PHYSICAL ENVIRONMENT OF CAMP SWIFT MILITARY RESERVATION, BASTROP COUNTY, TEXAS: BASELINE INFORMATION FOR NATIONAL GUARD LAND CONDITION—TREND ANALYSIS PROGRAM

by

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EXECUTIVE SUMMARY

The purpose of this report is to describe the physical environment of Camp Swift Military Reservation and to call attention to physical processes occurring on the base, to note availability of data, and to comment on potential limitations to land use. Camp Swift (11,740 ac) is one of 10 training areas administered by the Texas Adjutant General for activities of the Texas Army National Guard. The Bureau of Economic Geology reviewed existing information to identify essential baseline data (climate, geology, soil properties, hydrology, and present land condition) and made additional observations that will assist the Texas Adjutant General in preparing long-term environmental assessments mandated by the National Environmental Policy Act and U.S. Environmental Protection Agency regulations, and environmental land-management and land-condition monitoring plans required by the U.S. Army.

The information presented in this report was extracted from a number of sources. A particular wealth of data is available for Camp Swift, probably more than for any other training area, because it was the object of extensive environmental baseline and sensitivity studies for a proposed lignite lease in the late 1970's and early 1980's. These prior studies are referred to extensively in this report.

Camp Swift is located in east-central Texas in Bastrop County. The area is within the subtropical humid climatic region, with an average annual precipitation of about 35 inches. Intense thunderstorms commonly cause flooding in area creeks. The base is situated on the outcrop of the Calvert Bluff Formation of the Wilcox Group. Soils are underlain by weakly consolidated clayey sandstone, siltstone, and claystone. The Calvert Bluff Formation is underlain by the Simsboro Formation, which is the major aquifer and water supply for the region. Environmental baseline studies for the proposed lignite lease found that surface- and ground-water quality is generally good.

Observations made in the field and comparisons among various vintages of aerial photographs suggest that military training uses have been less damaging to the physical environment of Camp Swift than previous agricultural uses. The principal environmental impact has been the development of erosional gullies, virtually all of which predate establishment of the camp. The greatest potential for further environmental impact, in addition to enlargement of gullies, is disturbance of soils when the ground is saturated, resulting in rutting, and ultimately to erosion. Preservation of healthy, protective vegetative cover is of prime importance.

Land management should include plans to avoid environmentally sensitive areas at certain times of the year. Existing gullies, other erosional features, areas lacking protective vegetation, and perennial wet spots should be cataloged, and monitored for change. Engineering solutions will need to be employed to halt or slow advancement of gullies and other severe erosion. Sandy areas of the base, which may allow ground-water recharge, should be avoided by activities involving transfer of hazardous materials (fuels, for example) to prevent possible ground-water contamination. Existing wells, or new, strategically placed wells should be sampled periodically to monitor ground-water quality.

INTRODUCTION

Location

Camp Swift is located on the upper part of the Gulf Coastal Plain in north-central Bastrop County, Texas, 140 mi northwest of the Texas coastline (fig. 1). The area is within the Post Oak Belt ecological province, characterized by a low, rolling landscape covered by woodlands interspersed with natural grassland, cleared pasture, and farmland. Camp headquarters are located in the southeast corner of the base approximately 7.5 mi north of the City of Bastrop and 26 mi east-southeast of the City of Austin (fig. 1, plate 1). The network of roads on the base is accessed through gates on State Highway 95, Farm-to-Market Road 2336, U.S. Highway 290, and Bastrop County Road 356. The training base occupies 11,740 ac extending across the central and southern part of Elgin East and northern part of Lake Bastrop 7.5-minute topographic quadrangles, with one very small portion in the McDade quadrangle to the east (fig. 1) (U.S. Geological Survey, 1982a, b, c). The approximate coordinates of the base center are latitude 30°11' North and longitude 97°17.5' West. Most of the surface drains into Big Sandy Creek, which flows southwestward across the northern half of the property. Drainageways, main dirt roads, secondary dirt roads, training areas, and other reference points are shown in plate 1.

Brief History of Camp Swift

Camp Swift began as an active-duty U.S. Army training base in 1942 following U.S. entrance into World War II (Houston, 1959). The base originally encompassed about 55,900 ac (fig. 1), and included parkland, farmland, pasture, and woods. It was constructed in 108 days, involving up to 18,000 workers at one time; 44,000 military personnel occupied the base at the peak of activity (Houston, 1959). In the mid-1960's the active-duty base was decommissioned and

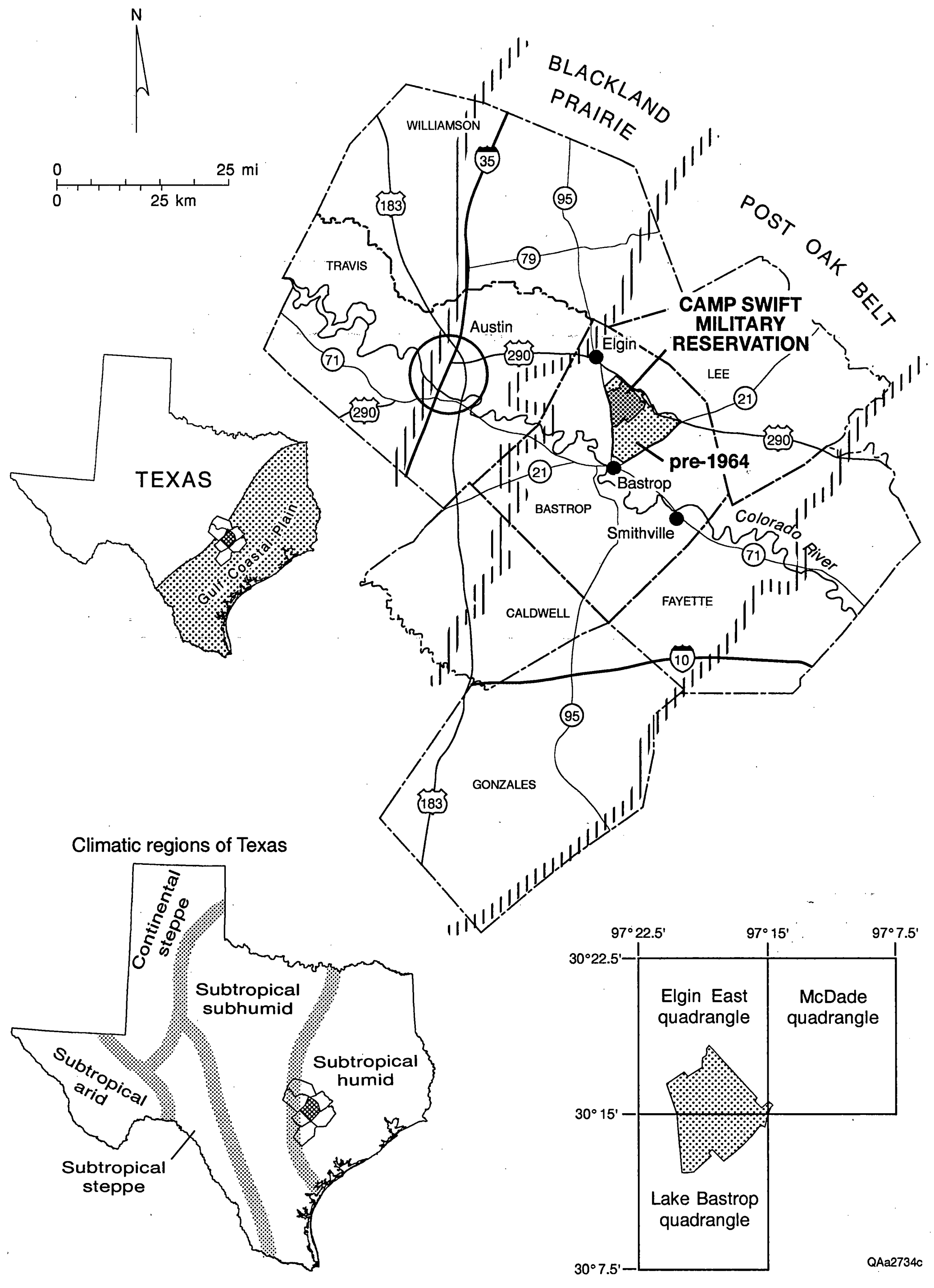

Figure 1. Index map of Central Texas region showing location of Camp Swift study area (darkly shaded area), major highways and towns, and immediate ecological provinces (Black Prairie and Post Oak Belt); lightly shaded area around Camp Swift indicates extent of base before transfer to Texas Army National Guard in 1964. Insets show climatic regions of Texas (after Larkin and Bomar, 1983) and 7.5-minute topographic quadrangles containing study area.

11,740 ac, including firing ranges and other training areas, transferred to the Texas Army National Guard for the present Camp Swift property; three-fourths of the original base area returned to private ownership. The main facilities of the original base occupied a 2000-ac area just south of the present base, south of Texas highway FM 2336; few of the original above-ground structures remain.

Elements of the Physical Environment

The physical environment of an area is controlled by its geology and climate (past and present). Climate influences natural processes, which modify the geological substrate and in turn determine other characteristics such as geomorphology (shape of the land surface), soil composition, and type and density of vegetation. Vegetation is an important element in the physical environment as it helps stabilize the landscape by limiting erosion.

Objective and Methods

The main objective of this work was to compile or call attention to available data that describe the physical environment of Camp Swift and to explain the significance of each element in an overall land-use and management perspective. Most of the data presented here were obtained from published reports, maps, and other literature. Some data were extracted from databases maintained by Federal or State agencies. Additional new information, relating chiefly to the present condition of land at Camp Swift, was collected by direct observation during 9 days of field work in January and February 1993. Some of the description of climate is based on data collected at recording stations at Robert Mueller Municipal Airport in Austin, about 22 mi west-northwest of Camp Swift; those data can be considered to reasonably approximate the conditions in the Camp Swift area. The information thus gathered has been reproduced in maps, tables, and other illustrations in this report.

Several vintages of aerial photographs were available and used to examine historical changes in the landscape and vegetative cover:

Vintage	Scale	Source
3/05/91	1:24,000	Texas Department of Highways and Public Transportation
5/14/81	1:24,000	Texas Natural Resources Information System
7/22/75	1:36,000	Texas Natural Resources Information System
1975	1:24,000	Photos printed in U.S. Soil Conservation Survey report for Bastrop County (see Baker, 1979)
1/25/53	1:70,000	Bureau of Economic Geology, Barnes collection
1938	1:12,000	Texas Natural Resources Information System

The most recent aerial photographs (3/05/91) were used in the field to locate and map features of special interest.

CLIMATE

Bastrop County is situated within the subtropical humid climatic region of Texas, near its approximate western boundary with the subtropical subhumid region (fig. 1) (Larkin and Bomar, 1983, p. 2). The climate is a modified marine climate dominated by onshore flow of tropical maritime air from the Gulf of Mexico; this onshore flow is modified by westward-decreasing moisture content and intermittent seasonal intrusions of continental air (Larkin and Bomar, 1983, p. 1). Climate influences soil development and, in combination with soil properties, controls the diversity, health, and seasonal changes of vegetation. Awareness of seasonal climatic variations and their effect on vegetation is important for optimizing land use while minimizing erosion.

The information on climate presented here was extracted from Arbingast and others (1976), Larkin and Bomar (1983), Bomar (1983), and Gaylord and others (1985); annual precipitation data were obtained from the Texas Natural Resources Information System. Current information may be obtained directly from the National Climatic Data Center in

Asheville, North Carolina, which receives monthly reports from all stations in the National Weather Service and the Cooperative Weather Observer Network.

Temperature

The climate in this region of Central Texas is characterized by warm summers and mild winters. Accordingly, the growing season is relatively long, with several opportunities through the year for reestablishment or improvement of vegetative cover. Temperature variations through the year closely follow the seasonal variations in the amount of sunshine striking the surface (fig. 2a, b). The average monthly high temperature for July and August in northern Bastrop County has been about 96°F, whereas average monthly low temperatures in December and January have ranged from 38°F to 43°F. Mean annual growing season in north-central Bastrop County is about 275 days (Arbingast and others, 1976, p. 17). Freezing conditions in Austin occur on an average of 21 days per year; average last and first freezes are March 1 and November 30 (Bomar, 1983, his tables B-1 and B-2). Temperature statistics and sources of data are summarized in table 1.

Wind

Winds in this part of Central Texas are dominantly from the south and southeast through most of the year. About 20 to 30 percent of the time during fall and winter months, winds blow from the north and northwest as intrusions of continental air (cold fronts) move through the area (fig. 3, table 1, appendix A).

High winds are an important agent of erosion if soils are loose or unprotected by vegetation. Winds of about 13 mph (moderate breeze) are strong enough to raise dust and move small branches (Bomar, 1983, table F-3); at greater speeds the wind is capable of moving larger silt and sand grains. Winds of this magnitude are most common in the winter and spring (about 30 percent of the time), and least common in the summer (about 15 percent of the time)

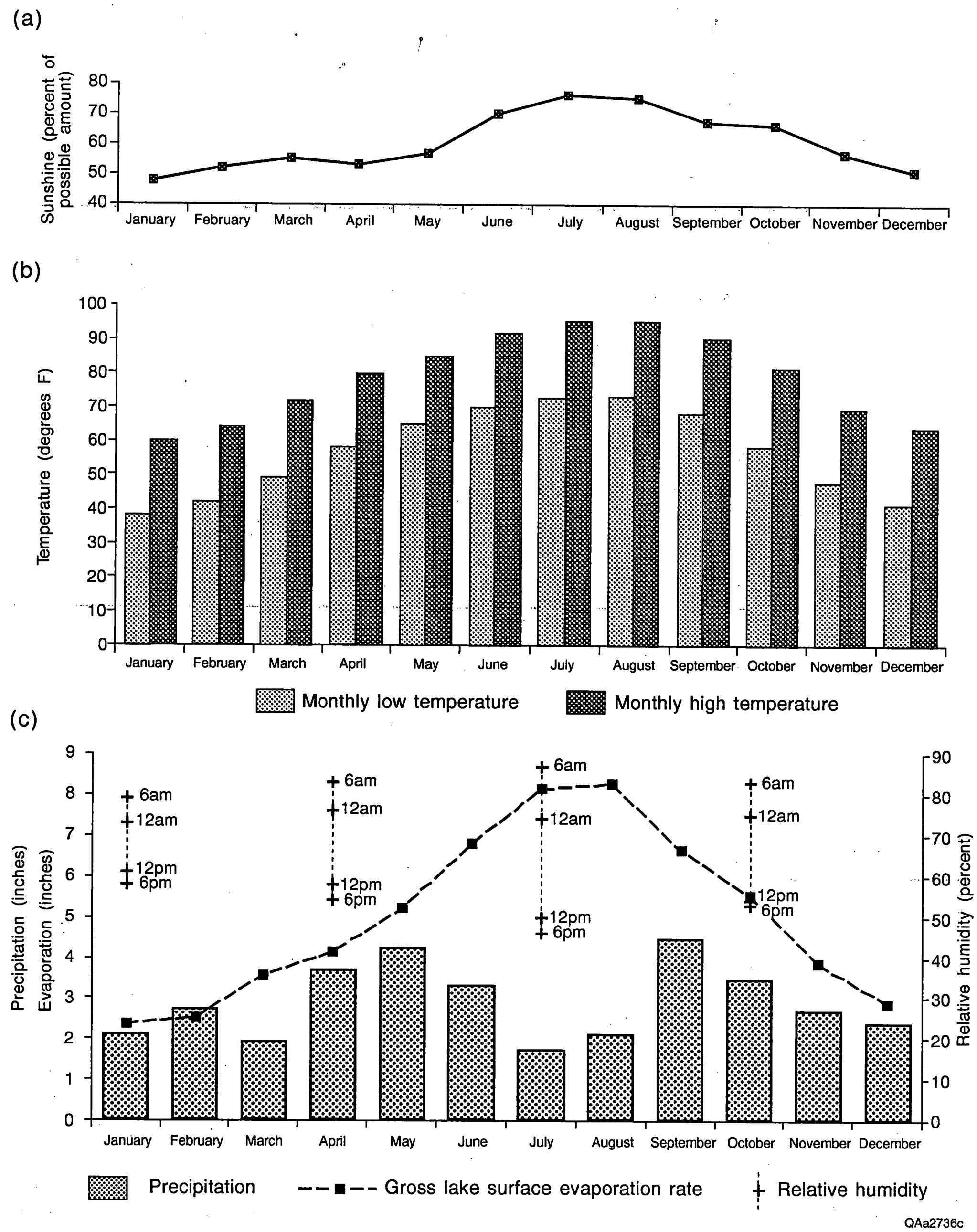

Figure 2. Climatic trends in Camp Swift area, north-central Bastrop County: (a) average amount of sunshine (1942–1980); (b) average monthly low and high temperatures (1951–1980); and (c) average monthly precipitation (1951–1980), average gross lake-surface evaporation rate (1950–1979), and average relative humidity (at 6 a.m., 12 p.m., 6 p.m., and 12 a.m., 1962–1980); see table 1 for data and sources. Soils are likely to be driest during the summer months, when precipitation is low and sunshine, temperature, and evaporation are at a maximum.

Table 1. Climatic statistics for Camp Swift area, north-central Bastrop County and Austin, Texas.

Month	Average Amount of Sunshine (percent of possible amount) [1]	Average Monthly Temperatures (°F) [2]		Average Number of Freezes [3]	Average Number of Days ≥100° F [4]	Average Monthly Precipitation (inches) [5]	Average Monthly Gross Lake Surface Evaporation Rate (inches) [6]	Average Relative Humidity (percent) [7]				Average Wind Direction and Speed (mph) [8]	Average Number of Cold Fronts [9]	Average Number of Days with Various Sky Conditions [10]		
		Low	High					6 a.m.	12 p.m.	6 p.m.	12 a.m.			Clear	Partly Cloudy	Cloudy
January	48	38.5	60.5	9	0	2.1	2.4	79	61	58	73	S 10	6	9	6	16
February	52	42.5	64.5	5	0	2.8	2.5									
March	55	49.5	72.5	1	0	1.9	3.5									
April	53	58.3	80.3	0	0	3.7	4.1	83	58	54	76	SSE 11	8	8	7	15
May	57	65.5	85.3	0	0	4.3	5.2									
June	70	70.5	92.0	0	1	3.3	6.8									
July	76	73.0	96.0	0	4	1.8	8.2	87	50	46	74	S 8	2	11	14	6
August	75	73.5	96.0	0	6	2.1	8.3									
September	67	68.5	90.8	0	<1	4.5	6.6									
October	66	58.8	81.8	0	0	3.5	5.5	83	54	53	75	S 8	5	13	9	9
November	57	48.3	70.0	1	0	2.7	3.9									
December	51	41.7	64.5	5	0	2.4	2.9									

Average annual low temperature [2]	57.3° F	Coldest observed temperature [11]	-2° F (January 31, 1949, Austin)
Average annual high temperature [2]	79.0° F	Hottest observed temperature [11]	109° F (July 26, 1954, Austin)
Average annual temperature [2]	68.5° F		
Average annual precipitation [5]	35.2 inches		
Average annual gross lake surface evaporation rate [6]	60.3 inches		

Notes:

(1) Average amount of sunshine at Robert Mueller Municipal Airport in Austin, Texas, 1942-1980, from U.S. Department of Commerce data summarized in Bomar (1983, table F-7).

(2) Average temperatures in north-central Bastrop County, 1951-1980, estimated from contour maps in Larkin and Bomar (1983, p. 19-50). Average monthly low temperature is average of daily minimum temperatures for the month; average monthly high temperature is average of daily maximum temperatures for the month. Average annual low temperature is average of monthly lows for the year; average annual high temperature is average of monthly highs for the year; average annual temperature is average of annual low and high temperatures. Original data from National Weather Service and Cooperative Observer Network.

(3) Average number of freezes per month at Robert Mueller Municipal Airport in Austin, Texas, 1951-1980, from Bomar (1983, table B-2).

(4) Average number of days per month with temperature 100° F or greater, at Robert Mueller Municipal Airport in Austin, Texas, 1951-1980, from Bomar (1983, table B-9).

(5) Average precipitation in north-central Bastrop County, 1951-1980, estimated from contour maps in Larkin and Bomar (1983, p. 4-18). Data from Cooperative Observer Network of the National Weather Service.

(6) Gross lake surface evaporation rates in north-central Bastrop County, 1951-1980, estimated from contour maps in Larkin and Bomar (1983, p. 51-56). Data from Texas Department of Water Resources Surface Water Data Unit.

(7) Average relative humidity at Robert Mueller Municipal Airport in Austin, Texas, 1962-1980, from U.S. Department of Commerce data summarized in Bomar (1983, table F-4).

(8) Average wind speed and direction at Robert Mueller Municipal Airport in Austin, Texas, for approximately 20-year period ending in 1980, from U.S. Department of Commerce data summarized in Bomar (1983, table F-2).

(9) Average number of cold fronts passing Robert Mueller Municipal Airport in Austin, Texas, 1961-1970, from Illinois State Water Survey data summarized in Bomar (1983, table F-5).

(10) Average number of days with various sky conditions at Robert Mueller Municipal Airport in Austin, Texas, 1942-1980, from U.S. Department of Commerce data summarized in Bomar (1983, table F-6).

(11) Information from Bomar (1983, table B-6).

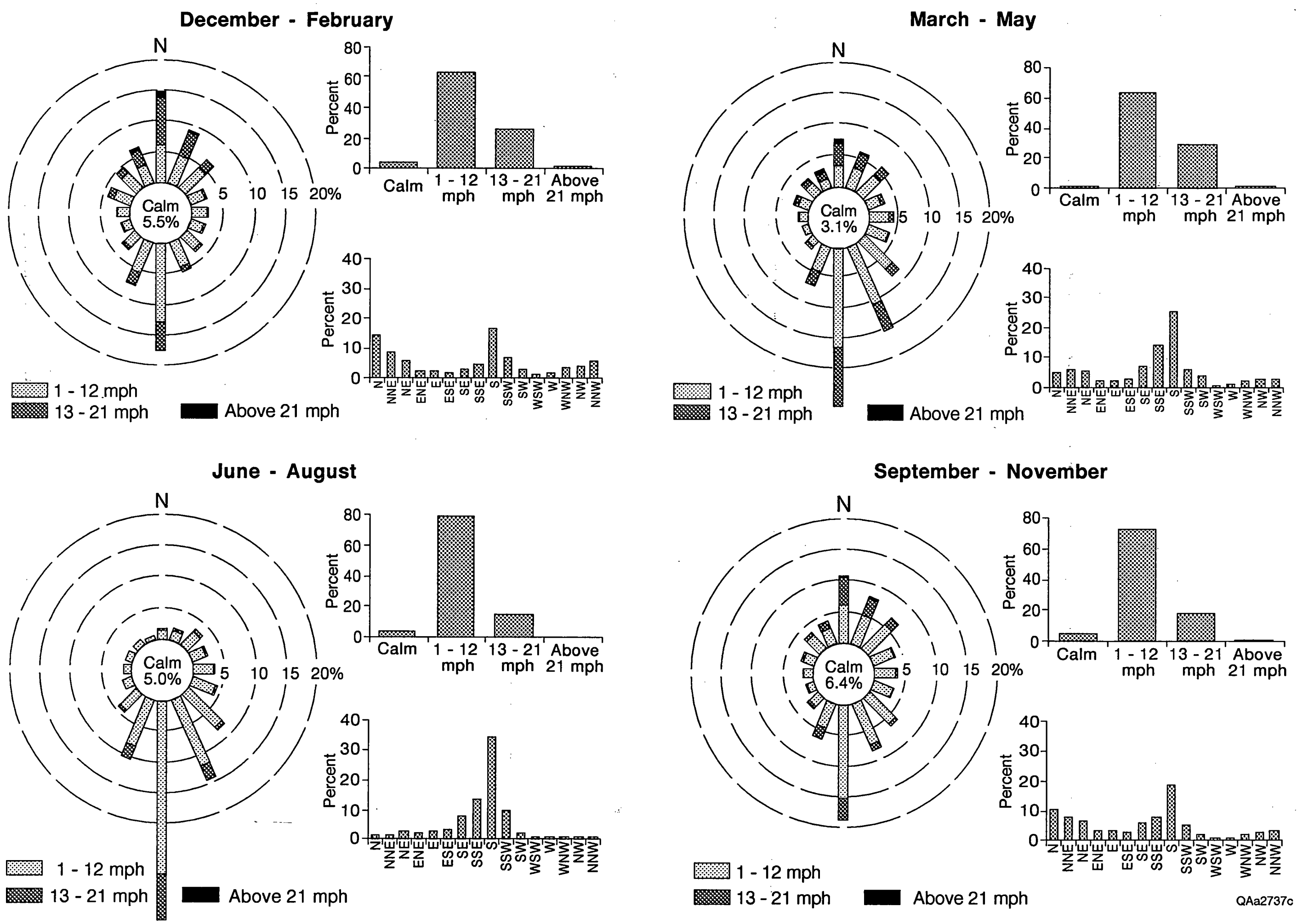

Figure 3. Average wind direction and speed at Robert Mueller Municipal Airport in Austin, 1961–1980. Arms of wind roses point in the direction *from which* the wind blows: for example, in the plot for December–February, the darkly shaded area on the arm pointing due south indicates that approximately 5 percent of the time the wind blew from the south at speeds between 13 and 21 mph. Data for these diagrams are given in appendix A; modified from plots presented in Larkin and Bomar (1983, p. 67–68 and 78–81). Bar diagrams beside each circular diagram indicate percentage of all winds by ranges of speed and by direction. Wind speeds of 13 mph and greater are capable of raising dust.

(fig. 3, appendix A). The greatest potential for wind erosion is probably during the winter when protective vegetation is likely to be minimal. However, this may be offset by relatively high soil-moisture content, which would tend to increase cohesion and resistance to erosion. High wind-erosion potential exists during late summer when rainfall and soil moisture are at a minimum and evaporation is at a maximum; however, this may be offset by dense protective vegetation at that time and the fact that the strongest winds generally blow from the south, carrying relatively humid air.

Precipitation, Evaporation, and Humidity

Precipitation is probably the biggest climatic factor controlling the types and density of vegetation in Texas. Most of the precipitation in east-central Texas comes in the form of rain. Rainfall amounts in this region are great enough to support a dense vegetative cover with a wide variety plants of all sizes. Rainfall distribution through time is a fundamental factor affecting potential for surface runoff and soil erosion. Intense rainfalls, typically associated with thunderstorms and of relatively short duration, generally exceed the infiltration capacity of the soil and lead to runoff and flooding. Lighter rainfalls are less likely to produce runoff, unless the soils are already saturated or if the rainfall events are of extended duration. Evaporation is another important factor to consider in land management because it is the principal process by which soils are able dry out and achieve their greatest strengths. Evaporation depends on temperature, precipitation, and moisture content (relative humidity) of the air. Relative humidity is a function of the amount of water vapor contained in the air, and reflects evaporation conditions in the source area of the air mass and along its journey to the point of measurement. Evaporation rates are maximized under conditions of dry air and warm temperatures.

The average annual precipitation in north-central Bastrop County is about 35 inches (fig. 4, table 1). The statistically greatest rainfall months are April (3.7 inches), May (4.3 inches),

	Austin	Smithville
Minimum	11.4 (in)	17.9 (in)
Maximum	52.2	59.3
Mean	31.8	37.1
Median	33.0	34.0

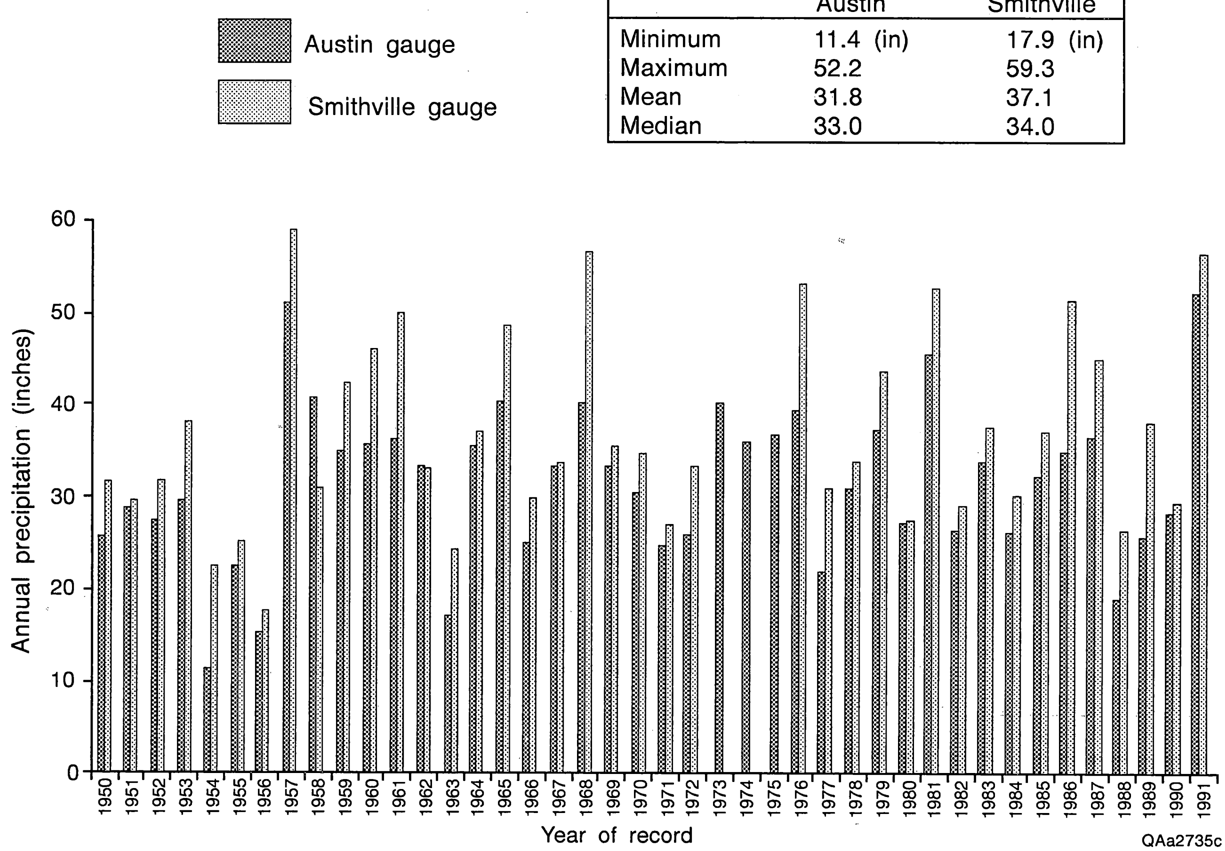

Figure 4. Annual precipitation recorded at Austin and Smithville stations, 1950–1991, with summary statistics; see appendix B for data and source. Records for Smithville were incomplete for 1973, 1974, and 1975. Precipitation in Texas generally increases from west to east; Austin is approximately 25 mi west-northwest of Camp Swift, and Smithville is approximately 15 mi south-southeast; average annual precipitation in the Camp Swift area for 1951–1980 was 35.2 inches (see table 1).

September (4.5 inches), and October (3.5 inches) (fig. 2c, table 1); most of this rain falls during brief but intense thunderstorms. A water budget calculated for this area by Hall (1981) indicated that during an average year, 80 to 85 percent of precipitation is lost to evapotranspiration. Peak gross-lake-surface evaporation rates in the northern Bastrop County area are obtained in July and August (about 8.25 inches) when sunshine is at a maximum and temperatures are greatest (fig. 2); at these times soils are likely to be driest. The lowest relative humidities of the year generally occur in late afternoon in midsummer (fig. 2c). The highest humidities of the year are during this same period in the early morning hours, when the air has cooled to its lowest temperature in the daily cycle. The high temperatures and evaporation rates of the summer daytime allow the air to hold large amounts of water, which causes the relative humidity to rise substantially as the air cools during nighttime.

Previous Major Storms

Heavy rainfalls commonly cause flooding on Big Sandy Creek and other tributaries. Large floods have occurred in Big Sandy Creek on several occasions during the past 3 years of abundant rainfall—at least one of these (December 1991) caused extensive damage to creek crossings and nearby roads (Captain James Junot, Camp Swift, personal communication, 1993). Two particularly notable storms that caused widespread flooding in Central Texas include a mammoth rainstorm on September 9 and 10, 1921, which produced 19.03 inches of rain in the Austin area in 24 hr (ninth greatest 1-day total in Texas for 1880 through 1983), and another on June 30, 1940, which produced 16.05 inches in Smithville, about 18 mi south-southeast of Camp Swift (16th greatest 1-day rainfall total) (Bomar, 1983, p. 69, his table C-5).

GEOLOGY

Structure and Stratigraphy

The Camp Swift area is situated near the northwestern limit of Gulf Coast Tertiary strata where they pinch out against underlying Cretaceous rocks (fig. 5). Camp Swift is underlain by strata of the Wilcox Group, which is an accumulation of deltaic, fluvial, and marginal marine sediments deposited during the early part of the Tertiary Period. Beds strike north-northeast and dip gently about 90 to 170 ft/mi (about 1° to 2°) toward the east-southeast (Gaylord and others, 1985, p. 22). The Wilcox Group consists of three formations (from oldest to youngest): the Hooper, the Simsboro, and the Calvert Bluff (fig. 5). According to geologic mapping by Proctor and others (1974), only the Calvert Bluff Formation (Paleocene and Eocene) crops out on the Camp Swift property (plate 2). The Simsboro Formation crops out about 1 mi northwest of Camp Swift, and the Hooper Formation about 1.5 mi further to the northwest in the vicinity of Elgin (fig. 5; plate 2). Both formations are important sources of fresh water for public and private water supplies, and both extend in the subsurface beneath Camp Swift.

Faults

Several northeast-striking faults offset Wilcox strata in the vicinity of Camp Swift and locally affect the regional dip of the formations (Gaylord and others, 1985). These include the Sayersville fault (Elliot, 1947), the "Well-Field" fault (Guyton, 1942), and the "Survey" fault (Gaylord and others, 1985, p. 24–27) (plate 2). The locations of these faults as shown must be considered approximate, as they are not apparent at the surface, and because they are plotted slightly differently in the lignite study by the Texas Resource Development Corporation (TRDC, 1979). The Sayersville fault displaces strata downward on the northwest side by as much as 250 ft; it is an important fault as it causes the Calvert Bluff outcrop belt to widen by as much

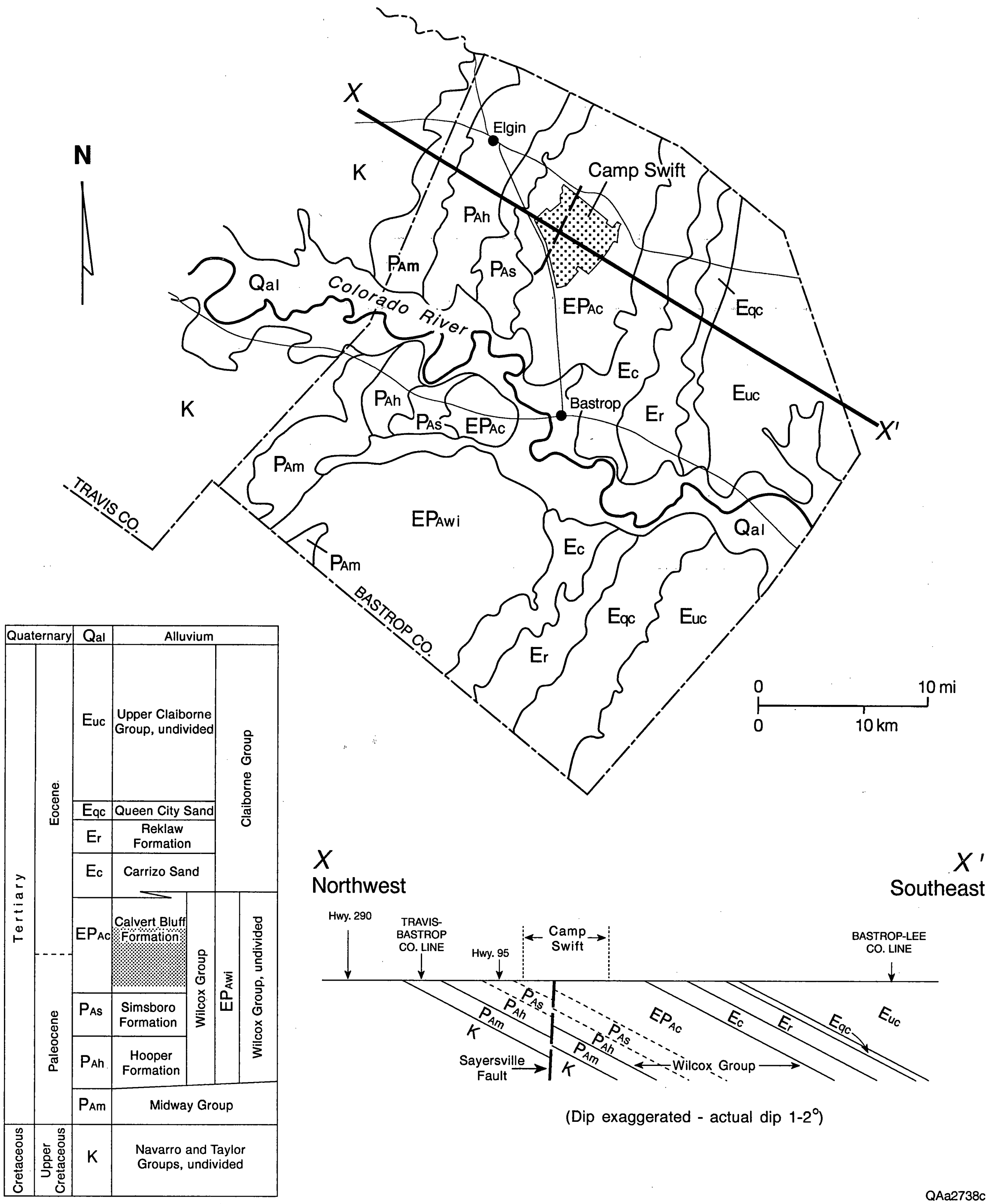

Figure 5. Generalized geologic map, schematic cross section, and stratigraphic column for Bastrop and easternmost Travis Counties (modified from Barnes, 1992; position of Sayersville fault from Gaylord and others (1985, fig. 2.3-2). Camp Swift is located within the outcrop belt of the Calvert Bluff Formation (Wilcox Group); approximate Calvert Bluff interval within base boundary is shaded in stratigraphic column. Dip of beds in the schematic cross section is exaggerated to show detail; actual dip is about 1° to 2° toward the southeast.

as 4 or 5 mi in this area. These faults are probably part of the Luling fault zone, which was described briefly by Weeks (1945).

Hooper Formation (Paleocene)

The Hooper Formation is about 500 ft thick beneath the Camp Swift area (plate 2). It was deposited in the delta front and interdistributary regions of a progradational delta (Bammel, 1979, p. 14), and consists of mudstone, sand, and sandstone, with a few thin, discontinuous beds of lignite.

There is some uncertainty as to the exact location of the Simsboro-Calvert Bluff contact at the surface; however, drillhole data and interpretations by the U.S. Geological Survey (Gaylord and others, 1985, fig. 2.3-3) are consistent with the geologic map of Proctor and others (1974).

Simsboro Formation (Paleocene)

Thickness of the Simsboro Formation varies from about 500 ft near its outcrop to possibly as much as 800 ft in downdip areas (plate 2) (Gaylord and others, 1985, p. 12). The Simsboro Formation is interpreted to have been deposited in a highly meandering channel section of the Mount Pleasant Fluvial System (Bammel, 1979). To the south of the Colorado River the Wilcox Group is not divided as the Simsboro Formation is no longer distinguishable from the other units (fig. 5) (Kaiser, 1978, p. 41). The Simsboro consists mostly of weakly to slightly consolidated, cross-bedded kaolinitic quartz sandstone, with some siltstone and claystone. Most of the Simsboro is light gray and commonly weathers to a reddish-brown; claystone and mudstone lenses are generally medium to dark gray. Stratigraphy of the Simsboro Formation is discussed by Bammel (1979); detailed descriptions of petrography are provided by Adams (1957) and Cast (1986).

Calvert Bluff Formation (Paleocene and Eocene)

The Calvert Bluff Formation is exposed in isolated outcrops throughout Camp Swift along streambeds, in pits, in gullies, and along roadways. Most of the formation is actually concealed by soils, which roughly approximate the composition of the underlying bedrock strata. Thickness of the Calvert Bluff varies from possibly as little as 25 ft adjacent to the Sayersville fault (along cross section B–B′, plate 2) to as much as 500 ft beneath the southeastern edge of Camp Swift (Gaylord and others, 1985, fig. 2.3-3) (plate 2). A complete section of Calvert Bluff Formation at the downdip edge of its outcrop belt, about 2 mi southeast of Camp Swift, is about 800 to 1,000 ft thick (Gaylord and others, 1985, p. 14). In the subsurface in east-central Bastrop County (Smithville area) the Calvert Bluff is about 1,200 ft thick (Kaiser, 1978, fig. 9).

The Calvert Bluff Formation consists of weakly to modestly consolidated, massive to thin bedded, clayey, fine- to very fine grained sandstone, siltstone, and claystone. The formation varies from light gray 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. The approximate subcrop of the main lignite seams (where they directly underlie the surficial soils) is shown in plate 2. Detailed descriptions of the stratigraphy of the Calvert Bluff Formation are provided in Kaiser (1978) and Ayers and others (1986); extensive lithologic and structural data are given in Ayers and Lewis (1985); petrography of the Calvert Bluff Formation is discussed by Wong (1986).

The Calvert Bluff Formation in this area is interpreted to have been deposited in meanderbelts in the transition zone between a lower alluvial plain of a fluvial system and a delta plain (Kaiser, 1978, p. 38). The principal sandstones occur mainly as elongate, northwest–southeast-trending lenticular bodies filling ancient distributary channels that locally incise and truncate the finer grained units. Such channels have been extensively mapped in the subsurface to the southeast of Camp Swift (Kaiser, 1978, figs. 8–12). At least two probable channels have been encountered in lignite exploration drill holes (TRDC, 1979 map II, cross sections A–A′, B–B′, E–E′, G–G′, and H–H′); one occupies a zone about 0.5 mi wide between the northeasternmost fringes of the base and the Southern Pacific Railroad line to the east and may be as much as 70 ft thick (plate 2); the other was encountered about 2 mi south of the Camp headquarters. Sandy portions of the Calvert Bluff Formation exposed at the surface (plate 2) may be genetically related to these or other channels, or may be distinct sandstones deposited in other environments outside of the main channels. The sands constitute localized aquifers within the Calvert Bluff Formation and serve as recharge zones where exposed at the surface.

Alluvium and Colluvium (Quaternary)

Unconsolidated alluvium and colluvium underlie stream valleys and form thin veneers on upland surfaces north of Big Sandy Creek. Principal areas of alluvium in stream valleys are shown in plate 2. The stream-valley alluvium consists of interbedded clay, silt, and sand, with varying amounts of gravel. The veneers on the upland surfaces appear very much like soils, and indeed are part of the soil profile, but differ from soils elsewhere on the base as they contain abundant pebbles and cobbles of petrified wood, quartzite, and other siliceous rocks. The veneers may be remnants of a terrace deposit or pediment formed prior to incision of the modern streams.

Economic Geology

Lignite

Major deposits of lignite are present and have been mined from the lower part of the Calvert Bluff Formation; noneconomic lignite is present in the Hooper Formation. Lignite was an important fuel in Texas in the latest 1880′s and early to mid-1900′s. Demand for lignite decreased as it was gradually replaced by oil and natural gas, and mining of the fuel for small-scale uses virtually ceased in 1946 (Dietrich and Lonsdale, 1958, p. 58). However, at about this same, interest in lignite for use in large power plants increased. The first major lignite-fired power plant in Texas began operation in 1955, using lignite from the Sandow mine in Milam County, to generate electrical power for aluminum refinement. By 1980 lignite was being used to generate 20 percent of the electricity in Texas (Kaiser and others, 1980, p. 1). Lignite mines operating in the Camp Swift region include the Powell Bend mine between Camp Swift and the Colorado River, the Sandow mine in southern Milam County, and the Fayette mine in Fayette County.

The first lignite mine in Bastrop County was opened in 1892, just north of the Southern Pacific Railroad about 1.2 mi southeast of Butler (Dietrich and Lonsdale, 1958, p. 60). Most of the production in Bastrop County was from underground mines and pits along the Missouri-Kansas-Texas Railroad line in the divide area between Big Sandy Creek and Piney Creek, extending from Sayersville to Bastrop, with some additional mining along the Southern Pacific Railroad in the McDade area (Dietrich and Lonsdale, 1958, p. 58–60; Fisher, 1963, p. 26–34, 118–119) (plate 2). Approximately 25 separate mines were in operation in Bastrop County, with as many as 14 active at one time during the peak of activity. The last shipment from Bastrop County (prior to the commencement of large-scale open-pit mining in recent years) was in 1944.

Little remains of these early mines. Henry and Basciano (1979, table 3) listed three abandoned mines in Bastrop County, but apparently, only one, near Dunstan (~2.75 mi south of present Camp Swift headquarters) still had recognizable surface evidence; the other two, near Sayersville (plate 2) and near McDade, could not be precisely located. Small-scale lignite mining probably also occurred within the area of Camp Swift as it straddles the principal lignite trend (see plate 2). One group of shallow pits along Upper Cut Road (plate 2, Area IA) is located in dark carbonaceous clay near the outcrop of one of the thicker lignite seams, and very likely originated as a lignite pit. Another group of pits north of Big Sandy Creek between State Highway 95 and the LCRA powerline (plate 2, Area IIIA) are in similar fine-grained carbonaceous material and may also have been mined for lignite.

Interest in lignite in the Camp Swift area peaked once again in the 1970's and early 1980's as a lease area was prepared and extensively studied by the Lower Colorado River Authority (see plate 2). Plans for mining have been abandoned, at least for the time being, because of competition from less expensive and cleaner-burning Wyoming coal (Dan Kuehn, Lower Colorado River Authority, personal communication, 1993). However, during lease investigations more than 70 exploratory holes were drilled on the property. Numerous geologic and hydrologic data were obtained. The information is compiled in a number of reports, including Bechtel (1974), Brown & Root (1978), TRDC (1979), Hall (1981), Science Applications, Inc. (SAI, 1982), Dravo (1983), Gaylord and others (1985), and Bond and McAndrews (1986), all of which can be inspected at the offices of the Fuels Procurement Section, Lower Colorado River Authority, Austin, Texas.

Oil and Gas

A limited amount of oil and gas exploration and production has occurred in the Camp Swift area. Most of this was associated with the now-abandoned Sayersville field, located about 1.3 mi west of Sayersville (TRDC, 1979, map II). The proximity of this abandoned field and general exploration, which probably occurred throughout the region, suggest the possibility that there may be one or more abandoned oil and gas exploratory holes on the Camp Swift property. An examination of data files provided to the Bureau of Economic Geology for a recent abandoned well study (Kreitler and others, 1991) indicated that there may be as many as 160 abandoned-wildcat wells within a 6-mi radius from the center of Camp Swift. A search of records maintained by the Railroad Commission of Texas may produce location information for these wells.

SURFACE HYDROLOGY

Principal Streams and Drainage Basins

Most of Camp Swift lies within the Big Sandy Creek drainage basin (fig. 6). Big Sandy Creek for most of its length is perennial, whereas its tributaries are intermittent. The drainage area of Big Sandy Creek upstream from the northeastern boundary of Camp Swift encompasses about 38.7 mi^2 (U.S. Geological Survey [USGS], 1980, p. 247), and includes most of Bastrop County and parts of neighboring counties north of the base and east of the City of Elgin (fig. 6). The drainage area of Big Sandy Creek upstream from the southwestern boundary of Camp Swift is about 63.8 mi^2 (USGS, 1980, p. 253). The difference between these two values, 25.1 mi^2 (about half of which is outside the base boundary), is the area that contributes directly to the Camp Swift segment of Big Sandy Creek, and includes subbasins drained by McLaughlin Creek, Dogwood Creek, and numerous other, unnamed tributaries (fig. 6). A large area in the southern part of Camp Swift (about one-third to one-fourth of the property) is within the Dogwood Branch subbasin (not to be confused with Dogwood Creek), which joins Big Sandy Creek about 1 mi west of the base headquarters. Three smaller subbasins, two north and one south of Dogwood Branch, also drain across the base boundary before joining Big Sandy Creek. A very small portion of Camp Swift along the southeastern boundary drains into neighboring Piney Creek (fig. 6).

Five recording rain gauges, two continuous-record streamflow gauges, two automatic water-quality and sediment samplers, two automatic water-quality samplers, and two partial-record flood-hydrographs were installed in the Big Sandy Creek drainage basin by the U.S. Geological Survey to collect data for an environmental impact study of the proposed Camp Swift lignite lease (figs. 6 and 7). The various gauges were operated and records are available for all or part of the period July 1979 to September 1985 (USGS, 1980 through 1985; Gaylord and others, 1985, p. 40–43). The records provide a quantitative description of stream characteristics.

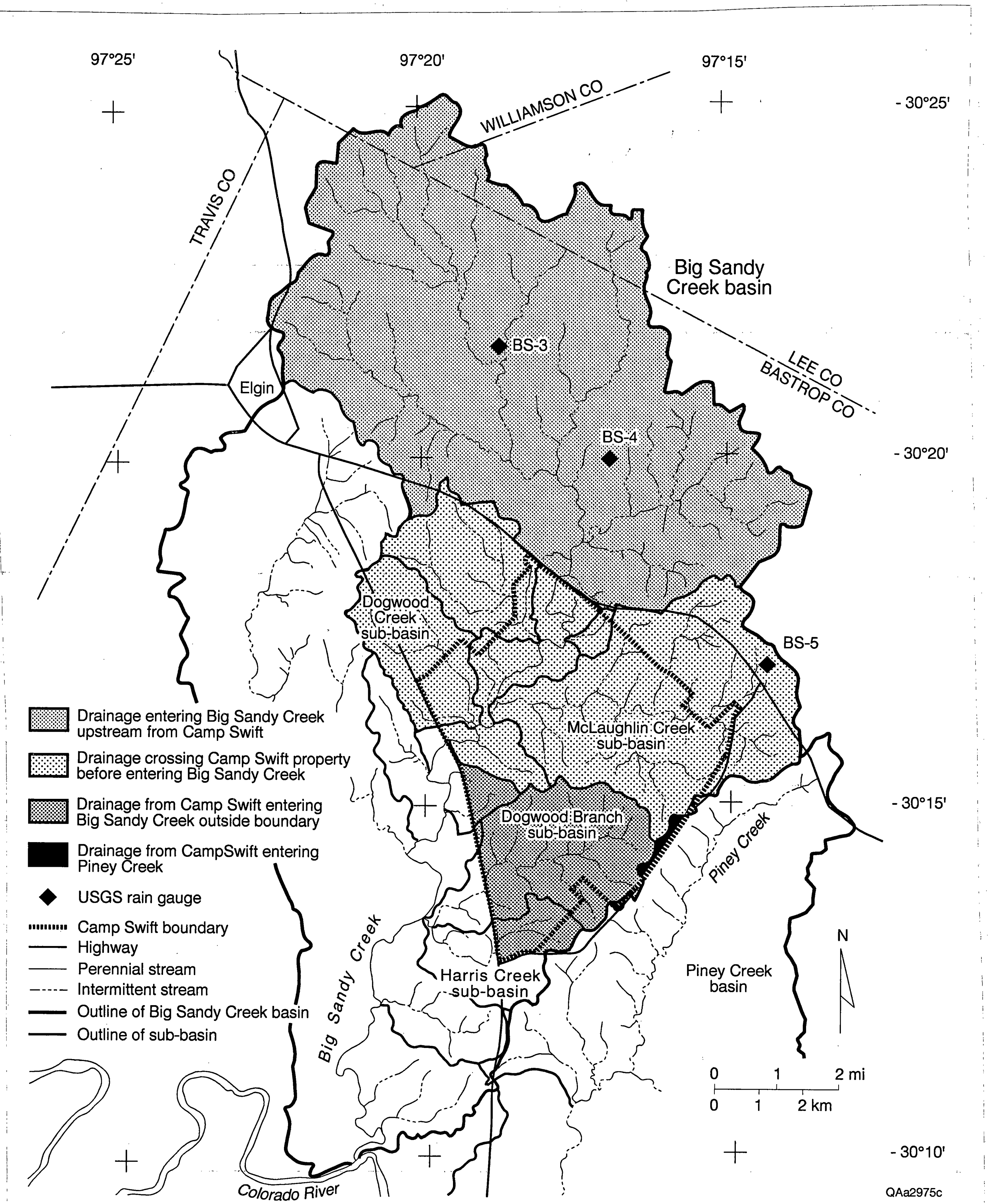

Figure 6. Surface drainage in the Camp Swift area. Streams and drainage basin outlines from U.S. Geological Survey/Army Map Service 15-minute topographic quadrangle maps; locations of rain gauges (BS-3, BS-4, and BS-5) from Gaylord and others (1985, fig. 4.2-1).

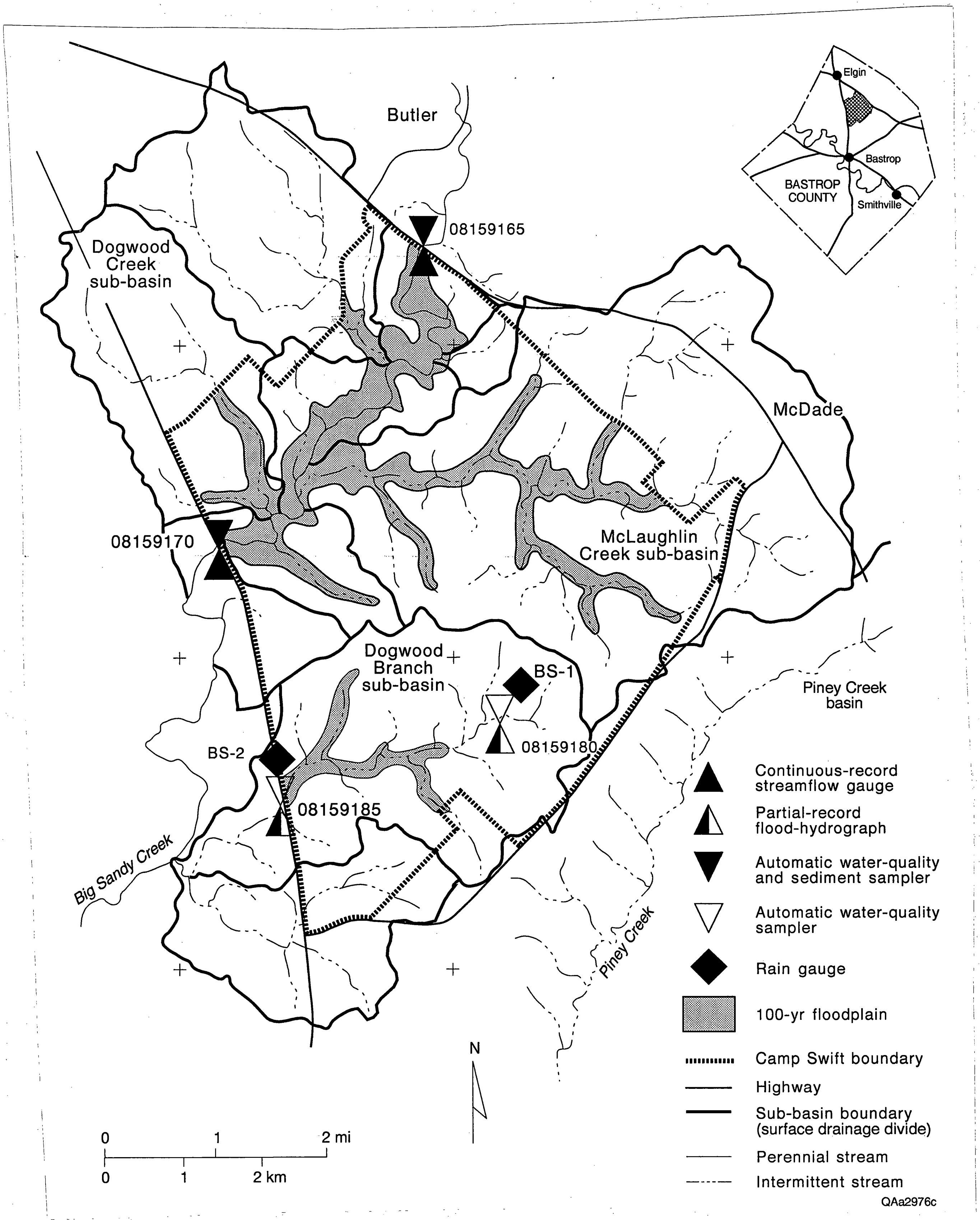

Figure 7. Second-order drainage basins on Camp Swift boundary, showing approximate distribution of 100-yr floodplains (from FEMA, 1991) and locations of USGS rain gauges, stream gauges, and automatic samplers (from Gaylord and others, 1985, fig. 4.2-1).

Streamflow

Streamflow characteristics for the Camp Swift area were investigated by Gaylord and others (1985). They reported (p. 49) that during the 3-yr period of their study (ending September 1982), surface runoff accounted for only 6 inches of the 99 inches of precipitation that fell within the portion of the Big Sandy Creek watershed between the two streamflow gauges. A very small portion was recharged to the ground-water system, whereas most of rest was lost to evapotranspiration. The streamflow characteristics of the Big Sandy Creek watershed are summarized by Gaylord and others (1985, p. 44–46): (1) the flow of Big Sandy Creek fluctuates very rapidly in response to rainfall in the watershed (fig. 8); (2) because the drainage area of Big Sandy Creek is relatively small, the duration of surface runoff from most storms is short; (3) the base flow of Big Sandy Creek is small (normally less than 0.5 ft^3/sec); (4) evapotranspiration probably has little effect on floodflows; (5a) soil characteristics have a significant effect on streamflow; (5b) because the shrink-swell potential, permeability, and moisture-content of these soils vary greatly in relation to antecedent precipitation, the runoff characteristics for a given storm can vary accordingly; (5c) after prolonged dry periods, the absorption characteristics of the soils can be very large and the surface runoff small; (5d) during wet periods, water storage capacity of the soils is greatly reduced and surface runoff may be large. Analyses of rainfall, runoff, and stream discharge are provided for selected storms in Gaylord and others (1985, p. 44–49).

A plot showing the mean daily discharge recorded at the streamflow gauge at the eastern boundary of Camp Swift is provided in figure 9. The figure shows that in normal years, the highest streamflows occur in May or June, which are typically heavy rainfall months in Central Texas. The plot also illustrates, however, that high flows can also occur during other months in which there is abnormal rainfall; the pattern for winter 1984–85 is similar to the heavy winter rains in Central Texas during the winters of 1991 and 1992.

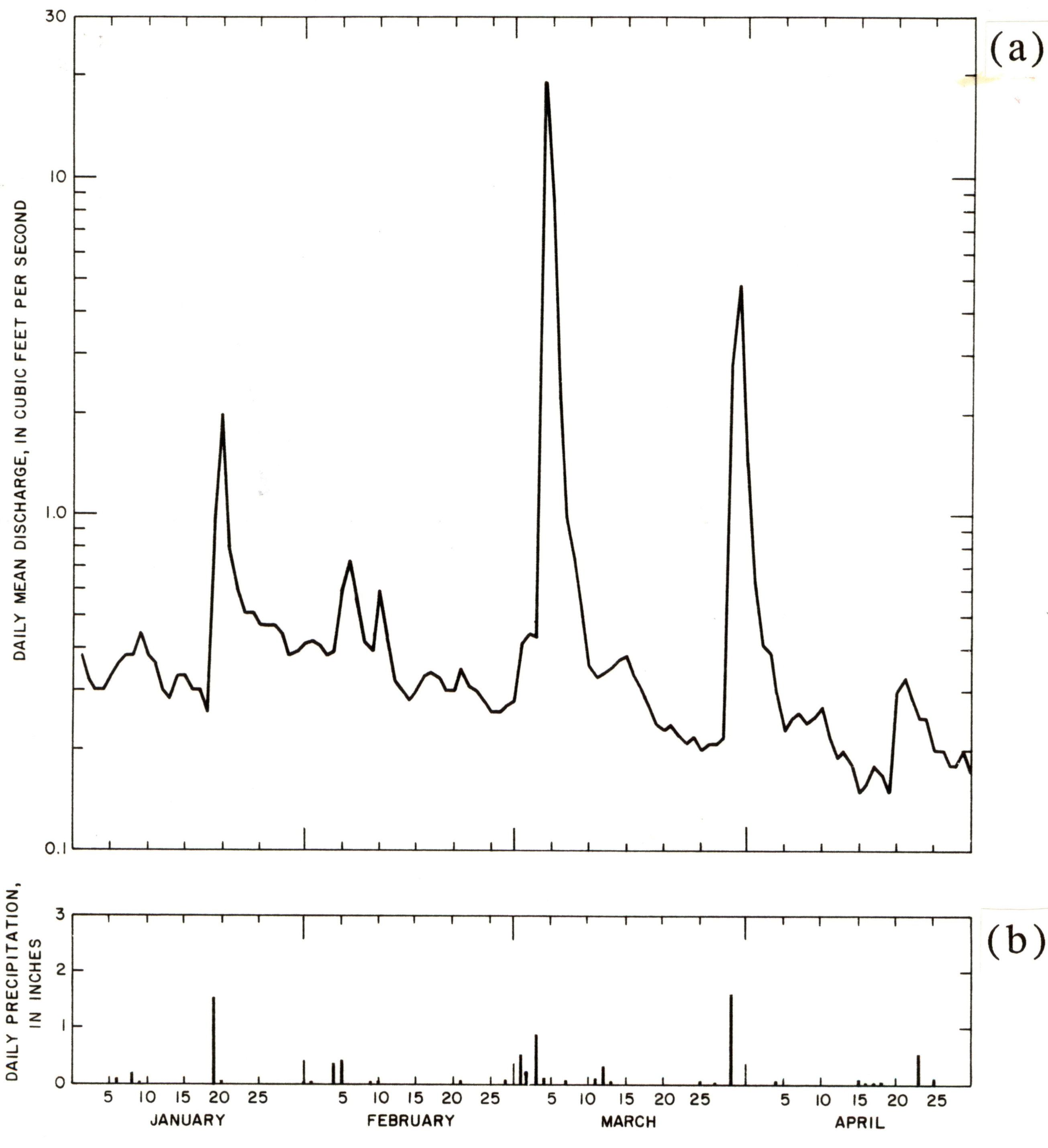

Figure 8. (a) Typical daily pattern of streamflow in Big Sandy Creek at western stream gauge and (b) rainfall, January–April, 1981; peak discharges occur shortly after rainfall events and last for several hours or several days, depending on conditions of soil moisture and subsequent rainfall (from Gaylord and others, 1985, fig. 5.0-1).

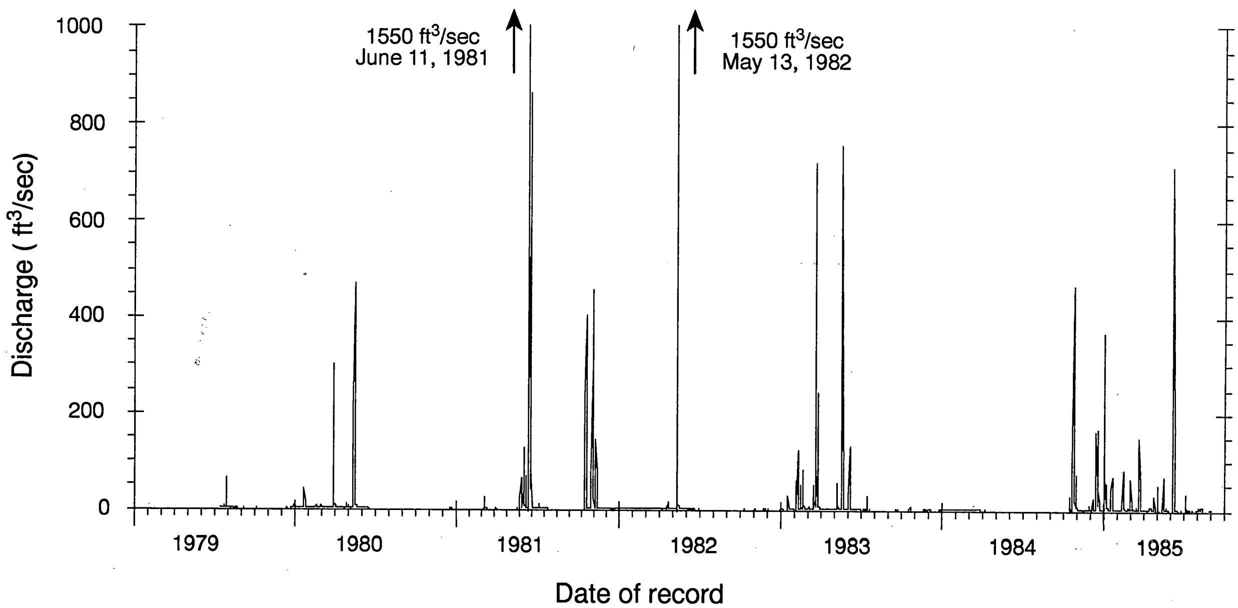

Figure 9. Plot showing mean daily discharge in Big Sandy Creek at eastern streamflow gauge (no. 08159165; see fig. 7), July 1979–September 1985. During normal years, the highest streamflows occur in May and June, which are typically heavy rainfall months in Central Texas. Gauge began operation in July 1979 and continued through September 1985. Data from USGS (1980, 1981, 1982d, 1983, 1984, 1985).

The average discharge of Big Sandy Creek at the eastern edge of the base for the 6 years of gauge operation was 8.82 ft^3/sec; average discharge at the western edge for the same period was 10.8 ft^3/sec (USGS, 1985). As noted by Gaylord and others (1985, p. 32), Big Sandy Creek is generally regarded as a perennial stream. However, the stream does stop flowing during long periods of less than normal precipitation. In the summer of 1980, for example, there were 61 days of no flow in Big Sandy Creek. At the other extreme, large and sometimes damaging floods occur on the creek following major storms. Peak discharges recorded by the streamflow gauges during the 6 yr of operation are summarized in table 2. Flows corresponding to 25-yr and 100-yr floods were estimated by the U.S. Bureau of Land Management (USBLM, 1980a, table 2-7, p. A4-5–A4-8), based on limited data for streams on Camp Swift, augmented by comparison with other creeks in the region. Estimated floodflows at the Big Sandy Creek streamflow gauge on the west side of Camp Swift are: 13,500 ft^3/sec (25-yr) and 20,850 ft^3/sec (100-yr); at the mouth of McLaughlin Creek: 4,530 ft^3/sec (25-yr) and 6,780 ft^3/sec (100-yr); where Dogwood Branch crosses Highway 95: 3,070 ft^3/sec (25-yr; recalculated according to data in appendix—value listed in table 2-7 apparently a typographical error) and 4,470 ft^3/sec (100-yr). The greatest discharge on Big Sandy Creek on the west side of Camp Swift during the period of gauge operation was 5,760 ft^3/sec, less than half the volume of the estimated 25-yr flood (see table 2). The 100-yr floodplains on the Camp Swift property are shown in figure 7. The floodplains are locally traversed by roads. Smaller floods have been a problem in the past and will continue to be a problem at creek crossings, in the area of the confluence of McLaughlin and Big Sandy Creeks, and near gate 7.

Surface Water Quality

Analyses of surface water quality were conducted for the lignite lease's Environmental Impact Statement and are summarized in Gaylord and others (1985, p. 60). The principal findings were that: (1) the quality of surface water in the Camp Swift area is generally suitable

Table 2. Peak discharges recorded at streamflow gauges on Big Sandy Creek, east and west sides of Camp Swift (data from U.S. Geological Survey, 1980, 1981, 1982d, 1983, 1984, and 1985).

	Gauge 08159165, east side of Camp Swift [1].				Gauge 08159170, west side of Camp Swift [1]			
Water Year [2]	Discharge (cu ft/s) [3]	Gauge height (ft) [4]	Date	Time	Discharge (cu ft/s) [3]	Gauge height (ft) [4]	Date	Time
1979 [5]	331	7.05	27-Jul	2400	256	8.81	28-Jul	
1980	989	12.20	27-Mar	2115	1,340	14.51	28-Mar	0215
	984	12.17	14-May	0230	1,720	15.78	14-May	0615
1981	412	7.82	31-May	0245				
	4,410	15.74	11-Jun	0645	5,760	21.54	11-Jun	1100
	1,970	12.70	13-Jun	1830	2,400	17.32	13-Jun	2345
	1,940	12.65	16-Jun	1400	1,940	16.36	16-Jun	1900
1982	4,140	15.74	13-May	1115	5,540	21.34	13-May	1500
1983	340	7.25	9-Feb	2100				
	1,740	12.25	23-Mar	1615	1,630	15.50	23-Mar	2000
	512	8.45	26-Mar	1345	659	11.70	26-Mar	1730
	1,170	10.94	21-May	1300	1,300	14.35	21-May	1815
1984	14	3.30	21-Oct	0200	6.6	2.76	21-Oct	1715
1985	729	9.92	20-Oct	2315				
	1,200	11.61	21-Oct	1715	948	13.04	21-Oct	2245
	518	8.81	24-Oct	0015				
	408	8.14	13-Dec	1730				
	408	8.14	16-Dec	1145				
	805	10.26	31-Dec	1545	905	12.86	31-Dec	1830
	343	7.67	10-Feb	2015				
	387	8.00	20-Mar	1415				
	2,320	13.51	6-Jun	1815	2,345	15.01	6-Jun	2345

Notes:

(1) Gauge locations shown in figure 7; elevation of east side gauge 422 ft, west side gauge 392 ft.

(2) Water year is October 1 to September 30.

(3) Mean daily discharge.

(4) Height of water surface above gauge elevation (gauge elevation is approximately equal to bottom of stream channel).

(5) Gauge began operation in July 1979.

for most uses but varies considerably in response to variations in discharge and related factors; (2) low flows in Big Sandy Creek are sustained principally by the inflow of shallow groundwater; (3) during low-flow periods, concentrations of major dissolved inorganic constituents (Ca, Mg, Na, K, SO_4, Cl, HCO_3) are large; (4) during the early stages of storm runoff, the concentrations of the major constituents also are large due to leaching of soluble weathered material that has accumulated at the land surface since the last storm (fig. 10); (5) as storm runoff continues and soluble material is flushed from the land surface, the concentrations of the major dissolved constituents decrease; (6) the concentrations of indicator bacteria also decrease with time during a runoff event; (7) concentrations of nitrogen species, phosphorus, and some other constituents increase during the early stages of a runoff event, then decrease (fig. 10).

Big Sandy Creek was inspected several times during visits to Camp Swift in February and March 1993. In each case, the water flowing onto the base was brown and was covered by a white to light-brown foam in turbulent areas immediately downstream from the New Road creek crossing. The appearance suggests that pollutants are present in the water. Water-quality analyses from 1978 to 1981 indicate that the various constituents were within Federal secondary drinking water standards (USOSM, 1982, p. II-6; Gaylord and others, 1985, table 10.3). No recent chemical analyses were found in the published literature. The foam may be forming from natural organic decay products washed into the stream from the watershed.

Stream Sediment

Suspended-sediment analysis was conducted by Gaylord and others (1985) for streams on the Camp Swift property. They noted that an earlier U.S. Soil Conservation Service study predicted a soil loss of approximately 0.54 ac-ft/mi^2 per year for the Camp Swift area. The results of their study, which they cautioned was of short duration and perhaps not representative, indicated a significantly smaller amount of suspended sediment than did the earlier study. This suggests that less soil is being eroded from Camp Swift, possibly because

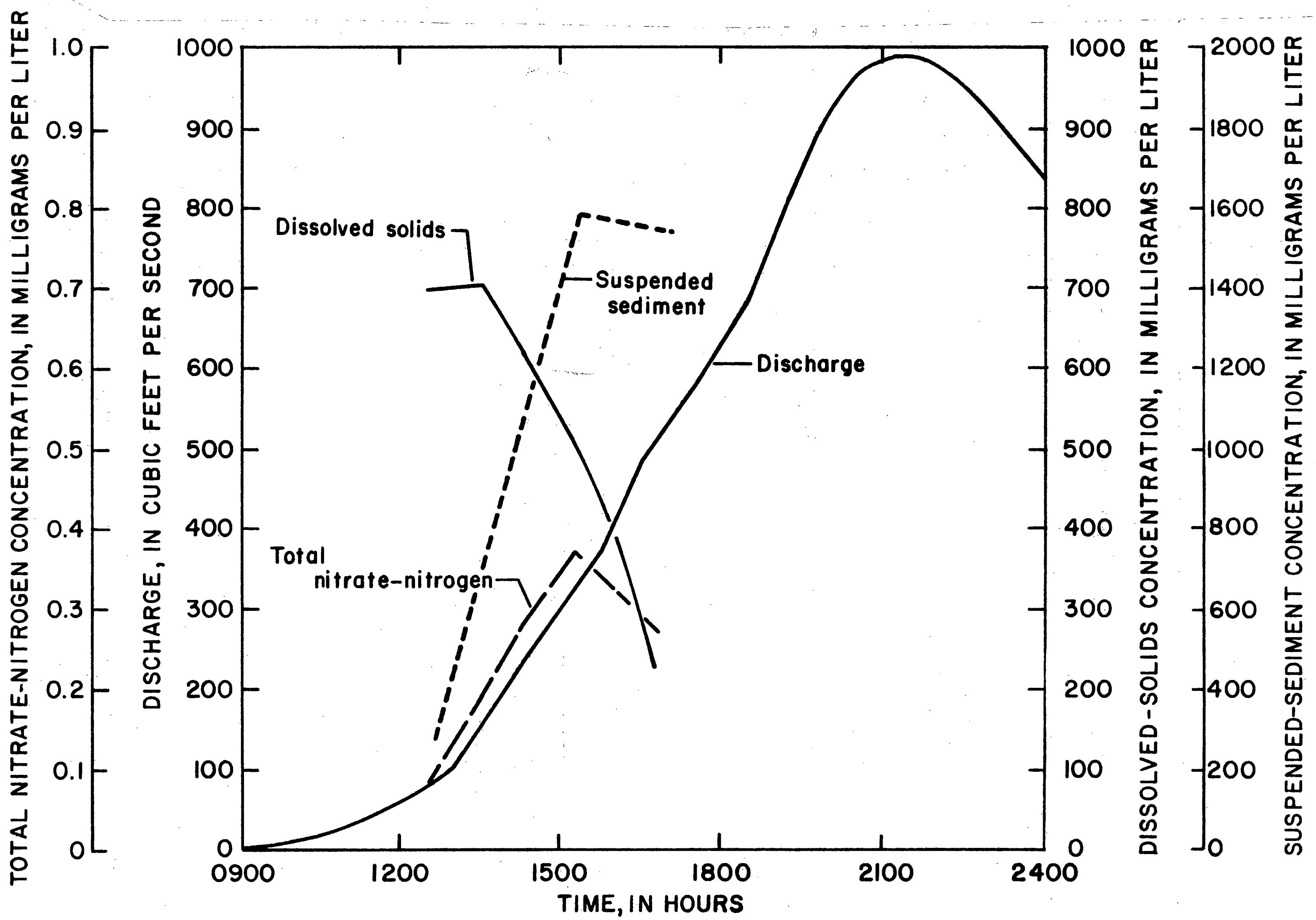

Figure 10. Changes in dissolved solids, total nitrate-nitrogen, and suspended-sediment concentrations with stream discharge at eastern gauging station on Big Sandy Creek, March 27, 1980. Plot shows that concentrations of major inorganic constituents are initially high, remain high during the earliest stages of storm runoff (due to leaching of soluble weathered material that has accumulated at the land surface since the last storm), and then decrease once they have been flushed; concentrations of suspended sediment and of nitrogen species increase dramatically during the early stages of storm runoff and then decrease as the supply of these materials is depleted. From Gaylord and others (1985, fig. 7.1-1).

vegetation on the base is not as heavily disturbed as in upstream areas where the lands are used for agricultural purposes. The results of Gaylord and others (1985) are summarized as follows: (1) for the sampling station on the eastern side of Camp Swift, instantaneous suspended-sediment discharges ranged from nearly zero during low flow to as much as 3,260 tons/day during flood runoff (fig. 11a), indicating a sediment yield of about 0.1 ac-ft/mi^2 per year; (2) particle-size distribution determined for samples from the same station indicated that the suspended sediment consists of approximately 10 percent sand, 11 percent silt, and 79 percent clay; (3) instantaneous suspended sediment discharges at the western boundary of Camp Swift ranged from about 0.01 tons/day during low flow to 1,670 tons/day during flood runoff (fig. 11b), indicating an average sediment yield of about 0.07 ac-ft/mi^2 for the entire area of the drainage upstream from that station; (4) suspended sediment passing this station was composed of 14 percent sand, 22 percent silt, and 64 percent clay; instantaneous suspended sediment discharge in Dogwood Branch ranged from about 0.22 to 51 tons/day (fig. 11c); sediment yield was not computed because the stream gauge at that location was not a continuous-record device; suspended sediment collected at this station consisted of approximately 1 percent sand, 7 percent silt, and 92 percent clay.

GEOMORPHOLOGY

Relief

Camp Swift is situated on the Texas Gulf Coastal Plain, a region characterized by extensive, nearly level areas with relatively few topographic features. However, Camp Swift is near enough to the Colorado River that the landscape is dissected by streams that have cut headward and downward in response to lowered base level of the Colorado River, which entrenched during times of lower sea level in the Pleistocene. The overall slope of the land surface and direction of drainage is toward the west and southwest.

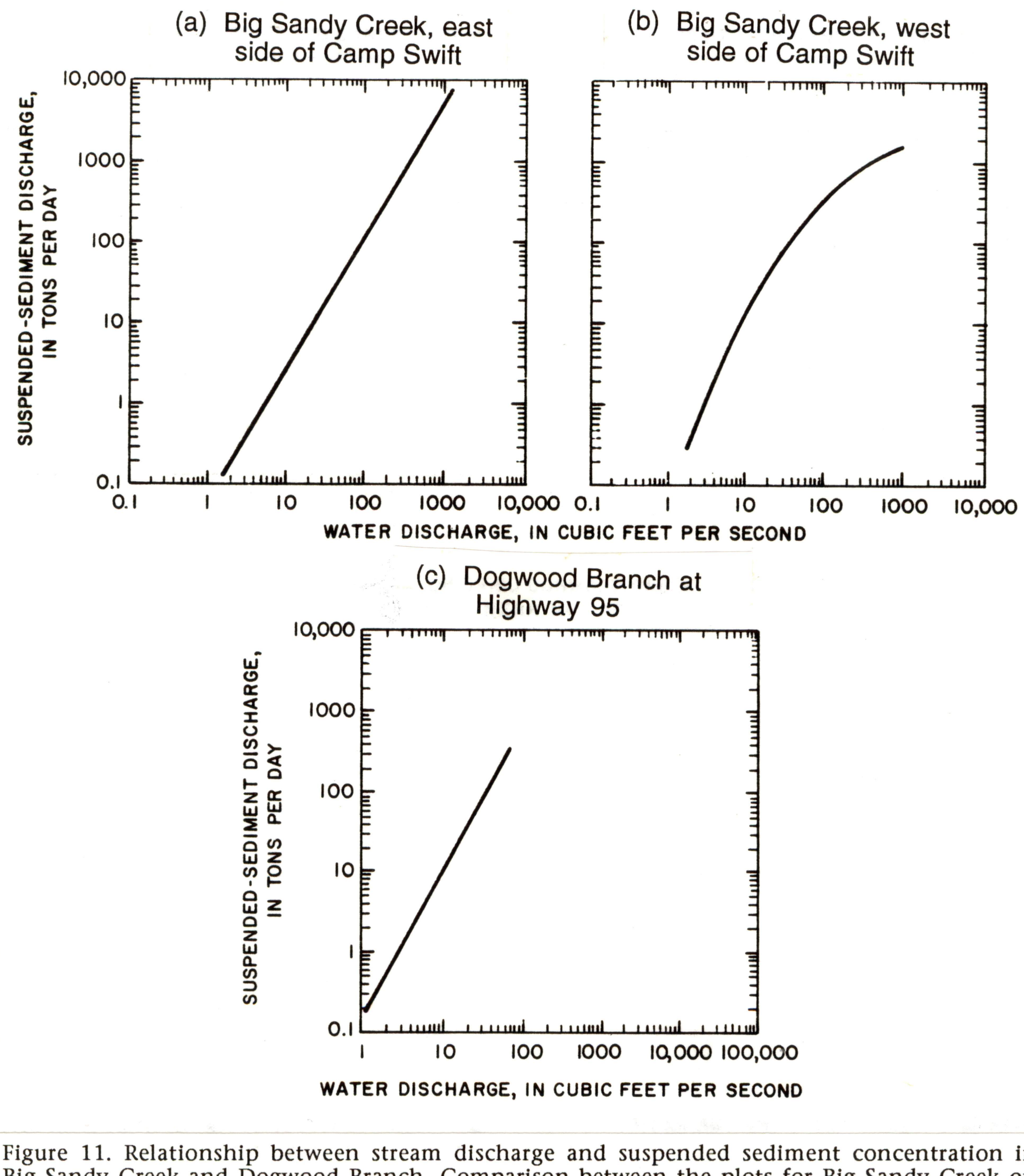

Figure 11. Relationship between stream discharge and suspended sediment concentration in Big Sandy Creek and Dogwood Branch. Comparison between the plots for Big Sandy Creek on the eastern side (upstream gauge, no. 08159165) and western side (downstream gauge, no. 08159170) of Camp Swift reveals that suspended sediment concentration decreases, implying that less erosion is occurring on the Camp Swift property than in areas upstream of the base. This can be construed as an improvement in water quality in Big Sandy Creek as it flows across Camp Swift. Modified from Gaylord and others (1985, fig. 7.2-1).

The highest elevation in the Camp Swift area is about 630 ft, on the Simsboro Formation about 2 mi northwest of the property (plate 3). The terrain there consists of smoothly rounded hills and ridges that rise as much as 30 to 40 ft above surrounding areas, and is generally forested. The landscape on the Calvert Bluff Formation, which contains more clay and is less resistant than the Simsboro, is typified by irregularly shaped hills with deeply incised streams (plate 3). Relief on the Calvert Bluff Formation locally exceeds 80 ft. The Calvert Bluff Formation supports a mix of woodland and grassland; many of the grassy areas were originally woodlands cleared for agricultural purposes. Elevations on the Calvert Bluff range from a minimum of about 395 ft where Big Sandy Creek crosses the western boundary of the base to about 570 ft at the top of a small hill of sandy Calvert Bluff Formation at the southeast edge of the base near Gate 2 (plate 3).

Slopes on the Camp Swift property commonly reach 5 percent (about 250 ft/mi) and locally are as great as 12 percent (about 600 ft/mi) (Baker, 1979). Northwest-facing slopes, which cut at high angles across bedding planes in bedrock strata, are typically steeper than southeast-facing slopes that are cut subparallel to bedding planes. The steepest slopes are in the southwestern half of Area IIIA and northwestern half of Area IA where Calvert Bluff strata are deeply incised by Big Sandy Creek and its tributaries (plate 3).

Floodplains are a major geomorphic feature of the Camp Swift landscape. The estimated 100-yr floodplains (Federal Emergency Management Agency [FEMA], 1991) vary from about 0.5 to 0.75 mi wide along Big Sandy Creek, and up to 0.25 mi wide along the main reaches of McLaughlin Creek, Dogwood Creek, Dogwood Branch, and several unnamed tributaries of Big Sandy (fig. 7). These floodplains typically are underlain by relatively permeable alluvium of mixed clay, sand, and gravel; slopes are typically less than 2 percent.

Stream Morphology

The drainage pattern in the vicinity of Camp Swift is intermediate between dendritic and trellised (figs. 7 and 8). The dendritic trend refers to the branching character and curving path of most of the secondary streams, and reflects erosion of moderately homogeneous, relatively unconsolidated rocks. The trellised pattern refers to the tendency toward structural control of the larger streams (Big Sandy Creek itself and major branches, and Piney Creek) that follow trends parallel (east-northeast to northeast) and perpendicular (northwest) to the strike of bedrock strata. The orientation of Big Sandy Creek may be in part influenced by the presence of the Sayersville fault (plate 2).

The largest stream on the Camp Swift property is Big Sandy Creek, which flows through a broad valley with steeply to gently sloping sides. The active channels of the larger streams, including Big Sandy Creek, most of McLaughlin Creek, and parts of Dogwood Branch for the most part have smooth, continuous profiles and broad cross sections indicating that they have become graded to a base level (base level for most of the streams is determined by Big Sandy Creek, which is controlled by the Colorado River). The gradient of Big Sandy Creek and major tributaries is approximately 1 ft/1,000 ft (SAI, 1982, p. 43). These streams have floodplains with Quaternary alluvial deposits (plate 2). Most of the smaller streams on Camp Swift are cutting downward and headward into surrounding uplands. The lower portions of these streams are typically graded down to their confluences with the larger streams and are characteristically deep (bottoms as much as 15 ft below adjacent upland rims), steep walled, and flat bottomed. Gradients in these lower portions is about 3 to 5 ft/1,000 ft (SAI, 1982, p. 43). The upper portions of these streams generally are shallow and have smooth, gentle cross sections that blend into the surrounding landscape. Intermediate portions of these streams are commonly narrow and steep sided, and have "V"-shaped bottoms; in many cases they are broken up into segments separated by "knickpoints" (abrupt vertical changes in the stream profile) formed at resistant geologic layers or at exposed masses of tree and shrub roots. Erosion and downward cutting are occurring most rapidly in these intermediate stream portions. Small side canyons and gullies commonly branch off of the main stream. The active erosion of these stream segments may be a relatively recent phenomenon related to increased runoff and reduced vegetative cover resulting from agricultural activities in the late 1800's and early 1900's. Several of the intermittent streams on Camp Swift are choked by sediment supplied from areas of active gullying. The deposits are fine-grained and noncohesive and may present a quicksand hazard when they are saturated; however, in most cases they are probably less than 1 ft thick.

SOILS

Soils on the Camp Swift training site can be assigned to three principal soil groups—Patilo-Demona-Silstid group (sandy soils covering about 40 percent of the area of Camp Swift), Axtell-Tabor-Crockett group (loamy soils covering about 50 percent of the area), and Sayers-Gowen-Uhland group (sandy to loamy soils covering about 10 percent of the area) (plate 4). These are informal groupings of similar soils intended for simplification and are slightly different from more strictly defined soil "associations" of the same or approximately the same name. All of the soil information presented here is summarized from detailed maps and text prepared by the U.S. Soil Conservation Service (Baker, 1979). The individual soils included in each group and their basic properties are listed in table 3. Specific engineering properties of the soils and the problems they may present are discussed in detail in Baker (1979).

Patilo-Demona-Silstid Group

The soils included in the Patilo-Demona-Silstid group occur mostly on the northern half of the Camp Swift property, and along a branch of McLaughlin Creek and in isolated patches on the southern half. Small areas of Rosanky soils are also included. These soils typically have a sandy surface layer and sandy clay to clay loam lower layers that are moderately permeable to moderately slowly permeable (Baker, 1979, p. 2). Within the boundary of Camp Swift they are

Table 3. Properties of soils on Camp Swift (from Baker, 1979).

Soil series	Soil unit	Surface texture	Slope (percent)	Permeability	Runoff	Erosion hazard	Shrink-swell potential	Corrosivity to uncoated steel	Corrosivity to concrete	Comments
Patilo-Demona-Silstid Group:										
Patilo complex	PaE	fine sand	1 to 12	moderately slow	slow	slight	very low to low	low to high	low to moderate	billowy sand surface layers possibly reworked by wind
Demona	DeC	loamy fine sand	1 to 5	slow	slow to medium	moderate	very low to moderate	low to high	moderate	
Silstid	SkC	loamy fine sand	1 to 5	moderate	slow	moderate	low	very low to moderate	moderate	
Rosanky	RoB	fine sandy loam	1 to 3	moderately slow	medium to rapid	moderate	very low to moderate	moderate to high	low to moderate	
Axtell-Tabor-Crockett Group:										
Axtell	AfA	fine sandy loam	0 to 1	very slow	slow to rapid	slight	low to high	low to high	moderate	
	AfC	fine sandy loam	1 to 5	very slow	slow to rapid	moderate	low to high	low to high	moderate	gullies in some areas
	AfC2	fine sandy loam	2 to 5	very slow	slow to rapid	severe	low to high	low to high	moderate	gullies; thin surface layer
	AfE2	fine sandy loam	5 to 12	very slow	slow to rapid	severe	low to high	low to high	moderate	gullies
Axtell-Tabor complex	AtD	gravelly sandy loam	1 to 8			slight	low to high	low to high	moderate	gullies in some steep areas
Crockett	CsC2	loam	2 to 5	very slow	slow to rapid	severe	low to high	moderate to high	low	gullies common
	CsD3	fine sandy loam	3 to 8	very slow	slow to rapid	severe	low to high	moderate to high	low	gullies
	CsE2	loam	5 to 10	very slow	slow to rapid	severe	low to high	moderate to high	low	gullies common
Ferris	FeF2	clay	5 to 20	very slow	rapid	severe	very high	high	low	gullies common; thin surface layer
Mabank	MaA	loam	0 to 1	very slow	very slow to medium	slight	low	moderate	moderate	
	MaB	loam	1 to 3	very slow	very slow to medium	moderate	low	moderate	moderate	
Tabor	TfA	fine sandy loam	0 to 1	very slow	slow to medium	slight	low	low	moderate	
	TfB	fine sandy loam	1 to 3	very slow	slow to medium	moderate	low	low	moderate	
Wilson	WsA	clay loam	0 to 1	very slow	very slow to medium	slight	low to high	high to very high	moderate to low	
	WsB	clay loam	1 to 3			slight	low to high	high to very high	moderate to low	
Sayers-Gowen-Uhland Group:										
Sayers	Sa	fine sandy loam	< 1	rapid	slow	slight	low	low	low	subject to flooding
Gowen	Gs	clay loam	< 0.5	moderate	slow to medium	slight	moderate	moderate	low	subject to flooding
Uhland	Uh	clay loam	< 1	moderately slow	slow	slight	moderate to low	high to moderate	low	subject to flooding

developed on sandy parts of the Calvert Bluff Formation, and locally on alluvium derived from the Calvert Bluff (on the south branch of McLaughlin Creek, for example). The Patilo-Demona-Silstid soils are especially widespread on the northern half of the base, probably because that area lies downslope from the outcrop belt of the Simsboro Formation, which is dominantly sand and covered almost exclusively by Patilo soils; it is reasonable to assume that much of the sand in soils in the northern half of the base was shed from the Simsboro outcrop belt and moved downslope by sheet wash. The various isolated small and large patches of Patilo-Demona-Silstid soils on the southern half of the base probably reflect sandy zones within the underlying Calvert Bluff Formation.

Erosion hazard of Patilo-Demona-Silstid soils is slight to moderate. Shrink-swell potential varies from very low in the sandy soils to moderate in the clayey soils. Corrosivity to uncoated steel varies from low in sandy soils to high in clayey soils; corrosivity to concrete is generally moderate.

Axtell-Tabor-Crockett Group

Soils included in the Axtell-Tabor-Crockett group occur mostly in the southern half of the Camp Swift area, and in several large areas in the extreme northern parts of the property. Small areas of Ferris, Mabank, and Wilson soils are also included. Soils in this group typically have a loamy surface layer and clayey lower layers that are very slowly permeable (Baker, 1979, p. 3–4). Axtell-Tabor-Crockett soils are developed on clayey strata within the Calvert Bluff Formation.

Erosion potential for soils in the Axtell-Tabor-Crockett group varies from moderate in intact areas to severe on steep slopes and on surfaces where vegetation has been disturbed. Shrink-swell potential varies from low in the sandy soils to high in the clayey soils. Corrosivity to uncoated steel is low in sandy soils to high in clayey soils; corrosivity to concrete is generally classed as moderate.

Sayers-Gowen-Uhland Group

Soils included in the Sayers-Gowen-Uhland are found on floodplains on bottomlands. These soils typically consist of clay loam to fine sandy loam; Sayers and Gowen soils are moderately to highly permeable, whereas Uhland soils have relatively low permeability (Baker, 1979, p. 16, 23, 28). Uhland soils are typically developed in lowest, nearly level parts of floodplains, whereas Gowen and Sayers soils are found higher on the floodplains where slopes are slightly greater.

Erosion potential for soils in the Sayers-Gowen-Uhland group is slight. Shrink-swell potential varies from low to moderate in proportion to clay content. Corrosivity to uncoated steel is low to moderate and locally high in Uhland soils; corrosivity to concrete is low.

Controls on Distribution of Soil Types

The distribution of soils is controlled mainly by the compositions of the underlying geologic units, modified by the effects of topography and drainage patterns. The relative amounts of sand and clay in a soil mostly reflect the distribution of grain sizes in the underlying strata but also reflect the ongoing process of soil erosion, in which the finest particles are preferentially dislodged by raindrops and carried away in the runoff, particularly on well-drained surfaces. In addition, the process of slope wash may cause a soil to extend downslope beyond the subcrop of the bedrock normally associated with that soil type; an example of this was previously noted where Patilo-Demona-Silstid soils extend far downslope from the outcrop belt of the Simsboro Formation.

VEGETATION

Camp Swift and most of Bastrop County lie within the Post Oak Belt (fig. 1), an ecological region that extends north-northeastward from Wilson and Karnes Counties in South Texas to

Fannin, Lamar, Red River, and Bowie Counties in northeast Texas. The region as a whole is characterized by interfingering of forest associations extending from areas of moisture surplus in the east and grassland associations extending from areas of moisture deficiency in the west, and thus represents an "ecotone," or transitional region (Blair, 1950, p. 100). The distribution of vegetation types is controlled principally by soil composition and climate, and secondarily by topography. Sandy soils tend to support oak-hickory forest, the dominant species being post oak, blackjack, and hickory, whereas clay soils originally supported tall-grass prairie but are now generally under cultivation. (This was the case described by Blair [1950, p. 100] for the Blackland Prairie to the west [fig. 1], but is probably also applicable to areas of clay soil in the Post Oak Belt.)

Historical accounts of different areas in the Post Oak Belt described a grassland with scattered large trees (mostly post oak) (Holm, 1975, p. 5). Some ecologists believe the oaks are relics of a more extensive forest from a moister climate that are able to maintain themselves by favorable moisture-holding characteristics of the sandy soils. Agricultural use since the mid-1800's has promoted the growth of the post oak forest (Holm, 1975, p. 5). Much of the land in the Post Oak Belt was cleared for natural and improved pasture and for some cultivated crops; much of the wooded area has been grazed by cattle, and present vegetation shows signs of disturbance. Conversion of grassland to dense woodland also resulted from the absence of fire.

Grassy areas of several types are present on Camp Swift. Large open areas present throughout the base were cleared for agricultural use prior to establishment of the base; several were cleared later or kept clear for military use. Small, isolated patches are common within wooded areas in the northern half of the base; these may represent natural grassland. Many of the open areas on clay soils in the southern half of the base may also be natural grasslands.

Camp Swift contains a number of densely wooded areas, particularly on sandy soils in the northern half. These woods existed prior to the establishment of the base in 1942, but they may have become so dense within only the previous 50 or 100 years due to grazing and absence of fire. The Camp Swift area is somewhat unique compared to surrounding areas of the

Post Oak Belt because agricultural use (with the possible exception of grazing) was stopped at the time that the base was established, and natural vegetation has recovered to some extent. The persistence and indeed expansion (back into clearings) of wooded areas (see fig. 16) on the base may be due to continued control of fires. Fires that have burned on the base have mostly been accidental or lightning-caused, locally destroying trees and favoring expansion of grasses and herbaceous species. Exceptions include a few clear areas (for example, Blackwell Drop zone) that have been burned-off periodically to keep them free of trees and shrubs.

Areas that were cleared in the past for pasture or for cultivation of crops are still readily apparent on the present-day Camp Swift property. Some remnants of fences, farm roads, structures, cisterns and other watering places, equipment, and possibly even cultivated trees and vines can be found in these areas. Many of these old clear areas show signs of erosion, ranging from subtle thinning of the soil profile to extreme gullying (see fig. 16). With the exception of a few special-use training areas, most of the cleared areas are being recolonized by various mixtures of vines, shrubs and trees (especially in sandy areas). In some cases it appears that gullies have locally promoted the growth of pine trees, possibly because of enhanced drainage in these areas of increased topographic relief. This was especially noticed in the case of present-day pine tree groves, which did not exist at the time of the 1953 aerial photographs, and consisted of only a few trees in the 1975 aerial photographs (see fig. 16). The lack of pines in the early aerial photographs suggests that they were selectively removed by earlier inhabitants for timber and other uses.

Three different associations of woody plant species in the Post Oak Belt were described by Holm (1975, p. 7–12)—upland, ephemeral stream, and bottomland. All three settings are present on the Camp Swift property.

Upland areas have relatively dry soils with textures ranging from fine sands to fine sandy clay loams. Dominant overstory species are post oak and blackjack oak, with scattered hickory. Understory species and shrubs appear in various numbers and density. Very sandy uplands in some places have little or no undergrowth of shrubby species, and the density of the overstory oaks is relatively high. The floor of these wooded sites is covered with herbaceous species and grasses. More typical areas have an open to dense second story and shrub cover. Woody vines are an important component in the wooded areas, typically forming dense thickets.

Ephemeral stream vegetation is similar to the upland association, with species composition changing gradationally from the upland areas. Vegetational composition is dependent on moisture availability throughout year and soil characteristics. Vegetation in many intermittent streams during dry periods is essentially the same as in upland areas. Streams which contain water most of the year and which have small floodplains with sandy clay loam soils exhibit vegetation characteristics similar to bottomland areas. Vegetation along and near these streams is dense, lush, and diverse in its natural state.

Bottomland-type vegetation is found in floodplains of major streams and rivers and is very similar to that found along intermittent streams that flow through much of the year. However, bottomlands are different from ephemeral streams in that soils are typically clay loams or silty clay loams developed over alluvial sediments, and commonly are less acidic than upland sandy soils. Bottoms are periodically flooded, moisture is generally available in the surface soils, and the water table is commonly shallow throughout the year. Vines occupy a prominent niche in the understory community and commonly form dense, nearly impenetrable thickets. Undisturbed natural communities are uncommon in the bottomlands of the Post Oak Belt because the fertile soil is desirable and used for row crops and pastureland.

GROUND-WATER HYDROLOGY

Ground water is the principal source of water for domestic and other uses in this region. The main well fields and individual wells that supply the communities and industries in the Camp Swift area are shown in figure 12. An environmental management plan for the Camp Swift training site must call attention to this fact and outline the precautions necessary to protect the ground water.

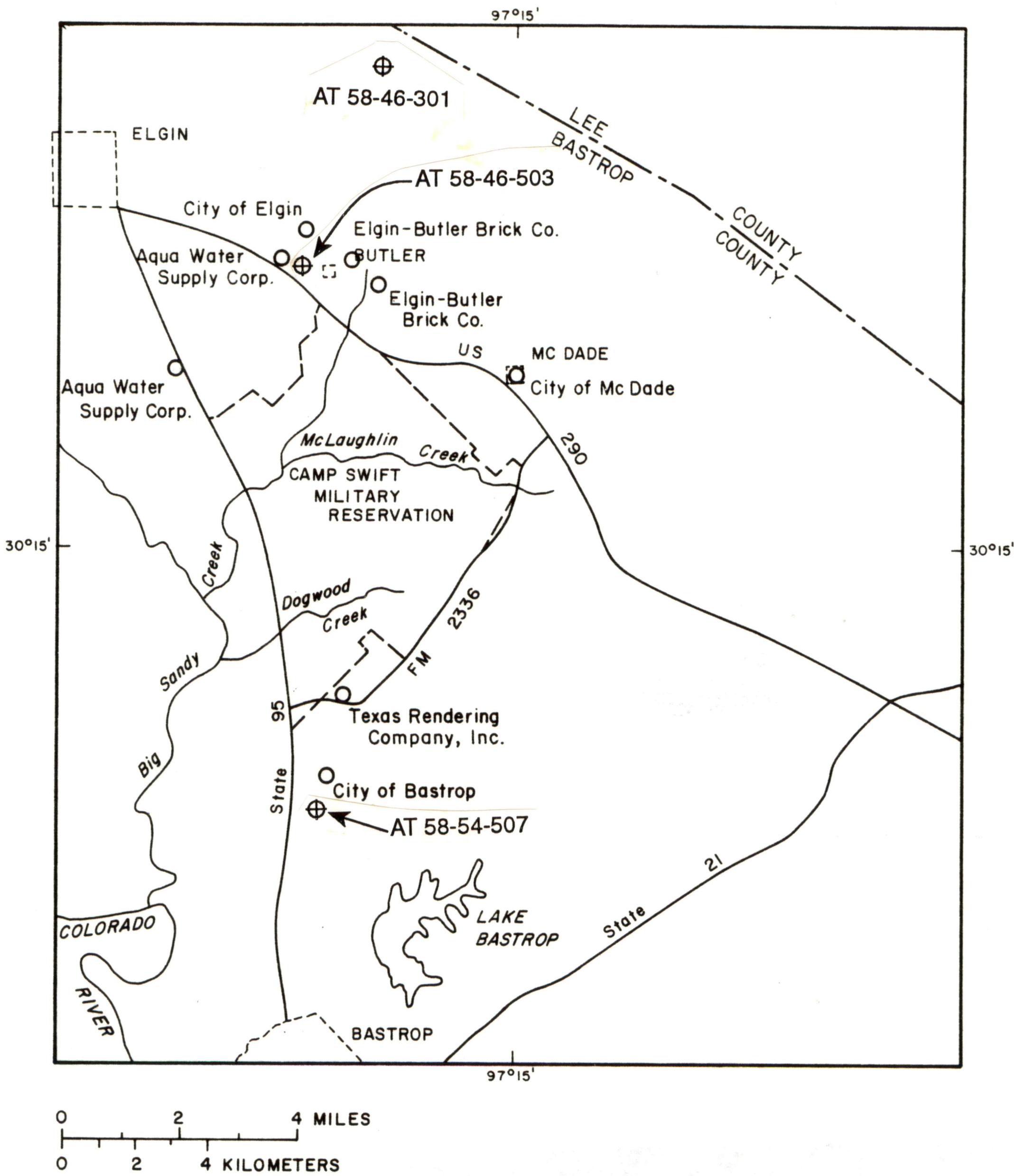

Figure 12. Principal ground-water withdrawal areas in the vicinity of Camp Swift. Most of the wells or well fields shown here pump from the Simsboro aquifer. Locations of three wells selected to illustrate historical changes in water levels (fig. 15) are indicated by circles with a cross. From Gaylord and others (1985, fig. 3.0-1).

There are no producing water wells on the present Camp Swift property. Wells that supplied the original Camp Swift are located about 1 mi south of the base in what is now the well field for the Bastrop municipal water supply (fig. 12). Several wells were drilled on the present Camp Swift property for aquifer tests and sampling purposes by the U.S. Geological Survey in 1980 (USBLM, 1980b, appendix 3; Gaylord and others, 1985, p. 56–59, 66–68); many more holes drilled on the base for lignite exploration were used to measure water levels (Gaylord and others, 1985, table 10.1). It is unknown whether these wells still exist or whether they were plugged and abandoned. A number of shallow hand-dug wells or cisterns are present on the Camp Swift property (Captain James Junot, Camp Swift, personal communication, 1993); some of these probably have been noted in earlier archeological surveys. It is possible that other abandoned domestic wells are also present on the property. An apparent well of recent vintage (employing plastic piping and fitted with a disconnected electrical box) was noted during field surveys in the northwestern part of Area III-A (see plate 1). The origin and purpose of this well are unknown.

Ground-water information presented here was extracted from published and unpublished reports and from records of the Texas Water Development Board (TWDB). No new measurements were made during the present investigation, but hydrologic data collection may be recommended at specific sites related to Camp Swift training as part of future environmental monitoring plans.

Hydrogeologic Units

Important hydrogeologic units in north-central Bastrop County are, in ascending order, the Hooper Formation, the Simsboro Formation, the Calvert Bluff Formation, and the Carrizo Sand (fig. 13); they are commonly referred to collectively as the Carrizo-Wilcox aquifer. They consist of a series of dominantly sand aquifers intercalated with dominantly shale aquitards. The regional dip of these strata varies between about 90 and 170 ft/mi and averages about 120 to

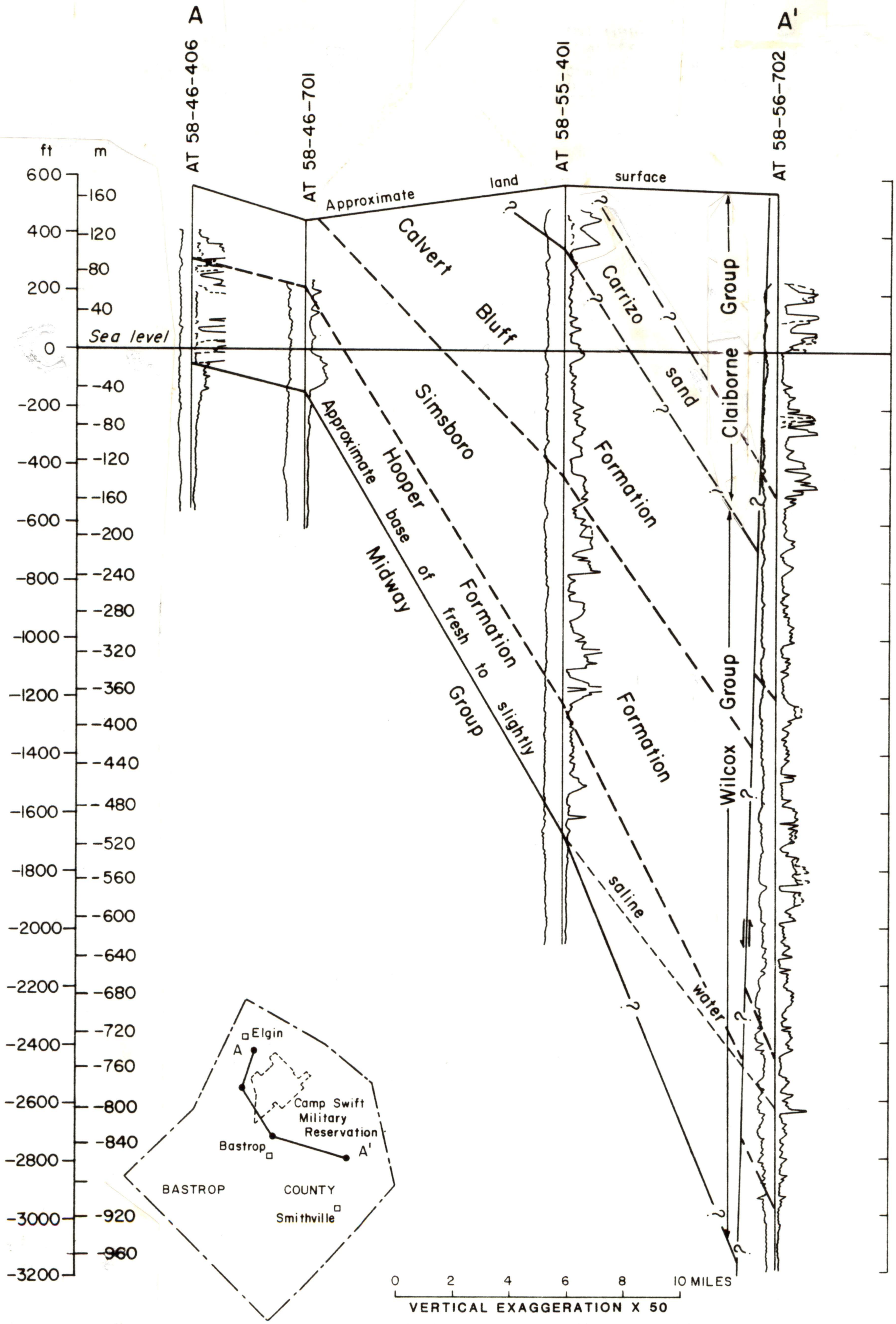

Figure 13. Schematic hydrogeologic cross section through the Camp Swift area. Ground-water flow is generally downdip and toward the south-southeast. Lines beside control wells are SP log (left side) and resistivity log (right side) curves. Modified from Follett (1970, fig. 25).

130 ft/mi toward the southeast (fig. 13) (Follett, 1970; Hall, 1981; Gaylord and others, 1985, p. 22). The principal fresh-water aquifer for the area is the Simsboro Formation; ground water is also extracted from sands in the Hooper Formation (fig. 12) (Follett, 1970; Hall, 1981; SAI, 1982). The Carrizo Sand is also an important aquifer, but it does not extend as far northwestward as Camp Swift, and therefore will not be discussed further (see fig. 5).

Hooper Aquifer

The Hooper Formation is dominantly shale, with a few thin lignite seams, and local channel sands. The channel sands, up to several tens of feet thick, are permeable aquifers confined by impervious layers of the shale and lignite. Wells have been dug by hand in the Hooper outcrop area immediately north and west of Camp Swift, to reach the water table in these channel sands. The Hooper aquifer is used by at least one public water supply system (Aqua Water Supply Corp., northwest of Camp Swift, see fig. 12) (USBLM, 1980b, p. A3–11).

Simsboro Aquifer

The Simsboro Formation contains the principal fresh-water aquifer in north-central Bastrop County. Northwest of Camp Swift where the Simsboro crops out, the aquifer is unconfined and exhibits water-table conditions. A short distance southeastward from the outcrop, beneath Camp Swift, the aquifer is confined by less permeable beds at the base of the overlying Calvert Bluff Formation. In confined portions of the aquifer, the water has sufficient hydraulic head to rise above the top of the formation in wells that penetrate the aquifer (artesian conditions), unless drawn down by pumping (fig. 14). This can be observed in Simsboro wells that are cased through the Calvert Bluff Formation. Under natural conditions, however, or in a well that is not cased, the higher water-table elevation in the overlying Calvert Bluff Formation imposes a net downward gradient between the two formations, causing ground water to leak downward from the Calvert Bluff, effectively "capping" the Simsboro. In a

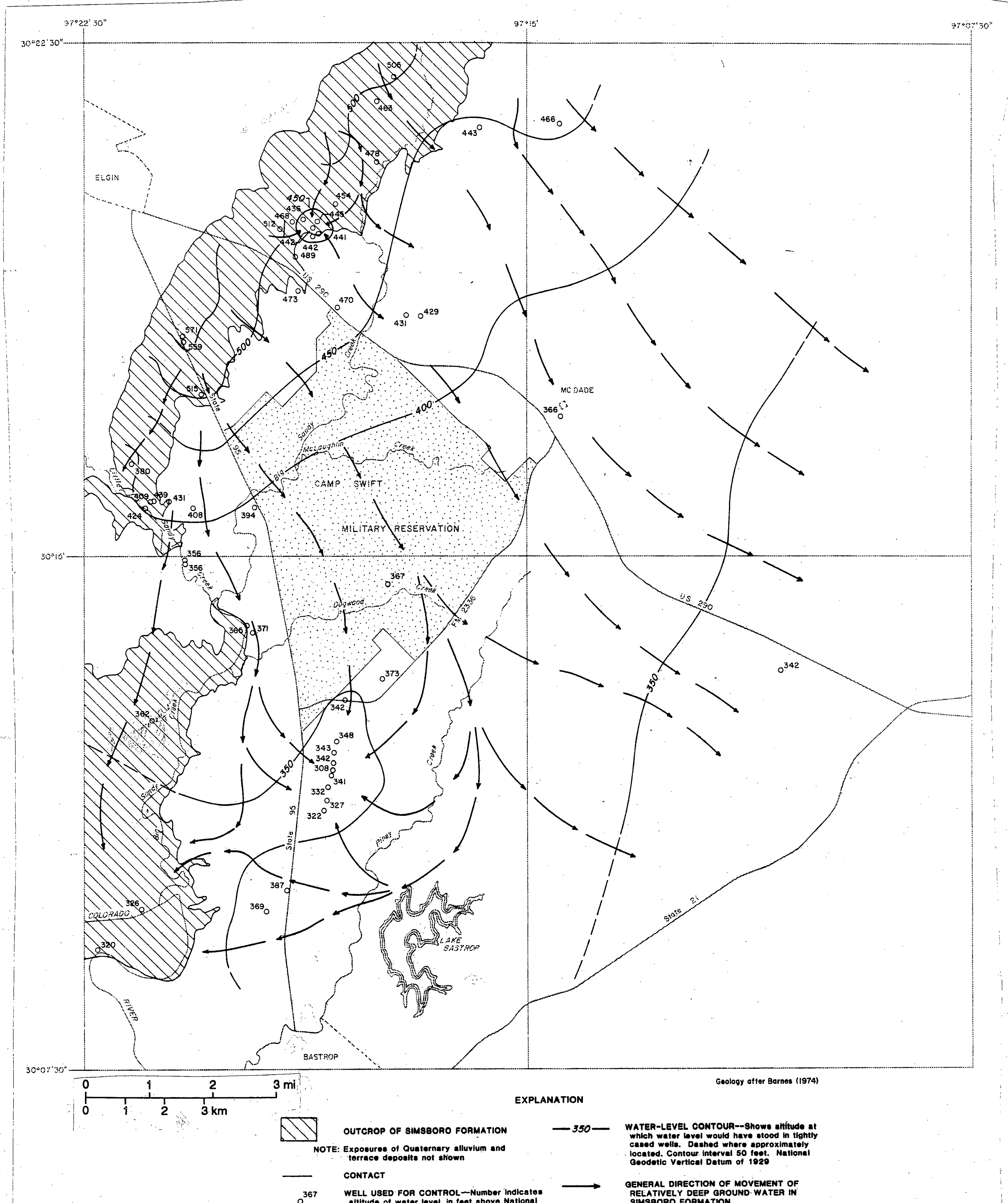

Figure 14. Altitude of water levels in wells completed in the Simsboro Formation. Ground-water flow is generally to the south and southeast; local cones of depression of the water surface are present around the well fields for the cities of Elgin and Bastrop (see fig. 12). From Gaylord and others (1985, fig. 6.1-3).

few areas, the Simsboro artesian water levels may actually be higher than the Calvert Bluff water table, allowing upward leakage from the Simsboro into the Calvert Bluff.

Water for use on the Camp Swift training site is readily available beneath the property in the Simsboro Formation and should be relatively inexpensive to produce. Transmissivity values reported for the Simsboro aquifer range from as low as 1,100 gallons/day/ft (gpd/ft) to as high as 84,000 gpd/ft (Guyton, 1942; Follett, 1970; USBLM, 1980b, appendix A3; Gaylord and others, 1985, p. 56–59). According to Hall (1981) representative transmissivities in the Simsboro aquifer are in the range of 20,000 to 30,000 gpd/ft, making it a highly productive aquifer. The aquifer has a high recharge efficiency that maintains water levels in response to local rainfall (fig. 15).

Calvert Bluff Aquifers

Ground water in the Calvert Bluff Formation exists under water-table conditions throughout the Camp Swift area (SAI, 1982, p. 7). The Calvert Bluff Formation is composed principally of siltstone- to claystone-shale, and contains some of the most economically important lignite beds of East and Central Texas. The Calvert Bluff Formation locally contains elongate, lenticular sand bodies that fill ancient channels (Bond and McAndrews, 1986, p. 5–6). These channel sands locally attain a 70-ft thickness and can serve as minor aquifers. Several of these channel sands are exposed at the surface along the northeastern fringe of Camp Swift and require protection as recharge zones in future environmental planning. Transmissivity and storage properties of the channel sands are probably comparable to those of the Simsboro aquifer. These sands are of sufficient thickness and extent to serve as local aquifers, but they are generally passed over in favor of higher water quality and better yields from the underlying Simsboro aquifer (see table 4).

The shale and lignite beds of the Calvert Bluff Formation serve as an aquitard above the Simsboro aquifer and may also confine sand bodies within the Calvert Bluff. The shale and lignite horizons at the base of the Calvert Bluff Formation are locally discontinuous; in these

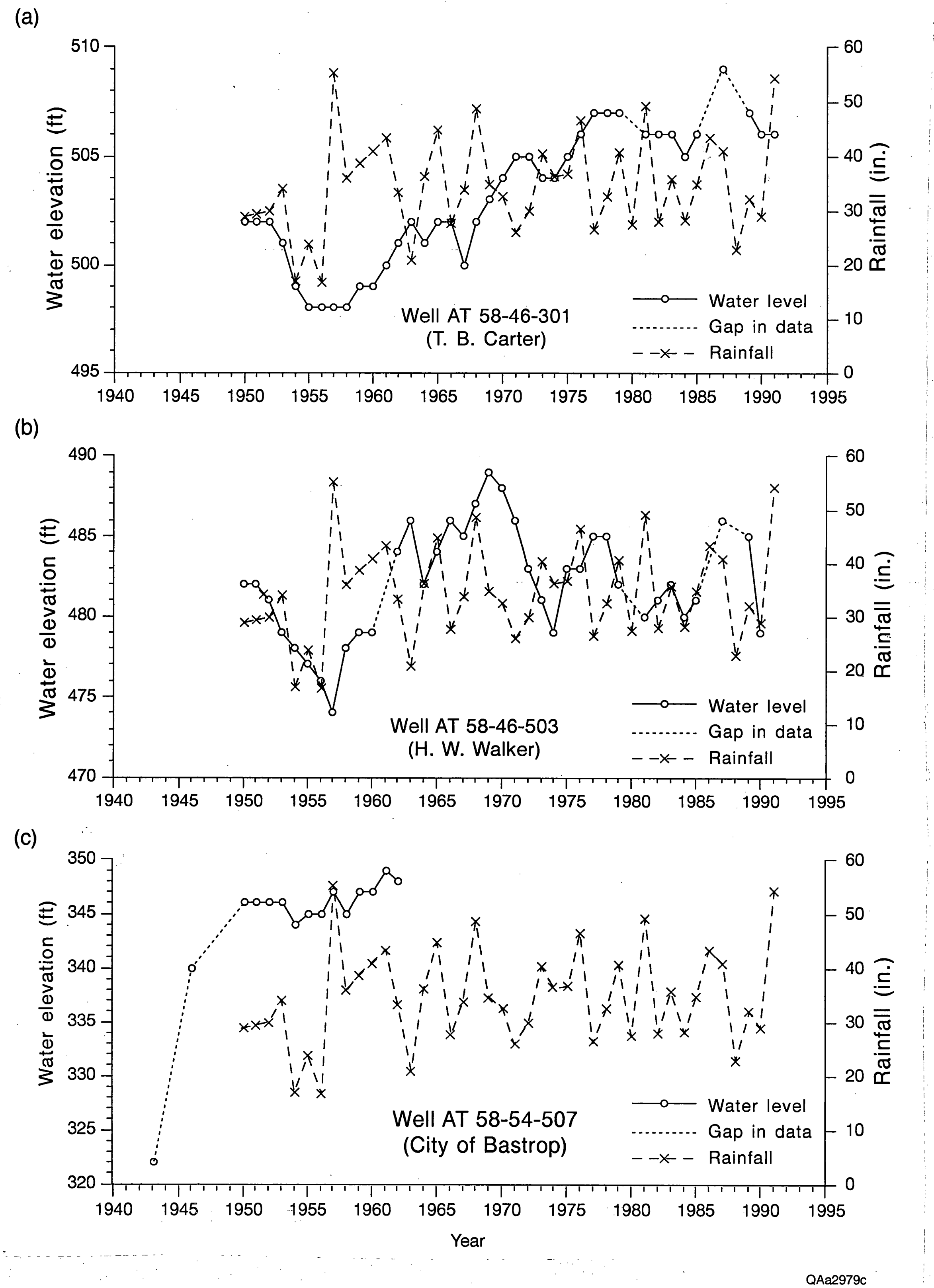

Figure 15. Historical water-level changes in selected wells completed in the Simsboro Formation. Water-level changes show a correlation with variations in annual precipitation, with a lag time of about 1 to 2 yr. Gaps in lines connecting water-level measurements indicate missing data for 1 or more yr. Well locations are shown in figure 12; water-level data and source are listed in appendix C; rainfall data and source are given in appendix A.

Table 4. Variations in total dissolved solids (TDS), hardness, and pH of waters from principal hydrogeologic units in the Camp Swift area (data from Texas Water Development Board, 1992a).

Formation	Number of wells	TDS (mg/L)			Mean hardness as $CaCO_3$ (mg/L)	pH		
		High	Mean	Low		High	Mean	Low
Hooper	18	1411	543	246	237	8.8	7.8	6.8
Simsboro	38	1116	428	129	185	8.6	7.3	5.7
Calvert Bluff	23	2187	650	226	279	8.3	7.2	5.1

areas leakage of ground water from the Calvert Bluff into the Simsboro aquifer may be substantial.

Ground-Water Recharge, Flow, and Discharge

Ground-water recharge in the Camp Swift area occurs mostly by direct infiltration of precipitation on the outcrops of the Simsboro and Calvert Bluff Formations (Gaylord and others, 1985, p. 50). Follett (1970) estimated that about 1.5 inches of precipitation per year is available for recharge; a water budget calculated by Hall (1981), indicated that during an average year, 80 to 85 percent of precipitation is lost to evapotranspiration and 10 percent to surface runoff, leaving 5 to 10 percent available for recharge below the root zone.

Depth to the Calvert Bluff water table beneath most parts of Camp Swift is about 50 ft (Gaylord and others, 1985, fig. 6.1-2). Near the surface where topography is the principal control, ground water flows through the unconfined portion of the aquifers in a pattern reflecting topography and surface drainage. Ground water at greater depths in the Calvert Bluff Formation and in the confined portion of the Simsboro generally flows downdip toward the south and southeast in the direction of the Colorado River (figs. 13 and 14). Ground-water flow is discussed in detail by SAI (1982, p. 8–11). Regional ground-water flow in the Wilcox Group is examined from a hydrochemical perspective by Macpherson (1986).

Discharge of shallow ground water occurs naturally through seeps and springs within the outcrop belts and by transpiration in areas with a shallow water table; discharge of deeper ground water occurs by leakage through semipermeable beds or along faults into other aquifers that have lower hydraulic head (SAI, 1982, p. 7; Gaylord and others, 1985, p. 50–54). Discharge also occurs artificially by pumped withdrawal through water-supply wells.

Water-level records were examined for three wells in the Camp Swift area to characterize historical water-level changes in the Simsboro aquifer (fig. 15) (TWDB, 1992c). Changes in the water levels show a strong correlation to variations in annual precipitation, with a lag time of about 1 to 2 yr. Relatively dry years are followed by decreases in ground-water levels, whereas relatively wet years are followed by increases in ground-water levels (fig. 15).

Hydrogeochemistry

The Wilcox hydrogeochemistry in Bastrop County, based on standard cation-anion chemical analyses of the Hooper, Simsboro, and Calvert Bluff waters (TWDB, 1992a), is characteristic of Wilcox ground-water chemistry in East Texas as described by Kreitler and Fogg (1980). The waters at the surface are relatively immature, oxidizing, acidic to neutral, and dominated by calcium-magnesium bicarbonate. Neither silica nor sulfate is as high as reported by Kreitler and Fogg (1980), and chloride is relatively low.

There are distinctive differences in the ground-water chemistry of the Hooper, Simsboro, and Calvert Bluff hydrologic units, although there is considerable range among high and low values of any single property within each unit (table 4). For example, measurements of total dissolved solids (TDS) and pH range widely in each hydrologic unit (table 4). The mean TDS is clearly different among waters in the Hooper, Simsboro, and Calvert Bluff units. Waters in the Calvert Bluff Formation have high TDS, including iron, calcium, sodium, and chloride (Bond and McAndrews, 1986, p. 6), and are generally passed over in favor of higher quality water in the underlying Simsboro Formation. Water in the Hooper generally has a higher pH than Simsboro and Calvert Bluff waters. Water in the Hooper Formation is generally a calcium bicarbonate type, water in the Simsboro Formation varies from calcium bicarbonate to sodium chloride type, and water in the Calvert Bluff Formation varies from mixed sodium calcium bicarbonate type to a mixed sulfate type in which there is no dominant cation (Gaylord and others, 1985, p. 66–68). The average hardness for the Hooper, Simsboro, and Calvert Bluff waters is 237, 185, and 279 mg/L, respectively (table 4). Waters with hardness values greater than 180 mg/L are designated as very hard. Typical sources and significance of selected constituents and properties commonly reported in water analyses are detailed in Hem (1985) and summarized in Gaylord and others (1985, table 10.7).

Examination of the cation-anion balances reveals that the units with higher clay contents (Hooper Formation, Calvert Bluff Formation) also have higher concentrations of calcium and sodium. This is especially true of the Calvert Bluff Formation. The mean hardnesses of the more clay-rich units are also greater than that of the Simsboro.

Detailed analyses of water samples from 13 wells in Camp Swift and surrounding areas are reported in Gaylord and others (1985, table 7.3-1).

ENVIRONMENTAL IMPACTS AT CAMP SWIFT

Observations made in the field and comparisons among aerial photographs of 1938 to 1991 vintage suggest that training uses are less damaging to the physical environment of Camp Swift than past agricultural uses. Most of the erosional gullies already existed at the time that the 1938 aerial photographs were taken, although they have continued to enlarge, some doubling in size since 1938. The various types of impacts observed on Camp Swift are discussed below.

Clearings

Areas that were cleared for agricultural use prior to establishment of Camp Swift are still readily apparent. Remnants of fences and possibly cultivated trees and vines were found. The effect of clearing, and in particular, of cultivation (tilling) and grazing has been to reduce overall density of vegetation and soil-holding capability. As a result, many of these old clear areas show signs of erosion, ranging from subtle thinning of the soil profile to extreme gullying, especially at breaks in slope. Most of the clearings are being recolonized by various mixtures of vines, shrubs and trees (especially in sandy areas). In some cases it appears that gullies have locally promoted the growth of pine trees, possibly because of enhanced drainage due to increased topographic relief (fig. 16). Most of the trees in the present-day pine groves did not

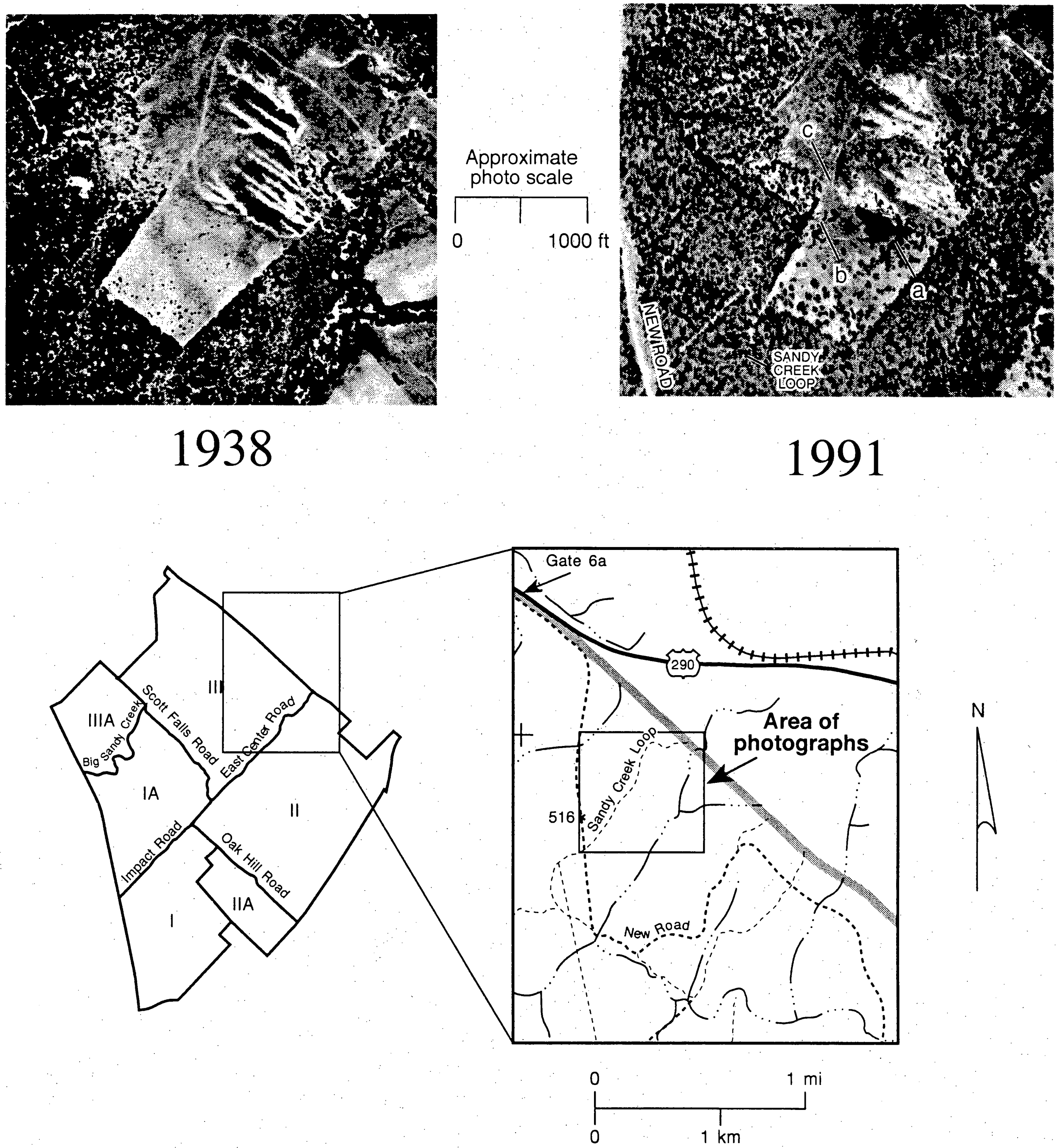

Figure 16. Changes in gullies and vegetation in east-central part of Training Area III, 1938-1991. Aerial photograph from 1938 shows severe gully erosion and cleared land with few trees. By 1991, much of the cleared area had been invaded by trees, and gullies had lengthed and widened, nearly doubling in area. Oak trees in surrounding woods are in full foliage and appear dark in 1938 photograph; oak trees are not prominent in 1991 photograph (taken March 5) because leaves are just emerging. Labeled features in 1991 photograph: (a) pine tree grove (most of the trees were absent from 1975 aerial photograph), (b) large gully in wooded area to west has reached Sandy Creek Loop, producing a dangerous 4- to 6-ft vertical drop immediately adjacent to roadway, (c) gully in clearing has nearly reached Sandy Creek Loop.

exist at the time of the 1953 aerial photographs, and only a few of the trees are present in the 1975 aerial photographs. The recolonization of old cleared areas may be due to continued control of fires. Exceptions include a few clear areas (for example, Blackwell Drop zone) that have been burned off periodically to keep them free of trees and shrubs.

Small, isolated, clear patches are common within wooded areas in the northern half of the base; these may represent natural grassland. Many of the open areas on clay soils in the southern half of the base may also be natural grasslands.

Roads and Vehicle Tracks

The present road network at Camp Swift includes roads that have been constructed relatively recently (New Road, for example), roads that have been improved from prior county roads (Scott Falls Road, Center Road, Oak Hill Road), old farm roads (Wine Cellar Road, Upper Cut Road, Lower Cut Road, and others), and roads that were added during construction of the military base in 1942 (Range Road, for example). Many of the jeep trails existed as farm roads before establishment of the base. Remnants of many more farm roads and trails were found throughout the base. Most are abandoned and overgrown. The roads and adjacent "bar ditches" channel runoff during storms, and are particularly susceptible to erosion because of the weakly consolidated nature of the exposed bedrock, and the lack of vegetation or artificial protective layer. Gullying is most severe along abandoned roads, which are not maintained, especially where they cross slopes.

Vehicle tracks from training exercises are common in some areas. These ruts will channel runoff and may become sites of accelerated erosion, depending on frequency of use, timing with respect to rainy seasons and growing seasons, and degree of slope. Most of the tracked areas observed appeared to be in good shape, because they are on gentle slopes and mostly overgrown by grasses and herbaceous plants.

A common problem to all of the roads, except those on the sandiest materials, is that they become very soft and easily rutted when wet. These ruts will channel runoff and increase erosion potential if the roads are not regraded.

Pits

There are a number of excavated pits scattered across Camp Swift. Several are shown in plates 1 and 2 of this report. The original purpose of some of some of the pits may have been to mine lignite; others were apparently quarried for sand or clay. Erosion is occurring around the edges of the pits to varying degrees. Some are internally drained, whereas others have outlets. Past erosion and potential for future erosion is most severe in those that are externally drained.

Gullies and Other Erosional Features

Severe gully erosion has occurred at the fringes of many of the cleared upland areas. In some cases the gullies have extended well into the clearings (fig. 16). Comparison of recent and older aerial photographs reveals that most of the gullies existed prior to 1938 and have as much as doubled in size since that time. Vegetation in most of the cleared areas appears to be returning. Many of the gulleys, however, are so strongly developed that active efforts will be needed to prevent or slow their advance. Sediment from these gullies is being deposited in adjacent streambeds. In most cases the deposited sediment appears to be stabilized by the bottomland vegetation.

Most of the tributary streams on Camp Swift have morphologies that indicate active downcutting and headward erosion into adjacent uplands. This may be in part due to the natural erosion process, but it has probably been accelerated by land clearing and increased runoff. Overall, the most severe erosion has occurred in areas underlain by fine-grained, poorly permeable strata such as claystone and clayey siltstone or clayey sandstone.

Lignite Exploration Boreholes

More than 70 holes were drilled on Camp Swift as part of the lignite exploration program in the 1970's. These holes should have been plugged according to environmental regulations. The holes may have been completely filled by cement, or individual plugs may have been set at certain depths, with remaining parts of the boreholes filled by liquids or sediment or simply allowed to cave. The exact plugging procedure used was not researched during this investigation. Records of these holes, and their plugging and abandonment should be on file at the Railroad Commission of Texas. It is possible that some of these holes were not properly plugged, or could not be properly plugged because of caving problems, or that proper plugs have since failed. Improperly plugged holes pose several environmental hazards—they can act as pathways for contaminants to enter the deep ground-water system, or they may cause depressions to form at the surface as material sloughs into open portions of the borehole. One small collapse depression near the top of a hill on the west side of New Road near Gate 6a (Area III) was pointed out by the Camp Swift Commander (Captain James Junot, personal communication, 1993). This depression is very near, or possibly directly above, one of the lignite exploration holes (see Bechtel, 1974; TRDC, 1979; and Gaylord and others, 1985, for approximate locations of drill holes).

Maintenance Facilities, Equipment, Disposal Sites, and Debris

Most of the original Camp Swift facilities that handled solvents, grease, fuels, and other hazardous materials, including artillery degreasing shops and equipment repair shops, were located south of FM 2336 on land that is not part of the present Camp Swift property. It is likely that some maintenance, cleaning, and fueling occurred on the present property as well. The present investigation did not find signs of surface contamination by liquids, with the exception of a few fuel-soaked spots in the clearing on the northeast side of the airstrip, and small drip spots around the Camp headquarters. However, there was not enough time during the present study to examine all areas thoroughly.

Small amounts of equipment and debris from earlier agricultural activities are scattered throughout the base. These include at least one automobile, several trailers, and miscellaneous iron and steel parts. There are also a number of dump sites, including recently constructed containers for holding trash generated during training activities, as well as piles of trash, lumber, and miscellaneous debris at various sites. Trash and debris, including old appliances, mattress springs, cans, and branches have been dumped in several gullies, possibly in an effort to halt erosion. Some of the items, such as appliances, may release hazardous materials into the environment as they corrode.

Shell casing, bullets, and shrapnel are present in a number of places. A small accumulation of spent hand-grenade fuses was noted alongside Center Road in the Demolition Area. Some of these items could release hazardous materials when corroding.

Numerous other features dot the Camp Swift landscape, including remnants of structures, cisterns, reservoirs, and abandoned equipment. These probably have not caused significant environmental impact.

Ground-Water Contamination

The standard analyses (TWDB, 1992a) and the special constituent analyses (TWDB, 1992b) of Bastrop County ground waters did not suggest water-quality impacts by activities at Camp Swift. There also is no evidence of increased concentrations of elements that may be present in munitions (lead, for example), nor is there any evidence of fuels or solvents having entered the ground water. Detailed analyses of samples from 13 wells in Camp Swift and surrounding areas indicated that concentrations of most constituents, including analyzed trace elements and organic compounds (chiefly pesticides), are within U.S. Environmental Protection Agency secondary standards (Gaylord and others, 1985, p. 66–68, table 7.3-1). Concentrations of dissolved iron and manganese in several samples exceeded the secondary standards. Bacteriological analyses indicated fecal contamination in some areas, which was thought to result from infiltration of wastes into poorly cased dug wells or from incomplete development of recently drilled wells.

CONSIDERATIONS FOR CAMP SWIFT LAND-MANAGEMENT PLAN

A practical land-management plan for Camp Swift will optimize land use for training and address the practicalities and legal requirements for land conservation. Such a plan must consider training demands and then delineate areas for various activities and conditions under which those activities can be conducted. One of the outcomes of a land-management plan will be restrictions on the use of some areas of the base.

Potential for Future Environmental Impact

The ongoing and most likely future impacts to Camp Swift are surface disturbance and continuing erosion. Different areas of Camp Swift can tolerate various amounts of land use before environmental degradation occurs. In some areas the destruction thresholds may be very low (for example, slopes underlain by low-permeability soils); in other areas the thresholds may be relatively high (horizontal or gently sloping surfaces underlain by permeable soils). Thus, carrying capacity of the various tracts of land should be considered.

Surface Disturbance and Erosion

The potential for surface disturbance is a function of soil strength, which in turn depends on soil texture and saturation (wetness). Areas underlain by fine-grained, clayey strata typically have relatively impermeable soils (mainly Axtell-Tabor-Crockett group) that remain saturated and soft throughout the wetter parts of the year. Under these conditions the surface is weak and easily disturbed by vehicle traffic. Areas underlain by coarser grained sandy strata have more permeable soils (mainly Patilo-Demona-Silstid group) that are stronger when wet. However, experience in the field showed that these soils are also weak in places and easily rutted under the weight of a vehicle. The potential for erosion is greatest during wet seasons, and rainfall, runoff, and density of vegetation are major factors. A major rainfall event at any time can render an area unsuitable for use.

Very sandy soils that occur on some parts of the base may be soft, noncohesive, and susceptible to erosion by wind. The greatest potential for wind erosion is probably during the winter when protective vegetation is likely to be minimal. This may be offset by relatively high soil-moisture content that would tend to increase cohesion and resistance to erosion. High wind erosion potential exists during late summer, when rainfall and soil moisture are at a minimum and evaporation is at a maximum; however, this may be offset by denser protective vegetation at that time.

Vegetative cover is a key factor in landscape stability. A healthy stand of vegetation will armor the soil against the direct impact of raindrops; roots help hold the soil in place. Training activities should be rotated through different areas and scheduled to optimize recovery of vegetation.

Erosion and headward extension of gullies will continue to be a problem in areas where gullies already exist. New gullies may form in areas of excessive runoff, especially if surfaces are not protected by vegetation.

Ground-Water Contamination

On the basis of the camp location and the surface drainage pattern, the Simsboro, Calvert Buff, and Carrizo aquifers could be affected by Camp Swift activities. The recharge area for the Simsboro aquifer is entirely outside of the boundary of the base. Contamination of the Simsboro by materials from Camp Swift would occur if (1) contaminants are carried off the base in surface waters and transported to recharge areas downstream, (2) contaminants drain or are washed into boreholes penetrating the Simsboro aquifer, or (3) contaminants infiltrate Calvert Bluff aquifers and eventually leak downward into the Simsboro (a process that would probably take hundreds or thousands of years). Contamination of Calvert Bluff aquifers is possible as the unit directly underlies Camp Swift (beneath the soil's veneer). Ground-water recharge rates through active or abandoned pits, especially those that are internally drained, may be several times those of undisturbed areas. The Camp Swift land-management plan should assume that potential for ground-water contamination is enhanced in these pits. Hazardous materials should not be stored, allowed to collect, or discarded in these locations. Potential for contamination of the Carrizo aquifer is minimal, as only very small areas along the southeastern edge of the base drain toward the recharge zone (outcrop) of the Carrizo Sand.

Perhaps the biggest unknown factor is the plugging status of the lignite exploration boreholes. All of these holes should have been plugged in accordance with regulations to protect the ground water. However, if plugs have failed, or if some holes could not be properly plugged, then those holes are possible direct pathways for contaminants to enter the main sands in the Calvert Bluff and Simsboro aquifers.

Precautions and Possible Limitations to Land Use

The main limitations to land use at Camp Swift are soil strength and erosion potential. Activities should be coordinated with climate. Areas underlain by clayey soils will need to be kept off limits when the soils are saturated, to minimize rutting and other damage to the topsoil and stabilizing vegetation. Very sandy soils may need to be avoided, or kept moistened during dry seasons to prevent wind erosion. Disturbance of slopes should be kept to a minimum, especially slopes that drain from cleared uplands. Disturbance of vegetation should be coordinated with growing seasons of species present, or certain species promoted, to maximize recovery of protective vegetation.

Creek crossings and floodplains will continue to be a problem for Camp roadways during large floods associated with heavy rainfalls. Contingency plans must be in place to ensure that scheduled military exercises can proceed when problem spots become impassable. Available stream gauge records and past experience with Camp Swift streams will help to determine frequencies and volumes of discharges that cause problem floods. This information can be used to determine the optimum engineering solutions.

Activities involving transfer of fuels, or other hazardous materials (effluent from wash racks, for example) should avoid sandy areas of the Calvert Bluff Formation as these are principal recharge areas for Calvert Bluff aquifers. Hazardous materials should not be stored, allowed to collect, or discarded in active or abandoned pits, unless special safeguards are provided, as these may be sites of enhanced ground-water recharge.

Suggestions for Research, Monitoring, and Remediation

It may well be worth the effort to research the records for lignite exploration holes (and any other holes) drilled on the Camp Swift property to confirm their locations and plugging status. In addition, lithologic and water-quality data gained from these exploratory holes may be used to delineate sandy, potential recharge areas in the Calvert Bluff Formation in the subsurface, and beneath the soil veneer.

At some time, a complete catalog of all gullies, pits, and other disturbed areas should be compiled. The catalog should include present sizes, and where possible, historical evidence from old aerial photographs to indicate vintages and rates of growth. Similarly, it will be useful to record the locations of particular problem areas, where soils remain wet for long periods or where they are particularly vulnerable under various conditions.

Land-management policy should include plans to monitor existing disturbed areas and to note rates of soil erosion and gully enlargement. Several representative gullies in each area of the base should be selected, and reference stakes installed by which to measure advancement of erosional escarpments.

Periodic monitoring of water quality (including chemistry and suspended sediment) of streams flowing across the base should be considered. Several existing area wells or several new, strategically located wells should be selected for periodic sampling and water-quality determinations. These may be wells already monitored by the Texas Water Development Board, and should include species that may not ordinarily be analyzed (for example, lead, solvents, oils, and fuels).

Possible sources of contaminants on Camp Swift (for example, storage tanks, active or abandoned landfills, sewage disposal sites, and maintenance facilities) should be cataloged, assessed, and monitored. Some of the trash and debris, such as appliances dumped in gullies or other trash piles, should probably be picked up and disposed of properly. Bullets (lead, some with copper jackets) and shell casings (copper and zinc) are probably not causing contamination because these metals in their elemental forms are not very soluble in natural waters (Hem, 1985, p. 141–144). Hand-grenade fuse composition should be examined to determine if any hazardous elements or compounds are present.

The Camp Swift land-management plan will need to address existing eroded areas. Some engineering solutions to slow down or halt gully advancement, or capture sediment before it enters Big Sandy Creek, will probably be necessary.

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Appendix A. Average wind direction and speed at Robert Mueller Municipal Airport in Austin, Texas, 1961–1980.

DECEMBER - FEBRUARY

(Calm 5.5 percent of time; average direction and speed in January: S 10 mph [1])

DIRECTION	Estimated percentage [2] 1 - 12 mph	13 - 21 mph	Above 21 mph	Cumulative Percentage
N	5.9	7.7	1.3	14.9
NNE	4.9	4.1	0.3	9.3
NE	4.6	1.6	0.0	6.2
ENE	2.4	0.3	0.0	2.7
E	2.6	0.1	0.0	2.7
ESE	2.0	0.2	0.0	2.2
SE	3.1	0.3	0.0	3.4
SSE	4.5	0.8	0.0	5.3
S	13.2	4.5	0.0	17.7
SSW	5.3	2.3	0.1	7.7
SW	2.4	0.6	0.0	3.0
WSW	1.5	0.1	0.0	1.6
W	2.1	0.1	0.0	2.2
WNW	2.9	1.1	0.0	4.0
NW	3.3	1.3	0.2	4.8
NNW	3.1	2.6	0.7	6.4
Totals	63.8	27.7	2.6	94.1

MARCH - MAY

(Calm 3.1 percent of time; average direction and speed in April: SSE 11 mph [1])

DIRECTION	Estimated percentage [2] 1 - 12 mph	13 - 21 mph	Above 21 mph	Cumulative Percentage
N	3.5	3.5	0.7	7.7
NNE	3.4	2.6	0.1	6.2
NE	3.8	1.8	0.0	5.6
ENE	2.2	0.5	0.0	2.7
E	3.2	0.4	0.0	3.6
ESE	3.1	0.3	0.0	3.4
SE	6.0	1.5	0.0	7.5
SSE	9.8	4.7	0.0	14.5
S	15.8	10.1	0.0	25.9
SSW	4.2	2.3	0.0	6.5
SW	1.6	0.4	0.0	2.0
WSW	0.9	0.0	0.0	0.9
W	1.3	0.1	0.0	1.4
WNW	1.7	0.5	0.1	2.4
NW	1.9	1.0	0.2	3.1
NNW	1.3	1.2	0.3	2.9
	63.7	31.1	1.4	96.3

JUNE - AUGUST

(Calm 5.0 percent of time; average direction and speed in July: S 8 mph [1])

DIRECTION	Estimated percentage [2] 1 - 12 mph	13 - 21 mph	Above 21 mph	Cumulative Percentage
N	1.4	0.4	0.0	1.8
NNE	1.6	0.3	0.0	1.9
NE	2.7	0.5	0.0	3.2
ENE	2.4	0.3	0.0	2.7
E	3.3	0.2	0.0	3.5
ESE	3.8	0.3	0.0	4.1
SE	7.7	0.7	0.0	8.4
SSE	11.9	2.5	0.0	14.4
S	28.0	7.3	0.0	35.3
SSW	8.1	2.3	0.0	10.4
SW	3.6	0.4	0.0	4.0
WSW	1.5	0.0	0.0	1.5
W	1.1	0.0	0.0	1.1
WNW	1.0	0.0	0.0	1.0
NW	1.1	0.0	0.0	1.1
NNW	0.7	0.0	0.0	0.7
Totals	79.7	15.4	0.0	95.1

SEPTEMBER - NOVEMBER

(Calm 6.4 percent of time; average direction and speed in October: S 8 mph [1])

DIRECTION	Estimated percentage [2] 1 - 12 mph	13 - 21 mph	Above 21 mph	Cumulative Percentage
N	6.3	4.5	0.3	11.1
NNE	5.1	2.8	0.3	8.2
NE	5.5	1.6	0.0	7.1
ENE	3.5	0.3	0.0	3.8
E	3.7	0.2	0.0	3.9
ESE	3.5	0.1	0.0	3.6
SE	6.1	0.4	0.0	6.5
SSE	7.3	1.0	0.0	8.3
S	15.4	3.7	0.0	19.1
SSW	4.6	1.6	0.0	6.2
SW	2.1	0.4	0.0	2.5
WSW	1.3	0.1	0.0	1.4
W	1.6	0.1	0.0	1.7
WNW	2.3	0.2	0.0	2.5
NW	3.2	0.4	0.0	3.6
NNW	2.8	1.2	0.0	4.0
	74.1	18.7	0.7	93.5

Notes:

(1) Average wind direction and speed for approximately 20-year period ending in 1980, reported in Bomar (1983, table F-2);

[2] Percentage of winds blowing from each of 16 principal directions within ranges of speed indicated, estimated from graphic plots in Larkin and Bomar (1983, p. 67-68, and 78-81), based on original U.S. Department of Commerce dataset of measurements made at 3-hr intervals at 12 a.m. (midnight), 3 a.m., 6 a.m., 9 a.m., 12 p.m. (noon), 3 p.m., 6 p.m., and 9 p.m.

Appendix B. Annual precipitation recorded at Austin and Smithville stations, 1950–1991.

Year	Austin	Smithville	Year	Austin	Smithville
1950	25.8	31.8	1971	24.9	27.1
1951	29.0	29.7	1972	26.1	33.5
1952	27.7	31.9	1973	40.4	incomplete
1953	29.7	38.3	1974	36.2	incomplete
1954	11.4	22.6	1975	36.8	incomplete
1955	22.5	25.3	1976	39.6	53.3
1956	15.4	17.9	1977	22.1	31.0
1957	51.3	59.3	1978	31.0	34.0
1958	41.0	31.2	1979	37.5	43.7
1959	35.0	42.4	1980	27.4	27.6
1960	35.8	46.1	1981	45.7	52.7
1961	36.4	50.2	1982	26.6	29.1
1962	33.5	33.3	1983	34.0	37.7
1963	17.3	24.4	1984	26.3	30.3
1964	35.5	37.1	1985	32.5	37.2
1965	40.6	48.9	1986	35.0	51.5
1966	25.2	30.0	1987	36.6	45.1
1967	33.5	33.9	1988	19.2	26.6
1968	40.4	56.7	1989	25.9	38.3
1969	33.6	35.7	1990	28.4	29.5
1970	30.6	34.7	1991	52.2	56.5
Minimum	11.4	17.9	Mean	31.8	37.1
Maximum	52.2	59.3	Median	33.0	34.0

Original data from National Weather Service, obtained through the Texas Natural Resources Information System; records for Smithville incomplete for years 1973, 1974, and 1975.

Appendix C. Water-level elevations in selected wells in northern Bastrop County (data from Texas Water Development Board, 1992c; well locations shown in Follett, 1970, fig. 23).

	Water level (ft, datum sea level)		
Year	Well 58 46 301	Well 58 46 503	Well 58 54 507
1943	no data	no data	322
1944	no data	no data	no data
1945	no data	no data	no data
1946	no data	no data	340
1947	no data	no data	no data
1948	no data	no data	no data
1949	no data	no data	no data
1950	502	482	346
1951	502	482	346
1952	502	481	346
1953	501	479	346
1954	499	478	344
1955	498	477	345
1956	498	476	345
1957	498	474	347
1958	498	478	345
1959	499	479	347
1960	499	479	347
1961	500	no data	349
1962	501	484	348
1963	502	486	no data
1964	501	482	no data
1965	502	484	no data
1966	502	486	no data
1967	500	485	no data
1968	502	487	no data
1969	503	489	no data
1970	504	488	no data
1971	505	486	no data
1972	505	483	no data
1973	504	481	no data
1974	504	479	no data
1975	505	483	no data
1976	506	483	no data
1977	507	485	no data
1978	507	485	no data
1979	507	482	no data
1980	no data	no data	no data
1981	506	480	no data
1982	506	481	no data
1983	506	482	no data
1984	505	480	no data
1985	506	481	no data
1986	no data	no data	no data
1987	509	486	no data
1988	no data	no data	no data
1989	507	485	no data
1990	506	479	no data
1991	506	no data	no data