Ground-Water and Surface-Water Hydrology of Camp Bowie, Brown County, Texas

Final Report

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EXECUTIVE SUMMARY

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

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

The sands of the Travis Peak Formation (Trinity Group, Cretaceous System) are the principal aquifers in the Camp Bowie area. Other water-yielding strata occur within the Trinity Group and the Strawn Group (Pennsylvanian System), as well as in alluvium along major streams. Water levels are strongly influenced by topography, and the depths to water are greater in wells on hilltops than in wells in valleys. Ground-water quality ranges from fresh to brackish. Ground-water composition varies widely. Waters from alluvium are typically calcium bicarbonate types, whereas waters from the Travis Peak Formation and Strawn Group either are mixed types or have no dominant cation or anion. Ground-water recharge on Camp Bowie originates as rainfall and percolates through fractures in limestone caps on the mesas, most infiltration occurring on topographically high Cretaceous rocks and in sandy areas of the Strawn Group. Ground water then moves downward toward topographically low regions, particularly to the mesa escarpment. Some water probably circulates deeper, crosses into the Strawn Group, and discharges to Pecan Bayou to the east or Indian Creek to the west. Some ground water discharges from the Travis Peak Formation into seeps, springs, or colluvium along the escarpment.

Camp Bowie resides in the Pecan Bayou drainage basin, which ultimately feeds the Colorado River. Surface water on the northwest side of the camp feeds locally intermittent creeks

that connect with intermittent Willis Creek to the north. In the north-central area of the camp, surface runoff feeds Lewis Creek, which drains northeast into Pecan Bayou. Runoff in the south-central area of the camp feeds Devils River, which drains east into Pecan Bayou. Drainage in the southern part of the camp is to Mackinally Creek just south of the camp and to an unnamed creek north of Mackinally Creek. A 100-yr storm would result in flooding halos around stream beds at Camp Bowie, the flooded areas becoming wider as the distance to Pecan Bayou decreases.

INTRODUCTION

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

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

Regional Setting

Camp Bowie is located south of Brownwood in Brown, County, Texas (fig. 1). The physiography of Camp Bowie is transitional between the rolling hills of the Grand Prairie Province on Cretaceous rocks to the east and the generally low-relief Osage Plains on Triassic, Permian,

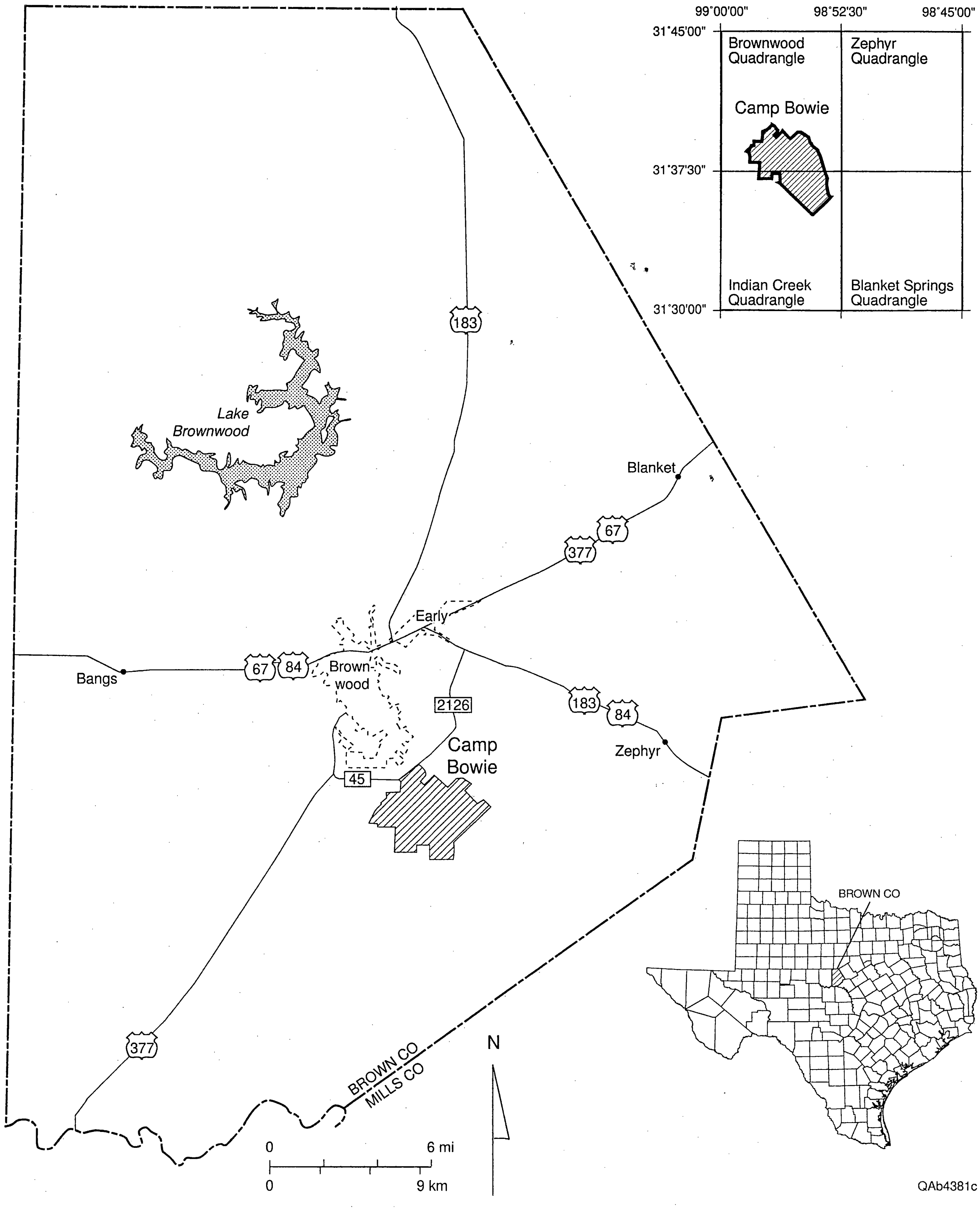

Figure 1. Index map showing location of Camp Bowie and major highways and towns.

and Pennsylvanian strata to the west (Sellards and others, 1932). The camp, dominated by a combination of highland ridges and flat-lying lowlands, is dissected by perennial and intermittent streams draining into the Colorado River Basin. Soils in the area include the Bolar–Brackett association, having shallow to moderately deep, gravelly, loamy soils over limestones; the Frio–Sunev–Winters association, having deep loamy soils over loamy and clayey alluvium; and the Leeray–Sagerton–Nukrum association, having deep loamy and clayey soils (Clower, 1980). There are two vegetation regions predominant in Brown County: the oak forest and prairie region in the north and the juniper-oak-mesquite savanna region in the south (Kier and others, 1977).

The camp lies in the subtropical subhumid zone of Texas, which is characterized by hot summers and dry winters (Larkin and Bomar, 1983). Continental and maritime tropical fronts with south-southwest- to south-southeast-prevailing winds influence the climate during much of the year. During the winter and spring months, however, maritime polar and Arctic air masses accompanying cold fronts force stronger, northerly winds through the area (Bomar, 1983).

Bomar (1983) summarized precipitation and temperature data for the Camp Bowie area. The average mean precipitation measured at Brownwood is 26.1 inches, and most of the rain falls between May and October. The average annual temperature is 65°F, the mean annual low being 53°F and the mean annual high being 78°F. The average high temperature in the warmest month reaches 97°F in July, and the average lowest temperature falls to 31°F during January.

The average annual gross lake surface evaporation rates in Brown County are between 73 and 75 inches, the highest monthly values of 10.5 inches occurring during the peak of the summer and the lowest monthly values of 2.75 inches occurring in January (Larkin and Bomar, 1983).

Geology and Hydrostratigraphy

Cretaceous and Pennsylvanian System rocks crop out at Camp Bowie (fig. 2). 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 lenses several hundred feet wide that were part of a Pennsylvanian delta system (Nance and Wermund, 1993). Cretaceous System rocks unconformably overlie the Strawn Group on Camp Bowie. 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

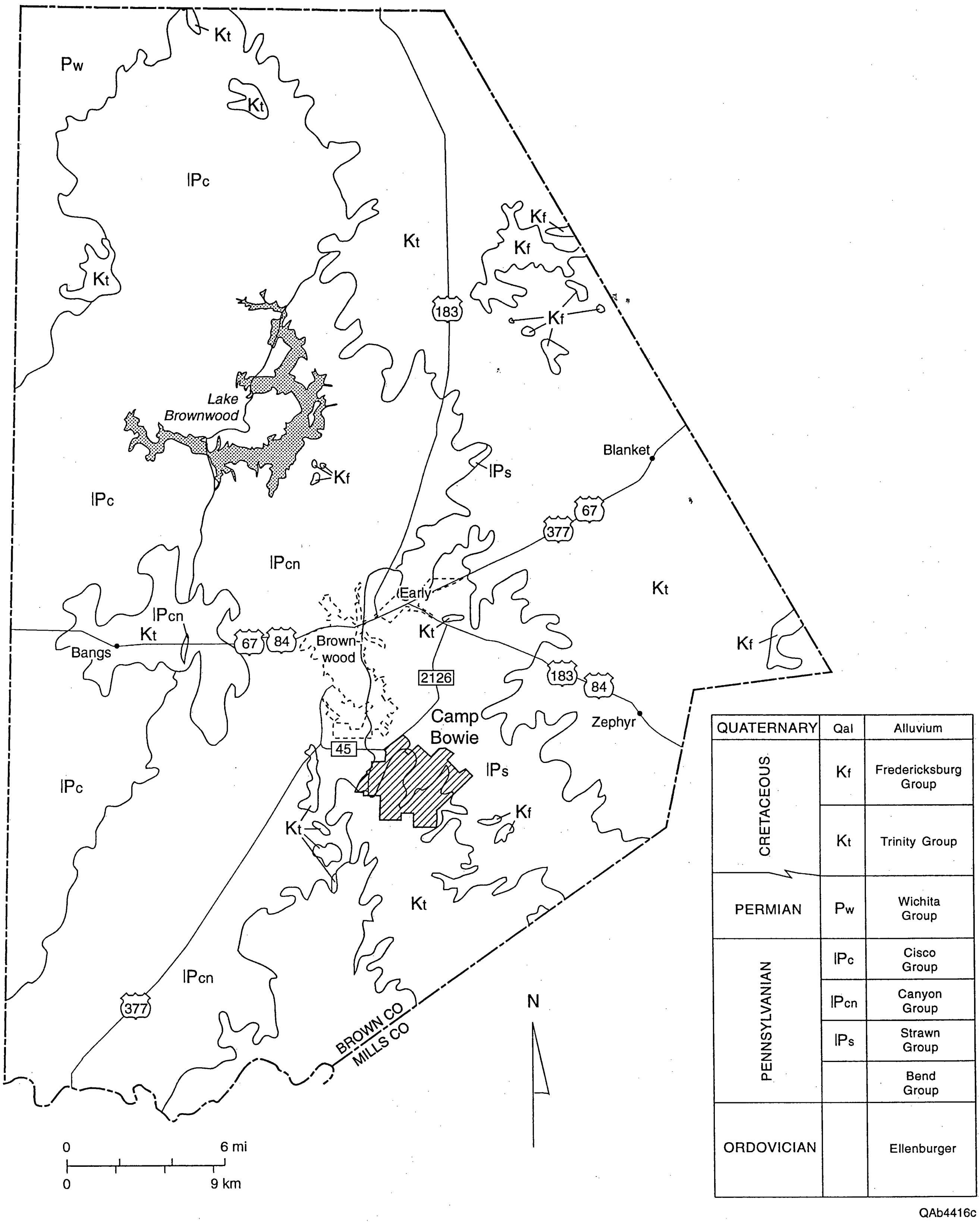

Figure 2. Generalized geologic map (after Thompson, 1967), schematic cross section (from Nance and Wermund, 1993), and stratigraphic column (after Thompson, 1967) for Brown County.

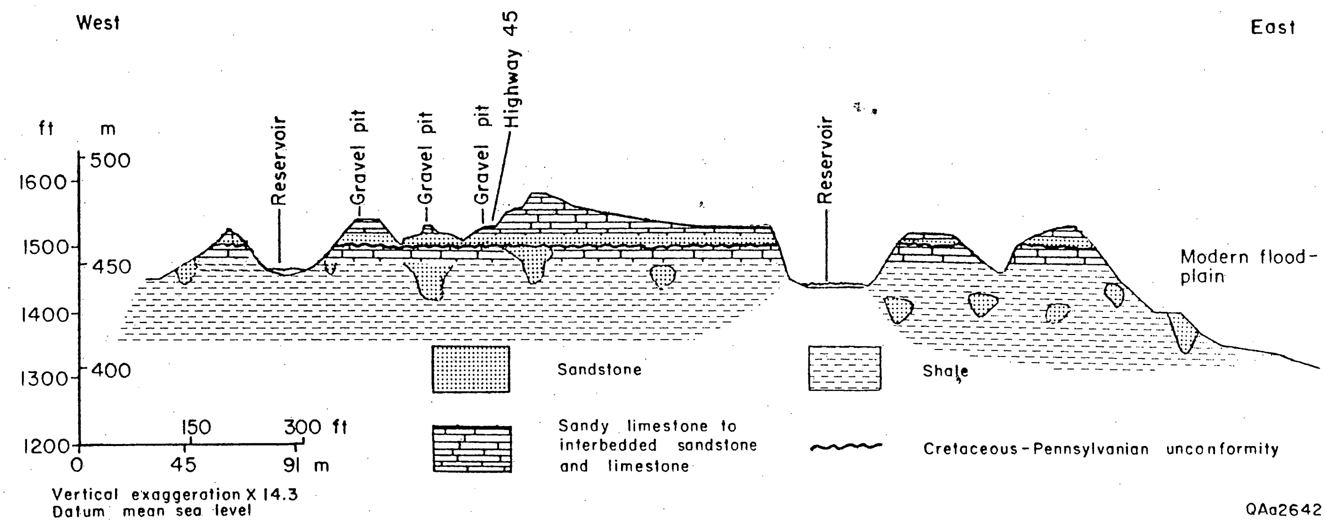

Figure 2 (cont.)

deposits consist of alluvium and colluvium produced by erosion of the Cretaceous and Pennsylvanian rocks. These deposits occur on hilltops, slopes, and terraces, as well as in floodplains of modern streams.

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, and about 6 percent are listed specifically as having been completed in the Twin Mountains Formation. About 10 percent of the wells listed with the TWDB are completed in the Strawn group, and less than 1 percent of the wells are completed in alluvium.

METHODS

Ground-Water Hydrology

Previously published hydrogeologic data provided a regional framework for our site-specific studies. A TWDB report on Brown County (Thompson, 1967) and a Texas BEG report (Nance and Wermund, 1993) supplied much of the regional hydrogeologic information. Our drilling and sampling studies were guided by these reports to specific areas that needed more study, particularly to sites at Camp Bowie.

Well Inventory

We conducted a well survey to locate and measure wells in and around Camp Bowie. For wells in the camp, detailed measurements and descriptions were taken, including well location, type, depth, water level, diameter, and casing construction. Camp personnel were interviewed concerning known or potential well locations. We drove on all roads in the camp to explore for evidence of wells. We also inventoried wells near the camp and measured water levels and well depths whenever possible. These data were essential for generating water-level maps of the camp and adjacent areas.

Monitor Well Installation

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

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

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

Well Testing

We conducted two types of well tests at Camp Bowie: one pumping test, in which aquifer properties are determined during long-term pumping, and three bail tests, in which water is rapidly removed from the wellbore and water-level recovery is monitored. To conduct the pumping test at a BEG-installed monitoring well, we installed a 2-inch Grundfos electrical submersible pump and a pressure transducer in the well. The well was allowed to rest unpumped after emplacement of the pump and transducer until water levels stabilized. Then the pump was started and water levels were measured with the pressure transducer and an electronic water-level meter. We measured pump discharge rate using a 12-gal carboy and a stopwatch. Once water-level drawdown reached a quasi-steady-state, the pump was turned off and water-level recovery was observed. Drawdown and recovery data were input into a spreadsheet and transmissivity was interpreted using the Neuman (1972) method.

We conducted bail tests at the second BEG-installed monitoring well and at two preexisting wells. At the monitoring well, we removed one bailer volume of water and monitored recovery with an electronic water-level meter. At the two preexisting wells, we installed a pump to rapidly remove water from the borehole. We then allowed the well to rest unpumped until water levels stabilized. When the pump was started, water levels were measured with an electronic water-level meter to verify that only well storage was being removed. Once the water reached the level of the pump, the pump was turned off and water-level recovery was measured. Recovery data were input onto a spreadsheet, and transmissivity was interpreted using the Cooper and others (1967) curve-matching method.

Ground-Water Sampling

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

Surface-Water Hydrology

Watershed Delineation

Watersheds in Camp Bowie were delineated using the hydrologic functions of ArcInfo Grid (ESRI, 1993). This method takes digital elevation model data (DEM) and determines flow directions and points of flow accumulation from hypsography. For each stream link between different order streams, the program determines subwatersheds, or drainage areas, corresponding to that stream link (Maidment, 1995).

Floodplain Analysis

We downloaded stream-gauge discharge rates from U.S. Geological Survey (USGS) computers for stream gauges near Camp Bowie. For each of the gauges, we made mean daily flow, flow duration, and flood frequency analysis plots. Flood frequency analysis plots were fit with a Log Pearson III distribution.

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

Our floodplain analysis consisted of (1) designing 100-yr 24-hr synthetic storms, (2) determining the 100-yr flood hydrographs at strategic points in the watersheds, (3) assessing 100-yr flooding surfaces, and (4) mapping the 100-yr floodplains on 1:2400 USGS topographic maps.

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

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

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

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

where C_t is a constant that varies between 1.8 and 2.2 for units of miles (Snyder, 1938), L is the distance from discharge point to the divide, L_c is the stream length, n is 0.35 for valley drainage areas (Linsley and others, 1982, p. 225), and s is the channel gradient. For this study, we chose a mean C_t value of 2.0. We assigned the routing storage coefficient as 0.20, a typical value for most natural streams (Linsley and others, 1982, p. 219). We measured L, L_c, and s from USGS 1:24000 topographic sheets. We estimated the routing traveltime constant, K, using the following equation (Linsley and others, 1982, p. 465–541):

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

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

We used HEC-RAS (Hydrologic Engineering Center, 1995) to estimate 100-yr flooding surfaces at the locations where we determined the flood hydrographs. Input to HEC-RAS included topographic cross sections at hydrograph locations, stream lengths between cross sections, Manning's n values, discharge rates, and stream-flow boundary conditions. We measured topographic cross sections from USGS 1:24000 topographic sheets perpendicular to the stream path. Using a map roll gauge, we measured stream lengths between cross sections from the topographic sheets. We assumed Manning's n values to be 0.06 on the banks (Hydrologic Engineering Center, 1995) and 0.05 in and near the stream channel. HEC-1 supplied the peak 100-yr discharge rates for each hydrograph location. We assigned the stream-flow boundary condition at the output end of the model as a critical depth boundary. In all simulations we assumed subcritical flow. After inputting the above information, HEC-RAS determined the flood surface at each of the chosen locations.

We mapped the 100-yr floodplains by transcribing the 100-yr flood surfaces estimated by HEC-RAS onto USGS 1:24000 topographic sheets and interpolating between and extrapolating from hydrograph locations. Once mapped, the floodplains were digitized in ArcInfo GIS and were printed.

GIS Data Preparation

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

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

GROUND-WATER HYDROLOGY

Well Inventory

Archeological reports, TWDB records, Mr. James Hillegas, and a field survey of the camp grounds provided information for locating wells at Camp Bowie. We found 14 wells or well sites during our survey (fig. 3):

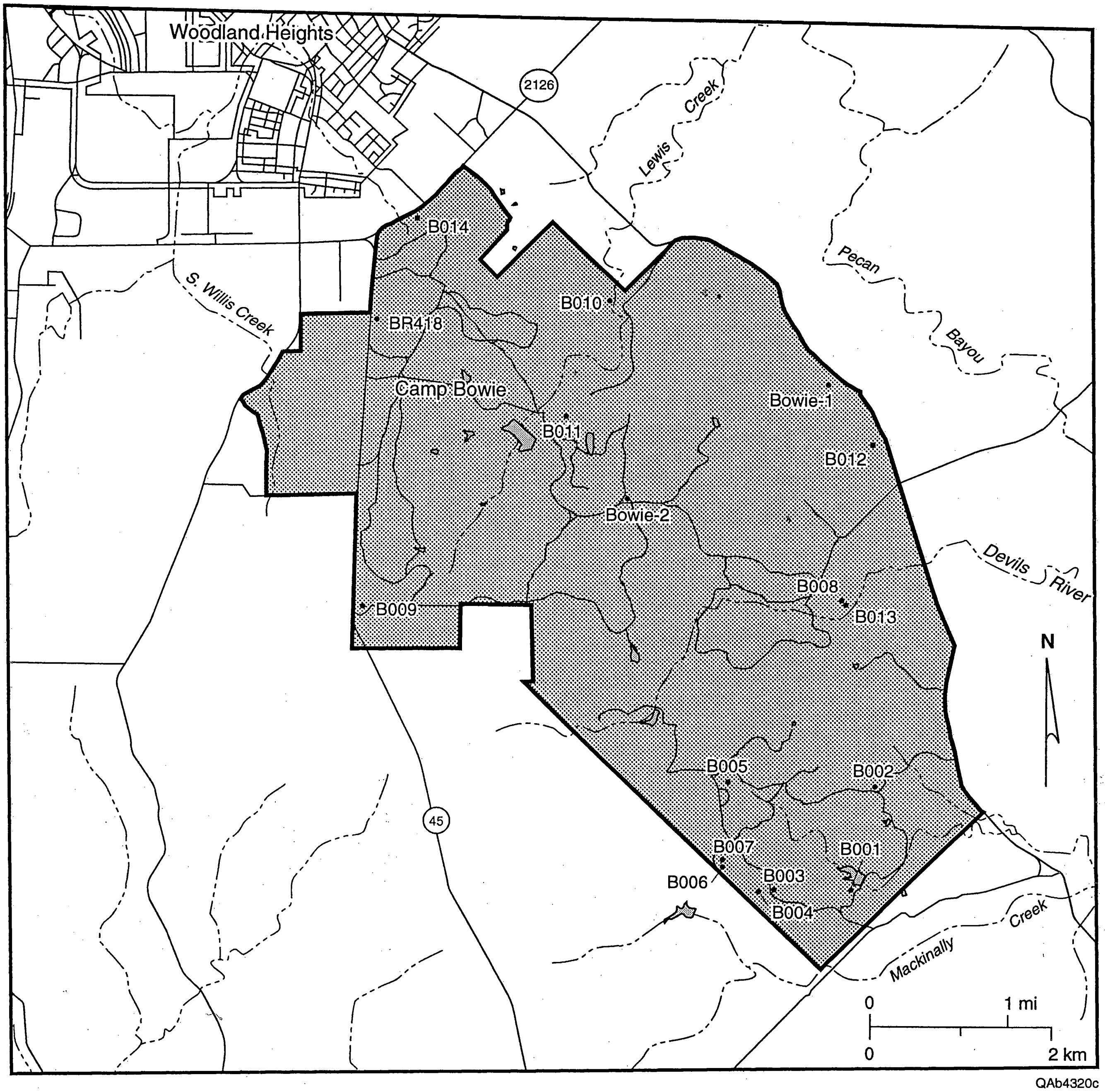

Figure 3. Well locations at Camp Bowie, including monitor wells drilled during this study.

- **CBW-B001** is an operational deep well that the camp sometimes uses 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 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 rises 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 the wellbore and a welded cap on the well. The casing rises 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 rises 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 is level with grade. The borehole is open and covered with a large rock.

- **CBW-B008** is a hand-dug well located in the midsoutheastern part of the camp. The well has a diameter of 21 inches and a stone crown that protrudes 1.58 ft above ground surface. The well is 11.4 ft deep and has 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 clear water.

- **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 northeastern part of the camp. The well has a diameter of 2.5 ft and a stone crown that stands 1.62 ft above ground surface. The well is

10.5 ft deep and has 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 murky water.

- **CBW-B011** is a hand-dug, bell-shaped cistern located in the northeast-central part of the camp. The well has a diameter of 3.0 ft and a stone crown that rises 0.88 ft above ground surface. The well is 9.1 ft deep and has 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 and 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 stands 1.4 ft above land surface. The borehole is open and covered with a well cap.

- **CBW-B014** is a 4-inch-diameter drilled well with no access for measuring depth of well and depth to water.

The cultural resources staff of the Office of the Adjutant General 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. This well possibly has been filled since the archeological survey. This site, 41BR418, apparently has a well pipe and filled cistern.

Texas Natural Resource Information System files report three wells within camp boundaries in the annexed property to the south. However, we could not find these wells, which suggests that they are not obvious from their locations or that their locations are misplotted.

A total of 114 wells were mapped during the perimeter well survey (fig. 4, app. 1). Well depths for 41 measured wells ranged from 7.5 to 600 ft. Of these, 27 were 100 ft deep or less, 6 were in the range of 101 to 200 ft, 3 were between 201 and 400 ft, and 5 were greater than 400 ft. Of the measured water-level elevations, 5 were less than 10 ft below ground surface, 5 were between 10 and 20 ft below ground surface, and 3 were between 20 and 28 ft below ground surface. The deepest well, at 600 ft, was dry and plugged. Only one electrical conductivity measurement was obtained. The value (850 micro-ohms) corresponds to a total dissolved solids

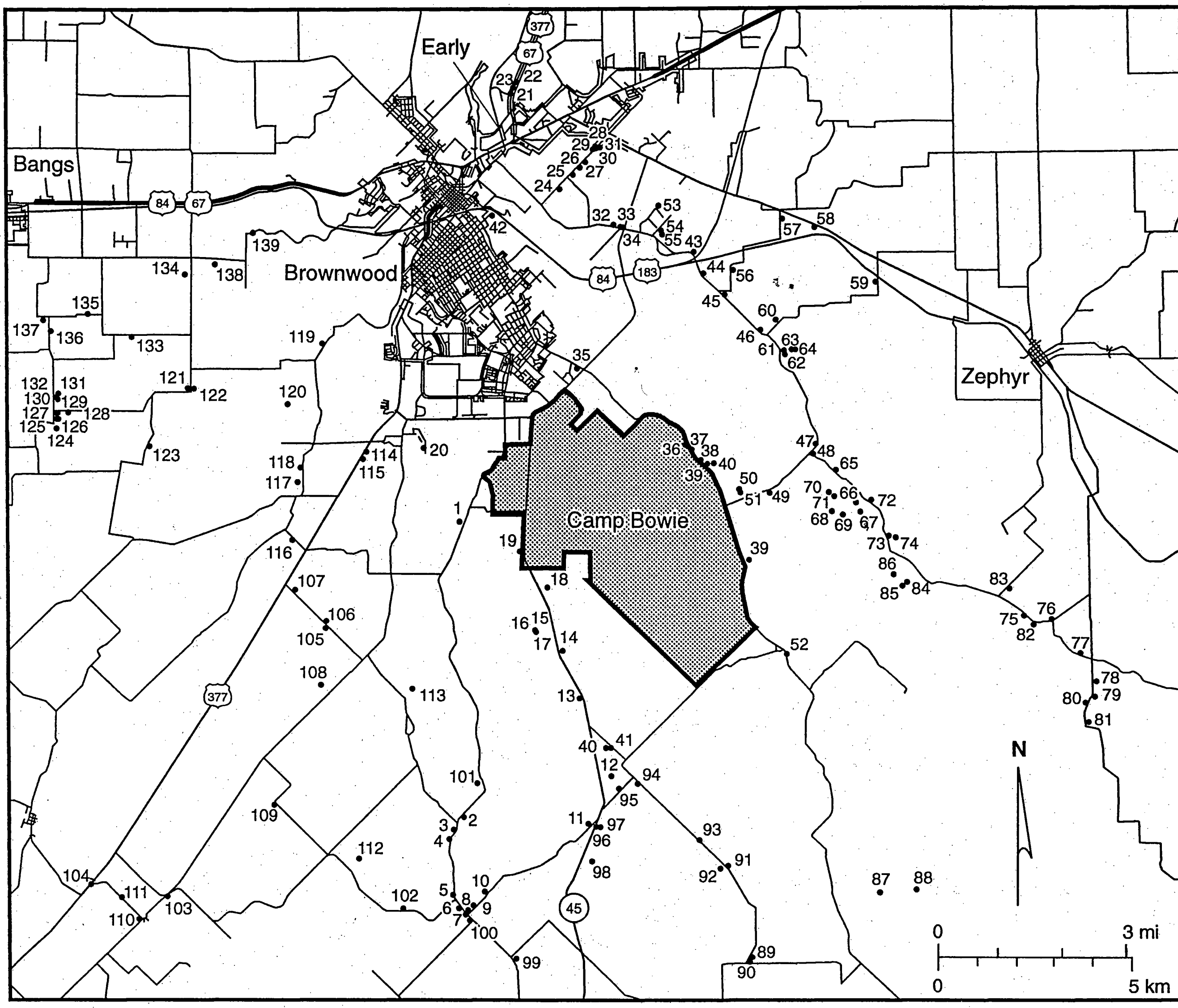

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Figure 4. Private wells located near Camp Bowie.

(TDS) value of about 550 mg/L, which is considered fresh water (<1000 mg/L TDS). The presence of a water supply system has reduced the reliance on wells for domestic water in the vicinity of Camp Bowie. However, many wells were not plugged after the water system was installed, and these remain available for measurements.

Wells in the vicinity of Indian Creek are approximately 500 ft deep and are reported to be flowing intermittently. The depth of the screened interval in these deep wells is unknown, but we suspect that the wells are completed at shallow intervals and that the deep pipe is used for well storage.

Monitoring Well Construction

We drilled and completed two wells at Camp Bowie: one in the Travis Peak Formation near the escarpment (BOWIE-2) and another in the alluvium/Strawn Group near the camp boundary (BOWIE-1). These wells are located in the eastern part of the camp (fig. 3). The well drilled into the Travis Peak Formation is 101.2 ft deep and was screened from 81.2 to 101.2 ft. The well drilled into the alluvium/Strawn Group is 53.8 ft deep. We used hollow-stem augering to install BOWIE-1. In BOWIE-2, we used hollow-stem augering to drill through the shallow unconsolidated deposits and solid-stem boring for the rest of the hole. Progress on the hole was delayed several times because of training at the camp and cold weather. Detailed well schematics and drilling reports are included in appendix 2.

Ground-Water Levels

TWDB files had sufficient water-level data to construct long-term hydrographs of the Travis Peak Formation (fig. 5). These hydrographs show similar patterns of water-level fluctuations that probably result from long-term variations in recharge to the aquifers. Hydrographs of well 41-09-303, located 11 mi northeast of Brownwood and about 1 mi from the edge of the Cretaceous outcrop, show 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. 5). Well 41-18-650, near Zephyr (east of Brownwood), is about 3 mi from the outcrop. Water levels in this well are generally similar to those of well 41-09-303 but are generally lower from 1980 to 1991 (fig. 5). Hydrographs of well 41-18-303, northeast of Zephyr and 5 mi from the outcrop, show water-level highstands during the early 1970's and mid-1990's (fig. 5).

Depths to water vary from formation to formation and vary spatially within formations. Two preexisting wells in the camp are 78 and 116 ft deep, having depths to water of 72.5 and 77 ft,

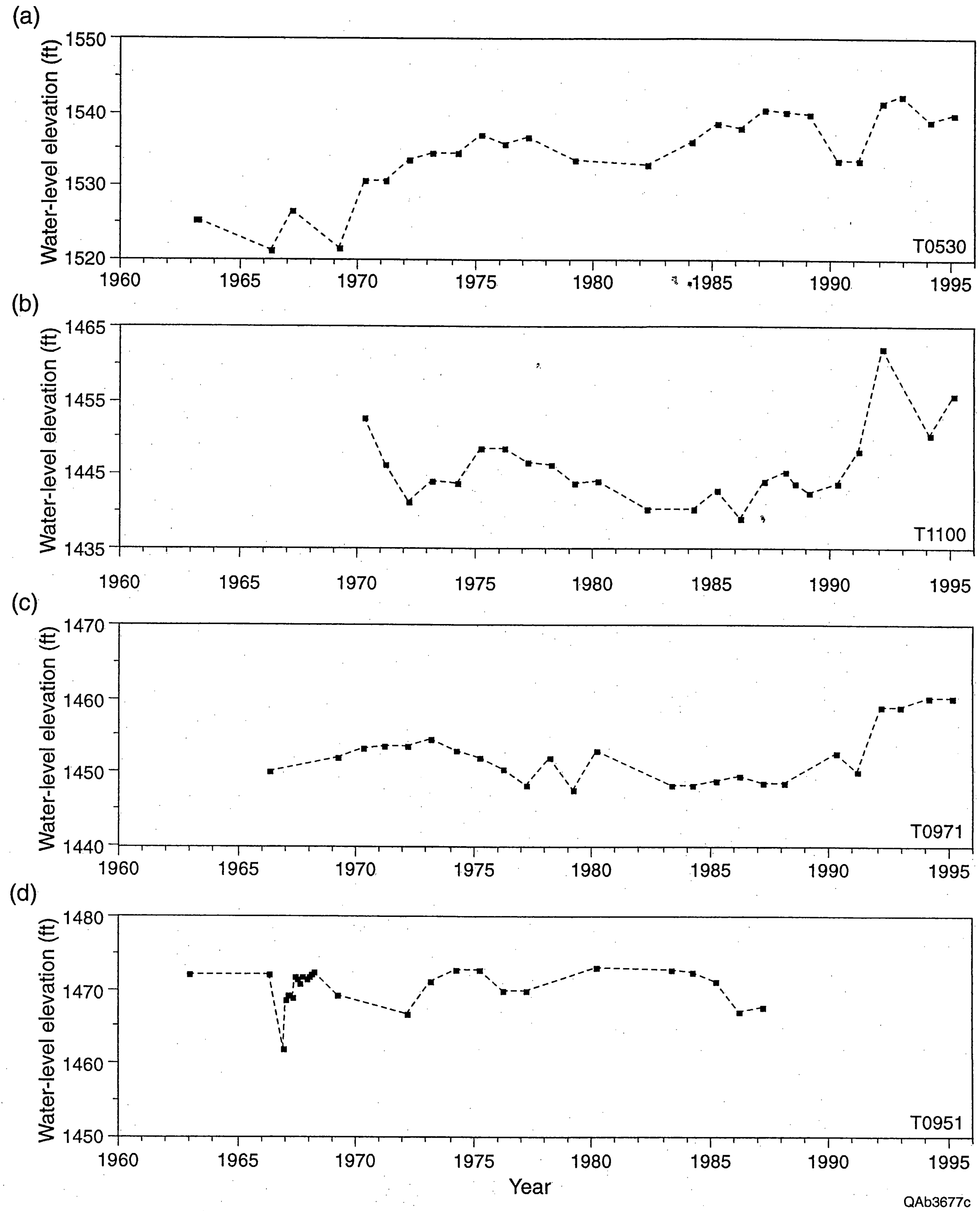

Figure 5. Water levels measured in Travis Peak Formation for wells (a) 41-09-303, (b) 41-18-650, (c) 41-18-303, and (d) 41-18-205 in Brown County.

respectively. These wells are probably completed in the Travis Peak Formation, although it is unclear whether they were completed within the sandstone intervals. Another well in the camp is about 200 ft deep and has a water level 11 ft below land surface. This well most 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.

Water levels in wells in the camp declined during the course of the project in response to low rainfall during the measurement period (table 1). We were not able to measure water levels in our monitor wells over an extended period of time. In well BOWIE-1, we made two measurements, one before and one after a large rainfall showing that the well did not respond immediately to this recharge event.

The Brownwood landfill, located along a part of the northwest boundary of the camp, has several shallow wells (<70 ft) completed in the Canyon and Strawn Groups that have a short period (~.5 yr) of detailed water-level measurements. Hydrographs of four of these wells, B-6A, B-7A, B-14, and B-14A, are shown in figure 6. Well B-7A is thought to have been completed in the Canyon Group, whereas the others were completed in the Strawn Group. Wells B-6A and B-7A showed large increases in water-level elevation in early 1992 (fig. 6a and 6b). These upswings agree with increases in water levels for wells in the Travis Peak (fig. 5a and 5b), suggesting a response to increased rainfall. Wells B14 and B14A have slight peaks during this same time, but the overall water-level increase is much smaller, suggesting less connection to the recharge events. These wells may be completed in clayey sections of the formation, whereas wells B-6A and B-7A may be completed in sandier sections of the aquifer.

Water levels in the Strawn Group and in the Travis Peak Formation are strongly influenced by topography, ground water flowing generally downslope. Figure 7 shows our interpretation of water levels in the Camp Bowie area based on measured water levels and our assumption of topographically influenced flow. Depth to water is greater in the Travis Peak Formation than in the Strawn Group and is greater beneath hill tops than in valleys. Ground water probably discharges from the edges of the Cretaceous mesas into colluvium and then into the Strawn Group or into local creeks and streams. Ground-water flow in the camp is directed mostly toward Pecan Bayou, lesser amounts being directed toward the northwest.

Hydraulic Properties

No pumping tests have been reported in wells in the Strawn Group or in the Travis Peak Formation in Brown County. The only reported aquifer tests are several well yield tests and a

Table 1. Water-level measurements in Camp Bowie wells.

Date	Time	Depth to water (ft)	Water-level elevation (ft)
BOWIE-1			
4/3/96	1120	28.42	1263.58
4/4/96	0845	28.43	1263.57
BOWIE-2			
4/4/96	1413	46.42	1181.28
CBW-B002			
10/3/95	1317	11.40	1411.10
1/2/96	1330	21.90	1400.60
4/4/96	0900	23.37	1399.13
CBW-B004			
10/3/95	1405	73.30	1417.37
1/2/96	1605	74.96	1415.71
4/4/96	0907	75.87	1414.80
CBW-B007			
10/3/95	1433	77.12	1432.88
1/2/96	1614	78.43	1431.57
4/4/96	0916	79.40	1430.60

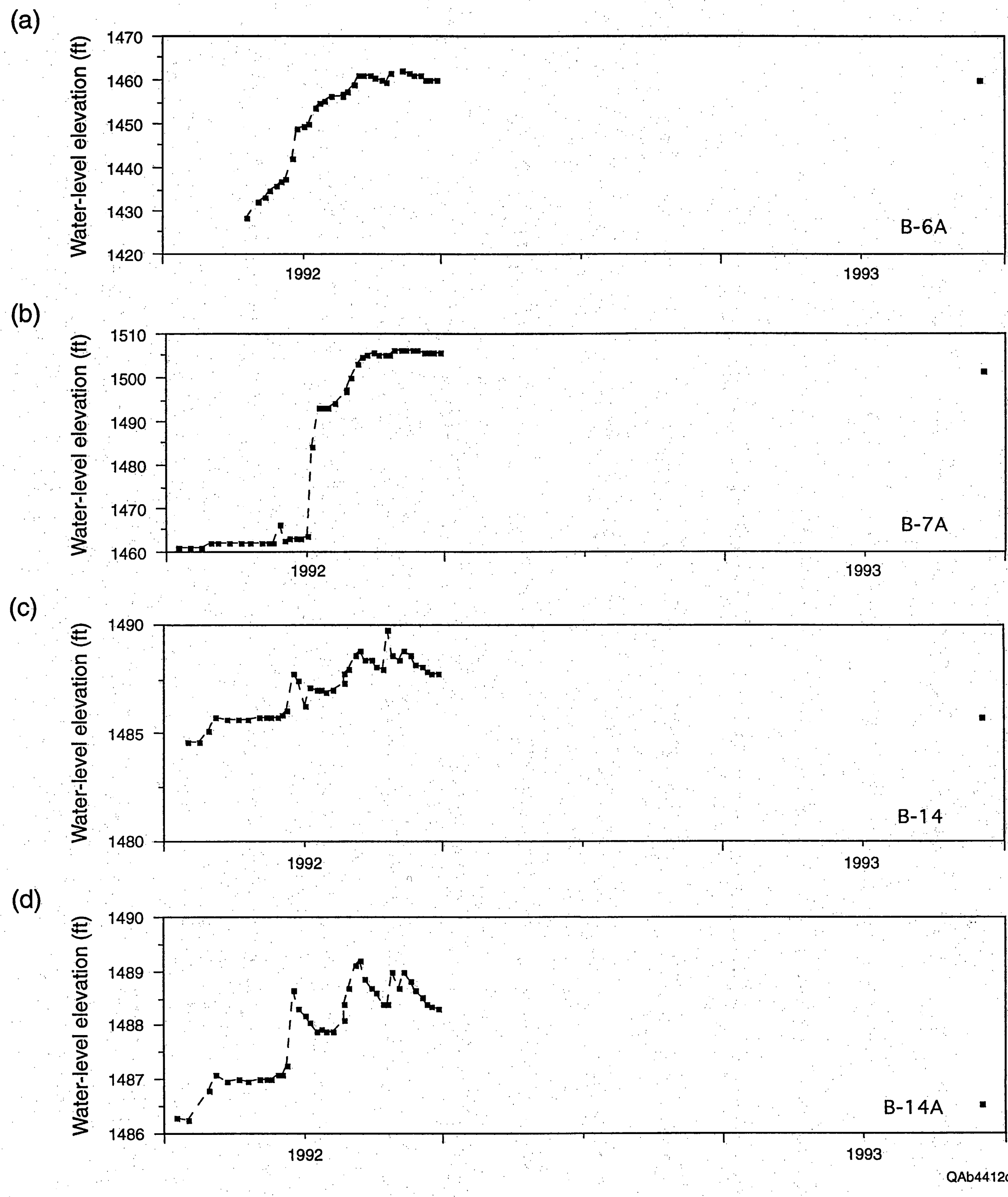

Figure 6. Water levels measured in Strawn and Canyon Groups in wells (a) B-6A, (b) B-7A, (c) B-14, and (d) B-14A in the Brownwood landfill next to Camp Bowie.

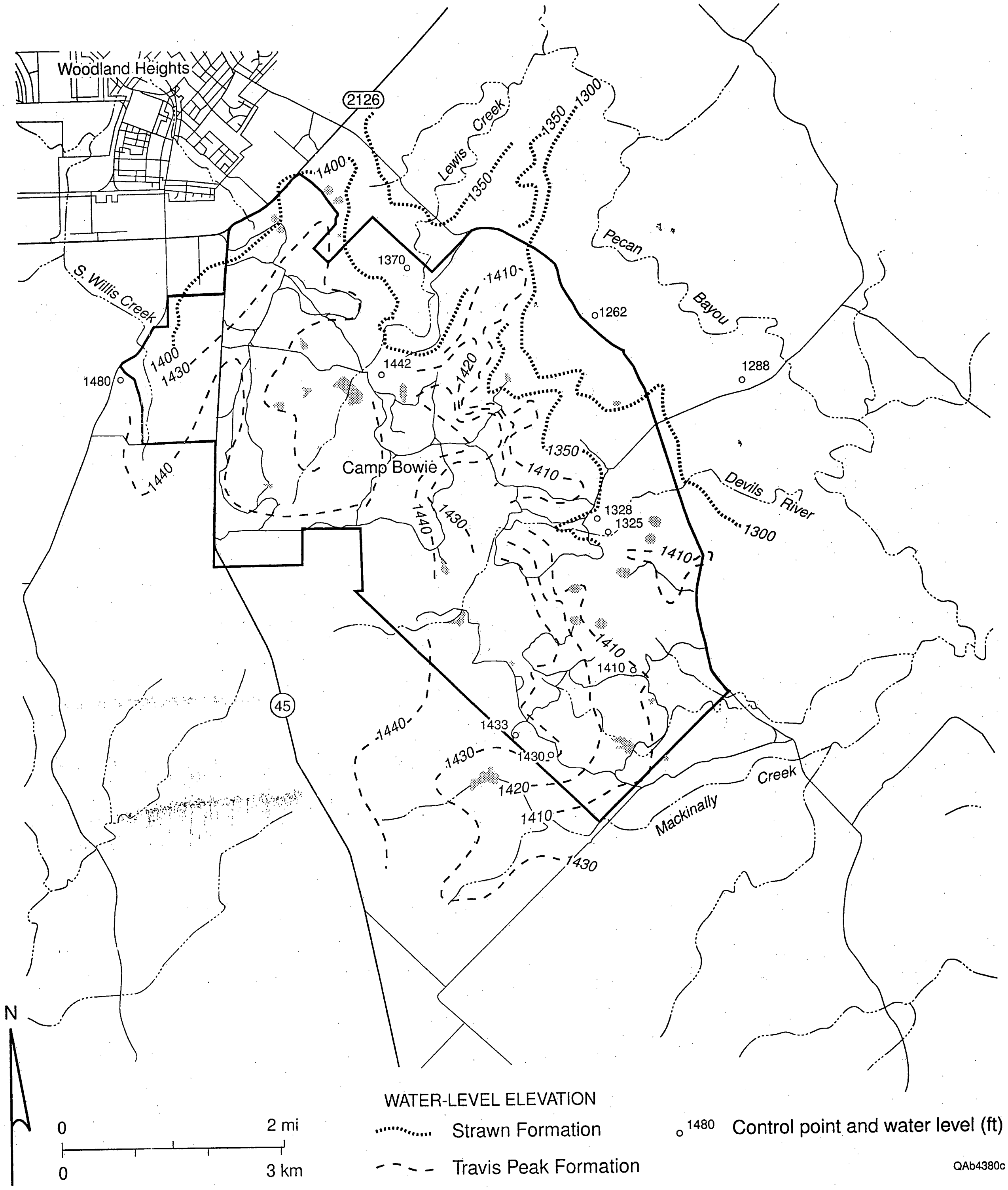

Figure 7. Map of water levels of Strawn Group and Travis Peak Formation in the Camp Bowie area.

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

We conducted site-specific aquifer tests in the monitor wells we drilled in the alluvium/Strawn Group and the Travis Peak Formation at Camp Bowie and in two preexisting wells. Monitor well BOWIE-1, drilled into the alluvium/Strawn Group, had a classic response of an unconfined aquifer that corresponded to transmissivity of about 8 to 9 ft^2/day (fig. 8). Monitor well BOWIE-2, drilled into the Travis Peak Formation, had a transmissivity of about 0.13 ft^2/day, judging from an interpretation of a bail test (fig. 9). Well CBW-B002, a preexisting well thought to have been completed in the Travis Peak Formation, had a transmissivity of 2 ft^2/day (fig. 10). Well CBW-B013, a preexisting well thought to have been completed in the Strawn Group, had a transmissivity of about 1 ft^2/day (fig. 11).

Ground-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, all of which are fresh (TDS < 1,000 mg/L) (fig. 12a). TDS for the Travis Peak Formation range from 420 to 1,247 mg/L, having a geometric mean of 708 mg/L (fig. 12b). A total of 22 percent of the samples is brackish (1,000 mg/L < TDS < 10,000 mg/L). TDS in the Strawn Group range from 104 to 4,750 mg/L, having a geometric mean of 955 mg/L (fig. 12c). Many of the samples (43 percent) are brackish.

Waters from the alluvium are predominantly calcium bicarbonate type (fig. 13a). 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. 13b). Waters from the Strawn Group are also mixed with magnesium bicarbonate and calcium bicarbonate waters, sodium chloride waters, and many waters having no dominant cation or anion composition (fig. 14).

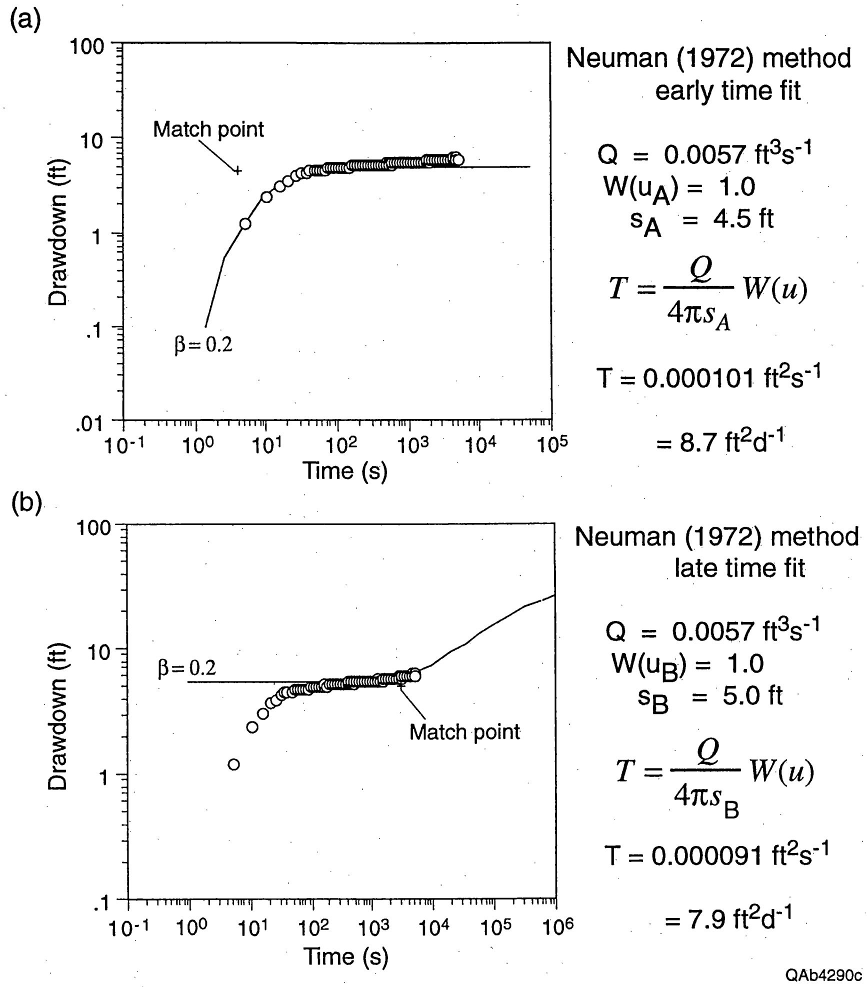

Figure 8. Results of a pumping test at BOWIE-1.

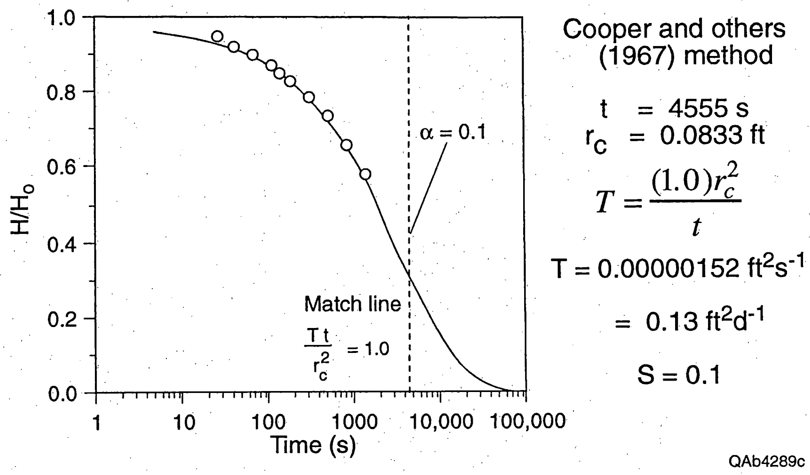

Figure 9. Results of a bail test at BOWIE-2.

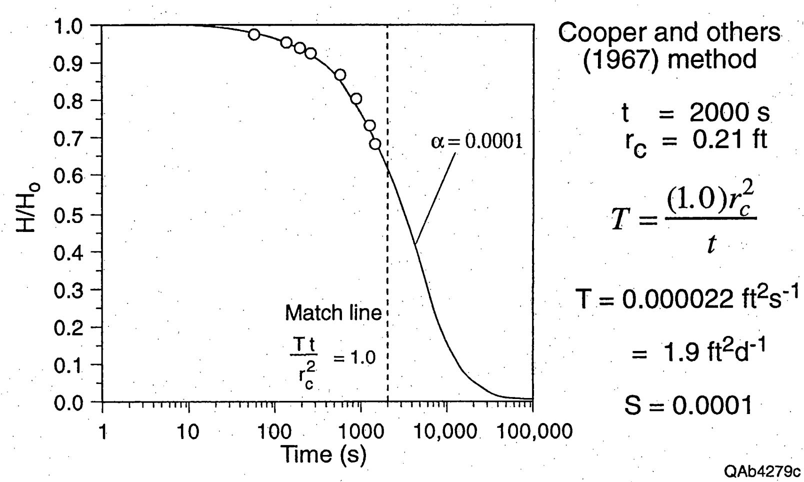

Figure 10. Results of a bail test at CBW-B002.

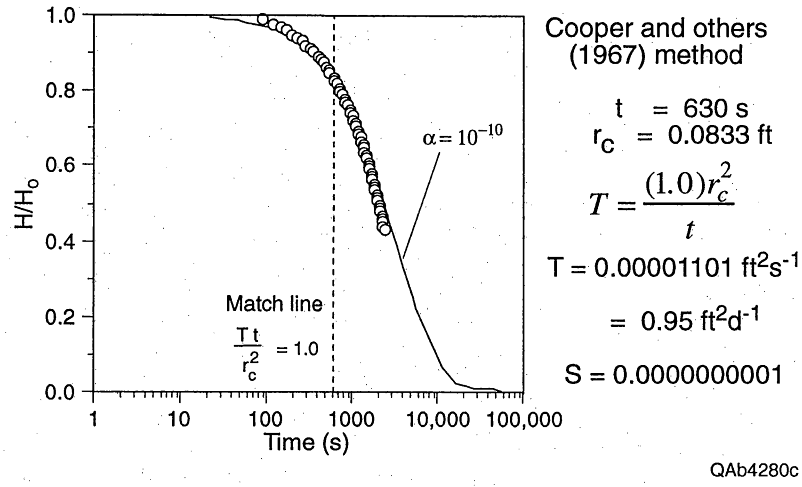

Figure 11. Results of a bail test at CBW-B013.

Table 2. Chemical analyses of selected ground-water samples 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. (mW)
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	Total TDS (mg/L)	Total alk (mg/L)	Spec. hardness (mg/L)	cond. (mW)
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

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. (mW)
Strawn Group (cont.):																		
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
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

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. (mW)
Strawn Group (cont.):																		
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
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

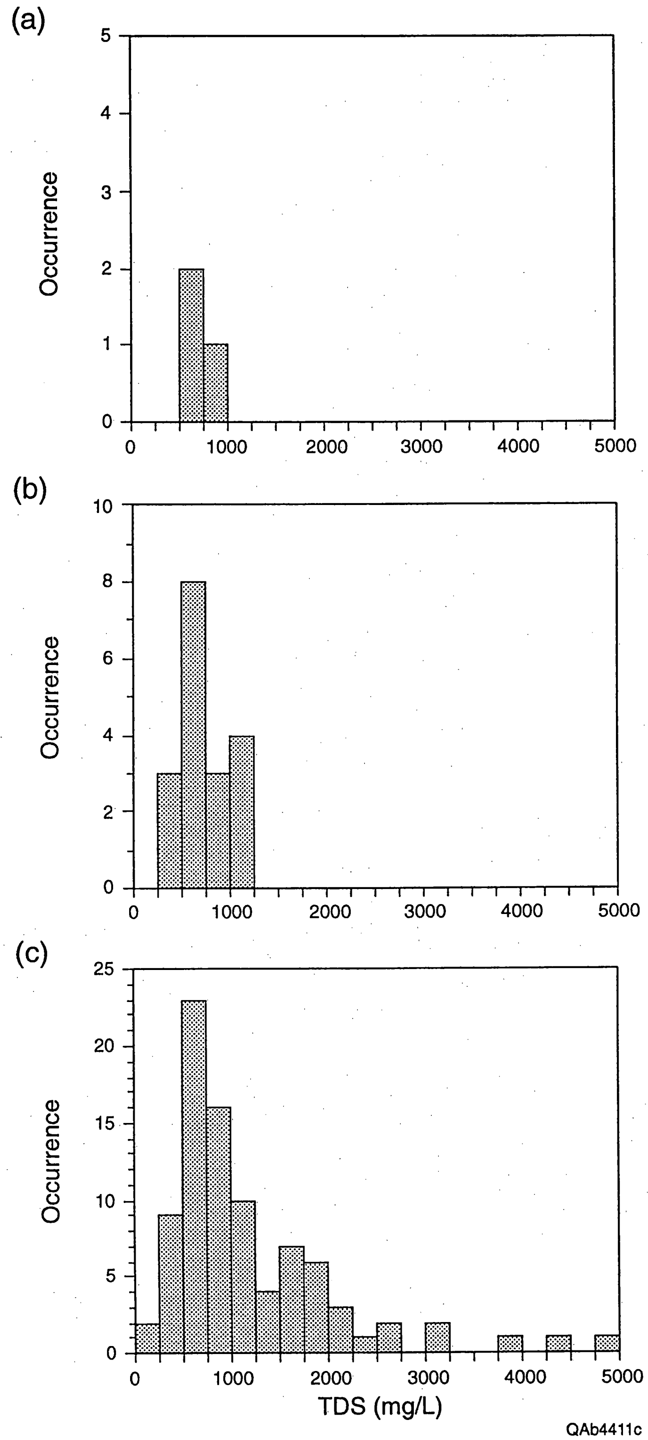

Figure 12. Histograms of total dissolved solids (TDS) in (a) alluvium, (b) Travis Peak Formation, and (c) Strawn Group of Brown County.

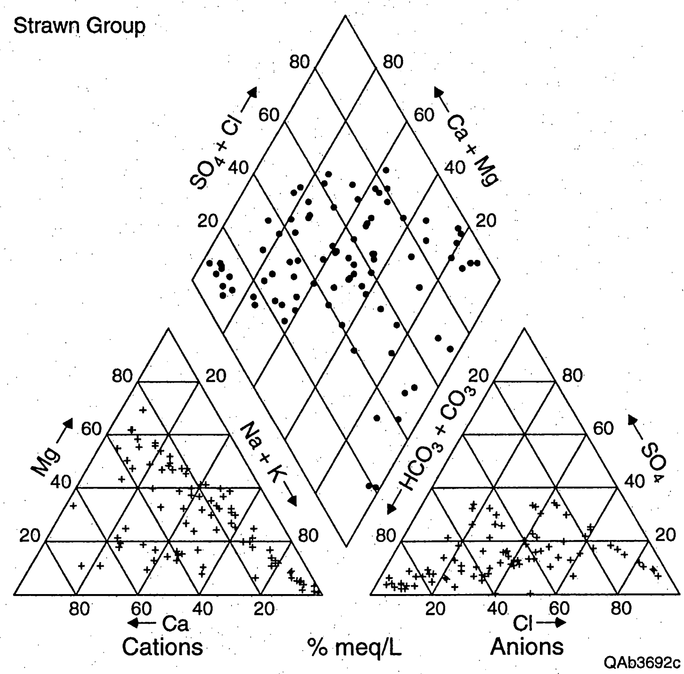

Figure 13. Trilinear diagram showing chemical composition of ground-water samples from (a) alluvium and (b) Travis Peak Formation in Brown County.

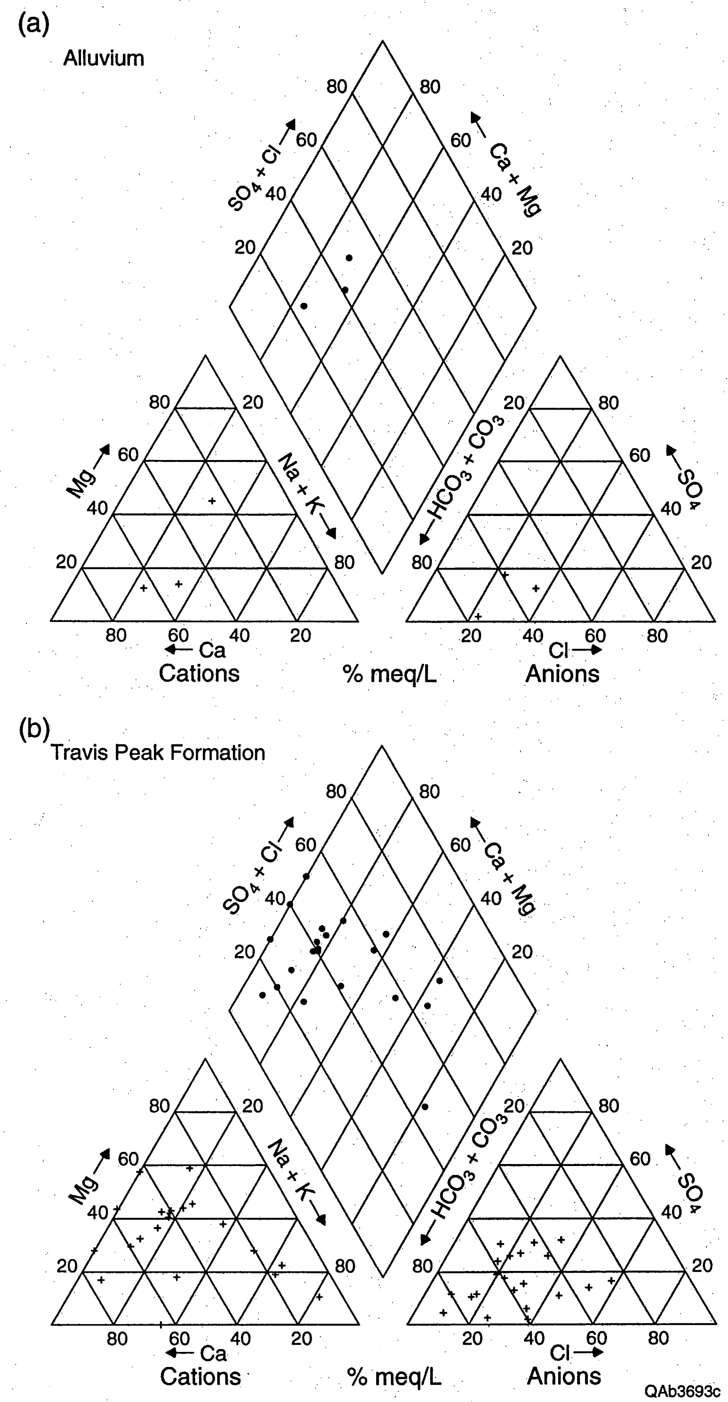

Figure 14. Trilinear diagram showing chemical composition of ground-water samples from Strawn Group of Brown County.

Results from the chemical analyses on ground water collected from the Camp Swift monitor wells are shown in table 3. Water samples collected from the Camp Swift monitor wells are calcium bicarbonate and calcium-magnesium-bicarbonate in composition (figs. 13b and 14). Tritium activity measured in BOWIE-2 (3±3 TU) indicates that water in that well is more than 25 years old.

Conceptual Flow Model

The hydrostratigraphy of the Camp Bowie area and results of our hydrogeologic analyses suggest the following conceptual ground-water flow model for the area. 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. When there is greater recharge, water levels rise and there is greater discharge to local streams. During times of low recharge, ground water moves toward and probably discharges at Pecan Bayou.

SURFACE-WATER HYDROLOGY

Principal Streams and Watershed Delineation

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

Table 3. Chemical analyses of ground-water samples from the Strawn and Canyon Group collected from ground-water monitoring wells at the Brownwood landfill along the northwest border of Camp Bowie. Units are mg/L unless otherwise indicated.

Well	Month	Day	Year	Cl	pH	Fe	Mn	Spec. Cond. (µmhos/cm)	TDS
B-01	3	25	1992	35	7.70	<0.1	<0.1	909	550
B-06	3	25	1992	145	7.90	<0.1	<0.1	1800	1100
	3	29	1993	80	7.80	<0.05	<0.05	1400	782
	3	30	1994	560	6.90	0.14	<0.5	6750	5250
	3	29	1995	114	7.29	<0.05	<0.05	1600	908
B-07	3	25	1992	33	7.70	<0.1	<0.1	900	596
	3	29	1993	31	7.60	<0.05	0.016	1160	666
	3	30	1994	95	7.90	0.11	<0.05	1320	756
B-14	5	20	1988	28	7.09	0.6	0.07	625	676
	3	02	1989	36	6.80	0.17	<0.05	1655	1010
	3	20	1990	7.5	7.40	<0.1	<0.1	800	500
	3	06	1991	26	7.30	6.71	na	938	600
	3	25	1992	30	7.80	<0.1	<0.1	980	616
	3	29	1993	18	7.80	<0.05	<0.05	845	474
	3	30	1994	30	7.30	0.12	<0.05	840	462
	3	29	1995	19.1	7.26	0.1	<0.01	922	534
B-16	3	29	1995	108	7.25	<0.05	<0.01	1510	886
Bowie-1	4	04	1996	45.0	6.56	na	na	na	816
Bowie-2	4	04	1996	50.4	6.65	na	na	na	745

Table 3 (cont.)

Well	Month	Day	Year	Zn	Ca	Mg	Na	K	CO3	HCO3	SO4	F	NO3	Alkalinity
B-01	3	25	1992	na	101	52	39	3.14	<1	537	67	1.6	7.3	440
B-06	3	25	1992	na	45	82	228	2.04	<1	598	225	1.0	1.64	490
	3	29	1993	NR	35.2	63	155	2.3	<1	555	135	1.9	2.2	455
	3	30	1994	NR	719	362	405	12.4	<5	432	3122	0.9	7.9	354
	3	29	1995	0.02	59.3	107	177	3.32	<1	642	228	1.3	0.7	526
B-07	3	25	1992	na	70	78	40	1.07	<1	598	28	1.2	0.4	490
	3	29	1993	NR	64.2	107.8	32.8	1.61	<1	659	97.8	0.7	0.6	540
	3	30	1994	NR	88.6	112	50.9	5.33	<5	639	125	0.8	0.3	524
B-14	5	20	1988	<0.05	83	10	31	na	0	687	81	0.6	0.2	564
	3	02	1989	na	na	na	32.4	na	na	na	na	1.9	<0.5	na
	3	20	1990	na	48	73.5	1.0	3.68	na	439	32	0.5	0.85	na
	3	06	1991	na	36	94	20	4.8	0	523	62.4	0.5	1.12	429
	3	25	1992	na	70	105	28.3	1.71	<1	695	68	0.7	0.28	570
	3	29	1993	NR	38	103	14	1.03	<1	567	39	0.6	0.3	465
	3	30	1994	NR	56.1	80.1	20.9	1.59	<5	512	32.8	0.5	0.2	420
	3	29	1995	0.02	55.6	85	12.1	1.3	<1.0	490	42.1	0.4	<0.1	598
B-16	3	29	1995	0.03	58.5	82	168	16.2	<1.0	637	203	1.3	0.724	522
Bowie-1	4	04	1996	na	122.2	24.0	64.7	4.2	0	491	60.9	1.3	3.4	na
Bowie-2	4	04	1996	na	71.5	64.5	32.6	3.9	0	489	25.2	1.3	6.7	na

NR: not reported.
na: not analyzed.

Table 3 (cont.)

Well	Month	Day	Year	As	Ba	Cd	Cr	Cu	Pb	Hg	Se	Ag
B-06	3	29	1993	NR	NR	NR	NR	NR	<0.005	NR	NR	NR
	3	30	1994	NR	NR	NR	NR	NR	<0.005	NR	NR	NR
	3	29	1995	<0.01	0.02	<0.0005	<0.005	<0.005	<0.0025	<0.0002	<0.005	0.003
B-07	3	29	1993	NR	NR	NR	NR	NR	<0.005	NR	NR	NR
	3	30	1994	NR	NR	NR	NR	NR	<0.005	NR	NR	NR
B-14	5	20	1988	<0.05	<1	<0.01	<0.05	0.2	0.02	<0.002	<0.01	<0.05
	3	2	1989	na	na	na	na	na	na	<0.002	na	na
	3	20	1990	na	na	na	na	na	na	<0.002	na	na
	3	6	1991	na	na	na	na	na	na	<0.002	na	na
	3	29	1993	NR	NR	NR	NR	NR	<0.005	NR	NR	NR
	3	30	1994	NR	NR	NR	NR	NR	0.008	NR	NR	NR
	3	29	1995	<0.01	0.14	<0.0005	<0.005	<0.005	<0.0025	<0.0002	<0.005	0.002
B-16	3	29	1995	<0.01	0.02	<0.0005	<0.005	<0.005	<0.0025	<0.0002	<0.005	0.002
Bowie-1	4	04	1996	na	na	na	na	na	na	na	na	na
Bowie-2	4	04	1996	na	na	na	na	na	na	na	na	na

Watersheds at Camp Bowie (fig. 15) were defined for the major tributaries to Pecan Bayou. Camp Bowie intersects a small part of the headwaters of Willis Creek, which extends just upstream from the camp. Headwaters of the Lewis Creek watershed are almost completely contained within the camp. About one-fifth of the Devils River watershed lies upstream outside the camp. Most of the headwaters for an unnamed tributary to Mackinally Creek are also contained within camp boundaries. A small area of Mackinally Creek is included in the southernmost part of the camp.

Flow Duration and Flood Frequency

Although there are no stream gauges at Camp Bowie, two gauges are 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 8,700 cfs in the Colorado River (fig. 17c).

Floodplain Analysis

Camp Bowie has several streams that drain into Pecan Bayou to the northeast. Existing as halos around the stream beds, the floodplains generally become wider as they approach Pecan Bayou (fig. 18). Floodplains are wider around higher order streams such as South Willis Creek, Lewis Creek, and Devils River. The 100-yr 24-hr rainfall is 9.5 inches, having a maximum SCS Type II distributed rainfall intensity of 4.04 inches/hr (fig. 19a). This 100-yr rainfall results in a maximum flow of 3,693 cfs in the tributary to Mackinally Creek in the south (fig. 19b for point A in fig. 15), 7,484 cfs for Devils River near the camp boundary (fig. 19c for point B in fig. 15), and 3,762 cfs for Lewis Creek near the camp boundary (fig. 19d for point C in fig. 15).

GIS DATA PREPARATION

Several layers of data and information were automated for inclusion into a geographical information system (GIS). These layers include

- Roads
- Watersheds
- Digital elevation map (DEM)
- Floodplains

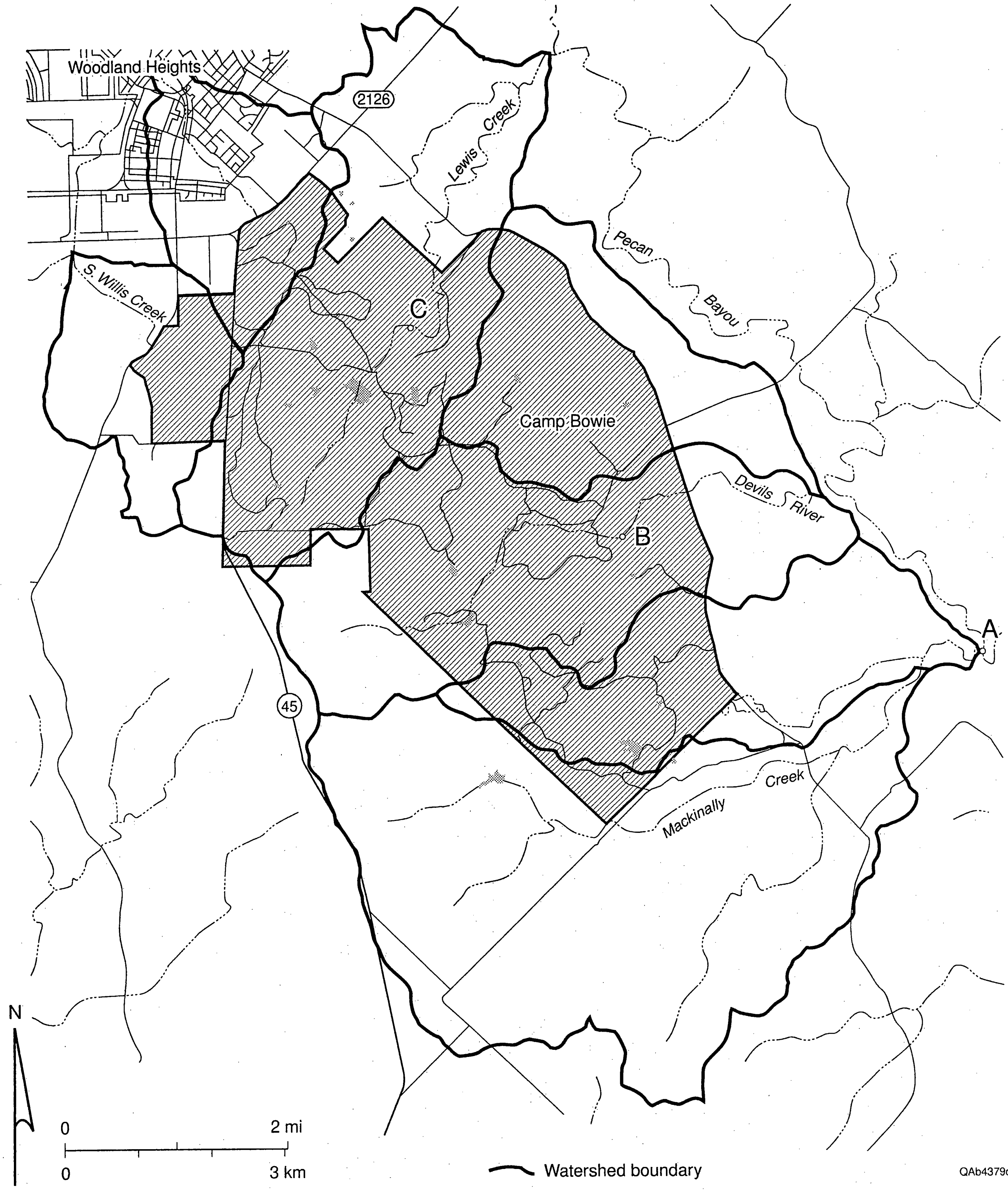

Figure 15. Watershed delineations of Camp Bowie.

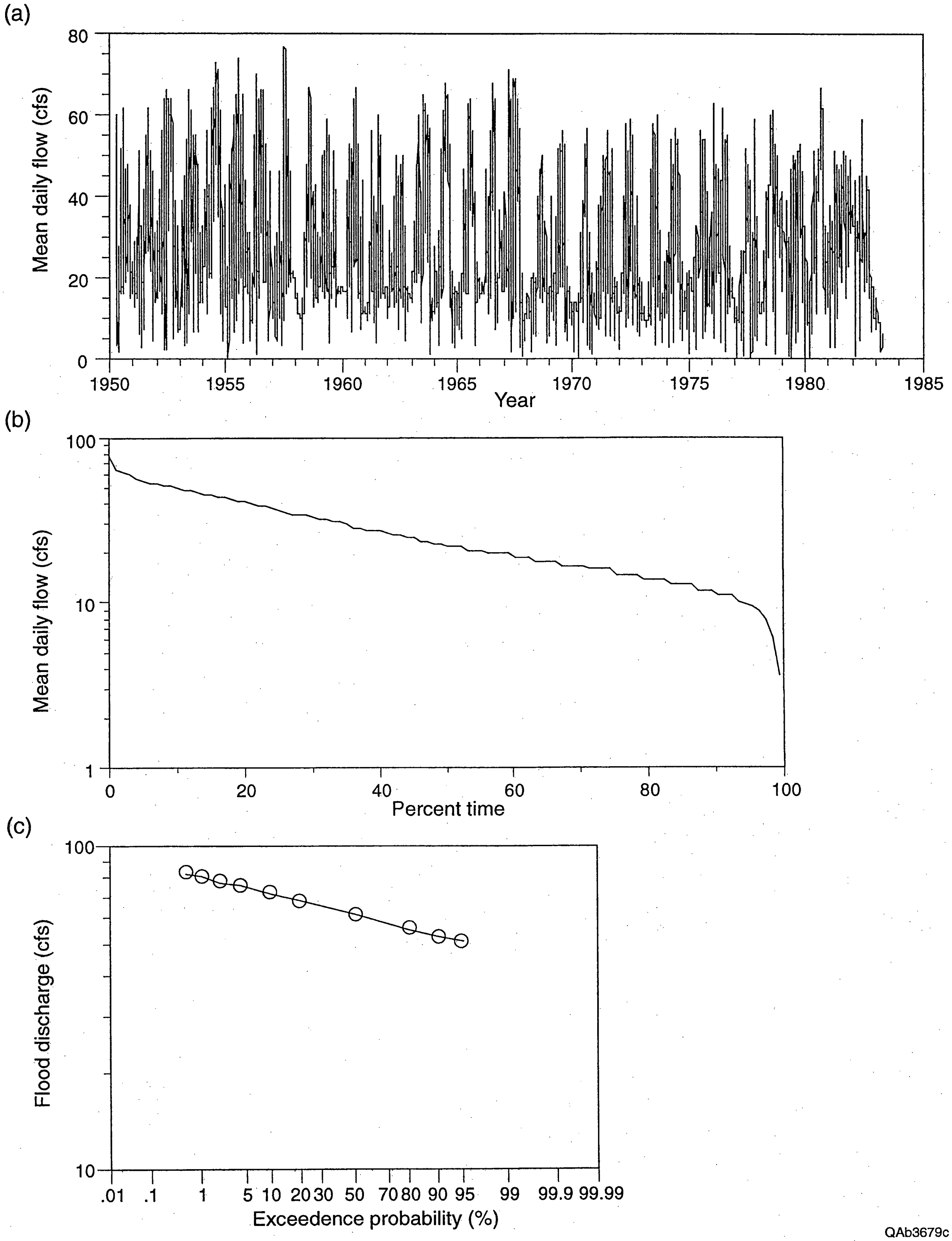

Figure 16. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis using a Log Pearson III fit for a stream gauge in Brown County WID No. 1 Canal near Brownwood.

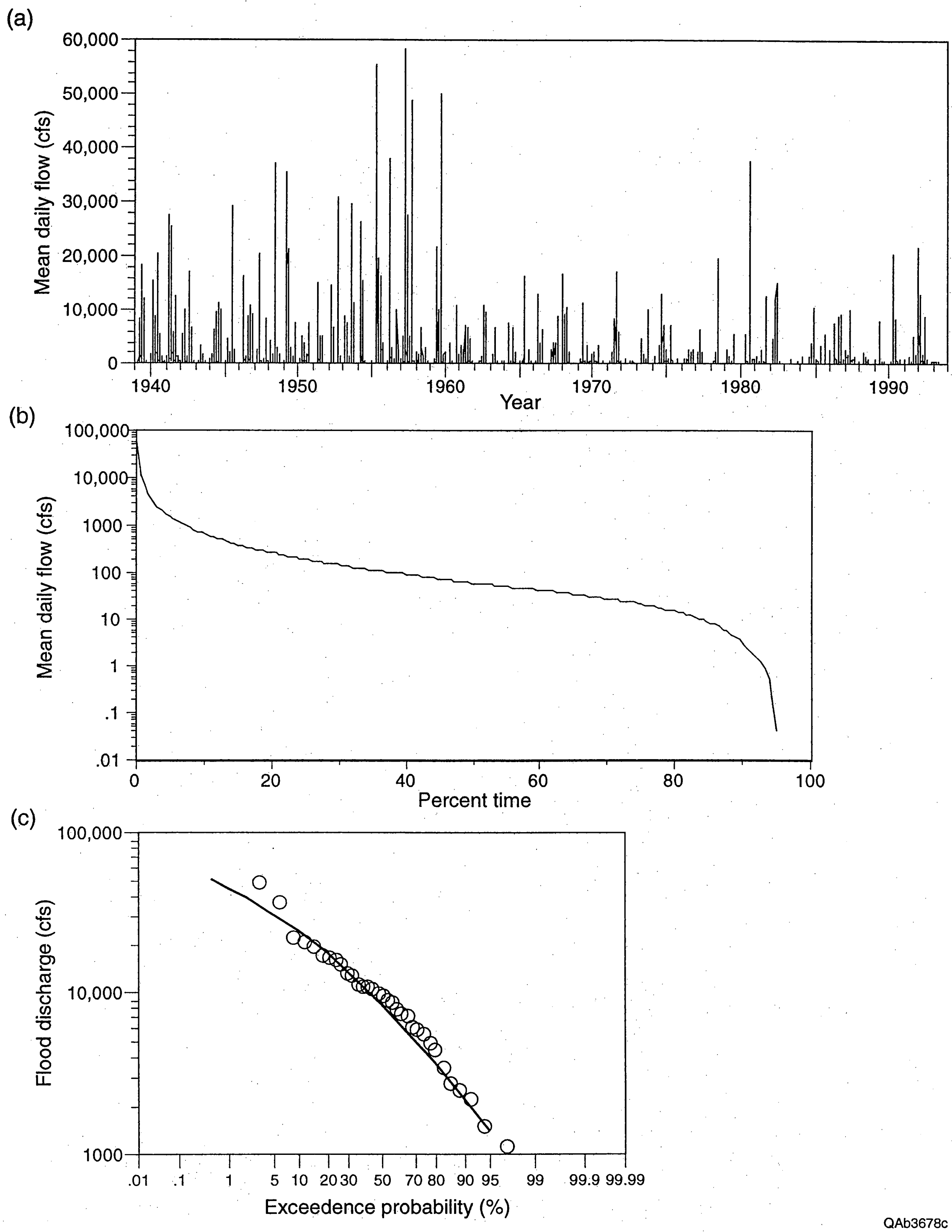

Figure 17. (a) Mean daily flow, (b) flow duration, and (c) flood frequency analysis using a Log Pearson III fit for a stream gauge in the Colorado River near Winchell.

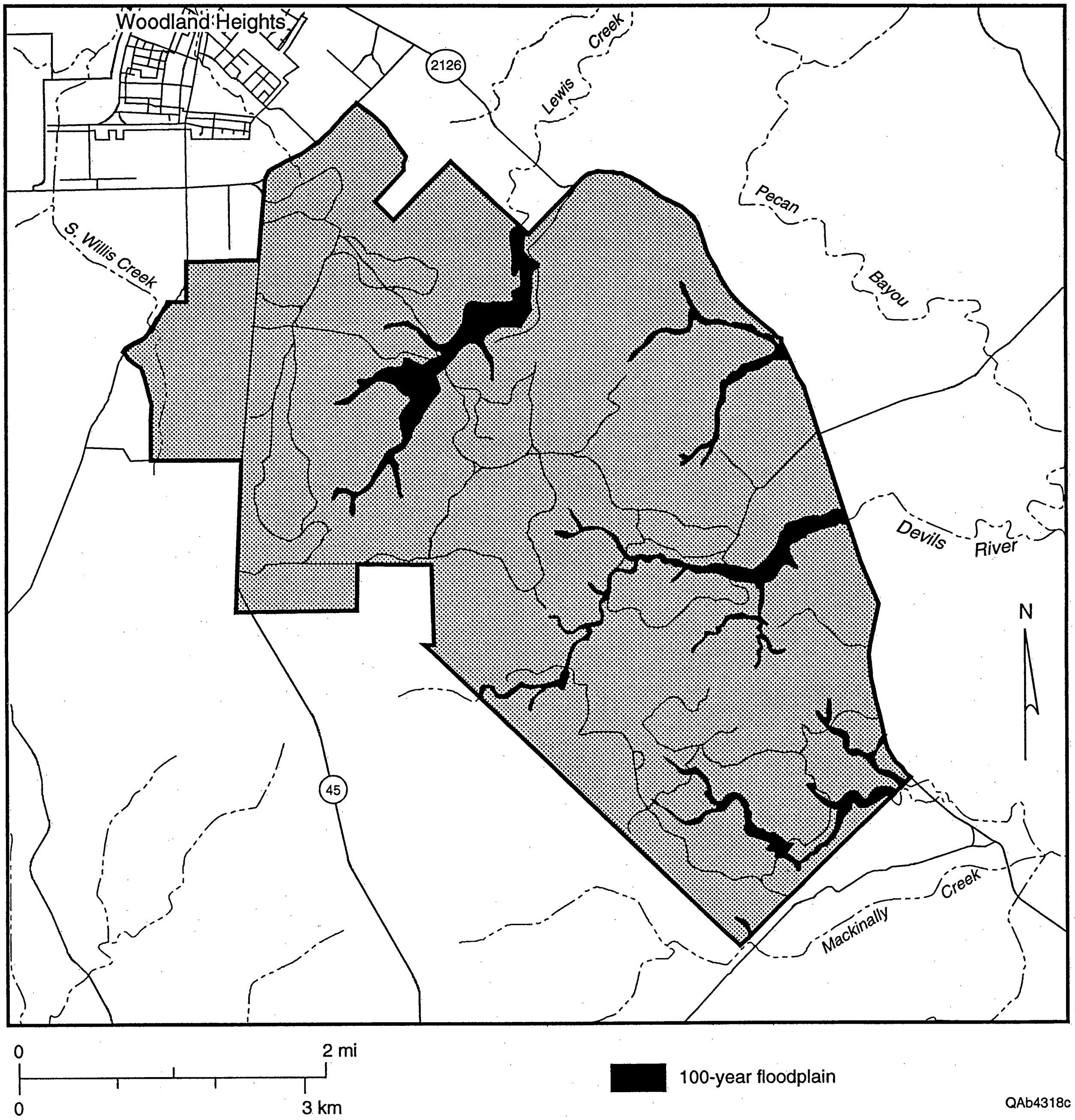

Figure 18. One-hundred-year floodplains of Camp Bowie.

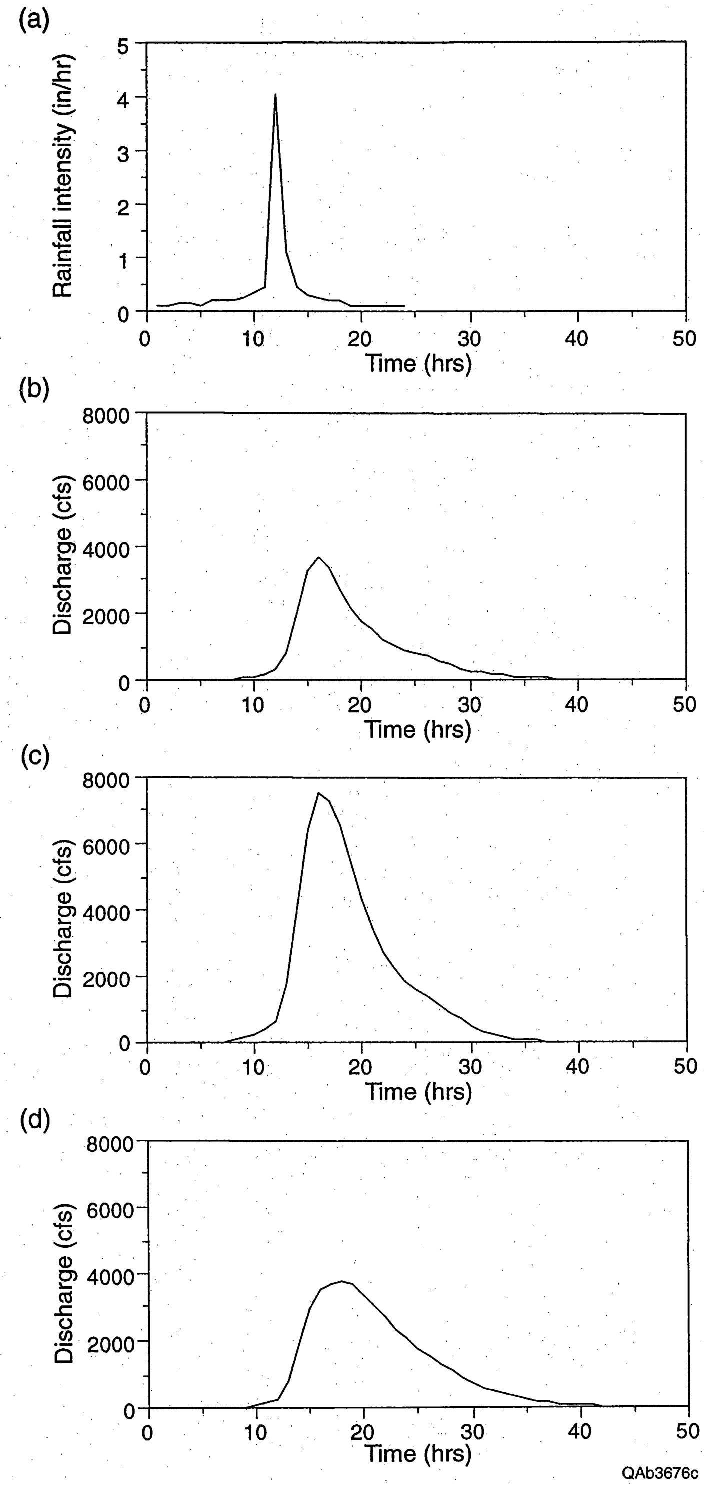

Figure 19. Flood hydrograph analysis of Camp Bowie: (a) 100-yr 24-hr SCS Type II distributed rainfall intensity and the 100-yr flood hydrographs near the camp boundary of (b) a tributary to Mackinally Creek (point A, fig. 15), (c) Devils River (point B, fig. 15), and (d) Lewis Creek (point C, fig. 15).

- Soil maps
- Location of off-camp wells
- Location of on-camp wells
- Water-level maps

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

SUMMARY

A well survey located 114 wells around Camp Bowie and 14 on the camp grounds. Most of the wells produce from sands of the Trinity Group (Cretaceous System), particularly the Twin Mountains Formation of the Trinity Group. Approximately 10 percent of the wells produce water from the Strawn Group (Pennsylvanian System). Water levels in the Strawn Group and in the Travis Peak Formation (stratigraphically equivalent to the Twin Mountains Formation) are strongly influenced by topography. Ground-water recharge at Camp Bowie occurs predominantly on the mesas formed by Cretaceous strata and on sandy areas of the Strawn Group. Ground water then flows toward topographically low areas, primarily at the edge of the mesa escarpment. Deeper circulation into the Strawn Group ultimately discharges to Pecan Bayou or to Indian Creek. Ground water from the Travis Peak Formation may discharge through seeps or springs or may enter colluvium formed by escarpment erosion. Ground-water quality is fresh to brackish. Water from alluvium is typically a calcium bicarbonate type, whereas water from deeper aquifers is more compositionally variable.

Camp Bowie resides within the Pecan Bayou drainage basin, which in turn feeds the Colorado River. Surface runoff from the camp flows first to various creeks that are tributaries to Pecan Bayou and then to Pecan Bayou. Flooded areas at Camp Bowie that would result from a 100-yr storm are adjacent to streams and creeks, the widest floodplains lying closest to Pecan Bayou.

Results of these ground-water and surface-water analyses suggest that ground-water quality can best be preserved by avoiding contamination in the recharge zone, whereas surface-water quality can best be preserved by avoiding contamination in the 100-yr floodplains.

ACKNOWLEDGMENTS

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Appendix 1

Perimeter Well Survey

Well inventory data base

Bureau of Economic Geology

Project National Guard **Area** Camp Bowie **Surveyer** Conrad Kuharic

Well #	Date	Time	Cond. (μΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Casing material	Well use	Owner
S001	8/7/95	-	-	-	-	-	-	-	-	-
S002	8/7/95	1820	-	~80-100	-	-	-	-	-	Dodd
S003	8/7/95	-	-	-	-	-	-	-	-	-
S004	8/7/95	-	-	-	-	-	-	-	-	Richmon
S005	8/7/95	-	-	140	-	-	-	-	-	-
S006	8/7/95	-	-	~500	-	-	-	-	-	-
S007	8/7/95	1445	-	483	3.93	0.00	4	iron	garden	Petzold
S008	8/7/95	-	-	-	-	-	-	-	-	Salazar
S009	8/7/95	-	-	-	-	-	-	-	-	-
S010	8/7/95	-	-	500	~32-40	-	-	-	domestic	John White
S011	8/7/95	-	-	-	-	-	-	-	-	-
S012	8/7/95	-	-	-	-	-	-	-	-	-
S013	8/7/95	-	-	-	-	-	-	-	-	-
S014	8/7/95	-	-	-	-	-	-	-	-	-
S015	8/7/95	1545	-	100	-	-	-	-	-	Treldon Cutbirth
S016	8/7/95	1545	-	100	-	-	-	-	-	Treldon Cutbirth
S017	8/7/95	-	-	600	-	-	-	-	-	Treldon Cutbirth
S018	8/7/95	-	-	-	-	-	-	-	-	-
S019	8/7/95	-	-	-	-	-	-	-	-	-
S020	8/7/95	-	-	-	-	-	7	iron	unused	Brownwood CC
S021	8/8/95	-	-	-	-	-	-	-	-	-
S022	8/8/95	-	-	-	-	-	-	-	-	-
S023	8/8/95	-	-	-	-	-	-	-	-	-
S024	8/8/95	0845	-	40	~30	-	7	steel	domestic	Preston Bishop
S025	8/8/95	-	-	-	-	-	-	-	-	-
S026	8/8/95	1600	-	100	10.78	1.20	-	-	domestic	Gerald Deviney
S027	8/8/95	-	-	-	-	-	-	-	-	-
S028	8/8/95	0915	-	25	8.26	0.00	-	concrete/tile	unused	Tony Goodson
S029	8/8/95	0925	-	~7.5	4.92	1.11	48	concrete	unused	Juanita Bailey
S030	8/8/95	-	-	-	-	-	-	-	-	-
S031	8/8/95	-	-	-	-	-	-	-	-	-
S032	8/8/95	-	-	50	-	-	4	PVC	-	Marie Harris
S033	8/8/95	-	-	-	-	-	-	-	-	-
S034	8/8/95	-	-	-	-	-	-	-	-	-

Well inventory data base

Bureau of Economic Geology

Project National Guard **Area** Camp Bowie **Surveyer** Conrad Kuharic

Well #	Date	Time	Cond. (μΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Casing material	Well use	Owner
S035	8/8/95	-	-	-	-	-	-	-	-	-
S036	2/2/95	-	-	29	dry	2.60	24	stone	unused	-
S037	8/8/95	-	-	-	-	-	-	-	-	-
S038	8/8/95	1140	-	50	28.03	0.16	4 in 7	PVC in iron	domestic	A.L. Speck
S039	8/8/95	-	-	~380	-	-	-	-	unused	Henry Vogler
S040	8/8/95	-	-	480	-	-	-	-	domestic	Weatherford
S041	8/8/95	1240	-	80	10.69	0.25	4	PVC	unused	Weatherford
S042	8/8/95	1440	-	30	16.56	0.70	7	iron	unused	USDA
S043	8/8/95	-	-	-	-	-	-	-	-	-
S044	8/8/95	-	-	-	-	-	-	-	-	Campbell
S045	8/8/95	-	-	-	-	-	-	-	-	Glenn Rawls
S046	8/8/95	-	-	-	-	-	-	-	-	-
S047	8/8/95	-	-	-	-	-	-	-	-	-
S048	8/8/95	-	-	-	-	-	-	-	-	-
S049	2/2/95	-	-	24.59	1.8	0.50	-	-	-	-
S050	8/8/95	-	-	~60	-	-	-	-	-	-
S051	8/8/95	-	-	~60	-	-	-	-	-	-
S052	8/8/95	-	-	-	-	-	-	-	-	-
S053	8/9/95	-	-	-	-	-	-	-	-	-
S054	8/9/95	-	-	-	-	-	-	-	-	-
S055	8/9/95	-	-	20 est.	-	-	-	-	-	-
S056	8/9/95	-	-	-	-	-	-	-	-	-
S057	8/9/95	-	-	-	-	-	-	-	-	-
S058	8/9/95	-	-	-	-	-	-	-	-	-
S059	8/9/95	-	-	-	-	-	-	-	-	-
S060	8/9/95	-	-	-	-	-	-	-	-	-
S061	8/9/95	1040	-	98	21.77	1.20	6	galvanized pipe	unused	Otis Lawrence
S062	8/9/95	-	850	100	-	-	-	-	domestic	Otis Lawrence
S063	8/9/95	1030	-	15	4.16	1.74	36 square	concrete	unused	Otis Lawrence
S064	8/9/95	-	-	-	-	-	-	-	unused	Louis Locker
S065	8/9/95	-	-	22	-	-	-	-	-	Joe Amadero
S066	8/9/95	1115	-	~60	22.32	0.44	4.5	PVC	unused	Lucky Ranch
S067	8/9/95	1118	-	~60	-	-	-	-	unused	Lucky Ranch
S068	8/9/95	1133	-	~60	-	-	-	-	unused	Lucky Ranch

Well inventory data base

Bureau of Economic Geology

Project National Guard **Area** Camp Bowie **Surveyer** Conrad Kuharic

Well #	Date	Time	Cond. (μΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Casing material	Well use	Owner
S069	8/9/95	1138	-	~60	-	-	5	iron	unused	Lucky Ranch
S070	8/9/95	-	-	~60	-	-	-	-	unused	Lucky Ranch
S071	8/9/95	1152	-	~60	19.27	0.00	5	PVC	unused	Lucky Ranch
S072	8/9/95	-	-	-	-	-	-	-	-	-
S073	8/9/95	-	-	-	-	-	-	-	-	-
S074	8/9/95	-	-	-	-	-	-	-	-	-
S075	8/9/95	-	-	-	-	-	-	-	-	-
S076	8/9/95	-	-	-	-	-	-	-	-	-
S077	8/9/95	-	-	-	-	-	-	-	-	Watts
S078	8/9/95	-	-	~260-270	~60	-	-	-	domestic	-
S079	8/9/95	-	-	-	-	-	-	-	-	-
S080	8/9/95	-	-	-	-	-	-	-	-	Ken Wesson
S081	8/9/95	-	-	-	-	-	-	-	-	-
S082	8/9/95	-	-	-	-	-	-	-	-	-
S083	8/9/95	-	-	-	-	-	-	-	-	Tearl Covington
S084	8/9/95	1345	-	65	-	-	-	-	domestic	James Bitter
S085	8/9/95	1352	-	-	10.99	0.35	5	iron	unused	James Bitter
S086	8/9/95	-	-	-	-	-	-	-	-	James Bitter
S087	8/9/95	-	-	-	-	-	-	-	-	-
S088	8/9/95	1515	-	200	~80	-	-	-	-	Joe Clayton
S089	8/9/95	-	-	200-250	-	-	-	-	unused	-
S090	8/9/95	-	-	200	~30	-	-	-	-	-
S091	8/9/95	-	-	-	-	-	-	-	-	Perkins Ranch
S092	8/9/95	-	-	-	-	-	-	-	-	Tom Hipsher
S093	8/9/95	-	-	-	-	-	-	-	-	-
S094	8/9/95	-	-	-	-	-	-	-	-	-
S095	8/9/95	-	-	140	~40	-	-	-	-	-
S096	8/9/95	1650	-	100	-	-	-	-	unused	Henry Newman
S097	8/9/95	1655	-	-	-	-	-	-	-	-
S098	8/9/95	-	-	-	-	-	-	-	-	-
S099	8/9/95	-	-	-	-	-	-	-	-	-
S100	8/9/95	-	-	>100	~at surface	-	-	-	-	Borkney
S101	8/9/95	1720	-	78	-	-	-	-	domestic	"Red" McBride
S102	8/10/95	-	-	-	-	-	-	-	-	-

Well inventory data base

Bureau of Economic Geology

Project National Guard **Area** Camp Bowie **Surveyer** Conrad Kuharic

Well #	Date	Time	Cond. (μΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Casing material	Well use	Owner
S103	8/10/95	-	-	-	-	-	-	-	-	-
S104	8/10/95	-	-	-	-	-	-	-	-	-
S105	8/10/95	-	-	-	-	-	-	-	-	-
S106	8/10/95	-	-	-	-	-	-	-	-	-
S107	8/10/95	-	-	114	~80	-	-	-	unused	-
S108	8/10/95	-	-	-	-	-	-	-	-	Wilson Ranch
S109	8/10/95	-	-	-	-	-	-	-	-	-
S110	8/10/95	-	-	-	-	-	-	-	unused	-
S111	8/10/95	-	-	-	-	-	-	-	-	Jess Shumate
S112	8/10/95	1155	-	-	17.88	1.12	36	stone	unused	James Baliff
S113	8/10/95	-	-	-	-	-	-	-	-	Benson
S114	8/10/95	-	-	-	-	-	-	-	-	-
S115	8/10/95	-	-	-	-	-	-	-	-	-
S116	8/10/95	-	-	-	-	-	-	-	-	-
S117	8/10/95	-	-	-	-	-	-	-	-	-
S118	8/10/95	-	-	-	-	-	-	-	-	H. C. Lewis
S119	8/10/95	-	-	-	-	-	-	-	-	-
S120	8/10/95	-	-	-	-	-	-	-	-	-
S121	8/10/95	-	-	-	-	-	-	-	unused	-
S122	8/10/95	-	-	-	-	-	-	-	-	-
S123	8/10/95	-	-	-	-	-	-	-	unused	-
S124	8/10/95	-	-	-	-	-	-	-	-	-
S125	8/10/95	-	-	-	-	-	-	-	-	-
S126	8/10/95	-	-	170	-	-	-	-	-	Russell Ratto
S127	8/10/95	-	-	-	-	-	-	-	-	-
S128	8/10/95	-	-	-	-	-	-	-	-	-
S129	8/10/95	-	-	-	-	-	-	-	-	Ratto
S130	8/10/95	-	-	-	-	-	-	-	unused	Mrs. Wilson
S131	8/10/95	-	-	~150	-	-	-	-	unused	Tommy Horten
S132	8/10/95	1500	-	-	12.85	0.76	5	PVC	unused	Tommy Horten
S133	8/10/95	-	-	-	-	-	-	-	-	-
S134	8/10/95	-	-	-	-	-	-	-	-	-
S135	8/10/95	-	-	-	-	-	-	-	unused	-
S136	8/10/95	-	-	-	-	-	-	-	-	-

Well inventory data base

Bureau of Economic Geology

Project National Guard **Area** Camp Bowie **Surveyer** Conrad Kuharic

Well #	Date	Time	Cond. (μΩ)	Well depth (ft)	Water level (ft BTOC)	Casing height (ft)	Diameter (in)	Casing material	Well use	Owner
S137	8/10/95	-	-	-	-	-	-	-	-	-
S138	8/10/95	-	-	-	-	-	-	-	-	-
S139	8/10/95	-	-	-	-	-	-	-	unused	-

all depths are reported by the owners
~ indicate owner supplied information
BTOC = below top of casing
land surface elevations estimated from USGS topographic maps

National Guard

Camp Bowie

Well #	Topographic quadrangle	Land surface elevation (ft)	Notes
S001	Brownwood	-	windmill in field, no access
S002	Indian Creek	-	no access port in cover plate
S003	Indian Creek	-	well house in pasture, behind locked gate
S004	Indian Creek	-	well house next to drive, no one home
S005	Indian Creek	-	depth from Mr. McBee
S006	Indian Creek	-	well house beside home, gate closed
S007	Indian Creek	1305	flowing at surface recently
S008	Indian Creek	-	windmill behind house, gate closed
S009	Indian Creek	-	well north of house, no one home
S010	Indian Creek	1352	-
S011	Indian Creek	-	windmill by abandoned house, gate locked
S012	Indian Creek	-	well house behind house, no one home
S013	Indian Creek	-	windmill, no access noted
S014	Indian Creek	-	pressure tank by residence, gate locked
S015	Indian Creek	-	cord down access port
S016	Indian Creek	-	cord down access port
S017	Indian Creek	-	dry hole, plugged
S018	Indian Creek	-	nonfunctional windmill, no one home
S019	Indian Creek	-	windmill, no access
S020	Brownwood	-	blocked at 3.04 ft
S021	Brownwood	-	wellhouse seen from road
S022	Brownwood	-	wellhead in yard
S023	Owens	-	brick wellhouse by road
S024	Brownwood	1332	no access port for measurement
S025	Brownwood	-	poss. hand-dug well at vacant home
S026	Brownwood	1349	hand dug to 30 ft, drilled to 100 ft
S027	Brownwood	-	well house seen from road
S028	Brownwood	1361	covered w/ poured concrete slab
S029	Brownwood	1356	SO28 & SO29 border a wetland
S030	Brownwood	-	old hand-dug well, no access
S031	Brownwood	-	old hand-dug well, no access
S032	Brownwood	-	steel plate over wellhead, no access
S033	Brownwood	-	Mrs. Harris says there's a well here
S034	Brownwood	-	Mrs. Harris says there's a well here

National Guard

Camp Bowie

Well #	Topographic quadrangle	Land surface elevation (ft)	Notes
S035	Brownwood	-	pressure tank by stalls, no one home
S036	Brownwood	-	hand-dug well in field, measured by A. Dutton
S037	Brownwood	-	well house on edge of plowed field
S038	Brownwood	1290	potable, but not too good
S039	Indian Creek	-	insufficient flow, abandoned
S040	Indian Creek	-	no access for measurement
S041	Indian Creek	1555	drilled by Jack Whittenberg
S042	Brownwood	1331	too saline for agriculture use
S043	Brownwood	-	well house in yard
S044	Brownwood	-	well house behind closed gate
S045	Brownwood	-	windmill
S046	Brownwood	-	old tank above poss. well
S047	Zephyr	-	tank w/ poss. well underneath
S048	Zephyr	-	pressure tank behind residence
S049	Brownwood	-	well house in trees, uneven grade by 0.3 ft
S050	Brownwood	-	unable to measure
S051	Brownwood	-	unable to measure
S052	Indian Creek	-	poss. hand-dug well in pasture, no access
S053	Brownwood	-	concrete cylinder w/ 3 in. slab on top, poss. well
S054	Brownwood	-	not a well
S055	Brownwood	-	well preceded current owner
S056	Brownwood	-	poss. well house, no one home
S057	Brownwood	-	pressure tank beside house, no one home
S058	Zephyr	-	windmill and tank, no one home
S059	Zephyr	-	well house in field, no access
S060	Brownwood	-	windmill
S061	Brownwood	1488	-
S062	Brownwood	-	good quality
S063	Zephyr	1470	-
S064	Zephyr	-	old windmill, 30 yds from S063
S065	Zephyr	-	-
S066	Zephyr	1304	-
S067	Zephyr	-	access blocked at 19.50 ft
S068	Zephyr	-	cord down access port

National Guard

Camp Bowie

Well #	Topographic quadrangle	Land surface elevation (ft)	Notes
S069	Zephyr	-	blocked at 27.50 ft, probably caved in
S070	Zephyr	-	access port blocked by cable
S071	Zephyr	1311	-
S072	Zephyr	-	windmill, no access
S073	Zephyr	-	well, appears abandoned
S074	Zephyr	-	windmill on hillside, near top, no access
S075	Blanket Springs	-	pressure tank next to old pumpjack
S076	Blanket Springs	-	pipe in swampy area, may have once been a windmill
S077	Blanket Springs	-	well house in front of house, no one home
S078	Blanket Springs	1405	Fe taste, no staining
S079	Blanket Springs	-	poss. well house, looks vacant
S080	Blanket Springs	-	-
S081	Blanket Springs	-	new owner, no knowledge of well details
S082	Blanket Springs	-	poss. well on vacant property
S083	Blanket Springs	-	multiple wells on property
S084	Blanket Springs	-	access port plug rusted on
S085	Blanket Springs	1287	-
S086	Blanket Springs	-	shallow well in cultivated field, not measured
S087	Blanket Springs	-	windmill on hill, no access
S088	Blanket Springs	1394	blocked at ~16 ft
S089	Indian Creek	-	windmill
S090	Indian Creek	-	pressure tank, slight sulphur taste
S091	Indian Creek	-	windmill, w/ power pole and box next to it
S092	Indian Creek	-	-
S093	Indian Creek	-	windmill
S094	Indian Creek	-	well house behind gate, in trees
S095	Indian Creek	-	-
S096	Indian Creek	-	cable down access port
S097	Indian Creek	-	old well, owner unsure of specifics
S098	Indian Creek	-	windmill in field, ~0.25 mi east of highway
S099	Indian Creek	-	windmill & well house east of roadway
S100	Indian Creek	1326	hearsay, well recovers slowly, sometimes flows
S101	Indian Creek	1404	third well at this location since late 1800s
S102	Indian Creek	-	hand-dug well next to ruins, north side of SR586

National Guard

Camp Bowie

Well #	Topographic quadrangle	Land surface elevation (ft)	Notes
S103	Brookesmith	-	poss. block well house
S104	Brookesmith	-	pressure tank and stone cistern
S105	Brookesmith	-	old windmill, no access
S106	Brookesmith	-	old windmill, no blades, no access
S107	Brookesmith	1498	owner thinks S105, S106 may have multiple wells
S108	Brookesmith	-	poss. well north of concrete tank in pasture, no access
S109	Brookesmith	-	windmill, may supply tank across road
S110	Brookesmith	-	windmill, no access
S111	Brookesmith	-	local driller, not a well location
S112	Brookesmith	1365	hand-dug well in pasture
S113	Indian Creek	-	well house, no one home
S114	Bangs East	-	windmill and tank on east side of US377
S115	Bangs East	-	pressure tank next to shop, east side of US377
S116	Bangs East	-	well house in yard
S117	Bangs East	-	windmill in pasture
S118	Bangs East	-	windmill in pasture, no access
S119	Bangs East	-	pressure tank next to driveway
S120	Bangs East	-	not actually a well, try neighbor Richard Campbell
S121	Bangs East	-	broken windmill, east of road
S122	Bangs East	-	windmill west of road, no access
S123	Bangs East	-	abandoned hand-dug well about 30 yds east of road
S124	Bangs East	-	windmill in pasture, no access
S125	Bangs East	-	pressure tank north of house, actually 3 wells on property
S126	Bangs East	-	unable to measure
S127	Bangs East	-	other well at S125
S128	Bangs East	-	other well at S125
S129	Bangs East	-	shallow well, owned by brother of S126
S130	Bangs East	-	broken windmill
S131	Bangs East	-	former domestic well, access blocked at about 7 ft
S132	Bangs East	1565	-
S133	Bangs East	-	well house in pasture, no access
S134	Bangs East	-	windmill in pasture, no access
S135	Bangs East	-	broken windmill in brush, no access
S136	Bangs East	-	windmill and tank, no access

National Guard

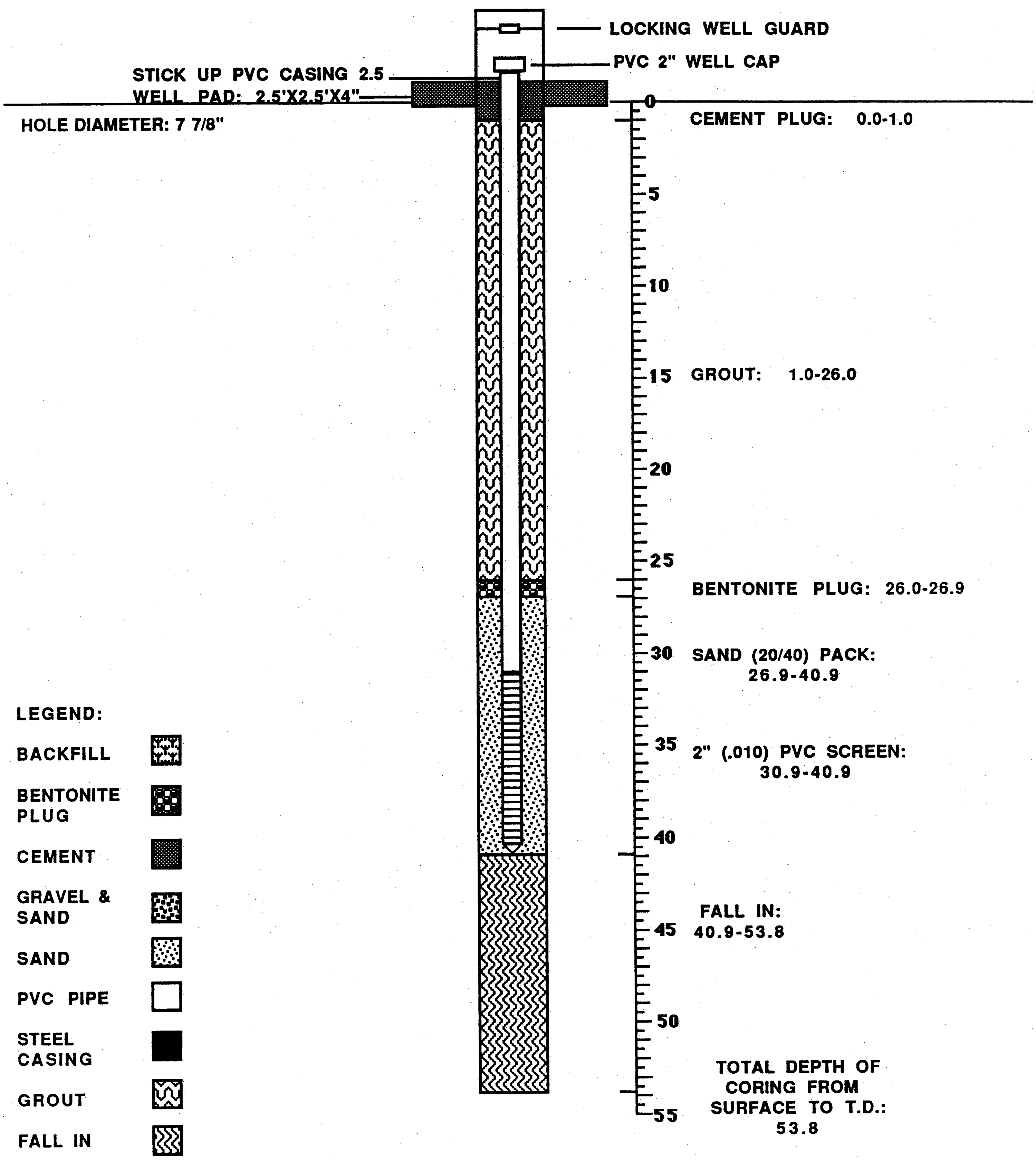
Camp Bowie

Well #	Topographic quadrangle	Land surface elevation (ft)	Notes
S137	Bangs East	-	windmill, no access
S138	Bangs East	-	windmill by house, no one home
S139	Bangs East	-	windmill, base overgrown w/ brush, no access

Appendix 2

Well Schematics and Drilling Reports for Monitor Wells

WATER MONITOR SCHEMATIC
CAMP BOWIE #1
DRILL DATE: 1/25/96
NATIONAL GUARD PROJECT



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

Please use black ink.

ATTENTION OWNER: *Confidentiality Privilege Notice on Reverse Side*

State of Texas WELL REPORT

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

Camp Bowie #1

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

2) ADDRESS OF WELL: County Brown — Camp Bowie Rt. 3 Box 181-A (Street, RFD or other) Brownwood (City) Texas (State) 76801-9734 (Zip) GRID # 41-17-9

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

4) PROPOSED USE (Check): ☒ Monitor ☐ Environmental Soil Boring ☐ Domestic ☐ Industrial ☐ Irrigation ☐ Injection ☐ Public Supply ☐ De-watering ☒ Testwell

If Public Supply well, were plans submitted to the TNRCC? ☐ Yes ☐ No

5) 31° 38' 42"
98° 54' 2"

N

6) WELL LOG:
Date Drilling:
Started 1/25 19 96
Completed 1/25 19 96

DIAMETER OF HOLE

Dia. (in.)	From (ft.)	To (ft.)
7 7/8	Surface	53.8

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

From (ft.)	To (ft.)	Description and color of formation material
0.0	3.7	Dark brown topsoil
3.7	8.7	Dark brown clay
8.7	13.7	light brown clay & sand caliche
13.7	23.6	Light brown sand, small pebbl-
		es & caliche
23.6	33.9	Pilot bitted
33.9	44.2	Grey shale
44.2	53.8	Pilot bitted

(Use reverse side if necessary)

8) Borehole Completion (Check): ☐ Open Hole ☒ Straight Wall ☐ Underreamed ☐ Gravel Packed ☐ Other

If Gravel Packed give interval . . . from ____ ft. to ____ ft.

CASING, BLANK PIPE, AND WELL SCREEN DATA:

Dia. (in.)	New or Used	Steel, Plastic, etc. Perf., Slotted, etc. Screen Mfg., if commercial	Setting (ft.) From	Setting (ft.) To	Gage Casting Screen
2"	N	1 - 2" x 5' PVC riser	2.5 Above Surface	0.9	.010
2"	N	3 - 2" x 10' PVC riser	0.9	30.9	.010
2"	N	1 - 2" x 10' PVC screen	30.9	40.9	.010
2"	N	1 - 2" x 6" point			

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

Cemented from 4" Above Surface ft. to 1.0 ft. No. of Sacks Used 3
____ ft. to ____ ft. No. of Sacks Used ____
Method used Hand Poured
Cemented by Drill Crew
Distance to septic system field lines or other concentrated contamination N/A ft.
Method of verification of above distance N/A

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

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

12) PACKERS: Type Depth

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

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

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

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

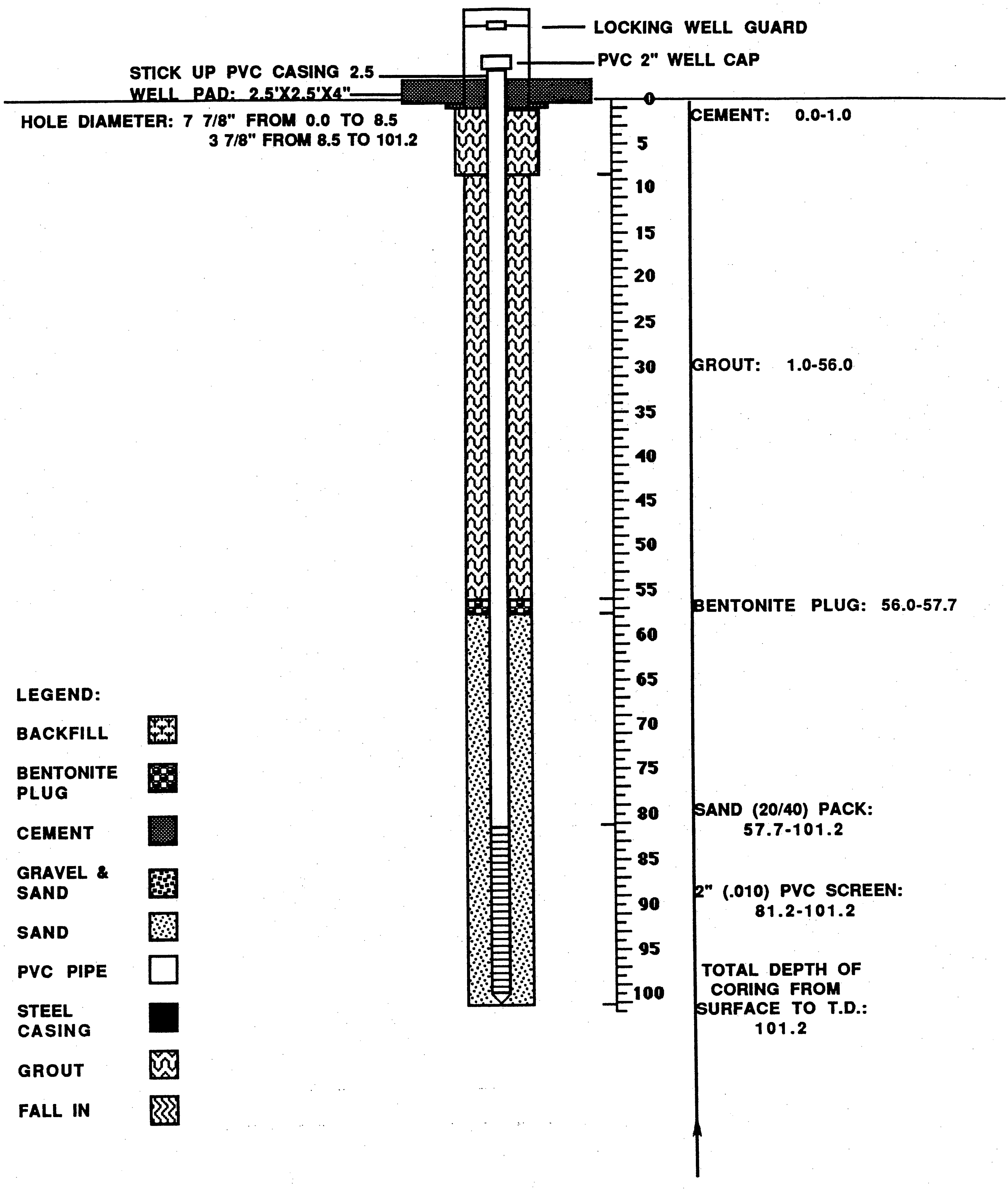
COMPANY NAME University of Texas/Bureau of Economic Geology (Type or Print) WELL DRILLER'S LICENSE NO. 3187-M

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

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

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

WATER MONITOR SCHEMATIC
CAMP BOWIE #2
DRILL DATE: 2/8/96
NATIONAL GUARD PROJECT



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

ATTENTION OWNER: *Confidentiality Privilege Notice on Reverse Side*

State of Texas WELL REPORT

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

Camp Bowie #2

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

2) ADDRESS OF WELL: County Brown Camp Bowie Rt. 3 Box 181-A (Street, RFD or other) Brownwood (City) Texas (State) 76801-9734 (Zip) GRID # 41-17-8

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

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

5) 31° 38' 0" 98° 55' 35" N

6) WELL LOG: Date Drilling: Started 1/11 19 96 Completed 2/8 19 96

DIAMETER OF HOLE

Dia. (in.)	From (ft.)	To (ft.)
7 7/8	Surface	8.5
3 7/8	8.5	101.2

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

From (ft.)	To (ft.)	Description and color of formation material
0.0	8.5	Brown topsoil
8.5	19.6	Weathered limestone
19.6	24.6	Red stone, chert
24.6	25.2	Soft clay with sandstone
25.2	76.4	Red sand, small pebbles
76.4	95.2	Brown sands with grey clay
95.2	101.2	Brown clay, pebbles

(Use reverse side if necessary)

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

CASING, BLANK PIPE, AND WELL SCREEN DATA:

Dia. (in.)	New or Used	Steel, Plastic, etc. Perf., Slotted, etc. Screen Mfg., if commercial	Setting (ft.) From	Setting (ft.) To	Gage Casting Screen
2"	N	PVC Schedule 40 riser	2.5' Above Surface	81.2	
2"	N	PVC Schedule 40 screen	81.2	101.2	.010

9) CEMENTING DATA: [Rule 338.44(1)]
Cemented from 4" Above Surface ft. to 1.0 ft. No. of Sacks Used 3.5
ft. to ft. No. of Sacks Used
Method used Hand Poured
Cemented by Drill Crew
Distance to septic system field lines or other concentrated contamination N/A ft.
Method of verification of above distance N/A

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

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

12) PACKERS: Type Depth

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

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

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

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

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

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

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

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

Appendix 3

Data Dictionary for GIS Coverages

GIS DATA DICTIONARY

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

Ellipsoid: Clarke 1866
Horizontal Datum: NAD27
Units: meters
Zone 14

The digital data represent the following.

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

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

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

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

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

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

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

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

TEXAS STATEWIDE MAPPING SYSTEM (NAD27)

Projection: Lambert Conformal Conic

Ellipsoid: Clarke 1866

Datum: North American 1927

Longitude of Origin: 100 degrees west (-100)

Latitude of Origin: 31 degrees 10 minutes north

Standard Parallel #1: 27 degrees 25 minutes north latitude

Standard Parallel #2: 34 degrees 55 minutes north latitude

False Easting: 3,000,000 ft

False Northing: 3,000,000 ft

Unit of Measure: feet (international)

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

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

CAMP BOWIE

Base maps: the USGS 7.5′ topographic quadrangles, Brookesmith, Bangs East, Indian Creek, and Brownwood, are in the State Plane coordinate system (Lambert Conformal Conic), Central Zone (5376), datum NAD27, units in feet.

Coverage name	Coverage type	Initial projection	Final projection	Source	Accuracy	Description
Quadutm	Polygon	UTM	UTM	TNRIS digital files	±100 ft	1:24,000-scale topographic quadrangles: Bangs East, Brownwood, Brookesmith, and Indian Creek
Browncnty	Polygon	UTM	UTM	TNRIS digital files	±100 ft	Outline of Brown County
Offcamprdutm	Arc	Texas State Plane	UTM	TXDOT digital county files	±50 ft	Highways and off-camp well locations
Arcamprdutm	Arc	Texas State Plane	UTM	TXDOT digital county files	±50 ft	Highway maps near the camp
Oncamproads	Arc	Texas State Plane	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.002	Roads and trails in the camp
Boundutm	Polygon	State Plane Central Zone	UTM	Texas Parks and Wildlife digital files	unknown	Camp boundary
Streamsutm	Arc	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft	Streams and rivers
Lakesutm	Polygon	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft	Lakes around study area
Wshedutm	Polygon	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft	Watersheds corresponding to stream segments
Fplainutm	Polygon	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.005	Floodplains
Fpstreamutm	Arc	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.004	Stream orders and cross sections used for the HEC-RAS model
Soilsutm	Polygon	Texas State Plane	UTM	STATSGO digital database	unknown	1:2,500,000-scale distribution of soils in the watersheds
Boswellsutm	Point	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.004	Location of off-camp wells
Bocwellsutm	Point	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.002	Location of on-camp wells
Wlevels	Arc	State Plane Central Zone	UTM	Digitized from USGS 7.5′ topographic quads	±40 ft RMS = 0.005	Digitized water-level contour maps