GEOLOGICAL AND CLIMATIC SURVEY
CAMP BOWIE MILITARY RESERVATION
BROWNWOOD, TEXAS

by

H. Seay Nance

and

E. G. Wermund

prepared for

Texas National Guard

Funding provided by the Texas Adjutant General's Department

under Interagency Contract Number IAC(92–93)1532

Bureau of Economic Geology

W. L. Fisher, Director

The University of Texas at Austin

Austin, Texas 78713-7508

June 1993

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SUMMARY

Camp Bowie, a Texas Army National Guard (TXARNG) training area located 6 mi south-southeast of Brownwood, Texas, and comprising 8,755 acres, is presently distributed as two parcels: an original reserve comprising 5,410 acres and a newly acquired adjacent tract to the southeast comprising 3,345 acres (fig. 1). The training area is used for vehicle maintenance and improving combat readiness in the TXARNG and is mandated for company and platoon-level training of reserve and active personnel in the use of armored vehicles and ≤.50-caliber (nonexplosive) training devices. The area is of a size sufficient to implement the Army Training and Evaluation Program (ARTEP). The overall plan includes discontinuing agricultural use and allowing the land to return to a natural, if not original, physical state (Adjutant General's Department of Texas, 1992).

Physiographically, Camp Bowie is on a transition between rolling hills developed on Cretaceous rocks of the Grand Prairie province in the east and the generally lower-relief Osage Plains developed on much older rocks (Triassic, Permian, and Pennsylvanian) to the west (Sellards and others, 1932; fig. 2). These physiographic provinces have also been called Cross Timbers and Prairies, and Rolling Plains, respectively (Gould, 1975). The area is in the Colorado River drainage basin and includes many small intermittent creeks. Water from these streams eventually drains into Pecan Bayou to the east of the camp or Indian Creek to the west. Pecan Bayou and Indian Creek drain south into the Colorado River (fig. 1).

Camp Bowie lies on and around the north edge of an 18-mi-long, 0.75–4.0-mi-wide northwest-trending ridge of Cretaceous-age, Travis Peak Formation sedimentary rocks. The highlands on the reservation are mildly rolling, stream-dissected ridges, developed on flat-lying limestone, conglomerate, sandstone, and shale. They have moderate slopes as steep as 30° leading down on the west, north, and east to relatively flat-lying (0–3-percent-slope) lowlands

developed on Pennsylvanian-age (Strawn Group) shales. Terracelike areas adjacent to the plateau slopes occur in places and comprise remnants of Pennsylvanian sandstone and limestone beds that lie stratigraphically above the shales of the lowlands.

The physical properties of soils reflect the composition of underlying bedrock. Soils developed on the Travis Peak are sandy loams under which sandy limestone and sandstone occur on the ridge slopes, and lime-rich clay loams under which limestones occur on the ridge top. The very thin, stony, moderately permeable soils having low runoff potential are capable of supporting heavy loads but are slow to recover when the characteristically thin vegetation cover has been destroyed by traffic or grazing. Soils developed on the slopes of the plateau are sandy in the upper parts where Travis Peak rocks occur and more clay rich on lower slopes where Pennsylvanian rocks occur. Slope soils are sandy or clay loams having rapid runoff potential. Soils developed on Pennsylvanian strata in lowland areas are relatively impermeable and have low runoff potential and moderate strength when dry but little strength when wet. Heavy vehicular traffic over wet lowland soil typically causes deep tracks that pond water and are slow to be filled by soil.

Camp Bowie lies in the subtropical subhumid zone of Texas, where summers are hot and winters are dry (Larkin and Bomar, 1983). On average, summer temperatures rise above 100°F during a quarter of the summer days and reach freezing during half the winter days. Annual temperatures average 65°F. Rainfall is concentrated in May and September; the driest months are December and January. Southerly winds dominate, but a significant northerly component appears in fall and especially winter.

Most Camp Bowie grounds are relatively undisturbed and vegetated. Degraded areas are mainly concentrated at and near four quarries, or "gravel pits" (fig. 1; plate NW), developed in limestone-rich Travis Peak deposits on the ridge tops. The most extensively degraded area lies at, and to the southeast of, the gravel pit and a large pond, which is east of and adjacent to the area that contains buildings, parking lots, and firing ranges (figs. 1, 3a, and 4; plate NW). Degradation is areally more restricted around the gravel pits on the grounds west of Highway 45 (figs. 1 and 3b). In these areas rock has been excavated, resulting in local relief of as much as 10 ft in the quarries. Much less intense but more widespread degradation has occurred in the form of vehicle tracks that crisscross the highland areas (fig. 5). These are most abundant in the north-central part of the original reservation. In lowlands, degradation mainly consists of relatively deep vehicle tracks. Thin coverage by grasses also suggests a history of livestock overgrazing.

Most potable ground water is produced from wells completed in Travis Peak sandstones and limestones; however, small amounts of water are produced from isolated sandstone lenses of the Strawn Group. Strawn waters contain higher concentrations of sodium and total dissolved solids than do Travis Peak waters.

Strategies for planning should aim at minimizing erosion, maximizing vegetation cover, and protecting against pollution of streams and ground water. These goals can best be achieved by restricting travel to main roadways whenever possible, bridging streams that are regularly traversed by motor vehicles, discontinuing livestock grazing, and avoiding spillage of contaminants. Regular testing of water quality in camp reservoirs is recommended.

DETAILS OF GEOLOGIC AND CLIMATIC ASSESSMENT

Methods

This survey of the physical environment of Camp Bowie comprises a compilation of information from published literature pertaining to regional geology and soils (Kier and others, 1976) and personal on-site reconnaissance. USGS topographic maps having reservation boundaries (provided by the Adjutant General's Department) and high-altitude aerial photographs (U.S. Department of Agriculture, 1980) were used for investigations on the ground. The original reservation was traveled extensively on several visits; however, travel into the newly acquired adjacent property (southeast) (fig. 1; plate SE) was not allowed during this investigation. Observations concerning the unvisited parts of Camp Bowie were based upon similarities to the original reservation as seen on aerial photographs and soil and topographic maps.

The area investigated for this report lies within boundaries shown on the topographic map (fig. 1). Since preparation of this map by the Adjutant General's Department, several adjustments have been made to camp boundaries by additions and subtractions of small parcels of land at the periphery of both the original reservation and the new acquisition. Although these new boundaries are not reflected in figure 1, exact mapping of the boundaries is not required to corroborate this assessment.

This report highlights the kinds of physical features and processes, both natural and human-influenced, that characterize Camp Bowie today and that may guide planning and future use. Hopefully the discussions and examples given here will sensitize planners to similar features when they encounter them in the field. Constraints of time and budget disallowed mapping of all significant features at Camp Bowie.

Bedrock geologic aspects of the reservation are discussed first because they are the foundation on which the actual terrain (landforms and streams) is constructed. The land forms and drainage system (geomorphology) are discussed next. Then come climatic influences because they continually modify the landforms, mainly by way of erosion, and affect the ground-water system by changing balances between aquifer recharge and discharge. Hydrology, or ground water, is next because of its importance to humans, animals, and plants in the area. Finally, guidelines for continued land use are presented to aid in planning for the future.

Geology

Camp Bowie lies at the north end of an 18-mi-long ridge of Cretaceous-age (~130 m.y. old) rocks that are called the Travis Peak Formation. This ridge is surrounded and underlain by Pennsylvanian-age (~300 m.y. old) rocks called the Strawn Group (Kier and others, 1976). The Strawn Group in this area is dominated by easily eroded shales (mud-rich rocks) that form the low-lying area around the Travis Peak ridge, as well as the low areas around the large reservoir at the center of the original reservation (figs. 1 and 6). In places, small (several-hundred-feet-wide) discontinuous lenses of sandstone (fig. 6) that were deposited in streams (distributary channels) that flowed across the muddy subtidal plain (prodelta) occur. All of this was part of a Pennsylvanian delta system on which rivers dumped their sediment load into the sea near a coastline. These kinds of deposits are illustrated schematically in cross section (fig. 6), although constraints of time and budget prevented detailed mapping of such units. Any ground water from wells drilled in the Strawn, however, probably produced from these sandstone lenses. In some places around the reservation the uppermost Strawn has thin sheetlike beds of interbedded sandstone and fossiliferous limestone (figs. 7 and 8) that form flat benches adjacent to the Travis Peak ridge. These are probably erosional remnants of deposits that developed as the sea rose and covered the delta deposits. An example of these can be found on the north side of the topographic promontory that lies just north of the word "spillway" on the topographic map (fig. 1), near the reservoir in the center of the original reservoir.

The Travis Peak Formation lies unconformably on the Strawn Group: 170 million yr elapsed between (1) deposition of the Strawn sediments (during which the Pennsylvanian rocks were uplifted) and (2) erosion of a relatively flat surface having local channels (Wichita Peneplain) on top of the Strawn, with subsequent Travis Peak deposition. This unconformity is regionally angular; that is, because the Pennsylvanian surface was tilted to the east during uplift, before deposition of the originally flat-lying Cretaceous rocks, the bedding planes of Strawn rocks are at an angle to Travis Peak bedding planes (fig. 8). Today even the Travis Peak tilts slightly to the east. However, the angles of tilt are fairly low at Camp Bowie (only a few degrees), and the unconformity appears essentially level in the cross section (fig. 6). This bedding tilt has caused asymmetry in the erosion of hill slopes that formed on the Travis Peak; slopes are significantly steeper on the west sides of ridges than on the east. The Travis Peak Formation is generally composed, from bottom to top, of conglomerate, sandstone, and limestone. The conglomerate (fig. 9) is composed of pebbles and small cobbles as much as

4 inches in diameter. The size of these clasts tends to decrease upward in the interval, and they are composed mostly of rounded fragments of quartz-rich sandstone. The sandstone fragments were originally eroded from exposed Pennsylvanian rocks to the west and delivered to their final sites of deposition by early Cretaceous-age rivers that had been entrenched in the landscape (Wichita Peneplain). The thickness of this conglomeratic interval varies from <1 ft to ~50 ft or more in thickness. Thicker deposits probably lie near the deepest parts of ancient river channels, whereas thinner deposits lie off to the sides of the main channels. An example of thicker conglomerate deposits is found on the east-northeast-trending, steep-sided ridge near the easternmost corner of the original reservation (at the end of the word "reservation" on the topographic map [fig. 1]). The ridge probably reflects the easterly course of a large Cretaceous river channel.

Overlying the conglomerates are sandstones (figs. 10 and 11) that generally fine upward in grain size and are crossbedded (that is, they have angular internal laminations that occurred during sand deposition in rapidly flowing river water). Where no conglomerates are present and the underlying material is Pennsylvanian shale, the lowermost Cretaceous sandstones (in some places) contain Pennsylvanian fossils (crinoids, fig. 12) eroded from the shale. Above the lowermost Travis Peak sandstone, thin limestone beds appear and are interbedded with more sandstone (fig. 13). The occurrences of limestone beds increase in number and thickness upwards in the Travis Peak, limestone becoming the dominant rock type at the tops of ridges.

Deposits recording geologic time since Travis Peak deposition include erosional products derived from Cretaceous and Pennsylvanian rocks. These comprise stones and soils found on hilltops, slopes, and on terraces and in floodplains of modern streams. These materials are transported from their original locations by sheet flow down smooth slopes and by stream flow within gullies and streams that lead to Devils River, Mackinally Creek, and Pecan Bayou on the east side of the camp, and to Indian Creek on the west side of the camp. Through these streams, runoff ultimately flows south to the Colorado River. In terms of geomorphology (study of landforms and physical processes affecting them), the streams combine to form a drainage net. The map-view pattern displayed by the drainage net in this area is dendritic, a form of drainage uncompelled by bedrock textures to form gridlike patterns (rectangular drainage) or radiating patterns (centripetal or radial drainage).

Topography and Geomorphology

Camp Bowie lies at the north end of an 18-mi-long ridge, upon which smaller ridges are superimposed within the reservation. These smaller ridges trend north–northeast, each at an elevation lower than its neighbor to the west. The highest ridge, on the west side of the camp and crossing Highway 45 at a low angle, rises between 1,590 and 1,600 ft at its highest points. This ridge is a drainage divide where streams draining the east side of the ridge eventually merge with Lewis Creek (a tributary to Pecan Bayou) and streams draining the west side flow to Willis Creek (a tributary of Indian Creek). Reservoirs have been constructed on Lewis and Willis Creeks. Pecan Bayou and Indian Creek drain to the Colorado River; neither of these three streams are on the reservation.

The east side of the main ridge leading to Lewis Creek slopes fairly gently (1–2 percent) along the tops of spurs extending off the main ridge but slopes markedly near the drainage axes to 7 percent. Slopes immediately adjacent to streams approach 30 percent. Because drainage axes converge near the central reservoir, the slopes around the reservoir are steeper than those near the main ridge (figs. 1 and 6). On the west side of the ridge, slopes are steeper than on the east side, averaging about 6 percent. Slopes decrease in proximity to the reservoir on Willis Creek. Slopes are gentler on the east side probably because the Travis Peak beds tilt somewhat to the east; this circumstance tends to erode the "edge-up" (west) side at a rate higher than on the east side. On the west side of the ridge softer rocks are relatively easy to erode: the overlying, more resistant beds collapse once the soft material is removed. On the east side, the beds essentially form a shield over softer beds, thus delaying their erosion.

The second highest ridge in the camp, at the top of the slopes on the east side of Lewis Creek, intersects the camp boundaries several times at the south edge of the original reservation and reaches about 1,550 ft in elevation. The east edge of this ridge forms an arc-shaped margin just within the camp boundaries, the north part of which splays out fanlike into mildly sloping (1–3 percent) spurs. The drainage divide on this ridge-spur feature trends north–northeast and intersects the camp's northeast boundary. Drainage to the west intersects Lewis Creek, whereas drainage to the east approaches Devils River and an unnamed creek that parallels Pecan Bayou. Like the main ridge, westerly slopes are steeper to the west of the axis of the second ridge. The steepest slopes (19 percent and more) along the east margin of the ridge-spur complex reflect the presence of easily eroded, shale-dominated rocks of the Strawn Group. Erosion of Strawn beds here leads eventually to the collapse of overlying Travis Peak rocks.

The southernmost ridge, above the steep slopes on the east side of Devils River within the new acquisition, rises to a height of around 1,500 ft. The drainage divide in this area trends along the west-east spur on the east side of the ridge axis and extends out onto the relatively flat area in the east part of the new acquisition. To the north of the divide, drainage approaches Devils River; to the south, drainage approaches Mackinally Creek. According to the topographic map and aerial photos (fig. 1; plate SW), a reservoir has been constructed on an unnamed stream draining the southeast margin of the ridge.

The relatively low lying area along the east boundary of the Travis Peak uplands is in shale-dominated rocks of the Strawn. The flat area east of the 1,310-ft contour is the modern floodplain of Pecan Bayou and its tributaries.

Soils

Soils at Camp Bowie include calcareous (bearing calcium carbonate) sandy loams, silty loams, and clay loams and reflect the bedrock upon which they developed. Sandy soils tend to develop on sandstone bedrock of the Travis Peak Formation; whereas clay-rich soils develop on limestone of the Travis Peak Formation, shale of the Pennsylvanian Strawn Group, and within modern stream courses. Travis Peak-related soils occur in topographically high areas; Strawn- and stream-related soils occur on sideslopes below Travis Peak rocks and in low elevations. In general, the soils of the topographically high areas are thinner, stonier, stronger, sandier, and more permeable than soils from low areas. Soils from topographically low areas are weaker, lower in permeability, and more clay rich than upland soils, and they have shrink-swell characteristics associated with clay content. In both high and low elevations, runoff rates and susceptibility to erosion increase with steepness of slope. Calcium carbonate in all of these soils tends to promote corrosion of uncoated metal, including iron and the lead and brass used in some ammunition.

Vehicular traffic on the two general soil types has very different results (figs. 5 and 8). On thin upland soil, grass is destroyed by repeated traffic, leaving it vulnerable to erosion during runoff. Vegetation, once destroyed, recovers slowly, especially on slopes that are episodically swept by runoff during rainstorms. On clay rich lowland soils, deep tracks develop, especially when wet, and commonly pool water in flat areas (fig. 5). The shrink–swell behavior of clays in lowland soils often causes shrinkage (desiccation) cracks to form as they dry. These cracks allow rain to penetrate 20 inches or more in places, until the cracks close by swelling as they get wetter. These soils have high water-storage capacity and tend to stay damp for extended periods, resulting in their reduced strength.

A generalized soil map (fig. 14) simplifies detailed maps developed by the U.S.D.A. Soil Conservation Service, organizing soil types into two basic categories—relatively permeable soils and relatively impermeable soils. These two categories are then subdivided on the basis of slope steepness and whether the soils occur in modern stream floodplains. This organization results in five map units: permeable soils in highland areas, low-permeability soils in highland areas, generally low permeability soils on slopes, low-permeability soils in relatively flat lowland areas, and modern stream floodplains.

These subdivisions allow the map user to (1) determine where spilled contaminants may be absorbed readily by permeable soils as opposed to where low-permeability soils will not readily absorb fluids, (2) determine where erosion due to runoff of rainwater is a concern, (3) determine where soil is strongest, and (4) identify flood-prone areas in modern stream beds.

Soil Descriptions

The brief soil descriptions that follow are based on soil classification by the Soil Conservation Service (U.S. Department of Agriculture). Soils are described from high ground (Travis Peak Formation and uppermost Strawn Group limestone and sandstone terrane) to low ground (shaly Strawn Group terrane and modern streams and their floodplains).

Highland Soils

The highlands, characterized by generally stony soils, developed on sandstone and limestone of the Travis Peak Formation or the uppermost Strawn Group.

Doudle-Real Association (DRA) soils occur in undulating areas over most of the campgrounds (slopes of 1–8 percent). These soils have fairly high permeability and moderate runoff. Permeability decreases and runoff potential increases on steeper slopes where these soils, in places, are distinguished as Bonti-Callahan Association (BCA) soils. Only one area in the northeast part of the original reservation has been identified as BCA soil. Clay loam occurs on ridge tops where the Travis Peak Formation is dominated by limestone. Somewhat sandier loam occurs where underlying bedrock is sandy limestone or very calcareous sandstone. Permeability is moderate in these soils. Grass cover, particularly thin here, does not recover quickly when removed. The permeability and runoff properties of DRA soils make them relatively susceptible to contamination (contrasted with more clay-rich soils of the area) by absorption of spilled toxic substances. Soil strength is good away from concentrations of clay-rich soil, which usually lies in slight depressions.

The Bonti-Throck Association soils occur on hilly areas (slopes of 10–30 percent) in the north-central and northeast parts of the original camp reservation and in the east-central part of the proposed acquisition property. These soils are well-drained sandy loams to clays that have low to moderately low permeabilities and rapid runoff. They have low capacities for storing water. The clays have shrink–swell characteristics that reflect moisture content and are most vulnerable to erosion when wet, particularly erosion from runoff. Erosion becomes most aggressive once vegetation has been removed.

Merta clay loams (MER) form on gently convex surfaces in the Travis Peak limestone in the extreme southwest part of the original reservation. The clay has probably remained as insoluble residue from dissolution of formerly occurring limestone. The clays have shrink–swell characteristics and permeability and runoff are low. Strength is low, too, especially when the clay is wet.

Menard-Hext Association (MHA) soils comprise sandy loams and loams that occur on undulating surfaces adjacent to but topographically lower than DRA soils. These soils occur on 1- to 5-percent slopes that are underlain by sandstones that dominate the lower parts of the Travis Peak Formation. These soils have been identified only at the westernmost extent of the camp. Like DRA soils, MHA soils are moderately permeable and have slow to moderate runoff, depending on steepness of slopes.

Pedernales fine sandy loam (PED) occurs on low slopes (1–5 percent) generally in positions intermediate between highland soils developed on sandstone and limestone of the Travis Peak Formation and lowland clay-rich soils developed on shale of the Strawn Group. These soils appear to have developed on limestone-capped benches at the top of the Strawn Group, and they occur around the periphery of the camp, especially on the east side (fig. 14). Sandy components of the soil have developed from sandstone that is interbedded with Strawn limestone. Although runoff is slow because of the low slopes, permeability is also moderately low. These soils are subject to considerable erosion on steeper slopes. Strength appears to be fairly high due to the presence of underlying limestone and sandstone beds under the thin soil.

Callahan-Throck Association soils (CTA) are gravelly clay and clay loam soils that developed on slopes slightly steeper (1–8 percent) than those of PED soils. These areas probably reflect erosive loss of bench-capping limestones that mark the top of the Strawn Group in many places. As with other clay-bearing soils, permeability is low, whereas runoff rates increase with slope.

Real soils are gravelly loams that occur on slopes (10–30 percent) generally adjacent to the gentler slopes of the lowlands. They developed on Strawn Group limestone, sandstone, and shale that have not formed benches as areas covered with PED soils have. Although permeability is moderate, runoff is high because of slope steepness.

Lowland Soils

Topographically lower areas are characterized by generally clay-rich soils developed on Strawn Group shales or on modern floodplains. In fact, lowlands (including positions of major stream courses) develop geomorphically because erosion of Strawn shales is relatively easy compared with erosion of the Travis Peak and uppermost Strawn limestones and sandstones that compose higher areas.

Nukrum silty clay forms on high terraces of modern streams mainly along the east boundary of both the original reservation and the proposed acquisition to the south. The surface of this soil forms deep cracks (as much as 20 inches deep) when dry, which allows penetration of rainwater. When wetted, however, the swelling clay closes the cracks and greatly reduces permeability. The storage capacity for water is high, and the soil is very weak when wet.

Frio silty clay loams occur in occasionally to frequently flooded areas in modern stream valleys. Because these areas are nearly level, runoff is slow. Permeability is also slow because stream deposits contain clay. Strength of soils is very low (fig. 15), and flooding potential limits permanent facilities' use. Contamination by fuel or other toxic spills not only endangers wildlife that use the streams but also humans because all streams drain eventually into reservoirs within Camp Bowie, Pecan Bayou (4 mi east), or the Colorado River (12 mi south).

Climate

Camp Bowie lies in the subtropical subhumid zone in Texas, a north-south trending area that extends from southernmost Texas north to the Red River and the southeastern Panhandle. This zone has hot summers and dry winters, most rainfall occurring in the spring and autumn.

Explanation of Climate Chart

A climate chart (fig. 16) reports pertinent climatic components (precipitation, temperature, sunshine, and lake evaporation rate) as monthly averages, and reports relative humidity for midseason months, which are linearly extrapolated for intervening months. The chart is based on measurements taken from 1951 through 1980 as reported in the *Climatic Atlas of Texas* by Larkin and Bomar (1983). These data, illustrated on one diagram, show correspondences between the various climatic components. Probable average climatic conditions for a given month can be determined by (1) sighting along a vertical line drawn from the month (listed on the horizontal axis) through the overlying curves and (2) sighting along a horizontal line to the appropriate scale for the value on each curve. For example, May has the following corresponding *average* conditions:

Precipitation: 4.25 inches

Temperature: 72°F

Low temperature: 60°F

High temperature: 84°F

Sunshine: 70 percent of possible maximum

Relative humidity: 53 percent

Lake evaporation: 6.3 inches

Climatic Statistics (Brownwood, Texas)

The following statistics convey information about normal climatic conditions around Camp Bowie, as well as about extreme conditions that can occur and that, although unpredictable in the short term, should be prepared for. These data are drawn from Bomar, 1983.

Annual average temperature: 65°F

Annual average high temperature: 77.9°F

Annual average low temperature: 52.7°F

High temperature (average) in warmest month: 96.9°F in July

Low temperature (average) in coldest month: 31.4°F in January

Highest recorded temperature: 111°F on August 7, 1964

Lowest recorded temperature: –2°F on January 23, 1940

First freeze date (average): November 16

Last freeze date (average): March 21

Number of freezes (average) in 1 yr: 51

Greatest number of freezes in one winter: 79 in 1976–77

Number (average) days w/temperatures ≥100°F: 25

Greatest number days w/temperatures ≥100°F: 53 in 1963 and 1964

Number (average) days w/temperatures ≥100°F in warmest months: 10 in July and August

Annual average rainfall: 26.1 inches

Rainfall (average) in wettest (average) month: 3.88 inches in May

Highest rainfall in one year: 42.3 inches in 1959; 42.2 inches in 1991

Lowest rainfall in one year: 12.8 inches in 1954

Temperature

Average monthly high and low temperatures differ by 24° to 27° over 1 yr, the greatest spread occurring in early winter and the narrowest spread occurring in late spring and early autumn. The temperature spread is typical of drier climates in which relatively sparse cloud cover allows abundant daytime heating and rapid loss of heat at night. Temperatures have ranged, historically, from -2°F to 111°F. Temperatures of 100°F or greater occur, on average, 28 percent of summer days. In the summers of 1963 and 1964, more than half the days were 100°F or greater. Freezes occur, on average, 57 percent of winter days. In the winter of 1976–77, freezes occurred 88 percent of the days.

Precipitation

Average annual precipitation for southern Brown County is 26 inches; however, as much as 62 percent more rain was recorded in 1952 and 1959. And yet only half that amount was recorded in 1954. Average highest monthly rainfalls (4.25 inches) occur in May, a secondary peak (3.75 inches) occurring in September. Average lowest monthly rainfalls (1.25 inches) occur in December, January, and February, secondary lows occurring in July and August (1.75 and 2 inches, respectively). Snowfall is scarce in the area, averaging 2.3 inches during years when it accumulates, although snowfall too little to accumulate is the rule for most years. Significant accumulations occur about one year in three, on average.

Flooding

Although the Brown County area is not noted for abundant annual rainfall, the amount received in some years is well above the average calculated from all the years of record (fig. 17). Since 1952, rainfall has ranged from as little as 12.8 inches to as much as 42.3 inches. The relatively modest average abundance of 26 inches per year is insufficient to maintain heavy vegetation coverage; thus soil and rocks are exposed to climatic elements. This situation has been exacerbated by grazing livestock. Because vegetation poses obstacles to runoff, its scarcity results in relatively rapid runoff from slopes into the drainage streams, and soils are eroded by the process. Because the ridges are narrow and the adjacent slopes are steep in many areas, rainwater does not reside in highland areas for long but rather collects in lower areas, particularly in the reservoirs constructed on local streams. A major flooding event may fill these reservoirs to a level at which most of the flat-lying surrounding areas are submerged for several days, so soils become saturated and may even stay damp for several weeks, depending on the season.

Studying historical behavior of individual streams has value because with such knowledge, likely contingencies can be prepared for. Unfortunately no flood records of the small streams in Camp Bowie exist. The nearest stream for which records have been kept is Pecan Bayou, just east of the reservation. Stream levels in Pecan Bayou are controlled by releases of water upstream at Lake Brownwood, which generally reflect rainfall intensities sufficient to fill the lake. In an indirect way, then, Pecan Bayou flood records can be used to gain a sense of the relative magnitude of flow changes in local streams due to rainfall.

The flooding history presented here (fig. 18) is based on a 16-yr record of Pecan Bayou near the town of Mullin, Mills County, 14 air-miles southeast of Camp Bowie. The flood history diagram plots discharge (cubic feet per second, or cfs) on a logarithmic scale, which illustrates values that vary across several orders of magnitude (10). A cutoff value of 500 cfs was used to emphasize more significant events. When several ≥500-cfs events occurred during 1 month, the two largest were plotted as two adjacent half-width bars sharing the space for that month. Five-hundred-cfs events occur several times during many years, but not every year. Most of the time, flow of Pecan Bayou at Mullin is 8–12 cfs, although periods of no-flow have occurred in dry months during several years. The average flow, which combines all flow records, is about 110 cfs. Peak flood levels of >500 cfs seldom last more than a few days. However, flood levels of >500 cfs have been maintained for as long as 1 month.

Probably the most significant aspect of the flood chart (fig. 18) is the increased frequency and magnitude of flooding over time, especially since mid-1984. Comparison of the flooding chart with the annual rainfall chart shows that exceptionally high floods occured in 1986 and 1990, years that also experienced higher-than-average rainfall.

Winds

Although wind records were unavailable specifically for Brownwood, records for surrounding areas (represented by Dallas, Waco, Abilene, and San Angelo, fig. 2) are sufficiently similar that wind conditions around Camp Bowie can be extrapolated.

Southerly (especially SSW–SSE) winds prevail in the Brownwood area year round. Higher winds (≥18 knots) blow mostly from due south but sometimes from the south–southwest or south–southeast. Northerly (NNW–NNE) winds become more common in fall and peak in winter, the higher winds generally blowing from due north. Least calm conditions, overall, commonly occur in spring and fall when temperature differences between frequently colliding air masses peak.

Hydrology

Methods

The ground-water hydrology reported here is based on published literature and records of the Texas Water Development Board (TWDB). Their measurements of water levels were used to examine the potentiometic-surface and water-table decline curves. Their measurements were also used to evaluate water chemistry and water quality. TWDB records have a useful longevity and have been recorded through 1992 in many representative wells.

No new measurements of drawdown in pumping wells were made in this study to determine new values of transmissivity, nor were new water samples collected for chemical analyses in order for us to examine changes in water quality. Future collections of ground-water data may be recommended for selected wells, depending on Camp Bowie's current and future training plans.

Hydrologic Units

Two hydrologic units are on the Camp Bowie training site, as shown in a schematic cross section (fig. 19). The deeper unit, the Strawn Group, has a lithology dominated by shale, throughout which sandstones occur in small (no more than 30 ft thick) channels, crevasse splays, and minor deltas, whose exact locations may differ from those in the schematic cross section. Generally the sandstones behave like aquifers, whereas the shales are aquitards. Frequently because the confining shales are very sandy or silty, they leak, and because the sandstone aquifers are not pressured, they are generally accessed by very shallow wells. Indeed, the Strawn Group at the surface near Camp Bowie performs much like an unconfined aquifer. Wells produce from depths as shallow as 4 ft; most Strawn wells produce from <30 ft (Texas Water Development Board, 1992c). According to Thompson (1967) the deepest Strawn water well produces from a depth of 496 ft in Brown County.

Because the Strawn provides only poor wells, TWDB records are sketchy for this group, and only 35 wells are reported for Brown County. Of these wells only one well was revisited to measure changes in water level. That well, about 6 mi east of Camp Bowie, was measured in 1966, 1967, and 1969. The water level rose nearly 20 ft during that period; relating the well to the geologic map, we can infer that the well was in a confined aquifer about 80 ft deep (Texas Water Development Board, 1992c). Although recharge is probably a slow process through the leaky silty shales, transmission of water through joints is possible. Information is unavailable for estimating transmissivity or for determining yield from any Strawn aquifers. Thompson (1967) found that Strawn wells generally yield <20 gpm, a supply adequate for domestic and livestock purposes.

Base level in the upper unconfined Strawn aquifer is controlled by Pecan Bayou and Indian Creek, tributaries of the Colorado River. Shallow Strawn ground water flows principally east and south from the Camp Bowie training site; deep Strawn waters flow west toward the Permian Basin.

The upper hydrologic unit, the Travis Peak Formation, which is a major confined aquifer near Waco (Klempt and others, 1976), has had artesian pressures in the past. However, the Travis Peak aquifer at the Camp Bowie training site is an unconfined aquifer contained in a topographically elevated ridge (fig. 19). The unit is self contained in a large outlier that is ~18 mi long, as much as 5 mi wide, and >120 ft thick lying on top of the Strawn Group. A thin soil cover lies on the ridge top. Permeability and porosity reside in conglomerates and sandstones that are locally cemented by carbonate cement. Thin limestones are also in the unit that are commonly fractured or jointed. The Strawn unit behaves mostly like an underlying confining layer except where lenticular sandstones are in contact with the base of the Travis Peak unit. The contact between the Strawn and Travis Peak units is not everywhere exposed in the field, but the onlapping Travis Peak coarse strata, probably stream deposits, undoubtedly locally entrench upper Strawn strata. The outlier is a large efficient recharge zone as well as an aquifer contributing to the many intermittent streams that are eroding headward into the ridge. In wet seasons numerous springs flow through the Travis Peak and at its contact with the Strawn. A high density of small dammed lakes lies on both sides of the ridge that reflects levels of ground water trapped in the outlier. Three such reservoirs lie within the camp boundaries as well.

Because the Travis Peak aquifer is composed principally of gravel and sand, its transmissivity is high, as much as 45,000 gpm before large drawdowns (Klempt and others, 1976). Locally in Brown County, this unit responds readily to local weather; drawdown does not occur consistently in local wells (fig. 20). Note that the Travis Peak aquifer water levels have moved upward in recent years in response to relatively larger annual rainfalls.

Water Quality

On the basis of standard analyses of 76 waters from Strawn wells, 48 were found to be sodium-bicarbonate types. The remainder are calcium-magnesium-bicarbonate waters, except four that appear to be transitional between the two water types (Texas Water Development Board, 1992a). The disproportionate number of sodium waters probably reflects base exchange of water-borne calcium and magnesium replacing sodium in abundant Strawn clay. On the basis of analyses of waters in 17 Travis Peak wells, 12 were found to be calcium-magnesium bicarbonate, four sodium bicarbonate, and one transitional. Abundant calcite (calcium carbonate) occurs in Travis Peak rocks from which calcium-bicarbonate waters would be expected.

The slight differences in the chemical composition of Strawn and Travis Peak waters are also reflected in comparisons of TDS and pH (table 1). Strawn waters contain slightly higher TDS than does the Travis Peak. However, no significant differences in pH are evident.

Measurements in neither standard analyses (Texas Water Development Board, 1992a) nor special constituent analyses (Texas Water Development Board, 1992b) of Brown County ground waters show water quality being impacted by Camp Bowie. No evidence exists of higher concentrations of elements composing munitions nor of leakage of fuels or solvents in the area. However, all but three wells monitored by the TWDB are located a good distance from Camp Bowie.

CONSIDERATIONS FOR PLANNING

Land Use

Future land use at Camp Bowie should be conscientiously planned to minimize further destruction of vegetative cover and avoid contamination of streams and ground water. Discontinuing grazing by livestock and minimizing unnecessary off-road travel, especially by heavy vehicles, would allow a more rapid revegetation of barren areas. Except when training requirements indicate otherwise, use of roads designated for travel to specific areas on the reservation is recommended. During dry spells the thin grass cover of the highlands is especially vulnerable; during these periods reduction in off-road travel is recommended. On the other hand, areas that have clay-rich soils should be avoided under wet conditions. May and September are historically the wettest months, although rainfall may be concentrated during brief storms at other times of the year. Qualitative testing of clay-soil strength before travel is recommended; some of these clay soils retain water at shallow depths even when they do not seem to be saturated at the surface. Driving up slopes is best accomplished at some angle to the slope rather than straight up, so that runoff velocities are reduced and, thus, erosion minimized.

Of special interest is the large quarry in the westernmost part of the camp, south-southwest of the reservoir (plate NW). This quarry is the property of Brownwood and is a landfill. Although technically not on the campgrounds, the landfill lies in the drainage basin of Willis Creek, which has had a reservoir constructed on it downstream of the landfill. The landfill reportedly has a clay liner to prevent downward percolation of contaminants (Captain T. Airheart, personal communication); however, we recommend regular testing of reservoir water quality to assure the integrity of protective measures.

Infilling dug pits or securing their margins would minimize gullying at rims. Recovery of the gravel pits will probably require importing soil and possibly planting native vegetation. Construction of small bridges on streams would prevent disruption of natural processes and minimize sediment transport from stream crossings out of the streambeds by means of tires or tracks. Contamination of streams by engine fluids would also be minimized.

The potential of these soils for corroding uncoated metal should be heeded if such metal is to be left in the open. The relatively low solubility of lead-corrosion products in water suggests that the chance of spent lead-based ammunition contaminating ground water is small.

Ground Water

Transfer of engine fluids and other potential contaminants should be made carefully, so as to prevent spills. No safe place for pouring contaminants onto the ground exists. They will either percolate into the soil, ultimately entering the ground-water system, or they will run off with rainwater and eroded sediment into streams. Such spills would percolate relatively quickly into the more permeable soils in the highlands. Although lowland soils are clay rich and have much lower permeabilities, runoff is minimal in some of these areas. Thus, residence time of any spilled fluid may well be sufficient to allow it to percolate into the ground. Clays can bind up various chemicals so that contaminated clay-rich soils remain contaminated indefinitely; contaminants may then, however, be absorbed by vegetation and become part of the food chain for indigenous wildlife to graze.

If one were to drill into the high ridge of the Travis Peak Formation at Camp Bowie, a water supply would probably be found. And because this water supply lies above the Strawn Group (where vehicle parking, maintenance, and firing-range practice occur), the higher Travis Peak aquifer could remain uncontaminated. It would require careful regulation of training activities in this unit, which is an unconfined aquifer acting both as a recharge zone and a source of water. The ridge areas should not be used for storing fuel or for washing vehicles.

The low-lying area in the shale-dominated Strawn Group is the setting best suited for maneuvering vehicles and firing live ammunition, as is currently the practice at the Camp Bowie training site. In future construction, detailed mapping of the sand facies of the Strawn Group should be done because of their capacity to supply ground water.

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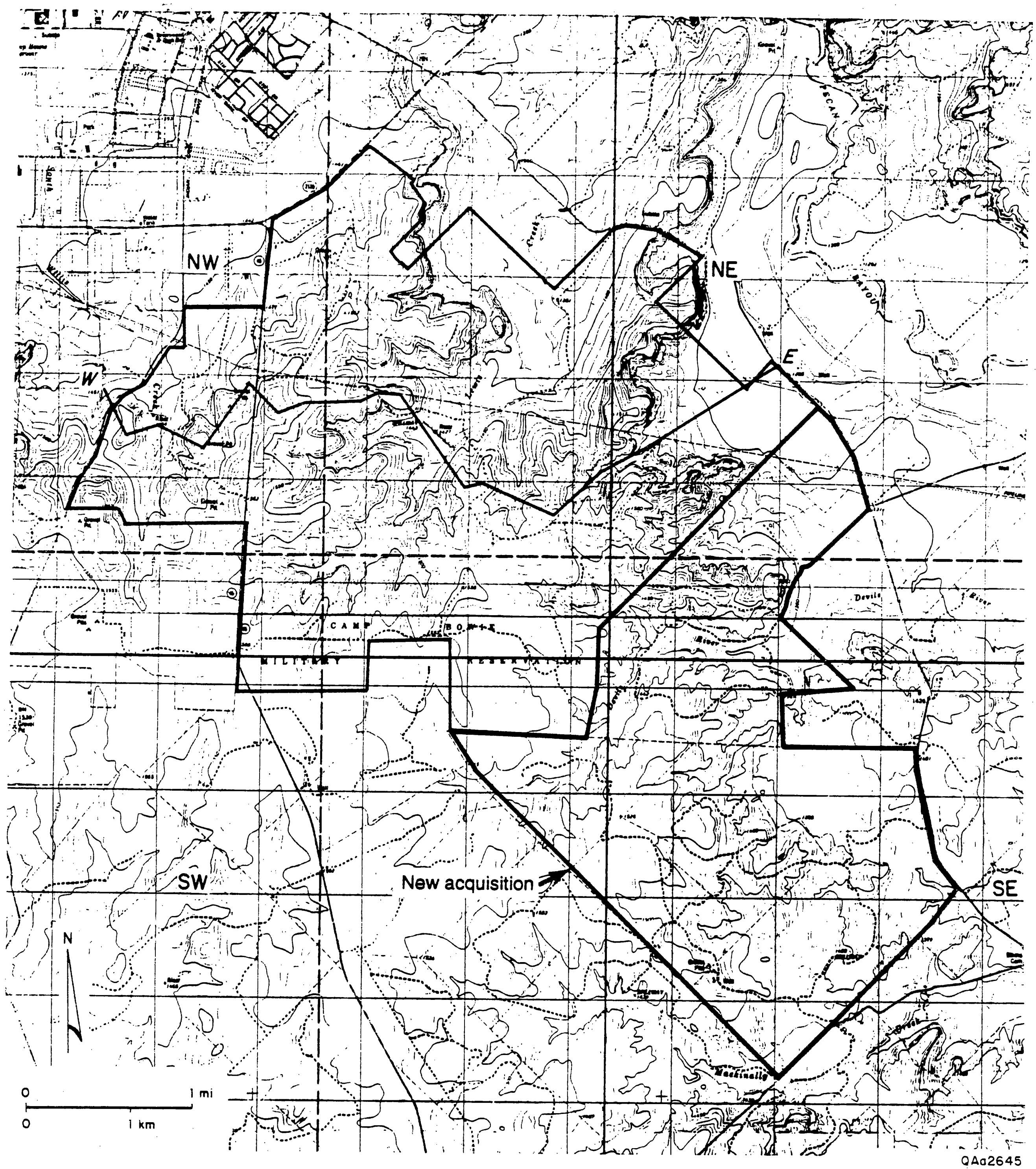


Figure 1. Topographic map of immediate Camp Bowie area. Shown are boundaries of the original reservation and of the new acquisition, location of west-east geologic and hydrologic cross sections W–E (figs. 6 and 19), and field of coverage of aerial photographs (plates NW, NE, SW, and SE).

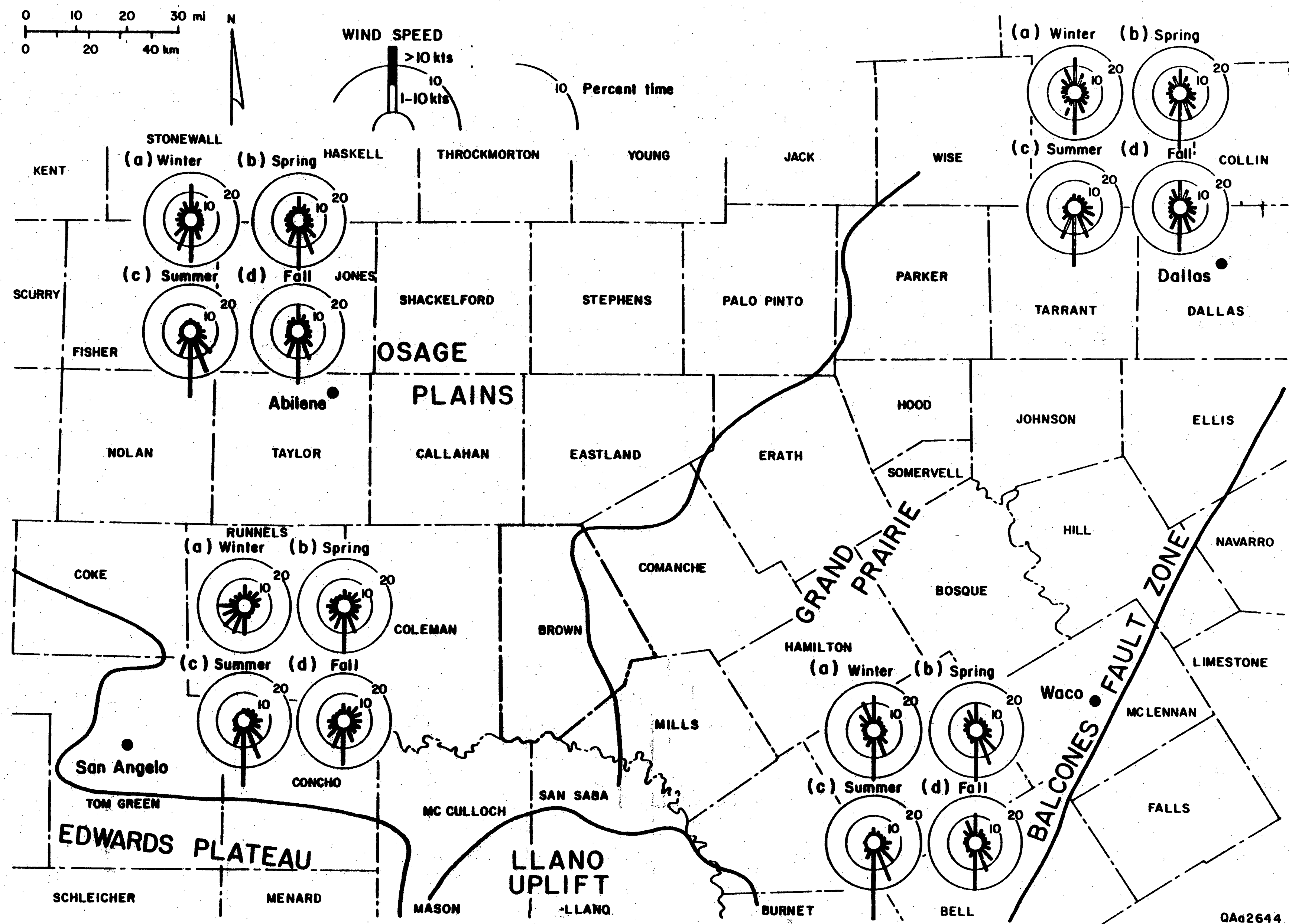


Figure 2. Map of north- and west-central Texas showing major physiographic provinces and seasonal wind roses in Abilene, San Angelo, Dallas, and Waco, Texas. Brown County boundary accented. Numbered circles on wind roses indicate percent of time wind blows.

(a)

(b)

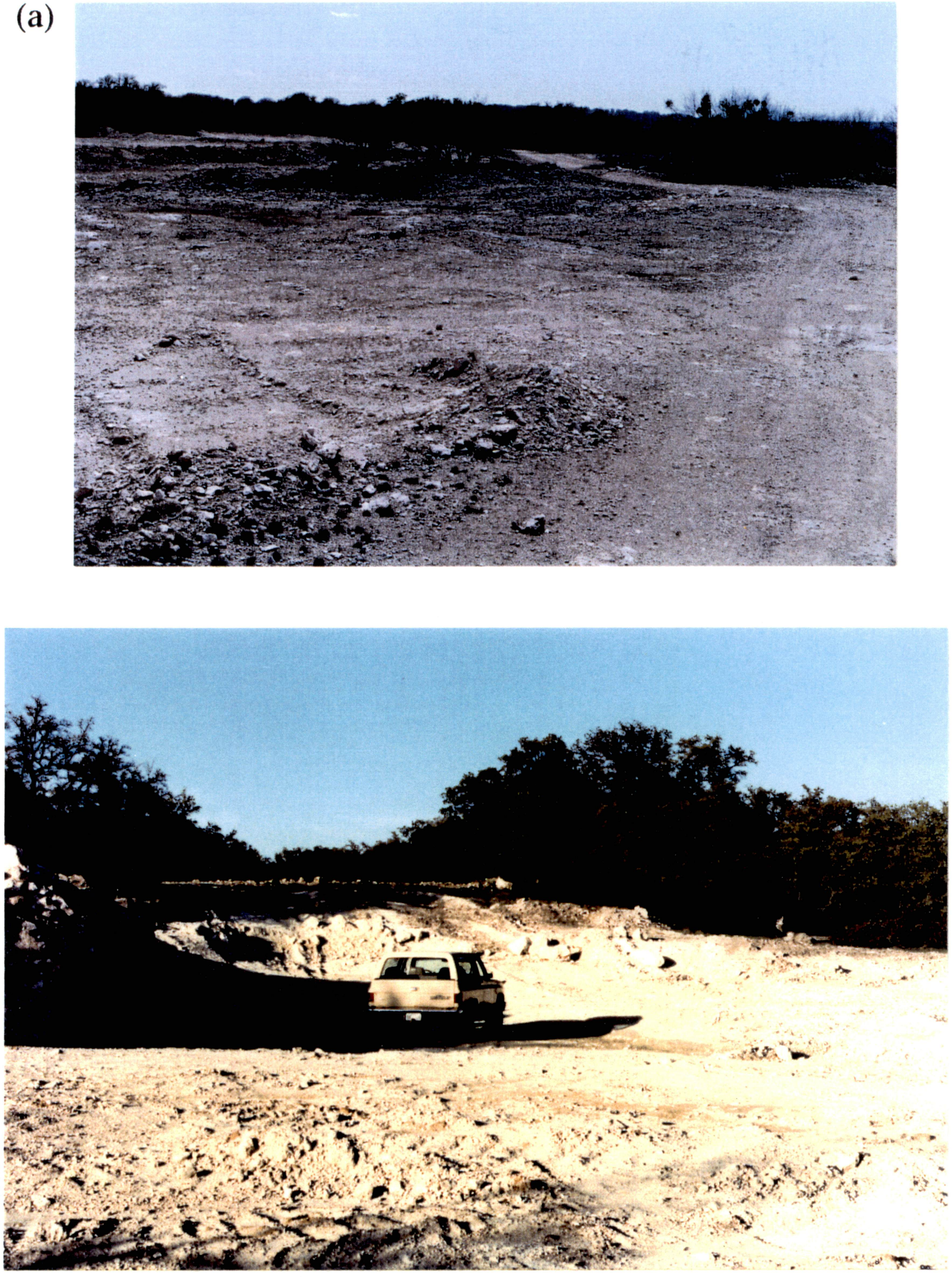


Figure 3. (a) Photograph of part of quarry (gravel pit) at top of Travis Peak Formation in northernmost part of original reservation, east of camp facilities (see plate NW); (b) photograph of part of quarry (gravel pit) at top of Travis Peak Formation in westernmost part of original reservation (second quarry to the south on plate NW).

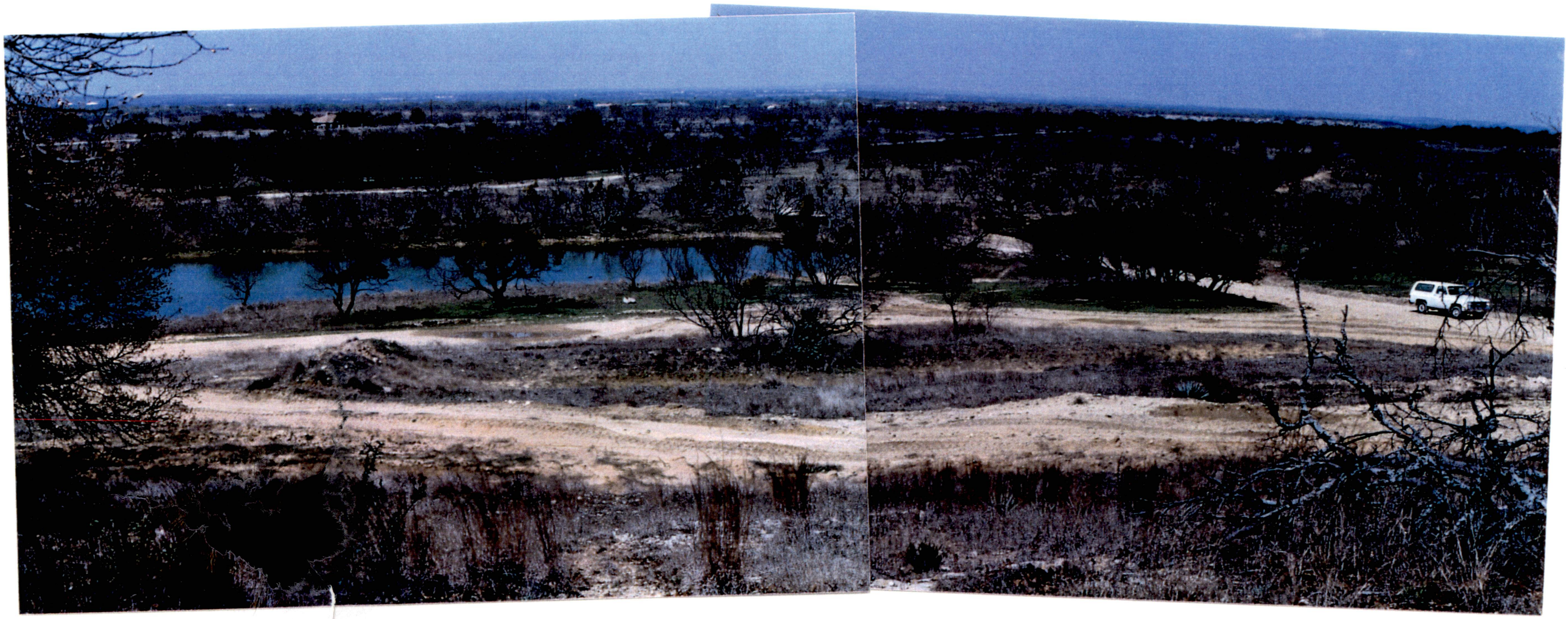


Figure 4. Photograph of pond north of quarry shown in figure 3a. Located in Strawn Group shales, this area shows the effects of heavy traffic.

Figure 5. Vehicle tracks in soil developed on Strawn Group: (a) early stage of degradation, (b) more advanced degradation (tracks 1.5 ft deep) containing small amount of pooled water, (c) quite advanced degradation showing signs of heavy traffic and much pooled water.

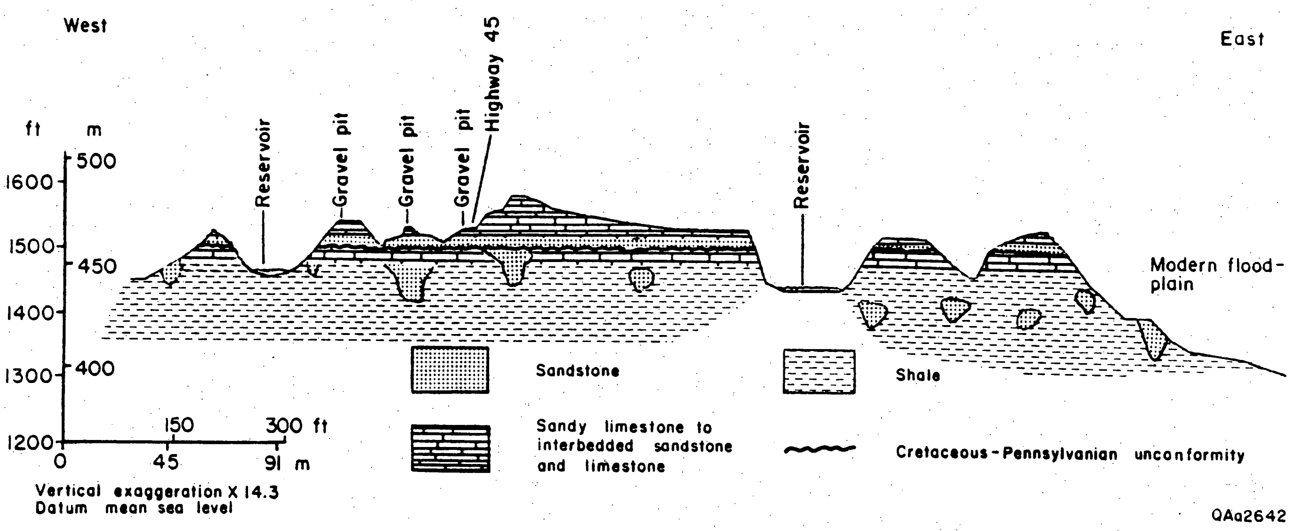


Figure 6. West-east geologic cross section W–E showing generalized distribution of rock types in Travis Peak Formation (above Cretaceous–Pennsylvanian unconformity) and Strawn Group (below unconformity). Location of Strawn sand lenses is schematic. Line of section shown in figure 1.

(a)

(b)

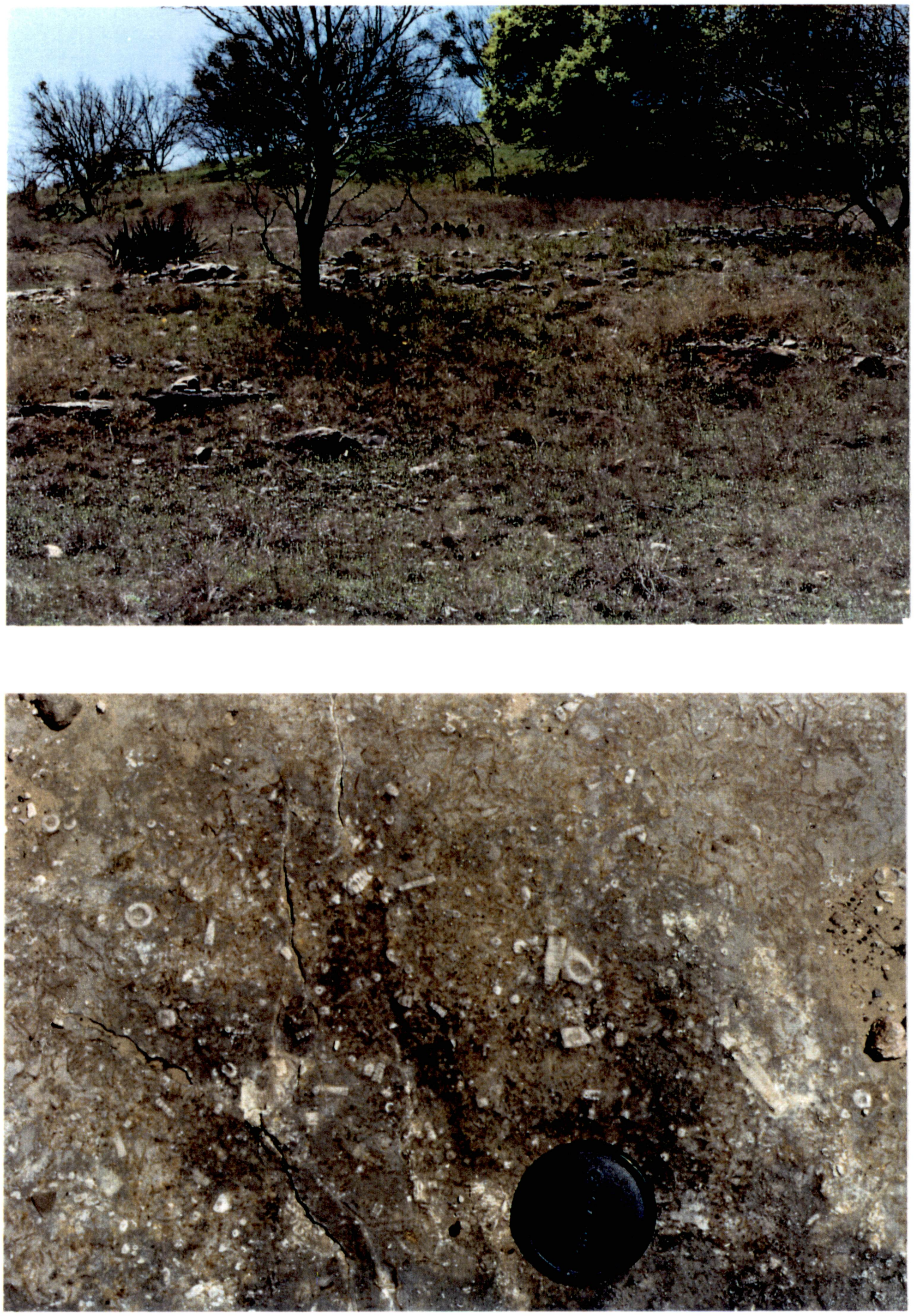


Figure 7. (a) Photograph of upper part of Strawn Group. Beds in foreground are sandstone and limestone. At the horizon in upper left part of photo is a limestone bench at the top of the Strawn. (b) Photograph of top of resistant fossiliferous limestone bed that forms top of bench.

Figure 8. Photograph of contact (arrow) between Travis Peak and underlying Strawn Group. Note slight divergence to left of Strawn beds (beneath arrow) and Travis Peak beds demonstrating angular unconformity. This is laterally equivalent to top of Strawn bench shown in figure 7a. Note that vehicle tracks up Travis Peak slope are shallow and stony, contrasting with deeper tracks in Strawn soils (figs. 4 and 5).

Figure 9. Photograph of well-cemented pebble conglomerate at base of Travis Peak Formation. Compass 2.75 inches in diameter.

Figure 10. Photograph of lowermost Travis Peak conglomerate (pebbly texture) that has a channel cut into top, which is filled by crossbedded sandstone. These are Cretaceous-age river deposits. Outcrop approximately 6 ft high.

Figure 11. Photograph of crossbedded channel sandstone unit, Travis Peak Formation. Most overlying rocks to the horizon are limestone. Outcrop approximately 5 ft high.

Figure 12. Photograph of Strawn Group shale that has fossils (crinoid stems) weathering from outcrop. Longest stem 4.75 inches long.

Figure 13. Photograph of sandstone-limestone couplets near top of Travis Peak Formation. Foreground sandstone; person standing next to limestone bed; receding slope behind person contains more sandstone having limestone present to horizon at the top of the Travis Peak Formation.

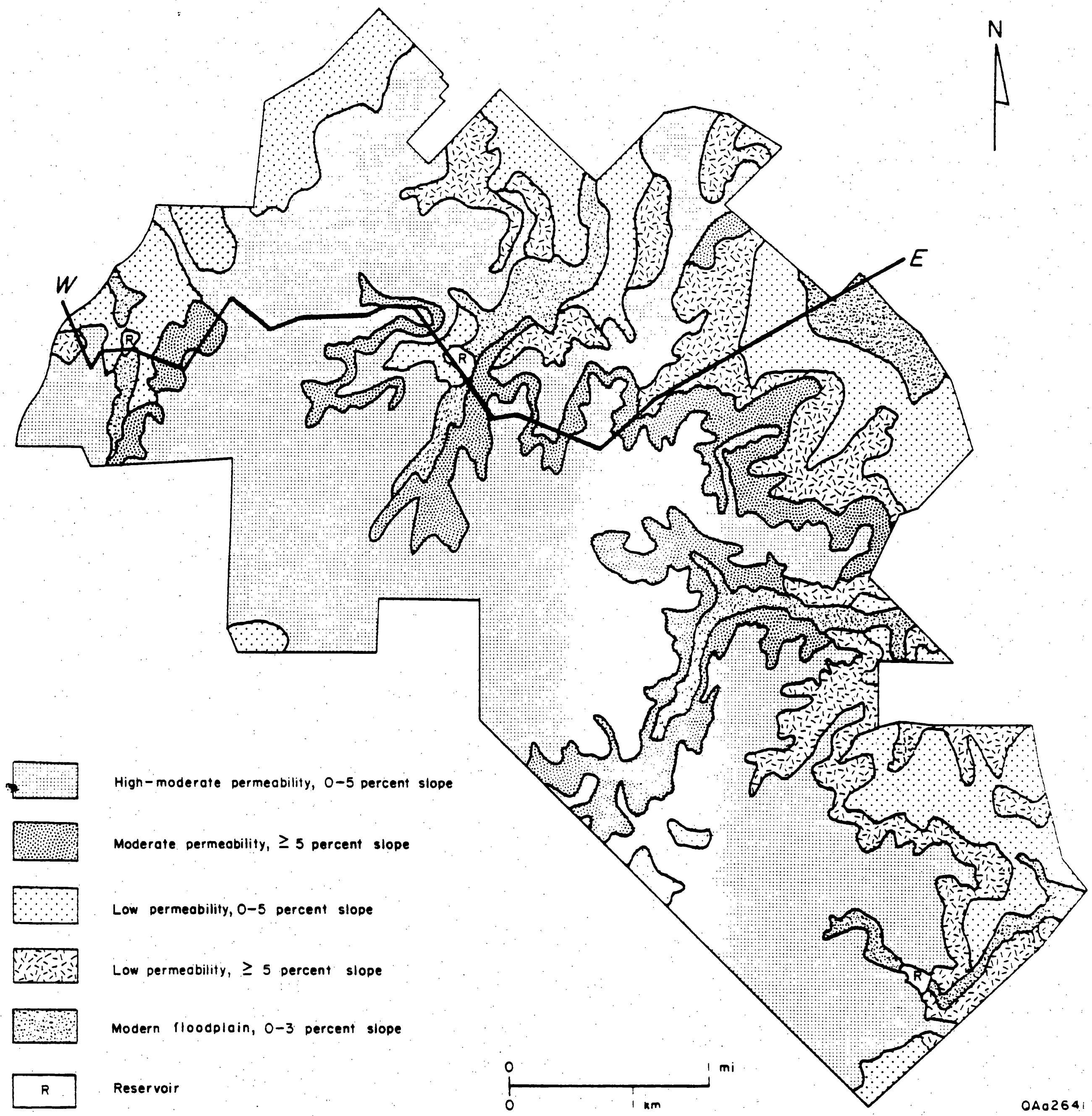


Figure 14. Generalized soil-distribution map. Ridges and adjacent slopes developed on Travis Peak rocks dominated by high-to-moderately permeable soils; lower areas low permeability soils developed on Strawn rocks and modern floodplains. Location of cross section W–E (fig. 6) same as that shown in figure 1.

Figure 15. Photograph of road across flowing stream. Runoff from heavy rain will wash abnormal amounts of sediment into stream from defoliated areas.

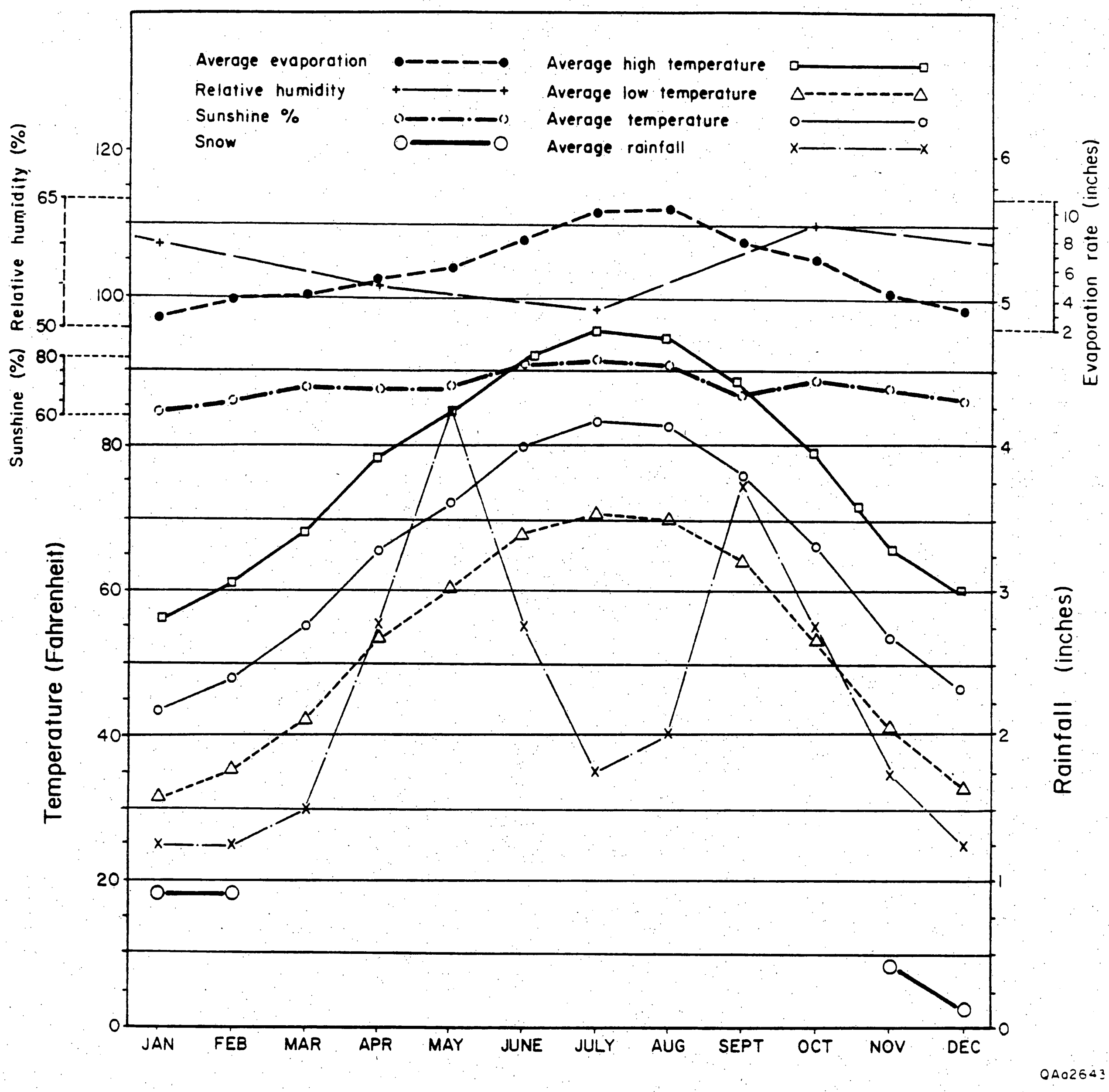


Figure 16. Climate chart for southern Brown County showing simultaneous display of monthly averages for eight climatic factors. Horizontal lines determine values along vertical axis.

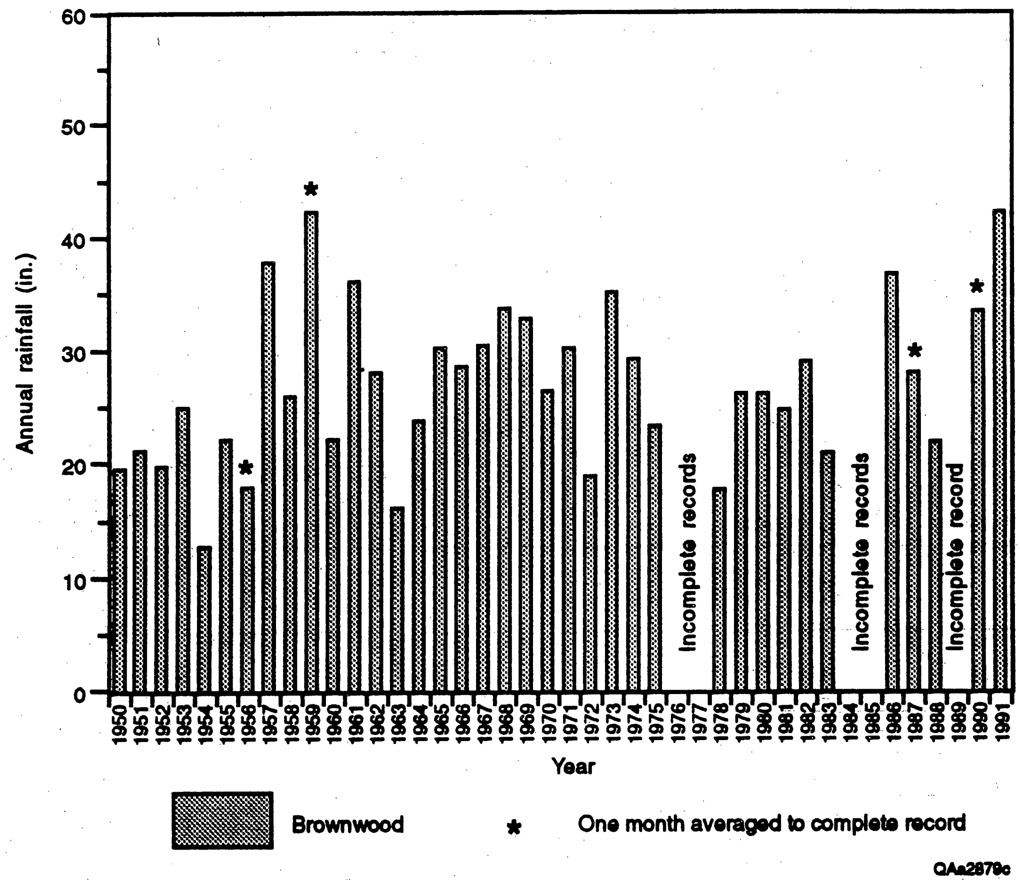


Figure 17. Graph of annual rainfall from 1950 through 1991, Brownwood, Texas.

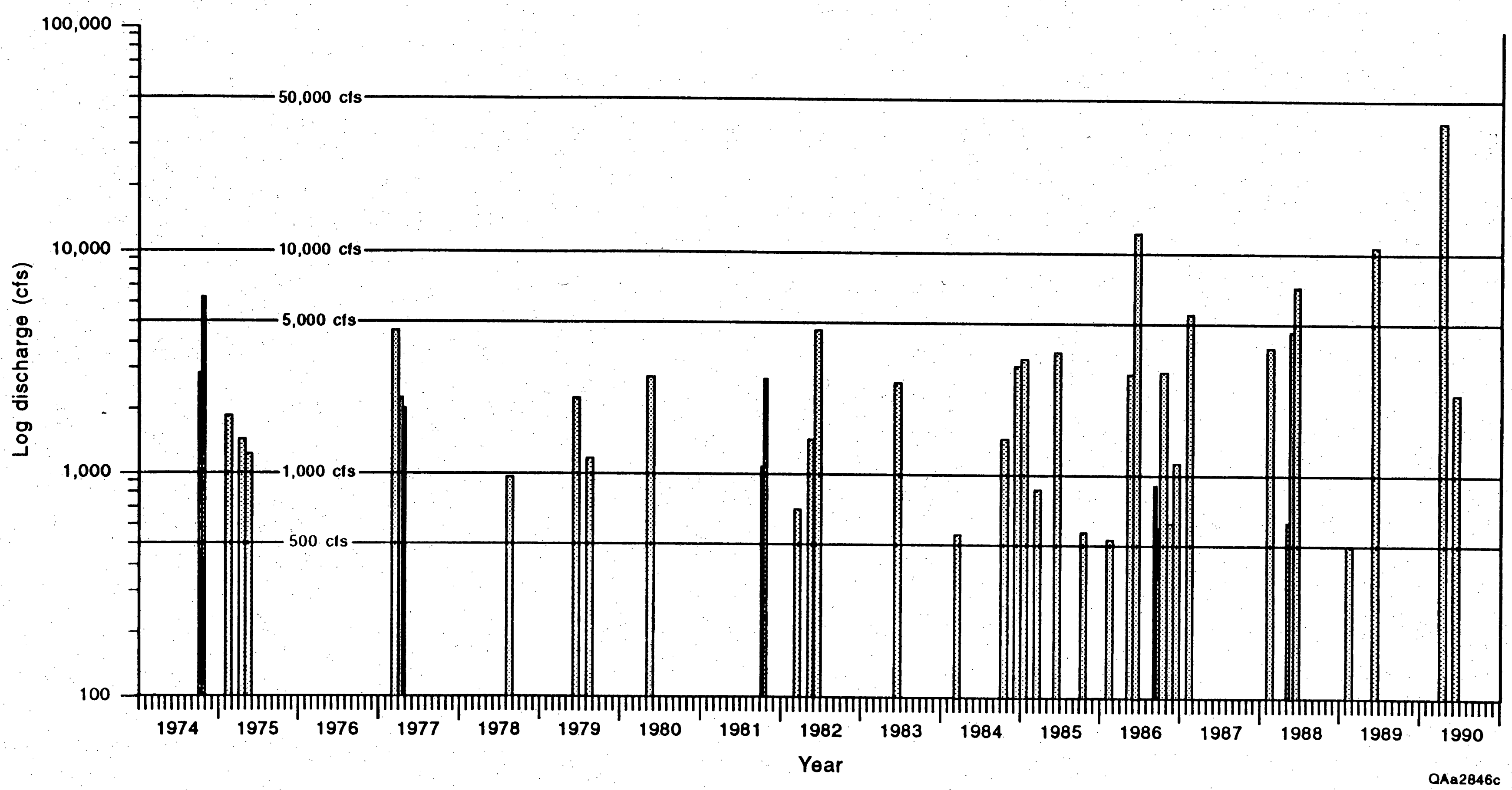


Figure 18. Graph of Pecan Bayou discharges individually exceeding 500 cubic ft per second, October 1974 through September 1990. Gauging station near Mullin, Texas. Note increase in frequency and volume of discharge since 1984. Peak discharges in 1989 (15,400 cfs) and 1990 (38,300 cfs) are record highs; 1968 held previous record (13,700 cfs).

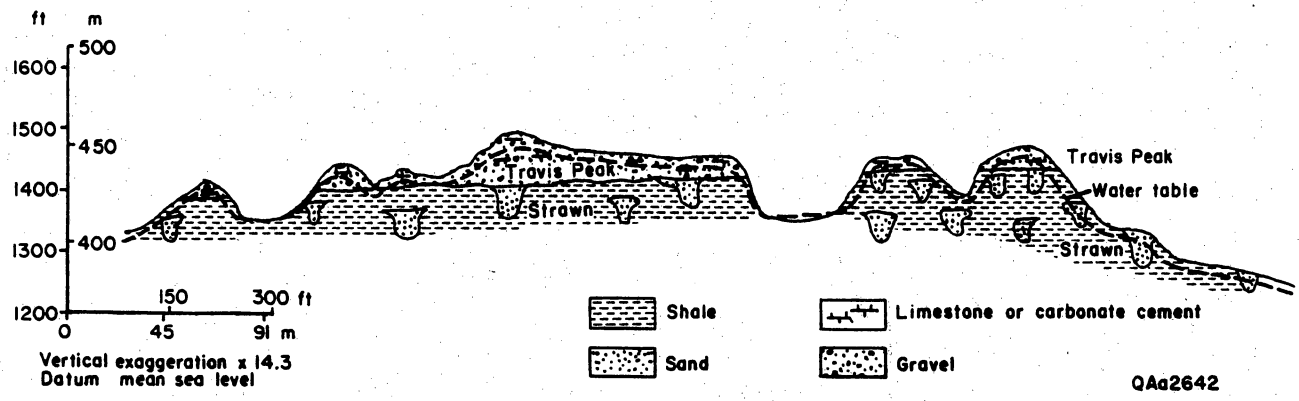
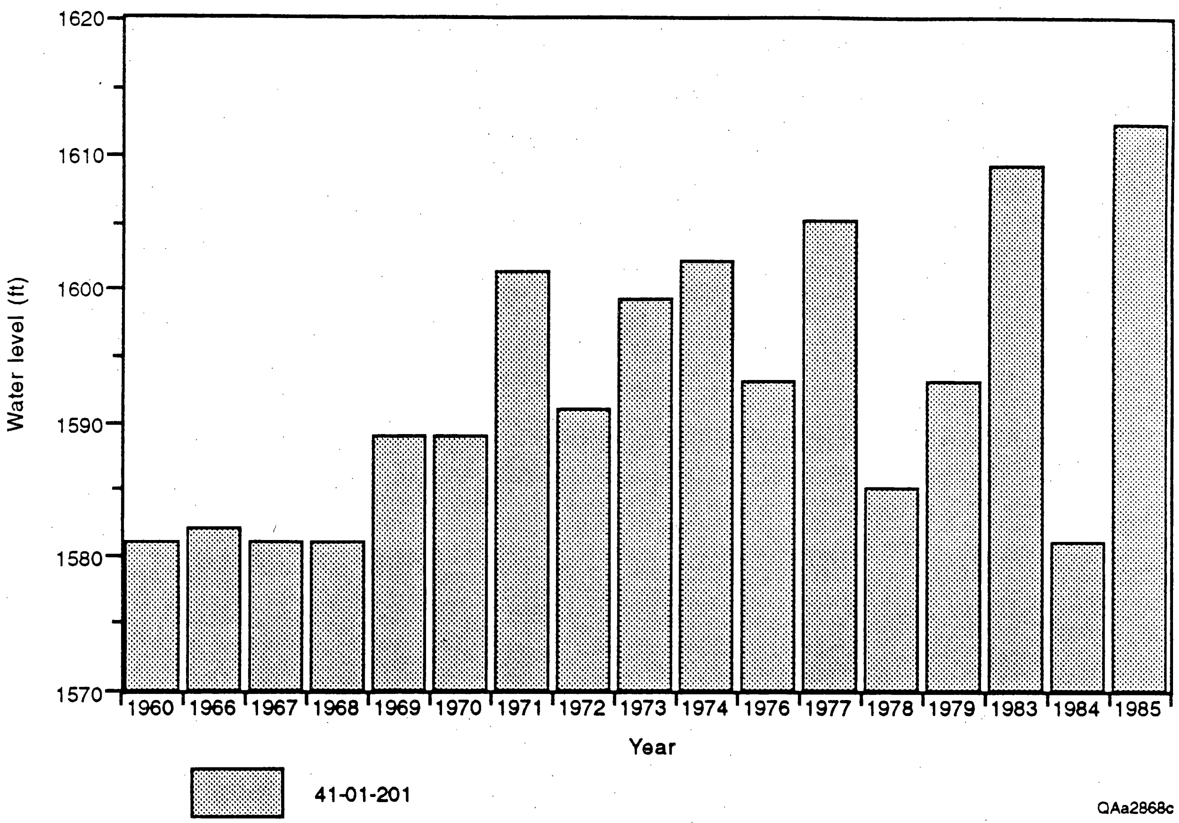


Figure 19. Schematic hydrologic cross section showing major Travis Peak and Strawn hydrologic units and probable average position of water table. Water is produced from sand-filled channels in the Strawn and from the Travis Peak generally.

(a)



(b)

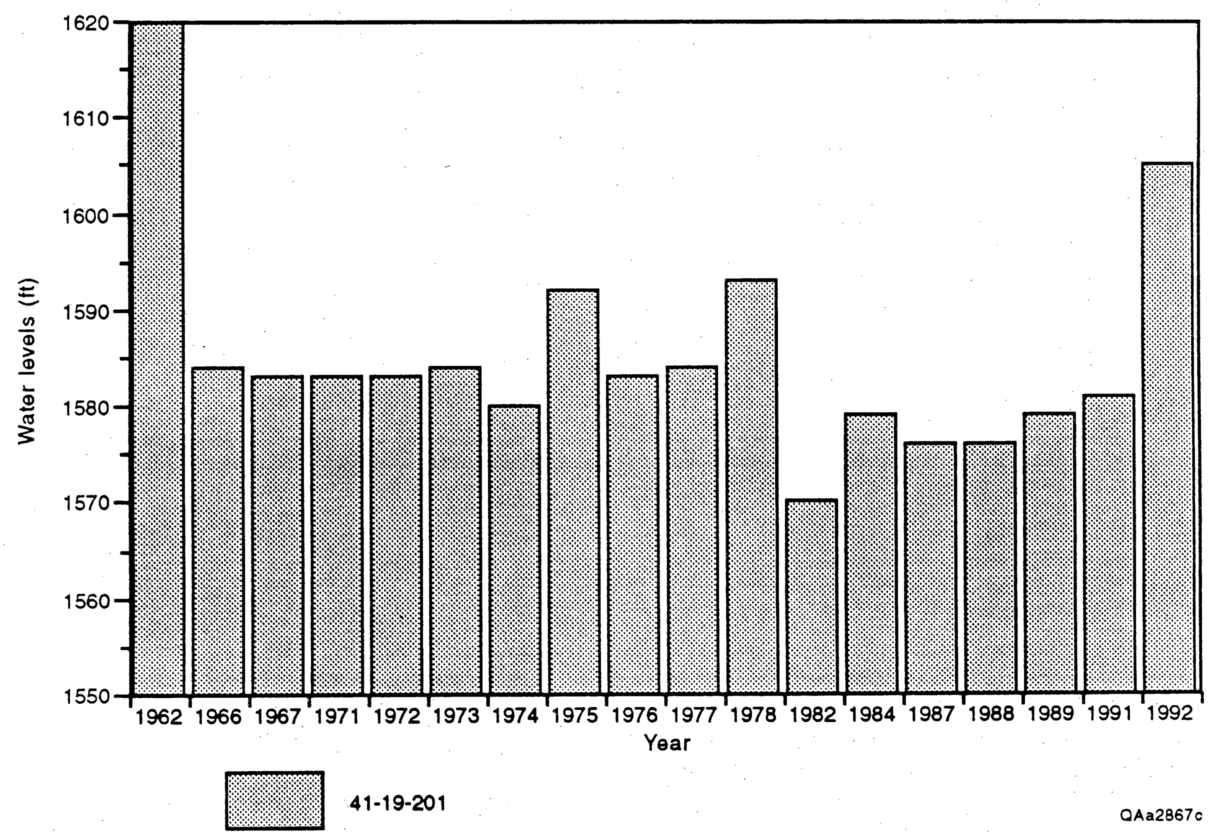


Figure 20. Annual average water levels of two wells completed in Travis Peak Formation, Brown County, Texas: (a) well 41-01-201, 1960–1985 and (b) well 41-19-201, 1962–1992.

Table 1. Water-quality data showing variations in total dissolved solids (TDS) and pH in Camp Bowie hydrologic units. Data from 81 Strawn wells and 10 Travis Peak wells.

Formation	TDS High	TDS Mean	TDS Low	pH High	pH Mean	pH Low
Strawn	4750	1260	104	8.2	7.6	6.0
Travis Peak	1247	705	420	8.2	7.7	7.1