HA-13

RECONNAISSANCE OF GROUND-WATER RESOURCES OF THE JACKSON PURCHASE REGION, KENTUCKY

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1962

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS ATLAS HA-13

Prepared in cooperation with the Department of Economic Development of Kentucky

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INTRODUCTION

SCOPE AND PURPOSE OF REPORT

Investigations of ground-water in Kentucky are being made by the U. S. Geological Survey in cooperation with the Kentucky Department of Economic Development, which, until July 1, 1956, was known as the Kentucky Agricultural and Industrial Development Board. The investigations are of three types:

1. Detailed studies of ground-water conditions in small areas with special problems or problems typical of larger areas.
2. Statewide inventory of large water supplies for public and industrial use.
3. Statewide reconnaissance studies of ground water.

This atlas is a result of an investigation of the third type and is 1 of a series of 5 which will cover the entire State. The chief purpose of this atlas is to present general information on the availability of ground water in the Jackson Purchase region of Kentucky.

LOCATION AND EXTENT OF AREA

The State of Kentucky lends itself readily to a regional division based on physiography and geology. These regions are: The Eastern Coal Field, the Blue Grass, the Mississippian Plateau, the Western Coal Field, and the Jackson Purchase. The locations of these 5 regions are shown on figure 1. The boundaries as shown there are drawn on county lines which approximate, though they do not coincide exactly with, the geologic and physiographic boundaries.

The Jackson Purchase region, eight counties in the extreme western part of the State, is bounded on the north by the Ohio River, on the west by the Ohio and Mississippi Rivers, on the south by the State of Tennessee, and on the east by Kentucky Lake. This tract of land was purchased from the Chickasaw Indians in 1818 and totals 2,396 square miles.

PREVIOUS INVESTIGATIONS

One of the earliest reports describing the geology of the Jackson Purchase is that of Loughridge (1888), which contains a geologic map showing the approximate boundaries of the outcrops of the rock formations in the region. A later report by Glenn (1906) describes both the geology and the water resources of western Kentucky, western Tennessee, and southern Illinois. The water-bearing characteristics of each formation and the ground-water conditions at many cities and small towns are described in some detail in Glenn's report. Davis (1923) described the geography of the Jackson Purchase and briefly mentioned the water resources of each of his geographic divisions within the Purchase.

A report by Roberts and Gildersleeve (1950) deals mainly with geology but also contains brief descriptions of the water-bearing characteristics of the formations. This report is probably the most comprehensive study of areal geology, structure, and mineral resources yet published on the Jackson Purchase.

The first detailed ground-water report on a part of the Purchase is that of Pree and Walker (1952) on the water resources of the Calvert City-Gilbertsville area. The large public and industrial water supplies are the subject of another report by Pree and Walker (1953). Pree, Walker, and MacCary (1957) have studied in detail the ground-water resources of three 7½-minute quadrangles in the Paducah area.

METHOD OF INVESTIGATION

The fieldwork on which this report is based was done by T. W. Lambert and L. M. MacCary during the period April to October 1954. Fieldwork included making an inventory of representative wells and springs and mapping the geology of small parts of the area. The data collected on wells include measurements of depth to water and, wherever possible, discharge and drawdown (lowering of water level due to pumping). Tests of specific capacity (rate of discharge per foot of drawdown) were made on several industrial, public-supply, and domestic wells. Samples of water from each aquifer were collected for chemical analysis. Samples of sand and clay were collected from several localities for mechanical (particle-size) analysis. Well logs and drill samples were examined to obtain information from which to draw isopach and structure maps of some of the formations.

The withdrawals from domestic wells were not determined by direct measurement but were estimated on the basis of the methods of obtaining and distributing the water. If water is obtained by a bucket or hand pump, each person will use less water than well be used where water is available under pressure at the tap. A modern domestic supply, as described in this report, in one which water is delivered to the home under pressure. The maximum daily requirement of such an installation is estimated to be about 500 gallons.

This report in large part is based on information furnished by well owners, operators, and drillers. Well logs were furnished by many drillers, and drill cuttings were furnished by Messrs. R. B. Elrod, Wayne Royster, and Don Taylor.

The investigation was made under the direct supervision of G. E. Hendrickson, district geologist, Louisville. Chemical analyses of water samples were made at the district Quality of Water Laboratory of the Geological Survey at Columbus, Ohio. Mechanical analyses of sediments were made at the Hydrologic Laboratory of the U. S. Geological Survey at Denver, Colo.

GEOGRAPHY

The Jackson Purchase is a plain of low relief bounded on the east by Kentucky Lake and on the north and west by flood plains of the Ohio and Mississippi Rivers. Steep bluffs occur where the uplands terminate along the Mississippi River flood plain.

The highest hills in the Purchase are along the Tennessee Valley divide south of Lynn Grove, Calloway County, and are 640 feet above sea level. The altitude is lowest, approximately 277 feet, on the flood plain of the Mississippi River in the detached part of Fulton County.

The Purchase is drained by the Mississippi River, either directly or by way of tributaries of which the Ohio River is the largest. The largest tributary of the Ohio draining a part of the region is the Tennessee River (Kentucky Lake).

CLIMATE

The Jackson Purchase has a humid continental climate, the average annual precipitation being 45.9 inches. The average January temperature is 37° F, and the average July temperature, is 80° F. The average growing season lasts 199 days. Figure 2 summarizes the climatological data for the period 1882 to 1955. Figure 3 shows precipitation for each month from 1950 through 1954, the period of record of the hydrographs of observation wells.

MINERAL RESOURCES

The chief mineral resources of the Jackson Purchase are clay, sand, gravel, and abundant ground water. Most of the high-grade clay is used for ceramic products and refractories, and the bulk of it comes from Graves County. Brick and field-tile clay is found in most of the Purchase. Some of the inferior grades are mixed with better grades in the manufacture of ornamented pottery.

Pliocene(?) sand and gravel deposits have great extent and furnish much of the so-called bank gravel used in surfacing rural roads. Molding and building sands are dredged from the beds of the Ohio, Tennessee, and Mississippi Rivers.

In the past, Pleistocene loess was used in the manufacture of brick at Paducah, Mayfield, and Fulton.

GEOLOGY

The rocks exposed in the Jackson Purchase range in age from Devonian to Recent. Most of the area is underlain by strata of sand, clay, and gravel of Tertiary age. The eastern part of the area is underlain by Cretaceous sand, clay, and gravel and Paleozoic limestone and chert. The rocks are described in order from oldest to youngest. The outcrop areas of the various rock units are shown on figures 4 and 5; cross sections of the geologic units are given in figures 6-9.

STRATIGRAPHY

PALEOZOIC

The oldest rocks exposed in the Purchase are of Devonian age and are found in a fault zone along Little Bear Creek in Marshall County. The Camden chert and the Jeffersonville limestone are exposed for about a quarter of a mile along the embayment that leads from the creek into Kentucky Lake. These formations, described by Luttrell and Livesay (1952), have only a small area of outcrop and are of little significance to the ground-water hydrology of the region.

The Fort Payne chert of Mississippian age crops out in a narrow area along the west shore of Kentucky Lake from the Blood River northward to within 3 miles of Kentucky Dam. It is 515 feet thick in a drill hole at the dam and 300 feet thick at Eggners Ferry to the south. The Fort Payne in this region is typically a dark bluish-gray nonfossiliferous limestone containing dark-blue to black banded chert. Some weathered sections consist of bleached chert with thin beds of clay or tripolite.

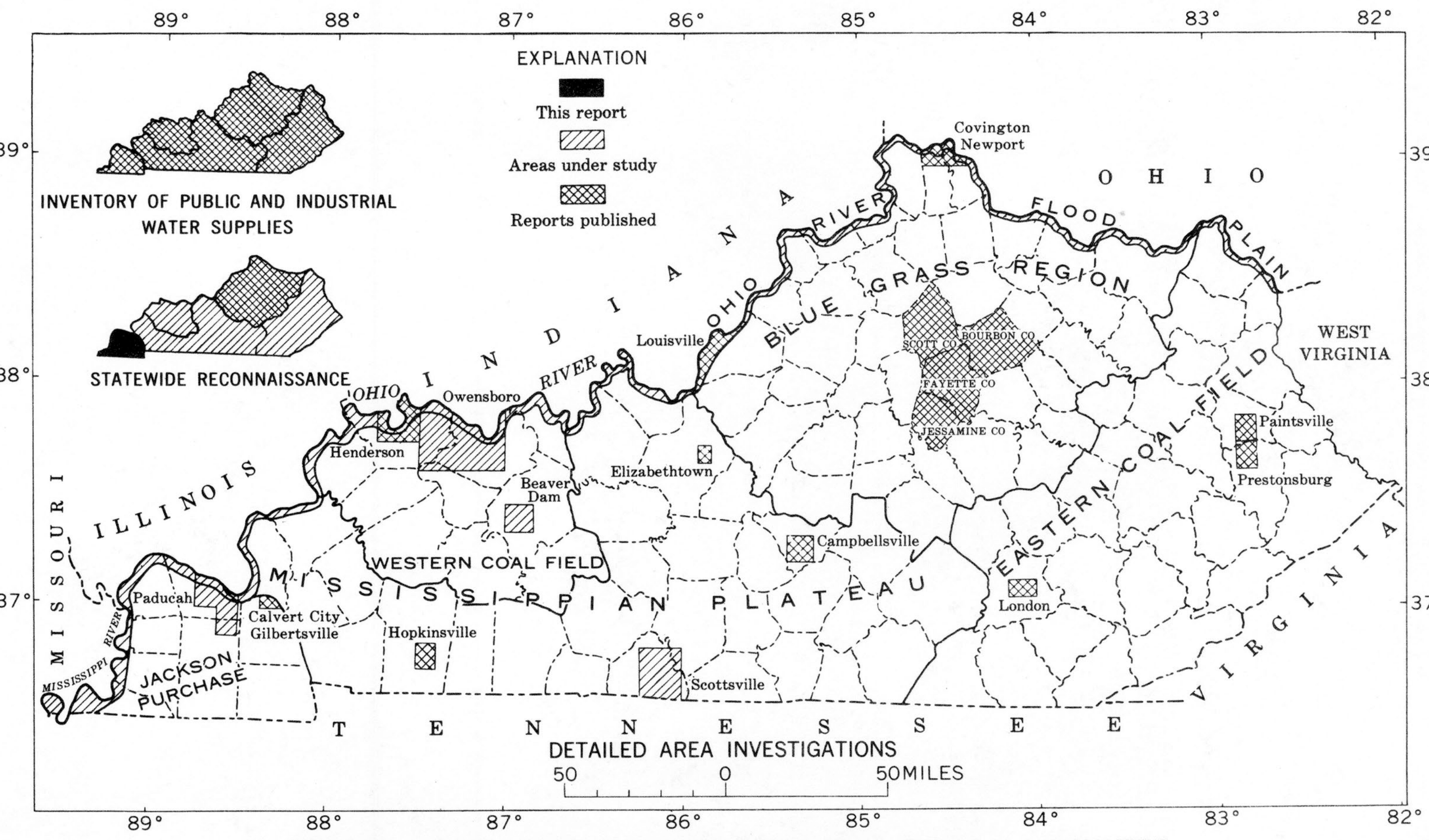


FIGURE 1—INDEX MAP SHOWING PROGRESS OF GROUND-WATER INVESTIGATIONS IN KENTUCKY

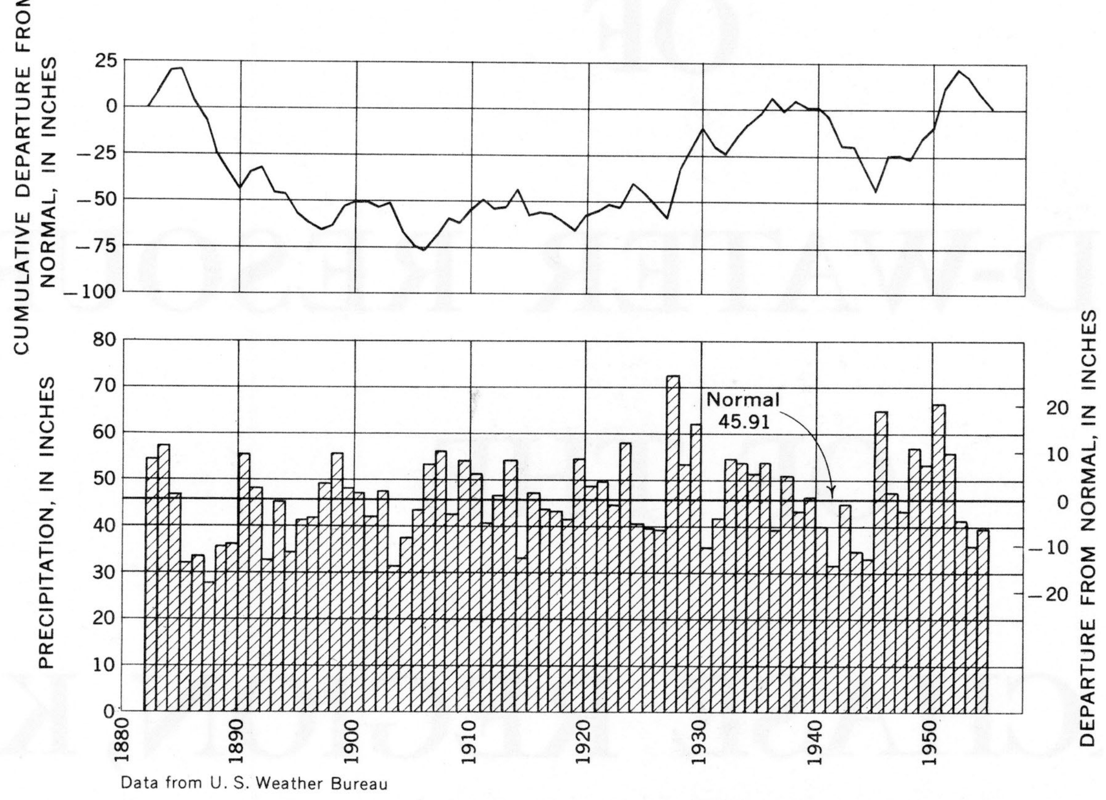


FIGURE 2—ANNUAL PRECIPITATION AND CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION AT PADUCAH, KENTUCKY

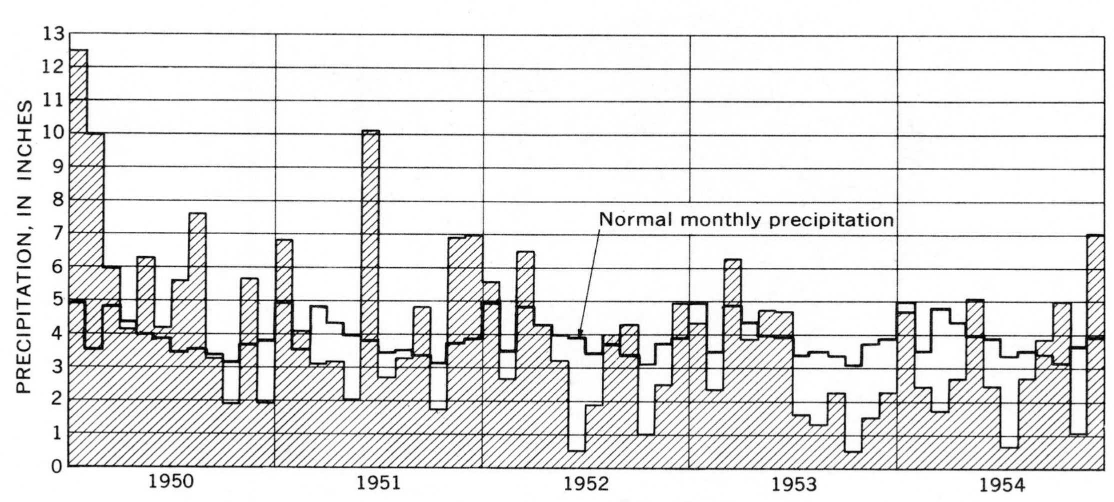


FIGURE 3—PRECIPITATION AT PADUCAH, KENTUCKY, 1950-54

The Fort Payne chert yields water to some wells along Kentucky Lake. The well at Kentucky Lake State Park produces approximately 60 gpm (gallons per minute) from this formation. The water is probably transmitted mainly through fractures in the chert.

The Warsaw limestone, also of Mississippian age, crops out at a few localities along Kentucky Lake. A good exposure on the west side of the lake is a few hundred feet south of the foot of the old road to the abandoned village of Birmingham. The Warsaw at this exposure is a gray crystalline fossiliferous limestone containing thin beds of chert. The limestone weathers to a nearly white honeycombed surface. Only a few feet of the formation is exposed above the high water level of Kentucky Lake.

A few wells along Bear Creek in Marshall County produce water from the Warsaw limestone. Fractures in the limestone are enlarged by solution adjacent to exposures, and the ground water is transmitted through these openings.

The St. Louis limestone of Mississippian age crops out in a few places west of Kentucky Lake. There is one exposure of dark-gray limestone and nodules of chert in a road cut near Kentucky Dam Village State Park. The St. Louis is a medium- to thick-bedded semilithographic dark-gray to black limestone containing thick beds of yellowish chert. The St. Louis underlies the area from Kentucky Dam to Calvert City and supplies water to wells drilled into it.

Mississippian rocks of Chester age probably underlie part of the Jackson Purchase near Paducah. The Tar Springs sandstone is exposed on the north bank of the Tennessee River about 7 miles upstream form Paducah, outside the Purchase. Rocks of Chester age have been reported in an oil test hole drilled in Paducah. These rocks probably are of minor importance as a source of ground water.

CRETACEOUS

The Tuscaloosa formation is the oldest Cretaceous deposit in western Kentucky. It is best exposed along Kentucky Lake in Marshall County. There is one small exposure on the shore of the lake at Hickory Point, and others are present near the tops of the ridges between Bear Creek and the lake. The Tuscaloosa is as much as 200 feet thick at Golden Pond in Trigg County, but probably less than 30 feet is exposed west of Kentucky Lake.

The Tuscaloosa is composed of well-rounded chert gravel in a matrix of sand and some clay. The particles of gravel range from ¼ inch to 10 inches in diameter and average 1½ inches. Marine fossils reworked from Paleozoic rocks are found in the Tuscaloosa.

The Tuscaloosa yields a small amount of water to wells in Marshall County. Yields are generally low owing to the presence of a clayey matrix.

Investigations by Moneymaker and Grant (1954) indicate that much of the basal Cretaceous gravel in the Purchase is younger than the Tuscaloosa. This later gravel is probably of late Selma or early Ripley age.

The Ripley formation, which overlies the Tuscaloosa, is exposed in Calloway and Marshall Counties, where it crops out in a belt paralleling Kentucky Lake. The Ripley in outcrop is nowhere more than 70 feet thick and in most exposures is 20 to 30 feet thick. The formation is covered by a thick mantle of Pliocene(?) gravel and Quaternary alluvium in McCracken and Ballard Counties. As much as 400 feet of Ripley has been penetrated in oil test holes drilled in the Jackson Purchase.

The Ripley formation is typically unconsolidated sand and interbedded clay but contains many thin beds of sand and clay cemented with iron oxide. The sand may be white, buff, yellow, or red, and the clay may range from white to dark gray. Marcasite concretions occur in the clay, and in some places leaf prints are found. In many exposures the sand is feldspathic and contains much white mica. In much of Marshall, McCracken, and Ballard Counties the Ripley is mostly clay and silt, but thin beds of sand are present near the base.

Where the Ripley is composed mostly of unindurated sand, it yields large quantities of water to wells. In areas where the Ripley is composed mostly of clay and silt, it may yield practically no water.

TERTIARY

Paleocene.—The Porters Creek clay of Paleocene age is exposed in a narrow arcuate belt extending from the Tennessee line northward through Calloway County and then northwestward across Marshall and McCracken Counties. There are no exposures in Ballard County because thick deposits of gravel of Pliocene(?) age and river alluvium cover the Porters Creek clay. The clay is 140 to 160 feet thick in the eastern half of the Jackson Purchase and thickens to 350 feet in the west. Most exposures reveal no more than 40 feet of the clay. The Porters Creek is a light- to slate-gray clay of very fine texture containing thin beds of mica flakes and very fine sand between laminae of clay. It is slippery when wet and dries into rectangular blocks.

In many exposures the Porters Creek clay is cut by random dikes of sand and sandstone as much as 2 feet wide and 50 feet long. In some places the thin beds of sand and the dikes contain a few casts of marine gastropods and pelecypods.

The Porters Creek clay probably will yield a little water from beds and dikes of sand and perhaps will yield some from joints. Ground-water circulation in the formation is poor, and the water may be hard and high in iron content.

Eocene.—Sand and clay of Eocene age underlie most of the Purchase west and south of the outcrops of the Porters Creek clay. There are few exposures of the Eocene deposits, owing to the presence of a mantle of gravel of Pliocene(?) age and loess of Pleistocene age over most of the western counties. As much as 30 feet of Eocene deposits is exposed in roadcuts and gullies. The Eocene deposits have a maximum thickness of 700 feet in oil test holes in Fulton County. They are composed of sand and include some layers indurated by iron oxide cement, clay, and a basal clayey conglomerate. The sand is fine to coarse and is composed chiefly of rounded quartz grains; feldspar, mica, and iron oxide also are present. Large lenses and beds of clay are mined at several localities. The clay may be white, yellow, gray, or dark brown and in places contains coarser material that gives it a gritty texture. White-burning clay is mined and shipped to manufactures of ceramics. Lignite is usually present in the clay, and concretions of marcasite are common.

The sand and clay of the Eocene interfinger in such a manner that a sand bed in one exposure may be correlative with a clay bed a few hundred feet away. The vertical and lateral ranges in lithology in the Eocene deposits make it difficult to predict the depth to productive aquifers. In many areas a productive sand lies in the uppermost 300 feet of the deposits, but in some places the shallow zones will not yield sufficient water for large users. A shallow aquifer at Fulton will yield as much as several hundred gallons per minute to individual tubular wells, but municipal and industrial wells are drilled to 600 feet to obtain larger amounts of water.

Pliocene(?).—Much of the upland surface of the Jackson Purchase is covered by a mantle of gravel and sand of Pliocene(?) age. The maximum thickness of the Pliocene(?) deposits is probably more than 50 feet, and the average is about 25 feet. The gravel consists mostly of subangular to rounded particles of chert, but some pebbles are quartzite. Many of the pebbles are 2 to 3 inches in diameter, but most are between ½ and 1 inch. The sand is medium to coarse grained and is composed of quartz and chert and some feldspar and hornblende. The sand may occur as a matrix in gravel or as separate layers. In many places, pebbles and sand grains are both stained and cemented together by iron oxide.

The gravel of Pliocene(?) age yields water to many shallow wells in the Jackson Purchase. The water moves chiefly through the unconsolidated sand and gravel. In many places it is perched or semiperched by beds of clay or indurated sand and gravel.

QUATERNARY

Pleistocene loess.—Thick deposits of loess occur along the Mississippi River bluffs in the Purchase. These deposits are approximately 40 feet thick on the bluffs and thin gradually away from the river. The loess is less than 10 feet thick in most of Graves County and gradually merge with a loamy soil in Calloway County. Along the Ohio River in McCracken County the loess reaches a maximum thickness of 20 to 25 feet. The loess is composed of angular silt-sized particles of quartz and small amounts of feldspar and mica. Calcareous concretions and small pebbles are common in some of the deposits of loess. The loess has vertical jointing which is responsible for the steep to vertical slopes in exposures along the river bluffs and in road cuts.

The loess is of little importance as an aquifer as it is fine grained and compact. The presence of mollusk shells and calcareous concretions may explain the high bicarbonate content of water from aquifers that lie beneath the loess.

Pleistocene and Recent alluvium.—Extensive deposits of gravel, sand, and clay occur along the flood plains of the Tennessee, Ohio, and Mississippi Rivers. Approximately 80 feet of alluvium was penetrated in the valley of the Tennessee River near Kentucky Dam, and bridge borings near Paducah penetrated 100 feet of alluvium in the Ohio River flood plain. The thickness of alluvium along the Mississippi River probably is more than 100 feet. Except for thin beds of fine sand and layers of mud along the river banks, there are few good exposures of alluvial deposits in the Purchase. Along the large rivers the alluvium ranges from coarse gravel to clay, but along the small streams it is mostly fine sand, silt, and clay.

As much as 300 gpm is pumped from single wells penetrating alluvial deposits in Ballard County, and many small domestic supplies come from the alluvium in Fulton County. The alluvium in the small stream valleys is fine grained and clayey, and wells penetrating it have small yields.

STRUCTURE

The Jackson Purchase lies in the extreme northeastern part of the Mississippi embayment. Structurally the embayment is a downwarped trough (geosyncline) of Paleozoic rocks which has been filled with Cretaceous and younger sediments. The Cretaceous and the overlying Tertiary strata deposited in the embayment become progressively thicker to the southwest. The outer rim of the embayment is delineated by outcrops of Paleozoic rocks. Dips in the Cretaceous, Paleocene, and Eocene beds are 20 to 30 feet per mile to the south and west. There is no observable dip in the Pliocene(?) and Quaternary deposits.

There is evidence that faulting similar to that exposed in the Kentucky fluorspar area has displaced the Paleozoic bedrocks beneath the Purchase. With more detailed information, some of the peculiar features delineated on the structure map on the base of the Cretaceous (top of the Paleozoic) might be shown to be due to faulting. Faulting and other structural features of the area are discussed by Freeman (1950, 1951, 1953).

GEOLOGIC HISTORY

During the Paleozoic era, most of the interior of North America was covered by a vast changing sea. Sediments were deposited in geosynclines and embayments during times of flooding by the sea and were eroded when the sea receded. These transgressions and regressions of the sea throughout the Paleozoic resulted in deposition of alternating limestone, sandstone, and shale.

Formation of the Mississippi embayment began during the Cretaceous period with a downwarping of the Paleozoic surface, which allowed the sea to move northward. Coarse sand and gravel were deposited near the shores of the embayment; finer sediments were carried offshore and deposited as beds of silt and clay. At even greater distances from the shore, limestone was formed. Toward the close of the Cretaceous the sea began to recede and became very shallow, so that most of the deposited material was exposed to wave action, which produced crossbedding in the Ripley formation.

During the Paleocene epoch the sea began to encroach upon the land again, and glauconitic sand was deposited in the Mississippi embayment. The sea continued to deepen, and fine-textured marine clay of the Midway group was deposited. At the close of Midway time the sea receded and estuarine and littoral conditions prevailed. The sandbeds and clay lenses of the Eocene series were deposited at this time. By the end of Eocene time the region was dry land and subject to erosion; however, it was not reduced to a peneplain. During the Pliocene epoch the somewhat irregular erosion surface was lowered slightly, and heavily laden streams deposited sand and gravel as they made their way to the sea. Probably most of the irregularities in the pre-Pliocene surface were covered by this sand and gravel.

In the Pleistocene epoch the northern part of North America was covered by vast continental ice sheets. As the glaciers melted, large amounts of sand, gravel, and rock debris were carried down the rivers and deposited as alluvium. Some of the material was reworked by water and wind, the latter carrying silt to form loess along the Mississippi and Ohio Rivers.

GROUND WATER

HYDROLOGIC CYCLE

Most water of economic importance in the Jackson Purchase region comes from local precipitation and from rivers flowing through the region. Rainfall or snowmelt soaks into the ground until the soil reaches field capacity. After the soil reaches field capacity, or even before when the rate of rainfall or snowmelt exceeds the infiltration capacity of the soil, water runs off over the surface to streams or ponds. Part of the water that enters the soil is evaporated directly, part is held by capillary forces until transpired by plants, and still another part—water entering the soil in excess of field capacity—seeps downward to be added to the ground-water body. The water in the ground-water body slowly seeps toward points of lower elevation, and eventually it discharges through springs or seeps into streams or is transpired by vegetation along the streams. The seepage and spring flow are the source of most of the base flow of streams during dry weather. The hydrologic cycle is extremely complicated and is affected and controlled by precipitation, temperature, nature of the soil, topography, plant cover, and geology.

If no net change occurs from 1 year to the next in the amount of water stored underground (ground water plus soil water), and if no underground flow bypasses the streams, the amount of stream runoff plus the amount of water lost by evapotranspiration is equal to the annual precipitation in a given area. In the Jackson Purchase region the annual rainfall is about 46 inches, and the average annual runoff is about 17 inches. Therefore, the average annual loss of water by evaporation and transpiration appears to be about 29 inches, or 63 percent of the average precipitation. Actually, some water moves down the dip in the Coastal Plain strata and bypasses the streams of the Jackson Purchase, so that the evapotranspiration from the Purchase is less than 29 inches. How much less is not known, but the ground-water outflow from the region, though large on an absolute scale, probably is not large enough to reduce the figure of 29 inches by any large amount.

FIGURE 4—GEOLOGIC MAP OF JACKSON PURCHASE REGION, KENTUCKY, PLIOCENE TO RECENT

SCALE 1:250 000

4 2 0 4 8 12 16 20 MILES

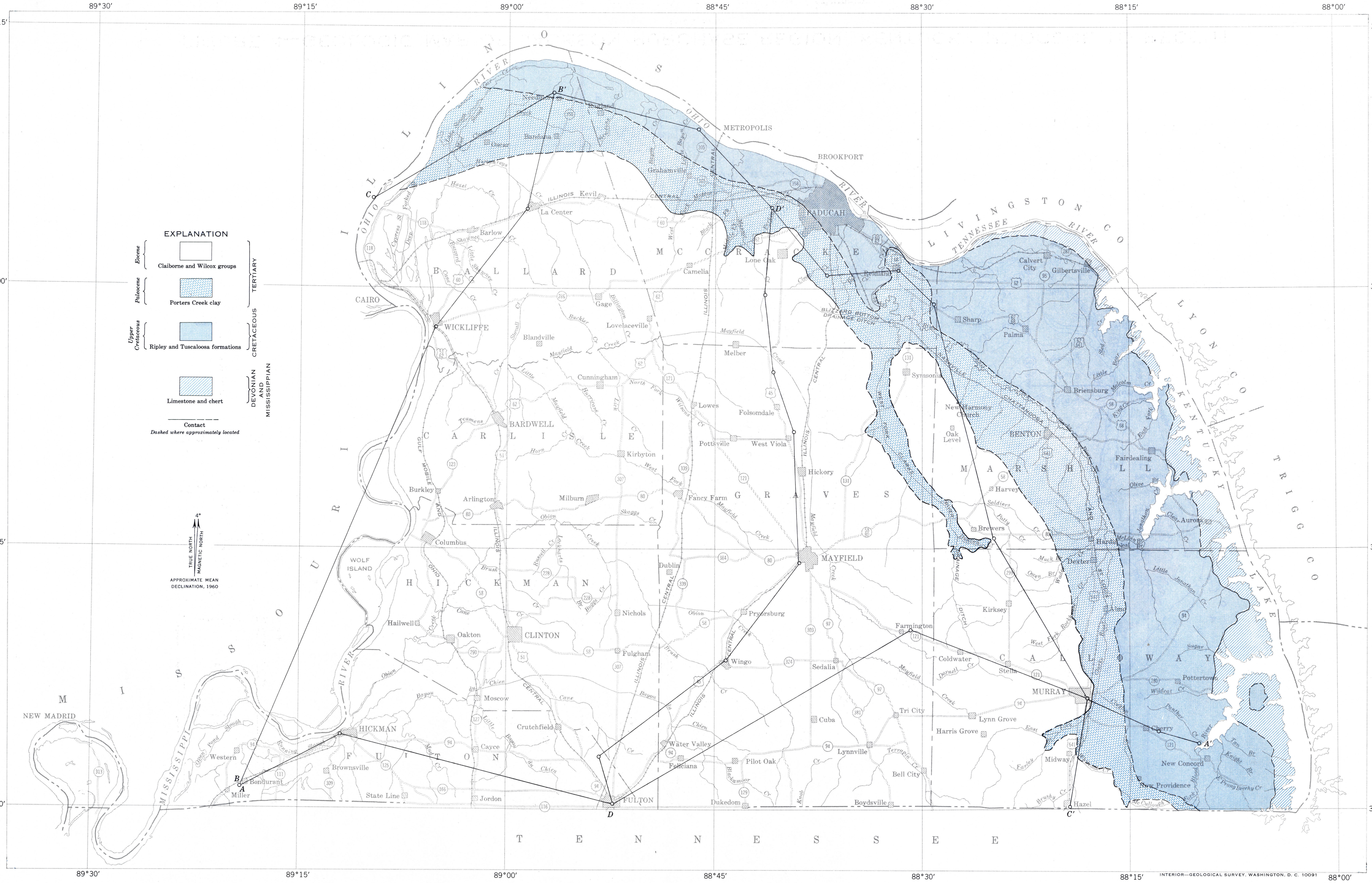


FIGURE 5—GEOLOGIC MAP OF JACKSON PURCHASE REGION, KENTUCKY, PALEOZOIC TO EOCENE

SCALE 1:250 000

4 2 0 4 8 12 16 20 MILES

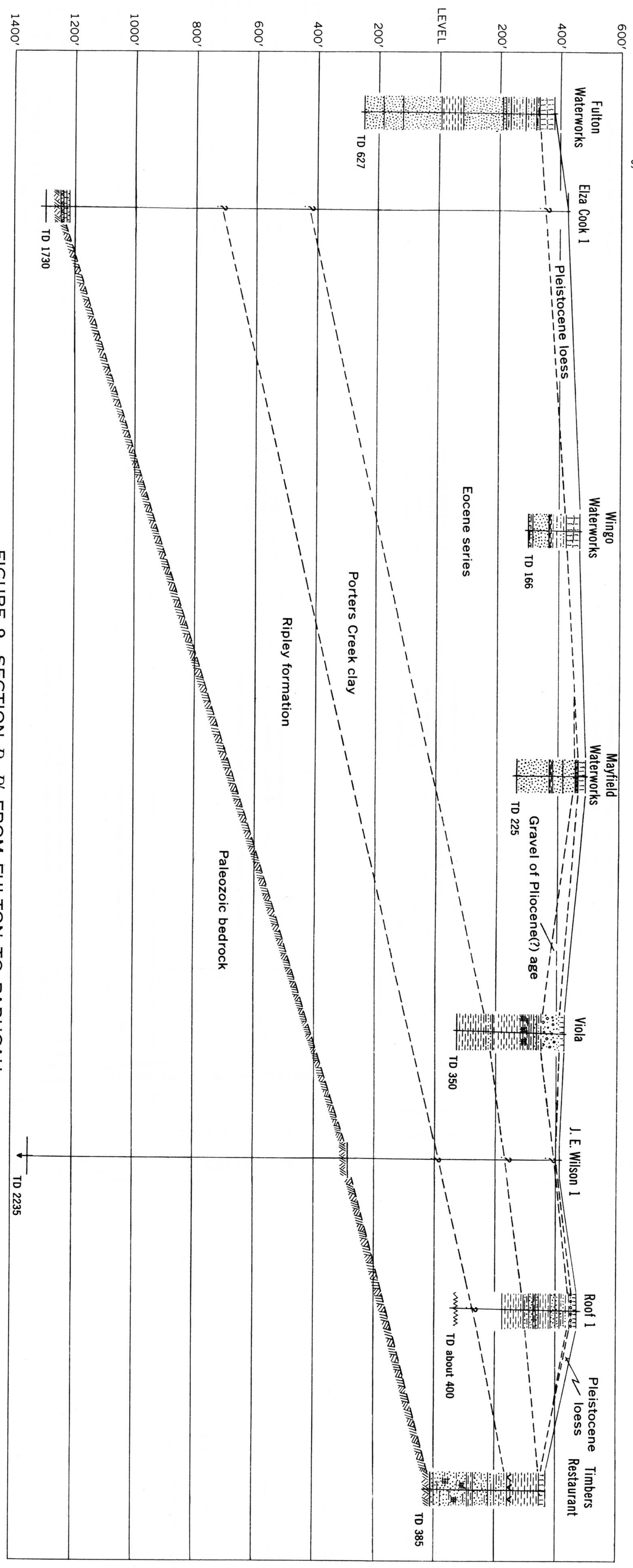


FIGURE 9—SECTION *D–D′* FROM FULTON TO PADUCAH

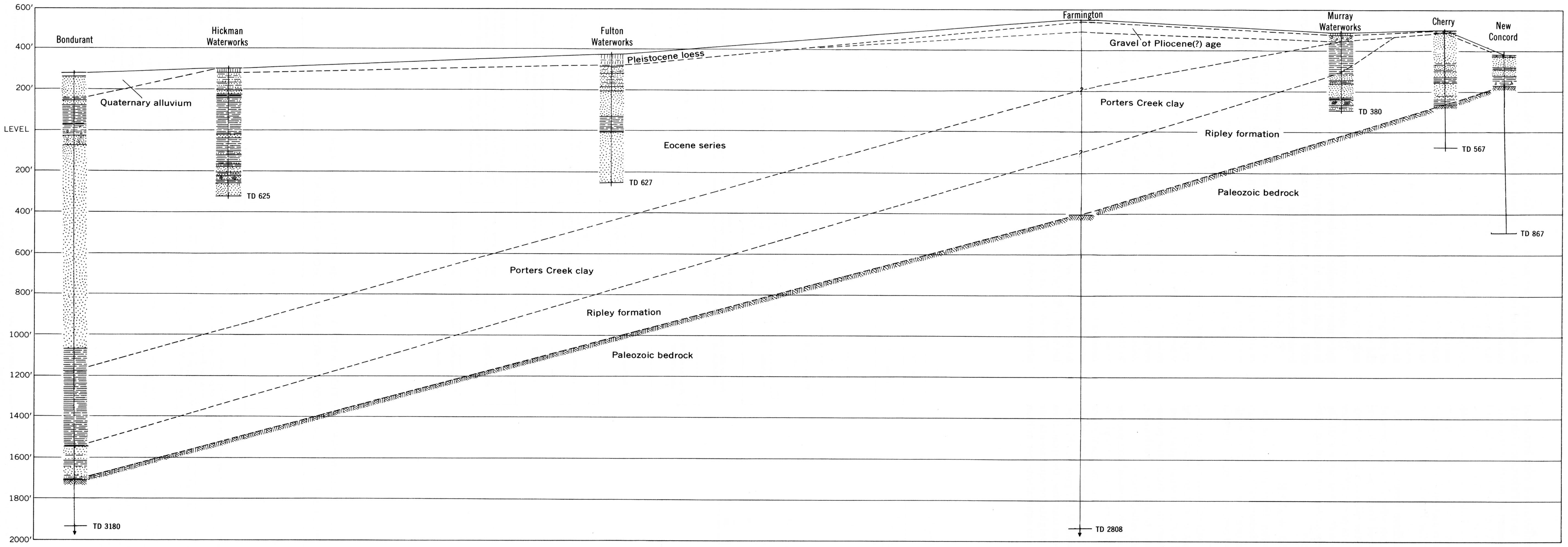


FIGURE 6—SECTION *A–A′* FROM BONDURANT TO NEW CONCORD

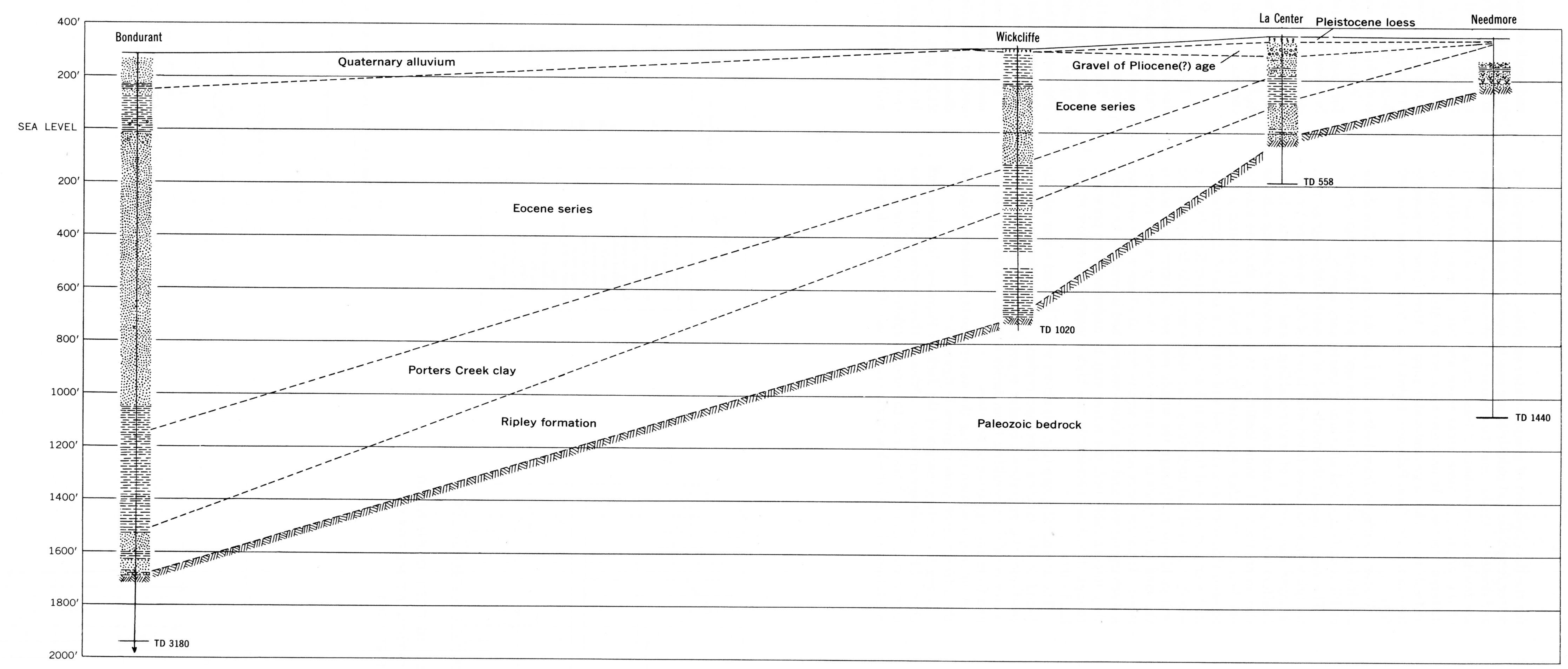


FIGURE 7—SECTION *B–B′* FROM BONDURANT TO NEEDMORE

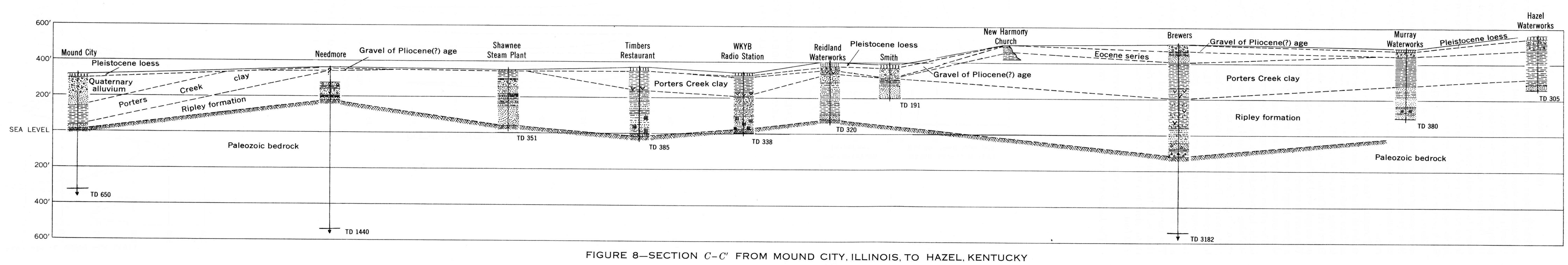
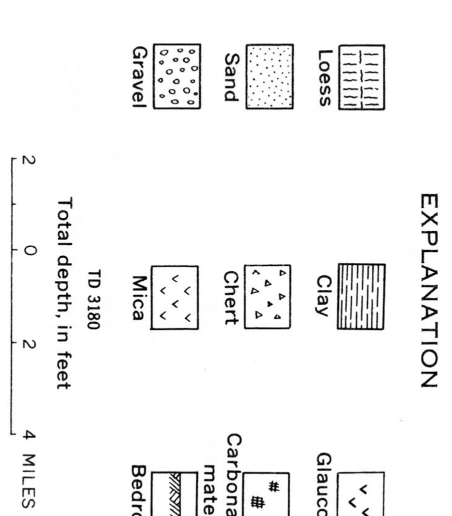


FIGURE 8—SECTION *C–C′* FROM MOUND CITY, ILLINOIS, TO HAZEL, KENTUCKY



FLUCTUATION OF WATER LEVELS

The amount of water stored in the ground-water reservoirs is indicated by water levels in wells and may change for several reasons. Usually the fluctuation in water level is caused by changes in nearby pumping and in local precipitation. In some instances the cause of the fluctuation may not be immediately apparent and can be attributed to a combination of factors. Minor fluctuations of water levels may be caused by changes in barometric pressure or in other loads applied to the aquifer, or by earthquakes and earth tides. Such minor fluctuations do not indicate changes in storage.

Many of the shallow wells in the Purchase show a rise in water level soon after heavy local rains. The hydrograph of one well near New Providence, Calloway County (fig. 10), shows two periods when the water level rose about 1½ feet within a few days after heavy rains.

Pumping from a well will produce a cone of depression in the water table or in the analogous piezometric (pressure-head-indicating) surface of an artesian aquifer, which is observed in nearby wells as a lowering of water level. The water level in an observation well at Bardwell, Carlisle County is lowered about 5 feet when the municipal supply well 52 feet away is pumped at a rate of 178 gpm (fig. 11). The area in which water levels are lowered as a result of pumping for a given length of time is much greater under artesian conditions than under water-table conditions.

The effect of river stage on the water level in an aquifer is shown in the hydrograph of an observation well at the Ashland Oil and Refining Co. near Reidland in McCracken County. The water level in this well fluctuates with the stage of the Tennessee River, 500 feet away. The rise is attributed to loading of the artesian aquifer by increase in river stage. (See fig. 12.)

Changes in atmospheric pressure cause water-level fluctuations in artesian wells. Figure 13 shows the water-level fluctuations in a well near Lone Oak produced by changes in atmospheric pressure. The barometric efficiency of this well is approximately 73 percent—that is, if the atmospheric pressure rises by 0.88 inch of mercury (equivalent to 1.00 foot of water), the water level in the well declines 0.73 foot.

GENERAL GROUND-WATER CONDITIONS

The Jackson Purchase is the most favorable region in Kentucky for the development of ground-water supplies. Large supplies of water for public and industrial use can be obtained at many places, and domestic supplies may be obtained at almost any place. There are few localities without at least one good aquifer within 500 feet of the surface; in some areas there are two or more aquifers at different depths. In only one area, central McCracken County, is difficult to develop a ground-water supply. Here it may be possible to obtain water from Paleozoic bedrock at a depth greater than 500 feet.

Water is pumped from bedrock of Paleozoic age, the Tuscaloosa and Ripley formations of Cretaceous age, sands of Eocene age, gravel of Pliocene(?) age, and alluvium of Quaternary age.

The region lies at the north end of a southward-plunging rock trough which has been filled with layers of clay, sand, and gravel. A layer may consist of water-yielding sand (that it, may be an aquifer) in one place and may consist of non-water-yielding silt and clay in another. In some localities, two or more aquifers may lie one beneath the other, separated by clay beds. In general, a bed of sand that overlies a clay bed will contain a zone of saturation in its lower part and will furnish at least enough water for a domestic supply. A sand bed underlying clay also is generally saturated and will yield water, although the supply may not be permanent unless the sand bed extends to an outcrop where the water can be replenished. If the recharge area of an aquifer is at a higher altitude than a discharging well and the water-bearing bed is overlain by a relatiely impermeable bed, the water may be under artesian pressure, though it will not necessarily rise high enough to overflow at the land surface.

The availability map (fig. 14) shows where ground water may be found in the Jackson Purchase region. In addition to general conditions this map shows, insofar as possible, the range in ground-water conditions resulting from facies changes within formations and from superposition of aquifers.

A columnar section listing the water-bearing characteristics of the different rock units is given in figure 15.

Along the eastern margin of the Jackson Purchase, limestone and chert of Paleozoic age crop out. Although these bedrock formations do not yield as much water as the unconsolidated formations to the west, they will yield fresh water in quantities sufficient for domestic and small commercial supplies. Water mineralized with brine and hydrogen sulfide is relatively uncommon in the Paleozoic bedrock in the Jackson Purchase, although it is present at depth in the bedrock in many other parts of Kentucky. An oil test hole in Ballard County is reported to have found fresh water in Ordivician limestone at a depth of 3,000 feet. Other oil test holes have found fresh water at shallower depths in the Paleozoic rocks elsewhere in the Purchase. It is likely that ground-water circulation extends to great depths in the consolidated rocks beneath the Purchase, at least for some distance west of the outcrops.

Water from wells and springs in the Jackson Purchase is suitable for domestic and most industrial uses; iron which may be present in objectionable concentrations is removed from most public and industrial water supplies. A few wells in the alluvium have a hardness (as $CaCO_3$) in excess of 400 ppm (parts per million), but water from the other aquifers is comparatively soft. Descriptions of the quality of water in each aquifer are given under the heading "Occurrence of ground water in geologic units."

QUALITY OF GROUND WATER

The general chemical character of water from aquifers in the Jackson Purchase is shown in table 1. Median rather than mean values of the amounts of dissolved constituents are shown, to minimize the effect of samples having unusual concentrations of certain constituents.

The principal ionic constituents in most natural waters are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate. Fluoride also occurs in ground water in small quantities. The metallic (basic) ions—calcium, magnesium, sodium, and potassium—are called cations. The acidic ions—bicarbonate, carbonate, sulfate, chloride, nitrate, and fluoride—are called anions.

The cations and anions will combine to form chemical compounds such as sodium chloride; conversely, salts, bases, and acids will dissociate in solution into their component ions. This combination or dissocation does not take place unit for unit by weight; for example, 22.991 ppm of sodium combines exactly with 35.457 ppm of chloride. In order to show how the anions and cations combine, the quantities can be expressed in chemical combining weights, or equivalents per million. Parts per million are converted to equivalents per million by dividing the parts per million by the combining or equivalent weight of the ion. Thus, a unit equivalent of the cation sodium combines exactly with a unit equivalent of the anion chloride to form the compound sodium chloride.

The hydrogen-ion concentrations, expressed as the pH (log of the reciprocal of the hydrogen-ion concentration, in moles per liter), is useful in indicating the corrosive tendencies of water. The pH scale ranges from 0 to 14; at a pH of 7, the midpoint of the scale, there are equal numbers of hydrogen and hydroxyl ions, and the water is said to be neutral. Values of pH smaller than 7 denote more hydrogen than hydroxyl ions, and the water is said to be acid; values of pH greater than 7 denote more hydroxyl than hydrogen ions, and the water is said to be alkaline. Acid solutions, generally, are more corrosive to metals than alkaline solutions.

The specific conductance of water is a measure of the ability of the water to conduct an electric current. The conductivity of water is related to the kind and amout of ionized substances in the water and is, therefore, a convenient means of indicating changes in concentrations of dissolved solids.

The dissolved-solids content represents the quantity of substances in solution, though the values reported may include some organic matter and water of crystallization. The U.S. Public Health Service recommends that the dissolved solids in a potable water supply preferably should not exceed 500 ppm, but 1,000 ppm is permitted if water of better quality is not available.

Hard water is usually recognized by the large amount of soap required to produce lather and by the deposit of insoluble salts formed when the water is heated. Hardness is due chiefly to the salts of calcium and magnesium, although aluminum, iron, manganese, and certain other metallic ions and free acid can contribute to the hardness. The hardness caused by calcium and magnesium equivalent to the bicarbonate and carbonate in a water is called carbonate hardness. The hardness caused by other compounds of calcium and magnesium is called noncarbonate hardness. The Geological Survey considers water having a hardness in the range from 0 to 60 ppm to be soft; that between 60 and 120 ppm, moderately hard; that between 120 and 200 ppm, hard; and that above 200 ppm, very hard.

The source and significance of the more common dissolved constituents in ground water are given in table 2.

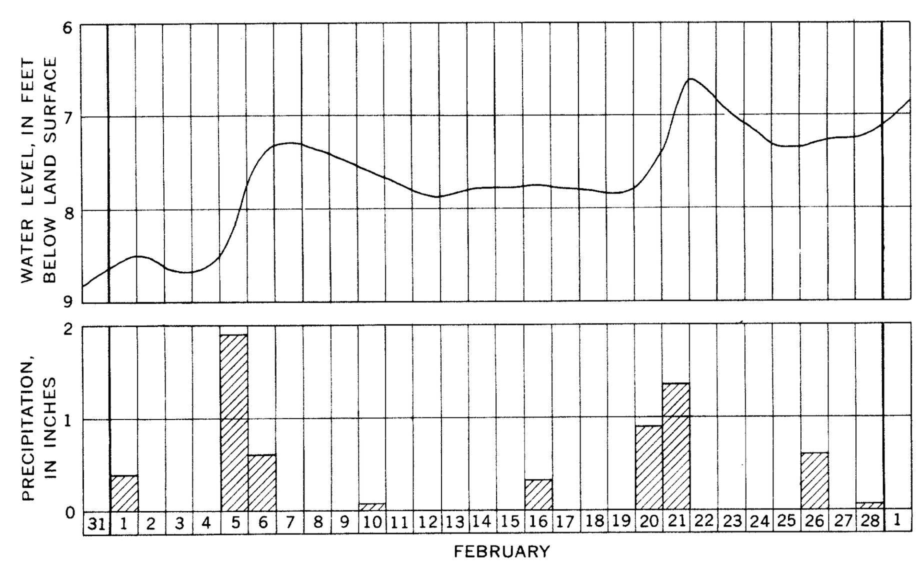


FIGURE 10—HYDROGRAPH OF A WELL 16 FEET DEEP NEAR NEW PROVIDENCE, AND PRECIPITATION AT MURRAY, CALLOWAY COUNTY, KENTUCKY

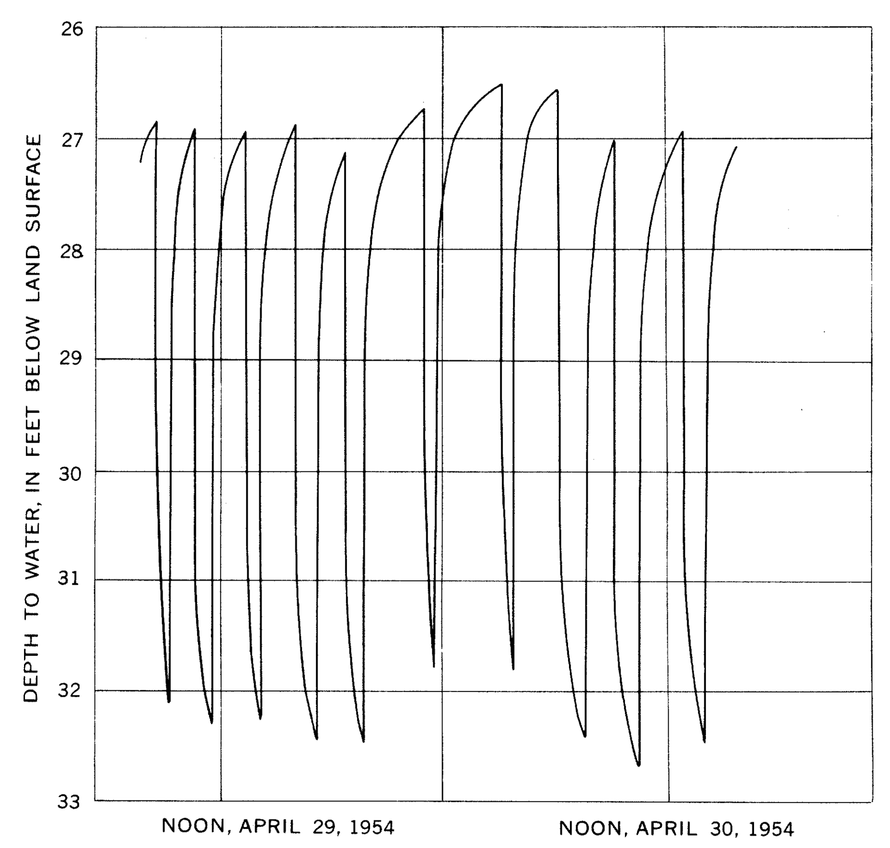


FIGURE 11—HYDROGRAPH OF A WELL 105 FEET DEEP, SHOWING FLUCTUATIONS CAUSED BY INTERMITTENTLY PUMPING 178 GPM FROM A WELL 52 FEET AWAY

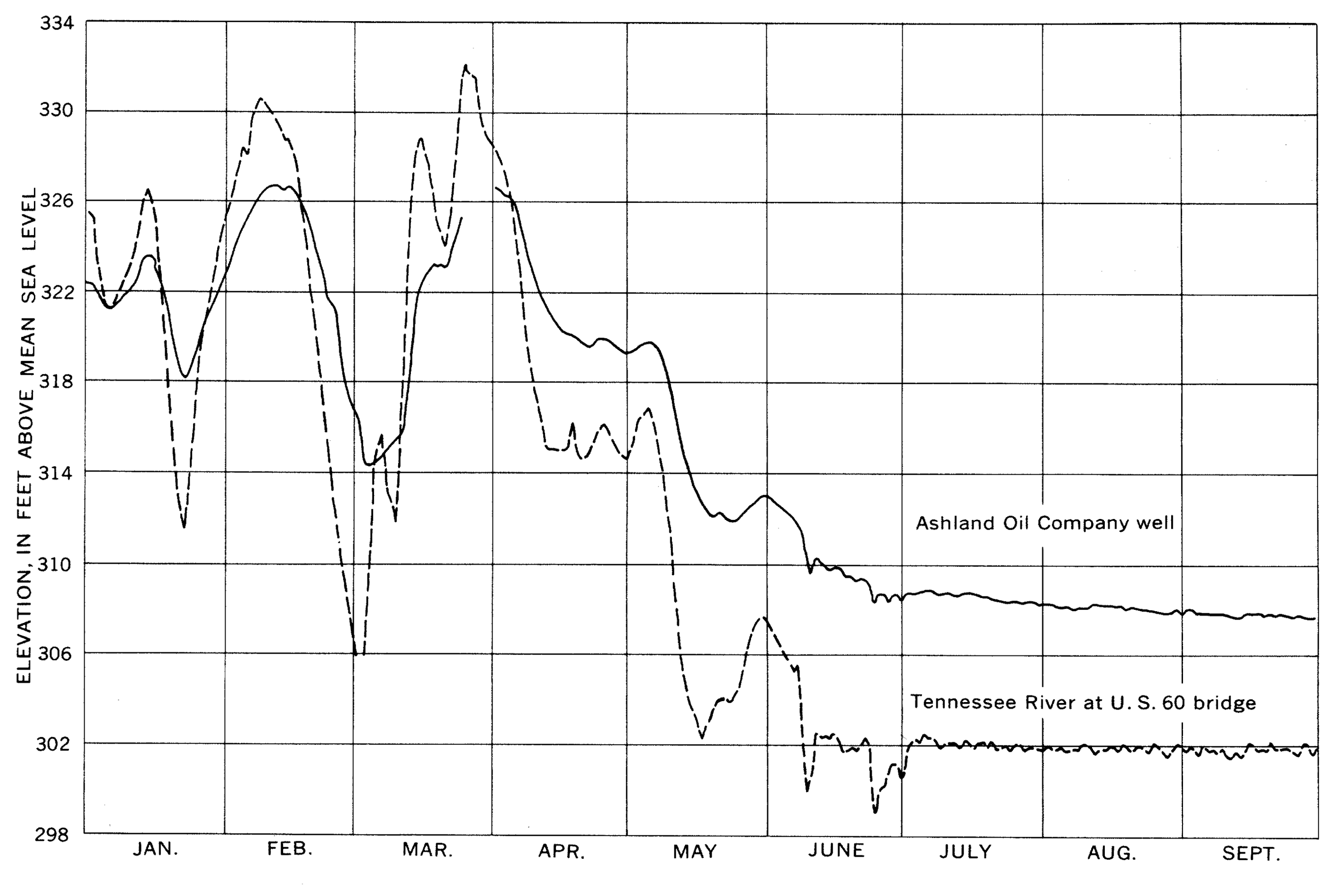


FIGURE 12—HYDROGRAPH OF A WELL 227 FEET DEEP IN THE RIPLEY FORMATION NEAR REIDLAND, MCCRACKEN COUNTY, KENTUCKY, AND STAGE OF THE TENNESSEE RIVER

Table 1.—Median values of dissolved constituents in water from aquifers in the Jackson Purchase region, Kentucky

Aquifer and type of supply	Dissolved constituents (epm)					
	Magnesium and calcium	Sodium and potassium	Bicarbonate	Sulfate	Chloride	Nitrate
Paleozoic bedrock:						
Drilled wells	2.71	0.22	2.73	0.17	0.09	.01
Springs	.35	.22	.42	.03	.09	.01
Tuscaloosa formation:						
Drilled wells	.82	.18	.72	.20	.08	.00
Ripley formation:						
Drilled wells	1.31	.36	1.19	.28	.10	.00
Dug wells	1.30	.51	1.34	.17	.35	.03
Eocene series:						
Drilled wells	.64	.41	.81	.07	.15	.03
Dug wells	1.50	1.09	.89	.18	1.36	0.44
Gravel of Pliocene(?) age:						
Drilled wells	2.40	.60	2.33	.05	.13	.15
Dug wells	1.75	1.28	.80	.08	.64	.30
Springs	.30	.31	.27	.12	.22	.06
Quaternary alluvium:						
Drilled wells	2.43	.43	1.84	.17	.49	.06
Dug wells	1.59	.84	1.37	.56	.39	.30

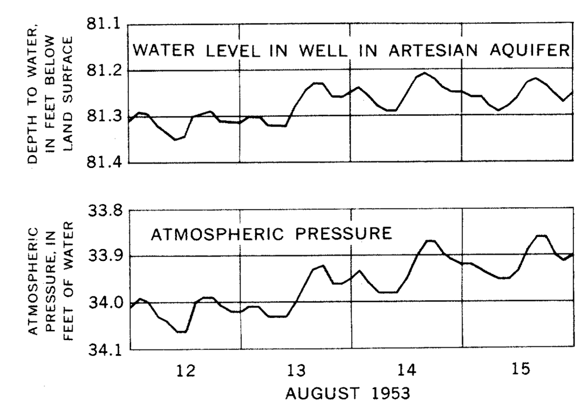


FIGURE 13—RELATIONSHIP OF WATER LEVELS AND ATMOSPHERIC PRESSURE

Table 2.—Chemical constituents commonly found in ground water

Constituent	Source	Significance
Silica (SiO_2)	Siliceous minerals present in nearly all rocks.	Forms hard scale in pipes and boilers. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	The common iron-bearing minerals present in most rocks.	Oxidizes to a reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown and is objectionable for food processing, beverages. Larger quantities impart taste and favor the growth of iron bacteria.
Manganese (Mn)	Manganese-bearing minerals.	Rarer than iron; in general has some objectionable features; brown to black stain.
Calcium (Ca) and magnesium (Mg).	Minerals that form limestone and dolomite and occur in some amount in almost all rocks. Gypsum also a common source of calcium.	Cause most of the hardness and scale-forming properties of water; soap consuming.
Sodium (Na) and potassium (K).	Feldspars and other common minerals; ancient brines, sea water; industrial brines and sewage.	In large amounts give salty taste; objectionable for specialized industrial water uses.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate minerals.	In combination with calcium and magnesium form carbonate hardness, which decomposes in boiling water with attendant formation of scale and release of corrosive carbon dioxide gas.
Sulfate (SO_4)	Gypsum, iron sulfides, and other, rarer minerals; common in waters from coal-mining operations and many industrial wastes.	Sulfates of calcium and magnesium form hard scale.
Chloride (Cl)	Found in small to large amounts in all soils and rocks, natural and artificial brines, sea water, sewage.	In large enough amounts gives salty taste; objectionable for various specialized industrial uses of water.
Fluoride (F)	Various minerals of widespread occurrence, in minute amounts.	In water consumed by children, more than about 1.5 ppm may cause mottling of the enamel of teeth; about 1.0 ppm tends to reduce decay of teeth.
Nitrate (NO_3)	Decayed organic matter, sewage, nitrate fertilizers, nitrates in soil.	Values higher than the local average may suggest pollution. There is evidence that more than about 45 ppm NO_3 may cause methemoglobinemia ("blue baby") of infants, sometimes fatal; waters of high nitrate content should not be used for baby feeding.[2]

California State Water Pollution Control Board (1952).

[2]Maxcy (1950).

FIGURE 15—GENERALIZED COLUMNAR SECTION AND WATER-BEARING CHARACTER OF THE ROCKS IN THE JACKSON PURCHASE REGION, KENTUCKY

SYSTEM	SERIES	GROUP	FORMATION OR UNIT	THICKNESS IN FEET	LITHOLOGY	TOPOGRAPHY	HYDROLOGY
QUATERNARY	Pleistocene and Recent		Alluvium	0–150	Sand and gravel in major stream valleys; silt, clay, and some sand and gravel in tributary valleys.	Flood plains and valley bottoms. Valley-train deposits beneath terraces along Ohio and Mississippi Rivers.	Known to yield as much as 350 gpm in major valleys. Yields sufficient water in tributary valleys for domestic use. Water ranges in hardness from 12 to 664 ppm and in dissolved solids from 53 to 1220 ppm. Iron may be present in objectionable amounts.
QUATERNARY	Pleistocene		Loess	0–40	Silt, compact, consisting of sharp, angular particles of quartz and small amounts of feldspar, hornblende, garnet, and epidote. Unleached beds calcareous.	Mississippi River bluffs and uplands adjacent to Ohio and Mississippi Rivers.	Yields small amounts of water to a few wells.
TERTIARY	Pliocene(?)		Gravel and sand	0–50	Gravel, iron-stained, mainly chert but includes small amounts of quartzite. Pebbles subangular to rounded; average diameter ½–1 inch. Sand, medium to coarse, orange or brick-red, and some gravel; mostly chert and quartz with some feldspar, hornblende, kyanite, and zircon. In places cemented by iron oxide into a hard conglomeratic sandstone.	Uplands and eroded edges of uplands above 370 feet.	Yield small quantities of water suitable for household use. One spring had measured discharge of 47 gpm. Most wells yield less than 10 gpm. Water-bearing gravel usually overlies clay or indurated layers. Water ranges in hardness from 8 to 724 ppm and in dissolved solids from 43 to 782 ppm. Iron content is generally low.
TERTIARY	Eocene	Wilcox and Claiborne	Sand and clay	0–1000	Sand, fine to coarse, gray, white, brown, or yellow. Particles mostly rounded to subrounded quartz and some feldspar and mica. Layers indurated by iron oxide at contact of sand and clay or at contact of sands of different permeability. Clay, jointed, smooth and fine to gritty. Color ranges from white to brown to black; depending on amount of lignite and iron oxide present. Marcasite concretions common.	Uplands and high-level erosional surface over most of area. Extend beneath river terraces along Mississippi valley.	Sand yields enough water for domestic use near outcrop area of Porters Creek clay and in areas of perched water. Drilled wells penetrating main zone of saturation where beds are thick yield as much as 1700 gpm. Hardness of water ranges from 7 to 212 ppm, and dissolved solids from 28 to 431 ppm. Iron may be present in objectionable amounts.
TERTIARY	Paleocene	Midway	Porters Creek clay	0–369	Clay, light- to slate-gray, in laminae separated by thin layers of mica and very fine sand. Clay well jointed and breaks with conchoidal fracture, in places cut by sandstone "dikes." Lower part of clay glauconitic, contains meager fauna consisting of Foraminifera and Pelecypoda.	Crops out along Clarks River valley and in the adjacent uplands from Tennessee Stateline to Paducah. West of Paducah it is truncated and covered by river alluvium.	Probably will yield a little water from joints and from sandstone "dikes." Water is probably hard and high in iron. Formation is important as a confining layer.
CRETACEOUS	Upper Cretaceous		Ripley formation	0–400	Sand and clay, interbedded; thin zones indurated by iron oxide at contacts of sand and clay. Sand is white, buff, yellow, and red; clay ranges from white to dark gray. Formation consists mostly of silt and clay in some areas.	Uplands and dissected ridges between Kentucky Lake and Clarks River. West of Paducah, it is truncated and covered by river alluvium.	Yields sufficient water for domestic use near outcrop area of Paleozoic bedrock and in areas of perched water. Where formation is thick, drilled wells yield as much as 830 gpm. In areas where formation is mostly silt and clay, there may not be sufficient saturated sand to furnish even a domestic supply. Hardness of water ranges from 13 to 182 ppm, and dissolved solids from 62 to 275 ppm. Iron may be present in objectionable amounts.
CRETACEOUS	Upper Cretaceous		Tuscaloosa formation	0–50	Gravel, rounded, and chert, in matrix of angular chert, sand, and clay. Average diameter of pebbles 1½ inches.	Dissected ridges adjacent to Kentucky Lake.	Yields small amounts of water to domestic wells. Yields are low, owing to clayey matrix and poor sorting. Hardness of water from 2 wells sampled was 26 and 57 ppm, and dissolved solids, 50 and 76 ppm.
DEVONIAN AND MISSISSIPPIAN			Limestone and chert		Limestone, chert, and shale. Chert beds commonly fractured to a depth of several hundred feet. Thin beds of clay and tripolite interbedded with chert in some places.	Dissected ridges adjacent to Kentucky Lake. Valley of Tennessee River from Gilbertsville to Calvert City.	Usually yield sufficient water for domestic use; known to yield 120 gpm in some localities. Fresh water found at depths exceeding 1000 feet. Hardness of water ranges from 17 to 238 ppm, and dissolved solids from 39 to 273 ppm.

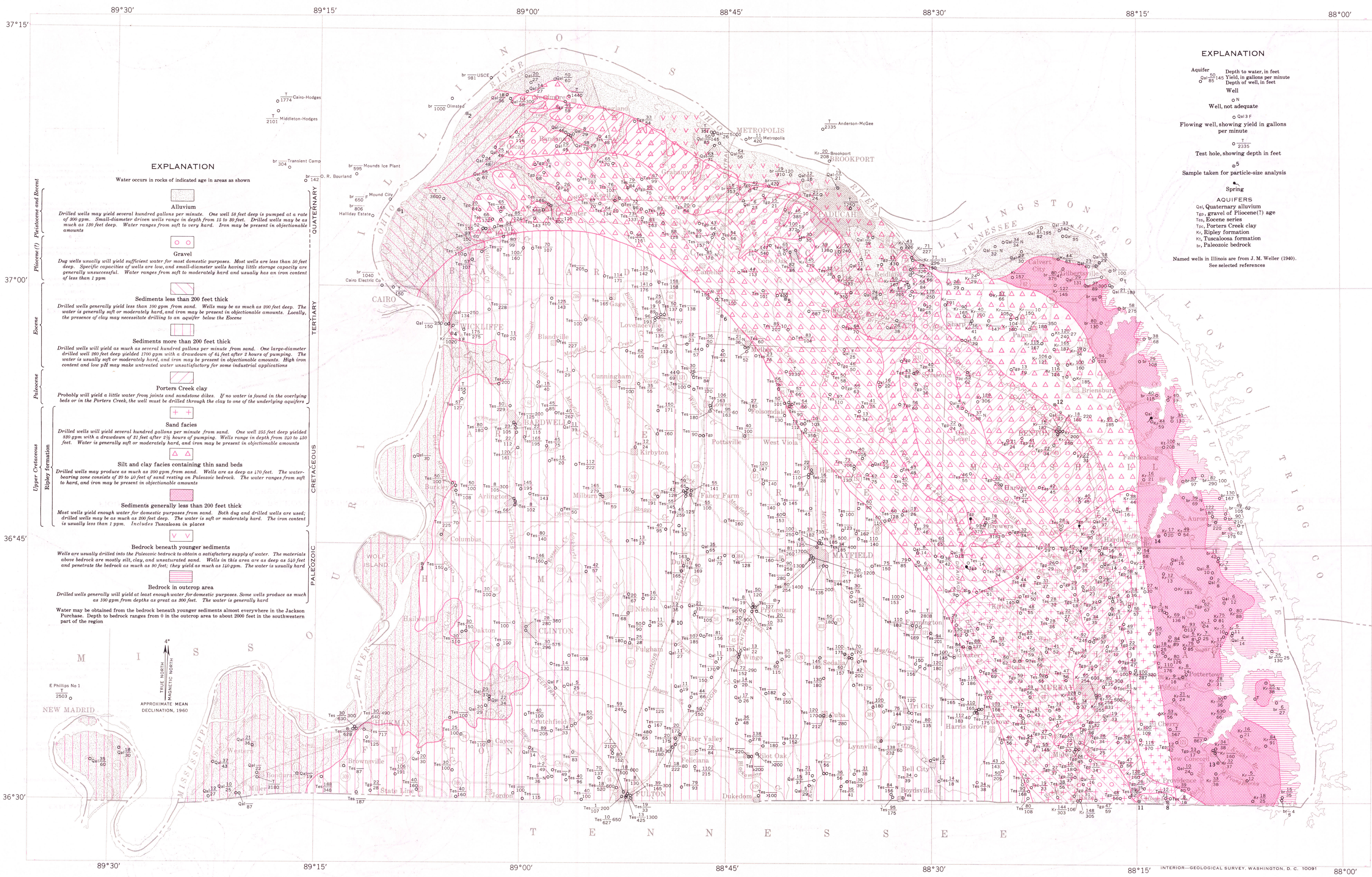


FIGURE 14—WATER-AVAILABILITY MAP OF JACKSON PURCHASE REGION, KENTUCKY

SCALE 1:250 000

4 2 0 4 8 12 16 20 MILES

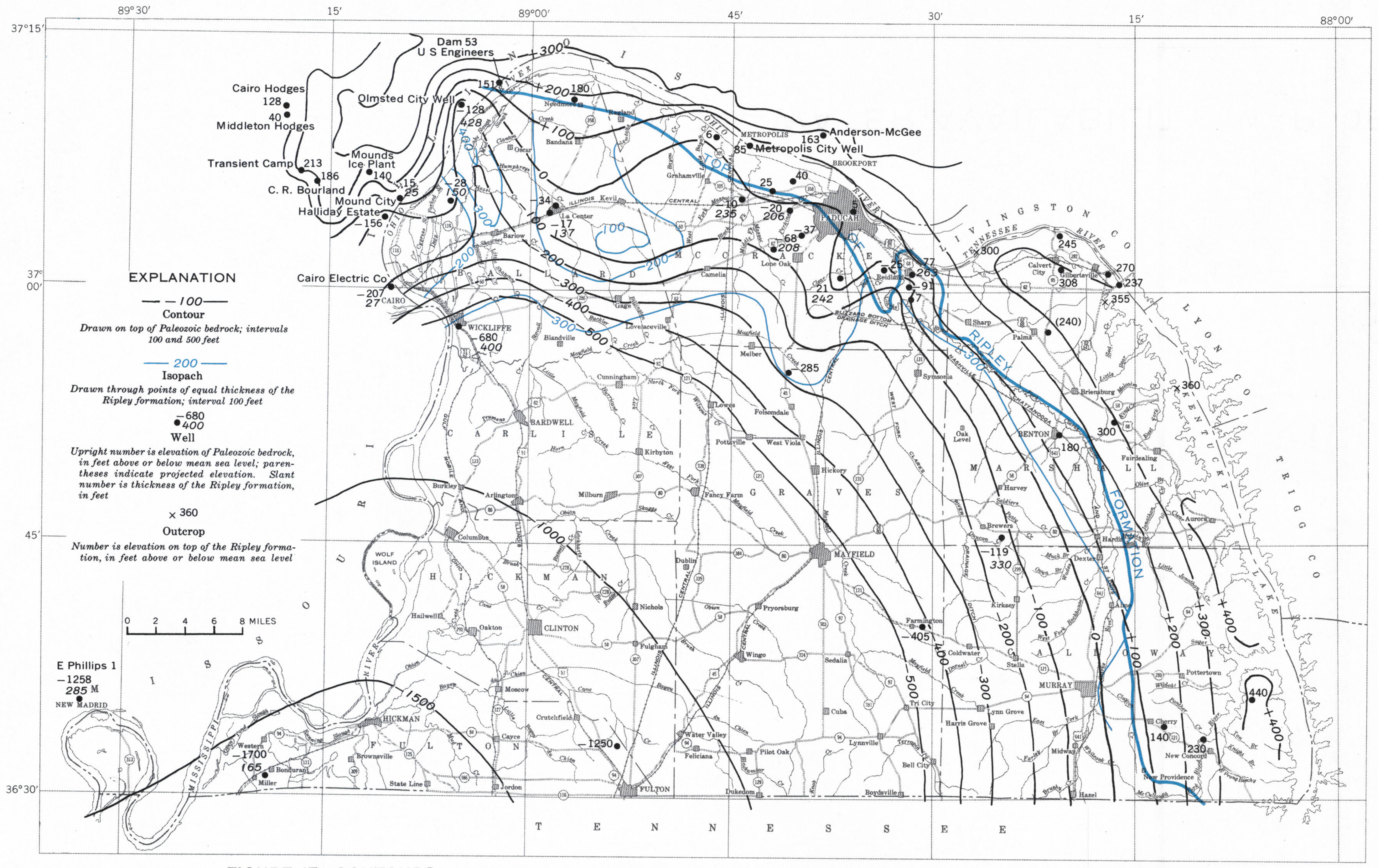


FIGURE 17—CONTOURS ON TOP OF PALEOZOIC BEDROCK AND ISOPACHS OF THE RIPLEY FORMATION, JACKSON PURCHASE REGION, KENTUCKY

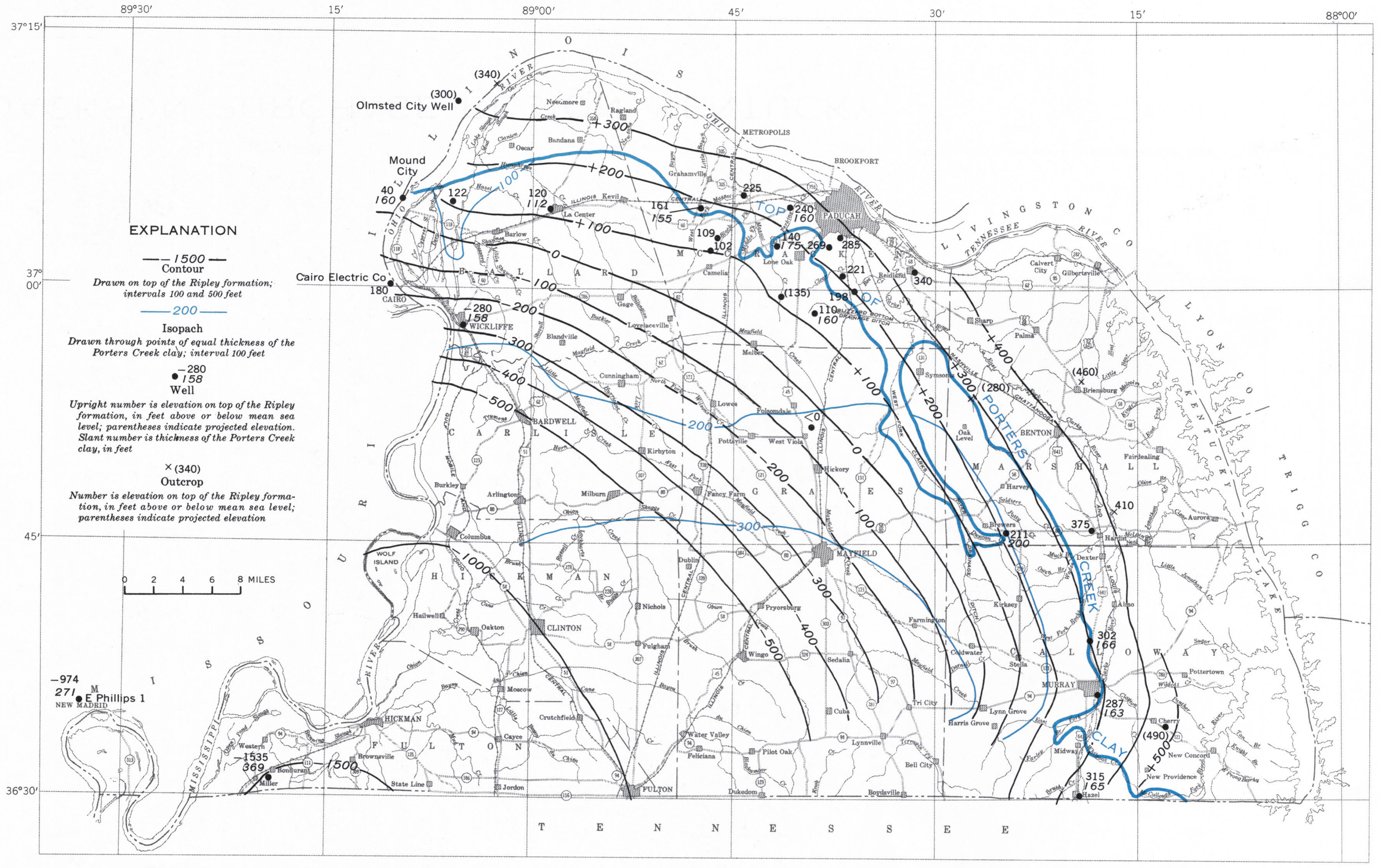


FIGURE 22—STRUCTURE CONTOURS ON TOP OF THE RIPLEY FORMATION AND ISOPACHS OF THE PORTERS CREEK CLAY, JACKSON PURCHASE REGION, KENTUCKY

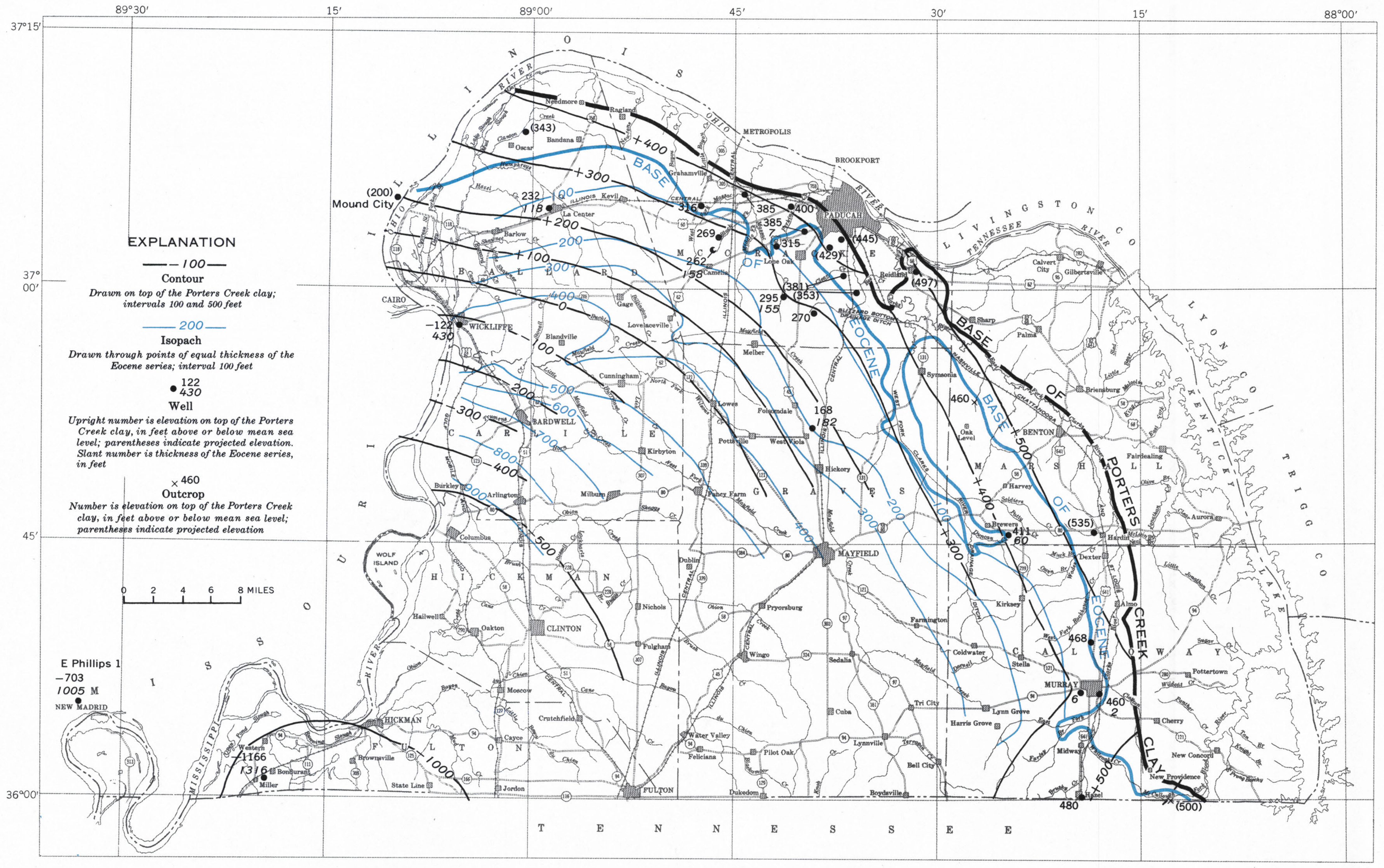


FIGURE 23—STRUCTURE CONTOURS ON TOP OF THE PORTERS CREEK CLAY AND ISOPACHS OF THE EOCENE SERIES, JACKSON PURCHASE REGION, KENTUCKY

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C. 10091

FIGURE 24—STRUCTURE CONTOURS ON TOP OF THE EOCENE SERIES, JACKSON PURCHASE REGION, KENTUCKY

METHODS OF OBTAINING GROUND WATER

Many types of wells are used in the Jackson Purchase. The type of well and casing is determined by the depth to water, the quantity of water desired, and the availability of funds. In the past, most wells were dug or augered by hand, but in recent years most wells have been drilled by machine. Hand-dug wells rarely exceed 60 feet in depth. Most dug wells are lined with brick or concrete tile; most hand-augered wells are cased with terra cotta tile. Neither the brick nor the tile offers a watertight seal, and therefore wells lined with these materials are liable to pollution from surface sources.

Large industrial and municipal wells are usually drilled by the hydraulic rotary process. In this method, a toothed bit is mounted on the end of a string of drill pipe. The pipe is rotated by machinery so that the bit cuts through the rock. During drilling, a "drilling-mud" consisting of a suspension of natural clay or artificially prepared constituents is pumped down the drill pipe and through holes in the bit. It then flows back up to the surface in the annular space between the drill pipe and the cylindrical walls of the hole. The drilling mud carries the rock cuttings to the surface, seals off porous formations to prevent the loss of drilling fluid, and exerts a hydrostatic force which prevents the walls of the hole from collapsing. In this way uncased holes can be drilled to great depths.

Many small-diameter domestic wells are drilled in unconsolidated material by the jetting process. In drilling by this method, a jet of water is forced against the formations through a small-diameter galvanized pipe. The pipe is rotated to aid the cutting action of the jet of water and to keep the hole straight. Additional lengths are attached as the hole is deepened. When water-bearing material is penetrated, a well screen is dropped through the pipe to the bottom of the hole. The jetting pipe thus serves also as well casing and pump column in wells drilled by this method. Wells can be jetted to depths of about 200 feet.

Cable-tool machines are used to drill in both consolidated rocks and unconsolidated deposits. This type of rig has a steel drill bit on the end of a rope or wire cable. By means of a motor-driven eccentric action, the bit is raised and then dropped against the rocks. The chisel-shaped bit cuts the rock in much the same way as does a masonry, star drill. When several feet of rock has been broken by the drill, the bit is hoisted from the hole and the debris removed with a bailer—a piece of thin-walled pipe having a flap valve in the bottom. Wells in unconsolidated rocks are drilled through casing, and the casing is periodically driven down so as to stay within a few feet of the tip of the drill bit.

Along the flood plains of the larger rivers, many hand-driven wells are used. These wells are installed by hammering down a small-diameter pipe into the alluvium. The lower end of the pipe is fitted with a well point and strainer. Driven wells are usually equipped with pitcher pumps; however, some of larger yield are pumped with small electric pumps.

In areas of unconsolidated deposits where the depth to water is less than about 100 feet, boring rigs (mechanical augers) can be used. These machines rotate a cylinder or bottomless bucket on the end of a steel shaft. As the shaft is rotated, blades at the bottom cut into the sediments and fill the bucket. The shaft and bucket are then lifted from the hole by a windlass, and the bucket is emptied. Boring rigs can penetrate but a short distance below the water table in certain loosely consolidated sediments. Bored wells are usually lines with concrete tiles. The tiles should be made watertight at each joint to prevent pollution from surface seepage.

The pumping equipment used in the Jackson Purchase depends on the depth to water, the type and yield of the well, and the quantity of water needed. Where the depth to water is less than 25 feet, as in some of the areas underlain by gravel of Pliocene(?) age and along the flood plains of the large rivers, wells can be pumped by hand pitcher pumps and by motor-driven cylindrical or centrifugal suction pumps. Most domestic wells in which the depth to water is greater than 25 feet use jet pumps or submerged-cylinder lift pumps. In some areas water is obtained from both dug and drilled wells with hand-operated buckets or bailers.

For yields greater than about 20 gpm, submersible or shaft-driven deep-well turbine pumps are used. Most industrial and municipal wells are equipped with such pumps. The shaft-driven pump consists of a submerged centrifugal pump unit connected to a motor at the surface by a vertical shaft. The submersible pump is similar, except that the motor is beneath and directly coupled to the pump, forming a single submerged unit suspended at the bottom of the discharge pipe.

Wells that bottom is unconsolidated sediments, except those of small yield in fairly coarse sand or gravel, require some form of screen or strainer to keep sand out of the well. For most domestic wells it is enough to install the screen and pump the well until the water clears. For large-capacity wells this procedure may not be satisfactory. The screen of large wells are selected so that the smaller particles of sand around the well will pass through the slots and be pumped out, in a process called developing the well. After the screen is installed, the well may be surged by forcing water into and out of the aquifer to wash the fines into the well. The fines are periodically removed during the surging process. The surging is accomplished by raising and lowering a piston within the casing, by alternately pressurizing and then relieving the pressure in the well by means of compressed air, or by intermittent pumping at a high rate. Large-capacity wells may be constructed with a gravel envelope around the screen which increases the effective size of the well.

OCCURRENCE OF GROUND WATER

PALEOZOIC

Limestone and chert of the Mississippian system crop out or lie at shallow depth in a narrow belt along Kentucky Lake. The oldest of these rocks that is of importance as an aquifer is the Fort Payne chert. The outcrop area is long and narrow, the chert being exposed on ridges and spurs and, in some places, on the lake shore. The Fort Payne consists of interbedded limestone and chert, but solution of the limestone to great depths has caused sagging, compaction, and fracturing of the chert bed. In some places all the carbonate minerals in the limestone have been removed, leaving a rubble of loose chert in a clayey matrix. The material is similar to an unconsolidated deposit in that wells require a casing and a perforated pipe or screen in the water-bearing zone. Ground water is transmitted in fractures in the chert and in solution openings in the limestone. Most small-diameter wells yield enough water for a modern domestic supply; one public-supply well at Kentucky Lake State Park, 10 inches in diameter and 175 feet deep, produces at the rate of 62 gpm. In some areas the Fort Payne contains residual clay or tripolitic material which clogs well screens. The Fort Payne is an important source of water to the many cottages, fishing camps, and resorts along Kentucky Lake.

Samples of water from 1 spring and 4 wells in the Fort Payne were collected for chemical analysis. Three of these samples were soft, one was hard, and one was very hard. The water is of the calcium magnesium bicarbonate type.

In western Ballard County in Kentucky and in Alexander and Pulaski Counties in Illinois, chert of Devonian and Mississippian age lies beneath the Ripley formation and river alluvium and contains water under artesian pressure. Wells drilled into these cherts flow with heads of 6 feet or more above ground level. The municipal well at Mound City, Ill., flowed 85,000 gpd (gallons per day) when it was first drilled. Several wells drilled in and near Cairo, Ill., have penetrated this chert zone. A well at the Halliday Estate is reported to have flowed an estimated half a million gallons per day when it was drilled in 1898 (Glenn, 1906).

The Warsaw limestone, exposed at only a few places south of Kentucky Dam, is of small importance as an aquifer. The water from the Warsaw is reported to be moderately hard and apparently can be obtained in quantities sufficient for a modern domestic supply.

Two wells obtain water from the St. Louis limestone. One well is near Gilbertsville and the other is at Calvert City. The St. Louis crops out in a narrow belt in the area extending from Kentucky Dam to Calvert City. In exposures the St. Louis exhibits solutionally enlarged joints and cracks, and it is these openings that transmit the water. One well at Calvert City produces 26 gpm from this limestone. The well is 6 inches in diameter and 375 feet deep. Water from this well has a hardness of 188 ppm and is of the calcium magnesium bicarbonate type. Water from the St. Louis is suitable for household purposes but would have to be treated for many industrial applications.

In the outcrop area of Mississippian rocks, most wells will yield sufficient water for a modern domestic supply, and some will yield enough for a small public supply (fig. 14). The 1-hour specific capacity of a well in Mississippian bedrock in McCracken County was 1.5 gpm per foot. (See fig. 16.)

The water in the bedrock of the Jackson Purchase differs in quality from that in the rest of Kentucky in one important respect. Connate salt and sulfur (hydrogen sulfide-bearing) water are uncommon in the Paleozoic rocks of the Purchase, even at depths as great as 3,000 feet. Fresh water reportedly has been found in the Ordovician and Silurian rocks at depth in several oil tests. This fact indicates that ground-water circulation is active at very great depths in the consolidated rocks underlying the Purchase.

CRETACEOUS

The Tuscaloosa formation is of minor importance as an aquifer in the Purchase, owing to its thinness and small area of outcrop. In some places this formation contains a clayey matrix which plugs well screens and makes the water turbid. The two wells tested yield soft water moderately high in sulfate and chloride content.

The Ripley formation is an important aquifer in Calloway, Marshall, McCracken, and Ballard Counties. It supplies many shallow wells in its outcrop area and many deep wells where the thickness of overlying beds is 500 feet or less. The Ripley, where present, is a good source of water in Calloway and Marshall Counties. The Ripley also supplies water to wells in much of McCracken County and the northern half of Ballard County. In Graves, Hickman, Carlisle, and Fulton Counties the Ripley lies too deep for economical water production under present conditions, but adequate supplies may be obtained from shallower aquifers in most places. The isopach map, figure 17, shows the variation in thickness of the Ripley formation in the Purchase. The formation ranges from 0 to 400 feet in thickness. The contours on the top of the Paleozoic bedrock (bottom of the Cretaceous), figure 17, show minor troughs superimposed on the major bedrock trough which underlies the whole of the embayment area. These minor depressions contain fillings of the Ripley, whereas the intertrough areas have only a thin cover of the formation. The Ripley changes in facies along its southeast-northwest strike. From Hazel to approximately a mile north of Murray in Calloway County, sand makes up the bulk of the formation. From this point northward, the amount of silt and clay increases until at Benton, Marshall County, the formation is composed mostly of silt and clay, there being only 25 or 30 feet of sand at the base. The amount of sand then increases from Benton to Sharpe and the McCracken County line. Under most of McCracken County the Ripley consists mostly of clay and silt, there being 25 feet or less of fine to medium sand at the base. From western McCracken County to Ballard County and thence to Dam 53 in Illinois, the amount of sand increases again. The facies changes affect the availability of water in the Ripley formation in accordance with the amount of sand in the formation. Little or no water can be obtained in areas where the formation is predominantly silt and clay, as in southern McCracken County. Large quantities of water are obtained from the formation where it is mostly sand. At Murray a city well has a measured yield of 831 gpm with a 31-foot drawdown after approximately 2 hours of pumping. (See fig. 18.) The well is 255 feet deep and penetrates 60 feet of sand in the Ripley formation; it is fitted with 50 feet of 10-inch screen. Although the two city wells at Benton penetrate only 25 feet of sand beneath 156 of clay, each produces 250 gpm. A similar situation exists at Reidland, where the new city well is screened in 26 feet of sand of the Ripley above the Paleozoic bedrock. This well is pumped at 150 gpm with a drawdown of 179 feet.

Horizontal and vertical samples were taken from two exposures of the Ripley for laboratory tests. The vertical coefficients of permeability, in meinzers (gallons per day per square foot at 60°F) were 320 and 380, and the horizontal coefficients were 780 and 600. These differences in permeability indicate that water will move horizontally (along the bedding) at a rate about 1½ to 2½ times as great as it will vertically (across the bedding). The porosity of 4 specimens of the sand of the Ripley ranged from 42.5 to 46.4 percent. Detailed information on the mechanical analyses of the samples of the Ripley appears in table 3 and figure 19.

The water levels in wells in the Ripley near Kentucky Lake are as much as 100 feet higher than the lake surface. Figure 20, the hydrograph of a well at Murray, about 9 miles from the lake, shows a general rise in water level throughout the period of record beginning in 1950. The water rose 4 feet between 1948 and 1954. This rise in water level may be due in part to the rise of the water level in the lake. In the area immediately west of Kentucky Lake, water discharges from the Ripley formation into the lake. The ground-water divide probably was farther west before the dam was built, and the rise in head in the discharge area resulted in an eastward shift of the ground-water divide.

Flowing wells are reported in the Ripley formation in Illinois along the Ohio and Mississippi River valleys and in Missouri along the Mississippi River valley southeast of Crowleys Ridge. Grohskopf (1955) reported that most wells in the Ripley will flow if the surface altitude is less than 300 feet and the well is properly constructed. He reported flows from this aquifer ranging from 16 to 720 gpm. The source of water flowing at a rate of half a gallon per minute from a well at the southern city limits of Wickcliffe, Ky., is probably the Ripley formation at a depth of 600 feet.

Although the quantity of water available from the Ripley formation differs from place to place, most wells will yield sufficient water for domestic purposes. Wells can be drilled as deep in the formation as necessary without danger of contamination by salt or sulfur water. Except for that in the outcrop area, the water in the Ripley formation is under artesian pressure. In most places the water rises to an altitude ranging between 300 and 315 feet.

Water samples from 29 wells in the Ripley formation were analyzed. Of these, 12 were soft, 10 were moderately hard, and 5 were hard. Hardness was not determined for samples from 2 wells. The dissolved-solids content ranged from 62 to 275 ppm. The pH ranged from 6.2 to 7.9; for most samples it was slightly greater than 7.0. The iron content of the water is generally high, and many samples had more than 0.3 ppm, the limit recommended by the U. S. Public Health Service for culinary and drinking water. One sample had 15 ppm of iron. The silica content of the samples ranged from 4.6 to 34 ppm. Both iron and silica appear to be related to the depth of the well; water from most wells more than 250 feet deep has relatively high concentrations of both iron and silica. Water from this formation is suitable for household uses and many industrial applications. The main objectionable features of the water, locally, are the high iron content and the low pH. The water is of the calcium bicarbonate type.

TERTIARY

PALEOCENE

Except in a few places where wells may get water from joints or thin sand seams, the Porters Creek clay is non-water-yielding. This geologic unit is important in the hydrology of the Jackson Purchase because it is relatively impermeable and therefore inhibits the passage of water from either above or below. The hydrologic properties and mechanical analyses of samples of this clay are given in table 3 and figure 21.

Although the Porters Creek clay is relatively impermeable in comparison to the sands above and below it, some water leaks through the clay. In the northeastern part of the Eocene outcrop the hydraulic head in the Eocene sands above the Porters Creek probably ranges from 0 to 100 feet above the hydraulic head in the Ripley formation below the clay. If the average head in the Eocene in this area is assumed to be 50 feet above the head in the Ripley, and if the thickness of the Porters Creek is 160 feet, the leakage from the Eocene through the Porters Creek clay to the Ripley per square mile per day can be computed. Using the formula $Q=PIA$, where the following values are substituted:

Q = quantity of water discharged in unit time, in gallons per day.

$P=0.0004=4\times10^{-4}$ gpd per sq ft = coefficient of permeability of the more permeable of two vertical samples of the Porters Creek clay, from laboratory permeability tests.

$I=h/l$ = head divided by the thickness of material traversed = 50/160.

A = cross-sectional area through which water must flow = 1 square mile = 2.8×10^{7} sq ft.

then

$$Q=4\times10^{-4}\times50/160\times2.8\times10^{7}.$$
$$=4\times10^{3}.$$
$$=4{,}000 \text{ gpd per sq mi.}$$

The quantity of water that moves through the joints and sand beds is greater than the amount that moves directly through clay of the type tested; therefore the average leakage per square mile probably is greater than computed.

The chances of obtaining even a moderate yield from wells in the Porters Creek clay are poor. Moderate yields can be obtained in the outcrop area of the Porters Creek by drilling through the clay into a water-bearing sand in the Ripley formation. In most places where the Porters Creek is beneath the surface, water may also be obtained in overlying gravel of Pliocene(?) age or from Quaternary alluvium.

Figure 22 is a combined structure and isopach map of the Porters Creek clay. The structure contours are drawn on top of the Ripley formation.

EOCENE

The Eocene series is the principal aquifer in Fulton, Hickman, Carlisle, and Graves Counties. It underlies half of McCracken County and approximately three-fourths of Ballard County also. This aquifer supplies most of the ground water in the region south and west of the outcrop of the Porters Creek clay. The depth to the water-bearing horizon becomes greater down the dip to the southwest. Although the deepest domestic wells usually do not exceed 350 feet, some public and industrial wells are more than 600 feet deep. The combined structure and isopach map, figure 23, shows that the thickness of the Eocene series increases gradually to the southwest and is greatest in Fulton County south of Hickman. Figure 24 is a contour map on the top of the Eocene series. In areas where the Eocene is composed mostly of clay, it is difficult to get a good well. The log of a well near Barkley Field, west of Paducah, shows that 114 of the 140 feet of the Eocene is clay. A well 4 miles south of Lone Oak penetrated mostly clay to a depth of 210 feet, and it is reported that a well 4 miles southwest of Hickman penetrated more than 250 feet of clay before entering a water-bearing sand. Large-capacity wells can be made in the Eocene if enough saturated sand is penetrated. Many of the wells at Fulton that have yields of 1,000 gpm are more than 500 feet deep. It is necessary to drill to this depth to penetrate enough saturated sand for such a large yield.

The Eocene series is generally a better aquifer than the Ripley formation. Except for the wells in Fulton, Fulton County, most wells in the Eocene series are shallower and have higher yields than those in the Ripley formation. The largest capacity well in the Eocene series is a public-supply well at Mayfield, Graves County. This 260-foot well had a 64-foot drawdown at a discharge of 1,700 gpm during a 2-hour specific-capacity test. (See fig. 25.) The public-supply well at Fulton had a measured discharge of 1,240 gpm and a 36-foot drawdown after 2 hours of pumping. (See fig 26.) This well in the Eocene series is 425 feet deep. Barlow, Clinton, Bardwell, Arlington, and other small towns obtain water from wells equipped with pumps which have capacities less than 300 gpm. The maximum possible yield of some of the wells may be greater than the capacities of the pumps.

Horizontal and vertical samples of sand were taken from six exposures of the Eocene series for mechanical analyses. The coefficients of permeability, in meinzers, of the vertical samples ranged from 160 to 700, and of the horizonal samples, from 54 to 1,000.

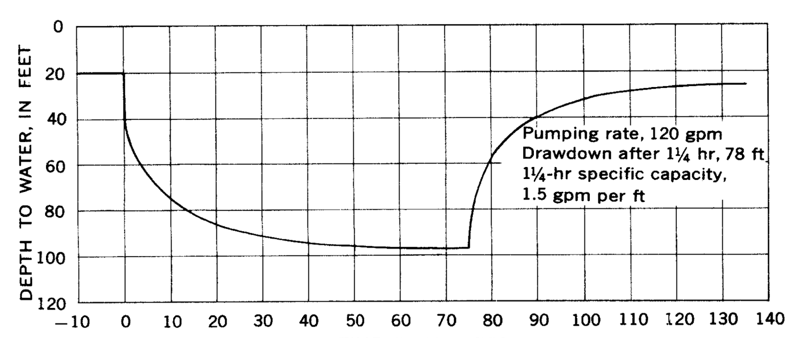


FIGURE 16—SPECIFIC-CAPACITY TEST OF A WELL 310 FEET DEEP IN PALEOZOIC BEDROCK, MC CRACKEN COUNTY, KENTUCKY

Table 3.—Hydrologic characteristics of geologic formations in the Jackson Purchase region, Kentucky

[Sample: H, horizontal; V, vertical]

Sample	Location	Geologic unit	Moisture content (percent, by dry weight)	Coefficient of permeability (gpd per sq/ft)	Average unit weight of solid constituents (gr per cc)	Unit weight of dry sample (gr per cc)	Porosity (percent, by volume)	Specific retention (percent, by volume)	Specific yield (percent, by volume)
1 V	6 miles west-northwest of Barlow, Ballard County	Quaternary (alluvium)	10.7	480	2.62	1.28	51.1	5.7	45.4
1 H	do	do	10.3	460	2.68	1.30	51.5	5.7	45.8
2 V	3 miles northwest of Oscar, Ballard County	do	10.8	300	2.68	1.42	47.0	7.1	39.9
2 H	do	do	9.6	240	2.67	1.45	45.7	6.7	39.0
3 V	2 miles south-southwest of Columbus, Hickman County	Pleistocene (loess)	23.8	6.1	2.74	1.39	49.3	16.2	33.1
3 H	do	do	20.7	4.1	2.74	1.35	50.7	16.0	34.7
4 V	0.5 mile south of Wickliffe, Ballard County	do	18.7	2	--	1.50	44.4	--	--
5 V	2.5 miles south of Lone Oak, McCracken County	Eocene (sand)	7.0	160	--	1.72	35.6	--	--
5 H	do	do	7.8	54	--	1.62	39.8	--	--
6 V	2.5 miles northwest of Melber, McCracken County	do	4.7	580	--	1.39	47.7	--	--
6 H	do	do	5.5	560	--	1.40	47.8	--	--
7 H	1 mile east-northeast of Pryorsburg, Graves County	Eocene (clay)	34.5	.0003	--	1.37	48.5	44.9	3.6
8 V	2 miles southeast of New Providence, Calloway County	Eocene (sand)	6.2	700	--	1.55	41.7	3.4	38.3
8 H	do	do	3.9	1,000	--	1.59	40.2	2.6	37.6
9 V	3.5 miles west-northwest of Kirksey, Calloway County	do	8.1	230	--	1.52	43.5	1.0	42.5
9 H	do	do	8.1	400	--	1.48	44.6	1.0	43.6
10 V	5 miles northwest of Wingo, Graves County	do	8.1	170	--	1.52	42.6	1.4	41.2
10 H	do	do	8.0	270	--	1.50	43.6	2.7	40.9
11 V	2 miles south-southwest of New Providence, Calloway County	Paleocene (Porters Creek clay)	47.7	.0004	--	1.18	56.9	32.3	24.6
12 V	1.5 miles southwest of Briensburg, Marshall County	do	30.0	.0003	--	1.49	43.6	12.6	31.0
13 V	0.5 mile south-southeast of New Concord, Calloway County	Cretaceous (Ripley formation)	4.7	320	--	1.51	43.4	--	--
13 H	do	do	3.0	780	--	1.45	45.7	--	--
14 V	4 miles west-southwest of Aurora, Marshall County	do	3.6	380	--	1.53	42.5	--	--
14 H	do	do	3.7	600	--	1.43	46.4	--	--

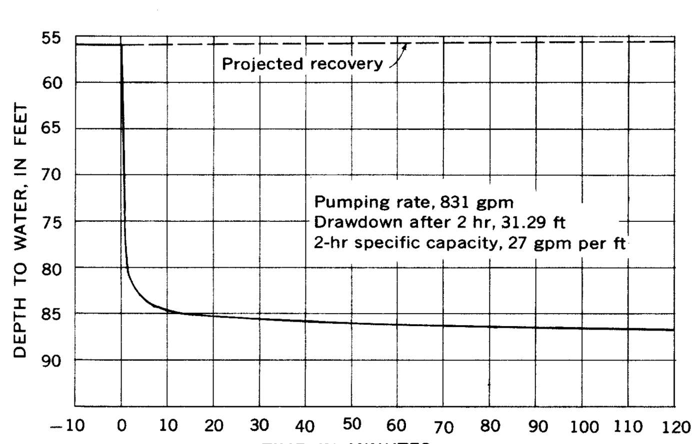


FIGURE 18—SPECIFIC-CAPACITY TEST OF A MUNICIPAL WELL 255 FEET DEEP IN THE RIPLEY FORMATION, MURRAY, CALLOWAY COUNTY, KENTUCKY

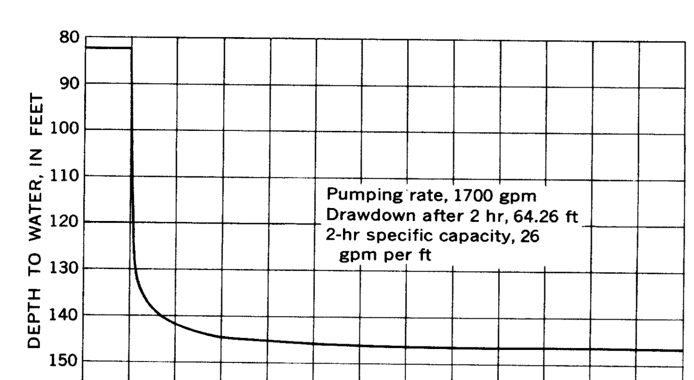


FIGURE 25—SPECIFIC-CAPACITY TEST OF A MUNICIPAL WELL 260 FEET DEEP IN THE EOCENE SERIES, MAYFIELD, GRAVES COUNTY, KENTUCKY

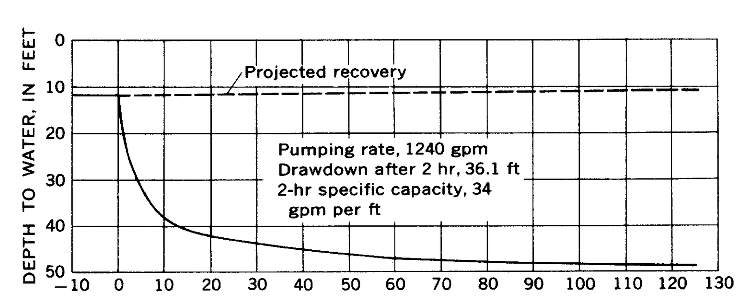


FIGURE 26—SPECIFIC-CAPACITY TEST OF A MUNICIPAL WELL 425 FEET DEEP IN THE EOCENE SERIES, FULTON, FULTON COUNTY, KENTUCKY

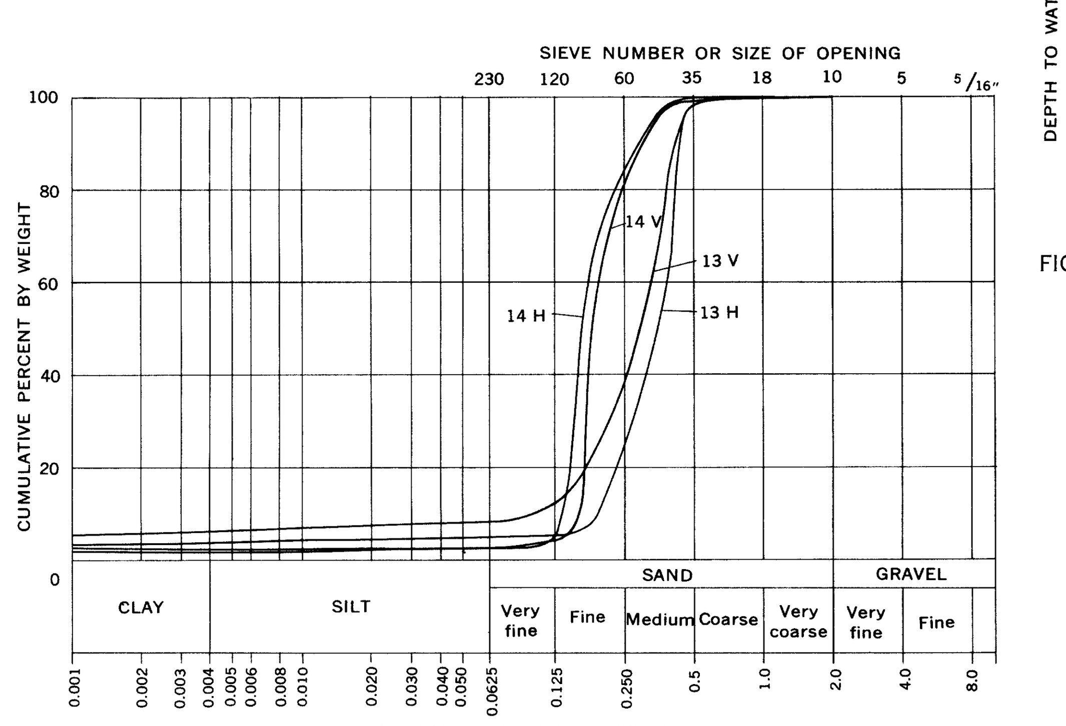


FIGURE 19—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 13 AND 14 OF THE RIPLEY FORMATION

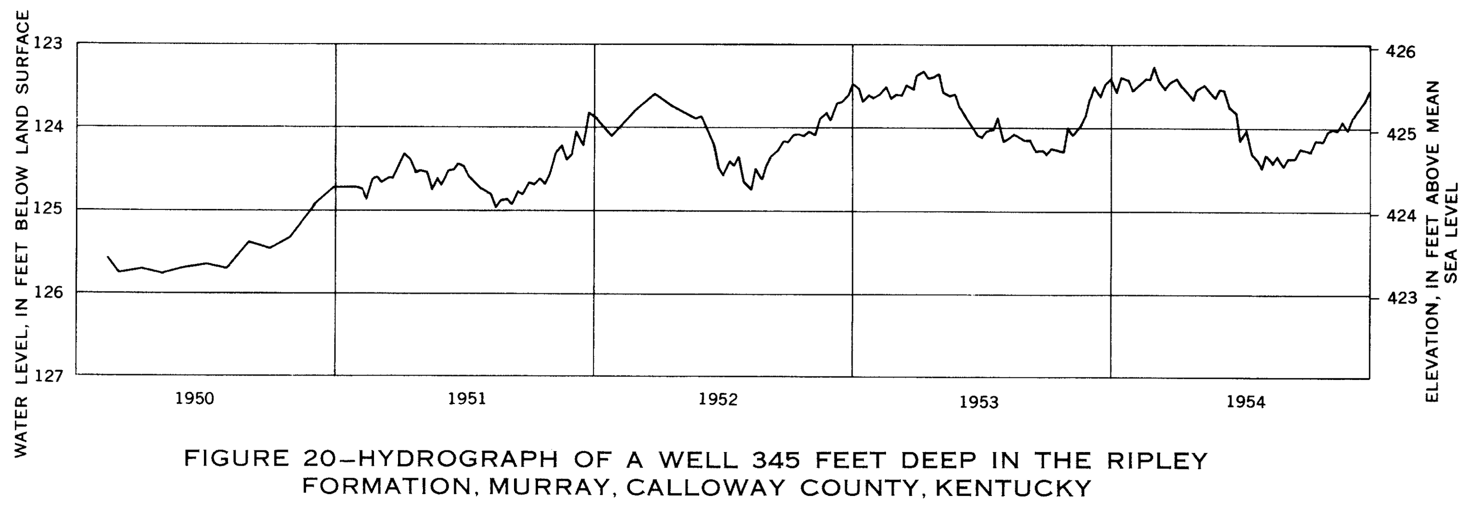


FIGURE 20—HYDROGRAPH OF A WELL 345 FEET DEEP IN THE RIPLEY FORMATION, MURRAY, CALLOWAY COUNTY, KENTUCKY

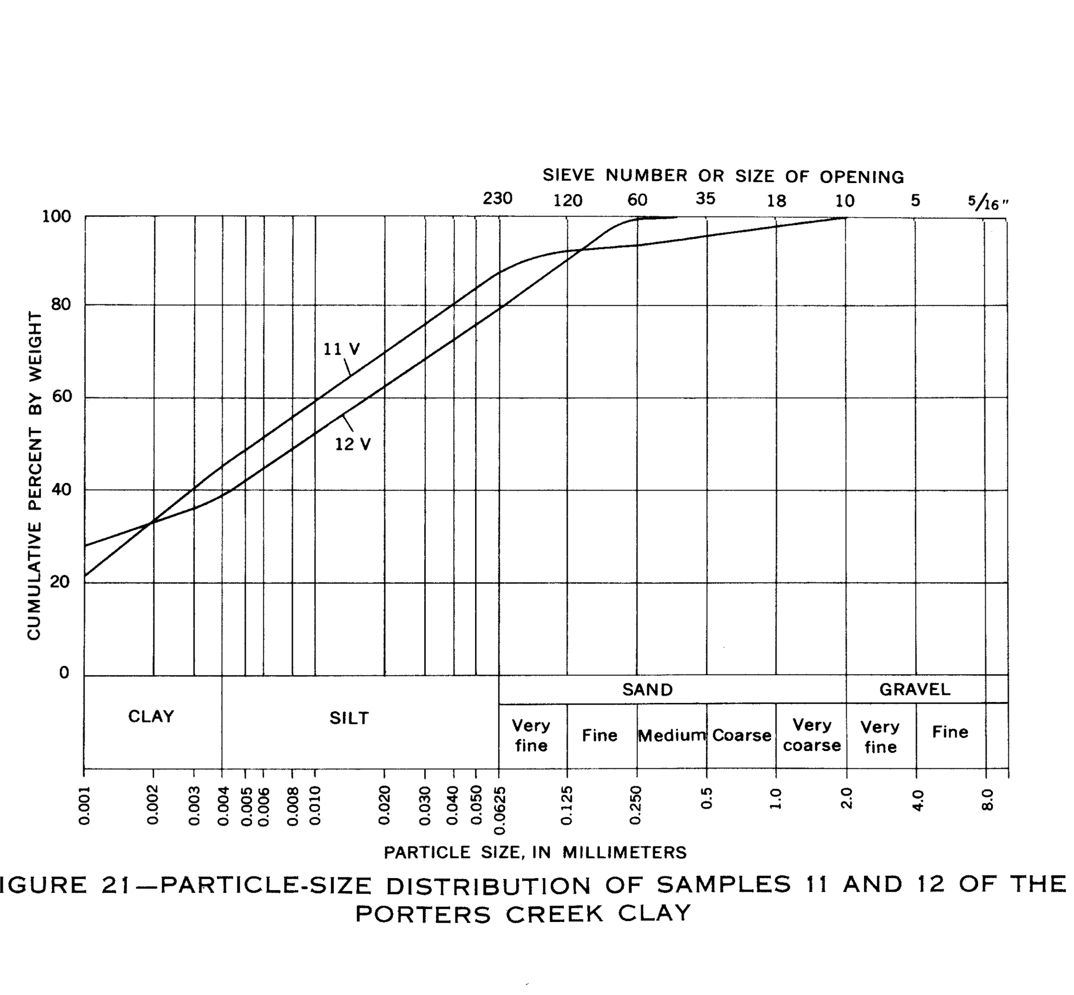


FIGURE 21—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 11 AND 12 OF THE PORTERS CREEK CLAY

The values obtained indicate that water will move horizontally through the Eocene at 1½ to 3 times the vertical rate. The porosity of the samples ranged from 35.6 to 47.8 percent. The coefficient of permeability of a horizontal clay sample was determined to be 0.0003, and the porosity was 48.5 percent. The hydrologic properties and particle size of the Eocene sands and clays are shown in figures 27 and 28 and table 3.

Figures 29 and 30, the hydrographs of wells at Viola and Fulton, show a seasonal variation in water level, which is high in the spring and low in the fall. A long-term trend related to precipitation is shown by the well near West Viola. The rainfall at a weather station 15 miles away was 66.60 inches in 1950, 55.79 inches in 1951, 41.33 inches in 1952, 35.84 inches in 1953, and 39.76 inches in 1954. The water level in this well dropped nearly 3 feet in the 4 years, owing to a deficiency in recharge. Figure 11, the hydrograph of a well at Bardwell, shows the effect caused by the pumping of a well 52 feet away at a rate of 178 gpm.

Rocks of the Eocene series generally will yield sufficient water for modern domestic supplies. As in the Ripley formation, wells can be drilled as deep as necessary without danger of contamination by salt or sulfur water. Some evidence suggests that water in the lower part of the series locally is of better quality than that in the upper part. Except for water in deep aquifers and in thin aquifers in areas underlain largely by clay, the water in the Eocene is unconfined. Water in the artesian aquifers may rise to within a few feet of the surface.

Water samples from 76 wells in the Eocene series were analyzed. Of these, 48 were soft, 14 were moderately hard, 6 were hard, and 8 were very hard. Thirty-two samples had a hardness of less than 30 ppm. The range in hardness was from 7 ppm for water from a well at Sedalia to 404 ppm for water from a well 2 miles south of Hickman. The dissolved solids ranged from a minimum of 28 ppm in water from a well at Cuba to a maximum of 431 ppm, including 91 ppm of nitrate, in water from a well at Milburn. More than half the samples had a dissolved-solids content of less than 120 ppm. Most of the wells yielding hard water high in dissolved solids are along the Mississippi River bluffs in Fulton, Hickman, and Carlisle Counties. The high hardness and dissolved solids may be the result of percolation of water through calcareous loess, which attains a thickness of 40 feet in these counties. Ground water from the area of loess generally contains carbonate and is alkaline, having a pH of 8.0 or higher. The pH of ground water from the Eocene ranges from 5.4 to 8.4. Most water in the Eocene series has an iron content higher than the limit of 0.3 ppm recommended by the U. S. Public Health Service. The iron content reported in some samples was probably due in part to the effect of corrosive waters of low pH on the steel well casing. The silica content of groundwater in the Eocene ranges from 6.6 to 59 ppm. The high content of iron and the low pH may present a problem in some industrial applications, but water in the Eocene is generally of good quality for domestic purposes. The water is of the sodium or calcium bicarbonate type. A nitrate content above the local average often indicates pollution of the water. With two exceptions, samples from all the drilled wells had nitrate contents less than 38 ppm. Samples from a few dug wells and tiled bored wells had nitrate contents greater than 100 ppm, and a sample from one bored well had a content of 439 ppm.

PLIOCENE(?)

Gravel of Pliocene(?) age covers most of the Eocene and older rocks in the Jackson Purchase. Although the gravel is not everywhere an aquifer, it supplies domestic wells in several areas. Dug wells 40 or 50 feet deep are most common. The gravel deposits are thickest in Marshall, McCracken, and Ballard Counties; they are thickest on the uplands and on the tops of hills and ridges. Water-bearing gravel occurs in Calloway, Marshall, McCracken, Ballard, and parts of Graves and Fulton Counties. The gravel is not generally capable of giving large yields because it is poorly sorted and is commonly cemented by iron oxide. Figure 31 shows the hydrograph of a well penetrating gravel of Pliocene(?) age on the upland near Symsonia, northeastern Graves County. Several drawdown tests were made to determine the specific capacity of wells in the gravel of Pliocene(?) age. In all except two wells the pumps broke suction in less than an hour. Those 2 wells had specific capacities of 5.1 and 12 gpm per foot of drawdown when tested. (See figs. 32 and 33.)

Springs are generally uncommon in the Jackson Purchase, although a few issue from the gravel of Pliocene(?) age. Most of these issue above cemented zones or above clay beds underlying the gravel. None yields more than 10 gpm except Hale Spring which flows approximately 50 gpm during wet weather. The measured discharge of a number of springs appears in table 4.

No samples of the sediments of Pliocene(?) age were collected for mechanical analysis. Detailed mechanical analyses of the sand and gravel are described by P. E. Potter in a thesis on file at the University of Chicago, entitled "The petrology and origin of the Lafayette gravel" (1952).

Areas in several counties in which the Pliocene(?) gravel is water bearing are shown on the availability map. The gravel is a good aquifer in the northern half of Ballard County and the northwestern third of McCracken County. Water occurs in the gravel beneath the uplands at Reidland and Symsonia. The ground water in the gravel of Pliocene(?) age is usually under water-table conditions, but artesian water may be found under layers cemented with iron oxide.

Water samples from 25 wells and springs in the gravel of Pliocene(?) age were analyzed. Of these, 12 were soft, 7 were moderately hard, 3 were hard, and 3 were very hard. The range in hardness was from 8 to 906 ppm, and in dissolved solids, 43 to 782 ppm. The pH ranged from 5.7 to 7.5. The iron content of ground water from the gravel generally is less than the limit of 0.3 ppm recommended by the U. S. Public Health Service. Only one sample had an iron content greater than 1 ppm. Four of the samples had a nitrate content greater than 44 ppm, the maximum value in water that might be safely used in infant feeding (Maxcy, 1950). The water in the gravel of Pliocene(?) age is of the calcium magnesium sulfate and calcium magnesium bicarbonate types.

QUATERNARY

The Pleistocene loess generally is not water bearing. The loess occurs as a blanket deposit over much of Fulton, Hickman, and Carlisle Counties. The thickness is greatest, about 40 feet, along the Mississippi River bluffs; it lessens to the east. One dug well in the loess was inventoried and was reported to furnish sufficient water for domestic use.

The coefficients of permeability of 2 vertical samples of loess were 2 and 6.1 meinzers; the porosities were 44.4 and 49.3 percent. (See fig. 34 and table 3.)

Alluvium of Pleistocene and Recent age in the Mississippi, Ohio, and Tennessee River valleys is an important source of water for irrigation and industry. As yet, there is little development of wells in the alluvium in the Jackson Purchase. The alluvium along the Clarks River and Obion and Mayfield Creeks probably will supply only domestic wells. The alluvium is 100 feet thick at Calvert City, 60 feet thick in northwestern Ballard County, and 120 feet thick in an oil test hole near Miller, Fulton County. Bridge borings indicate that the alluvium changes in lithology within short distances, both vertically and horizontally.

The potentially most productive areas of alluvium are in the Mississippi River bottoms, the Ohio River bottoms in Ballard County, and the Tennessee River valley below Kentucky Dam. The northwestern part of McCracken County also is potentially a good area for the development of wells in the alluvium of the Ohio valley. There is evidence that more than 50 feet of saturated sand and gravel can be found in both the Ohio and the Mississippi River flood plains. A 6-inch well in the bottoms in northwestern Ballard County penetrated nearly 50 feet of saturated sand and gravel. This well will produce more than 300 gpm. Many 1¼-and 1½-inch driven wells tap the alluvial aquifer at depths of 20 to 30 feet.

Water samples from 19 wells in the alluvium were analyzed. Of 16 tested for hardness, 6 were soft, 2 were moderately hard, 3 were hard, and 5 were very hard. The range in hardness was from 12 to 664 ppm. The range in dissolved solids in the 19 samples was from 53 to 1,220 ppm. The pH ranged from 5.5 to 7.4. Approximately two-thirds of the samples had an iron content higher than the limit recommended by the U. S. Public Health Service. The specific conductance decreased from 147 micromhos for a sample from Hazel to 114 micromhos for a sample from Almo and to a low of 66 micromhos for a sample from Hardin. Downstream from Benton the specific conductance of water from the alluvium increases to 389 micromhos in a sample from a well 1½ miles south of Sharpe and to 729 micromhos in a sample from a well at Paducah.

The alluvium was sampled at two localities for mechanical analysis. The coefficients of permeability were 480 and 300 meinzers for vertical samples and 460 and 240 meinzers for horizontal samples. The sieve analyses (fig. 35), which indicate that the alluvial sands are very well sorted, show that most of the particles fall in the range from 0.125 to 0.250 millimeter. (See also table 3.)

Two-hour specific-capacity tests were run on two wells in the alluvium. The results of these tests are shown graphically in figures 36 and 37.

The hydrograph of a well 3 miles southeast of Paducah (fig. 38) shows the changes in water level in the alluvium along the Tennessee River. The fluctuations shown largely reflect changes in river stage.

One area shown on the availability map includes the alluvium along the Ohio, Tennessee, and Mississippi Rivers. Most wells in this area will furnish at least sufficient water for domestic purposes. Many of the shallow driven wells in Fulton County went dry in 1954 after a 3-year drought. Water-table conditions exist in most of the alluvial area, but where large amounts of clay are present, as at Paducah, the water in the lower part of the alluvium may be under artesian pressure. Several flowing wells have been found in the alluvial area in the bottoms of Obion Creek. One well was flowing 5 gpm at the time it was tested. It is possible, however, that these wells penetrate the Eocene series and obtain the flowing water from it.

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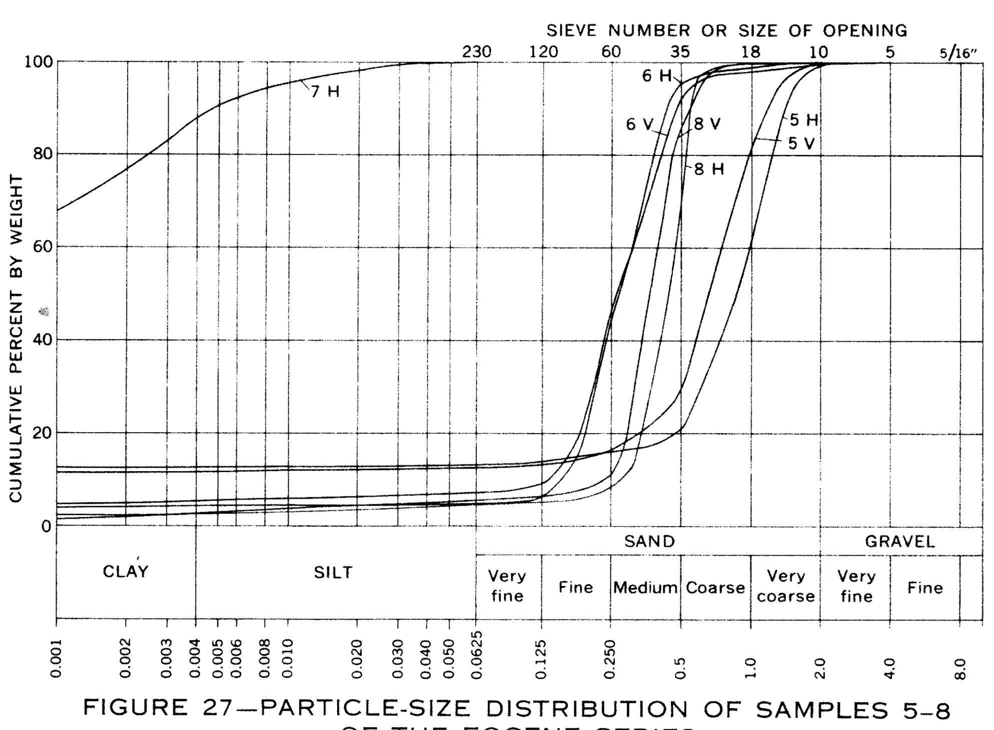

FIGURE 27—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 5-8 OF THE EOCENE SERIES

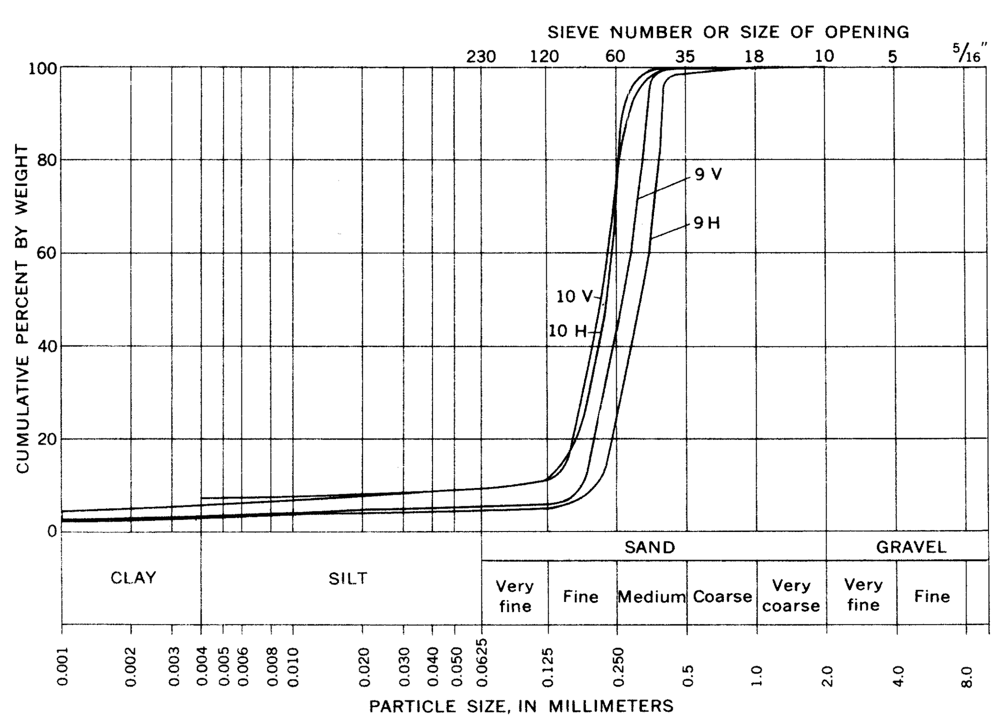

FIGURE 28—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 9 AND 10 OF THE EOCENE SERIES

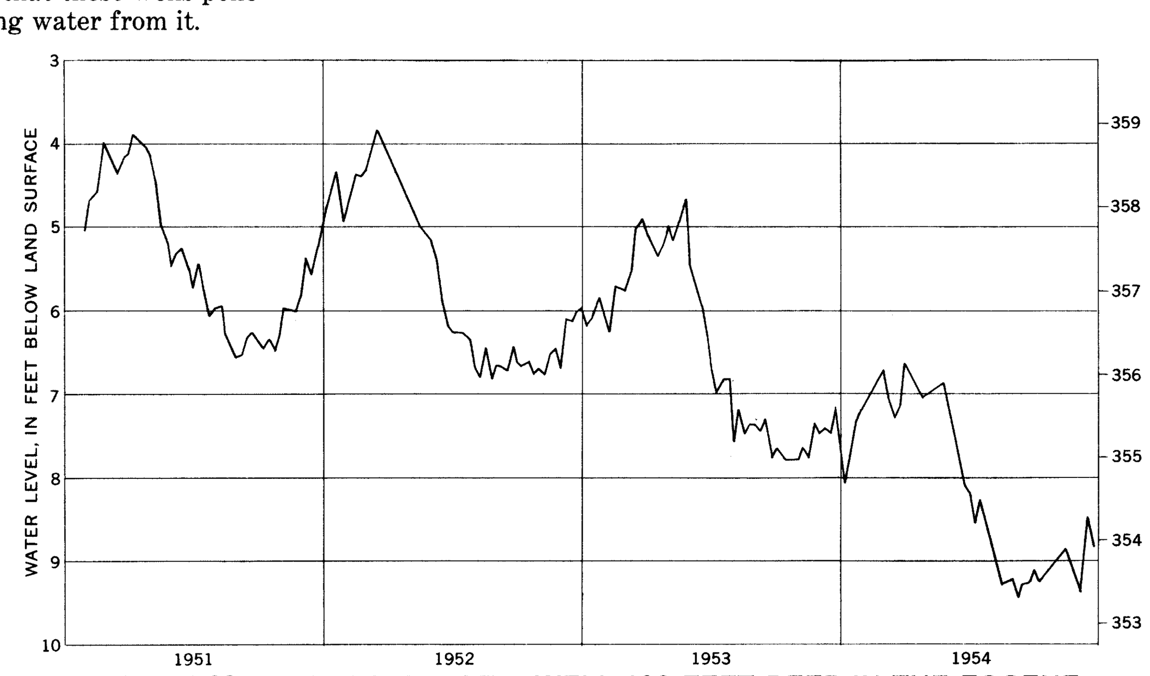

FIGURE 29—HYDROGRAPH OF A WELL 130 FEET DEEP IN THE EOCENE SERIES, FULTON, FULTON COUNTY, KENTUCKY

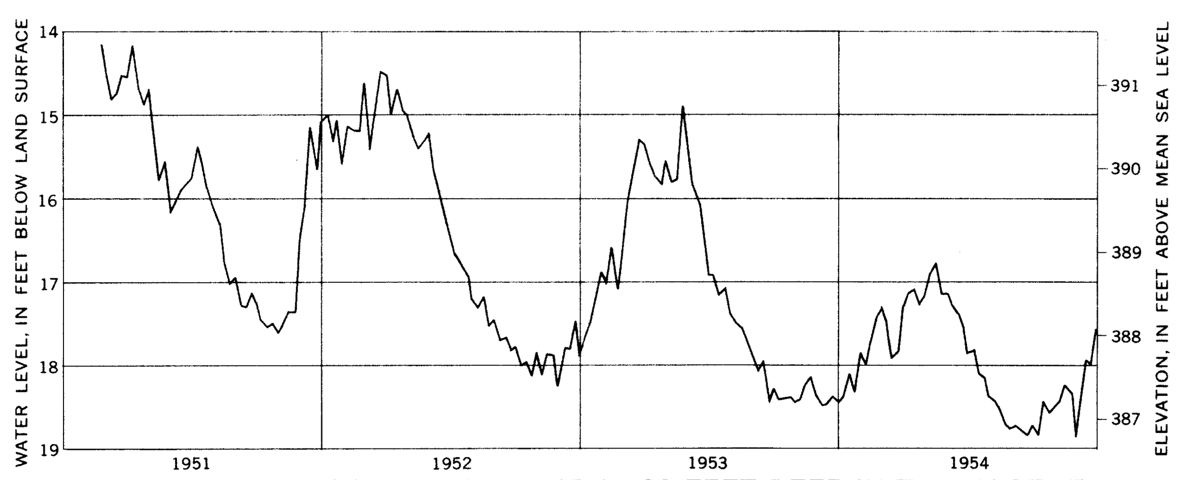

FIGURE 30—HYDROGRAPH OF A WELL 103 FEET DEEP IN THE EOCENE SERIES NEAR WEST VIOLA, GRAVES COUNTY, KENTUCKY

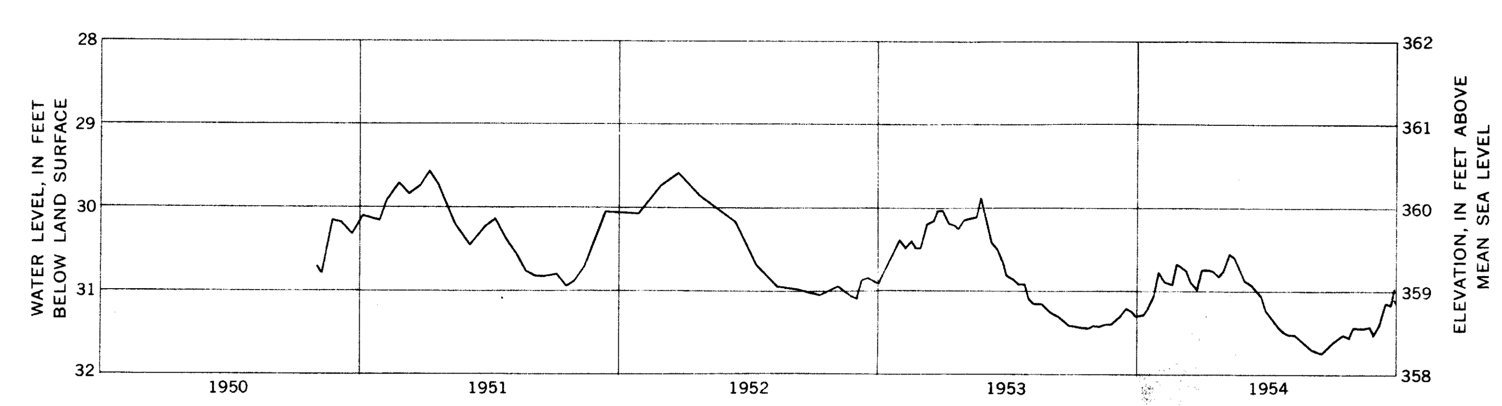

FIGURE 31—HYDROGRAPH OF A DUG WELL 36 FEET DEEP IN GRAVEL OF PLIOCENE(?) AGE, NEAR SYMSONIA, GRAVES COUNTY, KENTUCKY

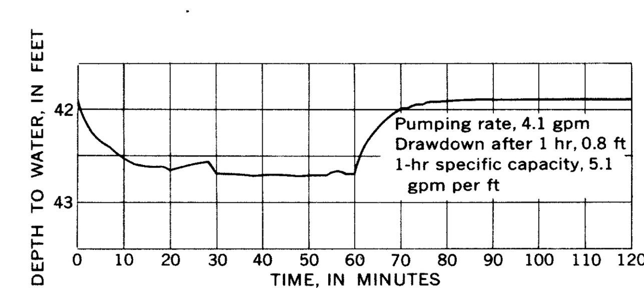

FIGURE 32—SPECIFIC-CAPACITY TEST OF A WELL 43 FEET DEEP IN GRAVEL OF PLIOCENE(?) AGE, FARMERS SUPPLY CO., SYMSONIA, GRAVES COUNTY, KENTUCKY

Table 4.—Flow and temperature of springs discharging from gravel of Pliocene(?) age in the Jackson Purchase region, Kentucky

Date of measurement	Discharge (gpm)	Temperature (°F)
Wadesboro Spring, Calloway County		
June 17, 1954	12	59
July 19	8.1	60
Aug. 10	8.5	60
Sept. 8	8.2	60
Oct. 7	8.2	--
Nov. 5	7.7	59
Dec. 3	7.5	60
Jan. 2, 1955	7.7	59
Jan. 31	7.1	58
Mar. 1	6.0	59
Mar. 28	10.7	59
Apr. 26	10.7	59
May 23	10.7	60
Peggy Ann Spring, near Hardin, Marshall County		
Aug. 10, 1954	2.4	59
Sept. 8	2.9	59
Oct. 7	2.6	60
Nov. 5	2.1	59
Dec. 3	1.7	59
Jan. 2, 1955	1.2	59
Jan. 31	2.3	57
Mar. 1	5.2	57
Mar. 28	3.3	54
Apr. 26	6.5	54
May 23	3.8	55
Hale Spring, near Hardin, Marshall County		
Aug. 5, 1954	50	58
Oct. 25	36	--

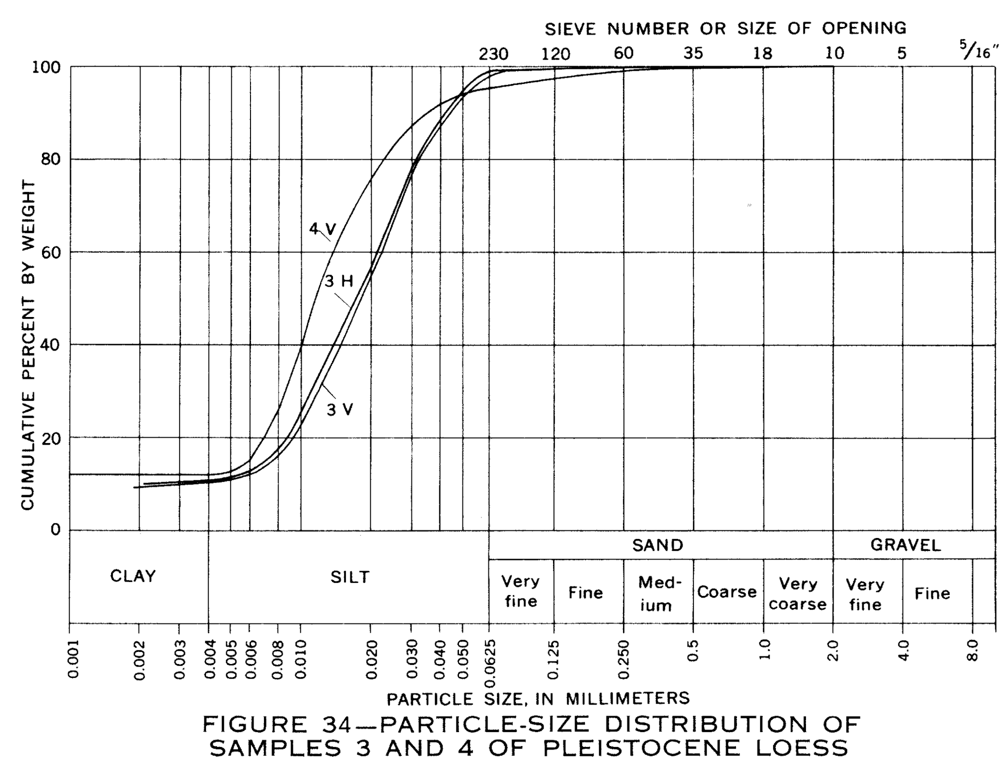

FIGURE 34—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 3 AND 4 OF PLEISTOCENE LOESS

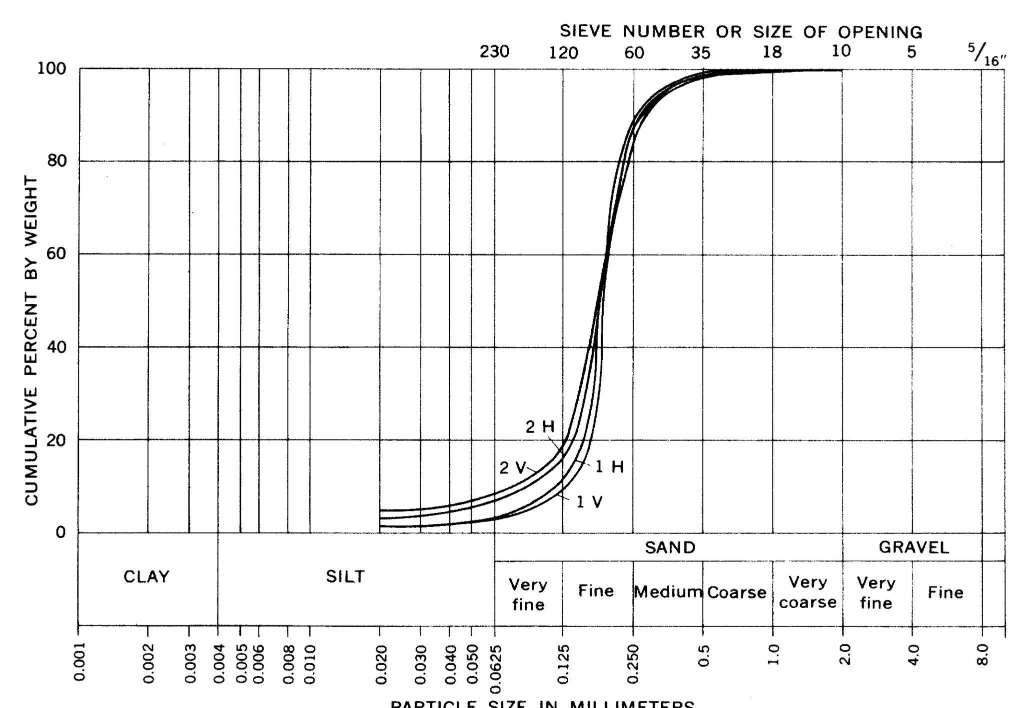

FIGURE 35—PARTICLE-SIZE DISTRIBUTION OF SAMPLES 1 AND 2 OF QUATERNARY ALLUVIUM

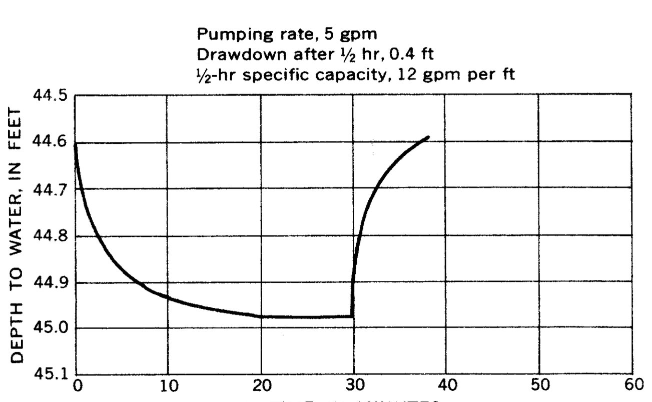

FIGURE 33—SPECIFIC-CAPACITY TEST OF A WELL 45 FEET DEEP IN GRAVEL OF PLIOCENE(?) AGE SOUTHEAST OF PADUCAH, MC CRACKEN COUNTY, KENTUCKY

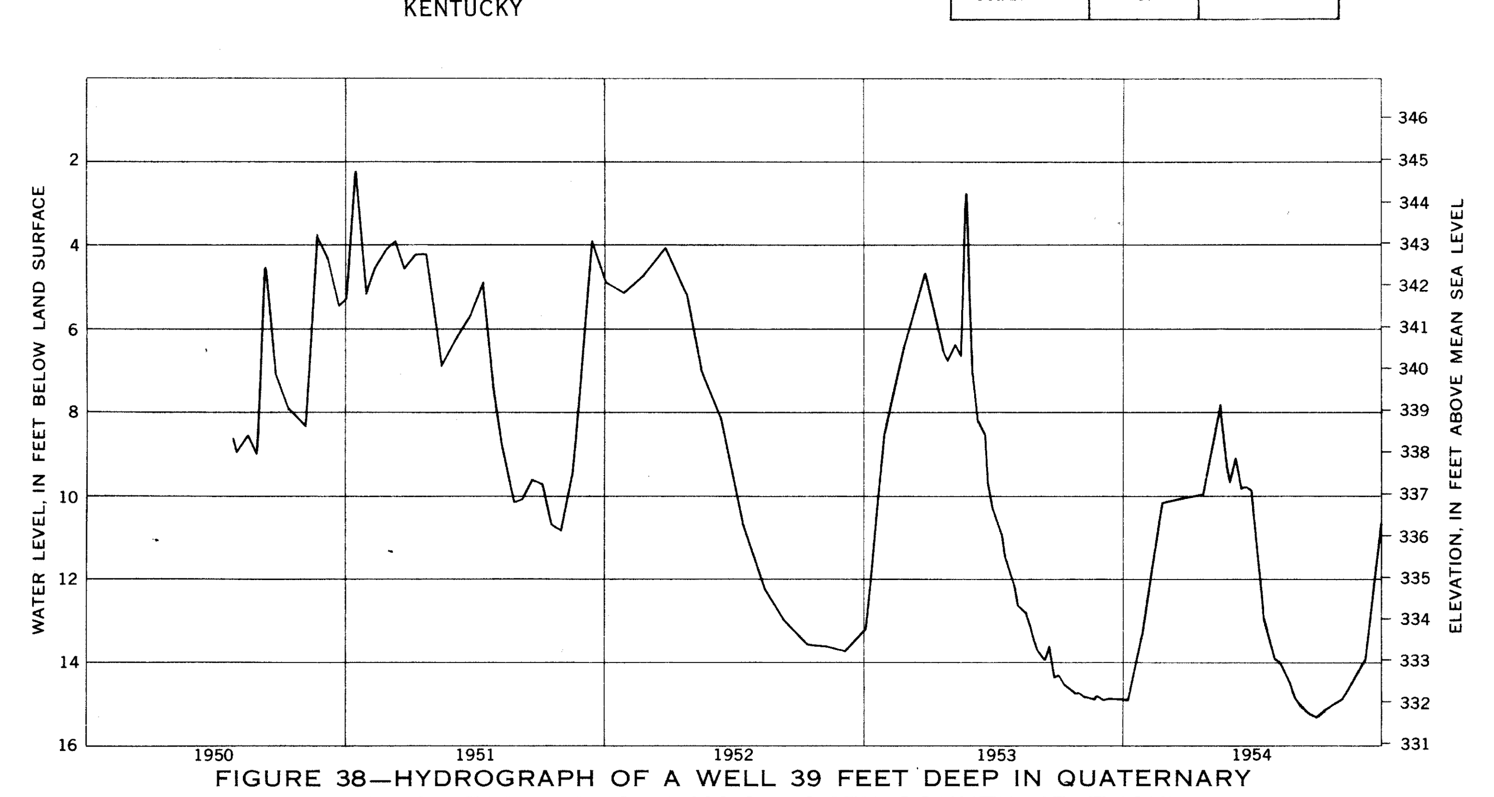

FIGURE 38—HYDROGRAPH OF A WELL 39 FEET DEEP IN QUATERNARY ALLUVIUM NEAR PADUCAH, MC CRACKEN COUNTY, KENTUCKY

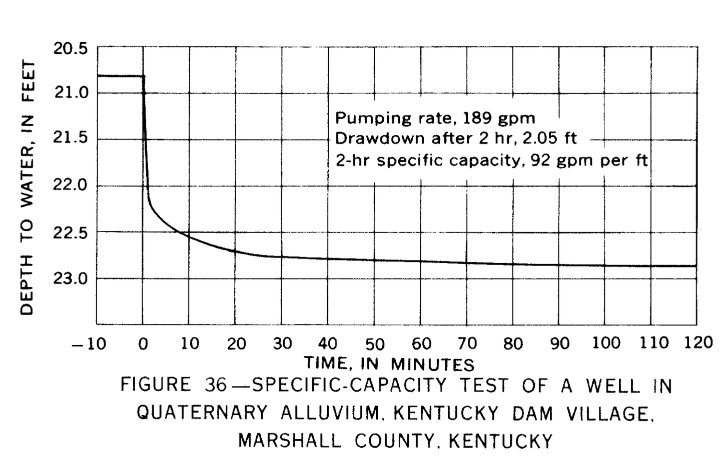

FIGURE 36—SPECIFIC-CAPACITY TEST OF A WELL IN QUATERNARY ALLUVIUM, KENTUCKY DAM VILLAGE, MARSHALL COUNTY, KENTUCKY

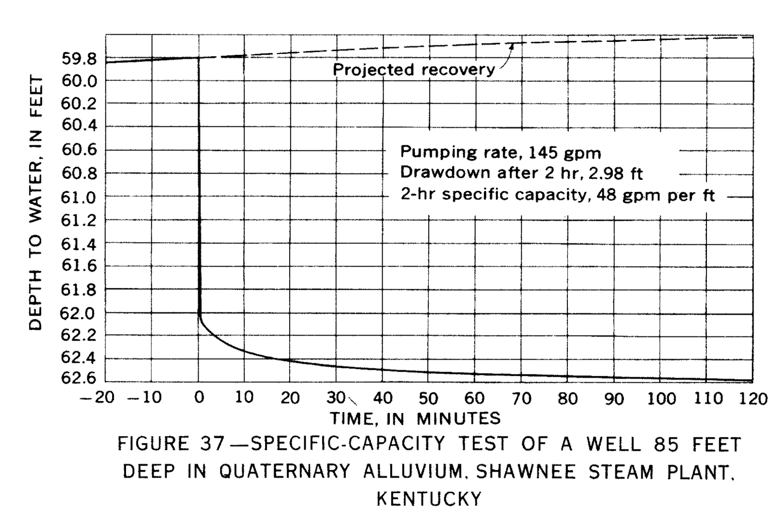

FIGURE 37—SPECIFIC-CAPACITY TEST OF A WELL 85 FEET DEEP IN QUATERNARY ALLUVIUM, SHAWNEE STEAM PLANT, KENTUCKY