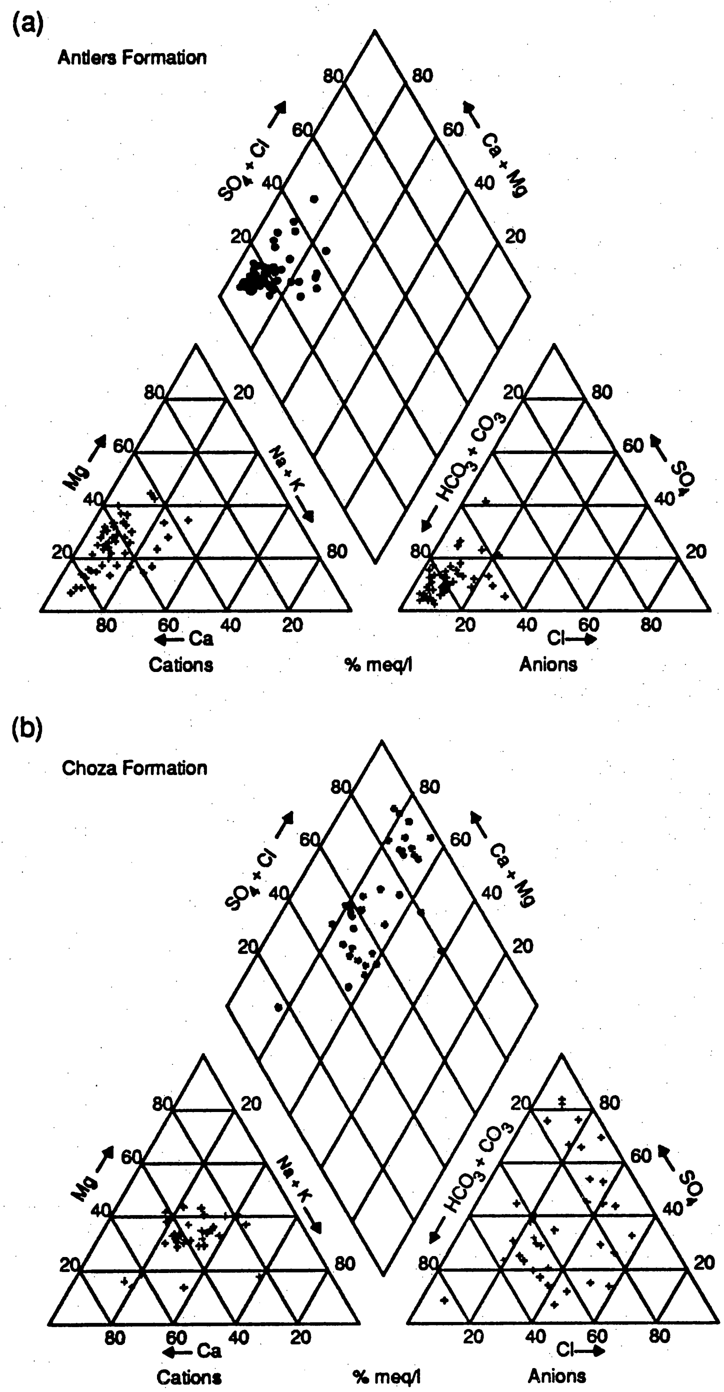


Figure 4. Trilinear diagram showing chemical composition of ground-water samples from the (a) Antlers and (b) Choza Formations in Taylor County.

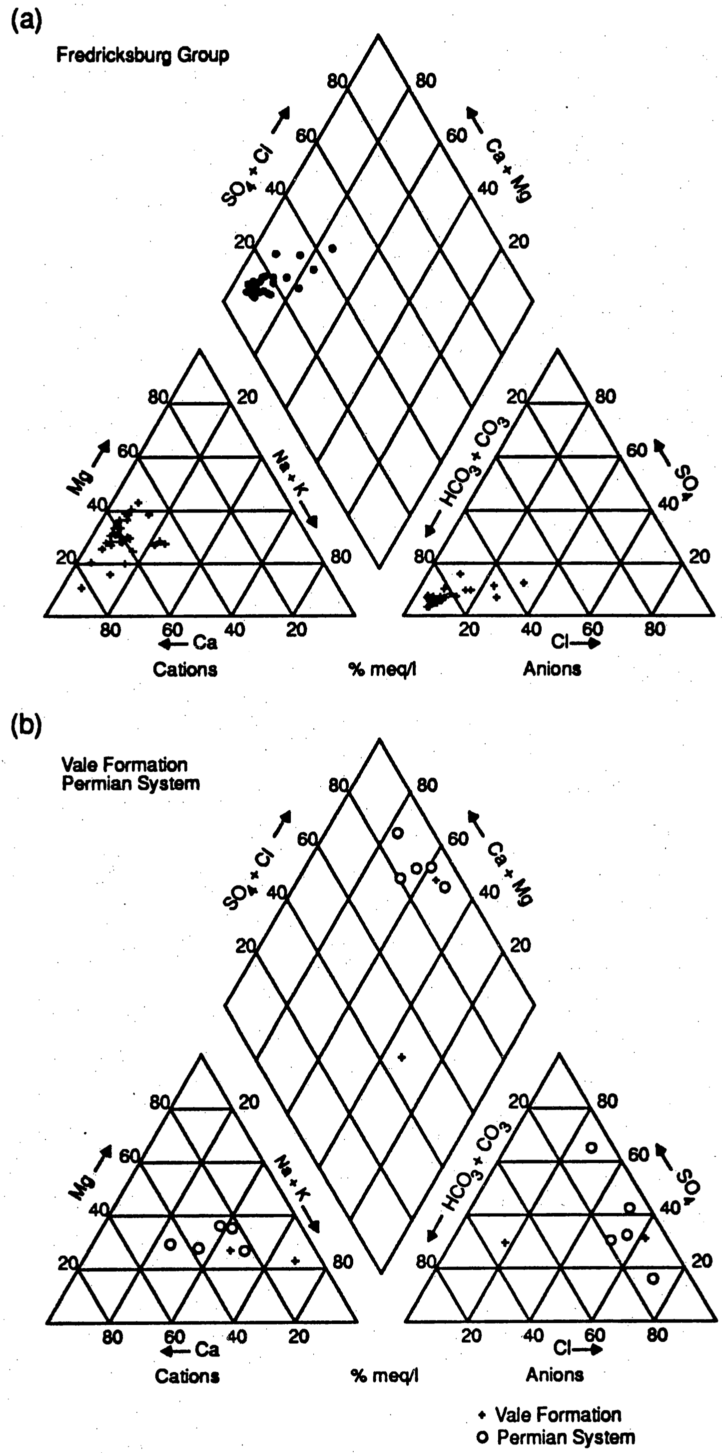


Figure 5. Trilinear diagram showing chemical composition of ground-water samples from (a) the Fredricksburg Group and (b) the Vale Formation and Permian System in Taylor County.

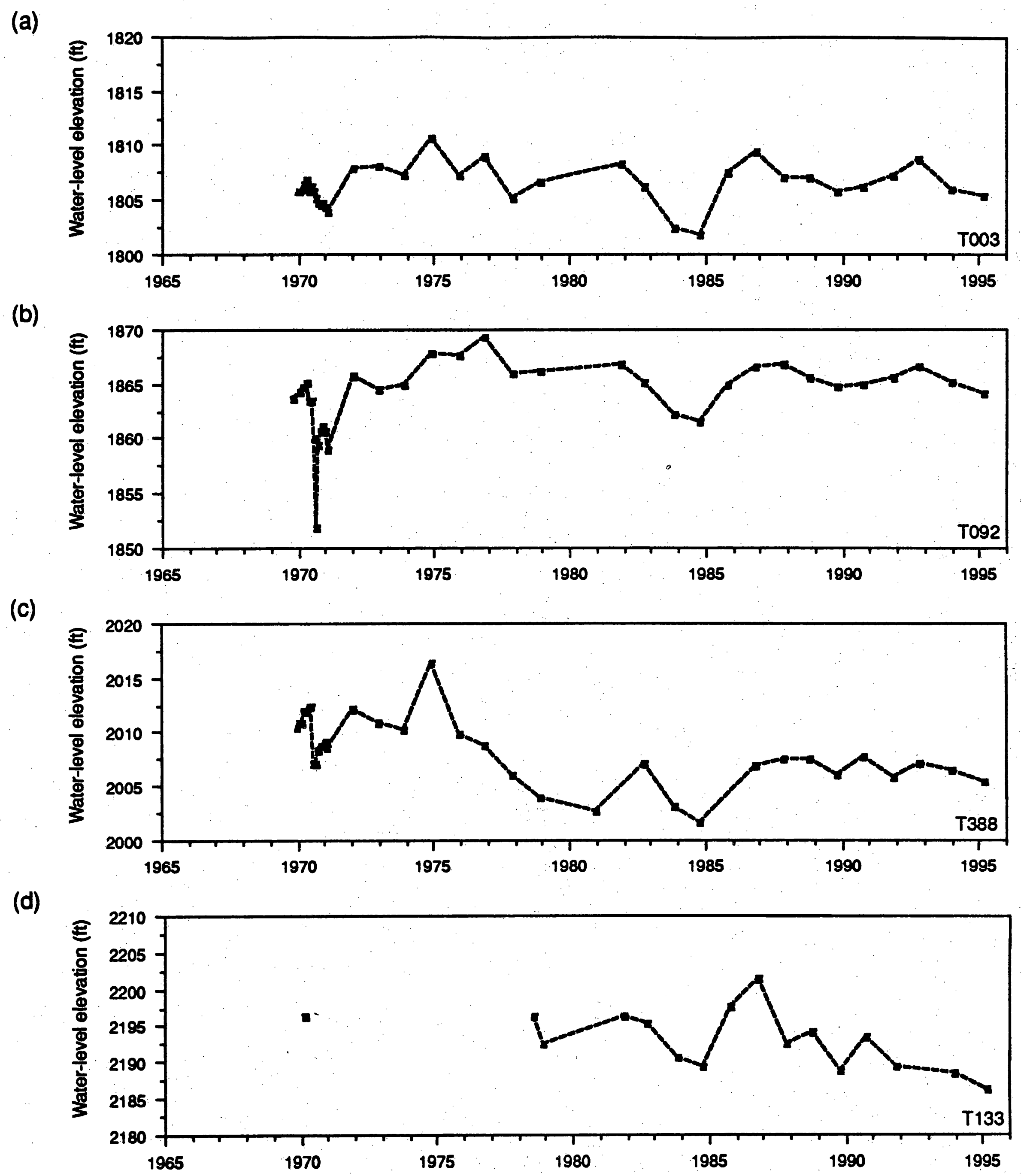


Figure 6. Water levels measured in the Choza Formation in wells (a) 29-32-913 and (b) 29-40-601, in the alluvium of Elm Creek in well (c) 30-50-118, and in the Antlers Formation in well (d) 29-48-601 for Taylor County.

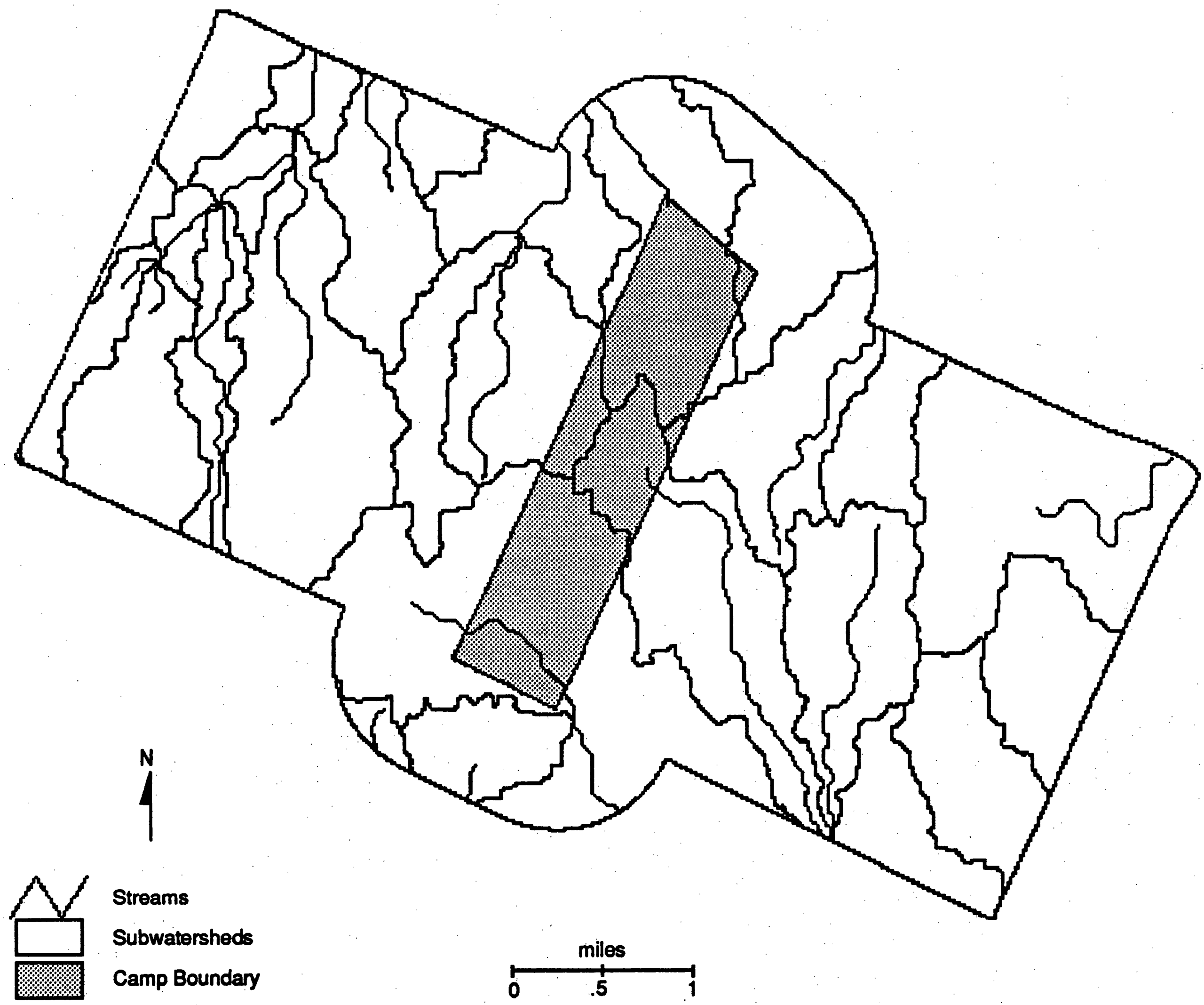


Figure 7. Watershed delineations for Camp Barkley.

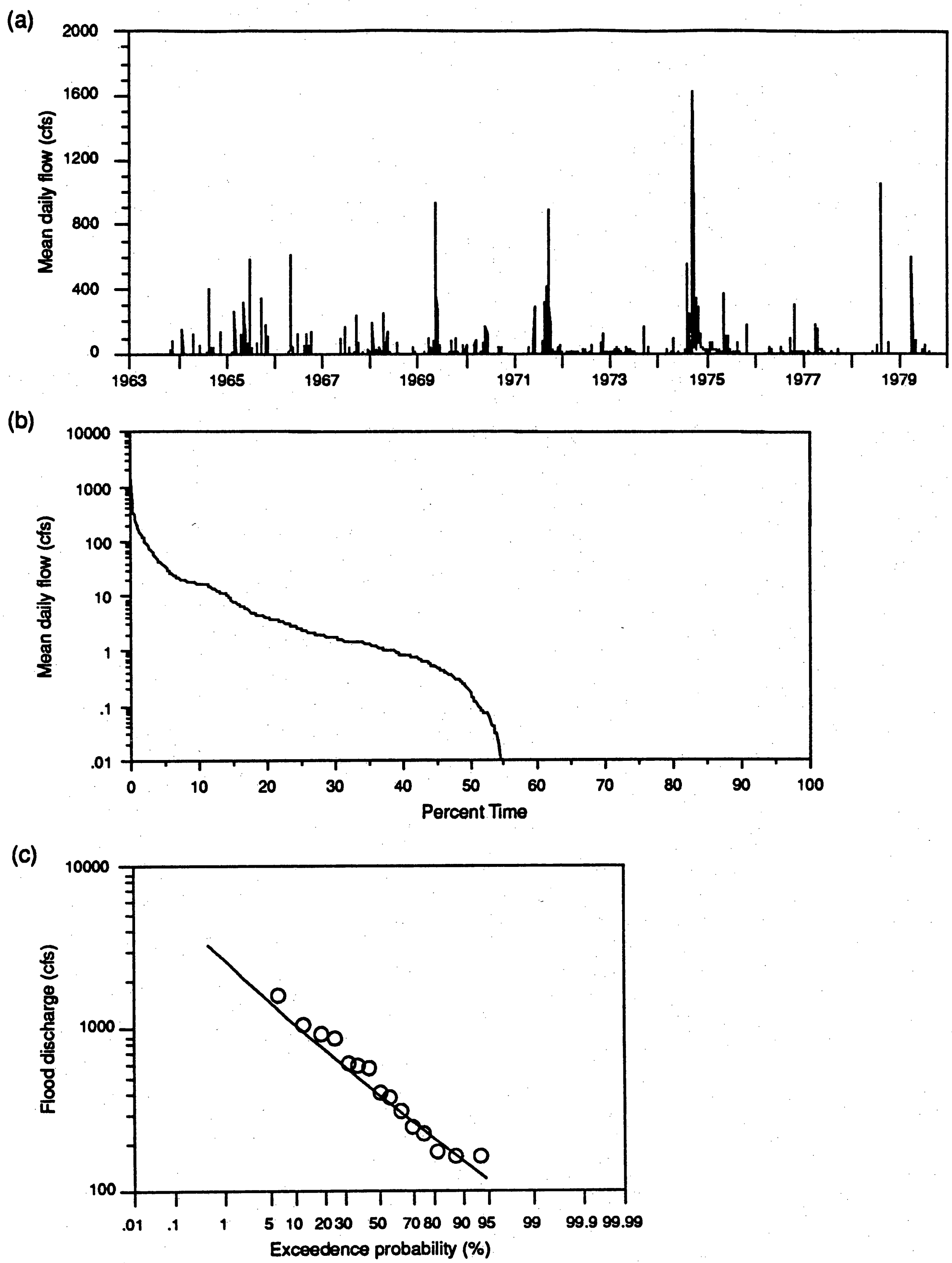


Figure 8. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis with a Log Pearson III fit for a stream gauge on Elm Creek near Abilene.

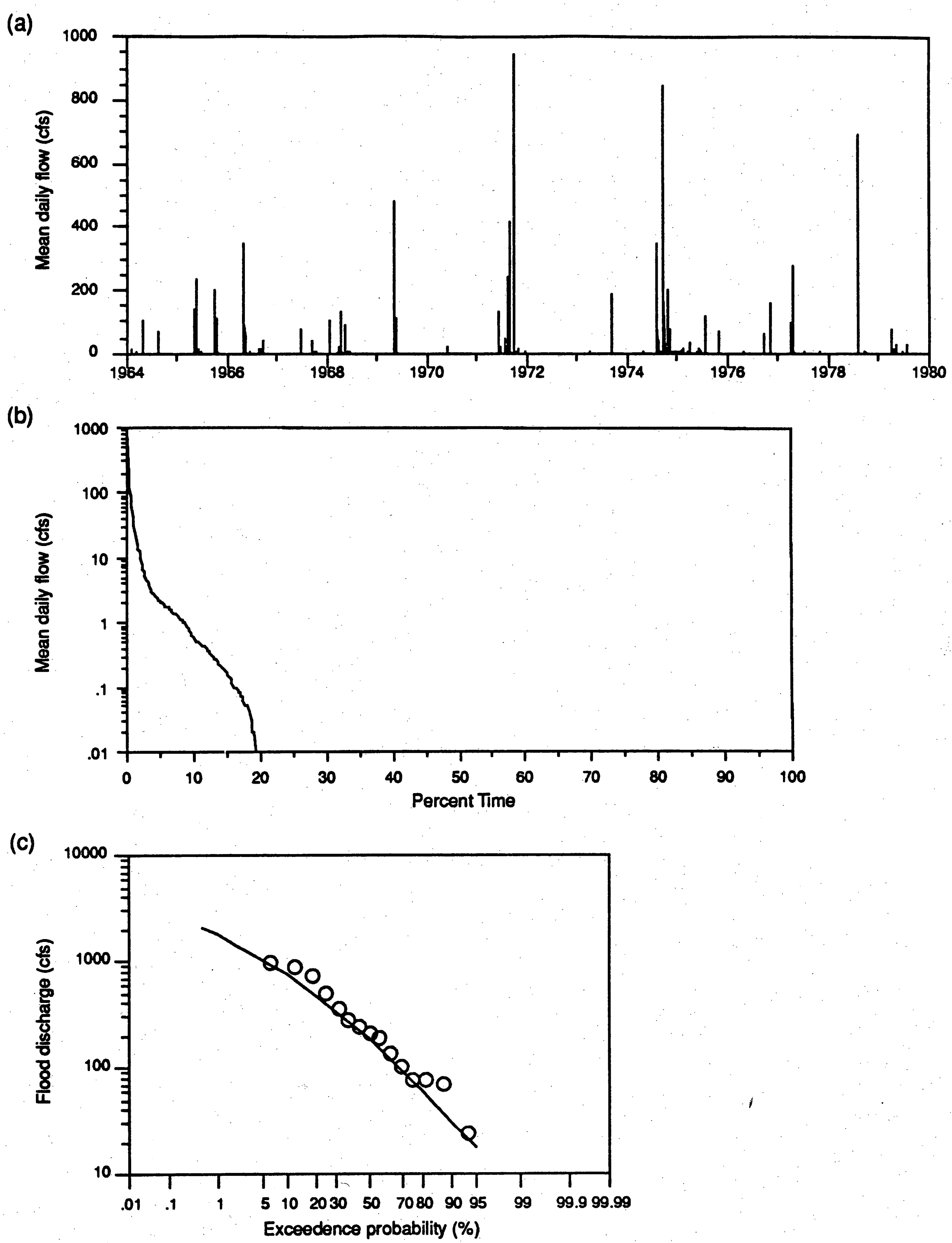


Figure 9. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis with a Log Pearson III fit for a stream gauge on Little Elm Creek near Abilene.

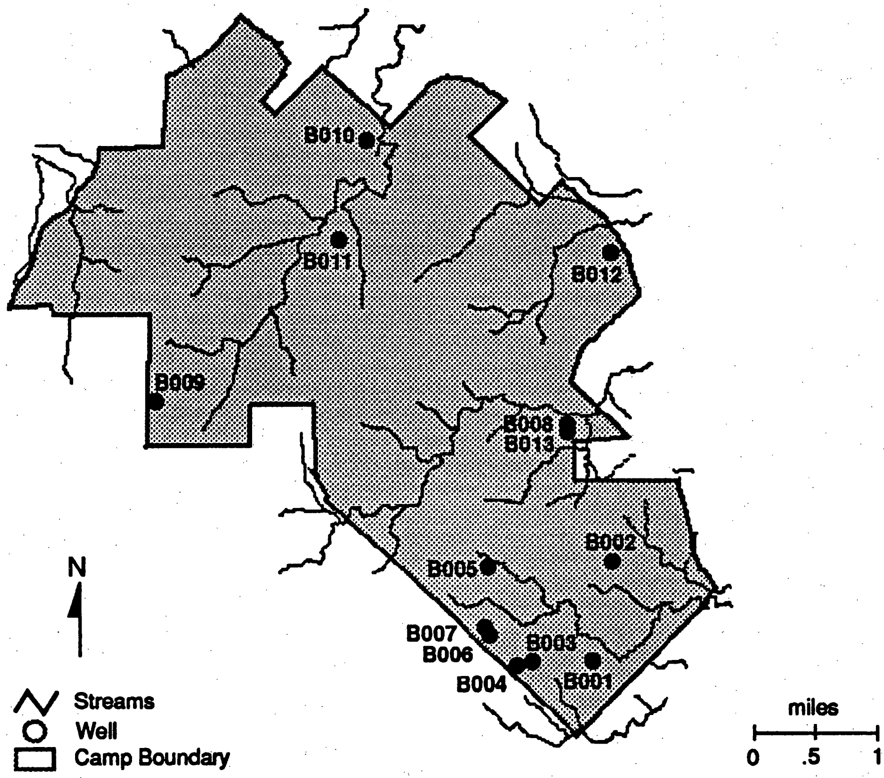


Figure 10. Well locations on Camp Bowie.

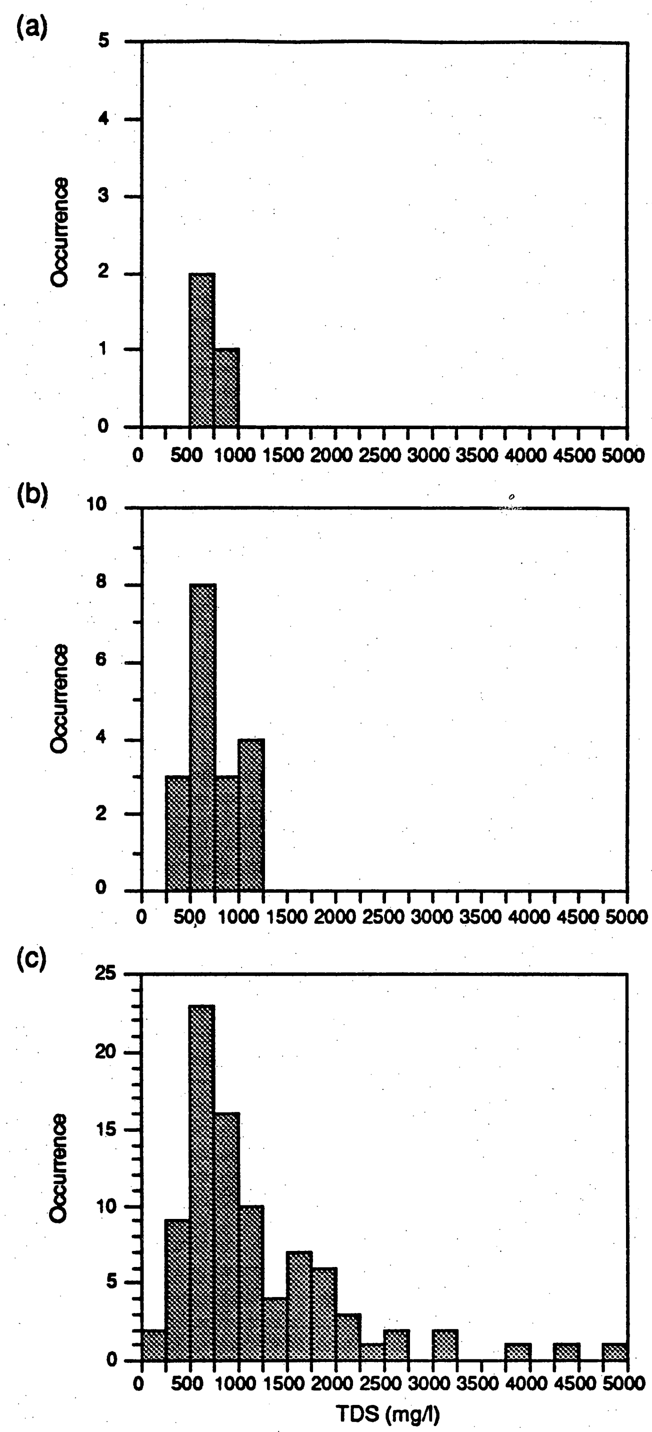


Figure 11. Histograms of total dissolved solids (TDS) in (a) the allvium, (b) the Travis Peak Formation, and (c) the Strawn Group of Brown County.

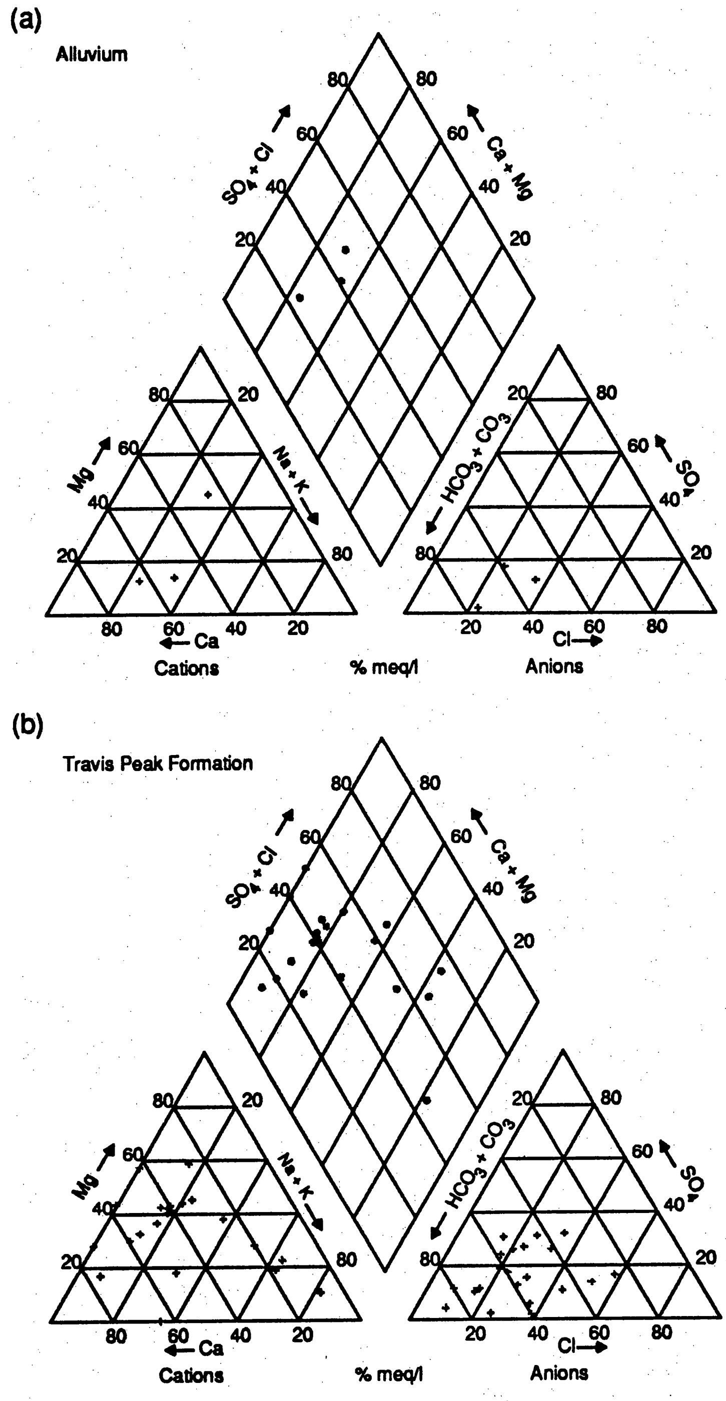


Figure 12. Trilinear diagram showing chemical composition of ground-water samples from the (a) alluvium and (b) the Travis Peak Formation in Brown County.

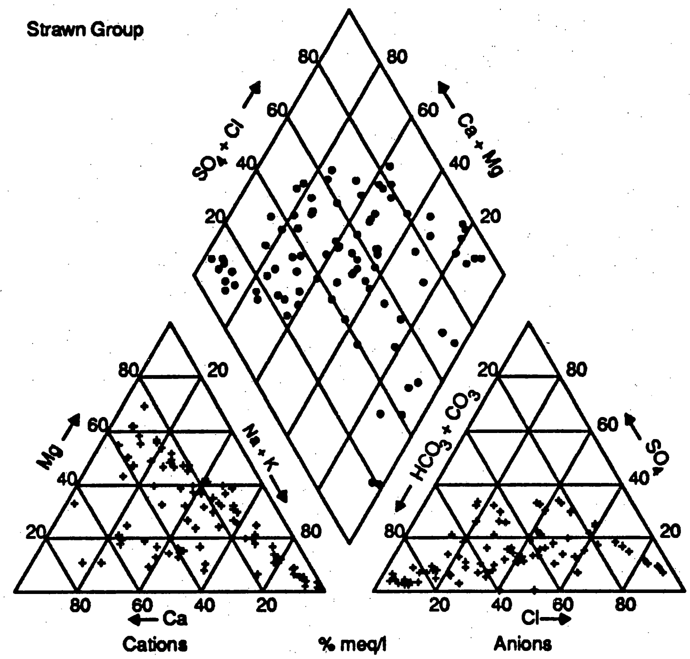


Figure 13. Trilinear diagram showing chemical composition of ground-water samples from the Strawn Group of Brown County.

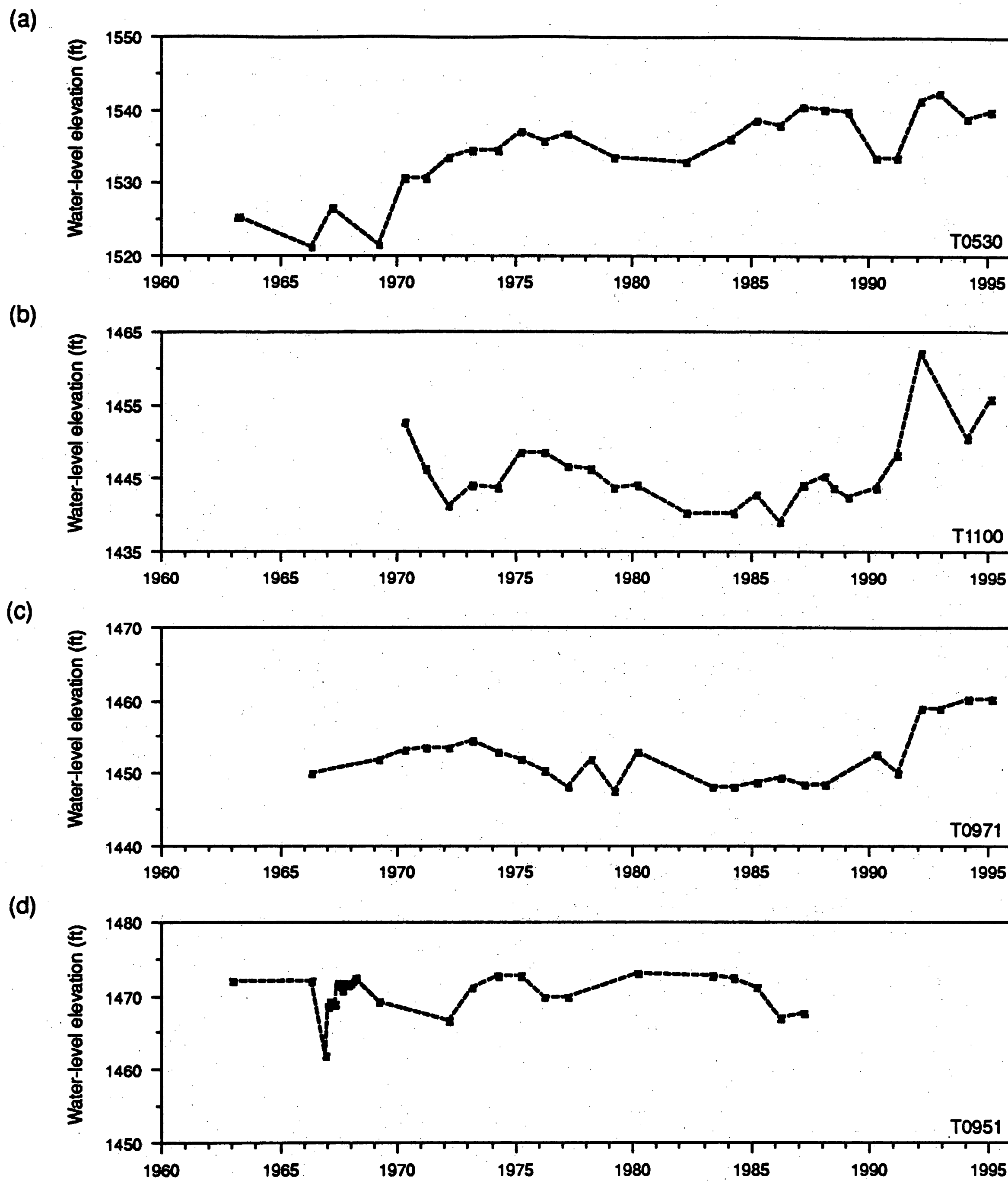


Figure 14. Water levels measured in the Travis Peak Formation for wells (a) 41-09-303, (b) 41-18-650, (c) 41-18-303, and (d) 41-18-205 in Brown County.

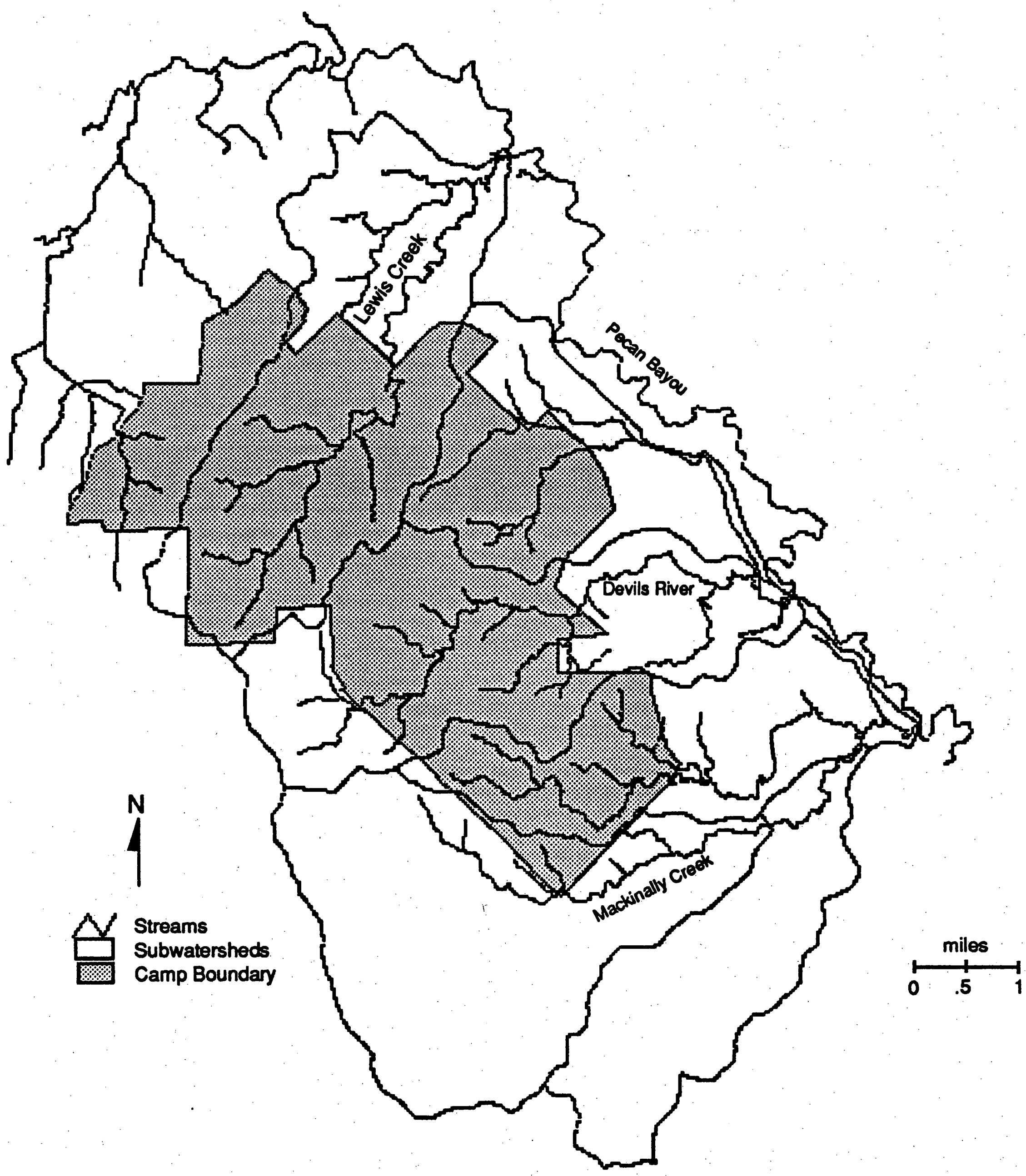


Figure 15. Watershed delineations for Camp Bowie.

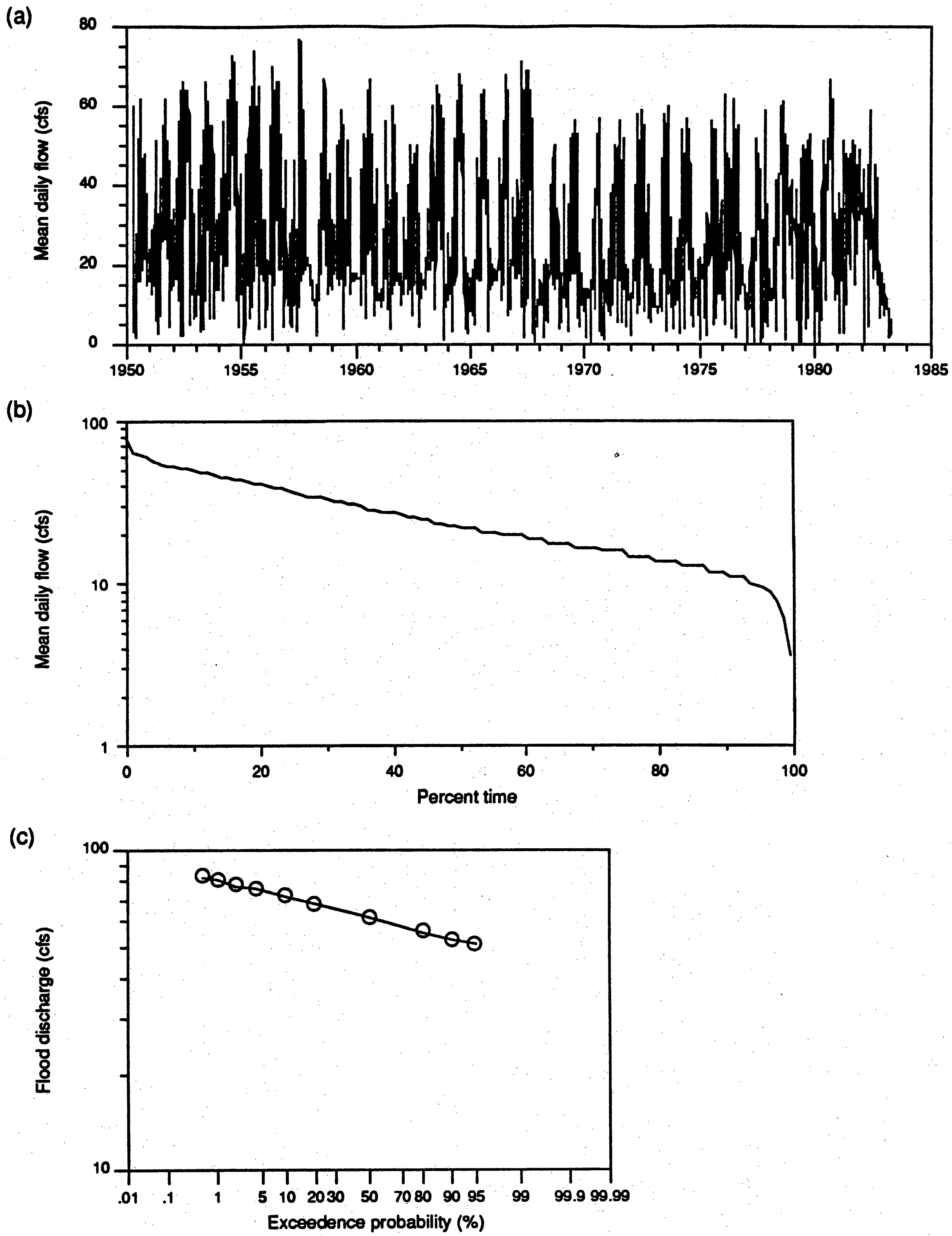


Figure 16. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis with a Log Pearson III fit for a stream gauge on Brown County WID No 1 Canal near Brownwood.

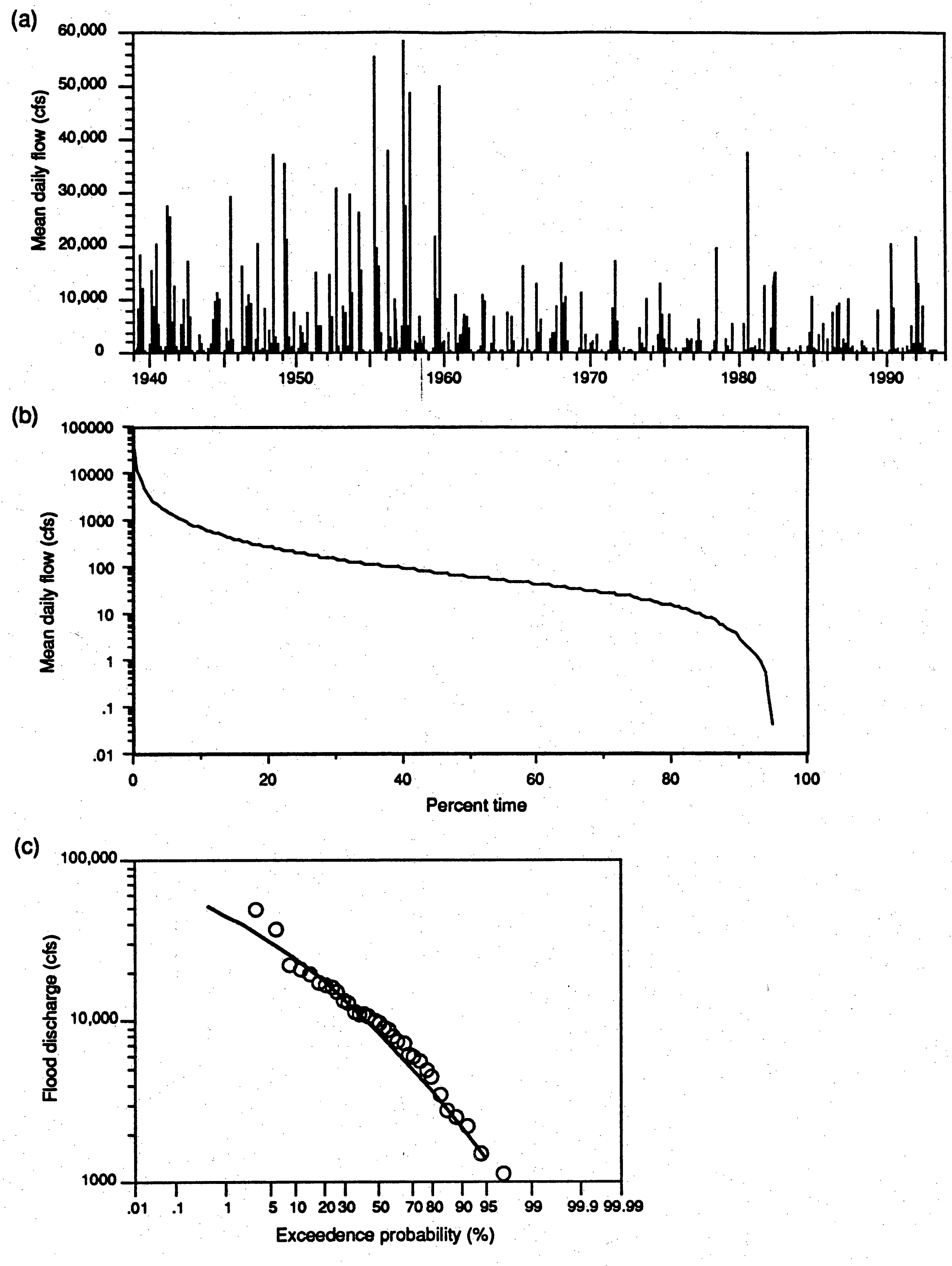


Figure 17. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis with a Log Pearson III fit for a stream gauge on the Colorado River near Winchell.

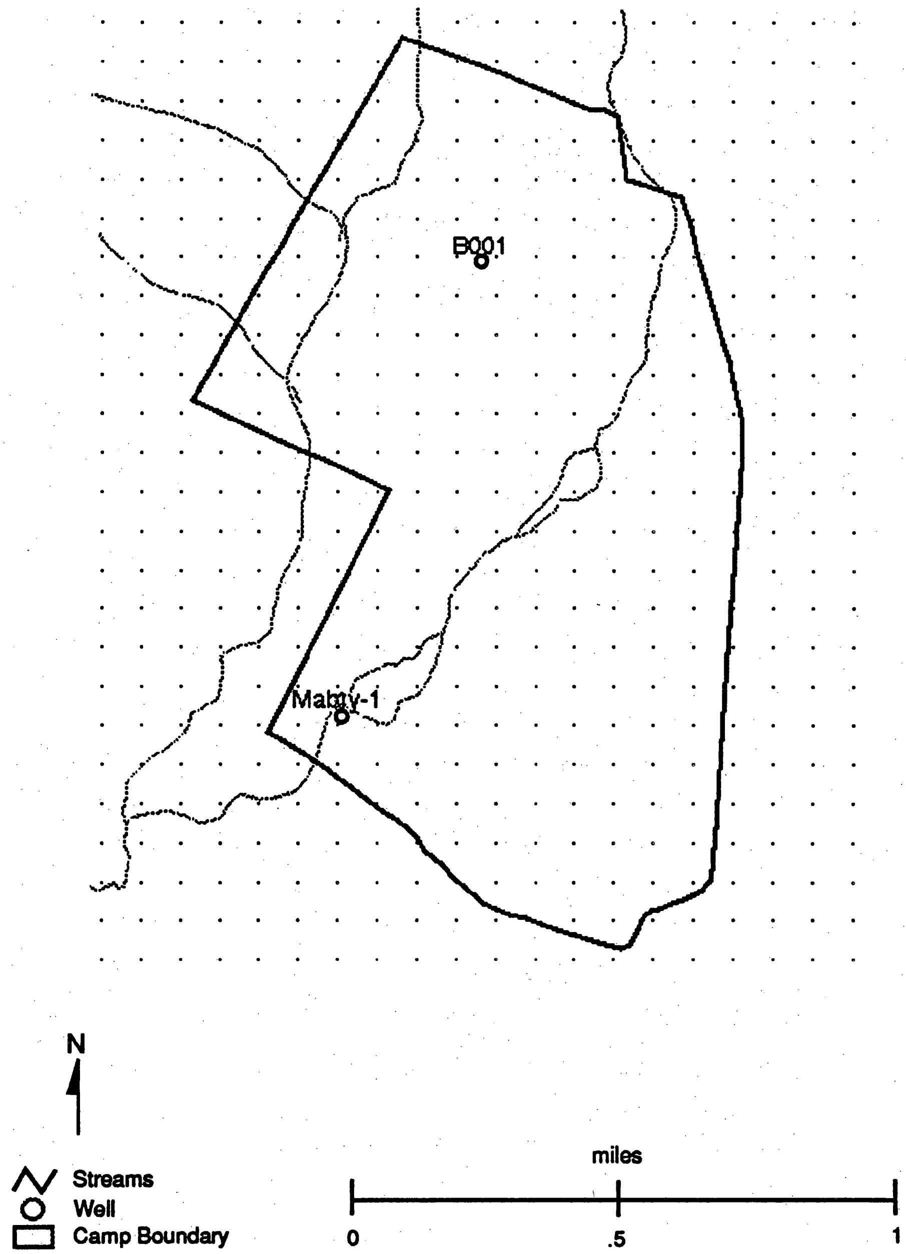


Figure 18. Well locations on Camp Mabry.

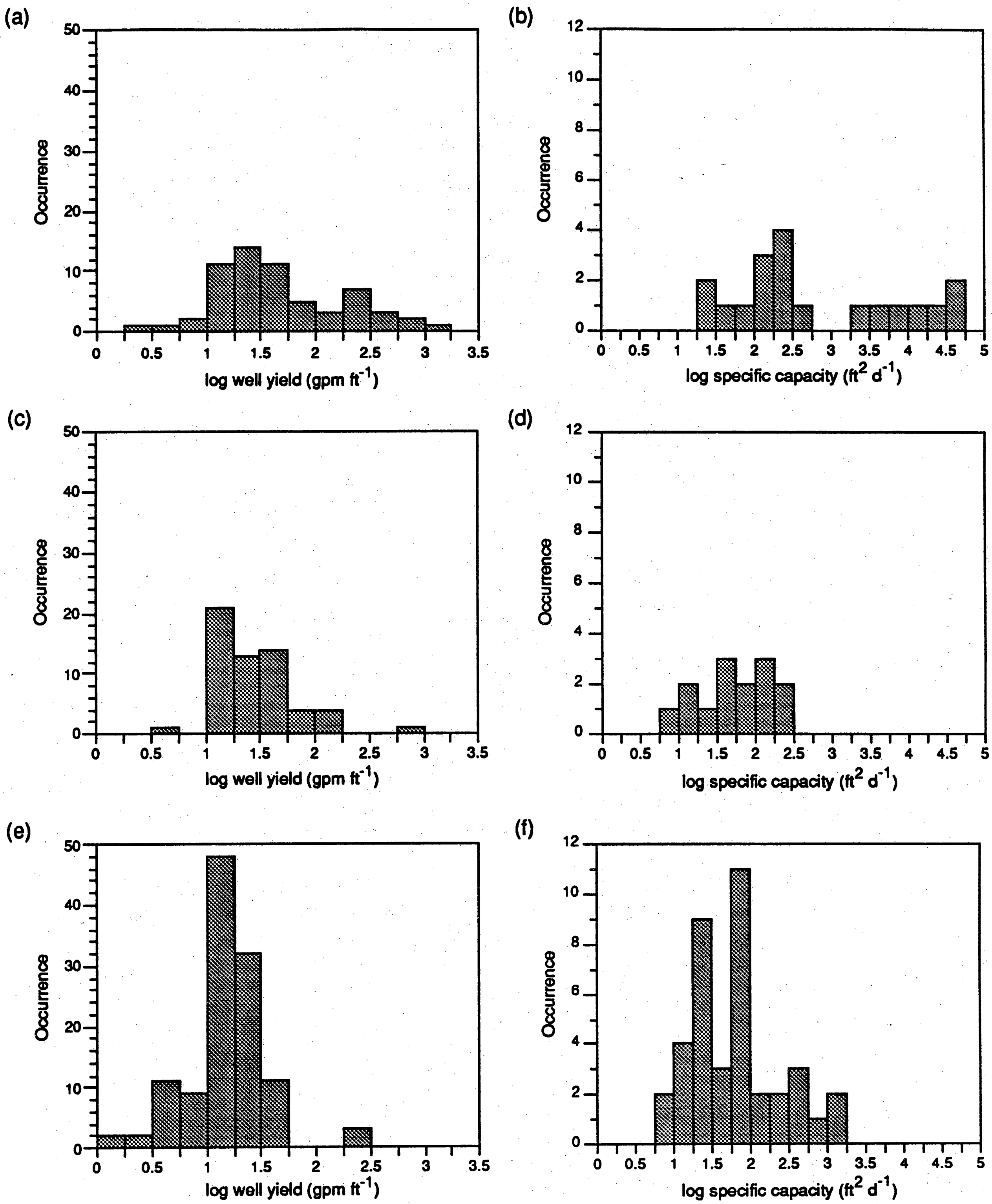


Figure 19. Well yields and specific capacity for the Edwards and associated limestones (a, b), the Lower trinity (c, d), and the Glen Rose Formation (e, f).

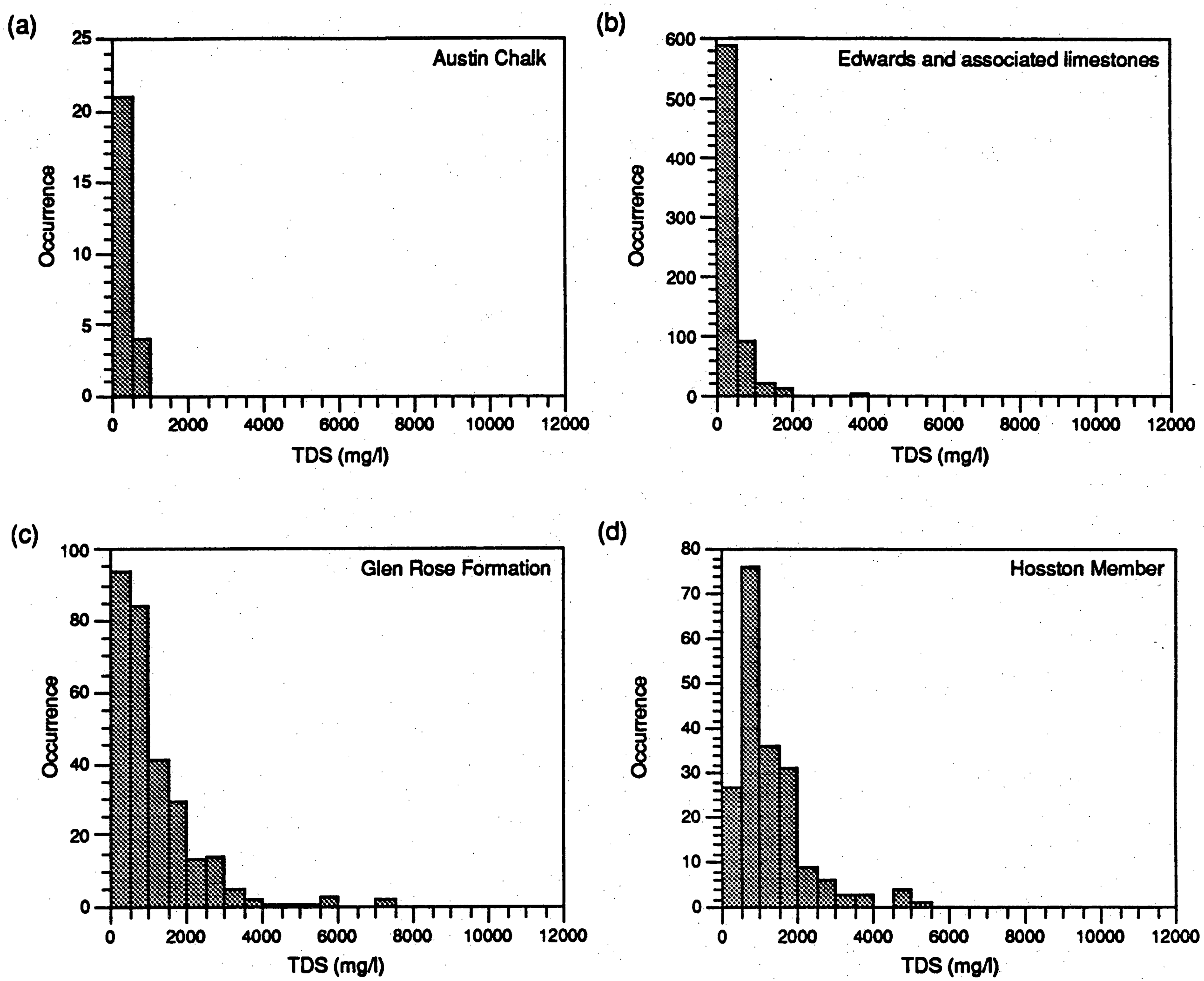


Figure 20. Histograms of total dissolved solids (TDS) in (a) the Austin Chalk, (b) the Edwards and associated limestones, (c) the Glen Rose Formation, and (d) the Hosston Member of the Travis Peak Formation (Lower Trinity) in Travis County.

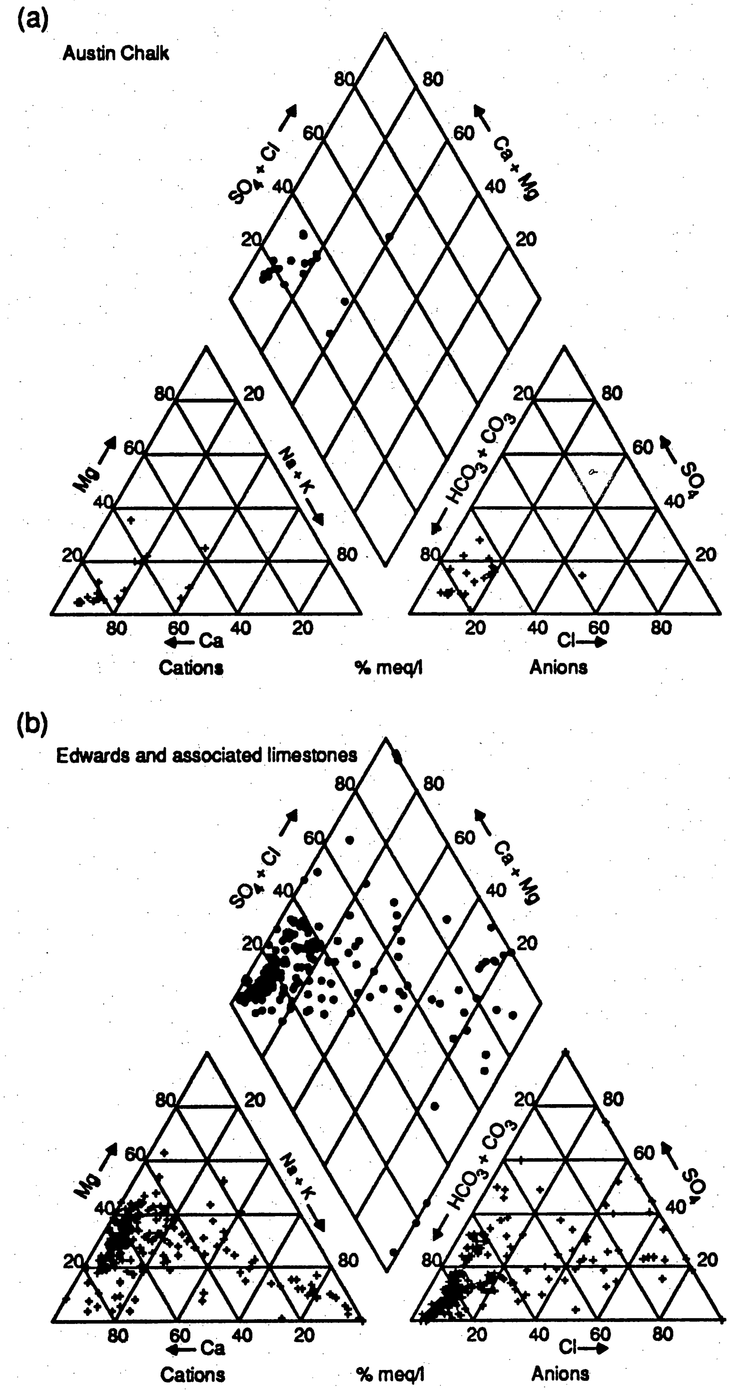
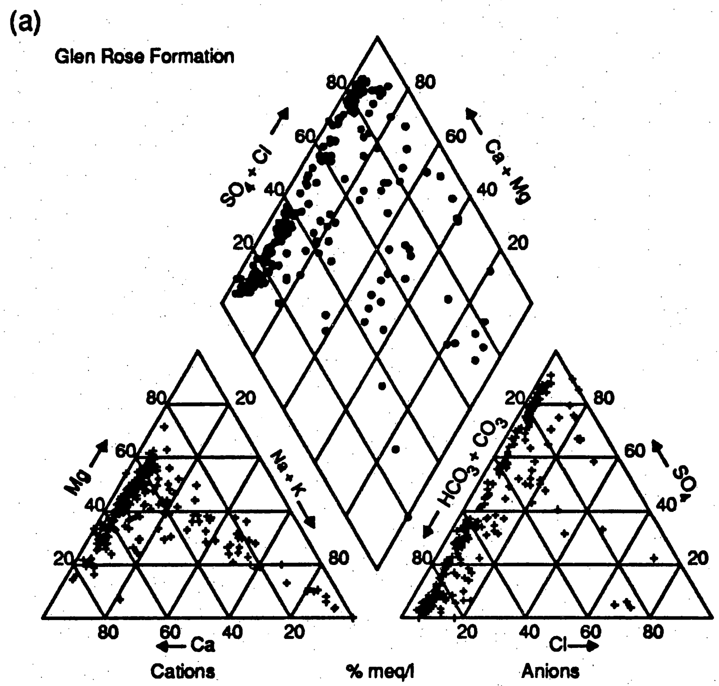


Figure 21. Trilinear diagram showing chemical composition of ground-water samples from the (a) Austin Chalk and the (b) the Edwards and associated limestones in Travis County.



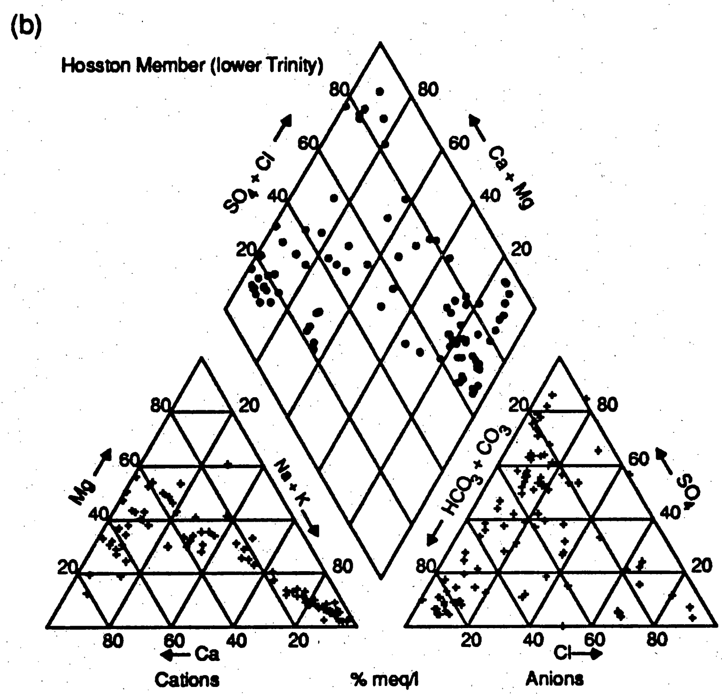


Figure 22. Trilinear diagram showing chemical composition of ground-water samples from the (a) Glen Rose Formation and the (b) Hosston Member of the Travis Peak Formation (Lower Trinity) in Travis County.

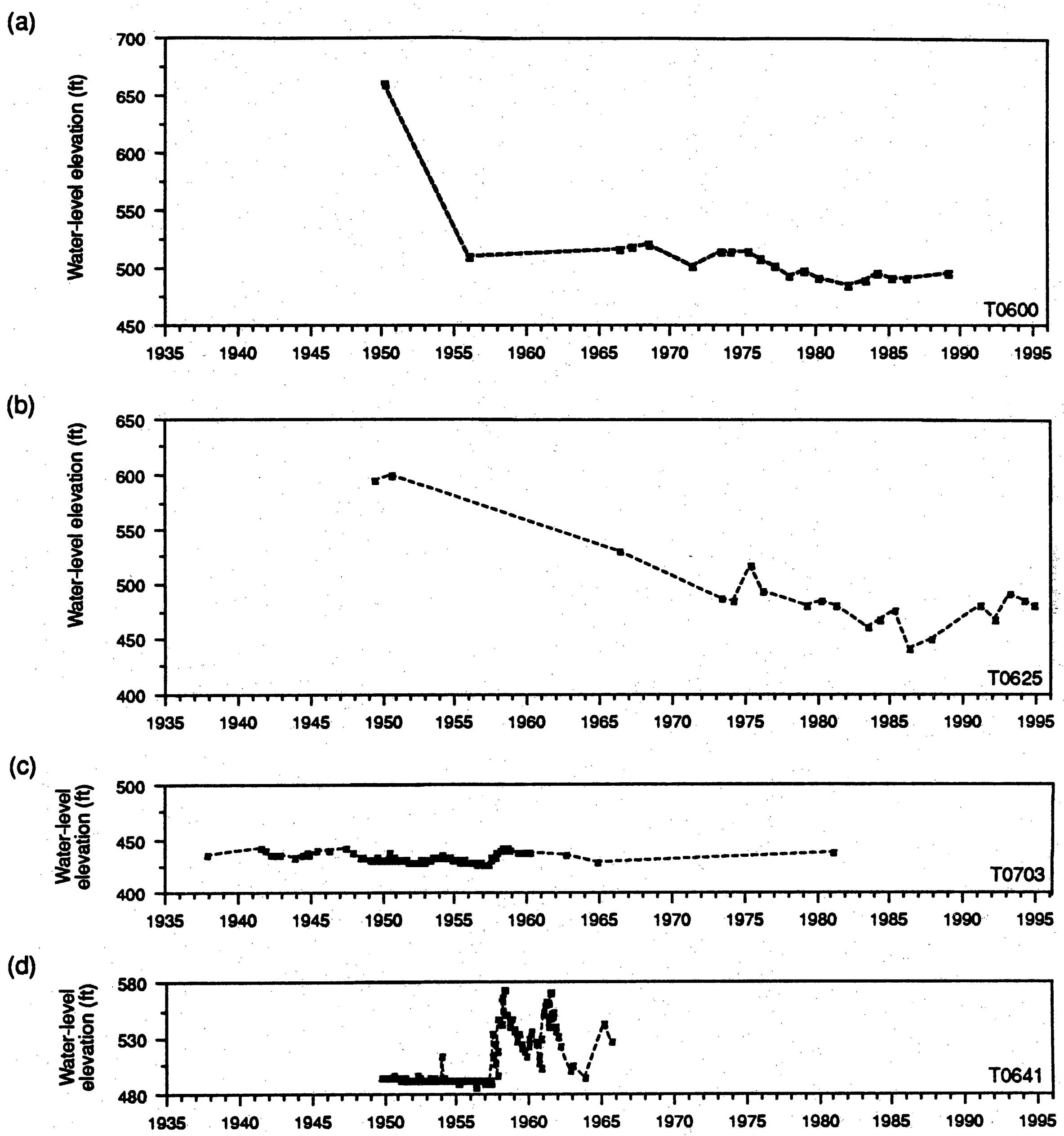


Figure 23. Water levels measured in Travis County in the Hosston Member in wells (a) 58-42-302 and (b) 58-42-502 and in the Edwards Formation and associated limestones in wells (c) 58-42-911 and (d) 58-42-602.

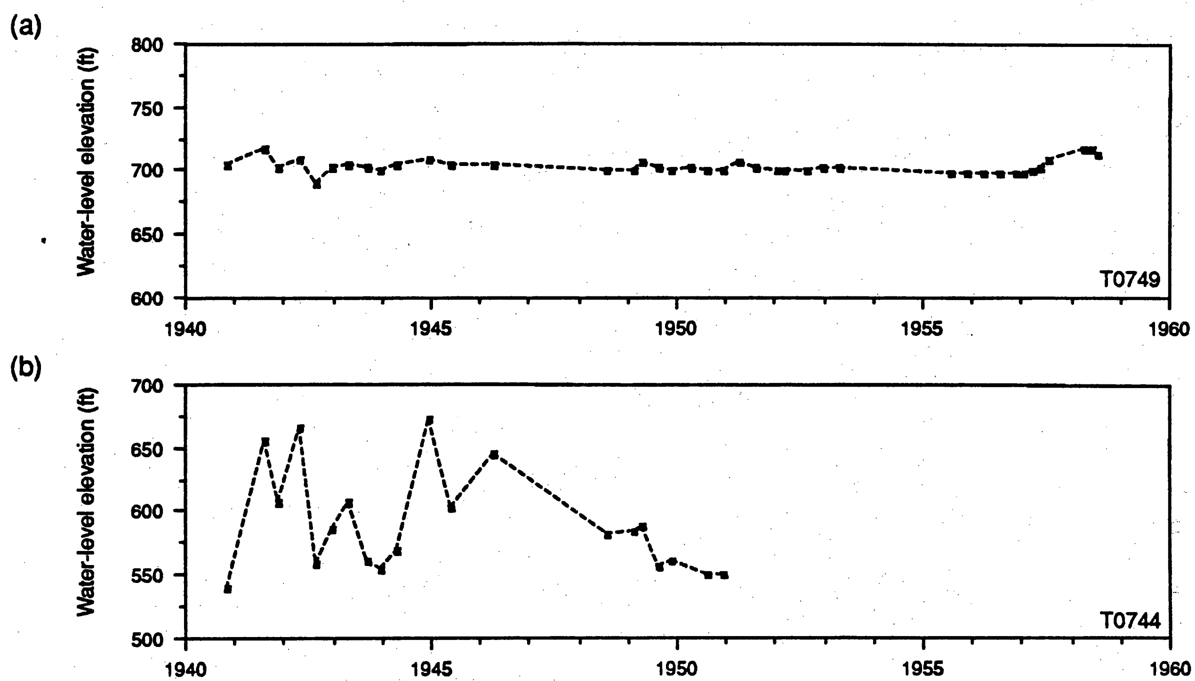


Figure 24. Water levels measured in Travis County in the Austin Chalk in wells (a) 58-43-502 and (b) 58-43-402. Well 58-43-502 is shallow (40 ft deep) and probably completed in weathered chalk while well 58-43-402 is deeper (184 ft deep) and, due to its large variations in water level, probably intersects a fault zone. These two wells are 0.3 miles apart.

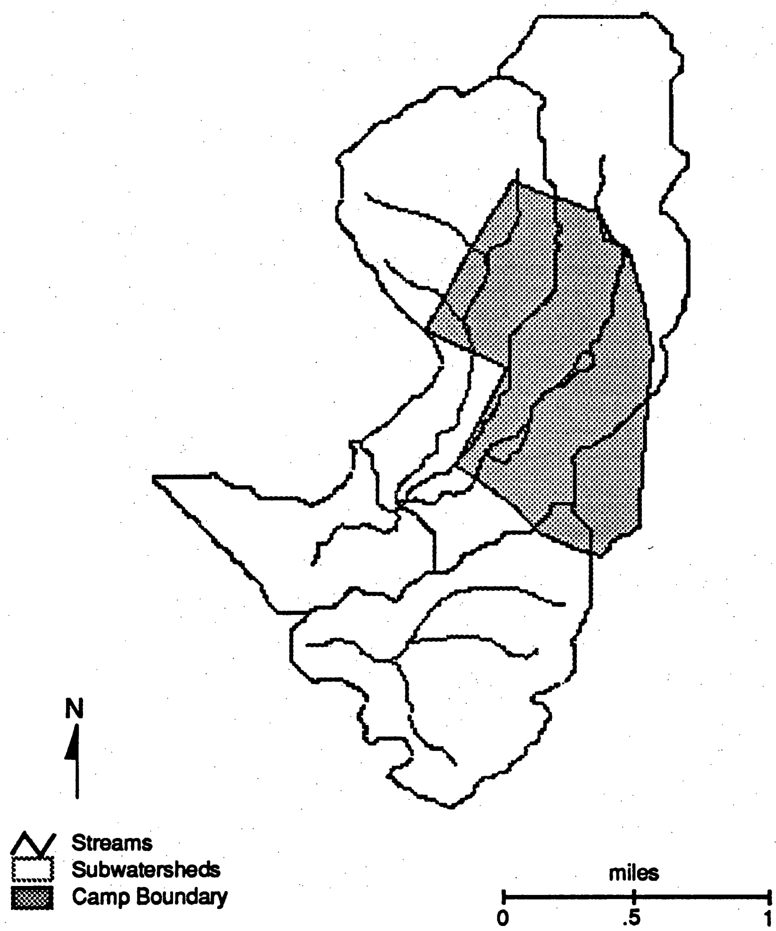


Figure 25. Watershed delineations for Camp Mabry.

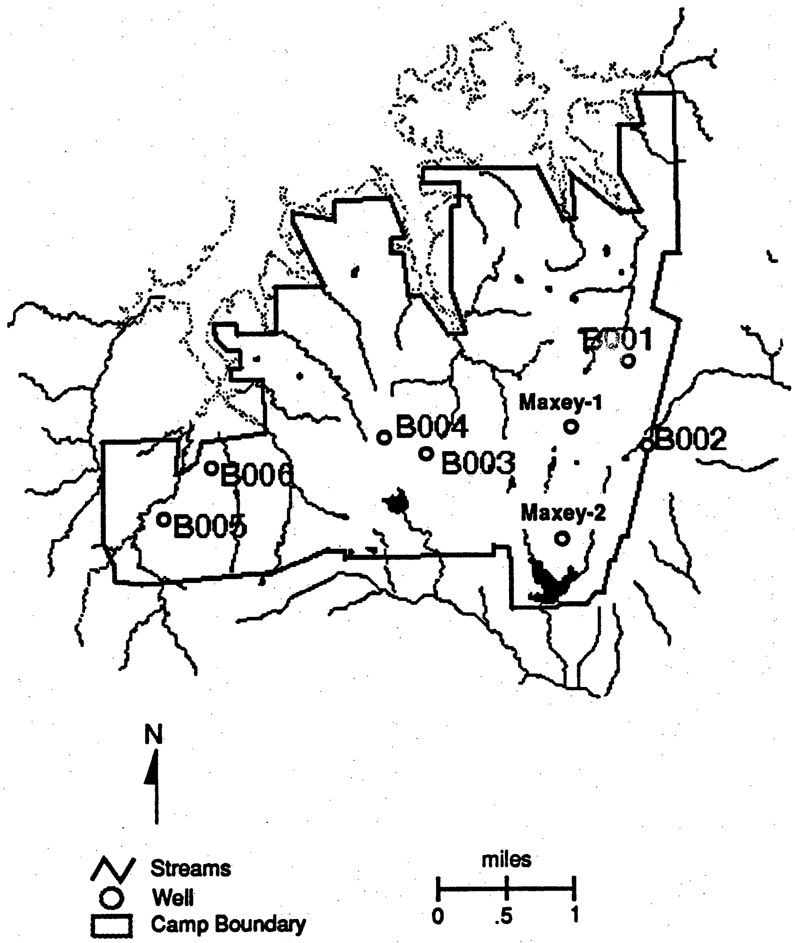


Figure 26. Wells locations on Camp Maxey.

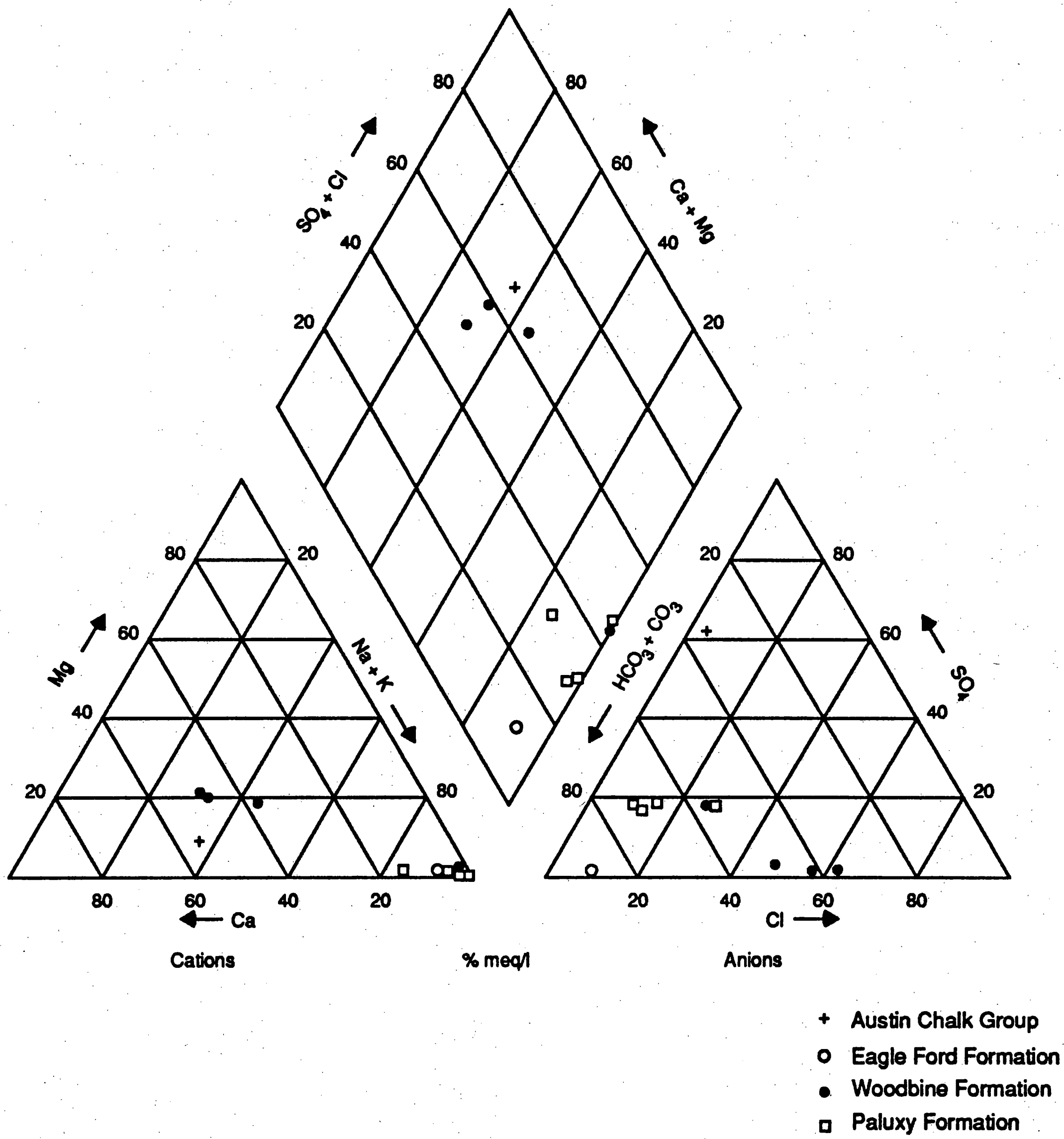


Figure 27. Trilinear diagram showing chemical composition of ground-water samples from the Paluxy Formation, the Woodbine Formation, the Eagle Ford Formation, and the Austin Chalk Group in Lamar County.

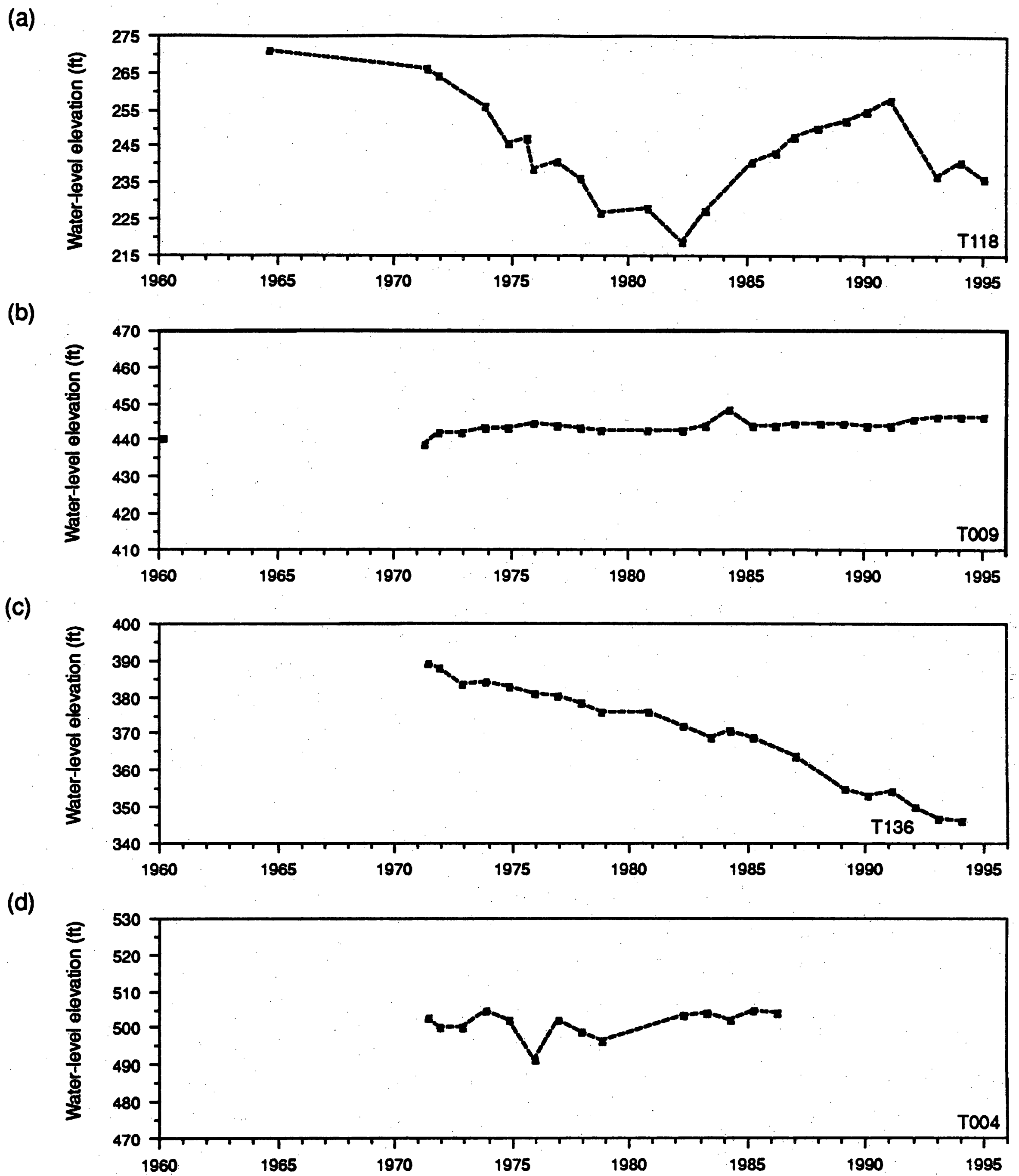


Figure 28. Water levels measured in the Woodbine Formation in wells (a) 17-27-201 and (b) 17-12-101 and in the Paluxy Formation in well (c) 17-29-601 and the Eagle Ford Formation in well (d) 17-10-801 in Lamar County.

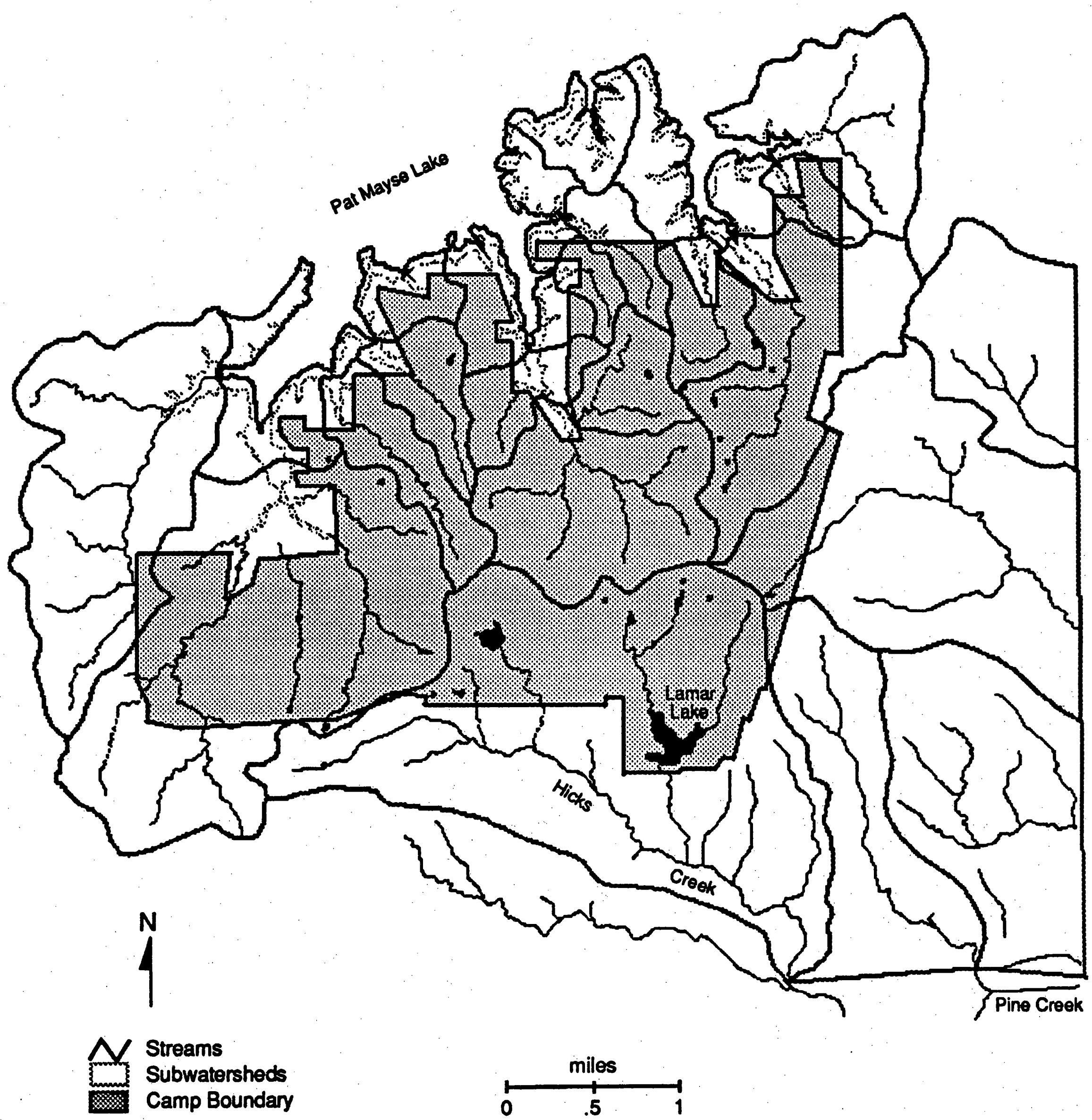


Figure 29. Watershed delineations for Camp Maxey.

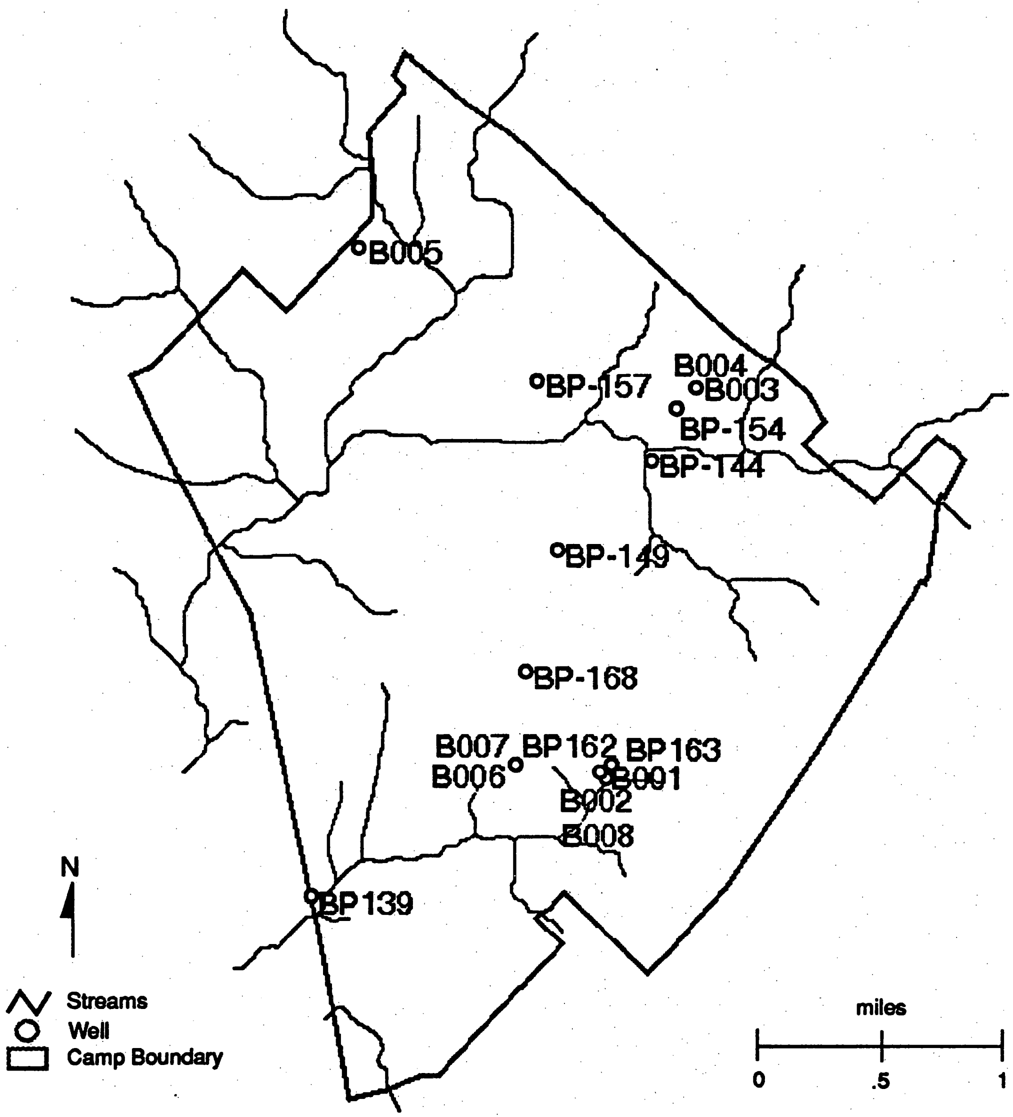


Figure 30. Well locations on Camp Swift.

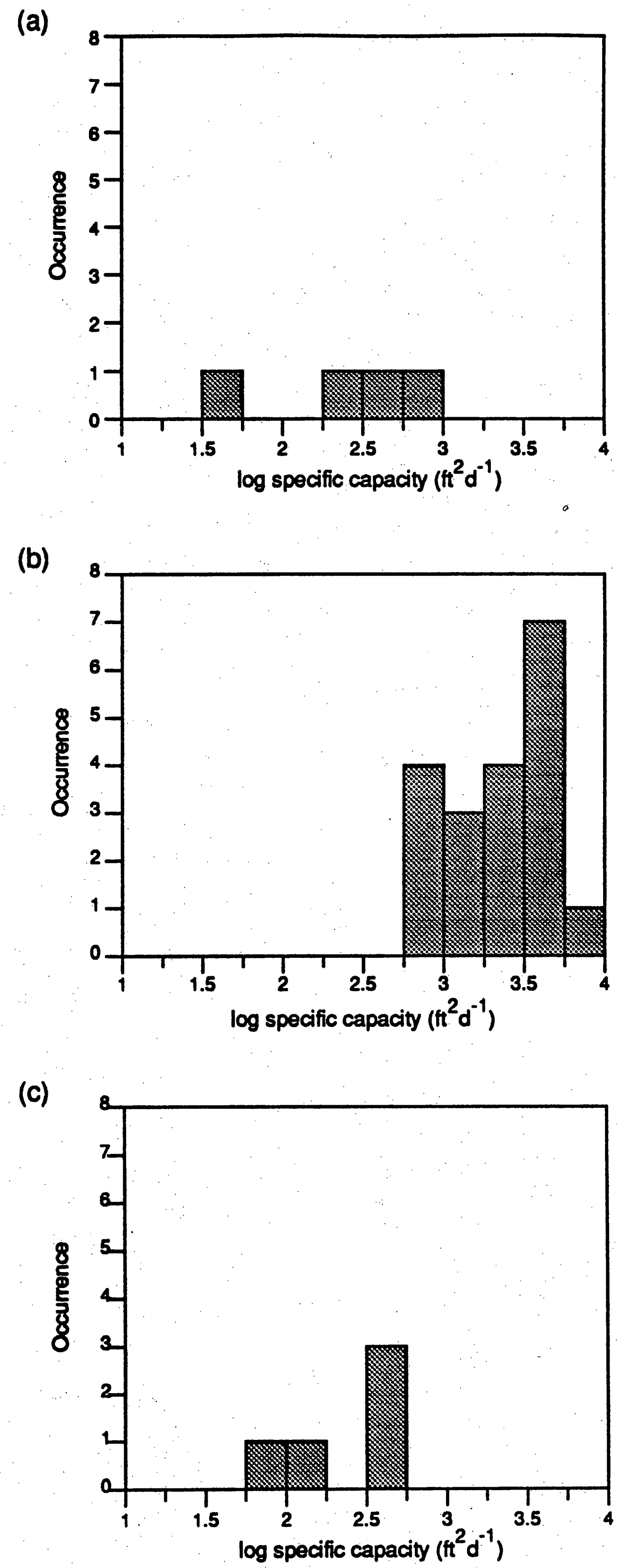


Figure 31. Histograms of specific capacity for the (a) Calvert Bluff, (b) Simsboro, and (c) Hooper Formations in Bastrop County.

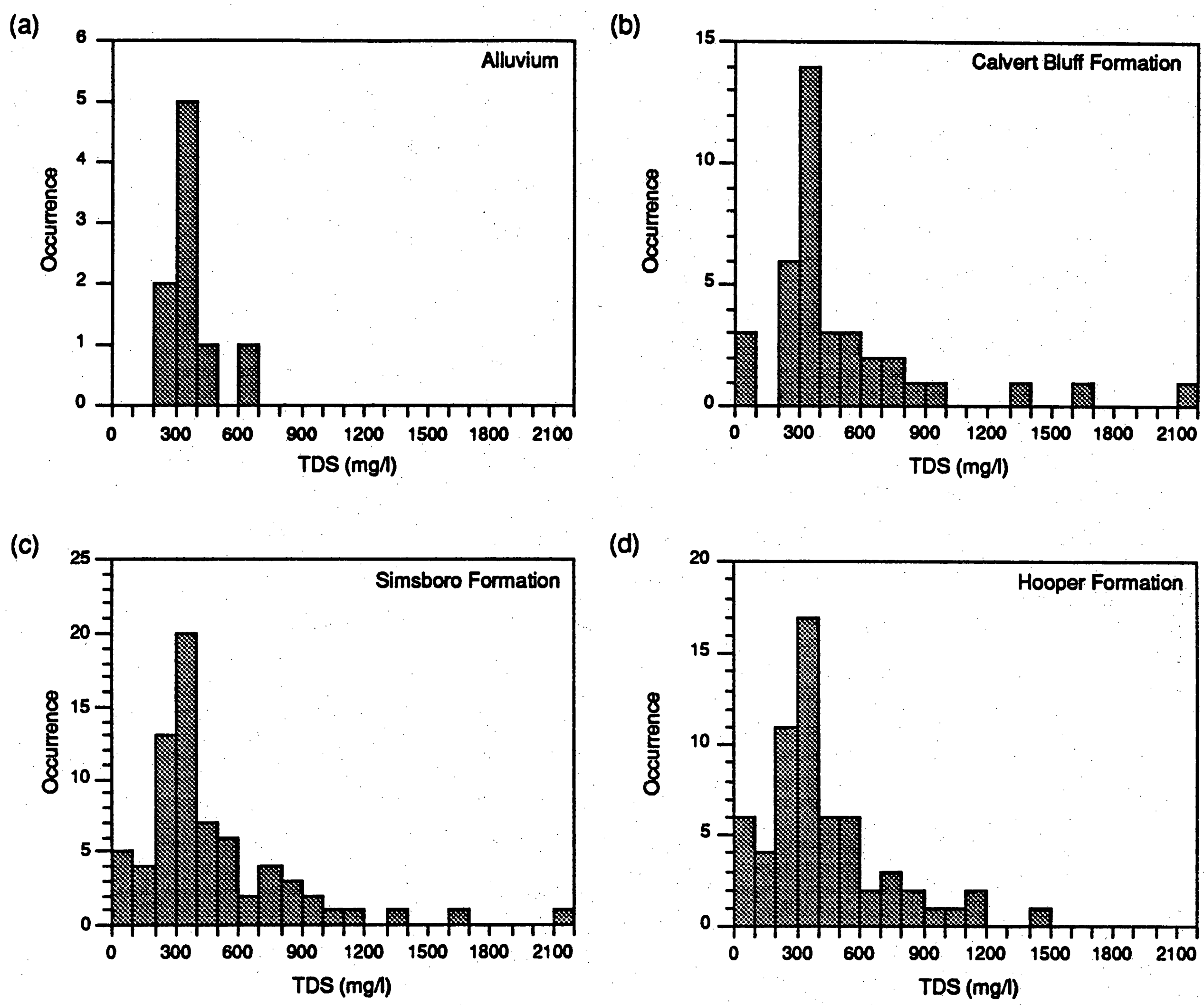


Figure 32. Histograms of total dissolved solids (TDS) in (a) the allvium, (b) the Calvert Bluff Formation, (c) the Simsboro Formation, and (d) the Hooper Formation of Bastrop County.

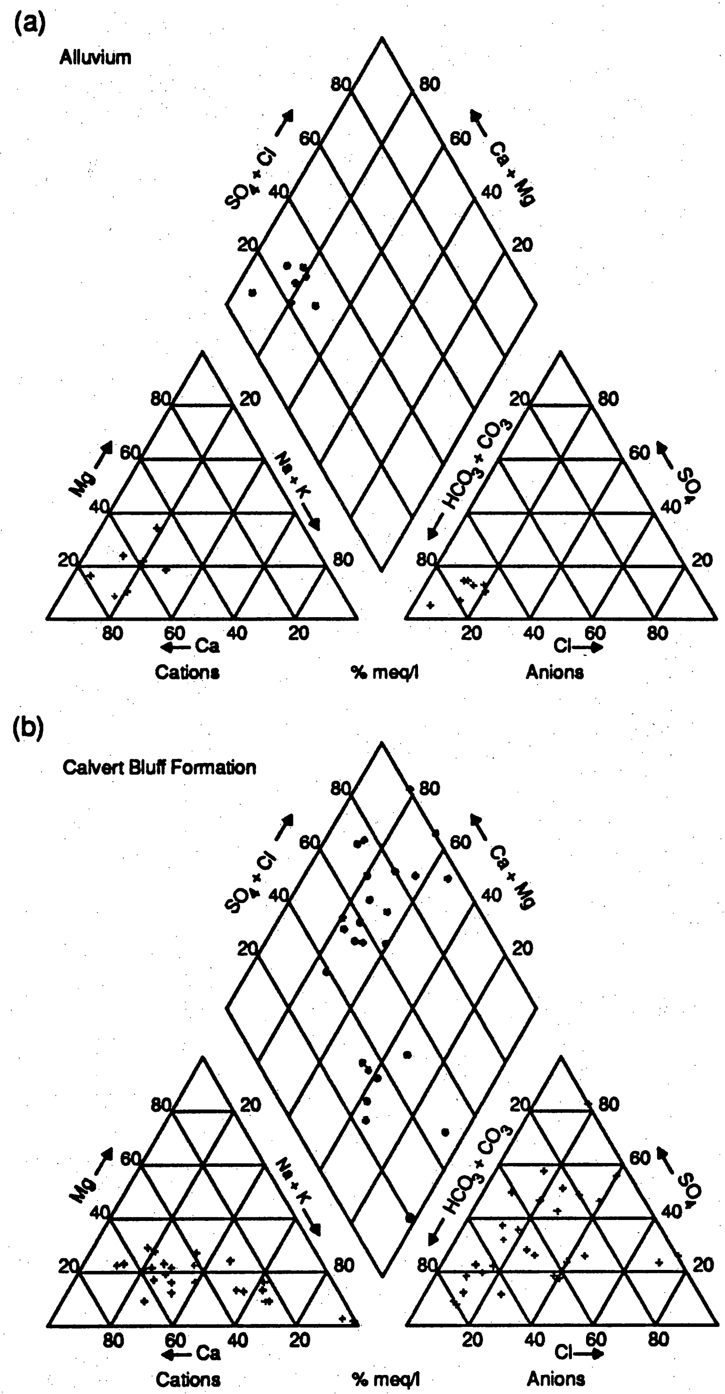


Figure 33. Trilinear diagram showing chemical composition of ground-water samples from the (a) alluvium and the (b) Calvert Bluff Formation in Bastrop County.

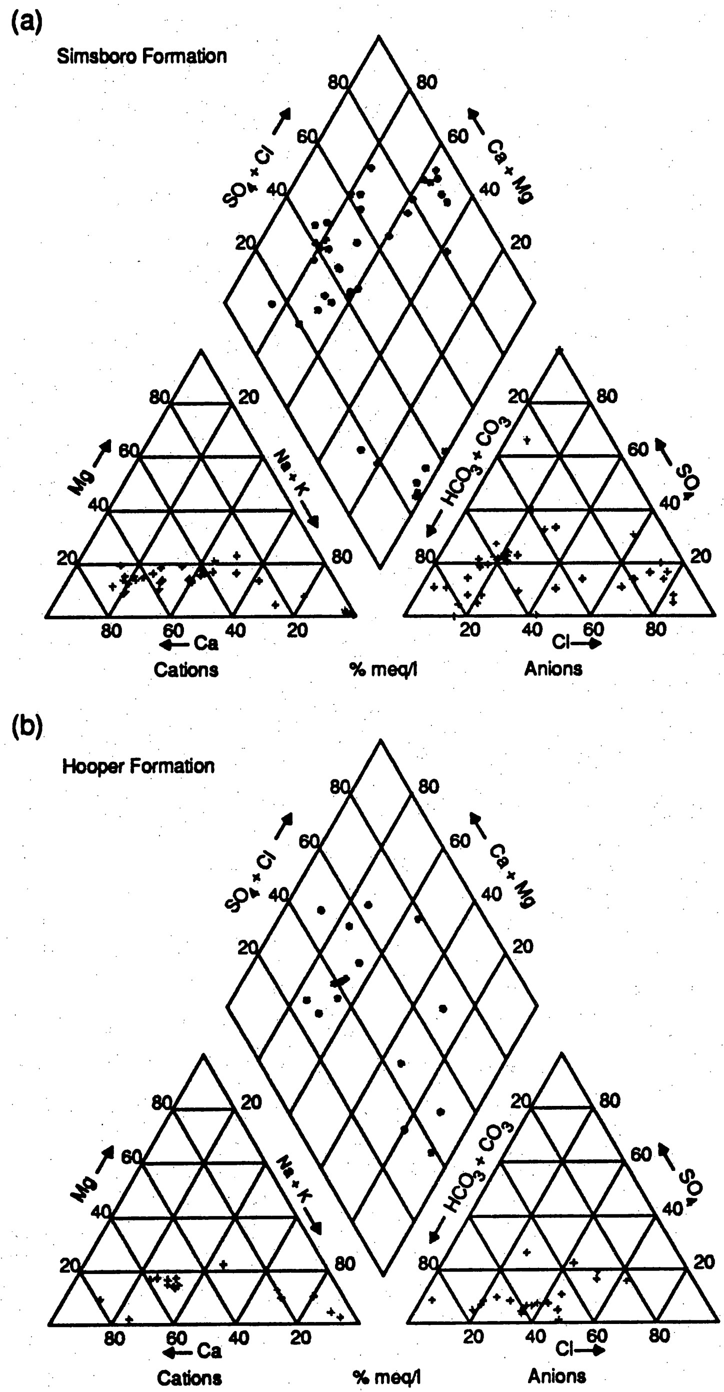


Figure 34. Trilinear diagram showing chemical composition of ground-water samples from the (a) Simsboro and the (b) the Hooper Formations in Bastrop County.

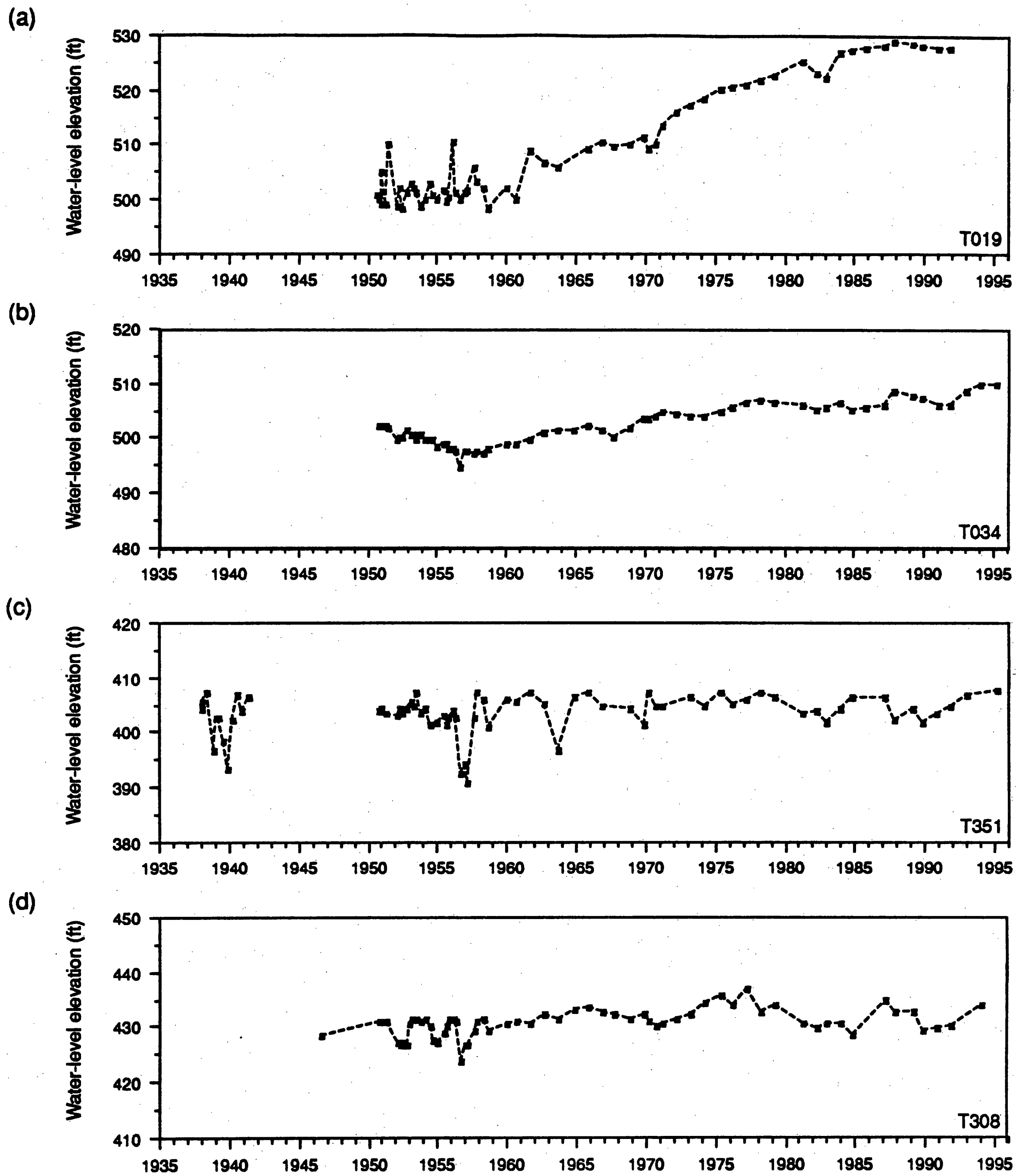


Figure 35. Water levels measured in Bastrop County in (a) the Hooper Formation in well 58-46-102, (b) the Simsboro Formation in well 58-46-301, (c) the Calvert Bluff Formation in well 58-61-201 and in (d) alluvium overlying the Wilcox Group in well 58-60-301.

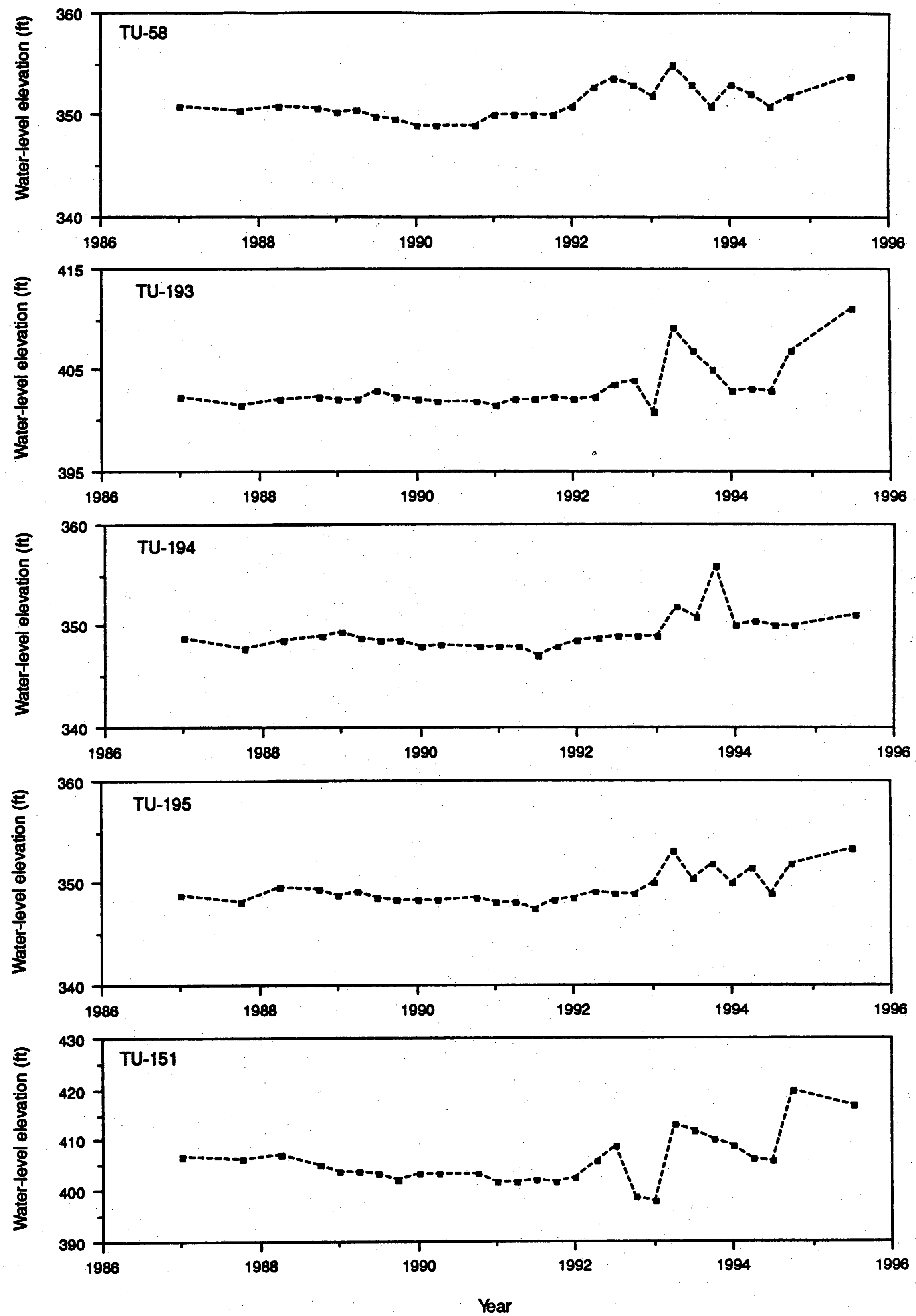


Figure 36. Water-level fluctuations in the Simsboro Formation underlying the Calvert Bluff Formation at the Powell Bend lignite mine just south-west of Camp Swift. Note that TB-151 (e) is at a different scale.

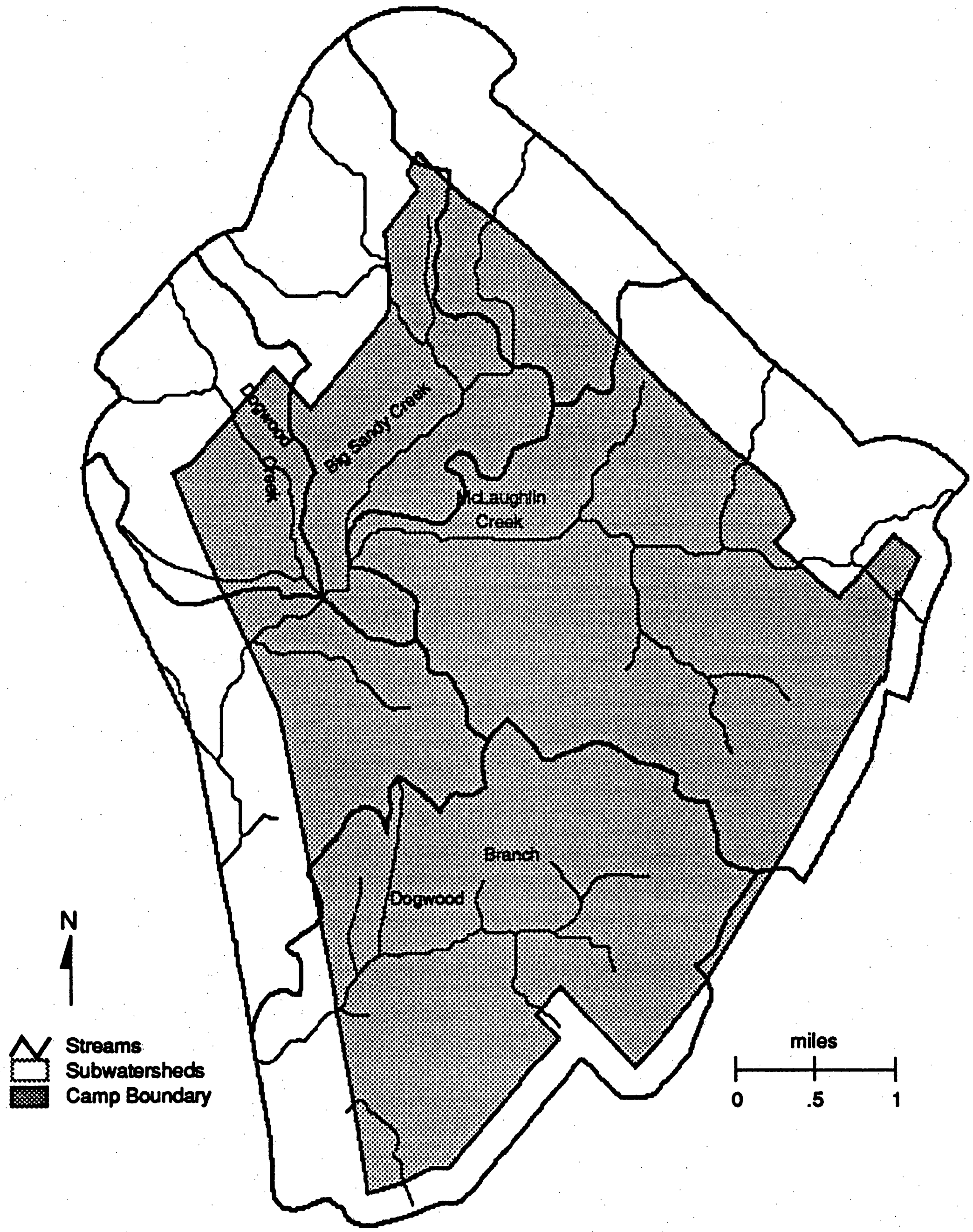


Figure 37. Watershed delineations for Camp Maxey.

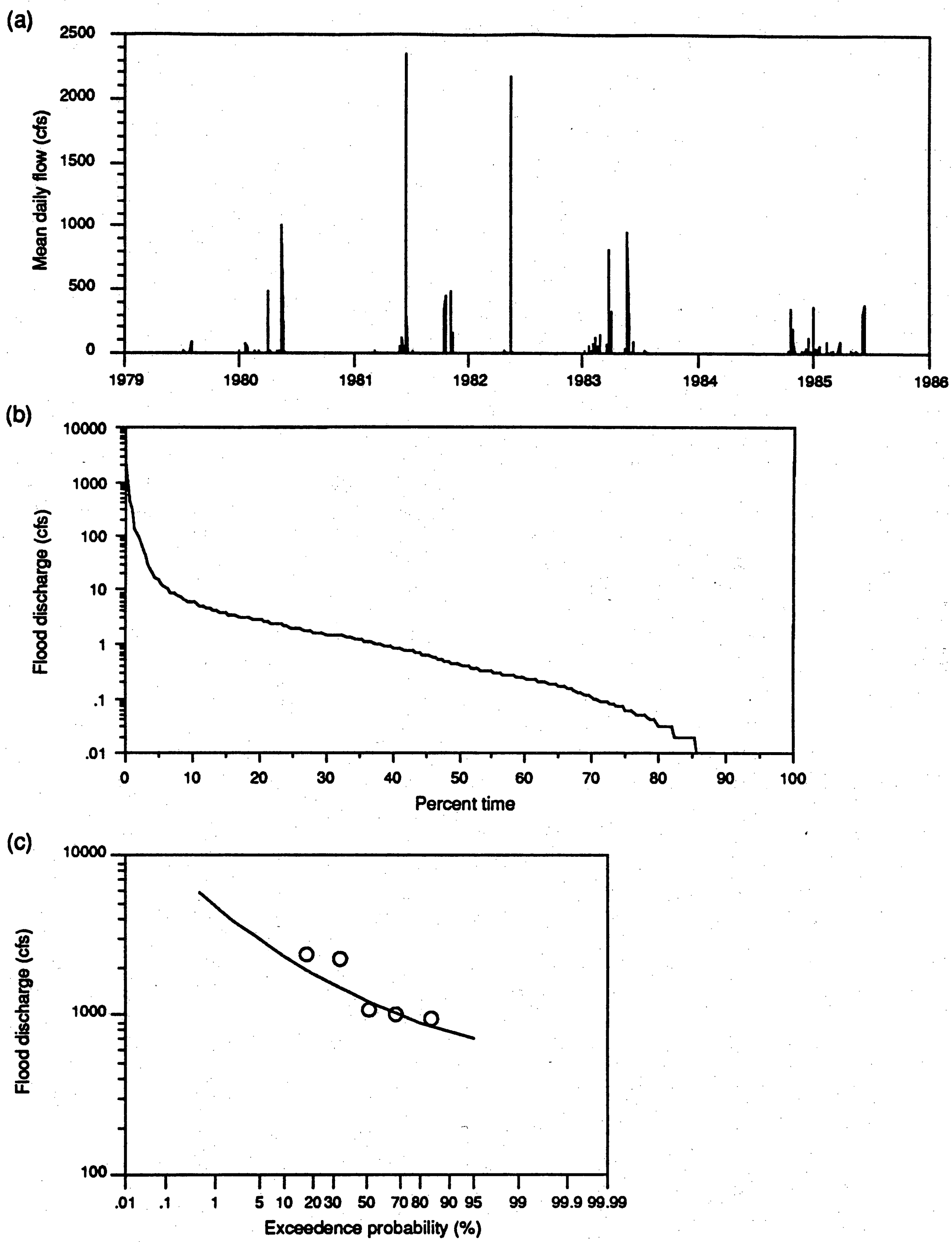


Figure 38. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis with a Log Pearson III fit for a stream gauge on Big Sandy Creek near Elgin.

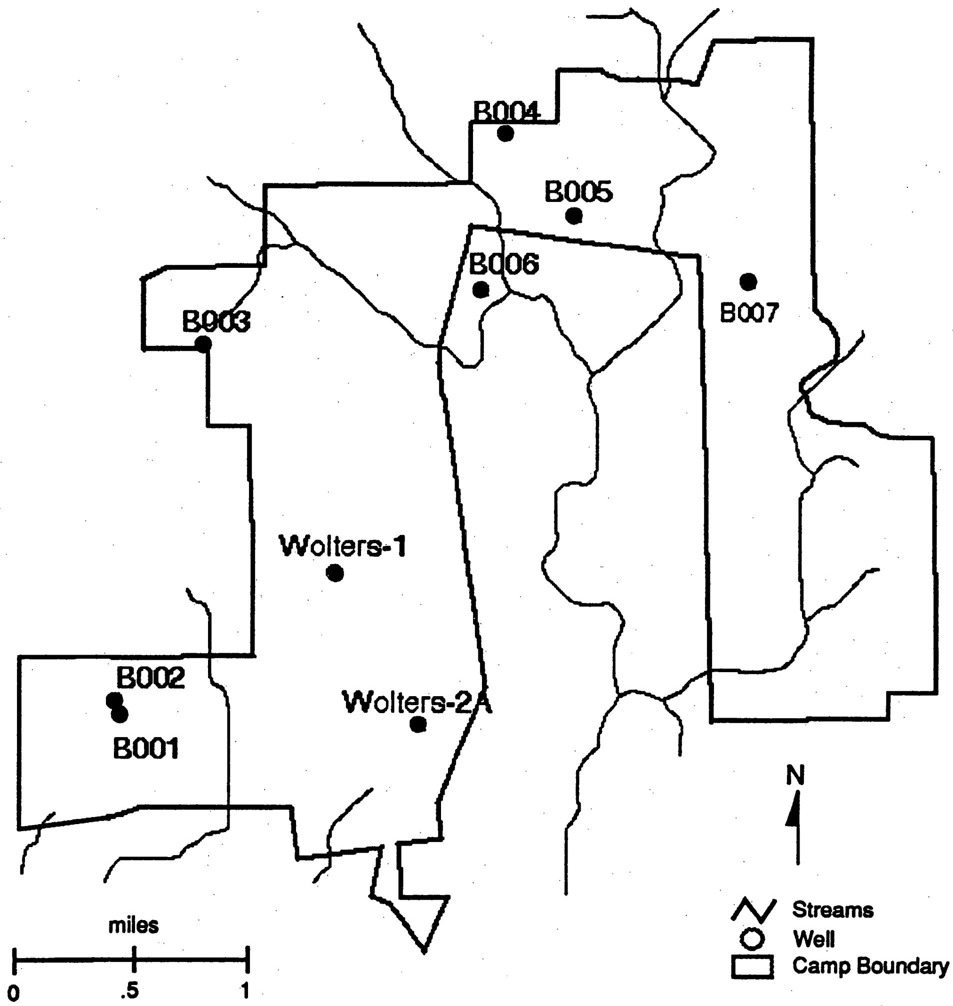


Figure 39. Locations of pre-existing and newly drilled wells on Fort Wolters.

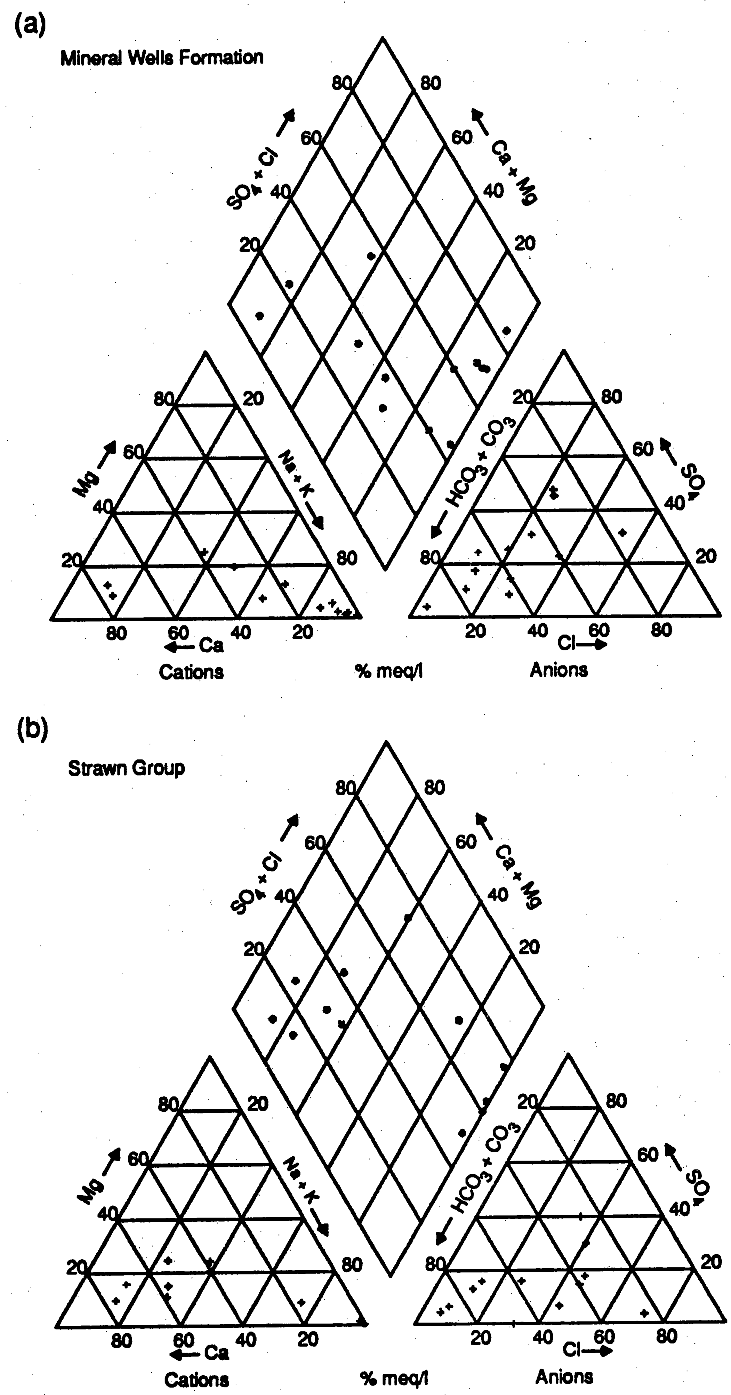


Figure 40. Trilinear diagram showing chemical composition of ground-water samples from the (a) Mineral Wells Formation and (b) the Strawn Group in Palo Pinto County.

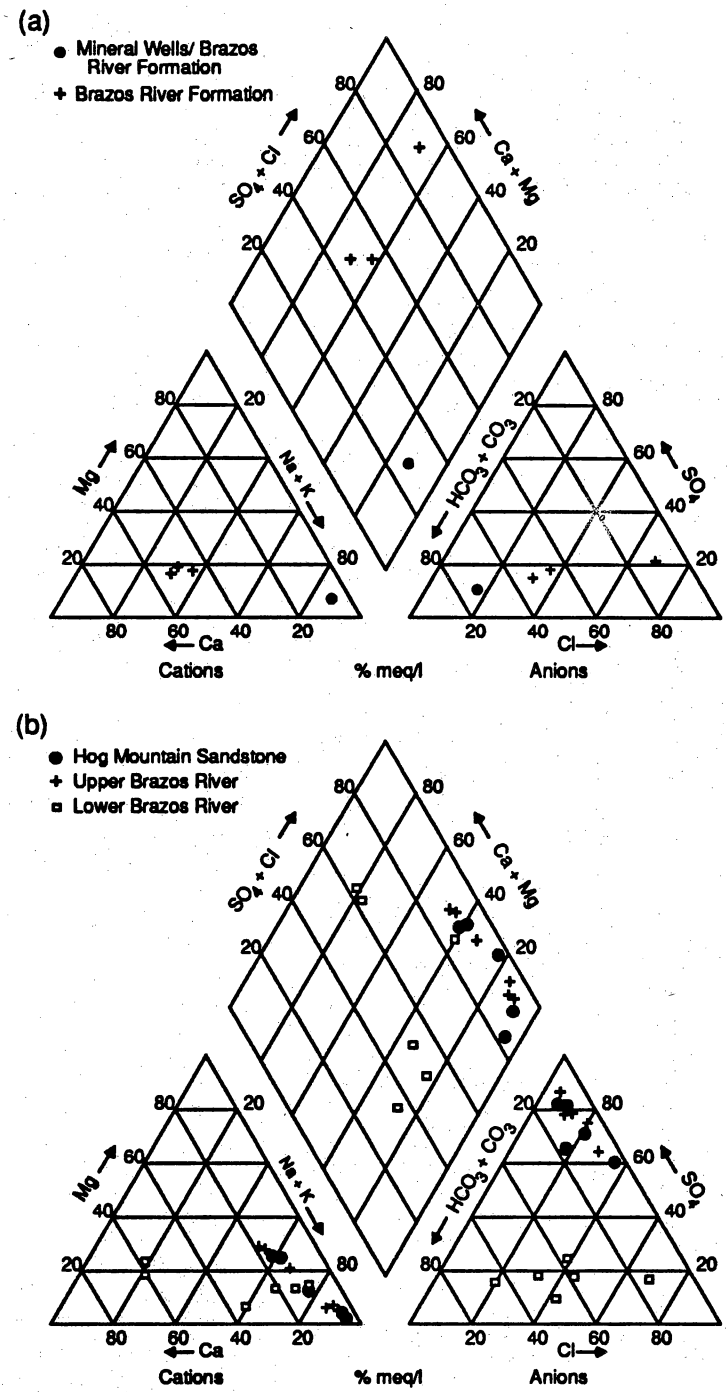


Figure 41. Trilinear diagram showing chemical composition of ground-water samples from (a) the Mineral Wells/Brazos River Formation (well completed in both formations) and the Brazos River Formation (TWDB data) in Palo Pinto County and (b) the Hog Mountain Sandstone and the Upper and Lower Brazos River Formation in the Mineral Wells area (Schoch, 1918; Plummer and Hornberger, 1935).

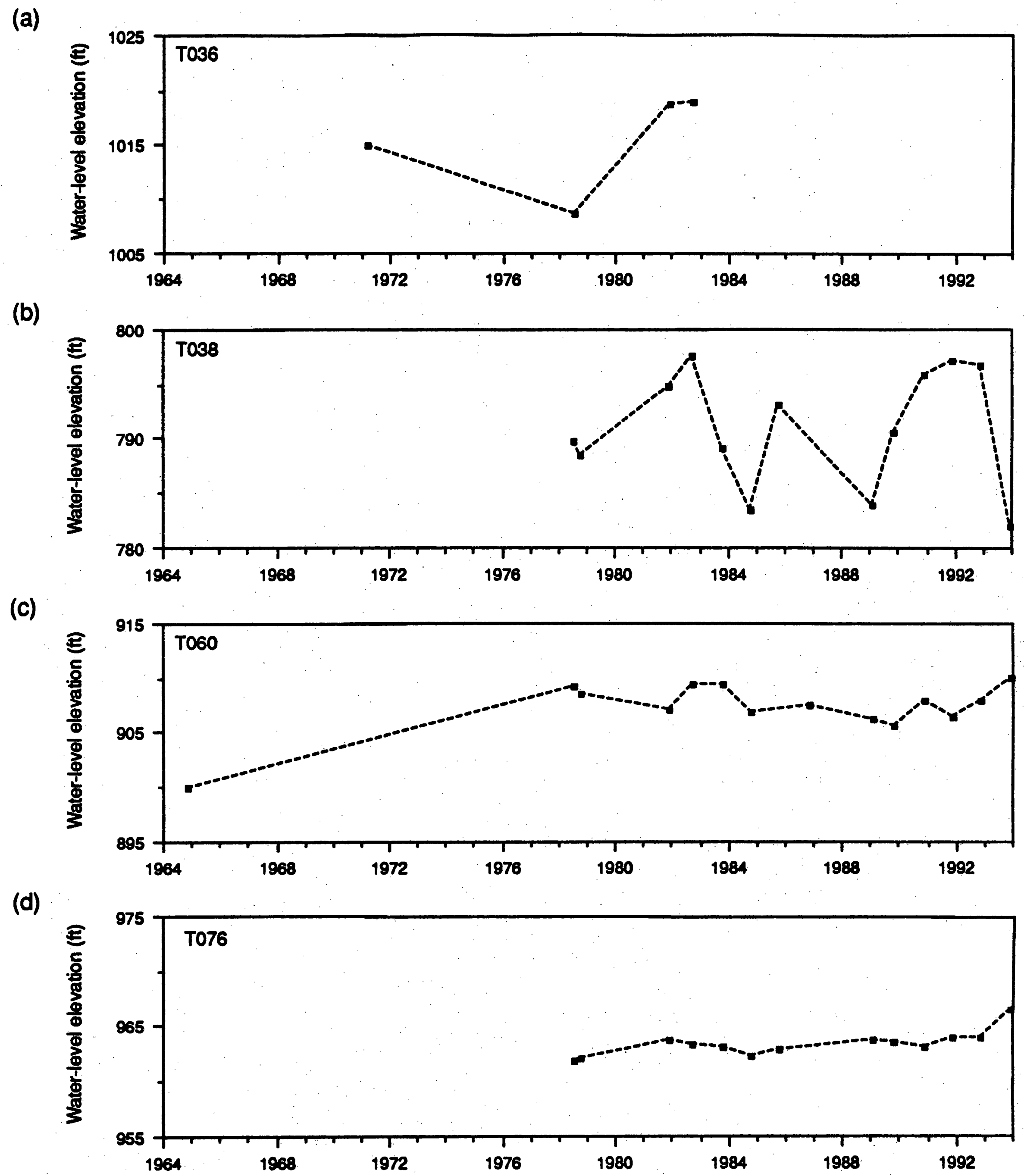


Figure 42. Water levels measured in the Mineral Wells Formation for wells (a) 31-14-805 and (b) 31-15-502, in the Brazos River Formation for well (c) 31-22-602, and in the Strawn Group in well (d) 31-31-502 in Palo Pinto County.

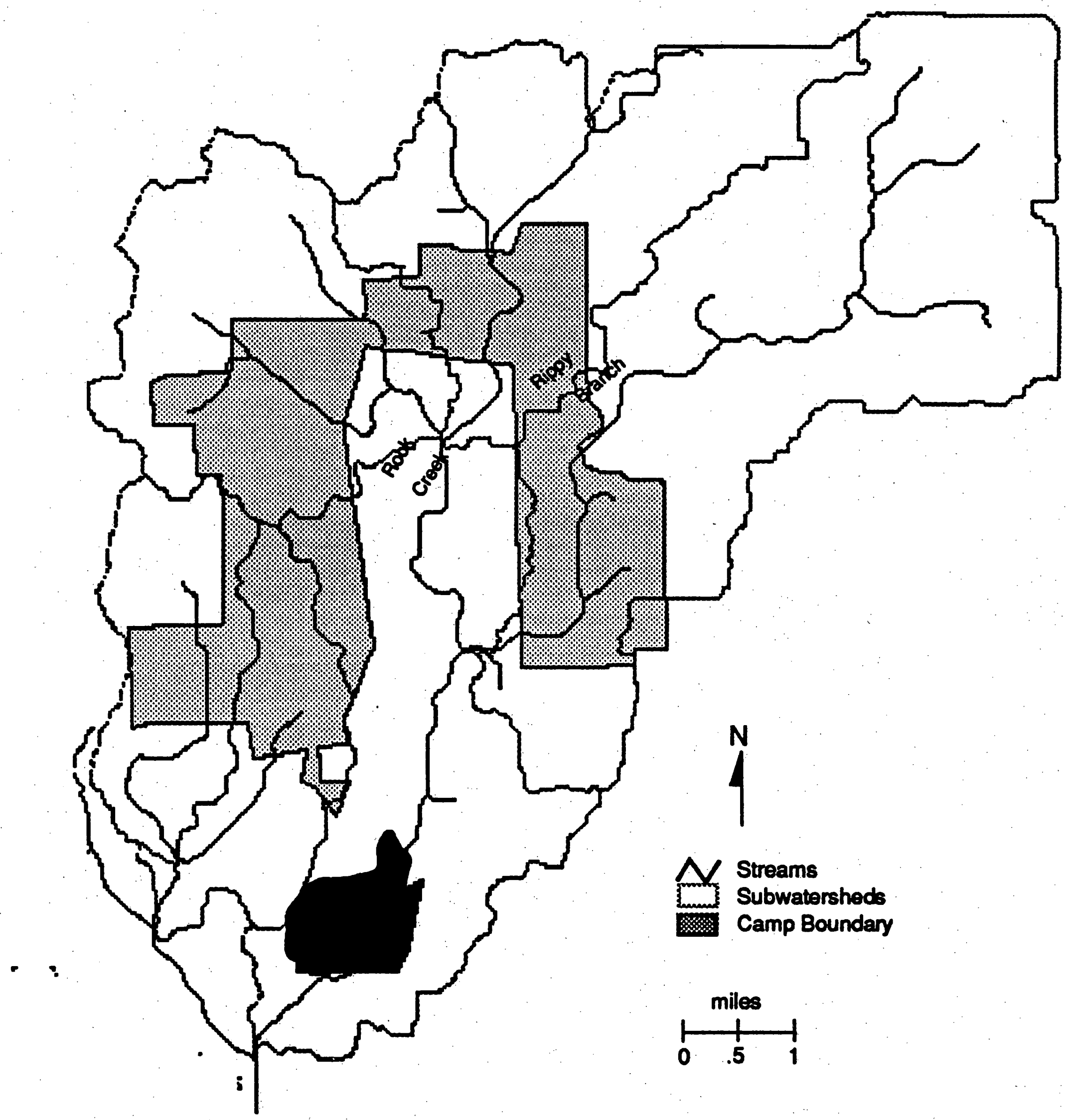


Figure 43. Watershed delineations for Fort Wolters.