SUMMARY OF SOME CURRENT AND POSSIBLE FUTURE ENVIRONMENTAL PROBLEMS RELATED TO GEOLOGY AND HYDROLOGY AT MEMPHIS, TENNESSEE

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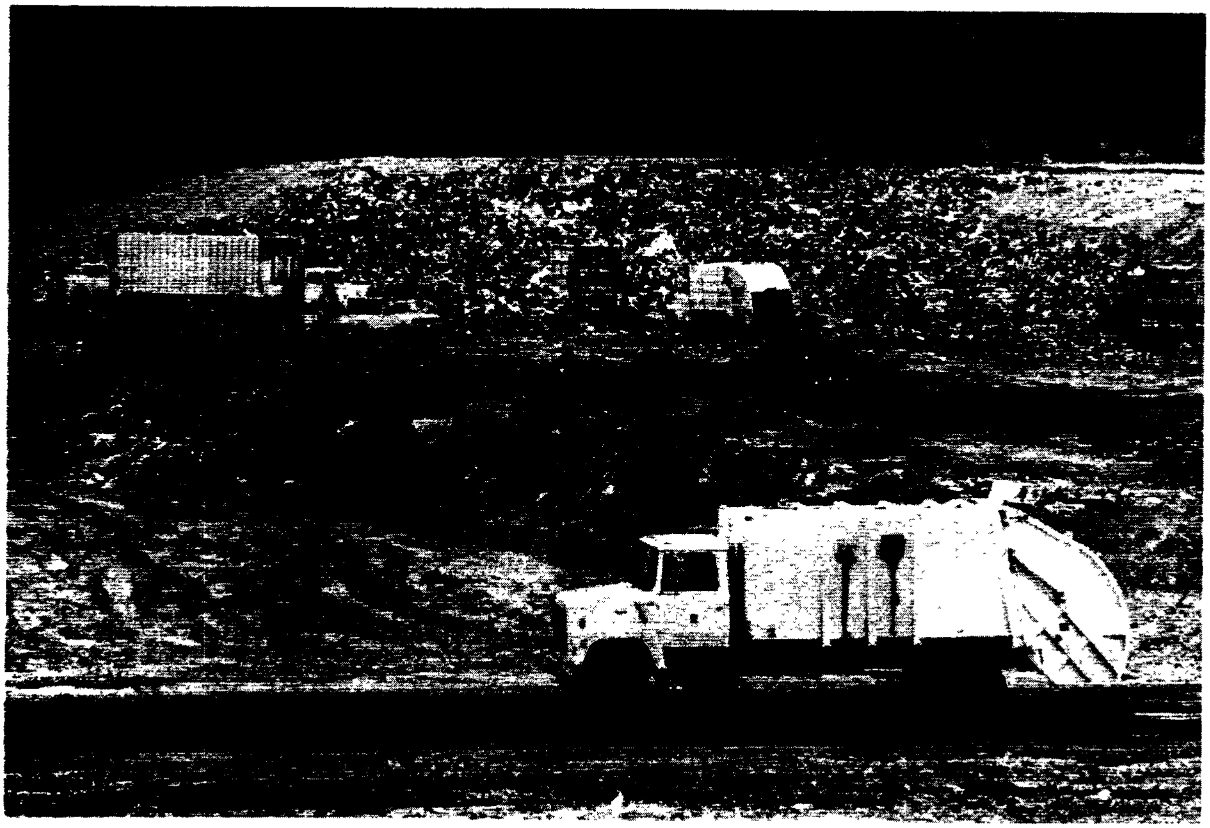

Prepared in cooperation with the
TENNESSEE DEPARTMENT OF CONSERVATION,
DIVISION OF GEOLOGY, AND
MEMPHIS STATE UNIVERSITY

BIBLIOGRAPHIC DATA SHEET

1. Report No. PB- 264 513/AS
2.
3. Recipient's Accession No.

4. Title and Subtitle
SUMMARY OF SOME CURRENT AND POSSIBLE FUTURE ENVIRONMENTAL PROBLEMS RELATED TO GEOLOGY AND HYDROLOGY AT MEMPHIS, TENNESSEE

5. Report Date
October, 1976

6.

7. Author(s)
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8. Performing Organization Rept. No. USGS/WRI-6-76

9. Performing Organization Name and Address
U. S. Geological Survey, Water Resources Division
A-413 Federal Building - U. S. Courthouse
Nashville, TN. 37203

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
U. S. Geological Survey, Water Resources Division
A-413 Federal Building - U. S. Courthouse
Nashville, TN. 37203

13. Type of Report & Period Covered
Final Report, No Period Covered

14.

15. Supplementary Notes
Prepared in cooperation with the Tennessee Department of Conservation, Division of Geology, and Memphis State University.

16. Abstracts
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17. Key Words and Document Analysis. 17a. Descriptors
*Hydrogeology, aggregate resources, foundation materials, earthquake hazards, flood hazards, water resources, solid waste disposal.

17b. Identifiers/Open-Ended Terms
Memphis, Tennessee

17c. COSATI Field/Group

18. Availability Statement
No restriction on distribution

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
40 pages.

22. Price
$4.00

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January 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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SUMMARY OF SOME CURRENT AND POSSIBLE FUTURE ENVIRONMENTAL PROBLEMS RELATED TO GEOLOGY AND HYDROLOGY AT MEMPHIS, TENNESSEE

By

William S. Parks[1/] and Richard W. Lounsbury[2/]

ABSTRACT

Memphis, Tennessee, like many other cities in the Nation, has some problems related to local geology and hydrology. The city is in the Coastal Plain physiographic province and is underlain at shallow depths by sand, clay, silt, gravel, and lignite. These post-Midway strata (Wilcox and younger) make up geologic units belonging to the uppermost Paleocene, Eocene, and Pliocene (?) Series of the Tertiary System and to the Pleistocene and Holocene Series of the Quaternary System. Environmental problems of immediate or future concern are associated with six general topics: (1) aggregate resources, (2) foundation materials, (3) earthquake hazards, (4) flood hazards, (5) water resources, and (6) solid waste disposal. Consideration of these topics in one report should provide an overall insight into the close interrelation of the problems and the need for coordinated studies of the geology and hydrology at Memphis.

INTRODUCTION

This report summarizes information concerning many aspects of the geology and hydrology at Memphis, Tenn. It also outlines some of the current problems related to the local geology and hydrology or ones that may arise as a result of urbanization and industrialization of the area. The report includes much of the information that was contained in the introductory text to the road log for a field-trip guide to the environmental geology at Memphis by Parks and Lounsbury (1975).

The content of the field-trip guide is included in the present report so that this general information about geologically and hydrologically related environmental problems at Memphis can be made readily available to those governmental agencies, companies, and individuals that are involved with the geology and hydrology in their work. In addition, some parts of this report will be supplemental to, or supplemented by, recent investigations by J. H. Criner and W. S. Parks (oral commun., 1975) on historic water-level changes in the Memphis area.

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2/ Chairman, Department of Geology, Memphis State University, Memphis, Tenn.

The Geological Survey's contribution to the report was made through a geologic mapping project now being conducted at Memphis in cooperation with the Tennessee Division of Geology. Information obtained from this project, which ordinarily would not be published as a part of the geologic maps, is incorporated herein.

Most measurements in the text of this report are given in English units, followed by metric units in parentheses. The metric equivalents are shown only to the number of significant figures consistent with the values for the English units. For use of those readers who may prefer to use metric units rather than English units, the conversion factors are listed below:

English	Multiply by	
inches (in)	25.4	millimetre (mm)
feet (ft)	0.3048	metres (m)
miles (mi)	1.609	kilometres (km)
acres	0.004047	square kilometres (km^2)
square miles (mi^2)	2.590	square kilometres (km^2)
gallons per minute (gal/min)	3.785	litres per minute (l/min)
million gallons per day (Mgal/d)	3.785	million litres per day(Ml/d)
gallons per minute per foot (gal/min)/ft	12.418	litres per minute per metre (l/min)/m
pounds per square foot (lb/ft^2)	4.883	kilograms per square metre (kg/m^2)
feet per second (ft/s)	0.3048	metres per second (m/s)
horsepower (hp)	0.7457	kilowatts (kw)
ton (short)	0.9072	tonne (t)
cubic feet per second (ft^3/s)	0.02832	cubic metres per second (m^3/s)

GENERAL GEOLOGY

Memphis is in Shelby County in the southwest corner of Tennessee in the East Gulf Coastal Plain section of the Coastal Plain physiographic province (fig. 1). The downtown part of Memphis is perched on loess hills and bluffs that border the broad, flat-lying Mississippi Alluvial Plain. The geologic formations at the surface and in the subsurface are made up of sand, clay, silt, chalk, gravel, and lignite and range in age from Late Cretaceous to Holocene. Other than local beds of ferruginous sandstone and some beds of limestone and calcareous sandstone, no well-consolidated rocks of any consequence are above the Paleozoic bedrock, which occurs at depth greater than 3,000 ft (900 m). Only the post-Midway formations (Wilcox and younger) will be considered in this report (table 1).

Structurally, Memphis is in the north-central part of the Mississippi embayment, a broad trough or syncline that plunges southward along an axis which approximates the course of the Mississippi River. In the Memphis area of Tennessee, the geologic formations dip gently westward into the embayment and southward down its axis. Correlations of geophysical logs made in wells--which were drilled through the highly variable, shallow stratigraphic sequence--indicate that the post-Midway geologic units lie nearly flat or dip at rates of a few tens of feet per mile.

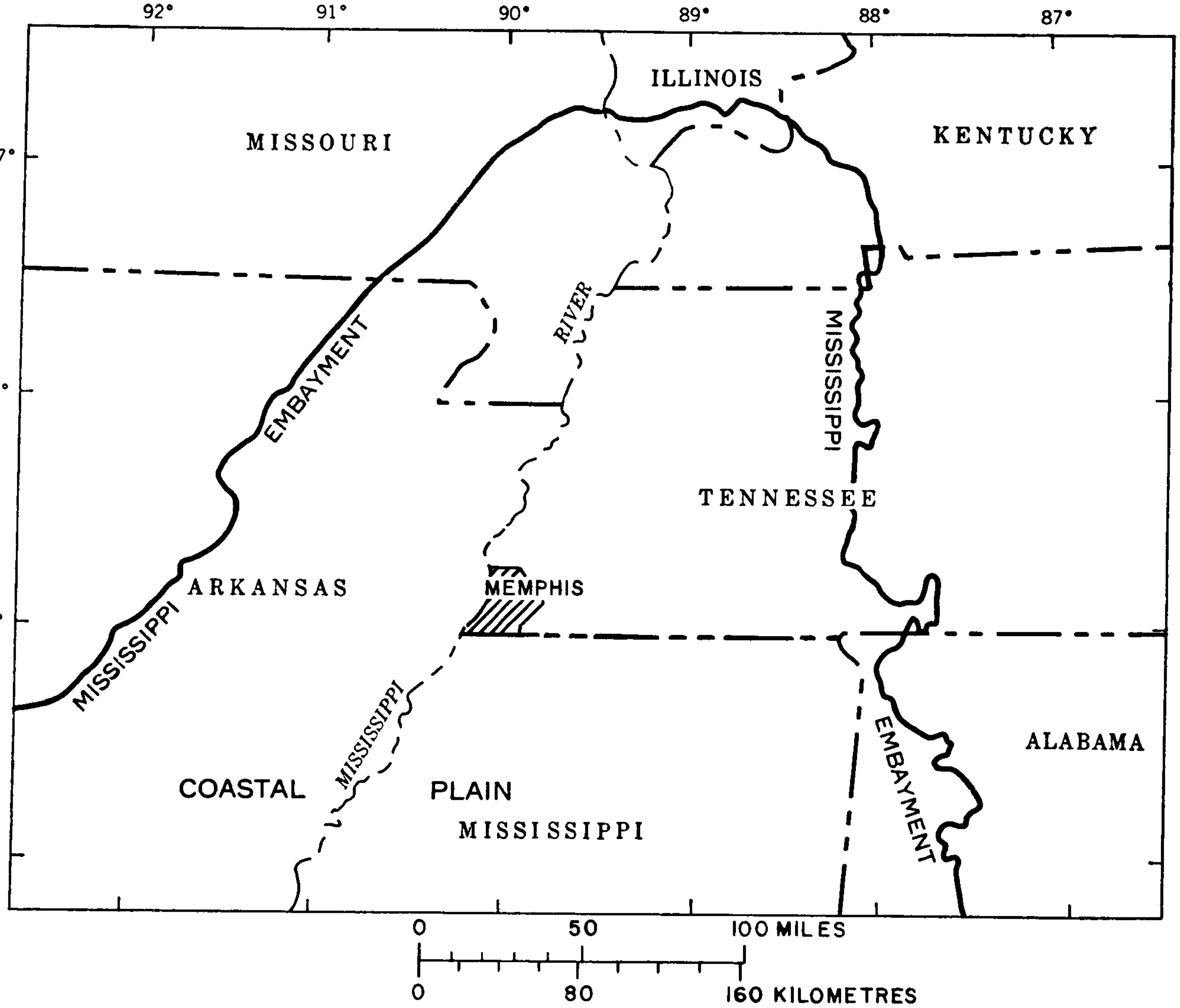


FIGURE 1. --REGIONAL LOCATION OF MEMPHIS. MODIFIED FROM CRINER, SUN AND NYMAN (1964).

Table 1.--Post-Midway geologic units underlying the Memphis area and their environmental significance.

System	Series	Group	Stratigraphic unit	Thickness (feet)
Quaternary	Holocene and Pleistocene		Alluvium	0-175
	Pleistocene		Loess	0-65
Quaternary and Tertiary(?)	Pleistocene and Pliocene (?)		Fluvial deposits (terrace deposits)	0-100
Tertiary	Eocene	?	Jackson Formation and upper part of Claiborne Group ("capping clay')	0-350
		Claiborne	Memphis Sand ("500-foot" sand)	500-880
		Wilcox	Flour Island Formation	160-350
	?		Fort Pillow Sand ("1400-foot" sand)	210-280
	Paleocene		Old Breastworks Formation	200-250

Table 1 (cont'd)

Lithology and environmental significance
Sand, gravel, silt, and clay. Provides borrow material for fills and levees and some aggregates for concrete and bituminous mixes. Used as foundation material or base on which fill is placed for residences and light buildings in flood plains. Lower sand and gravel beneath Mississippi Alluvial plain used as foundation material for heavy structures. Supplies water to a few industrial wells on Presidents and Mud Islands.
Silt, silty clay, and minor sand. Used generally as foundation material for residences and light buildings in upland areas. Provides material for fills placed in low places and flood plains. Thick deposits utilized for solid waste disposal.
Sand and gravel; minor ferruginous sandstone and clay. Provides most commercial aggregates for concrete and bituminous mixes. Used as a foundation material for heavy structures and high-rise buildings in upland areas. Supplies water to many shallow domestic wells in suburban and county areas. Some abandoned gravel pits utilized for solid waste disposal.
Clay, fine-grained sand, and lignite. Used as foundation material for heavy structures and for high-rise buildings where overlying fluvial deposits are thin or absent and where alluvial materials are unsuitable. Supplies water to some shallow wells completed in sands below the fluvial deposits, but generally considered to be of low permeability and to confine water in Memphis Sand. Lower boundary very poorly defined.
Fine- to coarse-grained sand; subordinate lenses of clay and lignite. Very good aquifer from which most water for public and industrial supplies is obtained. Upper boundary very poorly defined.
Clay, fine-grained sand, and lignite. Confines water in Memphis Sand and Fort Pillow Sand.
Fine- to medium-grained sand; subordinate lenses of clay and lignite. Once used as second principal aquifer for Memphis; now reserved for future use. Presently supplies water to a few industrial wells.
Clay, fine-grained sand, and lignite. Relatively impermeable lower confining bed for water in Fort Pillow Sand.

The geologic units at the surface in the Memphis area are considered to be uncomplicated by many geologists. Upland areas on which the urban sprawl is located consist of gently rolling to moderately steep hills developed on relatively thick loess (wind-blown silt), which is characteristic of the area. The uplands are separated by the almost flat alluvial plains of the Wolf and Loosahatchie Rivers and Nonconnah Creek. These relatively broad alluvial plains cross the urban area and join with a narrow strip of the much broader alluvial plain of the Mississippi River between the river and the bluffs.

Historical accounts tell of grand exposures along the bluffs facing the river at the front of Memphis and old Fort Pickering. However, through the decades, these exposures have been modified by the activities of man and are now largely covered by construction or obscured by vegetation. Many exposures of the loess and the fluvial deposits (terrace deposits) still exist along the bluffs away from urbanized areas and in many gravel pits scattered over southern and eastern Shelby County. Knowledge of the geologic formations older than the loess and fluvial deposits has been derived mostly from driller's logs and borehole geophysics.

AGGREGATE RESOURCES

Sand and gravel are abundant in the Memphis area in high-level fluvial deposits underlying loess and in the lower part of the alluvium. The fluvial deposits are presently the primary source of commercial aggregate. According to Babitzke, Hardeman, and Hershey (1974), Shelby County led the State in sand and gravel production in 1972. Seven mining operations in southern and eastern parts of the county produced about 3,111,000 short tons (2,822,000 t) of sand and gravel having a value of about $4,072,000. In addition to the Shelby County operations, other mines supplying aggregate to Memphis are located in southern Tipton County, Tenn., and DeSoto County, Miss. (fig. 2).

Commercial pits are opened in localities where the loess overburden generally is less than 30 ft (9 m). The overlying loess is stripped, and the sand and gravel are moved by truck and conveyor belts to washing and screening operations. In addition to these open pit operations, sand also is produced from the alluvium by dredging along the channel of Nonconnah Creek and in the flood plain of Wolf River.

The gravel consists chiefly of chert pebbles with minor quartz and quartzite (fig. 3). The chert pebbles and larger fragments are less than an inch to several inches in size, and the quartz and quartzite pebbles occur in the smaller fractions. Some chert pebbles have weathered to produce porous, undesirable particles, and other less durable aggregate occurs as limonitic chert. Locally, limonite cements the sand and gravel to form thin layers of ferruginous sandstone and conglomerate, and some thin solid bands of limonite are present. Clay lumps and friable particles comprise other deleterious substances. Most of the latter are removed in processing.

Most processed (washed and sized) gravel produced in the Memphis area is used by ready-mix concrete plants and by roofing contractors. Coarse aggregate, which is about 3/16 to 1½ in (5 to 38 mm) in size, is

Figure 3.--Sand and gravel of the fluvial deposits in pit for new processing plant in eastern Shelby County, Tenn.

the chief product marketed by the plants. Pea gravel, less than one-half inch (12 mm), is used primarily by roofing contractors, but some is blended in bituminous mixes or is used in surface coats. The over-sized rock, about 1½ to 3 in (38 to 76 mm), is used as coarse fill material, and some is used intermittently by a metal industry as a flux. The waste rock, 3 in (76 mm) or more in diameter, could be crushed to produce coarse aggregate for use in bituminous concrete. Sand produced with the gravel is used in Portland-cement concrete by the rock products industries, and some is used in fills for highways and building sites. Unprocessed sand and gravel, which is mined at several locations, is used as base materials for roads and highways.

As commercial deposits of sand and gravel close to Memphis have become exhausted, new pits have been opened farther to the east and south. Prior to the abandonment of pits, the State and County laws require the restoration of the land, including backfilling and grading and the elimination of waste piles and slopes steeper than 3 horizontal to 1 vertical. Drainage must meet requirements set forth by the Memphis-Shelby County Health and Engineering Departments and revegetation is required by the 1972 Tennessee Surface Mining Law. Rising land costs, increased demand for residential and commercial building sites, and zoning laws all tend to diminish the possible areas in which sand and gravel can be produced commercially in Shelby County. The proximity of sands and gravels in the fluvial deposits to the south in DeSoto and Tate Counties, Miss., may stimulate additional development of commercial deposits in these areas.

Other aggregate presently supplied to the Memphis area comes from relatively long distances. Some crushed limestone from Kentucky and

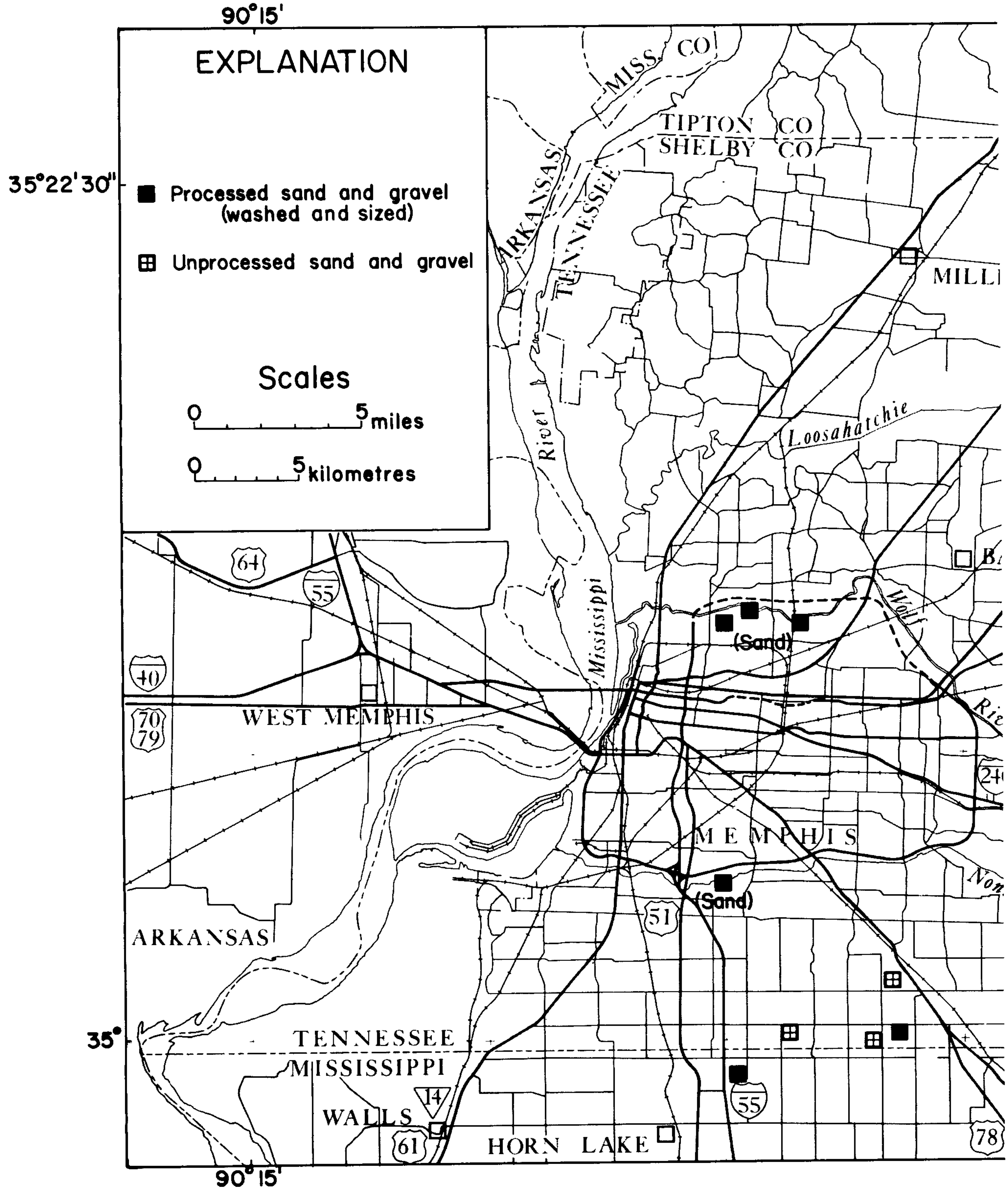
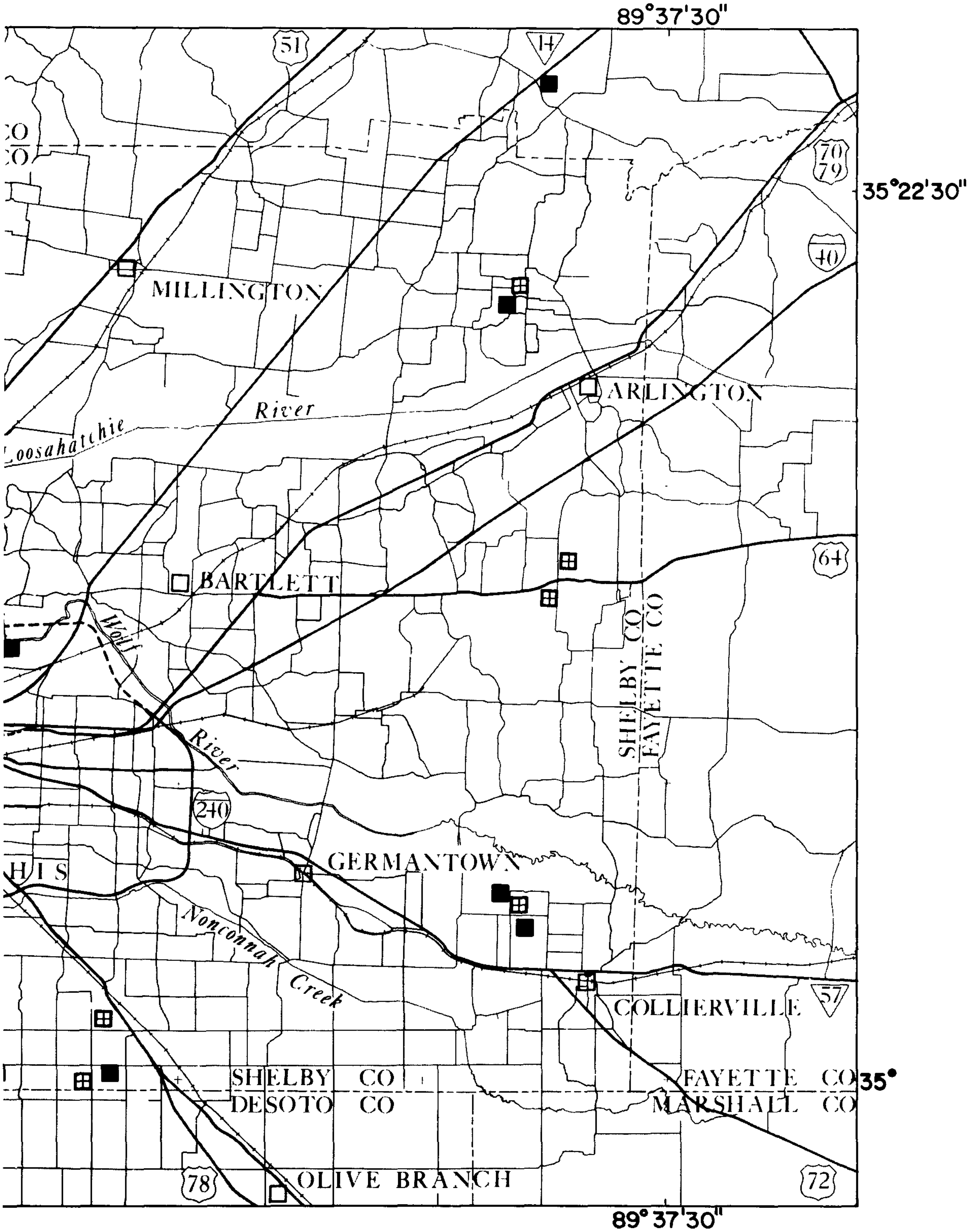


FIGURE 2. --LOCATION OF COMMERCIAL SAND AND



GRAVEL OPERATIONS NEAR MEMPHIS.

southern Illinois is transported by barge down the Mississippi River and is stock-piled on Presidents Island. The closest crushed limestone quarries producing aggregates in Tennessee are located near the Tennessee River and beyond, at distances of about 110 to 150 mi (177 to 241 km) to the east of Memphis. Crushed stone is shipped by rail and truck from these sources to Memphis.

Lightweight aggregate for the Memphis area is produced from expanded clay at plants near West Memphis and England, Ark. This lightweight aggregate is used in concrete for high-rise buildings in Memphis and in roofing slabs and lightweight concrete blocks.

FOUNDATION MATERIALS

Foundation materials in the Memphis area, for the most part, have good engineering characteristics, and foundation problems originating in these materials are minor. In the upland areas, where most land development is now taking place, loess is commonly the only foundation material of concern (fig. 4). Loess is silt that consists chiefly of very fine particles of quartz with minor amounts of carbonate rocks and mineral (dolomite and calcite), feldspar, and heavy minerals. Clay is particularly abundant in the deeply weathered upper part of the loess on hills and ridges and in reworked and redeposited loess on the valley slopes. This

Figure 4.--Loess exposed in bluff in southwestern Tipton County, Tenn.

deeply weathered or reworked loess, which is the material most commonly used for foundations, is clayey silt or silty clay. X-ray diffraction analyses show the chief clay minerals to be montmorillonite, illite, and mixed-layer montmorillonite-illite. Nevertheless, the amount of montmorillonite is not sufficient to cause serious expansive-clay problems in the area. The ranges and common values of some engineering properties of the clay-rich loess, including reworked and redeposited material, are summarized in table 2.

Table 2.--Some engineering properties of the clay-rich loess, including reworked and redeposited material.[3/]

	Range	Common values
Grain size distribution (percent):		
clay (<.002 mm)	8-45	20-25
silt (<.06 - .002 mm)	40-90	70-75
sand (2.0 - .06 mm)	1-15	< 5
Moisture contents (percent):	13-21	20-30
Atterberg limits (percent natural water content):		
liquid limits (Lw)	25-50	30-36
plastic limits (Pw)	14-30	20-25
plasticity index (Lw-Pw)	5-35	10-19
Unconfined compressive strength (pounds per square foot):	300-3700	1500-2000
Seismic velocity of compressional waves (feet per second):	850-2000	900-1100

3/ Based in part on oral communications with Frank Redus, Vice President, Test, Inc., Memphis, Tenn., 1974, and on data provided by James Bush, Materials Engineer, Barrow-Agee Laboratories, Inc., Memphis, Tenn., 1974.

Dry loess is easily excavated with machinery at relatively low cost. Large areas, some of which exceed half a square mile (1.3 km) in size, are readily leveled or shaped with bulldozers and land graders. The loess is pushed from high to low areas, and any excess material may be hauled to nearby flood plains for use in other fills. The resulting surface is suitable for residences and light commercial buildings. These structures, which are placed on "floating" slabs or spread footings, undergo little settlement distress, although some settling may occur as a result of inadequate compaction, poor drainage, or concrete placement in wet seasons.

Wet loess can form a slippery, relatively impermeable surface, which is virtually untrafficable and unworkable. In bare areas and on steep banks, loess is highly susceptible to erosion, particularly where disturbed during construction. Landslides and slumps occur on steep slopes and along the high bluffs facing the Mississippi Alluvial Plain. In the latter area, soil falls and slides may generate earth flows in prolonged wet weather, and mass movement of loess and underlying materials could be triggered by earthquakes. Owing to its unconsolidated nature and clay content, the loess is compressible to some extent and is not a suitable foundation material for heavy structures such as high-rise buildings.

Heavy constructions and large buildings are commonly placed on drilled piers terminating in the sand and gravel of the fluvial deposits, which underlie the loess at most places. The fluvial deposits are consolidated to varying degrees, depending on the proportions of sand to gravel, the nature of interstitial material, the amount of cementation by iron oxide, the extent of reworking as related to geologic age, and depth to the water table. The engineering characteristics of these foundation materials at any one locality are determined from samples obtained by auger borings, which are scheduled as a part of individual site investigations. For some sites, test boring information is supplemented by shallow seismic and resistivity surveys. These geophysical surveys are particularly valuable in the Memphis area for determining depth to the sand and gravel and the water table. For heavy construction in the upland areas where fluvial deposits are thin or absent beneath loess, dense stable materials can generally be found in the underlying Jackson Formation or Claiborne Group.

With diminishing availability of upland construction sites in the rapidly expanding Memphis area, industrial, commercial, and residential developments have extended into the alluvial plains of the Mississippi River and Nonconnah Creek. Many constructions are being located on man-made fills overlying alluvium. In these areas, particularly in the Mississippi Alluvial Plain, deposits of compressible clay occur in the alluvium at some localities. This clay could cause settlement failure under load. In addition to this hazard, sand in the upper part of the alluvium is less compacted than sand and gravel in the lower part, and the water table is relatively shallow. As a consequence, some of the finer sands may be susceptible to liquefaction in the event of an earthquake. Heavy constructions, such as certain industrial installations on Presidents Island and the Mississippi River bridges, require foundations in the deeper sand and gravel of the alluvium or in the sand and clay of the Jackson Formation or Claiborne Group. Footings in these areas may extend to 150 ft (46 m) depths.

EARTHQUAKE HAZARDS

Memphis has been included in seismic risk zone 3 where major destructive earthquakes could occur (Algermissen, 1969). Zone 3 is based on the proximity of the city to the epicentral region of the series of major earthquakes ("New Madrid earthquakes") that occurred in the Mississippi Valley in 1811-12. For the central Mississippi Valley, Stearns and Wilson (1972) have compiled one of the most complete records of historic earthquakes that is currently available. This compilation gives intensities in accordance with the Modified Mercalli Scale (table 3).

The earliest historic record of an earthquake in the Memphis area was experienced by a French missionary and his party in 1699. Other early reports of shocks were recorded by travelers along the Mississippi River and by inhabitants of the sparsely settled area. Included with these are the 1811-12 earthquakes which are among the most severe to have been experienced within historic time in the central and eastern United States. According to the isoseismal maps constructed by Stearns and Wilson (1972), the two major shocks of this series were of possible intensity of IX or X in the area that was later to become Memphis.

Other severe earthquakes that have caused damage at Memphis include an 1843 event with an estimated intensity of VII or VIII and an 1889 event with an estimated intensity of V to VII. Many earthquakes have been experienced at Memphis with intensities of from I through V, with III and IV predominant. From this record, it would seem that destructive earthquakes can occur in the Memphis area, but not as frequently as in other earthquake prone regions such as California or Alaska.

Strong shaking and possible ground failure would be the most likely effects in the Memphis area from a major earthquake. Because most mid-south constructions, including those in Memphis, have not been built according to aseismic design, damage is possible from a strong earthquake in the region. Mann and Howe (1973) evaluated the possible attenuation or damping effects of the loessial blanket under Memphis on the passage of earthquake waves and concluded that damage and loss of life would be great. More investigation and information are needed to understand the propagation of seismic waves in the Memphis earth materials and the possible damage that could occur from earthquake shaking.

One of the chief concerns in regard to structural damage at Memphis is the possible liquefaction of sands. Youd (1973a) states that liquefaction is the transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressure. Youd (1937b) also indicated that liquefaction can occur when seismic shaking causes re-orientation of sediment grains and load normally borne by sediment is transferred to water occupying pore space within the sediment. Liquefaction with limited flow may cause laterally spreading landslides and in areas of high water table may produce quick-condition failures. Kellogg (1973) suggested that liquefaction might occur in the softest, wettest soils of the Memphis area during an earthquake. Sands underlie most of the loess and are present under the finer alluvial deposits.

Table 3.--Modified Mercalli intensity scale

(Abridged version from Wood and Neumann, 1931)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, and so forth broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structure; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

Table 3 (cont'd)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Slumps and earth-flows in the Memphis area can be observed in the bluff areas north and south of the City. Most recent mass movements have been related to heavy precipitation (fig. 5), but earthquakes could trigger additional movement.

Seismic velocity surveys at Memphis indicate that compressional waves travel through the loess at velocities of 900 to 1,000 ft/s (275 to 300 m/s) under usual unsaturated conditions, and at greater velocities after prolonged precipitation. In the wetter alluvium, the velocities of these waves range from 2,000 to 4,000 ft/s (600 to 1,200 m/s), and in sand and gravel of the fluvial deposits velocities may be as great as 6,000 ft/s (1,800 m/s). Data on measured velocities of shear waves are not available. However, empirical relations suggest that these velocities may be only 500 ft/s (150 m/s) or less in loess near the surface, but probably increase with depth.

Monitoring of local seismicity can provide important data for evaluation of the local earthquake hazard. Prior to 1973, the nearest seismograph station was 60 mi (97 km) south of Memphis at the University of Mississippi Seismological Observatory near Oxford, Miss. In the Dyersburg area about 60 mi (97 km) north of Memphis, instruments have been installed for several periods of time in the past. St. Louis University recently expanded its seismograph network by adding instruments about 40 mi (64 km) west of Memphis on Crowleys Ridge and about 40 mi (64 km) east of Memphis.

The first seismograph in Memphis was placed in operation by Memphis State University in November 1973 (fig. 6). This long-period, vertical-component instrument was supplemented by the addition of two horizontal-component units in July 1975.

Figure 5.--Blocks of slumped loess in southwestern Tipton County, Tenn. At this locality, 10 feet (3 m) of the loess face of the bluff collapsed following an intense storm which dropped 6.53 inches (165.9 mm) of rain within 24 hours (U.S. Naval Air Station gage, Millington, Tenn., June 6-7, 1974).

FLOOD HAZARDS

Flood hazard no doubt was an important consideration to the original developers of Memphis as they selected the town site on the bluffs and well above the expected flood stages of the Mississippi River. The early town suffered little damage from the great floods on the river, and it became a refuge for people who were displaced from their homes in the nearby lowlying areas of Arkansas and Tennessee (Young, 1912). Nevertheless, as the community went through several stages of expansion, the choice upland areas were first to be occupied, and commercial, industrial, and residential development eventually encroached into the less desirable flood-prone lowland areas.

Early damaging floods at Memphis were caused by backwater from the Mississippi River which, during high stages, spread into low areas in the older sections of the city along the flood plains of Bayou Gayosa and Cypress Creek. Floodwater was also a threat to the commercial and industrial establishments near the old mouth of the Wolf River and along the margin of its flood plain in the northwestern parts of the central city.

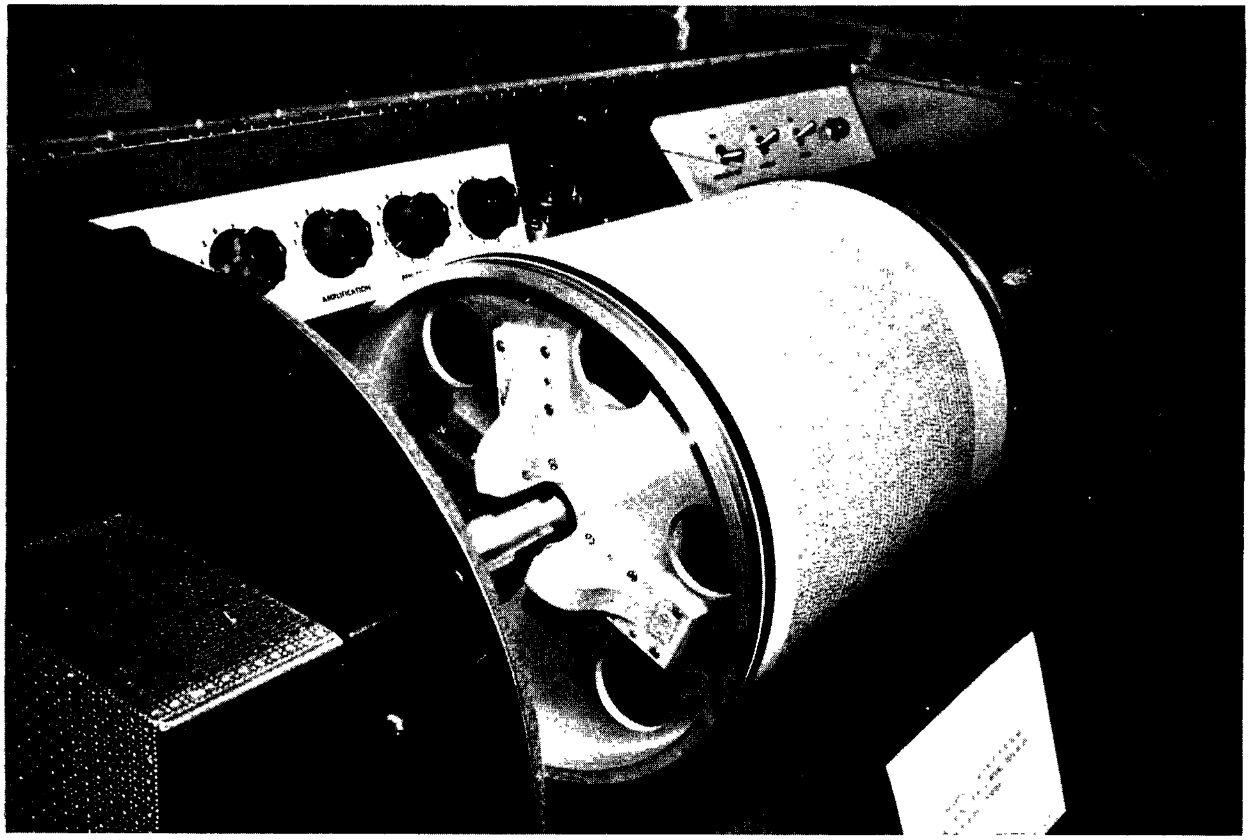


Figure 6.--Visual seismograph-recorder at Memphis State University.

Following the great floods on the Mississippi and Wolf Rivers in the winter of 1937, the U.S. Army Corps of Engineers designed and installed a system of floodwalls, levees, revetments, drainage structures, and pumping stations beginning near the old mouth of the drainage structures, and pumping stations beginning near the old mouth of the Wolf River and extending upstream for a distance of 9 mi (14.5 km). Several years later, levees and a pumping station were installed in the area extending upstream from the outlet of Nonconnah Creek for 3 mi (4.8 km). Both of these projects were undertaken to provide flood protection from the backwater of the Mississippi River. In 1951, the construction of the Tennessee Chute closure by the U.S. Army Corps of Engineers in conjunction with the President's Island Development lowered the Mississippi River backwater by as much as 2.5 ft (0.76 m) at the outlet of Nonconnah Creek.

In recent years, much consideration has been given to the potential flood hazards along the flood plains of Wolf and Loosahatchie Rivers and Nonconnah Creek (U.S. Soil Conservation Service, 1968, 1969, and 1970). As yet, the flood plains of the Wolf and Loosahatchie Rivers are relatively undeveloped except for agricultural purposes, a few encroachments in localized areas, and modifications related to highway and railroad construction, flood control, and sand mining. In the near future, however, the Wolf River flood plain will undergo considerable modification as a result of the building of the north loop of the circumferential Interstate

Highway 240 along its north side, and this activity probably will encourage much additional development.

Flood hazards of more immediate concern, which could result in flood damage to existing urban areas, are the result of encroachments into, and modifications of, the flood plain of Nonconnah Creek and the changes, brought about by urbanization, in the flow characteristics of the small streams that drain the upland areas of the city.

Nonconnah Creek flows northwesterly and westerly through southern Shelby County for about 28 mi (45 km). Prior to the end of World War II, the flood plain, which probably averages half a mile (0.8 km) in width along the lower 24 mi (38.6 km), was utilized primarily for agricultural purposes. Chief modifications included: (1) placement of fills for the highways, roads, and railroads that cross the flood plain; (2) construction of the levee system and pumping station below U.S. Highway 61 near Nonconnah Creek outlet at McKellar Lake; and (3) improvements to the channel from Bailey Station Road to U.S. Highway 51.

From the end of World War II to the present (1975), the Nonconnah Creek flood plain has undergone many additional changes, and its natural boundaries are difficult or impossible to recognize at many places. These later modifications include: (1) clearing and straightening various segments of the channel at several different times; (2) constructing of Interstate Highway 240 along the northern edge of the flood plain and Interstate Highway 55 across it; (3) placing many additional fills for improved roads and new bridges, commercial establishments, office and apartment complexes, and warehouses; (4) building residential developments at many places; and (5) altering the flood plain and channel by the removal of material from many borrow pits and a few sand-dredging operations. At present, changes in the flood plain are proceeding at a relatively rapid rate upstream from U.S. Highway 61 for a distance of about 12 mi (19 km). Figure 7 shows part of a large excavation in Nonconnah Creek flood plain from which fill material is being dredged.

Floods are known to have occurred frequently along Nonconnah Creek in the past, although no gaging station records were available for this stream prior to 1969. The largest documented flood occurred on May 9, 1958, after 4.76 in (121 mm) of rain fell in approximately 8 hours (U.S. Soil Conservation Service, 1968). This flood spread into several residential developments along the edge of the flood plain and displaced many people from their homes. The flood stages that were reached during this flood have dictated the altitudes to which many later fills in the Nonconnah Creek flood plain have been constructed in order to avoid flood hazard. The city now, however, requires that fills for developments be brought to the altitudes computed for the 100-year flood.

The flood information report of the U.S. Soil Conservation Service (1968) also includes flood-prone-area maps which show the expected altitude and the extent of the 100-year flood. These maps show that the 100-year flood would exceed the stages of the 1958 flood, and that large areas now under development would be affected. As a result of this information, several proposals to alleviate the flood hazard along Nonconnah Creek have

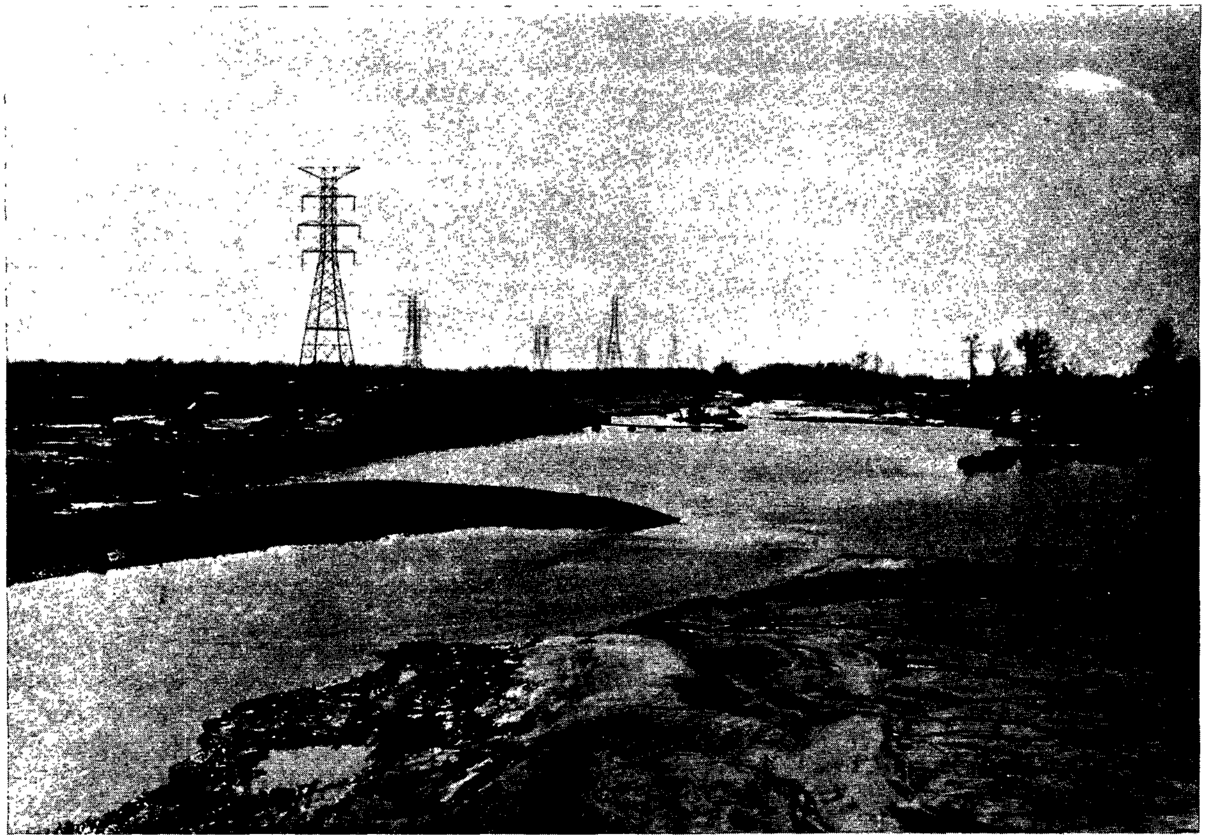


Figure 7.--Excavation (foreground) in flood plain of Nonconnah Creek from which alluvial materials are being dredged for use in the construction of a large fill (left background) for a new shopping mall.

been made. In brief, the latest proposal by the U.S. Army Corps of Engineers calls for (1) construction of a 1,900-acre (7.7 km^2) flood-control reservoir, the so-called "Nonconnah Lake," in the upstream area of Nonconnah Creek; (2) cleanout and enlargement of the channel and establishment of a 600 ft (183 m) wide greenway-floodway along the channel extending downstream from the reservoir to the mouth of Nonconnah Creek; and (3) installation of three floodwater-retarding structures on Johns Creek tributary.

In addition to the flood hazards along Nonconnah Creek, flooding along the small streams that drain the uplands has increased in frequency in recent years because of the high degree of urbanization taking place. In many areas, residential flood plains are either variously constructed or non-existent. Runoff has increased in volume because paved areas, buildings, compacted soil, and storm sewers have reduced the ground area once available for infiltration. Peak flows have increased, and runoff times have decreased, because storm sewers and channel improvements have reduced the retardation of flow by vegetation and natural irregular channels. These changes in flow characteristics have made apparent a need to re-evaluate existing design criteria for storm sewers and drains.

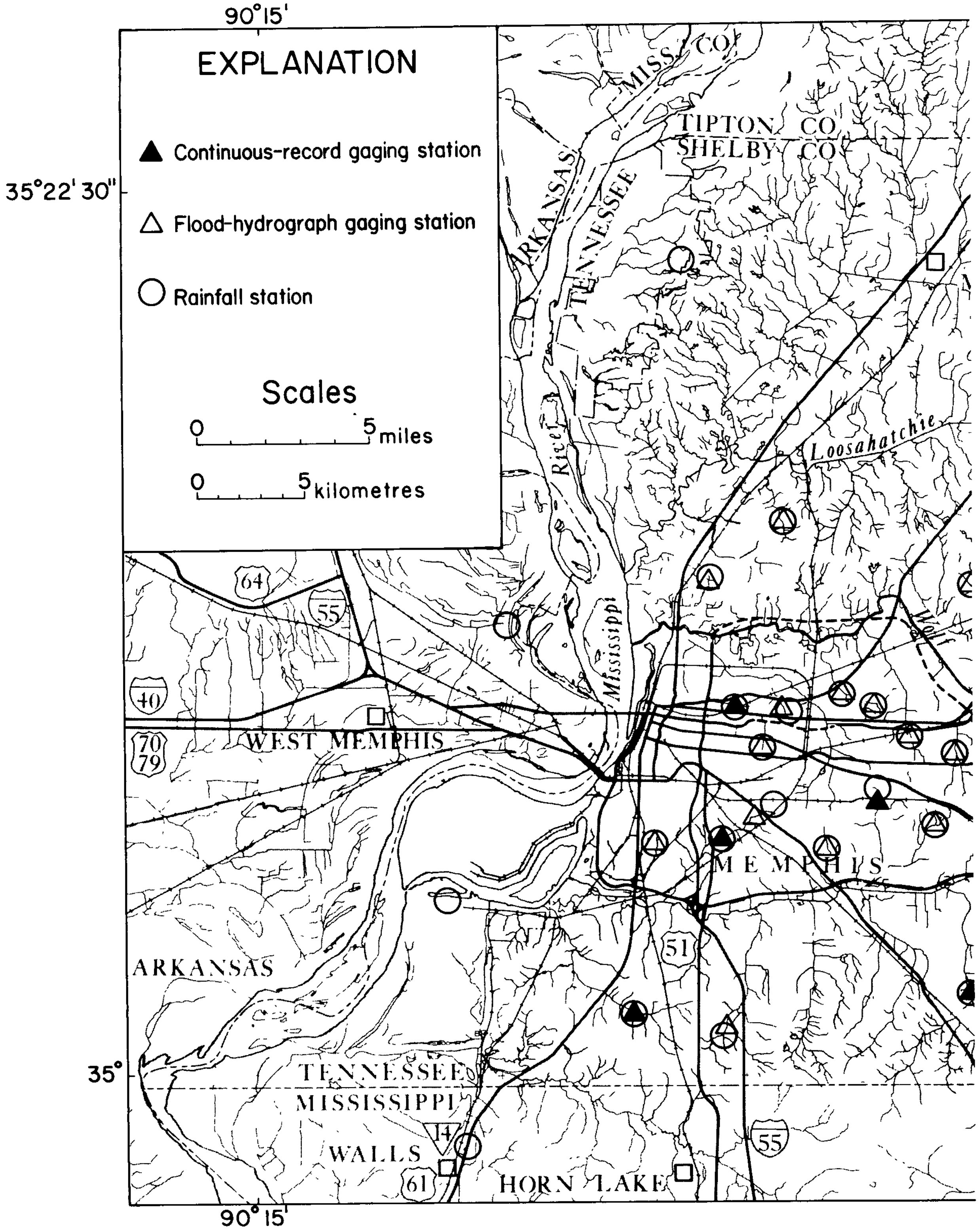
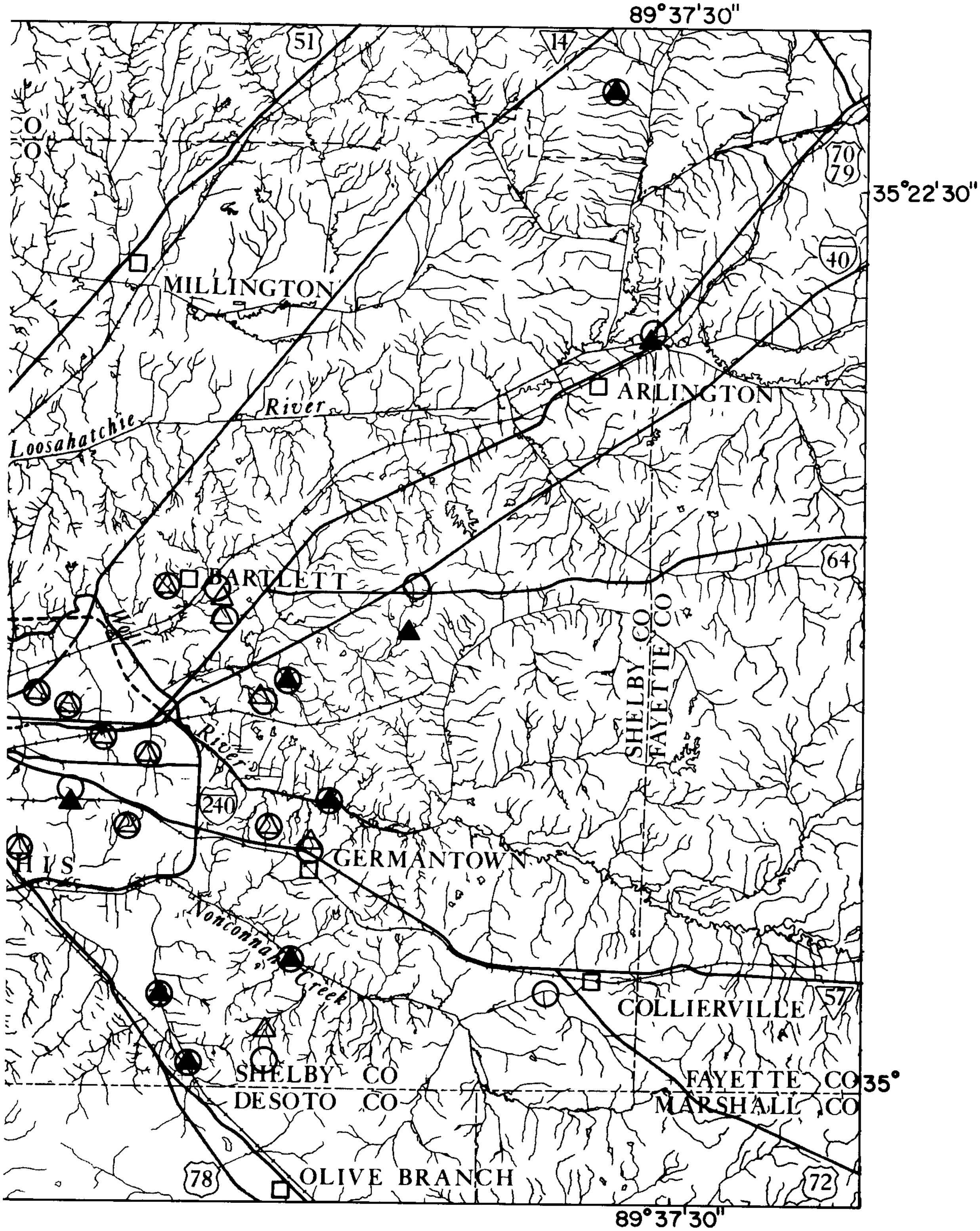


FIGURE 8. --LOCATION OF THE GEOLOGICAL SURVEY'S STREAMFLOW



AND RAINFALL GAGING STATIONS IN THE MEMPHIS AREA.

In May 1974, the U.S. Geological Survey began installation of about 30 gaging stations at selected sites to evaluate the effects of drainage basin size, channel size, degree or urbanization, and other significant factors on the rainfall-runoff relationships. The information gained from these stations will be used in a digital model, which should be useful in predicting storm runoff characteristics at other sites and should be an aid in the design of channel improvements, culverts, bridges, and storm sewers and drains. Figure 8 shows the location of the stream flow and rainfall gaging stations operated by the Geological Survey in the Memphis area.

WATER RESOURCES

Memphis is one of the largest cities in the Nation that depends solely on ground water for its water supply. Good-quality ground water in enormous quantities is available from depths above 2,000 ft (600 m) in the two principal aquifers--the Memphis Sand ("500-foot" sand) and the Fort Pillow Sand ("1400-foot" sand). Most water presently being pumped at Memphis is from the Memphis Sand, an excellent aquifer averaging about 800 ft (245 m) in thickness beneath the city. The Fort Pillow Sand, which averages about 225 ft (70 m) in thickness, was until recently the secondary source of supply for the municipal system. This aquifer is now being reserved by the city for future use, and it presently supplies only a few industrial wells. Several comprehensive reports are available which describe the hydrology and general geology of the principal aquifers (Schneider and Cushing, 1948; Criner and Armstrong, 1958; Criner, Sun and Nyman, 1964; Bell and Nyman, 1968).

Above the Memphis Sand and its confining bed are the shallow water-table aquifers consisting of the fluvial deposits and alluvium. Many small-capacity domestic wells pump from the fluvial deposits in outlying suburban and county areas. These wells are gradually being abandoned as the city's water system is extended into these areas. The alluvium has potential for high-capacity wells, but because of hardness and high amounts of iron and total dissolved solids, the water is less desirable for many purposes than that from the artesian aquifers. A few industrial wells on Presidents and Mud Islands pump from the alluvium.

Below the Fort Pillow Sand and above the Paleozoic rocks, only the McNairy Sand equivalent and the Coffee Sand of Late Cretaceous age have potential as aquifers. These two aquifers may not be developed because of their depths and the degree of mineralization of the water.

Withdrawal from the Memphis Sand in Shelby County in 1974 was estimated to be 190 Mgal/d (720 Ml/d) by J. H. Criner and W. S. Parks (oral commun., 1975). Of this total, 110 Mgal/d (415 Ml/d) was pumped by MLGW (Memphis Light, Gas and Water Division) for the city's water supply, and the balance was pumped by industries, independent utility districts, and commercial establishments. MLGW, a public owned utility, maintains the city's water supply system. This system is supplied by about 140 wells, most of which are in six principal fields--(1) Mallory (formerly Parkway), (2) Sheahan, (3) Allen, (4) McCord, (5) Lichterman, and (6) Davis. These well fields are spaced about 6 mi (10 km) apart (fig. 9). The present total production capacity of these well fields is about 140 Mgal/d (530 Ml/d). Each of the principal well fields is adjacent to pumping stations of the same name, where the water is treated and then pumped through an extensive distribution network. Treatment is primarily concerned with the removal of iron, hydrogen sulfide, and carbon dioxide and consists of aeration and rapid sand filtration. Although the raw water is bacteria free, the finished water is chlorinated as required by State law.

Wells now pumping from the Memphis Sand supply water for a variety of uses and, consequently, vary widely in well design and depth (fig. 10). The primary factor influencing well design is, of course, cost versus the amount of water needed. Secondary factors are the minimum depths to a satisfactory sand and the expected water level in the aquifer at a particular well site. Most wells range from about 300 ft (90 m) to about 700 ft (210 m) in depth, and water levels in 1974 ranged from about land surface to 212 ft (64.6 m) below land surface. If a generalization can be made as to a "typical" public or industrial well of modern construction, it would be about 500 ft (150 m) deep and would be cased with 20-inch (508 mm) diameter steel casing. The lower 80 ft (24.4 m), excluding the back pressure valve, would be 12-inch (305 mm) diameter stainless steel screen set in a gravel "pack", which would be placed in a 32-inch (813 mm) underreamed hole adjacent to a fine- to medium- or medium- to coarse-grained sand. The pump would be a 100-hp (74.6 kw) electric-powered turbine unit adjusted to produce between 1,000 and 1,500 gal/min (3,800 to 5,700 l/min). The specific capacity of this "typical" well would probably range from 25 to 30 (gal/min)/ft [(310 to 375 l/min)/m] of drawdown, depending on the characteristics of the sand. In well fields, the optimum spacing between wells, which was selected through experience by MLGW many years ago, is 1,000 ft (305 m) between wells capable of pumping 1,000 gal/min (3,800 l/min) or more.

Present water levels and cones of depression in the Memphis area are the results of pumping which began with the installation of the first artesian well in 1886 and has continued with the addition of many wells since that time. Initially, the potentiometric surface in the Memphis Sand probably was in equilibrium with the water table in the shallow aquifers, and some water probably was being discharged to the alluvium beneath the larger flood plains. At present, a large regional cone of depression is centered near downtown Memphis and extends outward to include most of Shelby County and parts of DeSoto County, Miss., and Crittenden County, Ark. Within this regional cone, are areally smaller subsidiary cones that have developed beneath the city's well fields and in a few areas of heavy industrial pumping. Through the years, water level declines have had a more or less direct relationship with the increase in total annual withdrawal for the area. Observation wells outside of the city's well fields and the areas of heavy industrial pumping indicate declines of about 1 1/2 ft (0.5 m) per year near the center of the major cone of depression and about 1 ft (0.3 m) per year to the east near Germantown. Since 1960, withdrawals from the Memphis Sand have increased annually at a rate of about 4.5 Mgal/d (17 Ml/d).

No detrimental effects to the environment are known to exist as a re-

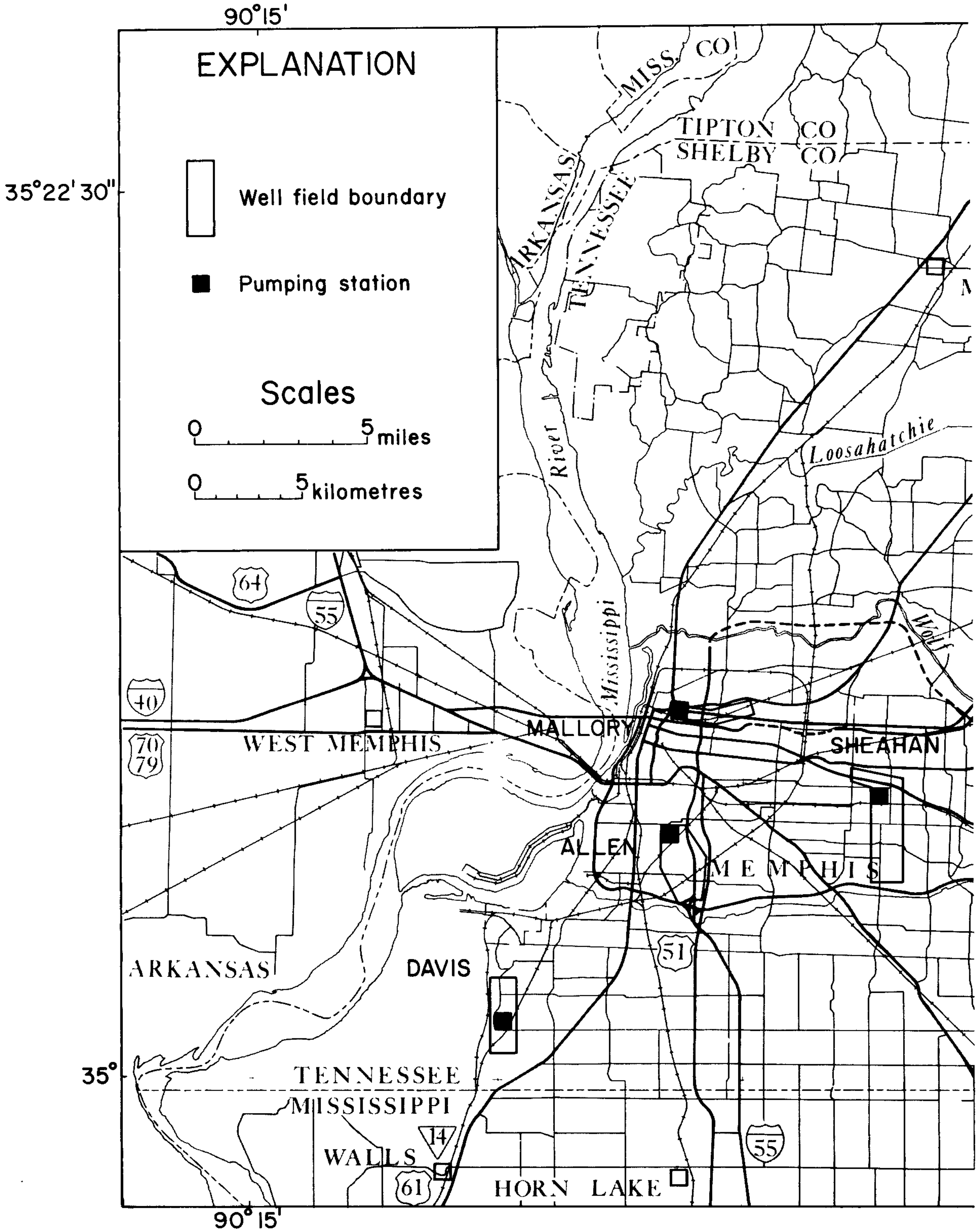
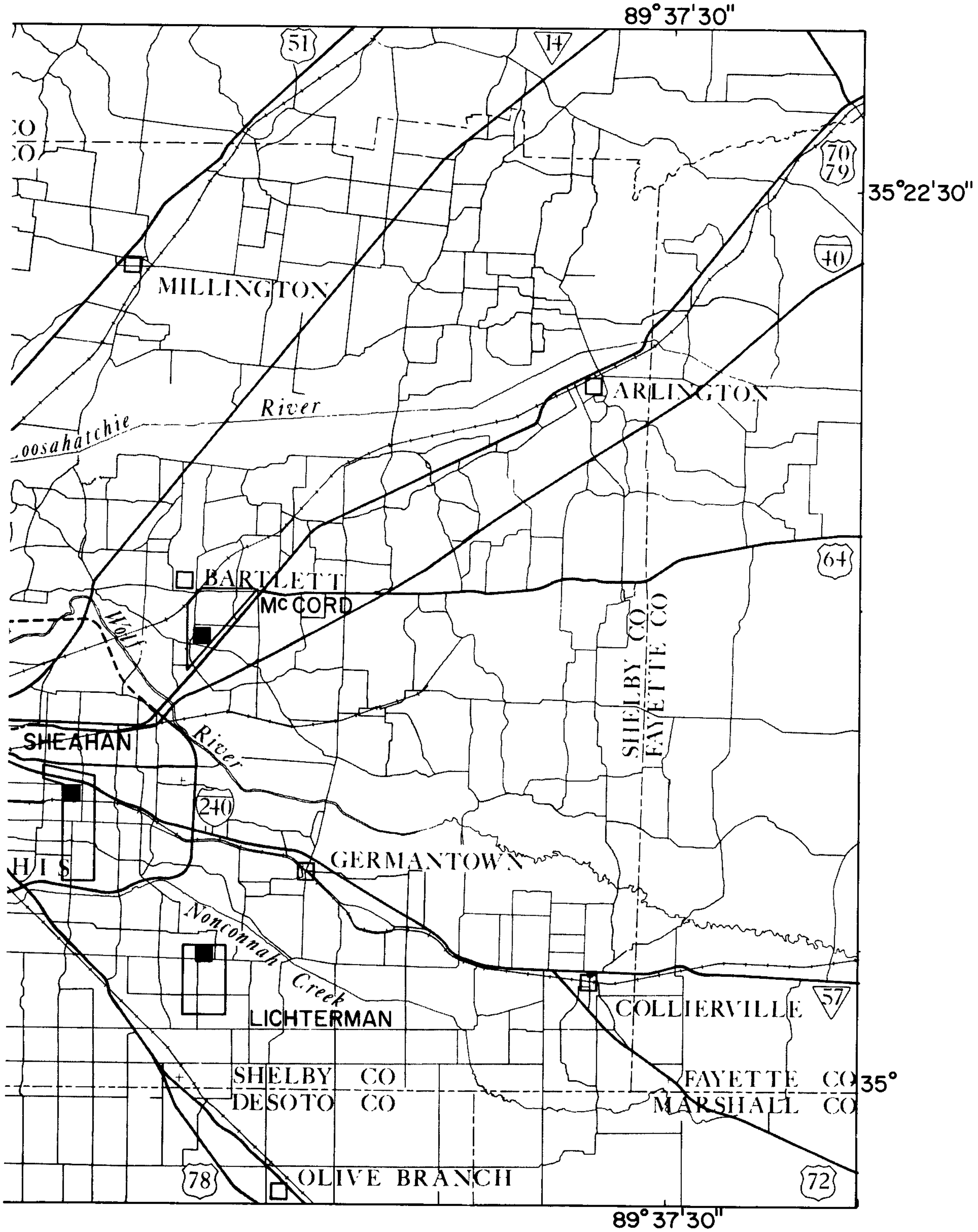


FIGURE 9.--LOCATION OF MEMPHIS LIGHT.



GAS AND WATER DIVISION'S WELL FIELDS.

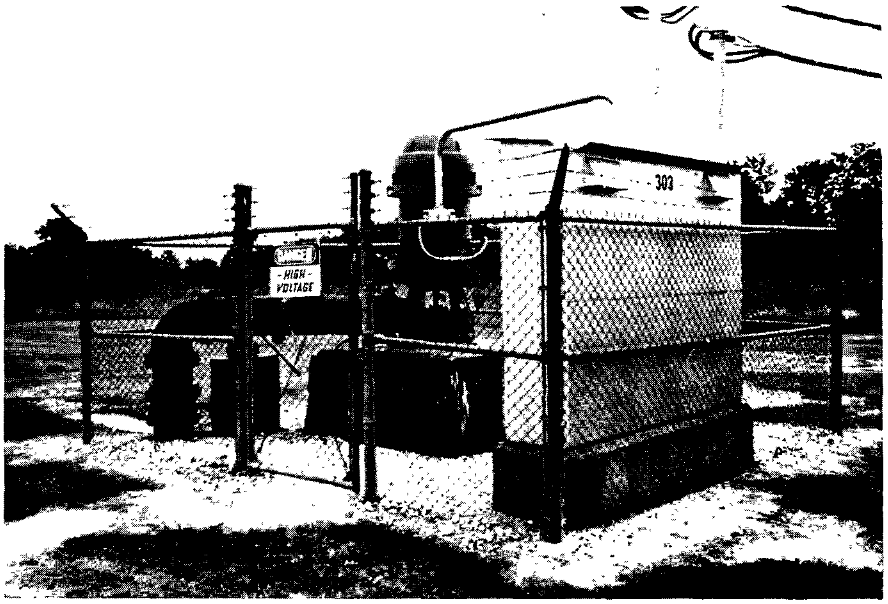


Figure 10.--Well in Lichterman field pumping from the Memphis Sand.

sult of the present degree of development of the ground-water supply at Memphis. However, inasmuch as annual withdrawals from the Memphis Sand are expected to increase steadily over the coming decades, problems could eventually arise that might restrict additional development of this aquifer. Two of these problems, which are related to local geology and hydrology, are: (1) contamination as a result of leakage of water to the Memphis Sand from near-surface sources, and (2) land subsidence as a result of the dewatering of clay and sand above and within the aquifer.

Contamination of water in the Memphis Sand could occur if contaminants enter into, and concentrate in, the shallow water-table aquifers. Present knowledge of the aquifer characteristics of the Memphis Sand indicates that the magnitudes of the cones of depression at Memphis are less extensive than those that are simulated by using analog methods and applicable mathematical formulas for artesian doncitions without leakage (J. H. Criner, oral commun., 1975). This indicates that part of the recharge to the aquifer is derived from leakage, and it is reasonable to assume that some, if not a large part, of this water is coming from near-surface sources (confining bed, fluvial deposits, or alluvium). Information from well logs shows that at many places the clay beds, making up the bulk of the confining bed above the Memphis Sand, are interbedded with numerous sand beds, and that at a few localities, sand is predominant. Therefore, although this confining bed serves as a barrier to the movement of ground water, it is imperfect as a sealant. Locally, the confining layer contains "windows" which could permit vertical water movement, and there is a distinct possibility that contaminants could enter the aquifer at those places. However, knowledge of the location of these "windows" is very incomplete because of the poor spatial distribution of reliable well logs.

Land subsidence has not been measured at Memphis. If it has occurred, any surface indications would be obscured by construction activities or by the effects of minor settling problems associated with the clayey loessial soils. Since pumping began, withdrawals no doubt have reduced pore pressures within the Memphis Sand, and it is probable that minor adjustments have taken place by compaction of the clay and sand within and above this aquifer. Nevertheless, the decline of pressure-head at pumping centers apparently has not caused extensive de-watering of the thick sequence of clay beds that are above the aquifer at many places.

Whether subsidence will take place in the Memphis area cannot be predicted without adequate information concerning the distribution, thickness, mineralogy, and preconsolidation characteristics of the clays. X-ray diffraction analyses of clay samples collected at random depths in six wells drilled through the confining bed into the Memphis Sand show that montmorillonite of the calcium type is the dominant clay mineral (Bell and Nyman, 1968, p. 20). If montmorillonite is as wide-spread in the stratigraphic sequence as is indicated by these analyses and if the ratio of clay to sand is high, then subsidence could become a serious problem in decades to come.

In 1969, the U.S. Geological Survey installed a subsidence-measuring device in a deep test hole drilled in the Davis well field on the outer margin of the major cone of depression in southwestern Shelby County. Other similar devices are planned for installation in the Mallory and Sheahan well fields, within the major cone of depression at Memphis.

Should Memphis ever need a source of water to supplement its present supply, the Mississippi River passes by its "doorstep" carrying tremendous volumes of water to the Gulf of Mexico daily. The lowest flow, since records began in 1933, is 79,200 ft^3/s (2,240 m^3/s) and the median flow, computed through 1960, is 360,000 ft^3/s (10,200 m^3/s).

SOLID WASTE DISPOSAL

Solid waste disposal was one of the first urban problems faced by the people of Memphis. In the early days waste disposal was left to the individual, who commonly disposed of it at the nearest and most convenient place. Filth was allowed to accumulate in yards and alleys, vacant lots, and streets, and sanitary conditions were poor. Following the yellow fever epidemic of 1873, the Board of Health attempted to clean up the community. Nevertheless, as time passed without a recurrence of the fever, the sanitation of the town again was neglected (Young, 1912). It was not until after the yellow fever epidemic of 1878 that a system was established for the collection and disposal of solid waste. Responsibility for this service was assumed by the Board of Health, and remained so, until the establishment of the Sanitation Department in 1919.

Collection of solid waste was first conducted with mule-drawn carts

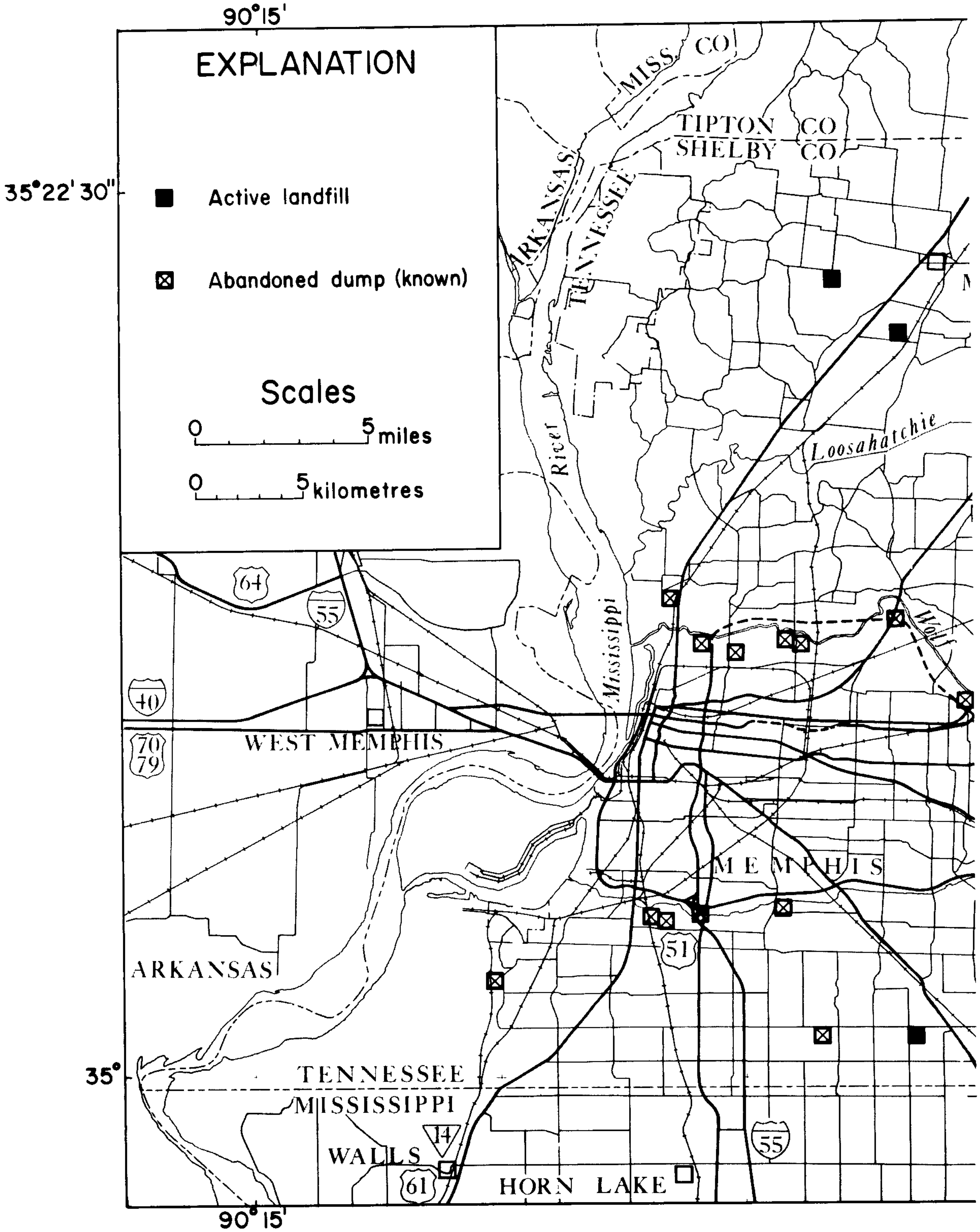
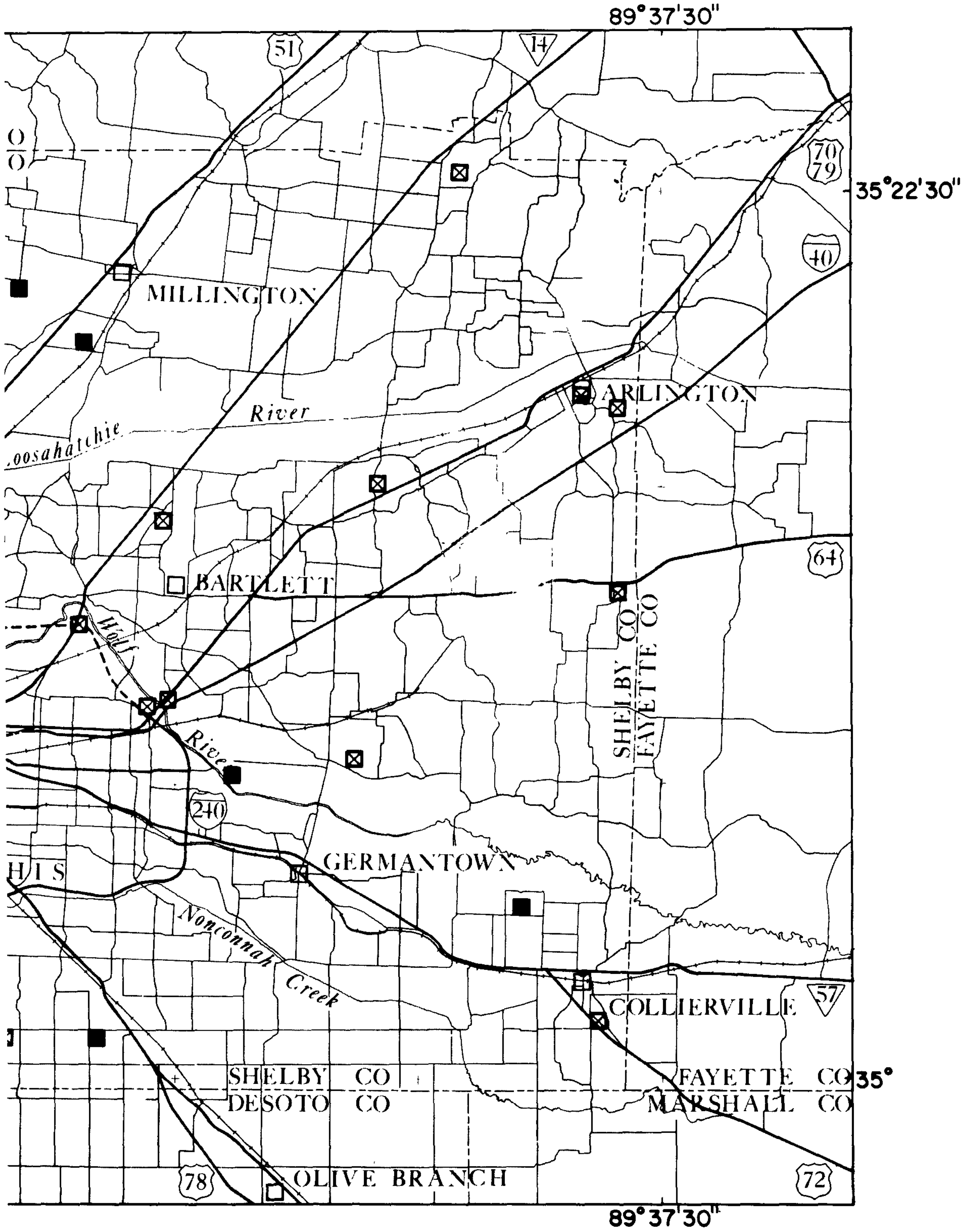


FIGURE 11. --LOCATION OF ACTIVE LANDFILLS



AND ABANDONED DUMPS IN SHELBY COUNTY.

and wagons. Refuse was separated by the originator into combustible and noncombustible components. Combustibles were hauled to city operated incinerators, and noncombustibles were hauled to open dumps along the bluffs adjacent to the Mississippi and Wolf Rivers. Eventually these gullies and low places were filled, and the dumps were closed and finally converted into parks, streets, and parking areas (Memphis-Shelby County Plan. Comm., 1968). With the closing of these dumps, new sites were acquired in the outskirts of the growing city. Open dumps gave way to covered dumps, and more modern methods of collection and processing were initiated as advancements in transportaiton and equipment permitted. Because of the rapid growth of the city and the increased volume of waste, dump sites could not always be found within the city limits. Therefore, arrangements were made to use sites located in less developed parts of the county.

In recent decades, Memphis has utilized two geologically and topographically different types of solid waste disposal sites--landfills in the flood plains of nearby streams and abandoned gravel pits in the upland areas (fig. 11). The flood plains of Nonconnah Creek and Wolf River have been favored sites for city operated landfills. Large abandoned sand pits and other landfills in the flood plain of the Wolf River have served as dump sites for the northern and eastern parts of the city, and landfills in the flood plain of Nonconnah Creek have served as dump sites for the southern parts. In addition, abandoned gravel pits in the eastern and southern parts of the county have been used as dump sites for subdivisions and outlying communities. Several of these pits were used for garbage disposal, while others have received trash and refuse from construction.

Both of these types of disposal sites have had advantages in that they have served a dual purpose. One, of course, was to provide the city with a low cost or no cost place for the disposal of its solid waste. The other was to improve land which otherwise was unusable because of the excavations made in mining or undesirable because of the high incidence of flooding. The disadvantages of the flood plain sites are (1) they are in poorly drained areas where the water table is high, which increases the risk of ground water and stream contamination from leachates, and (2) they are susceptible to flood damage which could cause pollution and health hazards should floods occur. The gravel pits, by the very reason of their existence, are made in permeable materials which could allow leachates to be carried directly into the water-table aquifers. Many of these pits contain water which may be perched or ponded or may be the water-table aquifer, depending on local conditions.

In May 1969, the Tennessee Legislature passed the Tennessee Solid Waste Disposal Act, which places responsibility for regulating disposal practices within the State in the hands of the Tennessee Department of Public Health. As a result of this act, the newly organized Division of Sanitation and Solid Waste Management has closed many dumps across the State. Most dumps at Memphis wereclosed under these new regulations, and a new burden was placed on the city administration to find new sites for State-approved landfills. Thus, solid waste disposal became an immediate problem in view of the large volumes of waste now generated by the city.

At present, the city operates one State-approved landfill, which consists of a large abandoned gravel pit in the southern part of the county (fig. 12). Before it was covered, the stratigraphic section in the northwest part of the pit consisted, from the base upward, of about 5 to 6 ft (1.5 to 1.8 m) of light-gray silty clay at the Jackson Formation or Claiborne Group, about 10 to 20 ft (3.0 to 6.1 m) of sand and gravel of the fluvial deposits, and about 15 to 20 ft (4.6 to 6.1 m) of the loess. The shallow subsurface conditions at the site were investigated for the city by Test, Inc. of Memphis. Several test holes were drilled, and this information was supplemented with resistivity surveys. From this work, it was determined that part of the pit was underlain by at least 50 ft (15.2 m) of impermeable clay of the Jackson or Claiborne. Water that was standing in low places and at various altitudes was concluded to be perched on the impermeable clay or ponded from silting of the sand and gravel by the eroded loess. This water was drained before dumping began. Loess from waste piles, made during the gravel operation, is being utilized as cover material along with additional loess that is hauled in.

In addition to this pit, the city has access to two other sites that are State approved as landfills. One site, which is oeprated by a private concern, is north of the Loosahatchie River near the small community of Lucy and serves the northern part of the city. At this site garbage is placed in excavations made in the clay-rich upper part of the loess and is covered with the excavated material. The other site, which is operated

Figure 12.--Garbage being dumped at landfill of City of Memphis in southern Shelby County, Tenn.

by the county, is in the Wolf River flood plain on the Shelby County Penal Farm property and serves the eastern part of the city.

Studies of the feasibility of using modern methods of burning combustibles as a supplemental energy source are presently being conducted for the City of Memphis and for the Tennessee Valley Authority by consultants. Most, if not all, of the solid waste at Memphis may be processed in this manner within the next several years.

SUMMARY AND CONCLUSIONS

Aggregate resources are abundant in the immediate vicinity of Memphis and in outlying areas. Nevertheless, the high cost of land and zoning restrictions could become significant factors in their continued development and use. Foundation materials at Memphis are suitable for residences and light buildings at most places. Site investigations are conducted to determine bearing capacities of foundation material for heavy constructions and high-rise building. Hazards to constructions are greatest in the flood plains of the major streams. Although there is the potential threat of a large magnitude earthquake in the central Mississippi Valley area, knowledge of the expected magnitudes, frequencies, and destructive effects of earthquakes in the Memphis area is at best rudimentary. Some information is now being collected with seismographs at Memphis and in outlying areas. An immediate problem is the hazard of floods along Nonconnah Creek, where fills and excavations are rapidly constricting or altering the natural flood plain, and along and along many small streams, where urbanization has brought about changes in the storm runoff characteristics. This hazard also could become significant along Wolf and Loosahatchie Rivers, depending on the extent of future development in these flood plains. Water is considered to be in great abundance at Memphis, especially if both ground- and surface-water resources are taken into account. However, contamination of ground-water supplies by leakage from near-surface sources and land subsidence could result from the continued increases in annual withdrawals from the major artesian aquifer. Solid waste disposal will continue to be a problem as the volume of waste generated by the city increases and as sites for landfills become difficult to acquire. To help alleviate this problem, modern methods of of burning combustibles as a supplemental energy source may be initiated.

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