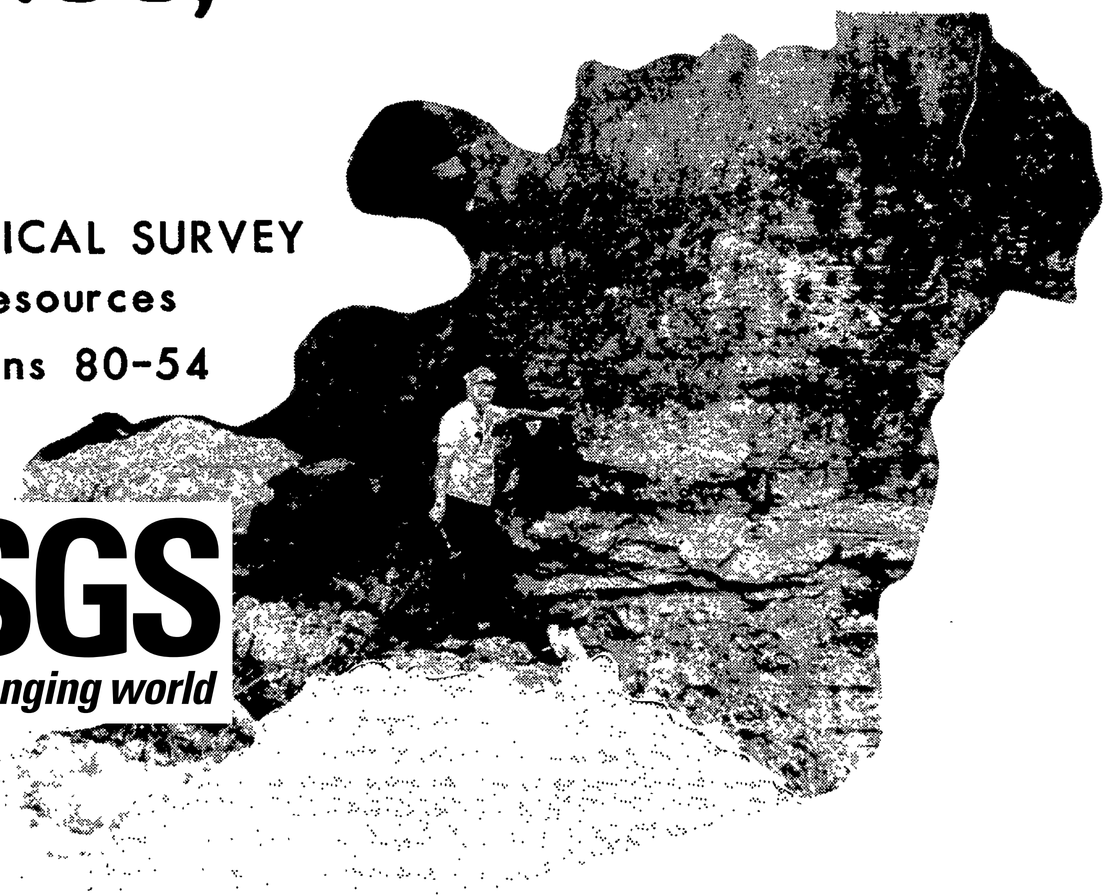
APPRAISAL OF HYDROLOGIC INFORMATION NEEDED IN ANTICIPATION OF LIGNITE MINING IN LAUDERDALE COUNTY, TENNESSEE



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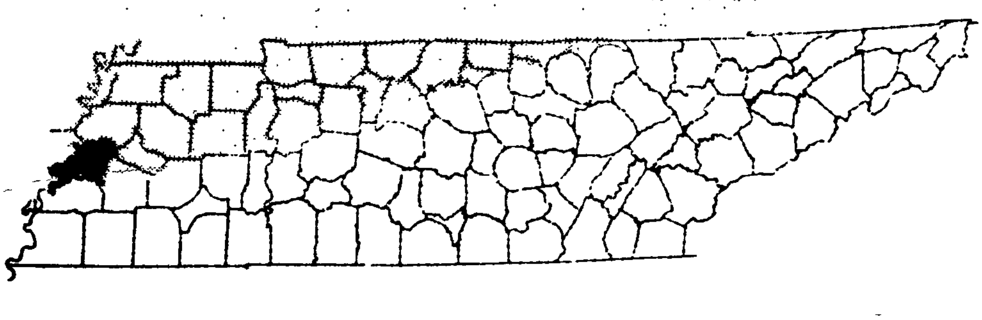

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By William S. Parks

U.S. GEOLOGICAL SURVEY

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Prepared in cooperation with the
TENNESSEE DEPARTMENT OF CONSERVATION,
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Cover Photograph

Dr. R. W. Lounsbury of
Memphis State University with hand
on top of lignite bed.

FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM OF UNITS

The following factors may be used to convert U.S. customary units (SI). Conversion factors are rounded to four significant digits, except the one with an asterisk after the last digit which is exact.

Multiply U.S. customary units	By	To obtain SI units
	Length	
inch (in)	25.4*	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	square hectometer (hm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
ton, short (2,000 lb)	0.9072	metric ton
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
cubic foot per second per	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile $(ft^3/s)/m^2$	0.109	cubic meter per second per square kilometer $(m^3/s)/km^2$
gallons per minute (gal/min)	0.06309	liter per second (L/s)
	6.309×10^{-5}	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Transmissivity	
cubic foot per day per foot $(ft^3/d)/ft$	0.0929	cubic meter per day per meter $(m^3/d)/m$

APPRAISAL OF HYDROLOGIC INFORMATION NEEDED IN ANTICIPATION OF LIGNITE MINING IN LAUDERDALE COUNTY, TENNESSEE

By William S. Parks

ABSTRACT

Lignite in western Tennessee occurs as lenses or beds at various stratigraphic horizons in the Coastal Plain sediments of Late Cretaceous and Tertiary age. The occurrence of this lignite has been known for many decades, but not until the energy crisis was it considered an important energy resource. In recent years, several energy companies have conducted extensive exploration programs in western Tennessee, and tremendous reserves of lignite have been found.

From available information, Lauderdale County was selected as one of the counties where strip-mining of lignite will most likely occur. Lignite in this county occurs in the Jackson and Cockfield Formations, undivided, of Tertiary age. The hydrology of the county is known only from regional studies and the collection of some site-specific data. Therefore, in anticipation of the future mining of lignite, a plan is needed for obtaining hydrologic and geologic information to adequately define the hydrologic system before mining begins and to monitor the effects of strip-mining once it is begun.

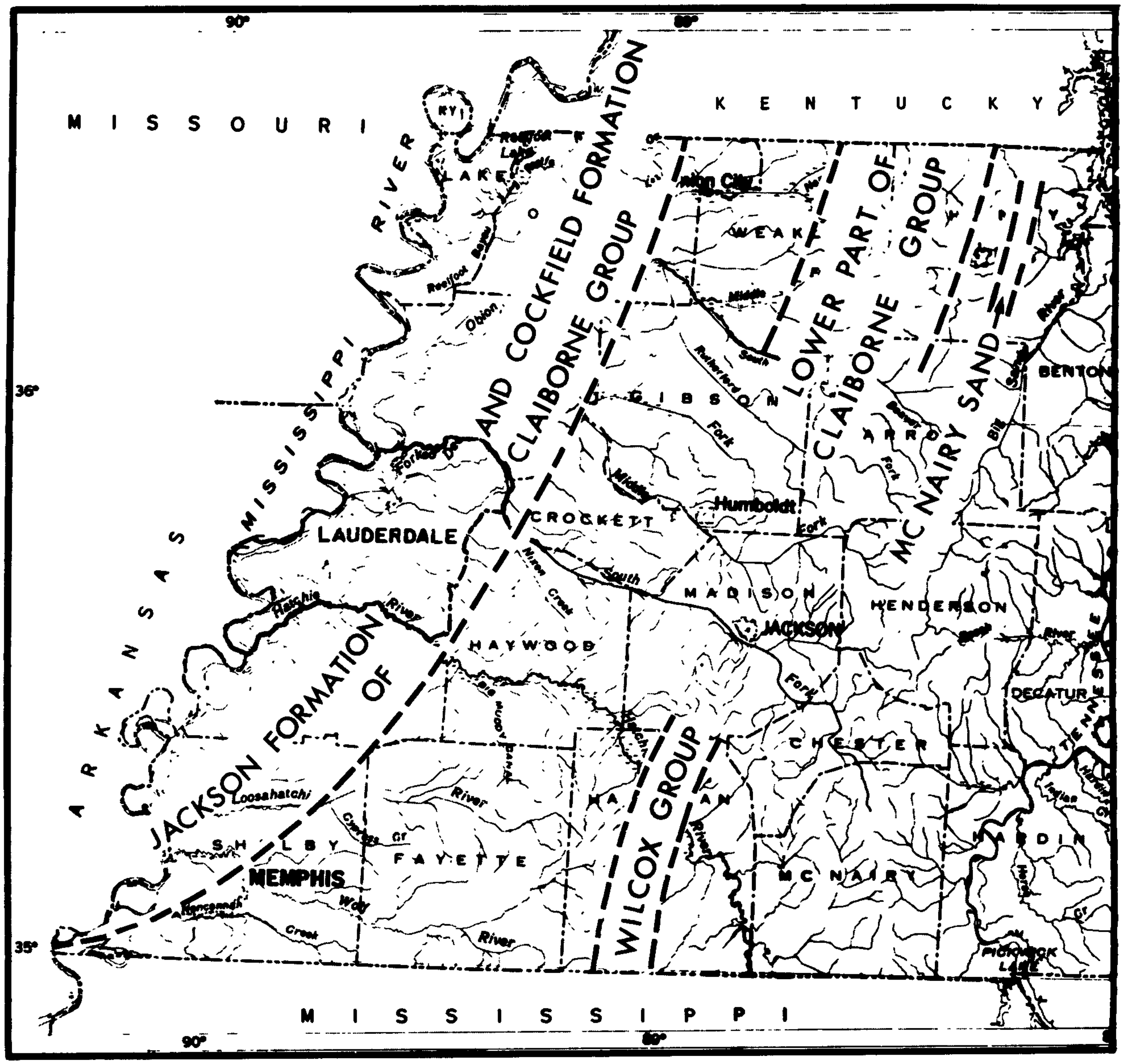
For this planning effort, available hydrologic, geologic, land use, and associated data were located and compiled; a summary description of the surface and shallow subsurface hydrologic system was prepared; the need for additional baseline hydrologic information was outlined; and plans to monitor the effects of strip-mining were proposed. This planning approach, although limited to a county area, has transferability to other Coastal Plain areas under consideration for strip-mining of lignite.

INTRODUCTION

Lignite in Western Tennessee

Lignite occurs as lenses or beds at various stratigraphic horizons in the Coastal Plain sediments of western Tennessee. The principal geologic units in which lignite is at or near the surface are the McNairy Sand of Late Cretaceous age and the Wilcox Group, Claiborne Group (including the Cockfield Formation), and Jackson Formation of Tertiary age.

Figure 1 shows the principal areas where lignite is known to be relatively common. Lignite in the McNairy Sand occurs in association with clay deposits east of Paris in Henry County. Lignite in the Wilcox Group may be present at many places along the outcrop belt, but is probably more common in Hardeman County where the formation is thickest and the outcrop belt is broadest. Lignite in the lower part of the Claiborne Group is present at many places, but is best known from beds encountered in mining for commercial ball clay in Henry and Weakley Counties. Lignite in the Jackson and Cockfield Formations is present in the western part of western Tennessee--principally in Lake, Obion, Dyer, Lauderdale, Tipton, and Shelby Counties.



Base map by U.S. Geological Survey and Tennessee Valley Authority

EXPLANATION

Areas shown are very generalized and are those where lignite localities seem to be common on the basis of available information. They do not indicate the outcrop areas for the particular formations. See text for additional details.

Figure 1.--Principal areas in western Tennessee where lignite is known to be relatively common and location of Lauderdale County.

The occurrence of lignite in western Tennessee probably has been known since the first explorers and settlers traveled through the area. Over the years, lignite has been more or less a curiosity to the general public as evidenced by accounts of finds of "coal" or lignite published in the newspapers from time to time (Nelson, 1912, p. 157).

Geologists and other scientists also have long known about the lignite in western Tennessee. Safford (1869, p. 428-431, 498-499) in an early report on the geology of Tennessee described exposures of lignite in Shelby and Tipton Counties. Nelson (1912) in a short report on lignite and lignitic clays gave background information on lignite as compared with coal and described a reported occurrence in Henry County. Roberts and Collins (1928, p. 124-127, 146-148, 327-336) in an unpublished report on the Tertiary and Quaternary geology of western Tennessee described lignite in Shelby, Tipton, and Hardeman Counties and included analyses. Born (1936, p. 68) in a summary of the state's mineral resources gave a brief description of the lignite and stated that it had been reported in Lake, Obion, Dyer, Lauderdale, Tipton, and Shelby Counties. Whitlatch (1940, p. 67-70, 74, 92, 115, 120, 121, 125, 182, 259, 265, 305, 314, 315) in a report on the clays of western Tennessee included much additional information on the occurrences of lignite in association with the clays. Parks and Lounsbury (1975, p. 49-51) in a field trip guide to the environmental geology of Memphis gave a detailed measured section which includes two lignite beds in southwestern Tipton county.

Lignite in western Tennessee, historically, has been considered of little or no value. Safford (1869, p. 499), Roberts and Collins (1928, p. 336), and Born (1936, p. 68) discouraged consideration of western Tennessee lignite as an important energy resource. Until recently, this thinking has remained prevalent among workers inventorying the state's mineral resources in view of the tremendous coal reserves present in eastern Tennessee. Reasons for past discouragement of thinking of lignite as an important energy resource are:

(1) a lack of demand for lignite as a fuel in view of other available fuels--wood, coal, and natural gas;
(2) the cover of loess and fluvial deposits which obscures the Upper Cretaceous and Eocene bedrock in extensive areas, making exploratory drilling necessary to determine the areal extent and thickness of the lignite;
(3) the mistaken concept based on outcrops and available bore hole records that the lignite occurs in localized deposits;
(4) the relatively low fuel value and high moisture and ash content of lignite; and
(5) the impurity of most lignites investigated along with the common mistake of reports of lignite turning out to be lignitic clays.

To some, lignite has been considered almost a nuisance (Tennessee Department of Conservation, 1977). Deposits exposed to air dry out and tend to undergo spontaneous combustion, producing a smoky, irritating fire; lignite burns are known to have occurred at several different localities in Mississippi (Williams, 1976, p. 12). Lignite bedded with commercial clay deposits has been considered overburden and has been removed and discarded as mine waste. In drilling for water, lignite is avoided in setting well screens because water associated with lignite imparts an unpleasant taste and color to well water.

With the advent of the energy crisis, new thinking has come about in considering the lignite of the Gulf Coastal Plain as an important future energy resource. In the past several years, energy companies have engaged in exploration programs in Texas, Louisiana, Arkansas, Mississippi, Tennessee, and Alabama.

Although specific data from these exploration programs is considered to be proprietary information, news releases, reports by the energy companies, extensive close-spaced test drilling and coring, and leasing of large acreages indicate that the energy companies have found very sizable deposits of potentially minable lignite in western Tennessee. In fact, Luppens (1978) of Phillips Coal Company, in a paper on exploration for Gulf Coastal Plain lignite deposits presented at the Second International Coal Exploration Symposium, stated that preliminary estimates of lignite reserves for Tennessee totaled 1.0 billion tons. Luppens also stated that all of these reserves are in the Wilcox and Claiborne and that typical seam thickness ranges from 2 to 9 ft. Much of Phillip's exploration program has been directed toward lignite in the Jackson and Cockfield Formations--principally in Lauderdale and Dyer Counties.

Not much published or in-file data is available on the characteristics of the "purer" lignite in western Tennessee. Luppens (1978), however, gives a "typical as-received proximate analysis" for lignite in the Claiborne. These are as follows:

Moisture content	45.41 percent
Ash	11.89 "
Volatile matter	26.56 "
Fixed carbon	16.14 "
Sulfur	0.59 "
Heating value	5379 Btu/lb

Wet, the lignite is high in moisture and volatile content; dry, it is high in ash. The high volatile content makes it readily convertible into gas or liquid form. But, the high moisture content of the wet and susceptibility to spontaneous combustion of the dry present problems in transportation and storage. Western Tennessee lignite is low in sulfur, making it desirable for steam electric generating plants.

Because it is not economically feasible to transport lignite long distances, utilization of this fuel will probably be near mine operations. Possible uses include steam-electric generation, gasification, distillation of liquid hydrocarbons, and extraction of waxes (Terry and others, 1979a, p. 4).

Sites for electric generating plants on the Mississippi River have been under consideration for many years. One site investigated by TVA is at Fulton in Lauderdale County (Tennessee Valley Authority, 1952). Although it was planned to use coal barged from Illinois and western Kentucky as fuel at this plant, sizable deposits of lignite in this area would be a convienent source of an alternate fuel.

Purpose and Scope of this Project

Outside of the Memphis area, the hydrologic system in western Tennessee is known only in general terms. The hydrology and geology are described in reports of regional scope and some site-specific studies; some ground-water and surface-water data are being collected on a continual basis as part of the state-wide hydrologic network. Nevertheless, much additional hydrologic and geologic information would be needed to adequately define the hydrologic system of Lauderdale County in anticipation of the future strip-mining of lignite.

The purpose of this project is to plan a comprehensive study of the hydrology of Lauderdale County as related to future strip-mining of lignite. Elements of this planning effort are to:

(1) locate and compile hydrologic, geologic, land use, and associated data for use in planning the study;
(2) prepare a description of the surface and shallow subsurface hydrologic system in Lauderdale County in terms of what is presently known;
(3) research background information concerning lignite and coal hydrology and other areas undergoing strip-mining;
(4) consider the impact of strip-mining lignite on the hydrologic system as presently known for Lauderdale County;
(5) ascertain what baseline hydrologic and geologic information are needed to adequately define the hydrologic system before mining begins; and
(6) propose a plan for the collection of hydrologic data to monitor the effects of strip-mining once it is begun.

Although this project is limited to a county area, the planning approach has transferability to other areas where strip-mining of lignite is under consideration. The project is regional in scope in that the environmental concerns of interstate streams and aquifers are involved and the planned study, if undertaken, would provide important information needed in refining concepts of the hydrologic system in this part of the Mississippi embayment.

The information provided in this report would be useful to those Federal and State agencies, energy companies, and private consultants involved in conducting environmental studies or preparing environmental impact statements. In addition, this report includes a summary of available information about the hydrology and geology of Lauderdale County which will be useful to those concerned with other water resources problems.

In preparing this report consideration was given to the need for geologic and hydrologic information to satisfy the minimum requirements for surface-mining permit applications as given by the U.S. Department of the Interior, Office of Surface Mining, Reclamation and Enforcement (1979, p. 15354-15357).

Location and Size of Project Area

Lauderdale County is in the western most tier of counties in western Tennessee about midway between the Mississippi and Kentucky state lines. Ripley, the county seat, is at about lat 35°44'45" N., long 89°31'50" W. Figure 1 shows the location of Lauderdale County.

The county covers an area of 477 mi^2 and is very irregular in shape. It is bounded on the north by Dyer, on the east by Crockett and Haywood, on the south by Tipton Counties in Tennessee and on the west by Mississippi County in Arkansas. Natural features that form part of the boundaries are the Mississippi River on the west, the Obion and Forked Deer Rivers on the northwest, the South Fork Forked Deer River on the northeast, and the Hatchie River on the south.

Population and Land Use

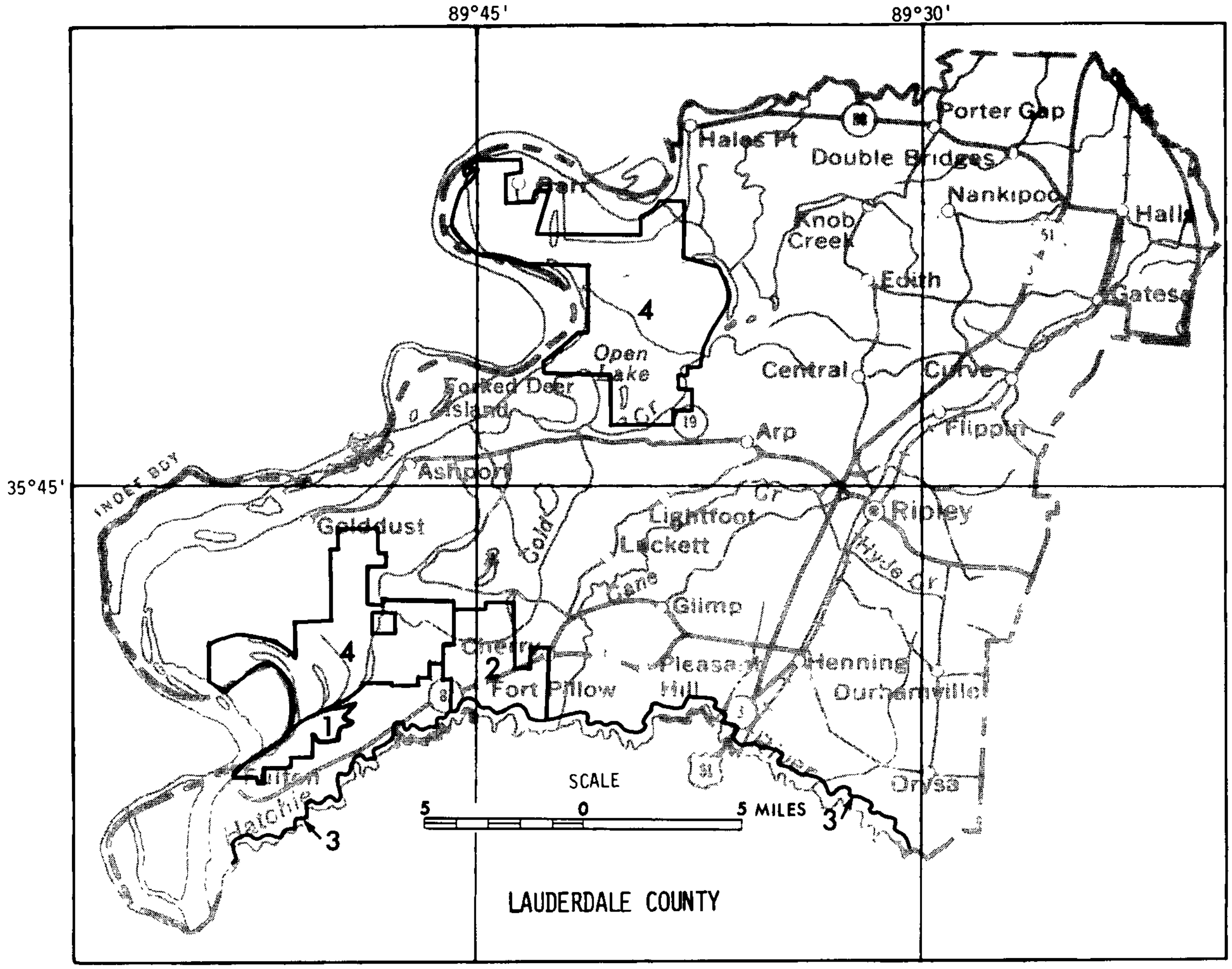
The population of Lauderdale County, according to the 1970 "Census of Population," was 20,271 of which 15,477 or 76.4 percent was considered to be rural. The only area considered to be urban is the incorporated town of Ripley (population 4,794). Other incorporated towns are Halls (2,323), Henning (605), and Gates (523). These towns are along U.S. Highway 51 and the Illinois Central Railroad, which cross the central part of the county in a northeast-southwest direction.

The area of the county, according to the 1974 "Census of Agriculture," consists of approximately 305,408 acres of which 204,788 acres or 67.1 percent are in farm land. Farms total 844 and average about 243 acres in size. A decrease in number and increase in size of farms and an increase in population of towns follows the population trend of movement from rural to urban areas or towns.

Aside from the land in the four incorporated towns, other areas designated for special land use which may need consideration in anticipation of future strip-mining of lignite are: (1) Fort Pillow State Historic Area, (2) Fort Pillow State Prison Farm, (3) Hatchie State Scenic River, and (4) Anderson-Tully Wildlife Management Areas. These special land-use areas comprise an estimated 40,729 acres or about 13.3 percent of the county area. Figure 2 shows their location and relative size.

Fort Pillow State Historic Area consists of 1,650 acres in the southwestern part of the county. This part was established to preserve the earthworks, artifacts, and general area surrounding the site of Fort Pillow--a Civil War fort. The management of this park is under the Tennessee Department of Conservation, Division of Parks and Recreation. In recent years, a park headquarters, museum, and other improvements have been built, and in 1977 the park was opened for use by the public. On May 30, 1974, the site of Fort Pillow was designated a "National Historic Landmark" by the U.S. Department of Interior.

Fort Pillow State Prison Farm consists of 5,779 acres in the southwestern part of the county. This farm is worked by the inmates of Fort Pillow State Prison and provides food for the prison population and



EXPLANATION

1 - Fort Pillow State Historic Area
2 - Fort Pillow State Prison Farm
3 - Hatchie State Scenic River
4 - Anderson-Tulley Wildlife Management Area(s)

Figure 2.--Location and relative size of special land-use areas.

financial support for the institution. The management of the farm is under the Tennessee Department of Corrections, Division of Agri-Industry. In addition to the prison facility, the farm has many buildings and other improvements related to the farming activity.

Hatchie State Scenic River established in 1969 by the Tennessee Legislature will consist of an estimated 3,300 acres in the southern part of the county, if the maximum easement of no more than 1,000 ft from the center of the river on each side is acquired. This easement will include the Hatchie River channel and a large part of the flood plain. The Hatchie River is one of the few remaining streams in Tennessee which is relatively unchanged by man's activities. Although many of the tributaries were dredged during 1917-26 (Speer and others, 1965, p. H8), the main channel and flood plain have not been subject to channelization and agricultural development. The Tennessee State Scenic Rivers Act of 1968 (Tennessee Code Annotated 11-1400) specifies certain restrictions on the use of scenic river areas, including mining and pollution from mining. Various aspects related to the future management of the Hatchie State Scenic River are being investigated by the Hatchie State Scenic River Task Force under the Scenic Rivers Program of the Tennessee Department of Conservation.

Anderson-Tully Wildlife Management Area(s) consist of two tracts of land comprising an estimated 30,000 acres in the western part of the county. These areas--approximately 18,000 acres in the northern tract in the vicinity of Open Lake and 12,000 acres in the southern tract near Fort Pillow State Historic Area--are owned by Anderson-Tully Company, a lumber concern. These acreages represent the largest single tracts of delta bottom-land hardwood timber left in Tennessee (Frank Zerfoss, oral commun., 1979). Presently, the Anderson-Tully property is under lease to the Tennessee Wildlife Resources Agency for the purpose of wildlife management.

AVAILABILITY OF HYDROLOGIC INFORMATION

Previous Investigations

Glenn (1906, p. 91-96) and Wells (1933, p. 210-219) in reports describing the ground-water resources in western Tennessee on a county-by-county basis gave general information about the stratigraphy and the ground-water supplies in Lauderdale County. Although the stratigraphy is now out-of date insofar as nomenclature is concerned, these reports provide historical data about early ground-water supplies and some information about the geology. Lanphere (1955) described the geologic source and chemical quality of public ground-water supplies in western Tennessee. This report (p. 38-39, 40, 57-58) includes details concerning the water-supply systems at Halls, Henning, and Ripley. Strausberg and Schreurs (1958, pl. 1, 2, 4; tables 4, 5) in an unpublished report on the ground-water resources of the Mississippi Valley of Tennessee included the locations of some wells in the Mississippi alluvial deposits in Lauderdale County and some data on water levels and quality of water.

Milhous (1959) compiled driller's logs and sample descriptions for Tennessee by counties. He gave logs for three early oil-test wells in the county (p. 233-239). Krinitzsky and Wire (1964) described the ground water in the alluvium of the Lower Mississippi Valley. They presented contour maps of the Tertiary surface and piezometric-surface maps for the Mississippi alluvial deposits. Moore (1965, pl. 1-8, fig. 4) in a report on the geology and hydrology of the Claiborne Group in western Tennessee included structure-contour maps, geophysical cross-sections, and a fence diagram along with maps of the apparent and potential coefficient of transmissibility, the down-dip changes in chemical quality of water, and the piezometric surface in the "500-foot" sand. These illustrations provide some general information about the Claiborne aquifers in Lauderdale County.

Speer and others (1965, table 2) in a report on the low-flow characteristics of streams in the Mississippi embayment in Tennessee, Kentucky and Illinois gave data concerning South Fork Forked Deer River at Chestnut Bluff, Cold Creek near Arp, Cane Creek at Ripley, and Cane Creek near Cherry. The Tennessee Department of Public Health (1964-65) published a ground-water survey of western Tennessee. Their report (table 18) includes a summary of the water-supply system at Ripley and gives chemical analyses and radiological data of composite raw water sampled in 1964-65. Moore and Brown (1969) detailed information on the stratigraphy and ground-water resource gained by a 3,183-ft test hole drilled into the Paleozoic rock on property within Fort Pillow State Historic Area. This report introduces some new nomenclature for the subsurface geologic units of western Tennessee and re-evaluates certain interpretations presented by Moore in his 1965 report.

Topographic and Geologic Maps

Lauderdale County is covered by 7.5-minute (scale 1:24,000) topographic quadrangles prepared and published by the Geological Survey. Figure 3 is part of the "Index to Topographic Maps of Tennessee", dated May 1978. The county is included on all or part of 20 quadrangles, as follows:

Armorel	1972	Chestnut Bluff	1952
Chic	1972	Osceola	1972
Knob Creek	1972	Golddust	1972
Fowlkes	1972	Ft Pillow	1972
Bonicord	1952	Ripley South	1972
Luxora	1972	Durhamville	1964
Rosa	1972	Nodena	1972
Open Lake	1972	Gilt Edge	1972
Ripley North	1972	Gift	1972
Gates	1952	Turnpike	1964

Most of the county is also included on all or part of five 15-minute (scale 1:62,500) topographic quadrangles as follows:

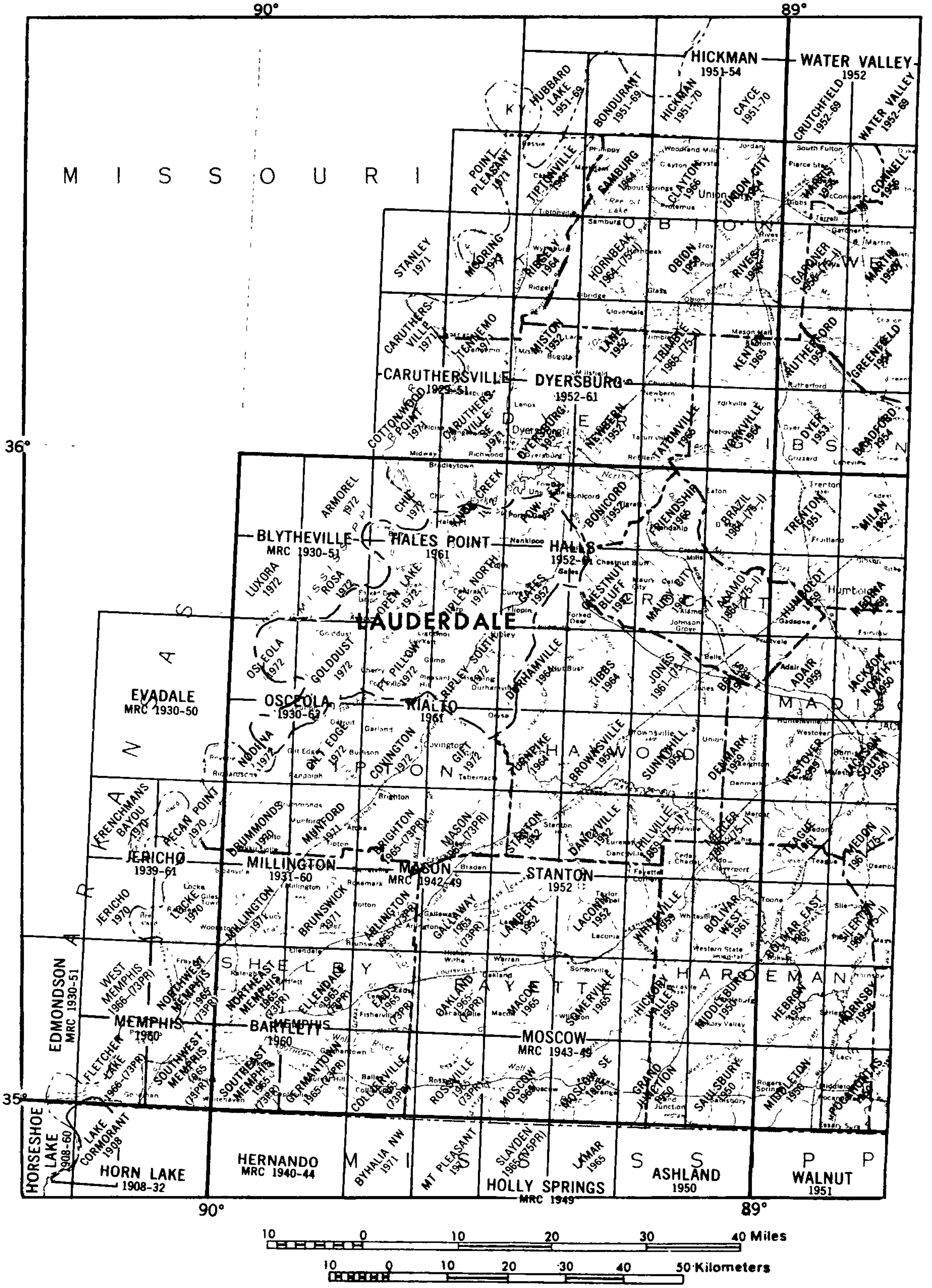


Figure 3.--Topographic quadrangles available (modified from U.S. Geological Survey "Index to Topographic maps of Tennessee," May 1978).

Blytheville	1930-51	Osceola	1930-63
Hales Point	1961	Rialto	1961
Halls	1952-61		

Detailed 15-minute geologic quadrangles are available for most of the Mississippi Alluvial Plain in Lauderdale County. These maps by Saucier and others (1964-78) were prepared and published by the U.S. Army Engineer Water-ways Experiment Station as a part of a geological investigation of the St. Francis River basin. Quadrangles including areas in the county are: (1) Blytheville, Ark.-Mo.-Tenn.; (2) Hales Point, Tenn.-Ark.; (3) Osceola, Ark.-Tenn.; and (4) Rialto, Tenn. The Halls, Tenn. quadrangle, which includes a small part of the Alluvial Plain, was not published as a part of the investigation.

No detailed geologic maps are available for the upland areas of Lauderdale County. The latest geologic map which covers the county is the "Geologic Map of Tennessee" (scale 1:250,000) by Hardeman and others (1966), published in four sheets. The west sheet for western Tennessee provides a very generalized geologic map of the county area.

Ground-Water Data

Only very general information and some site-specific data are available concerning the ground-water hydrology of Lauderdale County. Much of this information was collected as a result of regional studies of the principal aquifers and inventories of water supplies. Except for water-well records and water-use data being collected by the Tennessee Division of Water Resources (TDWR), little specific information regarding the ground-water resource has been collected over the past decade.

Well Records

The Geological Survey files contain schedules for about 50 wells in Lauderdale County drilled between 1929 and 1965. Most of these wells were inventoried in the late 1950's and early 1960's. Since 1963, however, records of approximately 600 wells have been submitted to the TDWR by water-well contractors. The locations of these wells have been provided by the drillers to TDWR on county maps (scale 1:125,000). About 20 percent of these records include a log of the formations penetrated. Land-surface altitudes and aquifer identifications are not indicated on most of these records.

Experience in working with driller's records for other areas in western Tennessee has shown that, although the well data is fair to good, the locations and formation logs are mostly fair to poor. Experience also has shown that many more wells probably exist which have not been inventoried, and the records for these wells would have to be obtained from the drillers or land owners, if available.

Of the 600 records in the TDWR files 49 percent are for wells less than 100 ft deep and 91 percent are for wells less than 200 ft deep (C. R. Lanphere, oral commun., 1979) These wells are mostly privately owned domestic and farm wells.

Geophysical Logs

The Geological Survey files contain geophysical logs for 15 wells drilled in Lauderdale County. Three are for oil-test wells, one is for the Fort Pillow test well, three are for water-supply wells at Fort Pillow State Prison Farm and the town of Ripley, and eight are for test holes drilled by Phillips Coal Company on the Fort Pillow State Prison Farm in conjunction with lignite exploration. The quality of these logs, which include both gamma ray and electric, is excellent to fair depending on the logging instrument used to make them. Figure 4 shows the location of wells and test holes for which geophysical logs are available.

The logs for the Fort Pillow test well and one of the oil-test wells provide important stratigraphic information about the geologic sequence above the Paleozoic rocks. The logs at Ripley, Fort Pillow State Farm, and the other two oil-test wells (only up-hole section logged) provide some site-specific information about the geology and ground-water resource.

The logs made of the Phillips test holes at Fort Pillow State Farm in conjunction with lignite exploration showed that the electric and gamma-ray logs made with the available Geological Survey logging instrument are inadequate to recognize lignite beds in the absence of other information. The gamma-gamma log used by Phillips, supplemented with resistance and gamma-ray logs, is the primary tool needed for this type of work. The gamma-gamma log indicates relative bulk densities, which is important in the recognition of lignite beds.

Water Levels

Except for miscellaneous measurements made in wells in the Mississippi alluvial deposits and the Memphis Sand for regional studies, the only water-level information collected by the Geological Survey for Lauderdale County is for the Fort Pillow test well.

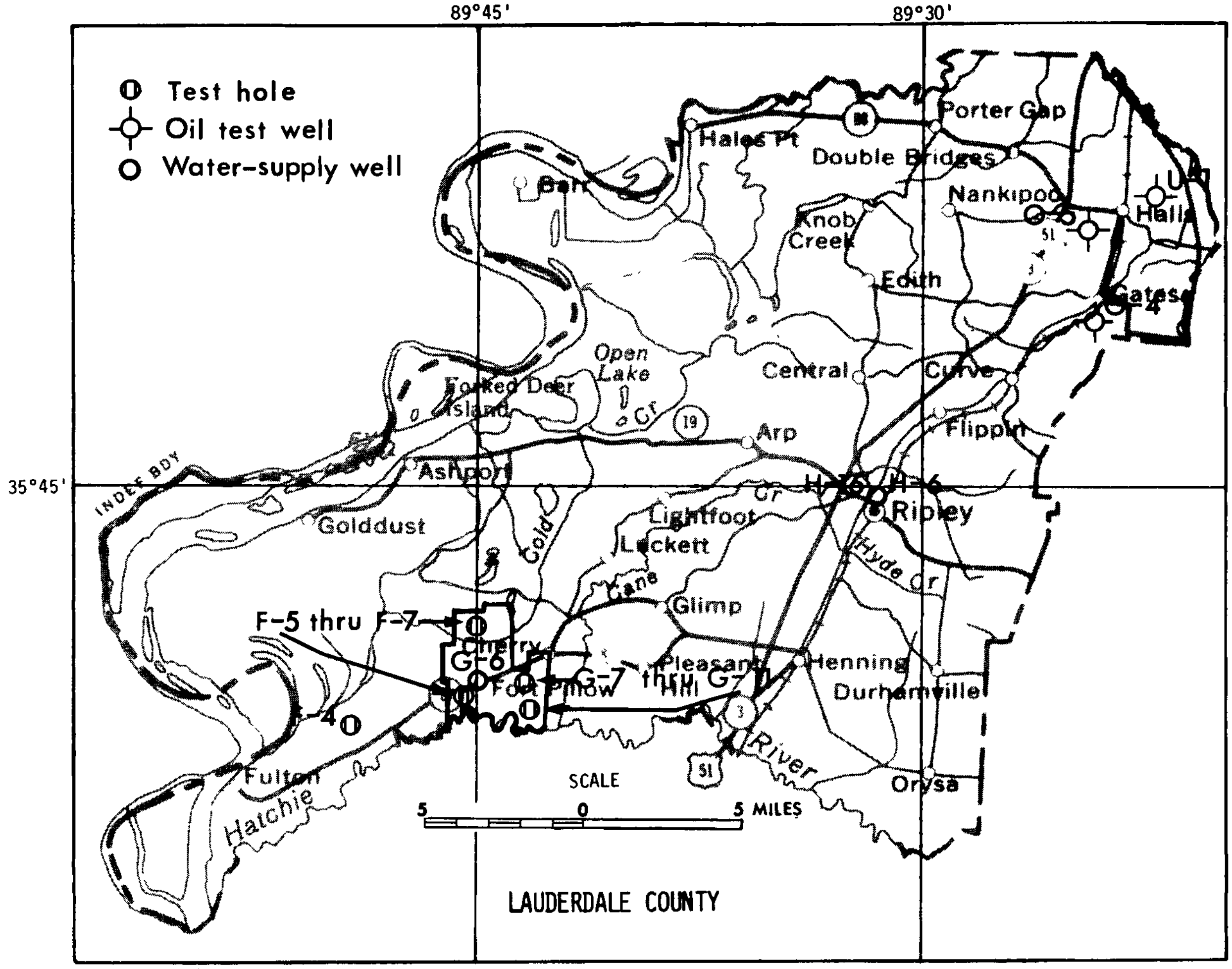
This well, located in the Fort Pillow State Historic Area, is screened in the Memphis Sand at a depth of 869 to 879 ft. An automatic recorder was installed on this well in April 1966, and water levels have been monitored since that time. For alternate periods of time, both analog and digital recorders have been used on this well; it is now equipped with a digital recorder.

Problems associated with the different kinds of recorders, the depth of the water level which approaches 200 ft below land surface, and the remoteness of this well for servicing has resulted in only fair quality records. Periods of lost record are relatively common inasmuch as time between servicing has been from 4 to 6 weeks.

Water levels for the Fort Pillow observation well are summarized in the Geological Survey's "Water Supply Paper" series and the annual reports "Water Resources Data for Tennessee".

Quality of Water

The Geological Survey files contain chemical analyses of water from 20 wells in Lauderdale County; these analyses are given in table 4 later in



EXPLANATION

F-4	Stratigraphic test hole at Fort Pillow State Historic Park
F-5 thru F-7	Lignite test holes at Fort Pillow State Prison Farm
G-6	Water-supply well at Fort Pillow State Prison Farm
G-7 thru G-11	Lignite test holes at Fort Pillow State Prison Farm
H-6 thru H-16	Water-supply wells at town of Ripley
O-4	Oil test well--Raymond Gear, Lee No. 1
O-5	Oil test well--Pure Oil Co., R. E. Craddock No. 1
U-1	Oil test well--Raymond Gear, Dyer Bros. No. 1

Well numbers are USGS local well-numbering system for Tennessee and are generally prefixed "Ld:" for Lauderdale County.

Figure 4.--Wells and test holes for which geophysical logs are available.

this report. Six analyses are for wells in the Mississippi alluvial deposits, two in the fluvial deposits, four in the Jackson and Cockfield Formations, and eight in the Memphis Sand. The wells were sampled between 1929 and 1965, but most were sampled during the 1950's. The data for the Memphis Sand includes analyses of water from deep water-supply wells at Ripley, Henning, Fort Pillow State Prison Farm, and the Fort Pillow test well.

As mentioned in "Previous Investigations", a publication by the Tennessee Department of Public Health (1964-65) includes chemical analyses and radiological data of composite raw water from the supply system at Ripley. These data are for samples taken monthly over a period of 12 months in 1964-65.

Pumping Tests

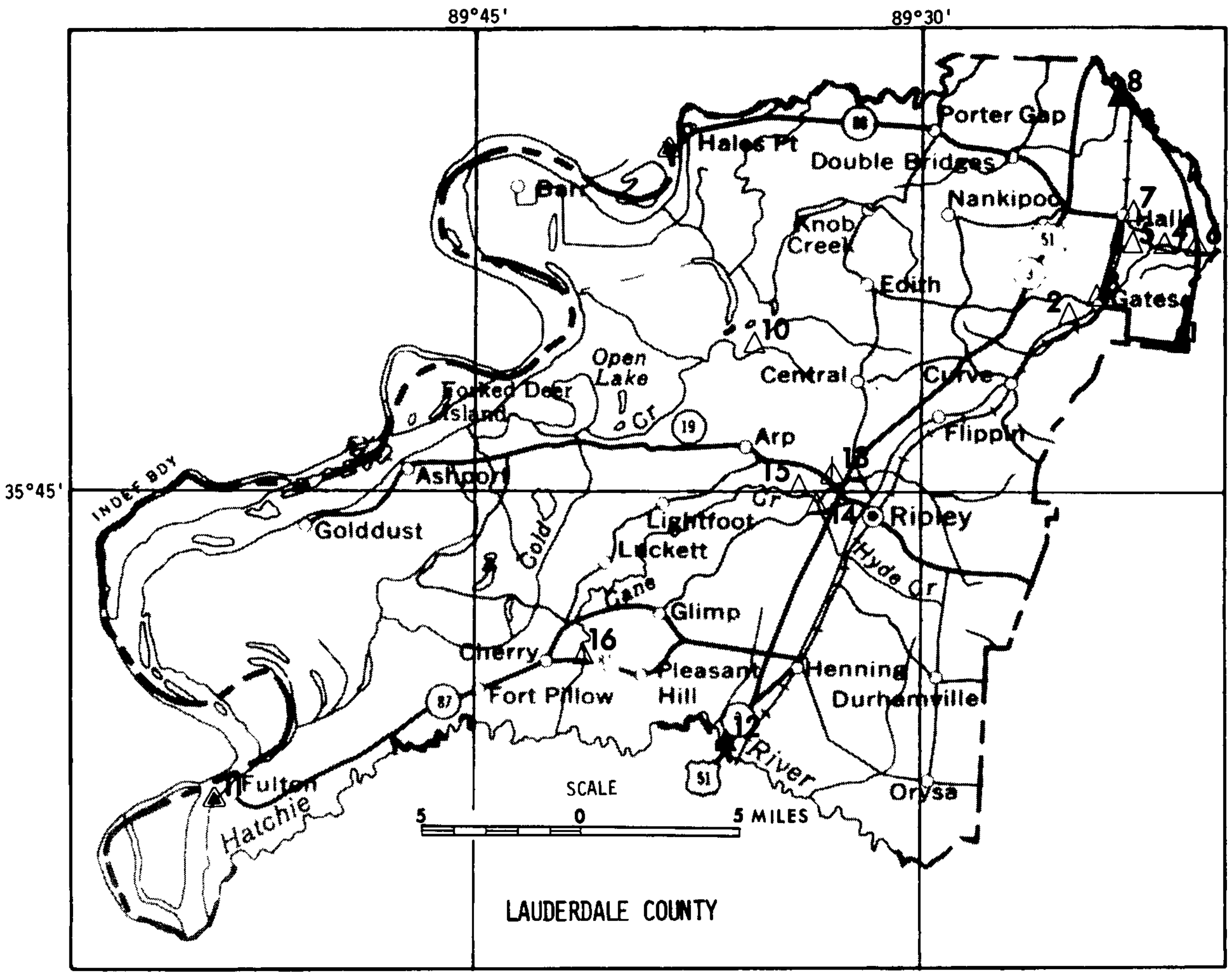
Two short-period pumping tests have been conducted in Lauderdale County--one on a deep well (755 ft deep) at Ripley in the Memphis Sand and the other using two shallow wells (239 and 241 ft deep) at the U.S. Military Reservation near Halls in the Jackson and Cockfield Formations. Values for transmissibility were determined from these tests; a value for storage coefficient was determined for the test at the U.S. Military Reservation at Halls. This is the only specific information available as to the hydrologic characteristics of the aquifers in the county.

Surface-Water Data

Information is available on the stream-flow characteristics of the major streams that receive drainage from Lauderdale County. Continuous-record gaging stations are being operated on the South Fork Forked Deer River and the Hatchie River and partial-record gaging stations are being operated on the Mississippi River at two sites. Not much information is available on the stream-flow characteristics of the tributary streams that drain the county. A continuous-record gaging station was once operated on Cane Creek, and infrequent discharge measurements have been made from time to time at miscellaneous sites. Figure 5 shows the location of existing and discontinued stream-flow gaging stations and miscellaneous data-collection sites. Other surface-water or related data available for the county includes flood-prone area maps, sediment data for the Hatchie River, and daily rainfall data at Ripley.

Continuous-Record Gaging Stations

Continuous-record gaging stations have been operated by the Geological Survey on the South Fork Forked Deer River at Chestnut Bluff (1929 to 1957) and on Cane Creek at Ripley (1957 to 1962). Daily, monthly, and yearly discharge have been published for each water year in the Survey's "Water Supply Papers" and "Surface Water Records of Tennessee." The description and summary for these stations at the time they were discontinued are as follows:



EXPLANATION

- ▲ Continuous-record gaging station
- ▲ Partial-record gaging station
- △ Measurement site without gage
- Discontinued gaging station

Map number	Station number	Location
1	07027800	South Fork Forked Deer River near Gates
2	07027970	Tisdale Creek at Gates (south)
3	07027971	Tisdale Creek at Gates (east)
4	07027980	Halls Creek near Chestnut Bluff
5	07027990	Halls Creek tributary near Halls
6	07028000	South Fork Forked Deer River at Chestnut Bluff
7	07028010	Drainage ditch at Halls
8	07028100	South Fork Forked Deer River near Halls
9	07029140	Mississippi River at mouth of Obion River
10	07029200	Cold Creek near Arp
11	07029220	Mississippi River at Fulton
12	07030050	Hatchie River at Rialto
13	07030100	Cane Creek at Ripley
14	07030110	Hyde Creek at Ripley
15	07030120	Cane Creek below Ripley
16	07030140	Cane Creek near Cherry

Figure 5.--Existing and discontinued stream-flow gaging stations and miscellaneous data-collection sites.

07028000 South Fork Forked Deer River at Chestnut Bluff, Tenn.

Location.--Lat 35°51'43", long 89°20'52", on left bank 20 ft downstream from county highway bridge, 0.8 mile west of Chestnut Bluff, Crockett County, 1.1 miles upstream from Halls Creek, 1.2 miles downstream from Black Creek, 2.9 miles east of Halls, 3.1 miles downstream from State Highway 88, and 16 miles upstream from confluence with North Fork. Records include flow of Halls Creek.

Drainage area.--1,100 sq mi, approximately, includes that of Halls Creek.

Records available.--July 1929 to September 1957 (after September 1949, flow of Halls Creek included), discontinued.

Gage. Water-stage recorder. Datum of gage is 256.88 ft (revised), unadjusted, above mean sea level. Prior to July 20, 1939, staff gage at same site and datum.

Average discharge.--28 years, 1,410 cfs.

Extremes.--Maximum discharge during year, 14,200 cfs Feb. 1 (gage height, 19.90 ft); minimum, 147 cfs Oct. 1 (gage height, 6.55 ft).

1929-57: Maximum discharge, 45,000 cfs Jan. 22, 1935 (gage height, 22.3 ft, from floodmarks), from rating curve extended above 21,000 cfs; minimum observed, 102 cfs Aug. 31, Sept. 1, 1936; minimum gage height observed, 3.2 ft Aug. 5-13, 1930.

Remarks.--Records fair except those for periods of no gage-height record or shifting control, which are poor.

Revisions (water years).--WSP. 1211: 1930, 1934, 1936, 1950. WSP 1281: 1935, 1937, 1946 (M), 1950 (M).

07030100 Cane Creek at Ripley, Tenn.

Location.--Lat 35°45'22", long 89°33'05", on upstream side of right bank pier of bridge on State Highway 19, 1.3 miles upstream from Hyde Creek, and 1.5 miles northwest of Ripley, Lauderdale County.

Drainage area.--30 sq mi, approximately.

Records available.--October 1957 to September 1962 (discontinued).

Gage.--Water-stage recorder. Datum of gage is 309.78 ft above mean sea level, from preliminary field elevations by U. S. Coast and Geodetic Survey. Prior to Nov. 14, 1957, staff gage at same site and datum.

Average discharge.--5 years, 52.3 cfs.

Extremes.--Maximum discharge during year, 3,350 cfs Feb. 27 (gage height, 14.52 ft) from rating curve extended above 1,200 cfs; minimum, 0.2 cfs Sept. 13; minimum gage height, 2.41 ft Aug. 23.

1957-62: Maximum discharge, that of Feb. 27, 1962; minimum, 0.1 cfs May 19, 24-26, Sept. 25, 1959; minimum gage height, 1.60 ft Sept. 7, 1958.

Remarks.--Records poor. Natural flow affected by upstream discharge of Ripley sewage effluent.

The U.S. Army Corps of Engineers presently maintains continuous-record gaging stations on the South Fork Forked Deer River near Halls (1939 to date), the South Fork Forked Deer River near Gates (1969 to date), and the Hatchie River at Rialto (1939 to date). Daily stages and computed discharges have been published in "Stages and Discharges of the Mississippi River and Its Outlets and Tributaries," and "Stages and Discharges of the Mississippi River and Tributaries in the Memphis District" by the Corps of Engineers. The description and summary for these stations from the 1976 issue of the latter report are as follows:

07028100 South Fork of Forked Deer River near Halls, Tenn.

Location.--Lat 35°55'45", long 89°23'25". Mile 11.3, railroad bridge about four miles north of Halls, the mouth of South Fork is 20.6 miles upstream from mouth of Forked Deer River, Forked Deer River is a tributary entering Obion River at mile 3.0.

Gage.--Automatic recorder on bridge.

General information.--Drainage area, 1,014 square miles. Bankfull stage, 8.5 feet. Discharge is affected by backwater during high Mississippi River stage.

Record available.--Stage, Jan. 19, 1939, to date. Discharge, 1939 to date. Computed daily, 1947 to date.

Extremes.--Highest, 15.21 feet on Mar. 16, 1975. Lowest, minus 3.61 feet on Sep. 5, 1975. Maximum, 34,320 cfs computed on Mar. 16, 1975. Minimum, 123 cfs observed on Oct. 18, 1956 (stage 0.68).

Daily eight a.m. stage in feet   Gage zero, 259.09 feet, M.S.L. (1929 adj.)

07027800 South Fork of Forked Deer River near Gates (East), Tenn.

Location.--Lat 35°49'03", long 89°21'21". State Highway 88 bridge, about four miles east of Gates and one mile west of Gillilands, on down stream side of bridge.

Gage.--Automatic recorder on bridge.

Records available.--Stage and daily discharge, Jan. 1, 1969 to date.

Extremes.--Highest, 21.19 feet on Mar. 16, 1975. Lowest, 7.25 feet on Jul. 2, 1969. Maximum, 35,328 cfs computed on Mar. 16, 1975. Minimum, 138 cfs computed for Dec. 9, 1971.

Daily eight a.m. stage in feet   Gage zero, 259.50 feet, M.S.L. (1929 adj.)

07030050 Hatchie River at Rialto, Tenn.

Location.--Lat 35°38'14", long 89°36'14". U.S. Highway 51 bridge at mile 34.0. The mouth of Hatchie River is 773.3 miles upstream on the Mississippi River from head of passes.

Gage.--Automatic Recorder on bridge.

General information.--Drainage area, 2,308 square miles. Bankfull stage is 12 feet. Discharge is affected by backwater during high Mississippi River stages.

Records available.--Stage, Jan. 7, 1939, to date (high water stages, 1932 to date). Prior to 1950, gage was located one mile upstream. Zero of gage prior to 1953 was minus 0.30 foot, M.S.L. Computed daily discharge, 1939 to date.

Extremes.--Highest, 23.54 feet on Jan. 22, 23, and 25, 1937. Lowest, minus 0.06 foot on Sept. 28, 1956. Maximum, 55,700 cfs computed for Jun. 13, 1946 (stage, 22.0). Discharge not determined for record high stage. Minimum, 180 cfs computed for Jul. 9, 10, Nov. 3 and 4, 1943 (stage, 0.0).

Daily eight a.m. stage in feet Gage zero, 239.81 feet, M.S.L. (1929 adj.)

Partial-Record Gaging Stations

The Corps of Engineers presently maintains two partial-record gaging stations on the Mississippi River in Lauderdale County--one at the mouth of the Obion River (1928 to date) and the other at Fulton (1879 to date). Daily stage has been published in "Stages of the Mississippi River and of Its Principal Tributaries," "Stages and Discharges of the Mississippi River and Its Outlets and Tributaries," and "Stages and Discharges of the Mississippi River and Tributaries in the Memphis District" by the Corps of Engineers. The description and summary for these stations from the 1976 issue of the latter report are as follows:

07029140 Mississippi River H. W. Gage 158 at Mouth of Obion River, Tenn.

Location.--Lat 35°54'14", long 89°38'24". High water gage at mile 819.1.

Gage.--Staff type in several sections.

General information.--Drainage area (revised), 924,000 square miles. The drainage area in the Great Divide Basin in southern Wyoming, approximately 4,000 square miles, is no longer included. Average low water plane, 4.6 feet on gage.

Records available.--Stage, July 1928 to date. Prior to Nov. 23, 1939, high stages only, from site one mile upstream.

Extremes.--Highest, 52.45 feet on Feb. 8, 1937. Lowest, 0.3 foot on Jan. 23, 1956.

Daily eight a.m. stage in feet Gage zero, 218.33 feet, M.S.L. (1929-58 adj.)

07029220 Mississippi River at Fulton, Tenn.

Location.--Lat 35°37'01", long 89°53'11". At Ferry Landing, mile 778.2

Gage.--Staff type in several sections.

General information.--Drainage area (revised), 924,300 square miles. The drainage area in the Great Divide Basin in southern Wyoming, approximately 4,000 square miles, is no longer included. Bankfull stage, 34 feet. Average low water plane, minus 1.4 feet on gage.

Records available.--Stage, Oct. 28, 1879, to date. Discharge, 1879 intermittently to 1893.

Extremes.--Highest, 47.25 feet on Feb. 9, 1937. Lowest, minus 7.70 feet on Jan. 2, 1964.

Daily eight a.m. stage in feet Gage zero, 208.61 feet, M.S.L. (1929-58 adj.)

Low-Flow and Miscellaneous Sites

Through the years, discharge measurements or observations of no flow have been made at several low-flow, partial-record stations, and miscellaneous sites on the streams that drain Lauderdale County. These data, which are scattered through many of the Survey's "Water-Supply Papers," are given in table 1 for accessibility.

Flood-Prone Area Maps

Flood-prone areas in Lauderdale County are shown on maps prepared and distributed by the Geological Survey under its reconnaissance flood mapping program. These flood-prone areas are delineated on topographic quadrangle base maps--some on the 15-minute and others on the 7.5 minute series. The county is included on all or part of the eight maps listed below. The date following the map name is the year of compilation of the flood information and the year in parenthesis is the edition of the base map.

15-minute (scale 1:62,500) series	
Blytheville, Ark.-Mo.-Tenn.	1969 (1955)
Hales Point, Tenn.-Ark.	1973 (1961)
Osceola, Tenn.-Ark.	1969 (1963)
Rialto, Tenn.	1973 (1961)

7.5-minute (scale 1:24,000) series	
Fowlkes, Tenn.	1973 (1952)
Gates, Tenn.	1973 (1952)
Turnpike, Tenn.	1973 (1964)

Table 1.--Available measurements at low-flow, partial-record stations and miscellaneous sites in Lauderdale County

Station number	Station name	Drainage area (mi^2)	Location	Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)
07027970	Tisdale Creek at Gates (South), TN	11.0	Lat 35°50'10" N., long 89°24'28" W. Lauderdale County, at former U.S. Hwy 51 bridge, at south edge of Gates.	07-13-50	0		
07027971	Tisdale Creek at Gates (East), TN	13.6	Lat 35°50'14" N., long 89°24'08" W. Lauderdale County, at Hwy 88 bridge, at east edge of Gates.	08-28-47	0.01		
07027980	Hall Creek near Chestnut Bluff, TN	28.5	Lat 35°51'48" N., long 89°21'49" W. Lauderdale County, at county road bridge, Halls to Chestnut Bluff Road.	03-05-45	95	05-11-51	0
				12-06-49	2	06-13-51	0
				01-11-50	50	12-10-52	52.7
				04-05-50	2	07-20-54	0
				07-13-50	2	09-01-54	0
				08-01-50	0	02-05-56	40
				09-08-50	0	04-11-56	10
				11-22-50	5	05-09-56	5
				02-15-51	0	10-16-56	0
07027990	Hall Creek Tributary near Halls, TN	0.34	Lat 35°52'08" N., long 89°22'44" W. Lauderdale County, at Halls to Chestnut Bluff county road culvert.	08-28-47	0		
07028010	Drainage ditch at Halls, TN	1.24	Lat 35°53'02" N., long 89°23'30" W. Lauderdale County, below sewer outfall at Halls.	02-10-50	0.89		
07029200	Cold Creek near Arp, TN	16.3	Lat 35°48'54" N., long 89°35'43" W. Lauderdale County, at county road bridge, 0.3 mi below unnamed tributary, 2.9 mi north of Arp.	08-28-58	1.03	10-13-59	1.24
				05-12-59	2.37	05-12-60	3.71
				06-19-59	1.32	10-11-61	1.23
				07-27-59	1.97	10-24-63	0.34
				09-14-59	0.88		
07030100	Cane Creek at Ripley, TN	33.9	Lat 35°45'22" N., long 89°33'05" W. Lauderdale County, at State Hwy 19 bridge, 1.5 mi northwest of Ripley.	08-28-47	0.96	02-18-63	0.92
				10-18-51	0.91	10-24-63	0.15
				06-26-52	0.68	11-10-69	0.13
				12-07-62	0.83	11-14-69	0.50
				01-10-63	0.81		
07030110	Hyde Creek at Ripley, TN	10.1	Lat 35°44'40" N., long 89°33'40" W. Lauderdale County, at first bridge above mouth, 1.5 mi west of Ripley.	08-28-47	0	10-18-51	0.04
07030120	Cane Creek below Ripley, TN	45.6	Lat 35°44'58" N., long 89°33'50" W. Lauderdale County, 300 ft below Hyde Creek, 1.75 mi west of Ripley.	06-26-52	0.68		
07030140	Cane Creek near Cherry, TN	83.8	Lat 35°40'30" N., long 89°41'21" W. Lauderdale County, at State Hwy 87-A bridge, 1.2 mi east of Cherry, at river mile 46.	08-28-58	0.2	05-12-60	7.94
				05-12-59	0.51	10-11-61	0.50
				06-19-59	2.26	10-24-63	0
				09-14-59	1.91	07-18-75	5.3

The flood-prone areas were delineated on the basis of readily available information. Criteria for the selection of flood-prone areas on these maps were: (1) urban areas where upstream drainage area exceeds 25 square miles, and (2) rural areas where upstream drainage exceeds 100 square miles. The flood-prone areas of the small tributaries were not delineated. The maps indicate only the areas that may be occasionally flooded, and provides no information on the frequency, depth, duration, and other details of flooding.

Sediment Data

Sediment data were collected by the Geological Survey in February, March, August, and September 1977 and in May 1978 at the site of the Corps of Engineers gaging station on the Hatchie River at Rialto. This work was conducted in conjunction with a cooperative study of sediment transport in the Hatchie River basin between the Survey and the Scenic Rivers Program, Tennessee Department of Conservation. Sediment data for the Hatchie River at Rialto is given in table 8 of this report.

Rainfall Data

Rainfall data are available for Lauderdale County and surrounding areas from weather stations maintained by the National Oceanic and Atmospheric Administration (NOAA) at Ripley, Dyersburg, Brownsville, and Covington in Tennessee and at Blytheville and Keiser in Arkansas. Figure 6 shows the general location of these stations. Most of these stations collect only daily precipitation and daily extremes of temperature. Precipitation is recorded at the stations at Dyersburg and Brownsville; other detailed meteorological data are collected at Dyersburg; data on evaporation and soil temperature are collected at Keiser. Data from these weather-stations are published in NOAA's monthly "Climatological Data" for Tennessee.

DESCRIPTION OF HYDROLOGIC SYSTEM

Geomorphic and Geologic Setting

Lauderdale County is situated in two major geomorphic (physiographic) subdivisions. The eastern three-quarters of the county is in the East Gulf Coastal Plain section and the western one-quarter is in the Mississippi Alluvial Plain section of the Coastal Plain province (Fenneman, 1938, p. 65-99). In Tennessee, the Coastal Plain may be subdivided into the West Tennessee Uplands and the West Tennessee Plain (Miller, 1974, p. 7). The Coastal Plain area of the county is entirely in the West Tennessee Plain. Figure 7 shows the generalized topography and major geomorphic subdivisions in the county.

The Coastal Plain (or West Tennessee Plain) in Lauderdale County is characterized by gently rolling to steep topography formed as the result of erosion of geologic formations of Tertiary and Quaternary age. During the later stages of Pleistocene glaciation this topography was covered by a relatively thick blanket of loess, which makes up the present land surface. The topography is broken at many places by the flat-lying flood plains of streams that cross the area. Perhaps the most distinctive feature of the Coastal Plain is the loess covered bluffs that rise abruptly above the

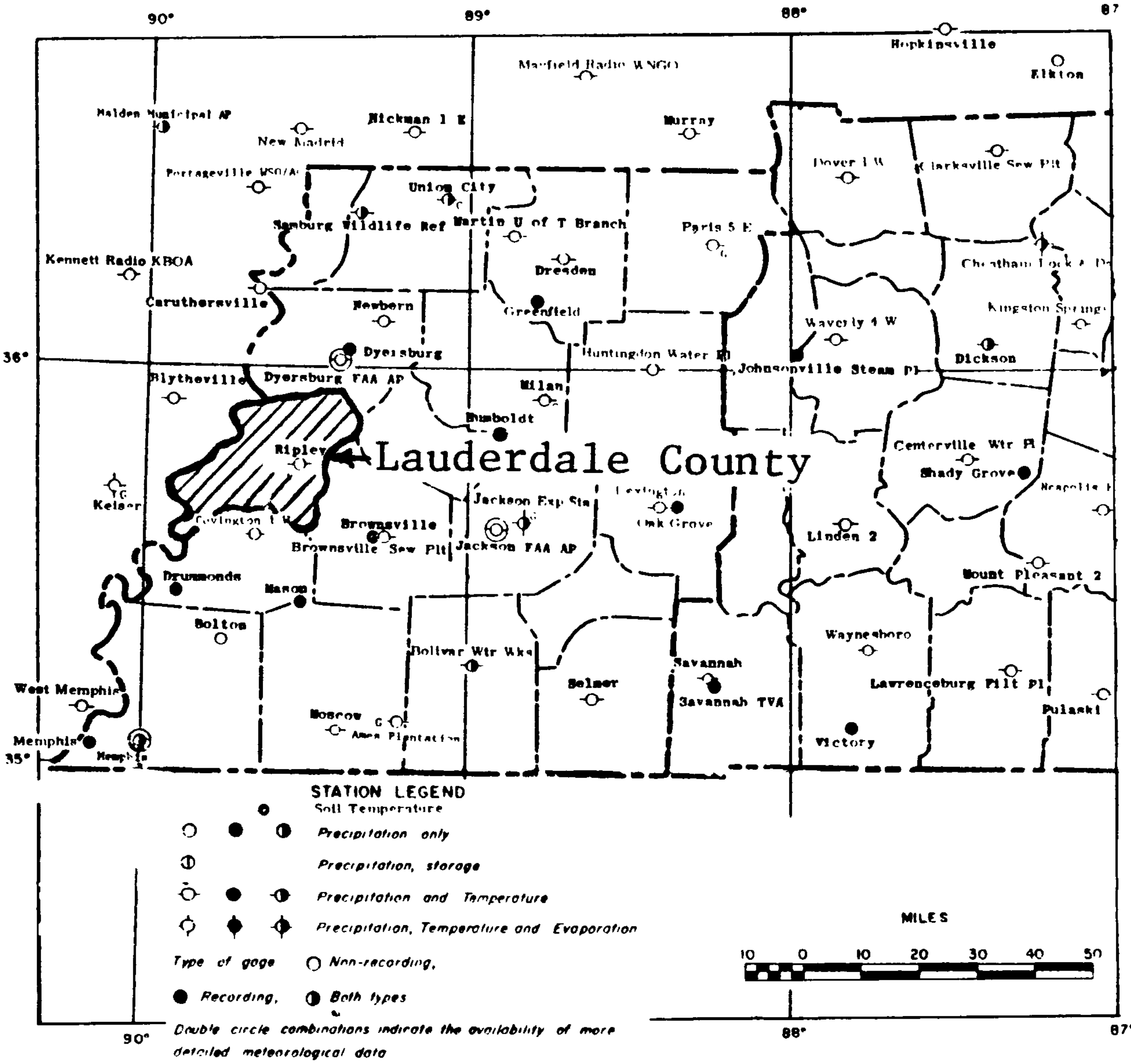
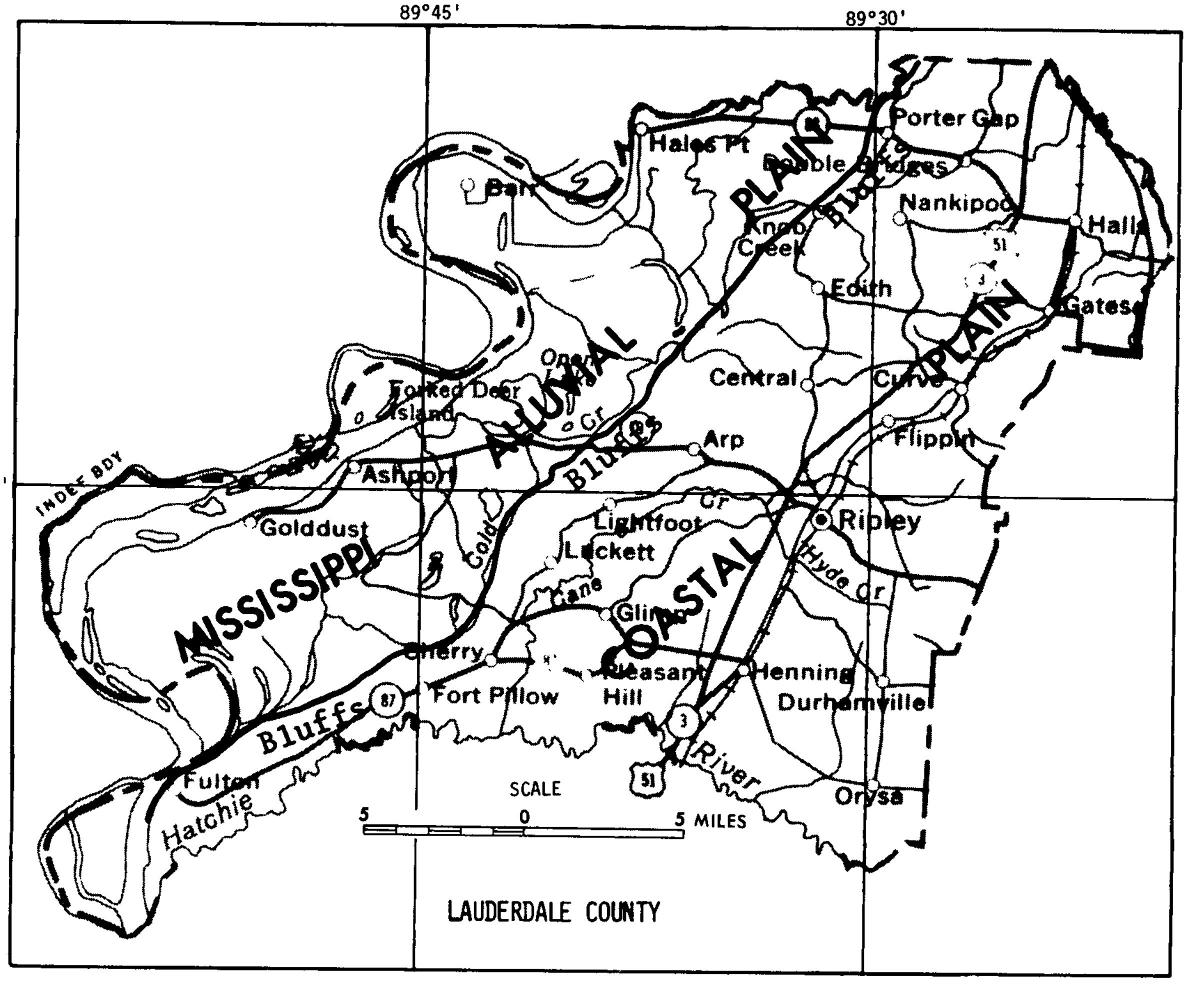


Figure 6.--Weather stations of National Oceanic and Atmospheric Administration in vicinity of Lauderdale County (modified from "Climatological Data" for Tennessee, v. 84, no. 4, April 1979).



EXPLANATION

Gently rolling to steep topography of the Coastal Plain terminates at a line of bluffs that mark the boundary with the flat-lying Mississippi Alluvial Plain.

Figure 7.--Generalized topography and major geomorphic subdivisions.

Mississippi Alluvial Plain at its eastern boundary. Land surface altitudes in the Coastal Plain are as low as 215 ft above sea level on the banks of the Hatchie River where it enters the Mississippi Alluvial Plain in the southwestern part of the county and are as high as 520 ft above sea level on hills near the communities of Dry Hill and Edith in the north-central part. Maximum local relief between the Coastal Plain and the Mississippi Alluvial Plain is about 250 ft on the bluffs west of Edith in the northern part.

The Mississippi Alluvial Plain in Lauderdale County is a relatively flat-lying area averaging about 6 mi in width and extending about 35 mi in length in a northeast-southwest direction. The Alluvial Plain is characterized by features typical of fluvial deposition--point bars, abandoned channels, and natural leeves. Local features include alluvial fans deposited outward from the base of the bluffs where streams draining the rugged topography of the dissected Coastal Plain enter the flat-lying Alluvial Plain. Land-surface altitudes in the Alluvial Plain are as low as 210 ft above sea level on the banks of the Mississippi River in the southwestern part of the county and are as high as 290 ft above sea level on the alluvial fan of Knob Creek in the northern part. Maximum local relief is probably no more than 10 or 20 ft.

Lauderdale County is in the north-central part of the Mississippi embayment, a broad trough or syncline that plunges southward along an axis which approximates the Mississippi River (Cushing and others, 1964, p. B21). This trough or syncline is filled with a wedge of several thousand feet of sediments of Cretaceous, Tertiary, and Quaternary age. These sediments make up geologic formations that dip gently westward into the embayment and southward down its axis. At present not much is known specifically concerning the existance of local structures such as faults. Figure 8 shows the regional location of Lauderdale County, and figure 9 is a diagrammatic cross-section of the Mississippi embayment.

The surface geology of Lauderdale County for the most part is relatively uncomplicated. The oldest geologic units at the surface are the Cockfield Formation of the Claiborne Group and the overlying Jackson Formation. Because of a similarity in lithology, these units cannot be subdivided on the basis of present information so in this report they are referred to as "Jackson and Cockfield Formations".

The Jackson and Cockfield Formations are exposed locally in the Coastal Plain at the lower altitudes along the bluffs and in stream channels. Above the Jackson and Cockfield are the fluvial deposits (terrace deposits) which are erosional remnants of ancient alluvial deposits of present streams or an ancient drainage system (Russell and Parks, 1975, p. B30). The fluvial deposits are exposed locally along the bluffs, on the steep valley walls, and in sand and gravel pits. The loess, which is primarily wind-blown silt, forms the principal surface formation in the Coastal Plain. The loess covers the underlying fluvial deposits and Jackson and Cockfield Formations at most places. The youngest geologic unit in the county is the alluvial deposits (alluvium) which underlies the Mississippi Alluvial Plain and the flood plains of streams in the county. Figure 10 shows the generalized surface geology of the county.

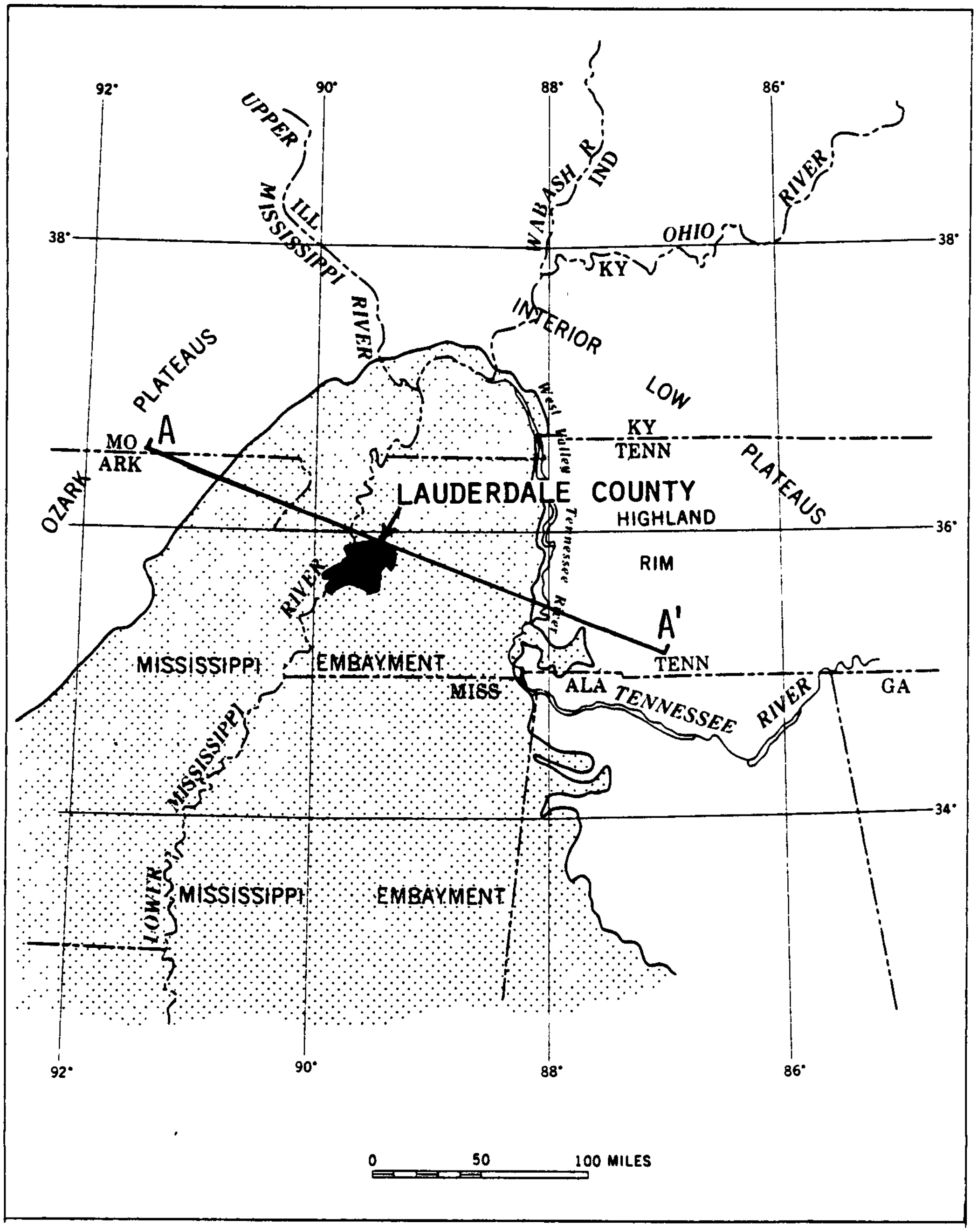


Figure 8.--Regional setting of Lauderdale County in the Mississippi embayment and location of cross-section A-A' shown in figure 9 (modified from Stearns and Wilson, 1972, fig. 2.9A-1).

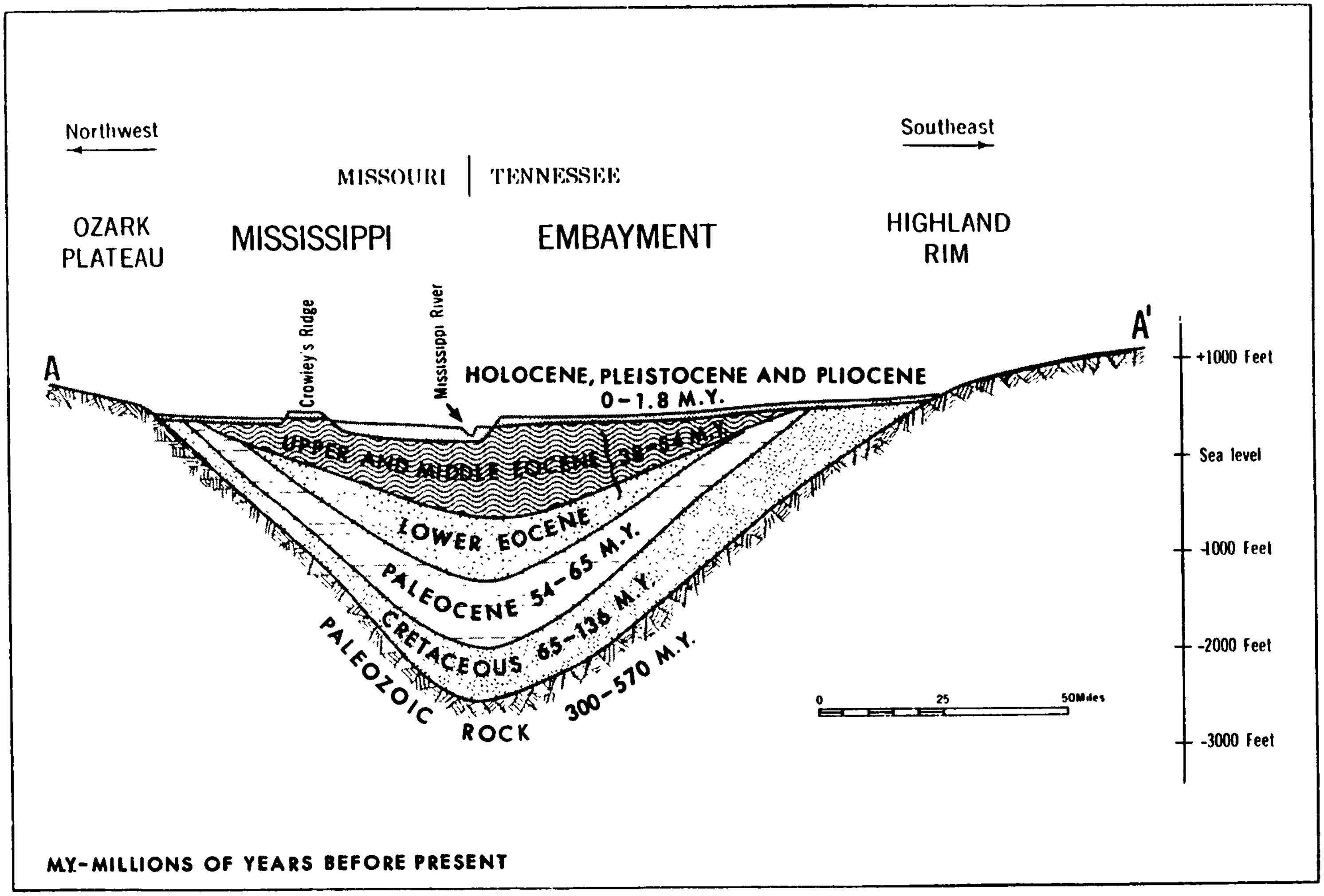
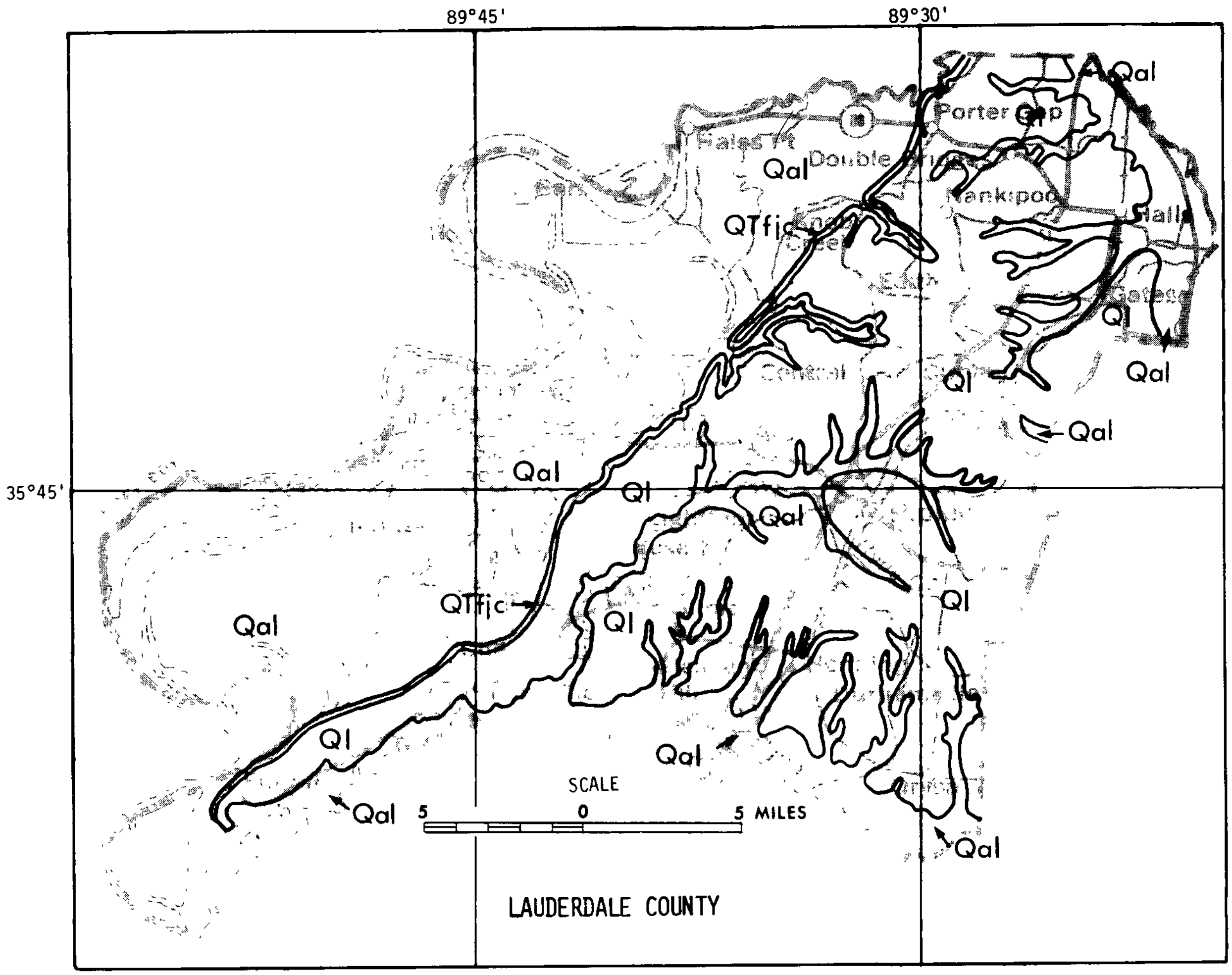


Figure 9--Diagrammatic cross-section showing the age of rocks of the Mississippi embayment--location shown in Figure 8 (modified from Stearns and Wilson, 1972, fig. 2.9A-40).



EXPLANATION

Qal --	Alluvial deposits	QUATERNARY
Ql --	Loess	
QTfjc --	Fluvial deposits, Jackson and Cockfield formations, undivided	QUATERNARY AND TERTIARY

Figure 10.--Generalized surface geology.

Lauderdale County is in a seismically active region and has been subject to major earthquakes in the past. The severest earthquakes known to have occurred in this region during recorded history were the three principal shocks of the new Madrid earthquakes of 1811-12. These principal shocks were also the severest earthquakes experienced within historic time in the central and eastern United States (Nuttli, 1974).

Water Use

Water use in Lauderdale County was inventoried in 1970 by Kernodle and Wilson (1973, tables 1-4) as part of a state-wide water-use survey. At that time, water use in the county amounted to an average daily withdrawal of about 3.5 Mgal/d of which 1.5 Mgal/d was ground water and 2.0 Mgal/d was surface water. The ground water was chiefly for municipal, industrial, commercial, and domestic use, and the surface water was for agricultural use. The report showed that 12 major users in the county were canvassed during the survey; the many domestic and farm wells were not canvassed.

Ground-Water System

From about 2,500 to 3,000 ft of sand, clay, silt, gravel, and lignite underlie Lauderdale County above the Paleozoic rocks. These deposits make up geologic units ranging in age from Late Cretaceous to Holocene. Although much of this sequence is saturated with fresh water (less than 1,000 mg/L of dissolved solids), only the post-Midway units (Wilcox Group and younger) will be considered in this report because these units contain the principal aquifers for present and future use. Table 2 gives the stratigraphic relations of the post-Midway geologic units and their hydrologic significance; figure 11 is a geohydrologic cross-section of western Tennessee through Lauderdale County.

Ground-water supplies in Lauderdale County are now derived from several aquifers, as follows: (1) Mississippi alluvial deposits, (2) fluvial deposits, (3) Jackson and Cockfield Formations and (4) Memphis Sand. The alluvial deposits beneath the flood plains of the streams in the county--particularly the Hatchie River and the South Fork Forked Deer River--may provide water to a few shallow wells. These deposits, however, are not described in this report because they are not considered an important source of ground-water supply.

An aquifer not presently used but worthy of mention is the Fort Pillow Sand ("1400-foot" sand). Although this aquifer is deeper than the Memphis Sand and does not have aquifer characteristics to produce as much water, the Fort Pillow Sand may have potential for supplying somewhat better quality water than is available from the shallow aquifers, as in northern Mississippi and eastern Arkansas. However, specific data on the quality of water from the Fort Pillow Sand in Lauderdale County are not available.

Table 3 gives records of wells in Lauderdale County for which water-quality analyses are available; figure 12 shows locations of these wells; table 4 gives analyses of the water.