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GROUND-WATER RESOURCES OF TIPPECANOE COUNTY, INDIANA

BY

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GROUND-WATER RESOURCES OF TIPPECANOE COUNTY, INDIANA

By Joseph S. Rosenshein

ABSTRACT

Tippecanoe County in central Indiana has an area of about 500 square miles. The land surface is flat to rolling, except where the Wabash River and its tributary streams have eroded deep valleys.

Most of Tippecanoe County is covered by glacial drift. The drift ranges in thickness from a thin veneer to about 435 feet and was deposited upon a bedrock surface that was eroded by a preglacial drainage system. Much of the surface drift consists of glacial till. Water-laid crossbedded sand and gravel are associated with the till. The subsurface glacial deposits also include much till with interbedded sand and gravel. Locally clay deposits are as much as 106 feet thick. Within the drift, five sheetlike water-bearing units numbered 1 to 5 are differentiated in parts of the county. Ground water within these units occurs under artesian or water-table conditions. Locally it occurs under both artesian and water-table conditions within the same unit.

The bedrock underlying the county consists of shale, siltstone, and limestone of Mississippian age and shale and limestone of Devonian age. These rocks crop out in small areas in the northeastern and the western parts of the county. The bedrock provides generally small and uncertain supplies of water to wells in the county and is especially important in the southwestern part, where water-bearing deposits in the drift are scarce. Except in that part, the sand and gravel deposits within the drift are the most important sources of ground water. All industrial and public water supplies and most of the domestic supplies are obtained from wells. In most of the county only the upper 100 to 150 feet of the unconsolidated deposits have been extensively drilled for water supplies. Any deeper water-bearing sand and gravel that may be present within the drift are potential sources of additional ground water for future use.

The ground-water reservoirs are recharged mainly by precipitation within the county. The average annual precipitation is about 38 inches. The most favorable areas of recharge are the stream valleys and the adjacent sand-and-gravel terraces. A large part of the county is covered by tight soils underlain by tight clayey till. Conditions are unfavorable in such areas for direct recharge to the ground-water reservoirs by precipitation, but some occurs nevertheless. Some recharge takes place by movement of water between different unconsolidated water-bearing deposits. In addition, recharge takes place by influent seepage to the ground-water reservoir from streams during periods of high river stage.

Ground water is discharged from the aquifers of Tippecanoe County by evapotranspiration, springs, and other effluent flow to streams, slow migration of water within the ground-water reservoirs to points of discharge outside the county, and pumping from wells. The estimated ground-water discharge to streams is about 140 million gallons daily.

Ground water is withdrawn from the aquifers in the county by dug, drilled, and driven wells. The estimated pumpage is about 20 million gallons daily. Of this amount industry uses about 12 mgd, public water supplies about 7 mgd, and domestic and farm supplies about 1.5 mgd. The estimated per capita use is about 115 gallons per day in the urban industrialized areas, about 50 gpd in the rural nonfarm areas, and about 25 gpd in the rural farm areas.

The quality of the ground water in Tippecanoe County is suitable for general use. The water is hard and may require special treatment for some types of industrial use and locally for household purposes.

INTRODUCTION

PURPOSE AND SCOPE

The investigation upon which this report is based was begun in 1945. The investigation was made by personnel of the United States Geological Survey and of the Water Resources Division of the Indiana Department of Conservation, as a part of the broad cooperative program established by these agencies in 1935 to inventory and evaluate the ground-water resources of Indiana.

The report is the fourth in the series of five county ground-water reports prepared for publication under the Indiana cooperative program. The data upon which this report is based and a description of the methods used in collecting the data are published as an appendix to this report in Bulletin No. 8, "Ground-Water Resources of Tippecanoe County, Indiana, Appendix: Basic Data."

Ground water is one of the most important mineral resources in Tippecanoe County. It is the principal source of water for domestic, industrial, and public supplies in the county. With decentralization and expansion of industry the demands for ground water can be expected to continue to increase. The greater number of wells drilled in the rural areas indicates the increased demands for ground water for rural domestic use. In the future, extensive demands for irrigation will require even greater development of ground water. The information in this report provides an aid to sound planning and development of the ground-water resources of the county.

The investigation was made under the general direction of A. N. Sayre, Chief of the Ground Water Branch of the U. S. Geological Survey, and under the immediate supervision of C. M. Roberts, District Geologist of the Ground Water Branch for Indiana.

LOCATION

Tippecanoe County (fig. 1) is in the west-central part of Indiana. The county is rectangular and includes about 500 square miles. It is bounded by Benton, Fountain, and Warren Counties on the west, by White and Carroll Counties on the north, by Carroll and Clinton Counties on the east, and by Montgomery County on the south.

PREVIOUS INVESTIGATIONS

Detailed information has not been published about the geology and ground-water resources of Tippecanoe County. Publications referring to Tippecanoe County are cited in various sections of the report and a list is given in the selected bibliography, page 35.

The geology of Tippecanoe County was first described by S. S. Gorby (1886, p. 61-96). Leverett and Taylor (1915, p. 95-96, 104, 116-117) briefly described and outlined some of the glacial features of Tippecanoe County. Prior to 1915 minor features of the glacial deposits were described by McBeth (1900, 1901, 1902, 1905, 1915). The ground-water resources of Tippecanoe County have been described in reports by Frank Leverett (1889) and Marshall Harrell (1935).

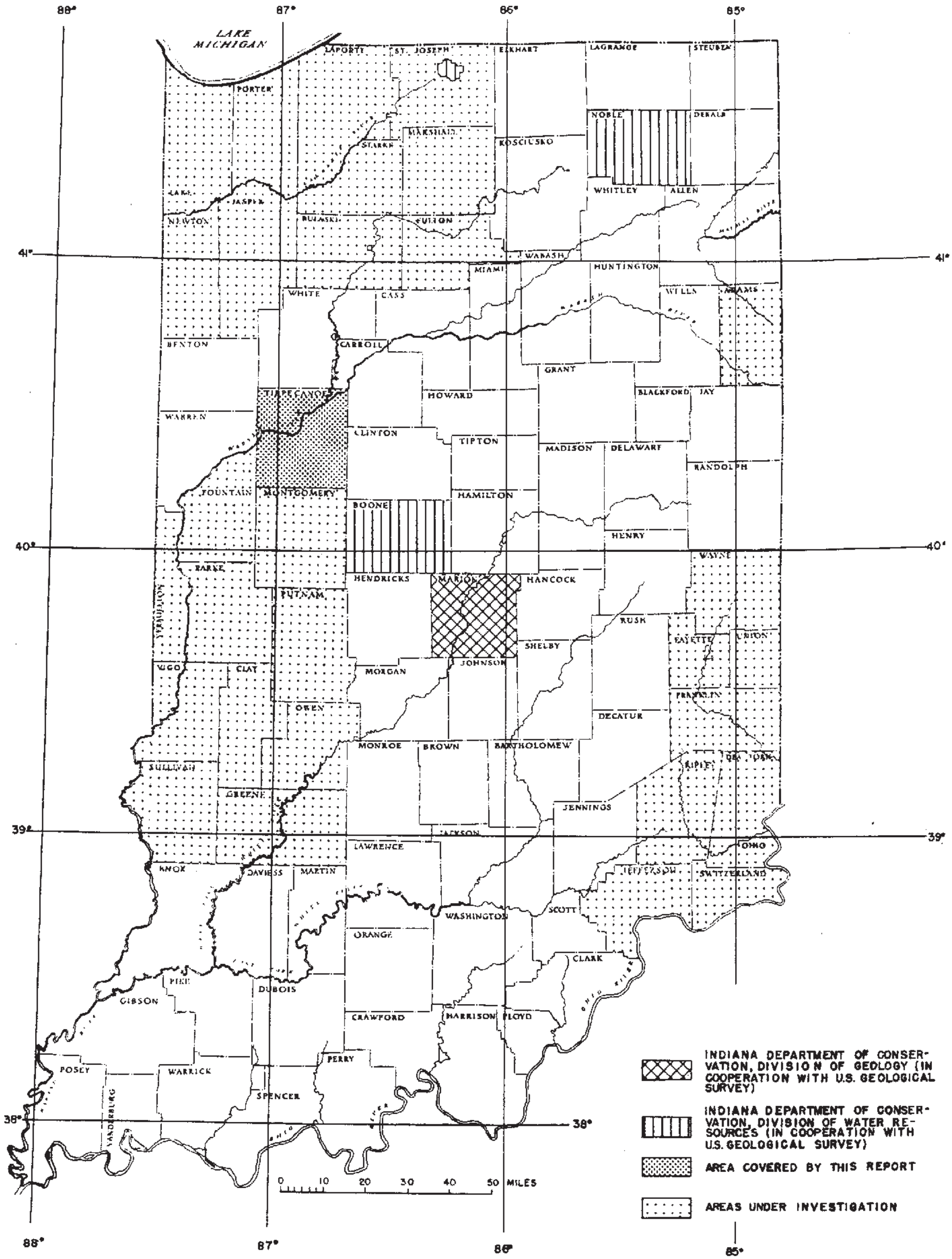

FIGURE 1.- MAP OF INDIANA SHOWING LOCATION OF AREAS ON WHICH REPORTS HAVE BEEN PUBLISHED, AREA DESCRIBED IN THIS REPORT, AND AREAS UNDER INVESTIGATION

WELL-NUMBERING SYSTEM

In the well-numbering system used in this report to locate and identify the wells, all numbers for wells in Tippecanoe County bear the prefix "Tc." Each township and range is assigned a letter symbol (tables 5 and 6). The number after the township symbol indicates the section in which the well is located. Within each section the wells are numbered consecutively. For example, well TcF 13-1 is the first well listed in Sec. 13, T. 23 N., R. 5 W.

ACKNOWLEDGEMENTS

The author wishes to thank all persons who contributed information and assisted in the preparation of the report. Dr. C. F. Deiss, Director of the Geological Survey, Indiana Department of Conservation and his staff supplied the seismic data used in the report; Mr. H. P. Ulrich of the Purdue University Agricultural Experimental Station supplied an unpublished soils map of Tippecanoe County; the well drillers in the county supplied logs of wells and related information; and Mr. O. J. Cosner, geologist, formerly of the Water Resources Division, Indiana Department of Conservation, assisted in the geologic reconnaissance.

GEOGRAPHY

Tippecanoe County has a population of 74,473 in 1950, according to the U. S. Census. The population had increased 46 percent from 1940 to 1950. Lafayette, with a population of 35,568, is the largest city and the industrial center of the county. It is served by three railroads, four bus lines, and many long distance truck lines. West Lafayette, with a population of 11,873, is the second largest city in the county and is the home of Purdue University.

Tippecanoe County's economy is diversified. Of 28,123 people employed in 1950, 5,746 were engaged in manufacturing, 4,338 in education, service, and government, 2,832 in retail trade, 2,375 in agriculture, and 1,675 in construction.

Tables 1 and 2 show the major crop and livestock production and quantity marketed in the county. Of the 500 square miles in the county, 92.4 percent is in farms.

Tippecanoe County has few mineral resources of economic importance. The large sand and gravel deposits and ground water are the chief mineral resources of the county. A number of sand and gravel pits are in operation, the largest of which is south of the Purdue University campus in West Lafayette.

Table 1.--Livestock production and value of product in Tippecanoe County, 1954 (1/)

Product	Number raised	Number sold	Value (dollars)
Cattle....	35,126	16,493	$2,392,304
Hogs......	91,393	108,471	4,694,796
Sheep.....	10,930	8,325	141,524
Chickens..	399,492	255,655	246,261
Turkeys...	31,650	....	....
Ducks.....	1,087	....	....

1/ Data from 1954 U. S. Census of Agriculture

Table 2.--Crop production and quantity marketed in Tippecanoe County, 1954 (1/)

Product	Acreage	Bushels harvested	Bushels sold
Corn	87,685	....	2,051,252
Wheat	31,800	740,123	687,888
Oats	19,989	870,862	234,985
Rye	1,195	23,411	15,503
Soybean	44,398	....	....
Hay	19,144	....	....

1/ Data from 1954 U. S. Census of Agriculture

Tippecanoe County has a climate characteristic of the northern midcontinent region. The average annual precipitation is about 38 inches and is nearly evenly distributed throughout the year, but with a slight concentration in the growing season from May through September. Figure 2 shows the annual precipitation at West Lafayette from 1923 through 1954. Table 3 shows the average monthly precipitation at the same station from 1880 through 1954.

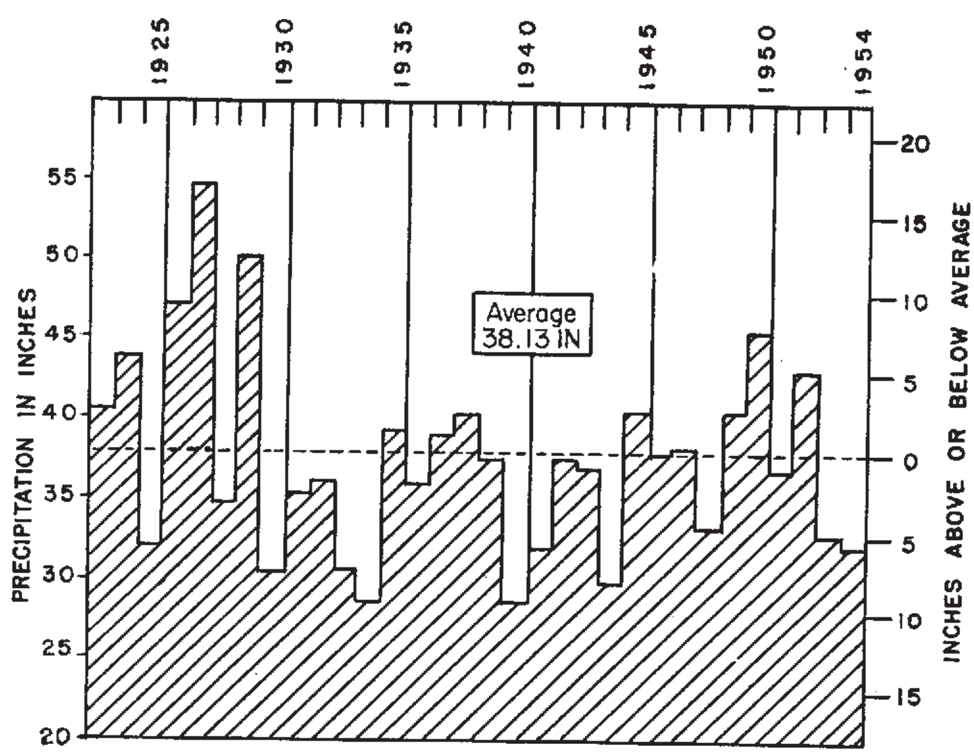

FIGURE 2.—GRAPH SHOWING ANNUAL PRECIPITATION AT WEST LAFAYETTE, IND.

Table 3.--Average monthly precipitation and temperature at West Lafayette weather station, 1880-1954 (1/)

Month	Average precipitation (inches)	Average temperature (°F)
January....	2.55	26.6
February...	2.30	28.9
March......	3.11	39.2
April......	3.48	50.9
May........	4.18	61.8
June.......	3.95	71.4
July.......	3.78	75.6
August.....	3.48	73.4
September..	3.24	66.8
October....	2.71	54.6
November...	2.79	41.0
December...	2.56	30.4

1/ Data from U. S. Weather Bureau

The average annual air temperature at West Lafayette is about 52°F. The coldest month is January and the warmest is July. Table 3 shows the average monthly temperature at West Lafayette from 1880 through 1954. The annual growing season averages 170 days.

TOPOGRAPHY AND DRAINAGE

The land surface of Tippecanoe County is flat to rolling, except where the major streams have cut deeply into the surface. The points of highest elevation are in the southeastern part of the county, and the points of lowest elevation are along the western edge of the county on the Wabash River flood plain. The maximum relief is about 330 feet.

All of Tippecanoe County lies within the drainage basin of the Wabash River and its tributaries. The Tippecanoe River, a principal tributary, enters the Wabash River in the northwestern part of T. 24 N., R. 3 W. (pl. 1).

The patterns of tributary streams of the Wabash River show the effect of glacial control upon their courses. Many of the streams make right angle bends; for example, the course of Little Wea Creek in the southwestern part of the county is partly controlled by a morainal ridge. Glacial control of Big Wea Creek's stream pattern is not as evident. An abandoned stream valley northwest of West Lafayette (Rosenshein and Cosner, 1956, pl. 2) apparently was associated with glacial drainage and is not a surficial reflection of preglacial drainage. Indian Creek and Burnett Creek flow through parts of this abandoned Valley. Burnett Creek has an unusual stream pattern. The creek flows first generally southeast, next northeast, and then sharply reverses its flow to the southwest near the Wabash River and continues roughly parallel to the Wabash for about three miles before entering it.

GEOLOGY AND WATER-BEARING CHARACTERISTICS OF THE CONSOLIDATED AND UNCONSOLIDATED ROCKS

A reconnaissance survey was made to obtain information about the lithology, structure, and regional distribution of the glacial deposits and consolidated rocks in Tippecanoe County. These geologic factors control the occurrence, movement, availability, recharge, and discharge of ground water in the county.

Artificial excavations, stream banks and terrace scarps, and other outcrops were examined to gather information on the physical characteristics of the rocks. Aerial photographs were used to locate and outline the areal extent of terraces and the significant glacial features. Additional information was obtained from an unpublished soils map of Tippecanoe County made available by the Purdue University Agricultural Experimental station.

BEDROCK GEOLOGY

The consolidated rocks underlying the drift-cover of Tippecanoe County are not extensively exposed. The oldest rocks exposed consist of shale of Devonian age. These rocks crop out along the face of the lowest terrace rising above the Wabash River in secs. 10 and 11, T. 24, N., R. 3 W., and in the channels of a number of small tributary streams. According to Gorby (1886) the rock is the New Albany shale.

The flat-lying shale is blue-black, fissile, and fossiliferous. The shale weathers to thin, flat chips and contains pyrite. The out-crops show a well defined joint system which influences the courses of the small streams flowing on the rock. Although the fracture system is well formed, the fractures do not appear to be open to movement of water.

Rocks of Mississippian age (Gorby, 1886) are exposed (pl. 1) in the western part of the county. These rocks consist chiefly of shale, siltstone, and limestone. In the NW¼ sec. 3, T. 22 N., R. 6 W., about seventy feet of Mississippian rocks are exposed in a stream cut. The rocks are fractured, but the fracture system is not well defined.

Rocks of Early Mississippian age crop out in the vicinity of Flint Creek. In the NE¼NE¼ sec. 24, T. 22 N., R. 6 W., a minor angular unconformity is exposed. At the base of the cut, gray shale crops out and is overlain by a bed of dense limestone. A dolomitic limestone containing chert rests non-conformably upon the underlying shale and limestone. Water is discharged from these rocks as seeps along the bedding planes of the shale and also as seeps at the contact of the shale with the overlying dense limestone.

GLACIAL GEOLOGY

The surface of Tippecanoe County has not been modified extensively by postglacial erosion. In the south half and in the northwestern part of the county, where the drainage is poorly developed, only a moderate amount of topographic relief exists. Locally kames and eskers stand above the flat to rolling morainal terrane. In the extreme southern part of the county the ground moraine is pitted. Many of the depressions are elongated, their long axes being either roughly perpendicular or roughly parallel to the trend of the morainal ridges.

The central and northeastern part of Tippecanoe County was deeply eroded by the Wabash River and its tributaries during late Pleistocene time. The greatest topographic relief is present along the stream valleys, and the glacial deposits that extend under the upland crop out in the valley walls.

The glacial deposits in Tippecanoe County range in thickness from a thin veneer to more than 296 feet. The thickest deposits of unconsolidated material are in the buried stream valleys. According to unpublished seismic data obtained from the files of the Indiana Geological Survey the greatest thickness of drift in the county is about 435 feet in the SW¼ sec. 27, T. 21 N., R. 4 W. The glacial deposits are very thin in the southern part of Tps. 21 and 22 N., Rs. 5 and 6 W.

Surficial deposits

The glacial drift 1/ of Tippecanoe County is composed of ice-laid and of water-laid (glaciofluvial) deposits. Material deposited directly by glacial ice that has undergone little or no water sorting, is called till. The character of the till depends in part upon the type of debris carried by the ice. The glacial debris was derived from the rocks over which the glacier traveled. The till can range in texture from fragments of boulder size to fine clay with a heterogeneous mixture of all intermediate grain sizes.

Tippecanoe County is extensively covered by till (pl. 1). In the northern and eastern parts of the county a gray-blue till ranging from about 3 feet to 20 feet in thickness is exposed in the walls of the stream valleys. The gray-blue till consists chiefly of clay with small and large pebbles embedded throughout and locally contains small-to medium-sized boulders. In the northeastern part of the county, the till contains many small fragments of blue-black to gray shale. The shale fragments have been derived locally from the blue-black shale that lies beneath the drift and north and east of the county. In the NW¼SW¼ sec. 23, T. 24 N., R. 3 W., about 15 feet of gray-blue till is exposed along Sugar Creek. This till is compact, calcareous, and clayey and contains pebbles and cobbles. The deposit shows a weak fissility, apparently caused by glacial compaction. The till is overlain by about three feet of water-laid sand and gravel. The contact between the two deposits is nonconformable.

At least two zones of gray-blue clayey till are exposed in the northeastern part of the county. Water-laid sand and gravel or cemented sand and gravel are interbedded with the till (Rosenshein, 1955, p. 176). The contact between till zones and the water-laid deposits is usually nonconformable.

In the SW¼SW¼ sec. 11, T. 24 N., R. 3 W., about 10 feet of deformed, compact calcareous, clayey maroon till rests upon the bedrock surface.

1/ Drift refers to any type of deposit related to glacial action and has a very general meaning.

Pebbles and cobbles in this till are partly or completely decomposed as a result of weathering. Water-laid sand and gravel, showing graded bedding, rest disconformably upon the till.

The till of the southwestern part of the county has a higher sand and gravel content than the other tills described. Locally, deposits of sand and gravel are interbedded with the till and form ridges which rise above the morainal terrane.

The physical character of the glaciofluvial deposits in Tippecanoe County depends upon a number of factors. Grain-size distribution is affected by the type of material carried by the glacier, the volume and velocity of water discharged, and the distance of transport from the ice front. The volume and velocity of the water varied with changes in climatic conditions affecting the ice. The coarser materials such as gravels, cobbles, and pebbles are the first to be deposited when a stream can no longer carry its original load because of decreased velocity. The velocity of a glacial stream may decrease where the water discharges into a lake or ponded area near the ice front or along the stream course, where the water spreads onto till plains or relatively flat bedrock surfaces, or where the width or the depth of the channel change. Within an area of transportation and deposition, the glacial material may be reworked many times, with the result that a deposit of relatively uniform grain size is formed. On the other hand, glacial materials moved only once by melt water may form rather heterogeneous deposits.

The areal extent of the surficial glaciofluvial deposits of Tippecanoe County is shown on plate 1. There are two principal types of water-laid deposits in the county, (1) deposits filling preglacial or interglacial drainageways and (2) local deposits forming elongated bodies in ground moraine. Intricately crossbedded water-laid deposits of type (1) crop out along the Wabash River and its tributaries. The tabular foreset and compound lenticular types of crossbedding are common (Lahee, 1952, p. 88-96; Shrock, 1948, p. 242-254). Each bed of the crossbedded material making up the bulk of the deposit is separated from another bed by a thin layer of gravel and pebbles. Within a bed the fine material may be concentrated at the top. Clay lenses are interbedded with the sand and gravel and marked changes in grain size take place vertically and horizontally, in a short distance. These physical features influence the movement of ground water and are important in the determination of water-bearing properties of the aquifers in the region.

Morainal ridges are present in the southern half of the county. The ridges are prominent in T. 21 N., Rs. 5 and 6 W., and the south half of T. 22 N., Rs. 5 and 6 W. The ridges consist in part of deposits of water-laid clay, sand, gravel, and boulders. The coarse texture of the material is revealed in a number of small gravel pits in the ridges. The stratification shown in the granular material ranges from weak to strong. A cut, in a morainal ridge in the NE¼NE¼ sec. 13, T. 21 N., R. 4 W., shows about 20 feet of coarsely crossbedded sand and gravel. Small clay lenses are present throughout the deposits. The sand and gravel are well sorted. In another cut in a larger morainal ridge in the NE¼SE¼ sec. 17, T. 21 N., R. 4 W., 15 to 20 feet of sand and gravel are exposed to the base of the pit. The floor of the pit consists of clay.

Pleistocene sandstone and comglomerate are associated with the glaciofluvial deposits and the till. The sandstone and conglomerate are interpreted (Rosenshein, 1955, p. 176) as a cemented phase of the glaciofluvial sequence and are limited in outcrop area to the Wabash River and parts of its related drainage system.

Subsurface deposits

The subsurface glacial deposits in Tippecanoe County are similar to those at the surface and consist of clay, silt, sand, and gravel. Clay and silt usually are not differentiated in description of the subsurface geologic material and are grouped under the general heading of clay.

Clay

Clay is reported in almost every driller's well log. Clay layers range from a few feet to more than 100 feet in thickness. The clays penetrated are gray-blue, gray, yellow, brown, and green. The gray-blue clays are the most widespread and are reported in drilled wells from all parts of the county. In places the clay deposits are sandy or gravelly. Where sandy and gravelly clay has been compacted and is hard to drill through, it is called hardpan. Locally the clay is interbedded with both saturated and unsaturated sand and gravel. In T. 22 N., Rs. 3 and 4 W., and in T. 23 N., R. 3 W., there is an indication of a buried moraine which has a considerable thickness of gray-blue clay. The clay is commonly from 40 to 80 feet thick and locally is more than 100 feet thick. In the central part of T. 22 N., R. 4 W., the buried moraine thickens.

Gray-blue clay was deposited directly upon the bedrock in some places. In well TcG 34-5 (Rosenshein and Cosner, 1956, p. 44), 7 feet of gray-blue clay lies on top of limestone. In another well, TcK 13-2 (Rosenshein and Cosner, 1956, p. 52), 25 feet of gray-blue clay lies on shale.

Gray-blue clay is overlain near the surface in many parts of the county by yellow clay. Yellow clay deposits up to 34 feet thick are widespread just beneath the soil. The average thickness of the yellow clay is about 15 feet. In some areas this clay is sandy. The clay is reported to be gravelly in well TcG 34-12 and bouldery in well TcG 14-1 (Rosenshein and Cosner, 1956, p. 37). In places the yellow clay is underlain by a brown clay or by unsaturated sand and gravel. A brown sandy clay or unsaturated sand and gravel is present where the yellow clay is absent.

Brown clay is reported at various levels in the stratigraphic sequence. The brown clay is not as prevalent as either the blue or the yellow clay. The brown clay is usually sandy and is reported sometimes as a hardpan. Brown clay layers range from 2 to 72 feet in thickness. At one location 26 feet of brown clay overlies brown shale (Well TcG 29-1; Rosenshein and Cosner, 1956, p. 40).

Green clay deposits are rare but have been recorded in a few wells. The thickest deposit is reported to be 27 feet. In well TcN 9-1 (Rosenshein and Cosner, 1956, p. 57), 7 feet of green "mud" is reported on top of a limestone.

Sand and gravel

The drift of Tippecanoe County contains many deposits of sand and gravel. These deposits are the chief source of ground water and range (pls. 4, 5, and 6) in size and shape from small lenses or pockets to extensive sheet-like deposits. Where bedrock is close to the surface, the coarse deposits thin out against the bedrock or are present only locally as in the south half of T. 22 N., Rs. 5 and 6 W., and in T. 21 N., Rs. 5 and 6 W., (pl. 3). The deposits range in grain size from coarse gravel to fine sand; some are clayey, silty or bouldery. In well TcG 17-8 (Rosenshein and Cosner, 1956, p. 38), 40 feet of coarse gravel, cobbles, and boulders was reported. Beds of sand and gravel range from 1 foot to 185 feet in thickness. Coarse-grained material may occur anywhere in the stratigraphic sequence, interbedded with clay or lying upon bedrock. A well log may report sand and gravel beds at different levels. Some coarse deposits are unsaturated, others water-bearing. The greatest reported thickness of unsaturated sand and gravel is 70 feet. In wells TcG 34-8 and TcG 9-7 (Rosenshein and Cosner, 1956, p. 37, 44), a water-bearing sand and gravel 76 feet thick was reported.

In areas where coarse-grained deposits lie directly on bedrock, thicknesses ranging from about 1 foot to about 80 feet have been reported.

Sand and gravel lie at or close to the surface in parts of T. 24 N., Rs. 3 and 4 W., T. 23 N., Rs. 3 and 6 W., and T. 22 N., Rs. 3 and 6 W. These deposits range from a few feet to 144 feet in thickness. In many places the coarse materials are underlain or overlain by clay. Where sand and gravel deposits lie at or very near the surface they are important to ground-water recharge.2/

Plates 4, 5, and 6 are maps showing the areal extent of individual unconsolidated water-bearing deposits in parts of Tippecanoe County. The maps were prepared from the subsurface information obtained from drillers' logs of wells and from seismic data. All available data were checked with respect to clearly determinable facts, such as location of wells and altitude of the land surface. Reports of materials penetrated by wells were interpreted in terms of geologic units known or thought to be present. Pertinent hydrologic facts such as altitude of the water levels in wells were taken into account. The results of the studies were plotted on a base map from which it was possible to evolve a three-dimensional picture of the extent, thickness, and vertical relations of 5 units, dominantly sand and gravel. These sand and gravel units together make up the composite glacial-drift aquifer underlying Tippecanoe County and are separately illustrated on plates 4, 5, and 6. Generalized cross-sections (pls. 7, 8, 9) were prepared to show the vertical relations of the various geologic units and to show the relations of the unconsolidated materials to bedrock. Interpretation of the configuration of the bedrock surface is based in large part on seismic data furnished by the Indiana Geological Survey.

The geology, ground-water conditions, and water-bearing characteristics of the mappable sand and gravel units are described in table 4. In evaluating the water supply of the units, the following factors were taken into consideration: (1) Well construction; (2) reported yields and drawdowns; (3) saturated thickness; (4) the coarseness of the deposits as indicated by the slot size of well screens; and (5) saturated thickness penetrated by the well. (See tables 2 and 3, Rosenshein and Cosner, 1956.) Variations in ground-water conditions from place to place in units 1 and 2 are indicated on the aquifer maps. Where the regional water surface lies below the bottom of a sand and gravel unit, the unit is unsaturated and therefore is not an aquifer. At a given point the approximate depth to the individual units can be determined by comparing the topographic map (Rosenshein and Cosner, 1956, pl. 2), with the detailed aquifer maps and subtracting the altitude at the top of the unit from the elevation of the land surface.

2/ For a detailed discussion of the areas of recharge see p. 17 and 18.

Table 4.--Summary of the physical characteristics and water-bearing properties of hydrologic units 1-5 outlined on plates 4, 5, and 6

Unit no.	Approximate altitude of top of unit (feet)	Thickness (feet)		Physical characteristics	Ground-water occurrence within the unit	Water supply	Remarks
		Maximum	Average				
1	640-660	41	About 30	The unit grades downward from clean sand and gravel to sand and gravel mixed with clay and silt. In the center of the area of deposition, the lower part of the unit has a higher percentage of gravel. Locally (TcK 13-4) the sand and gravel is interbedded with thin clay lenses. The underlying clay is absent in some areas, and unit 1 grades downward into the lower sand and gravel units.	Ground water occurs under both artesian and water-table conditions.	Domestic wells have been drilled into the unit. The well yields are from 8 to 15 gpm with drawdowns ranging from less than 1 foot to 2 feet. Larger well yields should be possible.	Southern boundary is not definable. The unit is covered by a thin veneer of clay that thickens to the northeast and to the south, the clay cover is as much as 60 feet thick. Increase in the thickness of clay is directly related to increase in surface elevation to the south. Unit 1 has been breached by Wildcat Creek in T. 22 and 23 N., R. 3 W. and by Wea Creek in T. 22 N., R. 4 W.
2	600-620	30+	About 30	The unit is separated from unit 1 by as much as 24 feet of clay. Unit 2 consists of crossbedded sand and gravel which locally (TcG 34-4) grades downward into fine sand. Along its northern edge the sand and gravel is interbedded with thin clay lenses. In places where the underlying clay is absent, unit 2 grades downward into the lower units such as subunit 5b.	Ground water occurs under both artesian and water-table conditions. The water-table conditions are caused chiefly by drainage of the ground water out of the unit where it has been breached by streams.	Most of the wells in the unit have been drilled for domestic and livestock use. The well yields are from 6 to 15 gpm with drawdowns ranging from less than 1 foot to 4 feet. A few wells have been drilled with yields ranging from 60 gpm with 3 feet of drawdown to 500 gpm. The development of large yields is complicated by the presence locally of fine sand, and to some extent, by the crossbedded character of the sand and gravel. Careful well development is an essential condition for obtaining large quantities of water from the unit.	Boundaries are not definable. The unit probably extends beyond the area indicated on pl. 5. The unit pinches out rapidly to the northeast and is absent from the northern half, T. 23 N., R. 3 W., where its stratigraphic position is occupied by a clay sequence more than 100 feet thick. Unit 2 thickens toward the Wabash River northwestward and pinches out against rock to the southwest. The unit has been breached by Wea Creek, Wildcat Creek, and the Wabash River, and crops out in the stream valleys either as a consolidated sandstone and conglomerate or as unconsolidated sand and gravel.
3	535-570	20+	--	The unit is overlain by clay. The upper part consists of fine sand grading downward into coarse sand, with some gravel. Locally the coarser material may be entirely absent as in well TcK 13-2 in which 20 feet of fine sand was reported.	Ground water occurs under artesian conditions.	Only domestic wells have been drilled into the unit, and the well yields range from 8 to 10 gpm with drawdowns of less than 1 foot reported. Larger yields may be possible.	Every well drilled into unit 3 has penetrated at least 15 feet of material.

Table 4.--Summary of the physical characteristics and water-bearing properties of hydrologic units 1-5 outlined on plates 4, 5, and 6--Continued

Unit no.	Approximate altitude of top of unit (feet)	Thickness (feet)		Physical characteristics	Ground-water occurrence within the unit	Water supply	Remarks
		Maximum	Average				
4	530-550	42	--	The unit is overlain by a clay sequence 21 to 123 feet thick. The upper part consists of fine sand that grades downward into sand and gravel. Locally the sand and gravel is interbedded with clay lenses up to 8 feet thick.	Ground water occurs under artesian conditions.	Only domestic wells have been drilled into the unit, and the well yields are from 6 to 15 gpm with drawdowns ranging from less than 1 foot to 6 feet. Larger yields may be possible.	The unit is identifiable only where the overlying sand and gravel are absent or have been completely penetrated by wells. Unit 4 underlies the buried moraine described in unit 2.
5	490-540	--	--	Unit 5 consists of a number of sheetlike sand and gravel beds that alternate with clay lenses. Because of the rapid changes in lithology and the localized character of the interbedded clays, the sand and gravel beds are mapped as a unit.	Ground water occurs under both artesian and water-table conditions.	Most of the industrial and public-supply wells in the county are drilled into this unit.	The unit has been divided into subunits 5a (mainly water table) and 5b (mainly artesian). The unit has been partly dissected by the Wabash River, exposing the upper part of the unit along the terrace faces.
5a	500-540	--	--	Subunit 5a is overlain by unsaturated crossbedded sand and gravel up to 64 feet thick (TcF 20-2) which grades downward into water-bearing crossbedded sand and gravel. Locally the unit is overlain by about 150 feet of clay. In grain size the water-bearing material ranges from fine sand to bouldery gravel.	Ground water occurs in most places under water-table conditions.	The yield of small-diameter wells ranges from 5 to 50 gpm and is more than adequate for domestic and livestock use. The yields from larger-diameter wells are from 300 to 1,100 gpm. The same limitations apply to the development of wells of large yield in this subunit as apply to unit 2.	The subunit is characterized by an unsaturated sand and gravel zone lying above the water-bearing sand and gravel zone. Subunit 5a pinches out against rock in the northern part of T. 23 N., R. 5 W.
5b	490-510	76+	About 40	The subunit is overlain by clay. The upper part of the unit consists of about 10 feet of sand which usually grades downward into sand and gravel. Locally (TcK 6-2) the unit may consist of as much as 45 feet of fine sand or a series of thin sand and gravel layers interbedded with clay.	Ground water occurs in most places under artesian conditions. The water levels of some wells drilled into the unit along the Wabash River reflect changes in river stage.	The yields of small-diameter wells in the subunit are 7 to 10 gpm with drawdowns less than 1 foot and are more than adequate for domestic and livestock use. The yield of 11 industrial and public supply wells ranges from 100 to 1,000 gpm.	5b is characterized by thick deposits of clay lying directly on top of the water-bearing sand and gravel. The subunit probably extends under the overlying material as fingerlike projections and also extends into the Wea plains area in the southern part of T. 23 N., R. 5 W.

Evidence of multiple glaciation

The well-log data of Tippecanoe County give evidence of several ice advances. The evidence consists of reports of buried muck zones, wood fragments, and red beds, each of which indicates a former land surface. Well logs that contain this information (Rosenshein and Cosner, 1956) are listed below.

Muck was reported in wells TcG 6-2, TcG 30-4, TcH 14-1, TcL 17-2, and TcO 5-1; in particular, 4 feet of muck was reported on top of rock in well TcO 5-1; red beds were reported in wells TcB 36-1, TcG 20-6, and TcH 15-1; chunks of wood were reported in well TcP 32-1. In addition to this type of evidence, the well data indicate that two separate moraines are buried in parts of T. 22 N., Rs. 3 and 4 W., and T. 23 N., Rs. 3 and 4 W.

Glacial history

During Pleistocene time, Tippecanoe County was covered by the ice of at least two glacial advances. In the early phases of the glaciation the preglacial topography must have exerted a strong influence upon the movement of the ice, and the parts of the county underlain by shallow rock probably remained as driftless areas. These areas may not have been covered by glacial deposits until the Wisconsin glacial advance. Subsurface evidence indicates also that the preglacial drainage system served in part as a sluiceway during the different glacial advances and retreats. In Tippecanoe County the buried valleys are filled with thick deposits of gravel, sand, and silt. These valley deposits show that the buried drainage continued as a factor tending to control glacial drainage during most of the Pleistocene glacial epoch.

The subsurface geologic data indicate that at least two buried moraines are present in Tippecanoe County. These moraines occur in parts of T. 22 N., Rs. 3 and 4 W., and T. 23 N., Rs. 3 and 4 W. The altitude of the top of the moraine in T. 22 N., R. 4 W., is from about 585 to 658 feet. The altitude of the top of the moraine in T. 23 N., R 3 W., is from about 635 to 658 feet. The moraines formed ridges around and over which sand and gravel were deposited. Sand and gravel deposits (unit 2) in parts of Tps. 22 and 23 N., Rs. 3 and 4 W., indicate the depressions that existed on either side of the buried moraines. A large part of the sand and gravel must have been derived from the rock debris carried by the glacier. The complexity of the sedimentary environment in which the deposits were formed is shown by the complex crossbedding of the sand and gravel and the presence of many interbedded clay layers.

The bedrock topography has acted as a control upon the type of glacial material deposited in the southwestern part of the county. The high bedrock surface is relatively flat and a predominantly clayey sequence (till) was deposited upon this surface. Also, the kames and eskers (pl. 1, Tps. 21 and 22 N., Rs. 5 and 6 W.), correlatives of the Bloomington morainic system (Leverett and Taylor, 1915), are most strongly formed in the areas where bedrock lies close to the surface.

RECENT DEPOSITS

The Recent deposits consist chiefly of alluvium deposited in river channels and on flood plains of the valley bottoms. Windblown sand and silt are associated with these deposits. A ridge of fine sand and silt in the northwestern part of the county (pl. 1) is probably of windblown origin.

Other areas of windblown sand are present along the Wabash River. The latter deposits have not been differentiated on plate 1. Some areas of the county are underlain at the surface by yellow clay. The clay has a fairly uniform grain size and is one of the youngest deposits in the area. The clay forms a thin veneer covering a part of the county and locally has a blocky appearance when dry.

BEDROCK TOPOGRAPHY

Plate 10 shows the configuration of the bedrock surface underlying Tippecanoe County. The map was compiled from records of more than 100 wells penetrating bedrock and from about 350 seismic determinations. The bedrock surface was deeply eroded by a preglacial drainage system. The pattern of the bedrock surface reflects the influence of lithology upon the rate of erosion and the development of the drainage. The areas of more resistant rock form the bedrock highs in the southwestern part of the county. The approximate depth to bedrock can be determined for any particular area by comparing the topographic map of Tippecanoe County (See pl. 2, Rosenshein and Cosner, 1956) with the bedrock contour map and subtracting the elevation of the bedrock surface from the elevation of the land surface.

HYDROLOGIC CYCLE

The water occurring on and near the surface of the earth is continously involved in a vast process of circulation of water between the oceans and the land, called the hydrologic cycle. Moisture is evaporated from large bodies of water such as the oceans and is transported by air currents to land areas where some of it is precipitated upon the land surface. Some precipitation is evaporated as it falls through the air. A part of the precipitation is retained upon the leaves of the vegetation and is then evaporated. Water that collects in surface depressions and does not drain off or soak into the ground, is also returned directly to the atmosphere by evaporation. Of the precipitation that reaches the land surface, some escapes over the surface as direct runoff to streams. Eventually the streams return much of this water to the oceans.

Part of the precipitation infiltrates or seeps into the ground through the natural openings in the soil and in the rocks. A variable percentage of this water is retained by the soil as soil moisture and is returned eventually to the atmosphere through transpiration by plants and by direct evaporation from the soil zone. The excess water continues to percolate down through the pores of the subsurface material. Some of the water is retained in the capillary openings in the subsurface material. The rest descends into the zone of saturation. The water in the ground-water reservoirs moves slowly through the pore spaces of the consolidated and unconsolidated rocks and is eventually discharged by evapotranspiration or through springs and seeps or is withdrawn from wells.

GROUND WATER

PRINCIPLES

All rocks have openings or pore spaces. The pore spaces are the openings (interstices) that exist between the individual particles (grains) making up the consolidated and unconsolidated rocks and the openings in the consolidated rocks caused by solution channeling, weathering, jointing, and faulting. These pore spaces may be microscopic or megascopic in size.

The volume of pore space, expressed as a percentage of the total volume of the rock, is called the porosity. In unconsolidated sedimentary rocks such as sand and gravel, the original porosity is a function of the grain-to-grain relationship - that is, the size, shape, degree of sorting, and compaction of the grains. The porosity of a rock may be increased after original cementation and compaction by deformation, (jointing and faulting) or chemical action (solution). Porosity resulting from such causes is secondary porosity.

Openings or pore spaces in subsurface material may be partly or completely filled with air, water, or some other fluid. The subsurface material throughout which the openings are completely filled with water under hydrostatic pressure is the zone of saturation. All water in the zone of saturation is called ground water. Ground water is the subsurface water that is available to wells and springs. All subsurface water that is not in the zone of saturation, such as soil moisture, water in the process of moving downward to the zone of saturation, or water suspended above the zone of saturation by capillary attraction, is in the zone of aeration (vadose zone).

The storage of ground water in the underground reservoir may be likened to the storage of surface water in a surface reservoir. The amount of available pore space determines the quantity of water that may be stored in a subsurface material.

An aquifer is any geologic formation, part of a formation or group of formations that is capable of yielding water to a well or spring in useful amounts. In order for a group of deposits to be considered as an aquifer, they must be interconnected hydraulically. From this aspect, an aquifer may include deposits of different geologic ages and may consist in part of consolidated and in part of unconsolidated deposits. The quantity of water that can be derived from an aquifer depends upon the size and interconnection of the pore spaces rather than upon the total percentage of pore space. The rate at which an aquifer can transmit water depends upon the permeability. Permeability is defined as the ability or capacity of a material to transmit water under pressure. A clay may have a porosity of 50 percent or more yet yield water at a relatively slow rate because of the small size of the pores. A sand and gravel may have a porosity of only 20 percent and yet yield water at a relatively high rate because of the large size and high degree of interconnection of the pores. Materials such as clay, till, or shale that have small capacities to transmit water or small permeabilities may be considered as importent aquifers if none better are available. If highly permeable water-bearing materials such as sand and gravel are present, however, the materials of lesser permeability would not be considerered as important aquifers.

The piezometric surface is the surface which is defined by the height at which water stands in wells penetrating an aquifer. The piezometric surface may stand above or below the top of an aquifer, according to whether the water is or is not under artesian pressure, and upon whether or not the porous materials are completely saturated.

OCCURRENCE

Ground water occurs in the unconsolidated sand and gravel and in the consolidated rocks in Tippecanoe County. In the unconsolidated sand and gravel the ground water occurs under both water-table and artesian conditions.

Ground water occurs under unconfined or water-table conditions if the water-bearing deposit is overlain directly by permeable unsaturated materials. In water-table conditions the upper surface of the water in the aquifer (the water-table) is in contact with the soil atmosphere, and the water does not rise in a well above the level at which it is encountered. Wells TcG 31-1 and TcG 31-3 (Rosenshein and Cosner, 1956, p. 42, 43) are examples of wells in the vicinity of which ground water occurs under water-table conditions in unconsolidated materials.

Ground water occurs under confined or artesian conditions if the water-bearing deposit is overlain directly by saturated material of substantially lesser permeability. In artesian conditions the water rises in the well above the depth at which the aquifer is encountered. The water need not flow to be considered artesian. Wells TcK 1-2 and TcK 17-2 (Rosenshein and Cosner, 1956, p. 51 and 53) are examples of artesian wells. Within the same hydrologic unit, ground water may occur under both water-table and artesian conditions. Unit 2 (pl. 5) provides examples of both conditions. In areas near points of recharge, on the one hand, and of discharge on the other, conditions may change from artesian at one time to water-table at another as the rate and the amount of discharge and recharge vary. During prolonged periods of deficient rainfall, the piezometric surface, usually above the top of the aquifer in a part of a water-bearing deposit, may decline into the aquifer, resulting in a change from artesian to water-table conditions. (See pl. 8, cross section E-E'.) Well TcL 17-3 (Rosenshein and Cosner, 1956, p. 56) is an example (pl. 8, cross section F-F') of a well in which these conditions probably occur.

In Tippecanoe County ground water is reported in the rocks of Mississippian and Devonian age. The water occurs in the interconnected fractures and bedding planes in the shales and in fractures and solution channels in the limestones. The size, shape, and number of these interconnected openings may change greatly in a horizontal or in a vertical direction across short distances. Therefore, the occurrence of ground water in consolidated rock is erratic. Where water-bearing sands and gravels occur directly on top of water-bearing rock, much of the water in the rock can be assumed to come from the overlying unconsolidated material.

RECHARGE

Recharge is the process by which water is added to the ground-water reservoir. In any area, the rate and quantity of recharge are dependent upon the intensity, type, and duration of precipitation, the vegatative cover, the topography and drainage, and the physical conditions of the soils and of the subsurface materials. Before recharge can occur, any soil moisture deficiency must be replenished. During the growing season, soil-moisture deficiencies are high owing to use of soil moisture by plants. Therefore, recharge occurs chiefly during the nongrowing seasons, when plant use is negligible and the moisture content of the soil is high.

A permeable soil is an important requirement for the absorption of moisture by the ground. A loosely granular soil will lose little water to overland runoff unless precipitation is heavy and prolonged; in other words, the rate of infiltration into the ground will be rapid. If the soils are tight and clayey, very little water can be absorbed by the ground during any period of precipitation and the infiltration rate will be slower. Furthermore, the absorbed water in tight soils is released very slowly to the subsurface material. In order that appreciable quantities of the water absorbed by the soil may infiltrate to the water-bearing zone, permeable materials must be present beneath the soil zone. Materials of low permeability, such as clay, close to the surface will greatly impede the rate of infiltration into an aquifer, as well as the total quantity of water that the subsurface material can absorb from the soil zone. This factor would in turn induce greater direct runoff.

Plate 2 is a map showing surface and near surface conditions related to recharge in Tippecanoe County. The map was prepared using data from an unpublished soils map of Tippecanoe County, prepared by the Purdue University Agricultural Experimental Station, that was modified by interpretation of subsurface geologic data, aerial photographs, and reconnaissance geologic mapping.

In Tippecanoe County the areas most favorable to recharge are in the stream valleys and on the terraces. Locally deposits of clay may occur in favorable areas therby decreasing recharge. A favorable area north and east of the Wabash River in T. 23 N., Rs. 4 and 5 W., is underlain by subunit 5a. This subunit is characterized by unsaturated sand and gravel lying directly above the water-bearing material. The sand and gravel may continue to the surface or may be cut off by clay deposits of small areal extent, occuring anywhere in the stratigraphic sequence. The movement of water to the water-bearing zone of subunit 5a is complicated by the presence of the clay, and water is undoubtedly deflected laterally in its downward movement. The lateral movement of water must continue either until the clay pinches out and vertical movement can be resumed, or until the water is discharged as springs where the clays crop out in the terrace scarps. Because perched-water conditions are not recorded from this area, the clays are believed not to prevent movement vertically downward over large areas. The downward migration of water to the water-bearing zone is further complicated by the complex crossbedded character of the sand and gravel deposits. The crossbedding produces selective zones of movement wherein the water tends to percolate along the sand and gravel layers and around the clay layers.

A large area of Tippecanoe County has been mapped as "less favorable to unfavorable" for ground-water recharge. These areas are principally in the northern part and in the southern parts of the county. The soil types of these areas are silty loam to silty clay loam formed mainly from clayey till. In such areas the proportion of the total precipitation that is absorbed is relatively small. The release of any absorbed moisture to the underlying water-bearing material must be rather slow and the amount is probably small. Over a large area of contact between clayey material and more permeable material, however, the quantities released per unit area, although in themselves small, may add up to a sizable quantity of water for recharge. In such areas, runoff would be great if the relief were greater; however, the surface is flat to moderately rolling and has an imperfect drainage pattern; thus, precipitation is in part held in the area, permitting some recharge.

In the southern part of the county the surface has many depressions. Runoff collects in these depressions during periods of intense or prolonged rainfall. Some of this water probably soaks into the ground, but much of it is lost to the atmosphere by evaporation or is removed by drainage ditches.

Recharge from precipitation. --In Tippecanoe County most of the ground-water recharge is from precipitation that falls on the county in the form of rain or snow. The annual precipitation is about 38 inches, and some portion of the precipitation reaches the ground-water reservoirs in most of the county. Locally, in the areas more favorable to rapid infiltration, a large percentage of the total precipitation undoubtedly is absorbed, although quantitative data are lacking.

Recharge from streams. --Some recharge to the ground-water reservoir takes place as the result of influent seepage of water from the Wabash River and its tributary streams during periods of high stage. The Wabash River has cut into subunit 5b. Changes in the river stage are reflected in the water-level fluctuations in test wells in sec. 31, T. 23 N., R. 4 W., and sec. 36, T. 23 N., R. 5 W., drilled into this unit. Also, the water level in observation well Tc 4 (TcG 17-10) in subunit 5b reflects the changes in river stage (fig. 4). During periods of high river stage, some recharge takes place by influent seepage into subunit 5b. Some additional recharge to this subunit takes place as a result of diversion of water from the river caused by pumping from wells. This condition is shown by the relationship of the water levels in observation well Tc 4 and the water levels at the stream gaging station at Lafayette, Indiana, which is about 2000 feet southwest of this well. During periods of light pumping the natural slope of the water surface is from the well to the Wabash River. However, during periods of heavy withdrawal the hydraulic gradient is reversed and the water surface slopes toward the observation well, thereby diverting water from the stream.

Subsurface recharge.--Some transfer of water occurs locally by movement of water between the different unconsolidated water-bearing deposits where one deposit grades downward into another both within the county and between it and adjacent counties. Although, so far as individual deposits are concerned, this type of inflow constitutes recharge, for the county as a whole it is balanced by similar outflow, or discharge.

DISCHARGE

Ground water is discharged in Tippecanoe County by natural and by artificial means. Under natural conditions discharge is by spring flow and seepage into the streams, migration within the ground-water reservoirs to points of discharge outside the county, and by evapotranspiration. Artificial discharge takes place through drainage ditches and by pumping from wells.

Natural discharge

During the investigation, evidence was observed of present and former spring activity along the Wabash River terraces, where the shallower water-bearing units are exposed. Ground water is discharged from these water-bearing units by springs. During periods of increased precipitation, recharge is increased and the discharge from springs is greater than usual. The calcareous tufa deposits (Rosenshein, 1955, p. 176) associated with the consolidated phases of unit 2 and subunit 5a indicate former spring activity. More spring activity doubtless would have been observed if the field observations had been made during a wet instead of a dry period. The natural drainage of the water-bearing units by springs and seeps along the terrace scarps partly explains the change in hydrologic conditions from artesian to water-table in unit 2 (pl. 7, cross section D-D') near the Wabash River.

Much of the natural discharge takes place by diffused effluent seepage, rather than concentrated spring flow, from the ground-water reservoir into the streams that drain the county. The Wabash River has cut into part of subunit 5b and changes in river stage cause water to move into and out of the deposits and thus to affect the ground-water level. The discharge of ground water to the streams in the county is important to the flow in the rivers. During long periods of deficient rainfall, the streamflow consists chiefly of ground-water discharge. The ground-water discharge into the streams from the ground-water reservoirs in the county is estimated to be about 140 million gallons per day.

The slope or hydraulic gradient of the ground-water surface (pl. 11) is toward the important streams. This slope bears out further the role played by the streams as the chief agents of natural ground-water discharge and the drainage effects of the stream upon the water-bearing deposits.

Some ground-water discharge must occur by slow migration of water within the ground-water reservoirs to points of discharge outside Tippecanoe County.

In areas where ground water stands near the surface, such as the flood plains, ground water is discharged directly to the atmosphere by plant transpiration. The greatest discharge by transpiration occurs during the growing season, starting about the first of May and continuing to about the end of September. No attempt has been made to evaluate the quantity of ground water discharged by plants in Tippecanoe County. The discharge, though substantial, must be very small in comparison to the evapotranspirative discharge of soil moisture that has never become ground water.

Artificial discharge

Artificial discharge is accomplished by wells and drainage ditches. Large areas of the county are drained artificially by ditches. Drainage ditches are constructed in areas of tight soils which are underlain by tight subsurface materials such as till. Water levels are characteristically shallow in such areas, and drainage of the ground water, as well as of excess surface water, is needed to permit cultivation.

FLUCTUATIONS OF WATER LEVELS

Within an aquifer, water is continually being subjected to changing conditions of recharge and discharge. These changing conditions are reflected as short-term or long-term fluctuations of the water levels in wells. Water-level fluctuations caused by natural factors, such as the seasonal changes in storage in the ground-water reservoir, are usually cyclic.

During the investigation a number of observation wells were established to determine the character of the water-level fluctuations; the magnitude of the changes in storage; and short-term, seasonal, and long-term trends of water levels in the underground reservoirs in Tippecanoe County. Figure 3 shows the fluctuations of water levels plotted against monthly precipitation in a shallow observation well, Tc 12 (TcO 20-3), and a deep observation well, Tc 7 (TcF 13-1). These observation wells are drilled in unconsolidated glacial material. Well Tc 7 is drilled into subunit 5a and well Tc 12 is drilled into drift. The water levels in both wells reflect seasonal changes caused by recharge from rainfall and by discharge under natural conditions. As shown by the hydrographs of the two observation wells, the highest water levels occur in the late winter and early spring at the time of high precipitation and minimum discharge by evapotranspiration. The water levels begin to decline with the advent of the growing season and continue to decline into late fall. Heavy rains during the growing season apparently have little affect upon the declining water levels as shown by the hydrographs of wells Tc 7 and Tc 12. In observation well Tc 12, the shallower well, the water-level changes are more responsive to sporadic precipitation. In observation well Tc 7, the deeper well, the water-level changes are more gradual and occur principally in response to prolonged precipitation. The hydrograph of observation well Tc 7 shows also an apparent time lag between the periods of heavy precipitation and the periods of rising water levels. In addition to the seasonal fluctuations, the hydrograph of well Tc 7 shows a general long-term water-level trend extending over a period of years, the highest springtime water levels occurring in 1950 and the lowest in 1954.

Water levels may be affected locally by short-term fluctuations caused by artificial influences such as pumping or by natural factors such as

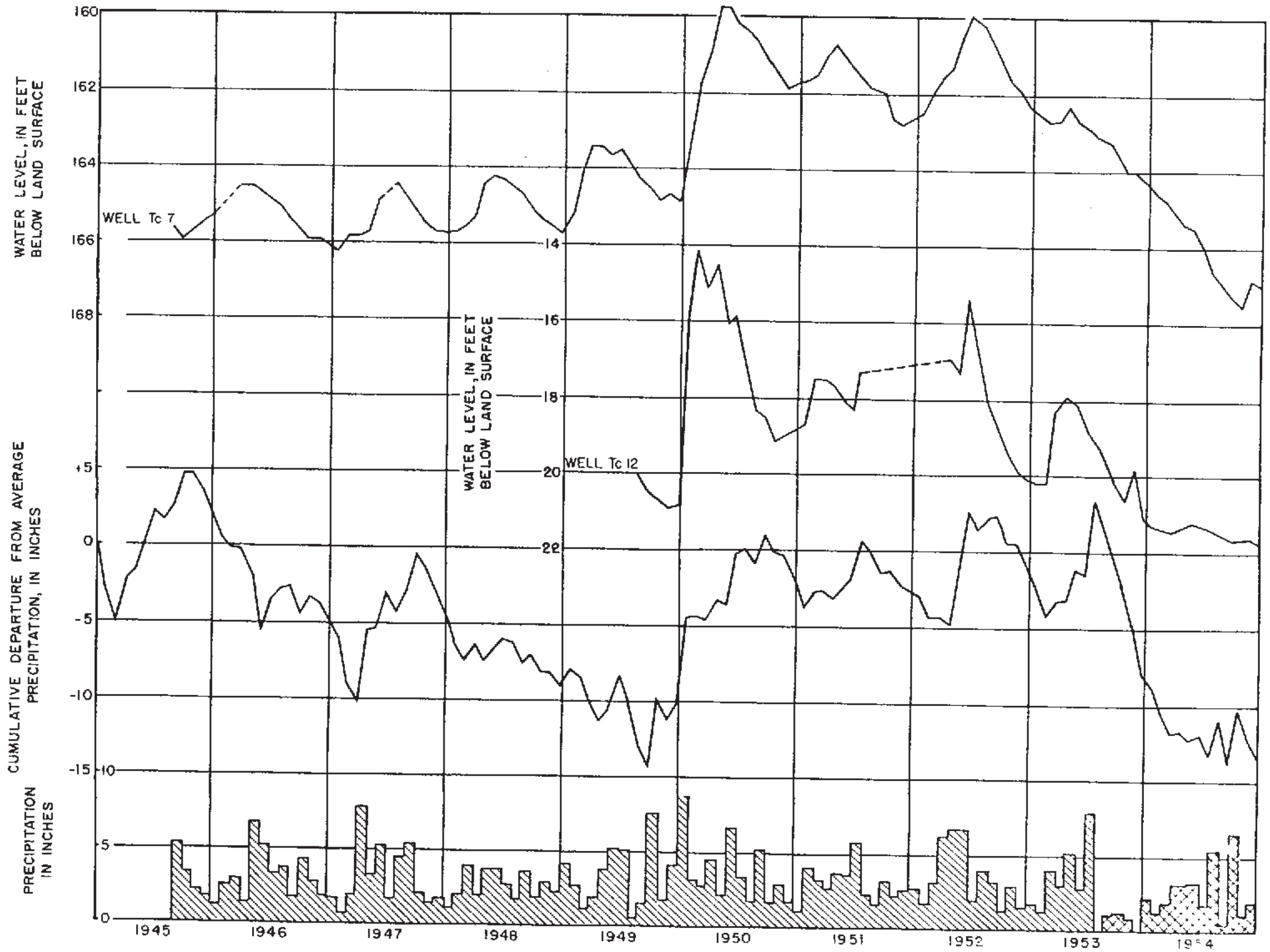

FIGURE 3.- HYDROGRAPHS SHOWING THE FLUCTUATIONS OF THE WATER LEVELS IN TWO WELLS IN TIPPECANOE COUNTY, CUMULATIVE DEPARTURE FROM AVERAGE PRECIPITATION, AND MONTHLY PRECIPITATION.

changes in river stage or barometric pressure. Figure 4 shows a hydrograph of observation well Tc 4 (TcG 17-10). This well is drilled into subunit 5b, an artesian aquifer, and is in the Canal Street well field of the Lafayette Waterworks. As the hydrograph indicates, the water level in the well reflects both daily changes of the Wabash River stage and the seasonal trend of the river levels. In addition, effects from pumping are superimposed upon the general pattern of the water-level fluctuations. The influence of the pumping upon the water levels is greatest during periods of low streamflow, as is indicated by the hydrograph for the period July through November. During this time most of the flow in the stream came from discharge of ground water.

INTRODUCTION TO DATA ON GROUND-WATER CONDITIONS BY TOWNSHIP

The principal aquifers in Tippecanoe County and their areal extent are shown on a map, plate 3. The delineation of areas on this plate is based upon:(1) type of source material and (2) general depths of drilled production wells in each area. The general statement in the explanation about range in well depths and the type of source material that can be expected in a given area should be useful as a guide to location and drilling of new wells. In addition, detailed aquifer maps (pls. 4, 5, and 6) have been prepared of the central part of the county to show the areal extent of mappable water-bearing sand and gravel deposits. The well data used to prepare the maps are published in an appendix to this report, Bulletin 8, "Ground-Water Resources of Tippecanoe County, Indiana, Appendix: Basic Data," which also has a map of Tippecanoe County showing the location of wells.

The unconsolidated deposits form a single complex hydrologic system, as is evidenced by the similarity of the water levels in wells tapping all water-bearing units. Ground water occuring in the underlying consolidated rocks also is probably related hydrologically to that occurring in the overlying sand and gravel units.

Tables 5 and 6, pages 24 and 25 summarize ground-water conditions by sources - bedrock, and sand and gravel. These tables show adequacy, ground-water potential, well yields, aquifer information, and unusual conditions by townships.

UTILIZATION

The demand for ground water has increased within the last 20 years. The advent of modern household conveniences such as automatic washing machines, flush toilets, and bath facilities have greatly increased the domestic demand for water. Industrial expansion and large-scale use of water for air conditioning also have increased withdrawals from ground-water sources.

About 7,000 million gallons of ground water is pumped yearly in Tippecanoe County. The average daily pumpage of ground water is about 20 million gallons. Of this daily amount, industry uses about 12 million gallons; public water systems about 7 million gallons; rural nonfarm establishments about 0.3 million gallons; farms about 0.2 million gallons for domestic supply and stock about 0.6 million gallons. The total quantity of ground water used by industry, including that purchased from public supplies, is about 13.5 million gallons daily. Table 7 shows the estimated use of ground water in various population areas on a per capita basis. The usage in the urban areas was obtained by means of a pumpage inventory of

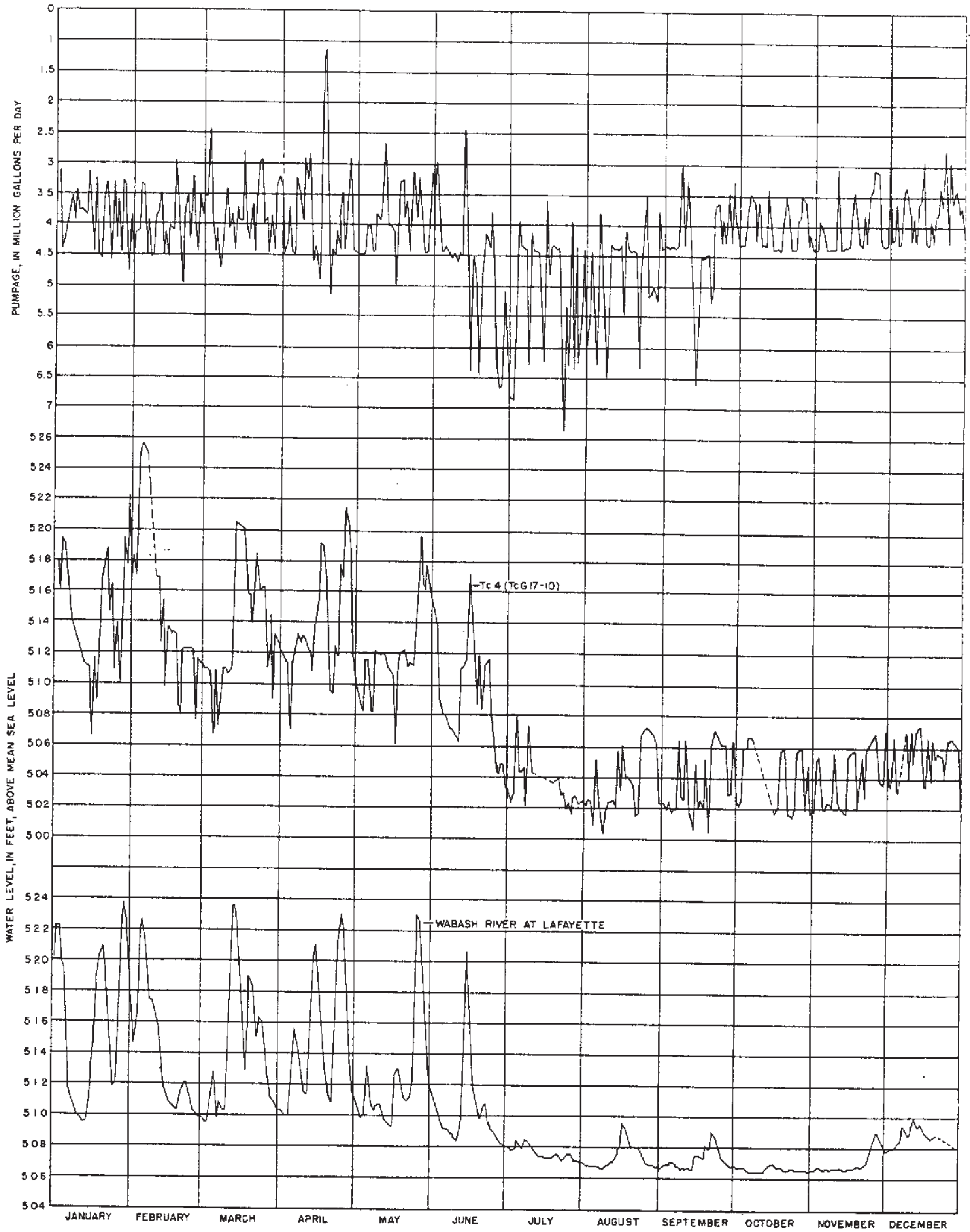

FIGURE 4.- GRAPH SHOWING PUMPAGE AT THE CANAL STREET STATION OF THE LAFAYETTE WATERWORKS, FLUCTUATIONS OF WATER LEVELS IN OBSERVATION WELL Tc 4(TcG17-10), AND MEAN GAGE HEIGHT OF THE WABASH RIVER AT LAFAYETTE, INDIANA IN 1952

Table 5.--Ground-water conditions by township: Source, bedrock

Location: Letters in parenthesis designate township in well-numbering system

Location	Remarks
T. 24 N., R. 6 W. (A)	No production reported from bedrock.
T. 24 N., R. 5 W. (B)	Ground water is derived from bedrock in secs. 26, 27, and 33-35. (See pl. 3.) Depths to bedrock range from 40 to 210 feet in this area. (See pl. 10.) Of 7 bedrock wells drilled, 3 were reported to have yielded no water.
T. 24 N., R. 4 W. (C)	No production reported from bedrock.
T. 24 N., R. 3 W. (D)	Some ground water is derived from bedrock in secs. 8-11, 14-17, 20, and 21. (See pl. 3.) Of 4 wells drilled in this area, 3 produced "sulfur" water and 1 was reported to be a dry hole. Two oil wells were drilled in secs. 10 and 22. Well TcD 10-1 (1/) penetrated two zones of water-bearing limestone, from 80 to 212 feet and 540 to 565 feet; well TcD 22-1 (1/) penetrated 15 feet of water-bearing shale at 80 feet and two zones of water-bearing limestone at 225 and 975 feet.
T. 23 N., R. 6 W. (E)	No production reported from bedrock.
T. 23 N., R. 5 W. (F)	Ground water is derived from bedrock in the north-central part of the township. (See pl. 3.) The area is underlain by a bedrock high, an extension of the similar area in T. 24 N., R. 5 W. Wells are generally 50 to 320 feet deep. (2/) Of 7 bedrock wells recorded, 5 were drilled in shale and 2 in limestone. Of the 5 wells drilled in shale 2 reported no water and 3, small amounts of water. Wells in the limestone are reported to yield about 2 gpm.
T. 23 N., R. 4 W. (G)	No production reported from bedrock.
T. 23 N., R. 3 W. (H)	Most wells are in sand and gravel but a few have been drilled into bedrock. Two wells drilled in sec. 21 flowed. The bedrock surface is high beneath the east-central part of the township, which is an area of localized production from rock.
T. 22 N., R. 6 W. (I)	Ground water is derived from bedrock in the southern two-thirds of the township. (See pl. 3.) In the area of bedrock production, the unconsolidated material ranges in thickness from a thin veneer to 70 feet and averages 45 feet in thickness. The bedrock wells range from 50 to 116 feet in depth. Production is derived from shale, and yields as high as 10 gpm have been reported.
T. 22 N., R. 5 W. (J)	Ground water is derived from bedrock in the southern half of the township. (See pl. 3.) The general range in well depths is from 50 to about 130 feet. (2/) Of the 20 rock wells recorded, 9 are reported to be drilled in limestone, 7 in shale, and 4 in undifferentiated bedrock. The wells finished in shale yielded very small quantities of water. In at least one well, TcJ 25-2 (1/), the shale is reported to be non-water-bearing. Well TcJ 24-5 (1/) produced 8 gpm from shale with a drawdown of 40 feet. Yields up to 15 gpm with small drawdowns are possible from the limestone, as indicated by well TcJ 19-1.(2/) Well TcJ 14-2 flowed. "Sulfur" water is reported in one limestone well.
T. 22 N., R. 4 W. (K)	In this area the bedrock is an extension of that in T. 22 N., R. 5 W., and ground-water conditions are similar.
T. 22 N., R. 3 W. (L)	No production reported from bedrock.
T. 21 N., R. 6 W. (M)	Some ground water is derived from bedrock. The few wells recorded in rock are less than 80 feet deep.
T. 21 N., R. 5 W. (N)	Ground water is derived chiefly from bedrock. (See pl. 3.) The bedrock wells are generally from 68 to more than 100 feet in depth. (2/) Few data are available on yields of bedrock wells in this township. An indication of the quantity of ground water that can be produced from bedrock is given by well TcN 9-1, which yielded 12 gpm with 10 feet of drawdown. Yields from bedrock wells may differ from place to place.
T. 21 N., R. 4 W. (O)	Ground water is reported from bedrock in localized areas. (See pl. 3.) The bedrock wells are generally less than 110 feet deep. (2/) Production from the bedrock (shale and limestone) is small as indicated by well TcO 5-2 (1/), which yields 8 gpm with 10 feet of drawdown, and by well TcO 26-1, which yields 10 gpm with 15 feet of drawdown.
T. 21 N., R. 3 W. (P)	Ground water is produced from bedrock in three small areas. (See pl. 3.) The bedrock wells are 80 to 120 feet deep, and the production is from shale and limestone. The yields from limestone are greater than those from shale. Of three wells drilled in shale, one was reported to have no water. Two limestone wells drilled in sec. 33 yielded about 8 and 17 gpm, respectively.

1/ See table 3, Rosenshein and Cosner, 1956.
2/ See table 2, Rosenshein and Cosner, 1956.

Table 6.--Ground-water conditions in Tippecanoe County by township: Source, sand and gravel

Location: Letter in parenthesis designates township in well-numbering system.
Ground-water potential: (1) Quantities greater than 500 gpm possible; (2) quantities greater than 100 gpm possible; (3) quantities greater than 10 gpm possible; (4) quantities greater than 10 gpm may be possible; (5) quantities limited.

Location	Approximate thickness of unconsolidated material		Ground-water potential	Remarks
	Range	Average		
T. 24 N., R. 6 W. (A)	56-312	200	(4)	See pl. 3. Areas of thickest unconsolidated deposits may yield large quanties.
T. 24 N., R. 5 W. (B)	40-332	200	(3)	Wells are generally 40 to 190 feet deep. (1/) The shallower wells are in the eastern and western thirds of the township; the deeper wells in the central third of the township. (See pl. 3.) Larger yields possible locally in the areas of thicker unconsolidated deposits or by production from several water-bearing zones.
T. 24 N., R. 4 W. (C)	85-304	220	(2)	Wells are generally 40 to 142 feet deep. (1/) The shallower wells are in the southern part of the township. (See pl. 3.) Large yields possible in the township as indicated by the two 100-gpm wells at Battle Ground (p.27) and by the overall thickness of unconsolidated material. (See pl. 10.)
T. 24 N., R. 3 W. (D)	0-235	125	(3)	Wells are generally 40 to 101 feet deep. (See pl. 3.) As much as 20 feet of saturated material is reported. Thick deposits of water-bearing material are probably present locally. The yields of five sand and gravel wells range from 8 to 12 gpm. (2/) Two of the wells have drawdowns of 5 to 6 feet.
T. 23 N., R. 6 W. (E)	121-420	275	(3)	Wells are generally 55 to more than 200 feet deep. (1/) Shallower wells are in the northeastern third of the township. (See pl. 3.) Well depth and the depth to water increase toward the edge of the upland, where the surface is deeply eroded by the Wabash River and Indian Creek. Wells drilled in bottom lands of the rivers are shallower than those drilled on the upland. At well TcE 34-1 (2/) the deeper unconsolidated material has more than 33 feet of saturated sand and gravel. Thick deposits of water-bearing sands and gravels are present also in the area of shallower production.
T. 23 N., R. 5 W. (F)	30-376	190	(2)	Wells are generally 40 to 265 feet deep. (1/) Shallower wells are drilled in the northwestern part and southern third of the township. (See pl. 3.) The deeper wells are drilled into subunit 5a, which is partly dissected by the Wabash River. Sand and gravel deposits of subunit 5a crop out along the Wabash River terrace scarps. (See pl. 6.) Where this subunit is breached by the Wabash River, the upper deposits are drained of ground water, resulting in progressively deeper water levels toward the valley walls. Yields from sand and gravel wells range from 7 to 300 gpm. The production is from several different water-bearing units, of which two are partly mapped, subunit 5a and subunit 5b.
T. 23 N., R. 4 W. (G)	109-305	190	(1)	Wells are 28 to more than 260 feet deep. (1/) Many of the deeper wells and deeper water levels occur along the terraces of the Wabash River and its tributaries. (See pl. 3.) Ground-water production comes from parts of units 2, 4, and 5. (See pls. 5 and 6.) Ground water occurs under both water-table and artesian conditions. (See table 4.) Locally more than one unit is present. Well logs record as much as 78 feet of saturated material. Well yields range from 5 to 1,400 gpm. The largest yielding wells are the industrial and public-supply wells in the Lafayette and West Lafayette areas. (See fig. 5 for areal distribution of pumpage.) Yields of domestic wells range from 5 to 10 gpm. Of 28 domestic and stock wells the yields of 24 are reported to be greater than 8 gpm, with drawdowns ranging from less than 1 foot to as much as 3 feet. The yields of 34 industrial and public-supply wells, 6 inches in diameter or larger, range from 90 to 1,400 gpm; 21 of them yielded 500 gpm or more.

1/ See Table 2, Rosenshein and Cosner, 1956.
2/ See Table 3, Rosenshein and Cosner, 1956.

Table 6--Ground-water conditions in Tippecanoe County by township: Source, sand and gravel--Continued

Location	Approximate thickness of unconsolidated material		Ground-water potential	Remarks
	Range	Average		
T. 23 N., R. 3 W. (H)	80-285	195	(2)	Wells are generally 32 to 169 feet deep. (1/) Production is from units 2, 3(?), and 4. (See pls. 5 and 6 and table 4.) Deeper wells are drilled into units 3(?) and 4. Flowing wells are present in parts of secs. 21, 28, and 33. The yields of these wells range from 48 to 240 gpm. The yields of nonflowing domestic and stock wells range from 8 to 60 gpm. Probably larger quantities of ground water can be obtained for irrigation and industrial use from the thicker parts of the several units in the area or by utilizing the production from more than one of the units.
T. 22 N., R. 6 W. (I)	0-158	55	(3)	Locally the unconsolidated material is at least 158 feet thick. The northern third of the township is an area of potential production from sand and gravel. (See pl. 3.)
T. 22 N., R. 5 W. (J)	20-315	115	(3)	Wells are 40 to 170 feet deep. (1/) The deeper wells are in the northeastern part of the township. In that area the yields of 4 wells ranged from 7 to 10 gpm with small drawdowns. More than 67 feet of water-bearing material is recorded in well TcJ 1-1. (2/) In the northern part of the township, the unconsolidated material is 115 to 315 feet thick and averages 210 feet. The range and distribution of well depths indicates that water-bearing material occurs in both shallow and deep unconsolidated deposits. In the central and eastern parts of the township the bedrock has been deeply eroded. (See pl. 10.) These areas are places of potential production from sand and gravel. Some production is obtained from shallow unconsolidated material along the eastern edge of the township.
T. 22 N., R. 4 W. (K)	20-337	200	(2)	Wells are from 32 to 194 feet deep. (1/) Of 55 wells drilled in unconsolidated material, 42 are less than 100 feet deep. (See pl. 3.) The deeper wells are generally in areas, where the shallower water-bearing units are either not very productive or absent. Well yields range from 8 to 240 gpm. The yields from domestic and stock wells range from 8 to 15 gpm, and very small drawdowns are reported. Only the upper 100 feet of the thick unconsolidated material is penetrated by wells. The deeper zones of unconsolidated material are potential sources of production from sand and gravel. Production of large quantities of ground water may be possible locally from the thicker zones.
T. 22 N., R. 3 W. (L)	199-340	250	(3)	Wells range from 26 to 196 feet in depth. Of 51 drilled wells 39 are less than 100 feet deep. Deeper wells are in two small areas along the northern and eastern part of the township (See pl. 3.) and are producing from units 3(?) and 4. Most production is from the two shallower water-bearing units, 1 and 2. Well yields range from 6 to 15 gpm and very small drawdowns are reported. Locally the water-bearing sand and gravel is 30 feet thick.
T. 21 N., R. 6 W. (M)	25-114	55	(5)	Parts of secs. 26, 27, 34, and 35 are areas of potential production from sand and gravel. (See pl. 3.)
T. 21 N., R. 5 W. (N)	44-108	60	(5)	See pl. 3.
T. 21 N., R. 4 W. (O)	45-370	210	(3)	Wells range generally from 43 to about 150 feet in depth. (1/) Most of the wells are less than 100 feet deep. (See pl. 3.) Saturated material, as thick as 99 feet, is reported in well logs. A deep trough is eroded into the bedrock surface in the central part of the area. Wells are drilled only into the upper parts of the unconsolidated material in this deep trough.
T. 21 N., R. 3 W. (P)	80-399	265	(2)	Wells range generally in depth from 28 to about 200 feet. (1/) Most of the wells are more than 50 and less than 100 feet deep. The deeper wells are in isolated areas (pl. 3) and shallower production is possible locally. The yields from 12 small-diameter wells range from 4 to 10 gpm. Yields greater than 8 gpm are reported in 9 of these 12 wells. Two larger diameter wells in Clarks Hill yielded 150 and 100 gpm, respectively. The range in well depths indicates that the unconsolidated material has several shallow and deep water-bearing zones. Locally as much as 30 feet of saturated sand and gravel is reported in wells.

1/ See Table 2, Rosenshein and Cosner, 1956.
2/ See Table 3, Rosenshein and Cosner, 1956.

industrial and public water supplies. The estimated use on farms and by farm and rural nonfarm establishments was obtained by evaluating the characteristics of the farm and rural nonfarm dwellings listed by the U. S. Census. The following factors were taken into consideration: (1) the number of occupied dwellings; (2) median number of persons per dwelling; (3) method of distribution of water supply; (4) toilet facilities; and (5) bathing facilities. The record of public supply pumpage is shown in table 8. Figure 5 shows the distribution and average daily public water supply and industrial pumpage in the Lafayette-West Lafayette area. This area uses the largest amount of ground water of any in Tippecanoe County.

Table 7.--Estimated per capita use of ground water in Tippecanoe County

Population area	Usage (gpd/person)
Urban (nonindustrial)......................................	75
a) Lafayette (public-supply pumpage, total)........	115
b) Lafayette (public-supply pumpage, nonindustrial)	75
Rural nonfarm (including towns having waterworks).........	50
Rural nonfarm (not including towns having waterworks)....	30
Rural farm..	25

MUNICIPAL WATER SUPPLIES

Four municipalities in Tippecanoe County use drilled wells to obtain ground water from unconsolidated material for water supply.

Battle Ground

A public water supply was established at Battle Ground in 1927. Water is obtained from two wells drilled into sand and gravel which are reported to be 85 feet deep. Each well is equipped with a 20-horsepower electric pump. The reported capacity of each pump is about 200 gpm, or 288,000 gpd, which is the estimated capacity of the treatment plant. The waterworks has one 40,000-gallon elevated storage tank. The population served by the plant increased from 448 in 1931 to about 634 in 1954. The estimated annual pumpage (table 8) increased during this period from 10 million gallons to 22 million gallons.

Clarks Hill

A public water supply was established at Clarks Hill about 1938. Originally, water was obtained from an 8-inch well 90 feet deep. In August 1954 another well 6 inches in diameter and 90 feet deep was drilled. Both wells are producing water from sand and gravel. Each well is equipped with a 100 gpm electric pump and the capacity of the treatment plant is reported to be 108,000 gallons per day. The waterworks has one 60,000-gallon elevated storage tank, 128 feet tall. The population served by the plant increased from about 432 in 1944 to 498 in 1954, with a corresponding increase in pumpage. (See table 8.)

Table 8.--Reported annual pumpage of municipal waterworks in Tippecanoe County, in millions of gallons

Year	Battle Ground	Clarks Hill	Lafayette	West Lafayette
1914	....	....	....	320.6
1915	....	....	....	371.3
1916	....	....	1,280.3	230.7
1917	....	....	1,353.3	238.3
1918	....	....	1,373.8	257.2
1919	....	....	1,347.4	267.0
1920	....	....	1,323.4	315.7
1921	....	....	1,266.5	305.2
1922	....	....	1,257.7	300.8
1923	....	....	1,326.5	332.3
1924	....	....	1,289.1	305.1
1925	....	....	1,066.3	367.8
1926	....	....	1,005.3	412.7
1927	....	....	1,056.4	435.5
1928	....	....	1,106.5	520.5
1929	....	....	1,115.1	817.5
1930	....	....	1,162.7	522.4
1931	e10	....	1,140.3	403.0
1932	e10	....	1,129.6	275.8
1933	e10	....	1,242.0	442.1
1934	e10	....	1,333.4	296.3
1935	e10	....	1,128.4	213.7
1936	e10	....	856.7	279.4
1937	e10	....	759.8	341.8
1938	e13	....	767.5	165.9
1939	e13	....	831.8	222.7
1940	e13	....	956.1	220.9
1941	e13	....	1,076.5	218.1
1942	e13	....	1,993.2	191.6
1943	....	....	1,040.5	197.9
1944	....	e7	1,057.5	212.9
1945	....	e7	1,118.7	202.1
1946	....	e8	1,298.8	245.0
1947	e17	e8	1,225.6	342.8
1948	e22	e8	1,234.7	320.2
1949	e22	e8	1,281.8	332.7
1950	e22	e8	1,274.8	335.1
1951	e22	e8	1,398.7	260.6
1952	e22	e8	1,187.2	360.9
1953	e22	e8	1,390.7	375.3
1954	e22	e8	1,386.2	323.7

e - estimated.

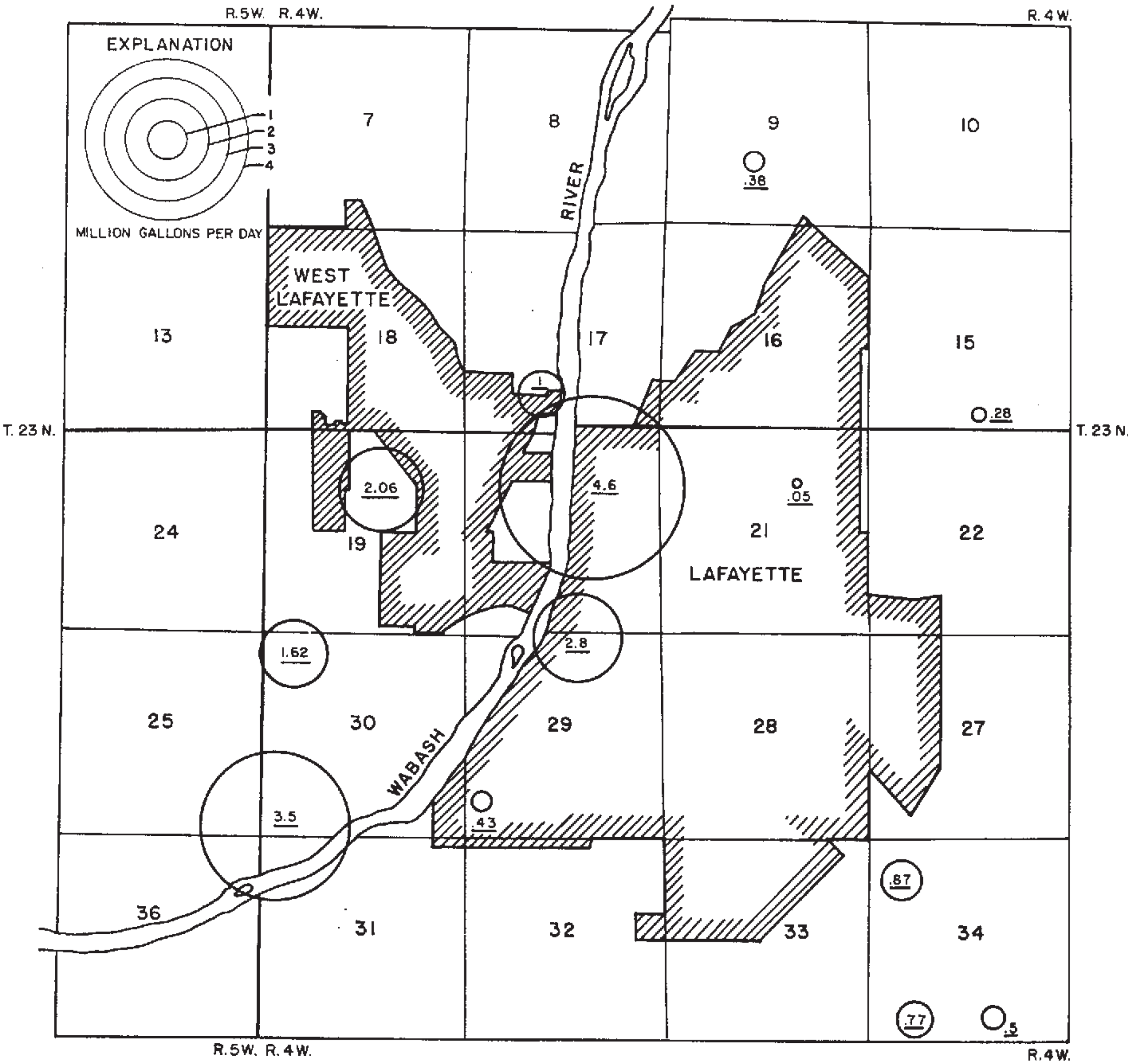

FIGURE 5.- DISTRIBUTION OF PUMPING AND AVERAGE PUMPAGE, IN MILLION GALLONS PER DAY, FROM PUBLIC-SUPPLY AND INDUSTRIAL WELLS IN THE LAFAYETTE-WEST LAFAYETTE AREA, INDIANA.

Lafayette

Ground water is obtained at Lafayette from fourteen 12-inch wells and one 16-inch well drilled in the sand and gravel of subunit 5b. All the wells are reported to be about 100 feet deep and the pumps are chiefly electric powered. The plant has a lined surface reservoir and a standpipe. The surface reservoir has a capacity of 4.9 million gallons. The number of service connections increased from 6,071 in 1916 to 10,397 in 1954. The reported annual pumpage (table 8) increased during this period from 1,280 million gallons to 1,386 million gallons.

West Lafayette

In 1914 the West Lafayette waterworks had 14 wells of which 5 were 12 inches in diameter and 9 were 9 inches in diameter. By 1937 the number of wells had increased to 21. During much of this period water was supplied to Purdue University, which now has its own ground-water supply. In 1954 water for West Lafayette was obtained from three 12-inch wells and a 16-inch well drilled into the sand and gravel of subunit 5b. The wells range in depth from 117 to 128 feet. The plant has one standpipe which has a capacity of 330,000 gallons. The number of connections increased from a reported 967 in 1914 to about 2,600 in 1954. The reported annual pumpage (table 8) increased during this period from 320 million gallons to 324 million gallons.

RECOVERY OF GROUND WATER

PRINCIPLES OF RECOVERY

The pumping of a well causes the water level in the well and in the aquifer in the vicinity of the well to be lowered. As the water level is drawn down, the water surface in the aquifer slopes toward the well and a cone of depression is formed with the vertex at the well.

At the start of pumping the water level in the well is drawn down rapidly. The rate of drawdown decreases as the volume of the aquifer affected by pumping increases and a larger part of the aquifer contributes water from storage. The water level will continue to decline in the aquifer and in the well until a quantity of water equal to the pumpage is added to the aquifer by an increase in recharge or the interception of natural discharge.

The rate of drawdown in a pumped well depends upon the pumping rate, the physical characteristics of the formation, and the construction of the well. The shape of the cone of depression in an aquifer is determined by the rate of pumping and the physical characteristics of the aquifer. In an aquifer under water-table conditions, the cone of depression spreads slowly and the rate of drawdown is relatively slow because of the large release of water from storage as the water-table aquifer is unwatered. In an aquifer under artesian conditions, the cone of depression spreads rapidly and the rate of drawdown is fast during the first few minutes of pumping, because the pressure in the aquifer is reduced at the point of pumping. The water derived from the artesian aquifer is not obtained by unwatering of the aquifer, but by the compaction of the aquifer and its associated beds and from the expansion of water which was compressed in the aquifer.

TYPES OF WELLS

Wells are the chief source of water for domestic, stock, public, and industrial supplies in Tippecanoe County. The wells range in diameter from 2 inches to 13 feet and are constructed by a number of different methods.

Dug wells, drilled wells, and driven wells are used in Tippecanoe County. The oldest wells in the county are dug wells. The dug wells were constructed by excavating a large hole, usually 3 feet or more in diameter, to the water-bearing zone and as far as possible into it. The sides of the well are cribbed or tiled to prevent caving. The dug well is the most effective type of well in tight material of small permeability, such as clayey till. The large diameter provides a large surface area of water-bearing material from which water can seep into the well. Furthermore, the large well acts as a reservoir for water during nonpumping periods. A principal disadvantage of the dug well lies in the difficulty of keeping the well free from surface contamination. Under prolonged drought conditions the dug well may go dry as the water surface declines below the bottom of the well; thus water supplies from dug wells are unreliable because of the shallow depth of well penetration into the water-bearing material. Also the dug well tends to become silted. Most dug wells in Tippecanoe County are used to water livestock.

Wells that are 4 inches in diameter and larger have been drilled in the county by the cable-tool (percussion) method. The cable-tool rig is mounted on the back of a truck or a trailer, and either a separate engine on the truck or a gasoline engine on the trailer provides the power for drilling. The method consists of a combination of drilling, driving, and bailing. After the well is started the casing is driven a short distance into the ground, and the hole is cleaned by bailing. When necessary, water is added to the hole to facilitate the drilling and bailing process. If coarse granular material, compacted clay, or rock are encountered, a percussion bit must be used to penetrate the deposits. The drill cuttings are then removed from the hole by a bailer. Generally the bailer consists of a hollow tube with a hinged flap valve at the bottom.

Most drillers operating in Tippecanoe County case the well throughout the full length of the hole where drilling in unconsolidated material. If it is necessary to drill consolidated rock, the casing is driven a few inches or a few feet into rock in order to set the casing. The rest of the hole is drilled as an uncased open hole in the rock. Usually black or galvanized steel pipe is used as casing.

After a well has penetrated to or into unconsolidated water-bearing material, the well may be finished with a screen or simply with an open end. (See Rosenshein and Cosner, 1956, p. 5 for a detailed description of a well screen.) The purpose of the screen is to keep the water-bearing material out of the well and at the same time allow the water to move into the well. The grain size of the water-bearing material determines the slot size of the screen that is selected. The screen is lowered into the hole, and the casing is pulled back from the hole either by means of jacks or by jarring tools, until all the screen is exposed to water-bearing formation. Usually, a lead fitting called a packer or a turned coupling has been attached to the upper end of the screen prior to lowering the screen into the well. If a packer is used, it is flanged out by a tool called a swage. The flanged packer seals the upper end of the screen tightly against the casing.

Some wells are finished as open-end holes, if the water-bearing material is sufficiently angular and compact and does not flow or heave into the bottom of the hole. In Tippecanoe County, most existing flowing artesian wells are finished with an open end.

A well finished with a screen in sand and gravel is usually developed by surging and pumping. The purpose of this process is to remove the finer material in the aquifer from the area immediately around the well screen. The length of time the driller spends in developing a well depends upon the characteristics of the water-bearing material, the size of the well, and the desired yield. Proper well development decreases the drawdown in the well by increasing the permeability of the aquifer near the well, helps prevent clogging of the screen, and decreases wear on the pump by decreasing the amount of fine material pumped into the well.

The drilled well has a number of advantages over the dug well. Drilled wells make use of deeper water-bearing zones, are faster and more economical to construct for a given yield, are much less susceptible to surface contamination, and under favorable conditions can be developed to yield much larger and more reliable supplies of ground water.

The gravel-packed well and the collector are two special types of wells used by some industries in Tippecanoe County. A gravel-packed well is a modification of the tubular well. An oversized hole is drilled into the water-bearing material and a smaller diameter casing with a screen is set inside the outer casing. Then a lining of clean gravel is poured around the screen, resulting in a gravel envelope between the screen and the water-bearing material. The collector is a large well or caisson 13 feet or more in diameter. The large diameter casing is sunk into the water-bearing material, and slotted pipe is forced out laterally into the water-bearing deposits by hydraulic jacks. A number of radially arranged horizontal pipes extend out into the material from one or more levels.

A few driven wells are used in the county where unconsolidated water-bearing material lies close to the surface. Such a well is constructed by driving a small-diameter pipe having a drive point attached to the end. Some 2-inch wells have been drilled by the hollow-rod (hydraulic) jetting method. Water is forced under pressure out of a hollow rod that is fitted with a jetting bit. As the material is washed out of the hole ahead of the casing, the casing sinks down into the hole. Jetted wells and driven wells are not installed in areas where water-bearing zones are deep, and where there is a predominance of very coarse granular material such as boulders, in consolidated rock, or in the case of jetted wells, where there are great thicknesses of unsaturated permeable material.

QUALITY OF GROUND WATER

All ground water contains dissolved minerals. The dissolved-mineral content of ground water is related to the materials through which the water flows, the length of time it is in contact with the materials, and the temperature and pressure. Much of the material deposited by the glaciers in Tippecanoe County was derived from sedimentary rocks containing calcium carbonate. The ground water obtained from the glacial deposits contains relatively large amounts of calcium bicarbonate and is hard.

Two important chemical properties of ground water are its hardness and the iron content. Hardness is a property which is readily recognized. Hard water increases the amount of soap needed to make a lather, causes scale in boilers and hot water heaters, and leaves curdy films on materials washed in the water. The two kinds of hardness are carbonate and non-carbonate hardness. Carbonate hardness is usually caused by the calcium and magnesium equivalent to the bicarbonate in the water. The remainder of the hardness is noncarbonate hardness and is caused by the sulfate, chlorides, and nitrates of calcium and magnesium. Water having a hardness of more than 200 parts per million is generally considered hard. An iron content of more than 0.3 part per million is ordinarily objectionable in water for domestic and many industrial uses. A higher concentration of iron in water tends to stain clothes, fixtures, and cooking utensils. Water containing iron in larger quantities has an objectionable taste. Most of the ground-water samples whose analyses are given in table 9 contain substantial amounts of iron.

The ground waters of Tippecanoe County are very hard. Table 9 shows the chemical analysis of water samples from a number of wells. One analysis is of highly mineralized water from bedrock which is not typical of potable water from that source; and the others are of water from unconsolidated material. Of the analyses of water from unconsolidated material one is from subunit 5a, six from subunit 5b, and the rest from undifferentiated sand and gravel deposits.

SUMMARY

The sand and gravel deposits within the glacial drift are the most important sources of ground water in Tippecanoe County. The deposits form a single but complex hydrologic system. Five water-bearing sand and gravel units are mapped in parts of the county. Most of the wells furnishing water for domestic purposes are drilled into these sand and gravel deposits. In most parts of the county, the deposits are potentially sources of larger quantities of ground water than are presently withdrawn. Locally, wells have yielded as much as 1,000 gpm. In the southwestern part of the county, the sand and gravel deposits are thin and ground water is obtained principally from bedrock. The bedrock yields small quantities of water and is generally an unreliable source of ground water.

In many parts of the county detailed information is lacking about the subsurface geology, hydrology, and chemical quality of the ground water. In many areas only the upper part of the drift has been penetrated by wells, and the deeper part of the drift may be a source of water for future development. Additional geologic and hydrologic data are needed for a better understanding of the ground-water conditions in these areas and to permit quantitative evaluation of the ground-water resources in Tippecanoe County.

Table 9.--Analyses of water from wells in Tippecanoe County, Ind.

(in parts per million, except pH)

Aquifer: Gr, gravel; Ls, limestone; Sd, sand; 5A and 5B subunit numbers (See text.)

Well No.	Location	Aquifer	Date of collection	Temperature (°)F	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$ Total	Noncarbonate	pH	Remarks
TcF 36-11	NW¼SE¼NW¼ sec. 36 T. 23 N., R. 5 W.	5b	5-15-52	---	12	.35	---	---	---	309	60	6	---	---	434	398	89	6.9	a/ Taken after 22 hrs. pumping.
Do----	do--------	5b	5-16-52	---	12	.35	---	---	---	301	52	6	---	---	429	396	95	6.8	a/ Taken after 55 hrs. pumping.
TcG 19-11	NW¼SW¼NW¼ sec. 19 T. 23 N., R. 4 W.	5a	2- 5-48	---	12	.2	---	---	---	---	---	4	---	---	---	342	80	7.3	b/
TcG 20-1	SW¼SW¼SE¼ sec. 20 T. 23 N., R. 4 W.	Ls	4-25-1858	55-56	8	---	382	131	2160	---	678	3800	---	---	7294	---	---	---	c/
TcG 22-3	SW¼ NE¼ sec. 22 T. 23 N., R. 4 W.	Sd, Gr	8-23-53	55	13	2.8	89	33	5.9+1.5	412	30	2	.2	.2	373	356	20	7.7	h/ From well no. 18 at Brown Rubber Co.
TcG 30-17	NW¼SW¼SE¼ sec. 30 T. 23 N., R. 4 W.	5b	9-12-54	54	10	.85	---	---	---	289	88	12	---	---	444	404	115	6.7	d/
TcG 31-12	NE¼NW¼NW¼ sec. 31 T. 23 N., R. 4 W.	5b	8- 1-52	52.5	16	.3	---	---	---	350	102	2	---	---	458	470	120	7.1	d/ Taken after 24 hrs. pumping.
Do----	do--------	5b	8- 3-52	54	16	.3	---	---	---	343	100	2	---	---	495	448	105	7.2	d/
TcK 4-2	SE¼SE¼ sec. 31 T. 22 N., R. 4 W.	Sd, Gr	5-17-30	---	4	---	77	35	---	---	---	19	---	---	334	---	---	---	e/
TcP 23-1	NW¼NE¼SW¼ sec. 23 T. 21 N., R. 3 W.	Gr	2-17-50	---	---	2.5	---	---	---	---	---	7	---	---	---	288	---	7.6	f/
---	NW¼SE¼ sec. 23 T. 24 N., R. 3 W.	Sd, Gr	10-26-49	---	---	1.6	---	---	---	---	---	9	---	---	---	272	---	8.3	f/ From unidentified well at Battle Ground Water-works.
---	SE¼SE¼ sec. 17 T. 23 N., R. 4 W.	5b	3-31-52	53	12	.05	102	36	13+3.6	376	96	20	.2	11	496	402	94	7.1	g/ Public Supply of Lafayette.

a/ Analysis by Harvey Wilke, Purdue University
b/ Analysis by Frederick G. Atkinson, Inc.
c/ Analysis by Dr. Charles M. Wetherill (Gorby, 1886, p. 70)
d/ Analysis by Charles W. Gates, Lafayette, Ind.
e/ Analysis by C. B. Hall, chemist, C. C. C. & St. Louis R. R.
f/ 1952, Data on Indiana public water supplies, Indiana State Board of Health, Bull. S. E. 10.
g/ Lohr, Brown, and Lamar, 1953, p. 41
h/ Analysis by U. S. Geological Survey

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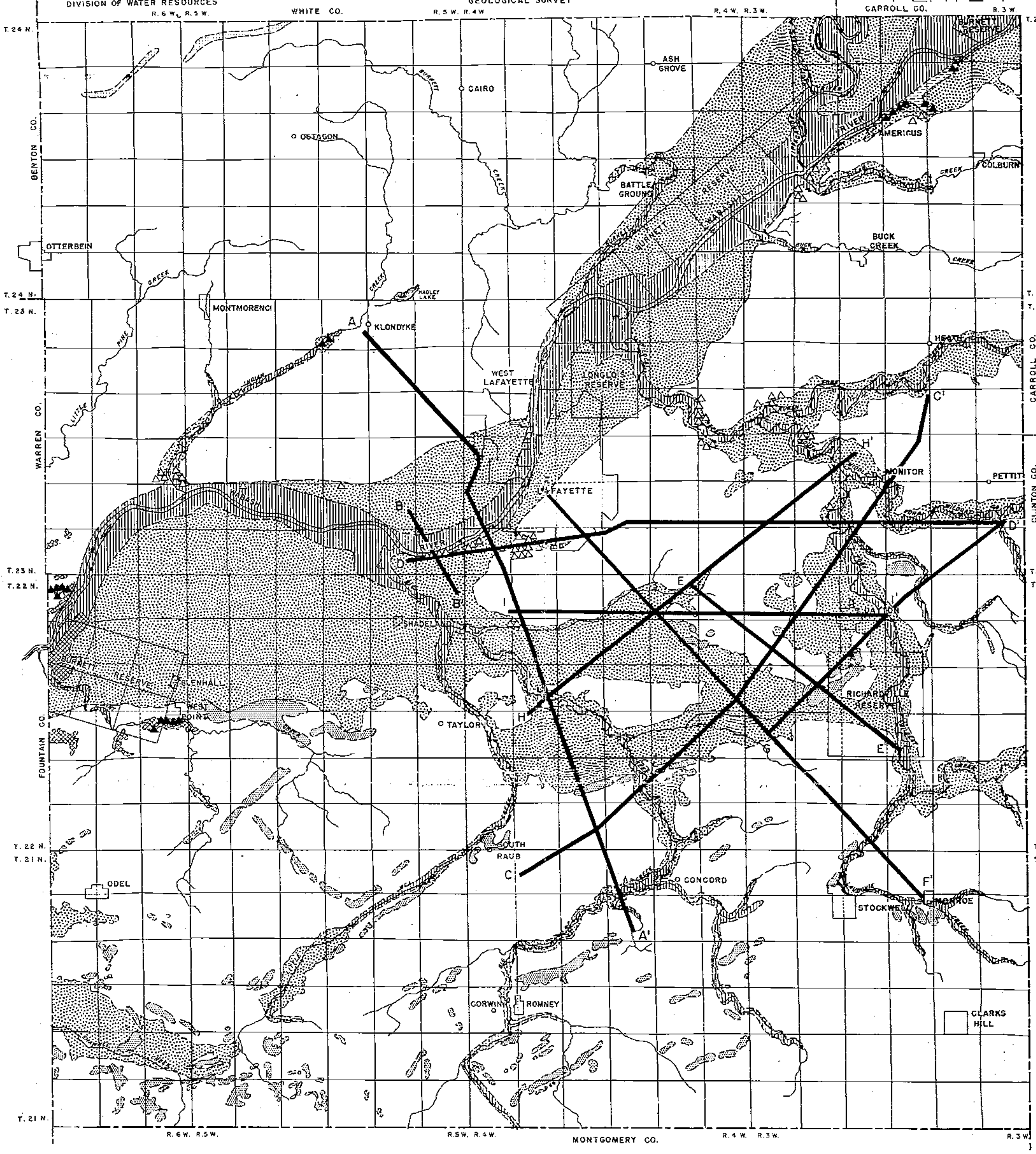
8. Ground-water resources of Tippecanoe County, Ind.: Appendix, Basic data. J. S. Rosenshein and O. J. Cosner. Ind. Dept. Cons., Div. Water Resources. 1956.

INDEX

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE I



SURFACE GEOLOGY
OF
TIPPECANOE COUNTY, INDIANA

0 1 2 3 4 5 6 MILES
0 5000 10000 15000 20000 FEET

COMPILED BY J. S. ROSENSHEIN

1958

EXPLANATION

QUATERNARY

RECENT
- SAND-RIDGE DEPOSITS
- ALLUVIUM

PLEISTOCENE
- GLACIOFLUVIAL DEPOSITS
- GROUND MORAINE; CHIEFLY WISCONSIN TILL
- MORAINAL-RIDGE DEPOSITS PARTLY STRATIFIED CLAY, SAND, AND GRAVEL.

MISSISSIPPIAN
- SILTSTONE, SHALE AND LIMESTONE

DEVONIAN
- SHALE

A —— A'
LINE OF CROSS SECTIONS SHOWN ON PLATE 7-9

Δ
OUTCROPS OF PLEISTOCENE SANDSTONE AND CONGLOMERATE

▲
OUTCROPS OF BEDROCK

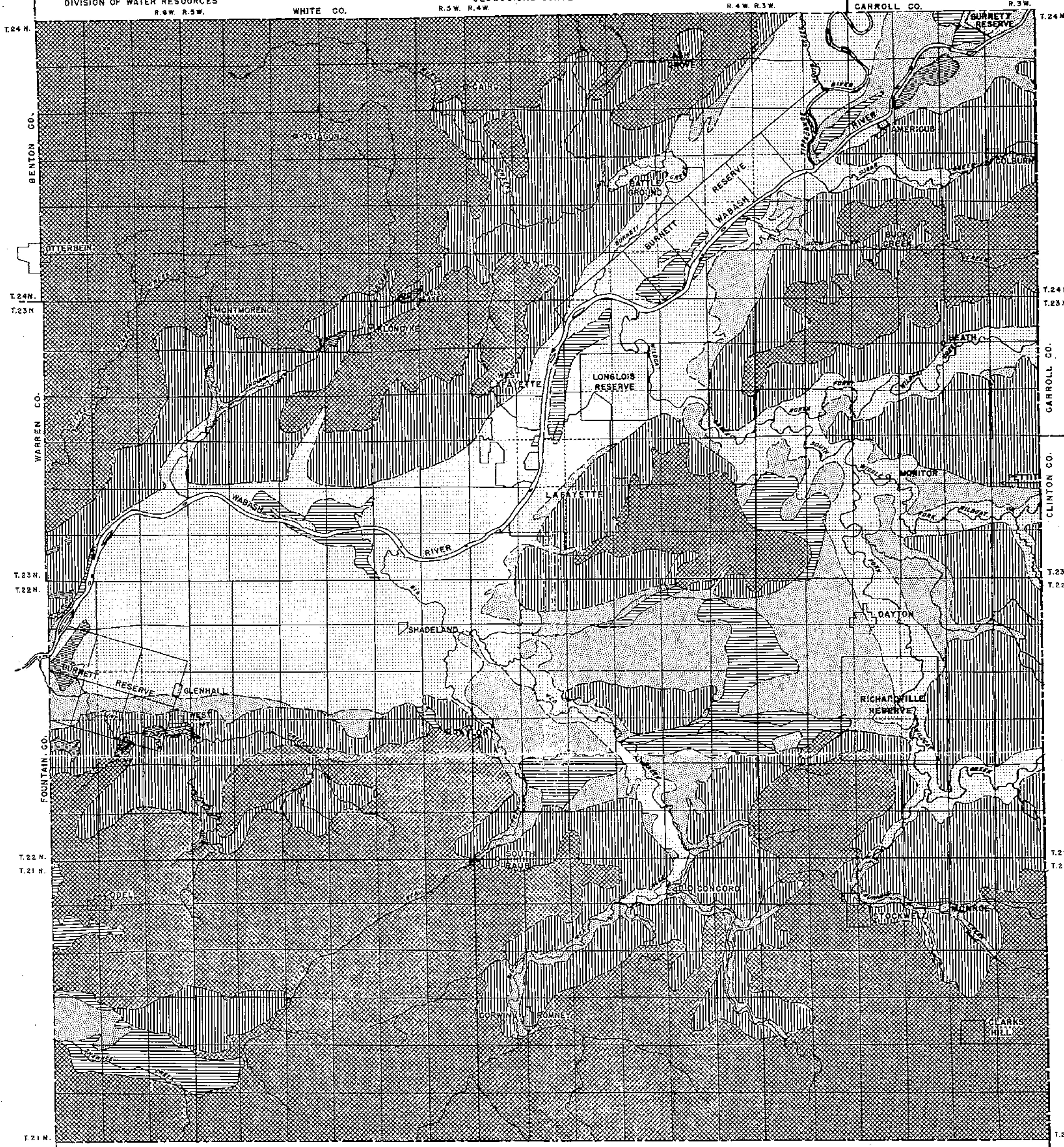
BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY BASE MAP OF TIPPECANOE COUNTY, INDIANA, MAY 1, 1952

SURFACE GEOLOGY COMPILED FROM UNPUBLISHED SOILS MAP, AIR PHOTOGRAPHS AND RECONNAISANCE GEOLOGIC SURVEY.

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 2



FAVORABLE FOR RECHARGE: SOIL, SANDY GRAVELLY LOAM TO LOAM; SUBSURFACE MATERIALS, WATER-LAID SAND AND GRAVEL AND SOME CLAY, LYING CLOSE TO SURFACE.

MODERATELY FAVORABLE FOR RECHARGE: SOIL, SILTY LOAM; SUBSURFACE MATERIALS, WATER-LAID SAND AND GRAVEL AND SOME CLAY, LYING CLOSE TO SURFACE.

SOMEWHAT FAVORABLE FOR RECHARGE: SOIL, SILTY CLAY LOAM; SUBSURFACE MATERIALS, WATER-LAID SAND AND GRAVEL AND SOME CLAYS, LYING CLOSE TO SURFACE.

MODERATELY UNFAVORABLE FOR RECHARGE: SOIL, SILTY LOAM; SUBSURFACE MATERIALS, CHIEFLY TILL.

UNFAVORABLE FOR RECHARGE: SOIL, SILTY CLAY LOAM; SUBSURFACE MATERIALS, CHIEFLY TILL.

UNFAVORABLE FOR RECHARGE: SOIL, SILTY CLAY LOAM; SUBSURFACE MATERIALS SHALLOW BEDROCK.

BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY BASE MAP OF TIPPECANOE COUNTY, INDIANA, MAY 1, 1952

MAP OF
TIPPECANOE COUNTY, INDIANA
SHOWING
SURFACE AND NEAR-SURFACE CONDITIONS AFFECTING GROUND-WATER RECHARGE

0 1 2 3 4 5 6 MILES
0 5000 10000 15000 20000 FEET

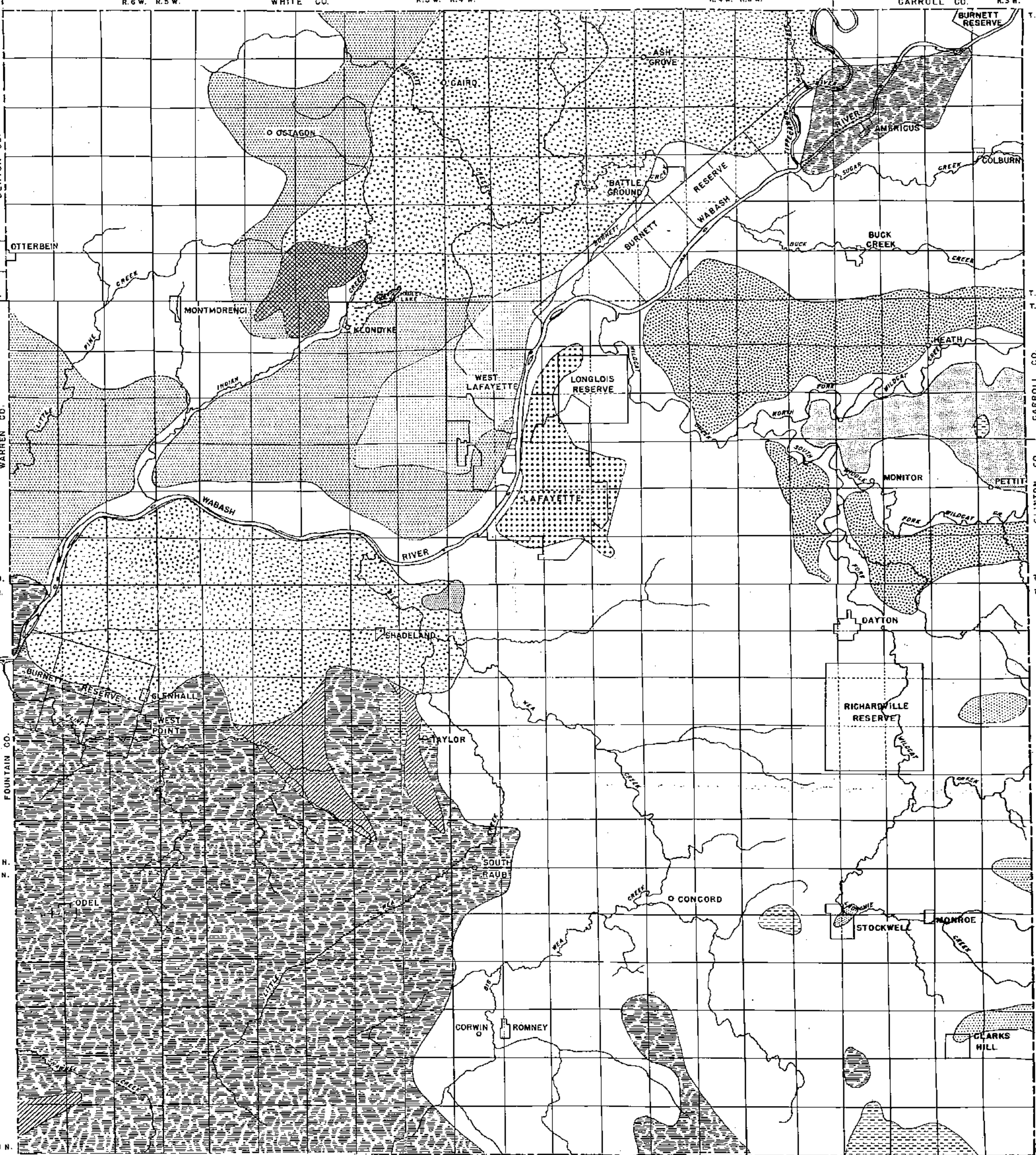
BASED UPON UNPUBLISHED SOILS MAP OF TIPPECANOE COUNTY, INDIANA. PREPARED BY PURDUE UNIVERSITY AGRICULTURAL EXPERIMENTAL STATION AND SURFACE AND SUBSURFACE INFORMATION.

COMPILED BY J. S. ROSENSHEIN
1958

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 3



PRODUCTION FROM SAND AND GRAVEL

WELL DEPTHS RANGE FROM 30 TO 100 FEET. YIELDS GENERALLY MORE THAN ADEQUATE FOR DOMESTIC USE. LARGER YIELDS POSSIBLE.

WELL DEPTHS RANGE FROM 70 TO 145 FEET. YIELDS GENERALLY MORE THAN ADEQUATE FOR DOMESTIC USE. LARGER YIELDS MAY BE POSSIBLE LOCALLY.

WELL DEPTHS RANGE FROM 110 TO 200 FEET, THE SHALLOWER WELLS BEING ON WESTERN EDGE. AREA OF INDUSTRIAL PUMPAGE AND LARGE YIELDS.

WELL DEPTHS RANGE FROM 100 TO 150 FEET. YIELDS MORE THAN ADEQUATE FOR DOMESTIC USE. MODERATELY LARGE YIELDS POSSIBLE LOCALLY.

WELL DEPTHS RANGE FROM 100 TO 150 FEET. THICK CLAY DEPOSITS OCCUR LOCALLY. YIELDS GENERALLY MORE THAN ADEQUATE FOR DOMESTIC USE. LARGER YIELDS MAY BE POSSIBLE.

WELL DEPTHS RANGE FROM 150 TO 200 FEET. SHALLOWER PRODUCTION MAY BE POSSIBLE. YIELDS GENERALLY MORE THAN ADEQUATE FOR DOMESTIC USE. LARGER YIELDS POSSIBLE LOCALLY.

WELL DEPTHS RANGE FROM 200 TO MORE THAN 260 FEET. YIELDS GENERALLY MORE THAN ADEQUATE FOR DOMESTIC USE. LARGER YIELDING WELLS PRESENT ALONG EASTERN EDGE.

UNDEVELOPED AREAS OF POTENTIAL PRODUCTION FROM SAND AND GRAVEL.

PRODUCTION FROM BEDROCK 1/

WELL DEPTHS RANGE FROM 50 TO 110 FEET. YIELDS ERRATIC, INADEQUATE TO ADEQUATE FOR DOMESTIC USE.

WELL DEPTHS MORE THAN 100 FEET. YIELDS ERRATIC, GENERALLY ADEQUATE FOR DOMESTIC USE.

WELL DEPTHS RANGE FOOM 50 TO MORE THAN 300 FEET. YIELDS INADEQUATE TO ADEQUATE FOR DOMESTIC USE.

1/ LOCALLY SOME PRODUCTION FROM SAND AND GRAVEL.

MAP OF
TIPPECANOE COUNTY, INDIANA
SHOWING
GROUND WATER CONDITIONS

0 1 2 3 4 5 6 MILES
0 5000 10000 15000 20000 FEET

BY J. S. ROSENSHEIN

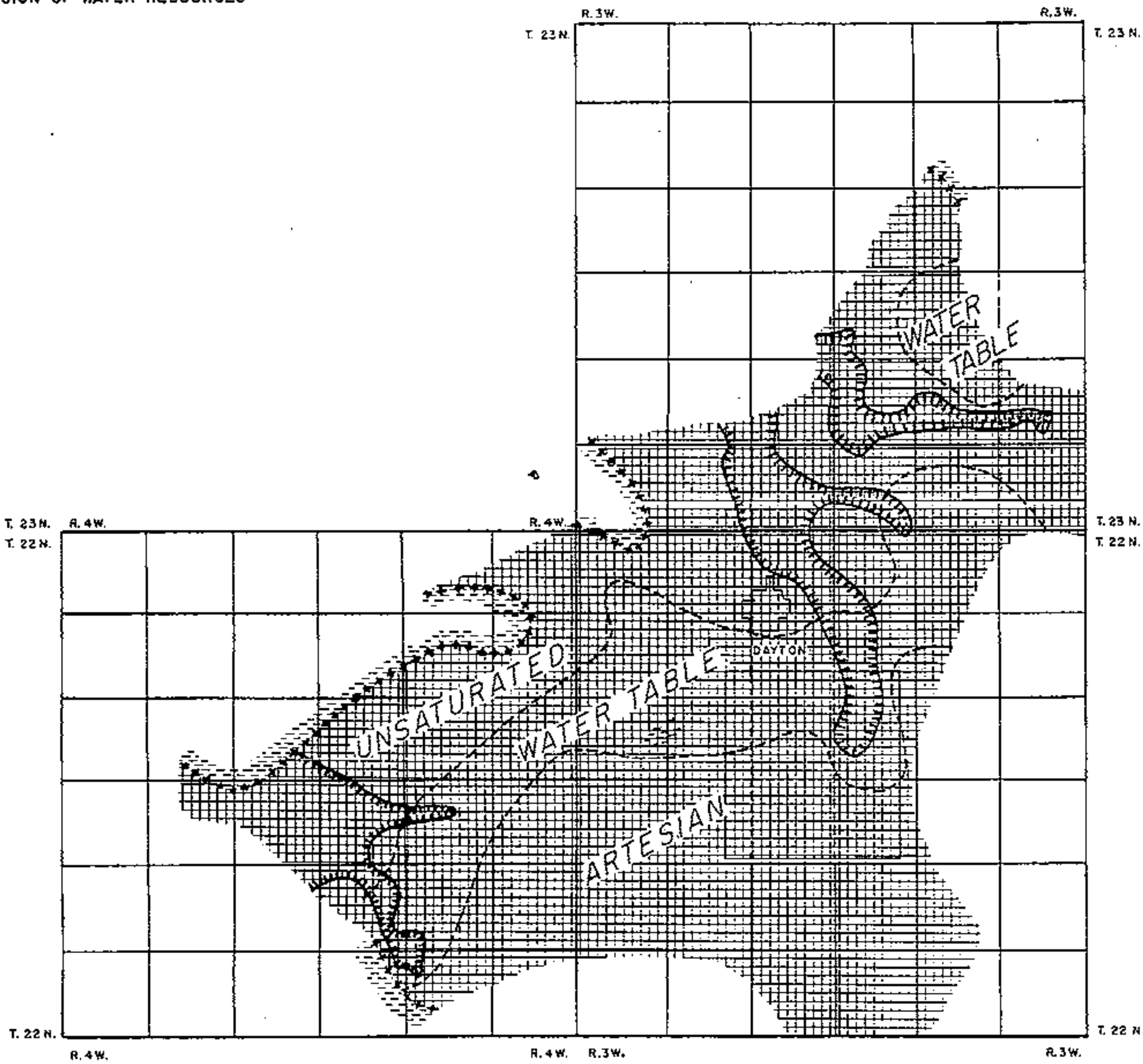
1958

BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY BASE MAP OF TIPPECANOE COUNTY, INDIANA, MAY 1, 1952

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 4



EXPLANATION

UNIT I
ALTITUDE OF TOP OF UNIT 640-660 FEET

SILT AND CLAY

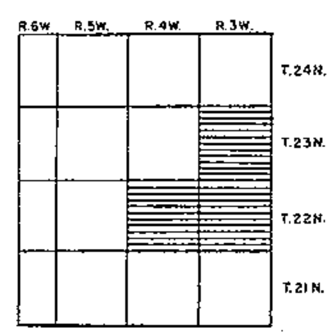
DRIFT UNDIFFERENTIATED

PART OF UNIT BREACHED BY STREAM

++++++
BOUNDARY OF UNIT

BOUNDARY BETWEEN GROUND-WATER CONDITIONS

SUBSURFACE EXTENT OF AND GROUND-WATER CONDITIONS IN SAND AND GRAVEL UNIT I



INDEX MAP OF TIPPECANOE COUNTY
SHOWING AREA COVERED BY PLATE 4

0 1 2 3 4 5 6 MILES
0 5000 10000 15000 20000 FEET

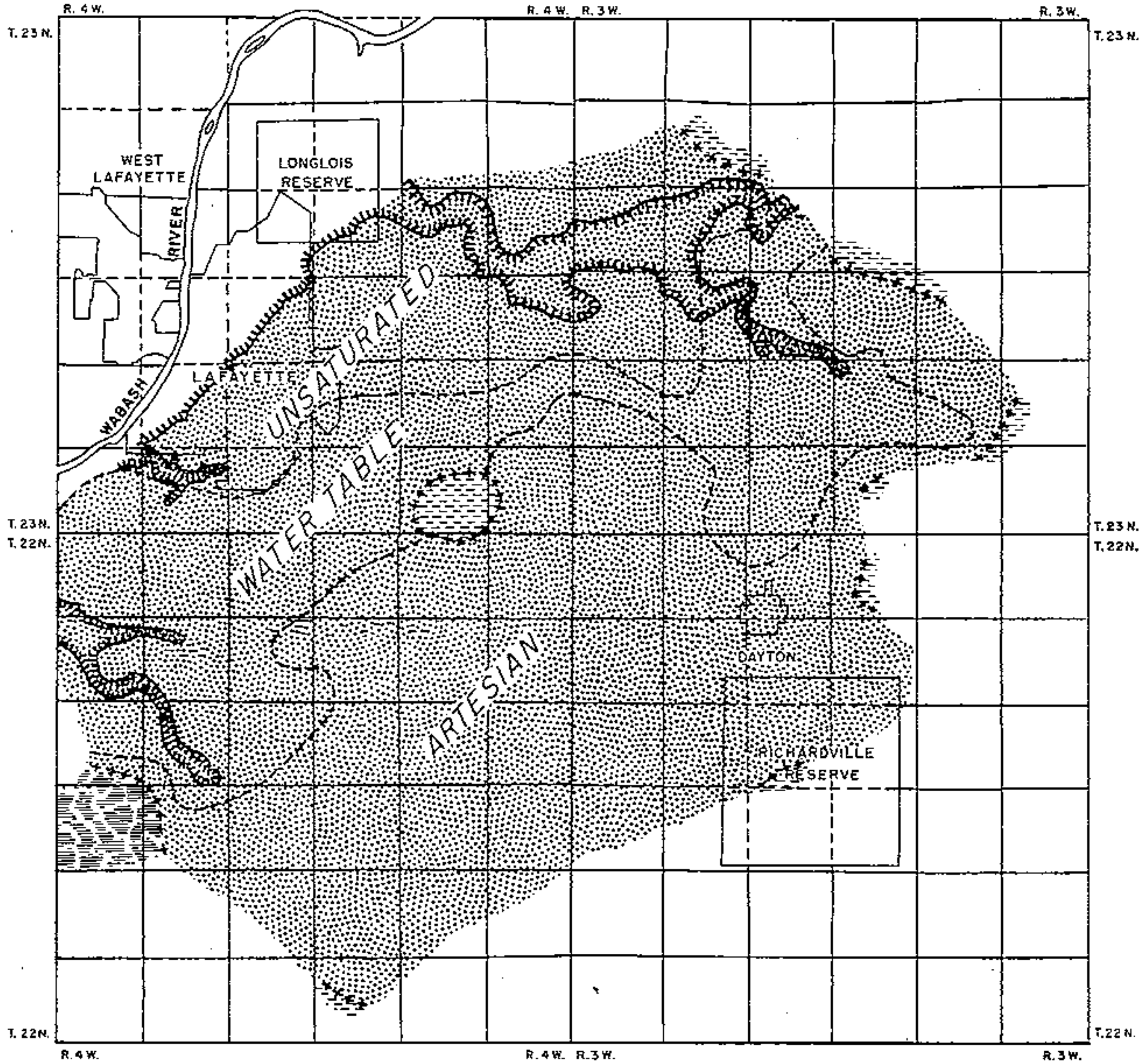
BY J. S. ROSENSHEIN
1958

BASE MODIFIED FROM INDIANA
DEPARTMENT OF CONSERVATION,
GEOLOGICAL SURVEY, BASE MAP
OF TIPPECANOE COUNTY, INDIANA
MAY 1, 1952

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 5



EXPLANATION

UNIT 2
ALTITUDE OF TOP OF UNIT 600-620 FEET

SILT AND CLAY

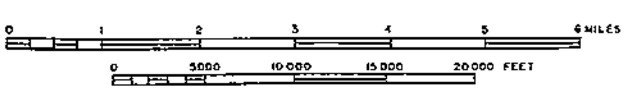
DRIFT UNDIFFERENTIATED

BEDROCK
ALTITUDE HIGHER THAN 620 FEET

PART OF UNIT BREACHED BY STREAM

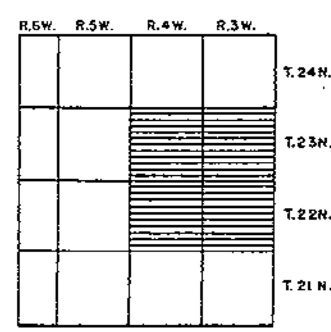
+++++
BOUNDARY OF UNIT

– – – – –
BOUNDARY BETWEEN GROUND-WATER CONDITIONS



BY J. S. ROSENSHEIN
1958

SUBSURFACE EXTENT OF AND GROUND-WATER CONDITIONS IN SAND AND GRAVEL UNIT 2



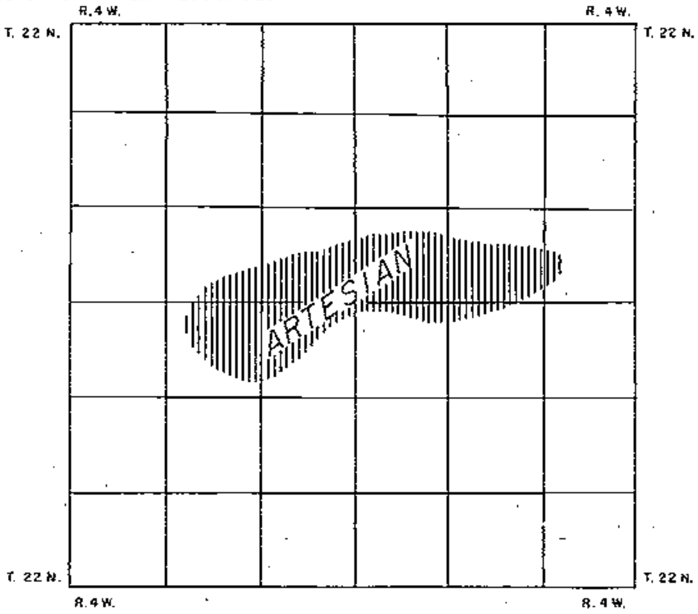
INDEX MAP OF TIPPECANOE COUNTY SHOWING AREA COVERED BY PLATE 5

BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION GEOLOGICAL SURVEY, BASE MAP OF TIPPECANOE COUNTY, INDIANA MAY 1, 1952

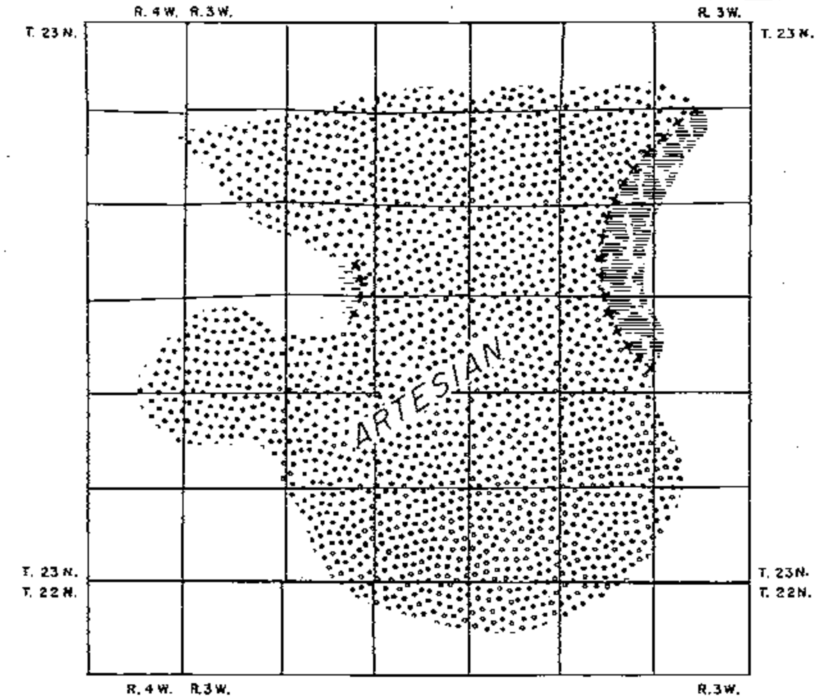
STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

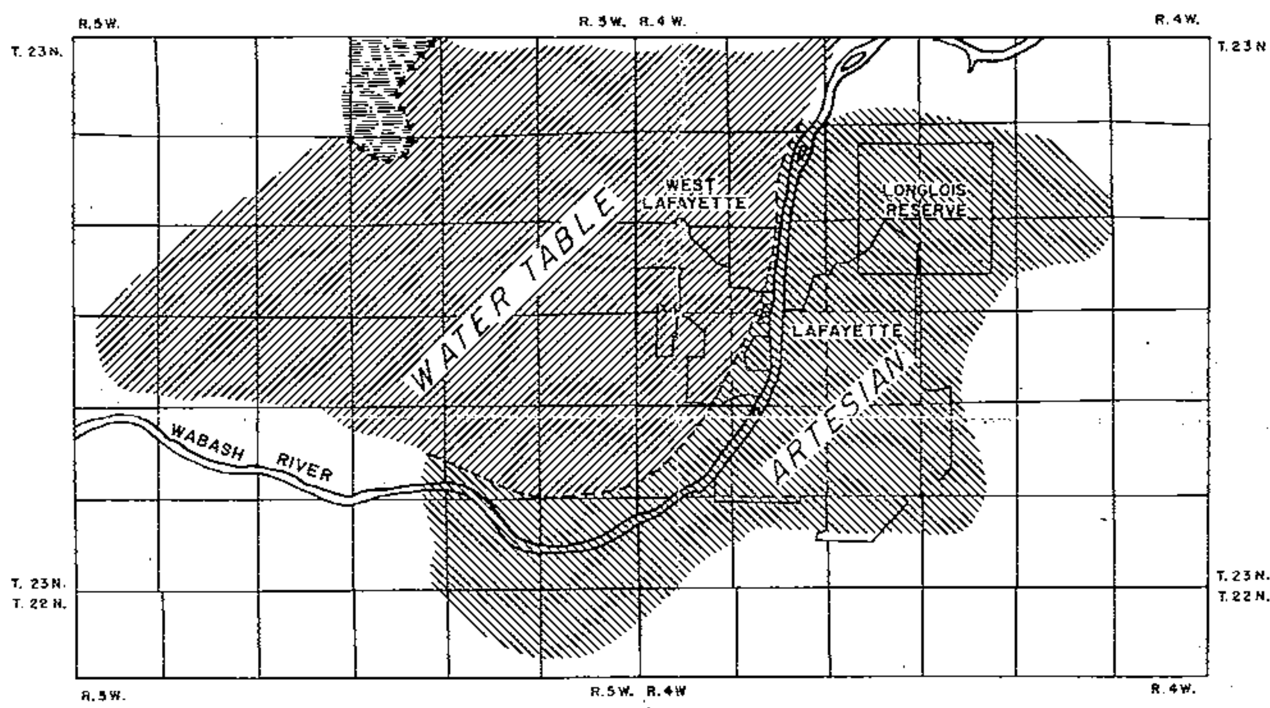
PLATE 6



UNIT 3



UNIT 4



UNIT 5

EXPLANATION

UNIT 3
ALTITUDE OF TOP OF UNIT 535-570 FEET

UNIT 4
ALTITUDE OF TOP OF UNIT 530-550 FEET

UNIT 5

SUBUNIT 5A
ALTITUDE OF TOP OF UNIT 500-540 FEET

SUBUNIT 5B
ALTITUDE OF TOP OF UNIT 490-510 FEET

SILT AND CLAY

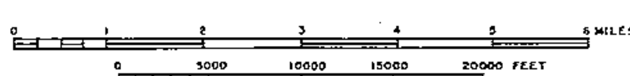
DRIFT UNDIFFERENTIATED

BEDROCK
ALTITUDE HIGHER THAN 550 FEET

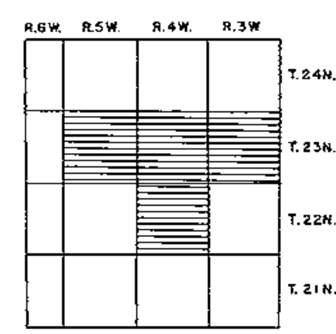
BOUNDARY OF UNIT

BOUNDARY BETWEEN GROUND-WATER CONDITIONS

SUBSURFACE EXTENT OF AND GROUND-WATER CONDITIONS IN SAND AND GRAVEL UNITS 3-5



BY J. S. ROSENSHEIN
1958



INDEX MAP OF TIPPECANOE COUNTY
SHOWING AREA COVERED BY PLATE 6

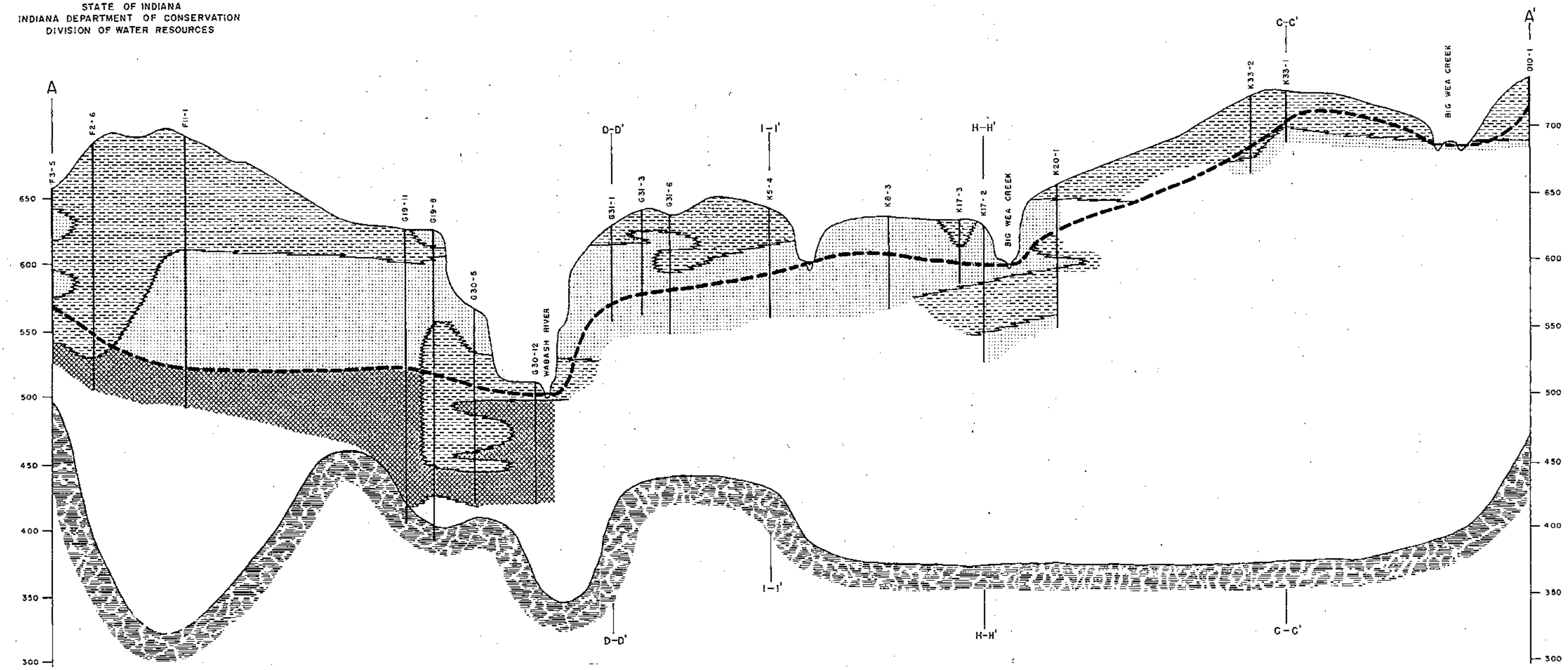
BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY, BASE MAP OF TIPPECANOE COUNTY, INDIANA MAY 1, 1952

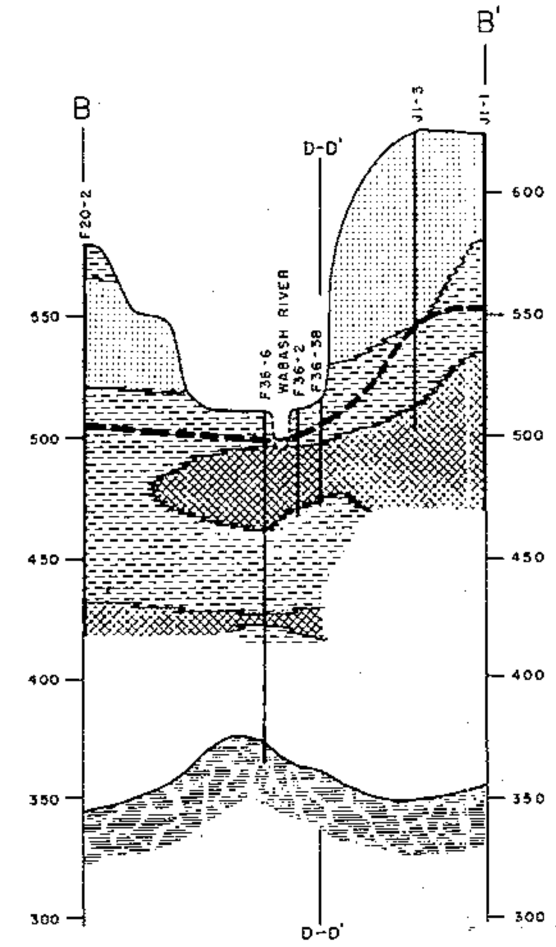
STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

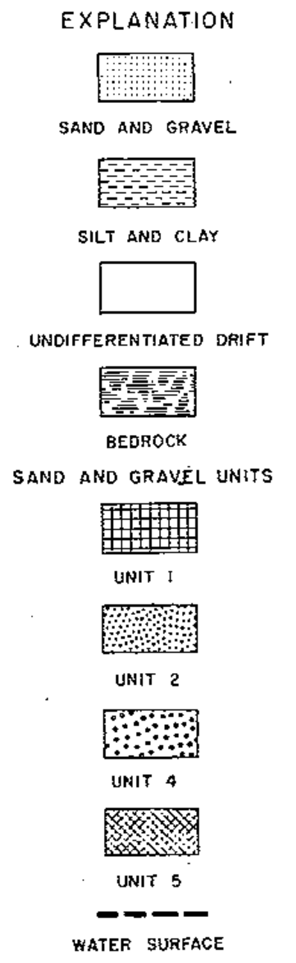
PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

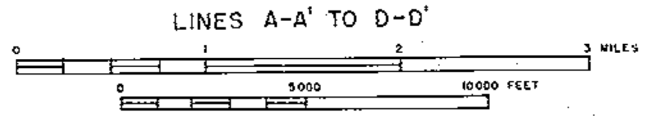
PLATE 7

CROSS SECTIONS
SHOWING
GENERALIZED GEOLOGY AND WATER-BEARING UNITS
LINES A-A' TO D-D'

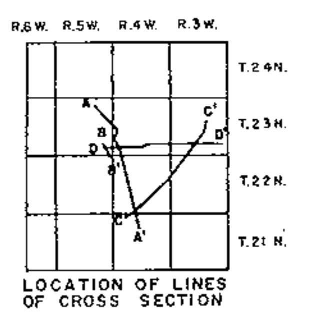


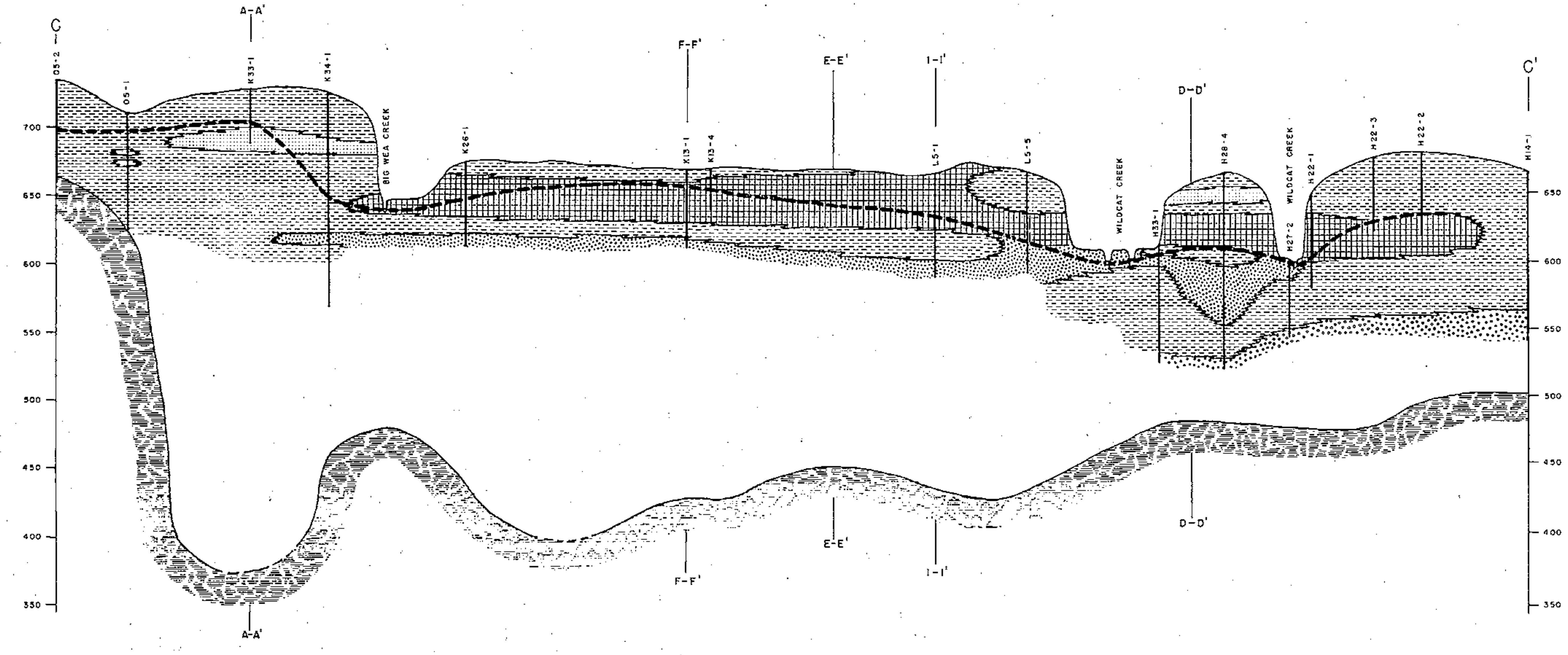


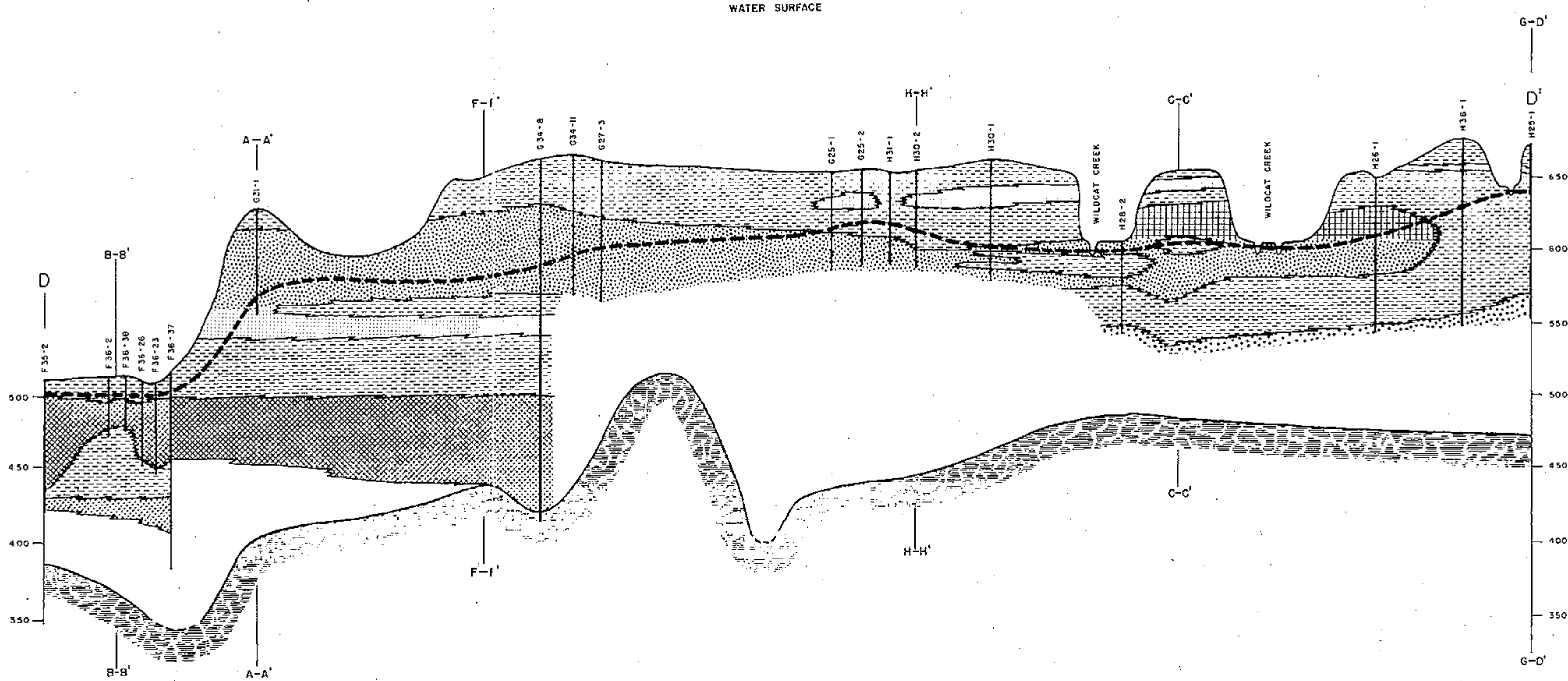




VERTICAL EXAGGERATION 65 TIMES
DATUM IS MEAN SEA LEVEL
BY J. S. ROSENSHEIN
1958







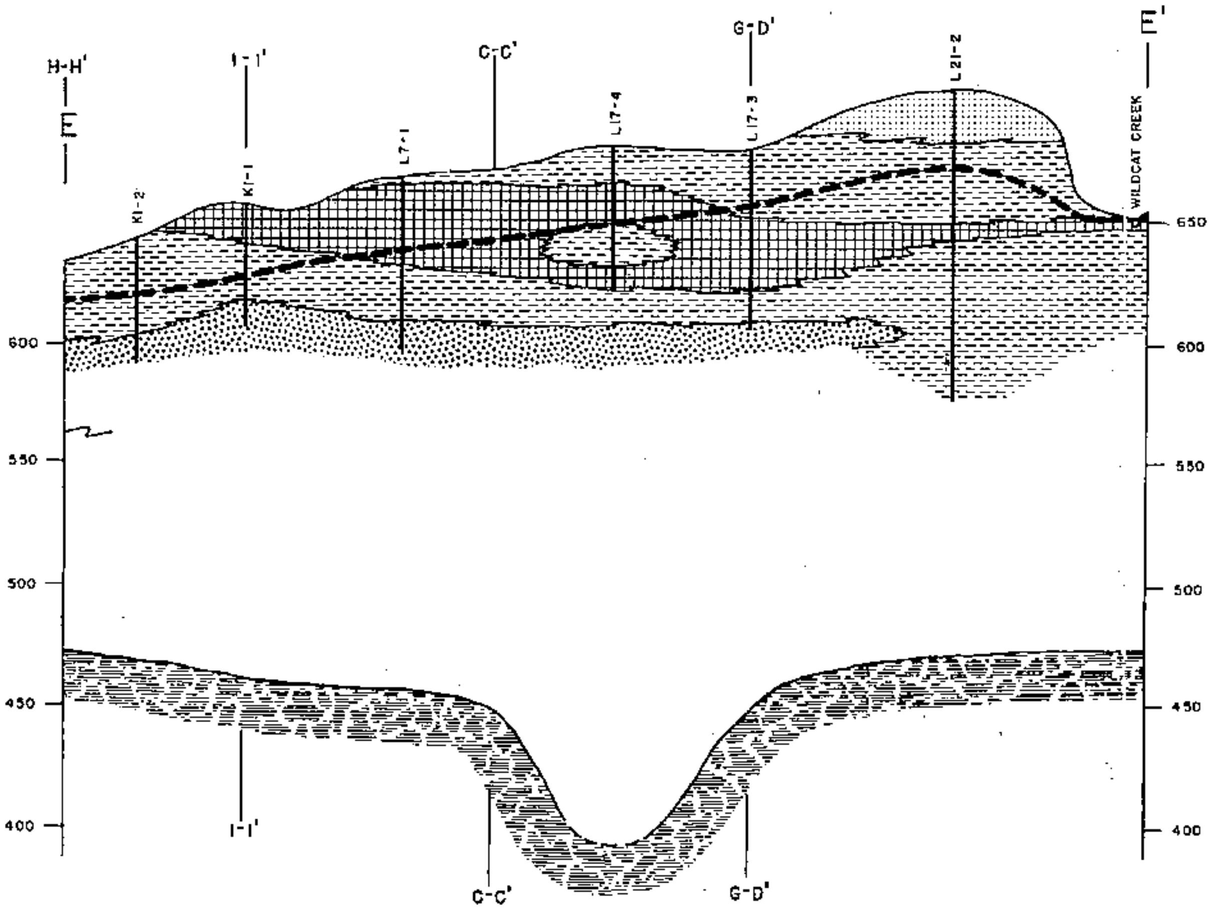
STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

CROSS SECTIONS
SHOWING
GENERALIZED GEOLOGY AND WATER-BEARING UNITS
LINES E-E' TO F-F'

0 1 2 3 MILES
0 5000 10000 FEET

VERTICAL EXAGGERATION 65 TIMES
DATUM IS MEAN SEA LEVEL
BY J. S. ROSENSHEIN
1958



EXPLANATION

SAND AND GRAVEL

SILT AND CLAY

UNDIFFERENTIATED DRIFT

BEDROCK

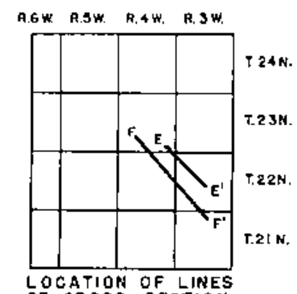
SAND AND GRAVEL UNITS

UNIT 1

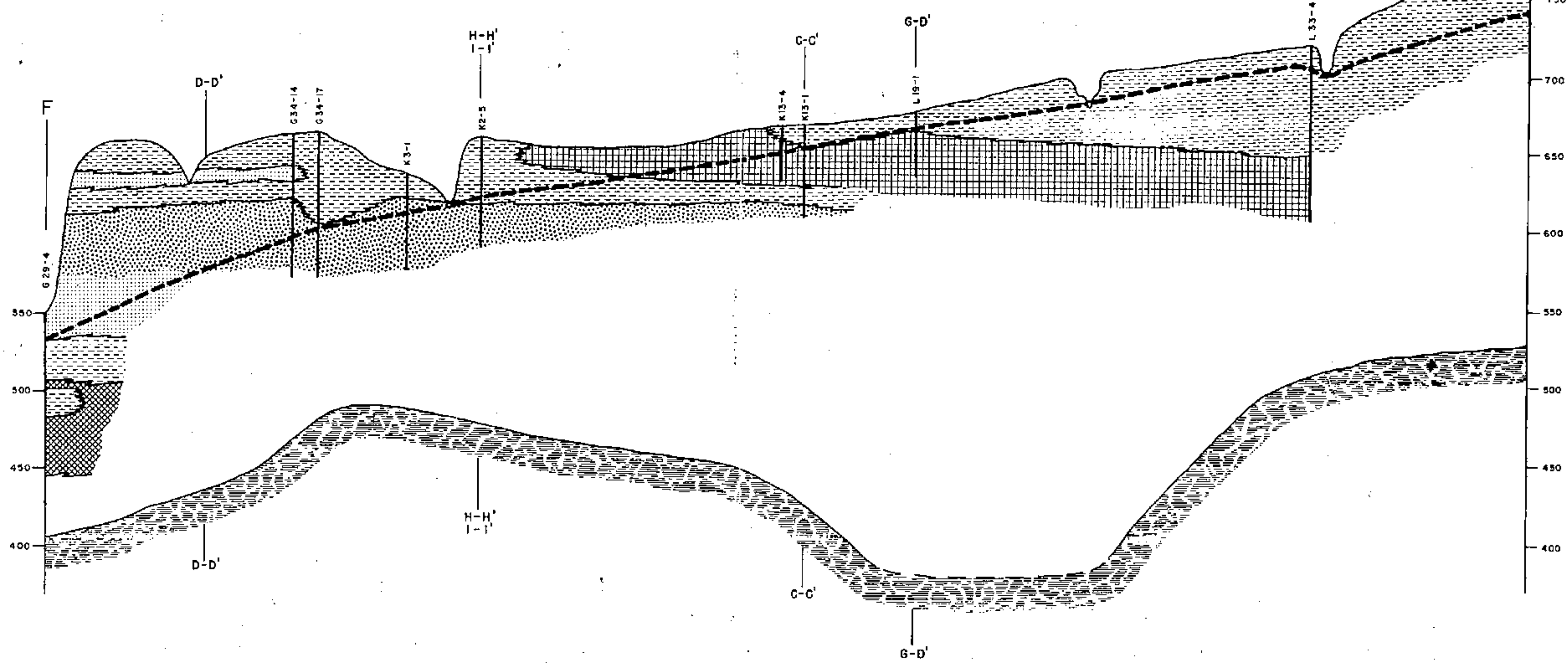
UNIT 2

UNIT 5

WATER SURFACE



LOCATION OF LINES OF CROSS SECTION



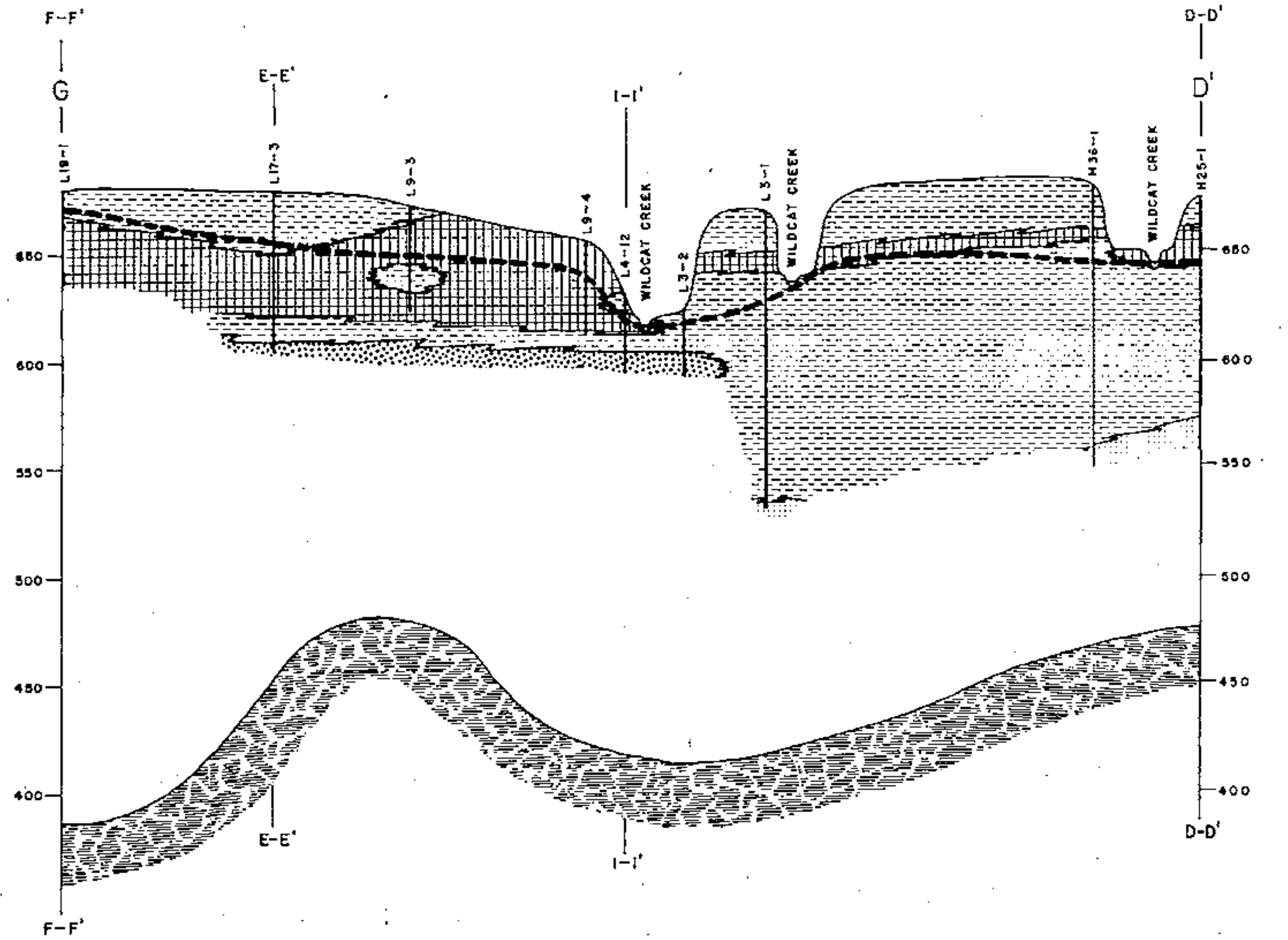
STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 9

CROSS SECTIONS
SHOWING
GENERALIZED GEOLOGY AND WATER-BEARING UNITS
LINES G-D' TO I-I'

VERTICAL EXAGGERATION 65 TIMES
DATUM IS MEAN SEA LEVEL
BY J. S. ROSENSHEIN
1958



EXPLANATION

SAND AND GRAVEL

SILT AND CLAY

UNDIFFERENTIATED DRIFT

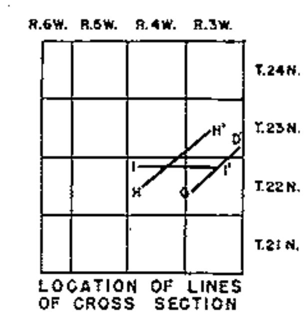
BEDROCK

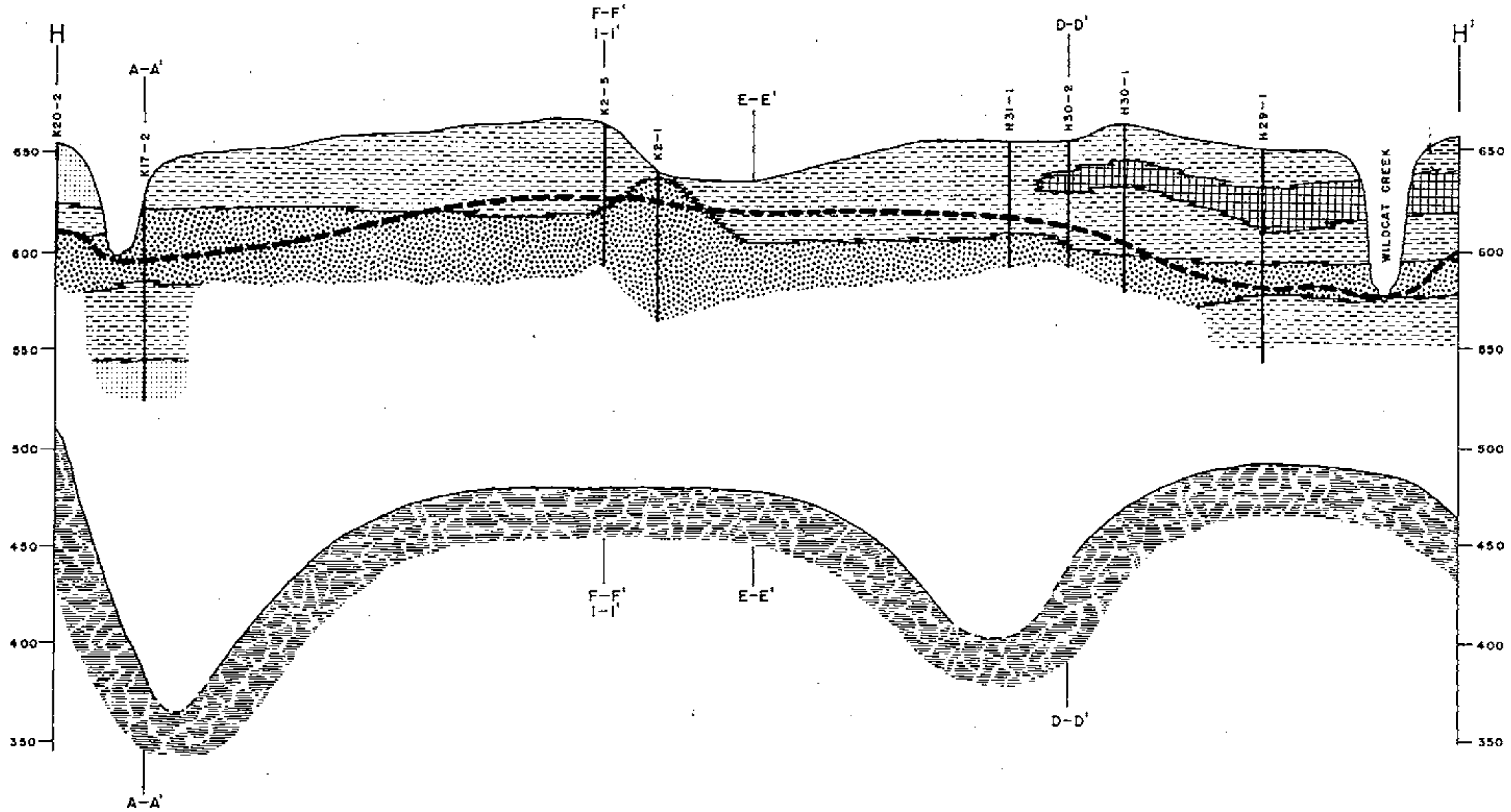
SAND AND GRAVEL UNITS

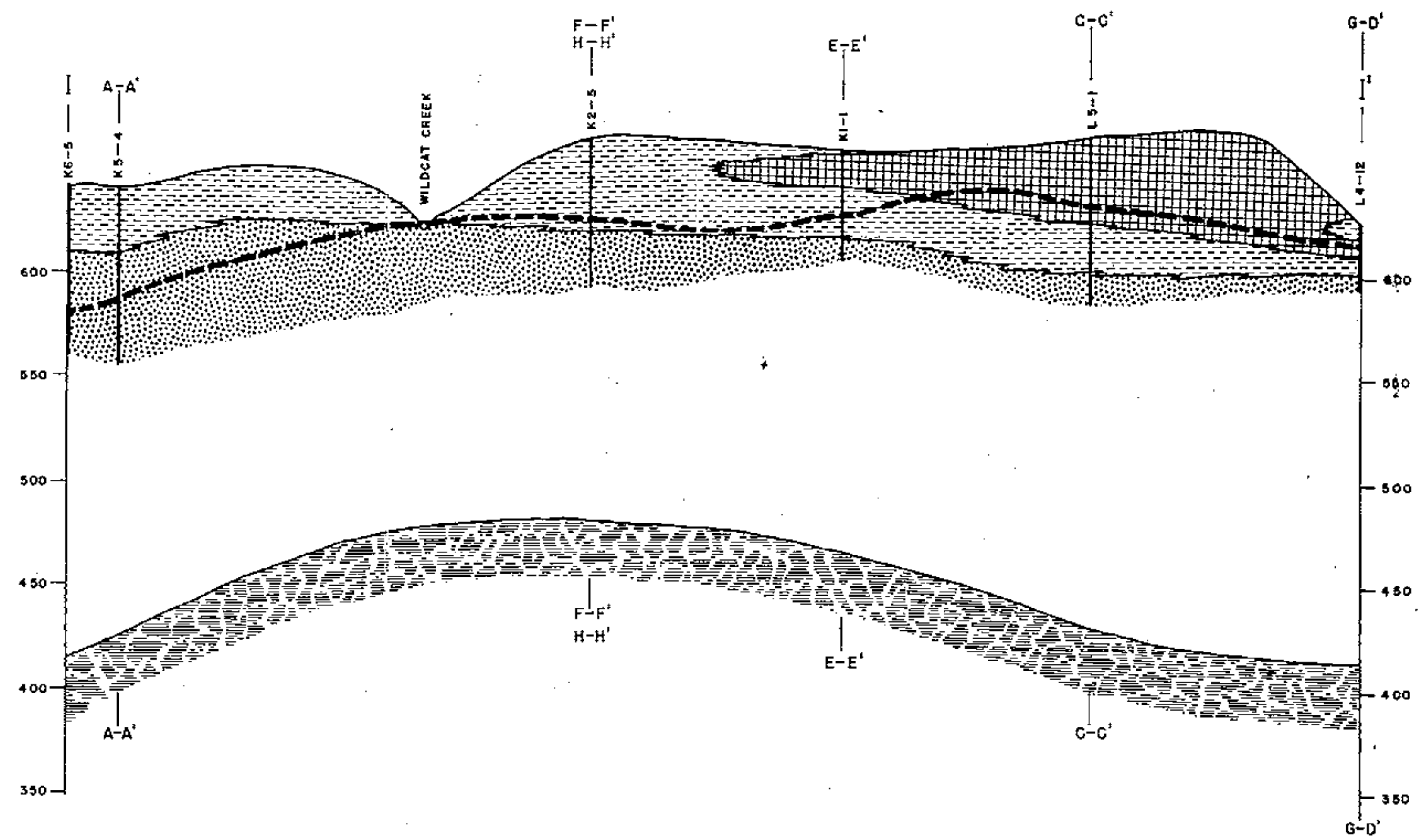
UNIT 1

UNIT 2

WATER SURFACE



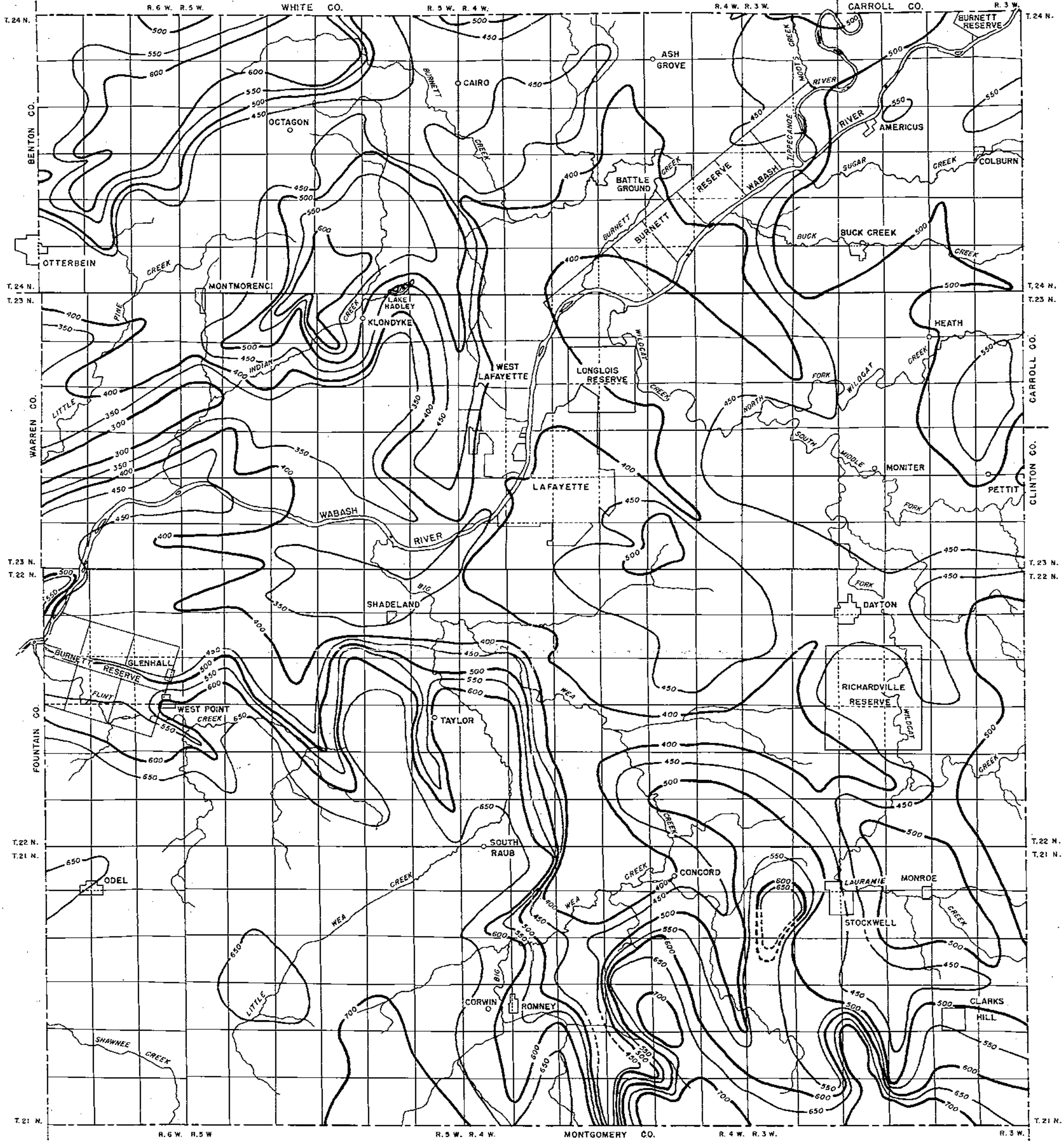




STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 10



BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY, BASE MAP OF TIPPECANOE COUNTY, INDIANA, MAY, 1952.

MAP OF
TIPPECANOE COUNTY, INDIANA
SHOWING
CONTOURS ON THE BEDROCK SURFACE

0 1 2 3 4 5 6 MILES
0 5000 10000 15000 20000 FEET

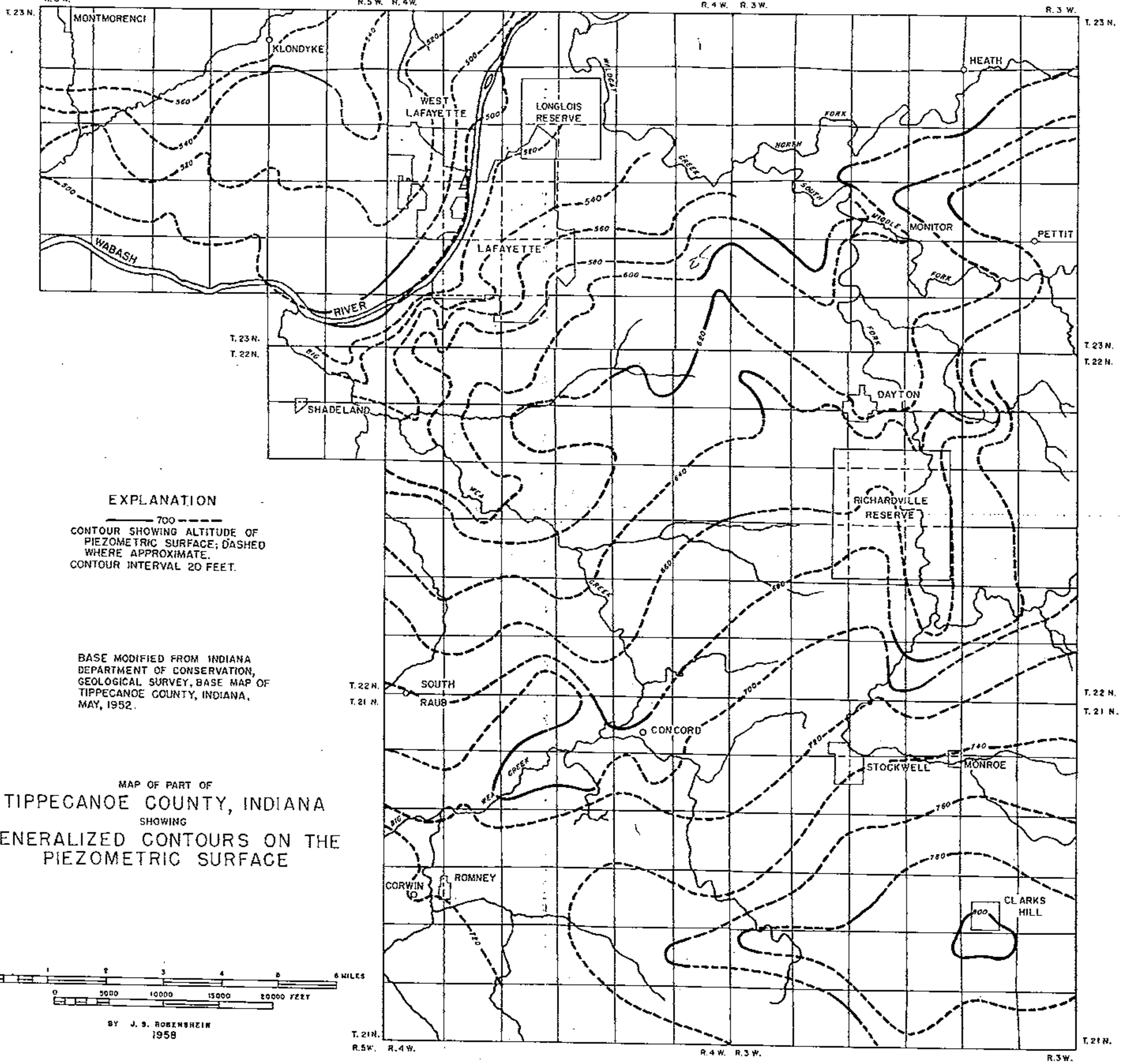
CONTOUR INTERVAL 50 FEET.
DATUM IS MEAN SEA LEVEL.
COMPILED BY J. S. ROSENSHEIN
1958

MAP COMPILED FROM SEISMIC DATA OBTAINED FROM THE INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY, AND SUBSURFACE GEOLOGIC DATA OBTAINED FROM DRILLERS' LOGS OF WELLS.

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

PREPARED BY THE
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE II



EXPLANATION

——— 700 – – – –
CONTOUR SHOWING ALTITUDE OF PIEZOMETRIC SURFACE; DASHED WHERE APPROXIMATE.
CONTOUR INTERVAL 20 FEET.

BASE MODIFIED FROM INDIANA DEPARTMENT OF CONSERVATION, GEOLOGICAL SURVEY, BASE MAP OF TIPPECANOE COUNTY, INDIANA, MAY, 1952.

MAP OF PART OF
TIPPECANOE COUNTY, INDIANA
SHOWING
GENERALIZED CONTOURS ON THE PIEZOMETRIC SURFACE

0 1 2 3 4 5 6 MILES
0 5000 10000 15000 20000 FEET

BY J. S. ROSENSHEIN
1958